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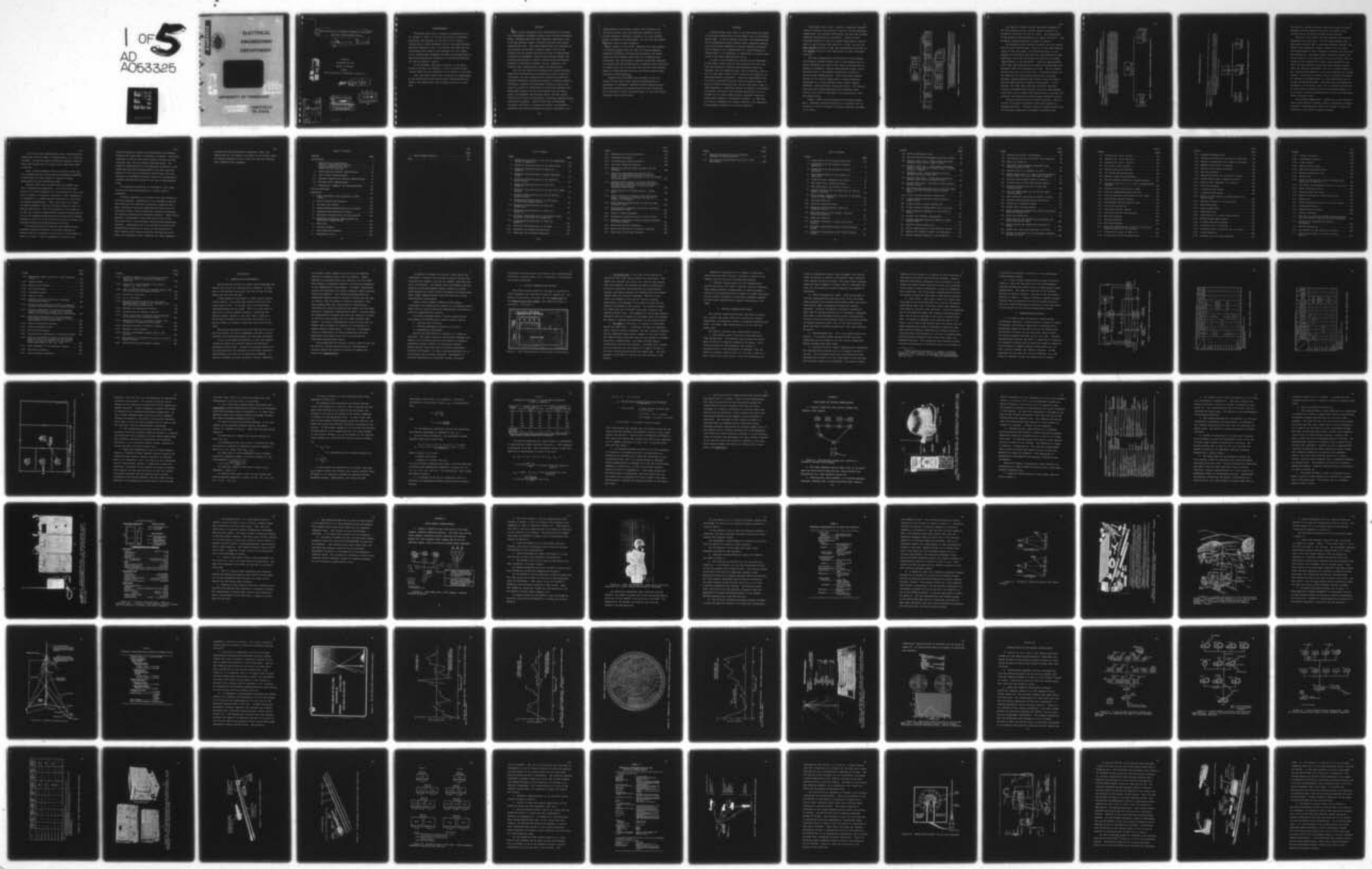

UNIVERSITY OF TENNESSEE

6 THE UTILIZATION OF BROADBAND ANTENNAS IN MILITARY TACTICAL COMMUNICATIONS NETS

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ABSTRACT

This thesis investigates the characteristics of current and developmental broadband antennas used with low and medium power, frequency modulated radio equipment operating in the 30-76 MHz frequency range in military tactical voice radio communication nets. The radio communication net structure of the Airborne and Airmobile Infantry combat units of the Airborne and Air Assault Divisions are used to display data on density of equipment, typical communications ranges, and problems encountered by tactical communications-electronics personnel in providing reliable, secure, responsive, and flexible radio communications within the battle area.

Data for the study were assembled from current military communications-electronics and electronic warfare training literature, military communications engineering references, standard electrical engineering textbooks on antenna analysis and design, research and development technical reports submitted to and by the communications-electronics research and development agencies of the United States Army and Marine Corps, and equipment specification sheets and test reports obtained from various manufacturers of military communications-electronics equipment. Much of these data is displayed throughout the thesis in figures and tables, and extensive appendices provide basic background material necessary to an

understanding of the theory, design, and utilization of military tactical radio communications equipment and the antenna equipment currently available, or in the advanced stages of research and development, for use with the various different items of radio equipment.

The results of this study, combined with field testing of various of these items of radio and antenna equipment conducted at military installations throughout the United States and West Germany, show that use of wideband omni-directional and, particularly, wideband directional antennas can enhance both the communications reliability and flexibility of combat units, and at the same time provide a much greater degree of communications security and defense against enemy electronic countermeasures.

Comments and conclusions are presented in the last chapter of the thesis which include recommendations on procurement of equipment, updating military communications-electronic engineering references and training literature, and utilization of newly developed items of radio and antenna equipment within combat units.

FOREWORD

Single channel voice radio is the most widely used means of electrical communication within combat units of the United States Army. It can be rapidly installed, and communications can be established quickly between widely separated elements. It is particularly adaptable to rapidly changing situations and is essential for communication over large distances or terrain where it is impossible or impractical to install wire lines or use other communications means.

In order to be accepted for purchase by the Department of the Army, a given item of radio equipment must not only have the particular technical characteristics which are required, such as frequency range, type of emission, type of service, and power output, but it also must be capable of as many applications as possible. Logistics requirements such as initial procurement and life cycle maintenance costs, as well as training considerations, dictate that major items of radio equipment or components thereof be capable (if possible) of man-pack, vehicular, and aircraft installation so as to provide for the least number of major equipment items and repair parts required in equipment inventory. In addition, new items of equipment are usually required to be compatible with equipment currently in the Army inventory.

Army combat units (armor, infantry, mechanized infantry, airborne infantry, and airmobile infantry) all have different capabilities, are employed differently, and thus have slightly different communications requirements. Items of radio equipment designed to meet the varied communications requirements of <u>all</u> the above type units can, at best, be only the <u>best possible</u> solution to <u>all</u> such requirements and cannot be the <u>optimum</u> solution to the requirements of each individual type unit.

The radio communication net structure of the airborne and airmobile infantry combat units of the Airborne and Air Assault Divisions are used in this study to display data on density of equipment, typical communications ranges, and to delineate many of the problems encountered in military tactical radio communications. These units were selected because of the author's familiarity, through successive assignments as a signal platoon leader, signal company commander, signal battalion operations officer, and infantry battalion and brigade communications-electronics staff officer, with both the structure, and, particularly, with the problem areas.

Figure 1 shows the organization of the Army Division Base. Personnel strength figures are not current, but are accurate to within 10 percent of current operating strengths in all cases.

DIVISION BASE

TYPE	TOE	OFF	WO	EM
INFANTRY DIV	7-	632	164	8024
INFANTRY DIV (MECH)	37-	595	112	8264
AIRBORNE DIV	57-	674	156	5492
AIRMOBILE DIV	67-	878	584	8167
ARMORED DIV	17-	596	112	8372

HQ & HQ CO

TOE	O	WO	EM
7-4-	45		109
37-4-	52	5	130
57-4-	43		93
67-2-	48		107
17-4-	52	5	130

MP CO

TOE	O	WO	EM
19-27-	9	1	184
19-27-	9	1	184
19-67-	7	1	148
19-87-	8	1	147
19-27-	9	1	184

AVN BN/GP[1]

TOE	O	WO	EM
1-75-	37	57	273
1-55-	56	57	260
1-100-	218	347	1427

ENGR BN[2]

TOE	O	WO	EM
5-155-	44	2	951
5-145-	44	2	971
5-25 -	32	2	544
5-215-	36	2	582
5-145-	44	2	971

SIG BN

TOE	O	WO	EM
11-35-	25	4	612
11-35-	25	4	612
11-215-	19	5	525
11-205-	12	3	321
11-35-	25	4	612

ARMD CAV SQDN/
CAV SQDN[3]

TOE	O	WO	EM
17-105-	45	36	824
17-105-	45	36	824
17-75 -	40	35	557
17-95 -	76	96	596
17-105-	45	36	824

DIV ARTY

TOE	O	WO	EM
6-100-	208	24	2553
6-300-	194	24	2580
6-200-	144	20	1466
6-700-	194	76	1578
6-300-	194	24	2580

SPT COMD

TOE	O	WO	EM
29-1 -	147	28	2083
29-21-	149	28	2194
29-51-	119	24	1488
29-41-	207	86	2841
29-11-	150	28	2271

BDE HQ & HQ CO

TOE	O	WO	EM
7-42-	24	4	142
17-42-	24	4	160
57-42-	25	4	137
67-42-	25	17	171
17-42-	24	4	160

NOTES: 1. The aviation battalion is organic to the Infantry Division and Airborne Division, only. The Airmobile Division has an Aviation Group consisting of three aviation battalions. The Armored Division and Infantry Division (Mech) have an aviation detachment organic to their Support Commands.

2. The enlisted strength of the Engr Bn of the Infantry Div, Infantry Div (Mech), and Armored Division is increased by two (2) when the battalion is equipped with M4T6 or class 60 bridging.

3. The Airmobile Division has a Cavalry Squadron consisting of a Hq & Hq troop, three (3) Air Cavalry troops and one (1) Cavalry Troop. The other divisions have a conventional Armored Cavalry Squadron.

Figure 1. Organization of the Army Division Base.

The number of combat maneuver battalions assigned to both the Airborne and Air Assault (shown on Figure 1 as Airmobile) Divisions is fixed at 9 each. The organization of the Airborne Infantry Battalion is shown in Figure 2. The Airmobile Infantry Battalion is shown in Figure 3.

The Airborne and Air Assault Divisions are both unique, one-of-a-kind organizations. Only one of each type division exists in the Army today. The Airborne Division is the smallest of the Army's type divisions (approximately 14,000 personnel), while the Air Assault Division is the largest (approximately 17,000 personnel). There are approximately 2,000 radio sets provided by the Tables of Organization and Equipment (TOE) of the Airborne Division. The Air Assault Division has over 2,700 radio sets. Fifty-seven percent of the radio sets of the Airborne Division are low power, portable, battery-operated sets, while in the Air Assault Division approximately 71 percent are portable. By comparison, the other three type Army Divisions (Armored, Infantry, and Mechanized Infantry) each have approximately 1,000 radio sets, of which only approximately 12 percent are portable, the remaining 88 percent being vehicular mounted.

Both the Airborne and Air Assault Divisions, using the tactics of vertical envelopment, habitually operate at extended distances. Reliable, effective communications over the distances frequently encountered in airborne and,

INFANTRY BATTALION AIRBORNE DIVISION
OR
INFANTRY BATTALION SEPARATE AIRBORNE BRIGADE (TOE 7-35-)

MISSION:--To close with the enemy by means of fire and maneuver in order to destroy or capture him or to repel his assault by fire, close combat and counterattack.

ASSIGNMENT:--Organic to Airborne Division, TOE 57G.

CAPABILITIES:--a. Close with the enemy by means of fire and maneuver in order to destroy or capture him; b. Repel enemy assault by fire, close combat and counterattack; c. Provide base of fire and maneuver elements; d. Seize and hold terrain. e. Conduct independent operations on a limited scale; f. Furnish limited antitank protection; g. Provide indirect fire support for organic and attached units; h. Conduct long-range patrolling when appropriately equipped; i. Participate in air-transported (airmobile) operations when provided with sufficient transportation; j. Maneuver in all types of terrain and climatic conditions; k. Capable of frequent airborne assault by parachute or assault aircraft with minimum marshalling and planning procedures; l. Dependent upon the Administration Company TOE 12-157G for personnel services; m. Individuals of this organization, except chaplain and medical personnel, can engage in effective coordinated defense of the unit's area or installation; n. Thirty percent mobile in organic transportation. One hundred percent mobile in medium transport aircraft.

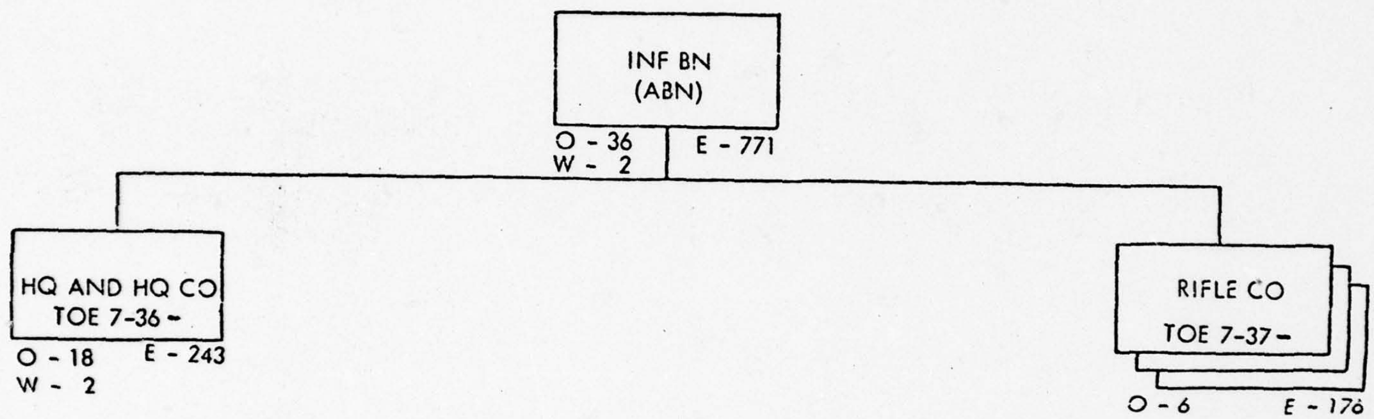

Figure 2. Organization of the Airborne Infantry Battalion.

INF BN, AIRMOBILE DIV (TOE 7-55-)

MISSION:--To close with the enemy by means of fire and maneuver in order to destroy or capture him or to repel his assault by fire, close combat, and counterattack.

ASSIGNMENT:--Organic to Airmobile Division, TOE 67T.

CAPABILITIES:--a. Close with the enemy by means of fire and maneuver in order to capture or destroy him. b. Repel enemy assault by fire, close combat, and counterattack. c. Provide base of fire and maneuver elements. d. Seize and control terrain for limited periods of time. e. Conduct independent operations on a limited scale. f. Provide communications, reconnaissance, indirect fire, antitank fire and limited logistical support. g. Conduct long-range patrolling. h. Participate in air assault operations.
j. Maneuver in all types of terrain and climatic conditions.

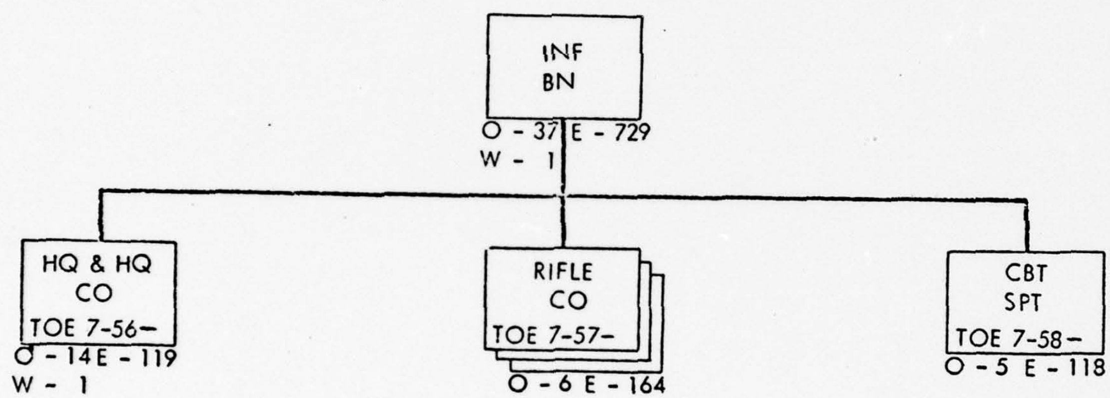

Figure 3. Organization of the Airmobile Infantry Battalion.

particularly, airmobile assault operations using low power, portable, battery operated radio sets is possible only through the use of high efficiency antenna systems.

Very few of the Army's tactical radio sets provide for adjustment of output power. All the high-frequency (HF), amplitude modulated (AM) or AM-single-sideband (AM-SSB) sets provide such capability, however, none of the low power, very-high-frequency (VHF), frequency modulated (FM) sets have this capability. The medium power, vehicular mounted, VHF FM sets provide a low power and a high power output, with no capability for adjustment of power output between the two. Thus, the only element in the radio communications system which the tactical communicator can use to effect changes to his radiated electromagnetic wave is by adjusting the antenna system. Usually this involves trying to increase the amount of radiated or received power in a desired direction so as to span increased distances. Although radio retransmission equipments are available, their use is frequently denied due to enemy forces' occupation of the intervening terrain, or in the case of aerial retransmission, lack of air superiority within the battle area.

The tactical communicator, taking note of the threat of enemy radio direction finding, jamming, deception, and other electronic countermeasures (ECM) will attempt to limit the radiation of his signals toward the enemy.

In tactical radio communications nets, radio operating frequencies and call signs are changed daily, or as often as necessary, to deny the enemy information regarding identification and disposition of tactical units (Electronic Order of Battle).

Thus, antenna equipment used with tactical radio sets must necessarily have a broad operating frequency bandwidth to facilitate the rapid change of frequency without deterioration of the transmitted signal.

Tactical radio sets currently under development will have a frequency-hop capability. Such radio sets would operate on a given frequency for a given period of time, then move at regular or irregular intervals to other frequencies in succession in a random pattern determined by a key which is changed electronically. These radio sets will require extremely broadband, high gain antenna systems in order to operate effectively. One of the purposes of this thesis is to show the increased communications capabilities provided by the use of broadband omnidirectional and directional antenna systems, as well as, in the case of directional antennas, the increased protection afforded against enemy ECM.

The characteristics of tactical radio communications equipment currently available in the Army Inventory of Adopted Items are presented in the context of the echelon in which it is used. Items of equipment currently in the advanced stages of research and development are presented following the items they are designed to replace. Particular attention is paid to the antenna systems available for use with each item, for the reasons enumerated above. The technical characteristics of the equipment presented in this study were obtained from Department of the Army Technical Manuals, in the case of currently adopted items, and from research and development technical reports or manufacturer's equipment specification sheets in the case of developmental items.

No classified information is disclosed in this study, nor were any classified documents or sources used as references.

Extensive appendices are provided which are intended to serve two purposes: Appendices A-J are intended to provide the electrical and electronic engineering community with a basic reference of military communications-electronics and electronic warfare terms, definitions, operating techniques, and military communications engineering symbols. Additionally, Appendix I and Appendix J show the present level of the literature used to train military communications-electronics personnel. Appendices K and L are provided to the military communications engineer as a basis for the prediction of radio communications system performance through the use of radio wave propagation charts (Appendix K), while Appendix L provides the basic mathematical equations, terms, and definitions for the analysis and design of the various types of antennas presented in this study and used with tactical radio communications equipment.

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INTRODUCTION

A. COMMUNICATIONS REQUIREMENTS

The US Army has arrived at a point where technology and reality have outrun our old tactics for fighting. We have come to the shocking realization that the old way of doing things will not work any more.

A good example of the change in combat reality facing today's soldier is an often-used statistic from the Arab-Israeli War of 1973. In 20 days, over 1,700 tanks were destroyed between the two sides. That is as many tanks as there are in five US armored divisions. Technology has improved weapons systems to the point where a tank has a 50-50 chance of being hit by the first round fired at it. We must retool our tactics to meet the reality of the next fight.

The US Army objectives in the next conflict are to win the first battle, win while outnumbered, and make the most effective use of powerful weapons and proficient personnel.

To win on the modern battlefield, we must have capable leaders who employ our powerful weapons and proficient personnel to best effect. Because of increased mobility on the battlefield and the complexity of the fight, much more responsibility will rest on the individual commander. A tactical commander requires a reliable, secure, responsive, and flexible signal communications system to adequately control the fighting forces under his command. Today's emphasis on increased dispersion, mobility, and the volume and strength of firepower increases the scope and complexity of the communications requirements. Therefore, centralized control and coordination of widely dispersed, mobile tactical forces are essential. The controlling headquarters and subordinate elements must be capable of moving over any type of terrain, under all kinds of climatic conditions. More than anything else, this requirement for mobility distinguishes the tactical communications system from the fixed military or commercial communications system. Tactical signal and communications elements must have the capability to move as rapidly or more rapidly than the combat elements they support. The signal communications system for any level of command must be capable of changing its configuration to support changing requirements. In general, a requirement exists to interconnect all major headquarters and their subordinate and lateral units with an integrated and compatible communications system.

The prerequisite for success in battle cannot be met and the forces on the battlefield cannot be concentrated or directed without the essential elements of command and control and communications.

In addition to command and control, there exists the requirement to support the fighting or maneuver forces with artillery fire support, tactical air support, and naval gun-fire, if available. Air defense units and elements have the mission of providing defense against hostile air attack, which entails air traffic control throughout the battle area. These combat support missions each have their own unique communications requirements.

Combat service support elements provide supply, maintenance, and administrative support to the fighting units. These elements require extensive communications facilities in order to accomplish their mission.

As briefly mentioned above, tactical communications requirements are determined by various factors, such as

1. Size and type of forces.
2. Tactical deployment (dispersal of forces).
3. Geographical environment.

Each of the above factors is subject to a number of variables. The type or means of communication employed will depend on the tactical situation and current or impending operations (attack, defense, or retrograde movement); whether special operations such as airborne (parachute), airmobile (helicopter), or river crossing operations are to be conducted; and the means available. Coordination of tactical communications, electronic warfare, and other electronic facilities (such as in-country civil communications facilities, airfield radar, etc.) is essential to the success of tactical operations.

B. TACTICAL COMMUNICATIONS DEFINED

The communications system for the Army in the field is widely dispersed over the entire theater of operations. The theater of operations is divided into the combat zone and the communications zone (COMMZ) (when adequate terrain is available). See Figure 4.

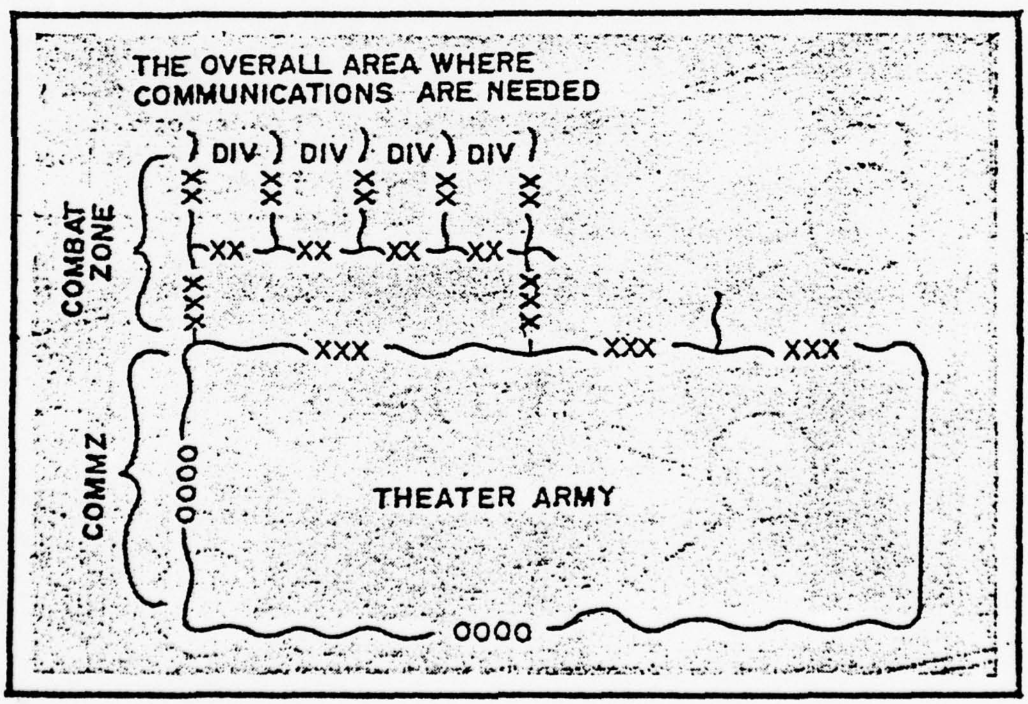

Figure 4. Army communications in the theater of operations.

1. The combat zone is that part of the theater of operations that combat forces require for operations. The combat zone includes the ground, air, and sea areas within which the commander can directly influence the progress or outcome of operations by maneuvering his ground gaining elements and through delivery of firepower with fire support systems under his control or command. The size of the combat zone depends on the area of interest, mission, organization, and equipment of the force involved and the physical environment of the country. For tactical control, the combat zone may be divided into corps, division, and separate brigade areas. The commander of the unified command designates the rear boundary of the combat zone; the boundary may change as required by displacement of the combat forces.

2. The COMMZ is that part of a theater of operations behind the combat zone. It contains the lines of communications, logistic support complexes, and other agencies required for the immediate combat service support of the field forces. The COMMZ includes sufficient area for the operation of supply, evacuation, transportation, and combat service support installations and for their defense. The COMMZ also includes any area necessary for the operation or support of Navy or Air Force elements based outside the combat zone. The rear boundary of the COMMZ is usually the rear boundary of the theater.

Territorial organization of a theater of operations varies with the type of theater, the type of forces in the theater, and the nature of the operations planned.

3. Tactical communications are all communications serving the Army in the field. Normally, tactical communications employ portable, transportable, or mobile equipment organic to the operating units in support of combat operations but may include semifixed or fixed-plant equipment operated by the US Army Communications Command, functioning in the COMMZ.

C. TACTICAL COMMUNICATIONS MEANS

The tactical communications means available are radio, wire, visual, and sound, which are classified as telecommunications, and messenger, which is a physical communications means. Of these, radio communication is by far the most widely used.

The types of tactical radio communication include:

1. Multichannel radio, using pulse-code-modulation (PCM) multiplexing. Multichannel radio provides the "backbone" of the Army integrated communication system. Multichannel systems are used throughout the theater of operations down to the headquarters of brigades, with the number of channels varying from 12 at the lower levels to as many as 96 at the higher levels. With the introduction of

tactical tropospheric scatter radio equipment, the line-of-sight limitation on long-haul multichannel radio communications systems has been overcome. This high traffic capacity means will pass telephone, teletype (TTY) or telegraph (TG), data, TV, and facsimile circuits throughout the theater of operations.

2. Radio teletypewriter (RATT). RATT is employed in tactical communications using high power HF AM and AM-SSB radio equipment with frequency-shift-keying (FSK) and narrow-shift-keying (NSK) teletypewriter modems and terminal equipment. Using an ionospheric refraction transmission path, RATT is normally employed as an alternate or supplementary means to the telecommunications center teletypewriter circuits routed over multichannel radio or wire/cable systems. At maneuver battalion level, this is the only electrical means available to provide printed page, hard copy, messages of record.

3. Radiotelegraph (CW). CW is very seldom used at any echelon. It has been largely replaced by RATT and telecommunications TTY because of the much faster transmission speeds available with those means.

4. Tactical satellite (radio) communications (TACSATCOM). The communications satellite acts as a repeater station in the sky. Newly developed radio sets with advanced antenna equipment have brought us to the stage where we now have man-pack portable equipment for TACSATCOM. This means is being

explored to the fullest as it appears to offer solutions to many pressing tactical communications problems. However, barring international agreements such as inclusion of protection of communications satellites within the provisions of the Hague or Geneva Conventions, it must be remembered that satellites, just as any other communications facility, can become a target for enemy ECM or other hostile action.*

5. Voice radio. Voice radio, using low, medium, and high power HF AM and AM-SSB radio sets, and low and medium power VHF FM radio sets is the most widely used communications means at Division level and below. VHF FM is preferred due to its relatively noise free reception characteristics. Also, VHF FM can be operated in the clear or speech-secure mode. HF AM-SSB is employed as an alternate means at all levels, and is used as the primary means for medium and long range communications using an ionospheric refraction path. Near-vertical-incidence refraction of HF AM-SSB signals is currently being investigated as a solution to communications with helicopters engaged in nap-of-the-earth flight over extended distances. This system has been tested at several military installations in the United States at distances up

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*"Race Intensifies Between U.S., Russia to Develop Satellite Killer by 1980," The Scripps-Howard Newspapers, Washington, D.C. Reported in The Knoxville News-Sentinel, July 10, 1977.

to 150 miles and offers a solution to a very perplexing communications problem.

6. A type division communications system is shown in Figure 5. Note that the majority of the communications services provided are based on one or another type of radio communication. The radio net structure of the Airborne Division is shown in Figure 6, and that of the Air Assault Division in Figure 7. Figure 8 displays a typical Division Tactical Area of Operations for the Air Assault Division. This area, 5400-10,800 square kilometers, is the area which must be spanned by the division communication system.

D. COMMUNICATIONS DISTANCES

1. In order to meet the tactical communications requirements imposed by a given tactical situation or scheme of maneuver, the tactical communicator is concerned with determining whether he can span or cover the required communications distances with the particular types of radio and antenna equipment provided by his unit's TOE. Detailed communications planning, and often, a great deal of ingenuity, are required to insure that the means and types of communications provided to support maneuver elements does not, in fact, retard or degrade the scheme of maneuver. If TOE equipment will not span the required distances, i.e., the scheme of maneuver exceeds the capabilities of organic

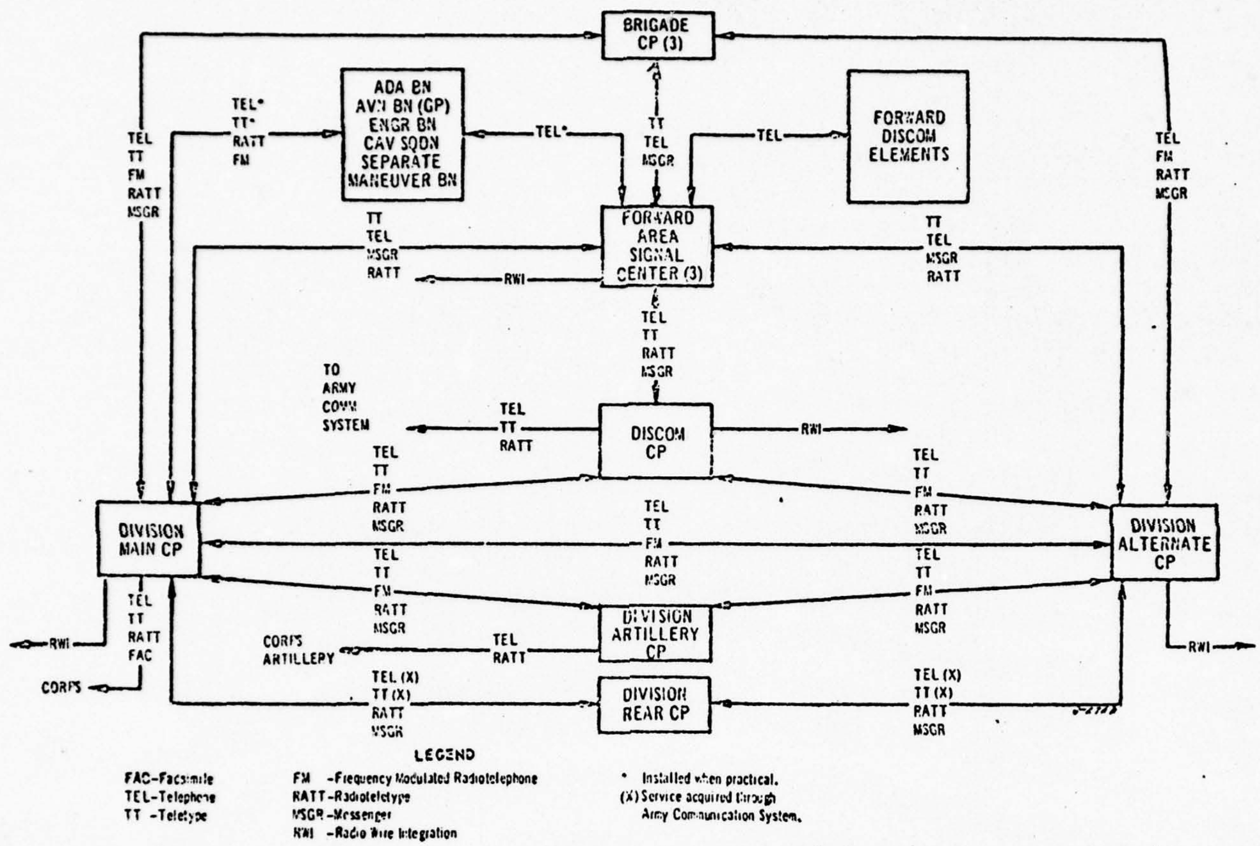


Figure 5. A type division communications system.

NOTE: In the columns below, X denotes receiver-transmitter and R denotes receiver only.

Elm \ Net	Div CG/ comd net (SSB voice)	Internal RATT nets: No. 1 (op/ intel)	Internal RATT nets: No. 2 (admin/ log)	Internal RATT nets: No. 3 (CP)	Div op/ intel net (FM-voice)	Div air req net (AM-voice-CW)	AF air req net (AM-voice-CW)	AF TAD net (UHF)	Army air req net (RATT)	Higher ech comd net (RATT)	Spot rept rcvr net (UHF)
Div main----------	X[1] NCS	X[1] NCS	X[1]	X[1]	X[1] NCS	X NCS	X[3] (TACP)	X[3] (TACP)	X	X[2]	X
Div rr------------	---	---	---	X[1]	---	---	---	---	---	---	---
DTOC-------------	X	---	---	---	X	---	---	---	---	---	---
Div altn ----------	X[1]	X[1]	X[1]	X[1]	X[1]	---	---	---	---	---	---
Div arty ----------	X CO & FDC	X[1]	X[1]	---	X FDC	---	---	---	---	---	---
Bde (3)-----------	X CO & CP	X[1]	---	X[1]	X CP	X	X[3] (TACP)	X[3] (TACP)	---	---	X
Mvr bn (9) --------	---	---	---	---	---	X	X[3] (TACP)	X[3] (TACP)	---	---	X
DISCOM ----------	X	---	X[1] NCS	X[1] NCS	---	---	---	---	---	---	---
Avn bn -----------	X CP	X[1]	X[1]	---	X CP	---	---	---	---	---	X
Cav sqdn----------	X CO & CP	X	X	---	X S3 & CP	X	X[3] (TACP)	X[3] (TACP)	---	---	X
Sig bn------------	X DSO	---	---	---	X S3	---	---	---	---	---	---
Engr bn-----------	X CP	X	X	---	X S3 & CP	---	---	---	---	---	---
MP co------------	X CP	---	---	---	X Monitor	---	---	---	---	---	---
Fwd area spt (3)-----	---	---	X[1]	---	---	---	---	---	---	---	---
Div ADA bn--------	X	X	---	X	X	---	---	---	---	---	---
DASC-------------	---	---	---	---	---	---	X[3]	X[3]	---	---	---

[1]Radio set provided by the division signal battalion.
[2]Radio set provided by the corps or army signal battalion, as appropriate.
[3]Radio set provided by the Air Force.

Figure 6. Type radio nets, Airborne Division.

NOTE: In the column below, X denotes receiver-transmitter and R denotes receiver only.

Net / Elm	Internal RATT nets: Div comd No. 1 (SSB RATT voice CW)	Div comd No. 2 (SSB RATT voice CW)	Div[1] admin/log No. 1, 2, 3 (SSB RATT voice CW)	Div admin/log No. 4 (SSB RATT voice CW)	Div G2 Air info (SSB RATT voice CW)	Div op/intel net (FM-voice)	Div comd/op net (FM-voice)	Div org acft req net (AM-voice-CW)	Spot rept rcvr net (UHF)	Div air req net (AM-voice-CW)	AF air req net (AM-voice-CW)	AF TAD net (UHF)	Army air req net (RATT)	Higher ech comd net (RATT)
Div main	x^{2}	x^{2} NCS	---	x^{2}	---	---	x^{2} NCS	---	---	---	---	---	---	---
DTOC	x^{2} NCS	---	---	---	x^{2} NCS	x^{2} NCS	---	$x^{2\,3}$	x^{2}	x^{2}	x^{5} (TACP)	x^{5} (TACP)	x^{4}	x^{4}
Div alte	$x^{2\,3}$	$x^{2\,3}$	---	---	---	$x^{2\,3}$	$x^{2\,3}$	---	---	---	---	---	---	---
Div arty	x^{2}	x^{2}	---	x^{2}	---	x^{2}	x	x	x	x	---	---	---	---
Bde (3)	x^{2}	x^{2}	x^{2}	---	---	x^{2}	x	x	x	x	x^{5} (TACP)	x^{5} (TACP)	---	---
Mvr Bn(8)	---	---	x	---	---	---	---	x	x	x	x^{5} (TACP)	x^{5} (TACP)	---	---
DISCOM	x^{2}	---	x^{2} NCS	x^{2} NCS	---	x	x^{2}	---	---	---	---	---	---	---
Div tr	---	---	---	x^{2}	---	---	---	---	---	---	---	---	---	---
Avn Gp	---	---	---	---	x	x	x	x	x	x	---	---	---	---
Cav sqdn	x	x	---	x	---	x	x	x	x	x	x^{5} (TACP)	x^{5} (TACP)	---	---
Engr bn	x	x	---	x	---	x	x^{3}	---	---	---	---	---	---	---
Sig bn	x^{2}	---	---	---	---	---	$x^{2\,3}$	---	---	---	---	---	---	---
MP Co	---	---	---	---	---	x	---	---	---	---	---	---	---	---
Fwd area spt	---	---	x	---	---	---	---	---	---	---	---	---	---	---
Div ADA Bn	---	x	---	x	---	---	---	---	---	---	---	---	---	---
DASC	---	---	---	---	---	---	---	---	---	---	x^{5}	x^{5}	---	---

[1] One net per brigade.
[2] Radio set provided by the division signal battalion.
[3] Normally monitor.
[4] Radio set provided by the corps or army signal battalion, as appropriate.
[5] Radio set provided by the Air Force.

Figure 7. Type radio nets, Air Assault Division.

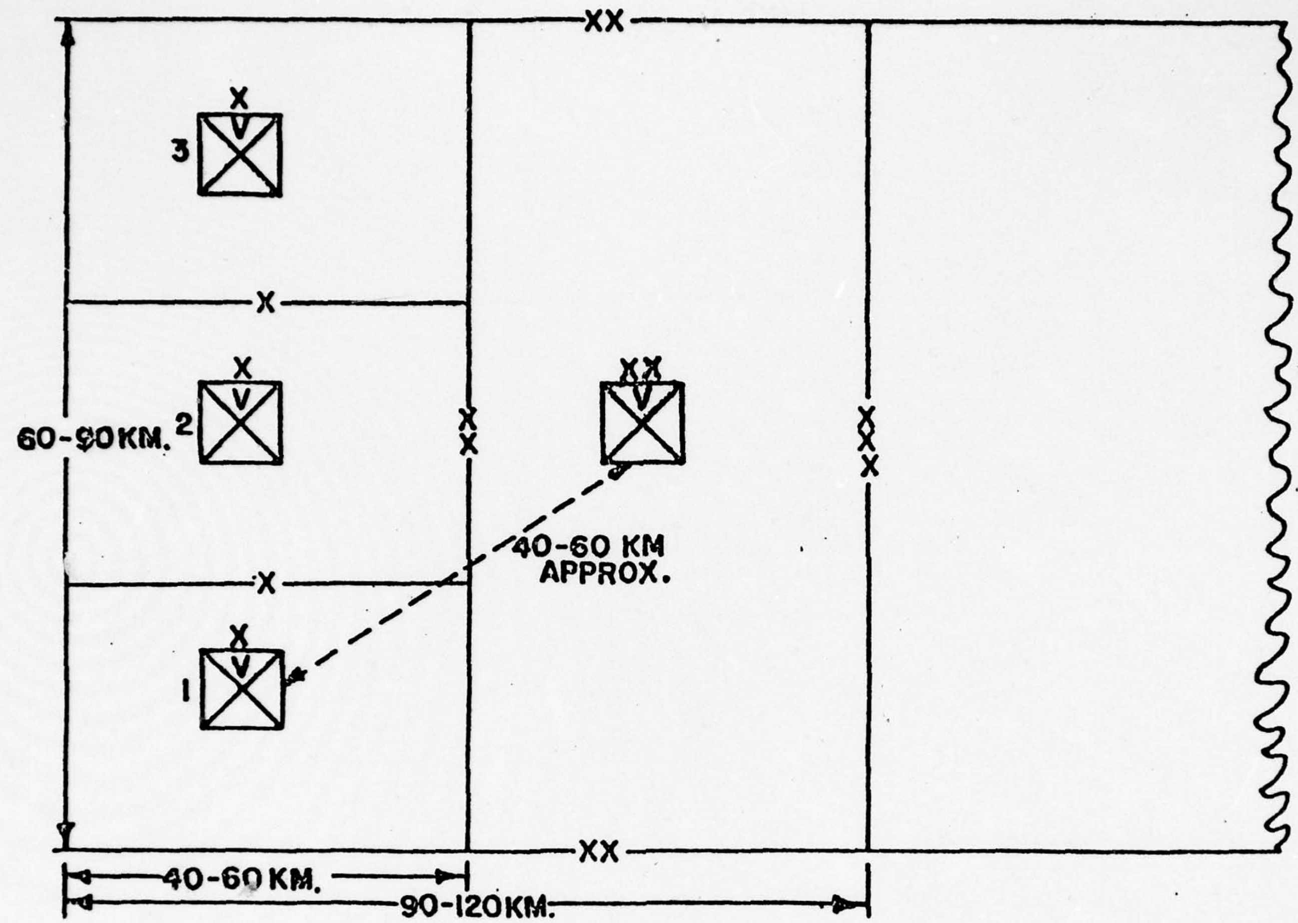


Figure 8. Typical tactical area of operations for the Air Assault Division.

equipment, then this fact must be recognized and appropriate corrective action taken. The scheme of maneuver may be changed to one involving distances which can be spanned with organic equipment. Special equipment to support the scheme of maneuver may be requested from higher headquarters. Or, use of field expedient means (such as the field expedient antennas of Appendix J, designed to increase the communications range of tactical radio equipment) may be used to meet the particular tactical communications requirement.

2. The communications planning distance range data provided in military equipment technical manuals is a nebulous figure derived from a composite of field tested ranges under many different conditions of transmission and reception. Generally it is an optimistic figure; however, extremes of terrain may make this figure high or low.

3. Radio wave propagation in the 30-76 MHz frequency range is a function of many variables such as siting of the transmitter and receiver (whether located on an elevated point, in a depression, etc.), the nature of the intervening terrain (obstructions, density of vegetation, ground conductivity), the height of the transmit and receive antennas above ground, the gain and efficiency of both the transmit and receive antennas, and the required field strength intensity at the receive antennas, plus many other factors. Generally, for propagation of radio waves in the 30-76 MHz

(low VHF) range, there is little or no ground wave, and communication is by the direct or space wave.

4. For a particular communications requirement, the approximate maximum communications distance may be calculated using the propagation charts of Appendix K. In order to be effective these curves require detailed knowledge of radio and antenna equipment parameters such as:

(a) Gain of transmit and receive antennas, in dB, with respect to the reference antennas used for the charts (Figure K-2, Appendix K) (G_t, G_r). (Note that the gain may be negative.)

(b) Efficiency of transmit and receive antennas, if known (E_t, E_r).

(c) Transmission line loss in dB (if transmission lines are used) as a function of operating frequency (Appendix I, Tables I-4, I-6, Figure I-34) (T_{L_t}, T_{L_r}).

(d) Input power to the transmission line or antenna terminals (transmitter power), in dB with respect to 1 kw. (From Appendix K, Figure K-1) (P).

$$P = 10 \log \frac{\text{input power} \times E_t}{1 \text{ kw}} .$$

(e) Effective length of the receive antenna (ℓ_{e_r}). (Appendix L, Table L-2).

(f) Antenna height gain, in dB, for the transmit and receive antennas (Appendix K, Figure K-6 (b), (f), (j), (n), (r), or (v)). (H_t, H_r).

(g) Type of terrain for the transmission path (from Appendix K, Figure K-5).

(h) Required field strength at the receive antenna, in dB, with respect to 1 μv/m (F). When a receiver has the same input resistance as is seen across the antenna connection, it is said to be matched to the antenna (Appendix L, Figure L-2, and Equations 16-19). In such a case, one-half of the induced voltage appears across the receiver, the other half across the internal (radiation) resistance of the antenna. If the receive antenna is in line with the direction of polarization of the transmitted wave, the total induced or open circuit voltage, V_{oc}, is the product of the received field strength (E) (μv/m) and the antenna effective length, ℓ_{e_r}.

$$E \times \ell_{e_r} = V_{oc}$$

$$= 2 \times \text{required receiver threshold voltage } (V_r)$$

$$E = \frac{2 \times V_r}{\ell_{e_r}} .$$

If the receiver and antenna are not matched, less than $V_{oc}/2$ appears across the receiver and a larger received field strength, E, is required to provide the required receiver threshold voltage. Additionally, the receive antenna efficiency, given by Eq. (53), Appendix L, should be multiplied by the effective length, ℓ_{e_r}, in determining E. Thus

$$E = \frac{2 \times V_r}{E_r \times \ell_{e_r}}$$

and

$$F = 20 \log \frac{E(\mu v/m)}{1 \ \mu v/m} .$$

(i) The density of vegetation between the transmitter and receiver (paragraph 3c, Appendix K) (V_t, V_r).

With the above information, the approximate maximum distance range can be found from

$$D = \frac{(G_t + P + T_{L_t} + H_t + R + V_t + V_r + H_r + T_{L_r} - F + G_r)\,dB}{12 \ dB/octave}$$

where 1 octave = 0.5-1 mile

2 octaves = 1-2 miles

3 octaves = 2-4 miles, and so on.

R is the starting reference level above 1 μv/m for each type of polarity and conductivity (Appendix K, Figure K-6 (a), (e), (i), (m), (q), and (u)). For convenience, these values are shown in Table 1.

5. An example of the use of propagation charts to determine the approximate maximum communications distance follows.

TABLE 1

REFERENCE LEVEL ABOVE 1 μv/m FOR THE PROPAGATION CURVES OF APPENDIX K

Frequency (MHz)	Vertical Polarity poor soil	good soil (dB)	sea water	Horizontal Polarity poor soil	good soil (dB)	sea water
30	72	88	112	73	72	72
40	70	85.8	111	74.3	73.7	74
50	68	83.7	110	75.7	75.3	76
60	66	81.5	109	77	77	78
70	65.1	80.6	108	78	78	78.9
80	64.2	79.6	107	79	79	79.8
Attenuation per octave 30-80 MHz	12	12	- *	12	12	12

* Curves for all frequencies are not linear across a wide enough distance range to permit a linear determination of attenuation.

(a) Using Transmitting Set, Radio AN/PRT-4, transmitting to Receiving Set, Radio, AN/PRR-9 (Chapter 1). The frequency of operation is 52 MHz. The intervening terrain is poor soil. There are no obstructions or trees in the path.

$$G_t = G_r = 0;\ E_t = 0.3,\ E_r = 0.2;\ T_{L_t} = T_{L_r} = 0$$

$$P = 10 \log \frac{0.45\text{w} \times E_t}{1 \text{ kw}} = -38.70 \text{ dB}$$ (from the figure on page 24)

$$\ell_{e_r} = 0.457\text{m} \quad H_t = H_r = 2 \text{ dB}$$ (6 ft-height of a man standing)

$$F = 20 \log \frac{\dfrac{2 \times 0.5\ \mu\text{v}}{0.2 \times 0.457\text{m}}}{1\ \mu\text{v/m}} = 20.78 \text{ dB}$$

$V_t = V_r = 0 \qquad R = 67.6\ \text{dB}$

$$\therefore \quad D = \frac{(0 - 38.70 + 0 + 2 + 67.6 + 0 + 0 + 2 + 0 - 20.78 + 0)}{12\ \text{dB/octave}}$$

$= 1.01$ octaves

1 octave is the distance from 0.5 to 1 mile

0.1 octave = (0.1 × 1 mile)

1.01 octave = 1.0 mile + 0.1 mile

$\therefore$ D (in miles) = 1.01 miles (1625.44 meters).

This value agrees very closely with the planning range for the squad radio set (AN/PRT-4 and AN/PRR-9) which is 1 mile (1600 meters) for channel 1, and 0.29 mile (460 meters) for channel 2. This value also agrees very closely with field tests conducted at Ft. Campbell, Kentucky, in June, 1977, to provide field data for this thesis.

6. If elevated antennas are used, or if the transmitter is located at an elevated site and is transmitting to a receiver at an elevated site, with lower elevations in the transmission path, then a far easier method to determine whether communication is feasible is to use the Profile Chart (Appendix H, Figure H-1), or the line-of-sight distance formula of Table H-3 (Appendix H). Both these methods are habitually used in multichannel radio path profiling, yet have found little acceptance for single channel radio path determinations, although the underlying theory is the same in both cases.

7. Good tactical radio communications does not just happen because we want it to happen. Many tactical communicators have come to grief because they arbitrarily applied the communications distance planning range data for their equipment to a tactical situation or to terrain where such data was overly optimistic, with the result that their communications systems did not support tactical maneuver or operations. The remainder of this thesis is devoted to providing data on standard items of radio and antenna equipment presently employed by the infantry combat units of the Airborne and Air Assault Divisions and to developmental items which are either presently available or in the advanced stages of research and development and which, if made available to not only the above type units but elsewhere in the Army, would greatly enhance the ability of combat units to move, shoot, and <u>communicate</u>.

CHAPTER I

RIFLE SQUAD AND PLATOON COMMUNICATIONS

A. Figure 9 shows the rifle platoon command net, infantry rifle company.

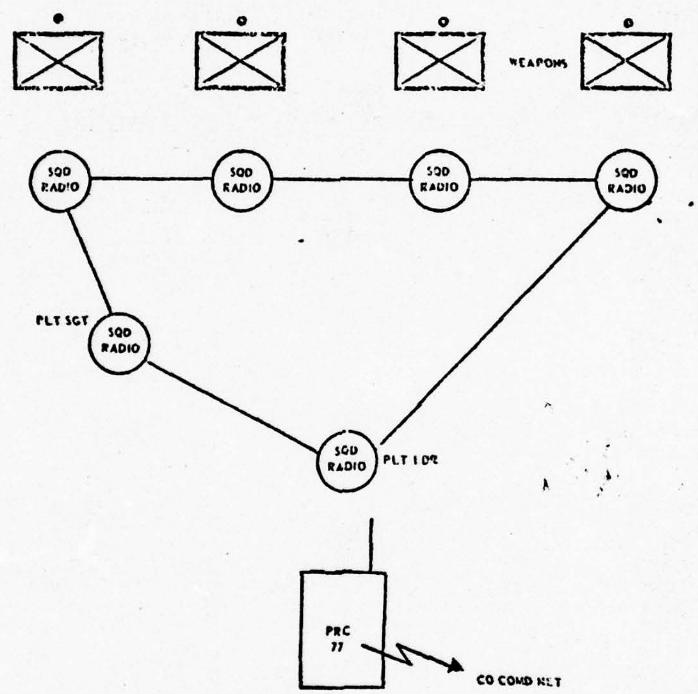


Figure 9. Rifle platoon command net, airborne or airmobile infantry rifle company.

B. The radio equipment used at squad level is the squad radio set consisting of Receiving Set, Radio AN/PRR-9 and Transmitting Set, Radio AN/PRT-4 (Figure 10).

1. Receiving Set, Radio AN/PRR-9, is a battery-operated, frequency modulated (FM), crystal-controlled radio receiver

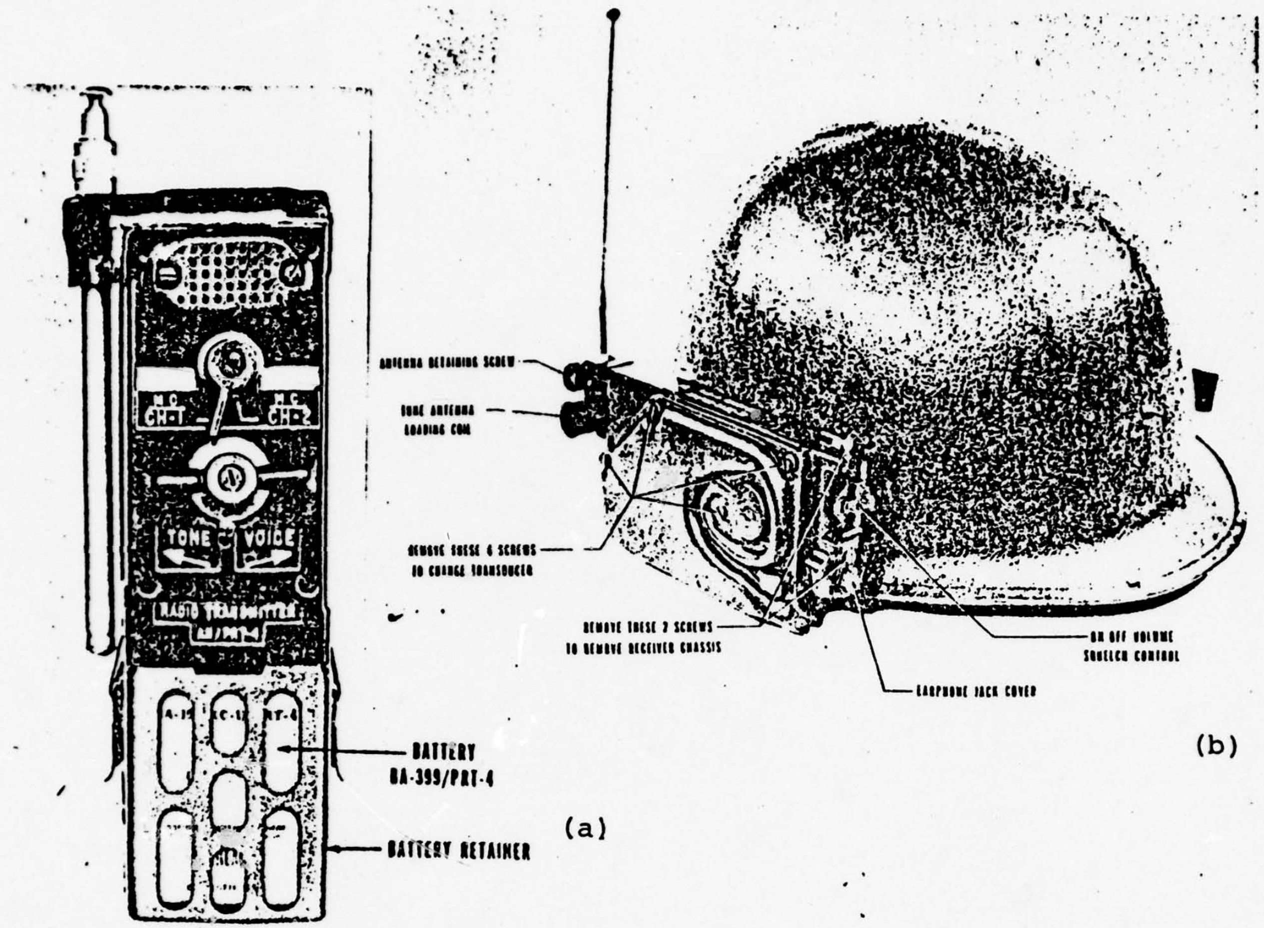


Figure 10. The squad radio set. (a) Transmitting Set, Radio, AN/PRT-4, shown with antenna collapsed; (b) Receiving Set, Radio AN/PRR-9, shown clipped to a steel helmet.

which is designed for quick attachment and use on the standard helmet. It receives voice and tone-modulated signals on a preset frequency in the band of 47 to 57 megahertz (MHz). The operating frequency is determined by the crystal installed in the receiver. An audio horn transducer is attached to the side of the receiver and directs sound under the rim of the helmet toward the operator's ear. The receiver also may be used with reduced range when carried in a shirt pocket or clipped to a harness. A headset is also supplied.

2. Transmitting Set, Radio AN/PRT-4 is a handheld, battery-operated, dual-channel, crystal-controlled frequency modulated transmitter designed for use in the 47 to 57 megahertz band. It transmits either audio tone or voice communications on either of two channels. The AN/PRT-4A rf signal, in addition, is modulated by a 150 cycle per second signal that is used to disable the squelch circuit of Radio Set AN/PRC-25 or Radio Set AN/PRC-77. The frequencies of operation are determined by the crystals installed in the transmitter.

When used together, Receiving Set, Radio AN/PRR-9 and Tansmitting Set, Radio AN/PRT-4 provide one-way, short-range, portable communications.

3. Technical characteristics of both these items are shown on Table 2.

TABLE 2

TECHNICAL CHARACTERISTICS OF THE SQUAD RADIO

a. Receiving Set, Radio AN/PRR-9

Frequency range	47 to 57 MHz
Tuning	Single-channel, crystal-controlled
Crystal type (pluckout)	CR-81/U
Crystal marking (pluckout)	in MHz, 10.7 below channel frequency
Receiver type	Double-conversion superheterodyne
Number of transistors	14
Number of diodes	6
Number of soldered-in crystals	1
Number of pluckout crystals	1
Number of printed circuit boards	2
Intermediate frequency, first conversion	10.7 MHz
Intermediate frequency, second conversion	455 kHz
Sensitivity at 5-milliwatt output with 5-volt power source	0.5 v max.
Image rejection	40 dB
If rejection	60 dB
Frequency stability	0.01%
Power output	5 mw nominal.
Squelch release point for 10 dB Noise reduction	less than 0.5 uv
Frequency response	300 to 2,500 Hz ±3
Battery type required	BA-505/U
Current drain 5 volts with squelch disabled	19.5 ma
With squelch activated	12.5 ma

b. Transmitting Set, Radio AN/PRT-4

Frequency range	47 to 57 MHz
Type of modulation	FM
Oscillator	Voltage-controlled, crystal-stabilized
Power output at 30% efficiency:	
Channel 1	450 mw at 12 vdc.
Channel 2	50 to 250 mw at 12 vdc.
Type of signal	Voice or internally generated tone.
Number of transistors	13 (AN/PRT-4)
	11 (AN/PRT-4A)
Number of diodes	8
Number of soldered-in crystals	1
Number of pluckout crystals	2
Crystal type (pluckout)	CR-81/U
Crystal marking (pluckout)	in MHz, 10.7 below channel frequency.
Printed circuit boards	3
Integrated circuits	1 (AN/PRT-4A)
Battery type required	BA-399/U
Battery drain:	
Channel 1	150 ma max at 12 vdc.
Channel 2	90 ma ± 5 max at 12 vdc.

4. The antenna provided with the AN/PRR-9 is an 18 inch, end fed monopole, AS-1998/PRR-9. (The basic analysis and design of monopole antennas is covered in Appendix L, paragraph 3e.) This antenna varies from 0.075-0.091λ over the operating frequency range. The antenna is only approximately 15-22 percent efficient.

5. The antenna provided with the AN/PRT-4 is a 24 inch collapsible (telescoping) end fed monopole, AS-1999/PRT-4. This antenna varies from 0.1-0.122λ over the operating frequency range. The antenna is only approximately 30 percent efficient.

6. Neither of these sets will accept other antennas. Field attempts to extend the transmission range of the set by using longer lengths of antenna were fruitless. The antenna loading coil in each set will not tune down far enough to allow for the additional inductive reactance presented by a longer antenna.

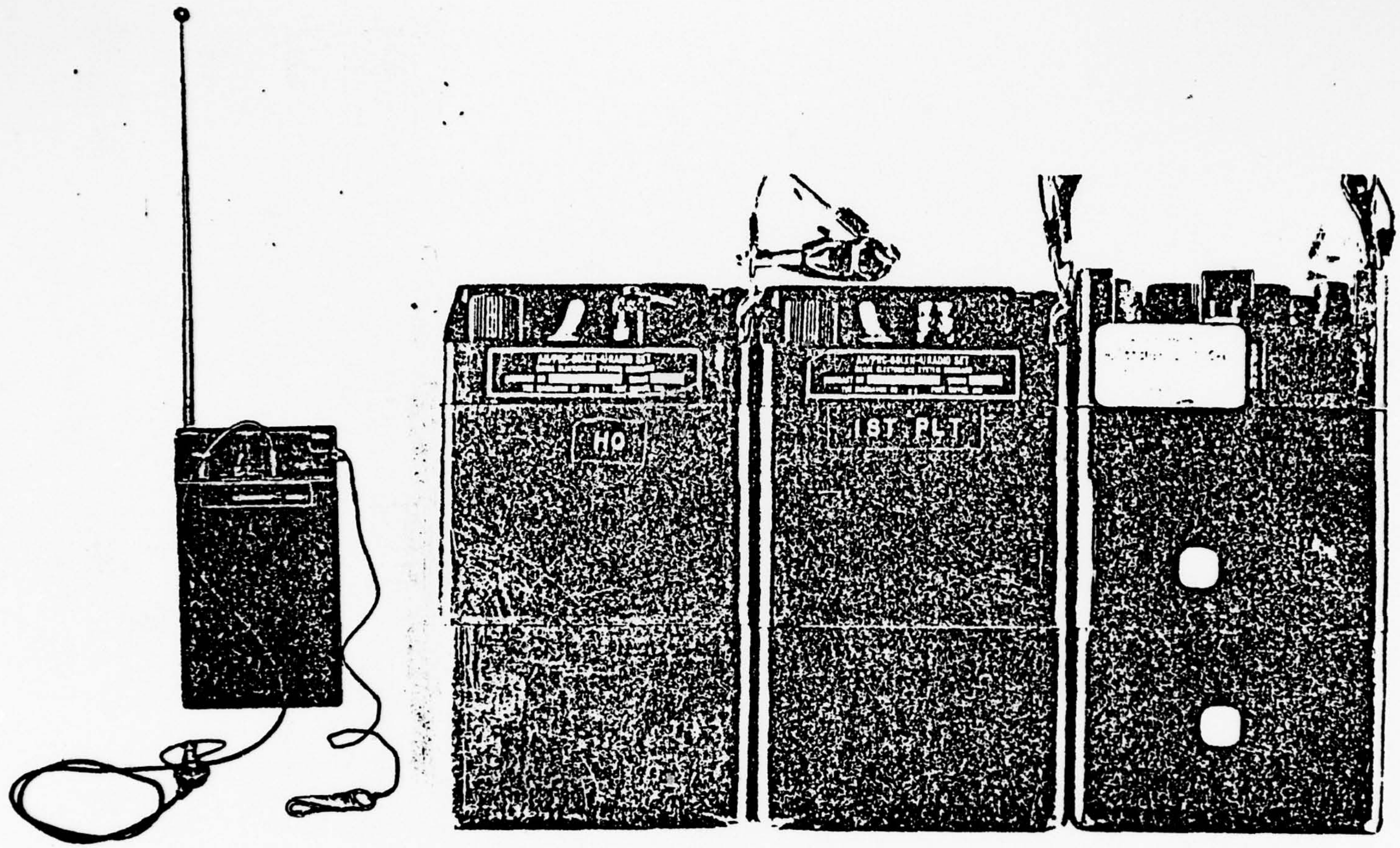
7. The squad radio set was designed to permit the rifle platoon leader to communicate over distances beyond the range of his own voice. The set provides that capability, although it does not have sufficient range to provide effective, reliable communications for a rifle squad on an independent combat or reconnaissance patrol. Additionally, the separate transmitter and receiver configuration is a negative factor to a squad leader or platoon leader who is

carrying a combat load of equipment. A transceiver with increased power output is needed to replace the present squad radio.

C. Radio Set AN/PRC-68 (Figure 11).

1. The AN/PRC-68 Model I Squad Radio Set is a lightweight (34 ounces with battery), pocket sized, VHF FM single channel transceiver designed specifically for use within rifle platoons. The radio set fits into the fatigue jacket pocket and can be used for short ranges with no visible antenna or at a range of one mile with a 12 inch telescoping antenna. The radio set provides short range, two-way voice communications on any of 1,000 available channels, spaced 50 KHz apart, within the tactical frequency band of 30-80 MHz. All communications channels are compatible with standard field tactical (FM) equipment. Channels are set in approximately 3 minutes by removing the cover housing and using a simple dial frequency scheme with no external test equipment needed. The front panel controls consist of a volume control, squelch switch, earphone jack, a speaker/microphone, and antenna mount. The earphone can serve as an external speaker/microphone. Technical characteristics of the Model I are shown in Figure 12.

2. The AN/PRC-68 Model II radio is identical to the Model I except an audio connector has replaced the earphone jack on the front panel. This allows use of a standard handset H-189 or H-250.



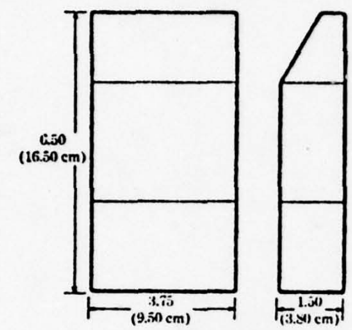
(a) (b)

Figure 11. Radio Set AN/PRC-68 (XN-4). (a) Shown with antenna extended. Courtesy of The Magnavox Company); (b) Three types of AN/PRC-68: the single channel, the single channel with an audio connector, and the multichannel (U.S. Marine Corps).

AN/PRC-68(XN-4)

OUTLINE DRAWING

(MAGNAVOX P/N 705558-801)



ANCILLARIES

Earphone - H-324(XN-4)/PRC-68 (2K ohm) MT P/N 705560-801

Lanyard - FSN 5985-933-2454

BATTERIES

BA-1588/u (Mercuric Oxide - consisting of eleven RM502CMC cells) MX P/N 538626-1

BA-( )/u (Manganese Alkaline - consisting of eleven MN1500 cells) MX P/N 538627-1

BB-( )/u (Nickel Cadmium - consisting of eleven GCE4505B cells) MX P/N 535170-1

SPECIFICATIONS

GENERAL

Frequency	30.00 MHz - 79.95 MHz
Available Channels	1000
Preset Channel	1
Channel Spacing	50 kHz
Modulation	FM
Range: Concealed antenna	300 yds (276 meters) minimum
Extended antenna	1 mile (1620 meters) minimum
MTBF	2000 hrs
MTTR	15 min
Operating Temperature Range	—40° to +65°C
Weight (including battery)	34 oz (0.95 kg)
Battery Life (BA-1588/u—HgO)	24 hours under an operating cycle of one minute transmit, one minute receive, and eight minutes standby.

TRANSMITTER

Power Output	1 watt (minimum)
Frequency Control	Built-in synthesizer
Frequency Stability	±0.005 percent
Spurious and Harmonic Radiation	50 dB below RF carrier level
Modulation Limiting	15 kHz deviation (maximum)
Squelch Tone (2-3 kHz deviation)	150 (±3) Hz

RECEIVER

Adjacent Channel Rejection	—60 dB
Image Rejection	—40 dB
Sensitivity	0.25 μV for 12 dB SINAD (0.6 μV for 20 dB quieting)
Squelch Sensitivity	0.25 uV
Selectivity: 6 dB down	bandwidth > ±15 kHz
60 dB down	bandwidth < ±50 kHz
Response to Spurious Signals	—60 dB
Frequency Stability	±0.005 percent
Audio Power Output	30 mW at < 10 percent distortion

Figure 12. Technical characteristics, Radio Set AN/PRC-68 (XN-4). (Courtesy of The Magnavox Company, Government and Industrial Division, Fort Wayne, Indiana.)

3. The AN/PRC-68 Model III, Multichannel Radio is similar to both the Model I and II but has a greater range and a differently arranged front panel. This radio set allows for 10 sequential channels (frequencies) selectable from the front panel. The preset channel (frequency) spacing is 200 KHz between channels. The front panel controls consist of a volume control, a power-off, power-on squelch switch, a channel selector switch, a speaker/microphone, antenna mount, and an audio connector. The standard handset H-189 or H-250 may be used. A range of 3 miles or more can be realized by use of the AT-892/PRC-25 antenna.

4. A secure voice module (SVM) is being developed for this radio set. Use of an actual SVM was accomplished. The radios were coupled to the SVM's and operated in the secure voice mode.

5. The U. S. Marine Corps Development and Education Command has conducted extensive field tests[26] of this radio set and has recommended that the Model III radio set be adopted into the Marine Corps inventory.

6. Adoption of this item into the Army inventory would alleviate the problem areas discussed in paragraph B7 above, and, additionally, would provide a secure voice capability down to rifle squad or fire team level, a capability which does not now exist.

7. The antenna provided for use with all three models of the AN/PRC-68 is a 12 inch telescoping end fed monopole. This antenna varies from 0.032-0.085λ over the operating frequency range. This antenna is only 10-15 percent efficient. It is tuned with a series iron core inductor.

8. The Model III AN/PRC-68 with the additional antenna connector allows for use of the AT-892/PRC-25 (36 inch end fed monopole). This antenna varies from 0.096-0.256λ over the operating frequency range and has an efficiency approaching 70 percent at the upper end of the operating frequency range. This increase in efficiency as well as the increased antenna effective length for reception accounts for the increase in communications range.

CHAPTER II

RIFLE COMPANY COMMUNICATIONS

A. Figure 13 shows the type radio nets of the rifle company, airborne infantry battalion. The radio nets of the rifle company, airmobile infantry battalion are similar except that the airmobile rifle company has no 1/4 ton vehicles (jeeps), thus no vehicular mounted radio equipment.

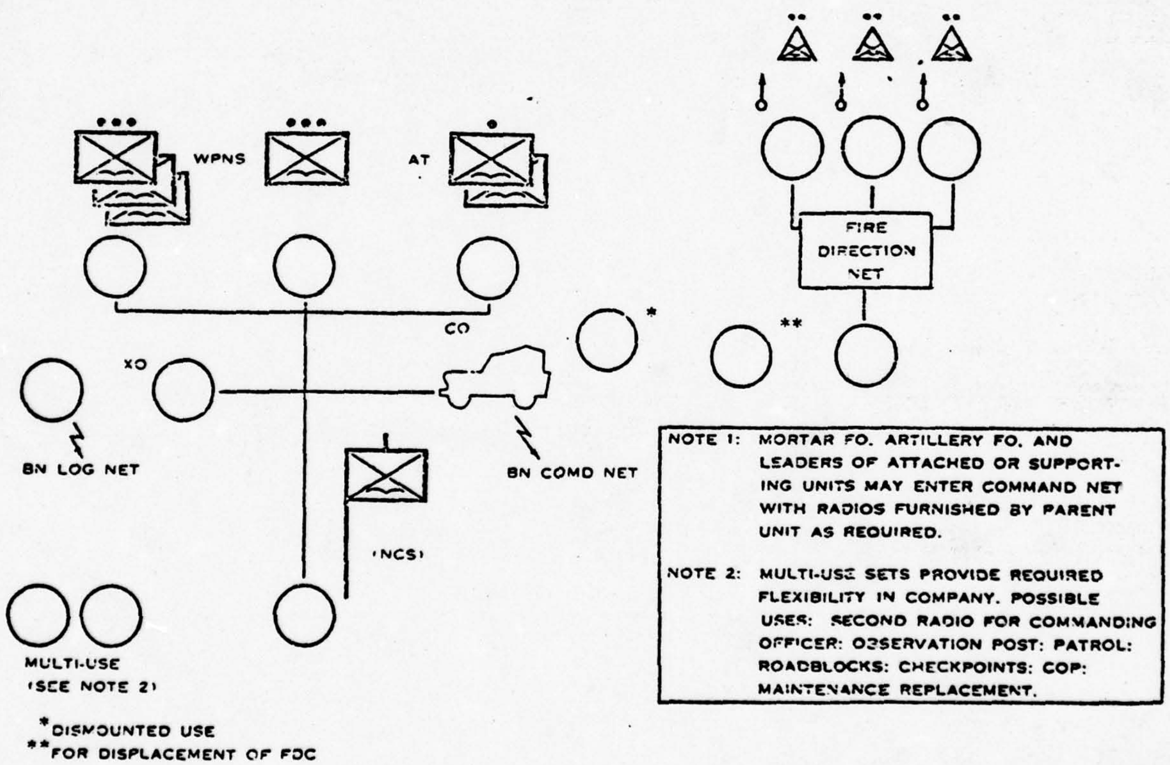


Figure 13. Type radio nets, rifle company, airborne infantry battalion.

B. The radio equipment used for communications from platoon to company in both the airborne and airmobile rifle companies is Radio Set AN/PRC-77 (Figure 14). Additionally, this set is used for communications from company to battalion in the airmobile rifle company. The airborne rifle company uses Radio Set AN/VRC-46 (Chapter III) to communicate from company to battalion.

1. Radio Set AN/PRC-77 is a short-range, man-pack portable, FM receiver-transmitter used to provide two-way, radiotelephone voice communication.

2. Receiver-Transmitter, Radio RT-841/PRC-77 is also used as part of Radio Sets AN/VRC-64 and AN/GRC-160.

3. The AN/PRC-77 can also be used in conjunction with other equipment (a through h below).

(a) Antenna Equipment RC-292 can be used in place of the whip antennas to extend the communication distance.

(b) The AN/PRC-77 can be connected to other FM radio sets for radio relay use by means of the cable in Retransmission Cable Kit MK-456/GRC. Such radios can be the AN/PRC-77, AN/PRC-25; the vehicular versions of these radios: Radio Sets AN/VRC-53, AN/VRC-64, AN/GRC-125, and AN/GRC-160; and the AN/VRC-12 series radios (Chapter III).

(c) Remote control of the AN/PRC-77 can be provided by Radio Set Control Group AN/GRA-39(*) and Radio Set Control AN/GRA-6.

Figure 14. Radio Set AN/PRC-77. Shown here in man-pack operation with 3-foot antenna AT-892/PRC-25 installed.

(d) Radio/wire integration (RWI) operation with the AN/PRC-77 and remote telephone facilities can be provided by Radio Set Control AN/GSA-7 with Oscillator 0-574/GRA. The AN/GRA-39(*) and AN/GRA-6 can also be used with the AN/PRC-77 for RWI operation.

(e) The AN/PRC-77 can be used with Antenna, Homing Loop AT-784/PRC for detection and location of homing beacons or other FM radios.

(f) The AN/PRC-77 can be used with Antenna AT-984A/G, a long-wire, multiple wavelength antenna, to extend the transmission and reception ranges.

(g) Loudspeaker, Electromagnetic LS-549/PRC can be used with the AN/PRC-77 to monitor radio reception.

(h) The AN/PRC-77 can be used with secure voice equipment and digital data equipment.

4. Technical characteristics of Radio Set AN/PRC-77 are shown on Table 3.

5. Two antennas are provided for use with Radio Set AN/PRC-77: A one section, 36 inch whip AT-892/PRC-25 which is used for general short-range service. This antenna varies from 0.096-0.243λ over the operating frequency range. Because of the built-in antenna matching network of the radio set, this antenna approaches about 50 percent efficiency. The other antenna issued with the radio set is a 10 foot, 6 section collapsible whip antenna. This antenna varies from 0.321-0.855λ over the operating frequency range and approaches 90 percent efficiency because of the antenna matching network built into the radio set.

C. The 150 foot, multiple wavelength antenna AT-984A/G is used with Radio Set AN/PRC-77 to extend the transmission

TABLE 3

TECHNICAL CHARACTERISTICS OF RADIO SET AN/PRC-77

Frequency range:	
Low band	30.00 to 52.95 mc ±3.5 k.c
High band	53.00 to 75.95 mc ±3.5 kc.
Number of channels	920.
Channel spacing	50 kc.
Types of transmission and reception:	
Transmission	Voice (300-3,500 cps) and 150-cps squelch tone.
Reception	Voice (no squelch) or voice and 150-cps squelch tone.
Security or digital data equipment.	Wideband (10 to 20,000 cps) without 150-cps squelch tone.
Transmission and reception power requirements:	
Transmission	12.5 to 15 volts dc, 780 ma average.
Reception	12.5 to 15 volts dc, 0.06 amp average.
Type of modulation	Frequency.
Transmitter output power	1.5 to 4.0 watts.
Type of squelch	Tone operated by 150-cps signal.
Distance range	5 miles (8 kilometers) (varies with conditions).
Types of antennas:	
Short antenna	Antenna AT-892/PRC-25; 3 feet long, semirigid steel tape.
Long antenna	Antenna AT-271A/PRC; 10 feet long, multisection whip.
Power source	Battery, Dry BA-4386/U, or BA-398/U.
Battery life	60 hours (with a 9:1 receive-transmit ratio).

and reception ranges. The radiation patterns and siting diagram for this antenna are shown on Figure 15. (The basic analysis and design of long-wire antennas is covered in Appendix L, paragraph 8.) When the full 150 foot length is used, this antenna varies from 4.598-11.602λ over the operating frequency range and gains from 3.7-8.6 dB with respect to a half-wave dipole are possible. This is an excellent antenna and, surprisingly, is used habitually by troops in the field. Whether erected as a straight long wire, as in Figure 15, as a Beverage antenna, or as a vertical half-rhombic, the multiple wavelength of this antenna provides excellent results with typical increases in communication ranges by a factor of three or more. This antenna can only be used with the AN/PRC-77 because of that set's internal matching network.

D. A commercial long wire, frequency adjustable antenna designed to be erected as a vertical half-rhombic antenna has been produced by the Radio Engineering Products Company, Montreal, Canada.[3] This antenna (Figure 16), type nomenclatured F61122, incorporates a 50 ohm matching transformer and terminating resistor and can be used with the AN/PRC-77 or any of the AN/VRC-12 series. A typical application is shown in Figure 17. The mast provided with this antenna system is the AB-1120/TRC Mast and is a lightweight sectional 30 foot guyed fiberglass mast which offers possible applications with not only this, but other antenna systems.

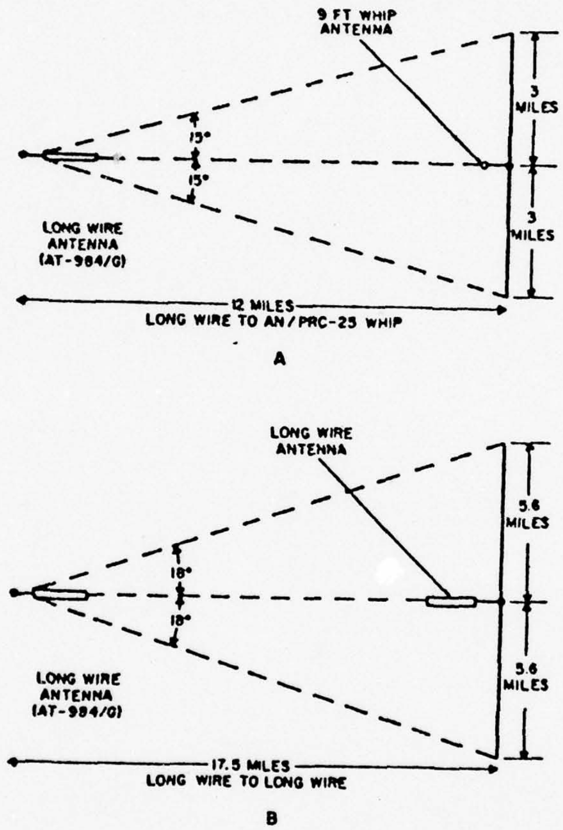
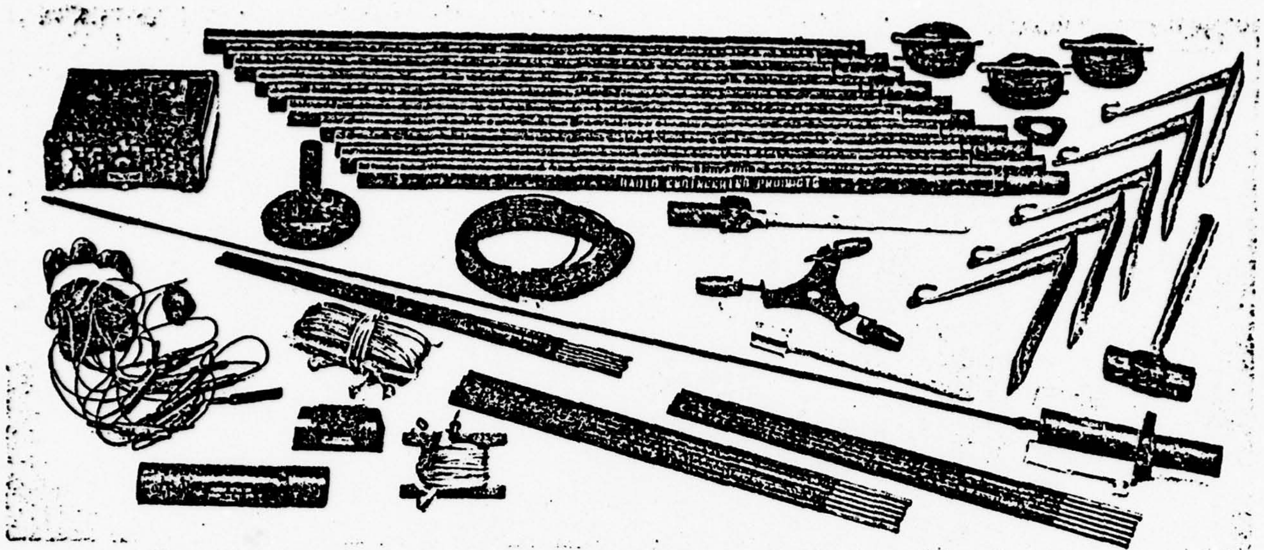


Figure 15. AT-984A/G, radiation patterns and siting diagram.



This antenna system consists of the following principal components:

AB-1120/TRC Mast: This is a lightweight sectional 30-ft guyed fiberglass mast arranged for mounting on the ground or a vehicle, intended to carry either the AS-2369/TRC half-rhombic antenna or the F61386 constant-impedance non-directional whip antenna. It can be erected by one man in a few minutes.

AS-2369/TRC Antenna: This is a vertical half-rhombic antenna with 50-ohm matching tranformer and terminating resistor, intended for use with the AB-1120/TRC Mast in the 30 to 76 MHz band. It has high forward gain, high front-to-back ratio, high directivity, low visibility, constant impedance over the band. The length is adjustable in three steps, permitting a trade-off of gain against size of site required. Max. power input 65 watts.

F61386 Antenna: This is a fixed-length 55-inch whip arranged for ground, mast, or vehicle mounting. It has a constant impedance over the band 30-76 MHz, and is a lightweight, small, non-tuned replacement for the AS-1729/VRC, RC-292 and other 30-76 MHz antennas. Max. power input 65 watts.

CU-1857/TRC Antenna Coupler: This is a 30-76 MHz duplexer for use with the two antennas described, and log-periodic and other constant-impedance antennas.

Figure 16. The Radio Engineering Products F61122 antenna system. (Courtesy of Radio Engineering Products, Montreal, Canada.)

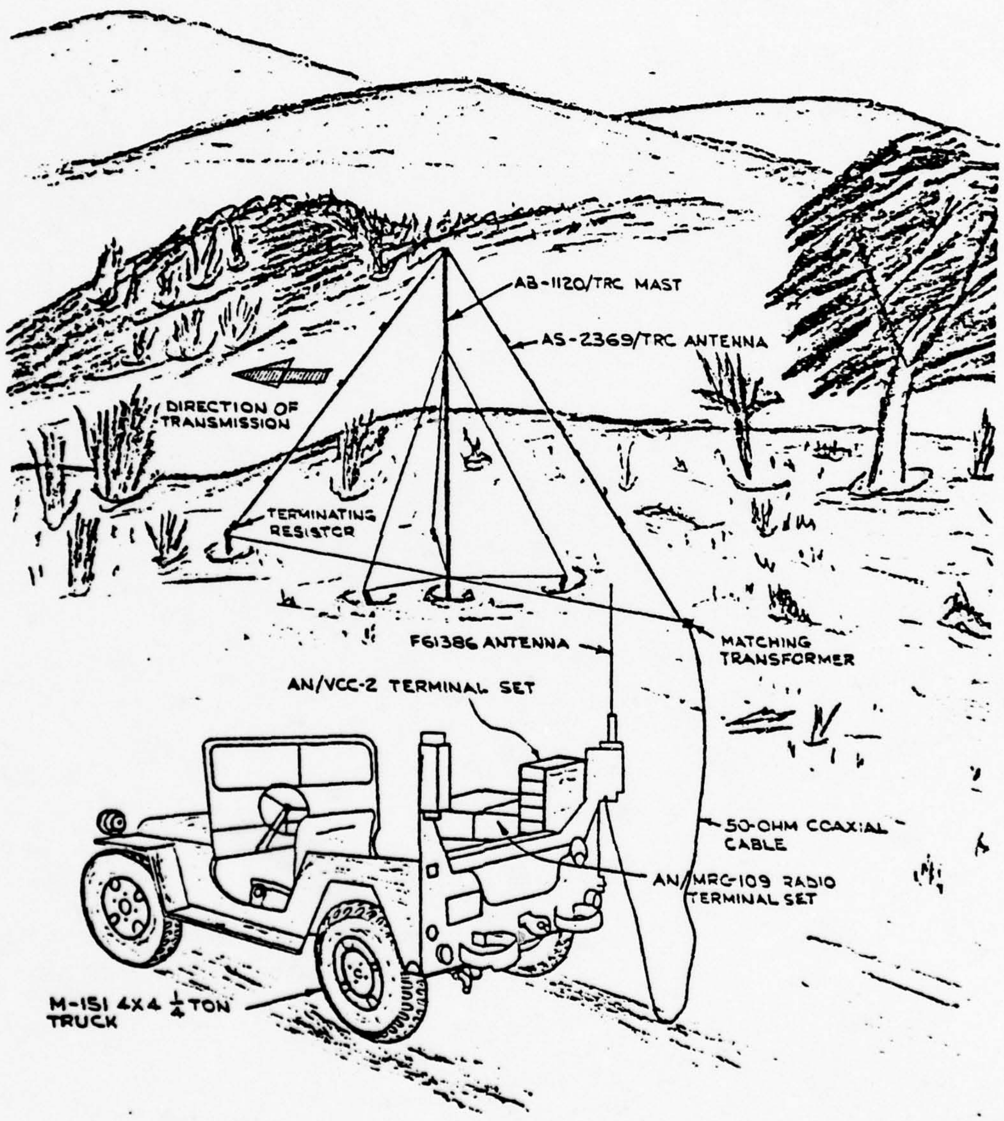


Figure 17. A typical installation of the F61122 antenna system. (The AN/MRC-109 Radio Terminal Set is a Marine Corps assemblage similar to the Army AN/GRC-163 described in Chapter IV.) (Courtesy of Radio Engineering Products, Montreal, Canada.)

E. Antenna Equipment RC-292 is used with Radio Set AN/PRC-77 to extend the communication range of the set. The RC-292 (Figure 18) is an elevated ground plane antenna. (Described in Appendix L, section 4.)

The technical characteristics of the RC-292 are shown in Table 4.

1. Within the frequency range 30-76 MHz, the RC-292 is tunable in 3 bands. Band 1: 30-36.5 MHz; Band 2: 36.5-50.5 MHz; and Band 3: 50.5-76 MHz. This broadband, elevated ground plane antenna provides a nominal SWR of 3:1 across each of the three bands; however, when the antenna is operated on a frequency outside the band for which the radiating and ground plane elements have been adjusted, high SWR results, with attendant loss in transmit power. This often occurs in the field where operating frequencies change often and radio operators are reluctant to drop the RC-292 and adjust the elements for the correct operating band. This antenna has been in the Army inventory since 1942. For many years it was the only antenna system available by which the range of tactical radio equipment could be extended.

2. The above described situation has led the U. S. Army Electronics Command (USAECOM) to investigate[6] the use of other antenna models and designs as possible replacements for the RC-292. Reference 6 investigated the feasibility of the Discone (Appendix L, section 6) and the Biconical

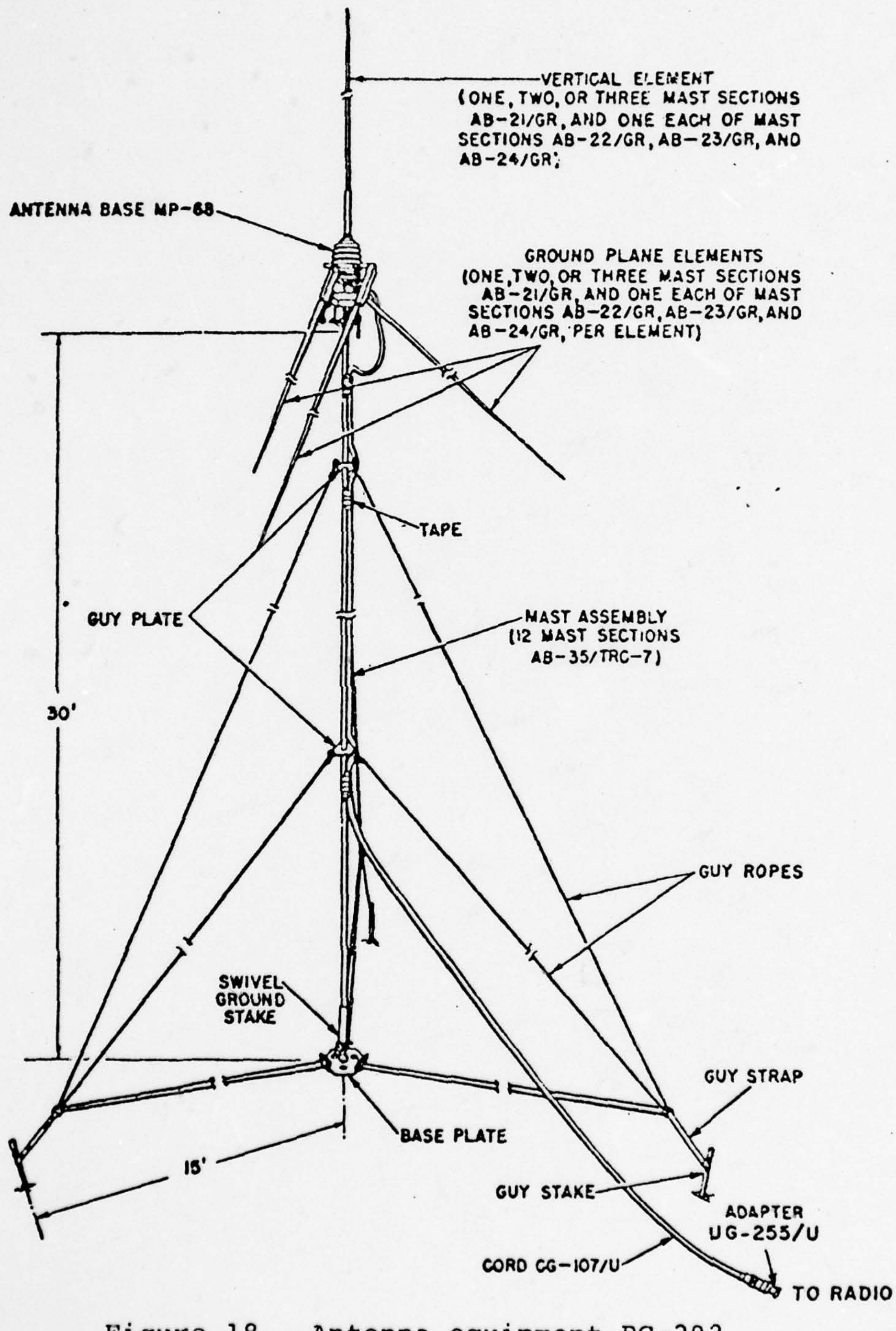


Figure 18. Antenna equipment RC-292.

TABLE 4

TECHNICAL CHARACTERISTICS, ANTENNA EQUIPMENT RC-292

Frequency range	20 to 76 MHz
Distance range when used with AN/VRC-12 series radios:	
Between two Antenna Equipments RC-292:	
Average terrain	36 miles.
Difficult terrain	30 miles.
Between Antenna Equipment RC-292 and vehicular whip antenna:	
Average terrain	25 miles.
Difficult terrain	20 miles.
Distance range using the AN/PRC radio sets:	
Between two Antenna Equipments RC-292	12 miles.
Between whip antenna and Antenna Equipment RC-292	8 miles.
Antenna erection time (2 men)	15 minutes.
Erected height	41 ½ feet maximum. 37 feet minimum.
Input impedance	50 ohms.
Type of radiation pattern	Nondirectional.

(Appendix L, section 5) antennas. This report followed a similar effort to develop an effective broadband biconical antenna.[36]

F. The result of references 6 and 36 is the type-nomenclatured AS-3166(*)/GRC broadband biconical antenna (Figure 19) which is pending a production contract and is due to replace the RC-292 on a one-for-one basis. Some of the technical characteristics are shown in Figures 20-23. This antenna has one very obvious disadvantage. From Figure 19, it is apparent that, in the dense trees in which tactical command posts are usually located, the top radials are going to be broken or bent badly as this antenna is erected in the vertical erection procedure (i.e., erecting the antenna from the bottom by adding additional mast sections to mast sections which are already vertical).

G. In reference 6, ECOM engineers discarded the discone antenna as a candidate for replacement of the RC-292 because of low relative gain performance at the lower end of the operating frequency band (30-50 MHz). HY-GAIN Electronics Corporation, Lincoln, Nebraska, has designed and produced the Model 4213, 30-88 MHz portable discone antenna system (Figure 24). This antenna was tested by the 101st Airborne Division (Air Assault) on Operation Reforger in the Fall of 1976 and was found to be superior to both the AS-3166(*)/GRC (paragraph F above) and the RC-292. The technical

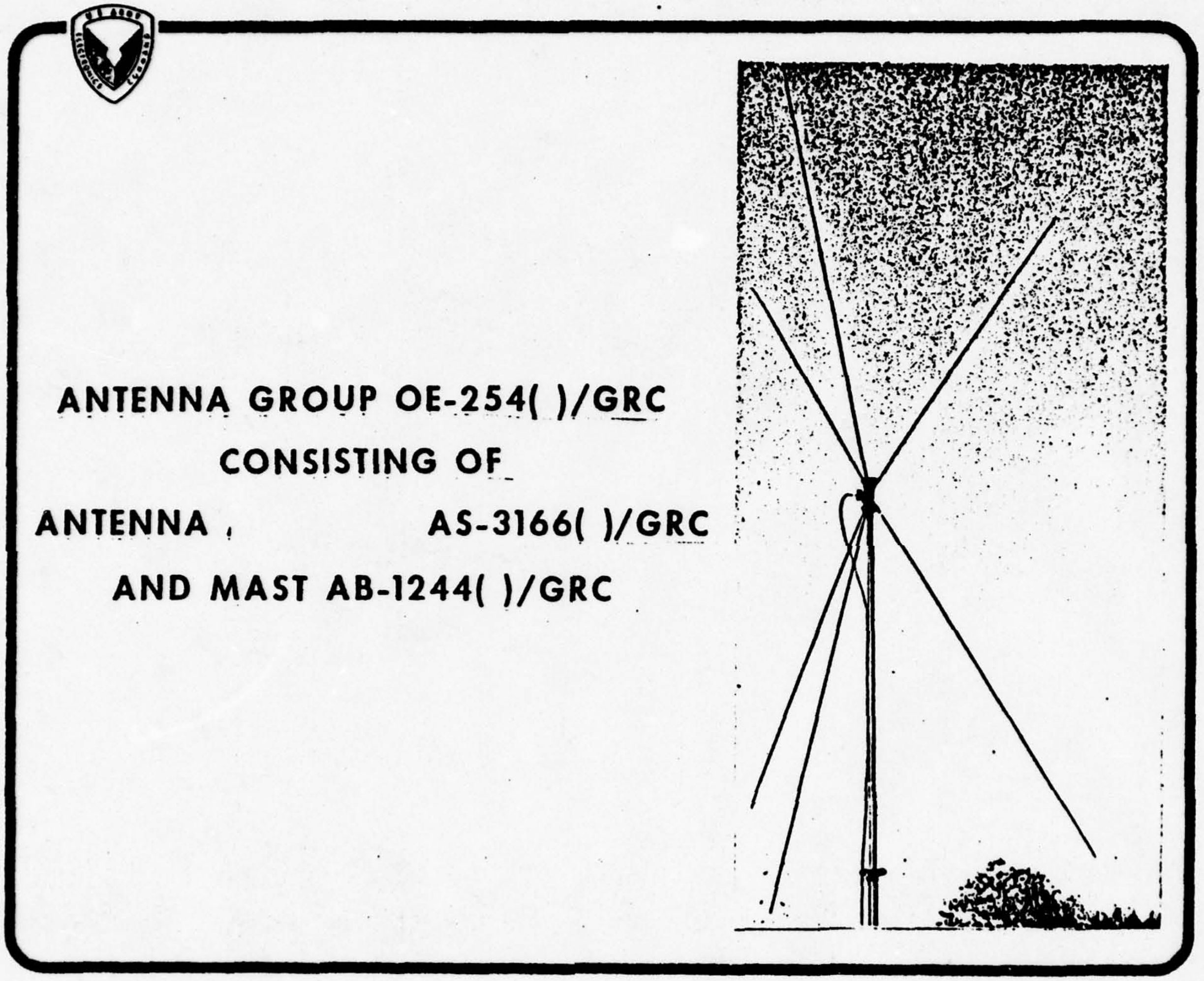


Figure 19. The AS-3166(*)/GRC broadband biconical antenna.

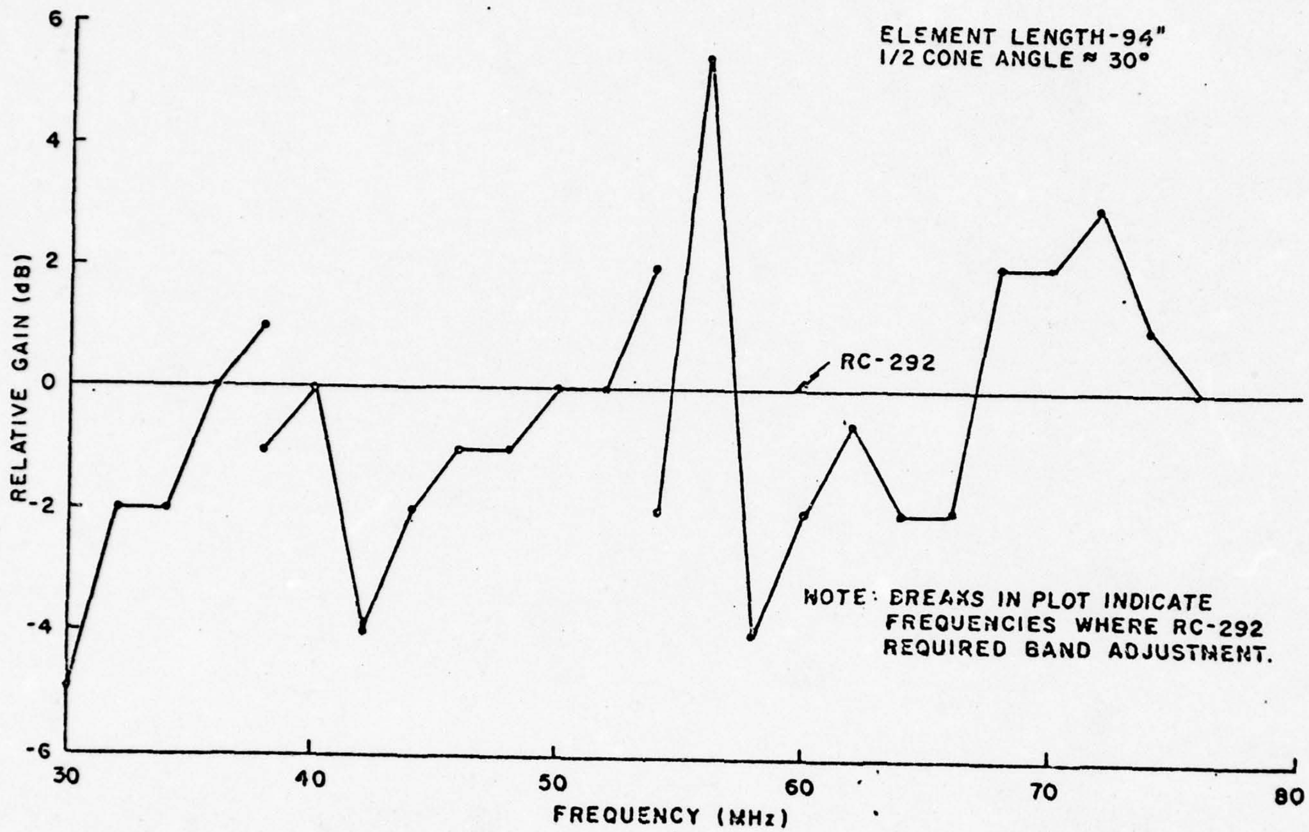


Figure 20. Relative gain plot. (Three radial biconical antenna versus RC-292, receive mode.)

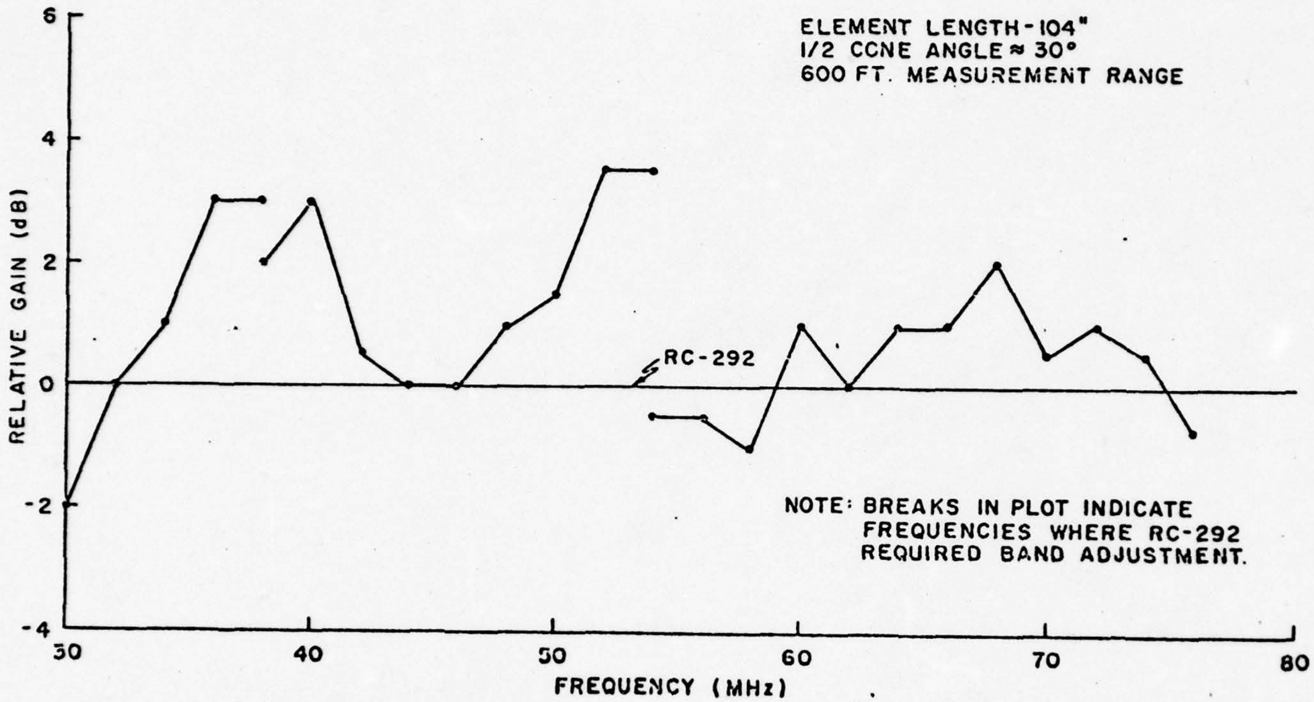


Figure 21. Relative gain plot. (Three radial biconical antenna versus RC-292, transmitmode.) (RC-292 tuned in 3 bands.)

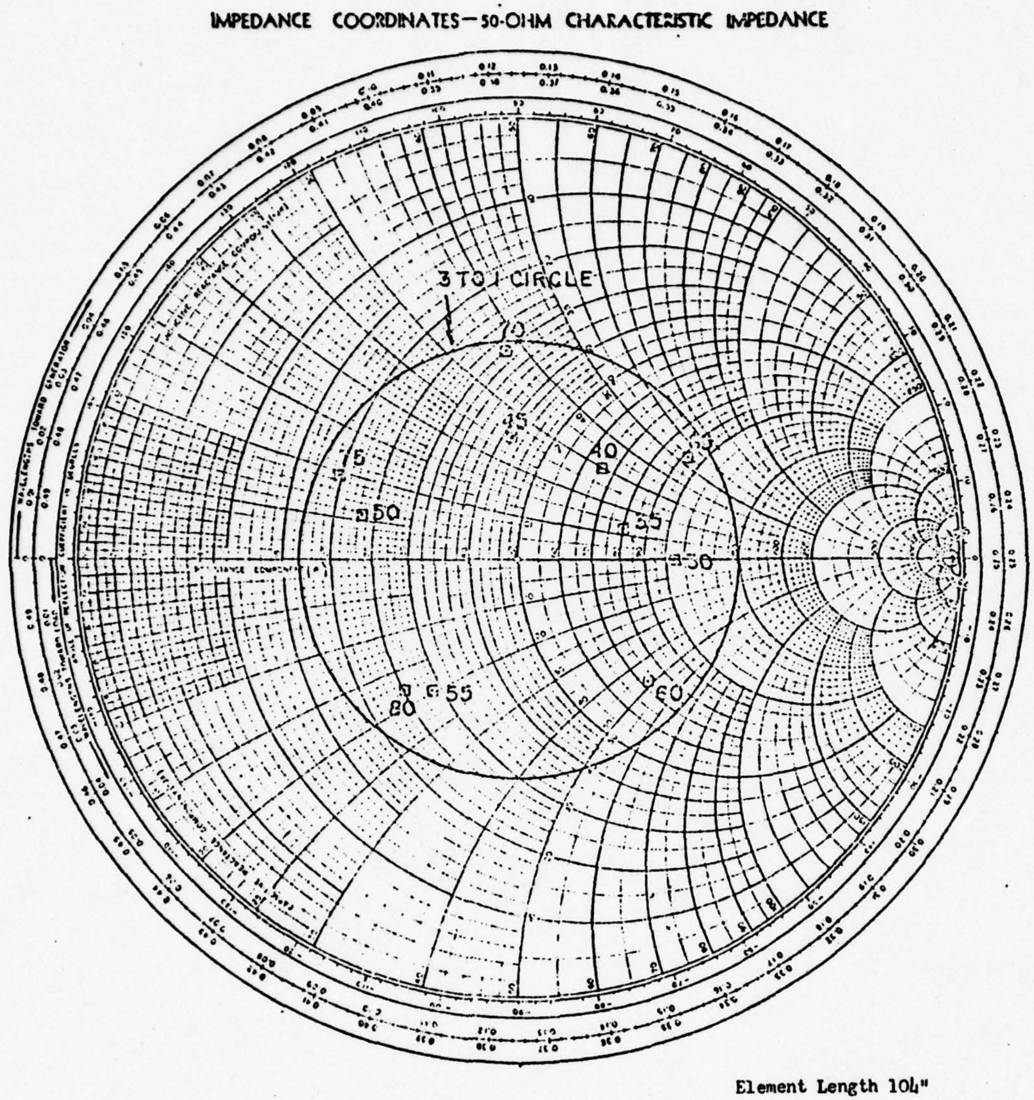


Figure 22. Impedance plot. (Three element biconical antenna with solid feed cone.)

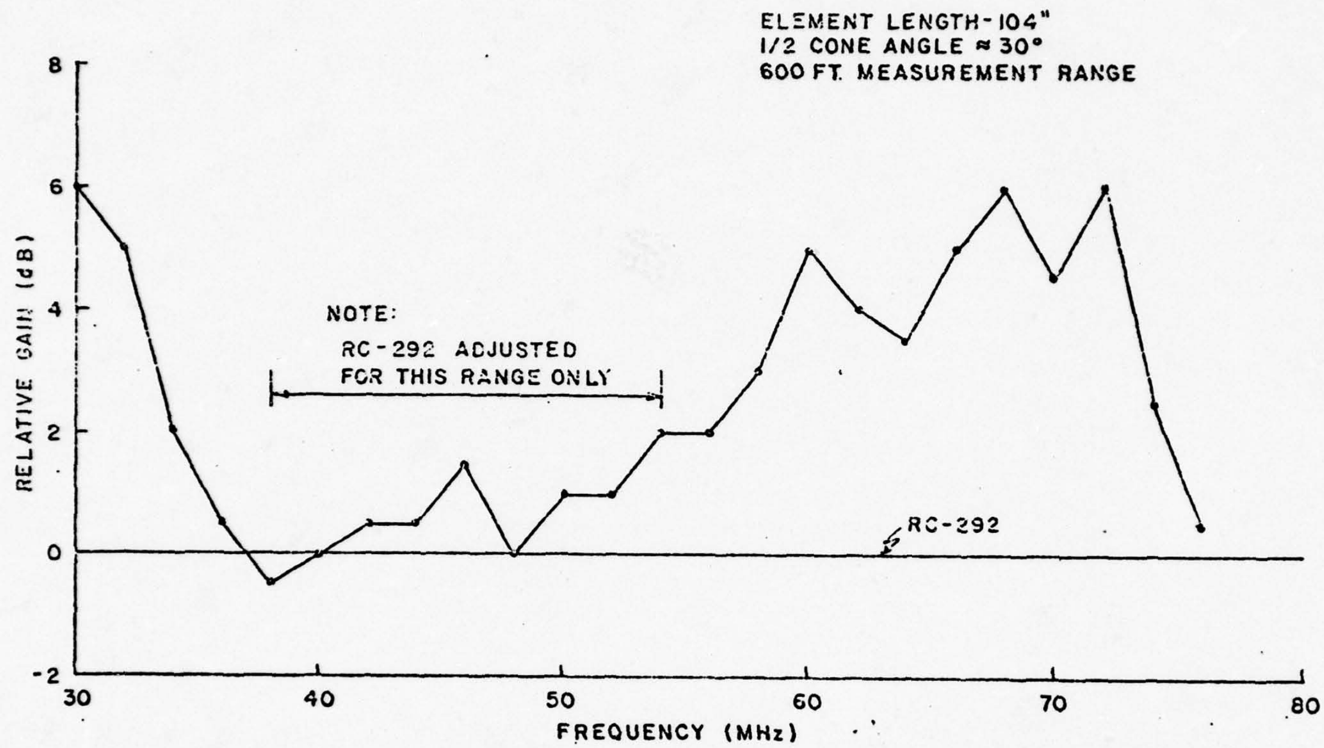
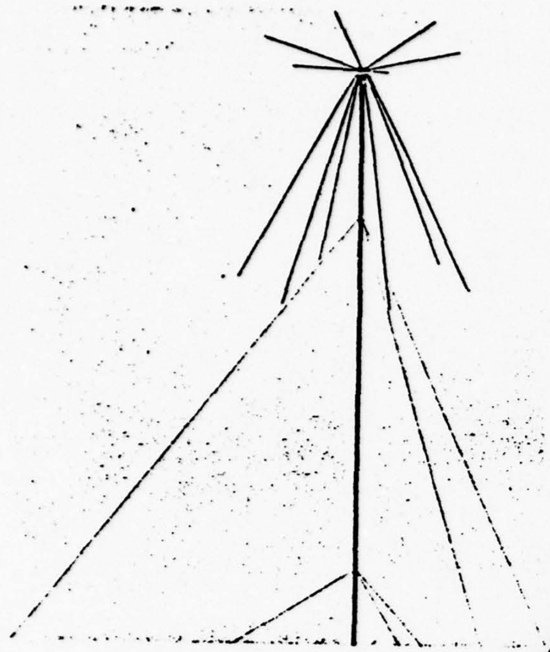


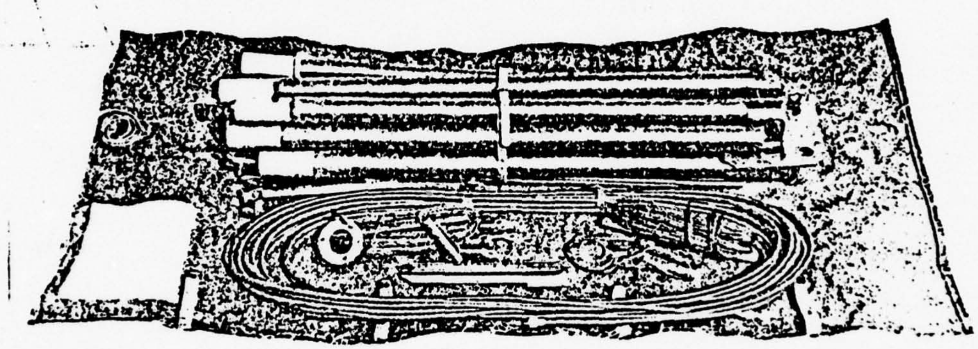
Figure 23. Relative gain plot. (Three radial biconical antenna versus RC-292, transmit mode.)



(a)

SPECIFICATION SUMMARY

Human Engineering:	
Erection Time	2 Men; 10 Minutes
Element Connections	Captivated Snap-in Sockets
Mast Sections	Mechanically Indexed Snap-lock
MECHANICAL:	
MAN-PACKED SYSTEM	
Length	51"
Width	13"
Height	11"
Net Weight	39 lbs.
Wind Load Rating	
No Ice	60 MPH
¼" Radial Ice	50 MPH
Erected Mast Height	30 Feet
Cone Dimensions	
Height	99"
Width	105"
Shipping Wt.	42 lbs.
Shipping Vol.	6 cu. ft.



(b)

Figure 24. HY-GAIN Model 4213, 30-88 MHz portable discone antenna system. (a) Antenna erected; (b) mechanical characteristics. (Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.)

(electrical) characteristics of the Model 4213 are shown on Figure 25. No relative gain data with respect to the RC-292 was available.

ELECTRICAL:

- Frequency Range (MHz) 30-88
- Power Rating (Watts) .. 500 Watts Continuous
  - PEP .... 1,000 Watts
- Polarization:
  - Vertical
- Input Connector .... UHF
- Input Impedance .... 50 ohms/unbalanced
- V.S.W.R. (MAX) 3.0:1
- Radiation Characteristics:
  - Pattern .... Omnidirectional
  - Circularity .... ± ½ dB

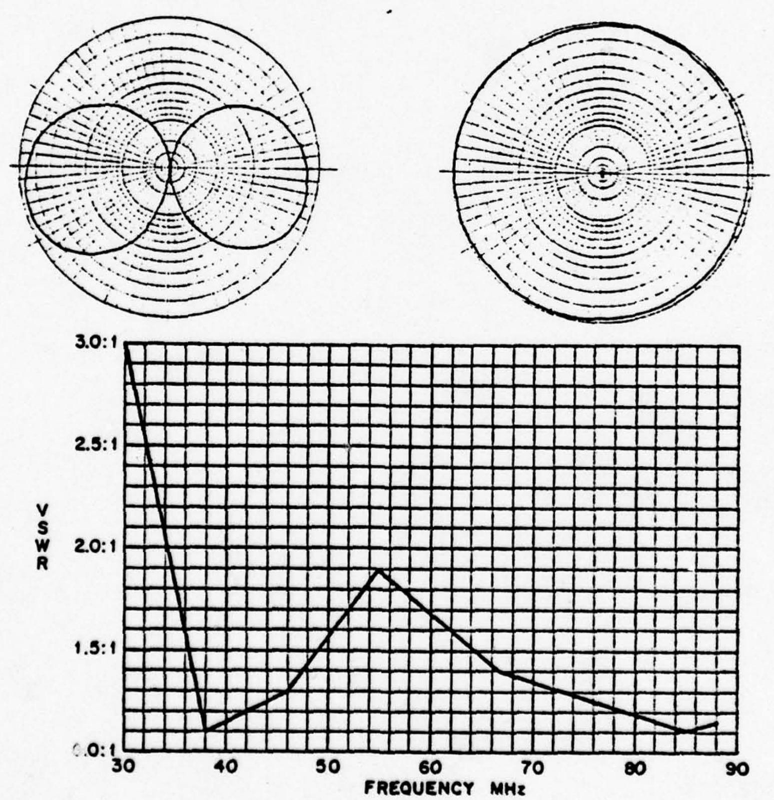


Figure 25. Electrical characteristics of the HY-GAIN Model 4213, 30-88 MHz portable discone antenna system. (Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.)

CHAPTER III

INFANTRY BATTALION AND BRIGADE COMMUNICATIONS

A. Figures 26 and 27 show a type infantry battalion command net and administrative/logistics (ADMIN/LOG) net. Figure 28 shows a type infantry brigade command net, while Figure 29 shows an entire type infantry brigade radio nets structure.

B. The principal equipment used for communications from the infantry battalion to the infantry brigade, and from the infantry brigade to division is the AN/VRC-12 series of radios. Figures 30-32 show the radio and antenna equipment used with the AN/VRC-12 series.

1. Radio sets AN/VRC-12 and AN/VRC-43 through AN/VRC-49, commonly referred to as the AN/VRC-12 series radios (Figure 33), are the most commonly used radio sets in the field army. All configurations of these radio sets consist of various combinations of two basic components: a receiver-transmitter and an auxiliary receiver. There are two versions of the receiver-transmitter: one with 10 pushbuttons for presetting channels (RT-246/VRC) and one with a built-in loudspeaker (RT-524/VRC). The receiver-transmitter with the pushbuttons was designed for use in tracked vehicles in which the control panel is generally inaccessible to the operator and noise from the vehicle would require the

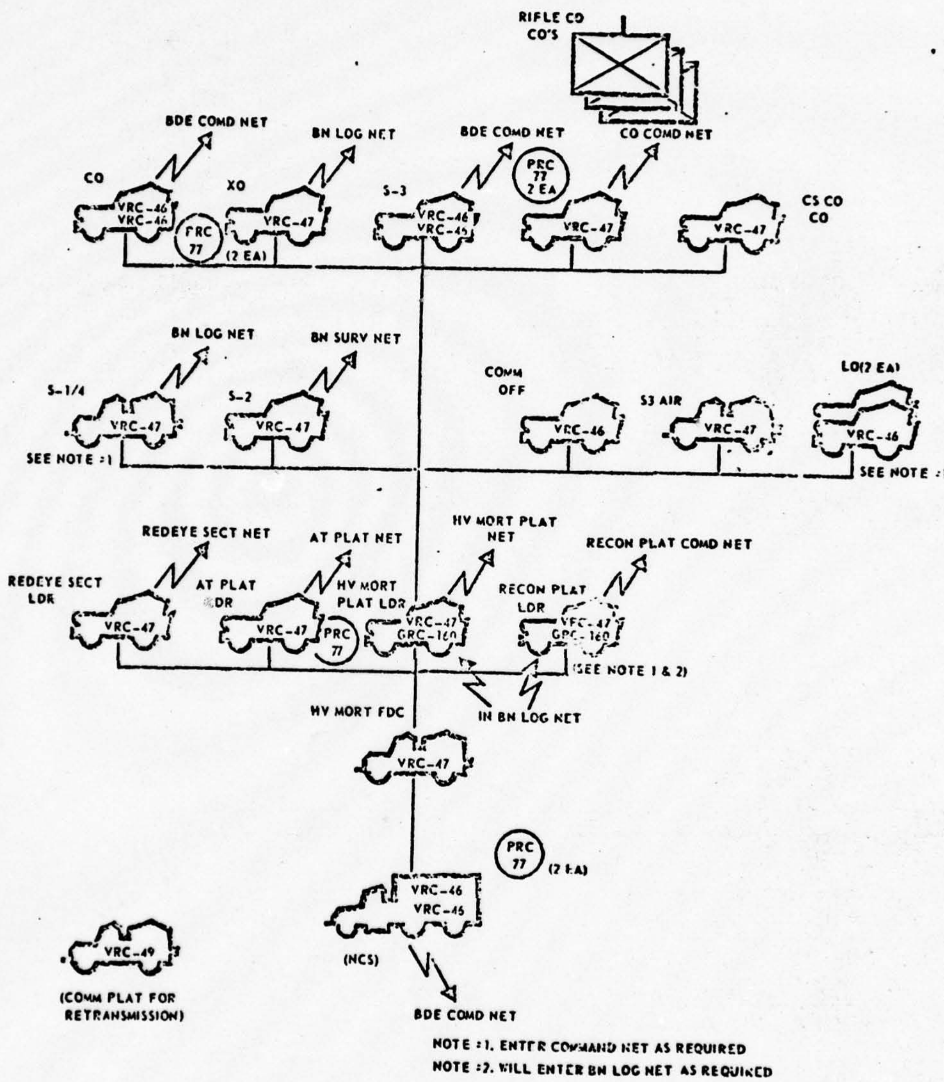


Figure 26. A type infantry battalion command net. Shown are the net structure and types of radio equipment employed.

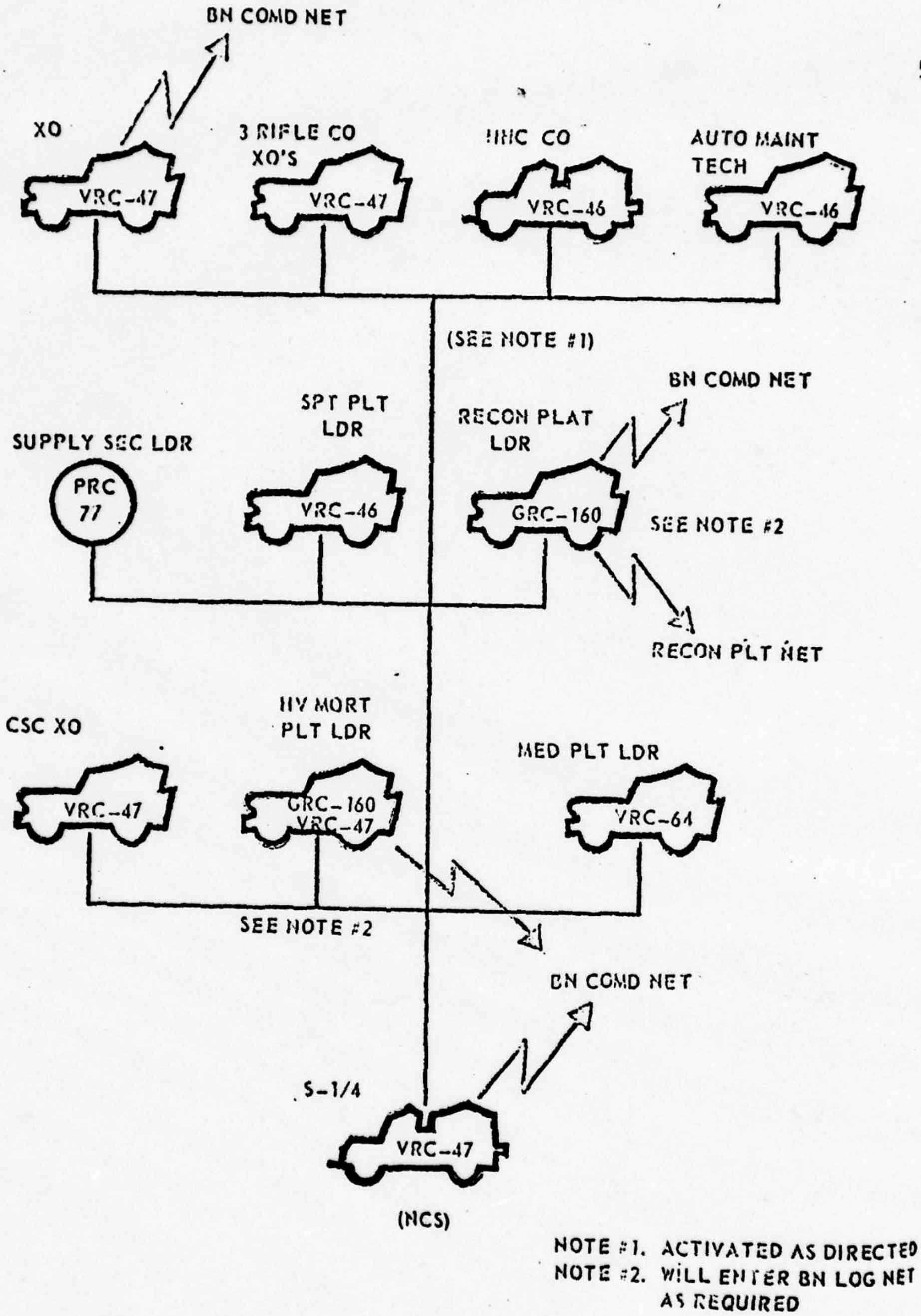


Figure 27. A type infantry battalion administrative/ logistics net. Shown are the net structure and types of radio equipment employed.

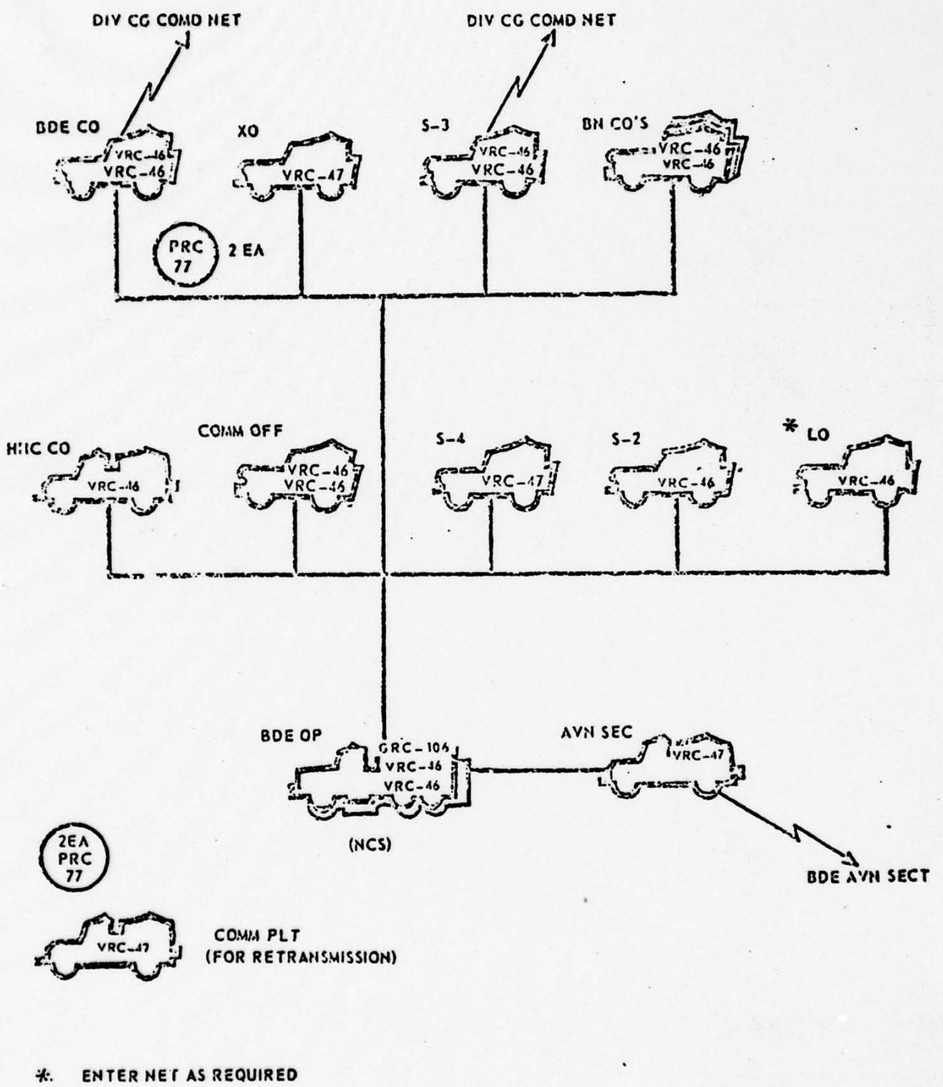
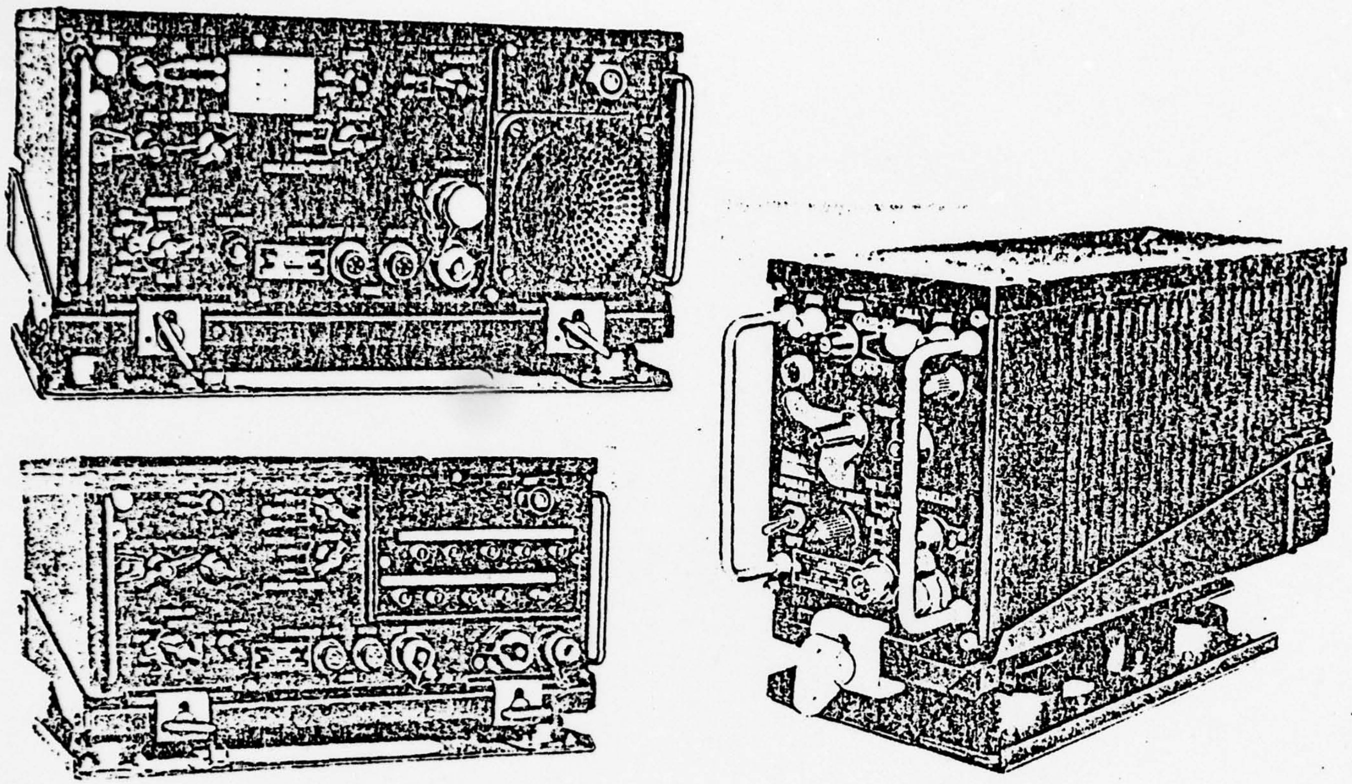


Figure 28. A type infantry brigade command net. Shown are the net structure and types of radio equipment employed.

Units	Brigade Command Net (FM) Voice	Brigade Log Net (FM) Voice[2]	Brigade RATT Net Opn, Intel Net[3]	Division Command Net (FM) Voice[4]	Division RATT Net Opn, Intel	Division RATT Net Admin Log	Air Force Air Req Net (AM/Voice/CW)	Division Air Req Net (AM/Voice/CW)	Spot Report Rcvr Net UHF	Air Force Tactical Air Direction Net UHF
Brigade CP	X^5	X	X^5	X	X		X^6 (TACP)	X	X	X^6 (TACP)
Brigade Trains	X	X^5				X				
Maneuver Bn	X	X	X				X^6 (TACP)	X	X	X^6 (TACP)
Engineer Bn	X^1	X^1		X						
Cavalry Sqd	X^1	X^1		X	X	X	X^6 (TACP)	X	X	X^5 (TACP)
Division Main				X^5	X^5	X	X^6 (TACP)			
Division Arty	X^1	X^1		X	X	X				
Support Command		X^1		X		X^5				

NOTES:
(1) Unit supporting brigade enters brigade nets as required.
(2) Brigade logistic net established as required. Used to establish communication in brigade trains as required.
(3) May be used for other type traffic as required.
(4) Other nets may be established as required, e.g., brigade intelligence net (FM) voice. Equipment for this net would be obtained by reducing stations in brigade command net and with similar adjustment at battalion.
(5) NCS - net control station.
(6) Radio set provided by Air Force.

Figure 29. A type infantry brigade radio nets structure.



(a) (b)

Figure 30. Radio equipment components of the AN/VRC-12 series. (a) Top: Receiver-Transmitter, Radio RT-524A/VRC; bottom: Receiver-Transmitter, Radio RT-246A/VRC. (b) Receiver, Radio R-442(*)/VRC.

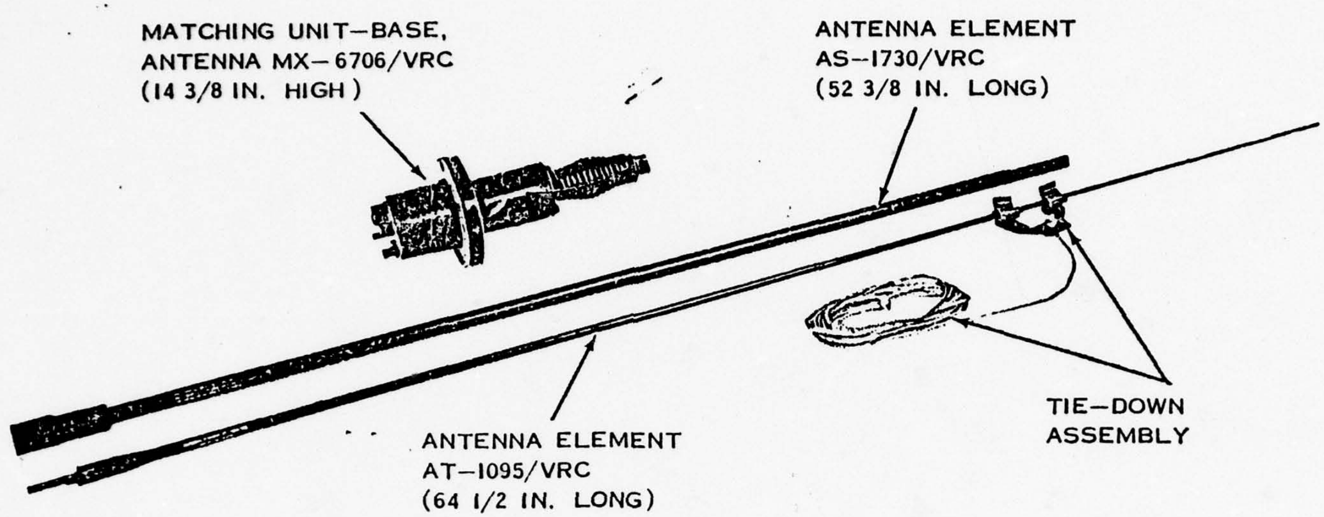


Figure 31. Antenna, AS-1729/VRC, disassembled.

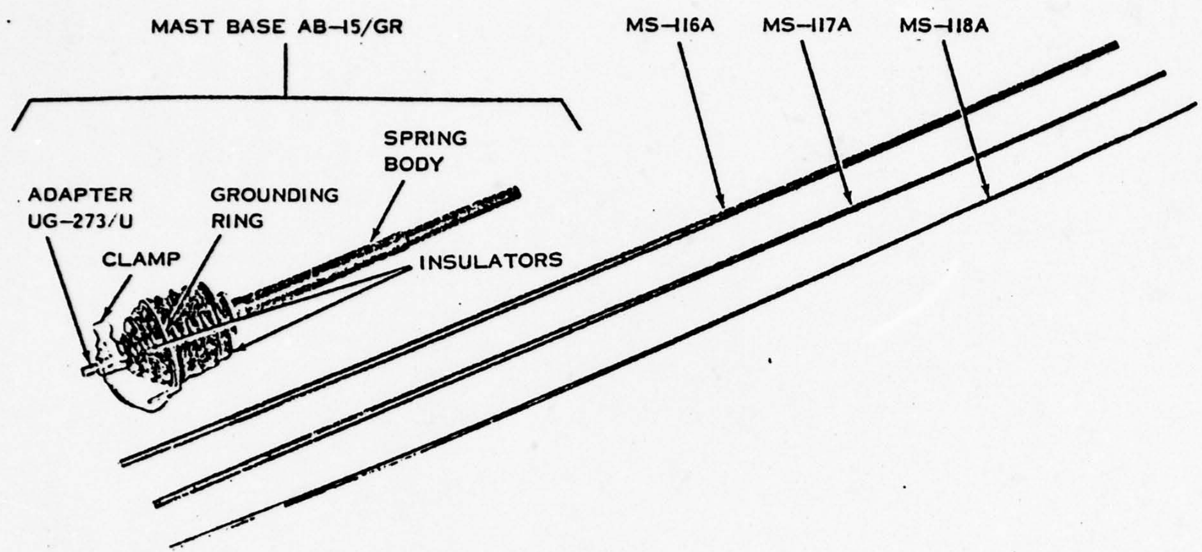
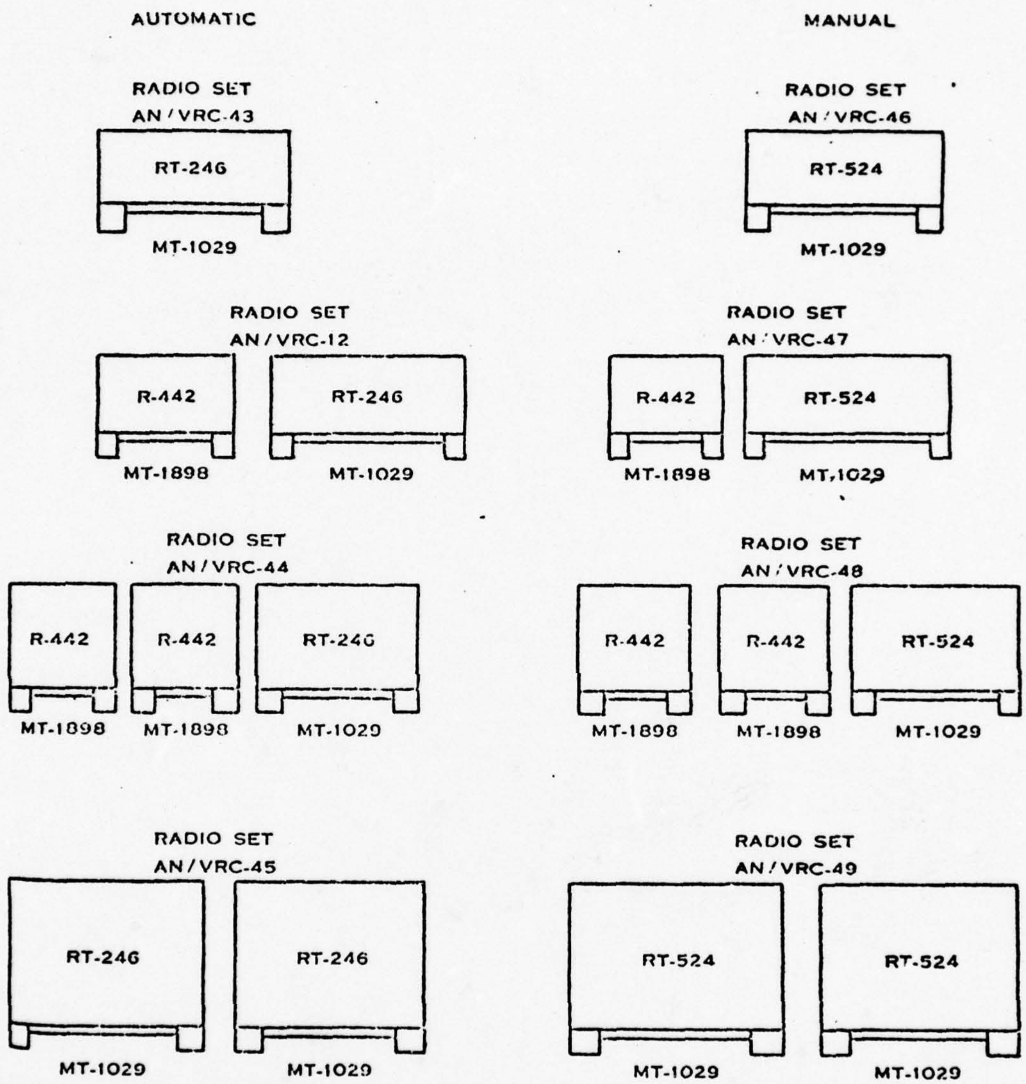


Figure 32. Antenna equipment used with Receiver, Radio R-442(*)/VRC.



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LEGEND:

RT-246—MEDIUM POWER RECEIVER-TRANSMITTER, 10 PRESET AUTOMATICALLY TUNED CHANNELS.

RT-524—MEDIUM POWER RECEIVER-TRANSMITTER, MANUALLY TUNED.

R-442—AUXILIARY RECEIVER.

Figure 33. AN/VRC-12 family radio sets. Radio equipment components comprising each type set.

use of a headset. The receiver-transmitter with the built-in loudspeaker is used in wheeled vehicles in which the operator has easy access to the control panel and the noise level permits monitoring with a loudspeaker. The auxiliary receiver R-442/VRC is manually tuned and can be used in both tracked and wheeled vehicles with the addition of a headset or an external loudspeaker. All configurations of radios of the AN/VRC-12 series have as a component at least one antenna AS-1729/VRC.

2. Technical characteristics of the AN/VRC-12 series radios are shown on Table 5.

3. Figure 34 shows some typical applications of the AN/VRC-12 series and some compatible radio sets.

4. The AS-1729/VRC antenna (Figure 31) issued with the AN/VRC-12 series is a center-fed whip (described in Appendix L, paragraph 3d). It consists of a Matching Unit-Base, Antenna MX-6707/VRC and a 10 foot center-fed whip antenna. The MX-6707/VRC matches the impedance of the 10 foot, center-fed whip antenna to the 50-ohm transmitter output impedance and receiver input impedance over the entire 30-76 MHz frequency range.

(a) The center-fed whip antenna consists of a lower section (AS-1730/VRC) and an upper section (AT-1095/VRC). The AS-1729/VRC is fed at its midpoint through a coaxial transmission line in the lower 5 foot section. The

TABLE 5

TECHNICAL CHARACTERISTICS OF THE AN/VRC-12 SERIES RADIOS

a. RT-246(*)/VRC and RT-524(*)/VRC.

(1) *General.*

Type of modulation	Frequency modulation (fm).
Frequency range	From 30.00 to 75.95 MHz at 0.05-MHz intervals.
Frequency stability	±3 kHz of selected frequency.
Number of frequency settings	920 settings.
Tuning facility	Manual tuning. And in RT-246(*)/VRC, 10 frequencies can be set up for automatic pushbutton tuning which can also be selected automatically by C-2742/VRC connected to RT-246(*)/VRC.
Antenna receptacle impedance	50 ohms; BNC receptacle.
Control of matching networks in antenna	Tuning receiver-transmitter also automatically selects proper matching networks in antenna (c below).
Operating conditions	Push-to-talk and release-to-receive.
Modes of operation	Voice (radiotelephone), retransmission (radio relay), and X-mode.
X-mode operation	Provides facility for digital data and secure voice communication.
Audio response capability:	
Narrow band (usual mode of operation)	500 to 3,000 Hz.
Wide band	500 to 20,000 Hz. Provided for R-442(*)/VRC used in Radio Terminal Set AN/GRC-163 (TM 11-5820-713-15).
Audio input and output control facilities	Five-pin panel receptacles; rear-mounted receptacle for remote control by radio-intercom system and C-2299/VRC; X-mode operation facility.
Operating power	22 to 30 volts dc.
Used in	Vehicles provided with 24-volt battery system.

(2) *Transmitting features.*

Output RF power (into ideal 50-ohm antenna):	
Low power	0.5 to 8 watts with 25 volts dc operating power; 0.5 to 10 watts with 30 volts dc operating power.
High power	35 watts minimum with 25 volts dc operating power.
Transmission distance (using whip antenna)	Approximately 5 miles (8 kilometers (km) on low power; approximately 25 miles (41 km) on high power.
Carrier deviation	Audio input of 2.8 millivolts produces RF carrier deviation of 8 ±2 kHz.
Squelch tone signal	150 Hz ±3; transmitted on all settings of SQUELCH switch except OLD ON position.
Audio input impedance	150-ohm microphone; 600 ohms for X-mode operation (at X-MODE receptacle.
Duty cycle	Capable of operating continuously in high power in 120-degree ambient temperature with input power of 22 volts dc; and for one hour with input power of 30 volts dc.
Power drain:	
Using low power	3 amperes at 25 volts dc.
Using high power	10 amperes at 25 volts dc.

(3) *Receiving functions.*

RF signal sensitivity	0.1 microvolt, minimum.
Audio output impedances (nominal):	
External loudspeaker	150 ohms.
Headphone	50 ohms.
To radio-intercom system	1,500 ohms.
X-mode	600 ohms.
Squelch types:	
Carrier (operative in OLD SQUELCH)	Responsive to carrier noise (approximately 7,300 Hz).
Tone (operative in NEW SQUELCH)	Responsive to 150-Hz squelch tone signal.
Power drain	0.75 ampere at 25 volts dc.

b. R-442(*)/VRC. The technical characteristics given in *a*(3) above for the receiver-transmitters are applicable to the R-442(*)/VRC.

c. Antennas AS-1729/VRC and AT-912/VRC.

Frequency range	30.00 to 76.00 MHz.
RF transmission power capability	70 watts maximum.
Antenna type	Vertically polarized, omnidirectional whip antenna.
Radio receptacle impedance	50 ohms; BNC type receptacle.
Frequency matching networks	10 sets which are automatically selected by tuning controls of receiver-transmitter. In AS-1729/VRC, these networks can be selected manually by control on MX-6707/VRC.

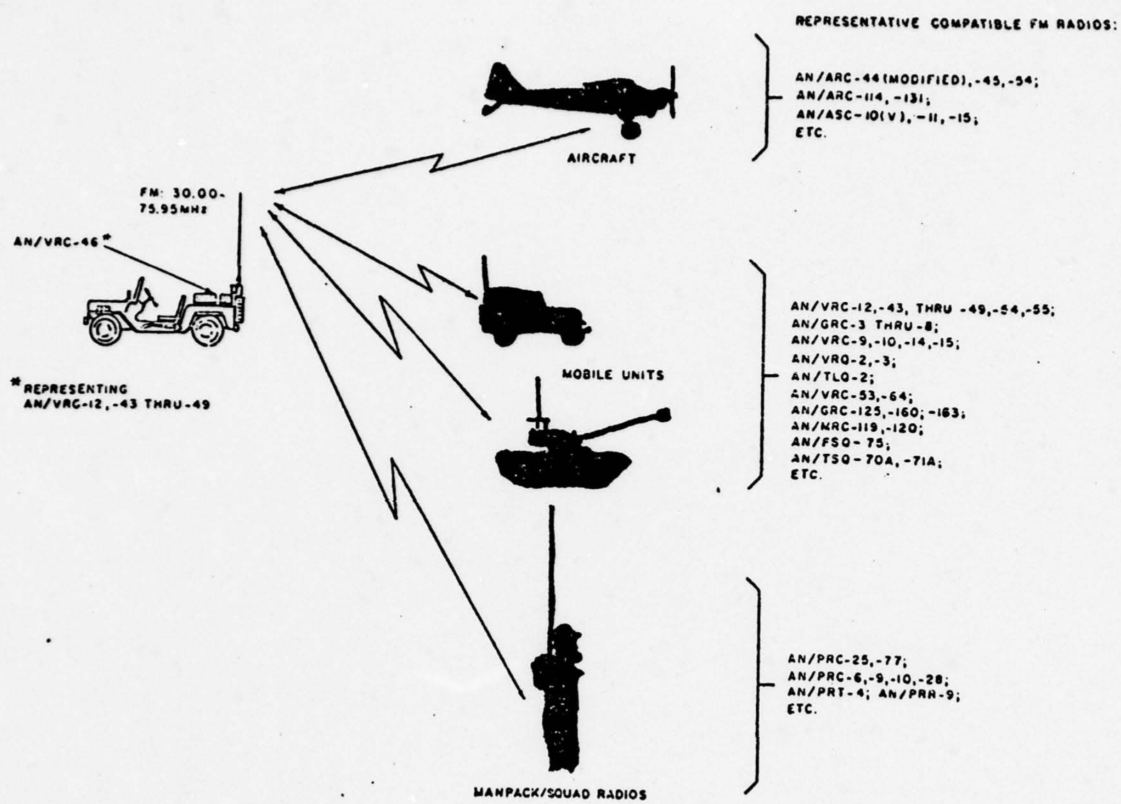

Figure 34. Typical applications of the AN/VRC-12 series.

transmission line consists of two parts: an upper portion that has a characteristic impedance of 125 ohms, and a lower portion that has a characteristic impedance of 50 ohms. The 125 ohm and 50 ohm sections act as a transformer to provide a good standing wave ratio (SWR) at the base of the whip antenna portion of the AS-1729/VRC. The upper 5 foot section, the radiating element, is an extension of the center conductor of the coaxial transmission line.

(b) The AS-1729/VRC impedance is matched to the receiver-transmitter by the MX-6707/VRC. Current distribution in the AS-1729/VRC is controlled at a particular frequency by a helical inner conductor sleeve choke and a selected shunt reactance in the MX-6707/VRC. (The shunt reactance is determined by the narrow frequency band in which the antenna is working. The MX-6707/VRC has 10 frequency sub-bands between 30-76 MHz. Each sub-band is from 3-5.5 MHz wide and is associated with some combination of capacitance and/or inductance which is used to tune the antenna for operation in that given sub-band.) These shunt reactances are manually selected by setting a multiposition switch on the bottom of the MX-6707/VRC or are automatically selected by use of control voltages from a compatible receiver-transmitter. Figure 35 shows the manual frequency selector switch on the bottom of the AS-1729/VRC. Figure 36 shows the connection of the antenna to the radio set.

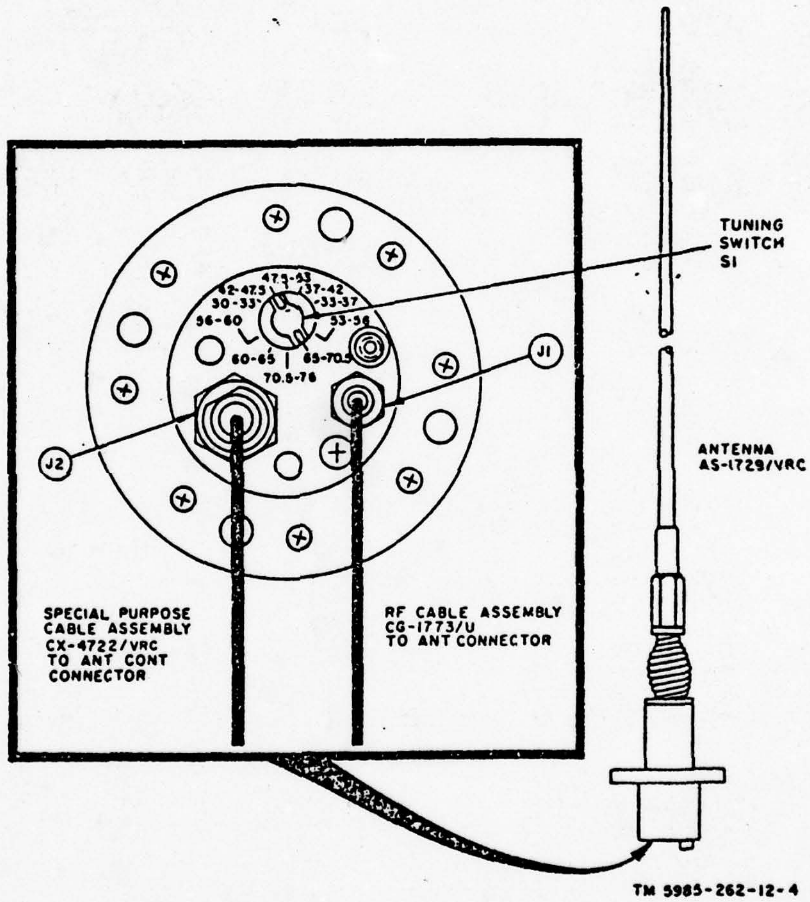

Figure 35. Antenna AS-1729/VRC, control and connectors.

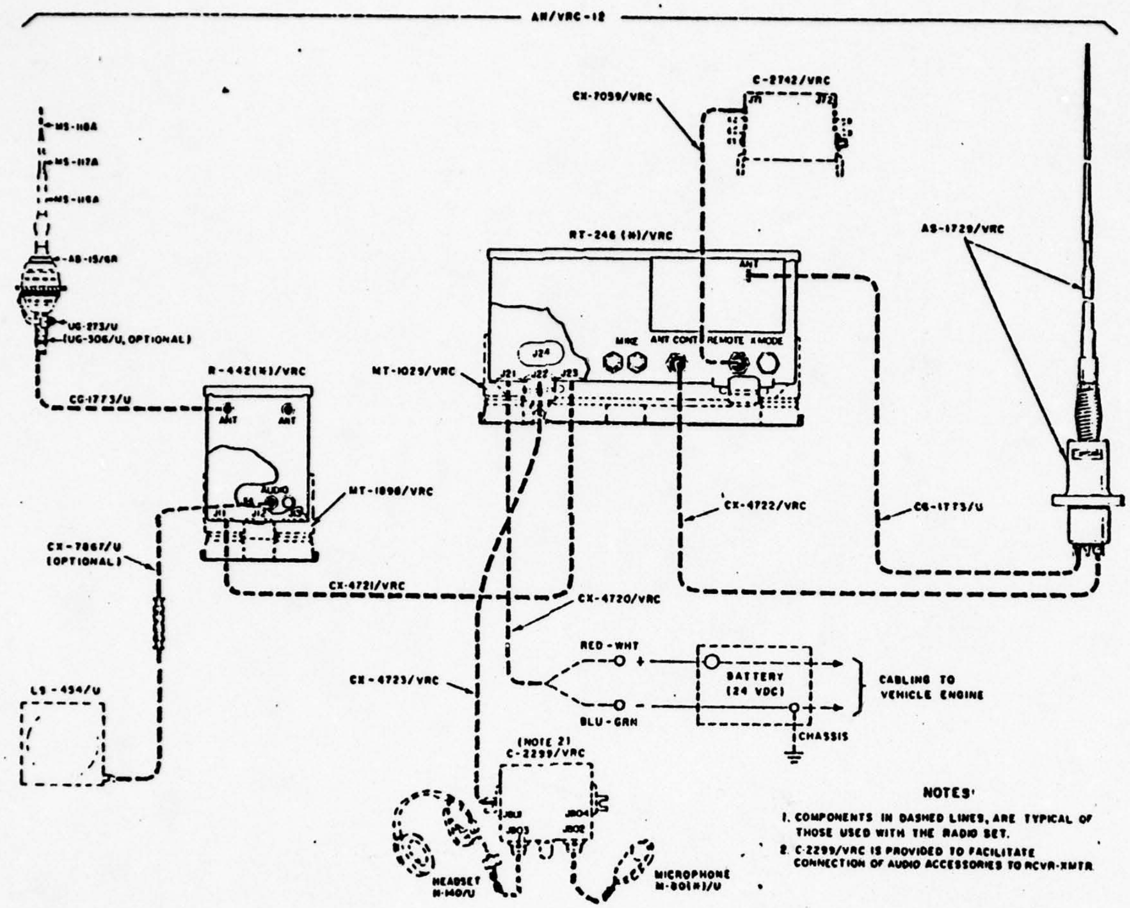

Figure 36. Typical cabling diagram for the AN/VRC-12.

(c) The AS-1729/VRC antenna replaced the AT-912/VRC (Figure 37) which was the basic center-fed antenna with a matching unit. The AT-912/VRC was introduced around 1960 as an improved antenna system for vehicular mounted antennas. It, in turn, replaced the basic end-fed monopole with a vehicular ground which is still used with the Receiver, R-442(*)/VRC (Figures 30 and 32, pages 56 and 58). The vehicular grounded end-fed monopole produced radiation patterns which varied with the geometry of the vehicle and the location of the antenna on the vehicle. Also, the end-fed monopole of Figure 32 is only slightly tunable, such tuning being accomplished by adding or subtracting antenna elements MS-116A, 117A, or 118A to vary the length and approximate a one-quarter wavelength. This antenna system produced relatively high SWR's and was not an efficient antenna. Adoption of the center-fed whip eliminated this problem. The AS-1729/VRC represents a product improvement over the AT-912/VRC in that the operating frequency can be manually as well as automatically selected. This feature adds versatility to the antenna system in that it can be mounted on an elevated mast as well as on a vehicle.

(d) The AS-1729/VRC antenna is scheduled to be replaced with the AS-2731(*)/GRC,[47] which is a 5-1/2 foot center-fed antenna. The AS-2731(*)/GRC has an average efficiency within 1 dB of the AS-1729/VRC over the 30-80 MHz frequency

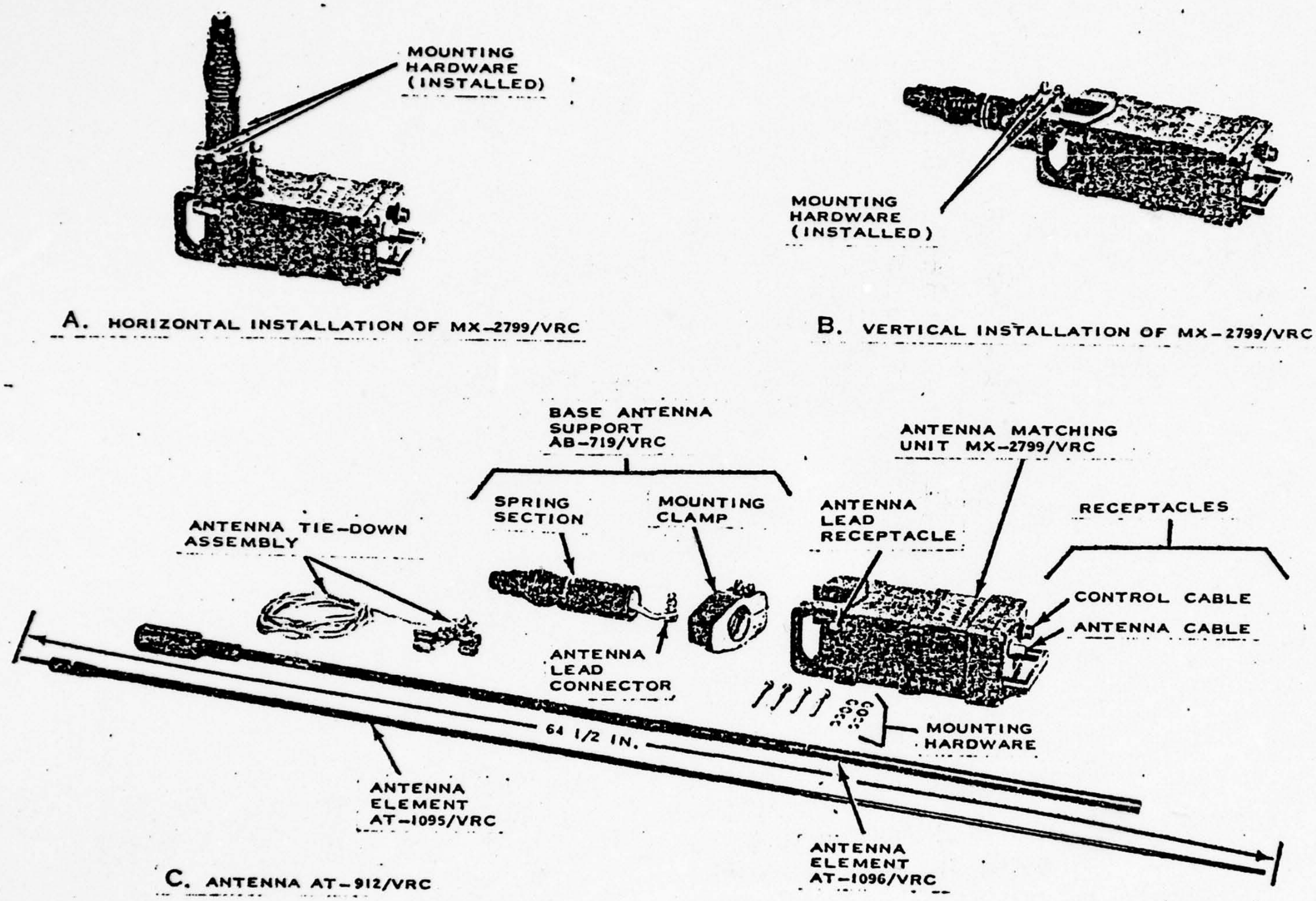

Figure 37. Antenna AT-912/VRC, disassembled.

range. It is designed for an SWR of 3.5:1 over the above frequency range and in field tests performed equally with the AS-1729/VRC. It has been accepted as a direct replacement for the AS-1729/VRC and is currently in production. The reduced height will be more readily adaptable to all types of vehicular applications, particularly armored vehicles; the 5-1/2 foot whip presents a lower silhouette and so will not strike telephone lines, tree limbs, or low-clearance obstructions thus minimizing antenna breakage; and logistics is simplified with a one section antenna compared with a two section antenna. Figure 38 shows a comparison of the sizes of the AS-1729/VRC and the AS-2731(*)/GRC.

C. The AN/VRC-12 series radios and the AN/PRC-77 previously discussed, as well as several other radio sets to be presented, are capable of secure voice operation (x-mode), i.e., they can be used with auxiliary speech encryption devices connected to the radio set which provide for secure (on line encrypted) voice communication. In the narrow-band mode, i.e., not encrypted or not speech secure, the 50 KHz operating channel provides a 30 KHz intelligence channel (±15 kHz maximum signal deviation) with a 10 kHz guard band on either side of the intelligence channel to prevent adjacent channel interference. In the wide-band mode (digital data or secure voice communication), these guard bands are removed and the intelligence channel occupies the entire 50 kHz operating (frequency) channel.

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THE UTILIZATION OF BROADBAND ANTENNAS IN MILITARY TACTICAL COMM--ETC(U)
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Figure 38. AS-1729/VRC and AS-2731(*)/GRC size comparison. (Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

1. Tactical communicators have long known (from experience) that there is a reduction in communications distance range when operating x-mode as opposed to clear (nonsecure) voice operation. The reasons for this reduction in distance range may be provided by considering either the spectral power density of the transmitted signal (the available output power is spread over a 50 KHz bandwidth as opposed to a 30 KHz bandwidth, or only 0.6 as much power is available per frequency component) or in terms of the required field intensity (Reference 15, p. 2-13), E_r, at the receive antenna. Using the second method, and considering the required field intensity in terms of the atmospheric noise increase due to increased receive bandwidth, we have

$$E_r = \frac{kE_c}{H_e\sqrt{\Delta f}}$$

where

E_r = received field intensity in microvolts per meter (μv/m),

k = experimentally obtained carrier-to-average noise ratio for the desired grade of communications per kHz bandwidth,

E_c = measured average received noise voltage referred to the antenna terminals,

H_e = antenna effective height in meters, and

Δf = the effective receiver bandwidth in kHz.

Since we are considering only the effect of a change in receive bandwidth, let $\frac{kE_c}{H_e} = C$, a constant, then

$$E_{r_1} = C\ \frac{1}{\sqrt{30}} = 0.183C \text{ for 30 kHz BW,}$$

and

$$E_{r_2} = C\ \frac{1}{\sqrt{50}} = 0.141C \text{ for 40 kHz BW,}$$

$$\therefore\ E_{r_1} = 1.29\ E_{r_2} \quad \text{or} \quad E_{r_2} = 0.77\ E_{r_1}\ .$$

The above shows that when operating x-mode as opposed to clear voice operation in tactical radio nets, one can expect at least a 23 percent reduction in received field strength at the receive antenna. In practice, this figure is usually greater due to the fact that most field radio equipment is not properly aligned for x-mode operation. This factor must be considered when planning communications distance ranges for tactical radio nets operating x-mode. In the infantry battalions and brigades these radio nets are usually command nets and operations/intelligence nets since voice security equipment has not been issued in sufficient quantity to secure all voice radio nets.

D. The only item of antenna equipment provided by the TOE's of the airborne and airmobile infantry battalions and brigades to extend the distance range of the AN/VRC-12 series is the RC-292 (Chapter II). From Table 4, page 42, the planning ranges between two AN/VRC-12 series radios using RC-292's (elevated 30 feet) is given as 36 miles (average terrain) and 30 miles (difficult terrain). These figures agree closely with field experience. (Distances are reduced, however, when operating x-mode, as explained in C above.)

E. In the airborne or airmobile assault, troops are deployed first, vehicles and other heavy equipment follow (sometimes much later). The radio equipment deployed in the assault consists only of portable, man-pack equipment which can be carried by personnel (who are also carrying a combat load of ammunition, rations, and other equipment). At present, the only radio and antenna equipment which can be carried in the assault is the AN/PRC-77 and RC-292.

The assaulting forces may be deployed over very wide areas since one of the distinct advantages of vertical envelopment techniques is the ability to put assaulting forces directly on their objectives. This wide area deployment, together with the present availability of only low power, short range portable radio equipment, places severe limitations on the ability of the commander to assemble, further deploy, and, in fact, command his assaulting forces. What is required to meet this limitation is a medium power, portable receiver-transmitter which would extend the distance range of the radio nets required in the airborne or airmobile assault.

Radio Set AN/PRC-70[21] (Figure 39) was initially designed to meet the requirements of Special Forces detachments. It has since been recommended for the Ranger battalions. This writer believes that this radio set can solve the problems described in the preceding paragraph. Additionally, this radio set has features not found on any other items of tactical radio equipment. The technical characteristics of the set are shown on Table 6. This radio set could provide a portable, man-pack (two man load with all antenna and necessary equipment, total weight 68.3 lbs.) radio set with approximately the same power output as the AN/VRC-12 series. Additionally, with its AM/SSB/FSK capabilities, the set could replace the AN/PRC-74 (details not presented in this thesis), 15 watt AM/SSB voice radio set authorized for the airborne and airmobile infantry battalions, and, used with the Digital Message Entry Device (DMED) (Chapter IV) would provide a suitable replacement for the AN/VSC-2 RATT equipment (details not presented) presently authorized in the above units. The AN/PRC-70 has been field tested at Ft. Bragg, North Carolina, and passed all service tests. Five sets were obtained on loan from the US Army Signal School, Ft. Gordon, Georgia, and were tested by the 101st Airborne Division (Air Assault) in early 1976. Those sets met the above communications requirements as no other radio set in the inventory c planned for adoption could do. It was recommended that the AN/PRC-70 be

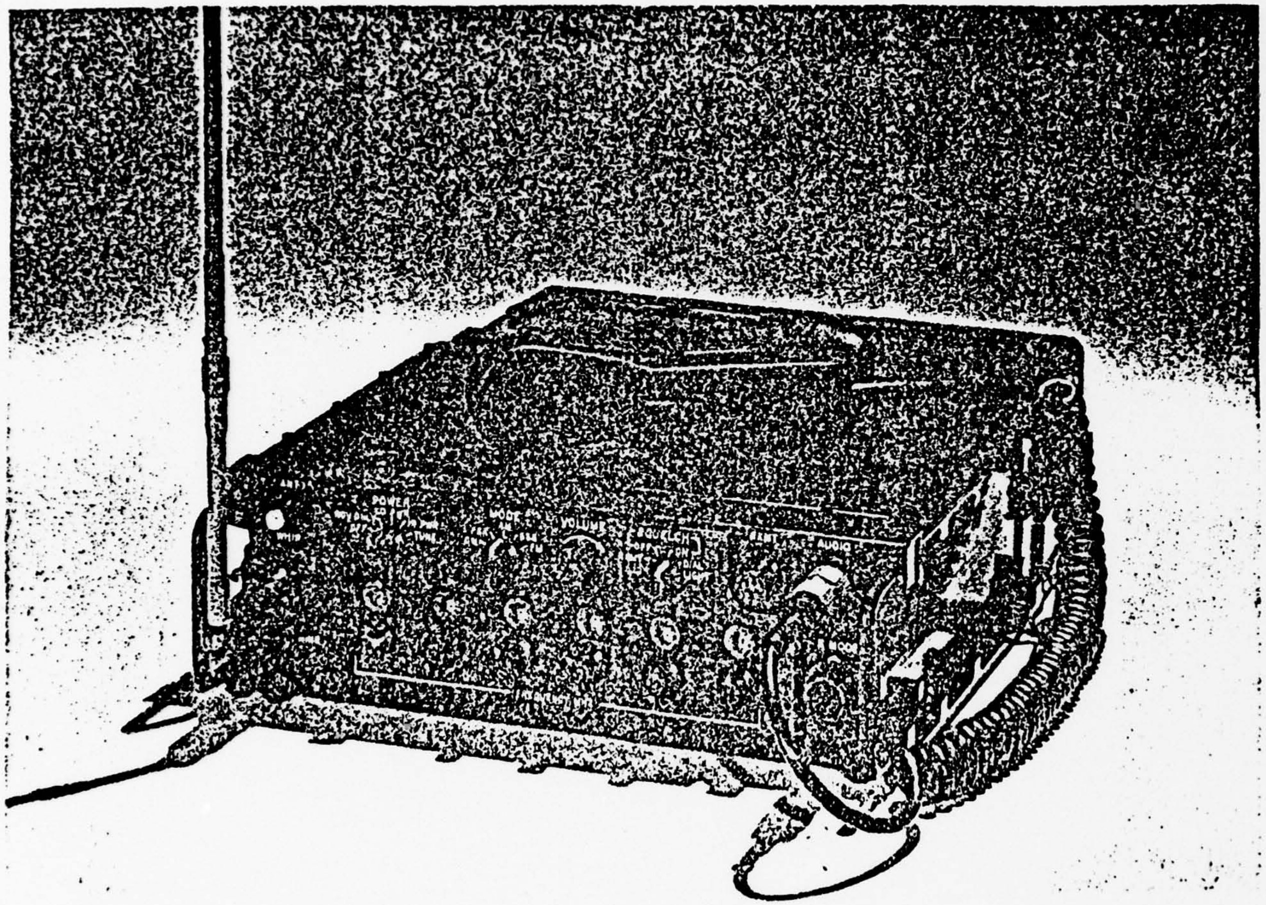


Figure 39. Radio Set AN/PRC-70. (Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

TABLE 6

TECHNICAL CHARACTERISTICS OF RADIO SET AN/PRC-70

a. Receiver-Transmitter RT-1133/PRC-70:	
Input Voltage	20 to 32 Vdc
Power Requirements	
Receive Mode	7 watts maximum
Low-power Xmit Mode	50 watts maximum
High-power Xmit Mode	
FSK, CW, FM, and AM	160 watts maximum
SSB	115 watts maximum
Power Output:	
High-power Mode	
CW, FM*, FSK	21-42 watts average
*FM 30.0000 to 75.9999 MHz only	(30 watts nominal)
SSB	21-42 watts peak envelope power (30 watts nominal)
AM	7.5 watts carrier, 7.5 watts upper sideband
Low-power Mode	transmitter output reduced 10 ± 1 dB below high power output in all modes
Frequency range	2.000 to 75.9999 MHz in 100 Hz steps
Duty cycle	9 to 1 receive-to-transmit ratio. Three minute maximum transmit time without external forced air cooling.
Modes: Upper sideband voice; 2 kHz Tone-keyed CW, FSK burst (Tones 1575 Hz and 2425 Hz); Compatible AM (2.000 - 75.9999 MHz); FM (30.0000 - 75.9999 MHz)	
Receiver Sensitivity:	
FM	0.60 uv
SSB, FSK, CW	0.25 to 0.50 uv (varies with frequency)
AM	2.50 uv
Receiver Signal-to-noise Ratio	10 dB at referenced sensitivity
Receiver Selectivity:	
FM	32 kHz @ 6 dB 70 kHz @ 60 dB
SSB, CW, FSK	2.8 kHz @ 6 dB 4.0 kHz @ 26 dB 6.0 kHz @ 60 dB
AM	6.0 kHz @ 6 dB 14.0 kHz @ 60 dB
b. Doublet Antenna AS-2975/PRC-70:	
Frequency Range	2 to 30 MHz
Input Impedance	72 ohms
c. Whip Antenna AS-2974/PRC-70:	
6 - foot Section	4 to 76 MHz
9 - foot Section	3 to 76 MHz
15 - foot Section	2 to 30 MHz
d. Low Radiating Angle Antenna AS-2973/PRC-70:	
Frequency Range	6 to 30 MHz

included in the TOE of the Air Assault Division. This radio set, as has been mentioned above, also has application to the Airborne Division and other light infantry units.

F. In addition to a requirement for a medium power, man-pack receiver-transmitter (paragraph E above), there exists a requirement for high gain, broadband directional antenna equipment in order to provide the capability to span increased distances with x-mode operated voice radio nets and decrease the vulnerability of tactical units to radio direction finding and other enemy ECM threats. The AS-2369/TRC antenna (Radio Engineering Products F61122 (Figure 16, page 38)) meets the requirement for increased distance range and should be adopted. The AS-2369/TRC, however, requires an extensive area for erection. Recently developed Log Periodic Dipole Array antenna systems (Appendix L, Section 7) offer the best possible solution to the conflicting requirements for increased communications distance ranges <u>and</u> increased transmission security. The excellent front-to-back ratio characteristic of the LPDA provides the capability to direct a transmitted signal in a desired direction and <u>away</u> from an undesired direction. This capability (shared by the AS-2369/TRC above) makes the LPDA and vertical half-rhombic antenna systems desirable alternatives to the omnidirectional antennas (AS-1729/TRC, AS-2731/GRC, and RC-292) presently provided, except when an omnidirectional capability is required. When this is the case, an LPDA (vertically polarized) or vertical half-rhombic antenna at the out-station, working against an RC-292 or its projected replacement the AS-3166(*)/GRC (Chapter II) at the NCS would provide an overall system gain and allow for increased communications distance ranges. The following LPDA equipment is currently available and has been tested by field units:

1. The 42A-1[27,30] (Figure 40) is a broadband transportable log periodic antenna for receiving and transmitting at all frequencies in the 30- to 80-MHz band. The antenna can be mounted for either horizontal or vertical polarization and disassembles into four sections for storage in a 5 foot carrying bag. All parts are captive to the boom/feeder system and the antenna may be assembled in a rapid manner without the aid of tools. The technical characteristics of the 42A-1 are shown on Table 7. Figures 41 and 42 give additional data.

The 42A-1 antenna provides 8.5 dBi nominal gain over the band. The average VSWR is less than 1.5:1 and the front-to-back ratio is nominally greater than 20 dB over the band. To assure uniform pattern characteristics when vertically polarized, a specially choked RF cable is provided.

The 42A-1 antenna mounts on a 2.375" O.D. mast and has provisions for providing either vertical or horizontal polarization. The antenna is available with a standard 8 foot section of dielectric mast for applications involving vertical polarization. The 42A-1 antenna weighs less than 50 pounds

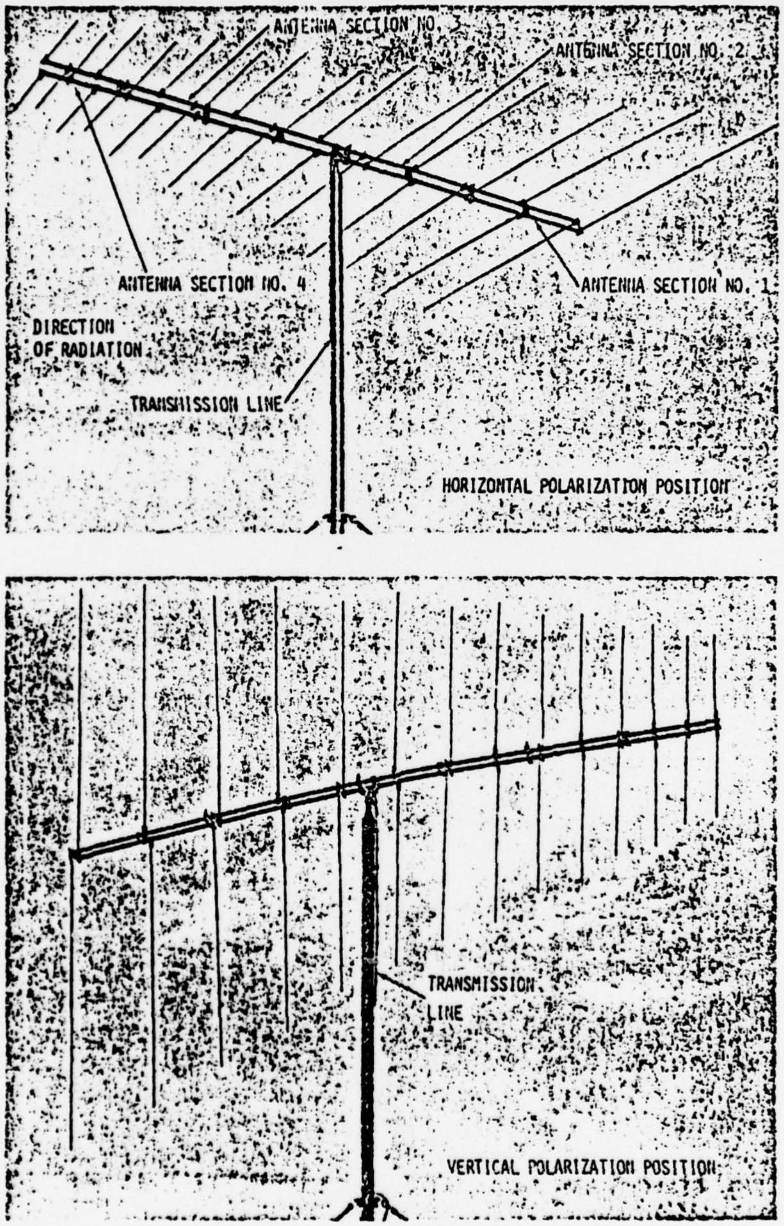


Figure 40. Type 42A-1 VHF broadband directional log periodic antenna array.

TABLE 7

TECHNICAL CHARACTERISTICS OF THE TYPE 42A-1 LPDA ANTENNA*

Model:	42A-1
Part Number:	72-11002-001
Frequency Range:	30- to 80-MHz
Impedance:	50 ohms unbalanced
VSWR:	Less than 2:1
Power:	100 W, (Higher power on special order)
Polarization:	Linear, Vertical or Horizontal
Gain, Free Space:	8 dBi, minimum
Beamwidth:	
• E-Plane:	60 degrees, nominal
• H-Plane:	100 degrees, nominal
Front-to-Back Ratio:	15 dB, minimum
Wind Load:	75 mph 50 mph with ¼" radial ice
Dimensions	
• Operating:	19' 1.6" (5.8 m) length. 17' 2.64" (5.25 m) width
• Packaged:	5' 1½" (1.56 m) X 2' 0" (0.61 m) X 1' 2" (0.356 m)
Weight	
• Antenna Array	49.5 lbs (22.4 kg)
• Carrying Case	11.3 lbs (5.1 kg)
Shipping Weight:	71.0 lbs (32.1 kg)
Shipping Volume:	12.8 cu. ft. (.35 cu. m.)
Ancillary Equipment	
• Canvas Storage Bag	P/N 72-11014-001
• RF Cable, 60 feet	P/N 72-11016-001
• Dielectric Mast	P/N 72-00136-001
• Variable Height Mast, Type 92M-1	P/N 74-51124-001

*Courtesy of Electrospace Systems, Inc., Richardson, Texas.

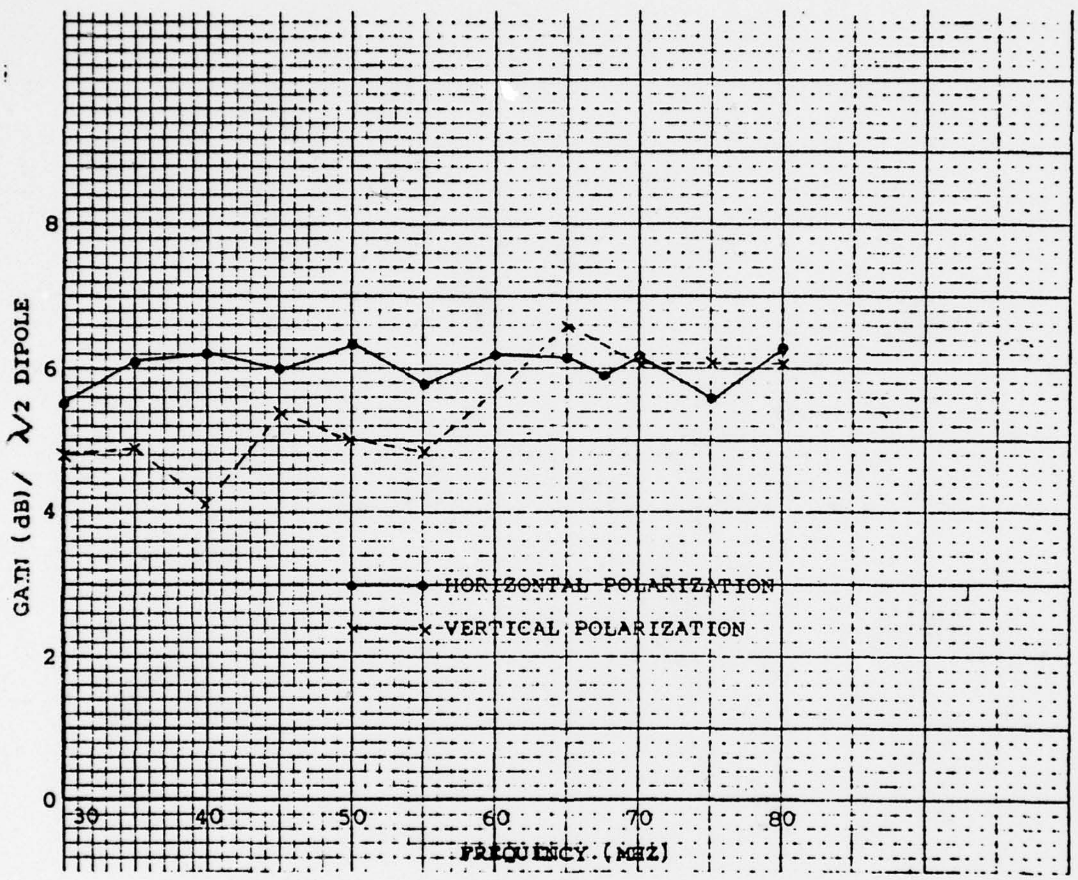


Figure 41. Measured gain vs. frequency of 42A-1.

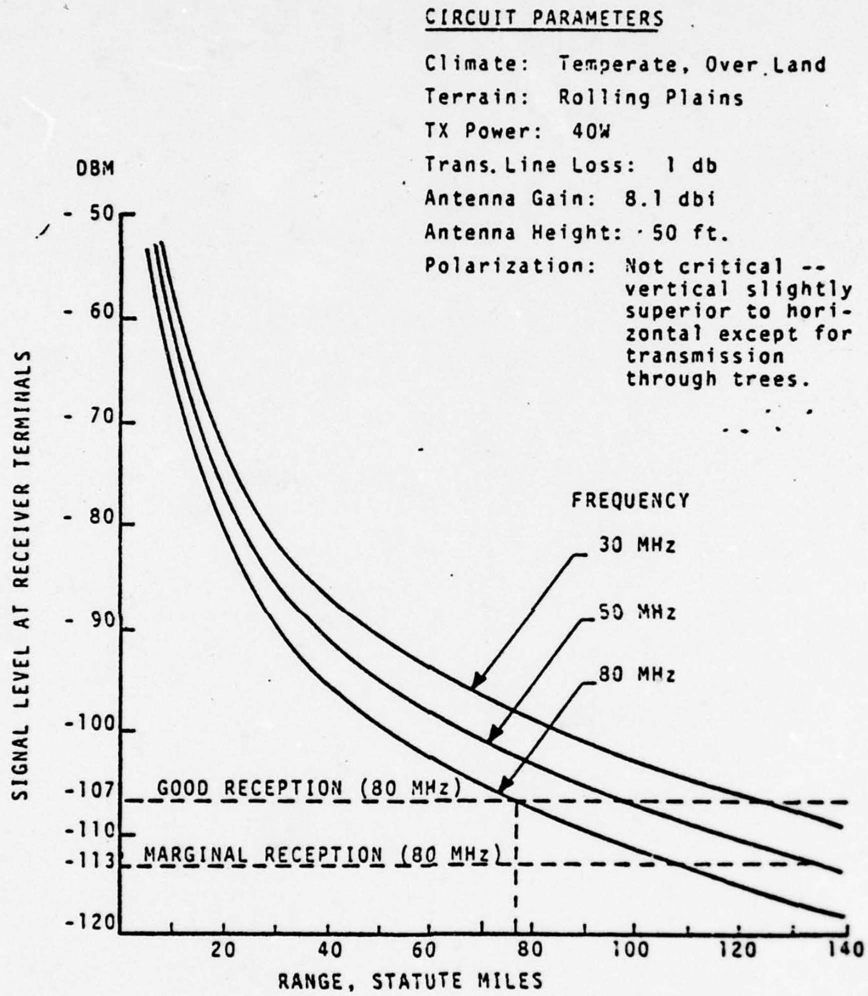


Figure 42. Median signal level vs. range between AN/VRC-12 series radio sets using Type 42A-1 antennas.

and can be erected without special tools or equipment. A compatible variable height mast is available on special order to provide quick and easy erection of the 42A-1 antenna to any height between 16 and 40 feet.

This antenna was tested by the author while assigned to the 101st Airborne Division (Air Assault) and proved to be the only means available to solve problems of the type described in paragraphs E and F above. The antenna allowed communication from an AN/VRC-12 series radio (using the 42A-1) to an AN/PRC-77 using a 3 foot whip antenna over a distance of 21.6 miles. On another test, ranges of over 100 miles were achieved using AN/VRC-12 series radios with both stations using the 42A-1. This antenna is comparatively heavy, and the mast required to erect the antenna weighs over 100 pounds. The combination of weight and cubage does not recommend this antenna to the airborne or airmobile infantry battalions, nor to the airmobile infantry brigade. It is, however, recommended for employment at division level in both type divisions, and at brigade level in the airborne division, where the vehicle density is greater. This antenna could not easily be carried by foot mobile troops.

2. The HY-GAIN Model LP-1402 (AS-2851/TR) (Figure 43) is a tactical portable LPDA antenna system designed to operate in the 30-76 MHz frequency range. The technical characteristics are shown on Table 8. It is supplied complete in a

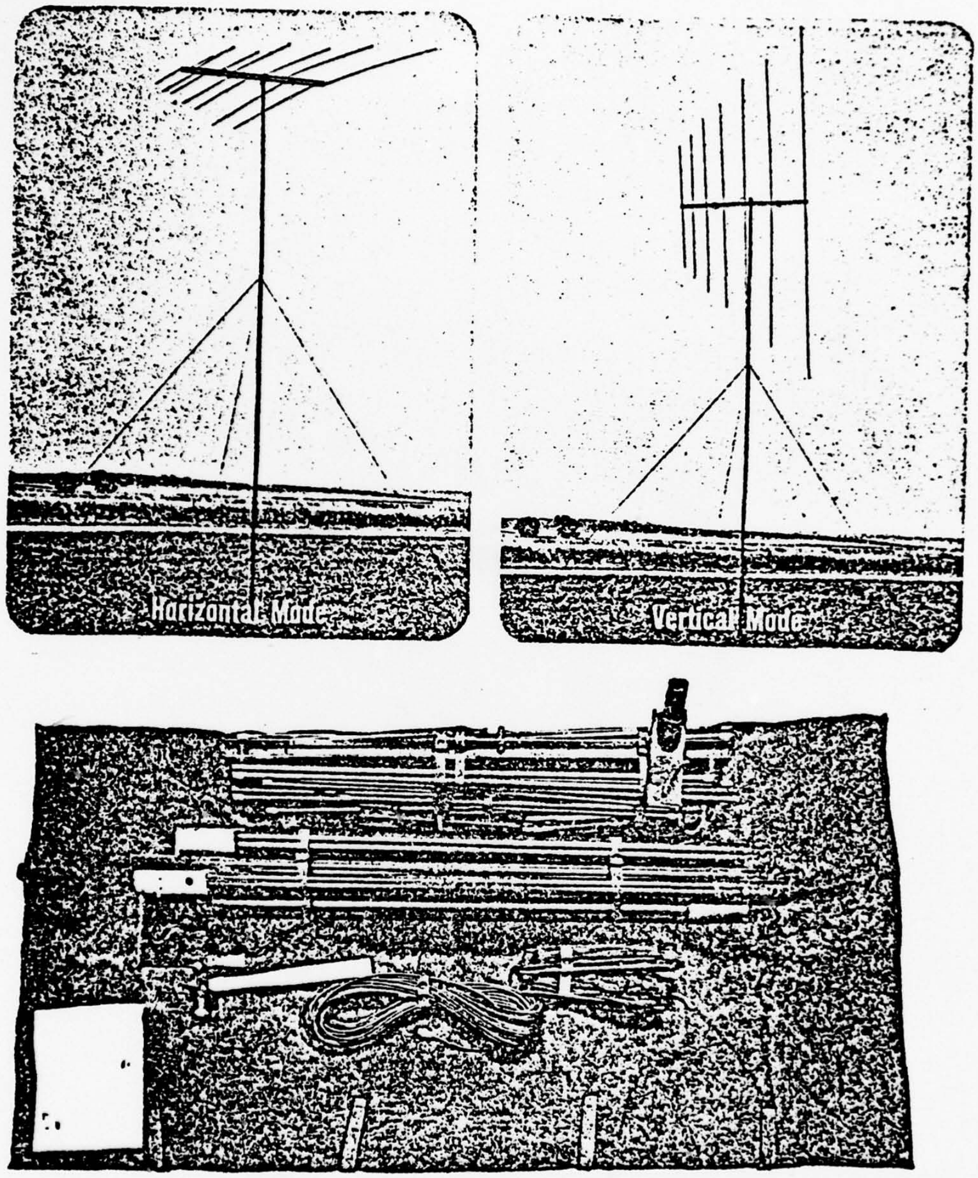


Figure 43. Tactical LPDA antenna system AS-2851/TR. (HY-GAIN Model LP-1402.) (Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.)

TABLE 8

TECHNICAL CHARACTERISTICS OF THE AS-2851/TR ANTENNA SYSTEM*

SPECIFICATION SUMMARY

HY-GAIN MODEL NUMBER	LP-1402
Electrical:	
Frequency Range (in MHz)	30.0 thru 76.0
Power Handling Capability	
Average P.E.P. (in Watts)	65/130
Polarization	Horizontal or Vertical
Forward Gain Over Average	
Soil Conditions (in db)	12
Front-to-Back Ratio (in db, nominal)	10
Maximum VSWR (with respect to 50 ohms)	2:1
Input Impedance (in ohms)	50
Input Connector	Type "N"
Half Power Beam Widths	
(Free Space)	-
E Plane (Average)	60°
H Plane (Average)	125°
Angle of Maximum Radiation	
30 MHz	22.5°
76 MHz	9°
Structural:	
Dielectric Support Pole Height	20 ft.
Longest Element	16 ft.
Total Number of Elements	7
Boom Length: Assembled	5'11"
Folded	36"
Antenna Net Weight	33 lbs.
Shipping Weight of System	35 lbs.
Shipping Volume (in cu. ft.)	3.2
Wind Loading Capability:	
No Ice (in MPH)	60
¼" Radial Ice (in MPH)	50

*Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.

back-pack and may be used for either vertical or horizontal polarization at 2-1/2 foot height increments up to 20 feet phase center heights above ground. The antenna may be erected by two men in less than 10 minutes. This antenna has been adopted by the US Marine Corps, and in comparison tests with the AS-2851/TR, 42A-1, AS-2169/G,[25] AS-2236/G (information on this antenna was not available), and LP-1403 (paragraph 3, following) by the 101st Airborne Division (Air Assault), the AS-2851/TR was determined to perform best in a field environment and have the best weight/cubage advantages. It was recommended that this antenna be adopted and issued for use down to battalion level in the Air Assault Division. Similar studies, if conducted, would prove this antenna applicable to the Airborne Division and other light infantry units also.

3. The HY-GAIN Model LP-1405 (Figure 44) is similar to the AS-2851/TR, but has an expanded frequency range. The technical characteristics are shown on Table 9. Figures 45 and 46 show additional technical information on radiation patterns, gain, and VSWR.

4. Recent studies conducted by the US Army and outlined in training literature (DA Training Circular 30-22 (Draft), Battlefield Survival and Electronic Warfare [The Electronic Direction Finding Threat]) have disclosed that a horizontally polarized signal, in addition to being attenuated less in dense woods, as was known, is much harder to RDF than a signal which is vertically polarized. Figure 47 shows the results with Radio Set AN/PRC-77 under various conditions. The use of tactical LPDA antenna systems with horizontal polarization would not only increase the communications distance range of tactical radio nets but would decrease the vulnerability of tactical units to RDF.

G. The AN/VRC-12 series radios are due for replacement in the 1980-85 time frame. New radio equipment incorporating state-of-the-art electronic and antenna design features is currently in the advanced stages of research and development.

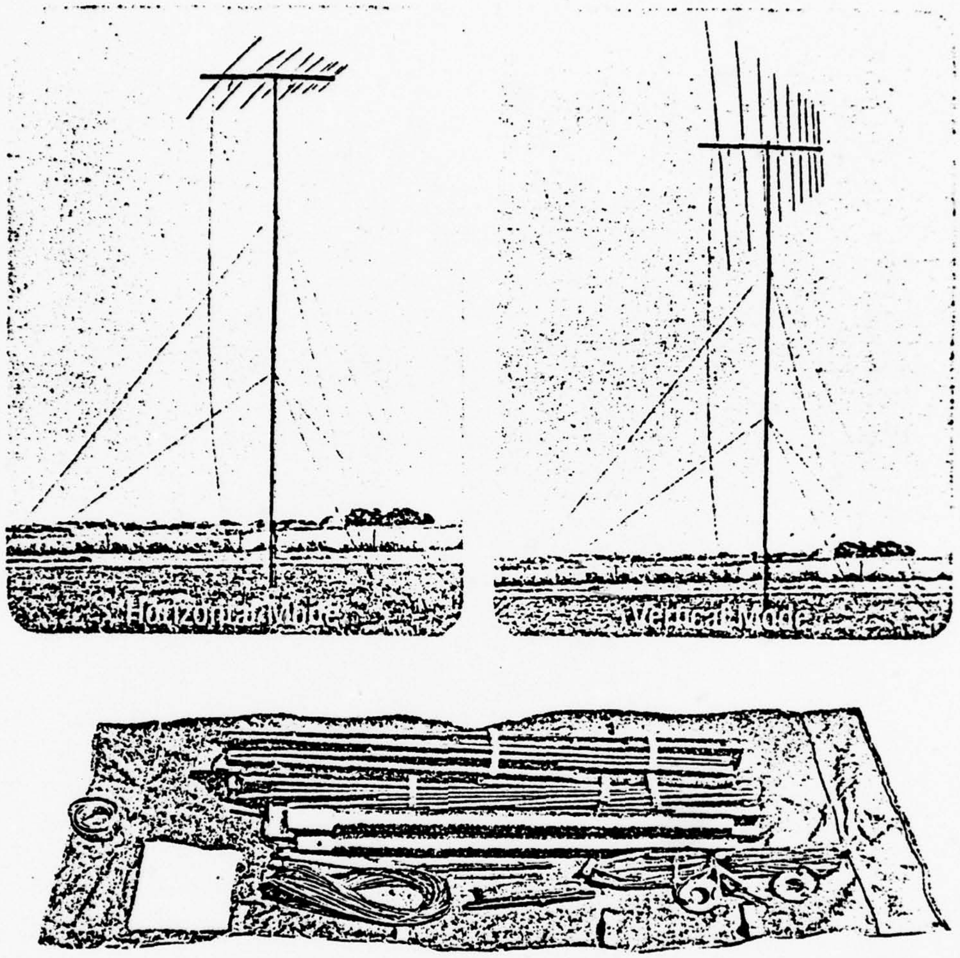


Figure 44. HY-GAIN Model LP-1403 LPDA antenna system.
(Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.)

TABLE 9

TECHNICAL CHARACTERISTICS OF HY-GAIN MODEL LP-1403 LPDA ANTENNA SYSTEM*

SPECIFICATION SUMMARY

HY-GAIN MODEL NUMBER	LP-1403
Electrical:	
Frequency Range (in MHz)	30.0 thru 88.0
Power Handling Capability	
Average/PEP (in Watts)	75/150
Polarization	Horizontal or Vertical
Forward Gain Over Average Soil	
Conditions (Directivity in dBi)	6
Front-to-Back Ratio (in dB, nominal)	12
Maximum VSWR (with respect to 50 ohms)	2:1
Input Impedance (in ohms)	50
Input Connector	BNC
Half Power Beam Widths (Free Space)	
E Plane (Average)	70°
H Plane (Average)	140°
Structural:	
Dielectric Support Pole Height	30 ft.
Longest Element	15.5 ft.
Total Number of Elements	9
Boom Length: Assembled	95 in.
Folded	47 in.
Antenna Net Weight	40 lbs.
Shipping Weight of System	42 lbs.
Shipping Volume (in cu. ft.)	6.25
Wind Loading Capability	
No Ice (in MPH)	60
¼" Radial Ice (in MPH)	50

*Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.

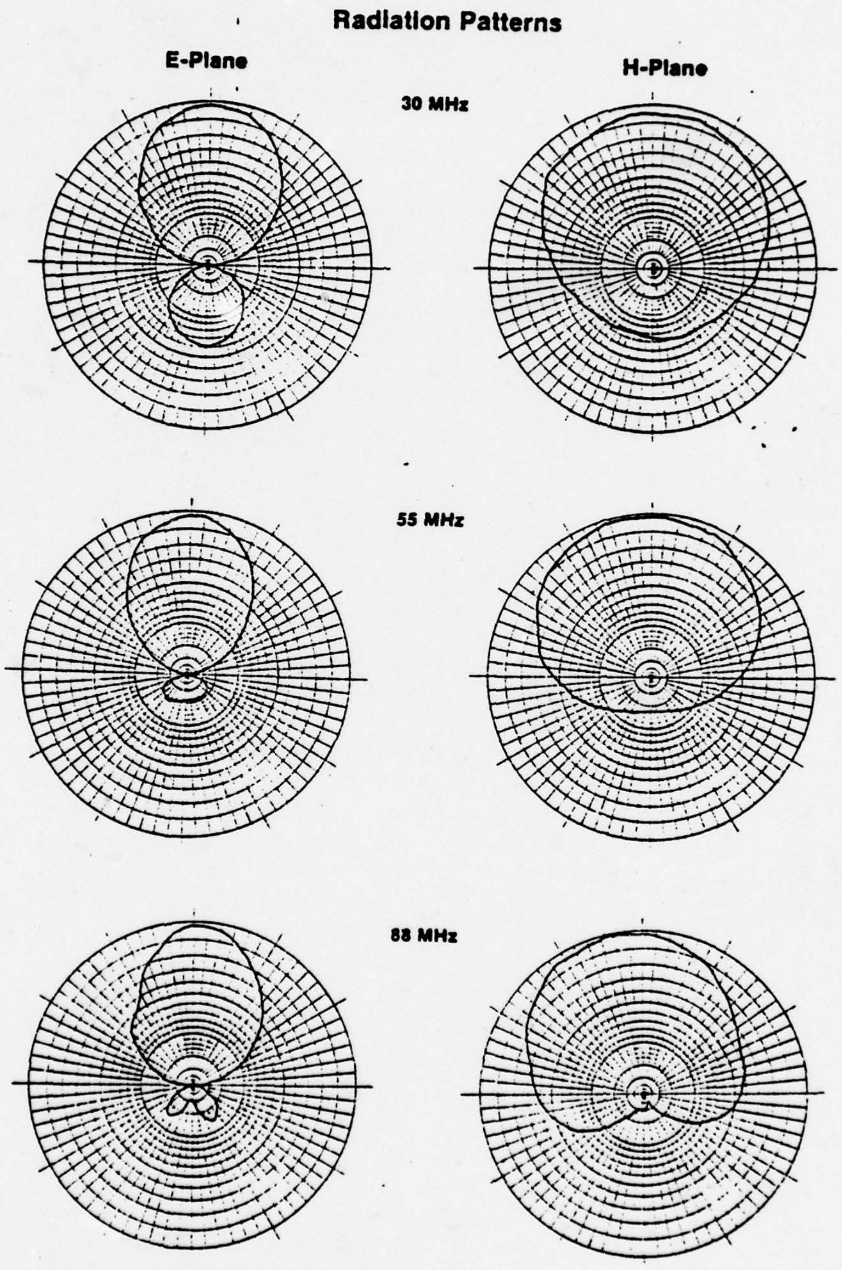
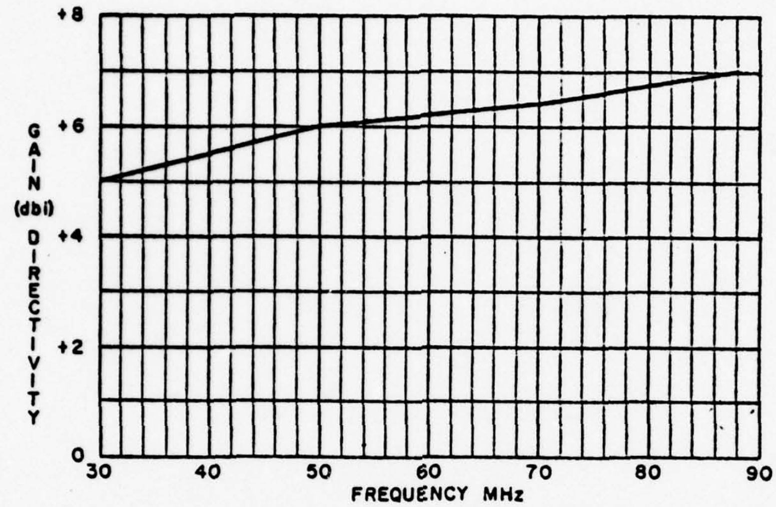


Figure 45. Radiation patterns for the LP-1403 LPDA antenna system. (Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.)



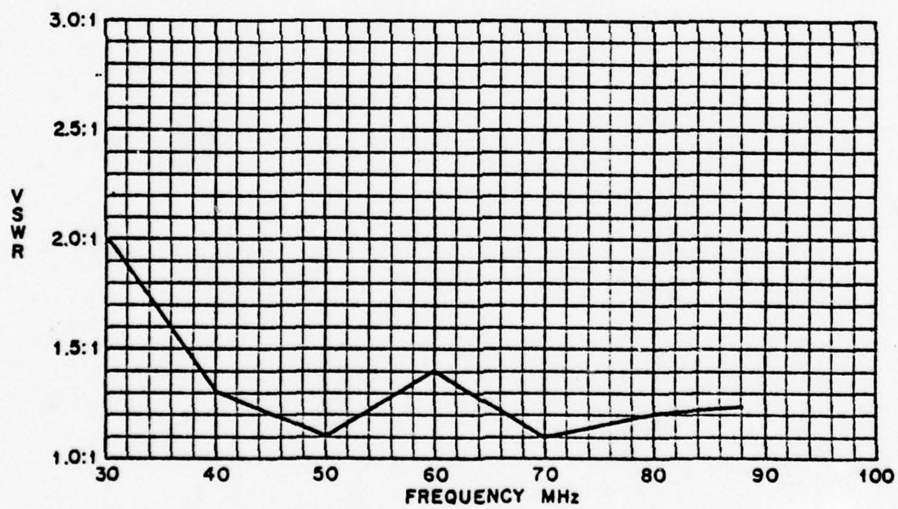


Figure 46. Gain and VSWR graphs for the LP-1403 LPDA antenna system. (Courtesy of HY-GAIN Electronics Corp., Lincoln, Nebraska.)

ECCM TECHNIQUES AFFECTING AN/PRC 77 RADIO

(RADIO IS 10 kms FROM ENEMY INTERCEPT/DF SYSTEM)

SITUATION	TRANSMIT POWER	FREQUENCY	APPROXIMATE ANTENNA HEIGHT	ANTENNA POLARITY	PROBABILITY OF INTERCEPT	PROBABILITY OF DIRECTION FINDING EXPRESSED AS CEP*
BASE SITUATION	HIGH POWER 2 WATTS	47 MHz	1 METER (AT - 892)	VERTICAL OMNIDIRECTIONAL	61%	1.3 kms
1	2 WATTS	47 MHz	3 METER (AT 271A)	VERTICAL OMNIDIRECTIONAL	61%	1.3 kms
2	2 WATTS	47MHz	10 METER (RC 292)	VERTICAL OMNIDIRECTIONAL	73%	.9 km
3	2 WATTS	47 MHz	3 METER AT 944 A G LONG WIRE OR FIELD EXPEDIENT DOUBLET	HORIZONTAL DIRECTIONAL	8%	DF SYSTEM CANNOT TAKE BEARINGS ON THIS SIGNAL
4	LOW POWER .1 WATT	47 MHz	1 METER (AT 892)	VERTICAL OMNIDIRECTIONAL	19%	5.6 kms
5	2 WATTS	31 MHz	1 METER (AT 892)	VERTICAL OMNIDIRECTIONAL	71%	1 km
6	2 WATTS	72 MHz	1 METER (AT 892)	VERTICAL OMNIDIRECTIONAL	51%	1.9 kms

LOOK WHAT GOOD ECCM CAN DO USING LOW POWER OR HORIZONTALLY POLARIZED AND DIRECTIONAL ANTENNA

FRIENDLY DATA

TERRAIN 3D ARMORED DIVISION'S TERRAIN IN EUROPE HILLS
TIME 1200 HOURS
SEASON SPRING AND FALL
SOIL GOOD CONDUCTIVITY
ANTENNA GAIN OF RADIO 2DB

ENEMY DATA

INTERCEPT POSITION IS IDEAL
DF POSITIONS ARE IDEAL
DF SYSTEM WORKING WITH 1° ACCURACY
AVERAGE OF 10 READINGS

*COMPUTED USING FORMULA FOR EQUAL RADIUS CIRCLE = $\sqrt{AB}$

Figure 47. ECCM techniques affecting an AN/PRC-77 radio.

This equipment and its associated speech security equipment will provide the frequency-hop capability mentioned in the Foreword to this thesis. A prototype family of equipment has been developed and type-nomenclatured the AN/URC-78(*). The basic receiver-transmitter (man-pack) is shown in Figure 48, the vehicular system in Figure 49, and the aircraft system in Figure 50. The technical characteristics of this set are shown on Table 10. The important new features which this new family provides are:

1. Higher power output on the basic receiver-transmitter, which will be the man-pack unit (comparable to the AN/PRC-77).

2. An improved automatic antenna matching network.

3. Provision for 25 kHz channel operation (thus improving frequency spectrum conservation).

4. Total integration of the same receiver-transmitter in all applications (man-pack, vehicular, and aircraft), thus easing the logistics required to support the system. The basic transmit and receive circuitry are shown in block diagram form in Figure 51.

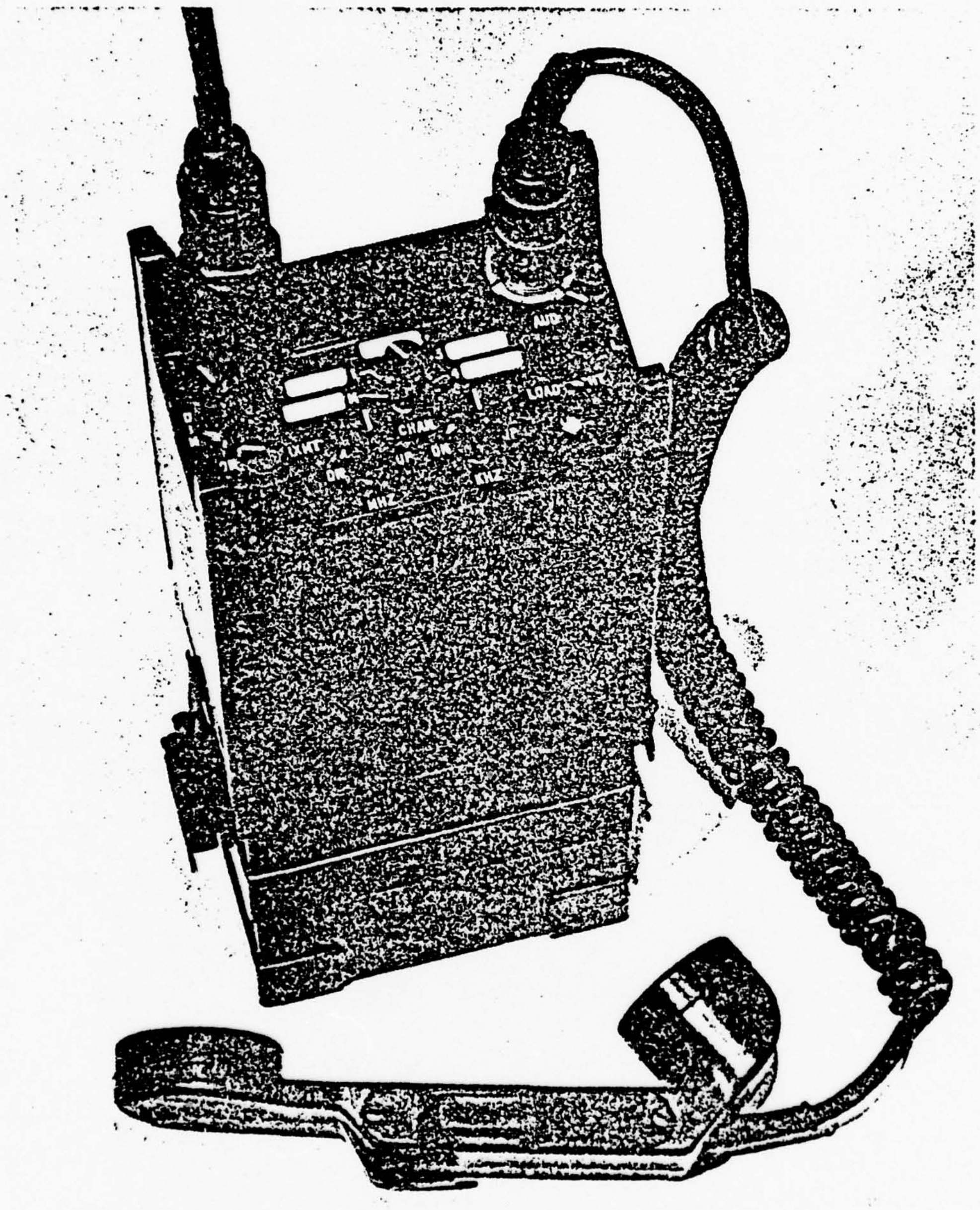


Figure 48. Man-pack receiver-transmitter AN/URC-78(*). (Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

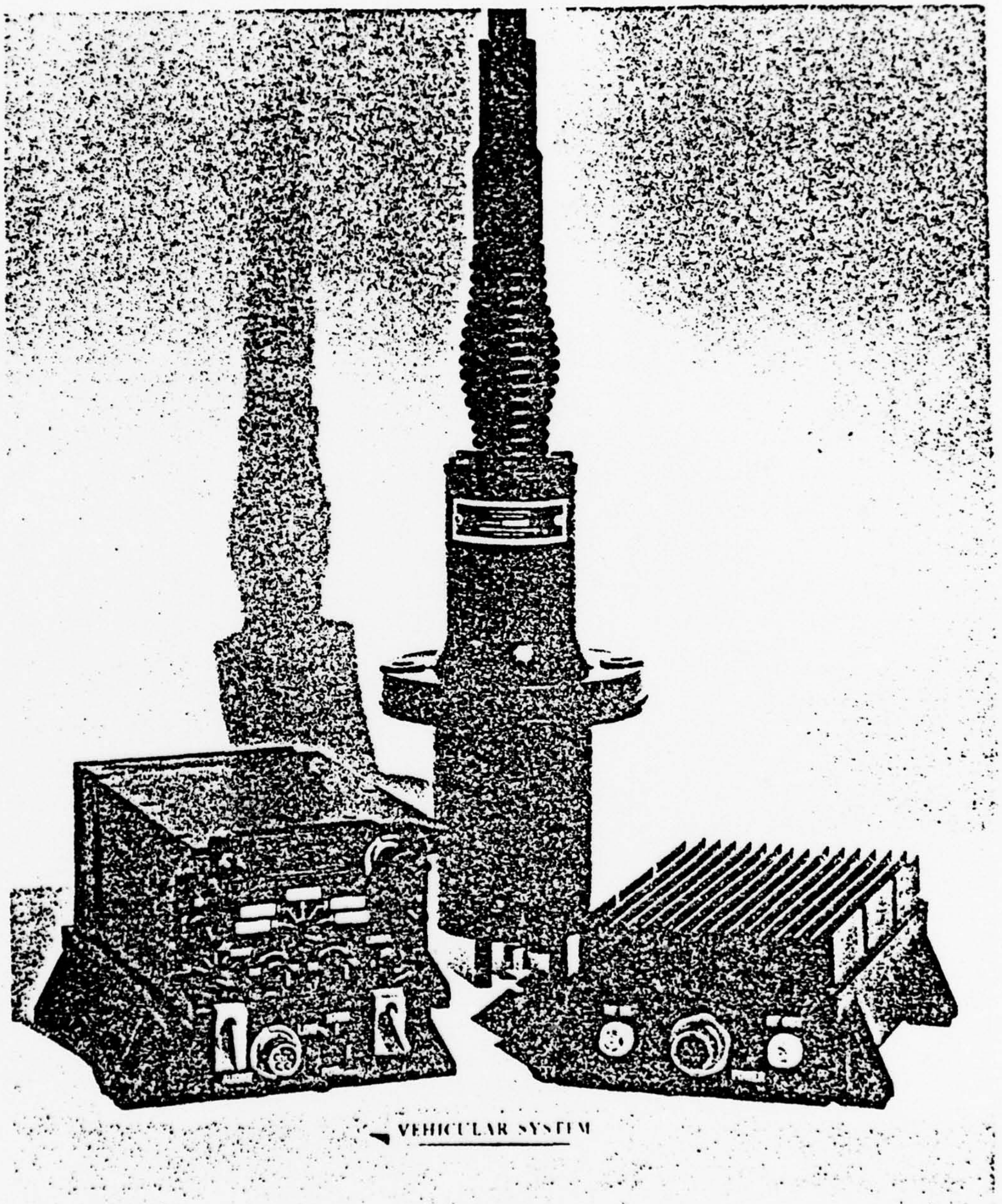


Figure 49. AN/URC-78(*) vehicular system. (Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

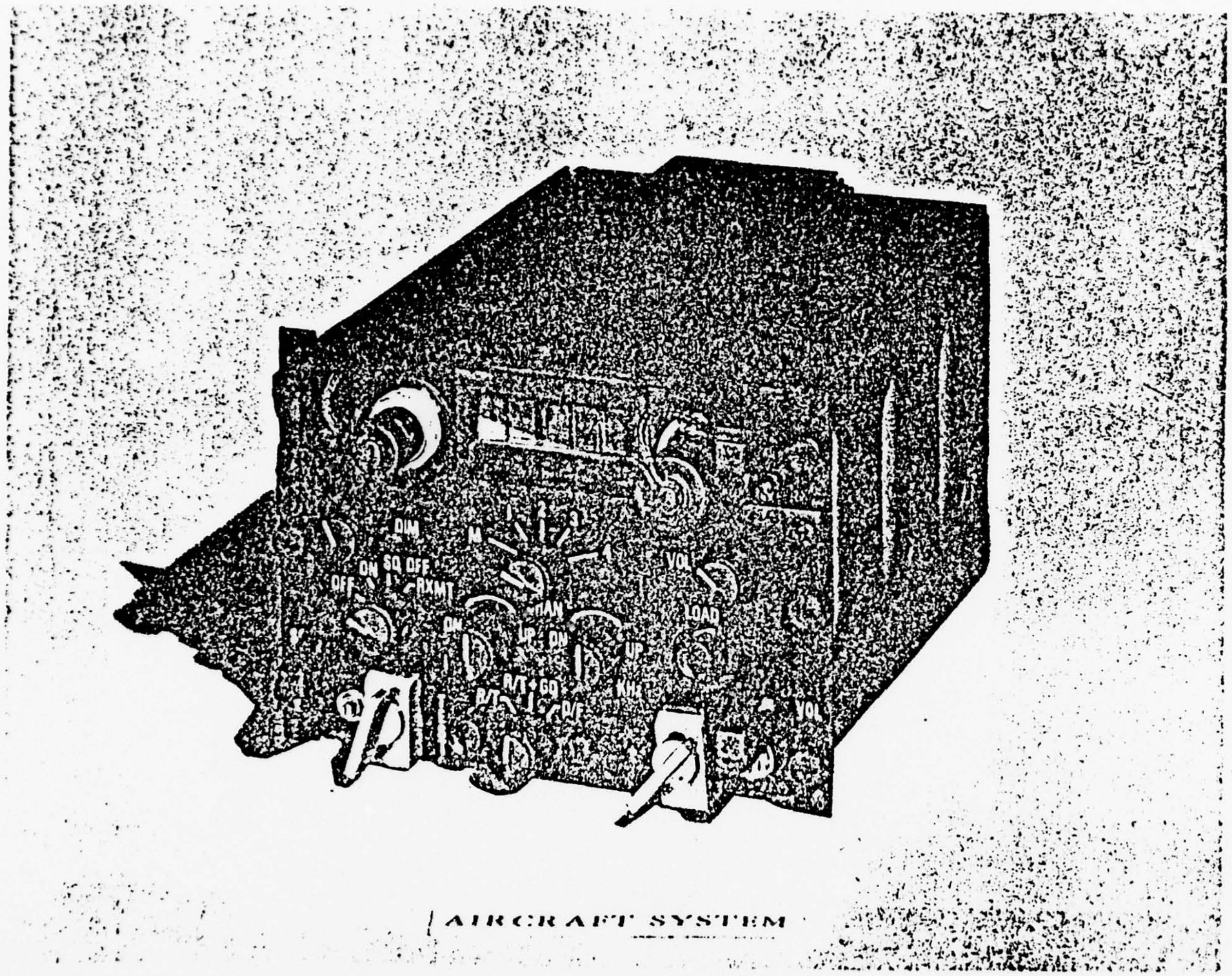


Figure 50. AN/URC-78(*) aircraft system. (Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

TABLE 10

TECHNICAL CHARACTERISTICS OF RADIO SET AN/URC-78(*)*

Frequency Range	30 - 79.795 MHz
Modes of Operation	25 kHz Channel Spacing 50 kHz Channel Spacing Wideband Secure Mode
Receiver-Transmitter:	
Weight	10 lbs with battery and antenna
Size	5"W X 3.25"H X 5.5"D
Battery	24 hours life for 14:1 Receive to Transmit duty cycle.
Preset Frequency Capability	4 preset frequencies
Manpack Antenna	Telescoping 1' to 4' whip
Receiver Sensitivity 10 dB S + N + D/N + D	25 kHz Channels - 118 dBm 50 kHz Channels - 116 dBm Wideband - 105 dBm
Audio Output:	
Headphone	50 mw into 600 ohms
Wideband	+10 dBm into 600 ohms
3rd Order Intermodulations	80 dB above 1 uv
Desensitization	+32 dBm at ± 10% f_o for 6 dB degradation of 26 dB S + N + D/N + D
Receive Power Consumption	900 mw maximum
RF Power Output	10 watts into 50 ohms
Transmitter Noise Floor with respect to 10 watt carrier	-125 dB for 30 kHz BW ±10% removed from f_o
Vehicular Applique:	
RF Power Output	40 (+15, -5) watts
Size	250 cu. in. maximum (includes R/T)
Aircraft Applique: (Includes guard band receiver, homing circuitry, and power supply)	
Size: Aircraft Applique and R/T	5.75"W X 4.125"H X 6.5"D maximum
Weight: Aircraft Applique and R/T	6.0 lbs maximum

*Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.

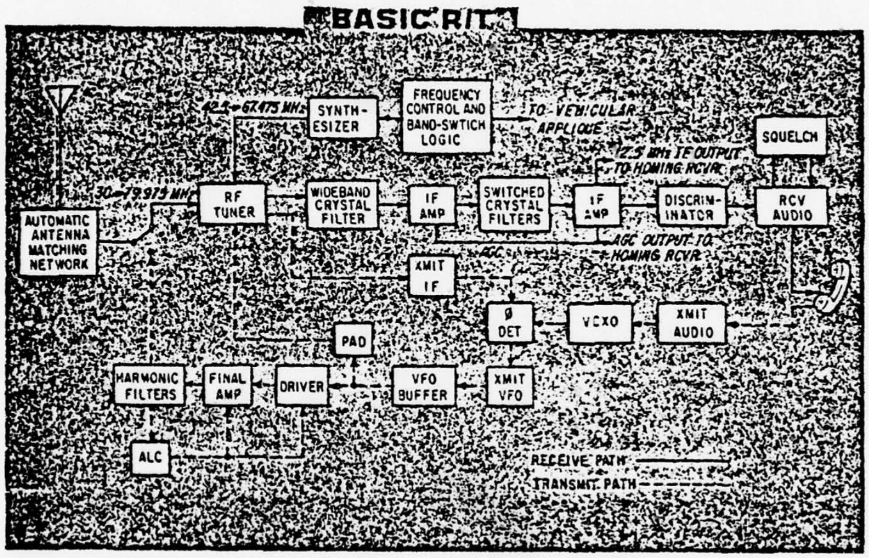


Figure 51. Block diagram of transmit and receive circuitry, Radio Set AN/URC-78(*). (Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

CHAPTER IV

DIVISION LEVEL COMMUNICATIONS

A. An example of a type division communications sytem was shown on Figure 5, page 10.

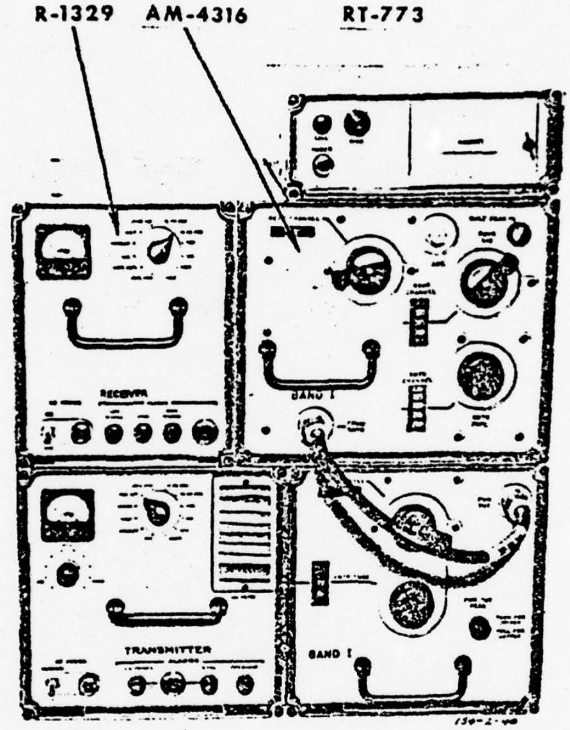
B. The "backbone" of the division level communications system is the multichannel radio network established to provide direct and area support throughout the division area. An example of that network is shown in Appendix D, page 167. The types of traffic routed over multichannel radio systems is discussed in the introduction to this thesis, pages 6-7.

C. Radio Set AN/GRC-103 (Figure 52) is a compact, transportable multichannel radio set used with various combinations of time division multiplexing, pulse-code modulation (TDM-PCM) equipment to provide 12 channel service between major commands within the division and area communications support on a limited basis.

1. The technical characteristics of the AN/GRC-103 are shown on Table 11.

2. The different configurations of the AN/GRC-103 and its associated carrier (multiplexing) equipment are shown on Table 12. The configuration used in the Airborne and Air Assault Divisions is the AN/MRC-127.

R-1329 AM-4316 RT-773



T-983 AM-4320

AN/GRC-103

Figure 52. Radio Set AN/GRC-103.

TABLE 11

TECHNICAL CHARACTERISTICS OF RADIO SET AN/GRC-103

Type of service: 500F9
Carrier: TD-660 (PCM only)
Baseband: 240 kHz
Frequency range: Band I, 220-404.5 MHz
Band II, 394.5-705 MHz
Band III, 695-1000 MHz
Planning range: 40-48 km
Power output: 25 w
Antenna: Corner reflector (AS-1852).
Power source: PU-625

SPECIAL FEATURES

Automatic frequency control.
Frequency separation: 16.5 MHz transmit to receive.
Duplexer in receive tuning head.
Weight: 150 lbs (GRC-103).

TABLE 12

DIFFERENT CONFIGURATIONS OF MULTICHANNEL RADIO EQUIPMENT USING RADIO SET AN/GRC-103

CONFIGURATIONS

Description	MRC-115 TML	MRC-126 TML	MRC-127 TML	TRC-113 RELAY	TRC-145 TML
GRC-103	2	1	2	3	2
TD-660	2	1	2		2
TD-754				3	2
CV-1548	2	1	2		2
Vehicle	1/4-ton tlr	Pallet 1/4-ton tlr	Pallet 1/4-ton tlr	1-1/4-ton	1-1/4-ton
Weight	1,900 lbs	1,550 lbs	2,050 lbs	1,945 lbs	2,150 lbs

3. The antenna used with the AN/GRC-103 is a corner reflector (described in Appendix I, paragraphs 11f and 11g) AS-1852/GRC-103.

D. A related item of tactical multichannel radio equipment is Radio Set AN/GRC-163 (Figures 53 and 54). This equipment was introduced on a limited production basis during the Vietnam War and proved to be very successful from the standpoint of communications, although there appear to have been problems in maintaining the system. This author used this equipment to great advantage in the 173d Airborne Brigade, where the equipment was used to provide telephone trunking and sole-user circuits from brigade headquarters down to the headquarters of assigned and attached infantry and artillery battalions. This system was apparently dropped from the inventory following the close-out from Vietnam. This assemblage, when used for communication between an infantry battalion headquarters and an infantry brigade headquarters can provide increased flexibility to the overall communications system by providing the battalion access to the division multichannel and wire/cable system. It must be remembered that an infantry brigade headquarters is a <u>tactical</u> headquarters only and not an administrative or logistical headquarters. All administrative and logistical support for the infantry battalion comes from elements of the Division Support Command, usually located in the Brigade

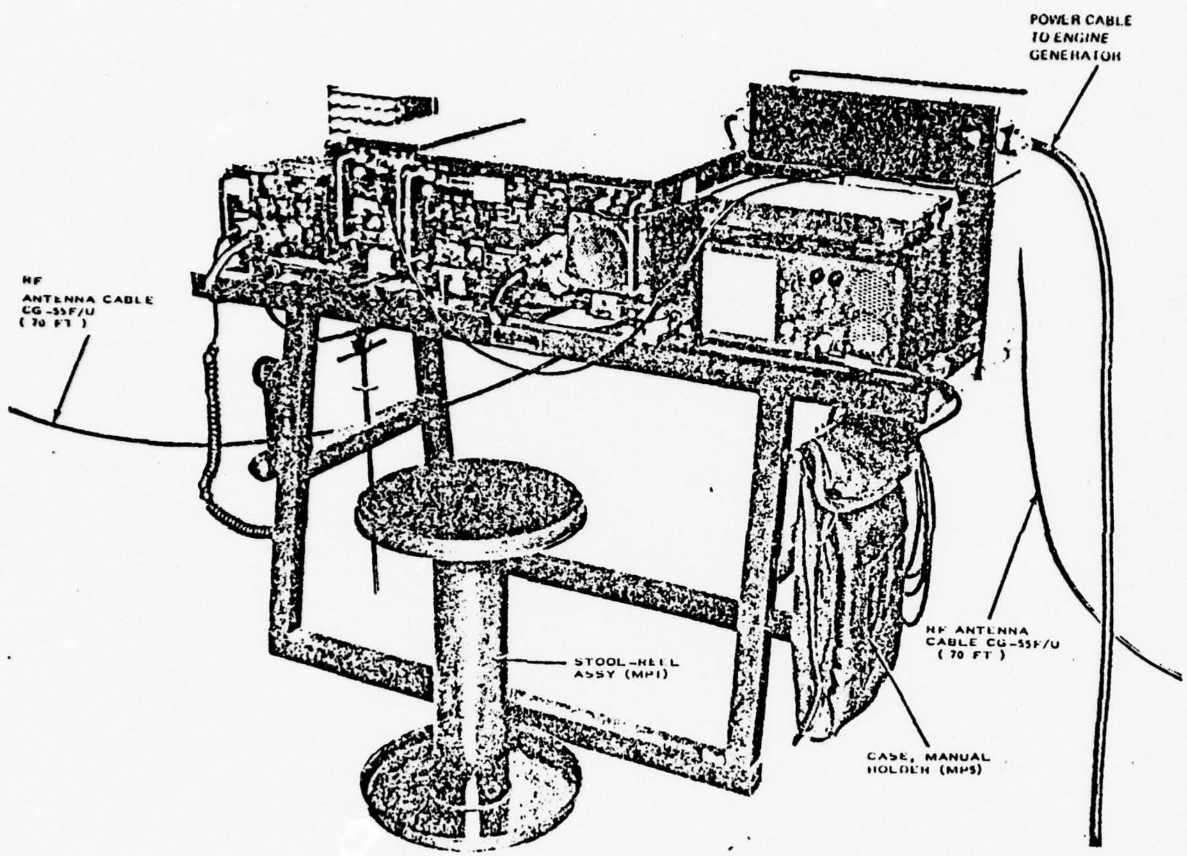


Figure 53. Radio Terminal Set AN/GRC-163; dismounted and less antennas and masts.

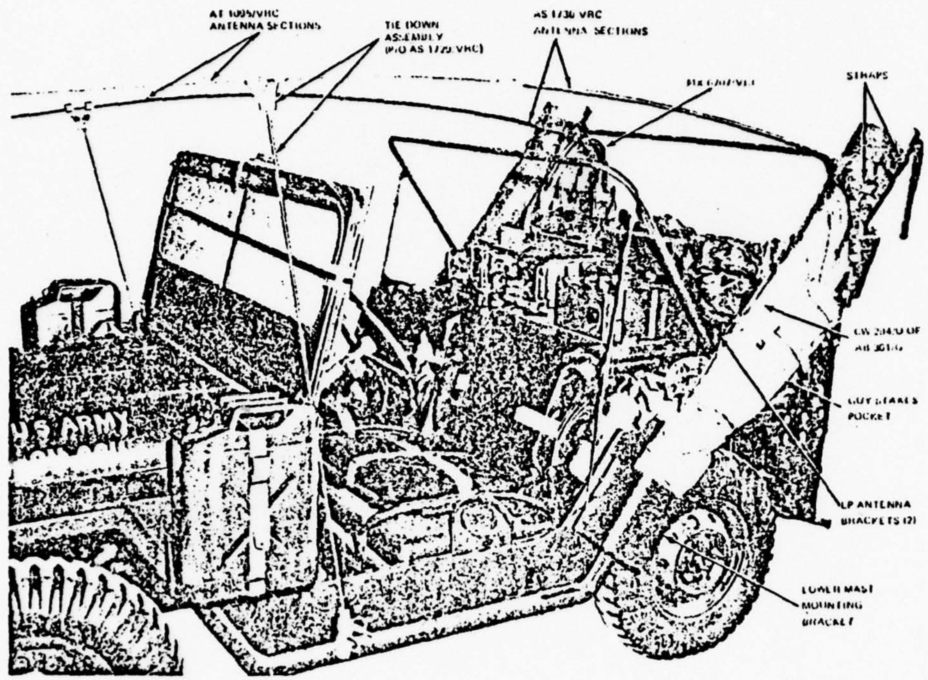


Figure 54. Radio Terminal Set AN/GRC-163 installed in M151A1.

area, well to the rear of the brigade headquarters. Usually, the infantry battalion does not even have direct communications to those support elements.

1. The antenna systems used with the AN/GRC-163 include a LPDA AS-2169/G which provides a gain of -2 dB to +2 dB across the 30-76 MHz operating frequency band, and the AS-1729/VRC (Chapter III), which is used as a vehicle mounted antenna or as an elevated ground plane antenna with a special counterpoise attachment which was developed for this system. (Figures 55 and 56).

2. Technical characteristics of the AN/GRC-163 are shown on Table 13.

3. The Marine Corps equivalent of the AN/GRC-163 is the Terminal Set, Telegraph-Telephone AN/VCC-1 (Figure 57). Additionally, the Marine Corps has developed, adopted, and deployed a 12 channel assemblage using the same basic components as the AN/GRC-163//AN/VCC-1. This item is nomenclatured AN/VCC-3 (Figure 58). (They also have an 8 channel assemblage, the AN/VCC-2, which is not shown.) Note that the AN/VCC-3 provides the same 12 channel capability as one half of the AN/MRC-127 (paragraphs C and D above) (the AN/MRC-127 contains two 12 channel terminals) but uses less expensive radio, carrier, and antenna components, and has a greater single hop communications range (40-48 km for the AN/MRC-127 versus up to 80 km for the AN/GRC-163//AN/VCC-1,3).

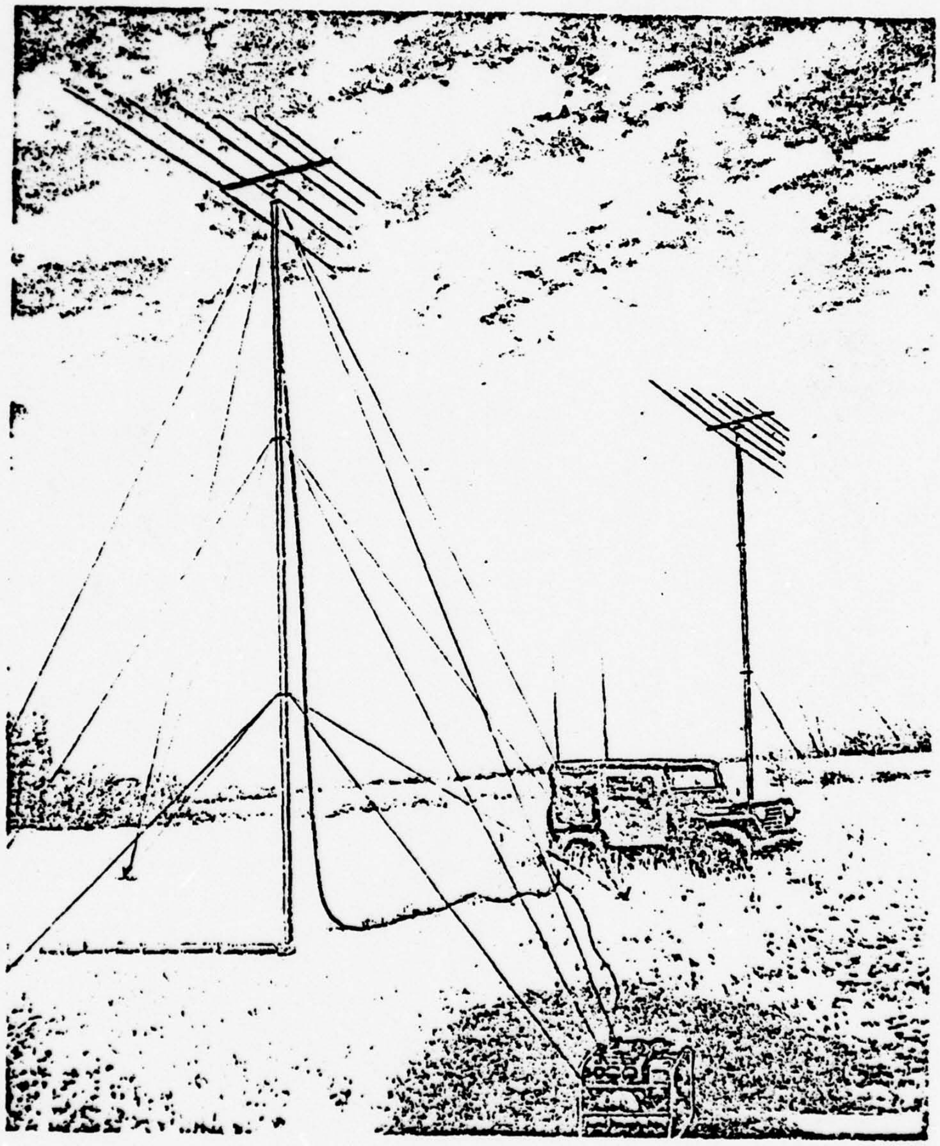


Figure 55. AN/GRC-163, shown with antennas, AS-2169/G.

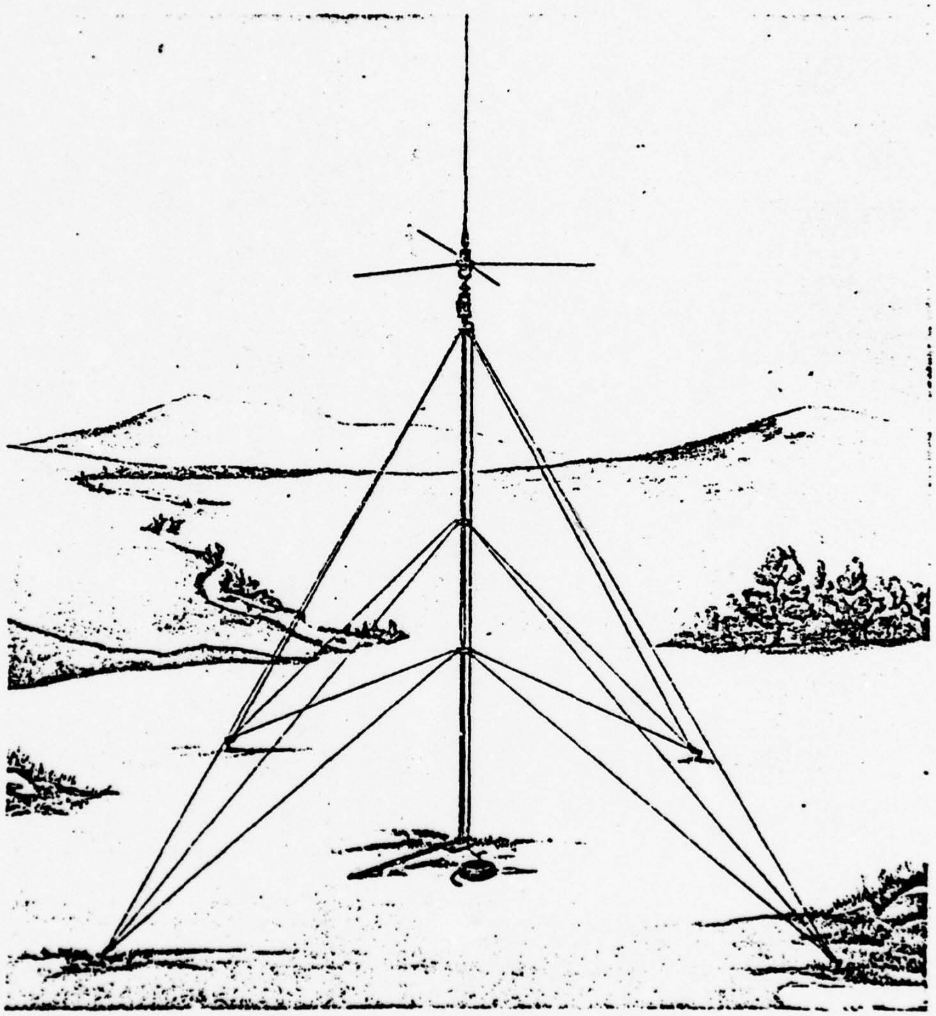


Figure 56. Antenna AS-1729/VRC with counterpoise, mounted on Mast AB-301/G.

TABLE 13

TECHNICAL CHARACTERISTICS OF RADIO SET AN/GRC-163

Frequency range (RT-524 (*)/VRC and R-442 (*)/VRC)	30.00 to 75.95 MHz.
Radio operating range (nominal):	
Using vehicle-mounted whip antennas	8 to 12 miles (13 to 20 kilometers (km), (approx)).
Using mast-mounted whip antennas	Up to 30 miles (up to 50 km (approx)).
Using mast-mounted LP antennas	Up to 50 miles (up to 80 km (approx)).
Transmission and reception	Simultaneous voice and radiotelegraph transmission and reception.
Number of channels:	
Voice (telephone)	Four plus one order wire for radio operator.
Vf telegraph	Two.
Power required:	
At 115 volts ac	50 to 60 Hz, or 400 Hz; 4 amperes.
At 230 volts ac	50 to 60 Hz; 2 amperes.

Terminal Set, Telegraph-Telephone AN/VCC-1 mounted in AN/MRC-109 Radio Set.

This Terminal Set consists of the following major items:

1 ea TH-81/GCC Terminal	1 ea J-2790/GCC Terminal Box
1 ea MT-3970/VCC Mount	1 ea CW-997/VCC Cover
1 ea CW-998/VCC-1 Cover	1 ea C-7674/VCC Control, Power Supply
1 ea CX-10913/GCC Cable Assembly, 50 ft.	1 ea CX-10914/VCC Cable Assembly, Power, 50 ft.
1 ea F-1210/VCC-1 Filter, Band-Pass	2 ea MT-4025/VCC Mounts
	1 ea MT-4081/VCC Mount
1 ea MT-4080/VCC Mount	1 ea C-7827/VCC Control, Terminal Set
1 ea SA-1632/VCC Switch, Antenna.	

The AN/MRC-109 Radio Set consists principally of one RT-524/VRC Receiver-Transmitter, one R-442/VRC Receiver, antennas, and other accessories, mounted in an M-151 1/4 ton 4 x 4 truck. This equipment provides 1 order-wire, 4 telephone and 4 telegraph channels over ranges in excess of 50 miles.

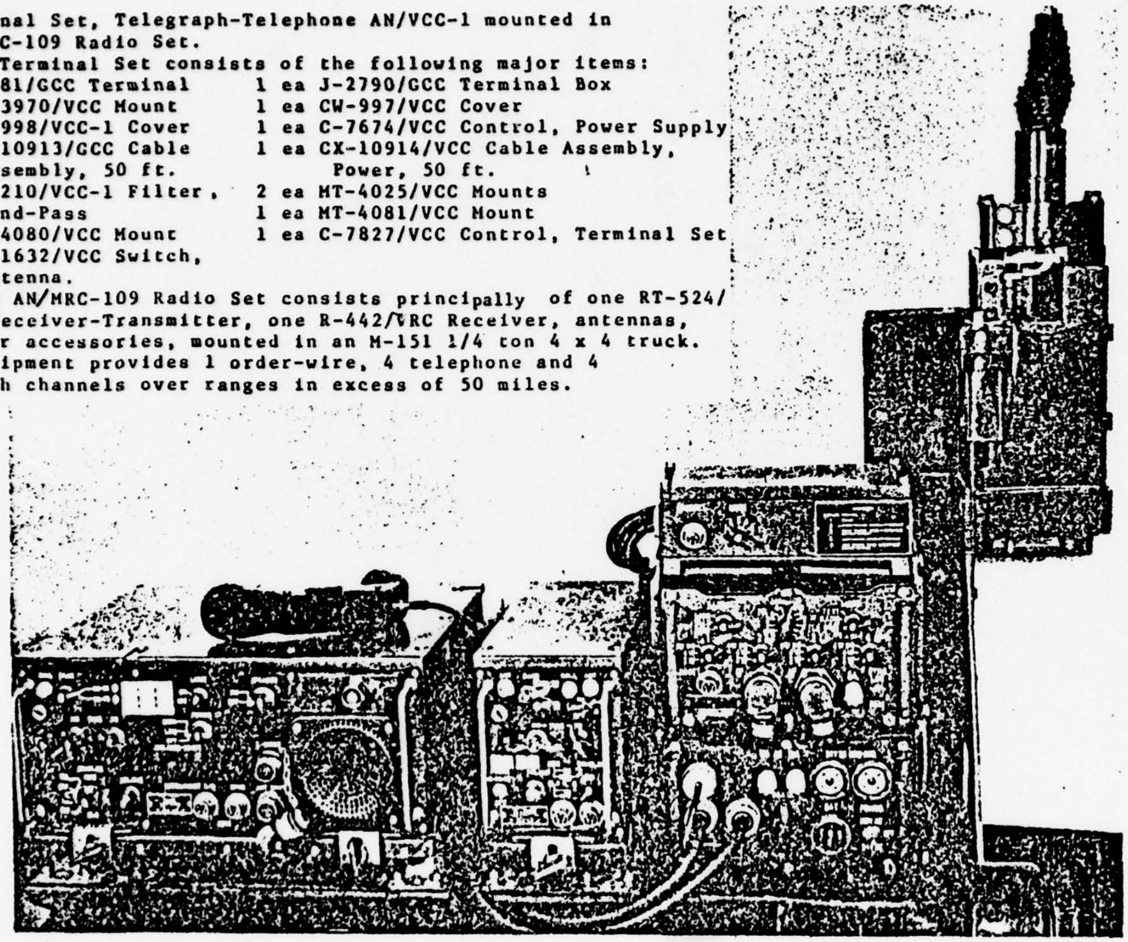


Figure 57. Terminal Set, TG-TP AN/VCC-1. (Courtesy of Radio Engineering Products, Montreal, Canada.)

Terminal Set, Telegraph-Telephone AN/VCC-3 mounted in AN/MRC-109 Radio Set.

This Terminal Set consists of the following major items:

3 ea TH-81/GCC Terminals	3 ea J-2790/GCC Terminal Boxes
3 ea MT-3970/VCC Mounts	1 ea CW-997/VCC Cover
1 ea CW-1042/VCC-3 Cover	1 ea C-7674/VCC Control, Power Supply
3 ea CX-10913/GCC Cable Assemblies, 50 ft.	1 ea CX-10914/VCC Cable Assembly, Power, 50ft.
1 ea F-1213/VCC-3 Filter, Band Pass	1 ea F-1214/VCC-3 Filter, Band Pass
4 ea MT-4025/VCC Mounts	1 ea MT-4081/VCC Mount
1 ea MT-4080/VCC Mount	1 ea C-7827/VCC Control Terminal Set
1 ea SA-1632/VCC Switch, Antenna	

The AN/MRC-109 Radio Set consists principally of one RT-524/VRC Receiver-Transmitter, one R-442/VRC Receiver, Radio, antennas, and acessories mounted in an M-151 1/4 ton 4 x 4 truck. This equipment provides 3 order-wire, 12 telephone, and 12 telegraph channels over ranges in excess of 50 miles.

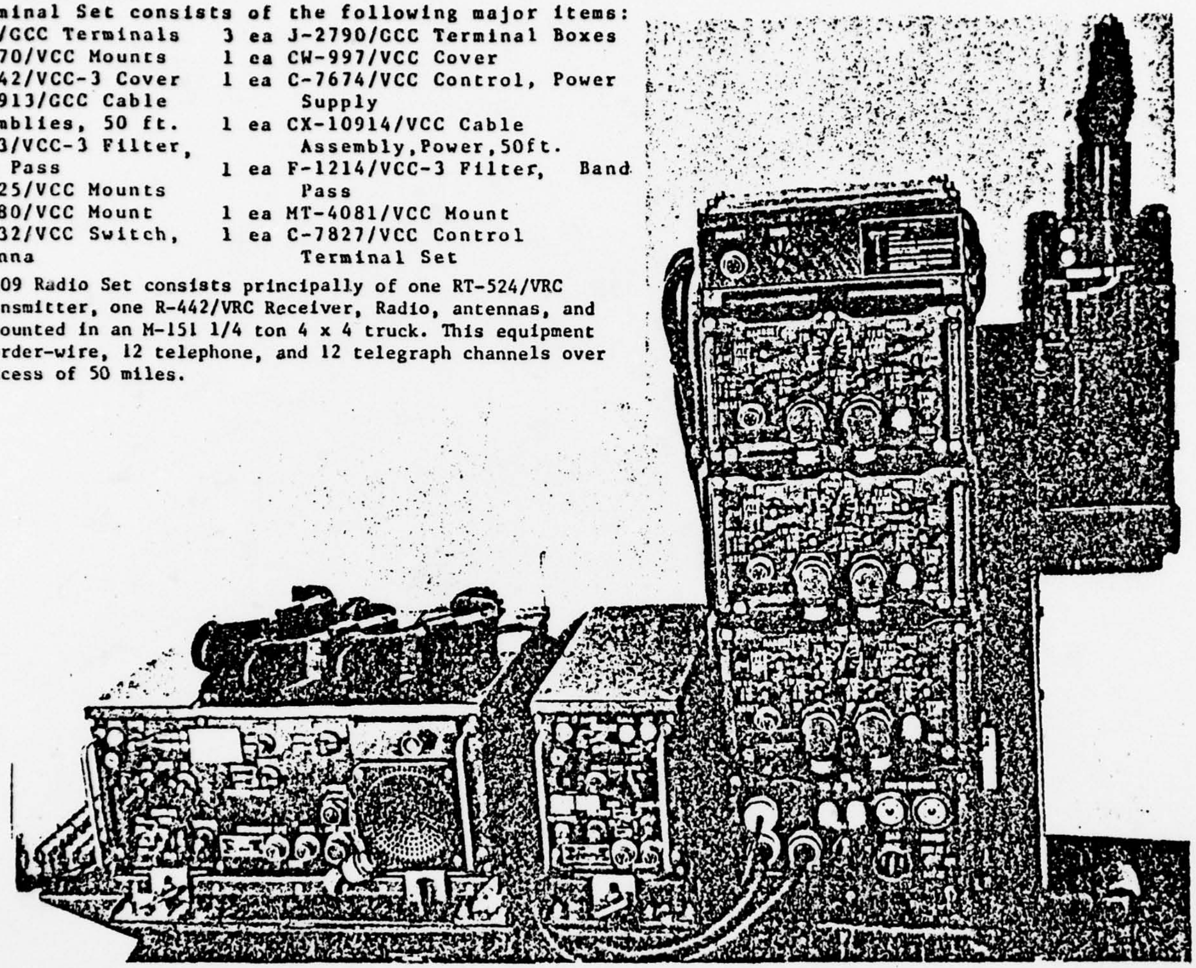
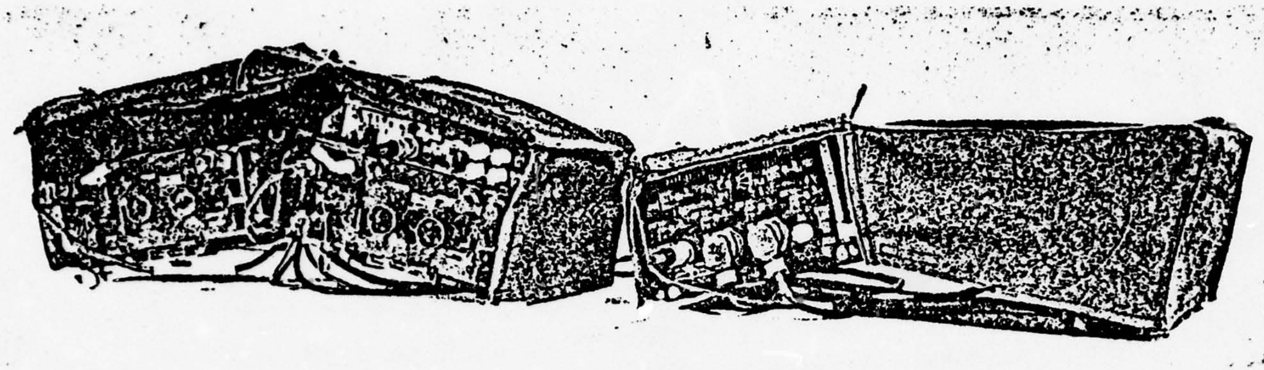


Figure 58. Terminal Set, TG-TP AN/VCC-3. (Courtesy of Radio Engineering Products, Montreal, Canada.)

4. Additionally, the Marine Corps has a 4 channel, man-pack multichannel radio capability in the AN/PCC-1 (Figure 59). This assemblage uses Radio Set AN/PRC-77 (Chapter II) to provide the same 4 channel capability as the AN/GRC-163//AN/VCC-1 over reduced distances. This assemblage would have particular application to the assault elements of the airborne and airmobile infantry battalions if the concept of extending multichannel radio down to battalion level were adopted.

E. At brigade level there are approximately (Figure 29, page 55) 10-12 VHF FM radio nets (or stations in nets) operating out of an area no more than 100 meters in diameter. At division level the number doubles or triples. At present each radio set requires its own separate antenna, which often makes our higher headquarters look like antenna forests. Figure 60 shows an extreme example from a major radio relay site located on a mountain top in South Vietnam. While this example overstates the case, nonetheless our higher headquarters are extremely easy RDF targets because of the large number of electromagnetic emissions which can be detected, located, and determined to be coming from a central area. One of the current areas of research and development is the design and construction of multichannel VHF antenna multicouplers in order to eliminate these large numbers of antennas around headquarters. These items would allow two or more receiver-transmitters to operate from the same broadband antenna, with isolation between the receiver-transmitters.



Terminal Set, Telegraph-Telephone AN/PCC-1 with two Receiver-Transmitter RT-505/PRC-25, Handset H-189/GR and Battery BB-451/U. Covers opened.

This Terminal Set consists of the following major items:

1 ea TH-81/GCC Terminal	1 ea J-2790/GCC Terminal Box
1 ea C-7673/PCC-1 Control Unit-Rectifier	2 ea F-1209/PCC-1 Filter, Band Pass
1 ea CW-996/PCC-1 Cover, Battery Box	
1 ea CW-1030/PCC-1 Cover, Terminal	2 ea F-1219/PCC-1 Filter, Band Pass
1 ea CW-1024/PCC-1 Cover, Radio Set	
1 ea CX-11753/U Cable Assembly, Power, 50 ft.	1 ea MT-4056/PCC-1 Mount
1 ea CX-10913/GCC-1 Cable Assembly, OW Extension, 50 ft.	1 ea MT-4057/PCC-1 Mount
1 ea Installation Kit.	

This provides an order-wire, 4 telephone and 4 telegraph channels over components of the AN/PRC-25 Radio Set. The Terminal Set and Radio Sets are carried by two men, and with a suitable antenna system have a range of 20 miles or more. This assembly operates approximately 30 hours from a fully-charged battery.

Figure 59. Terminal Set, TG-TP, AN/PCC-1. (Courtesy of Radio Engineering Products, Montreal, Canada.)

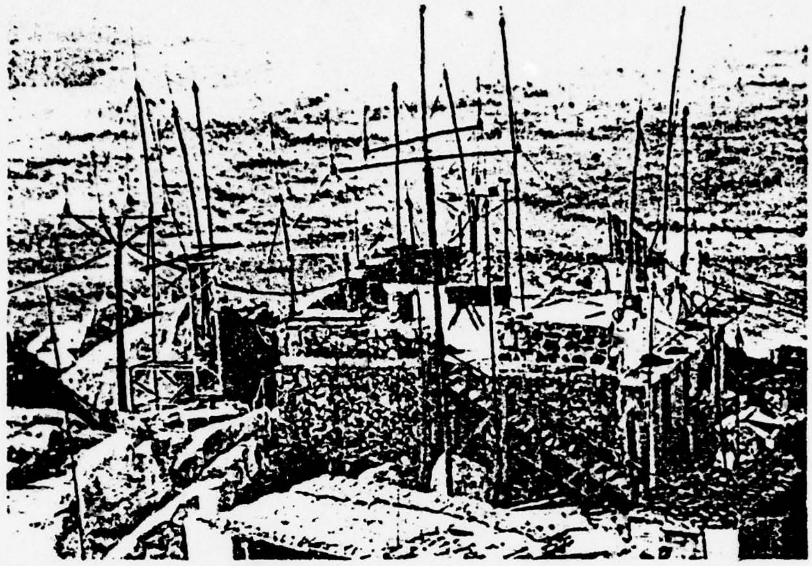
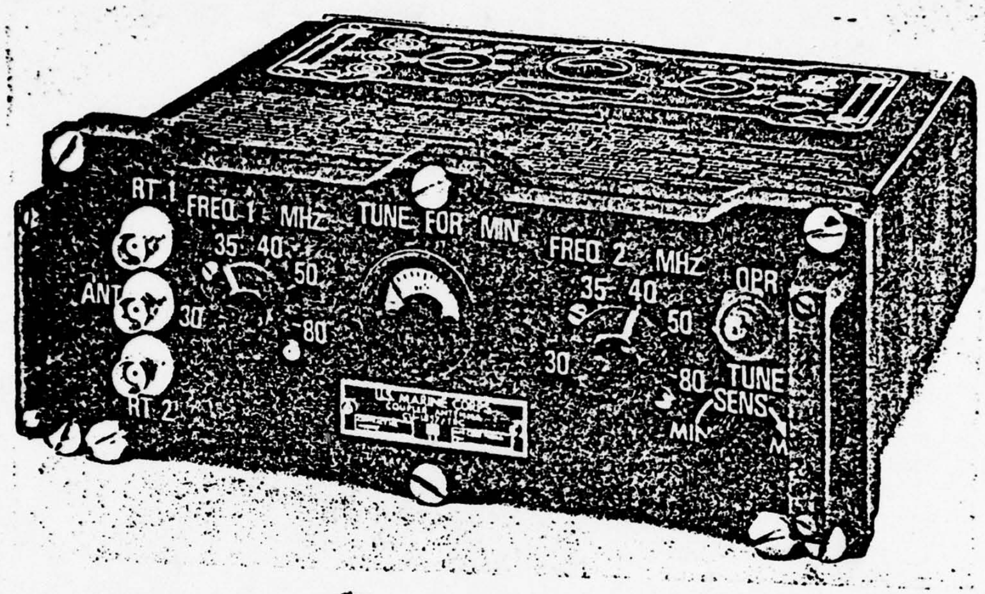


Figure 60. Nui Ba Den, South Vietnam. In the photo above there are 29 RC-292 VHF antennas, 2 HF whip antennas, and 1 multichannel radio antenna (VHF/UHF) within a radius of 50 feet.

1. The Marine Corps has already adopted a 2 channel Antenna Coupler CU-1857/TRC (Figure 61). Note that the isolation provided by the coupler is greater than can be obtained with separate antennas.

2. Collins Radio Company has submitted a proposal for a VHF Multicoupler of 2, 5, and 10 channels (Figure 62). Technical data on the method of operation and construction are provided in Figures 63 and 64, while the insertion loss for different numbers of communication channels is shown on Figure 65.

F. An area which has not been covered in this thesis but which bears mentioning is the subject of Radioteletypewriter (RATT) communications within the Airborne and Air



This antenna duplexer is intended for use with the AN/PRC-25, AN/PRC-77 and AN/VRC-12 series Radio Sets and other radio sets operating in the 30 to 76 MHz band. It permits operating a transmitter and a receiver, or two receivers, or two receiver-transmitters simultaneously with a single constant-impedance antenna, such as the AS-2369/TRC, a constant impedance whip, or a log-periodic array. It permits operation on frequency pairs spaced at only 1.5 MHz, and provides isolation between transmitter and receiver of about 45 dB. This figure is much better than can be obtained with separate antennas. It also provides about 45 dB suppression of transmitter hash at the receiver. The transmitter to antenna loss is about 1.5 dB at 1.5 MHz spacing.

Dimensions 3-1/2 inches h x 8 inches d x 8-7/8 inches w, weight 7-1/2 pounds.

Figure 61. Antenna Coupler CU-1857/TRC. (Courtesy of Radio Engineering Products, Montreal, Canada.)

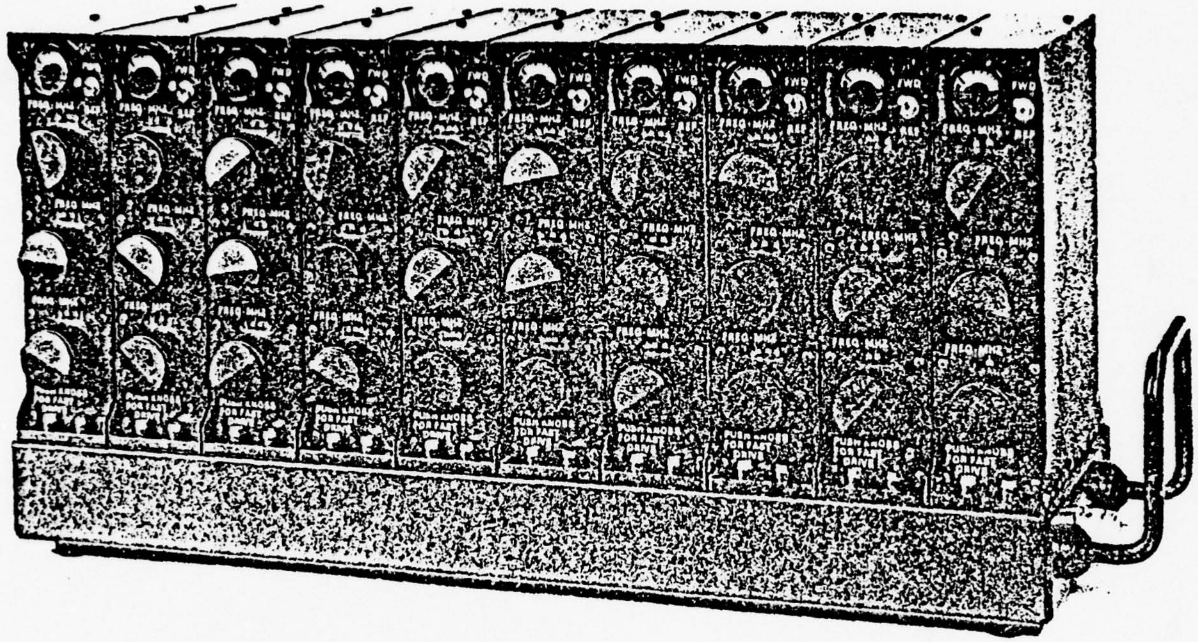


Figure 62. Ten channel VHF multicoupler. (Exploratory developmental model.)
(Courtesy of Collins Radio Company, Cedar Rapids, Iowa.)

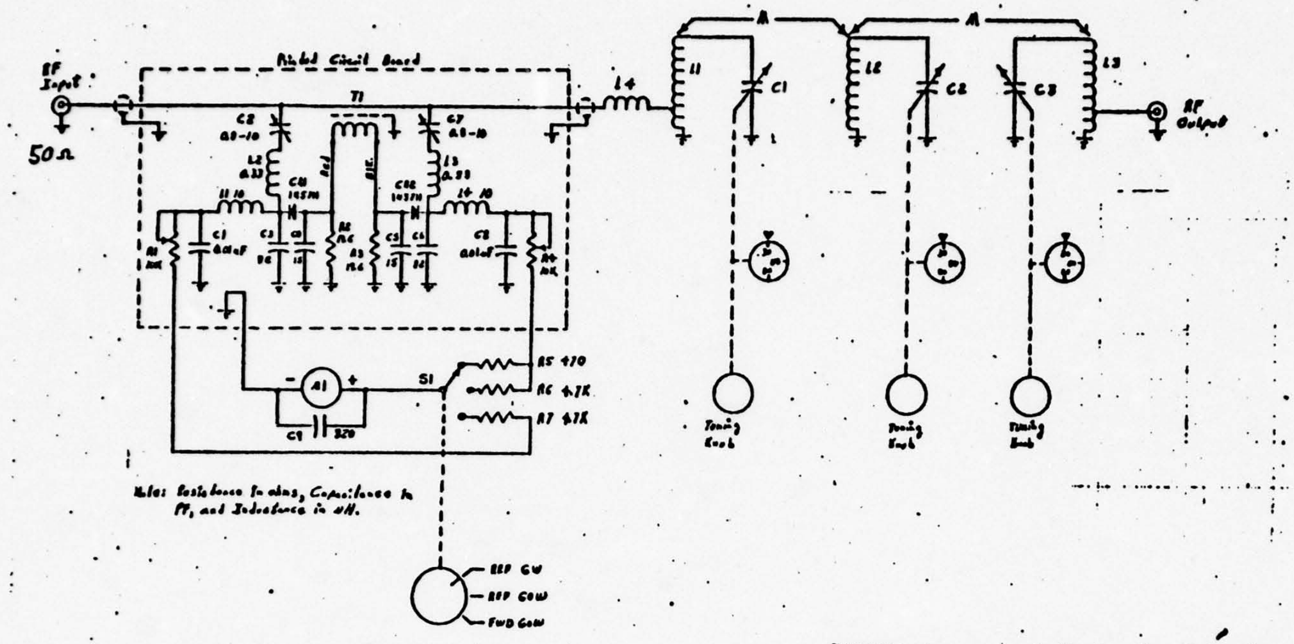


FIGURE 2-1 Manually Tuned Filter Schematic

Figure 63. Manually tuned filter schematic. (Courtesy of Collins Radio Company, Cedar Rapids, Iowa.)

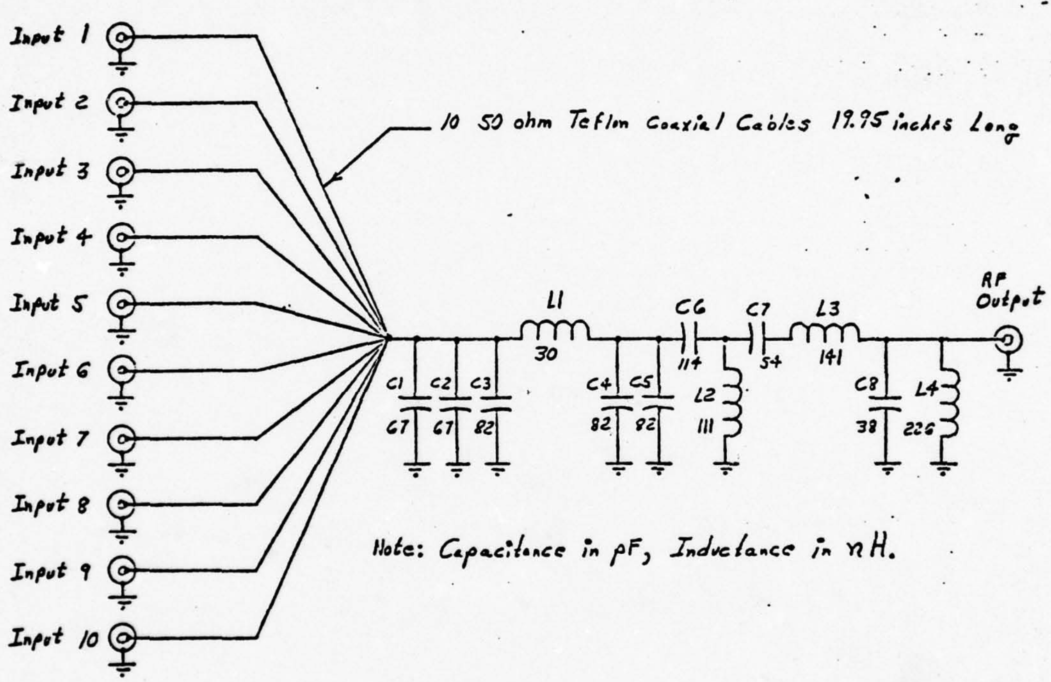


Figure 64. Matching network schematic (lumped elements). Ten channel VHF multicoupler. (Courtesy of Collins Radio Company, Cedar Rapids, Iowa.)

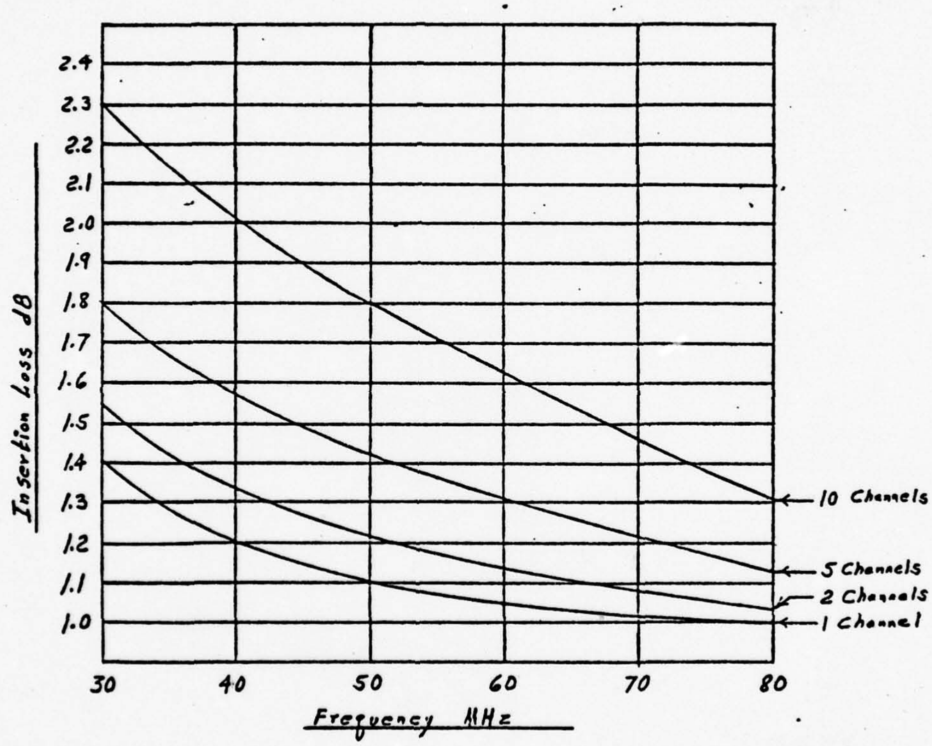


Figure 65. Insertion loss for 1, 2, 5, and 10 communication channels. (Courtesy of Collins Radio Company, Cedar Rapids, Iowa.)

Assault Divisions. As mentioned in the introduction, RATT is normally a supplementary or alternate means of communications; its full capabilities only being realized when long distance communications via ionospheric refraction are required. Telecommunications center teletypewriter circuits extend down to brigade level. The only means of page print, hard copy communication available to the infantry battalion, however, is a RATT set, the AN/VSC-2 (picture not available). The infantry battalion uses this set in an ADMIN/LOG, OP/INTEL, or General Purpose Net with the brigade headquarters. These nets receive very little traffic, however, due to the fact that the AN/VSC-2 has no tape transmit or receive capability, therefore the speed of transmission is limited to the speed at which the operator can type. Additionally, the radio component of the AN/VSC-2 is a high power AM/SSB transceiver, which is subject to the atmospheric noise characteristic of AM. Often, static crashes or other noise or signal interference cause the on-line encryption equipment to lose synchronization, thereby causing message garble at the receive station. The message, or at least the garbled portion of the message, must then be retransmitted at the same slow speed as before.

A device currently being developed by Cincinnati Electronics Corporation offers the possibility of hard copy message traffic down to the lowest tactical levels. The

Digital Message Device (DMED) (Figure 66) provides a means to enter and retrieve digital alphanumeric information in a free format style over many types of communications systems. Weighing just over 2 pounds (0.91 kg), the DMED occupies a volume of only 51 cubic inches (835.7 cu cm). It is a hand-held, self-contained unit. The DMED is flexible and versatile, and has total software control.

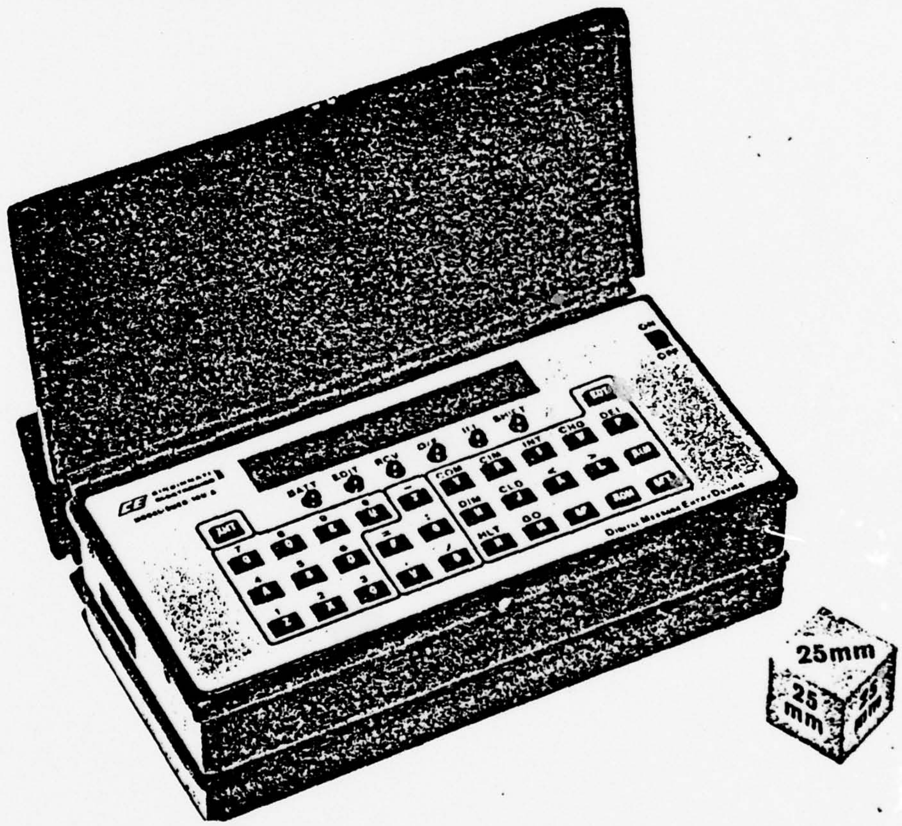


Figure 66. Digital Message Entry Device (DMED).
(Courtesy of Cincinnati Electronics Corp., Cincinnati, Ohio.)

The digital display consists of 16 alphanumeric LED characters, presenting the message in scroll form. The status display consists of 6 LED indicators, 5 of which are under software control. The keyboard includes 32 keys, each being assigned an alphanumeric value or functional meaning by software tables. A wide range of interface requirements may be met through the use of internal switch and strap options which alter the control and electrical data forms available on the 10 pins of the external connector. The DMED may be supplied with charger, carrying case and cables. A printer for the DMED is being developed.

The technical characteristics of the DMED are shown on Table 14.

Two of the outstanding features of this piece of equipment are that it has burst (very high speed) transmit and receive capability which would solve the problem of noise disruption of signal, and the device is being developed to interface with almost all tactical radio equipment which would allow its use on not only AM/SSB but also FM equipment. These capabilities would provide printed message communication by electrical means to any tactical level.

TABLE 14

TECHNICAL CHARACTERISTICS OF THE DMED*

Specifications

Display	16 alphanumeric LED characters, presenting message in scroll form
Message Memory	• 1020 characters ▪ 510 characters - Transmit ▪ 510 characters - Receive
Keyboard	32 keys on 0.5 inch matrix centers
Status Display	6 LED indicators
Technology	CMOS Microprocessor based
Input/Output	• Asynchronous • Serial (digital) • FSK modem available (two-tone) • Speed (transmit and receive) ▪ With Modem 150 300 600 1200 bps ▪ Baseband 150 300 600 1200 2400 4800 9600 19200 bps
Type of Code	• ASCII - 6 bit • Odd, parity • One start bit and two stop bits
Type of Message Entry Format	Free Format from available char. set
Keyboard Entry	Std. typewriter alphanumerics and punctuation
System Link Interface	Meets MIL-SPEC-188-100 interface requirement
Packaging	Hand-held, self-contained
Size	51 cubic inches - - 835.7 cu cm (approximate)
Weight	2 pounds (0.91 kg)

- Full Edit
  - Change any character in output message
  - Delete any character in output message
  - Insert any number of characters
- Reread input or output message as many times as needed.
- Message may be Scrolled across display at several speeds which are selected on keyboard and may be stopped any time, then restarted, continued, cleared, or reverse directions.
- Burst transmit and receive
- Acknowledges both correct and incorrect messages (switch option)
- Message registers may be cleared separately
- Display cleared separately
- Edit Cursor can be positioned as desired
- Status Display Options
  - Low Battery
  - Memory Overflow (output)
  - Edit Mode or Acknowledge
  - Shift Mode
  - Illegal operation
  - Receive

*Courtesy of the Cincinnati Electronics Corp., Cincinnati, Ohio.

CHAPTER V

CONCLUSIONS, COMMENTS, AND RECOMMENDATIONS

A. Tactical communications is the most critically important area in all the vast military communications system. People, quite literally, live or die depending upon whether or not a reliable communications system exists whereby they have access to the command and support elements which direct, assist, or maintain their activities.

The most important single means of tactical communication is the single channel voice radio, and the heart of that system is, as has been demonstrated, the antenna equipment used to radiate and receive the electromagnetic energy output of the radio set. Proper choice and installation of that antenna equipment allows the radio communications system to span the increased distances created by tactical maneuver, and, if properly sited, provides some measure of security against hostile ECM.

B. The conclusions, comments, and recommendations that follow are divided into two categories: equipment, to include radio, antenna, and peripheral items; and technical literature.

1. Equipment:

(a) Radio Set AN/PRC-68 should be adopted into the Army inventory without further test. Reference 26 provides the details of service tests performed by the Marine Corps and includes their recommendations. Adoption of this radio set will provide the capability for the rifle squad to maintain communications with command and supporting elements while on extended independent operations such as short range reconnaissance or combat patrols. The present squad radio does not provide that capability.

(b) The AS-2369/TRC vertical half-rhombic antenna system should be adopted into the Army inventory and issued down to maneuver battalion level as an optional antenna system for extending the range of portable or vehicular mounted radio equipment.

(c) Comparison tests should be made between the AS-3166 (*)/GRC broadband biconical antenna and the HY-GAIN Model 4213 before a production contract is let for either antenna by any of the services. It is obvious that a broadband omnidirectional antenna is required, however neither of these antenna systems appear to have sufficient gain with respect to the RC-292 to warrant replacing it.

(d) Radio Set AN/PRC-70 should be adopted as a Standard A item and incorporated into the TOE's of airborne and airmobile infantry battalions and brigades, as well as other units in the Airborne and Air Assault Divisions, for the reasons given in Chapter III, paragraph E.

(e) Log periodic dipole array (LPDA) antenna systems should be added to the TOE's of tactical units to supplement existing equipment. Virtually every medium, and selected low power, radio set should have a high gain, broadband directional antenna system to meet tactical situations where a broadband, omnidirectional system is not required or will not provide the required communications range.

1. The 42A-1 is an excellent antenna system and could readily enhance communications over extended distances. It is recommended that this antenna be employed at division level in the Air Assault Division, at brigade and above in the Airborne Division, and possibly lower in the AIM Division.

2. The AS-2851/TR appears to be the best tactical LPDA based on the tests reported in Chapter III, paragraph F2. This antenna is type classified, has been assigned a Federal Stock Number, and could be produced immediately. It should be issued as supplementary antenna equipment down to battalion level in all tactical units. Further usage and employment tests may warrant issuing this item down to company level or below.

(f) The Combat Development Agencies of the various branches of the Army should reexamine the AN/GRC-163 system. Liaison with the Marine Corps would determine how effectively their items are being utilized (refer to Chapter IV, paragraphs D3-4), and whether the costs involved are warranted by the enhanced capability of maneuver units to utilize the Division multichannel radio and telephone system.

(g) The VHF antenna multicouplers should be purchased and deployed. Use of these items would not only enhance communications at major headquarters by reducing mutual coupling between adjacent antennas and improve transmission security by reducing the number of electromagnetic emitters within a given area, but would reduce installation time because fewer antennas would need to be erected.

(h) The Digital Message Entry Device should be investigated as a solution to the problems of tactical RATT equipment. The potential dollar savings involved by replacing the present expensive, complicated, unreliable and slow AN/VSC-2 with a simple, comparatively inexpensive digital read-in, read-out burst transmission device which interfaces with most types of tactical radio equipment are enormous.

2. Military Communications-Electronics and Communications Engineering Literature:

(a) Reference 15, which is one of the basic reference books for the military communications engineer, is sadly out of date and due for revision. Most of the equipment items referenced therein are long obsolete. A revised edition of this text would greatly assist the communications engineer in planning tactical communications systems.

(b) Reference 16, a basic Bible for all communications-electronics personnel, is also out of date and needs revision. This text does not cover the LPDA because that antenna had not been invented when the text was written.

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APPENDICES

APPENDIX A

JOINT ELECTRONICS TYPE DESIGNATION SYSTEM (JETDS)

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JOINT ELECTRONICS TYPE DESIGNATION SYSTEM (JETDS)

A. Equipment Indicators

The type designation for a major equipment consists of an AN, a slant bar, a series of three letters, a dash, and a number. The AN indicates a major equipment; the first letter in the series of three letters indicates where it is used (installation); the second letter indicates what it is (type equipment); the third letter indicates what it does (purpose); and the number indicates the model number of the specific type. For example, AN/MRC-2 indicates model 2 of a mobile radio communications set. The AN indicates that it is a major equipment.

1. A COMPLETE SET — AN/GRC-106 A (X, Y OR Z) (V)
   - Indicates "JETDS" system
   - Installation
   - Type of Equipment
   - Purpose
   - Model Number
   - Modification Letter
   - Changes in Voltage, Phase of Frequency
   - Variable Grouping
2. SAMPLE OF A COMPONENT USED WITH A PARTICULAR SET: RT-662/GRC-106A
3. SAMPLE OF A COMPONENT NOT USED WITH A PARTICULAR SET: S-69/GRC
4. TABLE OF SET OR EQUIPMENT INDICATOR LETTERS:

INSTALLATION

- A - Piloted aircraft
- B - Underwater mobile, submarine
- D - Pilotless carrier
- F - Fixed ground
- G - General ground use
- K - Amphibious
- M - Mobile (ground)
- P - Portable
- S - Water
- T - Transportable (ground)
- U - General utility
- V - Vehicular (ground)
- W - Water surface and underwater comb.
- Z - Piloted-pilotless airborne vehicle combination

TYPE

- A - Invisible light, heat radiation
- C - Carrier
- D - Radiac
- G - Telegraph or teletype
- I - Interphone and public address
- J - Electromechanical or inertial wire covered
- K - Telemetering
- L - Countermeasures
- M - Meteorological
- N - Sound in air
- P - Radar
- Q - Sonar and underwater sound
- R - Radio
- S - Special or combinations of types
- T - Telephone (wire)
- V - Visual and visible light
- W - Armament
- X - Facsimile or television
- Y - Data Processing

PURPOSE

- B - Bombing
- C - Communications
- D - Direction finder reconnaissance and/or surveillance
- E - Ejection and/or release
- G - Fire control or searchlight directing
- H - Recording and/or reproducing
- K - Computing
- M - Maintenance and/or test assemblies
- N - Navigational aids
- Q - Special or combination of purposes
- R - Receiving, passive detecting
- S - Detecting and/or range and bearing, search
- T - Transmitting
- W - Automatic flight or remote control
- X - Identification and recognition

B. Component Indicators

The type designation of a component consists of one or two letters (see chart below), a dash, and a number. The letter or letters indicate the component, and the number indicates the model number. For example, RT-196 indicates the 196th model in the field of radio receivers and transmitters. If the component is part of, or is used with, a major equipment, you will have a longer type designation. For example, RT-196/PRC-6 indicates model 196 of a radio receiver and transmitter that is used with, or is a part of, model 6 of a portable radio communications set.

Indicator	Meaning
AB	Supports, Antenna
AM	Amplifiers
AS	Antenna Assemblies
AT	Antennas
BA	Battery, Primary Type
BB	Battery, Secondary Type
BZ	Signal Devices, Audible
C	Control Articles
CA	Commutator Assemblies, Sonar.
CB	Capacitor Bank
CG	Cables and Transmission Line, RF
CK	Crystal Kits
CM	Comparators
CN	Compensators
CP	Computers
CR	Crystals
CU	Coupling Devices
CV	Converters (electronic)
CW	Covers
CX	Cords
CY	Cases
DA	Antenna, Dummy
DT	Detecting Heads
DY	Dynamotors
E	Hoist Assembly
F	Filters

Indicator	Meaning
FN	Furniture
FR	Frequency Measuring Devices
G	Generators
GO	Goniometers
GP	Ground Rods
H	Head, Hand, and Chest Sets
HC	Crystal Holder
HD	Air Conditioning Apparatus
ID	Indicating Devices
IL	Insulators
IM	Intensity Measuring Devices
IP	Indicators, Cathode Ray Tube
J	Junction Devices
KY	Keying Devices
LC	Tools, Line Construction
LS	Loudspeakers
M	Microphones
MD	Modulators
ME	Meters, Portable
MK	Maintenance Kits or Equipments
ML	Meteorological Devices
MT	Mountings
MX	Miscellaneous
O	Oscillators
OA	Operating Assemblies
OC	Oceanographic Devices
OS	Oscilloscope, Test
PD	Prime Drivers
PF	Fittings, Pole
PH	Photographic Articles
PP	Power Supplies
PT	Plotting Equipments
PU	Power Equipments
R	Receivers
RD	Recorders and Reproducers
RE	Relay Assemblies

Indicator	Meaning
RF	Radio Frequency Component
RG	Cables and Transmission Line Bulk, RF
RL	Reel Assemblies
RP	Rope and Twine
RR	Reflectors
RT	Receiver and Transmitter
S	Shelters
SA	Switching Devices
SB	Switchboards
SG	Signal Generator
SM	Simulators
SN	Synchronizers
ST	Straps
T	Transmitters
TA	Telephone Apparatus
TD	Timing Devices
TF	Transformers
TG	Positioning Devices
TH	Telegraph Apparatus
TK	Tool Kits or Equipments
TL	Tools
TN	Tuning Units
TS	Test Equipment
TT	Teletypewriter and Facsimile Apparatus
TV	Tester, Tube
U	Connectors, Audio and Power
UG	Connectors, RF
V	Vehicles
VS	Signaling Equipment Visual
WD	Cables, Two Conductor
WF	Cables, Four Conductor
WM	Cables, Multiple Conductor
WS	Cables, Single Conductor
WT	Cables, Three Conductor
ZM	Impedance Measuring Devices

APPENDIX B

TYPE OF SERVICE AND OPERATION

1. Types of Service: 30 F 3

Indicates bandwidth in kilohertz (30)
Indicates type of modulation (F)
Indicates type of intelligence (3)

Types of Service Indicators:

Modulation	Intelligence (partial listing)
A-Amplitude	0 - None
F-Frequency or phase	1 - Telegraphy (CW, FSK, NSK)
	2 - Modulated CW (MCS)
P-Pulse	3 - Telephone (voice)
	3a- Single sideband, reduced carrier
	3b- Two independent sidebands, reduced carrier
	3h- Single sideband, full carrier
	3j- Single sideband, suppressed carrier
	4 - Facsimile
	5 - Television
	9 - Composite, or not otherwise covered

2. Types of Operation:

a. Duplex (radio), full duplex or FDX (cable): Simultaneous operation in opposite directions. Transmitting and receiving over two frequencies.

b. One half duplex, half duplex or HDX: System arranged to permit operation in either direction but not simultaneously, with a break-in capability.

c. One way reversible: Operation in one direction at a time without a break-in capability. Utilizes one radio frequency.

3. Bandwidth Factors. The factors used in the terms expressing the necessary bandwidths in Tables B-1, B-2, and B-3 are defined as follows:

B_n = Necessary bandwidth in cycles per second.
B = Telegraph speed in bands.
N = Maximum possible number of black plus white elements to be transmitted per second, in facsimile and television.
M = Maximum modulation frequency in cycles per second.
C = Subcarrier frequency in cycles per second.
D = Half the difference between the maximum and minimum values of the instantaneous frequency. Instantaneous frequency is the rate of change of phase.
t = Pulse duration in seconds.
K = An overall numerical factor which varies according to the emission and depends upon the allowable signal distortion.

TABLE B-1

BANDWIDTHS FOR AMPLITUDE MODULATION

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples: Details	Examples: Designation of Emission
Continuous wave telegraphy, A1	B_n=BK K=5 for fading circuits K=3 for nonfading circuits	Morse Code at 25 words per minute, B=20, K=5 Bandwidth: 100 c/s	0.1A1
		Four-channel time-division multiplex Seven-unit code, 42.5 bands per channel, B=170, K=5 Bandwidth: 850 c/s	0.85A1
Telegraphy modulated by an audio frequency, A2	B_n=BK+2M K=5 for fading circuits K=3 for nonfading circuits	Morse Code at 25 words per minute, B=20,M=1000, K=5 Bandwidth: 2100 c/s	2.1A2
Telephony, A3	B_n=M for single sideband B_n=2M for double sideband	Double sideband telephony, M=3000 Bandwidth: 6000 c/s	6A3
		Single sideband telephony, reduced carrier, M=3000 c/s Bandwidth: 3000 c/s	3A3A
		Telephony, two independent sidebands, M=3000. Bandwidth: 6000 c/s	6A3B
Sound broadcasting, A3	B_n=2M M may vary between 4000 and 10,000 depending on the quality desired.	Speech and music, M=4000 Bandwidth: 8000 c/s	8A3

TABLE B-1 (continued)

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples: Details	Examples: Designation of Emission
Facsimile, carrier modulated by tone and keying, A4	$B_n = KN + 2M$	The total number of picture elements (black plus white) transmitted per second is equal to the cylinder multiplied by the number of lines per unit length and by the speed of rotation of the cylinder in revolutions per second. Diameter of cylinder=70 mm Number of lines per mm=5 Speed of rotation=1 rps N=1100, M=1900 Bandwidth: 5450 c/s	5.45A4
Television (vision and sound), A5 and F3	Refer to relevant CCIR documents for the bandwidths of the commonly used television systems	Number of lines=625 Number of lines per second=15,625 Video bandwidth: 5 Mc/s Total vision bandwidth: 625 Mc/s FM sound bandwidth including guard bands: 0.75 Mc/s Total bandwidth: 7 Mc/s	6250A5C 750F3

TABLE B-2

BANDWIDTHS FOR FREQUENCY MODULATION

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples: Details	Examples: Designation of Emission
Frequency-shift telegraphy, F1	$B_n=2.6D+0.55B$ for $1.5 \frac{2D}{B} 5.5$ $B_n=2.1D+1.9B$ for $5.5 \frac{2D}{B} 20$	Four-channel time-division multiplex with 7-unit code, 42.5 bauds per channel, B=170, D=200. 2D/B=2.35; therefore, the first formula in column 2 applies. Bandwidth: 613 c/s	0.6F1
Commercial telephony, F3	$B_n=2M+2DK$ K is normally 1, but under certain conditions a higher value may be necessary	For an average case of commercial telephony, D=15,000, M=3000. Bandwidth 36,000 c/s	36F3
Sound broadcasting, F3	$B_n=2DK$	D=75,000, M=15,000 and assuming K=1 Bandwidth: 180,000 c/s	180F3
Facsimile, F4	$B_n=KN+2M=2D$ K=1.5	(See facsimile, amplitude modulation) Diameter of cylinder=70 mm Number of lines per mm=5 Speed of rotation=1 rps N=1100, M=1900, D=10,000. Bandwidth: 25,450 c/s	25.5F4

TABLE B-2 (continued)

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples: Details	Examples: Designation of Emission
Four-frequency diplex telegraphy, F6	If the channels are not synchronized, B_n=2.6D+ 2.75B where B is the speed of the higher speed channel. If the channels are synchronized, the bandwidth is as for F1, B being the speed of either channel.	Four-frequency diplex system with 400 c/s spacing between frequencies, channels not synchronized, 170 bauds keying in each channel, D=600, B=170. Bandwidth: 2027 c/s	2.05F6

TABLE B-3

BANDWIDTHS FOR PULSE MODULATION

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples: Details	Examples: Designation of Emission
Unmodulated pulse, PO	$B_n = \frac{2K}{t}$ K depends upon the ratio of pulse duration to pulse rise time. Its value usually falls between 1 and 10 and in many cases it does not exceed 6.	$t=3x10^{-6}$, K=6 Bandwidth: $4x10^5$ c/s	4000PO
Modulated pulse, P2 or P3	The bandwidth depends on the particular types of modulation used; many of these are still in the development stage.		

4. Frequency Tolerances

a. Frequency tolerance is the maximum permissible departure by the center frequency band occupied by an emission from the assigned frequency or by the characteristic frequency of an emission from the reference frequency. The frequency tolerance is expressed in parts in 10^6 or in cycles per second.

Note: Certain services may need tighter tolerances for technical and operational reasons.

b. The power shown for the various categories of stations is the mean power. Mean power is defined as the power supplied to the antenna transmission line by a transmitter during normal operation, averaged over a time sufficiently long, compared with the period of the lowest frequency encountered in the modulation. A time of 1/10 second, during which the mean power is greatest, will normally be selected.

TABLE B-4

FREQUENCY TOLERANCES

Frequency Bands (Lower Limit Exclusive, Upper Limit Inclusive) and Categories of Stations	Tolerances	
BAND: 10 to 535 kc/s:		
1. Fixed Stations:		
-10 to 50 kc/s	1000	
-50 to 535 kc/s	200	
2. Land Stations:		
(a) Coast Stations:		
-200 W or less	200	
-above 200 W	200	
(b) Aeronautical Stations	100	200*
3. Mobile Stations:		
(a) Ship Stations	500	
(b) Ship Emergency Transmitters	500	
(c) Survival Craft	500	
(d) Aircraft Stations	200	
(e) Land Mobile Stations	100	
4. Radionavigation Stations	100	
5. Radiolocation Stations	100	
BAND: 1605 to 4000 kc/s:		
1. Fixed Stations:		
-200 W or less	100	
-above 200W	50	
2. Land Stations:		
-200 W or less	100	
-above 200 W	50	
3. Mobile Stations:		
(a) Ship Stations	200	
(b) Survival Craft	200	
(c) Aircraft Stations	100	200*
(d) Land Mobile Stations	200	
4. Radionavigation Stations:		
-under 200 W	100	
-200 W and above	50	
5. Radiolocation Stations	50	
BAND: 4 to 29.7 Mc/s:		
1. Fixed Stations:		
-500 W or less	50	
-above 500W	15	

TABLE B-4 (continued)

Frequency Bands (Lower Limit Exclusive, Upper Limit Inclusive) and Categories of Stations	Tolerances	
BAND: 4 to 29.7 Mc/s (continued)		
2. Land Stations:		
(a) Coast Stations:		
-500 W or less	50	
-500 W to 5 kW	30	50*
-above 5 kW	15	
(b) Aeronautical Stations:		
-500 W or less	100	
-500 W to 5 kW	50	
-above 5 kW	50	
(c) Base Stations:		
-500 W or less	100	
-above 500 W	50	
3. Mobile Stations:		
(a) Ship Stations:		
(1) Class A1 emission	200	
(2) Other than A1:		
-500 W or less	50	
-above 50 W	50	
(b) Survival Craft	200	
(c) Aircraft Stations	100	200*
(d) Land Mobile Stations	100	
4. Broadcasting Stations	15	
BAND: 29.7 to 100 Mc/s[a]:		
1. Fixed Stations:		
-200 W or less	50	200*
-above 200 W	30	
2. Land Stations:		
(a) Coast and Aeronautical Stations:		
-15 W or less	50	
-above 15 W	20	
(b) Base Stations:		
-15 W or less	20	
-above 15 W	20	
3. Mobile Stations:		
-5 W or less	100	
-above 5 W	50	
4. Radionavigation Stations	100	
5. Broadcasting Stations (Other than TV):		
-10 W or less	3000 c/s	
-above 10 W	2000 c/s	
6. Broadcasting Stations (TV sound and vision)	1000 c/s	

TABLE B-4 (continued)

Frequency Bands (Lower Limit Exclusive, Upper Limit Inclusive) and Categories of Stations	Tolerances
BAND: 100 to 470 Mc/s[b]:	
1. Fixed Stations:	
-50 W or less	50 100*
-above 50 W	20 100*
2. Land Stations:	
(a) Coast Stations	20
(b) Aeronautical Stations	
(c) Base Stations:	
-5 W or less	50
-above 5 W	20
3. Mobile Stations:	
(a) Ship Stations in:	
-band 156-174 Mc/s	20
-outside band	50[c]
(b) Survival Craft Stations:	
-in band 156-174	20
-outside band	50[c]
(c) Aircraft Stations	50
(d) Land Mobile Stations:	
-5 W or less	50
-above 5 W	20
4. Radionavigation Stations	50[c,d] 200*[c,d]
5. Radiolocation Stations	50[c,d] 200*[c,d]
6. Broadcasting Stations (Other than TV):	
-10 W or less	2000 c/s
-above 10 W	2000 c/s
7. Broadcasting Stations (TV sound and vision)	1000 c/s
BAND: 470 to 960 Mc/s:	
1. Fixed Stations:	
-100 W or less	300[e]
-above 100 W	100[f]
2. Land Stations	300
3. Mobile Stations	300
4. Radiolocation Stations	500[d]
(a) High power crystal or high stability multistage radars	50[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	250[g]
5. Broadcasting Stations	1000 c/s

TABLE B-4 (continued)

Frequency Bands (Lower Limit Exclusive, Upper Limit Inclusive) and Categories of Stations	Tolerances
BAND: 960 to 1215 Mc/s:	
1. Aeronautical Radionavigation Stations	20
2. IFF Stations	500[d]
BAND: 1215 to 2450 Mc/s:	
1. Fixed Stations:	
-100 W or less	300[e]
-above 100 W	100[f]
2. Land Stations	300
3. Mobile Stations	300
4. Radionavigation Stations	500[d]
High power crystal or high stability multi-stage radars	100[g]
5. Radiolocation Stations	500[d]
High power crystal or high stability multi-stage radars	100[g]
BAND: 2450 to 4000 Mc/s:	
1. Fixed Stations:	
-100 W or less	300[e]
-above 100 W	100[f]
2. Land Stations	300
3. Mobile Stations	300
4. Radionavigation Stations	2000
(a) High power crystal or high stability multistage radars	100[f]
(b) Lower power non-crystal single stage or high power non-crystal controlled multistage radars	500[g]
5. Radiolocation Stations	2000
(a) High power crystal or high stability multistage radars	100[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	500[g]
BAND: 4000 to 105000 Mc/s (4000 to 10000 Mc/s for radars):	
1. Fixed Stations:	
-100 W or less	300[e]
-above 100 W	100
2. Land Stations	300
3. Mobile Stations	300

TABLE B-4 (continued)

Frequency Bands (Lower Limit Exclusive, Upper Limit Inclusive) and Categories of Stations	Tolerances
BAND: 4000 to 105000 Mc/s (4000 to 10000 Mc/s for radars) (continued)	
4. Radionavigation Stations	2000
(a) High power crystal or high stability multistage radars	250[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	1250[g]
5. Radiolocation Stations	2000
(a) High power crystal or high stability multistage radars	250[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	1250[g]
BAND: 10500 to 3000 Mc/S (10000 to 30000 Mc/s for radars):	
1. Fixed Stations	500
2. Radionavigation Stations	7500
(a) High power crystal or high stability multistage radars	500[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	2500[g]
3. Radiolocation Stations	7500
(a) High power crystal or high stability multistage radars	
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	2500[g]
BAND: 30000 to 40000 Mc/s:	
1. Fixed Stations	500
2. Radionavigation Stations	7500
(a) High power crystal or high stability multistage radars	1000[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	5000[g]
3. Radiolocation Stations	7500
(a) High power crystal or high stability multistage radars	1000[g]
(b) Lower power non-crystal single stage or high power non-crystal controlled multi-stage radars	5000[g]

TABLE B-4 (continued)

*Tolerances applicable until January 1, 1970 to all transmitters installed before January 1, 1964.

[a] For all equipments meeting the narrow-band technical standards for FM radiotelephony, the frequency stability in the band 30-42 Mc/s is:

(1) 20 parts per million for all fixed and base stations, and for mobile stations with power over 3 watts, and

(2) 50 parts per million for all mobile stations with power of 3 watts or less.

[b] For all equipments meeting the narrow-band technical standards for FM radiotelephony, the frequency stability in the bands 162-174 and 406-420 Mc/s is:

(1) 5 parts per million for all fixed and base stations, and for all mobile stations with power over 3 watts, and

(2) 50 parts per million for all mobile stations with power of 3 watts or less.

[c] This tolerance is not applicable to survival craft stations operating on the frequency 243 Mc/s.

[d] Where specific frequencies are not assigned to radar stations the bandwidth occupied by the emissions of such stations shall be maintained wholly within the band allocated to the service and the indicated tolerance does not apply.

[e] For transmitters using time division multiplex the tolerance of 300 may be increased to 500.

[f] This tolerance applies only to such emissions for which the necessary bandwidth does not exceed 3000 kc/s; for larger bandwidth emissions a tolerance of 300 applies.

[g] This is a design objective.

APPENDIX C

KEY WORDS AND PHRASES

In this section, you are provided with an explanation of key words and phrases used in the C-E field. Although some terms may have been explained within the text, this list will give you a compact, ready reference as a point of departure on each subject.

acknowledgement - A message from the addressee informing the originator that his communication has been received and is understood.

addressee - The activity or individual to whom a message is directed by the originator. Addressees are indicated as either ACTION or INFORMATION.

address indicating group (AIG) - An address group which represents a specific set of action or information addressees.

AIM Division - Armored, Infantry and Infantry (Mechanized) Division.

airhead - A designated area in a hostile or threatened territory which, when seized and held, insures the continuous air landing of troops and materiel, and provides maneuver space necessary for projected operations.

antenna polarization - The orientation of the antenna elements in either a vertical or horizontal position.

area signal center - This signal center provides communications to units within its assigned geographical area of responsibility. This ties the units into the area communications system and supplements their organic means for communications with higher, subordinate, or adjacent headquarters.

attenuation - Decrease in strength of a signal, beam, or wave as a result of absorption of energy and of scattering out of the path of a receiver.

audio frequency - A frequency which can be detected as a sound by the human ear. The range of audio frequencies extends from approximately 20 to 20,000 hertz.

authentication - A security measure designed to protect a communications system against fradulent transmissions.

automatic central office - A switch at which communications between subscribers is effected without the intervention of an operator. The electronic switches are controlled by the operation of a keysender on the originating subscriber's instrument.

automatic data processing system (ADPS) - Automatic data processing equipment linked together by communication and data transmission equipment to form an integrated system for the processing and conveyance of data.

bandwidth - *Necessary.* For a given class of emission, the minimum value of the occupied bandwidth sufficient to insure the transmission of information, at the rate and with the quality required, for the system employed under specified condition. Emissions necessary for the proper functioning of the receiving equipment, such as the emission of a carrier in a reduced carrier system, will be included in the necessary bandwidth. *Occupied.* The bandwidth occupied by an emission is the band of frequencies comprising 99 percent of the total radiated power, extended to include any discrete frequency on which the power is at least 0.25 percent of the total radiated power.

brevity code - A code which provides no security but which has as its sole purpose the shortening of messages rather than the concealment of their contents.

call sign - Any combination of characters/numbers or pronounceable words, which identifies a communication facility, command, authority, activity, or unit; used primarily for establishing and maintaining communications.

carrier wave - A wave, usually sinusoidal, which is modulated to transmit signals. The frequency of the wave is called the *carrier frequency*. The carrier wave is not transmitted in some types of modulation.

central office - A room, building or vehicle equipped so that telephone lines terminating there may be interconnected as required. The equipment may include a manual or automatic switch.

chaff - Radar confusion reflectors, which consist of thin, narrow metallic strips of various lengths and frequency responses, used to reflect echoes for confusion purposes.

chain of command - The succession of commanding officers from a superior to a subordinate through which command is exercised.

channel - A facility for telecommunications on a system or circuit. The number of independent channels on a system or circuit (derived by frequency or time division) is measured by the number of separate communication facilities that can be provided by it.

cipher, off-line - A method of encryption which is not associated with a particular transmission system and in which the resulting cryptogram can be transmitted by any means.

cipher, on-line - An automatic method of encryption associated with a particular transmission system, whereby signals are encrypted and passed directly through the line to operate the reciprocal equipment at the distant station.

cipher system - Any cryptosystem which, by means of a key, converts plain or encoded text or signals into unintelligible form, and vice versa.

circuit - *Communications term.* An electronic path between two or more points capable of providing a number of channels. *Engineering term.* A number of conductors connected together for the purpose of carrying an electrical current.

code - Any system of communications in which arbitrary groups of symbols represent units of plain text of varying length. Codes are provided primarily for one of three purposes: (1) In the broadest sense, coding is a means of converting information into a form suitable for communication and encryption; (2) Brevity codes are used to reduce the length of time necessary to transmit information; (3) Security codes are used to provide some degree of cryptographic protection for the information being transmitted.

code word - (1) A word which conveys a meaning other than its conventional one, prearranged by the correspondents. Its aim is to increase security. (2) A cryptonym used to identify sensitive intelligence data.

collective training - The preparation of soldiers to perform those team or unit tasks essential to the accomplishment of a unit's TOE or operational mission.

command and control - An arrangement of personnel, facilities, and the means for information acquisition, processing, and dissemination employed by a commander in planning, directing and controlling operations.

command post - A unit's headquarters from which command and control is centrally exercised.

command signal center - This signal center provides communications for command and control at division and corps headquarters and to units located in the immediate area as facilities permit.

command system - A communications network which connects an echelon of command with some or all of its subordinate echelons for the purpose of command and control.

common-user circuit - A circuit allocated to furnish communications paths between switching centers to provide communications service on a common basis to all connected stations or subscribers.

communications-electronics (C-E) - Embraces the design, development, installation, operation, and maintenance of electronics and electromechanical systems associated with the collecting, transmitting, storing, processing, recording, and displaying of data and information associated with all forms of military communications.

Communications-Electronics Operation Instructions (CEOI) - A series of orders issued for the technical control and coordination of the signal communication activities of a command.

Communications-Electronics Standing Instruction (CESI) - A series of instructions explaining the use of items included in the CEOI. The CESI may also include other technical instructions required to coordinate and control the communications-electronics operations of the command.

Communications Equipment Support Element (CESE) - Individual elements of the C-E system—radio, switch, multiplex, wire teams, maintenance, etc.

Communications Nodal Control Element (CNCE) - A dual function facility that incorporates both Facilities Control and Technical Control requirements. The technical control element of the CNCE contains patching, testing, conditioning, and monitoring equipment and provides technical control of circuits in and through the facility. The management element of the CNCE provides management and control of C-E functions within the node.

Communications System Control Element (CSCE) - Provides actual focal point for dynamic control, acts as operations center for command system, and directs organic and subordinate C-E systems. Maintains the data base. Replaces the term SYSCON.

Communications Security (COMSEC) - Measures taken by you to prevent unauthorized persons from gaining information of value from your communications. It includes cryptosecurity, physical security, transmission, and emission security.

Communications System Planning Element (CSPE) - Consists of the staff and operational planners at each element and provides all the long-range planning.

continuous wave (CW) - Morse code transmissions achieved by on and off keying of an unmodulated carrier wave, or by the keying of a modulating subcarrier wave with the carrier suppressed.

crossing area commander - The officer responsible for controlling the flow of troops, equipment, and supplies to be moved across the river by surface means.

cryptography - The art or science which treats the various means and methods for rendering plain text unintelligible, and reconverting cipher text into intelligible form.

cryptomaterial - All material, including documents, devices, equipments, and apparatus essential to the encryption, decryption, or authentication of telecommunications. When classified, it is designated CRYPTO and subject to special safeguards.

data link - A communication link suitable for transmission of data.

date/time group (DTG) - Depending upon national requirements, the DTG may indicate either the date and time when the message was officially released by the releasing officer, or the date and time when the message was handed into a communication facility for transmission. The DTG is expressed as six digits. The first two indicate the day of the month and the last four indicate the time of day. The six digits are followed by the zone suffix and the month expressed by the first three letters (e.g., 010900Z SEP represents 0900 hours on the first day of September). The last two digits of the year of origin may be added if required by national authorities.

dial central office - A switch at which communications between subscribers is effected without the intervention of an operator, by means of relays set in motion by the operation of a dial on the originating subscriber's instrument.

digital signal - A transmission in which information is represented by a series of discrete signal elements or digits (binary or other).

direct wave - A wave that travels directly between the transmitter and receiver antenna without reflections from any object.

display - The orderly presentation of information by communications-electronics means.

distortion - An undesired change in the waveform of the original signal. Distortion may exist in the amplitude, frequency, or phase of the waveform.

diversity system - A system of communications in which a single received signal is derived from a combination of, or selections from, a plurality of transmission channels or paths.

DRAGON - The M47 Dragon is a command-to-line-of-sight-guided, medium, antiarmor assault weapon system. Fired from a recoilless, disposable launcher, the missile is tracked optically and guided automatically through a wire link.

DRYAD - The unclassified term used to describe the numerical cipher/authentication system.

dual-hatted position - One officer assigned to serve in two separate areas of responsibility. (In this manual, it is used to refer to an individual serving as a C-E staff officer and signal unit commander.)

duplex operation - Duplex (or full Duplex) operation refers to communication between two points in both directions simultaneously.

Electromagnetic Compatibility (EMC) - The ability of communications-electronic equipments, subsystems, and systems to operate in their intended operational environments without suffering or causing unacceptable degradation because of unintentional electromagnetic radiation or response.

electromagnetic emission control - The control of friendly electronic emissions (e.g., radio, radar, and sonar transmissions) for the purpose of preventing or minimizing their use by unintended recipients.

electromagnetic environment - This is the environment in which communications and noncommunications emitters operate.

electromagnetic interference - Any electromagnetic disturbance which interrupts, obstructs or otherwise degrades or limits the effective performance of communications or noncommunications equipments. It can be induced intentionally, as in some forms of electronic warfare, or unintentionally, as a result of spurious emissions or responses, intermodulation products, etc.

Electronic Counter-Countermeasures (ECCM) - That division of EW involving actions taken to insure friendly effective use of the electromagnetic spectrum.

Electronic Countermeasures (ECM) - That major subdivision of electronic warfare involving actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing or affected by electromagnetic radiations, and to exploit the enemy's use of such radiations.

electronic deception - The deliberate radiation, reradiation, alteration, absorption or reflection of electromagnetic energy in a manner intended to mislead an enemy in the interpretation of use of information received by his electronic systems. There are two categories of deception: manipulative and imitative.

electronic emission security - Those measures taken to protect all transmissions from interception and electronic analysis.

electronic intelligence - The intelligence information product of activities engaged in the collection and processing, for subsequent intelligence purposes, of foreign, noncommunications, electromagnetic radiations emanating from other than nuclear detonations and radioactive sources.

electronic jamming - The deliberate radiation, reradiation, or reflection of electromagnetic energy with the object of impairing the use of electronic devices, equipment or systems being used by an enemy.

electronic search - A search of the electromagnetic spectrum, or portions thereof, in order to determine the existence, sources and pertinent characteristics of electromagnetic radiations.

Electronic Security (ELSEC) - The protection resulting from all measures designed to deny unauthorized persons information of value which might be derived from their interception and study of noncommunications electromagnetic radiation.

Electronic Warfare (EW) - That division of the military use of electronics involving actions taken to prevent or reduce an enemy's effective use of radiated electromagnetic energy, and actions taken to insure our own effective use of radiated electromagnetic energy.

Electronic Warfare Support Measures (ESM) - That division of EW involving actions taken to search for, intercept, locate, record and analyze radiated electromagnetic energy, for the purpose of exploiting such radiations in support of military operations. Thus, ESM provides a source of EW information required to conduct electronic countermeasures (ECM), electronic counter-countermeasures (ECCM), threat detection, warning, avoidance, target acquisition and homing.

encode - To convert a plain text message into unintelligible language by means of a cipher system.

engineering - The establishment, operation, maintenance and control of a communications system.

engineering circuit - An auxiliary circuit or channel for use by operating and maintenance personnel for communications incident to the establishment, operation, maintenance, and control of communications facilities. (An engineering circuit includes the functions of an *orderwire*.)

facsimile - A system of telecommunication for the transmission of fixed images with a view to their reception in a permanent form.

fading - A variation in strength of received signals due to variations, with time, in the conditions of propagation.

fixed plant - A permanently emplaced C-E facility.

four-wire circuit - A circuit using two pairs of conductors.

frequency - The number of recurrences of a periodic phenomenon in a unit of time. In specifying electrical frequency, the unit of time is the second, the frequency is expressed in hertz (Hz) (meaning cycle(s) per second). Radio frequencies are normally expressed kilohertz (kHz) at and below 999 kilohertz, and in megahertz (MHz) above this frequency.

frequency assignment - The process of designating a radio frequency for use at a specific station or by a specific military unit under specified conditions of operation.

frequency division multiplex (FDM) - A multiplex system in which the available transmission frequency range is divided into narrower bands, each used for a separate channel.

ground (earth) - The term applied to any conductor common to a number of circuits and which serves to maintain a constant potential, or to provide a bond of very low impedance between the points of connection to it. In many cases, the earth itself is used as the conductor.

ground wave - In propagation, that portion of the transmitted radio wave that travels near the surface of the earth.

gun ship - An unofficial term for the armed helicopter.

half-duplex operation - A telegraph system capable of operating in either direction, but not in both directions simultaneously. It's also called simplex.

hertz - A unit of frequency eqivalent to one cycle per second.

homing - A process whereby a mobile station is directed (or directs itself) towards a source of radio, radar, or other electromagnetic energy.

imitative electronic deception - The intrusion on the enemy's channels and the introduction of matter in imitation of his own for the purpose of deceiving or confusing him.

interception - The act of searching for and listening to and/or recording communications and electronic transmissions for the purpose of obtaining intelligence.

intercom - A telephone apparatus by means of which personnel can talk to each other within a signal center, an aircraft, tank, ship or activity.

interface - A point common to two or more systems or other entities across which useful information flow takes place.

interference - Any electrical disturbance which causes undesirable responses in electronic equipment.

Internal Defense And Development (IDAD) - Any direct operation undertaken by a host government or its allies to strengthen the local government politically, economically, socially, or militarily, or make more viable its national life.

ionosphere - The region of the atmosphere, extending from roughly 40 to 250 miles altitude, in which there is appreciable ionization. The presence of charged particles in this region profoundly affects the propagation of electromagnetic radiations of long wavelengths.

ionospheric scatter - The propagation of radio waves by scattering as a result of irregularities or discontinuities in the ionization of the ionosphere.

jamming - See electronic jamming.

joint - Connotes activities, operations, organizations, etc., in which elements of more than one service of the same nation participate.

Julian Time - A 7-figure group, in which the first 3 figures indicate the day of the year and the last 4 figures the time in hours and minutes.
Examples: 0900 hrs on 1 Jan is 0010900. 2200 hrs on 31 Dec is 3652200.
Note: Julian time is always GMT (ZULU time).
The time zone suffix is not used.

key list - A publication containing the key for a particular cryptosystem in a given cryptoperiod.

LASER - Light Amplification by Stimulated Emission of Radiation. A device that utilizes the natural oscillations of atoms for amplifying or generating electromagnetic waves in the region of the spectrum from the ultraviolet to the far-infrared, including the visible region.

LAW - The M72A2 (Light Antiarmor Weapon) is a close-in, lightweight, smoothbore, percussion-fired antiarmor weapon which is designed to give the individual infantryman the capability of defeating armored vehicles.

link - A general term used to indicate the existence of communications facilities between two points.

local loop - A circuit connecting an end instrument to a switching facility or distribution point.

log, circuit - A chronological record of events relating to the operation of a particular circuit.

log, station - A chronological record of station events; i.e., entries relating to message handling, equipment difficulties, personnel, etc.

long lines - Long lines include all forms of physical conductors used for communication purposes such as open wire systems, underground and overhead cables, and submarine cables, but do not include local circuits. They may also contain radio relay systems when they are integrated with the wire system.

manipulative electronic deception - The use of friendly electromagnetic radiations so as to falsify the information which a foreign nation can obtain from their analysis.

manual central office - A switch in which the lines are connected to a switchboard and interconnections are controlled by an operator.

message - Any thought or idea expressed briefly in a plain, coded or secret language, prepared in a form suitable for transmission by any means of communication.

message, service - A brief, concise message between operating or supervisory personnel at telecommunications centers or relay stations pertaining to any phase of traffic handling, status of communication facilities, circuit conditions, or other matters affecting communication operations.

MIJI Report (Meaconing, Intrusion,Jamming, Interference) - A report to a higher headquarters of an incident of interference in the reception of radio signals.

minimize - A condition wherein normal messages and telephone traffic is drastically reduced, in order that messages connected with an actual or simulated emergency will not be delayed.

mobilization - The process by which the armed forces or part of them are brought to a state of readiness for war or other national emergency. This includes assembling and organizing personnel, supplies and materiel for active military service.

modulation - The process in which the amplitude, frequency or phase of a carrier wave is varied with time in accordance with the waveform of a superimposed intelligence.

monitoring - The act of listening to, reviewing, and/or recording one's own or (by special agreement) other friendly forces' communications for the purpose of maintaining and improving standards of communications security or efficiency, or for reference.

MOS (Military Occupational Speciality) - A term used to identify a grouping of duty positions possessing such close occupational or functional relationship that an optimal degree of interchangeability among persons so classified exists at any given level of skill.

multi-axis - More than one line along which communications takes place.

multi-means - More than one method or system over which a message can be transmitted.

multiplex - Denotes the simultaneous use of a number of channels on a single circuit.

net - An organization of stations capable of direct communications with each other using a common frequency or channel.

net call sign - A call sign which represents all stations within a net.

Net Control Station (NCS) - A station designated to control traffic and enforce circuit discipline within a given net.

network - *Communication term.* - An organization of stations capable of intercommunication but not necessarily on the same channel. *Engineering term.* Two or more interrelated circuits.

noise - Any undesired sound. By extension, noise is any unwanted disturbance, such as undesired electromagnetic waves in any transmission channel or device. Cross talk, distortion products and intermodulation products are sometimes classed as noise.

on-the-job training - A training process whereby students or trainees acquire knowledge and skills through actual performance of duties under competent supervision, in accordance with an approved, planned program.

operational readiness training - That phase of training undertaken by units which have completed the formal phases of training and which are assigned the responsibility for maintaining the highest possible state of combat proficiency in order to accomplish operational missions.

operation order - A directive, usually formal, issued by a commander to subordinate commanders for the purpose of effecting the coordinated execution of an operation.

originator - The command by whose authority a message is sent. The originator is responsible for the functions of the drafter and releasing officer.

page copy - A message in page form which is the result of a transmission.

panel code - A prearranged code designed for visual communications between ground units and friendly aircraft.

phantom circuit - A telephone or telegraph circuit obtained by superimposing an additional circuit on two existing physical circuits by means of repeating coils.

plain text - Intelligible text or signals which have meaning and which can be read or acted upon without the application of any decryption.

POL - Petroleum, oil and lubricants.

precedence - A designation, assigned to a message by the originator, to indicate to communications personnel the relative order of handling, and to the addressee the order in which the message is to be noted.

preventive maintenance (PM) - The care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of failures either before they occur or before they develop into major defects.

procedure sign (PROSIGN) - One or more letters or characters or combination thereof used to facilitate communications by conveying, in a condensed standard form, certain frequently used orders, instructions, requests and information related to communications.

procedure word (PROWORD) - A word or phrase limited to radio telephone procedure and used in lieu of a prosign.

pulse code modulation - Pulsed modulation in which the signal is sampled periodically and each sample is quantized and transmitted as a digital binary code.

pyrotechnics - Ammunition containing chemicals that produce a smoke or brilliant light in burning, used for signaling or for lighting up an area at night.

quantization - A process in which the range of values of a wave is divided into a finite number of distinct subranges (called quanta), not necessarily equal, each of which is represented by an assigned or "quantized" value within the subrange.

radio direction finding (RDF) - Radio location in which only the direction of a station is determined by means of its emission. Since this technique can be used against all electronic emitters, it is sometimes simply referred to as direction finding (DF).

radio listening silence - Designated radio stations are instructed to monitor their receivers for incoming traffic but not to transmit for a specified period or until further ordered.

radio relay system - A radio transmission system in which the signals are received and transmitted from point to point by intermediate radio stations. This system, normally used in conjunction with carrier equipment, provides channels for both voice and teletypewriter operations.

radio silence - A period during which all or certain radio equipment capable of radiation is kept inoperative.

radio teletypewriter (RATT) - The system of communication by teletypewriter over radio circuits.

radio wire integration (RWI) - The interconnection of wire circuits with radio facilities.

readability - The ability to be understood, i.e., the readability of signals sent by any means of telecommunications.

reception - Listening to, copying, recording or viewing any form of emission.

REDEYE - A man-transportable guided missile, fired from the shoulder, designed to provide combat troops with the capability of destroying low-flying aircraft. Designated as XM-41.

releasing officer - The person who may authorize the transmission of a message for, and in the name of, the originator.

requirements density overlay - A transparent sheet bearing unit locations and C-E requirements, designed to emphasize the geographical density of C-E requirements when superimposed on a map.

retransmission - Employment of a radio communication set for the purpose of rebroadcasting a message on a different frequency simultaneously with the original broadcast by means of an electrically operated linkage device between the receiver and transmitter of the set.

ringing frequency - A signal of proper frequency sent out from a switchboard or other instrument to notify a distant terminal of a call.

routing - The process of determining and prescribing the path or method to be used in forwarding messages.

routing indicator - A group of letters assigned to identify a station within a tape relay network to facilitate routing of traffic. It indicates the status of the station and may indicate its geographical area. Routing indicators are composed in accordance with the routing indicator plan described in the ACP 121 series.

sampling - Of a signal. A process in which a continuous signal is approximately represented by a series of discrete values, usually regularly spaced.

sideband - The frequency band, above or below the carrier, produced by the process of modulation. *Double sideband (DSB).* - That method of communication in which the frequencies produced by the process of modulation are symmetrically spaced both above and below the carrier frequency and are all transmitted. *Single sideband (SSB).* - That system of carrier transmission in which one sideband is transmitted and the other suppressed. The carrier wave may be either transmitted or suppressed. *Independent sideband (twin sideband) (ISB).* - That method of communication in which the frequencies on opposite sides of the carrier, produced by the process of modulation, are not related to each other but are relocated separately to two sets of modulating signals. The carrier frequency may be transmitted, suppressed or partially suppressed.

signal center - See area and command signal centers.

signal intelligence (SIGINT) - The final product resulting from collection, evaluation, analysis, integration, and interpretation of information gathered from hostile electronic emitters. It includes communications intelligence (COMINT) and electronic intelligence (ELINT) and is used in determining enemy order of battle and planning future operations.

simplex operation - The operation of a circuit permitting communications in only one direction at a time; half duplex.

sole-user circuit (point-to-point) - A circuit from one subscriber to another subscriber on a fixed path.

space (spacing signal) - One of the two types of impulses used in teletypewriter transmission; normally that impulse during which no current flows through the teletypewriter selector magnet.

spot jamming - The jamming of a specific channel or frequency.

squelch - The reduction or elimination of the noise otherwise heard in a radio receiver when no carrier signal is present.

standing operating procedure (SOP) - A set of instructions covering those features of operations which lend themselvee to a definite or standardized procedure without loss of effectiveness.

strategic telecommunications - Continental, intercontinental and intercommand telecommunications facilities and services that are owned, leased, operated or controlled by the Department of the Army, which provide a means for the exercise of command and control, and logistic and administrative support of elements of the Department normally assigned down to the Army component commander within the theater of operations, and other Department of Defense and Governmental agencies as directed.

strip map - A map showing only a narrow geographical area between one point and another.

switchboard - An apparatus on which the various circuits from subscribers and other switchboards are terminated to enable communications either between two subscribers on the same switchboard or between subscribers on different switchboards.

synchronization - Identity in frequency (or time) and correspondence in phase between like processes at two or more points in a system.

system control - An engineering center within a telecommunications system at which technical control of facilities is exercised. See also Communications System Control Element.

system controller - An individual at a technical system control point who is responsible for maintaining quality control and channel switching of telecommunications.

Table of Organization and Equipment (TOE) - A table which prescribes the normal mission, organizational structure, personnel, and equipment requirements for a military unit and is the basis for an authorizations document.

tactical communications - Communications provided by, or under the operational control of, commanders of combat forces, combat troops, combat support troops, or forces assigned a combat service support mission.

Tactical Operations Center (TOC) - A facility from which selected special or general staff members assist in the direction, coordination, and control of current combat operations.

tandem switch - A switch used primarily as a switching point for traffic between other switches.

tape relay - A method of receiving and retransmitting messages in tape form.

telecommunications - Any transmission, emission or reception of signals, signs, writings, images, sounds, or information of any nature by wire, radio, visual, or other electromagnetic systems.

telecommunications center - An agency charged with the responsibility for acceptance, preparation for transmission, receipt, duplication and delivery of messages.

text - That part of a message which contains the thought or idea which the originator desires to be communicated.

time division multiplex (TDM) - A multiplex system in which the total available circuit time is divided between the number of channels to be transmitted.

TOW (Tube launched, Optically tracked, Wire command link) guided missile - The heavy antiarmor weapon system.

traffic (communication) - All transmitted and received messages.

traffic control point - A point where military police personnel regulate the flow of traffic to insure the orderly flow of traffic into and out of an area.

tropospheric scatter - The propagation of radio waves by scattering as a result of irregularities or discontinuities in the physical properties of the troposphere.

trunk circuit - A circuit directly connecting two distant central offices.

two-wire circuit - A circuit formed of two conductors.

verify - To insure that the meaning and phraseology of the transmitted message conveys the exact intention of the originator.

voice frequency - Any frequency within the part of the audio frequency range essential for the transmission of speech of commercial quality, i.e., 300-3000 Hz.

voice frequency telegraphy (VFTG) - Telegraphy using one or more carrier frequencies within the voice frequency range.

waveguide - A hollow structure, usually of rectangular cross section, used to transmit radio frequency energy over limited distances; e.g., from radar transmitter to antenna.

wavelength - A wavelength is the distance traveled in one period or cycle by a periodic disturbance. It is the distance between points of corresponding phase of two consecutive cycles. Wavelength is equal to the velocity divided by the frequency.

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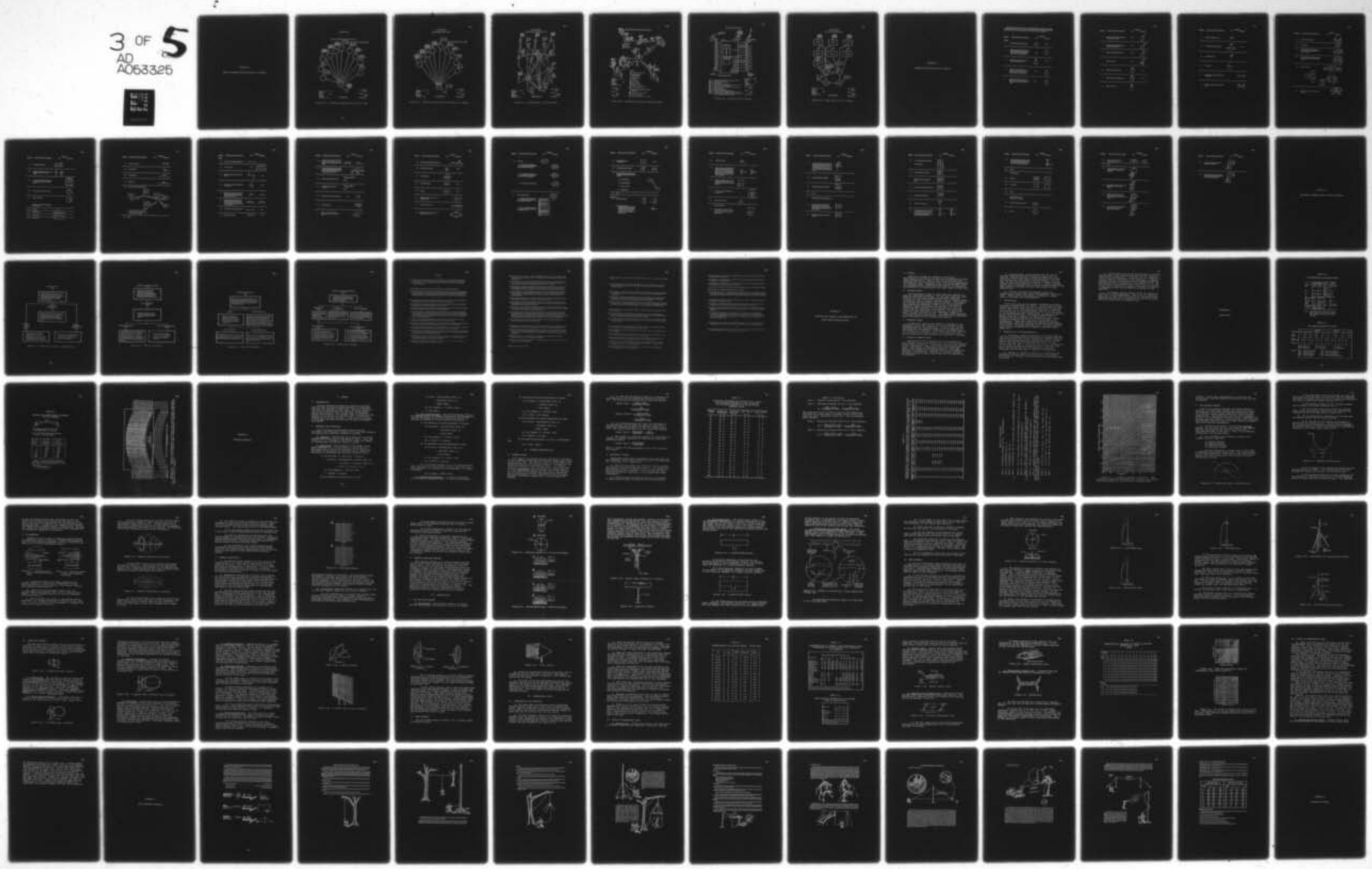

APPENDIX D

SAMPLE COMMUNICATIONS-ELECTRONICS DIAGRAMS

CLASSIFICATION

DIVISION COMMAND/OPERATIONS NET (FM)

NOTE: SEE CEOI FOR CALL SIGNS

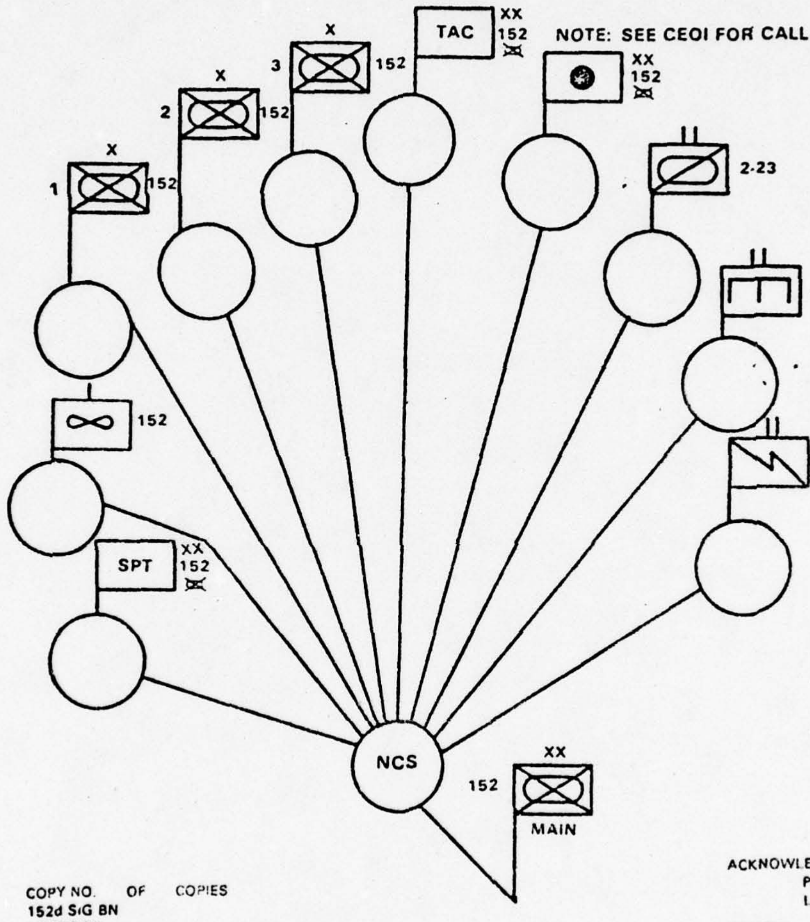

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Figure D-1. Division command/operations net (FM).

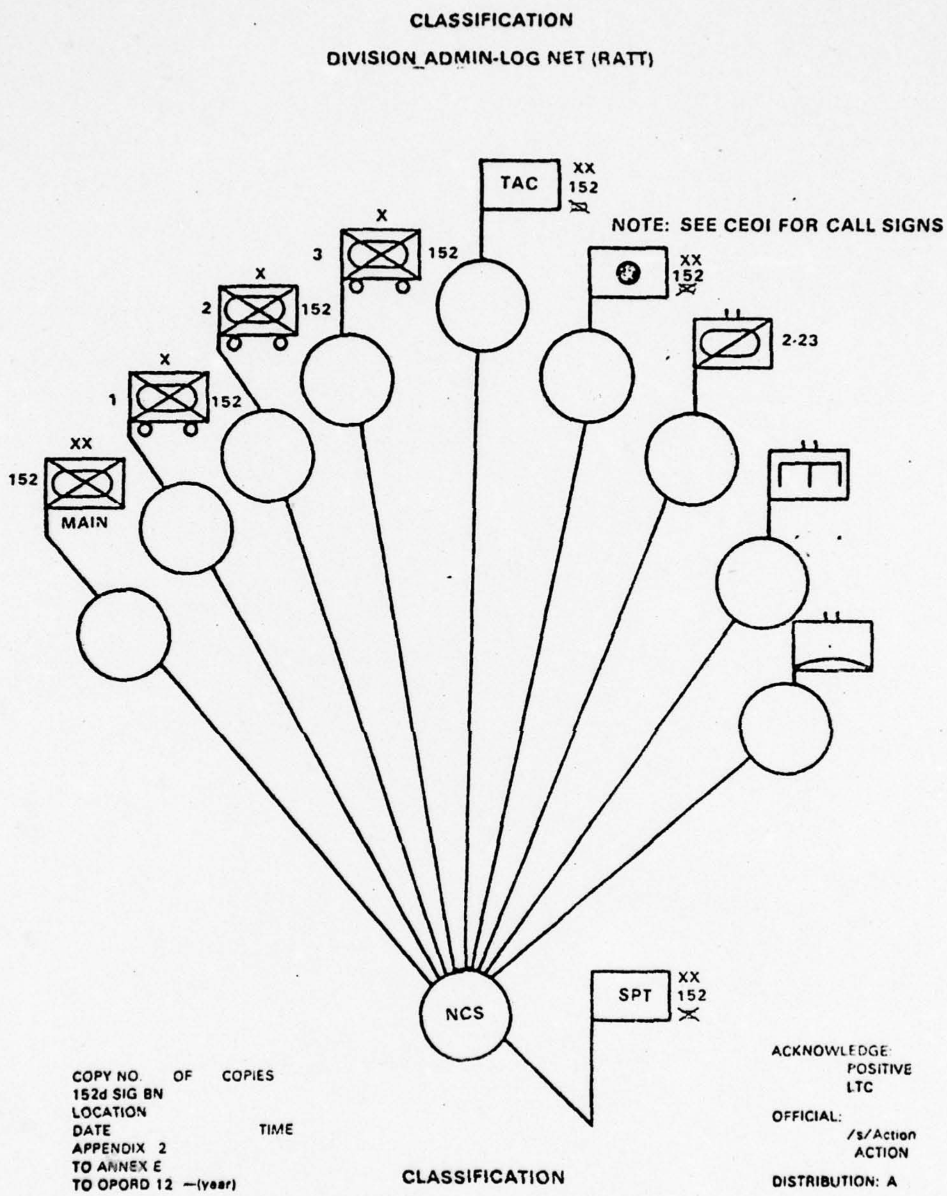


Figure D-2. Division administration/logistics net (RATT).

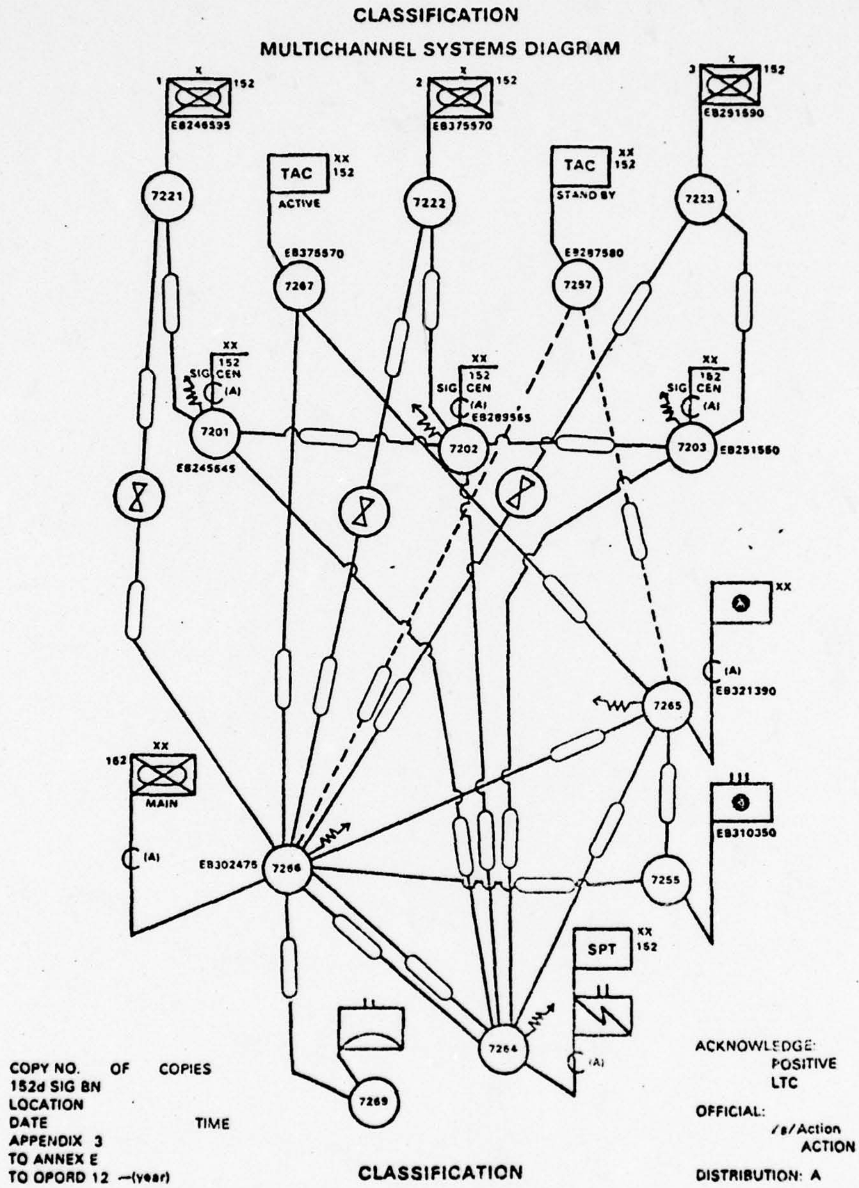


Figure D-3. Multichannel systems diagram.

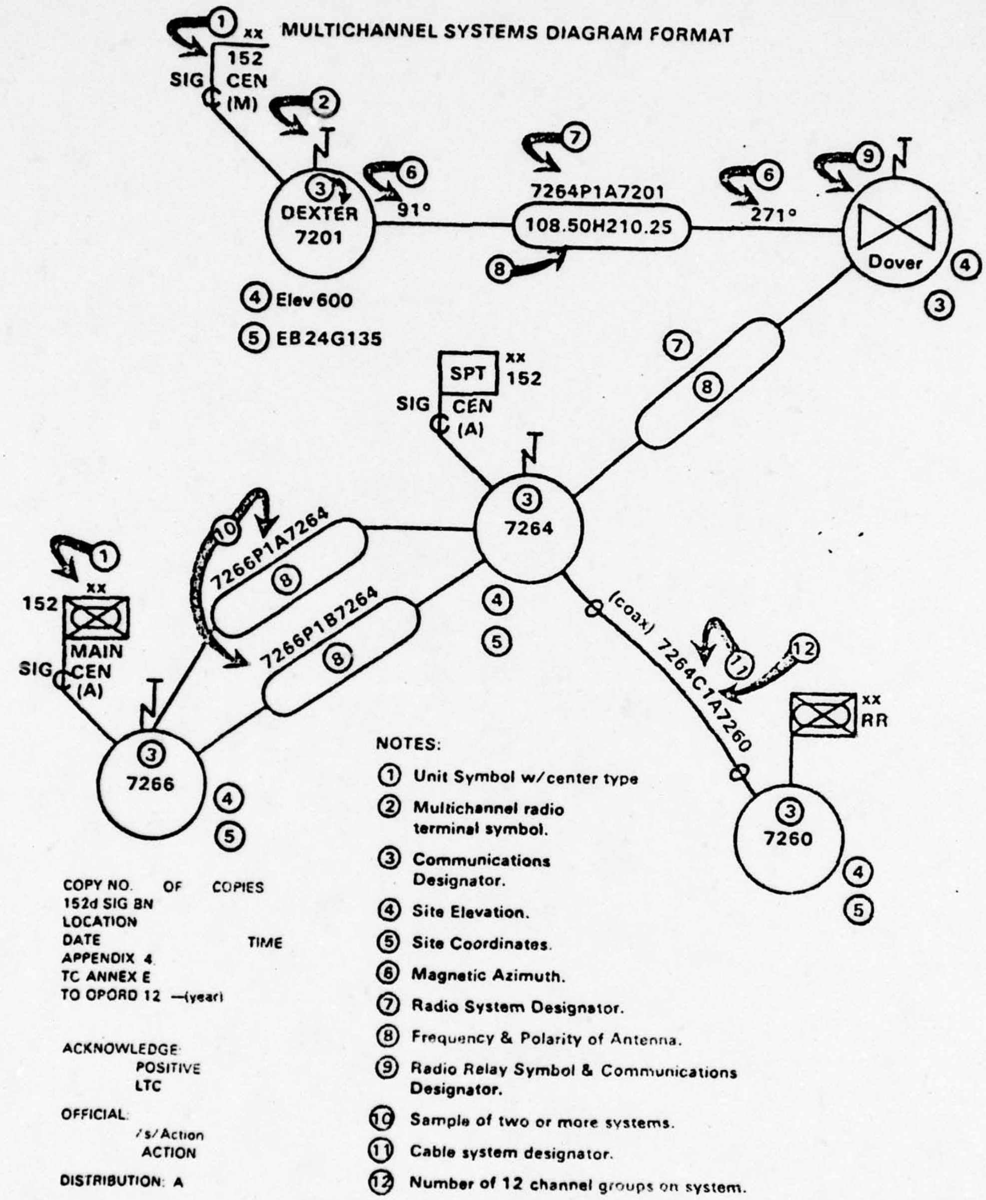
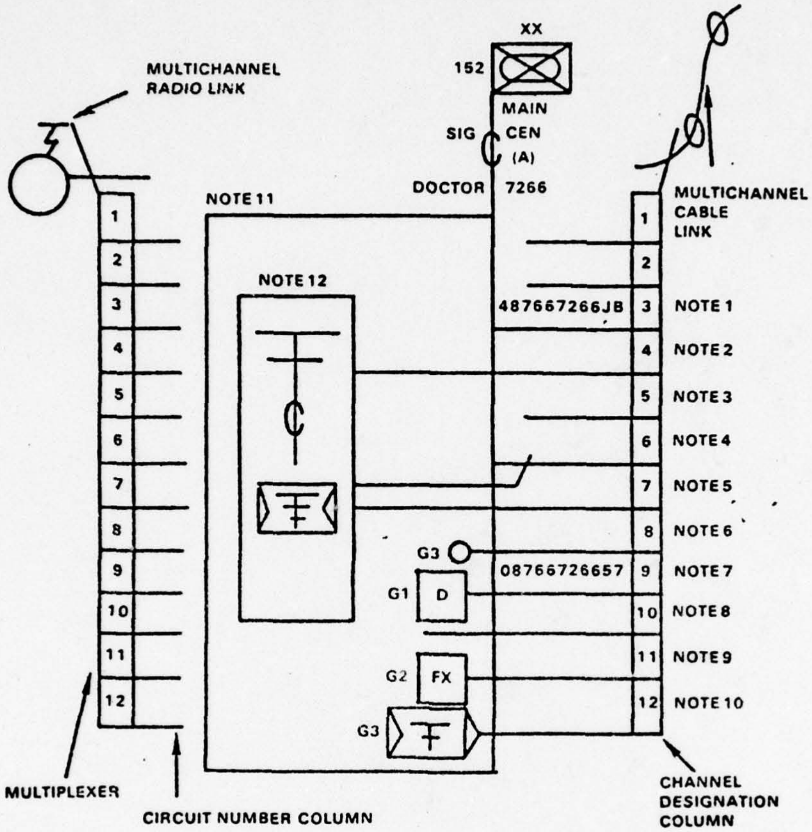


Figure D-4. Multichannel systems diagram format.

CIRCUIT DIAGRAM FORMAT



Note 1: Common-user telephone with sample circuit number.
Note 2: Common-user teletypewriter.
Note 3: Spare channel.
Note 4: Speech plus half duplex circuit.
Note 5: Point-to-point (sole-user teletypewriter) within the TCC.
Note 6: Point-to-point (sole-user telephone).
Note 7: Point-to-point (sole-user data circuit) with circuit number.
Note 8: Strap-thru channel.
Note 9: Point-to-point (Facsimile).
Note 10: Point-to-point (sole-user teletypewriter).
Note 11: Outer rectangle edge represents a telephone switchboard.
Note 12: Inner rectangle edge represents a teletypewriter switchboard within a telecommunications center (TCC).

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Figure D-5. Circuit diagram format.

CLASSIFICATION

TAPE RELAY TRAFFIC DIAGRAM

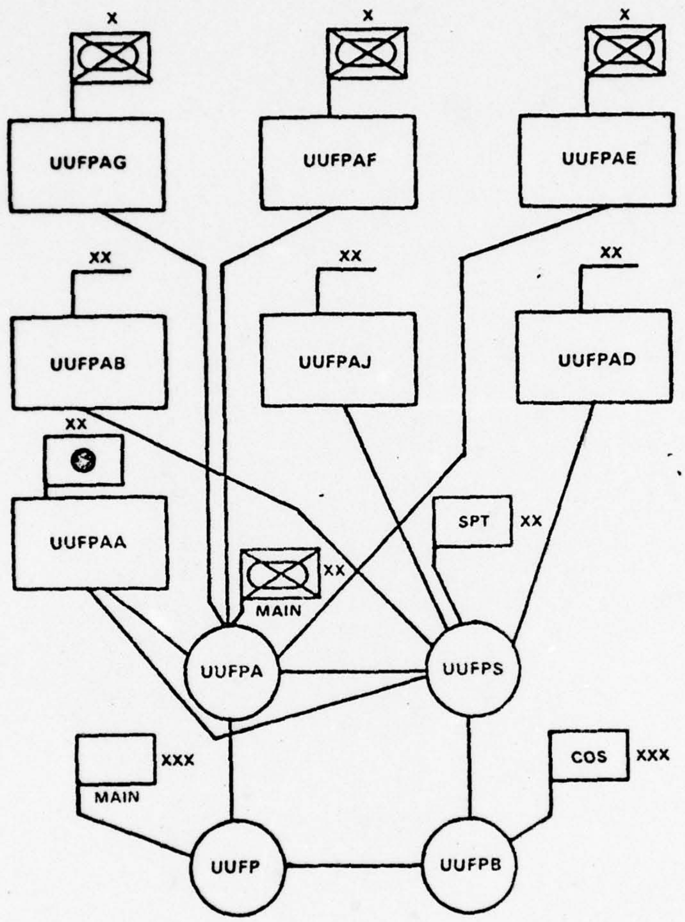

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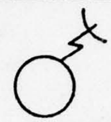
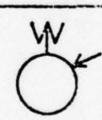
Figure D-6. Tape relay traffic diagram.

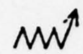
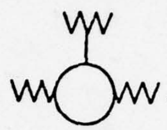
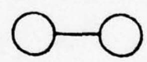
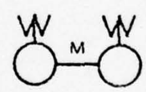
APPENDIX E

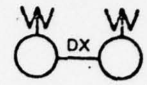
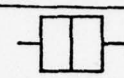
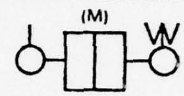
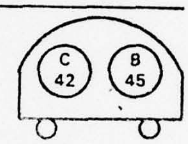
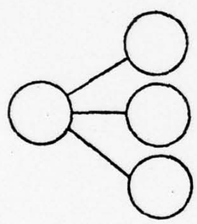
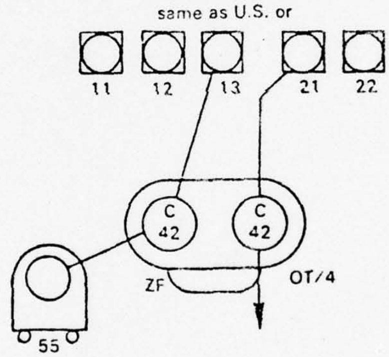
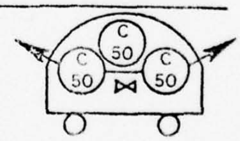
COMMUNICATIONS-ELECTRONICS SYMBOLS

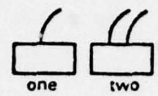
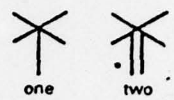
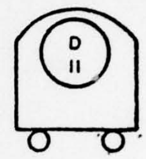
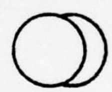
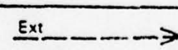
This appendix has incorporated the C-E symbols approved for use by the Standardization Agreement (STANAG) of the member nations of NATO, CENTO and SEATO. The STANAG symbols are presented here for the purpose of recognition and use as appropriate.

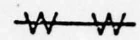
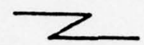
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
RADIO:			
1	General symbol for radio equipment.		same
2	Single channel transmitter or receiver (May be used to indicate a Single Channel Radio Access (SCRA) terminal (subscribers station where appropriate.)	same	
3	Single channel transmitter or receiver of the Combat Net Radio type.		same
4	Single channel transmitter or receiver telephony operation (May be used to indicate a single channel SCRA radio central station where appropriate.)	same	
5	Multichannel transmitter or receiver (May be used to indicate a multichannel SCRA radio central station where appropriate.	same	

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
6	Multichannel Line of Sight (LOS) Radio Relay equipment or station.	same	
7	Multichannel, Tropospheric (Forward) Scatter equipment or station.	same	
8	Multichannel Satellite Earth station.	same	
9	Radio relay station.	same	
10	Radio direction finding station.		same
11	Radio intercept or monitoring station.		same
12	Dummy Radio station.		

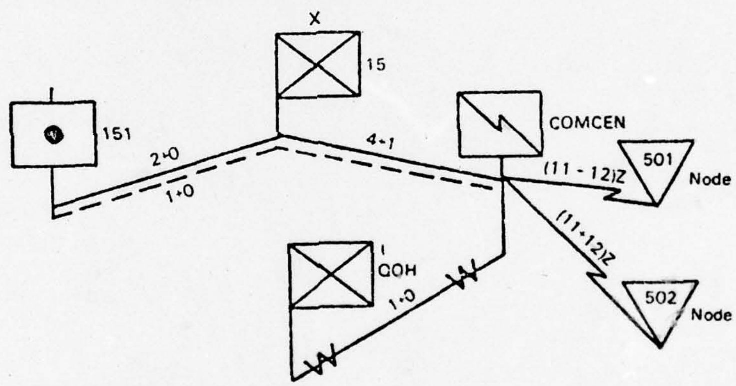
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
13	Radio-wire integration station.		
14	Communications jamming station.		same
15	Multipurpose jammer.		
16	Radar station.		
17	Automatically switched simplex rebroad-cast station.		
18	Manually switched simplex rebroadcast station.		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
19	Duplex rebroadcast station.		
20	Interface box.		
21	Interface between an SCRA terminal station and a net radio equipment with manual switching.		
22	C42 and B45 radio equipment co-located in an operational (non-armored) wheeled vehicle.		
23	Radio net systems.		same as U.S. or 
24	Mobile radio relay station with standby equipment.		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL	
		U.S.	STANAG
25	Remote control equipment.		
26	Antenna equipment for FM Voice (RC-292) *Three or more indicate number.		
27	A radio equipment type D11 mounted in an operational (non-armored) wheeled vehicle.		
28	A radio station under national control.		
29	Co-located equipment.		
	Symbols used in Field Manual diagrams (radio systems).		
30	FM Voice	see #34	
31	AM/SSB Voice		
32	AM/SSB RATT		
33	External Net		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
34	Combat radio net link		
35	Radio relay link		
36	Tropospheric link		
37	Satellite link		

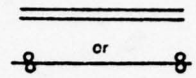
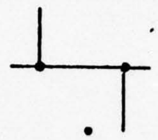
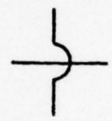
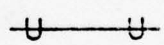
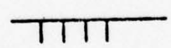
38 Communications diagram (STANAG):

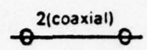
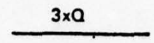
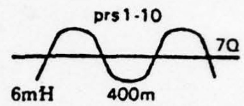
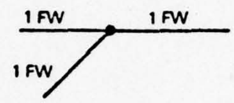
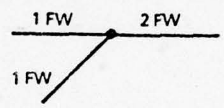
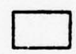
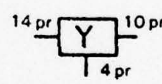
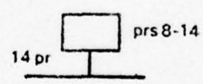


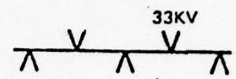
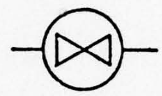
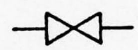
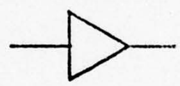
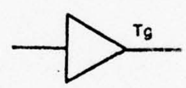
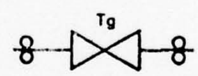
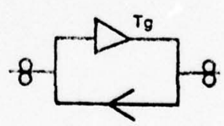
a. Shows only point to point facilities.

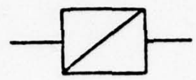
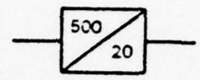
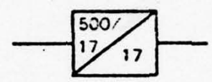
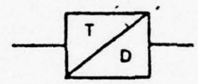
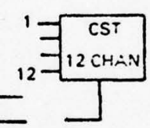
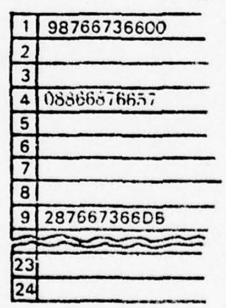
b. Dotted line shows "strap-thru" circuit from 151 Arty to COMCEN.

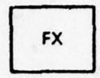
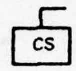
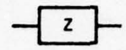
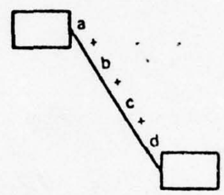
39 Spare.

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
WIRE:			
40	Two-wire circuit, duplex transmissions.		
41	Four-wire circuit.	same	
42	Electrical connection between wires or cables.		same
43	Cables or wires crossing on diagram but not connecting.		same
44	Field wire line on ground, U.S. numeral indicates number of field wire pairs; STANAG: numeral indicates number of quads. One quad = 2 pair.	8FW	4Q
45	Field wire and cable on ground, U.S.: number of field wire pairs and coaxial cables; STANAG: two ground cables, each containing 8 pairs laid up as 4 quads and 4 coaxial tubes.	16FW 4(coax)	2x(4Q+4C)
46	Underground or submarine wire or cable.		same
47	Overhead wire or cable.		same

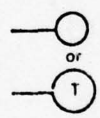
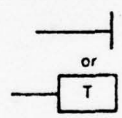
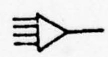
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
48	Cable on ground. U.S.: Number and type indicated above symbol (e.g. type: coaxial, SP4, etc); STANAG: three quad cables.		
49	Loaded cable (lumped loading). Example shows a 14 pr cable (laid up in quads) with first 10 pairs only loaded with 6mH coils spaced at 400 meter intervals.		
50	Field wire line spliced into another.		
51	Two field wires joining together (not spliced).		
52	General symbol for terminal equipment.	same	
53	Cable junction box.		
54	Cable test point (pair numbers 8-14 inclusive are terminated on the test box).		

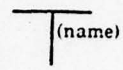
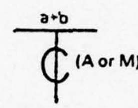
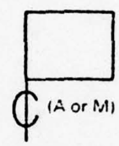
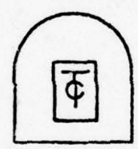
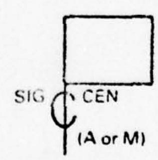
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
55	High voltage cables (Overhead assumed).		
56	Physical earth connection.		same
57	Attended repeater.		
58	Unattended repeater.		same
59	Amplifier.		same
60	Regenerative repeater ("Tg" or "D" for telegraph or data).		
61	Duplex telegraph repeater.		
62	Duplex telegraph circuit with regeneration in one direction only.		

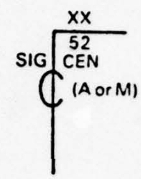
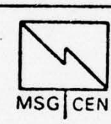
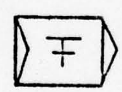
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
63	Converter		
	a. Voice frequency signaling unit where the two figures indicate 500Hz line tone and 20Hz ringing frequency.		
	b. Voice frequency signaling unit transmitting 500Hz tone chopped at 17Hz on receipt of 17Hz ringing signal.		
	c. Voice frequency tone dialing unit.		
64	Multiplexing equipment:		
	a. STANAG: 12 traffic channels, 1 service channel and 4 wire connection to the multiplexed input/output.		
	b. U.S.: 24 channel carrier system with sample circuit number designations on channels 1, 4, and 9.		

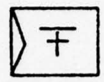
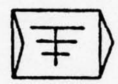
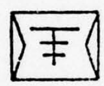
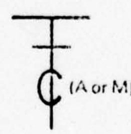
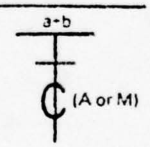
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
65	Facsimile instrument. (Also see #81)		same
66	On-line cryptographic machine.		
67	General method of showing what communications facilities exist between two locations: "a." = speech circuits; "b" = telegraph circuits; "c" = facsimile circuits; "d" = data circuits		
68	Spare		

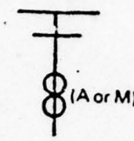
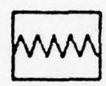
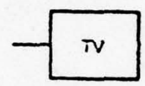
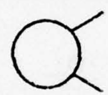
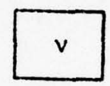
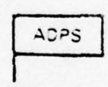
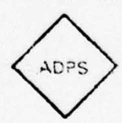
TELEPHONE:

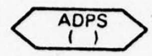
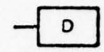
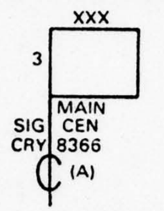
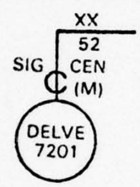
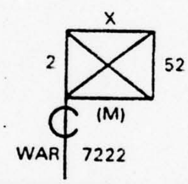
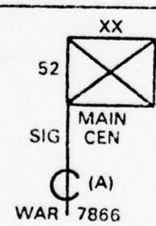
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
69	Telephone instrument.		
70	Telephone concentrator. (An instrument that permits several local subscribers to be connected to a SWBD via a smaller number of exchange lines. Subs would be connected only when originating or receiving a call.)		

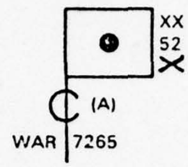
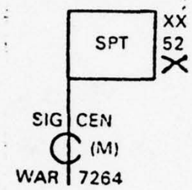
SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
71	Telephone test point.		
72	Telephone center or telephone switching central not at a headquarters or HQ echelon. An "A" or "M" indicates automatic or manual switching capability. STANAG: The "a" and "b" indicate the maximum number of trunks and local circuits respectively.		
73	Telephone switching central at a headquarters or HQ echelon. An "A" or "M" indicates automatic or manual switching capability.		
74	A telephone exchange installed in a container body.		
75	Circuit or system ground.		
	SIGNAL CENTERS		
76	Command signal center. The "C" and "A" or "M" will be added to indicate the use of either an automatic or manual telephone switch.		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
77	Area signal center not at a command post or headquarters. Size of unit is placed over the symbol. The unit's number is on the right of the staff and the "C" and "A" or "M" will be added to indicate the use of either an automatic or manual telephone switch.		
78	Signal center (Type not specified).		
79	Message center (Type not specified).		
80	Spare		
	TELETYPEWRITER and FACSIMILE:		
81	Teletypewriter (TTY), page printing, manual, operating half-duplex, Note: Change the doubtle 'T' to the letter 'F' to indicate facsimile equipment on numbers 81, 82, 83, & 89.		
82	TTY, page printing, manual operating full-duplex.		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
83	a. TTY, page printing, receive only.		
	b. Transmit only.		
84	TTY, tape printing, receive only.		
	TTY, tape printing, operating half-duplex.		
86	TTY, tape printing, operating full-duplex.		
87	TTY, tape transmitting only.		
88	Teleprinter or teletypewriter		
89	Teletypewriter switching center. The "A" or "M" designates either automatic or manual operation and the "a" + "b" indicates the maximum trunk and local circuits connected to the switch.		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
90	Telegraph traffic retransmission centers. The "A" indicates a computer controlled store and forward relay and the "M" shows it is a manual tape relay center.		
91	Spare		
	AUDIO-VISUAL		
92	Television.		
93	Visual station		
94	Spare.		
	AUTOMATIC DATA PROCESSING SYSTEM:		
95	Automatic Data Processing Center.		
96	Computer		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
97	Data terminal (Type: e.g. cards, papertape, mag tape, etc).		
98	Spare		
99	Command signal center, 3d Corps MAIN, identified by its communications designator.		
100	52d Infantry Division area signal center identified by its communications designator.		
101	Telephone switching central at 2d Brigade Headquarters, 52d Infantry Division, identifed by its communications desigantor.		
102	Command signal center at 52d Infantry Division MAIN identified by its communications designator.		

SERIAL	EXPLANATION OF SYMBOL	SYMBOL U.S.	SYMBOL STANAG
103	Telephone switching central at 52d Infantry Division Artillery.		
104	Command signal center at 52d Infantry Division Support Command identified by its communications designator.		

APPENDIX F

ELECTRONIC WARFARE TERMS AND RELATIONSHIPS

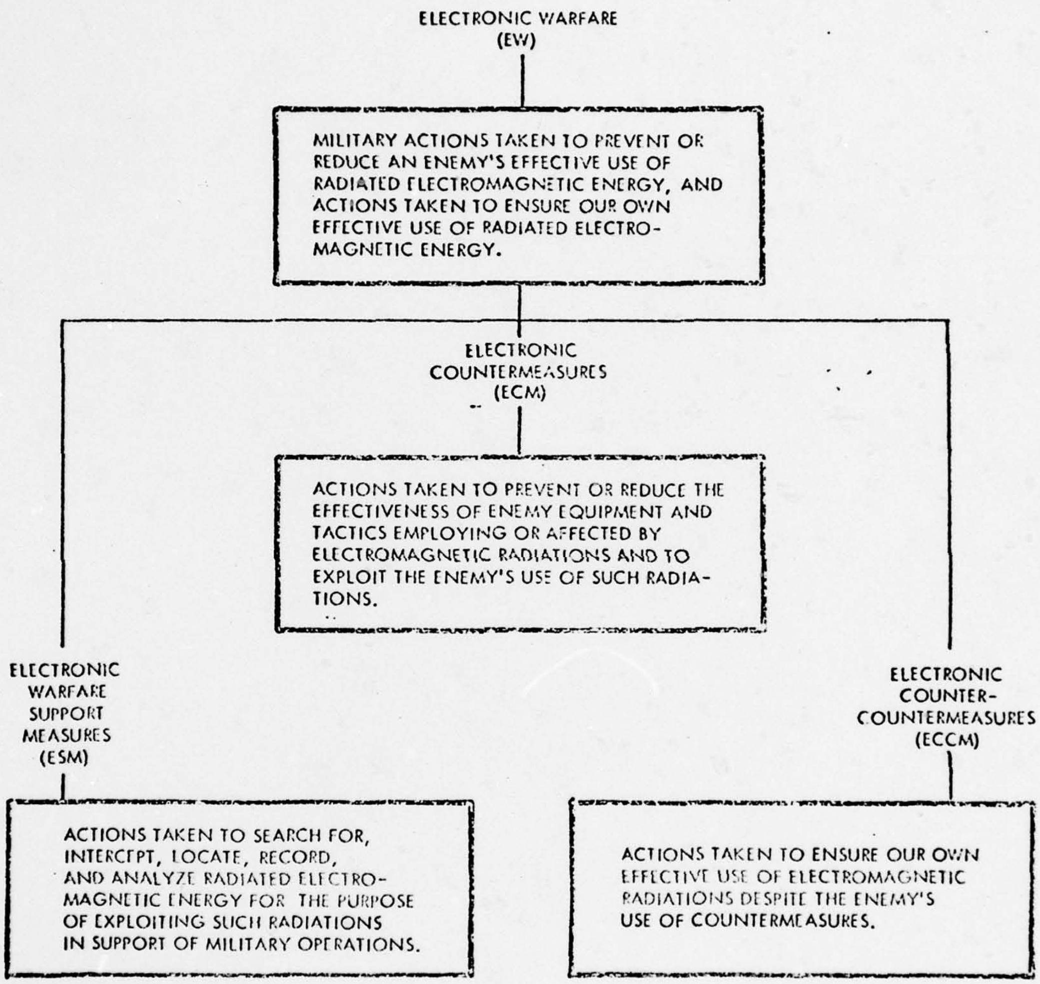


Figure F-1. Electronic warfare relationships.

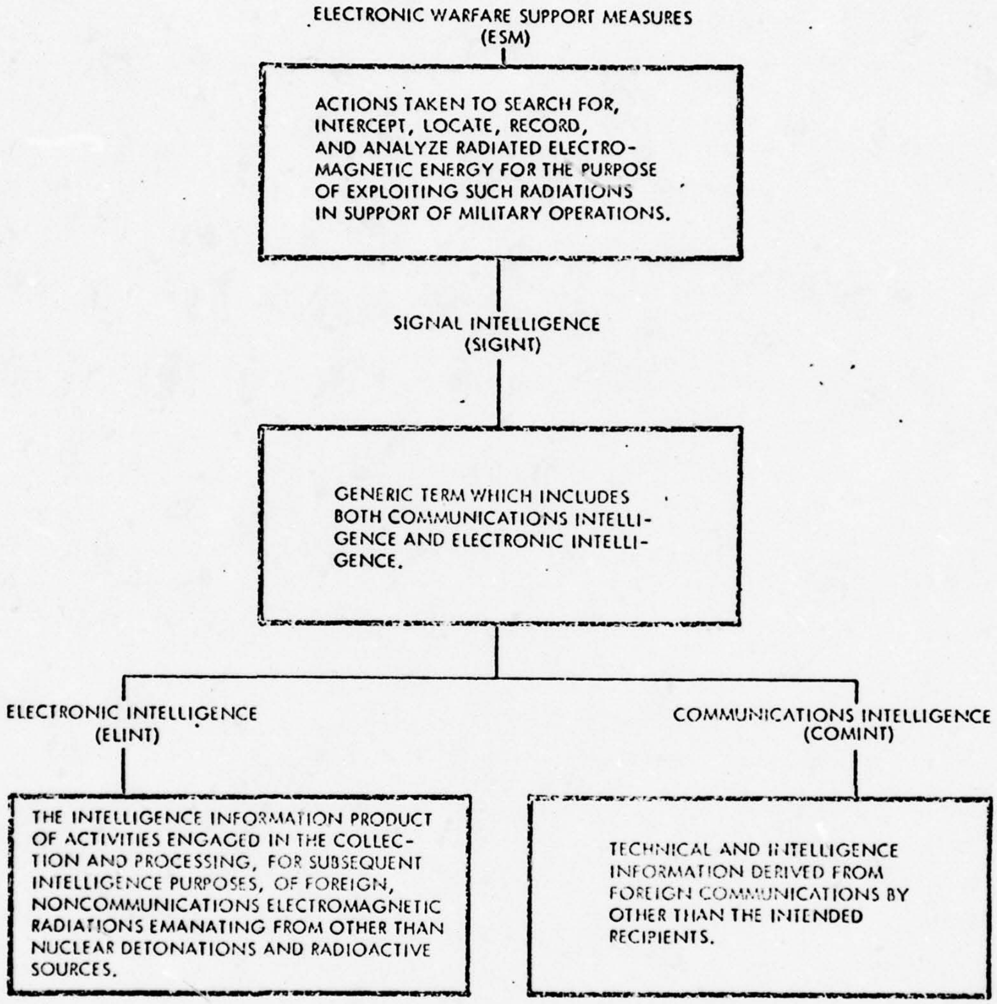


Figure F-2. ESM relationships.

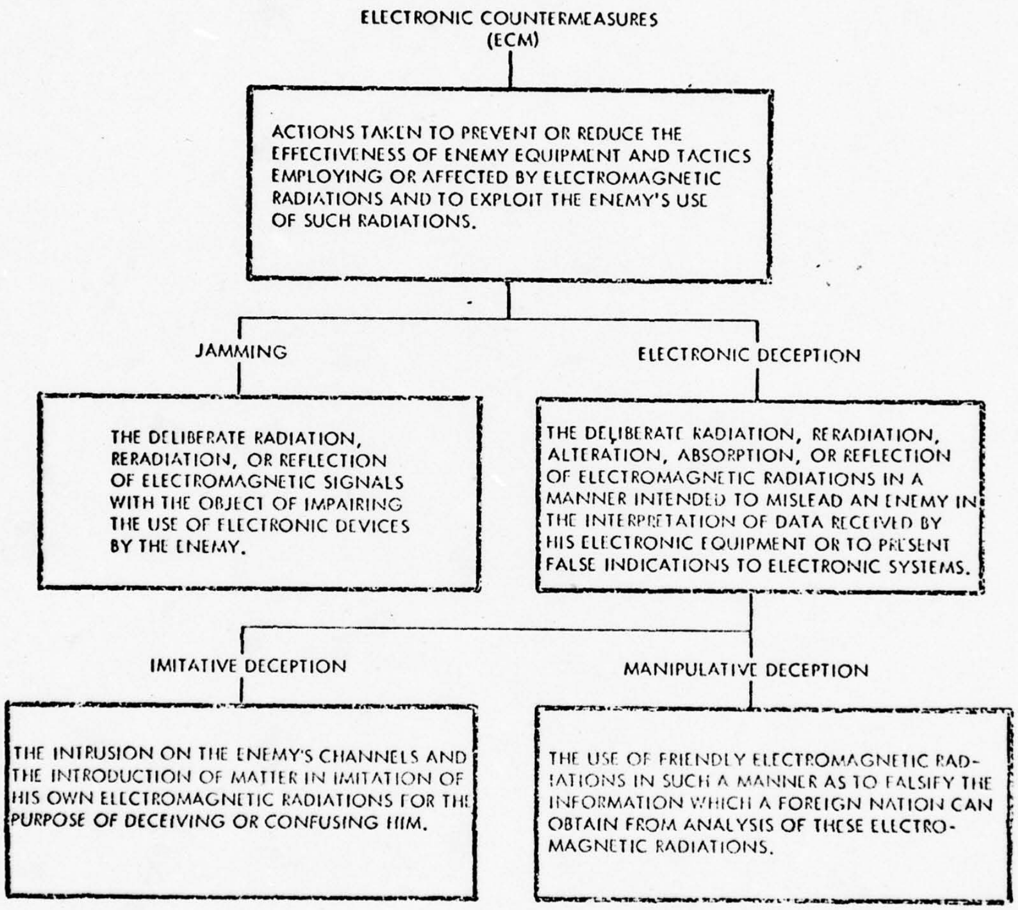


Figure F-3. ECM relationships.

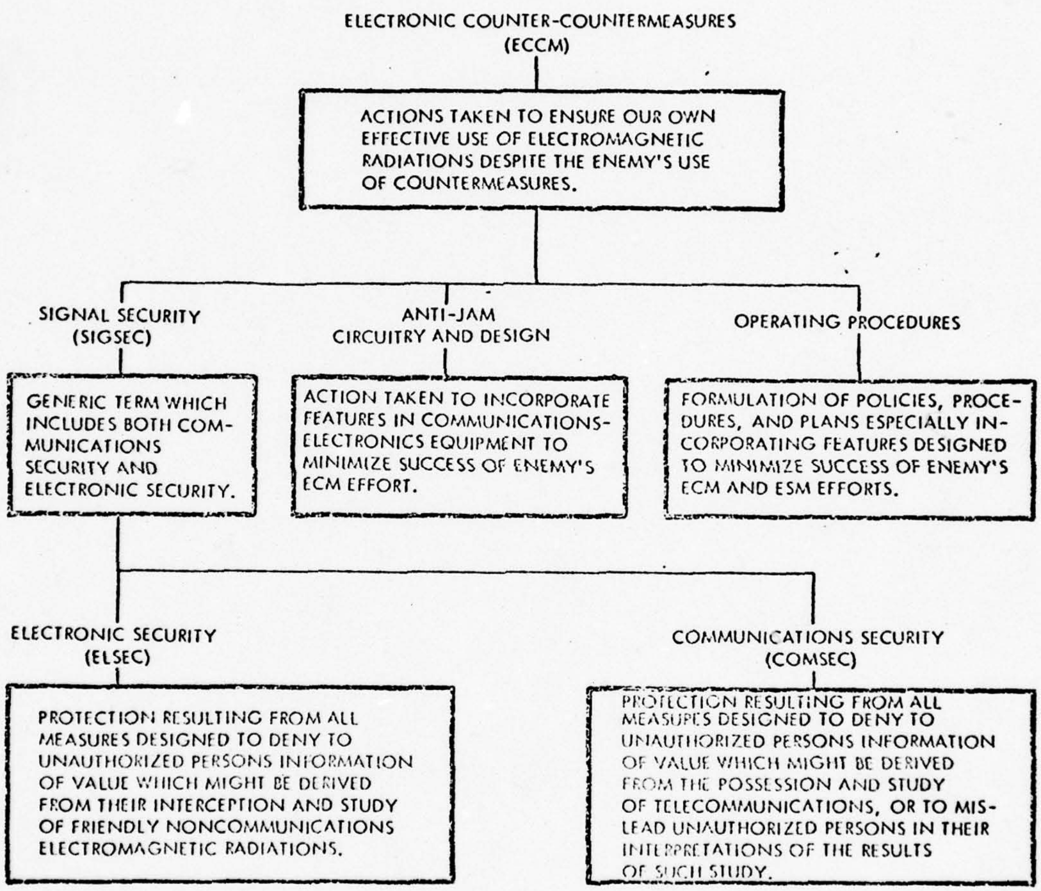


Figure F-4. ECCM relationships.

GLOSSARY

A

authentication system (cryptographic) - A system designed for purpose of authentication, that is to serve as a secure means of establishing the authenticity of a transmission or message or of challenging the identity of a station. Authentication systems may take the form of equipment, devices, or documents.

B

barrage jamming - Simultaneous electronic jamming over a broad band of frequencies.

brevity code - A code which provides no security but which has as its sole purpose the shortening of unclassified phrases, sentences or groups of sentences frequently employed, rather than concealment of their content. The vocabulary may remain in effect for an indefinite period of time. This type of code must be used in conjunction with a means of encipherment to provide security.

C

chaff - Radar confusion reflectors, which consist of thin, narrow metallic strips of various lengths and frequency responses, used to reflect echoes for confusion purposes.

combat intelligence - That knowledge of the enemy, weather and geographical features required by a commander in the planning and conduct of tactical operations.

communications intelligence - Technical and intelligence information derived from foreign communication by other than the intended recipients. Also called COMINT.

communications security - The protection resulting from all measures designed to deny to unauthorized persons information of value which might be derived from the possession and study of telecommunications, or to mislead unauthorized persons in their interpretations of the results of such study. Communications security includes cryptosecurity, physical security, and transmission security. Also called COMSEC.

compromise - The known or suspected exposure of clandestine personnel, installations, or other assets, or of classified information or material to an unauthorized person.

countermeasures - That form of military science which by the employment of devices and/or techniques has as its objective the impairment of the operational effectiveness of enemy activity.

cryptanalysis - The study of encrypted texts. The steps or processes involved in converting encrypted text into plain text without initial knowledge of the key employed in the encryption.

cryptoequipment - Any communications security equipment which converts information for transmission to a form which is unintelligible to an unauthorized interceptor, or which reconverts such information to its original form for authorized recipients.

cryptomaterial - All material, including documents, devices, equipments, and apparatus essential to the encryption, decryption, or authentication of telecommunications. When classified, it is designated CRYPTO and subject to special safeguards.

cryptosecurity - That component of communications security which results from the provision of technically sound cryptosystems and their proper use.

E

electronic counter-countermeasures - That major subdivision of electronic warfare involving actions taken to ensure our own effective use of electromagnetic radiations despite the enemy's use of countermeasures.

electronic countermeasures - That major subdivision of electronic warfare involving actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing or affected by electromagnetic radiations and to exploit the enemy's use of such radiations.

electronic deception - The deliberate radiation, reradiation, alteration, absorption, or reflection of electromagnetic radiations in a manner intended to mislead an enemy in the interpretation of data received by his electronic equipment or to present false indications to electronic systems.

electronic intelligence - The intelligence information product of activities engaged in the collection and processing, for subsequent intelligence purposes, of foreign, noncommunications, electromagnetic radiations emanating from other than nuclear detonations and radioactive sources. Also called ELINT.

electronic jamming - The deliberate radiation, reradiation, or reflection of electromagnetic signals with the object of impairing the use of electronic devices by the enemy.

electronic security - The protection resulting from all measures designed to deny to unauthorized persons information of value which might be derived from their interception and study of friendly noncommunications electromagnetic radiations.

electronic warfare - That division of the military use of electronics involving actions taken to prevent or reduce an enemy's effective use of radiated electromagnetic energy, and actions taken to ensure our own effective use of radiated electromagnetic energy.

electronic warfare support measures (ESM) - That division of EW involving actions taken to search for, intercept, locate, record, and analyze radiated electromagnetic energy for the purpose of exploiting such radiation in support of military operations. Thus, ESM provides a source of EW information required to conduct electronic countermeasures (ECM), electronic counter-countermeasures (ECCM), threat detection, warning, avoidance, target acquisition, and homing.

encode - That section of a code book in which the plain text equivalents of the code groups are in alphabetical, numerical, or other systematic order.

I

imitative electronic deception - The intrusion on the enemy's channels and the introduction of matter in imitation of his own electromagnetic radiations for the purpose of deceiving or confusing him.

intelligence - The product resulting from the collection, evaluation, analysis, integration, and interpretation of all information concerning one or more aspects of foreign countries or areas, which is immediately or potentially significant to the development and execution of plans, policies, and operations.

intelligence requirements - Any subject, general or specific, upon which there is a need for the collection of information or the production of intelligence.

interception - The act of listening in on and/or recording communications intended for another party for the purpose of obtaining intelligence.

J

jamming - See electronic jamming.

L

low grade cryptosystem - A system designed to provide temporary security, e.g., combat or operations codes.

M

manipulative electronic deception - The use of friendly electromagnetic radiations in such a manner as to falsify the information which a foreign nation can obtain from analysis of these electromagnetic radiations.

O

off line operation - A method of operation in which the processes of either encryption and transmission or reception and decryption are performed in separate steps, rather than automatically and simultaneously.

on line operation - A method of operation whereby messages are encrypted and simultaneously transmitted from one station to one or more stations where reciprocal equipment is automatically operated to permit reception and simultaneous decryption of the messages.

operations code - A code capable of being used for general communications within divisions or comparable organizations or by units operating separately. It is composed largely, though not exclusively, of single words or phrases and permits spelling. It is not to be confused with brevity codes.

P

padding - Words or phrases, unrelated to the text of a message, added prior to encryption and deleted upon decryption.

physical security - That part of security concerned with physical measures designed to safeguard personnel, to prevent unauthorized access to equipment, facilities, material and documents, and to safeguard them against espionage, sabotage, damage and theft.

pulse repetition frequency - In radar, the number of pulses that occur each second. Not to be confused with transmission frequency which is determined by the rate at which cycles are repeated within the transmitted pulse.

R

radar - Radio detection and ranging equipment that determines the distance and usually the direction of objects by transmission and return of electromagnetic energy.

radio direction finding - Radio location in which only the direction of a station is determined by means of its emissions.

radio fix - The location of a friendly or enemy radio transmitter, determined by finding the direction of the radio transmitter from two or more direction finding stations.

radio procedure - Standardized methods of transmission used by radio operators to save time and prevent confusion. By insuring uniformity, radio procedure increases security.

radio silence - A period during which all or certain radio equipment capable of radiation is kept inoperative. In combined or U.S. joint or intra-Service communications, the frequency bands and/or types of equipment affected will be specified.

rope - An element of chaff consisting of a long roll of metallic foil or wire which is designed for broad, low frequency response. See also chaff.

S

signal communications - Any means of transmitting messages, in plain or encrypted text other than by direct conversation or mail.

signal intelligence - A generic term which includes both communications intelligence and electronic intelligence. Also called SIGINT.

signal operation instructions (SOI) - A series of orders issued for technical control and coordination of the signal communication activities of a command.

signal security - A generic term which includes both communications security and electronic security.

spot jamming - The jamming of a specific channel or frequency.

standing signal instructions - A series of instructions explaining the use of items included in the signal operation instructions. The standing signal instructions may also include other technical instructions required to coordinate and control the communications electronics operations of a command.

T

target acquisition - The detection, identification and location of a target in sufficient detail to permit the effective employment of weapons.

target analysis - An examination of potential targets to determine military importance, priority of attack, and weapons required to obtain a desired level of damage or casualties.

transmission security - That component of communications security which results from all measures designed to protect transmissions from unauthorized interception, traffic analysis and imitative deception.

two part code - Randomized code, consisting of an encoding section in which the plain text groups are arranged in alphabetical or other significant order, accompanied by their code groups arranged in a nonalphabetical or random order, and a decoding section in which the code groups are arranged in alphabetical or numerical order and are accompanied by their meanings as given in the encoding section.

V

variants (communications) - Two or more cipher or code groups which have the same plain language equivalent; or two or more plain equivalents or designators used as a basis for encryption.

W

window - Strips of frequency cut metal foil, wire, or bars usually dropped from aircraft or expelled from shells or rockets as a radar countermeasure. See also chaff.

APPENDIX G

TECHNICAL AND TACTICAL CONSIDERATIONS IN FIELD RADIO COMMUNICATIONS

1. General

There are a number of technical and tactical characteristics of radio sets that must be considered in field radio communications. Some of these characteristics that determine the use of particular sets in military communication are—distance range, frequency range, type of emission (voice or continuous-wave), installation (man-carried or vehicular), and capability of communication with other types of radio sets.

2. Distance Range

The transmission range of field radio sets normally is based on ground-wave distance. For any given radio set, this distance will vary with changes in operating frequency, location of radio station and antenna, type of terrain, method of emission, type of antenna, and power output. The operator can increase the ground-wave range of the set by using the lower operating frequencies, which are not attenuated as rapidly as higher frequencies; by changing from voice to continuous-wave operation; or by substituting a long-wire antenna for the short-range whip antenna. Because of the effect of these variables, it is impossible to specify an exact distance range for any set. The rated ranges are based on average ground conditions for a specific type of operation, such as CW versus voice or fixed versus mobile.

3. Frequency Range

In some sets, such as the AN/PRC-77 or AN/VRC-12, the frequency range of the receiver is exactly the same as the frequency range of the transmitter. In other sets, such as the AN/GRC-19, the frequency ranges of the transmitter and the receiver are different. If different type radio sets are to be used for intercommunication, their frequency ranges must be considered before an operating frequency is assigned.

4. Methods of Communication

Most AM field sets have provisions for transmitting and receiving voice or CW signals and some have radio teletypewriter (RATT) capability. In addition, some sets are capable of tone transmission, known as modulated continuous wave (MCW). This method of telegraph transmission sometimes improves the readability of signals under certain conditions of noise or interference. When MCW is employed, the beat frequency oscillator (BFO) circuit used for CW reception is not required.

a. Radiotelegraph, which includes both CW and MCW, provides comparatively slow transmission speeds and, in addition, requires specially trained operators who achieve proficiency only after lengthy training periods. In a CW net, the speed of operation is normally no faster than the speed of the slowest operator in the net. However, CW will provide greater distance range and more reliable communication under adverse conditions than any other method of radio communication.

b. The use of CW has been replaced largely by frequency-shift-keyed (FSK) radio teletypewriter (RATT) circuits. These circuits are capable of handling a greater number of messages than radiotelegraph.

5. Installation

Field radio sets can be further classified as portable, vehicular, transportable, and mobile. Portable sets are low-powered and operate from dry cells installed within the case of the radio set or from hand-driven generators. Vehicular sets usually are of the medium-power class and operate from an electromechanical power supply which, in turn, is energized by the vehicular battery. For example, the AN/GRC-87 or AN/VRC-34 may use a vibrator and the AN/GRC-19 uses an alternator—both powered by the vehicular battery. Transportable and mobile radio sets may be either medium- or high-powered. These sets usually are powered by gasoline engine-driven generators which may be man-carried or mounted in a trailer. To permit operation from a protected position, remote control equipments are frequently used with field radio sets.

6. Capability of Intercommunication

a. Generally, communication between different types of radio sets is possible only if the sets can transmit over the required distance, and if they possess overlapping frequency ranges, use the same method of communication (voice or CW), and use the same type of modulation (AM or FM). A low-powered radio set with a rated distance range of approximately 1.6 KM cannot be used to communicate with a radio set 8 KM away, even though both sets are operating on the same frequency with the same type of modulation and emission.

b. Because of technical differences in operation, FM equipment cannot be used to communicate with AM equipment even though the distance ranges and operating frequencies may be similar.

c. If two radio sets use different methods of emission (one set uses voice, and the other set uses CW), they may not be able to communicate. CW signals are not audible in a receiver that is adjusted for voice reception. A separate circuit, the BFO, is provided with most communication-type receivers and must be switched on for reception of CW. If the receiver is not equipped with a BFO circuit, or if the circuit is not turned on or properly adjusted, CW reception is impossible unless the transmitter is capable of MCW operation.

d. In summary, several factors affect the ability of radio sets to intercommunicate. When a new or unfamiliar radio set is used, these factors must be considered by the communication officer in classifying the set and in determining its limitations and capabilities.

APPENDIX H

RADIO DATA

TABLE H-1

RF TRANSMISSION CHARACTERISTICS

Band	Range (Note) Day	Range (Note) Night	Power reqd	Antenna length
VLF	Long	Long	Extremely high	Very long
LF	Long	Long	Very high	Long
MF	Medium	Long	High to medium	Long
HF (3-10 MHz)	Short to long	Medium to long	Medium	Medium
HF (10-30 MHz)	Long	Medium to long	Low	Short
VHF	Short	Short	Low	Very short
UHF, SHF, and EHF	Line of sight (RLOS)	Line of sight (RLOS)	Low	Very short

Note: Long range: Over 1,500 miles. Medium range: 200 to 1,500 miles. Short range: Under 200 miles. Line of sight: Under 50 miles.

TABLE H-2

THE RADIO FREQUENCY SPECTRUM

Frequency	3 kHz	30 kHz	300 kHz	3000 kHz (3MHz)	30 MHz	300 MHz	3000 MHz (3GHz)	30 GHz	300 GHz
Wave length		30km	3km	300m	30m	3m	30cm	3cm	.3cm

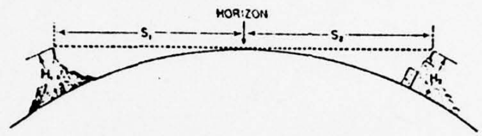
Band designation	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
Band no.	4	5	6	7	8	9	10	11

kHz - Kilohertz
MHz - Megahertz
GHz - Gigahertz
km - Kilometers
m - Meters
cm - Centimeters

Legend:
VLF - Very low frequency
LF - Low frequency
MF - Medium frequency
HF - High frequency
VHF - Very high frequency
UHF - Ultra high frequency
SHF - Super high frequency
EHF - Extremely high frequency

TABLE H-3

HORIZON AND LINE-OF-SIGHT DISTANCES
FOR VHF ANTENNAS



S (vhf distance to horizon) = $4.12 \sqrt{H}$
S is in kilometers, H is in meters.

Line-of-sight distance between two antennas:
$S_1 + S_2 = 4.12 (\sqrt{H_1} + \sqrt{H_2})$

$H_1 = H_2$ (Note 1)	$S_1 = S_2$ (Note 2)	$S_1 + S_2$ (Note 3)
Meters	Kilometers	Kilometers
1	4.12	8.24
2	5.85	11.7
5	9.23	18.5
10	13.0	26.0
50	29.1	58.2
100	41.2	82.4
500	92.3	185
1,000	130	260

Notes: 1. In the chart above, the heights of the antennas above ground are assumed to be equal ($H_1 = H_2$); however, H_1 and H_2 may vary at actual antenna sites.
2. Horizontal distance.
3. Line-of-sight distance.

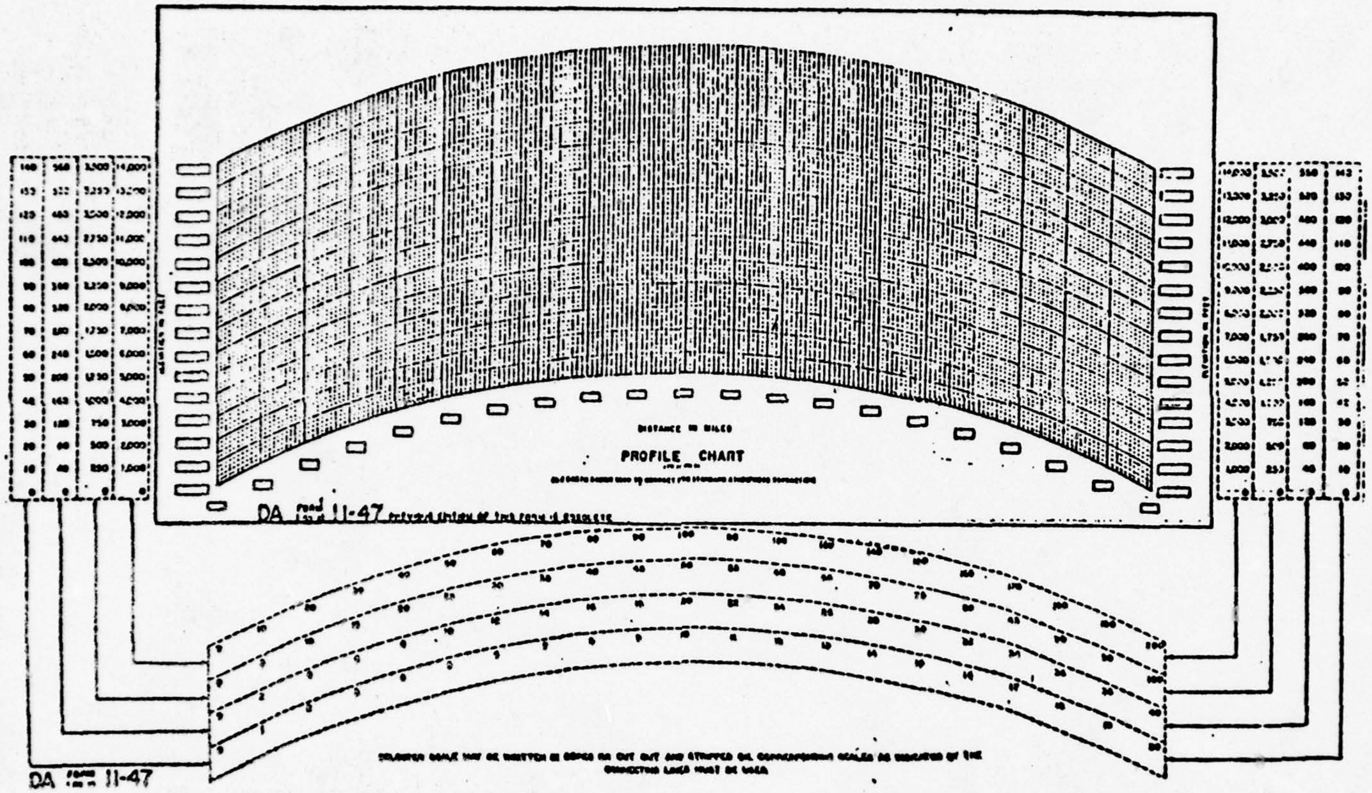


Figure H-1. Graphical determination of horizon and line-of-sight distances for VHF antennas. DA Form 11-47 Profile Chart (photographic reduction—the actual chart is 18 × 30 inches).

APPENDIX I

TACTICAL ANTENNAS

I. GENERAL

1. INTRODUCTION

Tactical antennas are specially designed to provide mobility with the least possible sacrifice of efficiency. They are also designed to take abuse. Some are mounted on the sides of vehicles that will move over rough terrain; others are mounted on top of single masts or suspended between sets of masts. The smallest ones are mounted on the helmets of the men who use the radio sets. All tactical antennas must be easy to install. Large ones must be easy to take apart and pack and they must be easy to transport when packed.

2. FREQUENCY AND WAVELENGTH

There are basic relationships between velocity, wavelength, and frequency of radiated RF energy that determine the physical and electrical lengths of antennas.

a. Velocity. The velocity of RF energy as it travels through space is the same as the speed of light. Thus, the velocity (v) of RF energy is 300,000,000 meters per second, or 186,000 miles (982,000,000 feet) per second.

b. Wavelength. The wavelength of RF energy, at any given frequency (f), is the distance in space from the beginning of one cycle to the beginning of the next cycle. The symbol for wavelength is the Greek letter, lambda (λ). Wavelength is determined from the basic formula: $\lambda = v/f$.

(1) To determine the wavelength in meters:

λ in meters = 300,000,000/f in Hertz (Hz); or,

= 300,000/f in kiloHertz (kHz); or,

= 300/f in megaHertz (MHz).

If, for example, f = 60 MHz, then:

$\lambda = 300/60 = 5$ meters.

(2) To determine the wavelength in feet:

λ in feet = 984,000,000/f (Hz); or,

= 984,000/f (kHz); or,

= 984/f (MHz).

If, for example, f = 60 MHz, then:

λ = 16.4 feet.

c. The Half-Wavelength. The half-wavelength ($\lambda/2$) is an important factor in antenna calculations and measurements. The half-wavelength or half-wave antenna is used as the standard of comparison in many antenna measurements.

(1) To determine the half-wavelength in meters:

$\lambda/2$ in meters = 150,000,000/f (Hz); or,

= 150,000/f (kHz); or

= 150/f (MHz).

If, for example, f = 60 MHz, then:

$\lambda/2$ = 150/60 = 2.5 meters.

(2) To determine the half-wavelength in feet:

$\lambda/2$ in feet = 492,000,000/f (Hz); or,

= 492,000/f (kHz); or,

= 492/f (MHz).

If, for example, f = 60 MHz, then:

$\lambda/2$ = 491/60 = 8.18 feet.

(3) In the upper portion of the very-high frequency (VHF) band and in the ultra-high frequency (UHF) band, it is often convenient to calculate the half-wavelength in inches, as follows:

$\lambda/2$ in inches = 5544/f (MHz).

d. The Quarter-Wavelength. The quarter-wavelength ($\lambda/4$) is another important factor in antenna calculations.

(1) To determine quarter-wavelength in meters:

$\lambda/4$ in meters = 75,000,000/f (Hz); or

= 75,000/f (kHz); or

= 75/f (MHz).

If, for example, f = 60 MHz, then:

$\lambda/4$ = 75/60 = 1.25 meters.

(2) To determine the quarter-wavelength in feet:

$\lambda/4$ in feet = 296,000,000/f (Hz); or,

= 296,000/f (kHz); or

= 296/f (MHz).

If, for example, f = 60 MHz, then:

$\lambda/4$ = 296/60 = 4.9 feet.

(3) The quarter-wavelength in inches is determined by:

$\lambda/4$ = 2272/f (MHz).

II. ANTENNA CHARACTERISTICS

3. ANTENNA LENGTH

The length of an antenna must be considered in two ways. It has a physical length and an electrical length, and the two are never the same. The physical length of a half-wave, non-loaded antenna will vary from 92 percent to 97 percent of the electrical length of a half-wave in space. The reduced velocity of the wave on the antenna, and a capacitive effect (known as end effect) make the antenna seem longer than it is. The contributing factors are the ratio of the diameter of the antenna to its length; the capacitance between the ends of the antenna; and the capacitive effect of terminal equipment (insulators, clamps, etc.) used to support the antenna.

a. To calculate the physical length of an antenna, use a correction of 0.95 for frequencies between 3.0 and 50.0 MHz. The figures given below are for a half-wave antenna.

$$\text{Length (feet)} = \frac{492 \times 0.95}{\text{Frequency in MHz}}$$

$$= \frac{468}{\text{Frequency in MHz}}$$

$$\text{Length (meters)} = \frac{150 \times 0.95}{\text{Frequency in MHz}}$$

$$= \frac{142.5}{\text{Frequency in MHz}}$$

b. For frequencies above 50.0 MHz, the end effect is more pronounced. To calculate the physical length of an antenna for frequencies above 50.0 MHz use a correction of 0.94. The figures given below are for a half-wave antenna.

$$\text{Length (feet)} = \frac{492 \times 0.94}{\text{Freq MHz}} = \frac{462}{\text{Freq MHz}}$$

c. The length of a long-wire antenna (one wavelength or longer) for harmonic operation is calculated by using the following formula:

$$\text{Length (feet)} = \frac{492\ (N-0.05)}{\text{Freq MHz}}$$

Where N = Number of half-wavelengths in the total length of the antenna.

4. RECIPROCITY THEORY

Reciprocity means that an antenna has the same gain, the same impedance, and the same directivity when it is receiving as it does when it is transmitting.

a. Many tactical radios are transceivers which use the same antenna for transmitting and receiving. The reciprocity characteristic makes it unnecessary to tune the antenna for both transmitting and receiving. If the antenna has been tuned accurately for receiving, it will perform well while transmitting.

b. Sometimes security requirements make it necessary to impose radio silence, and you will not be permitted to

TABLE I-1

ELECTRICAL WAVELENGTH AND PHYSICAL FULL-, HALF-, AND QUARTER-WAVELENGTH IN FEET AND INCHES FOR SELECTED FREQUENCIES IN THE 30-80 MHz FREQUENCY RANGE

Frequency (MHz)	λ (Note 1) (Electrical) ft	in	λ (Note 2) (Physical) ft	in	$\lambda_p/2$ (Note 3) ft	in	$\lambda_p/4$ (Note 4) ft	in
30	32	10	31	2	15	7	7	10
33	29	10	28	4	14	2	7	1
35	28	1	26	10	13	5	6	9
37	26	7	25	2	12	7	6	4
40	24	7	23	4	11	8	5	10
43	22	11	21	8	10	10	5	5
45	21	10	20	10	10	5	5	2
47	20	11	19	11	9	11	5	0
50	19	8	18	10	9	5	4	9
53	18	7	17	8	8	10	4	5
55	17	11	17	0	8	6	4	3
57	17	3	16	4	8	2	4	1
60	16	5	15	8	7	10	3	11
63	15	7	14	10	7	5	3	9
65	15	2	14	4	7	2	3	7
68	14	6	13	8	6	10	3	5
70	14	1	13	2	6	7	3	4
73	13	6	12	10	6	5	3	2
75	13	1	12	4	6	2	3	1
78	12	7	12	0	6	0	3	0
80	12	4	11	8	5	10	2	11

TABLE I-1 (continued)

Note 1. Reference paragraph 2b, this appendix.

Note 2. Reference paragraph 2b and 3, this appendix

$$\lambda_p = \frac{984 \times 0.95}{\text{Frequency in MHz}} \approx \frac{935}{\text{Frequency in MHz}} .$$

The correction factor of 0.95 is used for all frequencies 30-80 MHz due to the number of unknown factors such as the exact h/a ratio, capacitive values, etc. This is standard field practice.

Note 3. Reference paragraph 2c(2) and 3, this appendix.

$$\lambda_p/2 = \frac{984 \times 0.95 \times 0.5}{\text{Frequency in MHz}} \approx \frac{468}{\text{Frequency in MHz}} .$$

Note 4. Reference paragraph 2d(2) and 3, this appendix.

$$\lambda_p/4 = \frac{984 \times 0.95 \times 0.25}{\text{Frequency in MHz}} \approx \frac{234}{\text{Frequency in MHz}} .$$

TABLE I-2

ANTENNA HEIGHT (LENGTH) OF VARIOUS TACTICAL ANTENNAS AS A FUNCTION OF PHYSICAL WAVELENGTH FOR SELECTED FREQUENCIES IN THE 30-80 MHz FREQUENCY RANGE (h/λ_p)

Frequency (MHz)	12 in (Note 1)	18 in (Note 2)	24 in (Note 3)	36 in (Note 4)	72 in (Note 5)	108 in (Note 6)	120 in (Note 7)	180 in (Note 8)	82 in	61.5 in (Note 9)	41 in
30	0.032			0.096	0.192	0.288	0.321	0.481	0.219	0.164	0.109
33	0.035			0.106	0.212	0.317	0.353	0.529	0.241	0.181	0.120
35	0.037			0.112	0.224	0.337	0.374	0.561	0.256	0.192	0.128
37	0.039			0.118	0.237	0.356	0.395		0.270	0.203	0.135
40	0.042			0.128	0.256	0.385	0.427		0.292	0.219	0.146
43	0.046			0.138	0.276	0.413	0.459		0.314	0.235	0.157
45	0.048			0.144	0.288	0.433	0.481		0.329	0.246	0.164
47	0.050	0.075	0.100	0.151	0.301	0.452	0.502		0.343	0.257	0.172
50	0.053	0.080	0.107	0.160	0.321	0.481	0.534		0.365	0.274	0.183
53	0.057	0.085	0.113	0.170	0.340	0.510	0.566		0.387	0.290	0.193
55	0.059	0.088	0.118	0.176	0.353	0.529	0.588		0.402	0.301	0.201
57	0.061	0.091	0.122	0.183	0.365	0.548	0.609		0.416	0.312	0.208
60	0.064			0.192	0.385	0.577	0.641		0.438	0.329	0.219
63	0.067			0.202	0.404	0.606	0.673		0.460	0.345	0.230
65	0.069			0.208	0.417	0.625	0.694		0.475	0.356	0.237
68	0.073			0.218	0.436	0.654	0.726		0.496	0.372	0.248
70	0.075			0.224	0.449	0.673	0.748		0.511	0.383	0.256
73	0.078			0.234	0.468	0.702	0.780		0.533	0.340	0.266
75	0.080			0.240	0.481	0.721	0.801		0.548	0.411	0.274
78	0.083			0.250	0.500	0.750	0.833		0.569	0.427	0.285
80	0.085			0.256	0.513	0.769	0.855		0.584	0.438	0.292

TABLE I-2 (continued)

Note 1. Telescoping antenna (12 in.) AN/PRC-68(XN-4).

Note 2. AS-1998/PRR-9 (18 in.).

Note 3. AS-1999/PRT-4 (24 in.).

Note 4. AT-892/PRC-25 (36 in.) used with radio sets AN/PRC-25, -68(XN-4), and -77.

Note 5. Six ft. whip antenna, part of AS-2974/PRC-70 (6, 9, or 15 ft. whip).

Note 6. Nine ft. whip antenna, p/o AS-2974/PRC-70.

Note 7. Ten ft. whip antenna, AT-271A/PRC used with radio set AN/PRC-77; AT-912/VRC and AS-1729/VRC used with AN/VRC-12 series radios.

Note 8. Fifteen ft. whip antenna, p/o AS-2974/PRC-70.

Note 9. Antenna Equipment RC-292 used with radio sets AN/PRC-77, AN/VRC-12 series, and AN/PRC-70 to extend the range of the set. The three lengths shown are the approximate lengths of the vertical radiating element (nominally $\lambda/4$) for the three operating bands.

Band 1. 30-36.5 MHz (1 ea. AB-21, -22, -23, and -24/GR) (82 in.)

Band 2. 36.5-50.5 MHz (1 ea. AB-22, -23, and -24/GR) (61.5 in.).

Band 3. 50.5-75.95 MHz (1 ea. AB-22 and -24/GR) (41 in.).

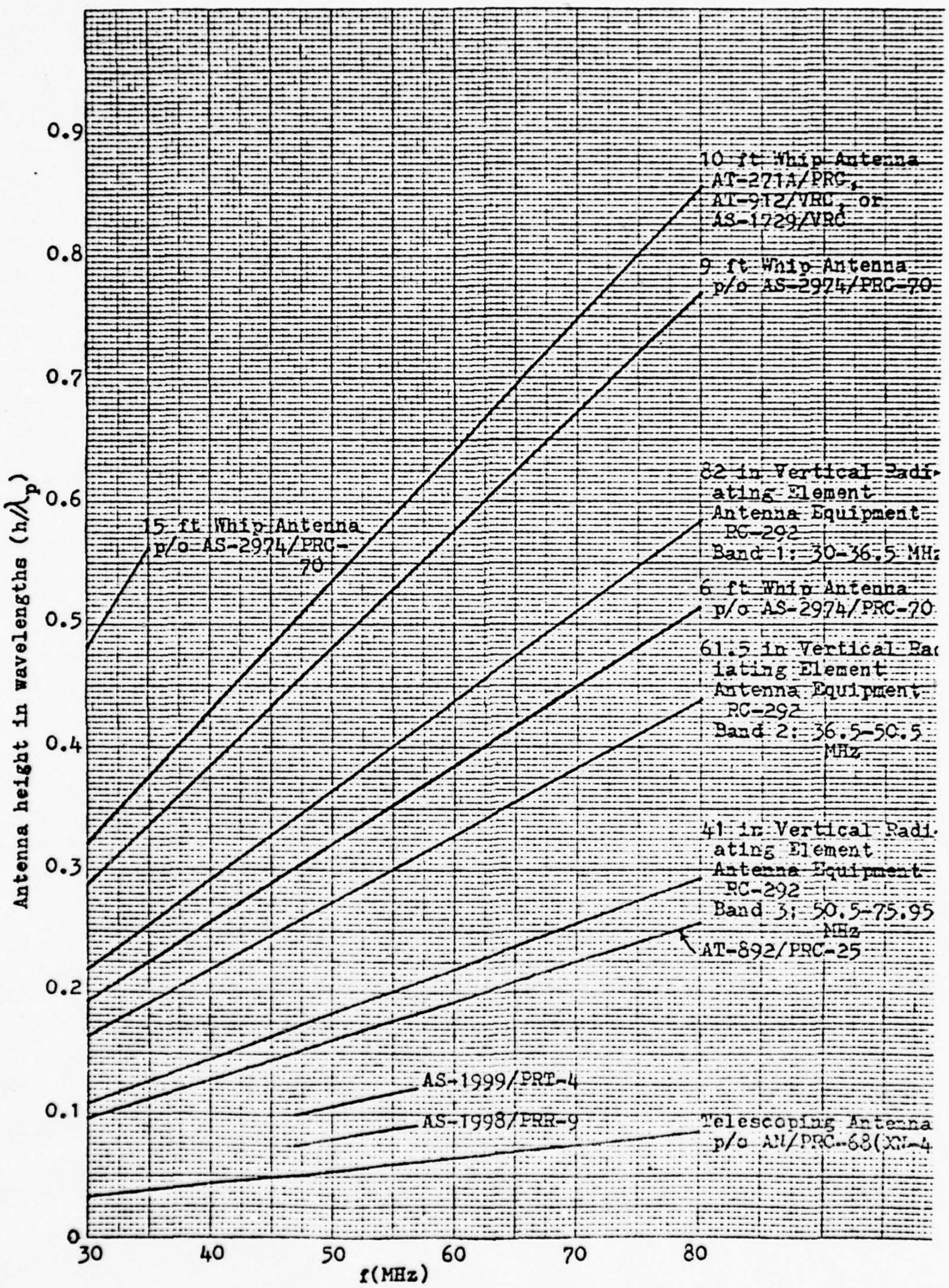


Figure I-1. A graphical display of Table I-2. The variation of physical wavelength with frequency for various tactical antennas over the 30-80 MHz frequency range.

transmit. Under these circumstances, you can tune the antenna while receiving signals from stations that are free to transmit.

5. THE RESONANT ANTENNA

Most of our tactical antennas are either half-wave antennas, or quarter-wave antennas that perform like half-wave antennas. The mobility requirements sometimes force us to use the shortest antenna that will provide reliable communication. And because most tactical radio equipment is small, it is necessarily limited in power. Therefore, the antennas used must radiate at the highest possible efficiency. The half-wave antenna is one of the most effective antennas that suits tactical requirements.

a. The half-wave antenna is the shortest resonant antenna. The RF energy fed to a half-wave antenna travels from the feed point to the ends of the antenna and is reflected back again in one cycle. Thus, it is constantly reinforced by the applied energy.

b. Four components of RF energy are present on a resonant antenna. They are:

(1) Applied voltage.
(2) Applied current.
(3) Reflected voltage.
(4) Reflected current.

c. The four components of energy react on each other to produce standing waves (Figure I-2). The standing waves in the figure represent a center-fed (current-fed) antenna. However, the same standing waves exist along an end-fed (voltage-fed) antenna.

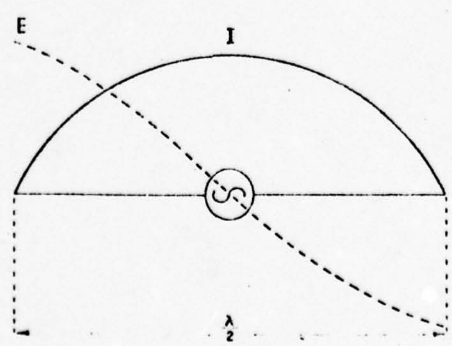


Figure I-2. Voltage and current standing waves.

(1) The half-waves of applied voltage move from the feed point toward the ends of the antenna, and the reflected half-waves of voltage move from the ends toward the feed point. They add to produce the voltage standing wave, E.

(2) The applied current and the reflected current add to produce the current standing wave, I.

(3) If you made voltage and current measurements along a half-wave antenna, and plotted your readings, the resultant curves would like those in Figure I-2.

d. You can determine the impedance of an antenna from the antenna current and the antenna voltage.

(1) At the ends of the antenna, the voltage is maximum and the current is zero. Dividing the voltage by the current should theoretically produce infinite impedance. In practical antennas, however, the impedance at the ends is actually a high, finite value (Figure I-3).

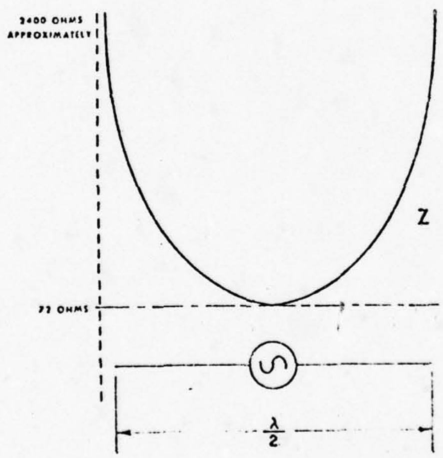


Figure I-3. Impedance standing wave.

(2) At the center of the antenna the voltage is zero and the current is maximum. The impedance should be zero, according to theory, but actually it is about 72 ohms.

(3) The difference between the actual impedance and the theoretical impedance exists because we cannot assemble perfect antennas and perfect antenna feeders. The materials

we use have defects which cause end leakage so that the current at the ends of the antenna does not fall to zero. Also, some reactance exists because of the thickness of the antenna material. In addition, the impedance match between the feeders and the antenna cannot be made perfect. So there will always be a difference between the actual impedance and the theoretical impedance of an antenna.

6. RF RADIATION

Figures I-4 and I-5 show a transmitter coupled through a transmission line to an antenna. Although the antenna is made up of two elements placed end to end, its action is the same as if it were one continuous element.

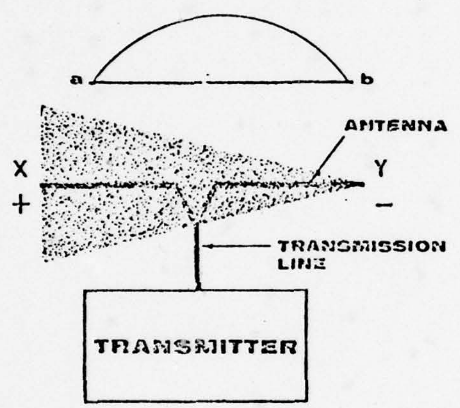


Figure I-4. Electron distribution with positive half-wave.

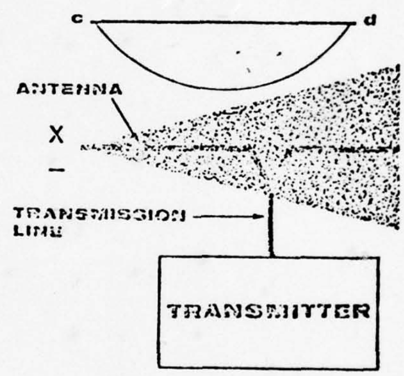


Figure I-5. Electron distribution with negative half-wave.

a. A positive half-wave of energy applied to the antenna (Figure I-4) (curve a-b), causes point X to be positive and point Y to be negative. This causes a flow of free electrons toward point X.

b. During the next half-cycle (Figure I-5), the negative half-wave of energy (curve c-d) is applied to the antenna. Point Y becomes positive, so the free electrons crowd toward point Y.

c. The RF voltage and current in the antenna produce two fields: an induction field and a radiation field. Each field, in turn, is made up of two components: a magnetic (H) field and an electric (E) field.

(1) The H field consists of circular lines of force that surround the antenna at right angles to the axis of the antenna element (Figure I-6). The amplitude of the H field varies sinusoidally from end to end, with the greatest magnitude located at the center of the antenna. The direction of the lines alternates as the current alternates.

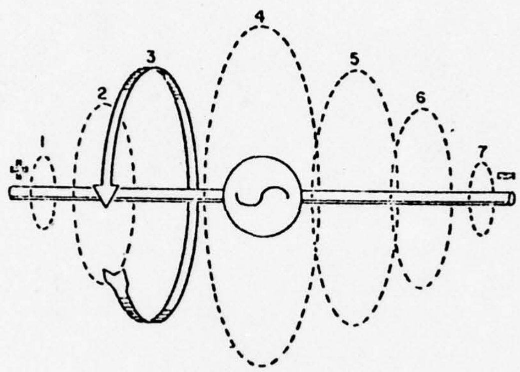


Figure I-6. Magnetic field about an antenna.

(2) The lines of the E field surround the antenna as shown in Figure I-7. They originate at the end of the antenna that is positive and terminate in the negative end. Figure I-7 is a cross section of the field, the actual field completely surrounds the antenna like a sphere.

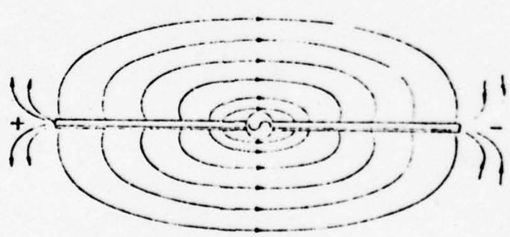


Figure I-7. Electric field about an antenna.

(3) The E and H lines of the induction field are 90 degrees out of phase with each other in time and space. But the E lines and the H lines of the radiation field are in phase with each other in time, and 90 degrees out of phase in space.

d. The radiation field is produced by the building and collapsing of the E and H fields about the antenna. They build up—collapse—build up with reversed polarity—and collapse again. The step-by-step action is described below.

(1) As the applied voltage and current increase, the E field and H field are produced and expand to maximum size.

(2) When the voltage and current decrease, the fields attempt to collapse back into the antenna. Because of the repulsion between lines of like polarity, a considerable portion of each field is prevented from returning to the antenna before the next half-cycle begins.

(3) The expansion of the fields produced by the succeeding half-cycle drives the residual fields farther away from the antenna and the fields travel outward from the antenna at the speed of light (300,000,000 meters per second).

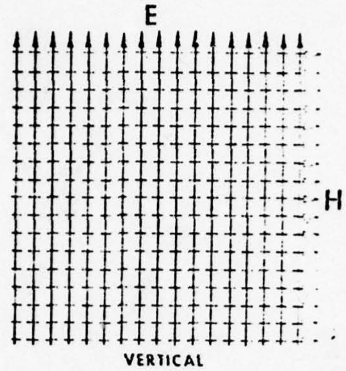
7. ANTENNA POLARIZATION

a. The radiated field (Figure I-7) will arrive at the receiving point in a plane that is perpendicular to the direction of travel. The E lines and H lines lie in this plane and are perpendicular to each other. If the E lines are vertical (A, Figure I-8), the field is vertically polarized; if they are horizontal (B, Figure I-8), the field is horizontally polarized.

b. Ground-wave transmission is widely used at medium and low frequencies, and requires vertical polarization. The E lines are perpendicular to the ground and can travel a considerable distance over the ground with a minimum of attenuation. Horizontal polarization cannot be used under these conditions because the earth acts as a fairly good conductor at low and medium frequencies and horizontally polarized E lines are shorted out.

c. Tactical communications systems sometimes use sky-wave transmission because obstructions between the stations make it impossible to transmit directly. The transmitted energy is reflected off the ionosphere to make it reach the receiving station. The ionosphere causes the energy to be elliptically polarized because the E and H lines rotate in a plane that is perpendicular to the line of travel. Thus, a wave that has been transmitted from a vertically polarized antenna could arrive at the receiving point with its

A



B

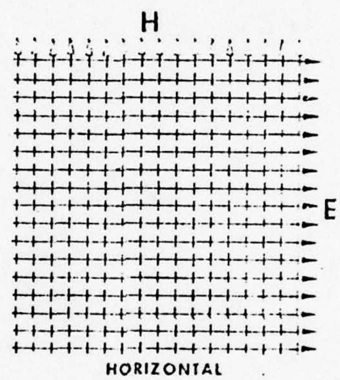


Figure I-8. Wave polarization.

polarization changed to horizontal. The polarization could be changed in the same way to any fixed angle between vertical or horizontal polarization, or it could be constantly changing. Any of these situations might require the use of polarization diversity using one horizontally and one vertically polarized antenna, both feeding signals through diversity equipment to the receiver.

d. Horizontally polarized antennas are preferred for use in the high frequency range for the following reasons.

(1) Less interference is received from man-made noise sources because vehicular ignition systems, rotating machinery, and many electrical appliances produce vertically polarized interference. The response to such interference is minimized by using horizontal polarization.

(2) Surrounding buildings and their interior wiring absorb less of the transmitted energy when horizontal polarization is used.

(3) At high frequencies, supports for horizontally polarized antennas are smaller than those required for vertically polarized antennas.

e. Either horizontal or vertical polarization is satisfactory with very-high frequencies (VHF) or ultra-high frequencies (UHF). The VHF or UHF radio waves travel directly from the transmitting antenna to the receiving antenna without reaching the ionosphere. The polarization produced by the transmitting antenna is maintained while the energy travels to the receiving antenna. The only restriction is that if a horizontally polarized antenna is used to transmit, a horizontal antenna must be used to receive; and, if the transmitting antenna is vertical the receiving antenna must be vertical.

8. ANTENNA RADIATION PATTERNS

The radiation pattern of an antenna depends upon the current distribution throughout its length and its height above ground. Since the current distribution along an antenna is uneven, the resulting electromagnetic wave distribution in space is also uneven. Electromagnetic energy is radiated with the greatest intensity where the current is greatest, thus producing the characteristic radiation pattern for each type of single-element antenna. For example, the current in the single-element half-wave antenna is greatest at the center of the antenna and most of the energy is radiated from the center (A, Figure I-9). Practically no energy radiates from the ends of the antenna in the direction in which the antenna is extended; the radiation is broad-side to the antenna (B, Figure I-9). The patterns in Figure I-9 do not show ground effects. Figure I-10 shows the effect of ground on the vertical patterns of half-wave antennas at different heights.

III. ANTENNA TYPES

9. THE HALF-WAVE ANTENNA

a. The Doublet. The half-wave antenna is commonly used in the horizontal position and is fed at the center.

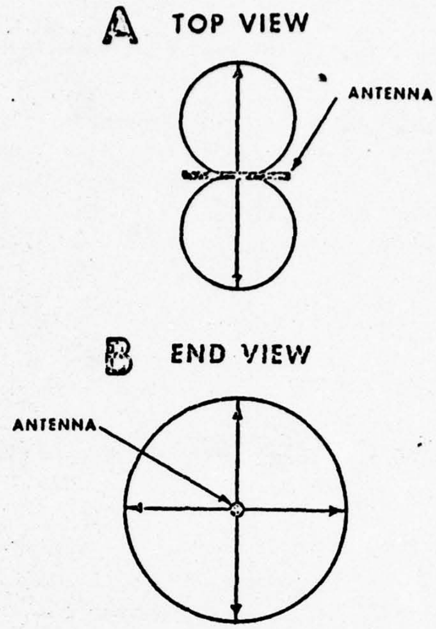


Figure I-9. Radiation pattern of a horizontal doublet.

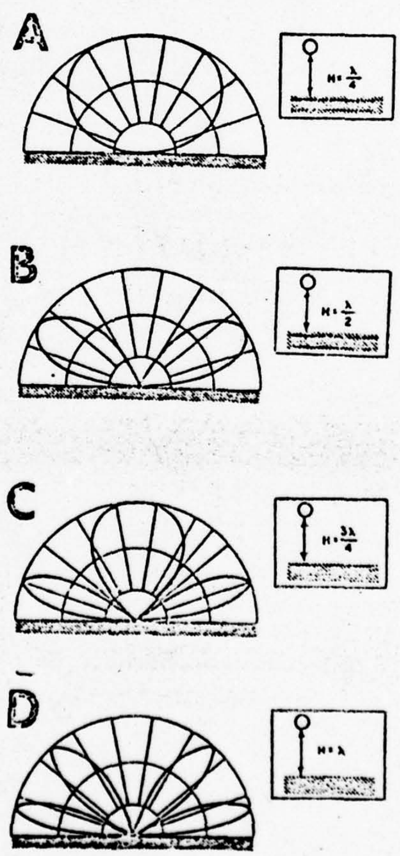


Figure I-10. Ground effects upon a radiation pattern.

This arrangement, called the doublet, consists of two quarter-wave elements placed end-to-end, with one conductor of the transmission line connected to each of the two adjoining ends of the elements. The impedance at the center of the doublet is 72 ohms, so the transmission line that feeds it is usually either a coaxial cable or 72-ohm open-wire line or ribbon. Figure I-11 shows the construction of the doublet (also called a Hertz antenna, or a dipole), and Figure I-12 shows a field expedient doublet made of field wire. The transmission line to the field-wire antenna must be kept short because of leakage through the insulation and because of the high resistance of the wire.

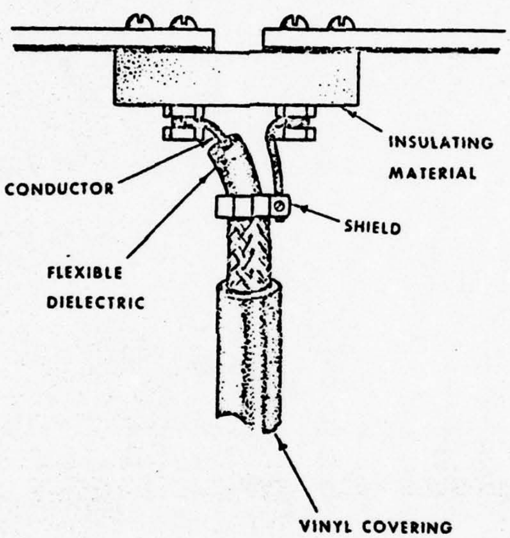


Figure I-11. Coaxial cable connected to a doublet.

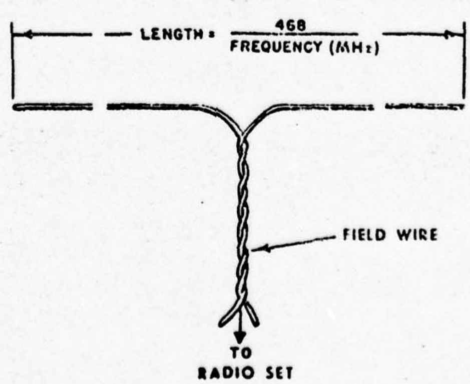


Figure I-12. Field wire doublet.

b. The Folded Dipole. The single folded dipole is a one-wavelength conductor with a quarter-wave portion at each end folded back to the center to provide a second conductor and feeder connections (Figure I-13). The result is a half-wave antenna with two parallel conductors, closely spaced. The following are some of the important characteristics of the folded dipole.

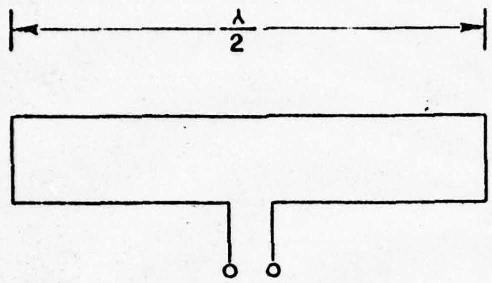


Figure I-13. A single-folded dipole.

(1) By proper selection of the ratio of the conductor diameters to the conductor spacing, the antenna can be designed to match impedances at ratios from 2 to 16 times the impedance of a single-conductor antenna.

(2) A third conductor (Figure I-14) can be added to the antenna to increase the impedance matching range from 6 to 25 times the impedance of a single conductor antenna.

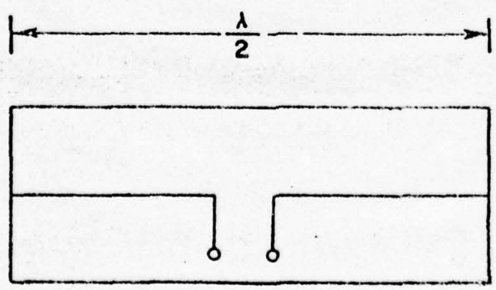


Figure I-14. A double-folded dipole.

(3) The folded dipole has the broad tuning, relatively stable impedance, and radiation resistance of a thick antenna. Once the impedance has been established by the construction

of the antenna, it is possible to vary the operating frequency over a comparatively wide range without a detrimental mismatch or serious loss of radiation resistance. This antenna behaves as though it were a metal sheet or ribbon as wide as the overall width across the conductors.

c. Construction of a Folded Dipole. The normal impedance of the two-conductor folded dipole with closely spaced, equal size conductors is about 300 ohms. A very serviceable low-cost folded dipole can be made from 300-ohm line ("TV ribbon"), as shown in Figure I-15.

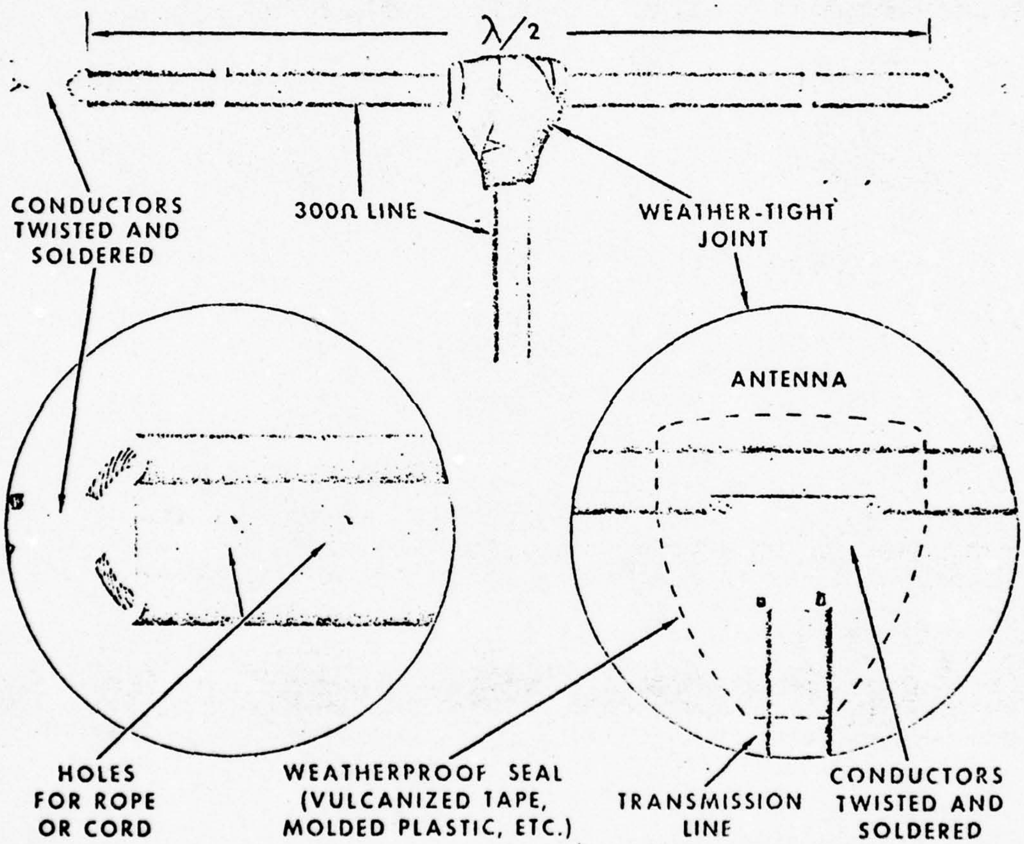


Figure I-15. Method of constructing a folded dipole from 300-ohm line.

(1) Determine the physical length of a half-wave in the line being used.

(2) Cut the ribbon to size, plus two or three inches for splicing. Leave enough at each end to insure that the half-wavelength is left intact after splicing.

(3) Twist the ends of the bare conductor together at each end, and solder. No insulation is required.

(4) Cut one conductor at the quarter-wave point. Leave enough bare wire on each side of the cut to permit splicing of another piece of 300-ohm line to the ends.

(5) After the connection is spliced and soldered, make a weatherproof seal over the joint. Tape the joint, and then use a soldering iron to vulcanize the tape. (Scraps of plastic insulation from the ribbon can be molded around the joint with a soldering iron to form a permanent seal.) The result is an impedance-matched, 300-ohm, folded dipole with a built-in transmission line.

(6) In an emergency, field wire can be used in the same way and its impedance will be very close to 300 ohms.

10. WHIP ANTENNAS

At the lower frequencies where wavelengths are long, it is impractical to use resonant-length tactical antennas with portable radio equipment—especially with vehicular-mounted radio sets. Tactical whip antennas are electrically short, vertical, base-loaded types, fed with a non-resonant coaxial cable of about 36 ohms impedance.

a. If the tactical antenna is to attain an efficiency comparable to that of a half-wave antenna, the height of the vertical radiator should be a quarter wavelength. However, this is not always possible, so the loaded whip is used instead. The missing quarter-wavelength of the antenna is supplied by the ground, a counterpoise, or any conducting surface that is big enough.

b. The whip antenna supplied with military radio sets is usually 4.5 meters (15 ft) long for the high-frequency tactical radio sets, and shorter for tactical FM sets. It is made shorter than a quarter-wavelength to keep it a practical length. (A quarter-wavelength antenna for 5.0 MHz would be over 14 meters (46 feet) long.) A tuning unit, either built into the radio set or supplied with it, compensates for the missing length of antenna. The tuning unit varies the electrical length of the antennas to accommodate a range of frequencies.

c. Whip antennas are employed with tactical radio sets, because they radiate in the horizontal plane (Figure I-16). Since stations in a radio net lie in random directions, and change their positions frequently, the radiation pattern of the whip is ideal for tactical net communications.

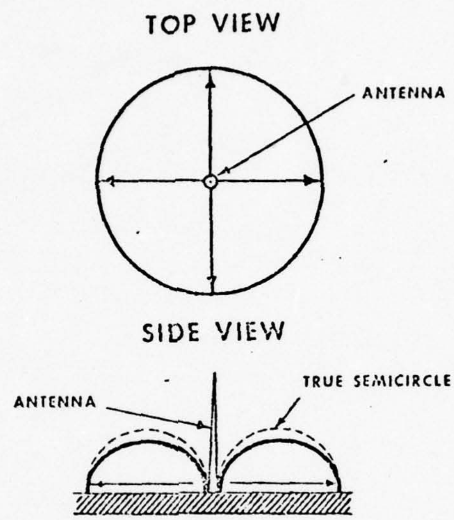


Figure I-16. Radiation pattern of a whip antenna.

d. The physical length of a tactical whip antenna is modified by inserting a lumped reactance at some point along the radiator. A series-lumped inductance is commonly inserted into a short antenna to increase its effective length. This is called base loading (Figure I-17) or center loading (Figure I-18) depending upon the placement of the loading coil. Because of the IR loss in the coil, which is determined by its Q and the point in the radiator where it is inserted, this method of resonating the antenna is less efficient than that of top loading (Figure I-19). It is impractical, however, to top-load tactical antennas because of the mechanical difficulties involved. Figures I-17 through I-19 show the current distribution for short vertical antennas employing base loading, center loading, and top loading. The solid curve shows the current distribution in the loaded whip; the dashed lines show how the current would be distributed on a full quarter-wave antenna.

e. When a whip antenna is installed at a height above the ground that is more than a small part of its length, its efficiency decreases and its directivity changes. Therefore, when we use a whip antenna at the top of a mast, we must supply an elevated substitute for the ground.

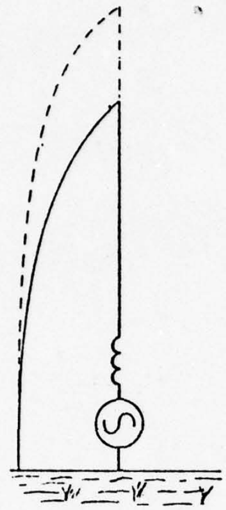


Figure I-17. Base-loaded whip.

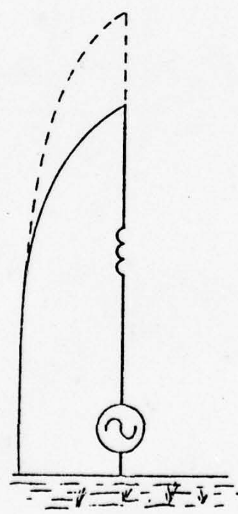


Figure I-18. Center-loaded whip.

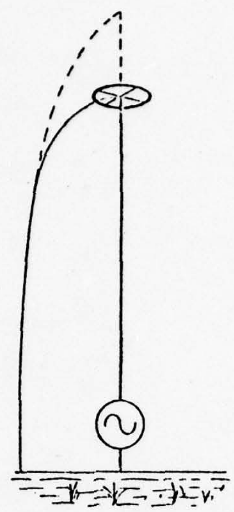


Figure I-19. Top-loaded whip.

(1) The ground-plane antenna (Figure I-20) solves the problem very effectively. It is a whip antenna that includes radial elements to serve as the ground. The coaxial feeder is connected with the inner conductor feeding the vertical element (whip), and the braid of the coaxial cable connected to the radials (the ground-plane) to keep them at ground potential.

(2) Using a metal disc to fill in the gaps between the radials does not improve the performance enough to make it worthwhile. Three or four radials are just as effective, cost less, and offer less wind resistance.

(3) When the radials are at right angles to the whip, the energy is reflected upwards, and a great portion of it is lost. If the ground plane is dropped to 50 degrees below the horizontal (Figure I-20), the maximum radiation from the antenna is brought down into the horizontal plane.

(4) The ground plane antenna is a broad-band type. It radiates efficiently over a wide range of frequencies.

f. The RC-292 (Figure I-21) is a ground plane antenna presently used with tactical FM sets. It can be tuned by using the proper length of antenna sections in the vertical element and in the ground plane.

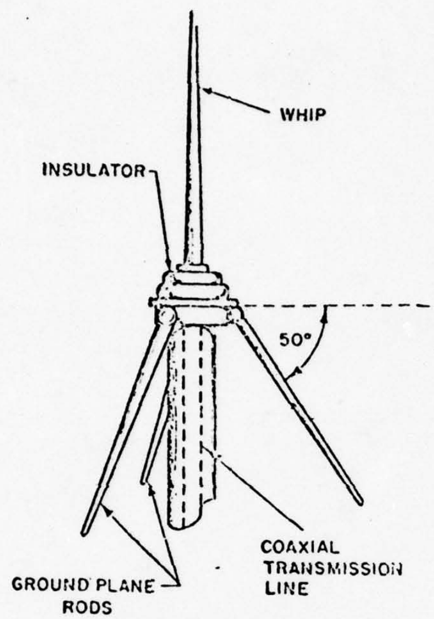


Figure I-20. Construction of a ground plane antenna.

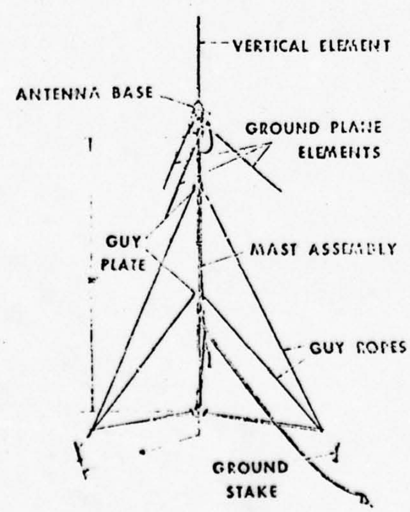


Figure I-21. RC-292 ground plane antenna.

11. DIRECTIVE ANTENNAS

The half-wave antenna (Figure I-22) is not directive; it radiates its energy in a full circle around itself. Only a small part of the energy is radiated in any given direction. If the antenna is made directive, the amount of RF energy that can be delivered in a given direction can be increased many times with no increase in transmitter output.

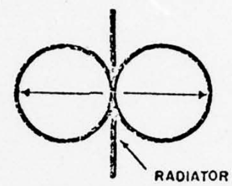


Figure I-22. A simple half-wave radiator.

a. Terminology. The direction in which we radiate the energy is the forward direction and the opposite direction is the backward direction. The element of the antenna that radiates the energy is called the radiator, and the elements that lie in the direction of radiation are the front of the antenna, and are the directors. The element behind the radiator is the reflector which intercepts the backward radiation and reflects it forward. The whole assembly is an array, and if a driven element (radiator) excites the other elements, it is called a parasitic array.

b. The Parasitic Reflector. A parasitic reflector is similar to the radiator. It is usually made of the same material, but approximately 5 percent longer (Figure I-23).

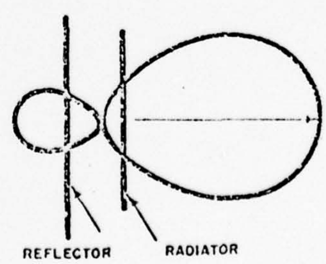


Figure I-23. A radiator with a reflector.

A parasitic reflector is excited by energy from the radiator and requires no energy source of its own. When the parasitic reflector is placed about 0.15 to 0.25 wavelength behind the radiator, its reradiated energy will be projected forward. All of the backward radiation, except that lost in the reflector, will be projected forward to reinforce the forward radiation. The half-wave antenna radiates its energy over a reduced area, and the power projected in the forward direction is increased.

c. Parasitic Directors. A parasitic director (Figure I-24) is 5 percent shorter than the radiator and is placed about 0.15 to 0.25 wavelength ahead of the radiator. One or more directors may be used in a yagi array. The radiator supplies the energy to excite the directors, which in turn project the RF energy forward in a beam. The directors produce a result that is similar to the action of an optical lens.

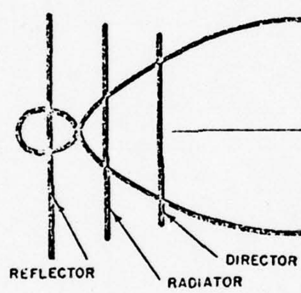


Figure I-24. A radiator with a reflector and a director.

d. Yagi Array. A yagi array uses two or more parasitic elements; it consists of one driven element, one reflector, and one or more directors (Figure I-24). Yagi arrays usually have an increased power gain of approximately 7 db (five times) over a half-wave antenna. Precise adjustment of element length and spacing can concentrate the signal in the forward direction, so that it can provide a gain of 9 db (eight times) over a half-wave antenna. However, such precise adjustments cannot always be made in tactical situations. Therefore, the array is modified by increasing the spacing between the elements making the adjustments less critical, and the array provides a reasonable impedance match to 52-ohm coaxial cable.

e. Impedance Matching. Impedance matching is a problem when a conventional dipole is used as the driven element or radiator in parasitic arrays. As the number of parasitic elements in the array is increased, the input impedance of the driven element is lowered. When a conventional dipole is used as the driven element in the three-element yagi array, the input impedance is approximately 8 ohms as compared to its original 73 ohms. A folded dipole used as the driven element will raise the input impedance without using a complex impedance-transformation device. The radiation resistance will be increased by a factor of four or more, varying with the design of the folded dipole.

f. Reflector Antennas. Reflectors are generally used to modify the radiation pattern of antennas for radio-relay applications. They increase the forward gain and directivity and reduce backward radiation. Reflectors intercept radio energy and reradiate it in another direction the same as a mirror reflects a light beam.

(1) The common types of reflectors are (Figures I-25 through I-28) the plane reflector, the corner reflector, and the parabolic reflector. Other types can be used, depending upon the desired directivity pattern.

(2) Most antenna reflectors are exposed to the weather, so there is a definite advantage in using a screen, a grill, or a perforated sheet. All three types offer low wind resistance, but they still reflect radio energy as well as a solid sheet. The simplest reflector, other than thin parasitic elements, consists of a flat sheet of perforated metal or a screen (Figure I-26), such as that used with Radio Relay Set AN/TRC-24. The gain obtained with this reflector can be increased by using several properly spaced elements.

(3) A flat reflector converts the normal bidirectional pattern into a large unidirectional pattern by reflecting backward radiation and projecting it forward. It increases forward gain but does not produce a beam.

g. Directivity and Gain. The forward gain in field intensity is a function of the spacing between the dipole element and the reflector, the number of dipole elements used, the size of the reflector, and its shape.

(1) A corner reflector consists of two flat reflecting sheets intersecting at right angles, forming a square corner (Figure I-27). Corner angles greater or less than 90 degrees can be used, but no net advantage is gained at angles less than 60 degrees.

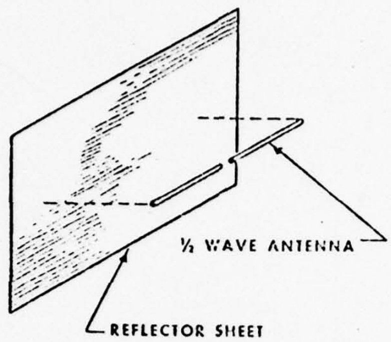


Figure I-25. A plane reflector.

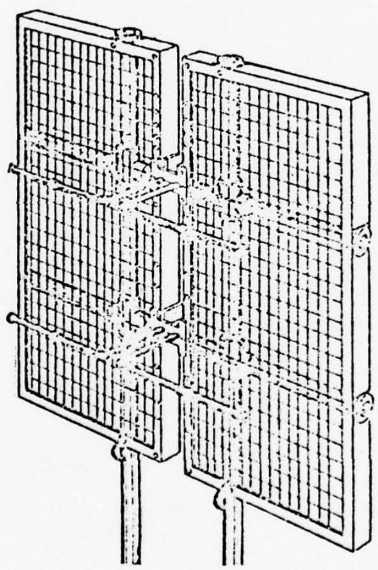


Figure I-26. A typical form of plane reflector.

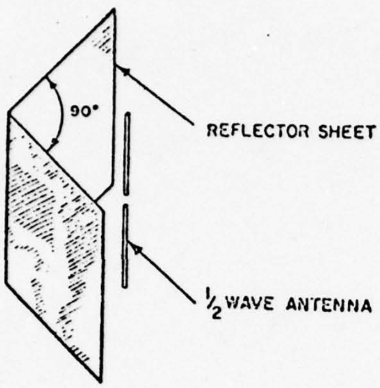


Figure I-27. A corner reflector.

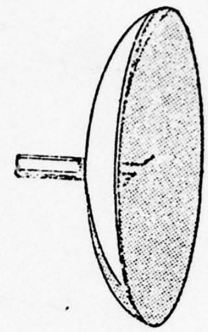


Figure I-28. A parabolic reflector.

(2) If a dipole radiator is located within the plane bisecting the corner angle and parallel to the intersection of the two sheets, gain figures from 10 to 15 db over an isotropic dipole can be obtained. One disadvantage of plane and corner reflector antennas is that they concentrate energy in one plane only.

(3) The antenna systems used in radar and radio-relay operations must have high directivity in both horizontal and vertical planes, to transfer a maximum amount of energy from one point to another. The reflector-type antenna most commonly used to accomplish this is the paraboloid or parabolic reflector shown in Figure I-28. If a half-wave dipole is placed at the focus of the reflector, nearly perfect beam-focusing takes place. The major factor contributing to the gain and beam-focusing is the total area of the reflecting surface. The included angle of the reflected beam is proportional to the wavelength of the RF energy, and inversely proportional to the diameter (aperture) of the reflector. The parabolic antenna provides the greatest forward gain of all the reflector antennas. Gains in excess of 60 db have been achieved with large antennas.

12. HORN ANTENNAS

The horn antenna shown in Figure I-29 is another highly directional antenna.

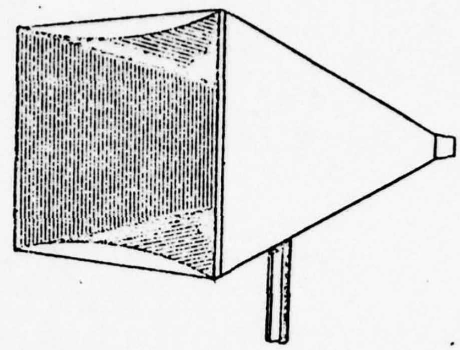


Figure I-29. A horn antenna.

a. Energy is transferred from the transmission line to a resonant cavity in the rear of the horn. The tapered portion of the horn provides an impedance match between the cavity and free space.

b. The taper of the horn determines the size of the aperture, and the size of the aperture determines the distribution of the energy field in the aperture. The radiation pattern of the horn is determined by a combination of the distribution of the field within the aperture, and the aperture size. Thus, the taper of the horn determines the radiation pattern.

IV. TRANSMISSION LINES

13. TRANSMISSION LINE IMPEDANCE

a. One requirement for efficient power transmission from the source to the load is that their impedances must match. When the impedance of the load equals the impedance of the source, the load is receiving the greatest amount of power that can be delivered to it by the source.

b. To obtain adequate antenna efficiency the antenna's impedance must be matched to that of the transmitter's output circuit. When impedances are matched, the efficiency of the antenna will be high because it will be handling the maximum current that the transmitter can supply to it.

c. Since the antenna usually cannot be attached directly to the transmitter it is necessary to transmit the power to the antenna through a transmission line. Each type of transmission line has a characteristic impedance; common values are 52 ohms, 75 ohms, 300 ohms, and 600 ohms.

d. When the output impedance of the transmitter matches the characteristic impedance of the transmission line, the transfer of power from transmitter to line occurs with a minimum of loss. A mismatch of impedance at this point causes poor transfer of power into the line, and causes reflection of power back into the transmitter that can often cause overheating and burn-out.

e. When the transmission line has been matched to the transmitter and is terminated in an antenna that matches the line's characteristic impedance, the line transfers maximum power into the antenna. Under these conditions the line is said to be flat—it is non-resonant, there are no reflections and no standing waves. When it is fed by a flat transmission line, the antenna is receiving maximum current and radiating very efficiently—the transmission line is not radiating.

f. When receiving, the proper transfer of signal energy from the antenna to the receiver requires the same careful attention to impedance matching. In the case of transceivers, the use of a common antenna frequently eliminates the receiving problems when the line and the antenna are matched for efficient transmissions.

g. Resonant transmission lines are not used as antenna feed lines with tactical equipment. They sometimes radiate energy that should be radiated only from the antenna. Reflection of energy within the line can cause serious losses and destroy the efficiency of the system.

h. Tables I-3, I-4, and I-6 show the characteristic impedances of typical transmission lines and typical coaxial cables. This information is useful when it is necessary to fabricate an emergency antenna from the line or cable on hand. Transmission lines used in military communications usually have characteristic impedances in the range from 36 ohms to 600 ohms.

14. TYPES OF TRANSMISSION LINES

a. Coaxial Line. Coaxial transmission line consists of a conductor inside another conductor, arranged so that the

TABLE I-3

CHARACTERISTICS OF COAXIAL CABLES. WEIGHT DATA

Type	Z (ohms)	Velocity factor	Capacitance per foot	Weight (100 ft)
RG-8/U	52	0.66	28.5 pf	11 lbs
RG-58/U	53	0.66	28.5 pf	3 lbs
RG-17/U	52	0.66	29.5 pf	46 lbs
RG-19/U	52	0.66	29.5 pf	74 lbs
RG-55/U	53	0.66	28.5 pf	4 lbs
RG-5/U	52	0.66	28.5 pf	9 lbs
RG-14/U	52	0.66	29.5 pf	22 lbs
RG-59/U	73	0.66	21 pf	3 lbs
RG-11/U	75	0.66	21 pf	10 lbs
RG-6/U	76	0.66	20 pf	8 lbs
RG-13/U	74	0.66	21 pf	13 lbs
RG-22/U	95	0.66	16 pf	12 lbs
RG-62/U	93	0.66	14 pf	4 lbs
RG-63/U	125	0.66	11 pf	8 lbs
RG-71/U	93	0.66	14 pf	5 lbs
RG-41/U	68	0.66	27 pf	15 lbs

TABLE I-4

CHARACTERISTICS OF COMMONLY USED TRANSMISSION LINES. ATTENUATION IN dB PER 100 FEET AS A FUNCTION OF FREQUENCY

Characteristics of Commonly-Used Transmission Lines

Type of Line	Z_0 *Ohms*	*Vel. %*	*pF per ft.*	*OD*	*Attenuation in dB per 100 feet* 3.5	7	14	21	28	50	144	420
RG58/A-AU	53	66	28.5	0.195	0.68	1.0	1.5	1.9	2.2	3.1	5.7	10.4
RG58 Foam Diel.	50	79	25.4	0.195	0.52	0.8	1.1	1.4	1.7	2.2	4.1	7.1
RG59/A-AU	73	66	21.0	0.242	0.64	0.90	1.3	1.6	1.8	2.4	4.2	7.2
RG59 Foam Diel.	75	79	16.9	0.242	0.48	0.70	1.0	1.2	1.4	2.0	3.4	6.1
RG8/A-AU	52	66	29.5	0.405	0.30	0.45	0.66	0.83	0.98	1.35	2.5	4.8
RG8 Foam Diel.	50	80	25.4	0.405	0.27	0.44	0.62	0.76	0.90	1.2	2.2	3.9
RG11/A-AU	75	66	20.5	0.405	0.38	0.55	0.80	0.98	1.15	1.55	2.8	4.9
Aluminum Jacket, Foam Diel.[1]												
3/8 inch	50	81	25.0	–	–	–	0.36	0.48	0.54	0.75	1.3	2.5
1/2 inch	50	81	25.0	–	–	–	0.27	0.35	0.40	0.55	1.0	1.8
3/8 inch	75	81	16.7	–	–	–	0.43	0.51	0.60	0.80	1.4	2.6
1/2 inch	75	81	16.7	–	–	–	0.34	0.40	0.48	0.60	1.2	1.9
Open-wire[2]	–	97	–		0.03	0.05	0.07	0.08	0.10	0.13	0.25	–
300-ohm Twin-lead	300	82	5.8		0.18	0.28	0.41	0.52	0.60	0.85	1.55	2.8
300-ohm tubular	300	80	4.6		0.07	0.25	0.39	0.48	0.53	0.75	1.3	1.9
Open-wire, TV type												
1/2 inch	400	95			0.028	0.05	0.09	0.13	0.17	0.30	0.75	–
1 inch	450	95			0.028	0.05	0.09	0.13	0.17	0.30	0.75	–

[1] Polyfoam dielectric type line information courtesy of Times Wire and Cable Co.

[2] Attenuation of open-wire line based on No. 12 conductors, neglecting radiation.

TABLE I-5

POWER HANDLING CAPABILITIES OF SELECTED TYPES OF COAXIAL CABLE

Type of Line	*Power Rating in Watts* 20-MHz	30-	60-	200-
RG58/A-AU	550	430	290	14
RG58 Foam Diel.[1]				
RG59/A-AU	860	680	440	208
RG8/A-AU	2000	1720	1250	680
RG11/A-AU	1800	1400	900	400

[1] Power handling capabilities of foam-type coaxial lines is approximately 30 percent greater than the polyethylene dielectric types.

inner conductor coincides with the axis of the outer conductor. Fixed coaxial lines consist of a conductor held in place inside a metal tube by means of plastic spacers.

b. Coaxial Cable. Coaxial cable was developed from coaxial line for use with mobile or transportable stations (Figure I-30). Coaxial cable consists of a single-strand inner conductor for small cables or a multistrand inner conductor for medium and large cables; a solid, but flexible, dielectric around the center conductor; a flexible metal braid around the dielectric; and, a vinyl jacket over the entire coaxial assembly. You may lay this cable on the ground or bury it for long periods with no undesirable effects on its performance.

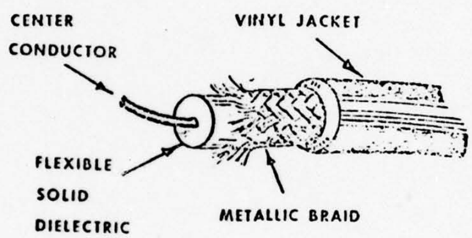


Figure I-30. Typical coaxial cable.

c. Open Wire Line (Figure I-31). Open wire lines are parallel wires held in position by insulated spacers. The characteristic impedance varies with changes in the spacing and in the diameter of the wire.

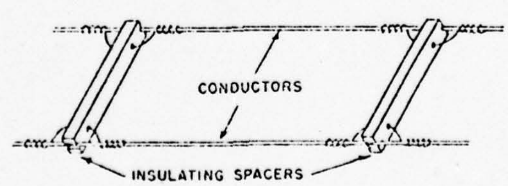


Figure I-31. Open wire transmission line.

(1) The most common form of open wire transmission line used in military communication has a characteristic impedance of 600 ohms.

(2) Ribbon transmission line (Figure I-32) is a modification of the open wire transmission line. It is available in various impedances, the most common being the 75-ohm, 150-ohm, and 300-ohm types.

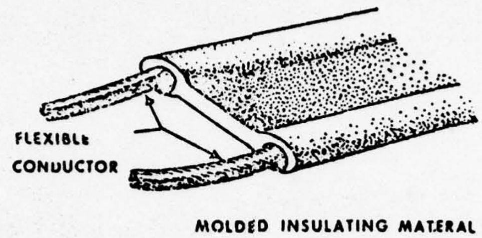


Figure I-32. Ribbon transmission line.

d. Twisted Pair (Figure I-33). Insulated wires may be twisted in pairs for use as a transmission line.

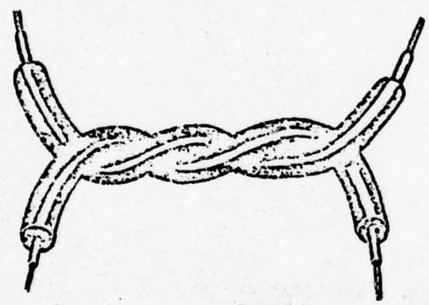


Figure I-33. Twisted pair.

(1) There are twisted pairs available for general use, but they can only be used to a limited extent as antenna feeders.

(2) Field wire can be used, but its high ohmic resistance requires that it be used only in short lengths. Otherwise, losses in the line are too high. In addition, the leakage between conductors becomes excessive above 15 MHz and makes the twisted-pair transmission line inefficient. The leakage can be great enough to cause overheating and burning of the insulation.

TABLE I-6

CHARACTERISTIC IMPEDANCE OF PARALLEL CONDUCTOR TRANSMISSION LINES (ohms)

Spacing (in) / Wire size	1	1.5	2	2.5	3	4	5	6	7	8	9	10	12	15
22	530	580	610	640	660	690	715	735	750	765	780	790	825	850
20	490	540	575	605	625	670	685	710	730	750	765	780	795	810
18	465	520	560	580	600	630	660	685	700	710	725	735	750	765
16	440	485	520	550	570	605	635	665	680	695	705	715	730	760
14	410	465	495	525	540	580	605	625	645	660	675	685	710	740
12	385	435	465	495	520	550	575	600	620	635	650	665	680	705
10	360	405	440	475	495	525	550	575	595	510	520	530	560	580
8	335	380	415	435	460	500	525	545	565	585	600	610	630	655
Tubing size (in)														
0.25	250	300	330	360	380	415	445	465						
0.375	200	240	280	310	330	365	390	405						
0.500	165	210	255	280	300	330	360	380						

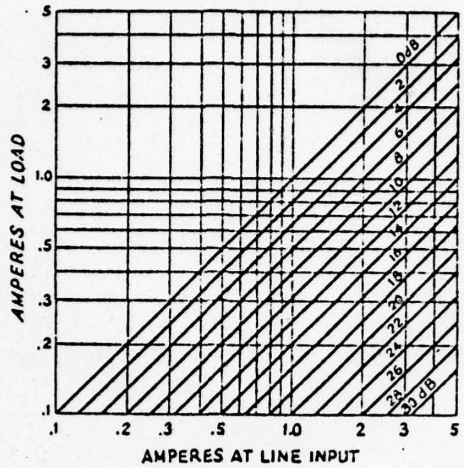


Figure I-34. Graph for calculating losses in transmission lines with an SWR of 1.

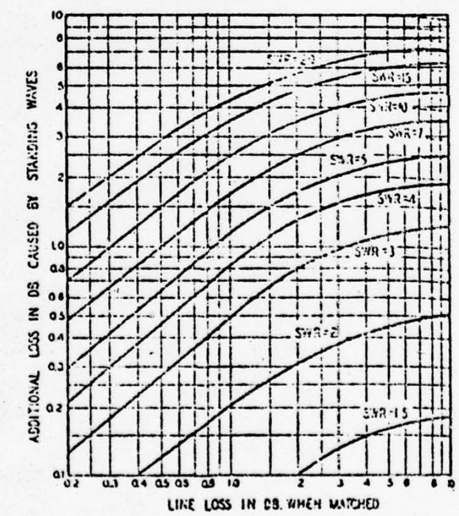


Figure I-35. The effect of standing-wave ratio on line loss. The ordinates give the additional loss in decibels for the loss, under perfectly matched conditions, shown on the horizontal scale.

15. LOSSES IN TRANSMISSION LINES

a. There are three ways by which power may be lost in a transmission line: by radiation, by heating of the conductors (I^2R), and by heating of the dielectric, if any. Radiation losses are in general the result from undesired coupling to the radiating antenna. They cannot readily be estimated or measured, so the following discussion is based only on conductor and dielectric losses.

Heat losses in both the conductor and the dielectric increase with frequency. Conductor losses also are greater the lower the characteristic impedance of the line, because a higher current flows in a low-impedance line for a given power input. The converse is true of dielectric losses because these increase with the voltage, which is greater on high-impedance lines. The dielectric loss in air-insulated lines is negligible (the only loss is in the insulating spacers) and such lines operate at high efficiency when radiation losses are low.

It is convenient to express the loss in a transmission line in decibels per unit length, since the loss in dB is directly proportional to the line length. Losses in various types of lines operated without standing waves (that is, terminated in a resistive load equal to the characteristic impedance of the line) are given in Table I-4, page 240.

When there are standing waves on the line the power loss increases as shown in Figure I-35, page 244. Whether or not the increase in loss is serious depends on what the original loss would have been if the line were perfectly matched. If the loss with perfect matching is very low, a large SWR will not greatly affect the efficiency of the line—i.e., the ratio of the power delivered to the load to the power put into the line.

EXAMPLE: An RC-292 antenna with its elements adjusted for Band 1 (30-36.5 MHz) is used to operate on a frequency of 50 MHz. The coaxial cable issued with the antenna equipment is 68 feet, 3 inches long and is type RG-8/A. Additionally, the voltage standing-wave ratio is determined through forward and reflected power readings using Radio Frequency Power Test Set TS-2609/U to be 4.6:1. If perfectly matched, the loss from Table I-4 would be $0.6825 \times 1.35 = 0.92$ dB. From Figure I-35 the additional loss because of the high SWR is 0.9 dB. The total loss is therefore $0.92 + 0.9 = 1.82$ dB. The efficiency of the line has decreased from approximately 81 percent (if the line were perfectly matched) to approximately 66 percent (VSWR of 4.6:1) because of the high VSWR.

b. Testing old coaxial cable. Unknown coaxial cable that has been exposed to the weather may have losses above the published figures for the cable type. A simple method for checking the losses in a cable is to use an rf ammeter. Connect one end of the cable to a nonreactive dummy load of the same impedance as the coax. At the other end of the line insert the rf ammeter and connect it to a transmitter. Tune up the rig and make a note of the exact amount of current. Without touching the transmitter tuning, move the ammeter to the other end of the line, at the dummy load, and note the meter reading. Compare the readings to Figure I-34, page 244, and this will give you the decibel loss that is present in the line. Keep in mind that the cable must be terminated in its characteristic impedance (SWR of 1); otherwise, the figures in Figure I-34 will not be accurate.

APPENDIX J

FIELD EXPEDIENT ANTENNAS

This appendix discusses the basic types of tactical antennas, and gives some field expedient solutions to their being broken or damaged. These solutions are only temporary, but they will help you get the message through.

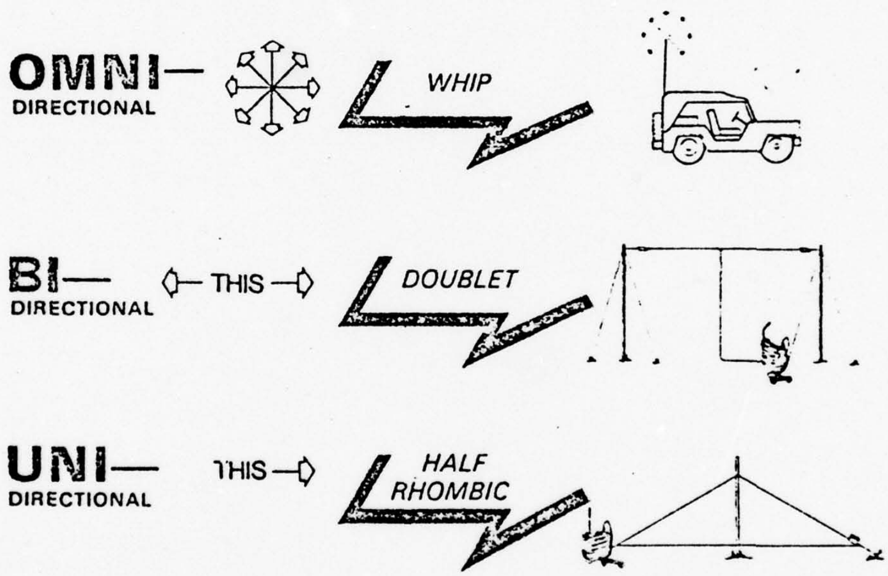
Field expedient antennas sometimes provide a way to beat the enemy's Electronic Warfare efforts. A field expedient bi- or uni-directional antenna can be used to prevent the enemy from intercepting transmissions. If you use a whip antenna, you can expect the enemy to intercept and locate your transmitter 73% of the time. If you use a horizontal/directional antenna, you can eliminate his ability to locate you and reduce his probability of intercept to only 8% of the time.* (*These figures apply to the PRC-77 radio, however, the same basic facts apply to all radios.*)

When you fabricate an antenna, there is one important fact that you have to keep in mind–the location of the station(s) you need to communicate with. Why? Because the direction and distance are critical factors and the selection of the right type of antenna is important. Basically, there are three types of antennas according to their directional characteristics. They are–

OMNI-Directional .... **All directions**

BI-Directional .... **Any two opposite directions**

UNI-Directional .... **Any one direction**



OMNI-DIRECTIONAL ANTENNAS

The vertical whip antenna is the most widely used omni-directional antenna found in the military. The tactical communicator is most familiar with the whip antenna used on vehicles, and the ground plane antenna which is usually mounted on masts or other structures.

The vertical whip is omni (all)-directional, and its efficiency is related to the transmitting frequency and antenna height. At lower frequencies its efficiency is very low, but as the frequency is increased, its efficiency also increases. The problem with height can be helped by placing the antenna on top of a hill or by fastening it to a pole or tree to increase its height above surrounding structures.

If your whip antenna is damaged or missing, here are some quick solutions to your problem.

Whip Antennas

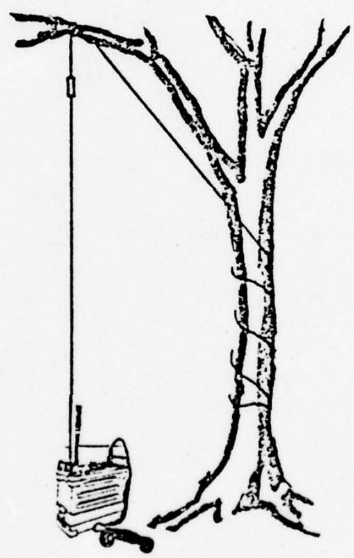
Here's how to put up some quarter-wave vertical antennas. These are used to replace regular whip antennas.

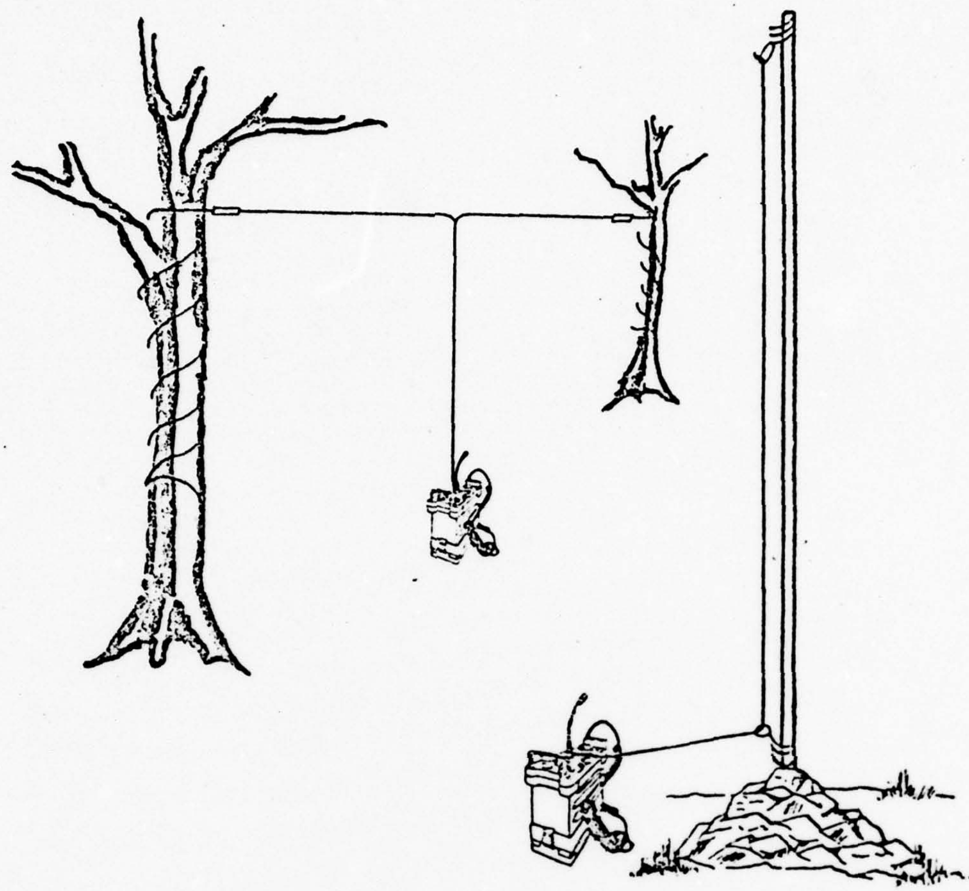
Step 1. Using the quick reference chart at the end of this appendix or the formula for a quarter wave, cut a wire to the required length.

Step 2. Attach an insulator to one end and attach the other end to the antenna connector on your radio.

Step 3. Tie a rope to the insulator end and throw the rope over a limb.

Step 4. Pull it up till it's vertical and it's ready to go. Don't forget to ground your radio.





The verticals shown here are constructed the same way, but each has a different means of support. They are all simple and quick to fabricate.

If you're using insulated wire, be sure to loop the wire around the handle of the radio before attaching it to the antenna connector. If your antenna is made of bare wire, use a stake and insulator to keep the antenna wire from pulling out of the antenna connector on the radio.

RC-292

The RC-292 is a highly effective, omni-directional antenna. It is usually much more effective than a whip antenna, and is particularily effective in the VHF frequency range.

When this antenna is damaged or not available, there are several field expedient versions that can easily be fabricated.

Three ways of replacing an RC-292 antenna for emergency operation.

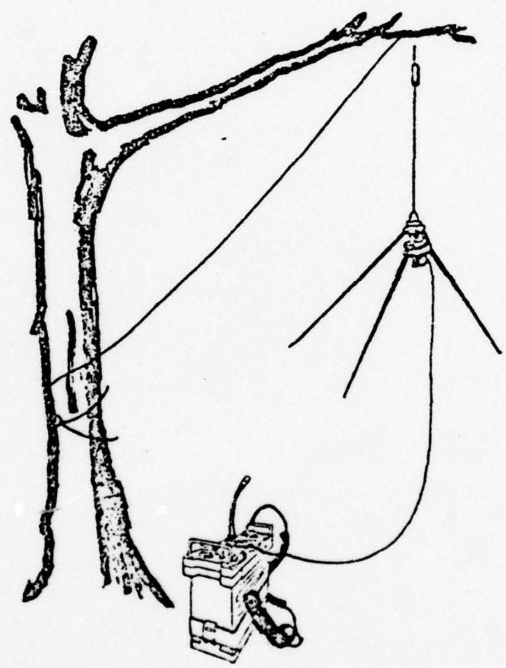
The first method is useful in heavily wooded areas where tree limbs can be used to raise the antenna.

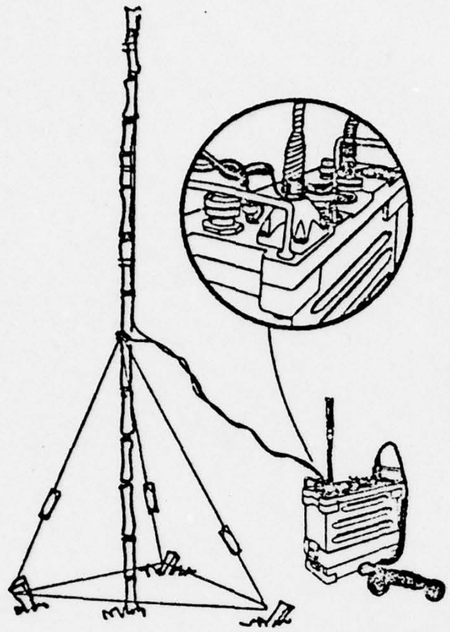
Step 1. Using the quick reference chart at the end of this appendix (or the formula, if you have it), cut all four wires for a quarter wave antenna. Connect them as shown.

Step 2. You'll need two insulators; one at each end to separate the vertical elements. You can attach a rope with a rock tied to it to throw the rope over a tree limb.

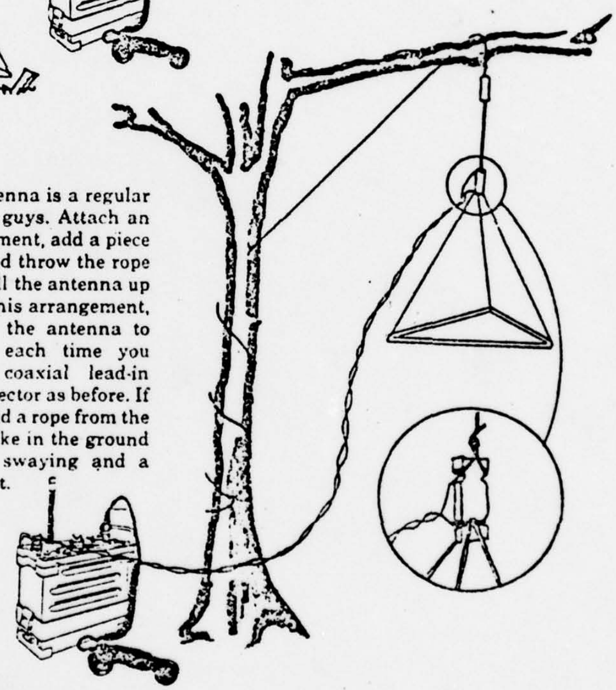
Step 3. Connect the WD-1 as shown, before you pull the antenna up in the air.

Step 4. At the radio, connect one wire of the WD-1 to the antenna connector and one wire to the radio chassis.





Here is a ground plane antenna for areas with no trees or mast substitutes. Compute and cut the four wires for a quarter wave. You can use a single pole in the middle to support the whole thing. The ground plane elements double as the guy wires. Use insulators to separate the ground plane elements from ground. The vertical element must also be insulated from the ground planes. Connect the vertical element to the output terminal of the radio and the ground planes to the radio ground. This antenna will work, but not nearly as well as one that is above ground level.



This ground plane antenna is a regular RC-292 *without a mast or guys.* Attach an insulator to the vertical element, add a piece of rope, tie on a weight, and throw the rope over a handy tree limb. Pull the antenna up as high as possible. With this arrangement, you can raise and lower the antenna to change element lengths each time you change frequency. The coaxial lead-in attaches to your radio connector as before. If you expect strong winds, add a rope from the bottom of the head to a stake in the ground below. This will prevent swaying and a signal that fades in and out.

BI-DIRECTIONAL ANTENNAS

The typical military half-wave antenna is a highly effective bi-directional antenna. It is normally used in the high frequency range.

HF Doublet

When a doublet isn't available, you can easily fabricate a replacement which will do a very good job. The antenna we'll show can replace your doublet when necessary. You'll need these items:

- -Two supports, 19-to 30-feet high.
- -Wire, any type that's long enough.
- -Rope or wire for halyards.
- -Three insulators.
- -A water can or similar heavy object.

Now build it!

Step 1. Cut the wire to your operating frequency using the chart or formula to compute the length needed for a half-wave antenna.

Step 2. Determine your direction of transmission, because the doublet antenna is BI-Directional and shoots straight out from both sides of the wire.

Step 3. Cut the wire in half and put an insulator on each wire end.

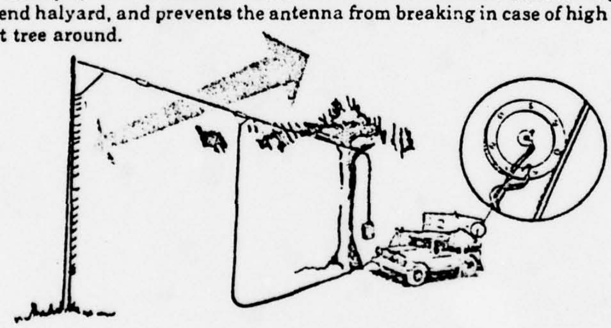
Step 4. Locate and erect the two supports. Be certain they are 3 or 4 feet further apart than the antenna's actual length, and broadside to the direction of communication.

Step 5. Separate the two wires of the WD-1 far enough to attach one wire to each end of the center insulator. Be sure it is long enough to drop nearly to the ground and then to your radio's position.

Step 6. Tie rope or wire to the two end insulators, then using whatever method is easiest, hang the antenna up between the supports, keeping it as level as possible.

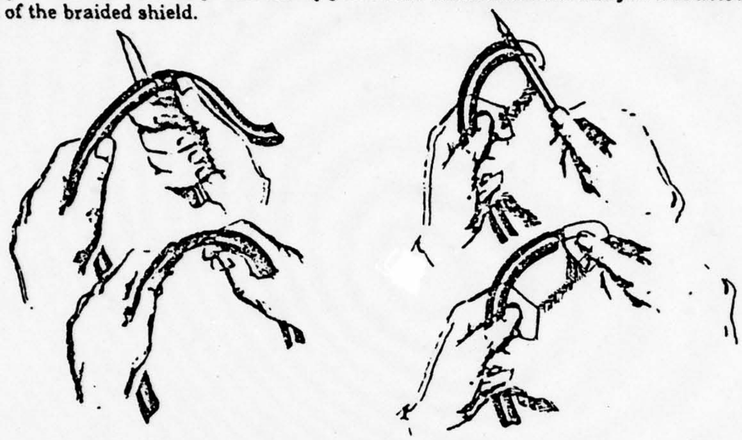
Step 7. Connect one wire of the WD-1 to the antenna connector of the radio set and the other wire of the WD-1 to a ground point on the radio. The ground point should be as close as possible to the antenna connector.

In this example, we've used a can tied to one end to demonstrate counterweight. This is tied to the tree end halyard, and prevents the antenna from breaking in case of high winds blowing the support tree around.

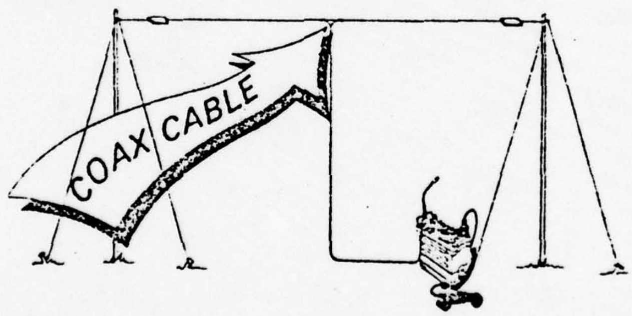


Coaxial Antenna

So you've got to replace your doublet and don't have any wire, just a long piece of coax cable. Figure the length of antenna you need using the formula or the quick reference chart. Let's say you need a 14' antenna; just measure off 7' of coax and mark the spot. Using a knife or sharp object, carefully cut through the rubber outer insulation, don't cut into the braid shield. After you cut it evenly all the way around, you'll be able to pull off the insulation leaving the braid shield exposed. Bend the coax in a loop and hold it in one hand. Using a nail or pencil carefully separate the braided shield from the insulated center conductor. Now gradually work the pencil in between the coax and the center conductor as shown. Keep the loop formed and stick a finger in the hole you've made with the pencil. Slowly pull on the center conductor and you'll be able to pull it out of the braided shield.

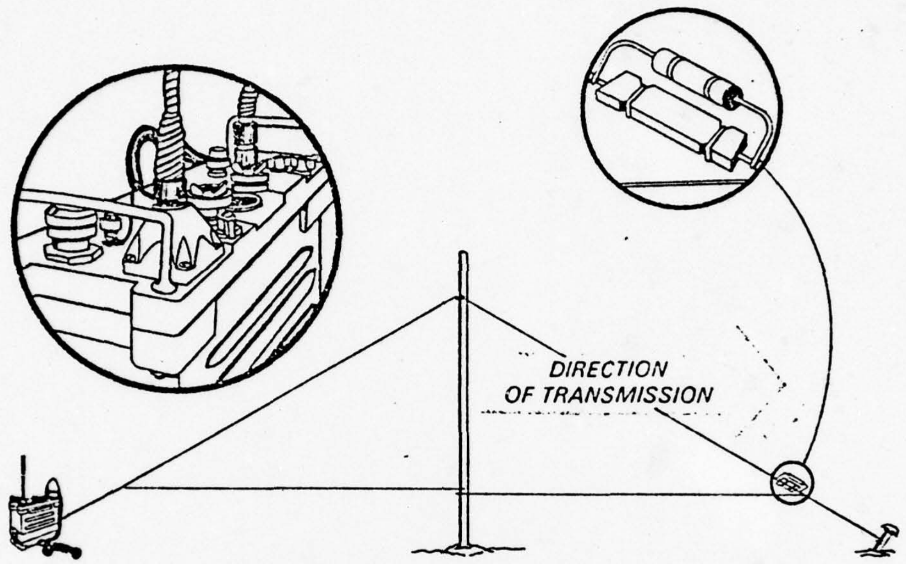


In this illustration, you see a coaxial antenna consisting of 7 feet of braided shield and 7 feet of insulated center conductor. Both are firmly attached to the remainder of the coax which is your lead-in cable. All you need to do now is tie an insulator on each end, attach ropes, find something to use as supports and put it up as flat as possible across the top. Now you have a good 14-foot doublet antenna.



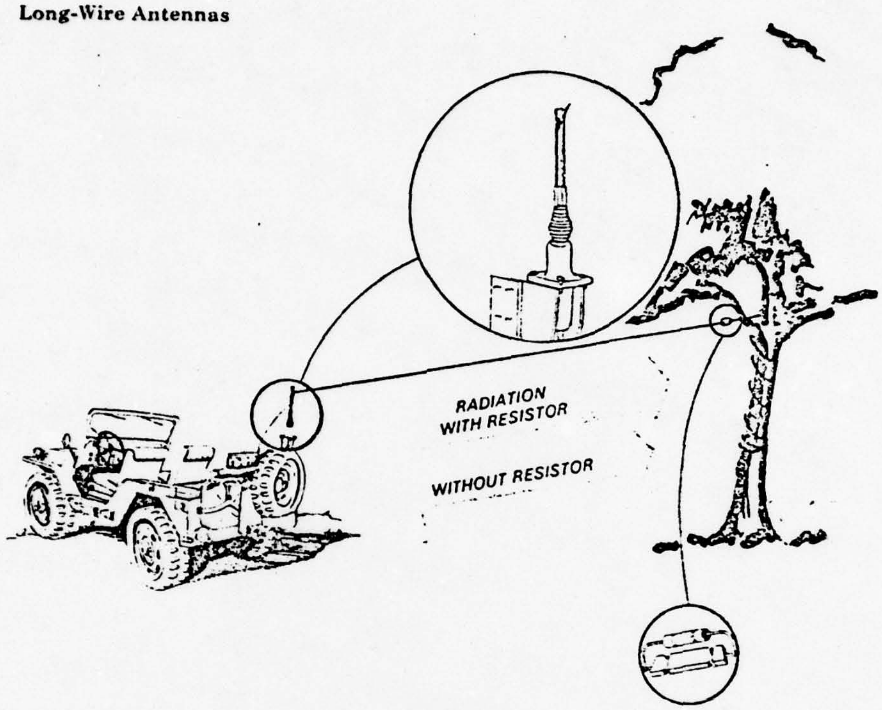
UNI-DIRECTIONAL ANTENNAS

Vertical Half Rhombic



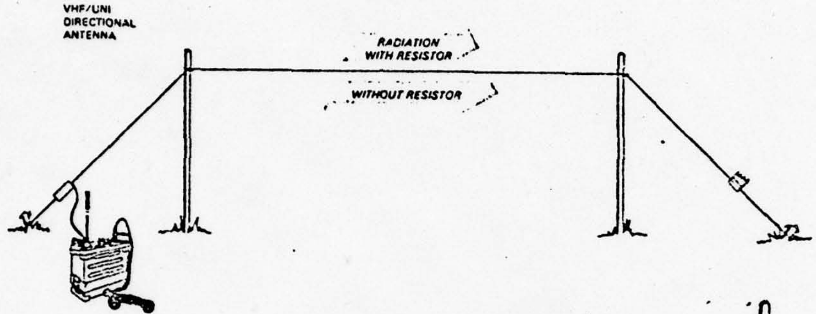
You say this antenna looks like the end of a big pup tent? Good! That means it's put up correctly. Use it to work out of a bad spot when your manpack's whip won't do the job. Tie insulators on both ends of 100 feet of any kind of wire. Run one end in the direction of the people you have to talk to, tie some wire to the other side of that insulator and stake it down with a metal stake. You need to support the center of the wire with a mast tree, pole or whatever's handy that is 20-30 feet high. Keeping the direction line straight, extend the near end till it's tight, attach more wire to the other side of the insulator and stake it down, again using a metal stake. Attach WD-1 lead-in wire as shown, and you're on the air. Here are a couple of tricks if you have the materiel and time.....Run a length of WD-1 from the ground side of both insulators, stretched so it's right under the antenna and about a foot high, then attach another piece from the near end ground stake to a screw on your radio set case. Why? Because it'll improve your signal. It's called a counterpoise. When you wire a 600-ohm, 1- or 2-watt carbon resistor across the insulator at the far end, you really improve your radio's punch in that direction. It's BI-Directional without the resistor and UNI-Directional with it.

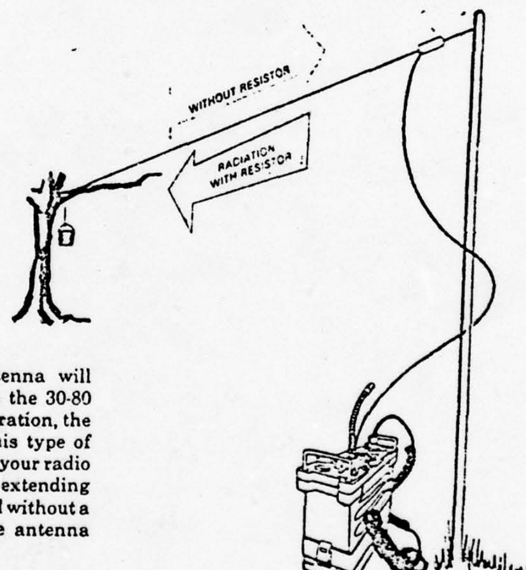
Long-Wire Antennas



This long wire is a quick fix for a broken vehicle antenna. Pick a support at least 15 feet high, in the direction you have to communicate. Move your vehicle so the support is on a line with the station you need to reach and 100 feet from you. Run a piece of WD-1 to the tree or pole you have selected as a support. Attach an insulator to a rope or wire and tie it to the support. Connect the 100-foot WD-1 to the insulator. Pull the slack out of the antenna. Wrap the WD-1 around the lower part of the broken whip and connect it to the ANT (connector) on the radio. Make sure you remove the control cable and antenna cable connected between the matching unit and radio. Now you're ready to operate. Remember to point your antenna in the right direction, and keep in mind that you should not tie the antenna close to the tree's foliage. By following the above steps, you have converted the original omni-directional antenna into a bi-directional antenna. If you add a 600-ohm carbon resistor to the end of the wire by the tree, you will convert the antenna to a UNI-Directional antenna. The wattage rating of the resistor MUST be at least half the output rating of the transmitter.

Here's another way of erecting a long wire antenna. Its overall length must be 3-7 wavelengths. Use the chart or formula to get the correct wire length. It's UNI-Directional with the 600 ohm resistor and BI-Directional without the resistor. The wattage rating of the resistor must be at least half the power output of the transmitter. You'll need to put some side guys on the 9-10' lance poles to hold them up. The antenna is erected as shown, use insulators wire, stakes etc, same as the others. You'll be able to communicate with increased range.





This 100-foot long wire antenna will work when you are operating in the 30-80 MHz frequency range. For HF operation, the antenna wire must be longer. This type of antenna will improve the range of your radio in both directions (BI-Directional) extending from the ends of the wire, if it's used without a resistor. If a resistor is used the antenna becomes UNI-Directional.

HOW TO DO IT.....WITH FORMULAS

- To figure a quarter wave length in feet: Divide 234 (constant) by your operating frequency in MHz. Example: 234 ÷ 44.8 = 5.22′ or 5′3″.
- To figure a half wave length in feet: Divide 468 (constant) by your operating frequency in MHz. Example 468 ÷ 56 = 8.36′ or 8′5″.
- To figure a full wave length in feet: Divide 936 (constant) by your operating frequency in MHz. Example: 936 ÷ 45 = 20.8′ or 20′10″.
- To convert feet to meters, multiply by .3048 (constant). Example: 110′ x .3048 = 33.5 meters.
- To convert meters to feet multiply by 3.28 (constant). Example: 100 (meters) x 3.28 = 328 feet.

QUICK REFERENCE CHART

High Frequency (HF) Antenna Length in Feet & Inches				Very High Frequency (VHF) Antenna Length in Feet & Inches			
Op Freq in MHZ	1/4 Wave	1/2 Wave	1 Wave	Op Freq in MHZ	1/4 Wave	1/2 Wave	1 Wave
2	117′	234′	468′	30	7′10″	15′7″	31′2″
3	78′	156′	312′	33	7′1″	14′2″	28′4″
4	58′6″	117′	234′	35	6′9″	13′5″	26′10″
5	46′9″	93′7″	187′4″	37	6′4″	12′7″	25′2″
6	39′	78′	156′	40	5′10″	11′8″	23′4″
7	33′5″	66′10″	133′8″	43	5′5″	10′10″	21′8″
8	29′3″	58′6″	117′	45	5′3″	10′5″	20′10″
9	26′	52′	104′	48	4′10″	9′8″	19′4″
10	23′5″	46′10″	93′8″	50	4′9″	9′5″	18′10″
11	21′3″	42′6″	85′	55	4′3″	8′6″	17′
12	19′6″	39′	78′	57	4′1″	8′2″	16′4″
13	18′	36′	72′	60	3′11″	7′10″	15′8″
14	16′9″	33′5″	66′10″	65	3′7″	7′2″	14′4″
15	15′7″	31′2″	62′4″	68	3′5″	6′10″	13′8″
16	14′7″	29′2″	58′4″	70	3′4″	6′7″	13′2″
17	13′9″	27′6″	55′	75	3′1″	6′2″	12′4″
18	13′	26′	52′	80	3′	5′11″	11′10″

REFERENCE LIST

There are many other antennas that can be constructed. If you'd care to become an expert, we recommend the following reading material.

- TM 11-666 Antennas and Radio Propagation
- FM 24-18 Field Radio Techniques
- FM 24-21 Tactical Multichannel Radio Communications Techniques
- FM 31-20 Special Forces Operational Techniques
- FM 31-73 Advisor Hand Book For Stability Operations
- TM 11-486-6 Electrical Communications Systems Engineering-Radio

APPENDIX K

PROPAGATION CURVES

AD-A053 325 TENNESSEE UNIV KNOXVILLE DEPT OF ELECTRICAL ENGINEERING F/G 17/2.1
THE UTILIZATION OF BROADBAND ANTENNAS IN MILITARY TACTICAL COMM--ETC(U)
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The radio propagation charts given in this appendix can be used to estimate the received field intensity of ground wave signals when transmitting (1) between an airplane and ground station, (2) from one plane to another, and (3) from one ground station to another ground station. This information covers plane elevations as high as 40,000 feet and distances up to 500 (statute) miles for both horizontal and vertical polarization and for three types of ground conditions, namely, sea water, good soil, and poor soil. Good soil means land of relatively high conductivity and high dielectric constant, land such as clay, loam, and alkali soil. Poor soil means land of relatively low conductivity and low dielectric constant, such as land consisting largely of rock, gravel, or sand.

The propagation charts assume a smooth spherical earth with an effective radius of 4/3 of the true earth radius. Some information is also included for estimating the effects of intervening hills and of trees in the vicinity of the antennas.

1. DESCRIPTION OF CHARTS

a. Propagation Charts. The propagation charts are divided into two groups, one for vertical polarization, and the other for horizontal polarization. Each of these two groups is divided into three sections of 4 charts each, one section for each type of ground condition.

The first chart in each section indicates the field intensity at various distances when both antennas are at reference height. The reference height is ground level (0 feet) for vertical polarization and 10 feet above ground level for horizontal polarization. This chart presents a family of curves, one curve for each frequency.

The second chart in each section indicates the gain in decibels that results when the antenna at a ground station is raised from reference height to any other height up to 200 feet.

The 2 remaining charts in each section cover the case when one antenna is elevated to considerable heights above the ground and the other antenna is at reference height. Each of these charts is for one specific frequency and presents a family of curves showing the field intensity when one antenna is elevated to various heights above the ground.

b. Power Correction. The propagation charts indicate the received field intensity in decibels above one microvolt per meter when the radiated power is one kilowatt. When the radiated power is less or greater than this value it is necessary to apply the correction shown in Figure K-1 to the field intensity shown on the chart. In estimating the radiated power, the losses in the ground and in the transmission line or in other coupling units should be subtracted from the rated power output of the transmitter.

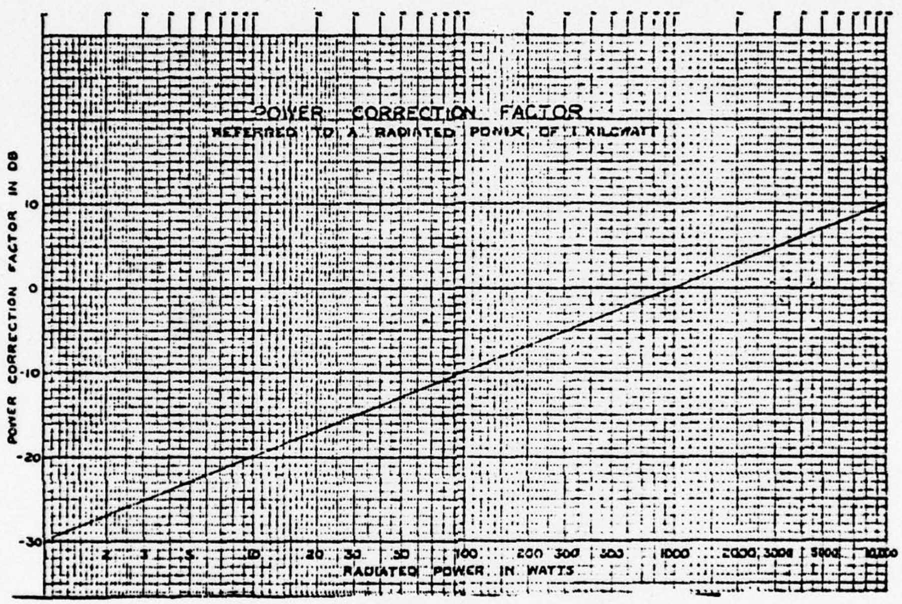

Figure K-1. Power correction factor.

c. Antenna Correction. The charts for horizontal polarization and the charts for vertical polarization with one antenna elevated assume that the transmitting antenna is a dipole whose length is one-half wavelength or less.* The

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*The computations are actually based on an ideal doublet but the difference between a half-wave dipole and the doublet is neglected since it amounts to only 0.4 db for the same radiated power. The change in input impedance which occurs when the height of a horizontal dipole is appreciably less than a quarter wavelength has also been neglected.

charts for vertical polarization with both antennas at ground level assume a vertical whip (one-quarter wavelength or less) working against a perfect counterpoise. In each case the field intensity shown on the charts is for a direction perpendicular to the radiating elements. In directions such that the angle is considerably less than 90 degrees, the field intensity is lower.

When a directional transmitting antenna is used, a correction should be made for its gain or loss, in decibels, relative to the reference antenna. The gain of a directional antenna is usually given in terms of its radiation compared to that from a half-wave dipole in the direction for which the field intensity for each antenna is a maximum.

For a given power, the field intensity from a whip antenna (connected to a perfectly conducting counterpoise) is 3 decibels or less than that from a dipole elevated more than a quarter wavelength above the ground. This difference, which is in addition to the values shown on the height gain charts, may be taken into account by the corrections shown in Figure K-2.

WHEN USING CURVES FOR	ANTENNA CORRECTION FACTOR WHEN TRANSMITTING ANTENNA IS		
	GROUNDED VERTICAL WHIP	DIPOLE	DIRECTIONAL ANTENNA
Vertical polarization with both antennas on ground	0	+3 db	3 db plus directivity gain referred to dipole
Vertical polarization with one antenna elevated	−3 db	0 db	directivity gain referred to dipole
Horizontal polarization	—	0 db	directivity gain referred to dipole

Figure K-2. Antenna correction factor.

2. HOW TO USE THE CHARTS

a. Plane-to-Ground or Ground-to-Plane Transmission. In plane-to-ground or ground-to-plane transmission, the received field intensity can be determined by referring to the chart which corresponds to the given type of polarization, type of ground, and frequency. When one antenna is at reference height, the received field intensity is obtained directly from the curve corresponding to the height of the plane, provided the radiated power is 1 kilowatt and the transmitting antenna is a dipole. For other values of radiated power, the power correction indicated on Figure K-1 should be made. When the transmitting antenna is other than a dipole, the antenna correction is as indicated in Figure 2.

At frequencies above 20 to 30 megacycles, the antenna at the ground station is ordinarily mounted on a mast and therefore is considerably higher than reference height. This causes an increase in the field intensity by an amount corresponding to the height gain correction shown on the second chart in each section. However, when the sum of the field intensity shown on the chart plus the height gain factor is greater than the "free space" value shown on the chart, the free space value should be used.*

EXAMPLE: A transmitter in a plane flying at 10,000 feet radiates 10 watts at a frequency of 60 megahertz, using a vertical half-wave dipole antenna. The receiving antenna is 100 miles from the plane and is mounted on a 30-foot mast. The intervening terrain is assumed to be good soil. The estimated received field for this example is:

42 + 7 - 20 + 0 = 29 decibels above 1 microvolt per meter.

The first factor (42 decibels) is obtained from the chart on page 278 for vertical polarization, good soil and 60 megahertz for a distance of 100 miles and a height of 10,000 feet. The second factor (7 decibels) is the gain due to raising the antenna at the ground station from reference height (0 feet) to 30 feet above ground level, and is obtained from the height gain curve on page 277 for vertical polarization over good soil. The third factor (-20 decibels) is the power correction factor obtained from Figure K-1. The fourth factor (0 decibel) is the antenna correction factor indicated in Figure K-2.

When transmitting to a plane from a ground station with a half-wave dipole antenna radiating 10 watts, the received field intensity at the plane is the same as that shown above for the same combination of heights and distance. However,

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*The ray reflected from the ground may reenforce or weaken the direct ray, depending on the distance, antenna heights, frequency and other factors. Thus the field intensity may be as high as 6 db above the free space field, and it may be 20 or 30 db below free space. The nulls are reasonably sharp, however, and in most conditions the field is equal to or greater than the free space value.

when the transmitting antenna is a grounded whip, the estimated field at a plane which is at an elevation of 10,000 feet and at a distance of 100 miles is 42 + 0 - 20 - 3 = 19 decibels above 1 microvolt per meter. In this case the height gain factor is 0 decibel and the antenna correction factor is -3 decibels as shown in Figure K-2

b. Plane-to-Plane Transmission. When transmitting between planes, both antennas are elevated to considerable heights above the ground, and it is usually assumed that the received field intensity is equal to the free space field as long as the planes are well within line of sight. For greater distances, the field intensity decreases more rapidly and the assumption of free space transmission is no longer accurate. The maximum distance for which a line-of-sight path exists over a smooth spherical earth can be obtained from Figure K-3.* In this chart the left-hand scale represents the height of one plane, the right-hand scale represents the height of the other plane, and the middle line represents the line-of-sight distance. The line-of-sight distance is obtained by laying a straight edge between the proper points on the left-hand and right-hand scales and by reading the distance at the intersection of the straight edge with the center line.

EXAMPLE: Two planes are separated by a distance of 100 miles. The first plane is at an elevation of 10,000 feet and the second is at an elevation of 5,000 feet. The field intensity at one plane produced by a transmitter on the other plane radiating 20 watts from a dipole is obtained as follows:

A straight line on Figure K-3 from 10,000 feet on the left-hand scale to 5,000 on the right-hand scale indicates a line-of-sight distance of 240 miles; so the planes are well within the line of sight at 100 miles. On any of the charts showing the free space field, the value for 100 miles is about 62 decibels above 1 microvolt per meter for 1 kilowatt radiated. The estimated field is 62 - 17 = 45 decibels above 1 microvolt per meter, where -17 decibels is the power correction factor for 20 watts from Figure K-1, page 261.

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*The distances shown are slightly greater than the true optical line of sight, since an effective earth's radius of 4/3 of the true earth's radius is assumed to account for some refraction in the lower atmosphere.

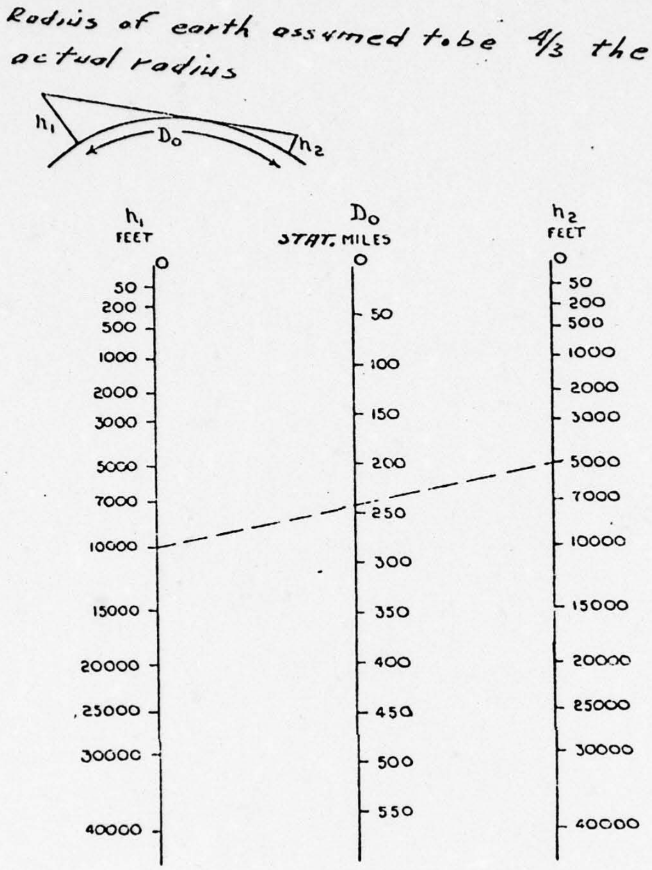

Figure K-3. Maximum distance for line-of-sight path.

c. <u>Ground-to-Ground Transmission</u>. The field intensity for ground-to-ground transmission for antenna heights of less than 200 feet can be determined by the following procedure. The field intensity at reference height (0 feet for vertical polarization and 10 feet for horizontal polarization) is obtained from the first chart in each section. Add to this value the height gain factor for the transmitting antenna and the height gain factor for the receiving antenna as shown on the second sheet in each section. Finally, the power correction shown on Figure K-1, page 261, and the antenna correction shown on Figure K-2, page 262, should be added.

When one antenna is higher than 200 feet, the field intensity for ground-to-ground transmission can be determined in the same manner as discussed above for plane-to-ground transmission. When the lower antenna is at reference height, the field intensity is obtained directly from the chart for the desired polarization, type of ground, and frequency from the curve for the height of the higher antenna. When the lower antenna is above reference height this value should be increased by the height gain correction factor.

EXAMPLE: A ground station operating on 30 megacycles radiates 50 watts from a 3-element vertical directive array located at a height of 100 feet. The gain of the 3-element antenna is assumed to be about 6 decibels referred to a dipole. The receiving antenna is mounted on a 50-foot mast and is 50 miles from the transmitter. The intervening terrain is assumed to be good soil. The estimated field intensity is

$0 + 10 + 5 - 13 + (6 + 3) = 11$ decibels above 1 microvolt per meter.

The first factor is the field intensity at 50 miles for both antennas at ground level. The next two factors are the height gain values for the 100-foot antenna and the 50-foot antenna, respectively. The fourth factor (-13 decibels) is the power correction for 50 watts from Figure K-1, page 261. The last factor is the gain of the 3-element array over the reference antenna and consists of two terms: (1) a 6-decibel gain of the array over a half-wave dipole and (2) a 3-decibel gain of a half-wave dipole over the reference antenna (whip at ground level) as indicated in Figure K-2, page 262.

In the alternate method the received field intensity is

$13 + 5 - 13 + 6 = 11$ decibels above 1 microvolt per meter.

The first factor (13 decibels) is obtained from the chart for vertical polarization, good soil, and 30 megacycles for a height of 100 feet at a distance of 50 miles. The second factor (5 decibels) is the height gain due to raising the lower antenna from reference height to 50 feet. The third factor (-13 decibels) is the power correction factor for 50 watts. The fourth factor is the gain of the 3-element array over the reference antenna (dipole).

3. EFFECTS OF HILLS, TREES, AND JUNGLE

a. Effect of Hills. The effect of hills can be divided into two parts, (1) the effect of placing antennas on hills, which is discussed in a later paragraph, and (2) the effect of hills and other obstacles in the transmission path.

Under certain conditions the field intensity behind a hill may be greater than would be obtained if the terrain between the antennas were level ground, but, in general, it may be assumed that intervening hills cause a loss in field intensity. This loss in decibels should be subtracted from the field intensity over a smooth spherical earth as obtained from the charts in this handbook. This additional loss, called shadow loss, is ordinarily small at frequencies below a few megacycles but it may be 20 to 30 decibels or more at the higher frequencies.

An estimate of the probable magnitude of the shadow loss can be obtained from Figure K-4 by the following procedure:*

1. Draw an approximate profile of the straight line path between the proposed locations of the two radio terminals, using the elevations obtained from contour maps.
2. On this profile, draw a triangle similar to the one shown at the top of Figure K-4. This triangle is formed by a line joining the base of the transmitting antenna with the base of the receiving antenna and a line from each antenna tangent to the hill that blocks the line of sight from that location.
3. From this triangle note: (1) the height H from the base of the triangle to the apex and (2) the distance D_1 along the base of the triangle from the nearer terminal to the foot of the perpendicular line H.
4. On Figure K-4 draw a straight line from the point representing D_1 on scale 1 through the point representing H on scale 2 and extend this line until it crosses scale 3.
5. Draw a second straight line from the intersection of the first line with scale 3 through the point representing the frequency on scale 4. Extend this line until it crosses scale 5 and read the shadow loss at this intersection.

The example shown in Figure K-4 indicates a shadow loss of nearly 10 decibels at 30 megacycles due to an "equivalent" 1000-foot hill located 10 miles from the nearer terminal. For a 1000-foot hill only one mile from the nearer terminal the expected shadow loss at 30 megacycles is about 19 decibels.

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*This method is based on the theory of diffraction of plane waves over a knife edge.

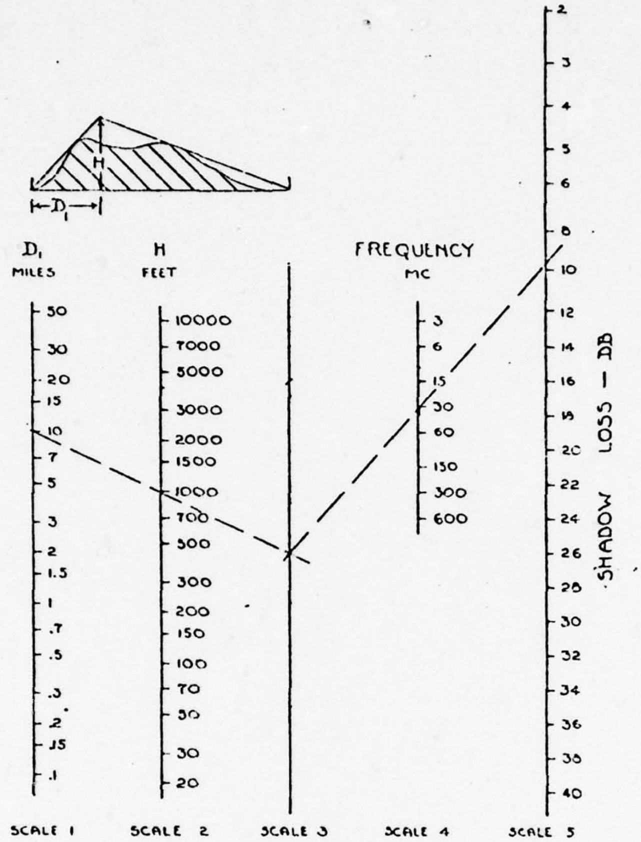


Figure K-4. Shadow loss.

The above method considers only the straight line path between the transmitter and the receiver. In practice, reflections from hills near the straight line path may have an appreciable effect. In some cases a stronger signal is obtained by way of devious routes such as river valleys or mountain passes than can be expected by diffraction over the straight line path.

<u>b. Effective Antenna Height</u>. The effective height of a dipole or other type of balanced antenna located above ground which is level for the first half mile or so in the direction of the other antenna is the height of the center of the antenna above the ground level at the base; that is, it is usually about equal to the height of the mast. The effective height of an antenna on the edge of a precipice (falling off in the direction of the other terminal) can usually be taken as the difference in elevation between the

center of the antenna and the bottom of the precipice. In the intermediate case where the antenna is placed on a hill sloping downward in the direction of the distant terminal, the effective height of the antenna depends on the steepness and uniformity of this slope. In general, the effective height of an antenna placed on a hill is greater than the mast height but is ordinarily less than the mast height plus the height of the hill.

c. Effect of Trees and Jungle Conditions. The attenuation due to trees is less for horizontal polarization than for vertical polarization, except at frequencies above 300 to 500 megacycles where it tends to be independent of the type of polarization. For horizontal polarization the average loss due to moderately thick trees is negligible at 30 megacycles and may be 1 or 2 decibels at 100 megacycles. For vertical polarization the corresponding loss is 2 to 3 decibels on the average at 30 megacycles and 5 to 10 decibels at 100 megacycles. These losses are doubled when both antennas are located in woods.

With both antennas in clearings so that each is more than 200 or 300 feet from the edge of the woods, the attenuation due to trees is small for vertical polarization as well as for horizontal polarization. With vertical polarization, there may be large and rapid variations in field intensity within a small area, due to reflections from nearby trees and buildings. These fluctuations may occur even over line-of-sight paths when trees or buildings are within a few hundred feet of the direct transmission path.

In jungles or in swamp land with heavy undergrowth, considerable attenuation for ground wave transmission is to be expected with horizontal as well as with vertical polarization. The attenuation due to the jungle can be minimized by locating the antennas in clearings and by raising the antennas near or above the top of the jungle. An alternate method of jungle communication is to use sky-wave transmission. In this case, half-wave horizontal antennas are best for distances up to 100 or 200 miles, and a frequency in the range of about 2 to 8 megacycles should be used, the optimum operating frequency depending upon the time of day and the season of the year.

4. LIMITATIONS

The field intensities estimated by the above-described methods are for the "ground wave" and do not include components of the signal that may be reflected from the ionosphere. In the frequency range of about 2 to 20 megacycles, which is frequently called the "short-wave range," there are reflections from the ionosphere which provide sky-wave transmission over greater distances than are feasible with ground waves. The sky-wave field intensities vary considerably, depending on the frequency, time of day, latitude, and season of the year. Information on the maximum and minimum frequencies to use for sky-wave transmissions can be obtained from the monthly bulletins prepared by the Interservice Radio Propagation Laboratory of the National Bureau of Standards.

The ground-wave data given in these charts are limited by several assumed ideal conditions, since it is impossible to take into account all factors affecting radio propagation. The principal assumptions are a smooth spherical earth with uniform ground constants, and a standard atmosphere in which the dielectric constant of the air varies uniformly as the height above the earth increases. The average bending of radio waves due to refraction in the standard atmosphere is included by assuming that the effective radius of the earth is increased to 4/3 of its actual value. Under other atmospheric conditions the field intensity at distances beyond the line of sight may be greater or less than the values shown on these charts. This dependence of radio propagation on the weather is small at frequencies of less than 30 megacycles, but its importance increases as the frequency increases.

The charts may be in error at short distances when the distance between antennas is less than one or two wavelengths or when it is appreciably greater than the horizontal distance along the ground.

The ground constants used in these computations are shown in Table K-1.

The information on the effects of hills, trees, and jungle agrees reasonably well with the available experimental evidence. However, the evidence is meager and further experience may indicate some modifications of these views.

TABLE K-1

TABLE OF GROUND CONSTANTS

Ground Condition	Conductivity MHOS per Meter	Conductivity E.M.U.	Dielectric Constant
Sea Water	4.	4×10^{-11}	80
Good Soil	.02	2×10^{-13}	30
Poor Soil	.001	10^{-14}	4

TABLE K-2

PROPAGATION CHARACTERISTICS OF LOCAL TERRAIN

Type of Surface	Relative Conductivity	Dielectric Constant
Sea Water	Good	80
Large Bodies of Fresh Water	Fair	80
Wet Soil	Fair	30
Flat, Loamy Soil	Fair	15
Dry, Rocky Terrain	Poor	7
Desert	Poor	4
Jungle	Unusable	

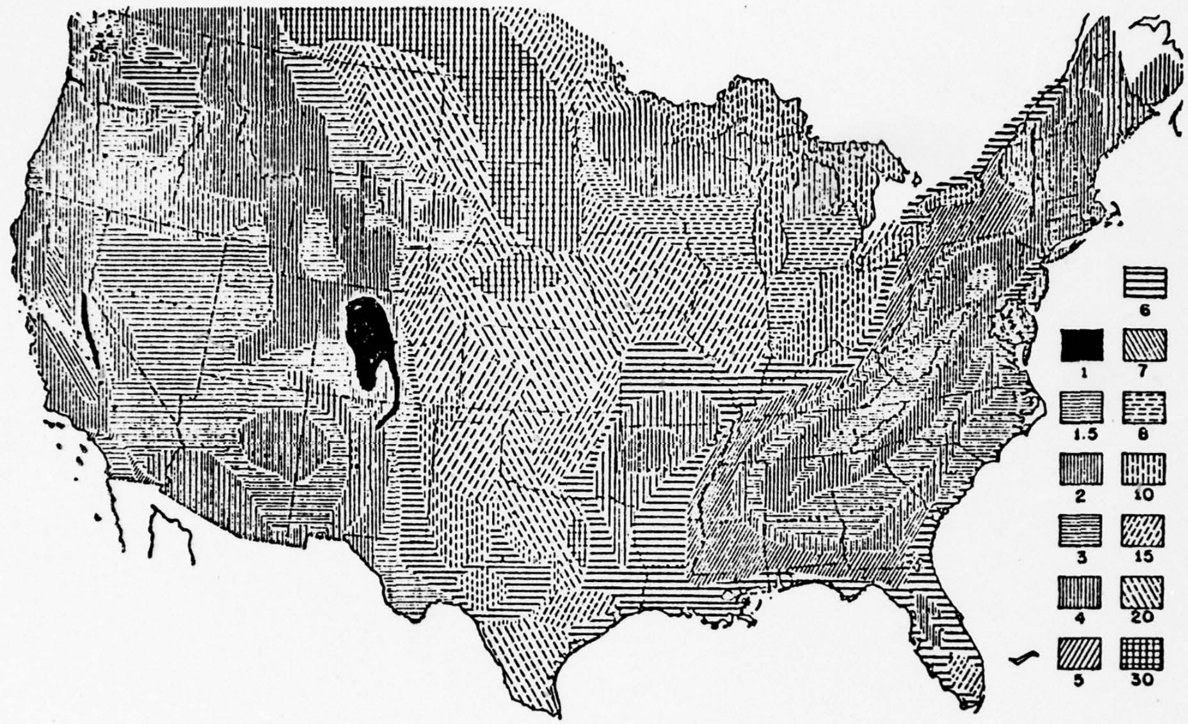


Figure K-5. Ground conductivity map of the United States. Numbers on the legend, when multiplied by 10^{-3}, indicate ground conductivity in mhos/meter. (Map by the Federal Communications Commission.) (Maps of foreign areas are available from the same source.)

Figure K-6. Propagation charts.

(a) Both antennas at ground level. One kw radiated from whip. Vertical polarity, poor soil.

(b) Antenna height gain correction factor. Vertical polarity, poor soil.

(c) One antenna at ground level; other antenna elevated to height indicated. One kw radiated. Vertical polarity, poor soil, 30 MHz.

(d) One antenna at ground level; other antenna elevated to height indicated. One kw radiated. Vertical polarity, poor soil. 60 MHz.

(e) Both antennas at ground level. One kw radiated from whip. Vertical polarity, good soil.

(f) Antenna height gain correction factor. Vertical polarity, good soil.

(g) One antenna at ground level; other antenna elevated to height indicated. One kw radiated. Vertical polarity, good soil, 30 MHz.

(h) One antenna at ground level; other antenna elevated to height indicated. One kw radiated. Vertical polarity, good soil, 60 MHz.

(i) Both antennas at ground level. One kw radiated from whip. Vertical polarity, sea water.

(j) Antenna height gain correction factor. Vertical polarity, sea water.

(k) One antenna at ground level; other antenna elevated to height indicated. One kw radiated. Vertical polarity, sea water, 30 MHz.

(l) One antenna at ground level; other antenna elevated to height indicated. One kw radiated. Vertical polarity, sea water, 60 MHz.

(m) Both antennas ten feet above ground level. One kw radiated from dipole. Horizontal polarity, poor soil.

(n) Antenna height gain correction factor. Horizontal polarity, poor soil.

(o) One antenna ten feet above ground level; other antenna elevated to height indicated. One kw radiated. Horizontal polarity, poor soil, 30 MHz.

(p) One antenna ten feet above ground level; other antenna elevated to height indicated. One kw radiated. Horizontal polarity, poor soil, 60 MHz.

(q) Both antennas ten feet above ground level. One kw radiated from dipole. Horizontal polarity, good soil.

(r) Antenna height gain correction factor. Horizontal polarity, good soil.

(s) One antenna ten feet above ground level; other antenna elevated to height indicated. One kw radiated. Horizontal polarity, good soil, 30 MHz.

Figure K-6 (continued)

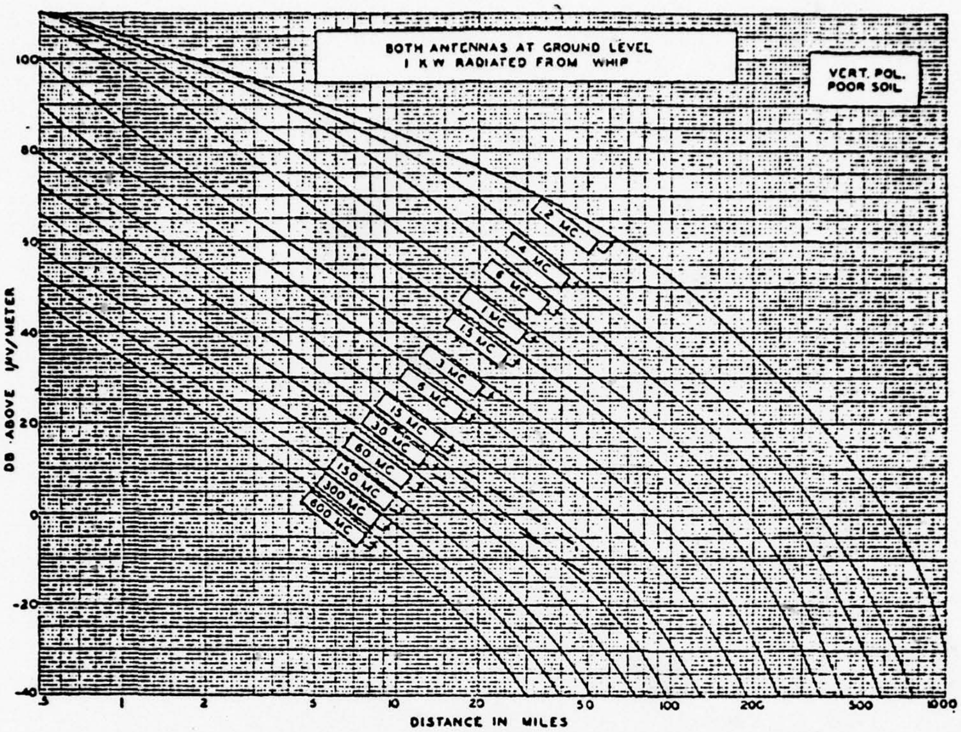
(t) One antenna ten feet above ground level; other antenna elevated to height indicated. One kw radiated. Horizontal polarity, good soil, 60 MHz.

(u) Both antennas ten feet above ground level. One kw radiated from dipole. Horizontal polarity, sea water.

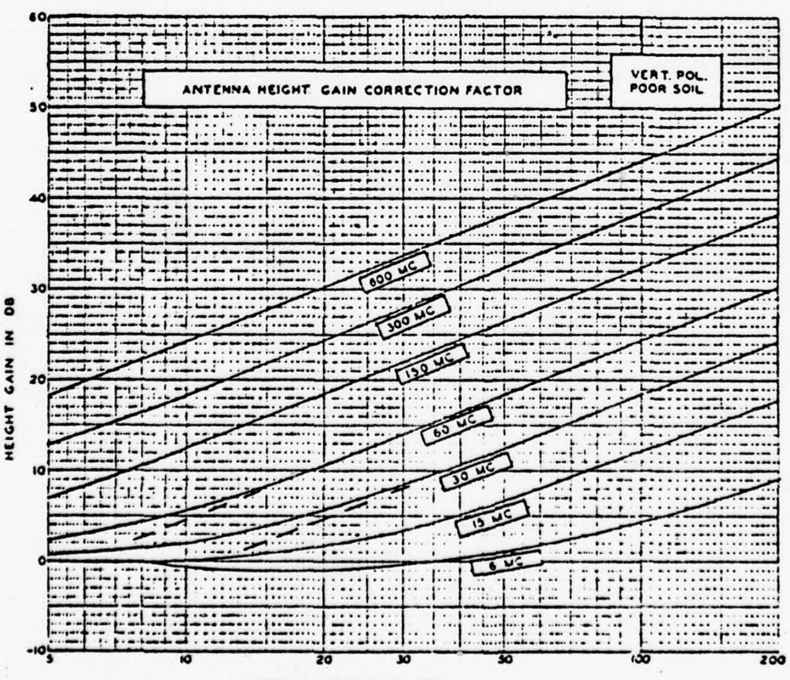
(v) Antenna height gain correction factor. Horizontal polarity, sea water.

(w) One antenna ten feet above ground level; other antenna elevated to height indicated. One kw radiated. Horizontal polarity, sea water, 30 MHz.

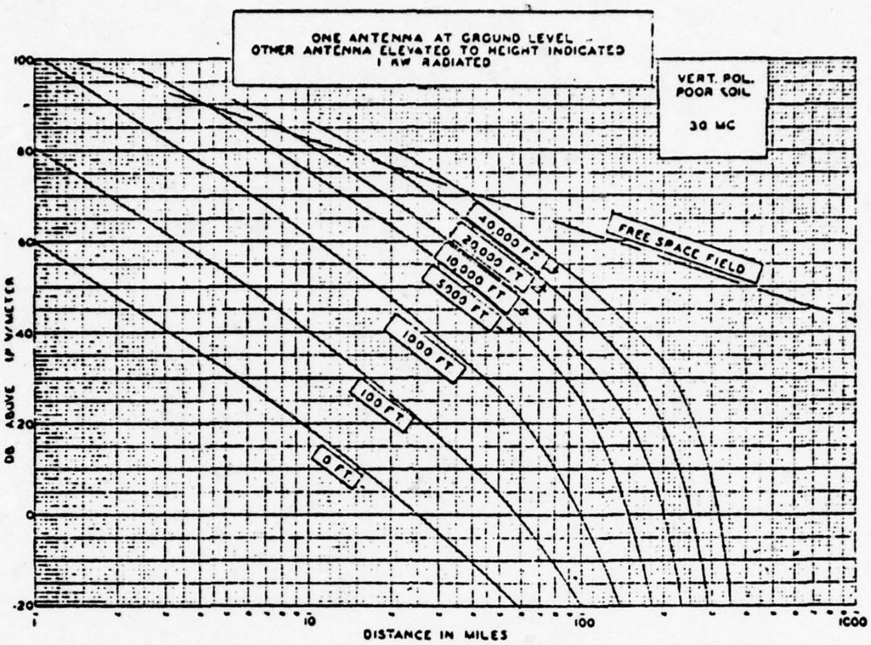
(x) One antenna ten feet above ground level; other antenna elevated to height indicated. One kw radiated. Horizontal polarity, sea water, 60 MHz.


BOTH ANTENNAS AT GROUND LEVEL
1 KW RADIATED FROM WHIP
VERT. POL.
POOR SOIL
DB ABOVE 1 μV/METER
DISTANCE IN MILES
2 MC
4 MC
6 MC
1 MC
1.5 MC
3 MC
8 MC
15 MC
30 MC
60 MC
150 MC
300 MC
600 MC

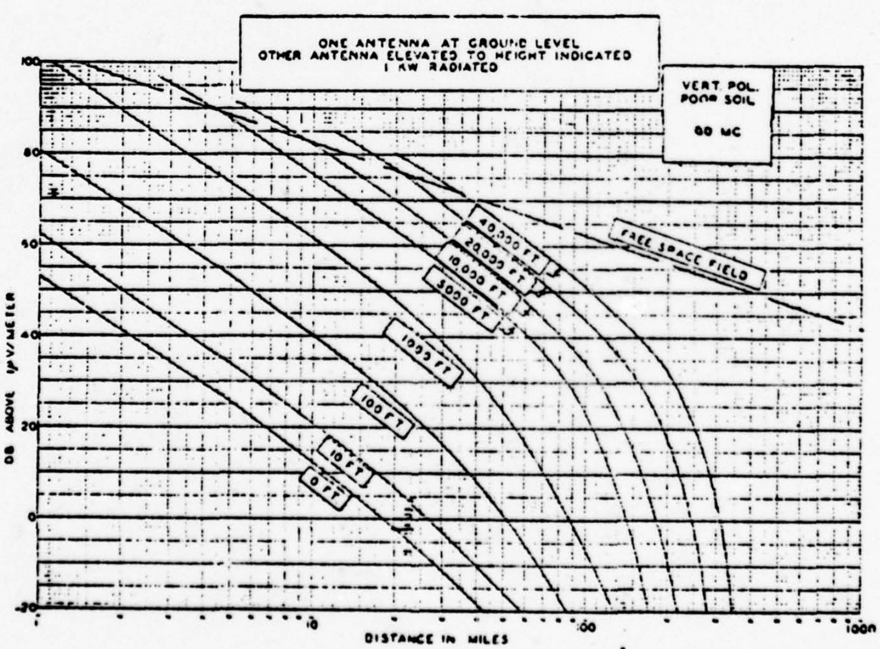
(a)


ANTENNA HEIGHT GAIN CORRECTION FACTOR
VERT. POL.
POOR SOIL
HEIGHT GAIN IN DB
ANTENNA HEIGHT IN FEET
600 MC
300 MC
150 MC
60 MC
30 MC
15 MC
6 MC

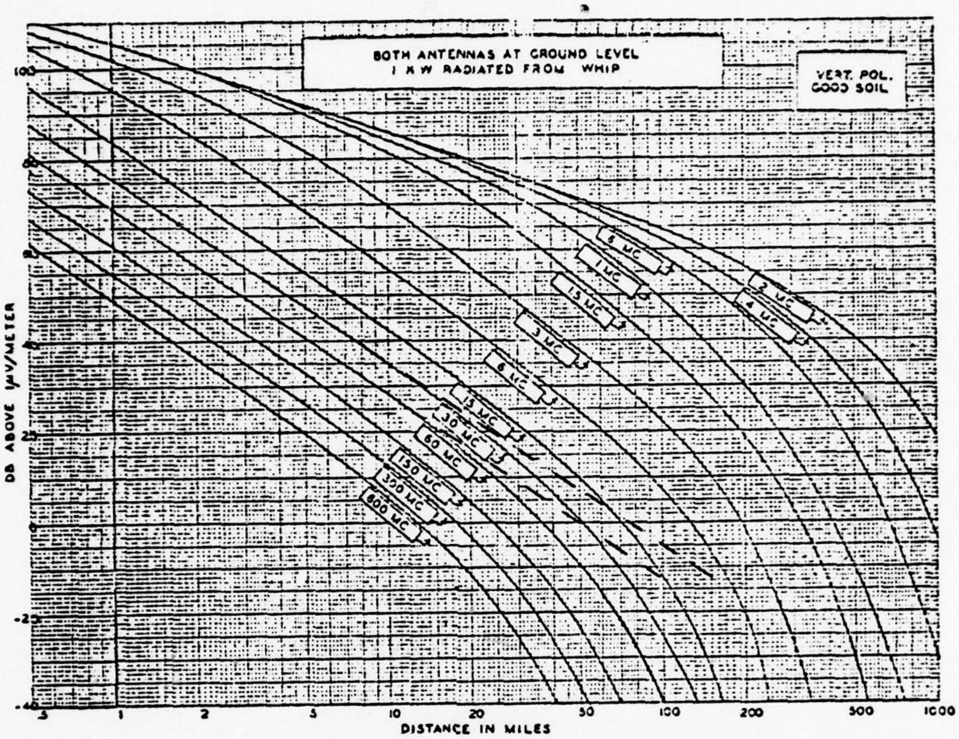
(b)


ONE ANTENNA AT GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
VERT. POL.
POOR SOIL
30 MC
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
0 FT
FREE SPACE FIELD
DB ABOVE 1μ V/METER
DISTANCE IN MILES

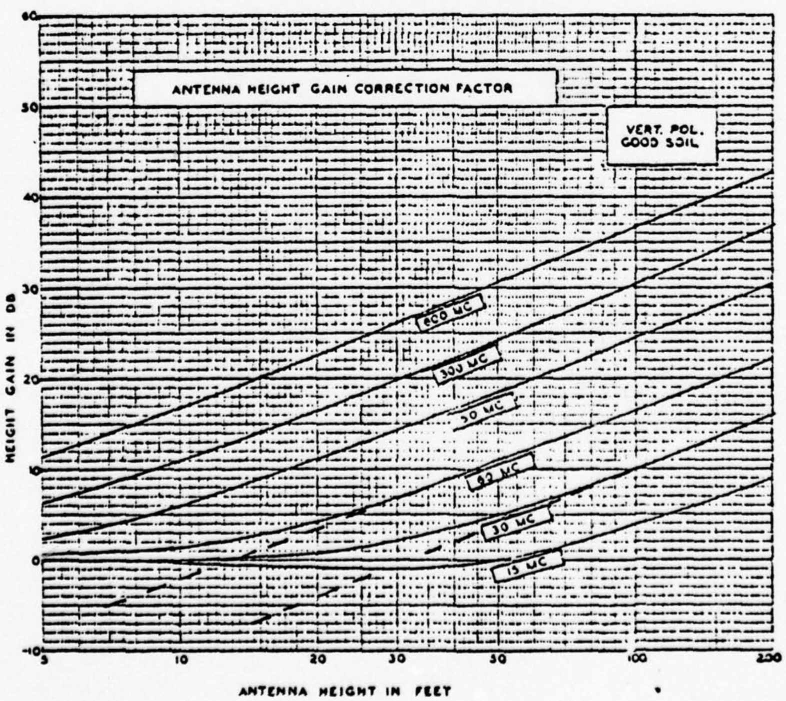
(c)


ONE ANTENNA AT GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
VERT. POL.
POOR SOIL
60 MC
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
10 FT
0 FT
FREE SPACE FIELD
DB ABOVE 1μV/METER
DISTANCE IN MILES

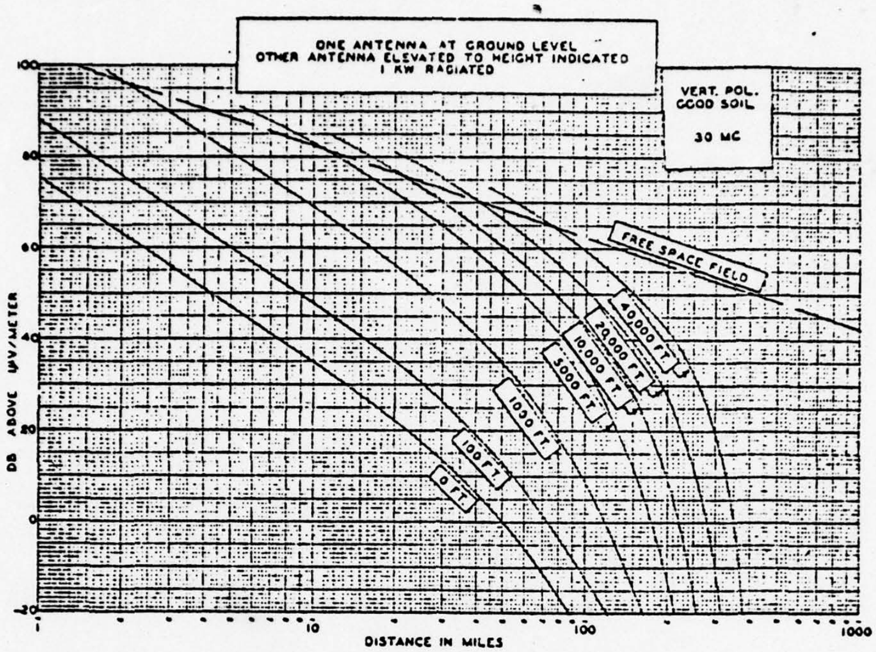
(d)


BOTH ANTENNAS AT GROUND LEVEL
1 KW RADIATED FROM WHIP
VERT. POL.
GOOD SOIL
DB ABOVE 1 μV/METER
DISTANCE IN MILES
.5 MC
1 MC
1.5 MC
3 MC
6 MC
15 MC
30 MC
60 MC
150 MC
300 MC
600 MC
2 MC
4 MC

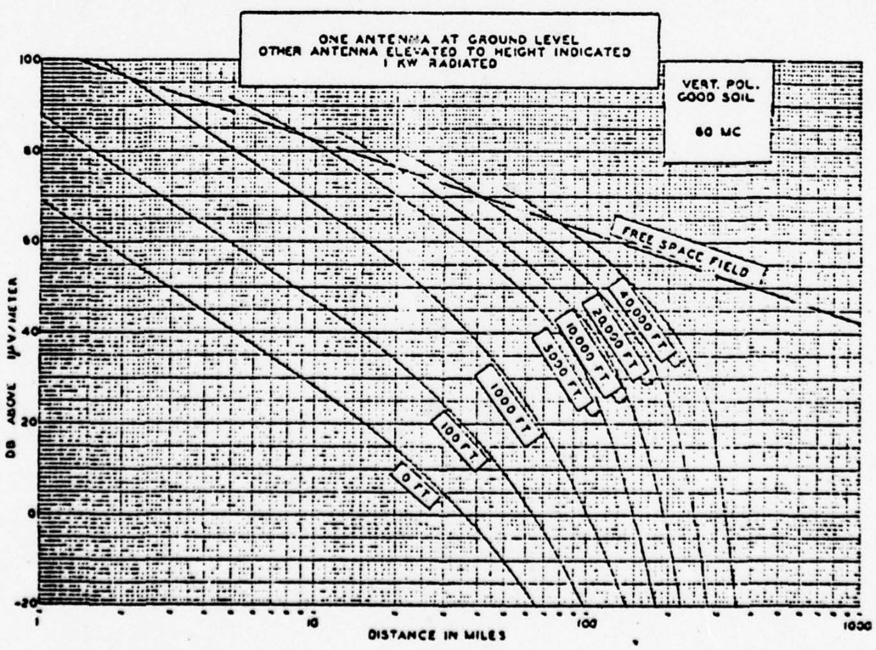
(e)


ANTENNA HEIGHT GAIN CORRECTION FACTOR
VERT. POL.
GOOD SOIL
HEIGHT GAIN IN DB
ANTENNA HEIGHT IN FEET
600 MC
300 MC
150 MC
60 MC
30 MC
15 MC

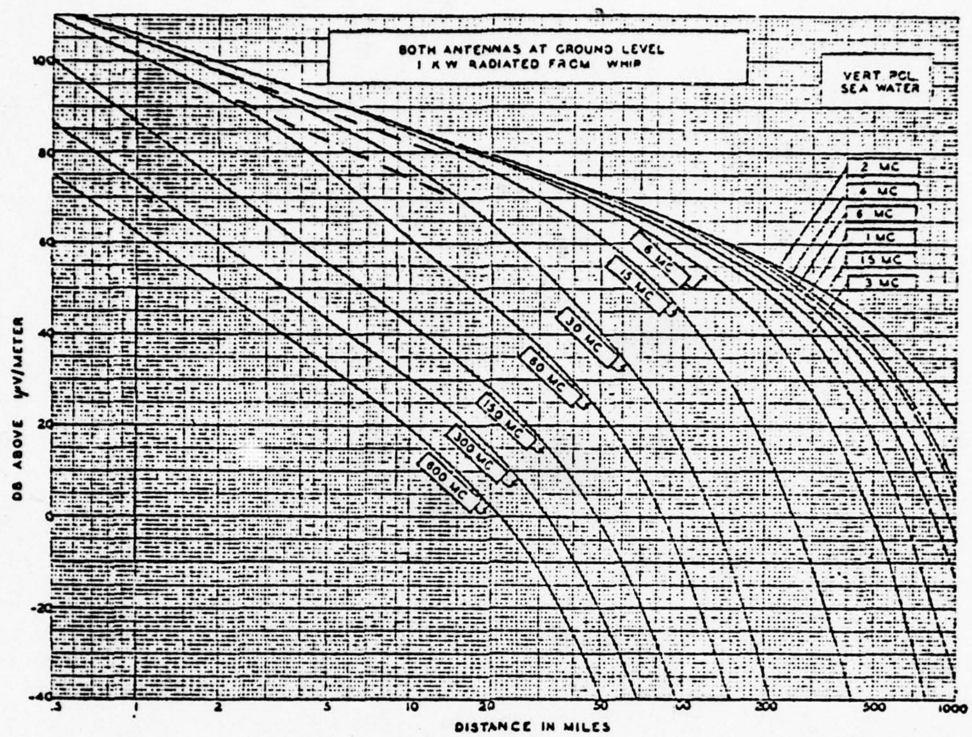
(f)


ONE ANTENNA AT GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
VERT. POL.
GOOD SOIL
30 MC
FREE SPACE FIELD
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
0 FT
DB ABOVE 1μV/METER
DISTANCE IN MILES

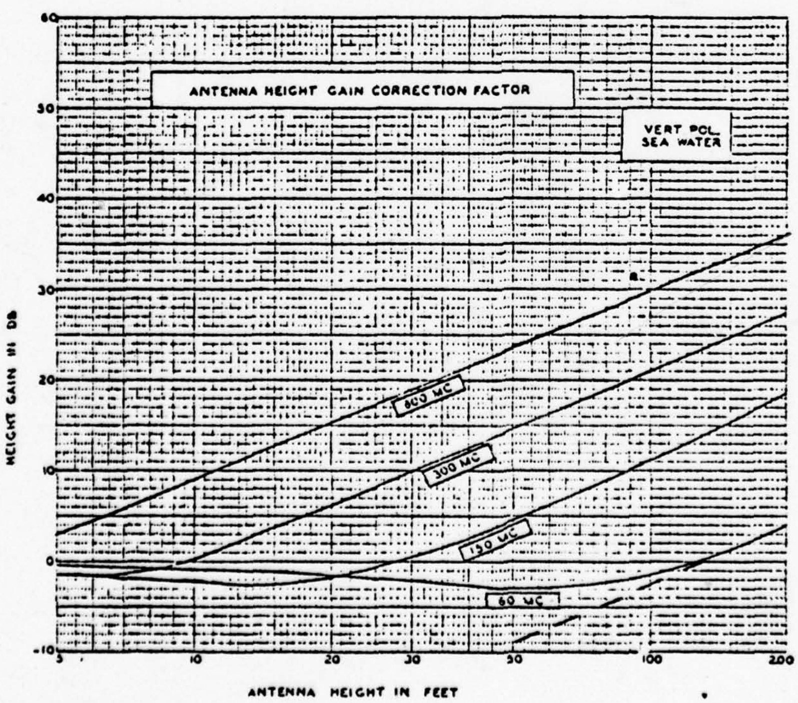
(g)


ONE ANTENNA AT GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
VERT. POL.
GOOD SOIL
60 MC
FREE SPACE FIELD
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
0 FT
DB ABOVE 1μV/METER
DISTANCE IN MILES

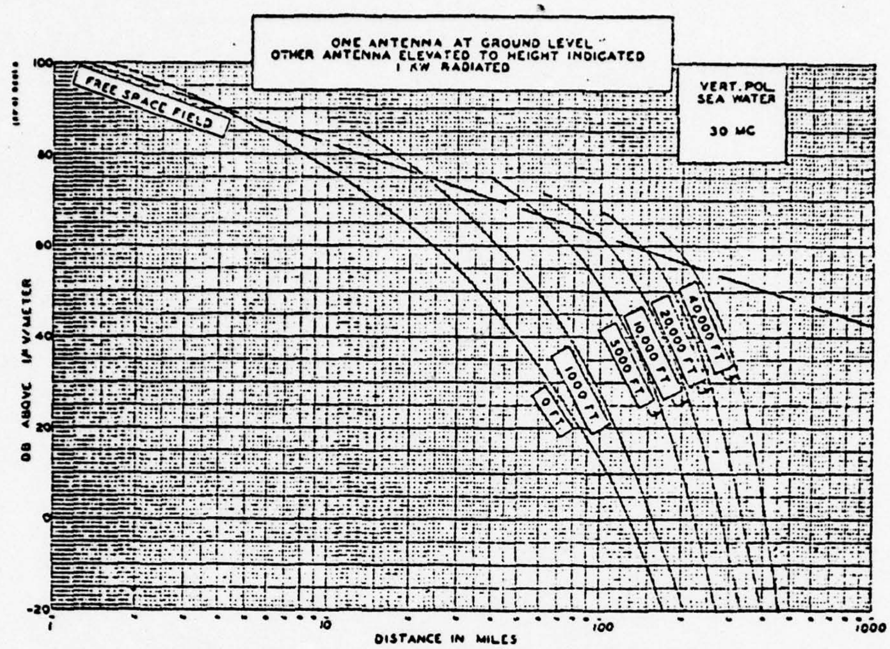
(h)


BOTH ANTENNAS AT GROUND LEVEL
1 KW RADIATED FROM WHIP
VERT POL
SEA WATER
2 MC
4 MC
6 MC
1 MC
1.5 MC
3 MC
6 MC
15 MC
30 MC
60 MC
150 MC
300 MC
600 MC
DB ABOVE μV/METER
DISTANCE IN MILES

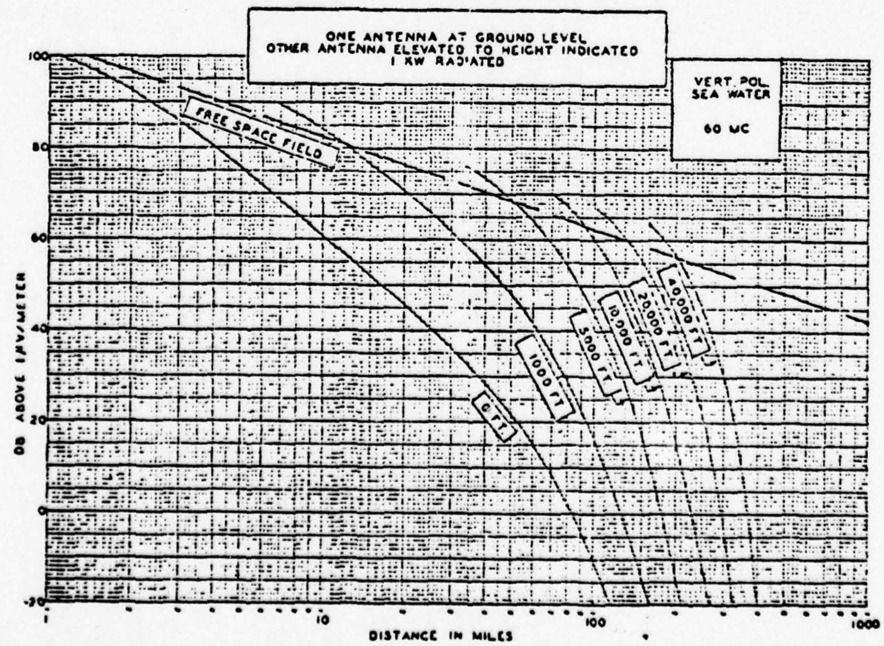
(i)


ANTENNA HEIGHT GAIN CORRECTION FACTOR
VERT POL
SEA WATER
600 MC
300 MC
150 MC
60 MC
HEIGHT GAIN IN DB
ANTENNA HEIGHT IN FEET

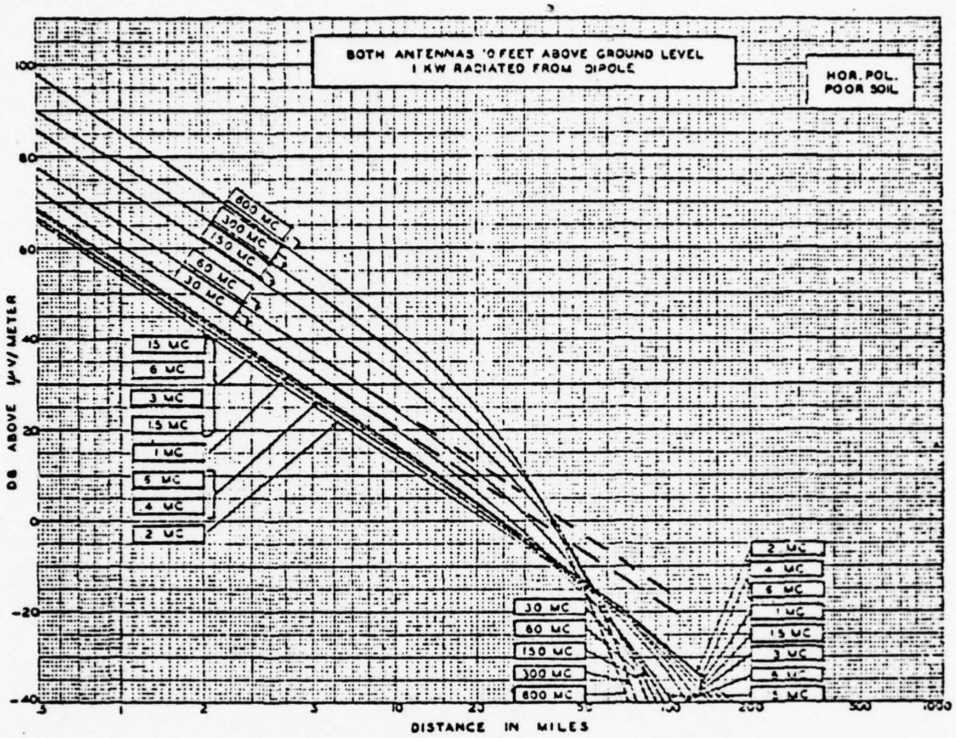
(j)


ONE ANTENNA AT GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
VERT. POL.
SEA WATER
30 MC
FREE SPACE FIELD
0 FT.
1000 FT.
5000 FT.
10,000 FT.
20,000 FT.
40,000 FT.
DB ABOVE 1 µV/METER
DISTANCE IN MILES

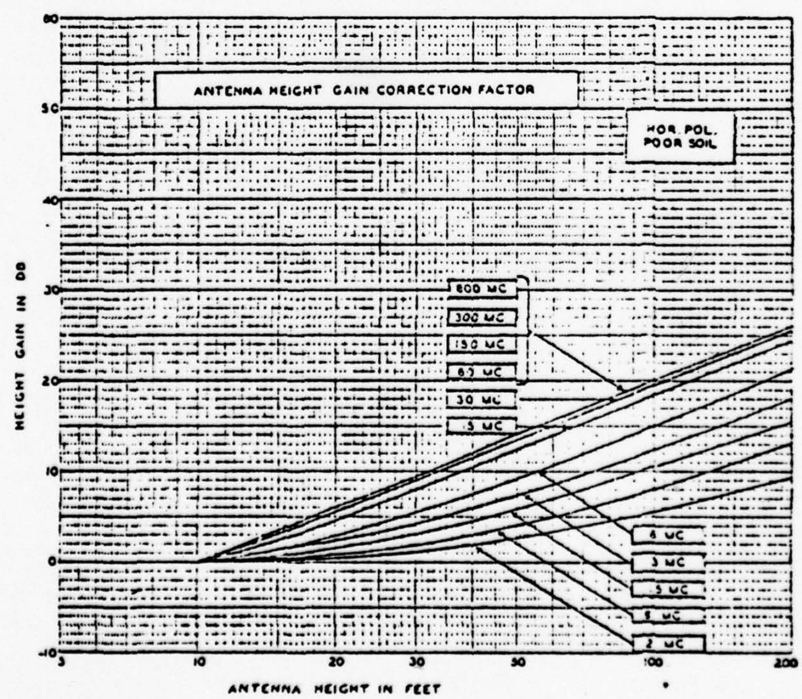
(k)


ONE ANTENNA AT GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
VERT. POL.
SEA WATER
60 MC
FREE SPACE FIELD
0 FT.
1000 FT.
5000 FT.
10,000 FT.
20,000 FT.
40,000 FT.
DB ABOVE 1 µV/METER
DISTANCE IN MILES

(l)


BOTH ANTENNAS 10 FEET ABOVE GROUND LEVEL
1 KW RADIATED FROM DIPOLE
HOR. POL.
POOR SOIL
DB ABOVE 1 μV/METER
DISTANCE IN MILES
600 MC
300 MC
150 MC
60 MC
30 MC
15 MC
6 MC
3 MC
1.5 MC
1 MC
.5 MC
.4 MC
2 MC

(m)


ANTENNA HEIGHT GAIN CORRECTION FACTOR
HOR. POL.
POOR SOIL
HEIGHT GAIN IN DB
ANTENNA HEIGHT IN FEET
600 MC
300 MC
150 MC
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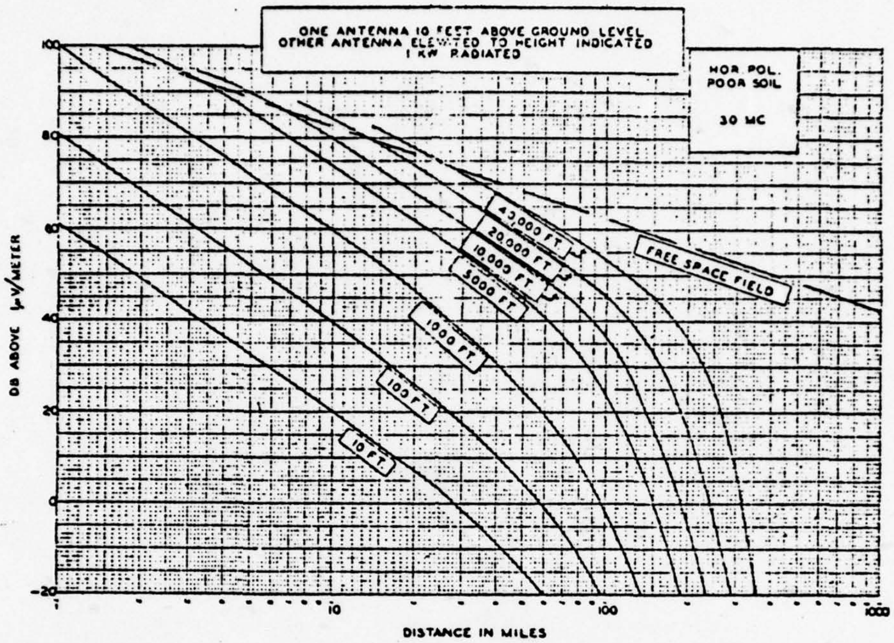
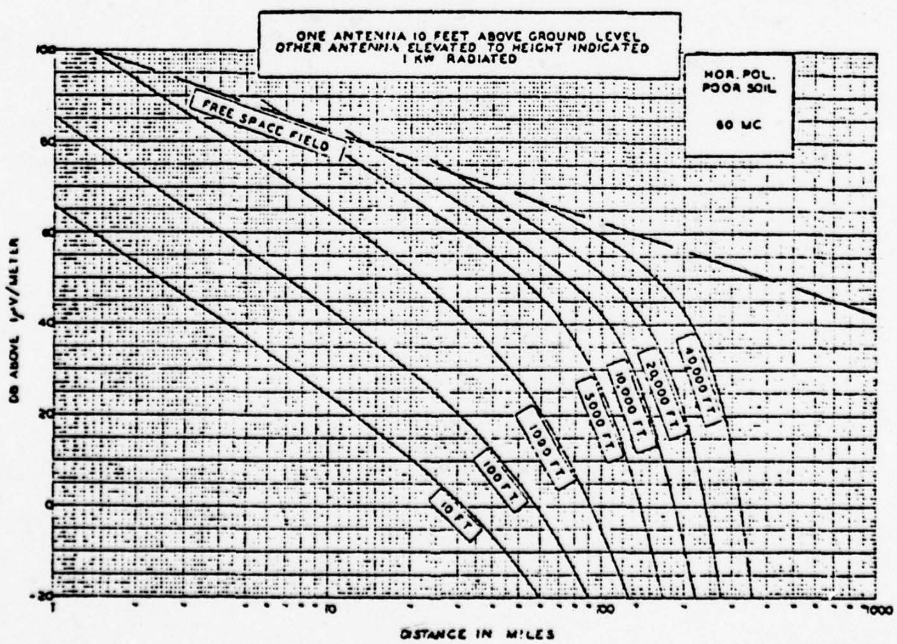
30 MC
15 MC
6 MC
3 MC
.5 MC
1 MC
2 MC

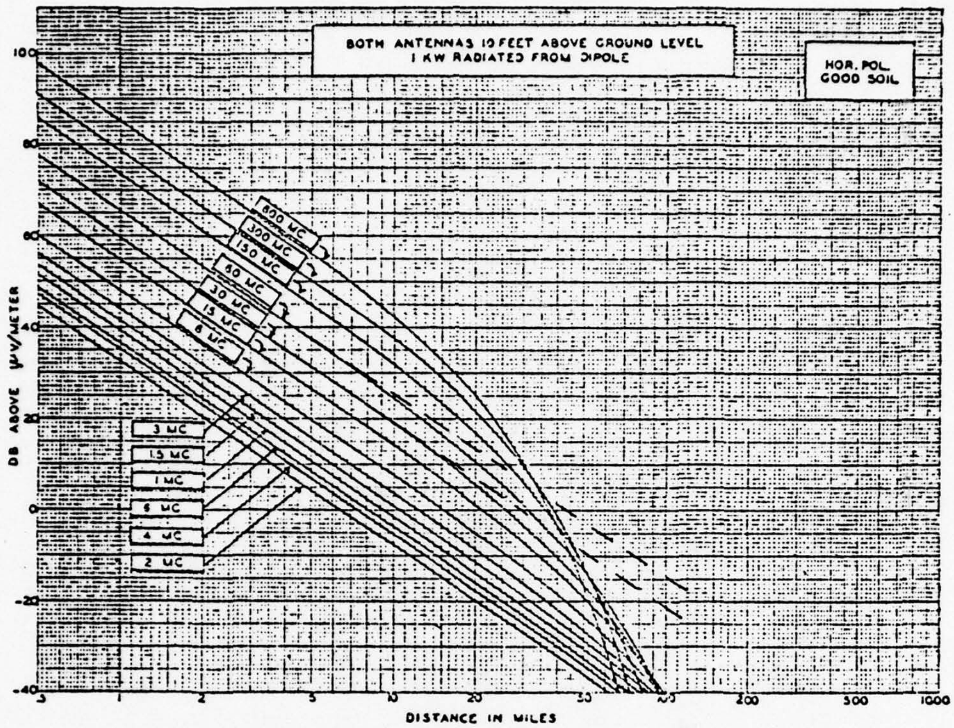
(n)


ONE ANTENNA 10 FEET ABOVE GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
HOR. POL.
POOR SOIL
30 MC
40,000 FT.
20,000 FT.
10,000 FT.
5000 FT.
1000 FT.
100 FT.
10 FT.
FREE SPACE FIELD
DB ABOVE 1 μV/METER
DISTANCE IN MILES

(o)

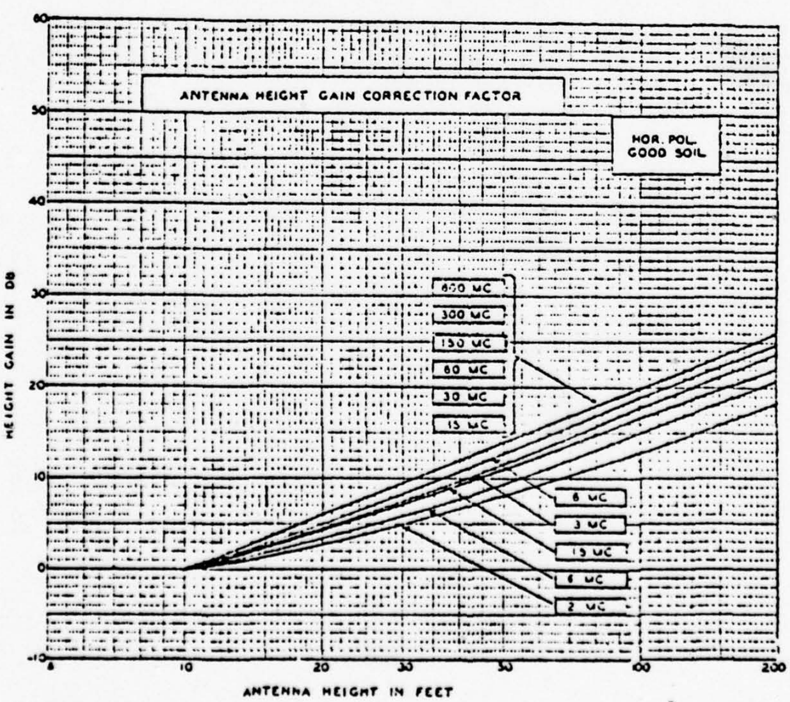

ONE ANTENNA 10 FEET ABOVE GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
HOR. POL.
POOR SOIL
60 MC
FREE SPACE FIELD
40,000 FT.
20,000 FT.
10,000 FT.
5000 FT.
1000 FT.
100 FT.
10 FT.
DB ABOVE 1 μV/METER
DISTANCE IN MILES

(p)



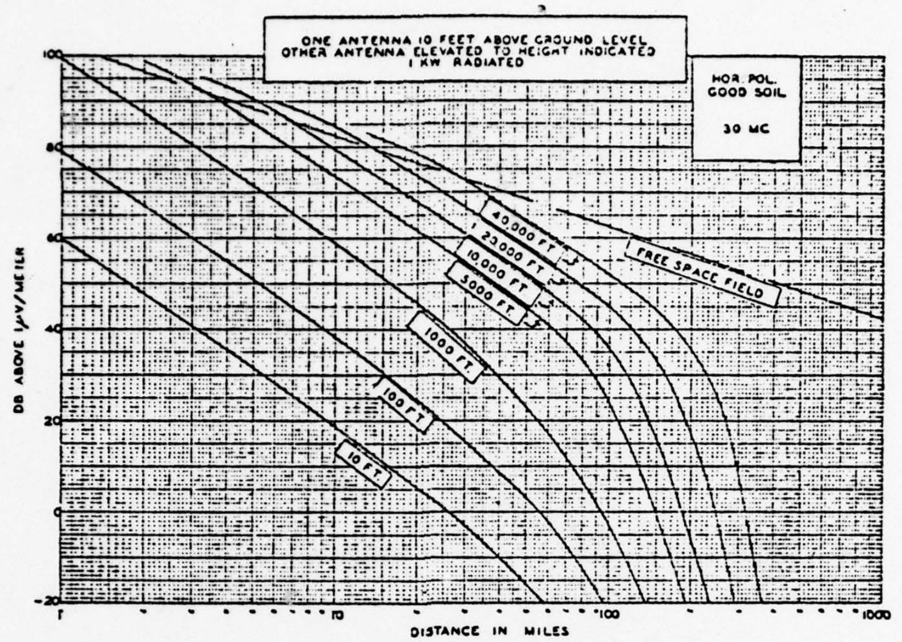
BOTH ANTENNAS 10 FEET ABOVE GROUND LEVEL
1 KW RADIATED FROM DIPOLE
HOR. POL.
GOOD SOIL
600 MC
300 MC
150 MC
60 MC
30 MC
15 MC
6 MC
3 MC
1.5 MC
1 MC
6 MC
4 MC
2 MC
DB ABOVE µV/METER
DISTANCE IN MILES

(q)

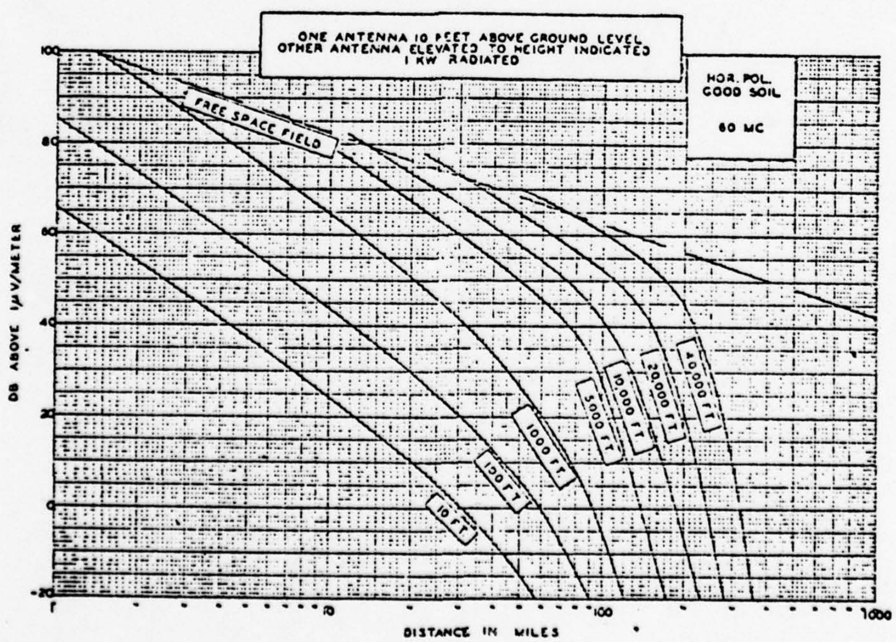


ANTENNA HEIGHT GAIN CORRECTION FACTOR
HOR. POL.
GOOD SOIL
600 MC
300 MC
150 MC
60 MC
30 MC
15 MC
6 MC
3 MC
1.5 MC
1 MC
2 MC
HEIGHT GAIN IN DB
ANTENNA HEIGHT IN FEET

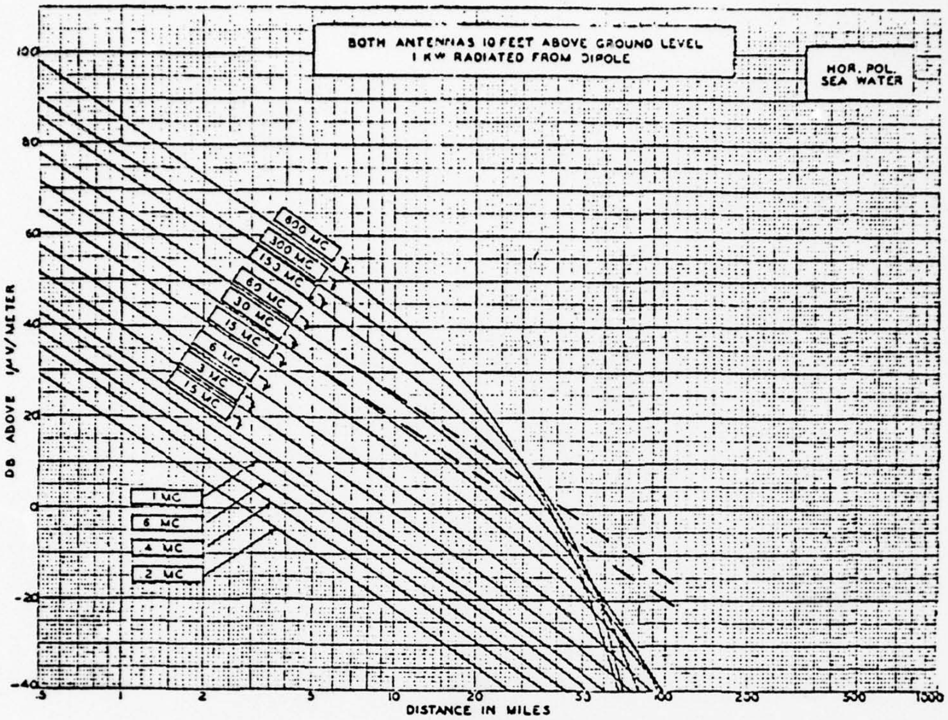
(r)


ONE ANTENNA 10 FEET ABOVE GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
HOR. POL.
GOOD SOIL
30 MC
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
10 FT
FREE SPACE FIELD
DB ABOVE 1 μV/METER
DISTANCE IN MILES
100
80
60
40
20
0
-20
1
10
100
1000

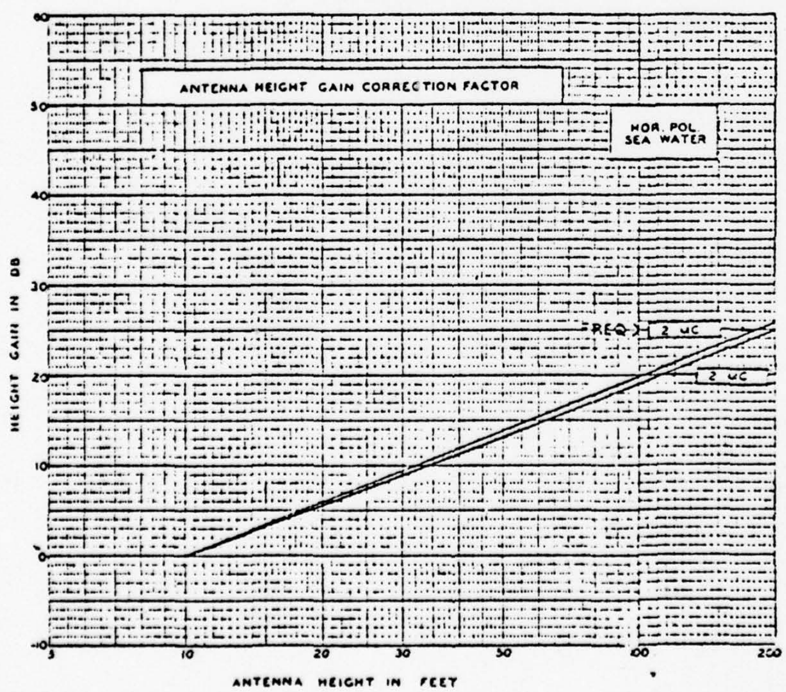
(s)


ONE ANTENNA 10 FEET ABOVE GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
HOR. POL.
GOOD SOIL
60 MC
FREE SPACE FIELD
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
10 FT
DB ABOVE 1 μV/METER
DISTANCE IN MILES
100
80
60
40
20
0
-20
1
10
100
1000

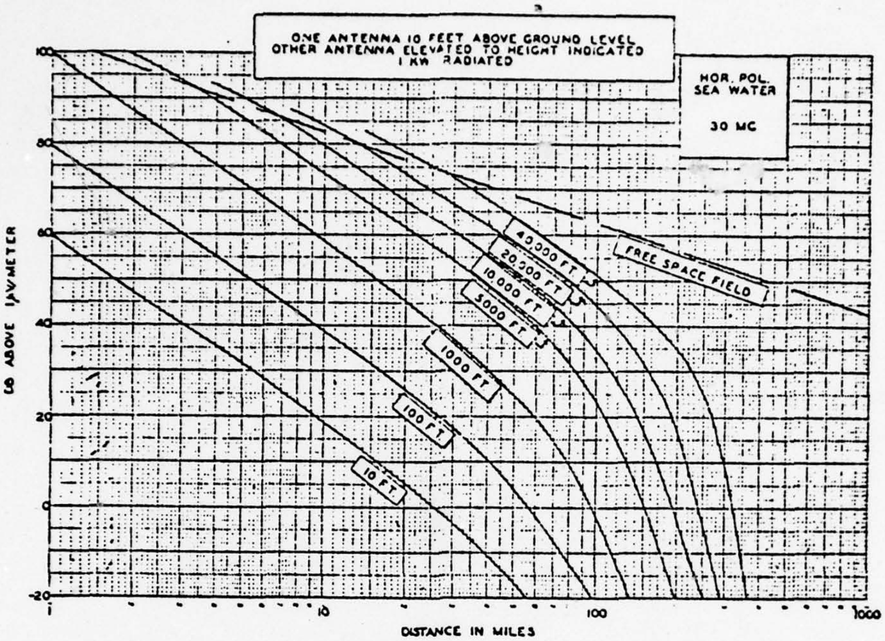
(t)


BOTH ANTENNAS 10 FEET ABOVE GROUND LEVEL
1 KW RADIATED FROM DIPOLE
HOR. POL.
SEA WATER
600 MC
300 MC
150 MC
60 MC
30 MC
15 MC
6 MC
3 MC
1.5 MC
1 MC
6 MC
4 MC
2 MC
DB ABOVE 1 µV/METER
DISTANCE IN MILES

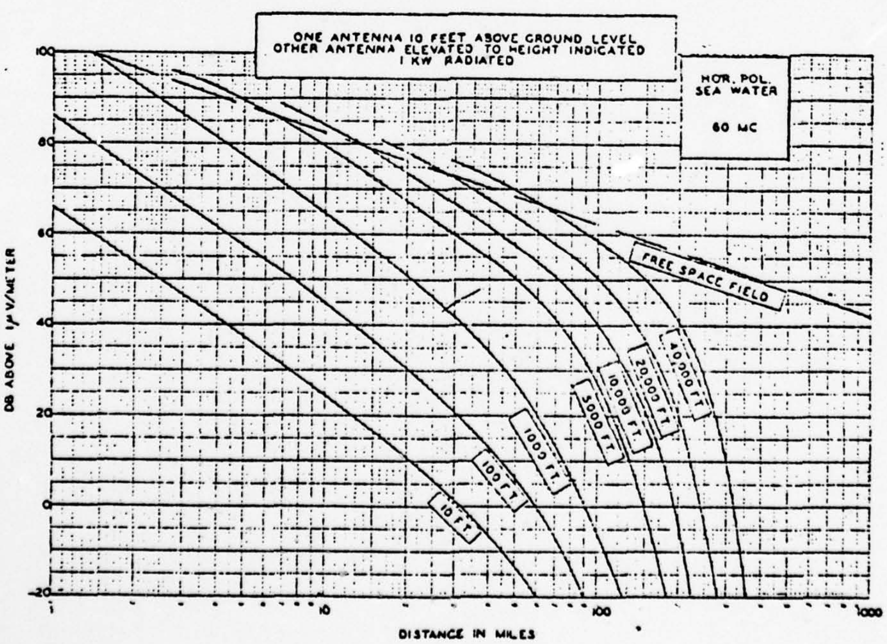
(u)


ANTENNA HEIGHT GAIN CORRECTION FACTOR
HOR. POL.
SEA WATER
FREQ
2 MC
2 MC
HEIGHT GAIN IN DB
ANTENNA HEIGHT IN FEET

(v)


ONE ANTENNA 10 FEET ABOVE GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
HOR. POL.
SEA WATER
30 MC
FREE SPACE FIELD
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
10 FT
DB ABOVE 1 µV/METER
DISTANCE IN MILES

(W)


ONE ANTENNA 10 FEET ABOVE GROUND LEVEL
OTHER ANTENNA ELEVATED TO HEIGHT INDICATED
1 KW RADIATED
HOR. POL.
SEA WATER
60 MC
FREE SPACE FIELD
40,000 FT
20,000 FT
10,000 FT
5000 FT
1000 FT
100 FT
10 FT
DB ABOVE 1 µV/METER
DISTANCE IN MILES

(x)

APPENDIX L

BASIC ANTENNA ANALYSIS

1. GENERAL

This appendix provides the basic mathematical equations, terms, and definitions for the analysis and design of the whip (end-fed monopole or center-fed sleeve) antenna, elevated ground plane antenna, the discone and biconical antennas, the log-periodic array, and long-wire antennas used in military tactical radio communications. This information was extracted from the technical literature (primarily References 1, 15, 16, 37, 38, 43, 50, and 51) and provides the means for a basic understanding of the performance characteristics of the above antennas.

The problem of antenna analysis is determining the radiation characteristics of the antenna. Different types of antennas have different current and charge distributions and different geometries. These differences result in different approaches to analyzing each antenna type. Usually, the physical picture is the same, but it is convenient to use different mathematical techniques for the analysis of different antennas. Therefore in this appendix we are concerned primarily with the mathematical techniques which are appropriate for analyzing antenna performance.

The performance of communications systems antennas can be understood from the one-way propagation equation. If a transmitter radiates an amount of power W_T equally in all directions, the power density at a distance R from the transmitter is

$$P = \frac{W_T}{4\pi R^2} . \tag{1}$$

A receiving antenna with an effective area A_R receives an amount of power given by

$$W_R = PA_R = \frac{W_T A_R}{4\pi R^2} \tag{2}$$

if there is no loss between the transmitter and the receiver. The loss between the transmitter and the receiver due to the intervening medium and any difference in the polarization of the two antennas is denoted by the constants C_m and C_p. These constants are unity if there is no loss. Taking these losses into consideration, Eq. (2) becomes

$$W_R = \frac{W_T A_R C_m C_p}{4\pi R^2} . \tag{3}$$

Antennas do not radiate their power equally in all directions. The ratio of the power per unit area radiated to a fixed distance in a given direction, to the power per unit area which would have been radiated if the transmitter radiated equally in all directions, is called the gain of the antenna. If the transmitter gain in the direction of the receiver is denoted by G_T, the received power is

$$W_R = \frac{W_T G_T A_R C_m C_p}{4\pi R^2} . \tag{4}$$

Antenna gain and effective area are related by

$$A_e = \frac{\lambda^2 G}{4\pi} , \tag{5}$$

where λ is the operating wavelength. Combining Eqs. (4) and (5) gives

$$W_R = \frac{W_T G_T G_R \lambda^2 C_m C_p}{(4\pi R)^2} , \tag{6}$$

where the wavelength and the range must be expressed in the same units. This is the basic one-way radio transmission formula. The above received power is usually referenced to 1 microwatt per square meter, and in communications systems engineering, the decibel is most frequently used to express the ratio of the received power to the reference of 1 $\mu w/m^2$, where the decibel is defined as

$$\begin{aligned} N_{dB} &= 10 \log(P_2/P_1) \qquad (7) \\ &= 10 \log \frac{\text{received power}}{\text{power reference}} \\ &= 10 \log (\text{received power}/1\ \mu wm^{-2}) . \end{aligned}$$

Power (W or P) may also be expressed as $P = I^2R$ or $P = E^2/R$, therefore the change in power level, in terms of changes in current and voltage, is

$$N_{dB} = 10 \log \frac{P_2}{P_1} = 10 \log (\frac{I_2}{I_1})^2 \frac{R_2}{R_1} \tag{8}$$

$$= 20 \log \frac{I_2}{I_1} + 10 \log \frac{R_2}{R_1}$$

$$= 20 \log \frac{E_2}{E_1} + 10 \log \frac{R_1}{R_2} .$$

The power level change, expressed in decibels, is correctly given in terms of voltage and current ratios only for the special case for which $R_1 = R_2$.

The radiation from an antenna or the intensity of an electromagnetic field is usually obtained by measuring the electric field intensity in microvolts per meter. The electric and magnetic field intensities of a plane wave in free space are related by the intrinsic impedance, η_o, of free space

$$\frac{\vec{E}}{\vec{H}} = \eta_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} \tag{9}$$

where

μ_o = permeability of free space

$= 4\pi 10^{-7}$ (kg·m/A·S^2, or Henry/meter)

ε_o = permittivity of free space

$$= \frac{1}{4\pi 10^{-7} c^2} \text{ (Farad/meter)}.$$

Therefore

$$\eta_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 120\pi\Omega \approx 377\Omega \tag{10}$$

where Ω = ohms.

If the received power ratio (expressed in decibels (Eq. 7) above 1 $\mu w/m^2$ is known, one can convert to electric field intensity, E, in decibels above 1 $\mu v/m$, by

$$E_{dB} = P_{dB} + 85.77 \ . \tag{11}$$

The gain of an antenna is often referenced to an electric field intensity value of 186.3 millivolts per meter, which is the value that a short, lossless, vertical antenna erected over perfectly conducting earth (an infinite, perfect ground plane) will produce at 1 mile with 1 kilowatt of input power when the measurements are made in the ground plane. (The electric field intensity at 1 kilometer for the same conditions is 300 millivolts per meter.) Therefore, antenna gain under actual operating conditions can be expressed with respect to the short theoretical antenna as

$$\text{Gain} = \left[\frac{\begin{array}{l}\text{field intensity (mv/meter) at}\\ \text{1 mile produced in required}\\ \text{direction by actual antenna}\\ \text{with 1 kw of input power}\end{array}}{\text{186.3 mv/meter}}\right]^2 . \tag{12}$$

The sensitivity of the communications system is limited by the presence of noise. The receiver available noise power is given by

$$W_n = KTB , \tag{13}$$

where K, Boltzmann's constant, is 1.38×10^{-23} joule per degree Kelvin, T is the effective noise temperature in degrees Kelvin, and B is the receiver bandwidth in cycles per second (Hertz). The effective noise temperature includes noise originating in the receiver and all natural and man-made interference signals. Since man-made interference can usually be brought under control, the limitations in a communications system are usually the thermally generated noise in the receiver and sensor, the antenna temperature, and galactic noise arriving from space.

The signal-to-noise ratio S_N at the receiver output can be found by combining Eqs. (6) and (13) to give

$$\frac{S}{N} = S_N = \frac{W_T G_T G_R \lambda^2 C_m C_p}{(4\pi R)^2 KTB} , \tag{14}$$

and

$$R = \left(\frac{W_T G_T G_R \lambda^2 C_m C_p}{(4\pi)^2 KTBS_N}\right)^{1/2} . \tag{15}$$

Equation (14) shows that several antenna parameters affect the communications system performance and some system parameters must be considered in the antenna design. It is thus necessary to consider the gain and polarization of the transmitting and receiving antennas, the bandwidth over which the antennas must operate, and the antenna temperature. Also to be considered is the impedance characteristic of the antenna which determines the loss due to reflections between the antenna and its connecting transmission line, since Eq. (14) does not include terms to account for this loss. In addition, the antenna temperature to be discussed later depends on the antenna patterns. Antenna design must take account of the transmitter power and the operating frequencies as well as those considerations included in the term accounting for the propagation medium, C_m. Propagation loss depends on such factors as the location of the antenna with respect to the ground, the properties of the ground, and the operating frequency. Additional factors must also be considered for situations in which propagation occurs beyond the line of sight between the transmitter and receiver.

In the case of frequency, phase, or pulse modulation, the radio receivers themselves produce quieting effects on noise.

The received signal strength must be above a threshold value if the receiver is to produce this quieting effect. When the noise exceeds the signal, the noise is the controlling factor in the output—and if it increases greatly, it usually blankets out the desired signal. Thus, in all systems of modulation, the signal-to-noise ratio must exceed an improvement threshold value so that the detector can make use of the signal carrier and its sidebands to improve the signal-to-noise ratio. In frequency and phase modulation, the signal pulses must be at least twice as high as the peak noise fluctuation. For signals greater than the noise threshold, the amount of noise reduction depends upon the type of modulation. The satisfactory carrier-to-noise ratio at the detector input has been determined to be about 12 decibels (dB) for frequency modulation.

Many communication systems have other unusual requirements. For instance, for systems designed to communicate with spacecraft at long distances, it is desirable to have a large antenna gain which requires a narrow beamwidth. This means, however, that the antenna beam must be accurately steered to follow the spacecraft. The resulting system requirements often put a greater burden on the mechanical design of the antenna than on the radio frequency design.

For the man-pack portable and vehicular antenna systems analyzed in this thesis, we shall see that the mechanical restrictions requiring electrically short antennas erected over small, imperfect ground planes severely restrict the transmission range (radiated electric field intensity) of the radio communication systems.

2. ANTENNA PARAMETERS

Several antenna parameters can be used to describe the characteristics and performance of antennas. These parameters can be arranged in several groups: antenna patterns, gain, impedance, miscellaneous electrical parameters, and mechanical parameters. Antenna performance also depends on the manner in which these parameters are affected by the environment at the antenna.

a. Antenna Patterns

The antenna pattern is a graphical representation in three dimensions of the radiation of the antenna as a function of direction. In practice, the three-dimensional pattern is measured and recorded in a series of two-dimensional patterns. Antenna performance is often described in terms of principal plane patterns. The E-plane pattern measures radiation as a function of direction in a plane containing a radius vector from the center of the antenna to the point of maximum radiation and the electric field intensity vector. The H-plane pattern is a graphical representation of the radiation of the antenna as a function of direction in a plane containing the radius vector in the direction of maximum radiation and the magnetic field intensity vector. The radiation pattern may be specified in terms of voltage or power. The radiation pattern provides information on the antenna beamwidth, antenna sidelobes, and antenna resolution and, to a large extent, it also determines the antenna noise temperature.

The antenna power pattern is a measure of the density of the power flowing through a sphere of large radius. This power density can be defined as the average Poynting vector:

$$\vec{P} = \vec{E} \times \vec{H} \ .$$

For the steady-state time periodic case, the average Poynting vector is given by

$$\vec{P}_{av} = \frac{1}{2} \operatorname{Re}(\vec{E} \times \vec{H}^*) \ ,$$

where the asterisk represents the complex conjugate.

An absolute power pattern is one in which the power density at a given distance from the antenna is expressed explicitly in watts per square meter. In practice, power patterns are often expressed in relative power with respect to the maximum value occurring at the peak of the main beam. This relative power pattern is termed the normalized power pattern. In normal practice, a measured power pattern is obtained by operating an antenna in conjunction with another antenna in a one-way communication system. For this case the power pattern depends on the polarization of the second antenna.

The antenna beamwidth is the angular width of the antenna radiation pattern between points where the power level has decreased to one-half of the maximum value. This beamwidth is also called the half-power beamwidth. Other widths of frequent interest are the -10 dB width and the -20 dB width, representing the angular widths between the points where the power has decreased to one-tenth and one-hundredth of its maximum value.

Antenna patterns are often classified according to their shape. Some common shapes are shown in Figure L-1. An isotropic pattern is one in which the power per unit solid angle, the radiation intensity, is equal in all directions. This pattern is often taken as a reference, although it is not realizable in practice. An omnidirectional pattern is one which has equal amplitudes in each direction in a plane passing through the antenna. This omnidirectional plane is usually horizontal for communication systems. A pencil beam pattern is one with a relatively narrow main lobe having a circular cross section. A fan beam pattern is one with a highly elliptical cross section, producing a beam which is narrow in one direction and broad at right angles.

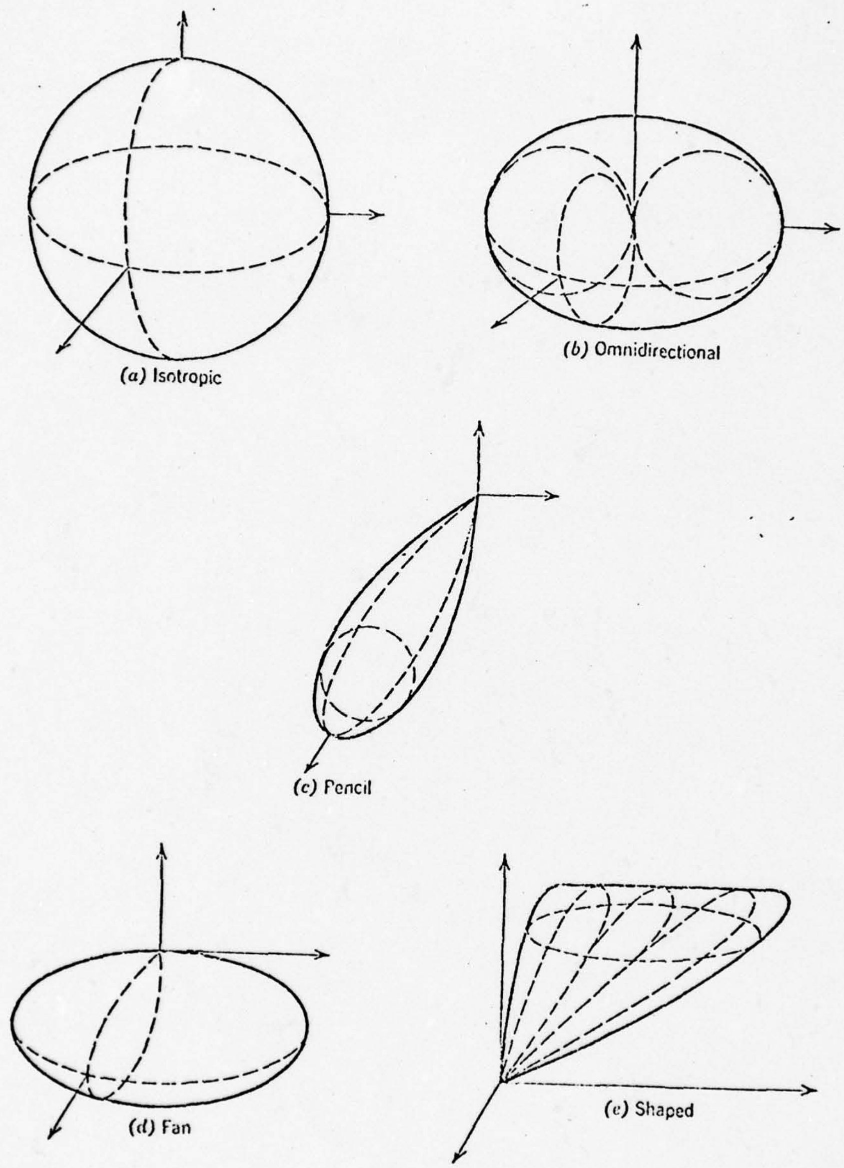


Figure L-1. Common antenna patterns.

A special class of fan beams is the shaped beam pattern. In this pattern the variation in radiated field with angle in a plane through the broad part of the beam is made to vary according to a prescribed function. A common pattern is a cosecant-squared shape which provides an equal received signal, as a function of angle, for a radar system.

The antenna beamwidth determines the resolution of the antenna or the minimum angular separation between two sources which can be distinguished by a receiving antenna.

The radiation patterns of most practical antennas contain a main lobe and several auxiliary lobes, termed side-lobes. A sidelobe occurring in space in the direction opposite to the main lobe is called the backlobe.

The sidelobe level of an antenna pattern is defined as the ratio in decibels of the amplitude at the peak of the main beam to the amplitude at the peak of the sidelobe in question. The sidelobes are generally counted from the main beam, with the first sidelobes being adjacent to the main beam and arranged on either side.

b. Impedance

The impedance of an antenna determines the efficiency with which it acts as a transducer between the propagation medium and the transmission line connecting it to the system with which it operates. In practice it is necessary to consider not only the self-impedance of the antenna but the mututal impedance between the antenna and other elements. One must also consider the effect of the ground and the nearby objects on the antenna impedance. If the antenna impedance does not match the transmission line, it may be necessary to insert a matching device. This also affects the efficiency.

The antenna is a two-terminal network, as illustrated in Figure L-2 which is usually connected to the remainder of the system by a transmission line. The simple equivalent circuit for an antenna is shown in Figure L-2. The two-terminal antenna impedance is denoted by Z_A and the system impedance terminating the transmission line by Z_T. The voltage induced in the receiving antenna by the incoming electromagnetic wave can be represented by the voltage generator V_R. The transmitter signal (if any) from the system can be represented by the signal generator V_T. In general, the antenna and terminating impedances will be complex as illustrated in Figure L-2(c). Antenna impedance consists of a radiation resistance R_r, a loss resistance R_L, and a reactance X_A. Terminating impedance may have both a resistive component R_T and a reactive component X_T.

The antenna current is given by

$$I = \frac{V_R - V_T}{Z_T} , \tag{16}$$

where

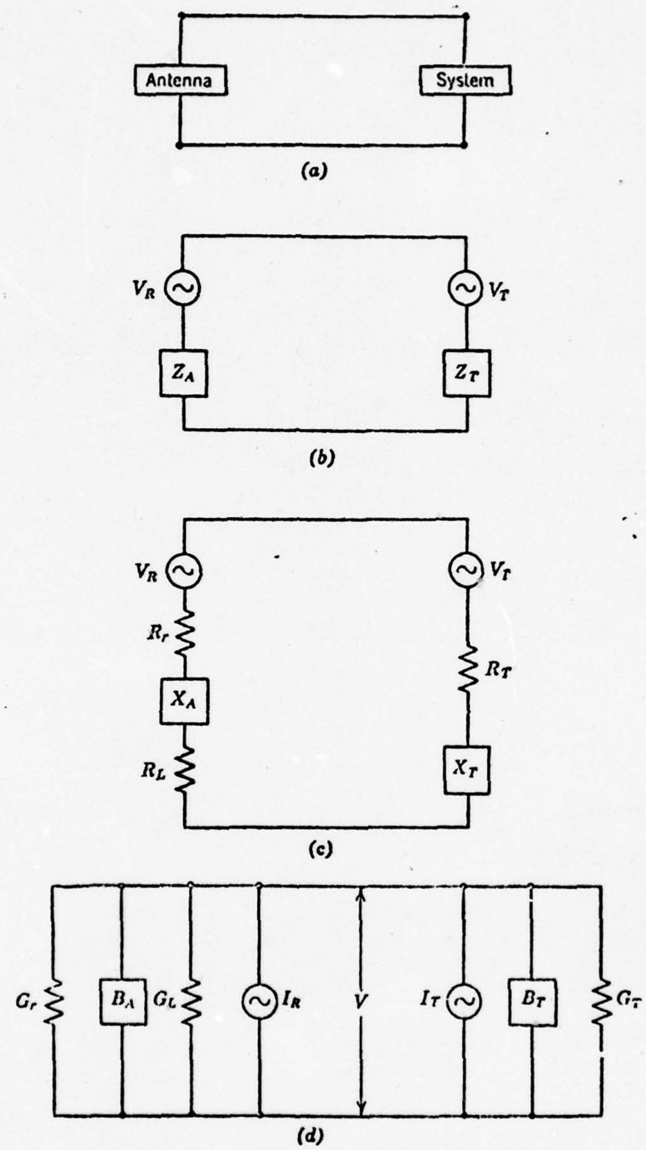


Figure L-2. Antenna impedance. (a) Antenna schematic. (b) Simple equivalent circuit. (c) Equivalent circuit showing impedance components. (d) Equivalent circuit showing admittance components.

$$Z_t = Z_A + Z_T \, . \tag{17}$$

The condition for maximum power transfer is

$$R_r + R_L + jX_A = R_T - jX_T \, . \tag{18}$$

The power delivered by the antenna to a receiver is

$$W_R = I^2 R_T = \frac{V_R{}^2 R_T}{|Z_t|^2} \, . \tag{19}$$

The power reradiated or scattered by the receiving antenna is

$$W_s = I^2 R_r = \frac{V_R{}^2 R_r}{|Z_t|^2} \, . \tag{20}$$

The power dissipated in the ohmic losses in the antenna is

$$W_L = I^2 R_L = \frac{V_R{}^2 R_L}{|Z_t|^2} \, . \tag{21}$$

For the transmitting case the power radiated by the antenna is

$$W_T = I^2 R_r = \frac{V_T{}^2 R_r}{|Z_t|^2} \, , \tag{22}$$

and the power dissipated in ohmic losses is

$$W_L = I^2 R_L = \frac{V_T{}^2 R_L}{|Z_t|^2} \, . \tag{23}$$

The antenna can also be represented in terms of admittance as shown in Figure L-2(d). For this case the voltage across the antenna is given by

$$V = \frac{I_R + I_T}{Y_t} , \tag{24}$$

where

$$Y_t = Y_A + Y_T , \tag{25}$$

and Y_A and Y_T are the antenna and terminating admittance. The condition for maximum power transfer is

$$G_r + G_L + jB_A = G_T - jB_T , \tag{26}$$

where G_r and G_L are the radiation and loss conductance and B_A is the antenna susceptance. The power delivered by the antenna to the receiver is

$$W_R = V^2 G_T = \frac{I_R^{\,2} G_T}{|Y_t^{\,2}|} . \tag{27}$$

The power reradiated as scattered power by the receiving antenna is

$$W_s = V^2 G_r = \frac{I_R^{\,2} G_r}{|Y_t|^2} . \tag{28}$$

The power dissipated in ohmic losses is

$$W_L = V^2 G_L = \frac{I_R^{\,2} G_L}{|Y_t|^2} . \tag{29}$$

For the transmitting case, the power radiated by the antenna is

$$W_T = V^2 G_r = \frac{I_T^{\,2} G_r}{|Y_t|^2} , \tag{30}$$

and the power dissipated in ohmic losses is

$$W_L = V^2 G_L = \frac{I_T^{\,2} G_L}{|Y_t|^2} . \tag{31}$$

Both the resistive and reactive components of antenna impedance are functions of frequency. Usually, the impedance of the system with which the antenna operates and the interconnecting transmission lines have much smaller variations with frequency than the antenna. There will therefore be a restricted frequency band within which the antenna is well matched to the transmission line. In practice, the antenna bandwidth is usually defined as a frequency band in which the ratio of the antenna impedance to the transmission line impedance (or vice versa) is less than 2 to 1. In other words, the voltage standing wave ratio (VSWR) at the input to the transmission line and terminated by the antenna will be less than two to one. There is, however, no accepted definition of antenna bandwidth, so it is desirable to state the defining VSWR when stating the bandwidth. (VSWR may be measured on tactical antenna systems using Test Set, RF Power TS-2609/u (Figure L-3), which is a through-line directional wattmeter which measures transmitted RF power (forward power) and load match (reflected power) in 50 ohm coaxial systems. It provides no loss to transmitted or received RF signals between 30 and 76 MHz. To obtain VSWR using this wattmeter, use the equation

$$\mathrm{VSWR} = \frac{1 + \sqrt{k}}{1 - \sqrt{k}} \quad \text{where } k = \frac{\text{reflected power}}{\text{forward power}} \text{ .)} \tag{32}$$

The impedance of an antenna depends on many factors including its geometry, its method of manufacture, and its proximity to surrounding objects. Consequently, only a small fraction of the antennas which have been invented have been analyzed thoroughly enough to have obtained theoretical expressions for antenna impedance. Even for those simple antennas for which theoretical expressions do exist, external influences generally make it desirable to verify the predicted impedance experimentally.

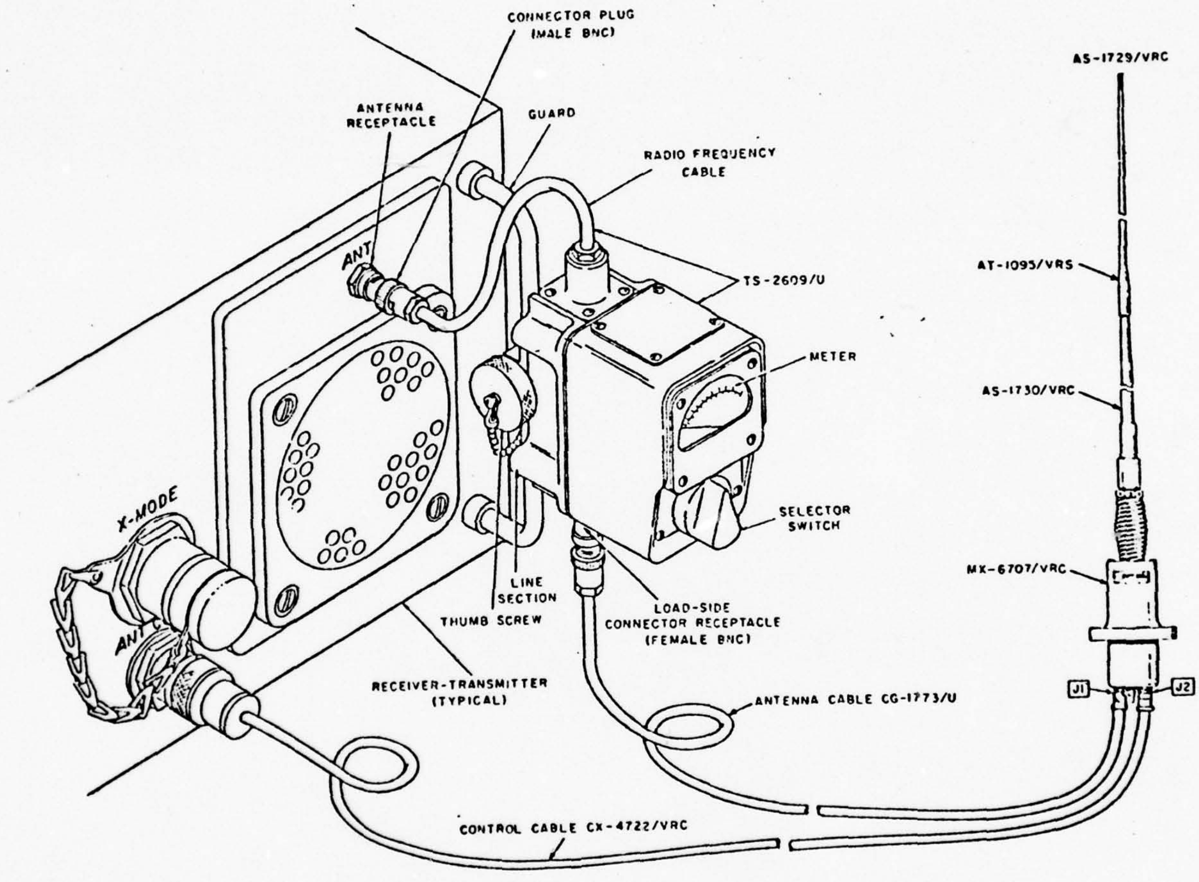


Figure L-3. Test Set, RF Power TS-2609/U connected between AS-1729/VRC and a typical receiver-transmitter.

c. Gain

The gain of an antenna is an important measure of its performance in a system. Antenna gain is the ratio of the maximum radiation intensity at the peak of the main beam to the radiation intensity in the same direction which would be produced by an isotropic radiator having the same input power.

The gain function describes the variation in radiated power with angle, and is defined by

$$G(\theta,\phi) = \frac{P(\theta,\phi)}{\frac{W_T}{4\pi}} \tag{33}$$

where $P(\theta,\phi)$ is the power radiated per unit solid angle in the direction θ, ϕ, and W_T is the total radiated power.

From this definition of gain it can be seen that a high-gain antenna has a main beam with a large amplitude and narrow beamwidth and sidelobes of relatively small amplitude.

If a three-dimensional antenna pattern is measured, and the pattern is integrated to give the ratio of the normalized power density at the peak of the main beam to the average power density, the resulting ratio is the antenna directivity, defined by

$$D = \frac{P_{max}}{P_{av}} . \tag{34}$$

For a perfectly efficient antenna, the directivity is equivalent to the gain. The relationship between the two is

$$G = \eta D \ , \tag{35}$$

where η is the antenna efficiency. Efficiencies of 50 to 75 percent are normally realized in practice.

It is often possible to make a rough approximation of the antenna gain from the antenna bandwidth. If it can be assumed that the total antenna power pattern can be approximated by an antenna beam of unit amplitude, and located entirely within a solid angle equal to the product of the half-power beamwidths in the θ and ϕ directions, the power density in the beam is

$$P_{max} \approx \frac{1}{\Theta_r \Phi_r} \ , \tag{36}$$

where Θ_r and Φ_r are the half-power beamwidths in radians in the θ and ϕ directions. For this case the average power density is

$$P_{av} = \frac{1}{4\pi} \ , \tag{37}$$

so that the directivity of Eq. (34) is

$$D \approx \frac{4\pi}{\Theta_r \Phi_r} \ . \tag{38}$$

If the half-power beamwidths are expressed in degrees and denoted by Θ_d and Φ_d, the directivity is approximately

$$D \approx \frac{41{,}253}{\Theta_d \Phi_d} . \tag{39}$$

Then, if the antenna has an efficiency of 70 percent, the gain is approximately

$$G \approx \frac{29{,}000}{\Theta_d \Phi_d} . \tag{40}$$

There is a constant relationship between the gain and effective area of an antenna. This can be demonstrated by considering a communications system with the transmitter at terminal 1 and the receiver at terminal 2. For this situation Eq. (4) can be rewritten as

$$G_1 A_2 = \frac{W_R (4\pi R)^2}{W_T C_m C_p} . \tag{41}$$

Now, if the transmitter and receiver are interchanged so that the transmitter is moved to terminal 2 and the receiver to terminal 1, Eq. (4) becomes

$$G_2 A_1 = \frac{W_R (4\pi R)^2}{W_T C_m C_p} \tag{42}$$

if the antenna components and the intervening propagating medium are reciprocal. Combining Eqs. (41) and (42) gives

$$G_1 A_2 = G_2 A_1 , \tag{43}$$

or

$$\frac{G_1}{A_1} = \frac{G_2}{A_2} . \tag{44}$$

Equation (44) shows that the ratio between the gain and the effective area of an antenna is a constant. Since the type of antenna used was not specified, this constant must be identical for all antennas. The value of the constant given in Eq. (5) is derived rigorously later from the theory of the short wire antenna.

In Eq. (2), the effective area is defined as the ratio of the received power to the power density of the incident wave. This area is a maximum when the received power is a maximum or when the impedances are matched in accordance with Eq. (18). The maximum effective area of a lossless antenna is therefore

$$A_e = \frac{W_{R_{max}}}{P} = \frac{V_R^{\,2}}{4R_r P} . \tag{45}$$

The effective area is actually the ratio of the power dissipated in a matched terminating impedance of a receiving antenna to the power density of the incident electromagnetic wave.

It is sometimes convenient to use the concept of effective height. If an antenna has an effective height h, the induced voltage V_R due to an incident field intensity E is

$$V_R = Eh \ . \tag{46}$$

If the propagating medium has a real intrinsic impedance Z_0, the incident power density is

$$P = \frac{E^2}{Z_0} \ . \tag{47}$$

Equations (45), (46), and (47) can be combined to show that the relationship between the effective area and the effective height is given by

$$A_e = \frac{h^2 Z_0}{4R_r} \ . \tag{48}$$

An antenna scattering area can be defined as the ratio of the power scattered by the antenna to the power density of the incident wave. For a matched lossless receiving antenna, this is

$$A_s = \frac{W_s}{P} = \frac{V_R^2}{4R_r P} \ , \tag{49}$$

which is equal to the maximum effective area. The scattering ratio β is the ratio of the scattering area to the effective area. This is given by

$$\beta = \frac{A_s}{A_e} = \frac{W_s/P}{W_R/P} = \frac{R_r}{R_T} . \quad (50)$$

The antenna efficiency is defined in Eq. (35) as the ratio of the gain to the maximum gain (directivity). From Eq. (44) it can be seen that a similar definition can be made in terms of antenna area. This can be written as

$$\eta = \frac{W_R/P}{W_{R_{max}}/P} = \left[\frac{V_R{}^2 R_T}{(R_r + R_L + R_T)^2}\right] \frac{4R_r}{V_R{}^2} , \quad (51)$$

or

$$\eta = \frac{4R_r R_T}{(R_r + R_L + R_T)^2} . \quad (52)$$

For a matched antenna, this becomes

$$\eta = \frac{R_r}{R_r + R_L} . \quad (53)$$

If the antenna is considered in terms of admittance, the effective area of Eq. (45) becomes

$$A_e = \frac{W_{R_{max}}}{P} = \frac{I_R{}^2}{4G_r P} . \quad (54)$$

For this case, if the antenna has an effective height h, the induced current I_R due to the incident magnetic field intensity amplitude H is

$$I_R = Hh \; . \tag{55}$$

If the propagating medium has the intrinsic impedance Z_0, the incident power density is

$$P = H^2 Z_0 \; , \tag{56}$$

so that Eq. (54) becomes

$$A_e = \frac{h^2}{4G_r Z_0} \; , \tag{57}$$

the effective height is

$$h = (4A_e G_r Z_0)^{1/2} \; , \tag{58}$$

and the efficiency of Eq. (52) becomes

$$\eta = \frac{4G_r G_T}{(G_r + G_L + G_T)^2} \; . \tag{59}$$

Most antennas are constructed of transmission lines and other elements that are reciprocal. These antennas obey the reciprocity theorem, which states that the transmitting and receiving patterns of an antenna are identical. A schematic diagram of a transmitting antenna and a receiving antenna connected to a four-terminal network representing the propagation medium is shown in Figure L-4. If antenna No. 1 on

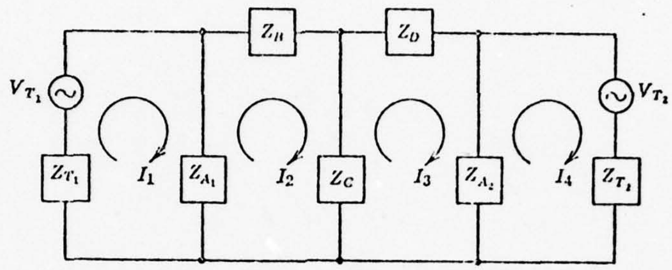


Figure L-4. Schematic of communication antenna arrangement.

the left side of the figure (with characteristic impedance Z_{A_1}) transmits, and the antenna on the right with impedance Z_{A_2} receives, then the transmitted voltage is V_{T_1}, and V_{T_2} is zero. For this situation the system impedance determinant is

$$|Z| = \begin{vmatrix} -Z_{11} & -Z_{A_1} & 0 & 0 \\ -Z_{A_1} & Z_{22} & -Z_C & 0 \\ 0 & -Z_C & Z_{33} & -Z_{A_2} \\ 0 & 0 & -Z_{A_2} & Z_{44} \end{vmatrix}, \qquad (60)$$

using the currents shown in the figure.

The ratio of the current in the receiver I_4 to the transmitter voltage V_{T_1} is

$$\frac{I_4}{V_{T_1}} = \frac{-\begin{vmatrix} -Z_{A_1} & Z_{22} & -Z_C \\ 0 & -Z_C & Z_{33} \\ 0 & 0 & -Z_{A_2} \end{vmatrix}}{|Z|} = \frac{Z_{A_1} Z_{A_2} Z_C}{|Z|} . \qquad (61)$$

Then, if the transmitter and the receiver are interchanged, so that V_{T_1} is zero and the transmitted signal is V_{T_2}, the ratio of the current in the receiver to transmitter voltage is

$$\frac{I_1}{V_{T_2}} = \frac{-\begin{vmatrix} -Z_{A_1} & 0 & 0 \\ Z_{22} & -Z_C & 0 \\ -Z_C & Z_{33} & -Z_{A_2} \end{vmatrix}}{|Z|} = \frac{Z_{A_1} Z_{A_2} Z_C}{|Z|} . \qquad (62)$$

From Eqs. (61) and (62) it can be seen that if $V_{T_1} = V_{T_2}$,

$$I_4 = I_1 . \qquad (63)$$

In other words, the received current due to a given transmitter voltage is the same regardless of which antennas are used as the transmitter and receiver antennas, respectively. Since Eq. (63) was obtained without regard to the directions in which the antennas were pointing, the transmitting and receiving antenna patterns are the same.

d. Polarization

The polarization of an antenna is defined as the locus of the tip of the time-varying electric field vector of the radiation from the antenna in the direction of the main beam. In practice, polarization of the radiated energy varies with the direction from the center of the antenna, so that different parts of the pattern and different sidelobes sometimes have different polarizations.

The polarization of a radiated wave can be linear at any angle or elliptical with any ellipticity and in either sense of rotation. The polarization depends on the relative magnitude and phase of the orthogonal components of the electric (E) field. Using the geometry and notation of Figure L-5, the electric field vector is given by

$$\vec{E} = \vec{a}_\theta E_\theta \cos \omega t + \vec{a}_\phi E_\phi \cos(\omega t + \alpha) \ , \tag{64}$$

where E_θ and E_ϕ are the amplitudes of the components in the θ and ϕ directions and α is the phase difference between the two components. This can be rewritten for convenience as

$$\vec{E} = \vec{a}_\theta u + \vec{a}_\phi v \ . \tag{65}$$

with a little manipulation it can be shown that

$$\frac{u^2}{E_\theta{}^2} - \frac{2uv \cos \alpha}{E_\theta E_\phi} + \frac{v^2}{E_\phi{}^2} - \sin^2\alpha = 0 \ . \tag{66}$$

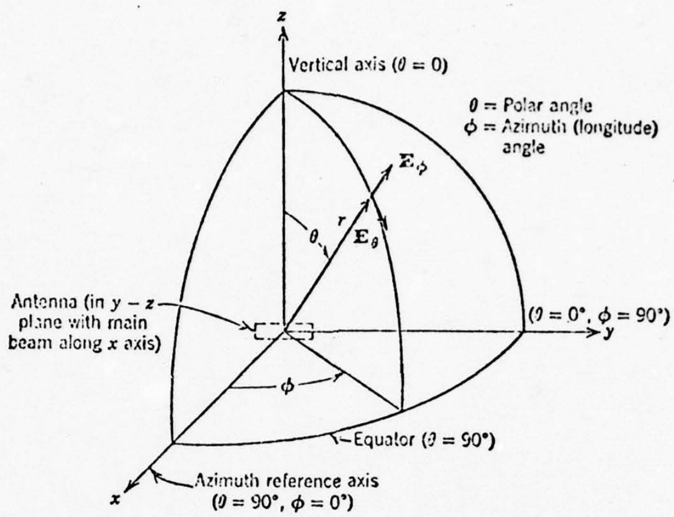


Figure L-5. Antenna coordinates.

The general equation of an ellipse is given by

$$Au^2 + Buv + Cv^2 + Du + Ev + F = 0, \quad B^2 - 4AC < 0 \ , \qquad (67)$$

so that for the polarization ellipse

$$A = \frac{1}{E_\theta^{\ 2}}, \quad B = \frac{-2\cos\alpha}{E_\theta E_\phi}, \quad C = \frac{1}{E_\phi^{\ 2}}, \quad D = E = 0, \quad F = -\sin^2\alpha \ , \qquad (68)$$

and

$$B^2 - 4AC = \frac{4}{E_\theta^{\ 2} E_\phi^{\ 2}}(\cos^2\alpha - 1) < 0, \quad \alpha \neq 0, \pi \ . \qquad (69)$$

Equation (66) therefore represents an ellipse in the θ,ϕ plane, with the center of the ellipse in the center of the plane and the major axis of the ellipse inclined to the θ axis by an angle ψ, which is given by

$$\tan 2\psi = \frac{2E_\theta E_\phi \cos \alpha}{E_\theta^2 - E_\phi^2} . \tag{70}$$

For the two components of the electric field which are exactly in phase or out of phase, Eq. (65) gives

$$\begin{aligned} \frac{u}{E_\theta} - \frac{v}{E_\phi} &= 0, \quad \alpha = 0 , \\ \frac{u}{E_\theta} + \frac{v}{E_\phi} &= 0, \quad \alpha = \pi , \end{aligned} \tag{71}$$

which represents a line through the origin with a slope,

$$\begin{aligned} m &= \frac{E_\phi}{E_\theta}, \quad \alpha = 0 , \\ m &= -\frac{E_\phi}{E_\theta}, \quad \alpha = \pi . \end{aligned} \tag{72}$$

For elliptical polarization the electric field vector rotates at a frequency equal to the frequency of the electromagnetic wave, and the locus of the tip of the electric field vector describes an ellipse. The polarization is defined as being left handed when the direction of the rotation of the electric field vector is counterclockwise when looking toward the departing wave at the transmitter. For this case

$$0 < \alpha < \pi . \tag{73}$$

For right-handed polarization, the field vector rotates clockwise when viewed from the transmitter as a departing wave and

$$\pi < \alpha < 2\pi \ . \tag{74}$$

If the two orthogonal electric field components have equal amplitude and a 90 degree phase shift, circular polarization results. For this case Eq. (66) becomes

$$\frac{u^2}{E_\theta^2} + \frac{v^2}{E_\phi^2} = 1 \ , \tag{75}$$

which is the equation of a circle centered at the origin.

<u>e. Noise Temperature</u>

Antenna noise temperature is a measure of the noise power which a receiving antenna delivers to the receiver at the antenna terminal. Most of this noise power comes from noise sources illuminated by the antenna pattern. This includes galactic noise arising from outer space, noise from celestial bodies within the antenna beam, and noise from ground sources in the antenna beam. Since most of these sources are relatively fixed with respect to earth coordinates at any given time, the antenna noise temperature depends on the positioning of the antenna and the size and location of the antenna sidelobes.

The antenna noise temperature is given by

$$T_a = \frac{P_n}{KB} , \tag{76}$$

where P_n is available noise power delivered to the antenna terminal, K is Boltzmann's constant, and B is the bandwidth. The antenna noise temperature for a given antenna orientation can be calculated by adding the contributions of the individual noise sources. If $T(\theta,\phi)$ is the source noise temperature at the angle θ,ϕ and $G(\theta,\phi)$ is the antenna gain function, then the antenna temperature is

$$T_a = \frac{\int_S T(\theta,\phi)G(\theta,\phi)dA}{\int_S G(\theta,\phi)dA} , \tag{77}$$

where the integration is performed over the surface S with the solid angle

$$dA = \sin\theta \; d\theta \; d\phi \; . \tag{78}$$

From Eq. (33)

$$\int_S G(\theta,\phi)dA = \frac{4\pi}{W_T} \int_S P(\theta,\phi)dA = 4\pi , \tag{79}$$

so that the antenna temperature is

$$T_a = \frac{1}{4} \int_S T(\theta,\phi)G(\theta,\phi)dA \ . \qquad (80)$$

The relationship between the noise temperature and the noise figure is given by

$$F = 1 + \frac{T_a}{T_o} \ , \qquad (81)$$

where F is the noise figure and T_o is the reference temperature of 290° Kelvin.

When low-noise operation is desired, it is necessary to keep the antenna backlobe and sidelobes to a minimum so that very little of the noisy earth will be illuminated when the antenna is pointed skyward. It is also desirable to keep transmission line losses to a minimum since this loss increases the antenna noise temperature.

f. Power Handling

The power-handling characteristics of an antenna must be considered when the antenna is used in conjunction with a high-power transmitter. The power-handling ability of an antenna is generally determined by the geometrical configuration of the various conductors. The spacing of conductors is selected to avoid voltage breakdown at high power. Sharp edges and discontinuities should be avoided. If the antenna operates in a low-pressure environment, it may be desirable to pressurize the critical areas with air or other gases. It is also desirable to avoid impedance mismatches which create standing waves and points of unnecessarily high voltage.

g. Mechanical Characteristics

Electrical antenna design must take cognizance of the required mechanical characteristics. For large, ground-based antennas, adequately positioning the antenna is a pre-determined direction and insuring that the antenna surface deviations are kept within specified limits often prescribe some of the electrical design characteristics. For airborne and spacecraft antennas, mechanical problems of integrating the antenna with the vehicle and designing the antenna to withstand the expected environment also impose limitations on the electrical design. The electrical antenna designer must be aware of the antenna fabrication problems and of the characteristics of the materials and structures available for use in antennas. The designer must also be aware of the size, weight, and tolerance restraints imposed on the antenna.

h. Environmental Effects

The antenna designer must consider carefully the environment in which the antenna is to operate. Antennas within the earth's atmosphere have to accommodate such factors as wind, rain, ice, snow, salt-spray, and the effect of surrounding objects on the antenna pattern and impedance.

Other factors which have to be considered are operating temperature and such mechanical forces as shock and vibration. The use of radomes must be considered for protection against the environment to obtain the proper performance at the least cost.

3. WIRE ANTENNAS

One of the simplest antennas is the one-dimensional wire antenna. Simple wire antennas are well understood both theoretically and experimentally. They include short and long wires, monopoles, dipoles, and loops.

a. The Short Electric Dipole

In the simple short wire antenna shown in Figure L-6, the wire is oriented along the z axis with its center at the center of the coordinate system.

The equations for the electric field can be obtained from the equation of the magnetic field using Maxwell's equations. Close to the antenna the fields are given by

$$\vec{H}_\phi = \frac{I_m L e^{-jkr} \sin\theta}{4\pi r^2}, \qquad (82a)$$

$$\vec{E}_r = \frac{2 I_m L e^{-jkr} \cos\theta}{j\omega\varepsilon 4\pi r^2}, \quad r < \frac{1}{k}, \qquad (82b)$$

$$\vec{E}_\theta = \frac{I_m L e^{-jkr} \sin\theta}{j\omega\varepsilon 4\pi r^3} . \tag{82c}$$

where k = phase constant

$$= \frac{2\pi}{\lambda} = \frac{\omega}{f\lambda} = \frac{\omega}{\nu} .$$

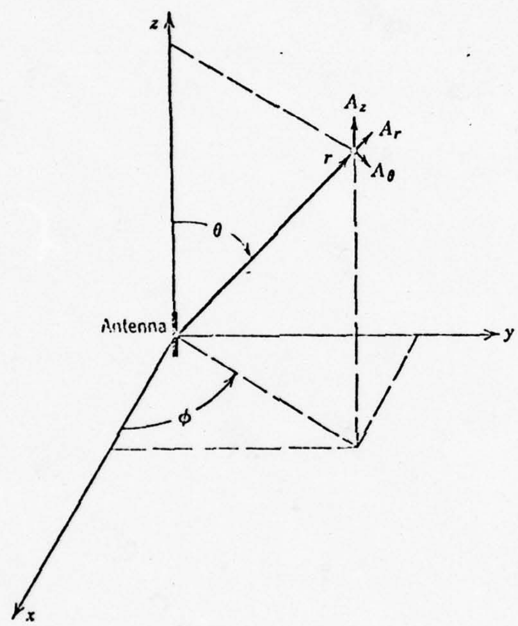


Figure L-6. Coordinates for the short wire antenna.

Equation (82a) describes the induction field which extends to a distance of approximately one-sixth wavelength from the antenna. In this region electric and magnetic fields are in phase quadrature, so that there is no average outward energy flow.

At large distances from the antenna only those terms which vary inversely with the distance are important. For this case the magnetic and electric fields are

$$\vec{H}_\phi = \frac{jkI_m Le^{-jkr}\sin\theta}{4\pi r} , \tag{83a}$$

$$\vec{E}_\theta = \frac{j\omega\mu I_m Le^{-jkr}\sin\theta}{4\pi r} , \quad r >> \frac{1}{k} . \tag{83b}$$

Therefore electric and magnetic fields are in time phase and have the ratio

$$\frac{E_\theta}{H_\phi} = \frac{\omega\mu}{k} = Z_o . \tag{84}$$

These are the characteristics of a plane wave approximating the spherical wave from the small wire at large distances. The radiation pattern is given as

$$\vec{P}_{av} = \frac{1}{2}(\vec{E} \times \vec{H}^*) = P_r(\theta) = \frac{Z_o k^2 I_m{}^2 L^2 \sin^2\theta}{32\pi^2 r^2} . \tag{85}$$

This power pattern is shown in Figures L-7 and L-8.

The total power flowing through a sphere of radius, r, is given by

$$W_T = \int_S \vec{P}\cdot d\vec{s} = \int_o^\pi P_r 2\pi r^2 \sin\theta \, d\theta$$

$$= \frac{Z_o k^2 I_m{}^2 L^2}{16\pi} \int_o^\pi \sin^3\theta \, d\theta = \frac{40\pi^2 I_m{}^2 L^2}{\lambda^2} . \tag{86}$$

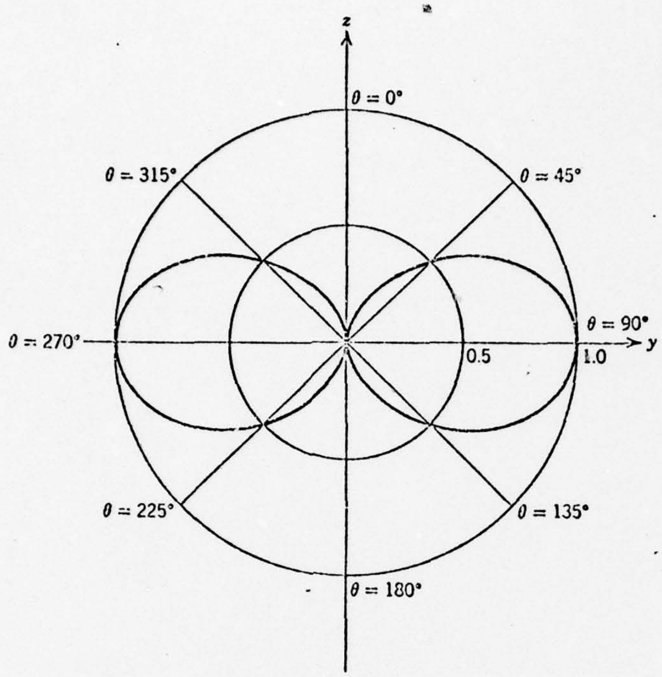


Figure L-7. Polar power pattern of a short electric dipole.

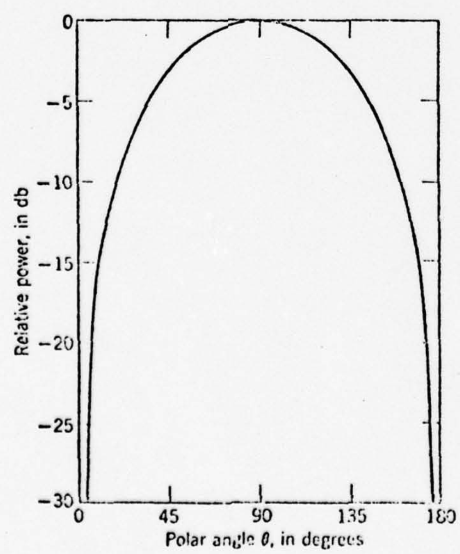


Figure L-8. Rectangular power pattern of a short Electric dipole.

The radiation resistance defined by Eq. (22) is

$$R_r = \frac{W_T}{I_{av}^2} = \frac{2W_T}{I_m^2} = 30\pi^2\left(\frac{L}{\lambda}\right)^2 . \tag{87}$$

The directivity of a short wire antenna can be found from the definition of Eq. (34). The ratio of the maximum to the average power density at a distance r from the antenna is

$$D = \frac{P_{max}}{P_{av}} = \frac{\dfrac{Z_o k^2 I_m^2 L^2}{32\pi^2 r^2}}{W_T/4\pi r^2} = \frac{3}{2} . \tag{88}$$

Since the current is uniform over the entire length of the short wire, the received voltage is

$$V_R = \int E\, dz = EL , \tag{89a}$$

and the effective height of the antenna from Eq. (46) is

$$h = L . \tag{89b}$$

The effective area of the short wire can be determined using Eq. (48) which gives

$$A_e = \frac{120\pi L^2}{4R_r} = \frac{3\lambda^2}{8\pi} = \frac{3}{2}\left(\frac{\lambda^2}{4}\right) . \tag{90}$$

Since the gain of the short wire for the lossless case is given by

$$G = D = \frac{3}{2}, \tag{91}$$

this verifies the relationship of Eq. (5) and

$$A_e = \frac{\lambda^2 G}{4\pi} . \tag{92}$$

The sinusoidal current distribution assumed above for the electric dipole is shown to be valid for the cylindrical dipole antenna for cases in which the antenna element is very thin.

b. The Dipole Antenna

One of the most commonly used antennas is the dipole antenna shown in Figure L-9. It consists of a wire whose length is an appreciable portion of a wavelength. The wire is fed by a voltage generator at its center. Since the antenna is relatively long, the current is not constant over the entire length.

It has been found experimentally that the current distribution on a wire antenna fed at the center is approximately sinusoidal with zero current at the ends of the antenna. That is, there is a standing wave pattern on the antenna with current nulls at the ends and at every half wavelength from the ends between the ends and the center. For the antenna of Figure L-9, the current on the antenna can be represented by

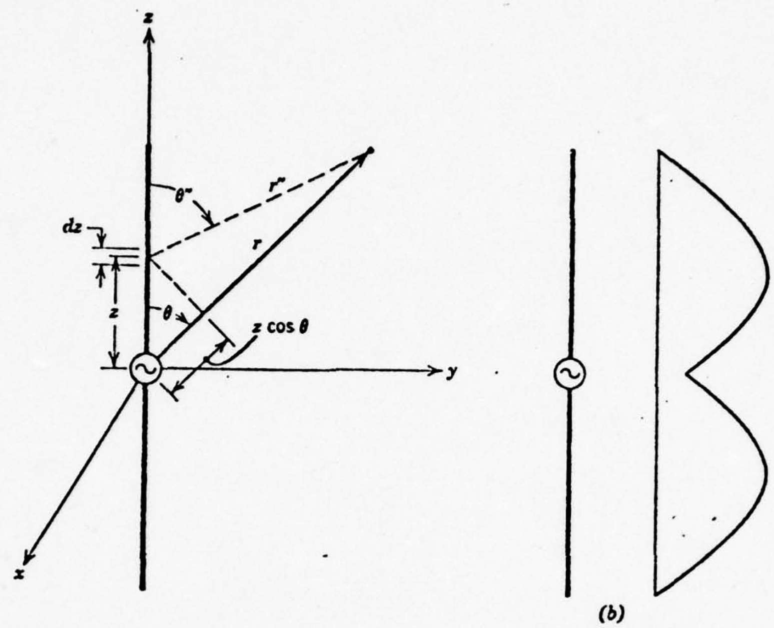


Figure L-9. Dipole antenna. (a) Coordinates. (b) Current distribution for a dipole antenna slightly less than one wavelength long.

$$I(z) = \begin{cases} I_m \sin\left[k\left(\frac{L}{2} - z\right)\right] , & z > 0 , \\ I_m \sin\left[k\left(\frac{L}{2} + z\right)\right] , & z < 0 . \end{cases} \qquad (93)$$

If the antenna is relatively short so that the electrical length of each arm is less than six degrees, the sinusoidal functions can be replaced by linear functions. Thus, for short dipole antennas, the current distribution is approximately triangular instead of sinusoidal. This current can be represented by

$$I = \left\{ \begin{array}{ll} \frac{2I_m}{L}\left(\frac{L}{2} - z\right) , & z > 0 \\ \\ \frac{2I_m}{L}\left(\frac{L}{2} + z\right) , & z < 0 \end{array} \right\} \frac{L}{\lambda} < \frac{1}{30} . \quad (94)$$

Therefore, the triangular current distribution gives a vector potential whose magnitude is one-half of the magnitude of a vector potential which would be obtained if the current distribution were uniform over the same wire length. Thus the far field of the short antenna is one-half of the field given by Eq. (83) and

$$\left. \begin{array}{l} \vec{H}_\phi = \dfrac{jkI_m Le^{-jkr}\sin\theta}{8\pi r} \\ \\ \vec{E}_\theta = \dfrac{j\omega\mu I_m Le^{-jkr}\sin\theta}{8\pi r} \end{array} \right\} \begin{array}{ll} r >> \dfrac{1}{k} & (95a) \\ \\ \dfrac{L}{\lambda} < \dfrac{1}{30} . & (95b) \end{array}$$

Also, the Poynting vector is

$$\vec{P}_r(\theta) = \frac{Z_o k^2 I_m{}^2 L^2}{128\pi^2 r^2} \sin^2\theta , \quad (96)$$

which shows that the power pattern of the short dipole is the same as the power pattern of the elemental wire. For this antenna the total radiated power is

$$W_T = 10\pi^2 \left(\frac{L}{\lambda}\right)^2 , \quad (97)$$

and the radiation resistance is

$$R_r = \frac{2W_T}{I_m^2} = 20\pi^2\left(\frac{L}{\lambda}\right)^2 . \tag{98}$$

Since the small dipole has the same pattern as the small wire, it also has the same directivity and the same effective area, given by

$$A_e = \frac{3\lambda^2}{8\pi} . \tag{99}$$

However, the triangular current distribution producing the lower radiation resistance also reduces the effective height of the antenna. Using the definition of Eq. (48), the effective height of a short dipole is

$$h = \left(\frac{4R_r A_e}{Z_o}\right)^{1/2} = \frac{L}{2} . \tag{100}$$

In other words, for the same maximum antenna current, the short dipole produces only one-half the radiated field that the short wire produces and therefore has only one-half the effective height.

A long dipole with a sinusoidal current distribution can be considered to consist of a large number of small elements of constant current such as that analyzed in Section 3a. The radiation field of this antenna is therefore a superposition of the radiation fields of each of the small segments. From

Eq. (83), it can be seen that the electric field at a great distance from the antenna due to the small current element dz is

$$dE_\theta = \frac{jkZ_o I(z)dze^{-jkr''}\sin\theta''}{4\pi r''} , \qquad (101)$$

when the geometry in Figure L-9, page , is used. Since the far field point is at a great distance from the antenna, the distances r and r are related by

$$r'' \approx r - z\cos\theta , \qquad (102a)$$

$$\theta'' \approx \theta , \qquad (102b)$$

and

$$\left|\frac{1}{r''}\right| \approx \left|\frac{1}{r}\right| . \qquad (102c)$$

The total electric field is therefore

$$\vec{E}_\theta = \frac{jkZ_o e^{-jkr}\sin\theta}{4\pi r}\left(\int_{-L/2}^{L/2} I(z)e^{jkz\cos\theta}\,dz\right) , \qquad (103)$$

Performing the integration gives

$$\vec{E}_\theta = \frac{jZ_o I_m e^{-jkr}}{2\pi r}\left(\frac{\cos\left(\frac{kL}{2}\cos\theta\right) - \cos\frac{kL}{2}}{\sin\theta}\right) . \qquad (104)$$

The Poynting vector is

$$\vec{P}_r = \frac{1}{2}|E_\theta||H_\phi| = \frac{1}{2}|E_\theta|\left|\frac{E}{Z_o}\right| = \frac{|E_\theta|^2}{2Z_o} , \tag{105}$$

and

$$\vec{P}_r = \frac{Z_o I_m^2}{8\pi^2 r^2}\left(\frac{\cos\left(k\frac{L}{2}\cos\theta\right) - \cos k\frac{L}{2}}{\sin\theta}\right)^2 , \tag{106}$$

and the total power radiated from the dipole is

$$W_T = \int_S \vec{P}\cdot\vec{ds} = \int_0^\pi P_r 2\pi r^2 \sin\theta d\theta = \frac{Z_o I_m^2}{4\pi}\int_0^\pi \frac{\left(\cos\left(k\frac{L}{2}\cos\theta\right) - \cos\right)\frac{kL}{2}}{\sin\theta} d\theta . \tag{107}$$

If the radiation resistance is defined in terms of the maximum current, it is

$$R_r = \frac{2W_T}{I_m^2} = \frac{Z_o}{2\pi}\int_0^\pi \frac{\left(\cos\left(\frac{kL}{2}\cos\theta\right) - \cos\frac{kL}{2}\right)^2}{\sin\theta} d\theta . \tag{108}$$

Integrating Eq. (108) gives

$$R_r = 60\left(C + \ln kL - C_i(kL) + \frac{1}{2}\sin(kL)\,[S_i(2kL) - 2S_i(kL)]\right.$$

$$\left. + \frac{1}{2}\cos(kL)\left(C + \ln\left(\frac{kL}{2}\right) + C_i(2kL) - 2C_i(kL)\right)\right) , \tag{109}$$

where C, Euler's constant, is

$$C = 0.5772 \ldots , \tag{110}$$

and the sine and cosine integrals are, respectively,

$$S_i(x) = \int_0^x \frac{\sin x}{x}\, dx, \qquad C_i(z) = -\int_x^\infty \frac{\cos x}{x}\, dx \,. \tag{111}$$

If the antenna is not fed at the point of current maximum, the radiation resistance as seen at the input terminal differs from the radiation resistance of Eq. (108). For the general case the radiation resistance at the input is

$$R_{in} = \frac{2W_T}{I_{in}^{\;2}} = R_r \left(\frac{I_m}{I_{in}}\right)^2 . \tag{112}$$

where I_{in} is the amplitude of the input current.

If the current maximum is at a distance d from the input terminals, the sinusoidal current distribution gives

$$I_{in} = I_m \cos kd \,, \tag{113}$$

and the radiation resistance seen at the input terminals is

$$R_{r_{in}} = \frac{R_r}{\cos^2 kd} . \tag{114}$$

The directivity pattern of the dipole is given by

$$F(\theta) = f(\theta)^2 = \left(\frac{\cos\left(k \frac{L}{2} \cos\theta\right) - \cos \frac{kL}{2}}{\sin \theta}\right)^2 . \tag{115}$$

If this pattern has a maximum value F_{max}, the directivity is

$$D = \frac{P_{max}}{W_T/4\pi} = \frac{Z_o F_{max}}{\pi R_r} = \frac{2F_{max}}{\int F(\theta) \sin\theta \, d\theta} , \tag{116}$$

the effective area is

$$A_e = \frac{\lambda^2 G}{4\pi} = \frac{\lambda^2 Z_o F_{max}}{\int 4\pi^2 R_r} , \tag{117}$$

and the effective height is

$$h = \frac{\lambda f_{max}}{\pi} , \tag{118}$$

where f_{max} is the maximum value of $f(\theta)$.

A special case of interest is that of a dipole antenna which is an odd number of half-wavelengths long. For this case the shape of the far field pattern is given by

$$f(\theta) = \frac{\cos\left[\left(\frac{2n - 1}{2}\right)\pi \cos\theta\right]}{\sin\theta} ,$$

$$L = \left(\frac{2n - 1}{2}\right) . \tag{119}$$

This pattern has zeros where $f(\theta)$ is zero or where

$$\cos\left[\left(\frac{2n - 1}{2}\right)\pi \cos\theta\right] = 0 , \tag{120}$$

or

$$\cos\theta = \pm \frac{2k - 1}{2n - 1} , \quad k = 0,1,\ldots, n . \tag{121}$$

Also, the numerator of the expression for the far field pattern is a maximum at

$$\cos\left[\left(\frac{2n-1}{2}\right)\pi \cos\theta\right] = \pm 1 . \tag{122}$$

or

$$\cos\theta = \frac{2k}{2n-1} , \qquad k = 0,1,\ldots,n-1 . \tag{123}$$

Thus there is a lobe broadside to the antenna ($\theta = 90°$) with unit normalized amplitude. Because of the term in the denominator of Eq. (119), the lobes given by Eq. (123) are all tangent to a unit cylinder whose axis coincides with the antenna. This is illustrated in the patterns of Figure L-10 for antennas one half-wavelength long and three half-wavelengths long.

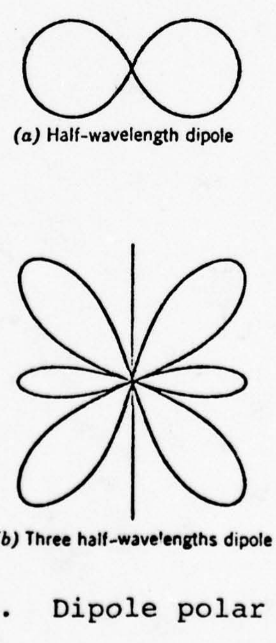


Figure L-10. Dipole polar patterns.

For the half-wave dipole, the field given by Eq. (104) is

$$\vec{E}_\theta = \frac{j60I_m e^{jkr}}{r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right] , \qquad L = \frac{\lambda}{2} . \tag{124}$$

The average power density of Eq. (106) is

$$P_r = \frac{15I_m{}^2}{\pi r^2}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]^2 . \tag{125}$$

The total power radiated is given by

$$\begin{aligned} W_T &= \int \vec{P}\cdot d\vec{s} = \int_0^\pi \frac{15I_m{}^2}{\pi r^2}\left(\frac{\cos\frac{\pi}{2}\cos\theta}{\sin}\right)^2 2\pi r^2 \sin\theta\, d\theta \\ &= 60I_m{}^2 \int_0^{\pi/2}\left(\frac{\cos\frac{\pi}{2}\cos\theta}{\sin\theta}\right) \sin\theta\, d\theta . \end{aligned} \tag{126}$$

Carrying out the integration gives

$$W_T = 15I_m{}^2 \int_0^{2\pi} \frac{1-\cos u}{u}\, du = 15I_m{}^2 C_i(2\pi) = 36.56I_m{}^2 . \tag{127}$$

The radiation resistance is

$$R_r = \frac{2W_T}{I_m{}^2} = R_r = 73.08 \approx 73.1 \tag{128}$$

and the directivity given by Eq. (116) is

$$D = \frac{120F_{max}}{R_r} = \frac{120}{73.1} = 1.64 \ . \tag{129}$$

The effective area for a perfectly efficient antenna, from Eq. (117), is

$$A_e = 0.131\lambda^2 \ , \tag{130}$$

and the effective height of Eq. (118) is

$$h = \frac{\lambda}{\pi} = 0.318\lambda \ . \tag{131}$$

The self-impedance of the dipole can be found from

$$X_A = 30S_i(2\pi n) \ . \tag{132}$$

For the half-wavelength dipole this reactance is

$$X_A = j42.5 \text{ ohms}, \qquad n = 1 \ . \tag{133}$$

c. <u>Cylindrical Antennas</u>

The fields and impedance of the electric dipole are determined by using the assumption that the current distribution on the antenna is sinusoidal. If the dipole radius is appreciable, this sinusoidal current assumption is not strictly valid.

All of the antennas discussed in this study have high h/a ratios, where h = height (or length) of the antenna element

a = radius of antenna element

therefore a sinusoidal current distribution can be assumed.

d. <u>Center-Fed Sleeve Antenna. The Sleeve Dipole</u>

The sleeve around the dipole serves to alter the current distribution to make the antenna more broadband. It also provides a more rugged mechanical structure (Figure I-11).

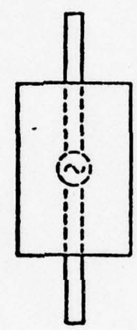


Figure L-11. The sleeve dipole.

The basic analysis of the sleeve dipole proceeds from that of the dipole itself. The gain (directivity) and effective height are given by Eqs. (129) and (131). The feedpoint impedance, however, is quite different. A typical sleeve dipole is the AS-1729/VRC (Chapter III). The AS-1729/VRC is fed at its midpoint through a coaxial transmission line in the lower 5-foot section (which is covered by the sleeve). The transmission line consists of two parts: an upper portion that has a characteristic impedance of 125 ohms, and a lower portion that has a characteristic impedance of 50 ohms. The 125 ohms and 50 ohms sections act as a transformer to provide a good SWR at the base of the whip antenna portion of the AS-1729/VRC. The upper 5-foot section, the radiating element, is an extension of the center conductor of the coaxial transmission line. The antenna feed-point impedance is matched to the receiver-transmitter output impedance (50 ohms) by a matching unit which consists of a group of shunt reactance components which are selected by a rotary switch controlled by the frequency selector switches on the receiver-transmitter.

e. The Monopole Antenna

1. The monopole antenna is a modification of the dipole antenna in which a plane conducting screen is placed at the center of the antenna at right angles to the antenna axis. Currents flowing on the conducting screen simulate the missing half of the dipole to create an image in much the same way as a mirror forms an optical image. A monopole antenna is often used instead of a dipole antenna for situations requiring an omnidirectional, vertically polarized antenna, because the monopole is shorter and cheaper to construct and because the earth can be used as the conducting ground plane. In practice, the ground plane radius is not infinite and a perfect image is not formed. A monopole with a finite ground plane of radius a is shown in Figure L-12.

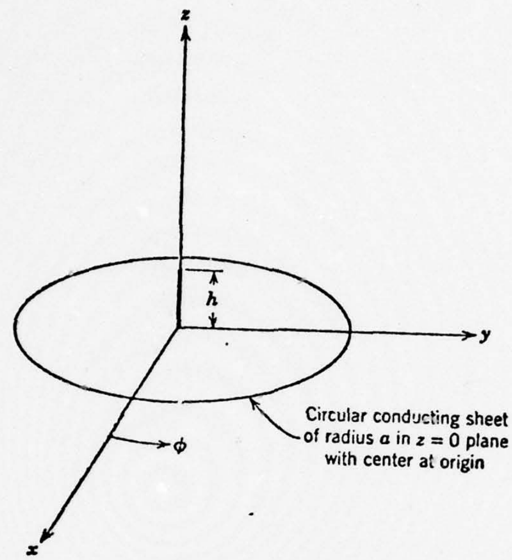


Figure L-12. A monopole antenna.

The current element is aligned with the z axis, has a length h, and is assumed to be infinitely thin. The current is

$$I = I(z)e^{j\omega t} . \tag{134}$$

If the impedance of the antenna over an infinite screen is denoted by Z^∞, then

$$Z - Z^\infty = \frac{Z_o}{j4\pi ka} e^{j2ka}\left(\frac{1 - \cos kh}{\sin kh}\right)^2 , \tag{135}$$

or

$$Z - Z^\infty = F\left(\frac{a}{\lambda}\right)\left(\frac{1 - \cos kh}{\sin kh}\right)^2 . \tag{136}$$

The variation of the complex value of $F(a/\lambda)$ is shown in Figure L-13. For a quarter-wavelength monopole the last term of Eq. (136) is unity, so that Figure L-13 can be interpreted as a change of impedance of a quarter-wavelength monopole antenna with frequency and ground plane diameter.

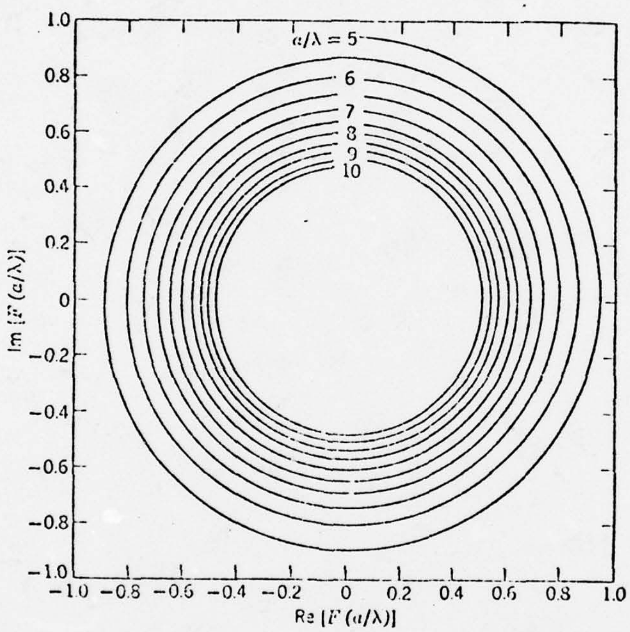


Figure L-13. Graph of $F(a/\lambda)$.

For thick monopole antennas the sinusoidal current distribution is no longer valid, and solutions to Hallen's integral equations must be found in order to determine the monopole impedance.

The pattern of a monopole with a large ground plane is, to a first approximation, the pattern of an equivalent dipole radiating into a single hemisphere. For an infinite ground plane the total radiated power is the integration of the Poynting vector over a hemisphere instead of a sphere, so that the monopole has one-half the total radiated power of a dipole and the radiation resistance of the monopole is one-half the radiation resistance of an equivalent dipole. However, the maximum power density is the same, so the directivity and the effective area of the monopole are twice as large as those of the dipole. The lower radiation resistance and increased effective area of the monopole give an effective height equal to that of a dipole.

2. For practical monopole antennas, the plane conducting screen is created by electrically connecting one end of a vertical antenna, usually a quarter-wavelength long, to the ground itself (using a grounding rod) or to an artificial ground (a counterpoise) consisting of a vehicle chassis or, in the case of portable equipment, to the case housing the transmitter-receiver. The effect is to make the quarter-wave antenna behave like a half-wave antenna. Here, the ground takes the place of the missing quarter-wavelength, and the reflections supply that part of the radiated energy that normally would be supplied by the lower half of an grounded half-wave antenna. (Appendix I, paragraph 10, gives details on current distributions with base, center, and top-loaded whip antennas which are grounded vertical monopoles.)

Figure L-14 below shows the radiation patterns of a grounded quarter-wave antenna, while Figure L-15 shows the patterns of grounded vertical antennas of 1/2, 5/8, 3/4, and 1 wavelength.

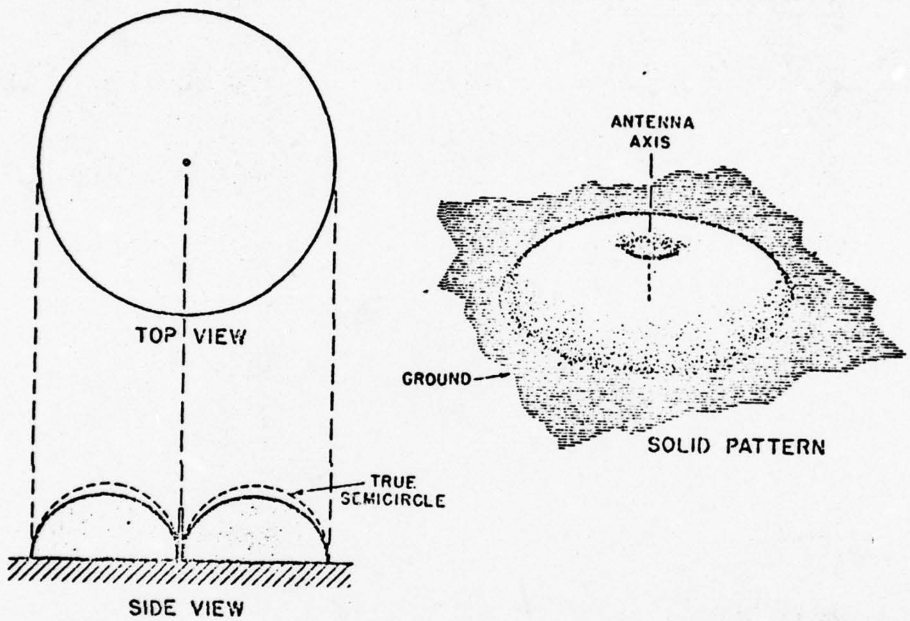


Figure 14. Radiation pattern produced by a grounded quarter-wave antenna.

3. From paragraph 3(e) (1) above, the radiation resistance of a grounded quarter-wave antenna is just half that of the ungrounded half-wave antenna. For very thin antennas, the value of the radiation resistance is 36 ohms. If large-diameter tubing is used for the antenna radiating element, that value is reduced.

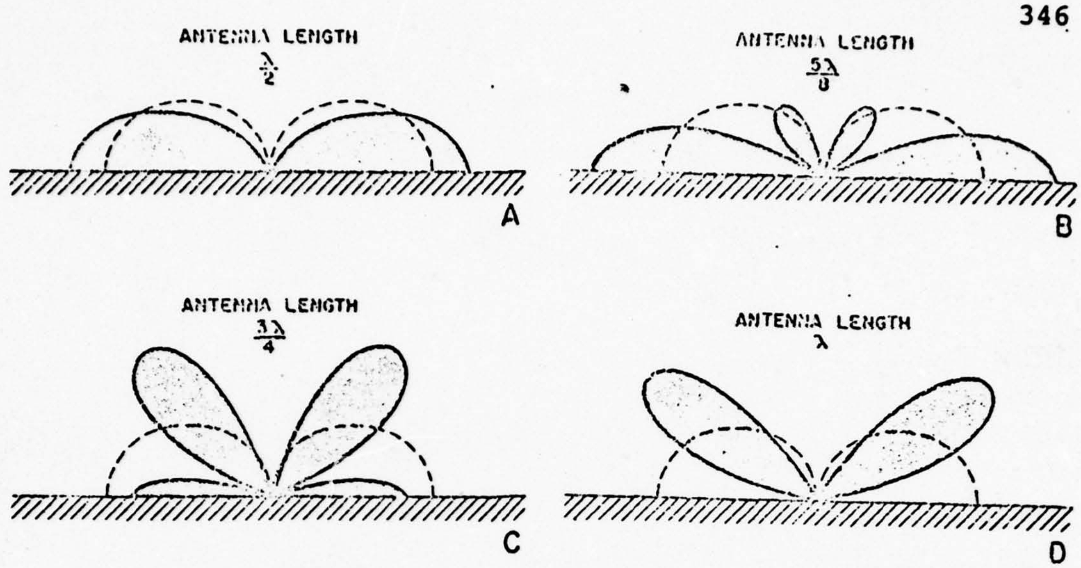


Figure L-15. Vertical-plane radiation patterns produced by grounded vertical antennas of various lengths.

When grounded vertical antennas shorter than a quarter wavelength are used, the radiation resistance is reduced still more. In general, for short grounded vertical (monopole) antennas (up to about one-eighth wavelength) the radiation resistance is given by

$$R_r = 40\pi^2 \left(\frac{h}{\lambda}\right)^2 . \qquad (137)$$

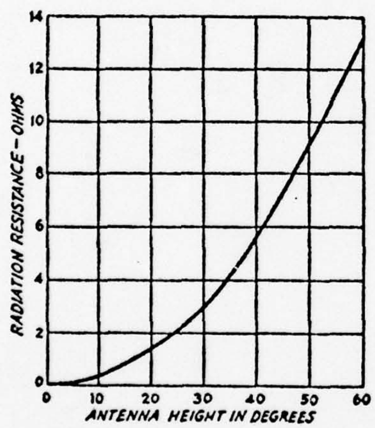
Table L-1 below shows the value of radiation resistance for various lengths of short monopoles.

Figure L-16 displays the same information graphically, where the antenna height (length) is expressed in electrical degrees, and λ = 360 degrees, $\lambda/2$ = 180 degrees, $\lambda/3$ = 120 degrees, and so on.

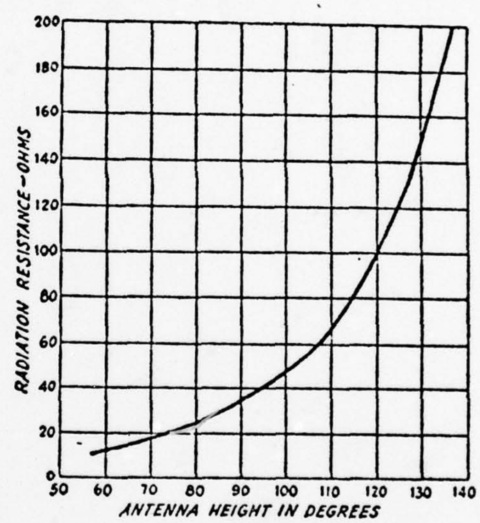
TABLE L-1

RADIATION RESISTANCE OF SHORT MONOPOLE ANTENNAS OF VARIOUS LENGTHS

Antenna Lengths (wavelengths)	Radiation Resistance (ohms)	Antenna Lengths (wavelengths)	Radiation Resistance (ohms)
0.30	60	0.15	8
0.25	36	0.10	2
0.20	20	0.05	1



(a)



(b)

Figure L-16. Radiation resistance vs. free-space antenna height in electrical degrees for a vertical antenna over perfectly conducting ground plane. (a) 0-60 degrees (0 - λ/6), and (b) 50-140 degrees (5λ/36 - 7λ/18). (These curves may also be used for center-fed antennas (in free space) by multiplying the radiation resistance by two; the height (length) in this case is half the actual antenna length.)

4. From Eq. (53), for a matched antenna, the antenna efficiency, η, is given by

$$\eta = \frac{R_r}{R_r + R_L} \tag{138}$$

which is just the ratio of the radiation resistance to the total resistance of the system. The total resistance includes radiation resistance, resistance in conductors and dielectrics, including the resistance of loading coils if used, and the resistance of the grounding system, usually referred to as "ground resistance."

In the case of the grounded antenna the ground resistance usually is not negligible, and if the antenna is short (compared with a quarter wavelength) the resistance of the necessary loading coil may become appreciable. To attain an efficiency comparable with that of a half-wave antenna, in a grounded antenna having a height of 1/4 wavelength or less, great care must be used to reduce both ground resistance and the resistance of any required loading inductors. Without a fairly elaborate grounding system, the efficiency is not likely to exceed 50 percent and may be much less, particularly at heights below 1/4 wavelength.

For example, the ohmic resistance of the loading coil used might be several ohms, the resistance of the ground (counterpoise) might be several ohms, and the resistance of the antenna itself might be 1 or 2 ohms, or more. The power that is dissipated in all these resistances may be considerably greater than the power that is radiated into space. If an antenna length used is 0.1λ, the radiation resistance is only 2 ohms, and the total ohmic resistance is approximately 8 ohms. Therefore, the efficiency of the 0.1λ monopole antenna is only approximately 20 percent.

A very approximate curve of reactance vs. height is given in Figure L-17. The actual reactance will depend on the height/radius (h/a) ratio, so this curve should be used only as a rough guide. It is based on a ratio of about 500 to 1. Thicker antennas can be expected to show lower reactance at a given height, and the thinner antennas should show more. At heights below and above the range covered by the curve, larger reactance values will be encountered, except for heights in the vicinity of 1/2 wavelength. In this region the reactance decreases, becoming zero when the antenna is resonant.

f. Basic Wire Antenna Parameters

Table L-2 lists the basic wire antenna parameters. In Table L-2,

$\langle P_r \rangle$ = outward power flow or radiated power

and

ℓ_E = antenna effective length where

$$|\ell_E| = \sqrt{\frac{GR_r}{\pi\eta}}\,\lambda \text{ meters} .$$

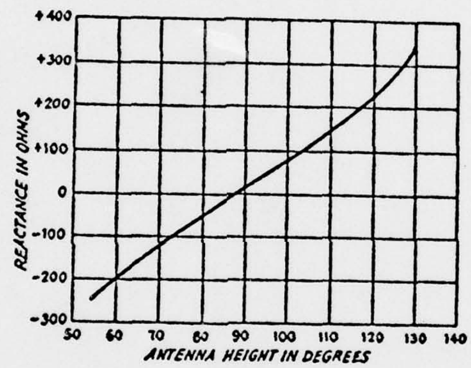


Figure L-17. Approximate reactance of a vertical antenna over perfectly conducting ground and having a height/radius (h/a) ratio of about 500. Actual values will vary considerably with h/a ratio. The remarks under Figure L-16 also apply to this curve.

TABLE L-2

BASIC WIRE ANTENNA PARAMETERS

Antenna	$\dfrac{\vec{E}}{\frac{\eta}{\pi}\frac{e^{-jkr}}{r}}$ $\frac{v.}{m.}$	R_r Ω	$\lvert E\rvert_{rms}$ $\theta=\pi/2$ $\langle P_r\rangle = 10^3$ $r = 1$ mile	G	ℓ_E m.
Isotropic	----	----	0.108	1.0	---
Hertzian Dipole	$\frac{jk\ell I}{4}\sin\theta\,\vec{a}_\theta$	$20(k\ell)^2$	0.132	1.5	ℓ
Hertzian Monopole	$\frac{jkh I}{2}\sin\theta\,\vec{a}_\theta$	$40(kh)^2$	0.186	3.0	2h
Short Dipole	$\frac{jk\ell I_t}{8}\sin\theta\,\vec{a}_\theta$	$5(k\ell)^2$	0.132	1.5	$\ell/2$
Short Monopole	$\frac{jkh I_t}{4}\sin\theta\,\vec{a}_\theta$	$10(kh)^2$	0.186	3.0	h
Magnetic Dipole	$\frac{\pi(ka)^2 I}{4}\sin\theta\,\vec{a}_\phi$	$20(\pi)^2(ka)^4$	0.132	1.5	πka^2
Mag. Dip. N-turn	$\frac{\pi(ka)^2 NI}{4}\sin\theta\,\vec{a}_\phi$	$20(N\pi)^2(ka)^4$	0.132	1.5	$N\pi ka^2$
$\lambda/2$ Dipole Sine ** Current	$\frac{jI_t}{2}\frac{\cos(\pi/2\cos\theta)}{\sin\theta}\vec{a}_\theta$	73.08	0.138	1.64	2/k
$\lambda/4$ Mono. Sine Current	$\frac{jI_t}{2}\frac{\cos(\pi/2\cos\theta)}{\sin\theta}\vec{a}_\theta$	36.54	0.195	3.28	2/k
Folded $\lambda/2$ Dipole Sine-Cur.	$jI_t\frac{\cos(\pi/2\cos\theta)}{\sin\theta}\vec{a}_\theta$	292.3	0.138	1.64	4/k
Folded $\lambda/4$ Mono. Sine-cur.	$jI_t\frac{\cos(\pi/2\cos\theta)}{\sin\theta}\vec{a}_\theta$	146.2	0.195	3.28	4/k
$\lambda/2$ Dipole 2-term current ***	$\frac{jI_t}{2}\left[\frac{\cos(\pi/2\cos\theta)}{\sin\theta} + \alpha\frac{1+\cos(\pi/2\cos\theta)}{4-\cos^2\theta}\right]\vec{a}_\theta$	87.8	0.138	1.64	$\frac{2.19-j0.24}{k}$
$\lambda/4$ Mono. 2-term current ***	$\frac{jI_t}{2}\left[\frac{\cos(\pi/2\cos\theta)}{\sin\theta} + \alpha\frac{1+\cos(\pi/2\cos\theta)}{4-\cos^2\theta}\right]\vec{a}_\theta$	43.9	0.195	3.28	$\frac{2.19-j0.24}{k}$

* Wire radius $<<\lambda$; ** $h/a = 75$; *** $h/a = 75$,

$\alpha = \frac{2b}{I_t}\frac{\pi}{\eta}\sin\theta$, $\frac{2b}{I_t} = 0.173 - j0.236$

4. GROUND-PLANE ANTENNA

a. A ground-plane antenna consists of a quarter-wave vertical radiator which, in effect, carries its own artificial ground. The artificial ground or ground plane consists of a flat disk of metal or a number of metal rods or spokes located at the bottom of the radiator and usually at right angles to it (A of Figure L-18). Since the metal disk or spokes are not connected directly to ground, they may be referred to as a counterpoise. This term is used rarely, however, this part of the antenna usually being called simply an elevated ground plane.

b. The ground-plane antenna is used when nondirectional horizontal radiation or reception is required. It is particularly useful in the very-high-frequency range and higher. At these frequencies, the length of a vertical quarter-wave antenna is not great. Any desire to operate such an antenna in conjunction with the actual ground would create high ground losses and would prevent efficient radiation or reception. The ground-plane antenna, on the other hand, is usually well elevated so that ground losses are minimized.

c. The elevated ground plane also prevents circulating currents from flowing in a vertical metal mast that might be used to support the antenna. These currents, if not prevented, would cause the vertical support itself to radiate

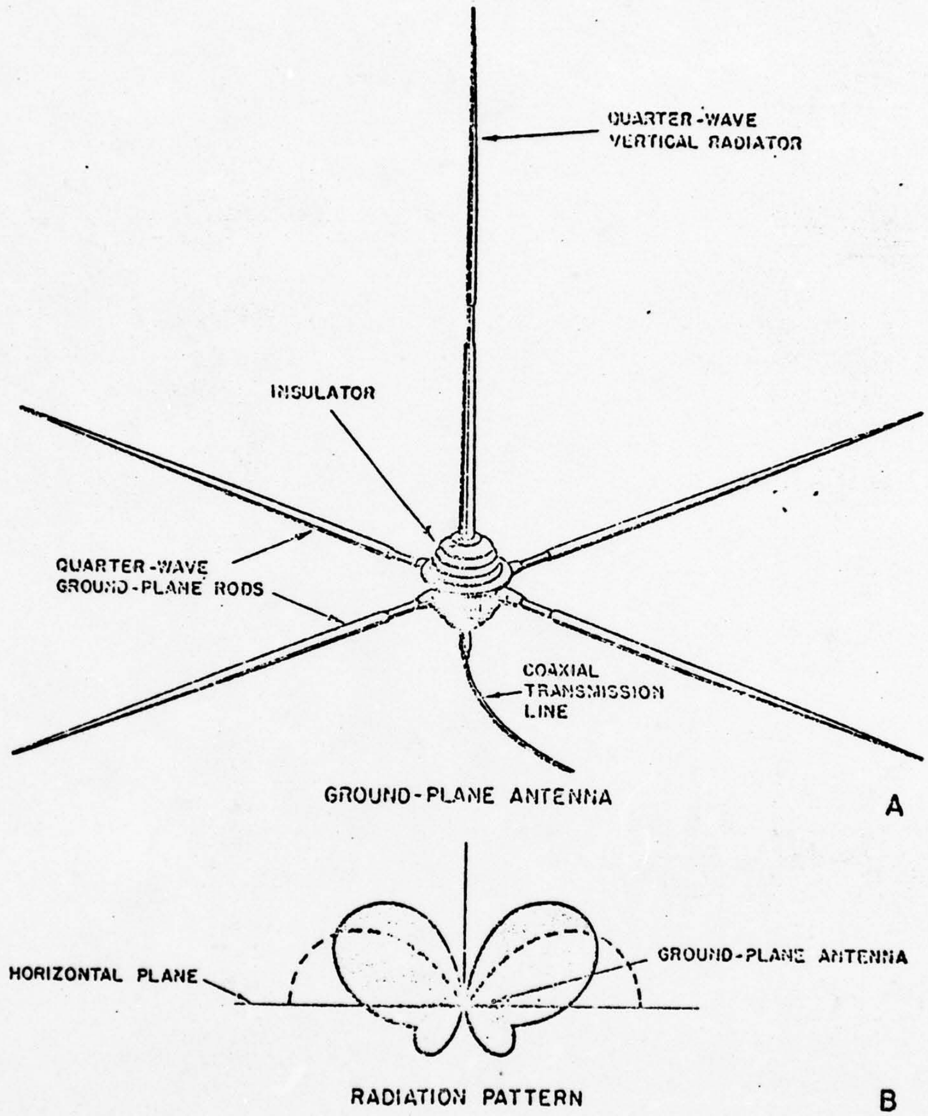


Figure L-18. Typical ground-plane antenna.

in the same manner as a long-wire antenna. As a result, undesired high-angle radiation would be produced.

d. The radiation produced by a vertical quarter-wave grounded antenna erected adjacent to the earth itself is maximum along the surface of the earth (at a vertical angle of 0°). The intensity of the radiation falls off at higher vertical angles until, at a vertical angle of 90°, no radiation occurs. A side view of this radiation pattern is shown dashed in B of Figure L-18. Since this type of radiation occurs at all horizontal angles, a top view of the pattern would be circular. When a ground-plane antenna is used, the limited size of the elevated ground plane alters the radiation as shown, and maximum radiation is no longer along the horizontal plane but occurs at some angle above.

e. When maximum radiation is required in the horizontal direction, it is common practice to bend down the spokes forming the elevated ground plane to an angle of about 50° below the horizontal. When the solid metal construction is used, the elevated ground plane takes the form of a cone, and the lobes of maximum radiation, shown in B, are pulled downward to a much lower vertical angle.

f. In almost all cases, coaxial line is used to feed the ground-plane antenna. The inner conductor of the coaxial line is connected to the quarter-wave vertical radiator; the outer conductor is connected to the elevated ground plane.

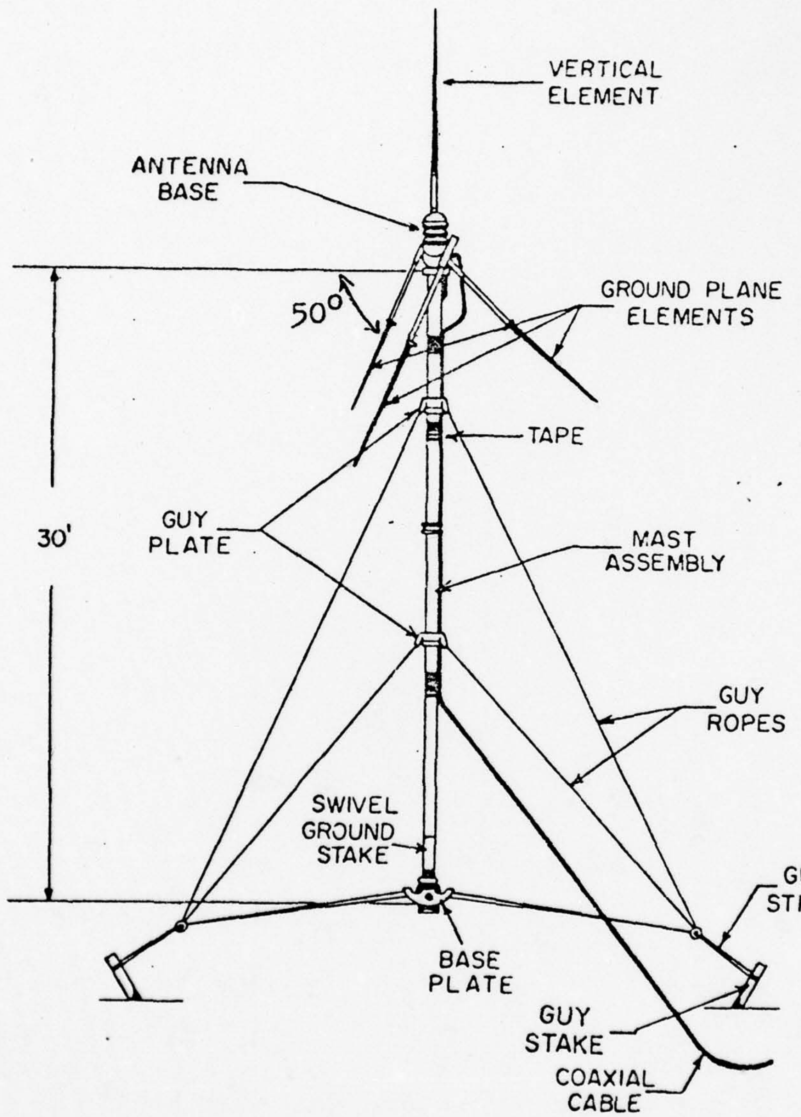


Figure L-19. Antenna equipment RC-292. The ground plane elements are bent downward 50° below the horizontal. The input impedance of this antenna is approximately 50 ohms.