DOCUMENT RESUME

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TITLE Antenna Construction & Propagation of Radio Waves, 5-1. Military Curriculum Materials for Vocational and Technical Education.

INSTITUTION Marine Corps, Washington, D.C.; Ohio State Univ., Columbus. National Center for Research in Vocational Education.

SPONS AGENCY Office of Education (DHEW), Washington, D.C.

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DESCRIPTORS *Electricity; Military Personnel; Military Training; Postsecondary Education; *Radio; Secondary Education; *Technical Education

IDENTIFIERS *Antennas; Military Curriculum Project; *Radio Waves; Wave Propagation

ABSTRACT

These military-developed curriculum materials consist of five individualized, self-paced chapters dealing with antenna construction and propagation of radio waves. Covered in the individual lessons are the following topics: basic electricity; antenna transmission-line fundamentals; quarter-wave antennas, half-wave antennas, and associated radio patterns; long-wire antennas and antenna propagation; and radio wave propagation. Each lesson contains reading assignments and review exercises. (MN)

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
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- Installing educational programs and products
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The National Center for Research in Vocational Education
The Ohio State University
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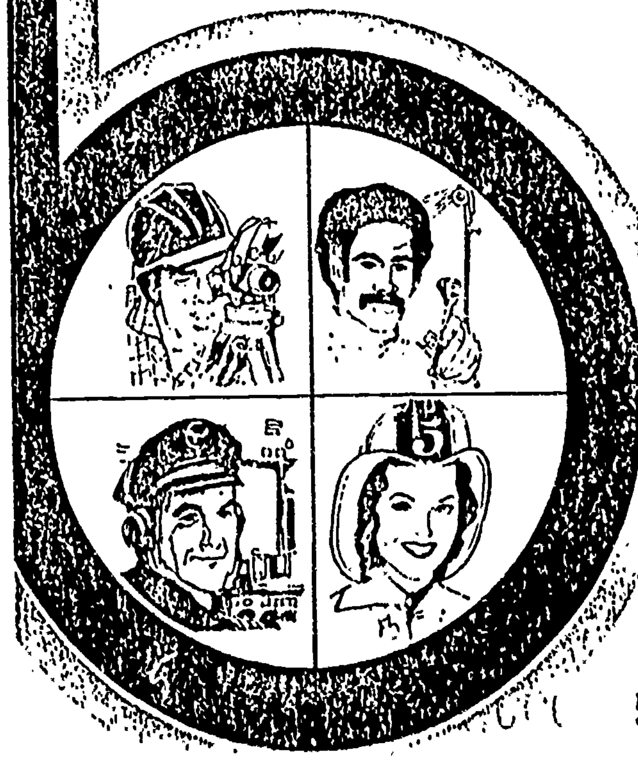
Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education



Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
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ANNTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

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ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

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Developed by:

United States Marine Corps

Development and Review Dates

April 1975

Occupational Area:

Communications

Cost:

Print Pages:

131

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Suggested Background:

None

Target Audiences:

Grades 10-adult

Organization of Materials:

Student lesson book with assignments and review exercises; text readings

Type of Instruction:

Individualized, self-paced

Type of Materials:			No. of Pages:	Average Completion Time:
Antenna Construction and Propagation of Radio Waves				
Lesson 1	–	Basic Electricity	10	Flexible
Lesson 2	–	Antenna and Transmission Line Fundamentals	18	Flexible
Lesson 3	–	Quarter-Wave, Half-Wave Antennas and Associated Radiation Patterns	25	Flexible
Lesson 4	–	Long-Wire Antennas and Antenna Propagation	36	Flexible
Lesson 5	–	Radio Wave Propagation	20	Flexible
Student Lesson Book			19	

Supplementary Materials Required:

None

Expires July 1, 1978

Course Description:

This course is designed to provide the student with the fundamentals of electricity, antenna construction, and wave propagation. It provides the theory background for using wave propagation in communication. The course consists of five lessons.

Lesson 1 — *Basic Electricity* has an introduction to electricity, and covers the composition of matter, conductors and insulators, basic laws, electric current, electromotive force, resistance, magnets, the nature of magnetism, and electric symbols.

Lesson 2 — *Antenna and Transmission Line Fundamentals* discusses the electromagnetic field, antenna theory, radiation, graphs, polarization, antenna input impedance, transmission line theory and the types of transmission line.

Lesson 3 — *Quarter-Wave, Half-Wave Antennas and Associated Radiation Patterns* contains two sections. Section I describes whip (Marconi), ground plane, bent, folded-top, top-loaded, and tower radiated antennas. Section II discusses Hertz, ground affected radiation patterns, single wire antennas, folded dipole, coaxial, conical and microwave antennas, and multielement arrays.

Lesson 4 — *Long-Wire Antennas and Antenna Installation* contains two sections. Section I describes the general characteristics of long-wire antennas, harmonically operated antennas in free space, and feeding long-wire antennas, resonant and nonresonant antennas, beverage or wave antennas, V antennas, half-rhombic antennas, and rhombic antennas. Section II covers site selection for installation, safety precautions, grounds and counterpoises, orientation, profiles, and field expedient methods.

Lesson 5 — *Radio Wave Propagation* contains three sections. Section I discusses general propagation factors, frequency spectrum, the atmosphere, and wave bending. Section II discusses general ground wave propagation, composition and characteristics of ground wave propagation, and tropospheric propagation. Section III discusses general sky wave propagation, the ionsphere, ionsphere characteristics, transmission paths, and frequency prediction.

Each lesson contains reading assignments and review exercises, but objectives and answers to the exercises are not given. The course is designed for student self-study. It can be used as a sub-unit in electrical communications.

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ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

Lesson 1

Basic Electricity

STUDY ASSIGNMENT: Information for MCI Students.
Course Introduction.
MCI 25.15b, Antenna Construction and Prooagation of Radio Waves, chap 1.

WRITTEN ASSIGNMENT:

A. Multiple Choice: Select the ONE answer which BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate box.

Value: 1 point each

1. A compound will retain its characteristics after it has been subdivided into

   a. atoms.
   b. molecules.
   c. protons.
   d. electrons.

2. The atomic nucleus is composed of

   a. atoms and molecules.
   b. neutrons and electrons.
   c. neutrons and protons.
   d. protons and electrons.

3. What prevents the electrons from being drawn toward the nucleus?

   a. Electrical repulsion
   b. Centrifugal force
   c. Atomic weight
   d. Centripetal force

4. The atom is the smallest particle of

   a. a molecule.
   b. an element.
   c. a proton.
   d. an electron.

5. An atom is said to be ionized if it has gained or lost one or more of its

   a. protons.
   b. electrons.
   c. neutrons.
   d. positrons.

6. When an atom is excited, free electrons are liberated from the

   a. nucleus.
   b. inner planetary orbit.
   c. central planetary orbit.
   d. outer planetary orbit.

7. Current flow is caused by the movement of

   a. free electrons.
   b. atoms.
   c. molecules.
   d. protons.

8. A good conductor is

   a. glass.
   b. rubber.
   c. dry wood.
   d. aluminum

9. A good insulator is

a. copper
b. brass
c. mica.
d. aluminum.

10. Assume that you have generated a static charge by rubbing a comb with a woolen cloth. If the comb is negatively charged, the woolen cloth has

a. lost electrons.
b. gained electrons.
c. lost protons.
d. gained protons.

11. According to the law of like and unlike charges, the protons within the nucleus of the atom must

a. absorb electrons.
b. neutralize each other.
c. repel each other.
d. attract each other.

12. Two charged bodies are 1 inch apart. What is the force of attraction or repulsion if one body has a charge of 2 coulombs and the other, a charge of 3 coulombs?

a. 1 newton
b. 1.5 newtons
c. 5 newtons
d. 6 newtons

13. Refer to question 12. What is the force of attraction or repulsion if the distance between the two charged bodies is increased to 2 inches?

a. 1 newton
b. 1.5 newtons
c. 5 newtons
d. 6 newtons

14. The field of force between charged bodies is called

a. a neutral field.
b. an electrostatic field.
c. a magnetic field.
d. an artificial field.

15. Electrons are held in orbit by the attraction of the _____ in the nucleus.

a. protons
b. neutrons
c. positrons
d. molecules

16. What is the practical unit for measuring an electrical charge?

a. Ohm
b. Volt
c. Coulomb
d. Ampere

17. What is the direction of the electric field between positive and negative charges?

a. Positive to negative
b. Negative to positive
c. Positive to positive
d. Negative to negative

18. The direction of electron flow in a conductor is from

a. positive to negative.
b. negative to positive.
c. positive to positive.
d. negative to negative.

19. Unit current flow is expressed in

a. amperes.
b. volts.
c. ohms.
d. newtons.

20 Identify the force that produces current flow in a conductor.

a. Electrostatic force
b. Artificial force
c. Electromotive force
d. Magnetic force

21. The unit of measure for the opposition to current flow is called a(an)

a. coulomb.
b. amp.
c. volt.
d. ohm.

22. Which symbol designates opposition to current flow?

a. E
b. O
c. R
d. I

23. An increase in temperature will cause the resistance of a copper conductor to

a. increase.
b. decrease.
c. remain the same.

24. Where does a bar magnet exhibit maximum attraction?

a. At its center
b. At its ends
c. Along its surfaces
d. Along its edges

25. What are the three groups of magnets?

a. Natural, permanent, and electromagnets
b. Artificial, permanent, and electromagnets
c. Bar, permanent, and natural
d. Artificial, natural, and electromagnets

26. According to Weber's theory, the molecules of an unmagnetized substance are arranged so that their poles are

a. alined.
b. opposed.
c. staggered
d. distributed at random.

27. Support for Weber's theory is found in the fact that when a permanent magnet is broken into several pieces,

a. they repel each other.
b. each piece has a north and a south pole.
c. they are demagnetized.
d. they distribute themselves at random.

28. Inside the magnet, magnetic lines of force pass from the _____ pole to the _____ pole.

a. south--south
b. north--north
c. south--north
d. north--south

29. Magnetic lines of force act so as to

a. cross at the poles.
b. repel each other.
c. merge at the poles.
d. attract each other.

30. If the distance between two north poles is increased from 4 inches to 8 inches, the force of repulsion between them is _____ to _____ its original value.

a. decreased--one-fourth
b. increased--four times
c. decreased--one-half
d. increased--twice

31. The space surrounding a magnet is called a(n)

a. natural field.
b. magnetic field.
c. artificial field.
d. neutral field.

Total Points: 31

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ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

Lesson 2

Antenna and Transmission Line Fundamentals

STUDY ASSIGNMENT: MCI 25.15b, Antenna Construction and Propagation of Radio Waves, chap 2.

WRITTEN ASSIGNMENT:

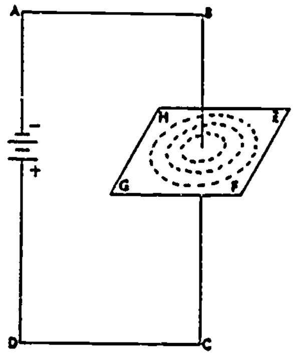
A. Multiple Choice: Select the ONE answer which BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate box.

Value: 1 point each

1. The magnetic field around a conductor is produced by

a. resistance.
b. voltage.
c. inductance.
d. current.

Note: Questions 2 through 5 refer to this diagram.



2. The direction of the magnetic field surrounding conductor ABCD is from point

a. B to point C.
b. C to point B.
c. H to point E.
d. F to point E.

3. Assume that a compass is placed in the field surrounding conductor BC. The needle of the compass will be alined so that its _____ pole faces point _____, and its _____ pole faces point _____.

a. north--E--south--F
b. south--E--north--F
c. north--E--south--H
d. south--G--north--H

4. If the current flow is doubled, the strength of the magnetic field at point G will increase _____ times.

a. 2
b. 3
c. 4
d. 8

5. If point F is moved twice as far from the conductor, the strength of the magnetic field will decrease to

a. 1/2.
b. 1/3.
c. 1/4.
d. 1/8.

6. The combined electric and magnetic field is called the _____ field.

a. electrostatic
b. electromagnetic
c. electric-magnetic
d. induction

7. When the electric field about a conductor carrying alternating current is maximum, the magnetic field is

a. decreasing.
b. increasing.
c. maximum.
d. minimum.

8. In geometric terms the two fields composing the electromagnetic field are _____ to each other.

a. parallel
b. perpendicular
c. complementary
d. coefficient

9. At what speed do radio waves travel?

a. 720 feet/sec
b. 1,100 feet/sec
c. 186,000 miles/sec
d. 300,000 miles/sec

10. What is the wavelength, in meters, of an antenna operating at 60 Megahertz?

a. 0.78
b. 5
c. 7.8
d. 50

11. What is the physical length, in feet, of a half-wave antenna operating at 60 Megahertz?

a. 0.78
b. 5
c. 7.8
d. 50

12. The formula for finding the wavelength of an antenna is

a. $\frac{3000}{f}$.
b. $\frac{300000}{f}$.
c. $\frac{3000000}{f}$.
d. $\frac{300000000}{f}$.

13. By attaching two one-quarter wavelength conductors to an RF generator we construct the basic antenna known as the ___________ antenna.

a. whip
b. long-wire
c. dipole
d. rhombic

14. One characteristic of a dipole antenna is that its

a. voltage is maximum at the center.
b. current is maximum at the center.
c. current is minimum at the center.
d. voltage is minimum at the ends.

15. An "E" energy loop that has broken away from an antenna is repelled into space by a(an) _______ field.

a. collapsing "E"
b. collapsing "H"
c. expanding "E"
d. expanding "H"

16. A radiator that emits stronger radiation in one direction than another is called

a. isotropic.
b. omnidirectional.
c. anisotropic.
d. bidirectional.

17. A radiation pattern is defined as the measurement of energy, taken at ______ angle(s) and at ________ distance(s) from the antenna.

a. a constant--a constant
b. a constant--various
c. various--a constant
d. various--various

18. A source of radiation is classified as being either _______ or ________.

a. horizontal--vertical
b. isotropic--anisotropic
c. polar--rectangular
d. concentric--eccentric

19. A characteristic of a polar-coordinate graph is

a. the antenna is located at the side.
b. lobes and nulls are not shown.
c. it shows the non-direction of radiated energy.
d. the antenna is located at the center.

20. The radiation pattern of a dipole antenna has _______ lobe(s) and ________ null(s).

a. 1--1
b. 2--2
c. 1--2
d. 2--1

21. Which component(s) of a radiated wave determine(s) its polarization?

a. "E" field
b. "H" field
c. "E" and "H" fields

22. The ratio of voltage to current at a point on the antenna is used to determine the antenna's

a. radiation resistance.
b. reactance.
c. input impedance.
d. power loss.

23. The equivalent circuit of a transmission line consists of resistance, inductance, and

a. reactance.
b. capacitance.
c. impedance.
d. radiation.

24. A characteristic impedance of an infinitely long transmission line is the impedance which is

a. "seen" by the transmitter.
b. "seen" by the antenna.
c. measured at any point on the line.
d. equivalent to all of the above.

25. When the antenna impedance is greater than the Z_0 of the transmission line, it appears as a(an)

a. open circuit.
b. short circuit.
c. inductance.
d. pure resistance.

26. When the antenna impedance is less than the Z_0 of the transmission line, it appears as a(an)

a. open circuit.
b. short circuit.
c. inductance.
d. pure resistance.

27. What type transmission line is most desirable for high-frequency applications?

 a. Coaxial
 b. Shielded-pair
 c. Twisted-pair
 d. Parallel 2-wire

28. What type transmission line is generally used for low-frequency applications at short distances?

 a. Coaxial
 b. Shielded-pair
 c. Twisted-pair
 d. Parallel 2-wire

Total Points: 28

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ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

Lesson 3

Quarter-wave, Halfwave Antennas and Associated Radiation Patterns

STUDY ASSIGNMENT: MCI 25.15b, Antenna Construction and Propagation of Radio Waves, chap 3.

WRITTEN ASSIGNMENT:

A. Multiple Choice: Select the ONE answer which BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate box.

Value: 1 point each

1. A whip antenna acts as a half-wave antenna because

   a. it has two sections.
   b. it is vertically polarized.
   c. the ground shorts out the electric field.
   d. the ground takes the place of the missing quarter-wavelength.

2. The quarter-wave antenna is known as the ______ antenna.

   a. Hertz
   b. Marconi
   c. doublet
   d. harmonic

3. Maximum radiation produced by a quarter-wave antenna is best described as

   a. unidirectional.
   b. bidirectional.
   c. parallel to the antenna.
   d. perpendicular to the antenna.

4. The vertical pattern of the whip antenna resembles the figure eight because

   a. it acts as a half-wave antenna.
   b. it acts as a full-wave antenna.
   c. there is no radiation from its ends.
   d. there is no radiation from its center.

5. The ground plane antenna is classed as a _____ antenna.

   a. quarter-wave
   b. half-wave
   c. full-wave
   d. multiple-wave

6. Maximum radiation produced by the ground plane antenna occurs at a vertical angle of _____ degrees.

   a. zero
   b. 45
   c. 90
   d. 120

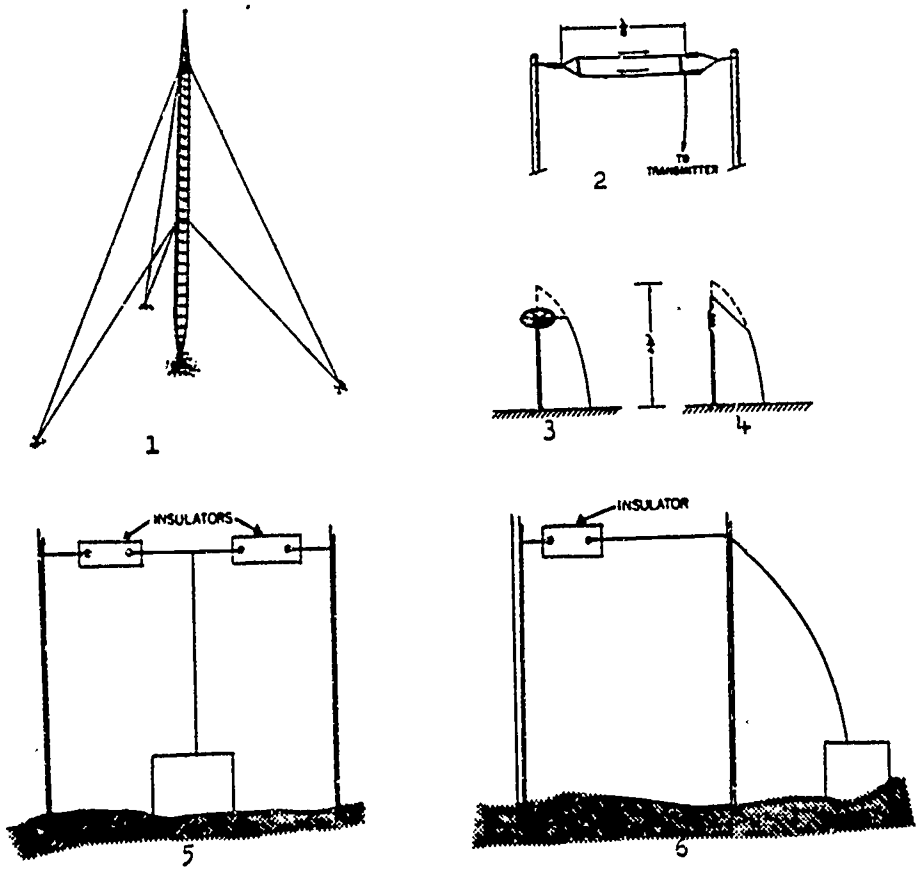
7. To obtain maximum radiation in the horizontal direction, you bend the spokes of the ground plane antenna to an angle of _____ below the horizontal plane.

   a. 15°
   b. 30°
   c. 50°
   d. 65°

8. The ground plane antenna is a whip antenna with a/an

   a. ground rod.
   b. effective artificial ground.
   c. elaborate counterpoise.
   d. buried radial system.

Questions 9 through 12 refer to the antenna illustrations.



9. Bent antenna

   a. 3 b. 6 c. 5 d. 4

10. Folded-top antenna

   a. 2 b. 3 c. 4 d. 5

11. Top-loaded antenna

   a. 6 b. 5 c. 4 d. 2

12. Tower radiated antenna

   a. 1 b. 3 c. 4

13. The inverted-L antenna is particularly useful for ______ propagation.

   a. ground wave
   b. sky wave
   c. duct
   d. troposcatter

14. Radiation produced by an inverted-L antenna is ______ that produced by a whip antenna of the same height.

a. less than b. greater than c. equal to

15. We fold the flattop of a bent antenna to

a. produce unidirectional radiation.
b. prevent ground currents.
c. produce current flow in one section only.
d. prevent horizontally polarized radiation.

16. How does top-loading affect the vertical antenna?

a. Decreases radiation resistance
b. Prevents harmonic radiation
c. Increases the effective length
d. Produces unidirectional radiation

17. What type of feeding is used with a noninsulated tower radiator?

a. Regenerative
b. Degenerative
c. Shunt
d. Series

18. What type of antenna is the Hertz?

a. Quarter-wave
b. Half-wave
c. Full-wave
d. Multiple-wave

19. A Hertz antenna consists of two conductors, each being a ______ in length.

a. full-wave b. half-wave c. quarter-wave

20. What is the direction of maximum radiation produced by the Hertz antenna?

a. Upward at vertical angle to plane of antenna
b. Along the earth's surface
c. Parallel to the antenna
d. Perpendicular to the antenna

21. A ground on an antenna can have the effect of either being

a. good or poor. b. excellent or fair. c. good or excellent.

22. A ground affected radiation pattern has a maximum reflection factor value of

a. 1
b. 2
c. 3
d. 4

23. If a horizontal Hertz antenna is located a half-wavelength above ground, and the vertical angle is 30°, what is the reflection factor?

a. 0
b. 1
c. 1.75
d. 2

24. When a horizontal half-wave antenna is mounted 2 wavelengths above ground, how many vertical lobes are produced?

a. 2
b. 4
c. 6
d. 8

25. A single-wire half-wave antenna is constructed of a single conductor wire of proper length and may be polarized either

a. electrically or manually.
b. vertically or horizontally.
c. as a stationary or mobile antenna.

26. What type of antenna is formed by adding additional elements in parallel with a half-wave antenna?

a. Coaxial
b. Inverted-L
c. Folded-dipole
(Single-wire

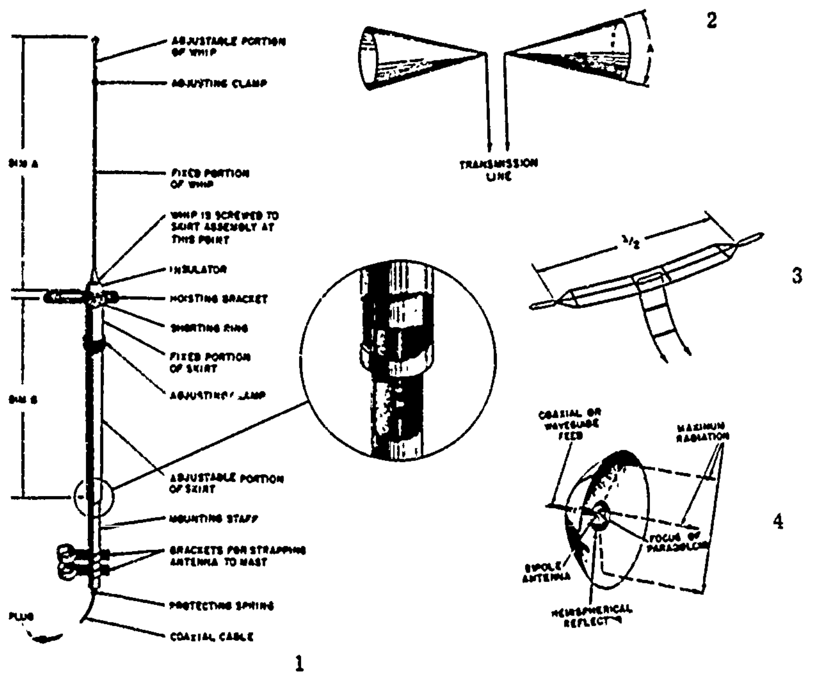
27. What component(s) of the coaxial antenna should be adjusted to change the frequency of operation?

a. Whip
b. Skirt
c. Either of the above
d. Both of the above

28. Why is a simple half-wave antenna seldom used in the microwave range?

a. Size is too great.
b. Signal pickup is poor.
c. Radiation resistance is too high.
d. Reflection factor is poor.

The antenna illustrations refer to questions 29 through 32.



29. Microwave antenna

a. 4 b. 3 c. 2 d. 1

30. Conical antenna

a. 1 b. 2 c. 3 d. 4

31. Folded-dipole antenna

a. 1 b. 2 c. 3 d. 4

32. Coaxial antenna

a. 4 b. 3 c. 2 d. 1

Total Points: 32

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ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

Lesson 4

Long-Wire Antennas and Antenna Installation

STUDY ASSIGNMENT: MCI 25.15b, Antenna Construction and Propagation of Radio Waves, chap 4.

WRITTEN ASSIGNMENT:

A. Multiple Choice: Select the ONE answer which BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate box.

Value: 1 point each

1. What is the length of a long-wire antenna?

   a. Quarter-wavelength
   b. Half-wavelength
   c. Shorter than a half-wavelength
   d. Longer than a half-wavelength

2. Two advantages long-wire antennas have over other antennas are

   a. construction and maintenance.
   b. polarization and construction.
   c. directivity and polarization.
   d. gain and directivity.

3. A long-wire antenna that has two or more half-waves of energy distributed along it is called a ______ antenna.

   a. Marconi
   b. Hertz
   c. harmonic
   d. nonharmonic

4. What is the length, in feet, of a 2-wavelength harmonic long-wire antenna operating at 20 MHz?

   a. 23.985
   b. 47.97
   c. 48.585
   d. 93.48

5. What is the length, in feet, of a 1-wavelength harmonic long-wire antenna operating at 30 MHz?

   a. 15.246
   b. 30.493
   c. 60.986
   d. 91.079

6. A current-fed antenna behaves as a true long-wire only at odd harmonics of the original frequency. Therefore, for operation on all harmonics, the best type of feeding is at the

   a. center of the antenna.
   b. odd harmonic on the antenna.
   c. end of the antenna.

7. If one end of an antenna is terminated in a resistance that is equal to the characteristic impedance of the antenna, waves can travel in one direction only and no standing waves are set up. This type antenna is known as a ______ antenna.

   a. resonant
   b. nonresonant
   c. matching

8. An antenna that is directional and is used primarily for either transmitting or receiving low-frequency signals is the ______ antenna.

a. Beverage   b. conical   c. coaxial

9. The radiation pattern for the V antenna is bidirectional, and occurs along

a. the left leg of the antenna.
b. the right leg of the antenna.
c. a line that bisects the apex angle of the legs.

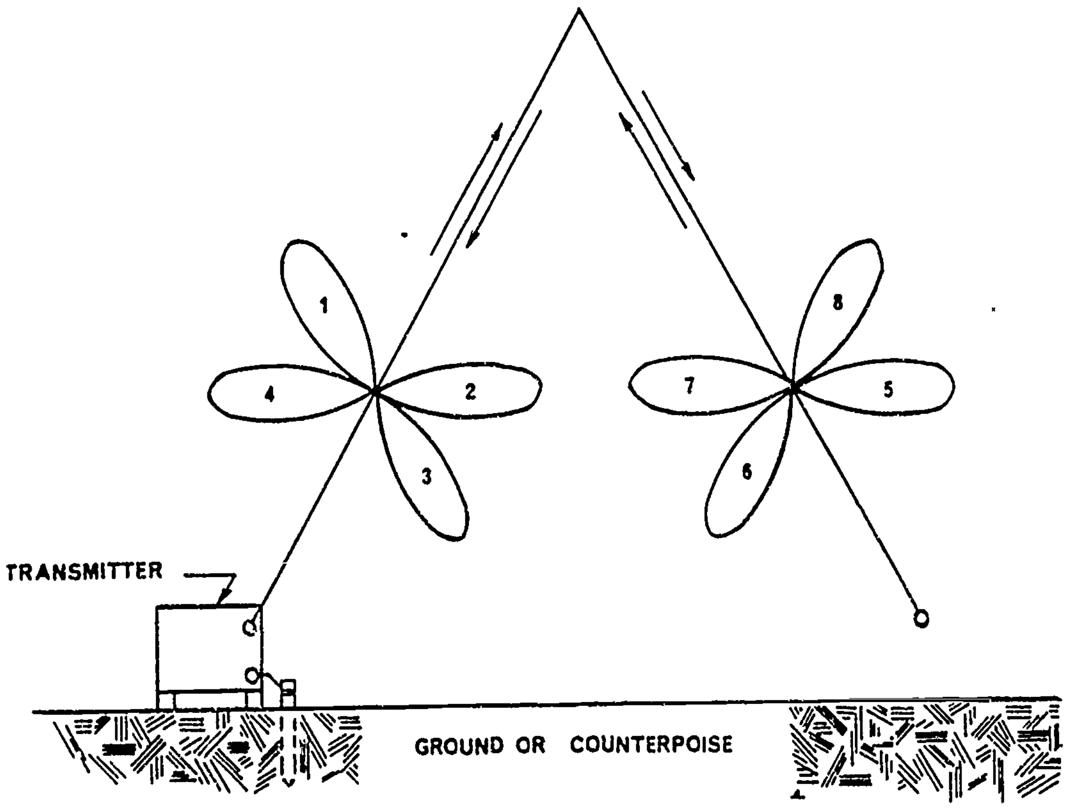
10. What would be the direction of maximum radiation produced by a terminated V antenna?

a. Along both legs
b. Toward the open mouth
c. Away from the open mouth

11. The half-rhombic antenna utilizes ______ polarization.

a. horizontal
b. vertical
c. circular
d. polar

Note: Questions 12 through 14 refer to the figure below.



12. What lobes of the half-rhombic antenna combine to form forward radiation?

a. 2 and 5   b. 4 and 7   c. 1, 3, 6, and 8

13. What lobes of the half-rhombic antenna combine to form rearward radiation?

a. 2 and 5   b. 4 and 7   c. 1, 3, 6, and 8

14. With the addition of a terminating resistor, what lobes combine to form strong forward radiation?

a. 2 and 5   b. 4 and 7   c. 1, 3, 6, and 8

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lsn 4; p. 2

15. A rhombic antenna consists of

  a. 1 half-rhombic mounted vertically.
  b. 2 long-wire V antennas mounted vertically.
  c. 3 conductors joined together in the shape of a triangle.
  d. 4 conductors joined together in the shape of a diamond.

16. What is the direction of maximum radiation produced by the rhombic antenna?

  a. At a vertical angle above the horizontal plane
  b. Perpendicular to the antenna
  c. Parallel to the antenna
  d. Along the earth's surface

17. A standard design rhombic antenna for military application operates in a frequency range of

  a. 2 to 30 MHz.
  b. 4 to 22 MHz.
  c. 4 to 30 MHz.
  d. 2 to 22 MHz.

18. To obtain desirable antenna sites, planning should always be preceded by a careful study of terrain maps and, whenever possible, by reconnaissance. Factors to be considered are size, availability, and

  a. accessibility to the site.
  b. location of the message center.
  c. drainage.

19. Increased distances can be covered when an antenna is located so that it overlooks

  a. dry ground.
  b. rocky terrain.
  c. water areas.
  d. heavy foliage.

20. A 30-foot antenna tower should be located at least ______ feet from powerlines.

  a. 30
  b. 60
  c. 90
  d. 120

21. To electrically raise the ground for use in transmitting radio waves a ______ is used.

  a. ground rod
  b. counterpoise
  c. salt solution
  d. saltpeter solution

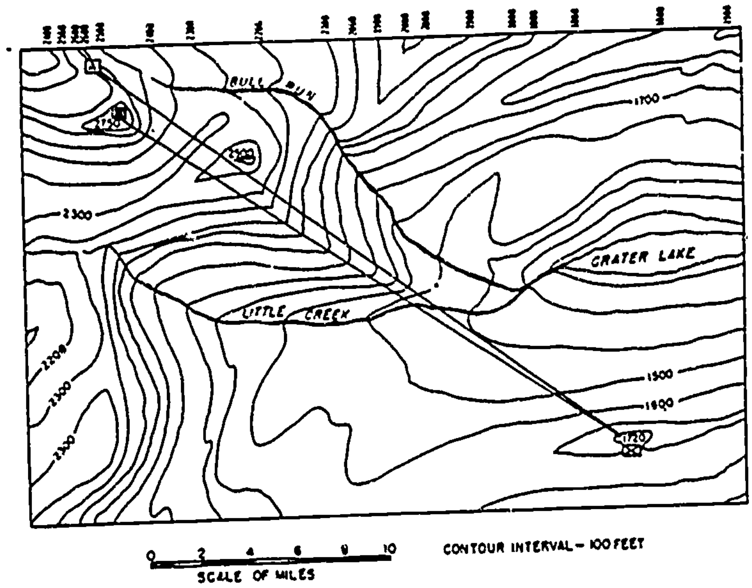
22. The long-wire,V, half- and full-rhombic antennas produce a radiation pattern that composes a relatively narrow beam. For maximum performance and efficiency, they require accurate

  a. erection.
  b. orientation.
  c. mechanical stability.

23. Two radio stations, each having a 32-foot antenna, could cover a maximum distance of_____ miles.

  a. 8
  b. 16
  c. 32
  d. 64

Note: Before you answer question 24 refer to the contour map below. Plot its profiles on the linear graph paper provided (next page) and apply the elevation corrections listed in table 4-1 in your MCI textbook.

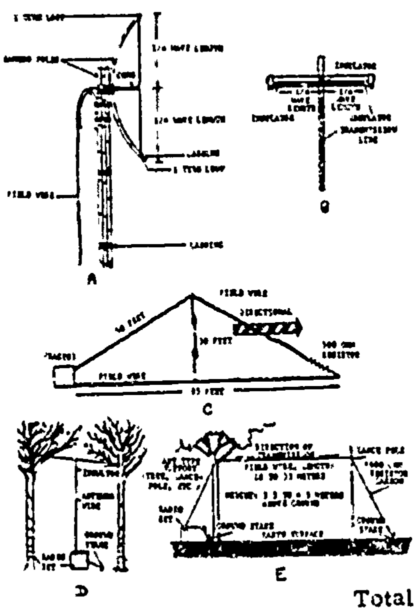


24. Refer again to the contour map above. Assume that two alternate transmission paths are proposed: point X to point A, and point X to point B. Fifty-foot antennas are utilized. Accordingly your plot of the profiles should show that

    a. both paths are unobstructed.
    b. only the path from point X to A is unobstructed.
    c. only the path from point X to B is unobstructed.
    d. both paths are obstructed.

B. Identification: The pictures of the field expedient antennas refer to questions 25 to 28. Identify the field expedient antenna by selecting the correct illustration. After the corresponding number on the answer sheet, blacken the appropriate box.

Value: 1 point each



25. Vertical antenna

26. Long-wire antenna

27. Half-rhombic antenna

28. Vertical half-wave antenna

Total Points: 28

* * *

(Plus 1 piece of graph paper)

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ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

Lesson 5

Radio Wave Propagation

STUDY ASSIGNMENT: MCI 25.15b, Antenna Construction and Propagation of Radio Waves, chap 5.

WRITTEN ASSIGNMENT:

A. Multiple Choice: Select the ONE answer which BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate box.

Value: 1 point each

1. The effect of the atmosphere on radio waves varies with the ______ of the transmitted wave.

   a. type of modulation
   b. polarization
   c. amplitude
   d. frequency

2. What frequency range, in Megahertz, is covered by vhf?

   a. Below 0.03
   b. 3.0 to 30
   c. 30 to 300
   d. 300 to 3,000

3. The three regions of the earth's atmosphere are troposphere, stratosphere, and

   a. jetstream.
   b. ionosphere.
   c. isothermal.

4. The stratosphere is located between ______ miles from the earth.

   a. 0-7
   b. 7-18
   c. 18-30
   d. 30-100

5. A smooth surface with good electrical conductivity will act as a(an)

   a. reflector.
   b. refractor.
   c. diffractor.
   d. insulator.

6. The angle of incidence of a radio wave is equal to the angle of

   a. refraction.
   b. reflection.
   c. diffraction.

7. In its paths of travel, the radio wave is altered by reflection, refraction, and

   a. rain.
   b. wind.
   c. diffraction.
   d. deflection.

8. A ground wave is composed of a surface wave, a ground-reflected wave, a direct wave, and a(an)

   a. ionospheric wave.
   b. tropospheric wave.
   c. troposcatter wave.
   d. stratospheric wave.

9. The field intensity of the ground wave depends on these factors: climatic conditions, nature of the transmission path, and the

   a. mineral properties of the terrain.
   b. reflection of the earth's curvature.
   c. characteristics of transmitting the radio wave.

10. The ground-reflected wave has a phase reversal of approximately

    a. 45°.
    b. 90°.
    c. 180°.
    d. 360°.

11. What method of polarization is best for surface wave transmission?

    a. Vertical
    b. Horizontal
    c. Polar
    d. Circular

12. Which condition causes refraction of a tropospheric wave?

    a. Temperature changes
    b. De-ionization
    c. Conductivity

13. At frequencies above 30 Megahertz, which ground wave component provides the best means of communication?

    a. Tropospheric
    b. Ground-reflected
    c. Direct
    d. Surface

14. Which band of frequencies is used for transoceanic communication?

    a. Vhf
    b. Hf
    c. Mf
    d. Lf

15. The area between a layer of hot dry air and a layer of cold moist air is called a(an)

    a. ionospheric layer.
    b. tropospheric duct.
    c. ionospheric disturbance.
    d. troposcatter region.

16. What is the primary use for troposcatter transmission?

    a. Uhf line-of-sight
    b. Uhf and shf microwave
    c. Lf multiple-hop
    d. Mf surface wave

17. The primary means of long-distance communications is through the use of ______ propagation.

    a. ground-wave
    b. subsurface
    c. sky wave
    d. transoceanic

18. How many distinct layers make up the ionosphere?

    a. 2
    b. 3
    c. 4
    d. 5

    Note: Questions 19 through 22 require you to identify the layer (a-e below) to which the respective statement applies.

    a. D
    b. E
    c. F
    d. F_1
    e. F_2

19. Is present at all times.

20. Is also known as the Kennelly-Heaviside region.

21. Most useful for long-distance communications.

22. Exists only during daylight hours.

23. The maximum frequency that can be propagated vertically into space is determined by the ______ of the F_2 layer.

a. temperature
b. moisture content
c. ionization density
d. altitude

24. The highest frequency that will be reflected by the ionosphere is called the

a. LUF.
b. FOT.
c. incidence frequency.
d. critical frequency.

25. The skip zone is equal to the

a. skip distance.
b. distance from the transmitter to the point where the first reflected wave returns.
c. skip distance minus the ground wave range.
d. skip distance plus the ground wave range.

Note: Questions 26 through 30 require you to identify the effect (a-c below) the indicated condition has on the maximum usable frequency.

a. Increase
b. Decrease
c. No effect

26. Increased sunspot activity.

27. Nighttime.

28. Ionospheric storm.

29. Formation of a sporadic E layer.

30. Predawn in winter.

31. The highest useful frequency reflected by the ionosphere is called the

a. MUF.
b. LUF.
c. FOT.

32. The degree of absorption in the D layer determines the

a. LUF.
b. MUF.
c. HUF.
d. FOT.

33. The lowest frequency that will return to earth from reflection of the ionosphere with enough strength to override the noise level is the

a. MUF.
b. LUF.
c. FOT.
d. critical frequency.

34. The FOT is normally selected to be ______% of the MUF.

a. 75
b. 85
c. 95
d. 100

35. The maximum angle at which the wave is reflected and returns to earth is the

a. maximum angle of incidence.
b. normal angle of incidence.
c. critical angle of incidence.

Total Points: 35

* * *

MCI 25.15b 22

ANTENNA CONSTRUCTION AND PROPAGATION OF RADIO WAVES

5-1

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23

SOURCE MATERIALS

FM 24-18	Field Radio Techniques, July 1965
MCO 5100.9B	Safety Precautions for the Installation and Use of Electronics Equipment, 31 Mar 71
NAVEDTRA 10086F	Basic Electricity, 1974
TM 11-666	Antennas and Radio Propagation, w/Ch 2, February 1960

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CONTENTS

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Chapter 1

BASIC ELECTRICITY

1-1. INTRODUCTION

a. Marines sometimes operate field radio equipment unaware of the vast electrical systems involved or of what happens when the transmitter is keyed. As long as the equipment operates properly and communications are established, the average operator tends to have little concern about what is actually taking place at the antenna. However, the situation may arise, and frequently does, where difficulty is encountered in establishing and maintaining good communications Therefore, an understanding of antenna operation, capabilities, and limitations is essential to determine and correct the problem area.

b. The word "electric" was used by the ancient Greeks to describe the forces of attraction and repulsion exhibited by amber after it had been rubbed with a cloth. Although the question "What is electricity?" has been baffling scientists for many years, they have developed productive theories by knowing what electricity does. The laws by which electricity operates are becoming more widely known and better understood. This chapter covers the principles of electricity that are basic to our explanation of antenna operation in the following chapters.

1-2. COMPOSITION OF MATTER

The objects that make up the world around us are said to be made of matter. Matter is defined as anything that has weight and takes up space. It may be found in three forms: liquids, solids, and gases. It is made up of electrons, protons, and neutrons, and exists in molecular form as atoms (fig 1-1).

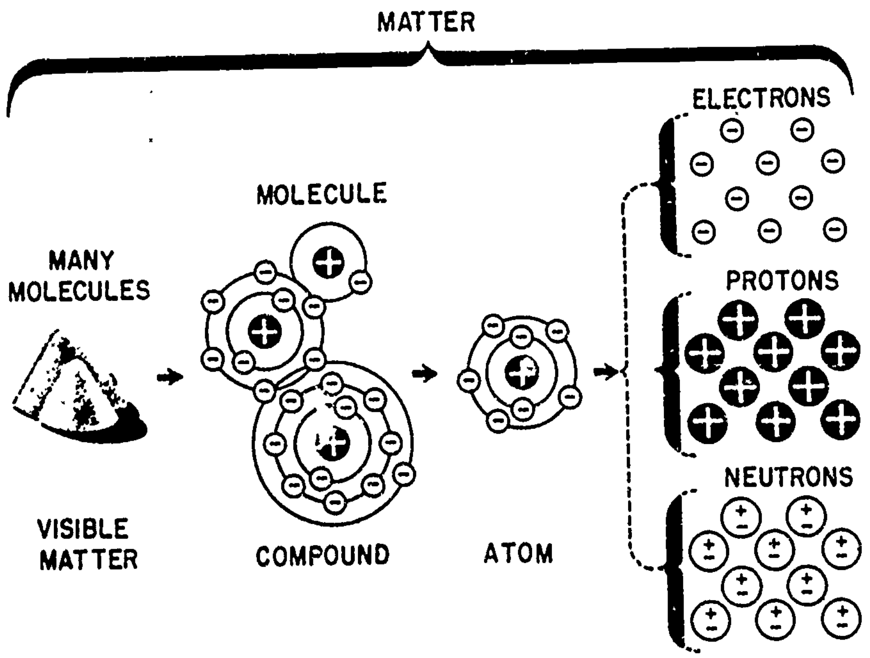


Fig 1-1. Composition of matter.

a. Molecule. If we take matter and break it down to the smallest particle that will still retain all the physical properties of the original matter, we have a molecule. For example, if a crystal of common salt were divided into very small particles, a point would be reached where no further division could be made that would leave the crystal in the form of salt. This ultimate particle of salt is called a molecule. Since salt is composed of sodium and chlorine, the salt molecule is the smallest physical form of this compound (or chemical union) of two elements.

b. Atom. The atom is the smallest particle that makes up that type of material called an element. The element retains its characteristics when subdivided into atoms.

Physicists have explored the interior of the atom and discovered many subdivisions in it. The core of the atom is called the nucleus. (It is comparable to the sun in our solar system, around which the planets revolve.) The nucleus contains protons (positively charged particles) and neutrons which are electrically neutral.

Most of the weight of the atom is in the protons and neutrons of the nucleus. Spinning around the nucleus are one or more smaller particles of negative electric charge. These are called electrons. Normally there is one proton for each electron in the atom. Thus the net positive charge of the nucleus is balanced by the net negative charge of the electrons spinning around the nucleus. Therefore, the atom is electrically neutral.

Electrons do not fall into the nucleus, even though strongly attracted to it, because of the centrifugal force of revolution.

The number of protons (usually the same as the number of electrons) determines the kind of element in question. Figure 1-2 shows a simplified diagram of several atoms of different materials based on the idea of planetary electrons describing orbits about the nucleus.

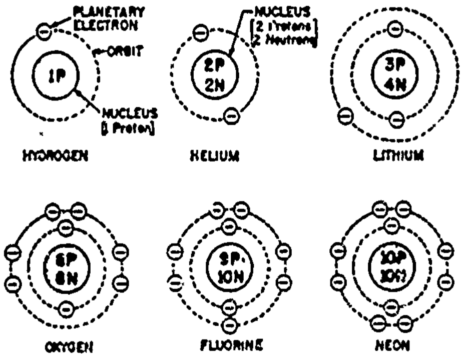


Fig 1-2. Atomic structure.

For example, hydrogen has a nucleus consisting of one proton with one electron rotating around it. The helium atom has a nucleus consisting of two protons and two neutrons with two electrons rotating about it.

The electrons in the outer orbits of certain elements are easily separated from their parent atoms. Electrons have many important characteristics. The weight of an electron is very small compared with that of a proton or neutron (approximately 1/1845). The electron has a weight of 9×10^{-28} gram and a negative charge of 1.6×10^{-19} coulomb. These two characteristics make the electron an extremely active particle with many possibilities for practical use.

c. Ionization. When an atom is in its normal state, its internal energy is at a minimum. If this energy is raised above normal, the atom is said to be excited. Excitation may be produced in many ways, such as collision with high-speed positive or negative particles which may give up all or part of their energy to the atom during the collision. The excess energy absorbed by an atom may be sufficient to cause loosely bound outer electrons to leave the atom. An atom that has lost or gained one or more electrons is said to be ionized. If the atom loses electrons, it becomes positively charged, and is referred to as a positive ion. Conversely, if it gains electrons, it becomes negatively charged, and is called a negative ion. Thus, an ion is a small particle of matter having a net positive or negative charge.

1-3. CONDUCTORS AND INSULATORS

a. Conductors. Materials that allow free motion of a large number of electrons are called conductors. Electrical energy is transferred through conductors by means of the movement of free electrons that move from atom to atom inside the conductor. Each electron moves to the neighboring atom where it replaces one or more electrons by forcing them out of their orbits. The replaced electrons repeat the process in other nearby atoms until the movement is transmitted throughout the length of the conductor. A good conductor is said to have low opposition or low resistance to current (electron) flow. Copper, silver, and aluminum are good conductors.

b. Insulators. Materials which require large amounts of energy to be expended in order to break electrons loose from the attraction of the nucleus are called insulators. Some such materials are rubber, glass, mica, and dry wood.

1-4. BASIC LAW

One of the basic laws of electricity is that like charges repel and unlike charges attract. Therefore, there is a force of attraction in the atom between the nucleus and the electrons revolving about it.

The word static means "standing still" or "at rest." Static electricity was formerly considered electricity at rest because the experimenters of long ago believed that electrical energy produced by friction did not move.

A simple experiment can easily produce static discharges. If a dry non-metallic comb is run vigorously through the hair several times and a cracking sound is heard, it indicates static discharges are taking place. Charges are first built up on the hair and the comb by the transfer of electrons from one to the other caused by the friction between them. The discharge is the rapid movement of electrons in the opposite direction from the comb to the hair as the charges try to neutralize each other.

a. Charged bodies. In the above experiment strands of hair may stand out at angles because the loss of electrons has caused the hair to become positively charged and like charges repel each other. Conversely, the comb has gained electrons and thus acquired a negative charge.

If the negatively charged comb is held near a piece of paper, the paper will be attracted to it and will cling for a short time. The negative charge on the comb will repel free electrons on the paper to the far side, leaving the side nearest the comb positively charged. Unlike charges attract; therefore, the paper is drawn into contact with the comb. During this contact some of the excess electrons move from the comb to the paper, giving the paper a negative charge. Thus the paper is first attracted to the comb and then repelled by it.

In summary, a charged body is one that has more or less electrons than the normal number of protons. It may be positively or negatively charged. A positively charged body has a deficiency of electrons whereas a negatively charged body has an excess of electrons.

b. Coulomb's law of charges. As noted, charged bodies attract each other when they have unlike charges and repel each other when they have like charges. The forces of attraction and repulsion, stated in newtons, change with the magnitude of the charges and also with the distance between them. This relation is stated in Coulomb's law of charges: charged bodies attract or repel each other with a force that is directly proportional to the product of the charges on the bodies and inversely proportional to the square of the distance between them.

The charge on one electron or proton might be used as the unit of electric charge, but it would be impractical because of its very small magnitude. The practical unit of charge is the coulomb.

1-5. ELECTRIC CURRENT

a. Free electrons. When an electron is removed from its orbit, it is referred to as a free electron. Some electrons of certain metallic atoms are so loosely bound to the nucleus that they are comparatively free to move from atom to atom. Therefore, a very small force or amount of energy will cause them to be removed from the atom and become free electrons. Such electrons make up the flow of an electrical current in electrical conductors. The space between and around charged bodies in which their influence is felt is called an electric field of force. The electric field requires no physical or mechanical connecting link. It can exist in air, glass, paper, or a vacuum. Electrostatic field and dielectric field are other names for this region of force.

Electric fields of force extend into the space surrounding their point of origin, and decrease in proportion to the square of the distance from their source. The electric field is related to the gravitational field that penetrates the space surrounding the earth, and acts through free space to cause all unsupported objects in that region to fall to the earth. Newton discovered the law of gravity which states that every object attracts every other object with a force that is directly proportional to the product of the masses of the objects and inversely proportional to the square of the distance between them.

Note the similarity between the law of gravity and the law of attraction of charged bodies. The gravitational fields hold the universe together, for with no gravitational field the planets would fly off into space rather than revolve around the sun. Similarly, electrons revolving around the positive nucleus of the atom are held in their orbits by the force of attraction of the positive nucleus. Thus, a field of force must exist between electrons and nucleus.

In diagrams, lines are used to represent the direction and intensity of the electric field of force. The intensity of the field (field strength) is indicated by the number of lines per unit area (density), and the direction is indicated by arrowheads on the lines pointing in the direction in which a charge will move when acted on by the field of force.

Arbitrarily it has been agreed to use a small positive charge for determining the direction of the field. The test shows that the direction of the field about a positive charge is away from the charge because a positive test charge is repelled, and that the direction about a negative charge is toward the charge because the positive test charge is attracted toward it. Therefore, (as in fig 1-3) the direction of the field between the positive and the negative charges is from positive to negative.

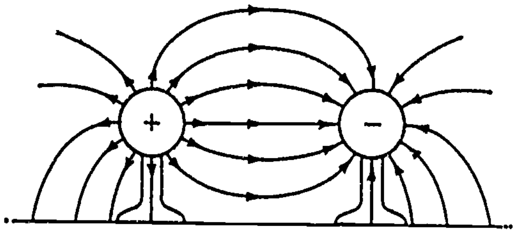


Fig 1-3. Direction of electric field about positive and negative charges.

The electric field about like charges is shown in figure 1-4. Note that the lines of force repel each other.

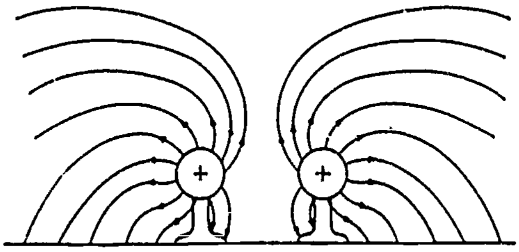


Fig 1-4. Electric field between two positively charged bodies.

In both figures 1-3 and 1-4, the lines terminate on material objects and extend from a positive charge to a negative charge. They are regarded as imaginary lines in space along which a real force acts. In both examples, the direction in which the force acts is that in which a positive test charge placed in the field will move, that is, from the positive charge to the negative charge.

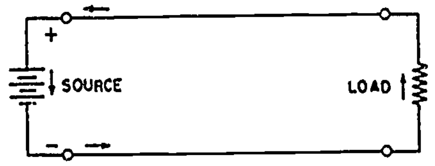


Fig 1-5. Current (electron) flow in a circuit.

b. Current. The free electrons in a conductor are moving constantly and changing positions in a vibratory manner. If a source of supply (battery or d.c. generator) is connected to the two ends of an electric circuit (fig 1-5), the free electrons begin to move along the wires in one direction around the circuit. The direction of current flow is considered to be out from the negative terminal of the source, up through the load, and back to the positive terminal. The flow of electrons through the circuit is called an electric current. To determine the amount of current, the unit, ampere, has been adopted. It is named after Andre Ampere who discovered the relation between the direction of current in a wire and the direction of the magnetic field around it. The symbol for ampere is I. A current flow of 1 ampere is equivalent to the flow of 6.28×10^{18} electrons past a fixed point.

A standard unit of electricity is moved through an electric circuit when 1 ampere of current flows for 1 second. This standard unit is equivalent to 6.28×10^{18} electrons. It is called the coulomb, and its symbol is Q. The rate of current flow in amperes and the quantity of electricity moved through a circuit are related by the common factor of time. Thus, the quantity of electric charge, in coulombs, moved through a circuit is equal to the product of the current in amperes, I, and the duration of current flow in seconds, t. Expressed as an equation, $Q = It$. For example, if a current of 2 amperes flows through a circuit for 10 seconds, the quantity of electricity moved through the circuit is $2 \times 10 = 20$ coulombs.

1-6. ELECTROMOTIVE FORCE

a. Force. The force that causes free electrons to move in a conductor as an electric current is called electromotive force, voltage, or difference in potential. When a difference in potential exists between two charged bodies connected by a conductor, electrons will flow along the conductor from the negatively charged body to the positively charged body until the two charges are equalized and the potential difference no longer exists. An example of this action is shown in the two water tanks connected by a pipe and valve in figure 1-6. At first the valve is closed and all the water is in tank A. Thus, the water pressure across the valve is maximum. When the valve is opened, water flows through the pipe from A to B until the water level becomes the same in both tanks. Then the water stops flowing because there is no longer a difference in water pressure between the two tanks.

b. Current flow. Current flow through an electric circuit is directly proportional to the difference in potential across the circuit, just as the flow of water through the pipe in figure 1-6 is directly proportional to the difference in water level in the two tanks.

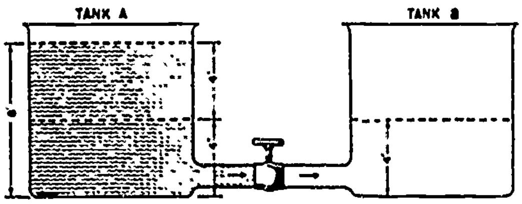


Fig 1-6. Water example of difference in potential.

The usual means of obtaining a voltage are batteries and generators. The unit of electric pressure is the volt, named after Alessandro Volta, who invented the first electric battery.

Note: A fundamental law of electricity is that the current is directly proportional to the applied voltage.

1-7. RESISTANCE

a. Definition. Electrical resistance is that quality of a substance that opposes current flow through it. The simple electric circuit of figure 1-5 has resistance to a varying degree in all parts of it, that is, in the source, in the load, and in the connecting wires. The size and material of the wires are such as to keep the resistance low so that current can flow as easily through them as water flows through the pipe between the tanks in figure 1-6 when the valve is opened. If the water pressure remains constant, the flow of water will vary with the opening of the valve. The smaller the opening, the greater the opposition to the flow, and the smaller the rate of flow.

In an electric circuit, the larger the diameter of the wires the lower will be their electrical resistance to the current flow through them. In the water example, pipe friction opposes the flow of the water between the tanks. The resistance of the pipe depends on its length, diameter, and the nature of its inside walls. Similarly, the electrical resistance of conductors depends on the length, diameter, and material of the wires. The symbol for resistance is R, and it is measured in ohms.

b. Temperature. Temperature also affects resistance. In most conductors (copper, aluminum, iron, etc.) resistance increases with temperature. Carbon is an exception. Its resistance decreases with an increase in temperature.

1-8. MAGNETS

a. Substance. A substance is said to be a magnet if it has the property of magnetism, that is, the ability to attract such substances as iron, steel, nickel, or cobalt, which are known as magnetic materials. A magnet exhibits two points of maximum attraction (one at each end or "magnetic pole"), but no attraction at its center. If a magnetized needle is suspended so that it rotates freely in a horizontal plane about its center, it will come to rest in approximately a north-south line of direction, with the same pole always pointing north. The magnetic pole that points north is called the north pole and the other, the south pole.

A magnetic field exists around a simple bar magnet. The field consists of imaginary lines along which a magnetic force acts. These lines flow from the north pole of the magnet and enter the south pole, returning to the north pole through the magnet itself, thus forming closed loops as shown in figure 1-7.

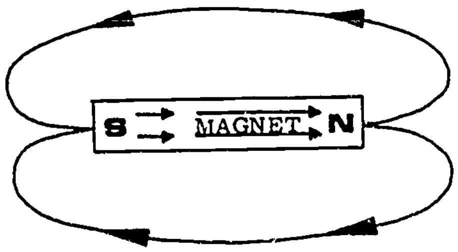


Fig 1-7. Lines of force in a bar magnet.

b. Groups of magnets. Magnets may be divided into three groups: (1) natural magnets, found in a natural state in the form of a mineral called magnetite; (2) permanent magnets, bars of hardened steel or some form of alloy (such as alnico) that have been permanently magnetized; and (3) electromagnets, composed of soft-iron cores around which coils of insulated wire are wound (fig 1-8.)

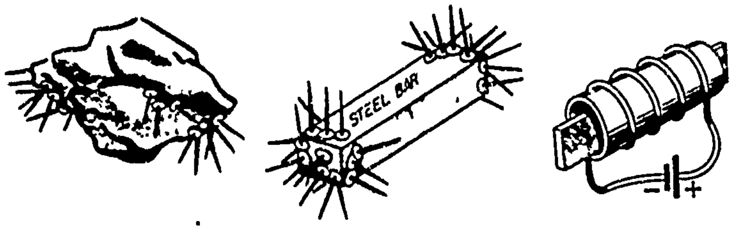


Fig 1-8. Three types of magnets.

1-9. NATURE OF MAGNETISM

Weber's theory of the nature of magnetism is based on the assumption that each of the molecules within a magnet is in itself a tiny magnet. The molecular magnets that make up an unmagnetized bar of iron or steel are arranged at random (fig 1-9A). In this arrangement, the magnetism of each of the molecules is neutralized by that of adjacent molecules, and no external magnetic effect is produced. When a magnetizing force is applied to an iron or steel bar, the molecules become alined so that the north poles point in one direction and the south poles point in the opposite direction (fig 1-9B).

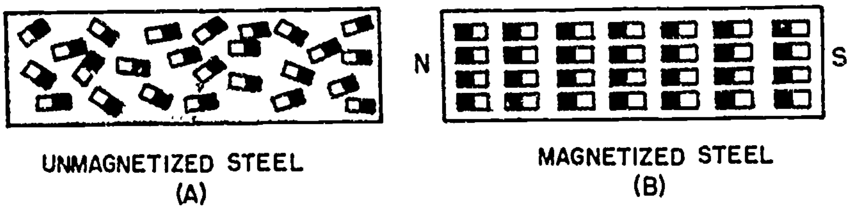


Fig 1-9. Molecular theory of magnetism.

If a bar magnet is broken into several parts (as in fig 1-10), each part constitutes a complete magnet. The north and south poles of these smaller magnets are in the same respective positions as in the original bar magnet. If this breaking process is repeated, smaller and smaller pieces would retain their magnetism until each was reduced to a molecule. Therefore, it is logical to assume that each of these molecules is in itself a magnet.

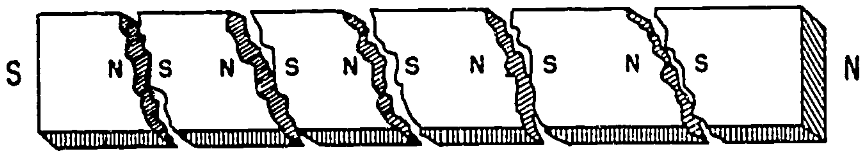


Fig 1-10. Magnetic poles in a broken magnet.

a. Magnetic fields and lines of force. As mentioned (para 1-8), the ends of the magnet where the attractive force is the greatest are called the poles. By using a compass, the line of direction of the magnetic force at various points near the magnet may be observed. The compass needle itself is a magnet. The "N" end of the compass needle always points toward the south pole (S, in fig 1-11), and thus a sense of direction is also indicated. At the center, the compass needle points in a direction that is parallel to the bar magnet.

When the compass is placed successively at several points near the bar magnet, the compass needle alines itself with the field at each position. The direction of the field is indicated by arrows, and represents the direction in which the north pole of the compass needle will point when placed in this field. A line along which a compass needle alines itself is called a magnetic line of force. As mentioned previously, the magnetic lines of force are assumed to flow from the north pole, pass through space, and enter the south pole. Then they pass from the south pole to the north pole inside the magnet to form a closed loop. Each line of force forms an independent closed loop, and does not merge with or cross other lines of force.

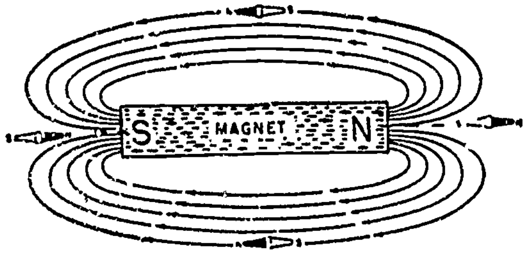


Fig 1-11. Magnetic lines of force.

The space surrounding a magnet, in which the magnetic force acts, is called a magnetic field. Michael Faraday was the first scientist to visualize the magnetic field as being in a state of stress and consisting of uniformly distributed lines of force. The entire quantity of magnetic lines surrounding a magnet is called magnetic flux. Flux in a magnet corresponds to current in an electric circuit.

The number of lines of force per unit area is called flux density, and is measured in lines per square inch or per square centimeter. Flux density is expressed by the equation $B = \frac{\Phi}{A}$. B is the flux density, Φ (Greek phi) is the total number of lines of flux, and A is the cross-sectional area of the magnetic circuit.

A visual representation of the magnetic field of a magnet can be obtained by placing a plate of glass over a magnet and sprinkling iron filings onto the glass. The filings arrange themselves in a pattern of definite paths between the poles (fig 1-12).

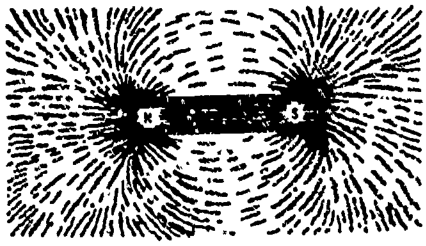


Fig 1-12. Magnetic field around a bar magnet.

b. Laws of attraction and repulsion. If a magnetized needle is suspended near a bar magnet as in figure 1-13, it will be seen that a north pole repels a north pole and a south pole repels a south pole. However, opposite poles will attract each other. Thus, the first two laws of magnetic attraction and repulsion are: Like magnetic poles repel each other. Unlike poles attract.

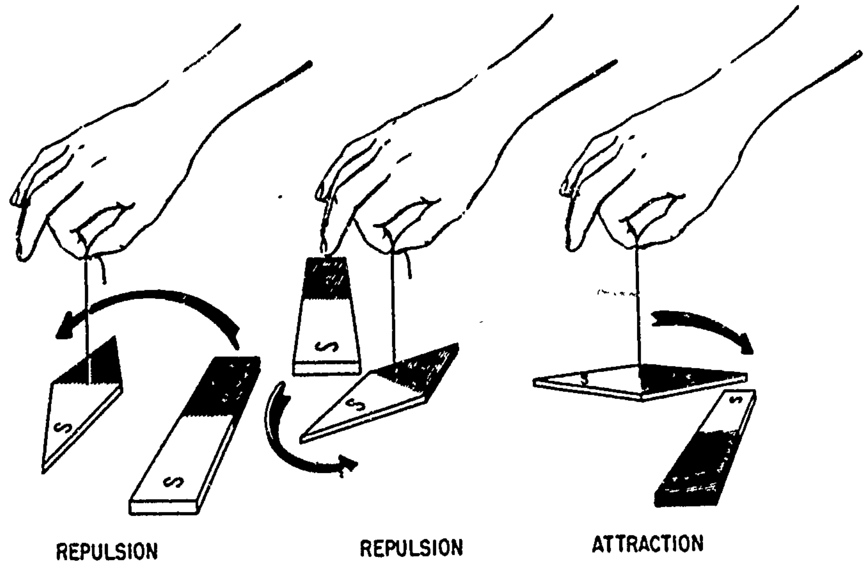


Fig 1-13. Laws of attraction and repulsion.

The flux patterns between adjacent unlike poles of bar magnets, as indicated by lines, are shown in figure 1-14A. Similar patterns for adjacent like poles are shown in figure 1-14B. The lines do not cross each other at any point, and they act as if they repel each other.

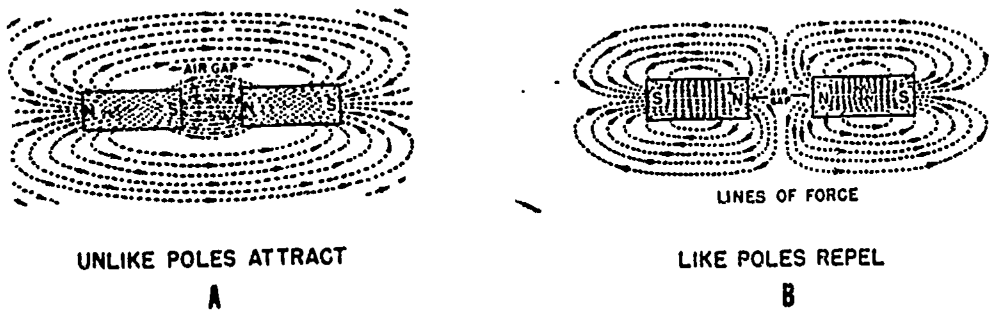


Fig 1-14. Lines of force between unlike and like poles.

Figure 1-15 shows the flux pattern around two bar magnets placed close together and parallel with each other. Figure 1-15A shows the flux pattern when opposite poles are adjacent, and figure 1-15B, the pattern when like poles are adjacent.

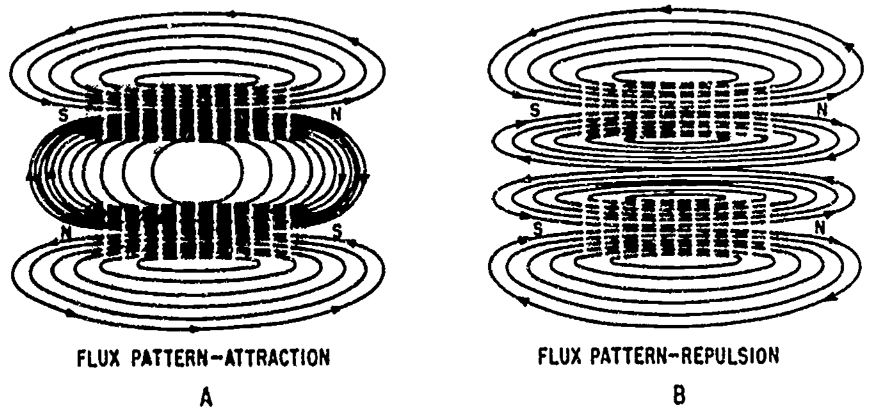
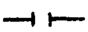


Fig 1-15. Flux patterns of adjacent bar magnets.

The third law states that the force of attraction or repulsion varies directly as the product of the separate pole strengths, and inversely as the square of the distance separating the magnetic poles. For example, if the distance between two north poles is increased from 2 feet to 4 feet, the force of repulsion between them is decreased to one-fourth of its original value. If either pole strength is doubled and the distance remains the same, the force between the poles will be doubled.

1-10. SYMBOLS

The following are some symbols used in this course:

Symbol	Meaning
	d. c. power source; battery
	a. c. power source; generator
	resistor; resistance is stated with the letter R
	coil; inductance is stated with the letter L
	capacitor; capacitance is stated with the letter C

Chapter 2

ANTENNA AND TRANSMISSION LINE FUNDAMENTALS

2-1. ELECTROMAGNETIC FIELD

a. Magnetic field. In 1819, Hans Christian Oersted, a Danish physicist, discovered that a definite relation exists between magnetism and electricity. He noted that an electric current is accompanied by certain magnetic effects and that these effects obey definite laws. If a compass is placed near a current-carrying conductor, the needle alines itself at right angles to the conductor, indicating the presence of a magnetic force. This force can be demonstrated by passing an electric current through a vertical conductor which passes through a horizontal piece of cardboard, as shown in figure 2-1. The magnitude and direction of force are determined by setting a compass at various points on the cardboard and noting the deflection. The direction of the force is assumed to be in the direction of the north pole. These deflections show that a magnetic field exists in circular form around the conductor. When the current flows upward, the field direction is clockwise, as viewed from the top; but if the polarity of the supply is reversed so that the current flows downward, the direction of the field is counterclockwise.

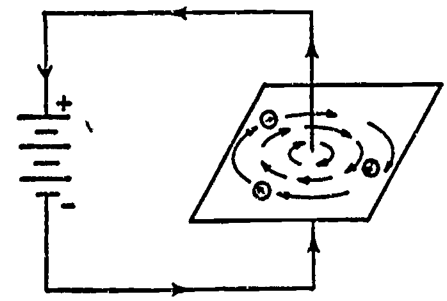


Fig 2-1. Magnetic field about a current-carrying conductor.

The relationship between the direction of the magnetic lines of force around a conductor and the direction of current flow in the conductor may be determined by the left-hand rule for a conductor. If the conductor is grasped with the thumb extended in the direction of electron flow, the fingers will point in the direction of the magnetic lines of force as illustrated in figure 2-2.

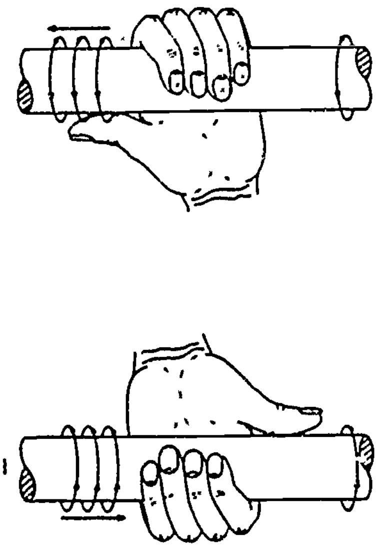


Fig 2-2. The left-hand rule.

b. Magnetic field strength. Figure 2-3 illustrates what happens to the strength of the magnetic or "H" field as the current flow through the conductor is varied and the distance of the meter from the conductor is held constant.

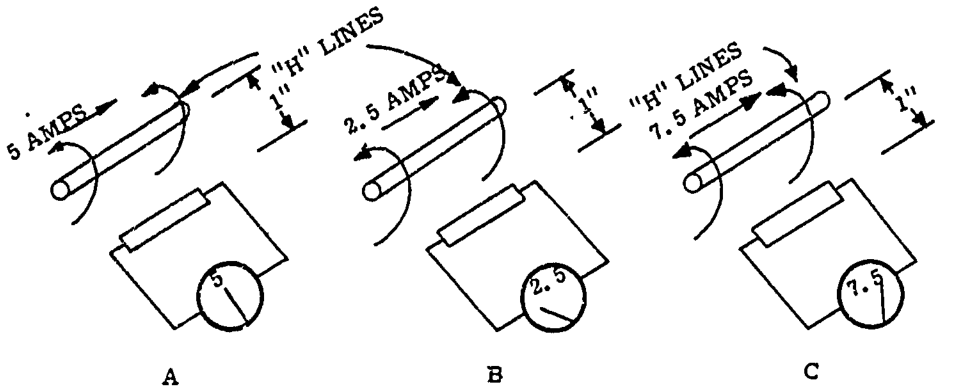


Fig 2-3. Effects on the "H" field as current through the conductor is varied.

With a current of 5 amperes flowing in the conductor and the meter placed 1 inch from the conductor, we have a meter reading of 5, as shown in figure 2-3A. If the current flow is decreased to 2.5 amperes (fig 2-3B), the meter also decreases to 2.5. In figure 2-3C, as the current is increased to 7.5 amperes, the meter reading also increases to 7.5. Thus, the strength of the "H" field is directly proportional to the current flow through the conductor.

As the point of measurement is varied, a different effect takes place. In figure 2-4A, we begin with the original condition of 5 amperes through the conductor and the meter placed 1 inch from the conductor. The meter reading is 5. As shown in figure 2-4B, the current is held constant at 5 amperes and the distance is increased to 2 inches. The meter reading decreases to 1.25. The distance has been doubled, but the meter reading has decreased to one-fourth of its original value. If we increase the distance to 3 inches, the meter reading is now 0.55. The distance has been tripled, but the meter reading has decreased to one-ninth its original value. Thus, the strength of the "H" field varies inversely with the square of the distance from the conductor.

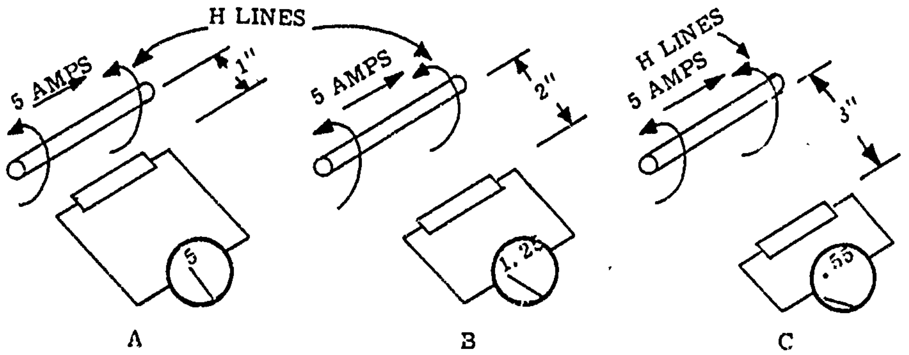


Fig 2-4. Effects on the "H" field as the distance from the conductor is varied.

c. Electric field. Surrounding every electrically charged body is a field of force. When a body is electrically charged, there is a greater or lesser concentration of electrons than normal. Thus, a difference in potential exists. An electric field is therefore associated with a difference in potential.

With the use of two conductors in our circuit of figure 2-5A, we have a form of capacitor. A capacitor is any two conductors which are separated by a dielectric. Thus, with our two conductors and the air between them serving as the dielectric, we have a capacitor.

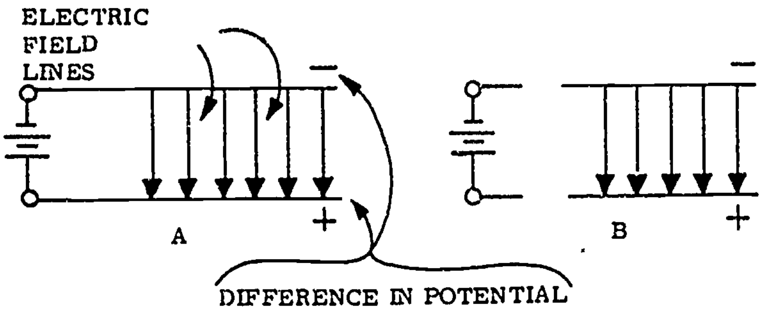


Fig 2-5. Electric field between capacitor plates.

Since the top wire in figure 2-5A has a negative polarity in respect to the bottom wire, a difference in potential exists. An electric field is associated with this difference in potential.

In figure 2-5B, the capacitor is charged and the source voltage removed. The capacitor remains in its charged state. Thus, electric lines of force exist between the two conductors.

In figure 2-6, if we gradually open the two conductors until they are vertical, the electric field now covers a greater area.

d. Electric field strength. In measuring the strength of the electric or "E" field, we will notice that a different action takes place as compared with measuring the magnetic field strength as the distance is varied.

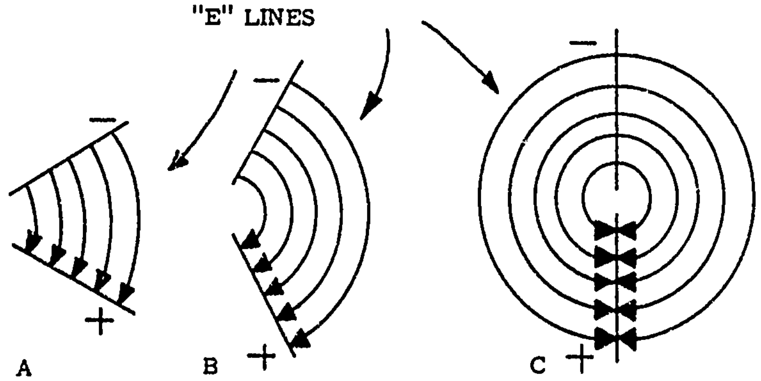


Fig 2-6. Open electric field.

In figure 2-7A, there are 6 amperes flowing in the conductor, and the meter is 1 inch from the conductor. The meter reads 6. If we increase the distance to 2 inches, as shown in figure 2-7B, the meter reading decreases to 3, only half its original value. In figure 2-7C, the meter is placed 3 inches from the conductor. Now it reads 2. This is one-third its original value. Thus, it can be seen that the strength of the "E" field is inversely proportional to the distance from the source.

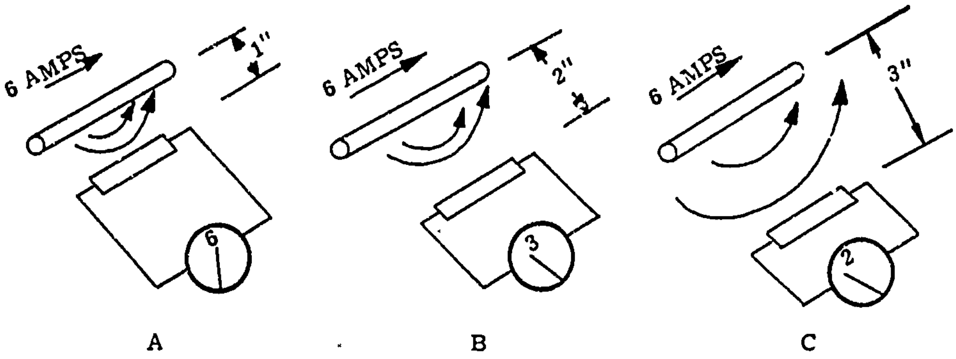


Fig 2-7. Effects on the "E" field as the distance from the conductor is varied.

From the preceding discussion we can see that there are two components of the electromagnetic field: the magnetic field and the electric field (fig 2-8). The diagram shows opposite charges applied to the ends of a conductor. Here the battery in figure 2-5 has been replaced by an a.c. generator, which will create continuously alternating charges; however, the action has been stopped in the diagram to show the fields created by instantaneous charges.

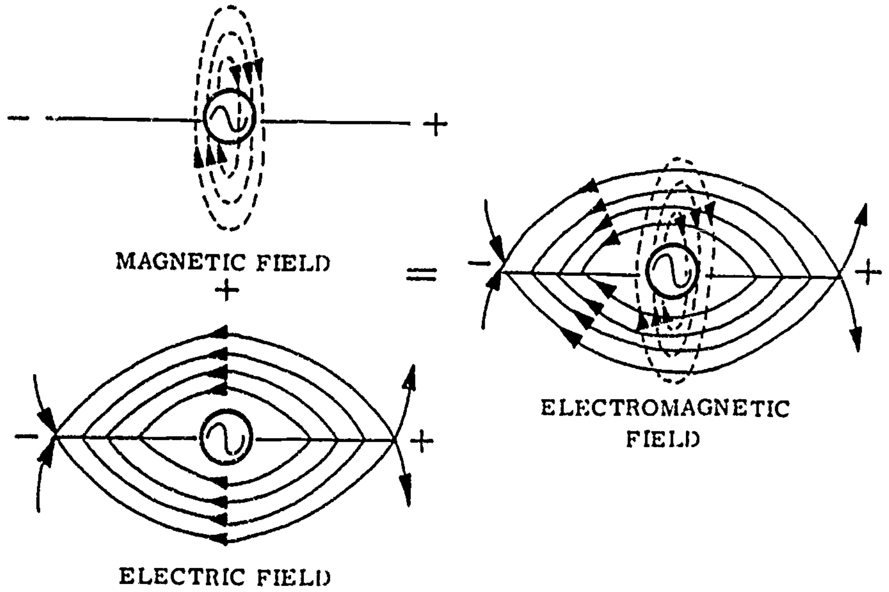


Fig 2-8. Components of the electromagnetic field.

Now we shall consider the action of both the magnetic and the electric fields, as shown in figure 2-9. There we can see that the two fields are at right angles to each other, and that in A of the figure maximum current is flowing upward in our two conductors. This current induces an

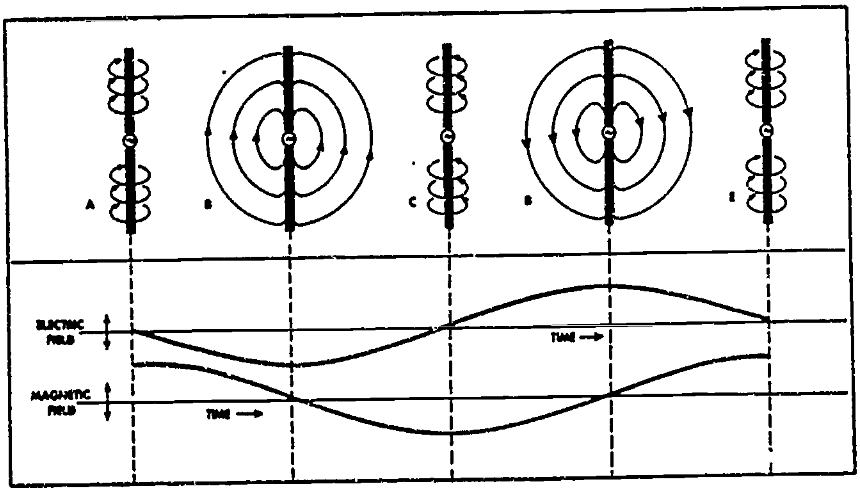


Fig 2-9. Comparison of the "E" and "H" fields.

intense magnetic field around the conductors. Current flow decreases with time, and the difference in potential between the conductors increases. Thus, the magnetic-field strength decreases and the electric-field strength increases. In figure 2-9B, current flow has instantaneously stopped, and the difference in potential between the conductors is maximum This action causes the magnetic field to fall to zero and the electric field to increase to maximum. In figure 2-9C, the generator polarity has reversed. Now maximum current is flowing downward in the two conductors, and there is no difference in potential between them. This sets up a magnetic field of maximum intensity in the opposite direction of figure 2-9A, and the strength of the electric field falls to zero. The current is decreasing, causing the magnetic field to decrease. As a result, the difference in potential is increasing, and the electric field is increasing in strength. In figure 2-9D, the current flow has instantaneously stopped and the strength of the magnetic field is zero. At this time, a maximum difference in potential exists between the two conductors, and the strength of the electric field is at maximum in the opposite direction of figure 2-9B. In figure 2-9E, the hertz (cycle) has been completed and starts again, as in figure 2-9A. We can see that the magnetic and electric fields reach their maximum and minimum values a quarter of a hertz apart. Thus, the two fields are at right angles to each other and 90° out of phase with each other. They are said to be in space and time quadrature.

2-2. ANTENNA THEORY

Since an electromagnetic field can be produced by a current-carrying conductor, we can use this conductor in the form of an antenna--a device for transferring electromagnetic energy into free space.

When an RF (radiofrequency) current flows through a transmitting antenna, electromagnetic energy is radiated from the antenna in the form of radio waves that travel in much the same way as waves do on the surface of a lake into which a rock has been thrown. Radio waves travel at the speed of light--186,000 miles (300 million meters) per second. The frequency of the radiated radio wave equals the frequency of the RF current.

a. Wavelength. Since the velocity of the radio wave is constant, we simply divide the velocity by the frequency of the wave to determine the wavelength. Stated in equation form:

$$\lambda = \frac{300,000,000}{f}$$

λ in meters is the symbol for wavelength; 300, 000, 000 is the velocity of the radio wave in meters per second; and f, the radio wave frequency in hertz (cycles per second). With this formula we can determine the proper wavelength of the conductors used in our antenna.

b. Physical length. Calculate the physical length of an antenna at approximately 5% less than the electrical length (wavelength) to compensate for the capacitance existing in the material used to construct the antenna. For a half-wave antenna the formula is

$$L = \frac{468}{f}$$

L is the length of one-half wavelength in feet, and f is the frequency of the radio wave in Megahertz (MHz). This formula does not apply to antennas longer than one-half wavelength. Calculations for other types of antenna will be shown in following chapters.

c. Basic antenna (dipole theory). If we attach two conductors to the terminals of an RF generator so that each conductor is one-quarter wavelength long at the generator frequency, we construct a type of antenna commonly known as a dipole (fig 2-10A).

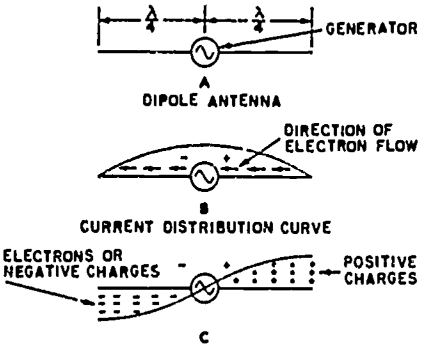


Fig 2-10. Voltage and current distribution of a dipole antenna.

At one instant, the generator is of the polarity shown. Since like charges repel, electrons will flow away from the negative terminal while the positive terminal will attract electrons (fig 2-10B). The curve indicates that current flow is maximum at the center and zero at the ends. This current produces the magnetic or "H" field.

Figure 2-10C shows the difference in potential near the ends of the antenna to be maximum. Since like charges repel, most of the charges are trying to get as far away from the generator terminals as possible. Thus, there is maximum accumulation of electrons at the left end of the antenna and a minimum at the right end. Our electric or "E" field is associated with this difference in potential.

When the generator reverses polarity, the magnetic and electric fields collapse and then build up in the opposite direction. This cycle will continue at a rate dependent on the frequency of the generator voltage.

From the foregoing discussion, it can be seen that the fields about a dipole antenna are in constant motion.

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2-3. RADIATION

a. Basic theory. The exact manner in which the electrical energy leaves the antenna is a highly complex operation. The complete explanation would involve the use of advanced mathematics, which is beyond the scope of this manual. Our coverage is limited to a description of the manner in which energy loops are formed, and the path they travel upon leaving the antenna.

(1) Consider the electric field as previously discussed. It is at highest intensity when maximum difference in potential exists between the ends of the antenna (fig 2-11A). As the output of the RF generator decreases, the charges built up at the ends of the antenna move toward the center and the "E" field begins to decrease in intensity (fig 2-11B). The collapsing "E" field causes the "E" lines near the ends of the antenna to move along the surface of the conductor toward the center. Since "E" lines repel other "E" lines, the center of the field is forced outward. Finally, the repulsion effect is great enough that the "E" lines form an energy loop and break away from the conductor (fig 2-11C). When the RF generator reverses polarity, "E" lines begin to build up in the opposite direction (fig 2-11D). This new "E" field causes the energy loop that has broken free to be repelled still farther into space (fig 2-11E).

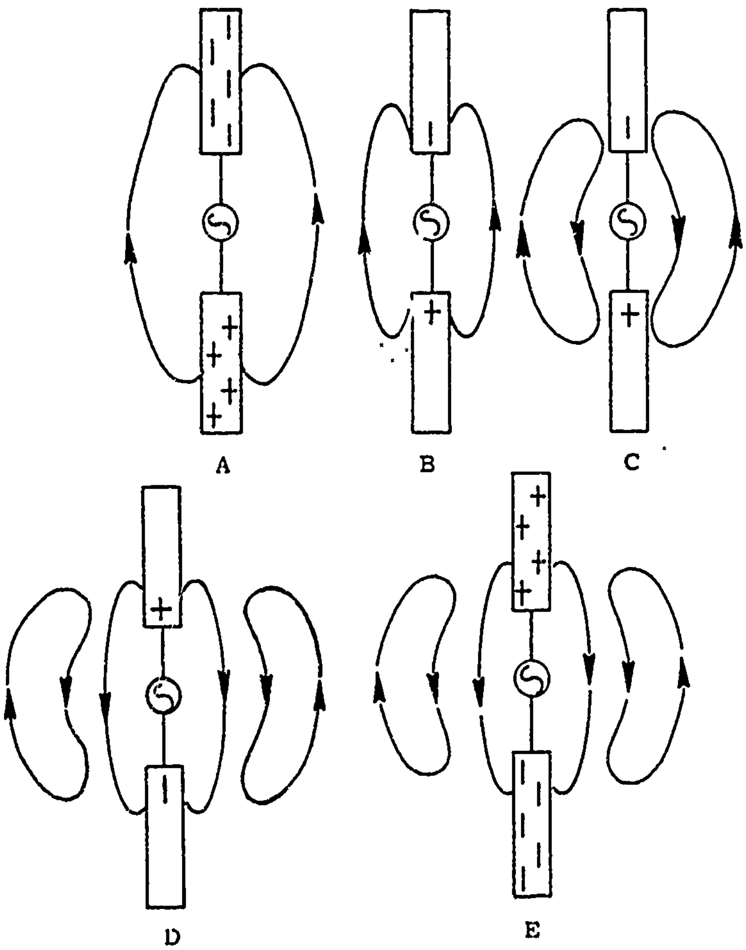

Fig 2-11. Development of radiation.

(2) This action can be understood more easily by comparing it to what takes place when an object is continuously dropped on the surface of a lake. The same type of action takes place at the antenna, except that water takes the place of free space and the electric field is replaced by the object. Figure 2-12A illustrates an object about to strike the water's surface. Figure 2-12B shows the wave being formed as the object strikes the water. In figure 2-12C, the object has sunk below the water's surface and the water closes over it. The initial velocity of the object forces the wave to move radially outward. Figure 2-12D shows the leading wave continuing to move outward with the following waves gradually decreasing in amplitude.

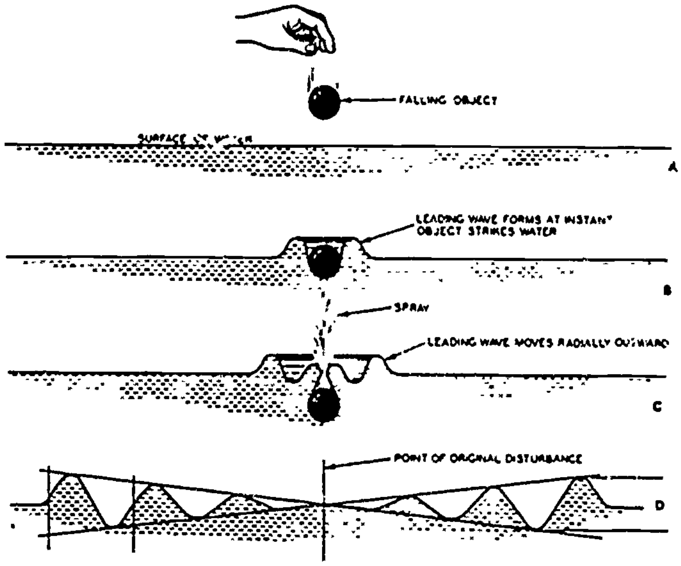

Fig 2-12. Wave motion on the water's surface.

Of course, figure 2-12 does not duplicate the action of radiation; but if we were to tie a string to the object we could produce continuous wave motion, as shown in figure 2-13. If the object were pulled sharply upward after its initial fall (fig 2-13A), and dropped again, continuous wave motion could be produced (fig 2-13B). The upward and downward motion of the object continually striking the water's surface would keep reinforcing the decreasing amplitude of the succeeding waves.

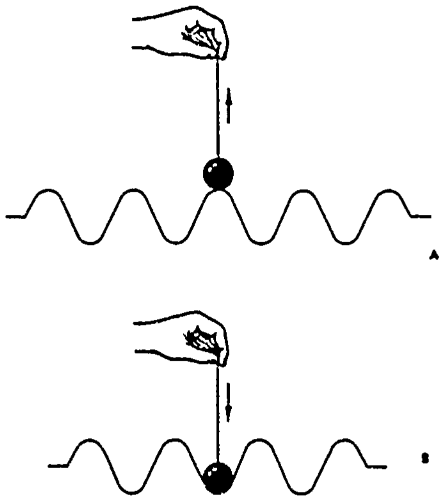

Fig 2-13. Formation of continuous waves on the water's surface.

(3) In (2) above, the magnetic field was ignored. By the same reasoning, magnetic lines of force may become detached from the antenna and resultant energy loops repelled into space.

As the RF generator alternately changes polarity, a continuous beam of energy in the form of electric and magnetic lines of force will be repelled away from the antenna.

The two will combine, forming a radiated electromagnetic field. (Note that no field is radiated from the ends of the antenna.) As the field advances, the energy becomes spread out over a greater area. The shape of this area or pattern is determined by the type of antenna used.

b. Basic patterns. Since the antenna is usually designed to have a specific pattern for use with a particular installation, it is desirable to put the radiation pattern on paper where it can be examined. The radiation pattern is a measurement of the energy radiated from an antenna, taken at various angles and at a constant distance from the antenna.

(1) Isotropic radiation. A source of radiant energy, such as the sun, radiates light equally in all directions. A radiator of this type is known as an isotropic source of radiation. This simply means that the energy coming from the source is found to be constant at a fixed distance, from whatever angle it is measured. Assume that a measuring device is moved in a circle around the sun. At any point along the circle, the distance from the measuring device to the sun is the same; and the measured radiation remains the same.

If measured radiation is plotted against various positions taken along the circle around the sun, the result is the graph in figure 2-14. Assume that the radiation is measured on a scale of 0 to 10 units, and that the radiation measured is shown to be 7 units at each position. The graph of the measured radiation, therefore, is a straight line plotted against positions along the circle. The graph of measured radiation just described is a form of radiation pattern. The straight line represents the radiation pattern of an isotropic source taken in the plane of the measuring circle.

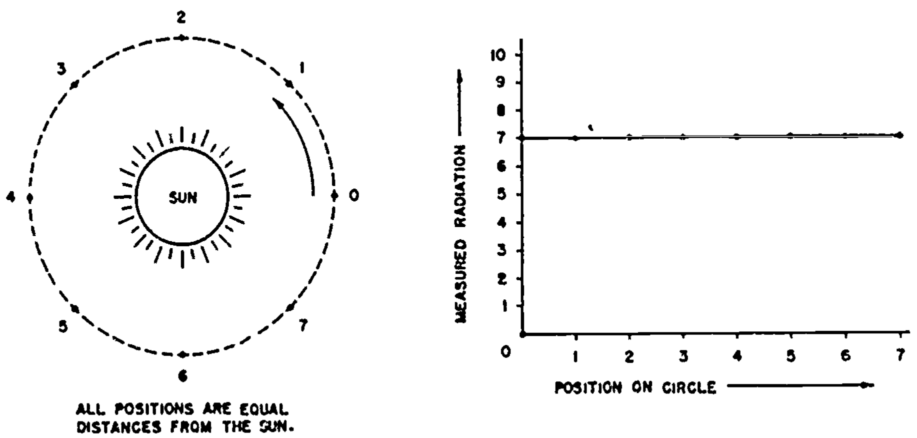

Fig 2-14. Isotropic radiation.

(2) Anisotropic radiation. It is possible to have a radiator which emits stronger radiation in one direction than in another. Such sources are called anisotropic. An example, shown in figure 2-15, is the ordinary flashlight. The beam illuminates only a portion of the total space surrounding the flashlight. If a circle is drawn having the light source as center, the radiation can be measured at different positions along the circle. Each position used for measurement is the same distance from the light source. In other words, conditions are exactly those used in measuring the light radiated from the isotropic source.

At position 0 on the circle, which is directly behind the light source, the radiation measured is negligible. A zero value accordingly is assigned to this position on the graph at the right. Until position 4 is reached, the radiation remains negligible. Between 4 and 6, the circle passes from comparative darkness into the flashlight beam. This is an area of sharp transition from darkness to brightness, as can be observed easily on the graph. Radiation is relatively constant moving from positions 6 to 10, reaching a maximum at position 8, which is directly in the path of the beam. Between 10 and 12, the measured radiation falls off sharply, becoming and remaining negligible from 13 to 16.

Radiation from a light source and radiation from an antenna are both in the form of electromagnetic waves. The measurement of radiation from an antenna, therefore, follows the same basic procedures as the one just described for the sun and the flashlight. These measurements can be graphed to obtain a radiation pattern for the antenna.

2-4. GRAPHS

Before proceeding with the study of antenna patterns, it is necessary to consider in detail methods used to graph measured values of radiatior.

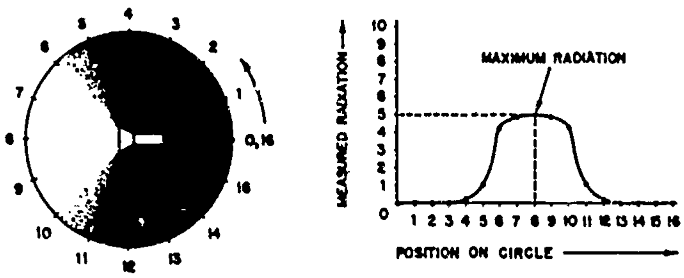

Fig 2-15. Anisotropic radiation.

a. Rectangular-coordinate graph. Figures 2-14 and 2-15 show the rectangular-coordinate type of graph used to plot the measured value of radiation against the position at which the measurement is taken. The numbered positions along the circle are laid out along the horizontal axis of the graph from 0 to 7. The units of measured radiation are laid out along the vertical axis from 0 to 10. Units on both axes usually are chosen so that the pattern occupies a convenient area of the graph.

The horizontal and vertical axes are at right angles to each other. The point at which the axes cross each other is called the origin. In this case, the origin has the value of zero on both axes. Now, assume that a radiation value of 7 units is measured at position 2. From position 2 on the horizontal axis, a line (vertical dashes) is projected running parallel to the vertical axis. From 7 on the vertical scale, a line (horizontal dashes) is projected running parallel to the horizontal axis. The point at which the two lines intersect represents the value of 7 radiation units at position 2. Note that this is the only point on the graph that can represent this value.

The vertical and horizontal axes plus the two dashed lines used to plot the point enclose an area forming a rectangular-shaped area. Therefore this type of graph is called rectangular coordinate. A new rectangle is formed for each different point plotted. In figure 2-14, all the points plotted lie along a straight line extending from 7 units on the vertical scale to the projection of position 7 on the horizontal scale. Thus the straight line is the characteristic pattern in rectangular coordinates of an isotropic source of radiation.

b. Polar-coordinate graph. Although the rectangular-coordinate method of graphical analysis is used widely, another method has proved to be more practical in studying radiation patterns. the polar-coordinate type of graphical analysis (B, fig 2-16). For convenience, the graph of figure 2-14 is reproduced in A of figure 2-16. Note the great difference in shape of the radiation pattern when it is transferred from the rectangular-coordinate to the polar-coordinate graph. The scale of values used in both graphs is identical, and the measurements taken are both the same. The basic difference, which results in the difference in physical appearance, is in the type of axes used.

In the rectangular-coordinate graph, points are located by means of projections from a pair of axes at right angles to each other. These axes remain stationary at all times. In the polar-coordinate graph, one axis consists of concentric circles, and the other axis consists of a rotating radius extending from the center of the concentric circles. Recall how radiation was measured by traveling in a circle around the sun. Assume a radius, R, drawn from the sun as center to position 0 on the circle. Moving to position 1, the radius moves to position 1; moving to position 2, the radius also moves to position 2; and so on. This moving radius constitutes the moving axis of the polar-coordinate graph.

The positions of the radius are marked on the polar-coordinate graph for each position at which a measurement is taken. Note how the radius indicates the actual direction from which the measurement was taken. This is a distinct advantage over the rectangular-coordinate system, in which the position is indicated along a straightline axis having no physical relation to the position on the circle. Having established the direction in which the measurement was taken by means of the rotating axis, it remains to devise means for indicating the measured radiation.

The rotating axis passes from the center of the graph to some position marked on the edge of the graph. In so doing, it intersects a set of concentric circles spaced at equal distances from each other. Going out from the center, the circles get larger and larger. These circles are used to indicate the measured radiation. They are numbered successively from the center outward, the center indicating a zero measurement. In the graph in B of figure 2-16, a radiation scale going from 0 to 10 units is used. Consequently, 10 concentric circles go from the center to the circumference of the graph. These circles are marked 1, 2, 3, and so on, with 10 designating the largest circle. This scale corresponds to the scale marked on the vertical axis of the rectangular-coordinate graph in A, figure 2-16.

In brief, the rotating radius of the polar-coordinate graph serves the same purpose as the stationary horizontal axis of the rectangular-coordinate graph. It has the advantage of indicating the actual direction from which the measurement is taken. The concentric circles serve the same purpose as the vertical scale on the rectangular-coordinate graph. They allow the same scale to be used no matter what the position of the rotating radius. The distance from the source is constant for both types of graphs.

At position 0 in B, figure 2-16, the radius extends from the center outward to the right. The radiation measured is 7 units in this position. This point is recorded by going out seven circles along the radius. The point is the place where the radius intersects the seventh circle. Recording of the radiation measured in position 1 follows the same procedure. Since the source is isotropic, the measured radiation again is 7 units. The radius is rotated to position 1, and its intersection with the seventh circle is marked.

When all points are recorded through position 7, they all lie on the seventh concentric circle. Therefore, the radiation pattern of the isotropic source is a circle. This contrasts sharply with the straight-line pattern obtained with a rectangular-coordinate-type graph. The advantages of the polar-coordinate graph are evident immediately. The source, which is at the center of the observation circle, is at the center of the graph. Also, the direction taken by the radiated energy can be seen directly from the graph. For these reasons, the polar-coordinate graph is more useful in plotting radiation patterns.

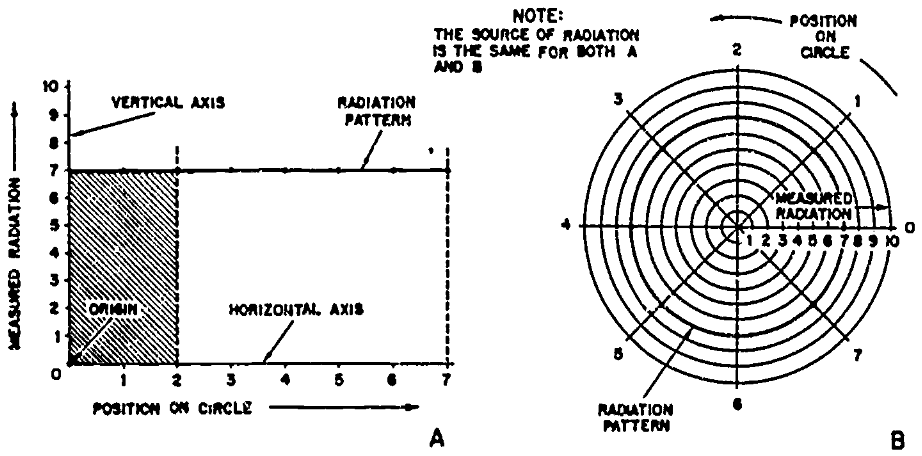

Fig 2-16. Comparison of rectangular- and polar-coordinate graphs for an isotropic source.

In figure 2-15 the radiation pattern of the common flashlight is graphed in rectangular coordinates. This graph is reproduced for convenience in A of figure 2-17. From the physical picture of the flashlight beam, it is evident that the light source is anisotropic in nature. This is not evident in the radiation pattern traced on the rectangular-coordinate graph. Conversely, the radiation pattern of the flashlight shown in B of figure 2-17 bears some physical resemblance to the actual beam. This is the same pattern, drawn with polar coordinates.

The positions on the circle marked off on the two polar-coordinate graphs given have been selected and numbered arbitrarily. It is possible to mark off positions around the circle in a standard way so that one radiation pattern can be compared easily with another. The standard method is based on the fact that a circle is divided into 360°. The radius extending from the center horizontally to the right (position 0 in B of fig 2-17) is designated 0°. Advancing to position 4 rotates the radius until it is at right angles to the 0° radius. This radius position accordingly is marked 90°. Therefore, position 8 is 180°, position 12 is 270°, and position 16 is 360°, by the same reasoning. The various radii drawn on the graph are marked according to the angle each radius makes with the reference radius at 0°.

In B of figure 2-17, the polar-coordinate graph shows a definite area enclosed by the radiation pattern, indicating the general direction of radiation from the source. This area is called a lobe. Outside of this area, no radiation is emitted in any direction. For example, at an angle of 45° (position 2), the radiation is zero. Such a point is called a null. Practically speaking, there is usually some radiation in every direction. A null, therefore, also is used to indicate directions of minimum radiation. In the pattern given, there is one lobe and one continuous null.

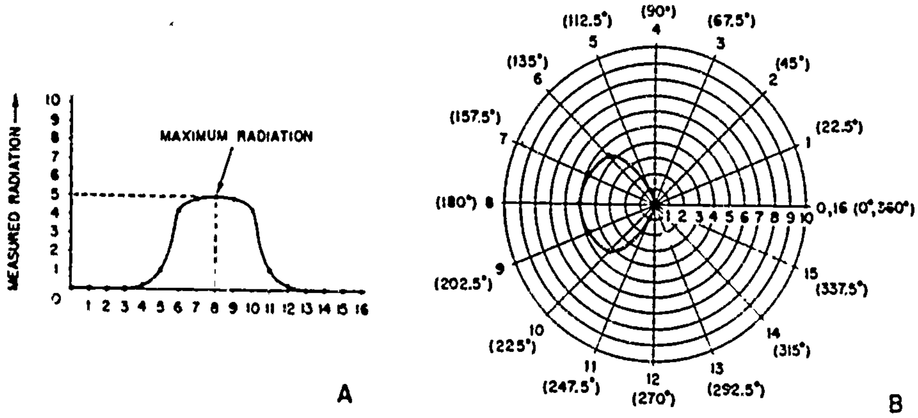

Fig 2-17. Comparison of rectangular- and polar-coordinate graphs for anisotropic source.

2-5. POLARIZATION

a. Radiated wave. Since the dipole antenna is a source of radiation, its radiation pattern can be measured. Figure 2-18 is a 3-dimensional view of this radiation pattern. It resembles the shape of a doughnut.

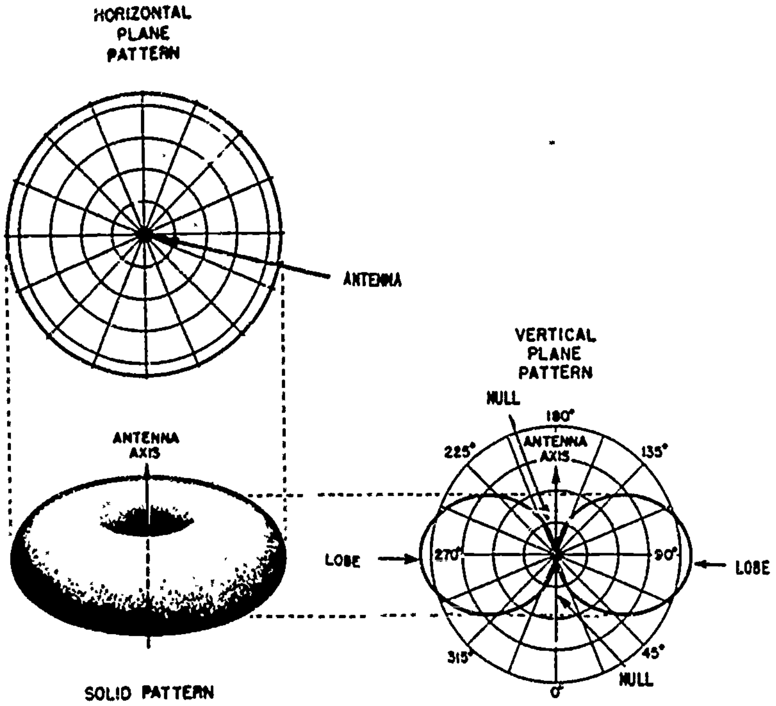

Fig 2-18. Radiation pattern of a dipole antenna.

From this view, two types of patterns can be drawn. The first view is obtained by cutting a top view through the center of the doughnut in a horizontal plane. The antenna becomes simply a dot in a large circle. Note that the radiation is constant in any direction along the horizontal plane.

A vertical plane pattern can be obtained by slicing the doughnut in half down through the center of the antenna. This pattern exhibits two lobes and two nulls. The reason for this figure-eight pattern is that no energy is radiated from the ends of the antenna.

The antenna shown is mounted vertically. Should it be mounted horizontally, the radiation pattern shown in figure 2-18 would be reversed. This means that an antenna could be either horizontally or vertically polarized.

b. "E" field. Polarization of a radiated wave is determined by the direction of the lines of force in the "E" field. The wave is said to be vertically polarized when the lines are perpendicular to the earth's surface. If the lines of force of the "E" field are parallel to the earth's surface, the wave is said to be horizontally polarized.

When an electromagnetic field is radiated from an antenna, the "E" field is built up from one end of the antenna to the other. Therefore, the lines of force of the "E" field are always parallel to the position of the antenna. Simply stated, a vertically positioned antenna produces a vertically polarized wave, and a horizontally positioned antenna produces a horizontally polarized wave.

2-6. ANTENNA INPUT IMPEDANCE

a. Input. The input impedance of the antenna is defined as the impedance "seen" by the transmitter at the input terminals of the antenna.

b. Impedance. Since different conditions of current and voltage exist at different points along the half-wave antenna, the impedance at these points must vary. If the voltage is divided by the current at each point, an impedance curve for the antenna can be developed, as shown in figure 2-19. It is calculated to be approximately 73 ohms at the center and 2,500 ohms at the ends.

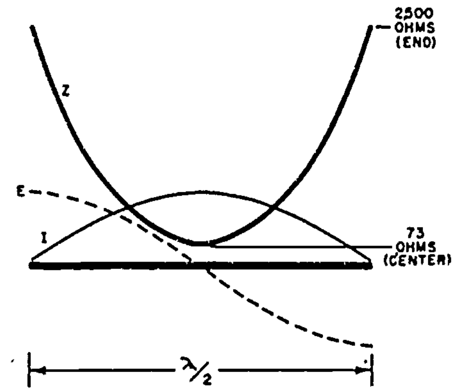

Fig 2-19. Impedance curve for a half-wave antenna.

This impedance is made up of resistance and reactance. If the antenna is cut exactly to length, the reactance is zero. If the antenna is made shorter, capacitive reactance is present. Conversely, when the antenna is made longer, inductive reactance is present. These reactive components are undesirable since they reduce the amount of power radiated from the antenna.

Note: The input impedance of the antenna is of extreme importance since it determines the type of transmission line used to couple it to the transmitter.

2-7. TRANSMISSION LINE THEORY

a. Properties. A transmission line is a device for transferring electrical energy from one location to another. It is used to couple energy from the transmitter to the antenna. At times the transmitter can be connected directly to the antenna, but generally the antenna is located some distance away, and a transmission line must be used as a connecting link. Its function is to transfer the power output of the transmitter to the antenna with minimum loss. How well the losses are kept down depends on the characteristics of the transmission line used.

A transmission line has the properties of inductance (L), capacitance (C), and resistance (R), just as in any conventional electronic circuit. The only difference is that these properties are generally components in conventional circuits. Figure 2-20 illustrates a transmission line (A) and its equivalent circuit (B).

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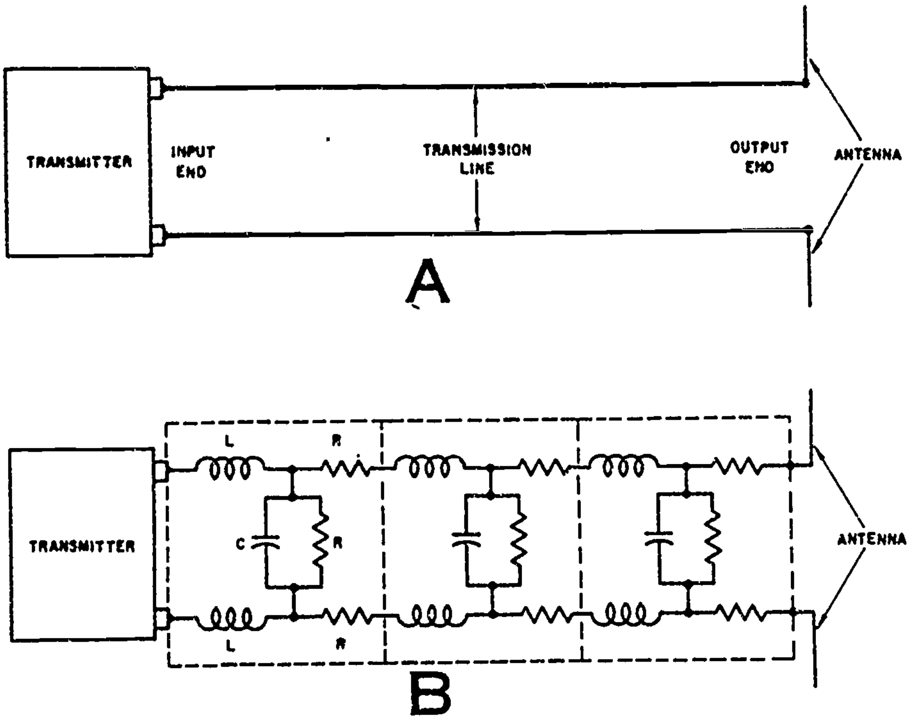

Fig 2-20. A transmission line and its equivalent circuit.

Any coil of wire has the property of inductance. Two conductors, separated by a dielectric (air in this case), make up a capacitor. Any conductor has some amount of resistance. All these properties make up the characteristic impedance of the transmission line.

b. Characteristic impedance. The ratio of voltage to current at the input end is the input impedance. It is the impedance "seen" by the transmitter, and is made up of the transmission line and the antenna. The output impedance is the ratio of voltage to current at the output end. This is the impedance the antenna "sees," and is composed of the transmission line and the transmitter. If an infinitely long transmission line could be used, the ratio of voltage to current would be some specific value of impedance at any point on the line. This value of impedance is known as the characteristic impedance of the transmission line.

For the transmission line to perform its function of transferring power with minimum losses, the antenna impedance must equal the characteristic impedance of the transmission line. The symbol for characteristic impedance is Z_o (pronounced zee-sub-oh).

If the antenna impedance is equal to the characteristic impedance, Z_o, of the transmission line, regardless of its length, the same value of impedance will appear at the transmitter. Thus, we have a good match and minimum reflected power loss.

c. Line reflections. In general there are two types of reflections: open end and shorted end. These result when the transmission line is not terminated in its characteristic impedance, Z_o.

(1) Open end. When the antenna impedance is greater than the Z_o of the transmission line, it appears similar to an open circuit. Voltage maximums will appear at the end of the line and at half-wave intervals back from the end. Current minimums will be at the end of the line and at odd quarter-wave intervals back from the end. This condition is illustrated in figure 2-21.

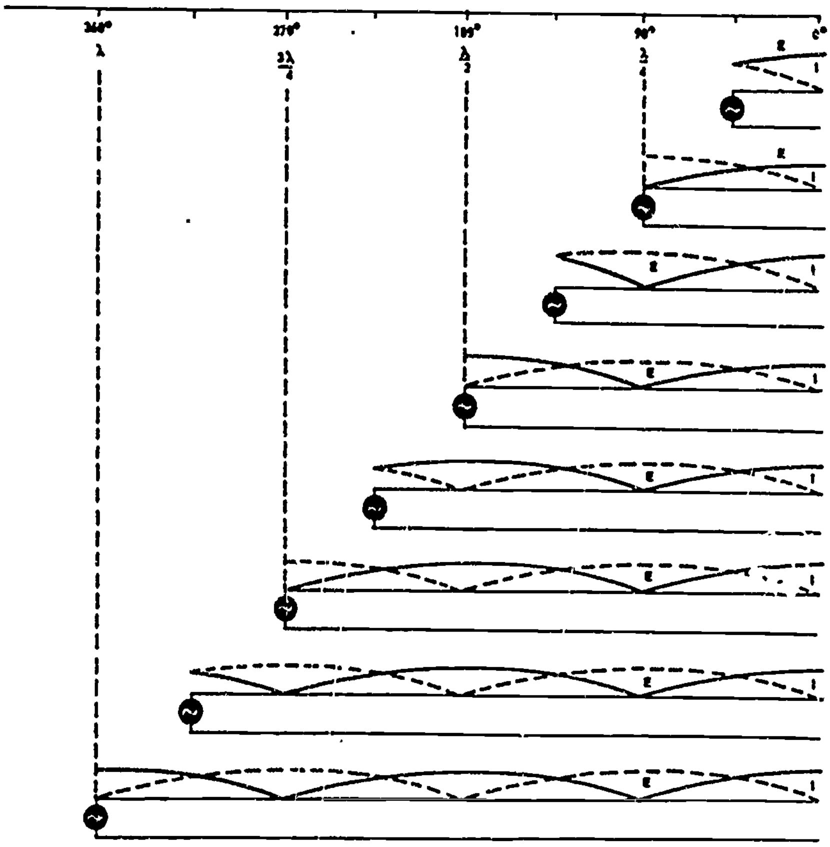

Fig 2-21. Voltage and current on an open transmission line.

(2) Shorted end. When the antenna impedance is less than the Z_0 of the transmission line, it appears similar to a short circuit. The existing condition is just the opposite of the open transmission line. Current maximums will appear at the end of the line and at half-wave intervals back from the end. Voltage minimums will be at the end of the line and at odd quarter-wave intervals back from the end. This condition is shown in figure 2-22.

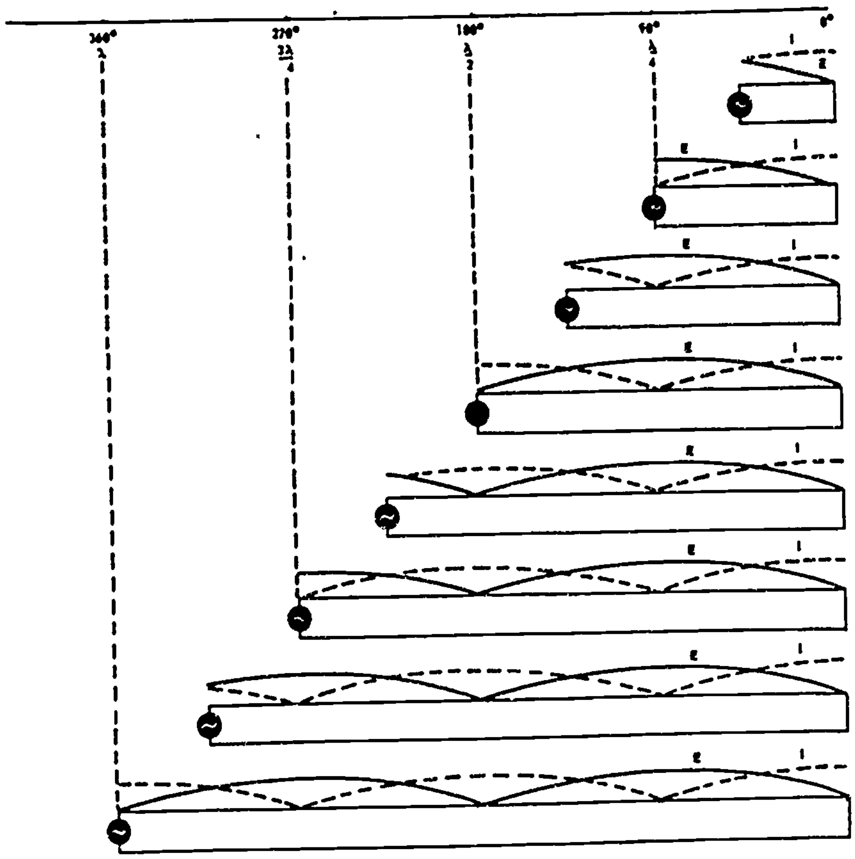

Fig 2-22. Voltage and current on a shorted transmission line.

2-8. TYPES OF TRANSMISSION LINE

In general there are four types of transmission line: parallel 2-wire, twisted-pair, shielded-pair, and coaxial (fig 2-23).

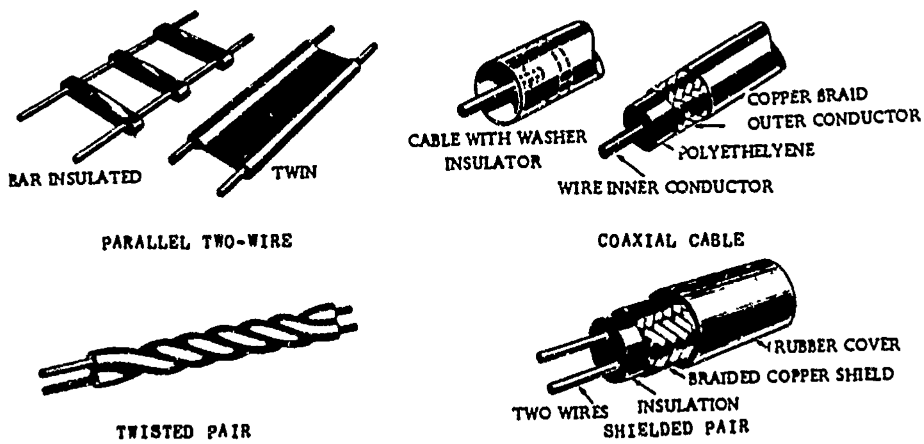

Fig 2-23. Four general types of transmission line.

a. Parallel 2-wire. Consists of two parallel conductors separated by insulators or spreaders at various intervals. It is available in two types: spreader bar and twin lead. The spreader bar type uses ceramic or polystyrene bars as spacers between the two conductors. The impedance for this type line is from 50 to 700 ohms. Twin lead consists of two conductors that are molded into a low-loss polyethylene plastic. It is available in impedances ranging from 75 to 300 ohms. It is commonly used for TV sets.

b. Twisted-pair. Consists of two insulated conductors twisted together. Two features of the twisting are: holding the lines together and canceling out the effects of nearby magnetic and electric fields. The impedance is generally 70 to 100 ohms. Due to losses in insulation, this type of line is generally used for low frequencies and short distances.

c. Shielded-pair. Consists of two conductors separated and surrounded by insulation material. The insulation material is then covered with a flexible copper braid that acts as a shield. The shield is then coated with rubber or a similar material to protect it against moisture and friction. Because of the shield, the line is not affected by nearby electric or magnetic fields.

d. Coaxial. Consists of two conductors, one of which is hollow. The other is centered inside the hollow conductor to provide uniform characteristics throughout the cable. The center conductor is surrounded by a polyethylene plastic. The outer conductor is a flexible copper braid.

The coaxial type is commonly called coaxial cable. Since it has extremely low losses at high frequencies, it is very desirable for communication applications, and is the type used most in this field.

Chapter 3

QUARTER-WAVE, HALF-WAVE ANTENNAS AND ASSOCIATED RADIATION PATTERNS

Section I. QUARTER-WAVE ANTENNAS

3-1. WHIP ANTENNA (MARCONI)

a. The ground is a fairly good conductor for medium and low frequencies, and acts as a large mirror for radiated energy. This results in the ground reflecting a large amount of energy that is radiated downward from an antenna mounted over it. It is just as though a mirror image of the antenna is produced, the image being located the same distance below the surface of the ground as the actual antenna is located above it. Even in the high-frequency range and higher, many ground reflections occur, especially if the antenna is erected over highly conducting earth, salt water or a ground screen.

Utilizing this characteristic of the ground, an antenna of only a quarter-wavelength can be made into the equivalent of a half-wave antenna. If such an antenna is erected vertically and its lower end is connected electrically to the ground (fig 3-1), the quarter-wave antenna behaves like the half-wave antenna discussed in chapter 2. 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 ungrounded half-wave antenna. This antenna is named for Guglielmo Marconi, an Italian physicist known for his development of wireless telegraphy.

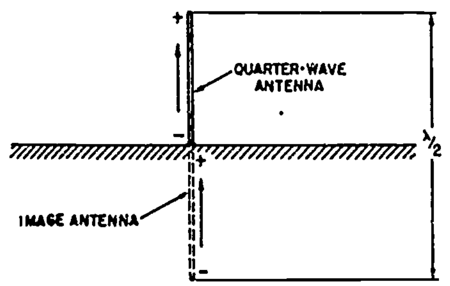

Fig 3-1. Quarter-wave antenna connected to ground.

When the charge on the quarter-wave grounded antenna is maximum positive at its upper end, the charge at the lower end of the image antenna is maximum negative. Current begins to flow toward the positive end of the quarter-wave antenna, as illustrated by the arrow in figure 3-1. Current in the image antenna begins to flow away from the negative end of the image. Note that the current flow is up in both cases. This is similar to conditions in a vertical half-wave antenna that has negative polarity at the bottom and positive polarity at the top. It is just as though the half-wave antenna were driven halfway into the earth.

It must not be assumed that, if a hole were dug into the earth under the antenna to a depth of a quarter-wave, an electric and a magnetic field (as described in chapter 2) would be found. Actually, the fields produced by the grounded quarter-wave whip antenna terminate a short distance below the ground surface. None of the radiated field from the antenna penetrates the earth to any great extent. The following assumption with reference to a lighted flashlight will help to clarify the concept.

Assume that you are standing before a mirror with a lighted flashlight held in your hand in such a way (fig 3-2) that its light is reflected by the mirror into your eyes, that is, the head of the actual flashlight is pointed away from you, whereas the head of the image flashlight is pointed toward you. This is a 180° shift in position. The effect is the same as if a flashlight were located behind the mirror the same distance as the actual flashlight is located before the mirror, without the mirror in the way. The image flashlight in the mirror is shining directly into your eyes, although it is not a physical object as drawn in the figure; and if you looked behind the mirror you would find no flashlight. If the mirror were removed, there would be no reflected ray and the effect would be as though the image flashlight had disappeared.

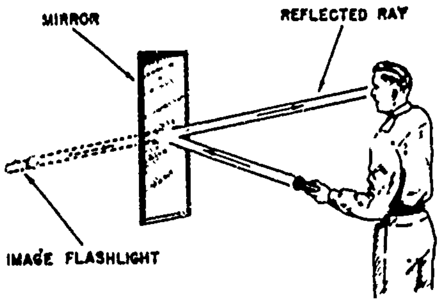

Fig 3-2. Formation of image flashlight.

The idea of an image flashlight can be applied to an image antenna formed by the ground. No antenna actually is located deep in the ground, but, because of the reflection of energy, conditions are similar to those that would occur without the reflecting surface and with a source of energy located as shown by the dashed lines in figures 3-1 and 3-2. Just as the position of the image flashlight is reversed, the polarity of charge on the image antenna is opposite to that of the actual antenna.

b. Radiation pattern. The radiation pattern produced by a quarter-wave antenna resembles the pattern of a vertical half-wave antenna. Maximum radiation is at right angles to the antenna along the surface of the ground. Figure 3-3 illustrates the radiation pattern of a quarter-wave antenna.

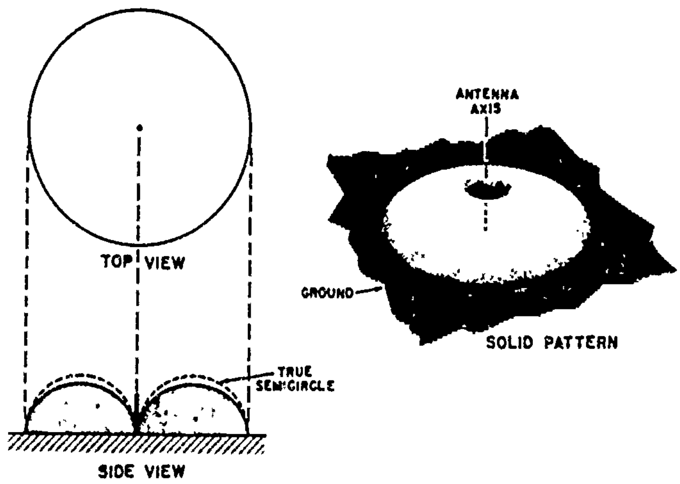

Fig 3-3. Radiation pattern of a quarter-wave antenna.

The top view of the radiation pattern is a circle. Thus, the quarter-wave antenna is omnidirectional in the horizontal plane.

In the vertical plane the pattern resembles half a figure eight. This is due to the ground reflections and the fact that there is no radiation off the ends of the antenna.

Figure 3-4 illustrates common quarter-wave whip antennas.

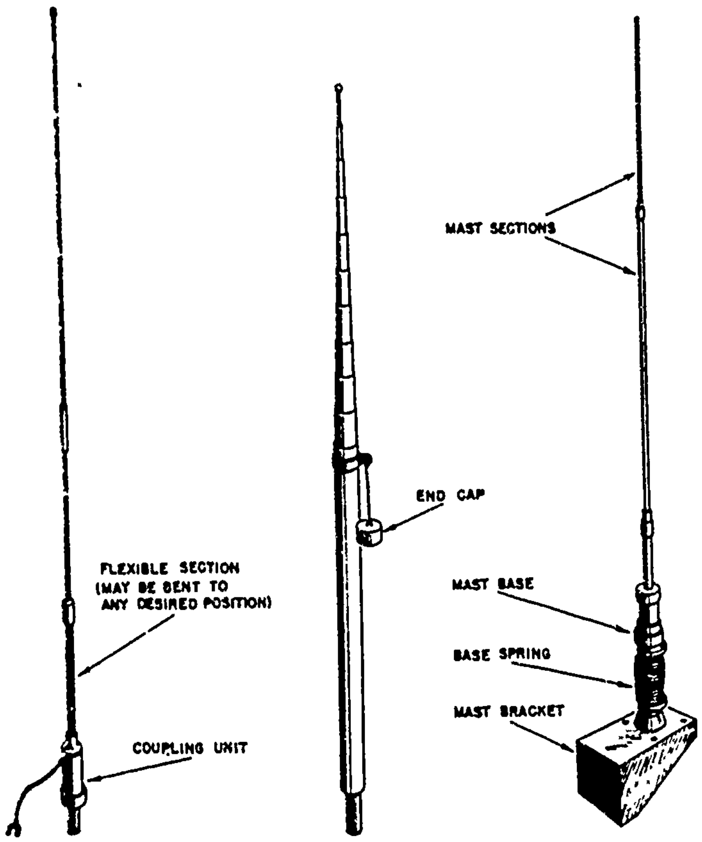

Fig 3-4. Common quarter-wave whip antennas.

Note: The formula for determining the length of a quarter-wave whip antenna is $L = \frac{234}{f}$ (L is the length in feet and f is the frequency in megahertz).

3-2. GROUND PLANE ANTENNA

a. Ground characteristic. 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 spikes located at the bottom of the radiator and usually at right angles to it (fig 3-5). Since the metal disk or spokes are not connected directly to ground, they may be referred to as a counterpoise or an elevated ground plane.

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.

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.

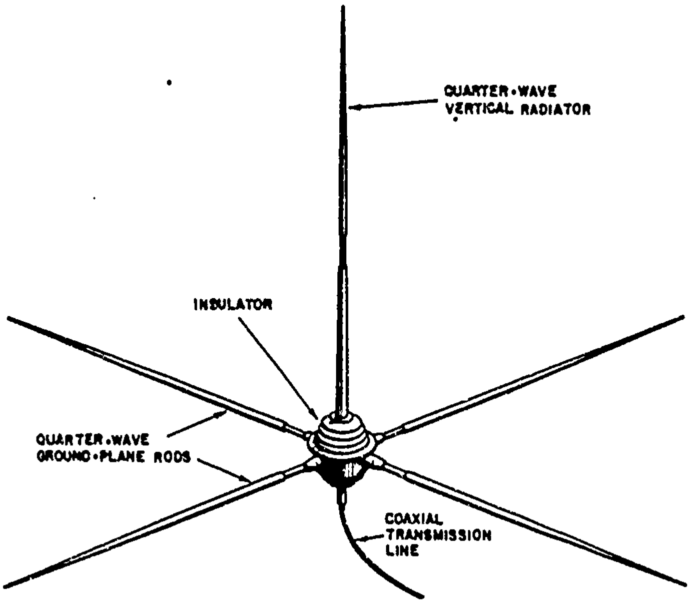

Fig 3-5. Typical ground plane antenna.

b. Radiation pattern. 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^{o}). The intensity of the radiation falls off at higher vertical angles until, at a vertical angle of 90^{o}, no radiation occurs. A side view of this radiation pattern is shown dashed in figure 3-6. 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.

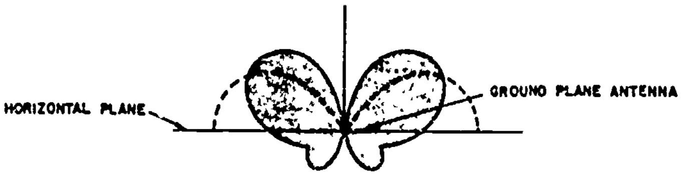

Fig 3-6. Radiation pattern of a ground plane antenna.

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 solid-metal construction is used, the elevated ground plane takes the form of a cone, and the lobes of maximum radiation (fig 3-6) are pulled downward to a much lower vertical angle.

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.

The input impedance of a ground plane antenna with elevated ground plane at right angles to the radiator is between 20 and 25 ohms. Since this is a lower value of impedance than is found in most coaxial lines, a quarter-wave matching section sometimes is inserted between the

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antenna and its transmission line. The matching section can be constructed of two quarter-wave sections of coaxial line connected in parallel to produce the required low impedance. In some ground plane antennas, the radiator is folded back on itself so that it resembles one half of a folded dipole. Under these conditions, the input impedance of the antenna is raised to about 80 ohms, so that a coaxial transmission line having a characteristic impedance near this value can be used. When the ground plane rods are bent downward below the horizontal, the input impedance is raised to about 50 ohms. If more information is desired see section III, chapter 3 of TM 11-666.

Note: The remaining antennas in this section are modifications of the quarter-wave antenna.

3-3. BENT ANTENNA

a. Description. A bent antenna is an antenna so constructed that a portion of it is mounted horizontally (fig 3-7). Such an antenna takes the form of an inverted L or T. In an inverted-L antenna, a fairly long horizontal portion, or flattop, is used; and the vertical downlead, which forms an important part of the radiating system, is connected to one end of the flattop. The length of the antenna is measured from the far end of the flattop to the point at which the downlead is connected to the transmitter. In the T antenna, a horizontal portion, or flattop, also is used. Here the downlead, which is a part of the radiating system, is connected to the center of the flattop. The overall length of the T antenna is equal to the entire length of the downlead plus one-half the length of the flattop.

The purpose of the bent antenna is to afford satisfactory operation when it is not convenient to erect tall vertical antennas. This is particularly necessary when operation at low frequencies is required.

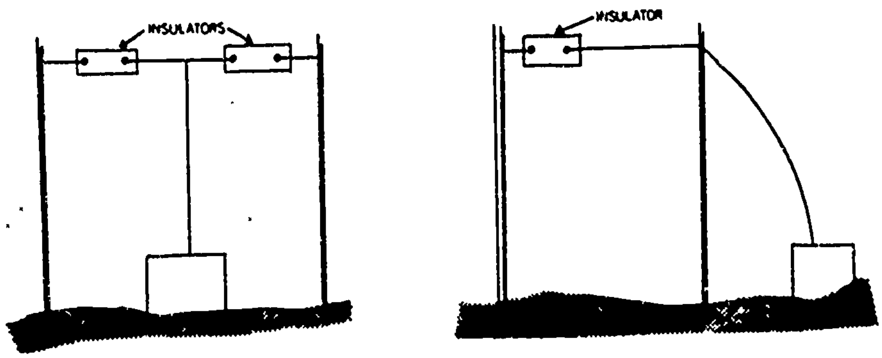


Fig 3-7. Bent antennas (T Bent, L Bent).

b. Characteristic. When the length of the flattop of a bent antenna (the entire length of the inverted-L or the entire length of the downlead plus one half the length of the flattop of the T) is 1 quarter-wavelength long, there are several advantages. First, the high-angle radiation is reduced and more energy is propagated along the surface of the earth. This is particularly important when ground wave transmission is used. Second, because more of the antenna is carrying a high value of current, a greater amount of radiation occurs.

When the vertical downlead of a bent antenna is approximately a quarter-wavelength, the current in the downlead falls to a minimum value at the end connected to the transmitter. Here the radiation resistance of the antenna has high value because the ratio between the radiation resistance and the ohmic resistance of the antenna is a maximum, and a large proportion of the power applied to the antenna is radiated.

Bent antennas of only a quarter-wavelength (including downlead) frequently are used in the field. The radiation produced by such antennas is considerably greater than would be produced by a simple vertical antenna having the same length as the height of the bent antenna.

When bent antennas are used at low frequencies, it is common to construct the flattop of several connected conductors. This increases considerably the capacitance between the flattop and the ground. As a result, the resonant frequency of the antenna is reduced, and the antenna operates as a simple vertical antenna of much greater height. The higher capacitance produced by this type of flattop raises the position of the current maximum still higher above the ground.

One common military bent antenna used at frequencies from about 1.5 to 12.5 Megahertz is an inverted-L type with a single-wire counterpoise (fig 3-8). This antenna is designed to operate with a total length of about 1 quarter-wavelength at a lower portion of its frequency range and three-quarters of a wavelength at the upper portion. It affords a low-impedance load on the radio set with which it is used. This antenna is particularly suitable for ground-wave transmission although it is very efficient for sky wave use.

Small jumpers are provided at the various insulators so that these may be shorted out if it is required to increase the length of the flattop and counterpoise. Clip leads at E and Z connect the counterpoise and the flattop to the leads which run to the radio set. When operation from 1.5 to 2 MHz or from 4.5 to 6 MHz is required, all jumpers are connected so that the lengths of the antenna and the counterpoise are each 100 feet. When operation from 2 to 3 MHz or from 6 to 9 MHz is required, the connections at A and X are broken. The antenna and the counterpoise then are each 80 feet long. When operation from 3 to 4.5 MHz or from 9 to 12.5 MHz is required, the connections at A, B, C, D, X, and Y are broken, making the length of the antenna 60 feet and the length of the counterpoise 45 feet.

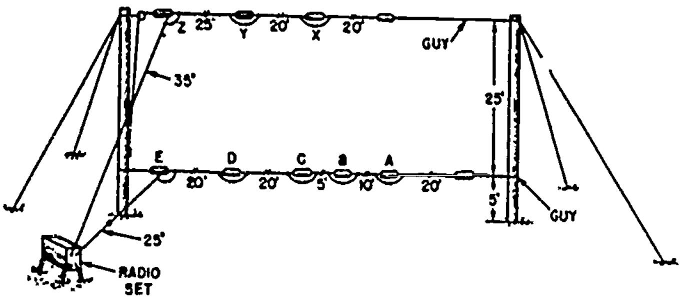


Fig 3-8. Inverted-L antenna with counterpoise.

An inverted-L antenna used for military communication in the frequency range below 800 kHz consists of a flattop constructed of five parallel conductors from 250 to 400 feet long and separated from each other by about 3 feet. The vertical downlead is connected to each of the flattop conductors at one end of the antenna. An extensive underground radial ground system is used with this antenna.

An inverted-L antenna used for low-frequency military communication is shown in figure 3-9. The flattop consists of three conductors, each 100 feet long, which are joined at one end and fan out at the other end to a maximum separation of about 30 feet. A counterpoise is used with this antenna, which is shaped like the flattop. Because of the appearance of this antenna, it commonly is referred to as a crowfoot antenna.

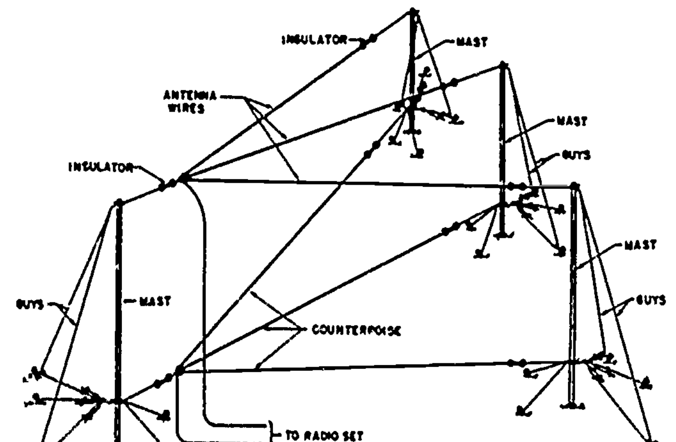


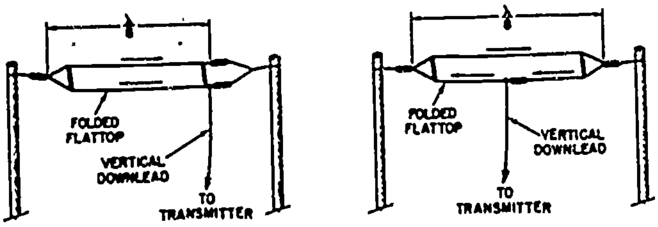
Fig 3-9. Crowfoot antenna.

3-4. FOLDED-TOP, TOP LOADED, TOWER RADIATING ANTENNAS

a. Folded top. A folded-top antenna is a modified bent antenna in which the flattop is folded in such a way that it prevents radiation. If radiation from the flattop is prevented or at least reduced considerably, more energy can be radiated from the vertical downlead of the antenna. The main advantage of preventing radiation from the horizontal flattop is that this part of the antenna may produce considerable radiation that is horizontally polarized. In addition, this energy is radiated at high vertical angles. Since the radiation does not add to the vertically polarized ground wave required, its elimination will improve the operation of the antenna. Another advantage of the folded-top antenna is that less horizontal space is required for its erection.

The simplest method of preventing radiation of energy from the flattop portion of the antenna is to fold the flattop in such a way that adjacent conductors carry current flowing in opposite directions. In this way, the field produced around one conductor is opposite in direction to that produced around the adjacent conductor. As a result, almost complete cancellation of fields occurs, and radiation is largely prevented. Unless an even number of conductors is used, appreciable cancellation will not occur.

Two folded-top antennas are shown in figure 3-10. In both cases, the quarter-wave flattop, which is required to bring the current maximum to the top of the vertical downlead, is folded in such a way as to prevent radiation from the flattop. In A, the downlead to the transmitter is connected to one end of the folded section. This section consists of a quarter-wavelength of wire that is doubled back on itself so that the overall length of the folded section is one-eighth wavelength. Note that the two wires forming the folded section are connected at the left and are not connected at the right. At any instant, the current in the two wires flows in opposite directions as shown by the arrows. Consequently, the field produced by one conductor is opposite in direction to that produced by the other conductor. Therefore, negligible radiation occurs from the folded section. In B, the downlead is connected to the center of the folded flattop. Note that the downlead is connected to the left half of one of the two conductors forming the folded top, and the direction of current flow in the folded quarter-wave section is as indicated by the arrows. Other arrangements can be used in addition to those shown. For example, the top quarter-wave section can be folded into four lengths, each of which is a sixteenth-wavelength.



A B

Fig 3-10. Folded-top antennas.

b. Top-loaded. Both the bent and folded-top antennas operate at frequencies that are much lower than the length of the vertical portion of the antenna would seem to indicate. The length not supplied by the vertical downlead is furnished by the bent or folded flattop. As a result, the standing wave of current appears higher on the vertical section of the antenna and its radiation resistance rises. Consequently, greater effective radiation occurs and at smaller vertical angles. Another method of increasing the effective length of a vertical antenna to obtain these advantages is to use top loading. This usually is accomplished by adding a concentrated amount of capacitance or inductance at or near the top of the vertical antenna. Such an antenna is a top-loaded antenna.

When inductance is used, the inductor simply is inserted in series with the antenna near the top. When capacitance is used, a capacitor cannot be inserted in series with the antenna, since this would reduce the total capacitance of the antenna, making it appear electrically shorter rather than longer as is desired. Shunt capacitance must be used instead so that the total capacitance between the antenna and ground is increased. The common method of producing the required shunt capacitance is to use a disk or hat made of sheet metal, mesh, or wire skeleton. The disk is centered on the top of the antenna and mounted at right angles to it. Such an arrangement provides an added capacitance of about 1pf (picofarad) for each inch of disk diameter.

Sometimes both inductance and capacitance are used. The hat then must be insulated from the top of the vertical antenna and an inductor inserted between the hat and the antenna. The inductor frequently is made variable so that an adjustment of the amount of the top-loading is possible. This is more convenient than trying to make such an adjustment by varying the amount of shunt capacitance, since this would involve a change in the size of the top-loading disk.

The low-frequency bent antennas already discussed actually use some top-loading to increase the electrical length of the antenna and to produce the advantages mentioned above. The antennas shown in figure 3-9 utilize two or more insulators as the flattop to provide an increase in shunt capacitance. The term, top-loaded antenna, however, usually refers only to those vertical antennas in which the shunt capacitance is supplied by a structure (such as a disk), the size of which is small compared with the length of the antenna. Because of the small size of the top-loading disk, little radiation is produced. Figure 3-11 shows the current distribution on top-loaded antennas which are somewhat shorter than a quarter-wavelength. The current is the same as would be produced if the top-loading disk or coil were removed and the actual height of the antenna extended as shown.

In general, as the ground resistance is increased, the size of the top-loading disk can be reduced. However, large ground resistances require top-loading coils with higher inductance values. As the size of the top-loading disk is increased, the effective length of the antenna is increased. For example, the length of the antenna shown (fig 3-11A) can be reduced further physically if the top-loading disk is increased in size. The actual size of the top-loading disk or coil required has been determined experimentally for a large number of special cases.

It is desirable to increase the radiation resistance of an antenna so that a greater proportion of the input power can be radiated. Assume that a vertical antenna having a length of 0.2 wavelength, used without a top-loading disk, has a radiation resistance of 20 ohms. If a small top-loading disk is installed, which has such a size as to increase the effective length of the antennas by about 0.05 wavelength, the radiation resistance is increased to 34 ohms. If the size of the disk is increased so that the effective length of the antenna is increased by about 0.1 wavelength, the radiation resistance rises to 45 ohms. A further increase in disk size, so that the effective antenna length is increased by about 0.15 wavelength, causes the radiation resistance to rise to 50 ohms.

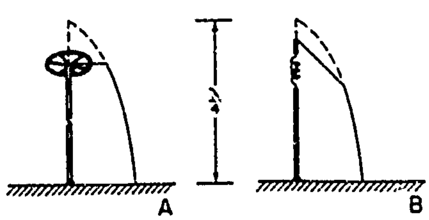


Fig 3-11. Top-loaded antennas.

c. Tower radiators. Most of the antennas discussed so far have been constructed of suitably supported wire. Since vertical supports are required for such antennas, it seems reasonable to consider use of the support itself as the antenna. This support must be constructed of metal so that it can be used as the antenna. Metal masts are used in the field, and large metal towers are used for fixed-station installation as vertical radiators.

Metal masts usually are made of aluminum alloy or steel tubing, sectionalized with metal coupling so that they can be taken apart for easy portability. Some short antenna masts, approximately 25 feet high, use a telescoping-section construction. Masts usually are supported by means of guys. These guys are made of metal wire sections connected by insulators (fig 3-12).

Mast and tower radiators can be subdivided into insulated and noninsulated types. An insulated mast or towe uses special compression-type base insulators that carry the weight of the structure and handle the RF voltage that exists. A spark gap is used across the base insulator for lightning protection (fig 3-12). In noninsulated towers and masts, the base of the structure is in direct contact with the base support which is in the earth. When the insulated tower is used, the energy applied to the tower must be series-fed. Shunt feeding is used with the noninsulated tower.

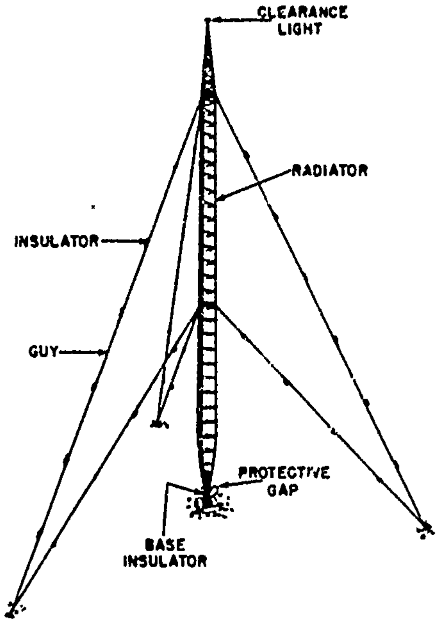


Fig 3-12. Insulated guyed-tower radiator.

When insulated masts or towers are used, the output of the transmitter is applied between the lower end of the structure and ground. The transmitter output is, in effect, connected directly across the base insulator, as shown in figure 3-13A, and is referred to as series feeding.

A shunt-fed noninsulated mast or tower arrangement is shown in figure 3-13B. The output of the transmitter is connected through a capacitor to point X, about one-fifth of the way up to the tower. The inclined wire usually makes an angle of about 45° with respect to ground. The exciting voltage from the transmitter is developed between point X and ground, across the lower section of the tower. This section can be considered as a portion of a 1-turn loop made up of the inclined wire (with capacitor), the portion of the tower between point X and ground, and the ground return between the bottom of the tower and the transmission line ground connection. Since the transmission line usually sees an inductive reactance in the direction of point X, a series capacitor is used to cancel out this reactance.

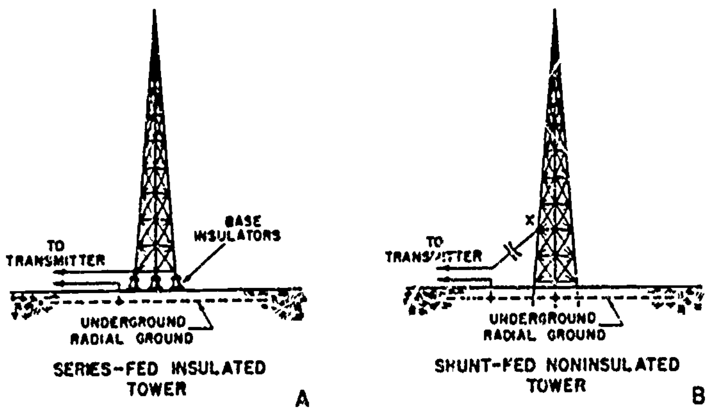


Fig 3-13. Series- and shunt-fed tower radiators.

Section II. HALF-WAVE ANTENNAS

3-5. HERTZ

The Hertz or half-wave dipole consists of two conductors, each of a quarter-wavelength. It operates independently of ground. From the basic antenna (fig 3-14), many complex antennas are constructed. The formula for construction is $L = \frac{468}{f}$ (L is the length in feet and f is the frequency in megahertz).

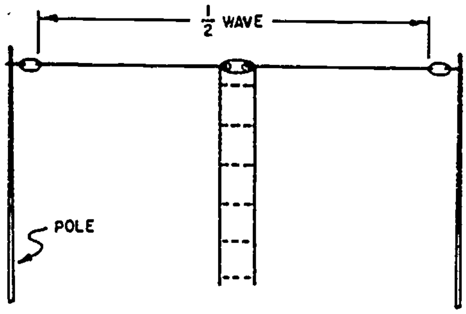


Fig 3-14. Basic Hertz antenna.

Current is maximum at the center and minimum at the ends. Voltage is maximum at the ends and minimum at the center. Its radiation pattern is pictured in figure 3-15, where the antenna shown is positioned vertically. Maximum radiation is perpendicular to the antenna axis. Since there is no radiation from the ends of the antenna, again we have our figure-eight pattern in the vertical plane. Thus, the antenna is directional in the vertical plane. As shown, radiation is constant in any direction in the horizontal plane. Mounting the antenna horizontally would reverse the pattern illustrated in figure 3-15.

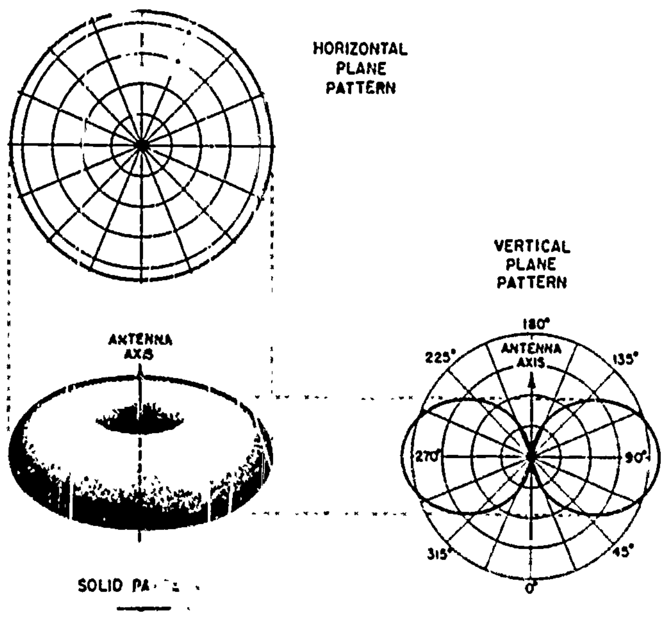


Fig 3-15. Radiation pattern of a dipole (half-wave) antenna.

a. Radiation pattern factors. The half-wave antenna has been discussed previously without reference to the effect produced by the presence of ground on the radiation pattern. Since all practical antennas are erected over the earth and not out in free space, it is necessary to determine just what effect the ground produces. The presence of ground may alter completely the radiation pattern produced by the antenna, and ground also will have an effect on some of the electrical characteristics of the antenna.

In general, the ground has the greatest effect on those antennas which must be mounted fairly close to it in terms of wavelength. For example, medium- and high-frequency antennas elevated above ground by only a fraction of a wavelength will have radiation patterns that are quite different from the free-space patterns.

In the succeeding paragraphs, several examples of practical half-wave antennas are discussed. These include the conventional single-wire half-wave dipole, the folded dipole, the coaxial antenna, and the conical antenna.

b. Ground effects. Assume that a horizontal half-wave antenna is erected at a height, H, from a ground plane, as illustrated in figure 3-16, with 3-16B being an end view of the antenna. Some of the energy that leaves the antenna travels directly to distant point P (direct wave). The direction followed by the direct wave makes a certain angle, A, in respect to the horizontal.

Some of the energy leaving the antenna travels downward toward the ground plane. Since this ground plane is a good reflector, the downward traveling wave from the horizontal antenna is reflected with practically no loss, and a reflected wave of energy travels outward toward the distant point, P.

The signal strength at point P depends on the amplitudes and phase relations of the direct and reflected waves. If the ground is a good conductor so that very little absorption of energy occurs during the reflection process, the reflected wave has the same amplitude as the direct wave. If these two equal-amplitude waves arrive at the distant point in phase, the resultant signal strength is twice that of the direct wave alone. On the other hand, if these waves arrive 180° out of phase, the resultant signal strength is zero. Intermediate values of signal strength occur with intermediate phase relations between the reflected and the direct wave.

Assume that point P is so located that it receives twice the signal strength. Now assume that a second point, Q, is located slightly below point P. The distances to point Q might be such that the direct and reflected waves arrive 180° out of phase. As a result, cancellation occurs, the received signal strength is zero, and a null is produced. Because of ground reflections, then, it is possible that the radiation pattern may be broken up into a series of lobes. The signal strength at the center of the lobes will be about twice that which would be received if the antenna were not in the vicinity of a ground plane. These lobes are separated by nulls where the received signal strength is zero.

It is sometimes convenient in making calculations to use the idea of an image antenna. This is an imaginary antenna assumed to be located the same distance, H, below ground as the actual antenna is located above ground. The reflected wave is assumed to come from the image antenna, as shown in B of figure 3-16. When a horizontal antenna is used, to take into account the phase reversal that takes place when reflection occurs, the current in the image antenna is assumed to be 180° out of phase with the current in the actual antenna. When a vertical antenna is used, the current in the image antenna is considered to flow in the same direction the current flows in the actual antenna.

From the above discussion you can see that the effect of ground is either good or poor.

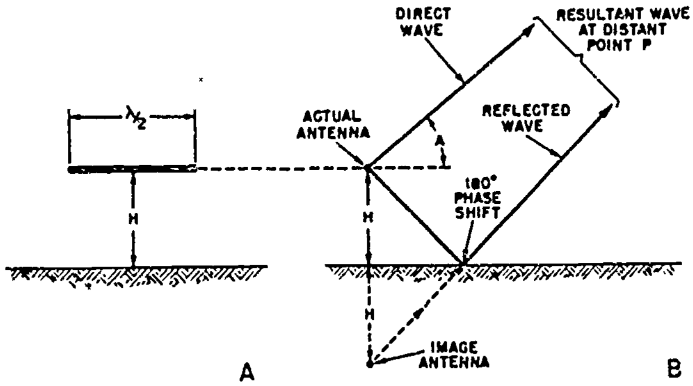


Fig 3-16. Reflection produced by ground plane.

3-6. GROUND-AFFECTED RADIATION PATTERNS

a. Reflection factor.

(1) The reflection factor is a term by which the free-space radiation pattern of an antenna must be multiplied in order to determine the radiated field strength of a practical antenna at a given vertical angle. The maximum value of the reflection factor is 2. At such vertical angles, the direct and reflected waves are in phase, and twice the free-space signal strength occurs. The minimum value of the reflection factor is 0. At such vertical angles, the direct and reflected waves are of opposite phase, and complete cancellation occurs. The reflection factor then may vary from 0 to 2 at vertical angles measured above the plane of the ground. Reflection factors are not given for angles below the surface of the earth.

(2) The value of the reflection factor depends on the height of the antenna above the ground plane as well as the orientation. The following guide gives the value of the factor for horizontal half-wave antennas at various vertical angles when the antenna is located a quarter-wavelength above ground:

Vertical angle (degrees)	Reflection factor	Vertical angle (degrees)	Reflection factor
0	0	50	1.8
10	.5	60	1.95
20	1.0	70	2.0
30	1.5	80	2.0
40	1.75	90	2.0

(3) When the horizontal antenna is located a half-wavelength above ground, the following guide can be used to obtain the reflection factor:

Vertical angle (degrees)	Reflection factor	Vertical angle (degrees)	Reflection factor
0	0	50	1.4
10	1.0	60	.75
20	1.75	70	.4
30	2.0	80	.1
40	1.75	90	0

(4) When the horizontal antenna is located three-quarters of a wavelength above ground, the following guide is used to obtain the reflection factor:

Vertical angle (degrees)	Reflection factor	Vertical angle (degrees)	Reflection factor
0.	0	50	1.
10	1.5	60	1.7
20	2.0	70	1.9
30	1.5	80	2.0
40	0	90	2.0

(5) When a height of 1 wavelength above ground is used, the following guide shows the reflection factor:

Vertical angle (degrees)	Reflection factor	Vertical angle (degrees)	Reflection factor
0.	0	50.	1.95
10	1.8	60.	1.4
20	1.6	70.	.6
30	0	80.	.1
40	1.6	90.	0

(6) The guides in (3), (4), (5) above can also be used with a half-wave vertical antenna. The height above ground is measured from the center of the vertical antenna. It is necessary, however, to subtract the given values of reflection factor from 2. Then, if the reflection factor given in the charts for a certain height and vertical angle is 1, the reflection factor for a vertical antenna is 2 minus 1, or 1. If the reflection factor for the horizontal antenna is 2, the factor for the vertical half-wave antenna is 2 minus 2, or 0. If the reflection factor for the horizontal antenna is 0, then the vertical antenna reflection factor is 2 minus 0, or 2.

b. Horizontal half-wave antenna.

(1) When the foregoing reflection factors are applied to the free-space radiation pattern of a horizontal half-wave antenna, the patterns shown in figure 3-17 are produced. Patterns A, C, E, and G are the vertical radiation patterns in the plane of the antenna itself. B, D, F, and H are the vertical radiation patterns in the plane which is at right angles to the antenna. Patterns A and B are for antenna heights of a quarter-wavelength, C and D are for antenna heights of a half-wavelength; E and F are for heights of three-quarters of a wavelength; G and H are for heights of 1 wavelength.

(2) Figure 3-18 permits a better visualization of the radiation pattern produced. Here the actual solid radiation pattern is shown for a horizontal half-wave antenna located a half-wavelength above ground. In the vertical plane at right angles to the antenna, D of figure 3-17 shows two large lobes whose maximum values occur at an angle of 30° with the horizontal. This pattern is reproduced in perspective at the upper left of figure 3-18. In the vertical plane which includes the antenna, C of figure 3-17 shows two small lobes with maximum values occurring at an angle of about 40° with the horizontal. This pattern is reproduced in perspective at the upper right of figure 3-18. If these two plane views are connected smoothly, the solid pattern shown in the center of figure 3-18 is produced.

(3) In similar manner, solid radiation patterns can be visualized from the plane views shown in figure 3-17. Picture the pattern as being produced by the smooth transition from one vertical plane view shown to the other vertical plane view shown as an angle of 90° is covered.

(4) Although vertical patterns are shown for only four specific heights above ground, it is not too difficult to predict the patterns produced at intermediate heights. This is true since the patterns do not change abruptly as the height of the antenna is increased gradually. Instead, there must be a smooth transition from the pattern shown for a height of a quarter-wavelength to the pattern shown for a height of a half-wavelength.

(5) At heights less than a quarter-wavelength above ground, the vertical patterns produced by a horizontal half-wave antenna are almost perfectly circular. As the antenna is raised, the vertical pattern is flattened somewhat at its top, at a vertical angle of 90° (B of fig 3-17). As the height is increased above a quarter-wavelength, a depression begins to appear at the top of the pattern, and the pattern width increases. The depression grows deeper and deeper, and as the antenna height approaches a half-wavelength, the pattern splits into two separate lobes. The radiation at a vertical angle of 90° (straight up) is zero at this height, as in D of figure 3-17. As the antenna height increases still more, a lobe of radiation begins to grow out of the center of the pattern at a vertical angle of 90°. As this lobe increases in amplitude with increasing antenna height, the two side lobes are spread farther apart so that their maximums occur at lower vertical angles. This vertical lobe has its maximum amplitude and begins to flatten somewhat (F of fig 3-17) at an antenna height of 3 quarter-wavelengths. As the antenna height is increased still more, the vertical lobe develops a depression that grows deeper as the height is increased. Finally, at a height of 1 wavelength, the center lobe splits into two separate lobes and the radiation at a vertical angle of 90° is again zero. Now four distinct lobes exist (H of fig 3-17).

(6) The patterns that are produced at antenna heights in excess of 1 wavelength also can be determined by studying figure 3-17. When the height of the horizontal antenna is an odd number of quarter-wavelengths above ground, a lobe of maximum radiation is produced at a vertical angle of 90° straight up.

(7) Consider an antenna with a height of 1 quarter-wavelength above ground. Assume that the instantaneous electric field immediately around the antenna is maximum in a given direction, designated as positive. A portion of this field moves downward at a distance of a quarter-wavelength to the ground. Upon being reflected, a 180° phase shift occurs, and the instantaneous electric field is now maximum in the opposite direction, designated as negative. This negative field now moves upward from the ground for a distance of a quarter-wavelength. By the time the reflected field returns to the antenna, a total distance of a half-wavelength has been covered. Meanwhile, since one-half cycle of operation has elapsed during the time required for the downgoing wave to move from the antenna to the ground and from the ground back to the antenna again, the polarity of the energy on the antenna itself has reversed. As a result, the reflected wave arrives back at the antenna in exactly the right phase to reinforce the direct wave. The reinforcement occurs not only at heights of a quarter-wavelength above ground, but also at heights of three-quarters of a wavelength, and so on. Consequently, a lobe of maximum radiation is produced at a 90° vertical angle for all antenna heights which are an odd number of quarter-wavelengths from ground.

(8) When the height of the antenna is an even number of quarter-wavelengths above ground, a null (zero radiated energy) occurs at the 90° vertical angle. Consider the action of the horizontal half-wave antenna that is located at a distance of a half-wavelength above ground. The portion of the radiated field from this antenna which travels downward toward the ground must cover a total distance of 1 wavelength before it arrives back at the antenna. The direction of this field is reversed by the reflection process. During the time that is required for the reflected wave to cover the distance, the field immediately surrounding the antenna has gone through 1 complete cycle and is now back to its original direction or polarity. The reflected wave, therefore, with its field reversed by the reflection process, becomes 180° out of phase with the direct wave from the antenna. As a result, cancellation occurs at the vertical angle of 90°, and a null is produced. This cancellation, as described above, occurs not only at heights of a half-wavelength above ground, but also at heights of 1 wavelength, 1½ wavelengths, and so on. Consequently, null is produced at a 90° vertical angle for all antenna heights which are an even number of quarter-wavelengths from ground.

(9) One other factor can be observed from the patterns in figure 3-17, which can be used to determine the vertical radiation pattern of a horizontal half-wave antenna at heights greater than are shown. At a height of 1 quarter-wavelength above ground, the radiation pattern is seen to consist of one lobe only. At a height of a half-wavelength ($\lambda/2$) above ground, the radiation pattern consists of two lobes. At a height of three-quarters of a wavelength, the pattern consists of three lobes. At a height of a full-wavelength (λ) above ground, the radiation pattern consists of four lobes. Consequently, the number of vertical lobes produced is numerically equal to the height of the antenna above ground

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in quarter-wavelengths and continues for any antenna height. It is possible to get a fairly good idea of the vertical radiation pattern of a horizontal half-wave antenna at any height above ground. For example, if the antenna is located at a height of 2 wavelengths above ground, which is an even number of quarter-waves, a null is produced at a vertical angle of 90°. Then, since 2 wavelengths represent 8 quarter-wavelengths, the radiation pattern consists of eight lobes.

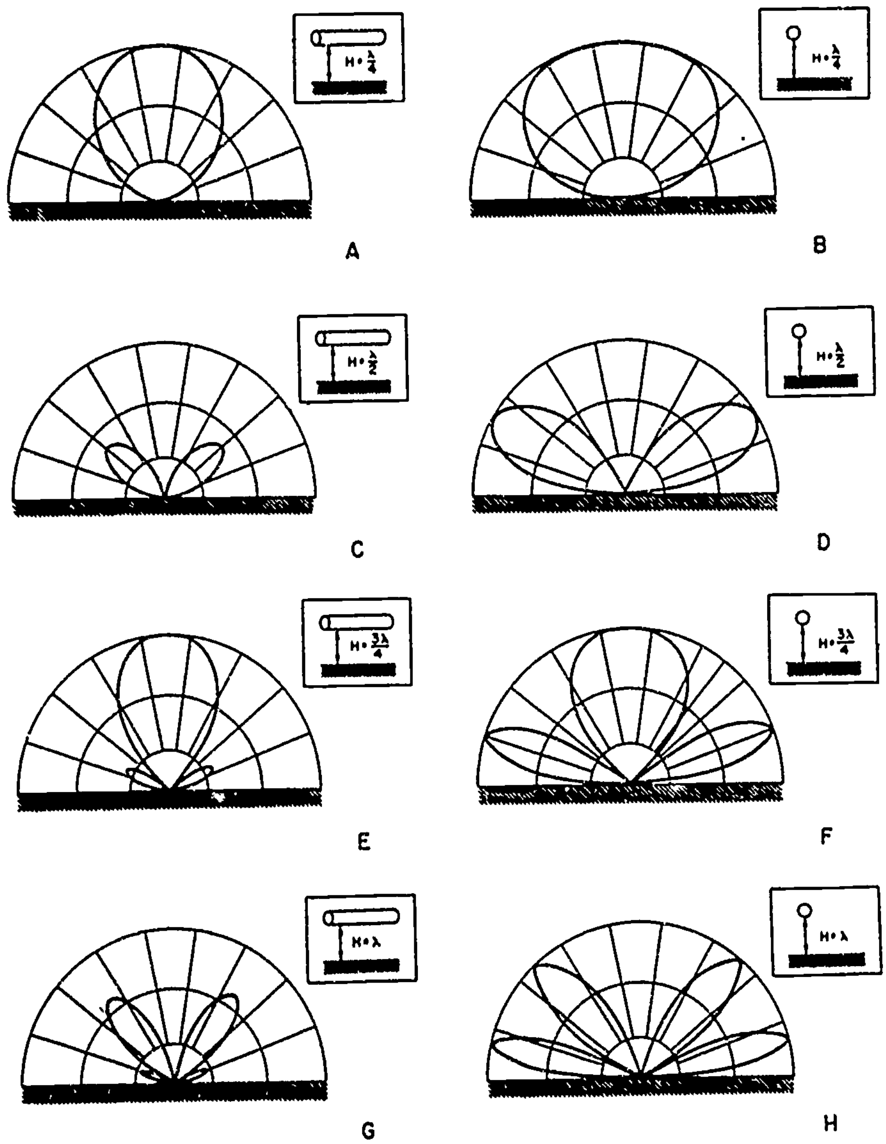

Fig 3-17. Vertical-plane radiation patterns of horizontal half-wave antennas.

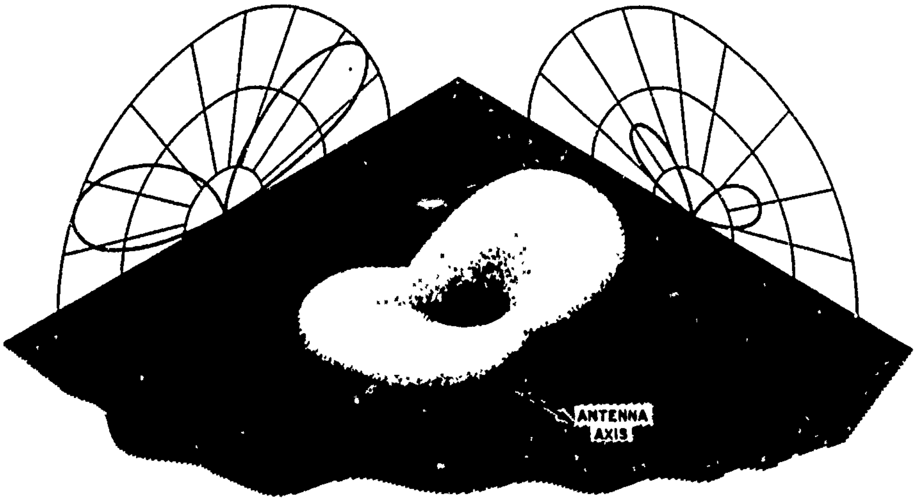

Fig 3-18. Radiation pattern of a horizontal half-wave antenna located a half-wavelength above ground.

c. Vertical half-wave antenna.

(1) When the proper reflection factors are applied to the free-space radiation pattern of a vertical half-wave antenna, the patterns shown in figure 3-19 are produced. Only a simple plane view need be shown here because the vertical half-wave antenna is non-directional in the horizontal plane. Its free-space horizontal radiation pattern is a circle. Therefore the effect of the reflection factor is the same in all horizontal directions.

(2) To visualize more clearly the solid radiation pattern, it is necessary only to picture the plane patterns (fig 3-19) being rotated. One such solid radiation pattern is shown in figure 3-20, where the pattern is produced by a vertical half-wave antenna the center of which is a half-wavelength above ground.

(3) In general, two effects are shown when the patterns of figure 3-19 are observed. First, there is always a null at the vertical angle of 90° because there is no radiation from the end of the vertical antenna. Therefore, regardless of the value of the reflection factor at this angle, no radiation occurs directly upward. At all antenna heights, then, the vertical half-wave antenna produces a null at 90°. The second effect noted is that, as the antenna is raised above ground, a greater number of lobes appears in the pattern. At a height of 1 quarter-wavelength, for example, two lobes appear (A of fig 3-19). When the antenna is raised to 1 half-wavelength, four lobes appear, as in B. The amplitude of the upper lobes is much smaller than that of the lobes which lie along the ground. At a height of three-quarters of a wavelength, there are still four lobes, but the amplitude of the upper lobes has increased, as shown in C. When the antenna is raised to a height of a full wavelength, as in D, six lobes appear.

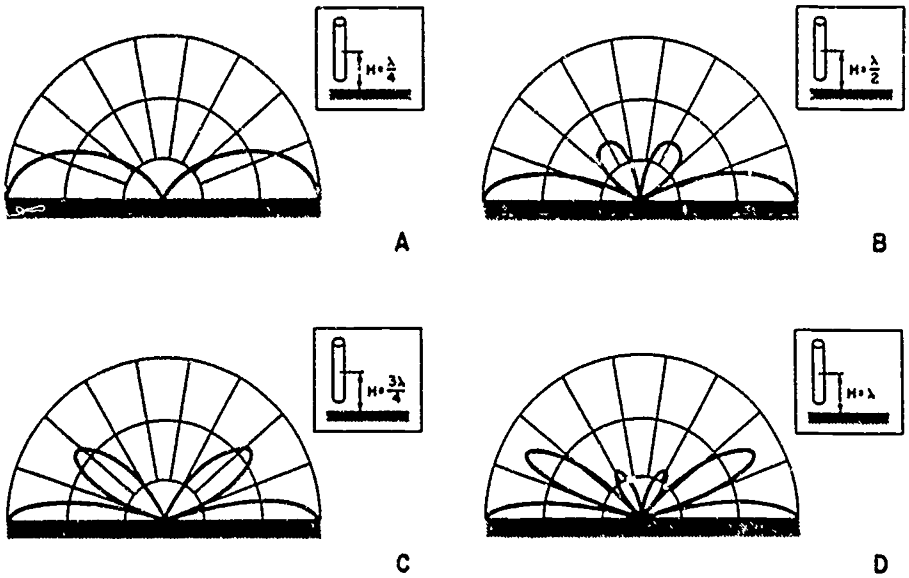

Fig 3-19. Vertical-plane radiation patterns produced by vertical half-wave antennas.

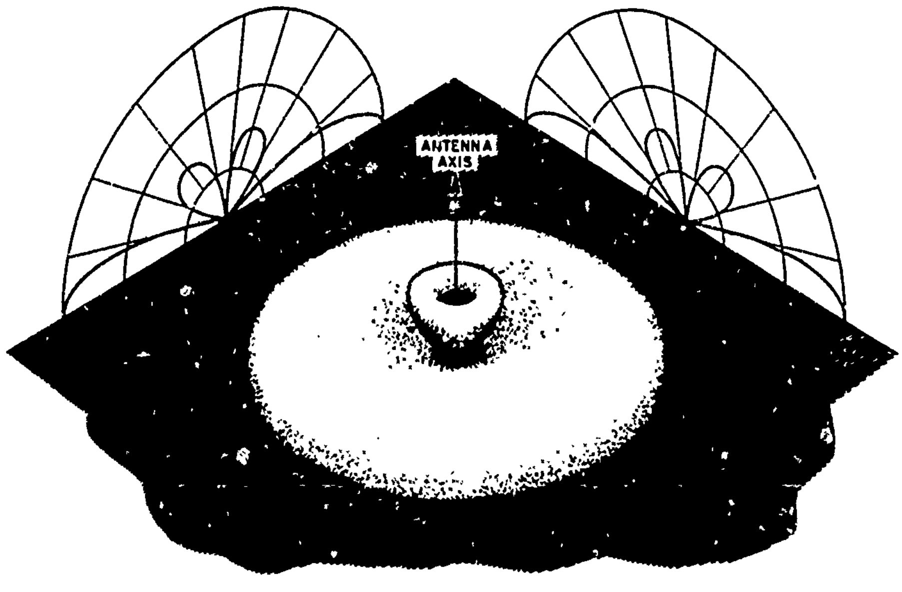

Fig 3-20. Radiation pattern of a vertical half-wave antenna located a half wavelength above ground.

3-7. SINGLE-WIRE ANTENNA

a. General.

(1) A single-wire half-wave antenna is one constructed of a single conductor of proper length. In the high-frequency range, the conductor is usually a stranded copper-alloy wire which is suspended between two upright supports. In the vhf and uhf frequency ranges, aluminum tubing frequently is used, and the antenna length is sufficiently short that the tubing need be supported only at the center.

(2) The single-wire antenna can be mounted either vertically, to produce a vertically polarized radio wave, or horizontally, to produce a horizontally polarized wave.

b. Typical military antenna

(1) The typical military half-wave antenna (fig 3-21) is suitable for transmission and reception. It can be used in conjunction with a transmitter having an output power of less than 100 watts. All of the component parts required for the installation are furnished in kit form. When the antenna is disassembled, it is highly portable.

(2) Sufficient antenna wire is provided to construct a half-wave antenna resonant to a frequency as low as 1.5 MHz, that is 312 feet long. If the antenna is to operate on a frequency as high as 18 MHz, the length is shortened to 24.3 feet.

(3) A single-wire transmission line can also be used with this antenna. The single-wire line is connected at a point 0.18-wavelength from one end of the antenna, giving it a proper impedance match.

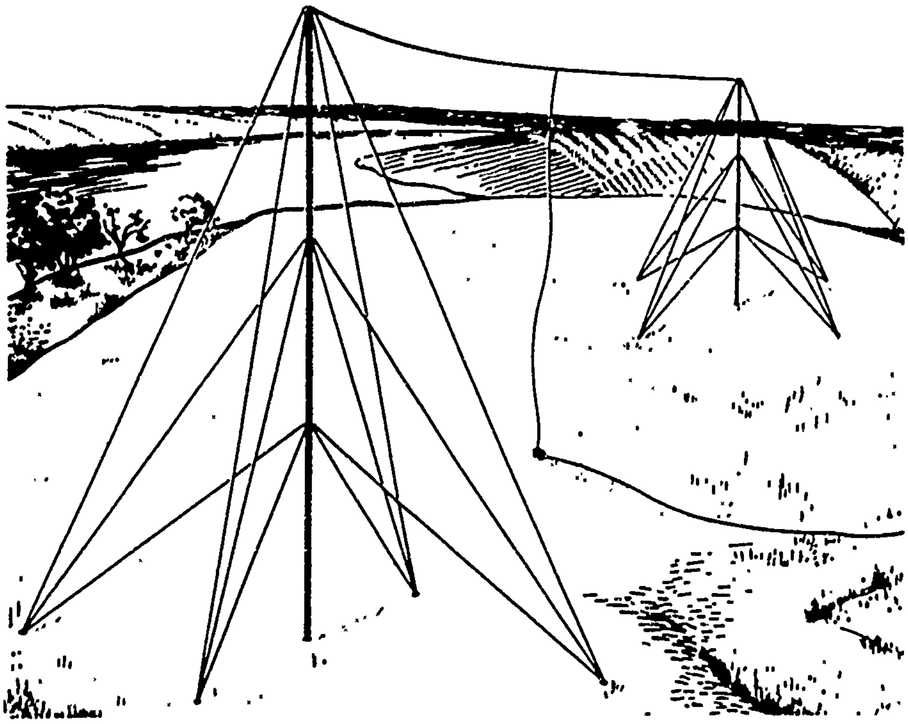

Fig 3-21. Single-wire antenna.

3-8. FOLDED DIPOLE, COAXIAL, CONICAL AND MICROWAVE ANTENNAS

a. Folded Dipole.

(1) The folded-dipole antenna consists of an ordinary half-wave antenna (dipole) which has one or more additional conductors connected across the ends of the antenna. The additional conductors are mounted parallel to the dipole elements at a distance that is a very small fraction of a wavelength in which spacings of several inches are common (fig 3-22). In A, the 2-wire folded dipole is constructed of metal tubing. In B, the 3-wire folded dipole is made of wire. The electrical length of both antennas is a half-wavelength.

(2) Consider first the simple, 2-wire folded dipole. Assume that the additional conductor is removed at points 1 and 2. Assume further that the charge remaining on the simple half-wave antenna is such that the end of the antenna at point 1 is maximum positive

and the end of the antenna at point 2 is maximum negative. Ordinarily, current then would start to flow from point 2 toward point 1. Now, if the additional conductor is connected as shown in the figure, this current finds two paths available. Consequently, the current divides so that about half flows from right to left in the additional conductor and the remaining half flows in the same direction in the lower conductor, making up the simple half-wave antenna. This occurs with no change in input power.

(3) Since impedance varies inversely as the square of the current ($Z=P/I^2$), a reduction in the current flowing in that branch of the folded dipole to which the transmission line is connected results in an increase in the input impedance of the antenna. As the current is reduced to half its original value, the impedance of the antenna increases to four times 73 ohms, or close to 300 ohms. Therefore, a 300-ohm transmission line can be connected to the folded dipole, and a correct impedance match occurs.

(4) If three conductors are used instead of two, a given input power will produce only one-third the original current in each conductor. As a result, the input impedance of the antenna rises to nine times 73 ohms, or about 600 ohms. This provides the proper impedance match for an ordinary 600-ohm transmission line, and the folded-dipole antenna provides an impedance step-up that can be used to produce an impedance match to common transmission lines.

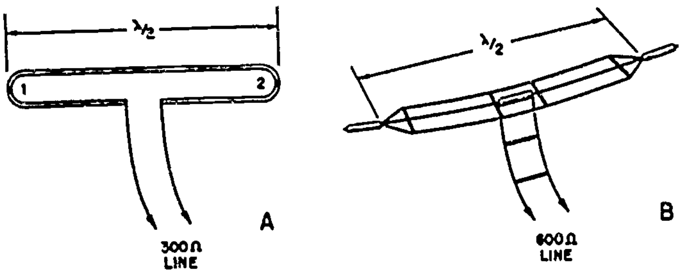

Fig 3-22. Folded-dipole antenna.

b. Coaxial antenna. The coaxial or sleeve antenna is a common vertical radiator that is used in the vhf and uhf bands. In figure 3-23, the typical military coaxial antenna consists of a vertical half-wave antenna so constructed as to provide a convenient, mechanical feed arrangement. The antenna is fed by means of a flexible coaxial cable which runs up through the supporting staff.

(1) The inner conductor of the coaxial cable is connected to the upper portion of the antenna, designated as the whip. The outer conductor of the cable is connected through a shorting ring to the top of an outer skirt. This skirt or sleeve is a hollow metal cylinder mounted around the outside of the mounting staff which supports the antenna. A small air space exists between the skirt and the outer surface of the mounting staff, except at the location of the shorting ring. The skirt then acts as the lower portion of the antenna.

(2) The skirt has an additional function. In conjunction with the outer surface of the metal mounting staff, it forms a quarter-wave section of transmission line which is short-circuited at one end by the shorting ring. The impedance at the bottom end of the line so formed is very high. As a result, current flow is minimized on the mounting staff and on the outer conductor of coaxial cable. Such current, if allowed to flow, would produce radiation at a high vertical angle. By reducing this current to a minimum value, the radiation is reduced. In this way, the low-angle line-of-sight transmission required in the vhf and uhf bands is produced.

(3) The dimensions of the whip and especially of the skirt are highly critical. The upper radiating portion (whip) (DIM A, fig 3-23) is made 95 percent of a free-space quarter-wavelength. The length of the lower radiating portion (skirt) (DIM B) is made equal to a free-space quarter-wavelength. Actually, the skirt should be somewhat shorter than this value to produce maximum efficiency as a radiator. Its length, however, is chosen for best operation as a quarter-wave line, which produces slightly higher radiation efficiency. Adjusting clamps are provided both for the skirt and for the whip so that the antenna may be adjusted for any frequency in a given band.

(4) One particular military coaxial antenna has a frequency range of from 30 to 40 MHz. Another military coaxial antenna has a frequency range of 70 to 100 MHz. Markings sometimes are provided on the elements themselves to show the correct whip and sleeve lengths for various resonant frequencies. For example, a coaxial antenna suitable for 35 MHz would have a whip length of 80 inches and a skirt length of 84 inches.

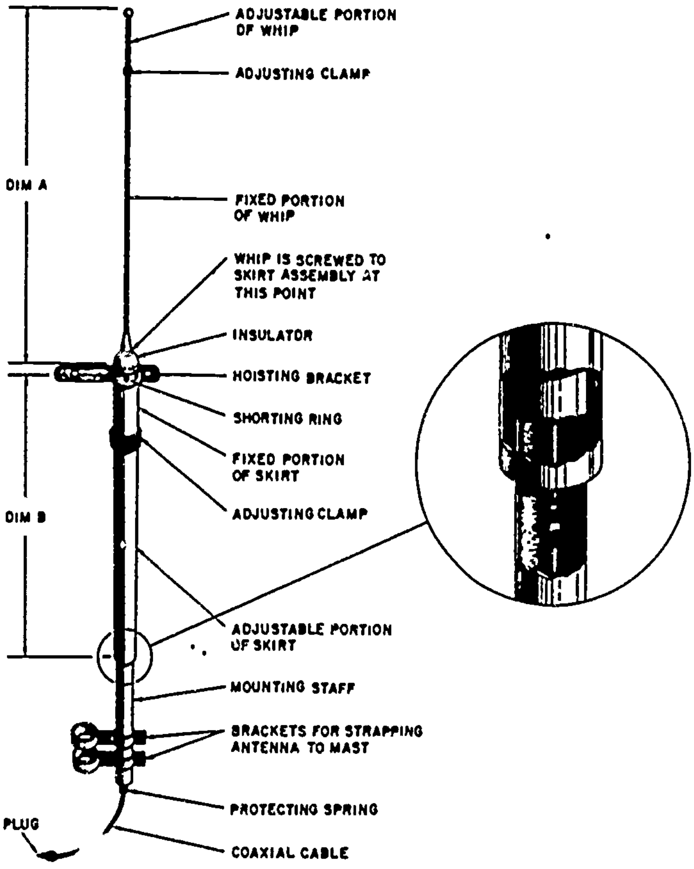

Fig 3-23. Military coaxial antenna.

c. Conical antenna.

(1) The conical antenna is one of a large number of special antennas developed to operate satisfactorily over a wide frequency band. One type of conical antenna, constructed of two solid metal cones, is shown in figure 3-24. Frequently the conical antenna is constructed of metal mesh or is simply a framework of metal rods that form the required shape. The cones are arranged on a common horizontal or vertical axis, depending on whether horizontal or vertical polarization is required.

(2) If the conical antenna is to operate as a half-wave antenna, its overall length must be considerably shorter than a free-space half-wavelength. This is the result of the large end effect produced by the bases of the cones forming the antenna. As the apex angle, A, is increased, the length of antenna required is reduced. For example, if angle A is 10°, the overall length required is about 75 percent of a free-space half-wavelength. With angle A at 20°, the length is only about 70 percent of a free-space half-wavelength. When such short lengths are used, the input impedance is approximately 40 ohms. When the conical antenna is operated as a full-wave antenna, the overall length commonly is made 73 percent of a free-space wavelength and the input impedance is several hundred ohms. When such an antenna has an apex angle of 10°, the input impedance is 950 ohms; with an apex angle of 20°, the input impedance is 600 ohms, with an apex angle of 30°, the input impedance is 300 ohms. The value may be reduced by using large apex angles, in excess of 30°.

(3) The large, cross-sectional area of the conical antenna accounts for its wide frequency response. Like the folded dipole, the conical antenna has a large capacitance but a small inductance per unit length. The radiation pattern of the conical antenna is similar to that produced by an ordinary half-wave antenna which is similarly oriented. Figure 3-25 shows a typical military conical antenna.

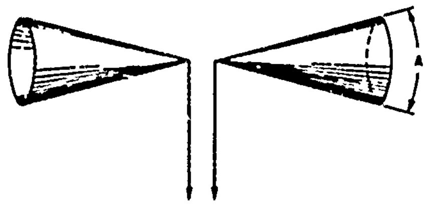

Fig 3-24. Simplified conical antenna.

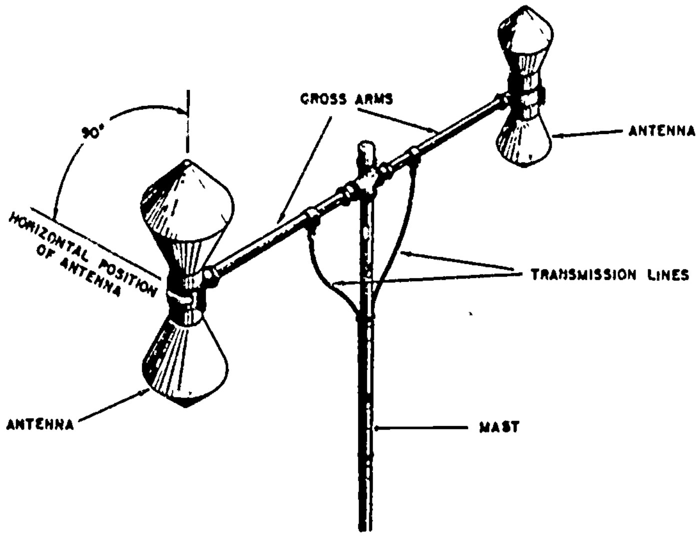

Fig 3-25. Military conical antenna.

d. Microwave antenna.

The half-wave antenna can be used at any operating frequency. When microwave frequencies (at the upper part of the uhf band and higher) are used, the antenna length required is extremely small. For example, the microwave frequency of 5,000 MHz has a free-space half-wavelength of only little more than 1 inch. The length of the half-wave antenna at this frequency would have a value somewhat less than this small distance.

The small size of a microwave, half-wave antenna is both a disadvantage and an advantage. The electrical characteristics of the microwave antenna are exactly like those of its larger, lower frequency counterpart. It has about the same radiation pattern, the same distribution of standing waves along its length, and the same radiation resistance for similar conditions. However, the amount of signal pick-up when such a small antenna is used for receiving is reduced greatly. Any receiving antenna is able to pick up energy from a section of an incoming wave front that extends less than a quarter-wavelength away from the antenna. Therefore, a receiving antenna that is 50 to 100 feet long is able to pick up a far greater amount of energy than can a microwave antenna only about an inch in length. So poor is the signal pick-up that a simple, half-wave antenna rarely is able to pick up enough microwave energy to overcome the noises generated within the receiver itself. As a result, a simple, half-wave antenna seldom is used alone in the microwave range.

The great advantage of the small size of microwave, half-wave antennas is that it becomes convenient to use a large number of these together to form an array of antennas. All antenna arrays have two things in common. First, an array produces a concentration of radiated energy in certain directions; that is, the array is highly directional--it has gain. Second, an array occupies a greater space than does the single half-wave antenna, since it is made up of a number of half-wave antennas, and the greater the number of individual antennas that make up the array, the greater are the directivity and gain. In the microwave range, the construction of very elaborate arrays of half-wave antennas can be accomplished in a reasonably small space. Some microwave arrays are made up of as many as 32, 64, 100, or even 250 individual half-wave dipoles.

Other microwave antennas are composed of a single half-wave dipole or an array that is used in conjunction with specially shaped reflectors.

One commonly used reflector, shown in A of figure 3-26, is the corner reflector type. The reflector is composed of two flat, metal sheets which meet at an angle to form a corner. Wire mesh or metal tubing sometimes is used instead of the solid metal. The half-wave, microwave antenna is located so that it bisects the corner angle because maximum radiation occurs out of the corner. The field strength produced by such an arrangement is considerably more than would be produced by the antenna alone.

Another commonly used reflector is the paraboloidal type (fig 3-26 B). The shape is similar to that of reflectors used in searchlights that concentrate energy from a light bulb into a narrow, well-defined beam. The reflector is constructed of solid metal or metal mesh. A half-wave, microwave antenna is located at the focal point of the paraboloid. Energy arriving at any angle from the antenna is reflected by the paraboloid in parallel rays. This results in a very narrow beam of radio energy in the direction shown. A small, metal, hemispherical reflector prevents direct radiation from the half-wave antenna from interfering with the beam produced by the paraboloidal reflector. The small reflector causes all of the energy from the antenna to be directed back into the paraboloid.

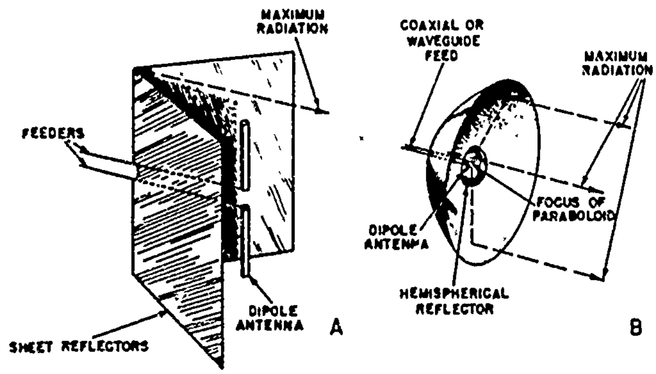

Fig 3-26. Special reflectors for half-wave antennas.

3-9. MULTIELEMENT ARRAYS

One means of attaining increased antenna gain and directivity is by use of the multielement array. The long wire, regardless of its length, is looked upon as a single radiating or receiving element; the array is a combination of elements which, considered separately, could be individual antennas. These elements act together or upon each other to produce a given radiation pattern. Various factors influence the choice of methods used to produce high directivity. Whereas the long-wire antenna often is preferred where reception or transmission on more than one frequency is required and where gain or directivity requirements are moderate, the more exact phasing and determination of element lengths in the array make for a more regular radiation pattern. Since fewer minor lobes are developed, available power is concentrated in the major lobe or lobes, and therefore there is greater gain and sharper directivity in the favored direction. In a given available space, the elements of an array can be so arranged as to provide greater gain than a long-wire antenna confined to the same space.

a. Parasitic array. Of the several types of multielement array antennas the one we will concern ourselves with is the parasitic array. Definitions for terms used in this paragraph are as follows:

(1) Driven element. A driven element is connected directly to the transmission line. It obtains its power directly from the transmitter or, in reception, it applies the received energy directly to the receiver.

(2) Parasitic element. A parasitic element derives its power from another element in the array. It is not connected to any other element but is placed close enough to receive radiation and in this way is excited.

(3) Director element. This is a parasitic element placed in front of the driven element so that it operates to reinforce the radiation from the driven element (fig 3-27A).

(4) Reflector element. This is a parasitic element placed to the rear of the driven element so that it operates to reflect the radiation back to the driven element, thereby reinforcing the radiation from it (fig 3-27B).

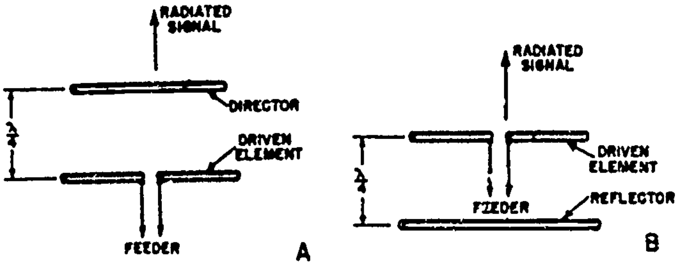

Fig 3-27. Position of the director and reflector to the driven element.

A parasitic array consists of one or more parasitic elements placed in parallel with each other (fig 3-28).

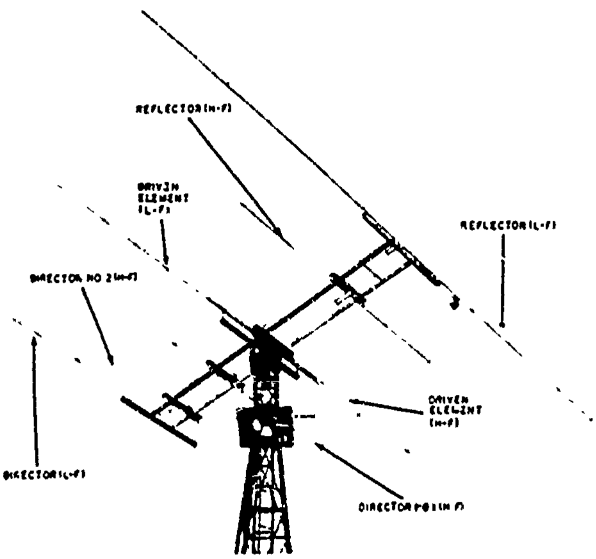

Fig 3-28. A parasitic array used for receiving and transmitting HF and LF.

b. Radiation. When a parasitic element is placed at a fraction of a wavelength from the driven element, it will re-radiate the radiated energy it intercepts. The parasitic element is effectively a tuned circuit coupled to the driven element much as the two windings of a transformer are coupled together. The radiated energy from the driven element causes a voltage to be developed in the parasitic element which sets up a magnetic field. This magnetic field extends over to the driven element, which then has a voltage induced in it. The magnitude and phase of the induced voltage depend on the length of the parasitic element and the spacing between the elements. The length and spacing are arranged so that the phase and magnitude of the induced voltage cause a unidirectional, horizontal radiation pattern.

(1) Consider the parasitic array in B of figure 3-27; the reflector and driven elements are spaced a quarter-wavelength apart. The radiated signal coming from the driven element strikes the reflector after a quarter-cycle. This causes the voltage on the reflector to be 180° out of phase with the driven element.

(2) The reflector now sets up a magnetic field which induces a voltage back to the driven element. This voltage is now in phase with the driven element voltage and reinforces the radiated signal.

(3) The director in A of figure 3-27 gives the antenna directivity so that the radiation patterns of both A and B of figure 3-27 appear as shown in figure 3-29.

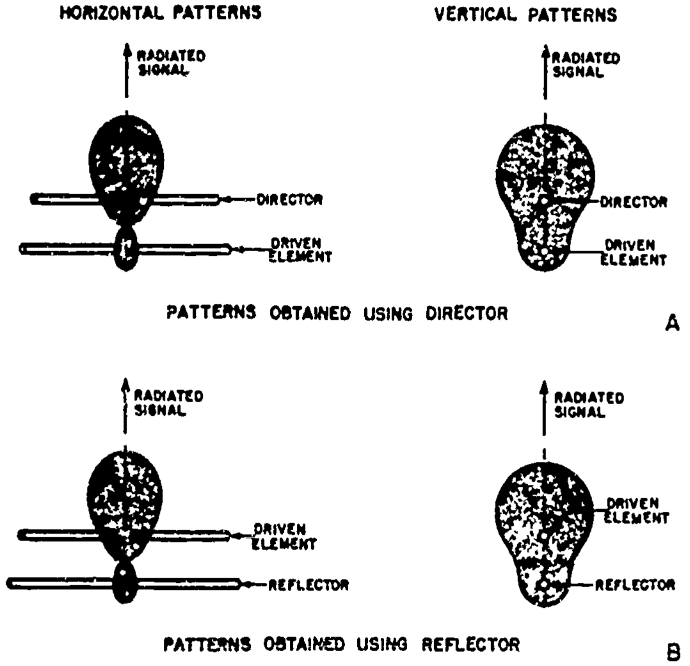

Fig 3-29. Patterns obtained using a parasitic element.

c. Directivity. Directivity is achieved through the length of the elements, the space between the elements, and the number of elements used in the array.

(1) If the array contains two parasitic elements (a driven element, a reflector, and a director), it is known as a three-element beam. If more directors are added, the higher the element beam will be. For example, a five-element beam will have a driven element, a reflector, and three directors. Most parasitic arrays do not exceed the five-element beam.

(2) Parasitic elements are usually positioned as shown in figure 3-30. Section A shows a three-element beam, B a four-element beam, and C a five-element beam. Many variations may be found, but the spacing between elements is typical of those normally encountered. Frequently the best spacing is found experimentally. Regardless of the number of directors on an array, only one reflector is used.

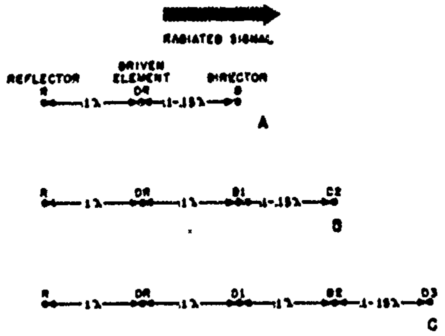

Fig 3-30. Spacing between elements of multiparasitic arrays.

(3) In a three-element beam, the director is slightly shorter and the reflector is slightly longer than the driven element. As each director is added, it is slightly shorter than the one nearer to the driven element.

Note: For more detailed information see TM 11-666, chapter 5.

Chapter 4

LONG-WIRE ANTENNAS AND ANTENNA INSTALLATION

Section I. LONG-WIRE ANTENNAS

4-1. INTRODUCTION

Long-wire antennas are long single wires (longer than a half wavelength) in which the current in adjacent half-wave sections flows in opposite directions. Such antennas have two basic advantages over the antennas discussed previously. These advantages are increased gain and directivity.

a. Antenna gain.

(1) All the antennas discussed so far have been basic half- and quarter-wave antennas that radiate equally in all directions. Greatest amounts of power are radiated in directions that are broadside to the antenna itself, and very little power is radiated off the antenna ends. Consequently the basic antennas already discussed have a certain degree of directivity, which is the ability to radiate and receive energy better in some directions than in others.

(2) An isotropic antenna is one that radiates equally in all directions. Actually, every antenna radiates more energy in certain directions than in others. The imaginary isotropic antenna can be used only as a standard for comparison.

(3) Since no antenna is truly isotropic, it is common practice to use a basic half-wave antenna as a standard for reference. The reference field strength is the field intensity at a fixed point produced by the half-wave antenna in the direction of its maximum radiation. The reference power is the power applied to the standard antenna. If any antenna produces a greater field strength at the same fixed point than does the standard antenna, it is said to have gain with respect to the standard. Conversely, if the antenna produces less field strength at the fixed point than does the standard antenna, it is said to have loss with respect to the standard.

(4) In practice, the procedure is first to set up the antenna to be checked. A given amount of input power is applied, and the field strength is measured at a distant receiving point. Then, the half-wave antenna is set up at the same position and height above the earth, and oriented so that a field having the same polarization as the original antenna is produced. Exactly the same power is applied to the half-wave antenna as was applied to the other antenna. The field strength then is measured at the same distant receiving point. Comparison between the two field strengths indicates whether the antenna being checked produces a gain or loss in field strength compared with the reference antenna.

(5) Another method used to measure the gain (or loss) of an antenna involves an actual measurement of the input power to the antenna. The amount of input power applied to the antenna to be checked is measured, the field strength at a certain distant point is noted, and the half-wave antenna is set up in the preceding method. The power applied to this reference antenna then is adjusted until exactly the same field strength is produced at the distant point. If more power must be applied to the reference antenna to produce the same field strength at the point as produced by the antenna under test, the antenna under test has a gain with respect to the reference antenna. On the other hand, if less power must be applied to the half-wave reference antenna to produce the same field strength, the antenna under test has a loss with respect to the reference antenna. The ratio between the two input powers (reference antennas divided by tested antennas) gives the gain (or loss) of the antenna being tested. Because an accurate measurement of different field strengths cannot be made as easily as an accurate measurement of different antenna input powers, this method is preferred to that described in (4) above.

(6) If a certain antenna has a gain of 10 dB, it produces a field strength that is over three times greater than that produced by the half-wave antenna with the same input power. This antenna produces the same field strength as that produced by the half-wave antenna when the power applied to the half-wave antenna is 10 times greater than that applied to the antenna under test.

b. Directivity.

(1) Since all antennas are directional to a certain degree, the term directional usually is applied only to those antennas that are highly directional. The main advantage to be gained from the use of the long-wire antennas and arrays is in their greater directional qualities. These antennas all concentrate a larger amount of available radiated energy into a smaller sector.

(2) Some antennas are directional in some planes but practically nondirectional in others. Consider, for example, the basic half-wave antenna that is mounted in a vertical position. If a vertical plane is passed through the center of the antenna and the radiation pattern is drawn on that plane, the pattern would take the form of a figure 8. Maximum radiation occurs in the two directions that are at right angles to the antenna itself and no radiation occurs off the ends. The antenna is said to have two lobes of radiated energy and two nulls. Consequently, this antenna is said to be bidirectional (it radiates in two directions) in the vertical plane. If the horizontal plane is considered, however, it is seen that the antenna radiates equally in all directions. The antenna therefore is nondirectional in the horizontal plane. When highly directional antennas are used, it is important to know in which plane the desired directivity occurs.

(3) Highly directional antennas are designed to produce a large increase in radiated or received energy in one direction. The idea, however, may be to prevent radiation (or reception) in a certain direction. For example, assume that two powerful transmitters are located near each other. To prevent these transmitters from interfering with each other, it is necessary to use directional antennas with respective nulls pointing toward each other. Under these conditions, the antennas may be adjusted to produce the least amount of radiated energy in the direction of each other, rather than the greatest amount of energy in any given direction.

4-2. GENERAL CHARACTERISTICS

a. Harmonic. If the length of a long-wire antenna is such that two or more half-waves of energy are distributed along it, it often is referred to as a harmonic antenna. Consider the half-wave antenna shown in A of figure 4-1. At a given instant, the polarity of the RF generator connected to the center of the antenna is positive at its left-hand terminal and negative at its right-hand terminal. As a result, current in the left half of the antenna flows toward the generator, whereas current in the right half of the antenna flows away from the generator. In both halves of the half-wave antenna, current flows in the same direction, from left to right, as shown by the wave of current above the antenna wire.

b. Nonharmonic. Now assume that the antenna just discussed is lengthened until it is 2 half-wavelengths, as in B. With the RF generator still connected at the center and with the same instantaneous polarities as in A, current in the left side of the antenna must flow toward the generator, and current in the right side must flow away from the generator. Since the antenna is now 2 half-wavelengths, 2 half-waves of current can be accommodated on the antenna and the current polarity is the same in both halves of the antenna. It is important to note that this is not a true long wire or harmonically operated antenna since there is no reversal of current flow in adjacent half-wave sections. Instead, this arrangement is simply 2 half-wave antennas operating in phase at their fundamental frequency. Such an arrangement is called a driven c[illegible]ar array, and has characteristics quite different from those to be discussed for the tru[illegible]monically operated or long-wire antenna.

The antenna in B can be converted into a true long-wire, harmonically operated antenna simply by moving the generator to a current loop as shown in C. With the RF generator polarity as shown, current flows from left to right in the half-wave section of the antenna. The direction of current flow then is reversed in the second half-wave section. If the generator is moved to the extreme end of the antenna as shown in D, the antenna is also a long-wire antenna, and the current distribution on the antenna is exactly the same as in C.

The harmonically operated antenna, therefore, must be fed either at a current loop or at its end for proper operation. If the antenna is any odd number of half-wave lengths ($1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, and so on) so that a current loop occurs at the center of the antenna, center feeding can be used.

As the length of an antenna is increased, it is natural to expect a change in the radiation pattern produced by the antenna. A long-wire antenna can be considered one made up of a number of half-wave sections fed 180° out of phase and spaced a half-wavelength apart. As a result, there is no longer zero radiation off the ends of the antenna, but considerable radiation occurs in the direction of the long wire as a result of the combined fields produced by the individual half-wave sections. In addition, radiation also occurs broadside to the long wire. Consequently, the resultant maximum radiation is neither completely at right angles to the long wire nor completely along the line of the long wire. Instead, the maximum radiation occurs at some acute angle in respect to the wire, the exact angle being determined by the length of the antenna.

It will be shown that as the length of a long-wire antenna is increased, the following characteristic changes occur. First, the gain of the antenna increases considerably compared with that of the basic half-wave antenna, especially when the long wire is many wavelengths. Second, the direction along which maximum radiation occurs makes a smaller angle with respect to the wire itself. Consequently, as the antenna is made longer, its major lobe of radiation lies closer to the direction of the wire itself. Third, more minor lobes are produced as the antenna length is increased.

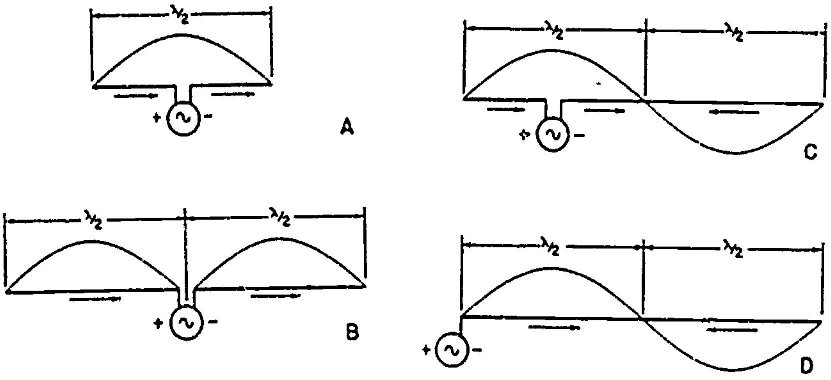

Fig 4-1. Harmonically and nonharmonically operated antennas.

4-3. HARMONICALLY OPERATED ANTENNAS IN FREE SPACE

a. Calculation of length.

(1) It already has been pointed out that the electrical and physical lengths of a half-wave antenna are not the same because of the reduction in wave velocity on the antenna resulting from its thickness and because of end effect. The main factor producing end effect is the use of insulators at the antenna ends. These introduce additional capacitances to the antenna which lower its resonant frequency and increase the electrical length of the antenna. Consequently, the half-wave antenna is foreshortened by 5 percent to compensate for these effects.

(2) Since, in a long-wire antenna, the insulators are used at the ends and not between adjacent half-wave sections, it is only the half-wave sections at the antenna ends that are affected by end effects. Therefore, a harmonically operated antenna of 1 wavelength is foreshortened by only $2\frac{1}{2}$ percent overall, 1 of 2 wavelengths is foreshortened by $1\frac{1}{4}$ percent overall, and so on. This convenient formula is used to determine the length in feet of a harmonic antenna for any given frequency in Megahertz:

$$\text{length} = \frac{492(H - 0.05)}{\text{frequency}}$$

H is the number of half-waves on the antenna. In the following example we will use 20 MHz for the frequency and H will be 3.

$$\text{length} = \frac{492\ (H - 0.05)}{20\ \text{MHz}}$$

$$\text{length} = \frac{492\ (3 - 0.05)}{20\ \text{MHz}}$$

$$\text{length} = \frac{492\ (2.95)}{20\ \text{MHz}}$$

$$\text{length} = \frac{1451.40}{20\ \text{MHz}}$$

$$\text{length} = 72.57$$

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b. Radiation patterns.

(1) Figure 4-2 shows the radiation patterns of harmonic antennas up to 3 wavelengths. The field strength produced by the half-wave antenna is shown for comparison. Note that as the antenna length is increased, more lobes are produced. The $1\frac{1}{2}$-wavelength antenna, which operates on the third harmonic, has three lobes--two major lobes and one minor lobe, the latter lying at right angles to the antenna. The 3-wavelength antenna, which operates on the 6th harmonic, has 6 lobes--2 major lobes and 4 minor lobes.

(2) The harmonic antennas which operate on the even harmonics (2d, 4th, and so on) have an even number of half-wave patterns distributed along their length. Since the adjacent half-wave sections have currents of opposite phase, a distant point in space located equidistant from the ends of the antenna is acted on by equal and opposite fields. Cancellation of fields occurs and a null is produced on a plane at right angles to the antenna, cutting it at the center. On the other hand, harmonic antennas which operate on the odd harmonics have an odd number of half-wave sections. Complete cancellation of radiated fields does not occur at points equidistant from the ends of the antenna because of the odd half-wave section. This results in a minor lobe being produced in a direction that is perpendicular to the antenna, and coming from its center.

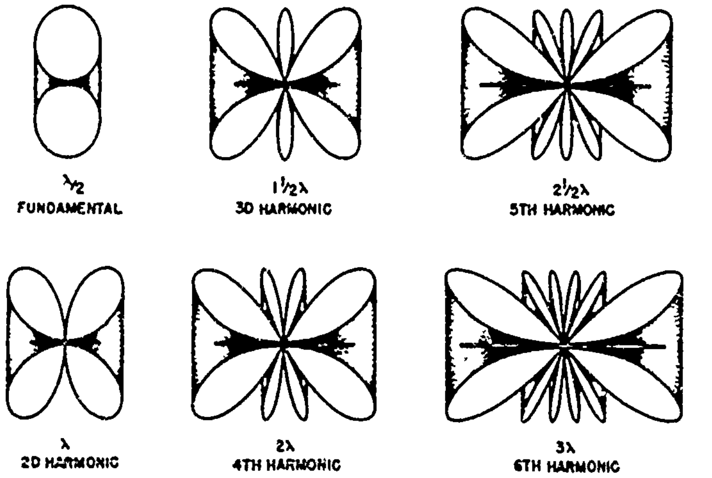


Fig 4-2. Radiation patterns of various harmonic antennas.

(3) The radiation patterns of a harmonic antenna are modified considerably by the presence of the earth under the antenna. Some of the energy radiated from the antenna travels downward toward the earth, where it is reflected. If the reflected energy arrives at some distant point in phase with the direct energy from the antenna, then reinforcement of the signal strength occurs. On the other hand, if the reflected energy arrives 180° out of phase with the direct energy, a reduction or cancellation of signal strength takes place.

(4) Energy reflected from ground will induce a voltage into the harmonic antenna. This causes a current to flow which combines with the original antenna current. The total antenna current then will be greater or less than the original antenna current, depending on the height of the antenna. Consequently, the radiation resistance of the harmonic antenna varies, depending on the height above ground. In this respect, the behavior of the harmonic antenna is the same as the half-wave antenna.

4-4. END FEEDING LONG-WIRE ANTENNAS

Both resonant and nonresonant lines can be used to feed long-wire antennas. The same general principles apply here as in the half-wave antennas. A current-fed antenna behaves as a true long-wire only at odd harmonics of the original frequency. Therefore, for operation on all harmonics, end feeding is preferred.

a. Resonant lines.

An end-fed long-wire antenna with a resonant feeder line is shown in figure 4-3A. Operation on all harmonic frequencies is possible with this arrangement, provided the tuning unit at the input end of the resonant line has sufficient range to match the input impedance of the transmitter.

b. Nonresonant lines.

Arrangements for using nonresonant lines are shown in figure 4-3B and C. In both, quarter-wave matching sections are used to match the nonresonant line to the long-wire antenna. In B, the feeder is tapped on the matching section at a point where an impedance match occurs. In C, the feeder is connected to a Q-matching section (the Q-matching device is an open quarter-wave section of line placed in series with the untuned transmission line), the characteristic impedance of which is made equal to the square root of the product of the radiation resistance of the long-wire antenna and the impedance of the nonresonant line. When matching sections of line are used with nonresonant feeders, it must be realized that these operate over only a narrow band of frequencies.

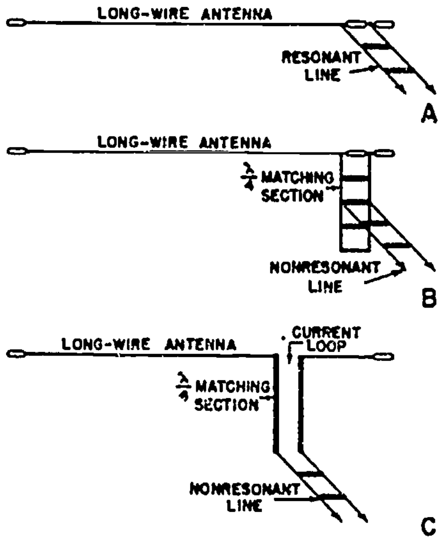


Fig 4-3. Feeding long-wire antennas.

4-5. RESONANT AND NONRESONANT ANTENNAS

a. Resonant. Only resonant antennas have been discussed so far. These have standing waves of voltage and current distributed along their length, which are set up by the reflection of waves at the ends of the antenna.

If one end of an antenna is terminated in a resistance that is equal to the characteristic impedance of the antenna, waves can travel in one direction only. As a result, no standing waves are set up. Instead, the current and voltage are distributed uniformly along the length of the antenna. Such an antenna is known as a nonresonant antenna.

b. Nonresonant. The radiation pattern of a nonresonant antenna is quite different from the pattern produced by a resonant antenna. Consider the radiation patterns shown in figure 4-2. Assume that all these resonant antennas are made nonresonant by connecting a terminating resistor between one end of each antenna and ground. All of the antennas then radiate only in the direction of the terminating resistor. The lobes of energy to the otherside are largely attenuated. Consequently, the major lobes takes the form of a single cone of radiation surrounding the antenna in the direction of the terminating resistor. The antennas are converted from bidirectional types (which produce maximum radiation in two directions) to unidirectional types (which produce maximum radiation in only one direction). If a radiation pattern were drawn to show the radiation at the vertical angle at which maximum radiation occurs, a single major lobe of radiation would appear in the direction of the antenna itself and toward the terminating resistor.

An important characteristic of a nonresonant antenna is that it radiates efficiently over a very wide frequency range. Therefore, it is not necessary to cut the antenna for any exact length so long as it is at least several wavelengths.

4-6. BEVERAGE OR WAVE ANTENNA

a. Description and design.

(1) One type of nonresonant, long-wire antenna is the Beverage or wave antenna (fig 4-4) which consists of a single wire (preferably of 2 or more wavelengths) parallel with the earth and supported on poles at a height of 10 to 20 feet above ground. The far end of the wire is connected to ground through a noninductive resistor of about 500 ohms. This resistor must be able to dissipate about one-third of the power fed into the antenna. This is about the characteristic impedance of a single-wire transmission line with a ground return. A reasonably good ground, such as a number of ground rods or a counterpoise, should be used at both ends of the antenna.

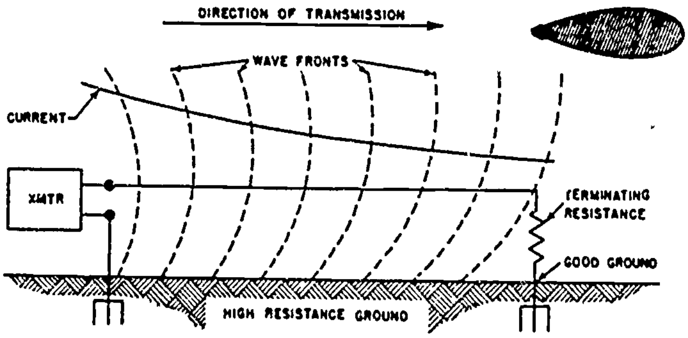


Fig 4-4. Beverage or wave antenna.

(2) Sometimes two or more antenna wires are used in parallel instead of a single wire. This reduces the characteristic impedance of the antenna and ground-return circuit and permits a lower value of terminating resistance to be used. The input impedance of the antenna is reasonably constant with frequency, and the antenna may be used over a wide frequency range without changing its length.

(3) The wave antenna is directional, and is used primarily for either transmitting or receiving low-frequency signals. Maximum reception or radiation is in line with the wire and off the terminated end. There is a minimum of radiation in the opposite direction if the antenna is terminated properly. The forward lobe may be made narrower and the gain increased by using a longer antenna wire. However, if extremely long-wave antennas are used, the forward gain falls off.

(4) At frequencies below 800 kilohertz, a properly located wave antenna should give results equivalent to a vertical antenna several hundred feet high. One particular military wave antenna (fig 4-5) consists of three conductors arranged in the form of an equilateral triangle 5 feet on a side, erected about 15 feet above ground on short telephone poles, and usually of 2 wavelengths. At a frequency of 500 kilohertz, such an antenna would be almost 4,000 feet long. If ground space limitations prevent the use of such a long antenna, an antenna under 1 wavelength can be used. A reduction of forward gain will result under these conditions.

Fig 4-5. Three-wire wave antenna.

b. <u>Wave tilt.</u>

(1) The operation of the wave antenna depends on a process known as wave tilt. When a vertically polarized radio wave travels over the surface of an imperfect conductor, such as the earth, the wave fronts lean forward in the direction of propagation. This is caused by the slower propagation constant of the earth. The amount of forward tilt depends on the frequency of the R F wave and the characteristics of the surface over which the wave is traveling. At the lower frequencies at which the wave antenna is used, the wave tilt is approximately proportional to the square root of the product of frequency and soil resistivity. As the resistance of the surface is increased, the wave travel along the surface is reduced and a greater wave tilt results. Consequently, over rocky and sandy soil, a considerable forward tilt results, whereas over salt marshes and sea water, almost no tilt occurs. This means that wave antennas, which depend on wave tilt for proper operation, should not be installed over highly conducting surfaces, but, instead, should be installed only over poor or medium soil. Wave antennas also give good results when installed over ground which has a permanent layer of ice (such as permafrost) a short distance below the surface, or over certain types of ground found in northern or polar regions which are very moist in the summer and have poor conductivity because of lack of mineral content. Actually, it is the average ground conductivity for a considerable distance below the surface that is important rather than the character of a thin top-soil layer.

(2) The wave antenna operates in conjunction with ground, so that a vertically polarized radio wave is radiated. However, because of the forward wave tilt, there is a horizontal component of the electrical field. The vertical and horizontal components are not exactly in phase, and the resultant polarization of the radiated wave, therefore, is a long oval. The wave is radiated in the direction of the tilt which is off the end of the antenna that is terminated in the resistance load (fig 4-4).

(3) Since the wave antenna is a grounded antenna with a wide frequency range, it usually is fed by means of an unbalanced, nonresonant transmission line. The input impedance of the single-wire antenna is approximately 500 ohms, so that the characteristic impedance of the line also must be 500 ohms.

(4) The most common feeding arrangement is a single-wire transmission line connected to the end of the antenna. If coaxial line is to be used, an impedance-matching transformer is inserted between the transmission line and the antenna.

4-7. V ANTENNA

a. Description and design. The V antenna consists of two horizontal, long wires arranged to form a V, and fed at the apex with currents of opposite polarity. Major lobes from each wire combine in such a way that maximum radiation occurs in the direction of a line that bisects the angle between the two wires. Figure 4-6 shows a V antenna with the individual radiation patterns of each of the wires. The shaded lobes produced by each individual leg of the V lie in exactly the same direction. These lobes combine to form the shaded lobes in the resultant pattern. Most of the other lobes are more or less attenuated. The pattern is bidirectional, and radiation occurs along a line that bisects the apex angle in both directions. As with other long-wire antennas, the greater the leg length the higher the gain and directivity of the antenna. The gain of the V antenna is about twice that of a single long-wire antenna, since the radiation from the lobes of two wires combines to produce the radiation pattern of the V antenna. In practice, the gain may be even higher than this value because of the effects of one leg of the V on the other.

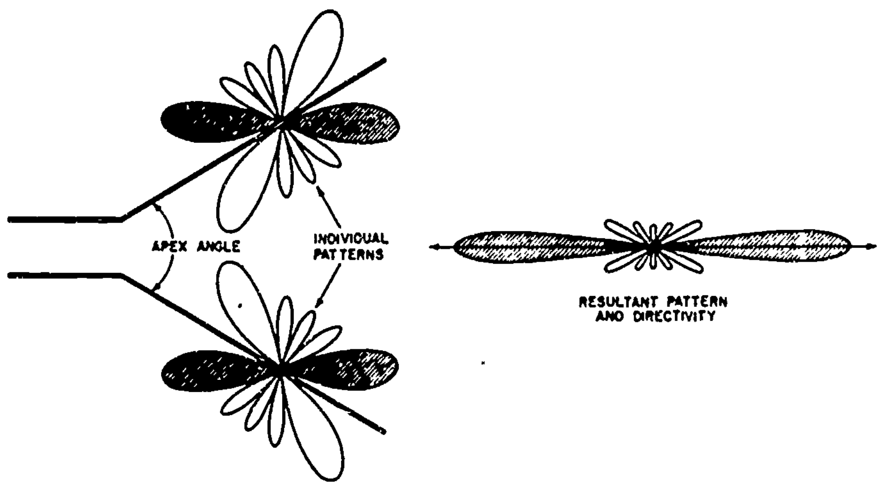


Fig 4-6. Formation of the V antenna radiation pattern.

b. Radiation pattern. The optimum apex angle for the V antenna is, ordinarily, twice the angle between the lobe of maximum radiation and the wire itself when the wire is used as a conventional long-wire antenna. Here, the lobes of maximum radiation from the two long wires making up the V antenna are in the same direction so that they combine as shown in figure 4-7. In practice, a somewhat smaller angle than this value is used when the V antenna legs are shorter than about 3 wavelengths. This increases slightly the gain of the antenna.

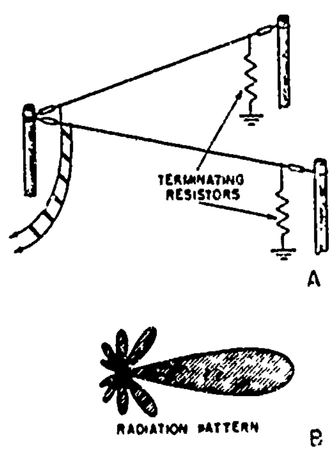


Fig 4-7. Unidirectional V antenna.

(1) The following guide shows the optimum apex angle for V antennas with equal legs of various lengths:

Antenna length (wavelengths)	Optimum apex angle (degrees)	Antenna length (wavelengths)	Optimum apex angle (degrees)
1	90	6	40
2	70	8	35
3	58	10	33
4	50		

(2) When the V antenna is to be operated over a wide frequency range, an average optimum apex angle should be used. Reasonably good results are obtained by noting the optimum apex angle for the antenna at its lowest operating frequency and the angle for its highest operating frequency, and then using the average of these two values.

(3) The V antenna does not radiate the major portion of its energy along the surface of the earth. Instead, the energy is radiated upward at a certain vertical angle in respect to the earth. The size of this angle depends on the length of the antenna legs and the height of the antenna above ground. In general, as the antenna length is increased or as the height above ground is increased, the vertical angle at which maximum radiation occurs gradually becomes smaller. The vertical angle is measured in respect to the horizontal antenna wires.

4-8. HALF-RHOMBIC ANTENNA

a. Description and design. The half-rhombic antenna is a terminated vertical antenna with an unbalanced transmission line. A ground or counterpoise is utilized producing a vertically polarized radio wave.

(1) Assume that a unidirectional half-rhombic antenna using a single-wire counterpoise is to be designed. It is desirable that legs of the antenna be many wavelengths in order to provide maximum gain and directivity. For satisfactory performance, each leg of a half-rhombic antenna must be at least 1 wavelength at the lowest frequency of operation. In practice, a leg of at least 2 wavelengths at the lowest frequency generally is used, and some half-rhombic antennas use legs of 10 or 12 wavelengths. The leg length usually is limited by the size of the available site and the directivity required.

(2) The half-rhombic antenna maintains its characteristics over a wide frequency range. Frequency ranges of 2 to 1 and 4 to 1 are common in practice. For example, a half-rhombic antenna designed for a frequency of 10 MHz would operate satisfactorily to 20 MHz and would be useful to 40 MHz. Depending on the amount of change in gain and directivity that can be tolerated, an even greater frequency range can be accommodated. In general, as the frequency is raised, greater gain and directivity occur.

(3) The factor that most frequently limits the size of the half-rhombic antenna is the height of the apex above ground. If a very tall support is available for the apex, a large antenna can be erected. It is necessary that the single support required be made of wood, or other nonconductor, so that the operation of the antenna is not affected. Steel masts, or wooden masts using metal guy wires, should not be installed.

(4) The typical military half-rhombic antenna shown in figure 4-8 consists of a 100-foot antenna wire erected over a single 30-foot wooden mast (supported by three rope guys) and an 85-foot counterpoise wire laid along the ground. The antenna and counterpoise are terminated in a 500-ohm resistor contained in a small terminal box at the far end of the antenna.

(5) The antenna shown can be used with low-power transmitters or receivers operating at frequencies from 30 to 70 MHz, and equipped with either an RF output impedance of 500 ohms or a suitable antenna-matching network. At 30 MHz, the leg is 1 1/2 wavelengths; and at 70 MHz it is 3 1/2 wavelengths. A power gain of 4 or 5 occurs at the lowest frequency, and a power gain of about 10 occurs at the highest operating frequency.

(6) Since the transmitter or receiver used with the half-rhombic antenna generally is located at the end of the antenna, direct connections can be made to the antenna. If a transmission line must be used between the antenna and the radio set, a 2-wire line with a characteristic impedance of 500 ohms can be used.

(7) A large half-rhombic antenna designed for frequencies from 3 to 18 MHz has a ground-projected length of 625 feet and an apex height of 225 feet. The antenna is supported by a hydrogen-filled balloon in low winds or by a kite in high winds. A balloon- or kite-supported half-rhombic antenna, designed for frequencies of 1 to 8 MHz, has a ground-projected length of 1,600 feet and an apex height of 560 feet.

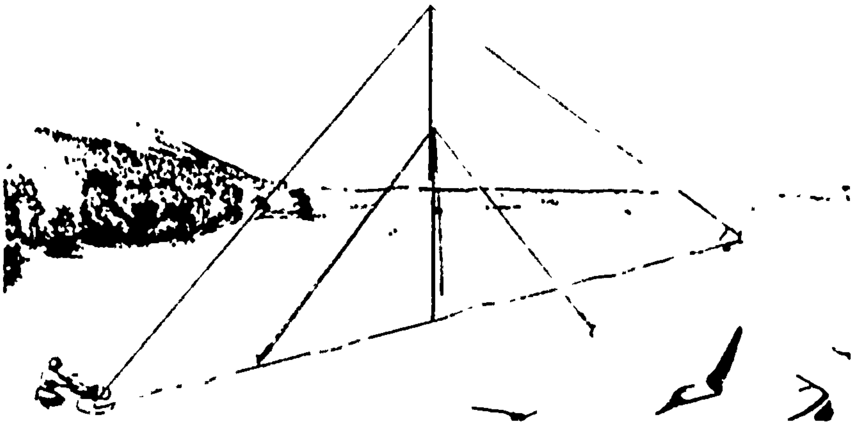
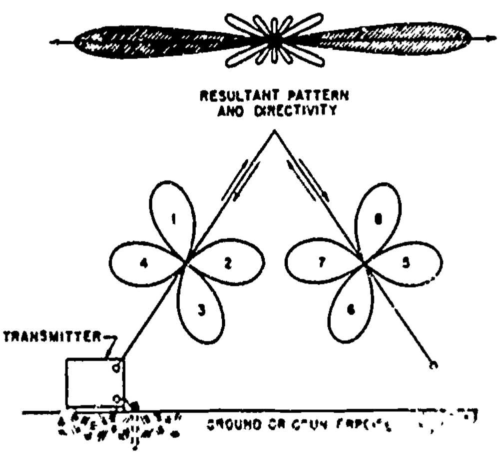


Fig 4-8. Typical military half-rhombic antenna.

b. Polarization and directional characteristics.

(1) The development of the radiation pattern produced by the half-rhombic antenna is shown in figure 4-9. The half-rhombic antenna has not been terminated. Assume that each leg is 2 wavelengths and that the angle between the two legs is correct. A transmitter is connected between the end of the antenna and a good ground. A single-wire counterpoise frequently is used which extends for the entire projection of the antenna length on the ground. Current from the transmitter flows toward the unterminated end of the antenna where it is reflected back along the antenna, as shown by the arrows. As a result of this reflection, standing waves are set up on the antenna and lobes of radiation appear as shown.

(2) Lobe 2 combines with lobe 5 to produce strong forward radiation from left to right. Lobe 4 combines with lobe 7 to produce strong rear radiation from right to left. These lobes exhibit bidirectional directivity along the direction of the antenna itself. The remaining lobes combine in various ways to produce several minor lobes in other directions. As a transmitting antenna, maximum energy is radiated in the directions shown by the large 2-headed arrow; and as a receiving antenna best reception occurs in these same directions.



[illegible]

(3) When a terminating resistor of about 500 ohms is connected between the far end of the antenna and ground (or counterpoise), conditions become different. Current from the transmitter can flow only toward the resistor (fig 4-10). This resistor absorbs any energy that is not radiated, and, in so doing, prevents any reflection of energy back along the antenna. As a result of using the terminating resistor lobes 3, 4, 7, and 8 disappear and only the forward lobes remain. Lobes 2 and 5 combine to produce intense radiation in the forward direction, from left to right, whereas lobes 1 and 6 produce minor lobes. Consequently, when this half-rhombic antenna is used for transmission, it is unidirectional, and radiates maximum energy along the antenna in the direction of the terminating resistor (fig 4-10).

(4) When the antenna is used for receiving, the antenna current will flow from the terminating resistor toward the feed point. Signals originating from the direction of the resistor will produce maximum effect on the receiver. Under these conditions, all arrows in figure 4-10 would be shown reversed.

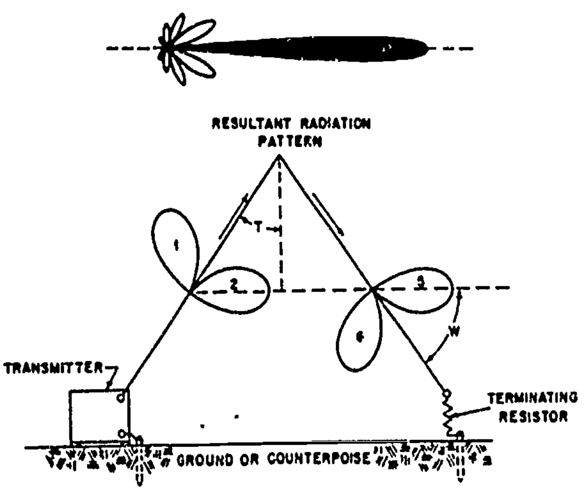


Fig 4-10. Terminated half-rhombic antenna and resultant radiation pattern.

4-9. RHOMBIC ANTENNA

a. Description and operation. The highest development of the long-wire antenna is the rhombic antenna (fig 4-11). It consists of four conductors joined to form a rhombus, or diamond. All sides of the antenna have the same length and the opposite corner angles are equal. In common with previous nonresonant antennas, the rhombic antenna radiates best in the direction of the terminating resistor and receives best from the direction of the resistor. Maximum radiation does not occur in the same direction as the plane of the antenna, that is, horizontally. Instead, it occurs at some vertical angle above the horizontal plane, as shown by the wave angle, W. The title angle, T, is one-half the angle between the two legs making up one side of the antenna.

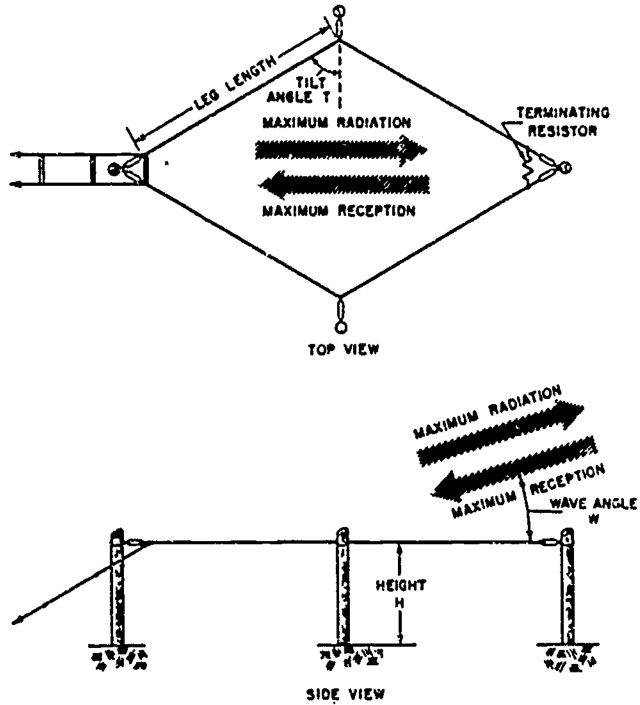


Fig 4-11. Basic rhombic antenna.

Figure 4-12 shows the individual radiation patterns produced by the four legs of the rhombic antenna and the resultant radiation pattern. If the tilt angle, T, is properly chosen for the length of the legs used, the shaded lobes all add together to form an intense forward lobe in the direction of the terminating resistor. Since the greatest percentage of rhombic antennas are used at high frequencies where the lengths of the legs are several hundred feet, most rhombics are horizontal. Therefore, the horizontal polarization is most common.

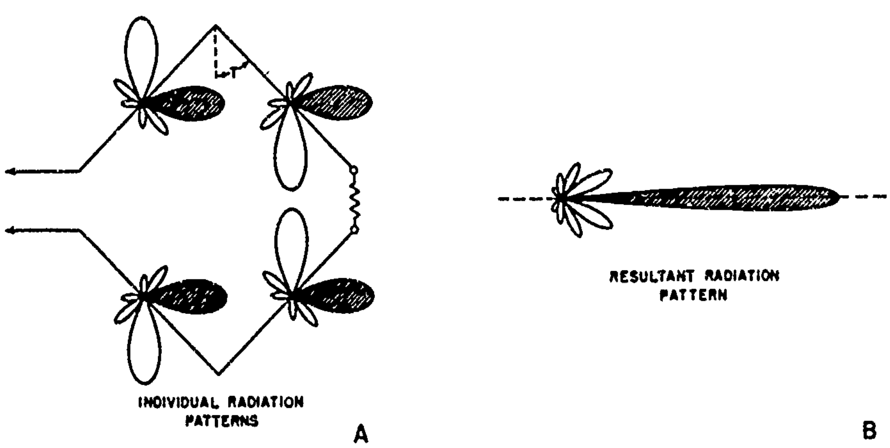


Fig 4-12. Formation of the rhombic radiation pattern.

(1) Advantages. The rhombic antenna is used widely for long-distance high-frequency transmission and reception, for reasons explained below. It is one of the most common fixed-station antennas, being very useful in point-to-point work.

(a) The rhombic antenna is useful over a wide frequency range, a range of 2 to 1 being covered easily with excellent results. Although it is true that some changes in gain, directivity, and characteristic impedance do occur with change in operating frequency, these changes are small enough to be neglected. A frequency range of 4 to 1 can be covered by a typical rhombic antenna with good results, and standard military rhombics cover a frequency range of 5 to 1 or 6 to 1 satisfactorily.

(b) Another advantage of the rhombic antenna is that it is much easier to construct and maintain than other antennas of comparable gain and directivity. Only four supporting poles of common heights from 50 to 75 feet are needed for the antenna, which has a simple form, being made up of four straight lengths of wire.

(c) The rhombic antenna also has the advantage of being noncritical so far as operation and adjustment are concerned. This follows from the broad frequency characteristics of the antenna.

(d) Still another advantage is that the voltages present on the antenna are much lower than those that would be produced by the same imput power on a resonant antenna. This is particularly important when high transmitter powers are used or when high-altitude operation is required. The lower voltages mean less possibility of corona loss.

(2) Disadvantages.

(a) The rhombic antenna is not without its disadvantages. Probably the principal one is that a fairly large antenna site is required for its erection. Each leg is made at least 1 or 2 wavelengths at the lowest operating frequency, and when increased gain and directivity are required, legs of from 8 to 12 wavelengths are used. Such requirements mean that high-frequency rhombic antennas have leg lengths of several hundred feet, and so they can be used only when a large plot of land is available.

(b) Another disadvantage is that the horizontal and vertical patterns depend on each other. If a rhombic antenna is made to have a narrow horizontal beam, the beam is also lower in the vertical direction. Therefore, it is impossible to obtain high vertical angle radiation except with a very broad horizontal pattern and low gain. Rhombic antennas are used, however, for long-distance sky wave coverage at the high frequencies. Under these conditions, low vertical angles of radiation (less than 20°) are desirable. With the rhombic antenna, a considerable amount of the input power is dissipated uselessly in the terminating resistor. However, this resistor is required in order to make the antenna unidirectional, and the great gain of the antenna more than makes up for this loss.

b. Standard designs.

(1) Many rhombic antennas used for military applications are based on certain standardized dimensions which make satisfactory operation possible over a frequency range of from 4 to 22 MHz. This range includes the frequencies that commonly are used for long-distance point-to-point sky wave communication between fixed stations.

(2) The seven standard sizes used are designated as rhombic antennas A through G, inclusive (fig 4-13). Antenna A is the largest rhombic, and it is used when communication is required between points over 3,000 miles apart. The leg of this antenna is about 1½ wavelengths at the lowest operating frequency (4 MHz) and about 8½ wavelengths at the highest operating frequency (22 MHz). Antenna G, the smallest rhombic, is used when communication is required between points that are from 200 to 400 miles apart. The leg of this antenna is somewhat less than 1 wavelength at the lowest operating frequency and about 5 wavelengths at the highest operating frequency. Rhombic antennas B through F inclusive have intermediate ranges and leg lengths.

(3) Complete kits are available, which include all necessary material for the construction of standard military rhombic antennas. The four large poles or metal supports used are designated as side poles, front pole, and rear pole in the isometric view of rhombic antenna (fig 4-13). Terminating resistors (or a dissipation line) are connected at the corner of the antenna supported by the front pole. The transmission line which connects the transmitter or receiver to the antenna is attached to the corner supported by the rear pole. As shown in the plan view, the side poles and the front pole are located 3 feet from the corners of the antenna which they support, and the rear pole is located 8 inches from the corner which it supports. These distances permit the installation of strain insulators and supporting harnesses which attach the antenna to the poles.

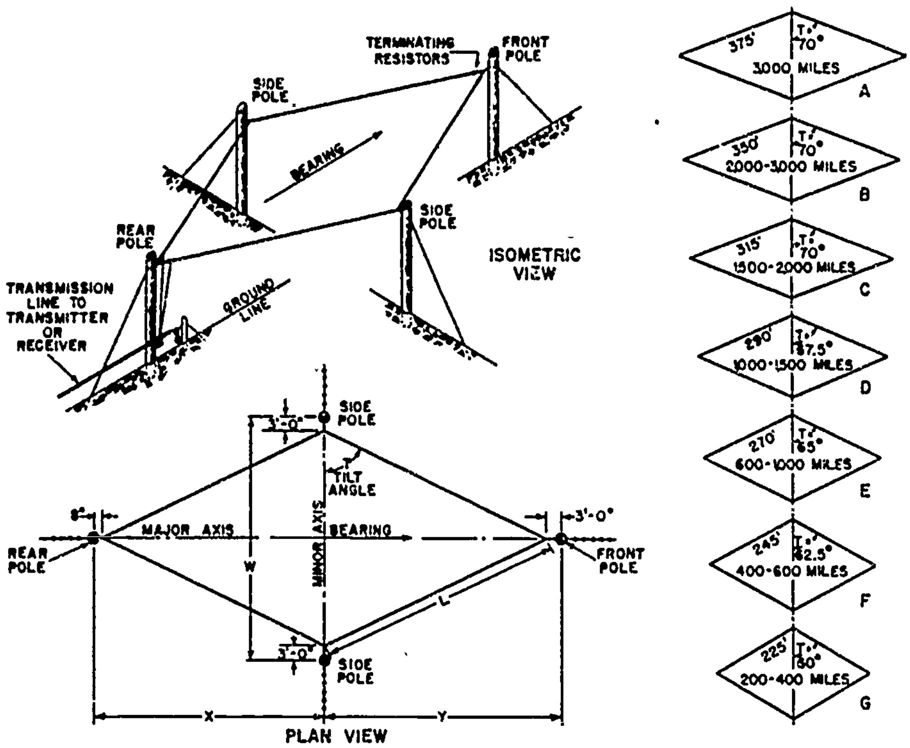


Fig 4-13. Standard military rhombic antennas.

(4) The guide given below indicates the essential dimensions used in the seven standard rhombic antennas, along with the useful ranges of these antennas. The various letters designate dimensions that are indicated in the plan view of figure 4-13. All linear dimensions are given in feet. L refers to the leg length measured from corner to corner. This includes the length of the strain insulators used at the front and rear poles. T refers to the size of the tilt angle in degrees, as previously defined. H is the average height of the antenna above average ground level. The harness which ties the antenna corners to the poles usually is attached to the poles at a height 1 to 2 feet above H. W is the pole spacing along the minor axis of the antenna. X is the distance between the rear pole and the point at which the axes cross as measured along the major axis, and Y is the distance between the front pole and the point at which the axes cross as measured along the major axis.

Type	Range (miles)	L (feet)	T (degrees)	H (feet)	W (feet)	X (feet)	Y (feet)
A	3,000+	375	70	65	262.4	352.7	355
B	2,000-3,000	350	70	60	245.6	329.5	331.8
C	1,500-2,000	315	70	57	221.6	296.7	299
D	1,000-1,500	290	67.5	55	228	268.7	271
E	600-1,000	270	65	53	234	245.4	247.7
F	400-600	245	62.5	51	232	219	221.3
G	200-400	225	60	50	231	195.7	198

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Section II. INSTALLATION

4-10. SITE SELECTION

a. Terrain requirements. The choice of an antenna site will depend on the nature of the local and intervening terrain and the tactical situation. Planning should always be preceded by a careful study of terrain maps and, whenever possible, by reconnaissance, in order to obtain detailed information concerning the availability, accessibility, and size of desirable sites.

(1) Availability. Several tentative locations should be proposed. For temporary locations, consider the length of time the site will be used. Permanent sites should be carefully coordinated with adjacent units to prevent future building programs from rendering the site unsuitable for use.

(2) Accessibility. Any fixed radio station utilizing high power equipment and large antennas must have access to a good road system to permit movement of equipment and supplies. It should be close to existing or planned utilities such as power and water.

(3) Size. The area selected must be large enough for the installation of necessary buildings, as well as the antennas. Also, space must be provided to allow sufficient separation of transmitting and receiving antennas.

b. Technical factors. Factors to be considered will depend on the type of equipment used and the tactical situation.

(1) Location. A radio station must be located in a position that will assure communication with all other stations with which it is to operate. To obtain efficient transmission and reception, the following factors should be considered:

(a) Hills and mountains between stations normally limit the range of radio sets. In mountainous or hilly terrain, positions relatively high on the slopes (fig 4-14) should be selected. Locations at the base of a cliff or in a deep ravine or valley (fig 4-14) should be avoided. For operation at frequencies above 30 MHz, a location that will give line-of-sight communication should be selected whenever possible.

(b) Dry ground has high resistance and limits the range of the radio set. If possible, the station should be located near moist ground, which has much less resistance. Water, and in particular salt water, will greatly increase the distances that can be covered.

(c) Trees with heavy foliage absorb radio waves, and leafy trees have a more adverse effect than evergreens. The antenna should be kept clear of all foliage and dense brush.

(2) Man-made obstructions.

(a) A position in a tunnel or beneath an underpass or steel bridge (fig 4-14) should not be selected. Transmission and reception under these conditions are almost impossible because of high absorption of RF waves.

(b) Buildings located between radio stations, particularly steel and reinforced concrete structures, hinder transmission and reception.

(c) All types of pole wire lines, such as telephone, telegraph, and high-tension powerlines, should be avoided in selecting a site for a radio station. Such wire lines absorb power from radiating antennas located in their vicinity. They also introduce hum and noise interference in receiving antennas.

(d) Positions adjacent to heavily traveled roads and highways should be avoided. In addition to the noise and confusion caused by tanks and trucks, ignition systems in these vehicles may cause electrical interference.

(e) Battery-charging units and generators should not be located close to the radio station.

(f) Radio stations should not be located close to each other.

(g) Radio stations should be located in relatively quiet areas. Copying weak signals requires great concentration by the operator, and his attention should not be diverted by extraneous noises.

(3) Local command requirements. Radio stations should be located some distance from the unit headquarters or command post that they serve. Thus, long-range enemy artillery fire, missiles, or aerial bombardment, directed at the stations as a result of enemy direction finding, will not strike the command post area.

(4) Cover and concealment. The locations selected should provide the best cover and concealment possible, consistent with good transmission and reception. Perfect cover and concealment may impair transmission and reception. The amount of permissible impairment depends on the range required, the power of the transmitter, the sensitivity of the receiver, the efficiency of the antenna system, and the nature of the terrain. When a set is being used to communicate over a distance that is well under the maximum range, some sacrifice of communication efficiency can be made to permit better concealment of the set from enemy observation.

(5) Practical considerations.

(a) Pack sets have sufficiently long cordage to permit operation from cover, while the radio set is below the surface of the surrounding terrain and the antenna is in the clear.

(b) Some sets can be controlled remotely from distances of 100 feet or more. Sets of this type can be set up in a relatively exposed position, while the operator remains concealed.

(c) Antennas of all radio sets must extend above the surface of the ground to permit normal communications.

(d) Small tactical set antennas are usually of the whip type. These antennas are difficult to see from a distance, especially if they are not silhouetted against the sky.

(e) Open crests of hills and mountains must be avoided. A slightly defiladed position just behind the crest gives better concealment and sometimes provides better transmission.

(f) All permanent and semipermanent positions should be properly camouflaged for protection against both aerial and ground observation. However, the antenna should not touch trees, brush, or camouflage material.

(6) Local communications. Contact must be maintained between the radio set and the message center at all times, either by local messenger or field telephone. The station should also be readily accessible to the unit commander and his staff.

(7) Final considerations. It is almost impossible to select a site that will satisfy all technical and tactical requirements for a radio set. Therefore, a compromise is usually necessary, and the best site available is selected. It is also a good idea to select both a primary and an alternate site. Then, if radio communication cannot be established at the primary location, the set can be moved a short distance to the alternate position.

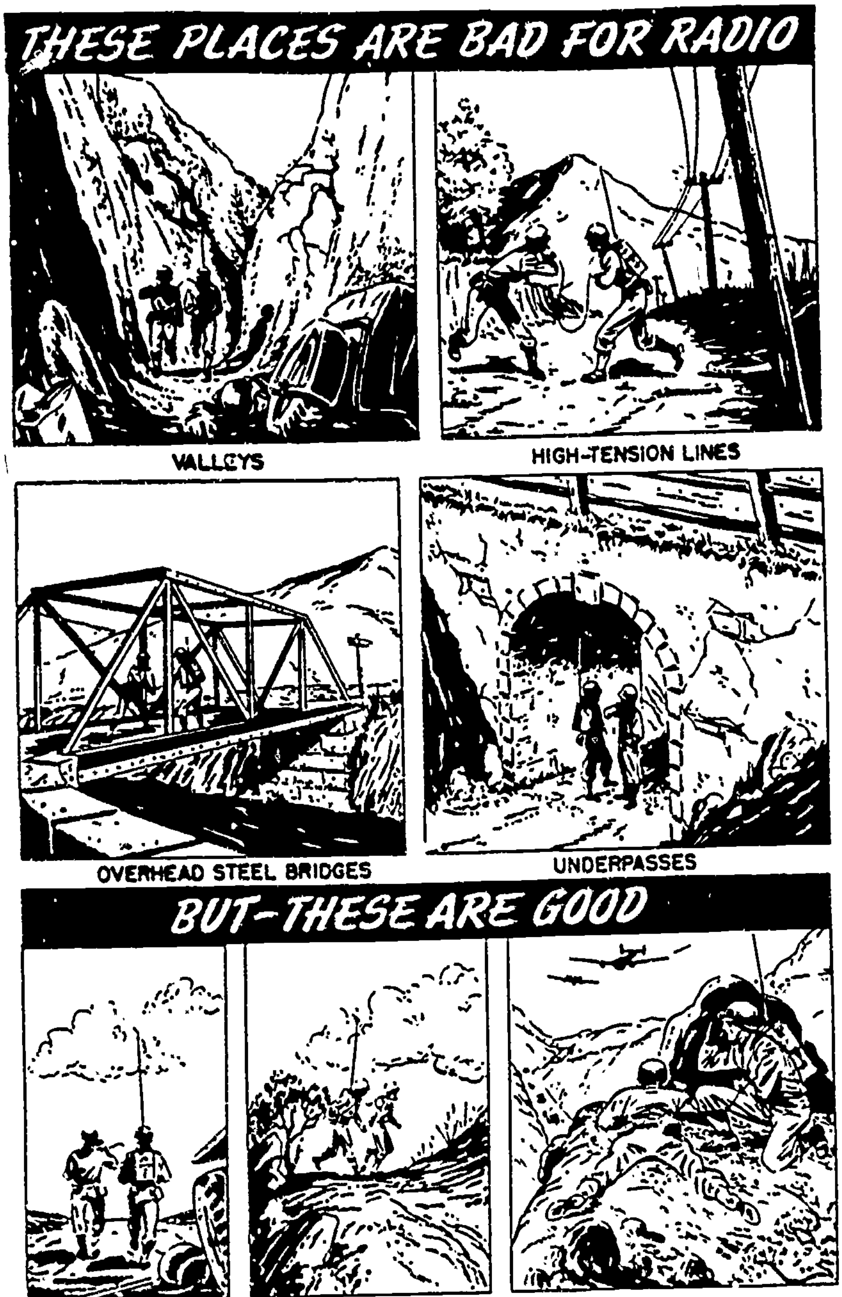

Fig 4-14. Siting.

4-11. SAFETY PRECAUTIONS

During installation and use of vehicular-whip and other antennas, field masts, towers, and metal poles, accidents have occurred which resulted in damage to equipment, serious injury, and DEATH due to the failure of personnel to observe safety precautions. The installation or use of such assemblies is not always limited to placing the equipment in operation, but in some instances the primary purpose is field demonstrations, training of riggers or linemen, and similar endeavors. Prior to installing or erecting any equipment, the area must be carefully surveyed for location of powerlines, their height above ground level, and proximity to the installation site. In addition, overhead obstructions that may be encountered when mobile operations are contemplated should be considered. When an installation in the vicinity of powerlines is planned, the responsible authority will warn all who are to participate in the exercise that contact of the structure with high-tension powerlines in the course of erection can--and has--caused instant death. A WARNING to this effect should precede the order to begin erection. The technical manual relating to the equipment should be thoroughly read before attempting any installation or erection. The CAUTION and WARNING notices are placed in these manuals for the protection of personnel, and must be observed. Safety precautions to be followed in order to prevent serious injury or fatality are outlined below.

a. Whip antennas (fig 4-15).

(1) Never lean against or grasp a whip antenna when a transmitter is operating. Severe burns may result.

(2) When operating with vehicular equipment, never pass under powerlines if you have any doubt about adequate overhead clearance between the lines and the antenna.

(3) When mobile operation is mandatory, insure that the height of the antenna from the ground meets local requirements as prescribed. In any event, make certain that the antenna will clear known overhead obstructions and powerlines.

(4) Never permit arms or legs to extend over the sides of a vehicle. If the antenna contacts a powerline, the body will act as an electrical conductor upon contact with the ground, wet bushes, trees, or other foliage. Serious shock or DEATH may result.

(5) Never dismount from a vehicle unless certain that the whip antenna is not in contact with powerlines. A vehicle is normally insulated from the ground, and personnel are relatively safe while inside the vehicle. However, if the antenna is in contact with powerlines, an individual in contact with both the ground and the vehicle is grounded electrically (fig 4-15), and fatal shock may result.

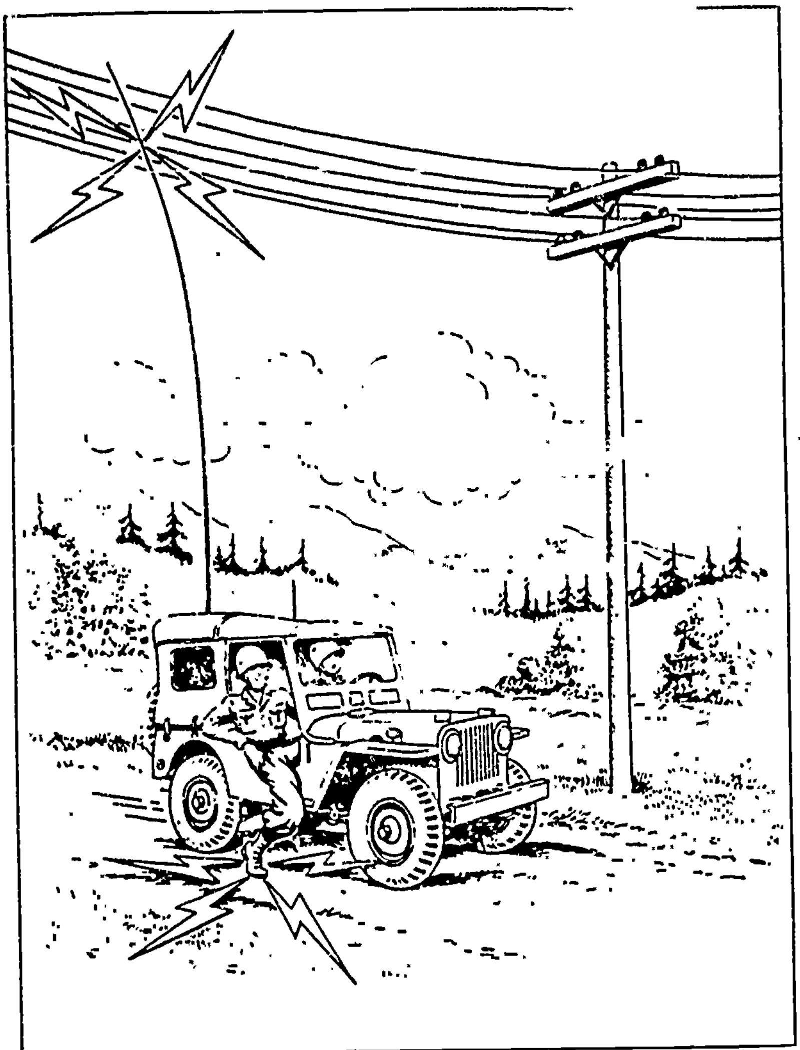

Fig 4-15. Vehicular whip antenna--dangerous contact.

b. Masts, towers, and antenna assemblies.

(1) Masts, towers, and antennas must be installed away from powerlines as far as possible. As a basic guide, a distance of twice the height of the structure should be maintained.

(2) Guys will be kept as far away from powerlines as possible, thereby eliminating the possibility of a powerline falling across the guy lines.

(3) All structures (e.g., masts, towers, and antennas) should have adequate lightning arrester protection as prescribed in the technical manual or deemed necessary by the authority in charge of erection.

(4) Never touch a structure or any attachment connected to it, if the possibility exists that it may be electrically energized. The area around a suspected energized structure should be roped off and guards posted to prevent anyone from entering the area. Immediately thereafter proper authority should be notified so that remedial action can be taken.

(5) Avoid work on a structure during an electrical storm or when a storm is imminent.

(6) All ropes and guys will be inspected for worn spots, frays, rotten portions, and other imperfections, prior to being placed in use. Ropes or guys that show such imperfections should not be used.

(7) Never attempt to support a structure, using fewer guys than prescribed in the technical manual.

(8) All temporary guys shall be left in place until permanent guys have been installed.

(9) In erecting a structure such as Mast AB-301-G, normal procedure requires that the side guy lines be attached and anchored in position prior to erection. When erection is accomplished, misalinement of these guys can cause them to overtighten and buckle the structure. Close observation of the side guys during erection should be maintained to prevent overtightening.

(10) Guy lines must be properly attached and controlled to prevent the structure from passing over its upright position (90°). Failure to control the erection in this manner may cause the structure to fall over the men pulling it erect.

(11) When hoisting objects by means of ropes, personnel should stand clear of the hoisting area.

(12) Do not fasten guy lines over sharp-edged surfaces which may abrade or cut them, unless absolutely necessary, and then only after protective padding has been placed over the sharp edges.

(13) Only personnel required for the erection of a structure will be in the erection area.

(14) All anchors must be securely entrenched in the ground. In marshy or sandy terrain, special provisions must be made to obtain required anchor-holding strength.

(15) When selecting anchor locations for guys, avoid locations that will cause the lines to pass over roadways. When roadways cannot be avoided, maximum overhead clearance must be maintained. Guy lines over roadways will be plainly marked with warning flags tied in strips to the guys. Warning signs indicating the height of the overhead obstructions will be posted.

(16) If in the course of installation it becomes necessary to suspend operations, do not do so until sufficient guys are attached to safely support the structure.

(17) Ropes, davits, and guys must be of sufficient strength to provide adequate support.

(18) When work aloft is necessary, avoid unnecessary climbing or movement on the structure.

(19) Personnel engaged in the installation of a structure should be adequately instructed in the overall method of erection.

(20) Erection of a structure should be accomplished with trained personnel in accordance with the applicable technical manual. To do otherwise may result in serious injury to personnel or damage to equipment.

(21) Specific safety devices such as safety belts, rubber gloves, safety shoes, etc., shall be used for the protection of personnel, when provided. The few seconds saved by not using these devices does not compensate for the hazards involved.

(22) It is not feasible to mention every type of equipment and every hazard which may be encountered. Nevertheless, CAUTION and commonsense must be exercised at all times. The precautions listed here are of a general nature, and can be applied in general to all types of equipment.

4-12. GROUNDS AND COUNTERPOISES

When the grounded type of antenna is used, it is important that the ground has the least possible amount of resistance. This is necessary to minimize ground losses and provide a good reflecting surface for energy radiated downward from the antenna. The problem is, how to make a ground connection with the very minimum of resistance.

a. Ground rod. The most common type of ground connection is the ground rod. These are made of galvanized iron, steel, or copper-plated steel in various lengths. Generally, one end is pointed so it may be driven into the earth easily, while the other end is fitted with a clamp to attach the ground lead. A good ground connection can be made by using several ground rods connected in parallel and spaced 6 to 10 feet apart.

b. Counterpoise. When a ground rod cannot be used because of high resistance in the soil, a counterpoise may be used. The counterpoise is used to electrically raise the ground for use in transmitting radio waves. The counterpoise has a geometrical form (fig 4-16), is constructed

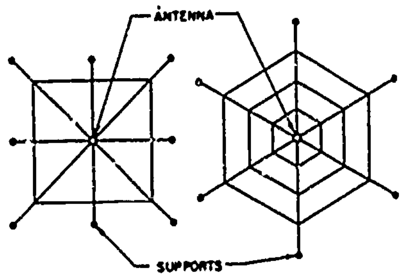

Fig 4-16. Typical counterpoises.

of wire and erected a short distance above the ground. It is also insulated from ground. The size of the counterpoise is not critical, but is generally larger than the antenna. The counterpoise should extend equal lengths at all angles from the antenna. Short jumpers between the conductors prevent absorption of RF energy.

c. Methods of reducing ground resistance. When an antenna must be erected over soil having a high resistance, it is good practice to treat the soil to reduce this resistance. Several substances can be used. Listed in order of preference, they are: sodium chloride (salt), calcium chloride, copper sulfate (blue vitriol), magnesium sulfate (Epsom salt), and potassium nitrate (saltpeter). The type of soil and its moisture content determine the required amount of treatment.

4-13. ORIENTATION

a. Radiation. The long-wire V, half- and full-rhombic, and array antennas produce a radiation pattern that composes a relatively narrow beam. For maximum performance and efficiency, they require accurate orientation. Best results are obtained when the antenna is oriented in the horizontal-short path direction to the distant station, except in the case of long-range transmission for which the antenna should be oriented by use of the great-circle bearing to the distant station.

b. Position and bearing. To orient the antenna correctly, the exact position and bearing of each radio station must be known. All that is needed is a map, protractor, and compass. Proceed in the following manner:

(1) From the map determine the magnetic bearing of the distant station, using the protractor. Be sure to add or subtract the correction factor from grid north, to obtain the correct magnetic bearing.

(2) At the antenna location, using the compass, sight and plot the magnetic bearing to the distant station.

(3) Erect the antenna so that maximum radiation occurs in the same direction as the plotted magnetic bearing to the distant station.

Figure 4-17 illustrates the orientation of two terminated full-rhombic antennas. The antennas and radiation pattern are drawn oversized for clarity. --Assume the site to be in the upper right-hand corner of the map.

(a) Draw a line between the proposed sites. Line up the protractor with one of the north-south grid lines. Measure the angle between it and the line drawn between proposed sites. This is 40°. Next, add this to 180°, for a grid azimuth of 220°. Now subtract 5.5° to determine the magnetic bearing--214.5°.

(b) At the antenna location, using the compass, sight and plot a bearing of 214.5°.

(c) Erect the antennas so that maximum radiation will occur along the bearing of 214.5°. In the case of the terminated full-rhombic, maximum radiation bisects the antenna in the direction of termination.

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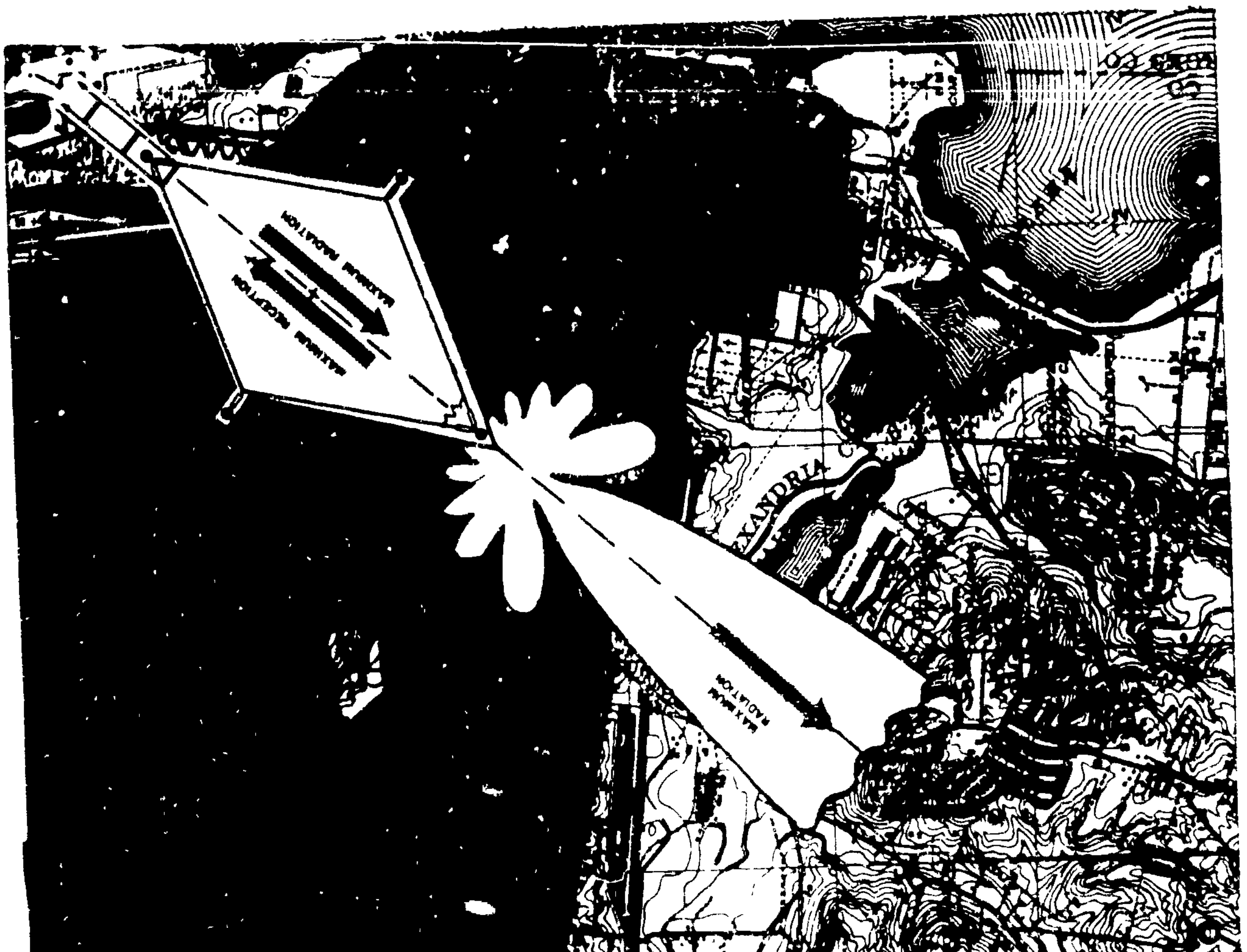

Fig 4-17. Orientation--two terminated full-rhombic antennas.

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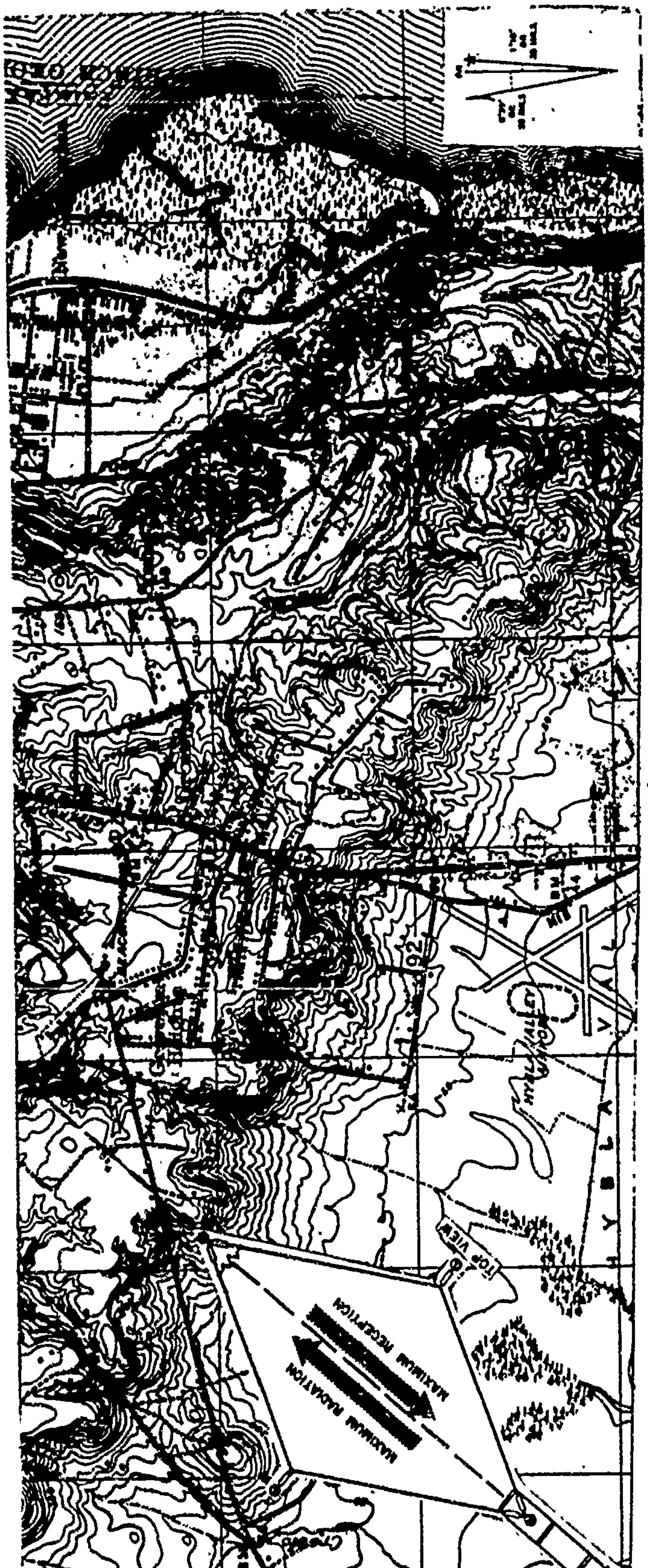


Fig 4-7 (continued)

4-14. PROFILES

a. Line of sight. Since vhf radio waves tend to travel in straight lines, the radio stations should be located so that line-of-sight transmission can be used.

b. Distance. The curvature of the earth limits the distance over which line-of-sight transmission may be used. To determine the maximum distance between two radio stations with the intervening terrain at sea level, the following formula is used.

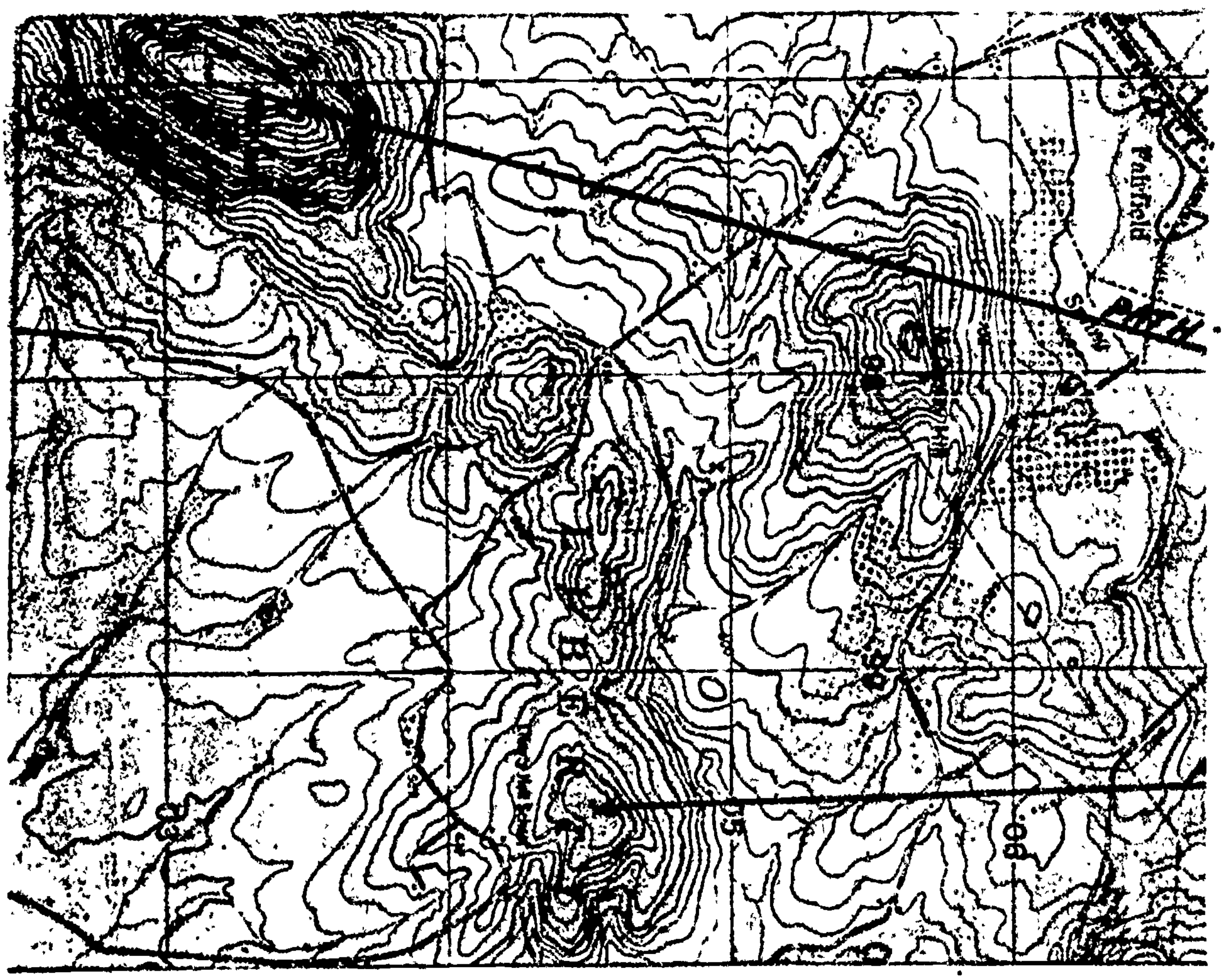
$$D = \sqrt{2Ht} + \sqrt{2Hr}$$

D is the distance in miles; Ht the height of the transmitting antenna in feet, and Hr the height of the receiving antenna in feet.

For example, with both antennas 50 feet above sea level, the maximum distance that can be covered before the line-of-sight would be obstructed by the curvature of the earth is 20 miles. When the intervening terrain is not at sea level, a profile map should be used to see if a line-of-sight path exists.

(1) By plotting the profiles or contours of the map on a graph, it is possible to visually determine if a line-of-sight transmission path exists. Since profile graph paper is often not accessible, we will consider only profiles plotted on any linear graph paper and then corrected for the curvature of the earth. The procedure for plotting the profile is as follows:

(a) Determine from the terrain map (fig 4-18) the scales to be used for distance and elevation.



Scale: 2.5 inches = 1 mile

Contour interval = 20 feet

Fig 4-18. Terrain map showing two transmission paths.

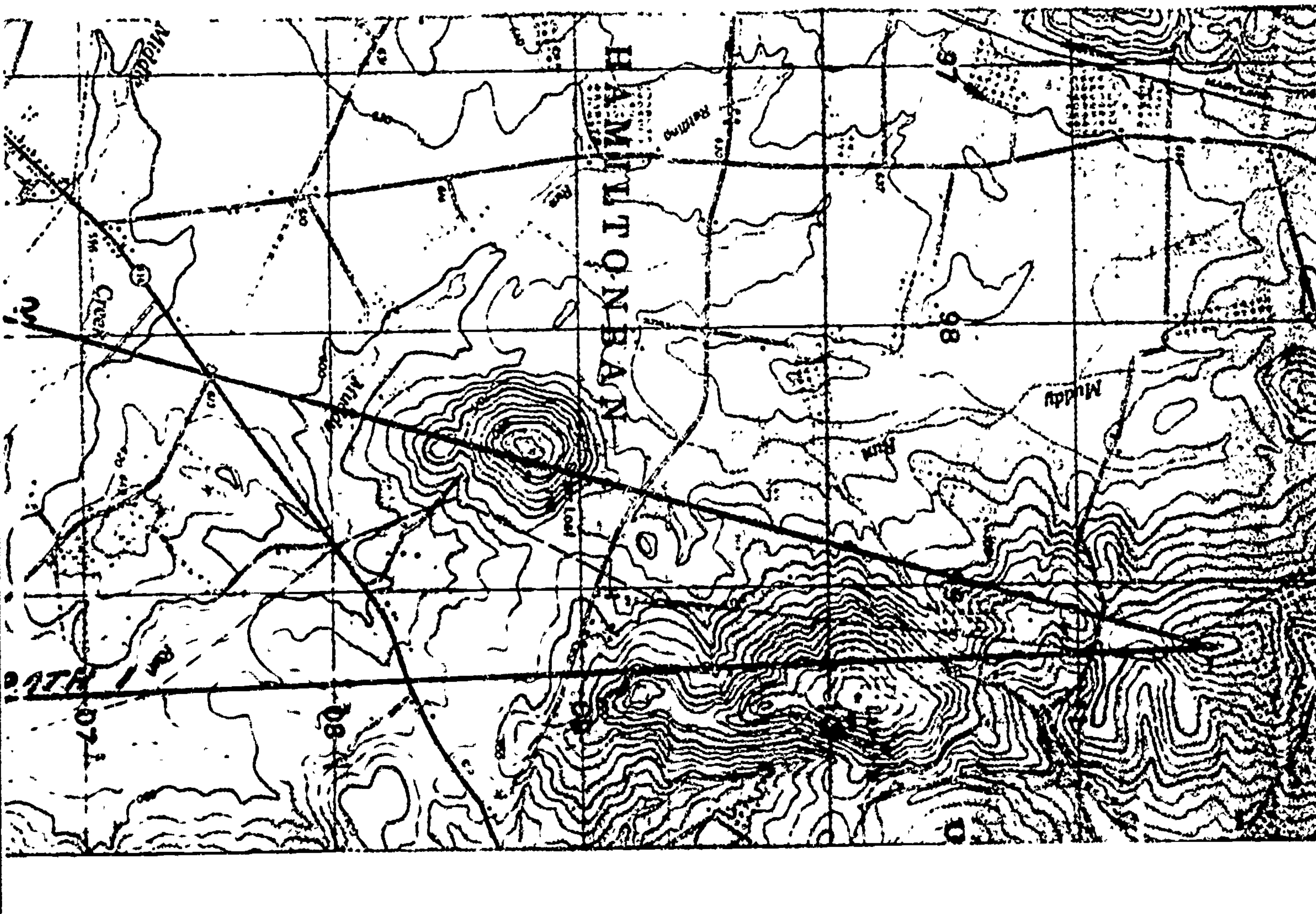


Fig 4-8. (continued)

(b) Draw a line on the terrain map between the proposed sites (paths 1 and 2). Measure these lines and convert them to distance (4.3 miles for path 1 and 5.1 miles for path 2).

(c) Using path 1 as an example, determine the elevation at each site. Hill 735 with a 40-foot antenna has a total elevation of 775 feet. This point is marked on the vertical scale of the graph (fig 4-19) above 0 mile. Hill 914 with a 40-foot antenna brings its total elevation to 954 feet. This point is plotted on the vertical scale above 4.3 miles, since that is the distance between the two stations. Every 20 lines on the horizontal axis represents 1 mile of distance, and every line on the vertical axis represents 20 feet of elevation.

(d) Draw a dashed line between these two points to denote the apparent line-of-sight.

(e) Inspect the terrain map, noting all high- and low-altitude points. Plot all these points on the graph paper and join them with a dashed line.

(f) Correction must be made for the earth's curvature to determine a true line-of-sight picture. A high or low point is selected which is as near to the halfway point as possible. (See point A, fig 4-19.) By means of the figures shown in the table below, the elevation of all prominent points in both directions from the central point must be corrected. Table 4-1 shows the corrected elevation to be 3 feet at a distance of 2 miles from the central point.

Table 4-1. Elevation Correction Factors

Conversion to sea level elevations to line-of-sight elevations		Conversion to sea level elevations to line-of-sight elevations	
D (Miles from reference point)	Elevation correction (ft)	D (Miles from reference point)	Elevation correction (ft)
2	3	22	324
4	11	24	384
6	24	26	455
8	43	28	520
10	67	30	600
12	96	32	680
14	130	34	770
16	170	36	862
18	217		
20	266		

The new plots are connected by a solid line curve and a straight line is drawn to the corrected sites. This line represents the true line-of-sight.

(2) As indicated by a profile (fig 4-19), path 1 is obstructed and would not be a good line-of-sight transmission path.

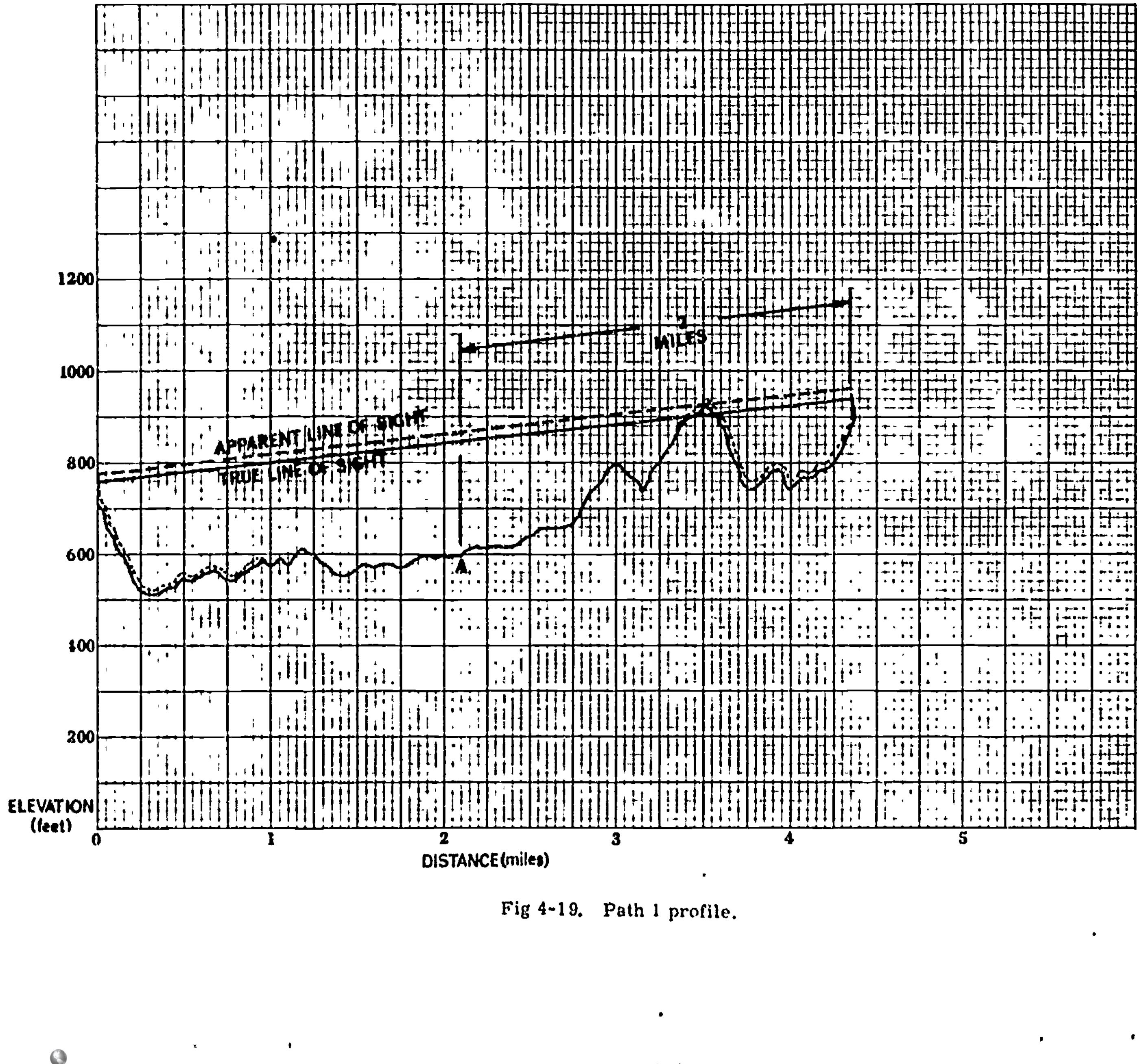


Fig 4-19. Path 1 profile.

(3) Path 2 as illustrated in figure 4-20 is unobstructed and would make an excellent line-of-sight transmission path.

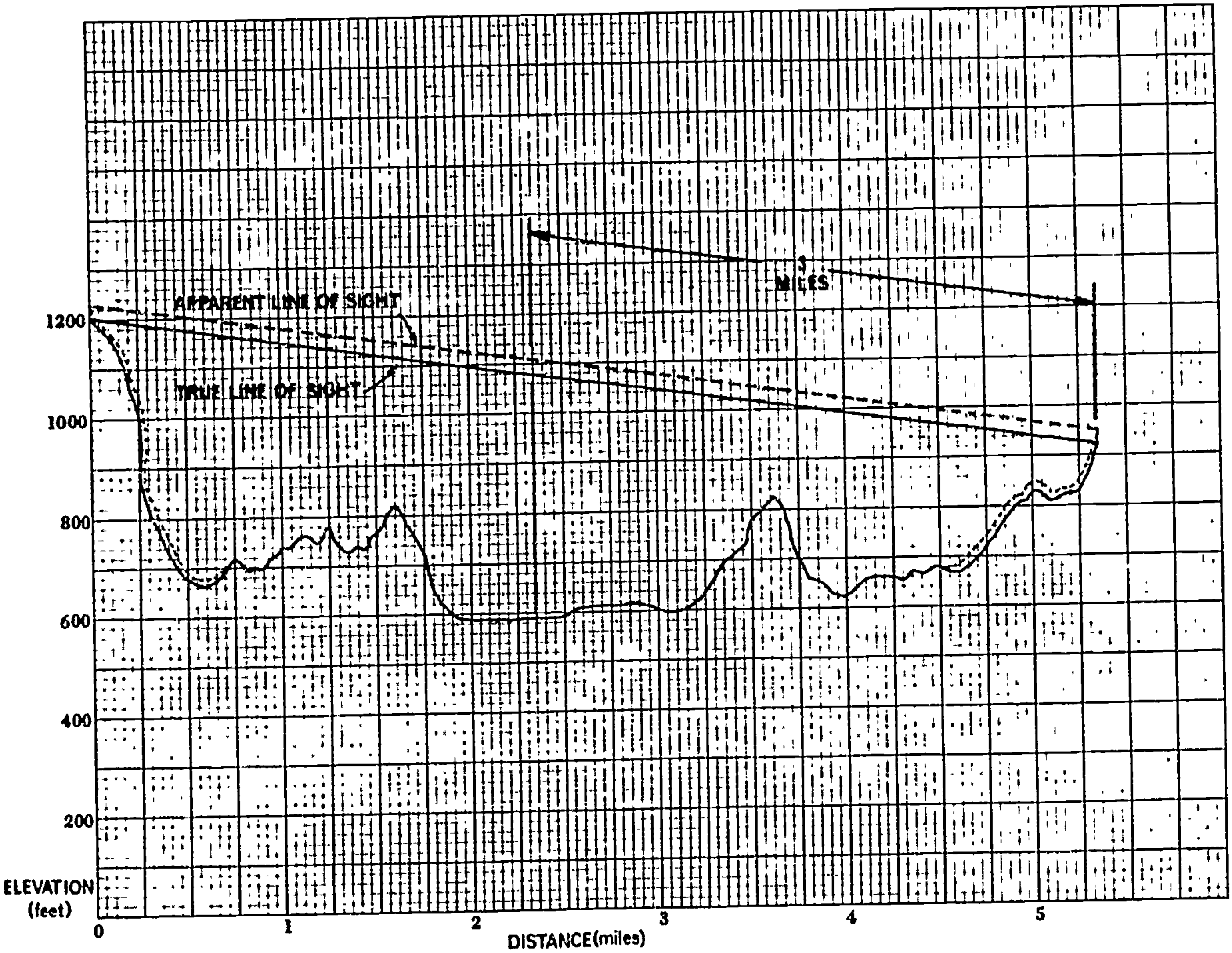


Fig 4-20. Path 2 profile.

(4) As can be seen, the amount of corrected elevation increases as the distance from the central reference point increases because of the curvature of the earth.

4-15. FIELD EXPEDIENT METHODS

a. Introduction. Antennas are sometimes broken or damaged, thereby causing failure or poor communications. If a spare is available, the damaged antenna can be replaced. When there is no spare, it may be necessary to make or construct an emergency antenna. The following considerations will aid in the construction of an emergency antenna.

(1) Copper or aluminum is the best wire for antennas. In emergencies, any type may be used.

(2) The exact length of many antennas is critical. For this reason, the length of the emergency antenna should be the same as that of the antenna it replaces.

(3) Antennas supported by trees can usually survive heavy windstorms if a stout branch or trunk is used as the support. A little slack should be provided in the guys to prevent breaking or stretching as the tree sways.

(4) Guys used to hold antenna supports should be made of rope or wire.

(5) Wire guys may affect the operation of the antenna unless cut into several short lengths and fastened together with insulators. Lead weights of approximately 5 oz attached to the slack guys will maintain a constant tension on the antenna and prevent it from swaying.

(6) The height at which an antenna is placed above ground will have an effect upon its operation. The antenna height should be changed until the best performance is gained.

(7) If a whip antenna is broken, the two sections can be connected as shown in figure 4-21A. Figure 4-21B shows a method of repair when one of the sections is lost or unusable. Add a piece of wire that is nearly the same in length as the missing section to restore the antenna to its original length. Next, clean the two sections thoroughly to insure good electrical connections. If possible, solder the connections. Then lash the pole support securely to both sections of the antenna.

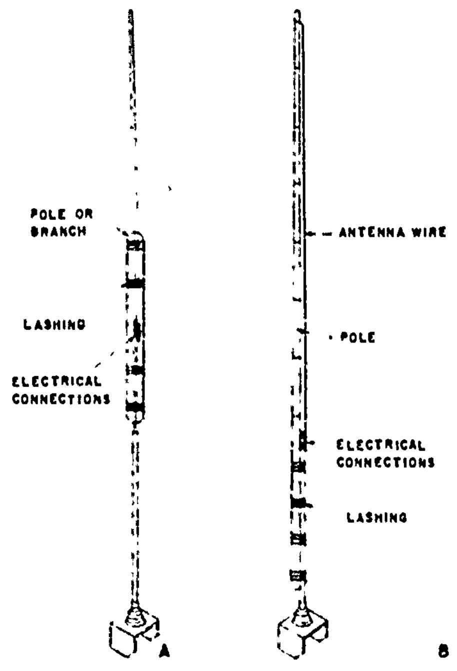


Fig 4-21. Whip antenna repair.

(8) Usually insulators are made of glass or porcelain. If an insulator breaks and a spare is not available, glass, rubber, or dry wood can be inserted in its place. Figure 4-22 shows two types of improvised wooden insulators--for emergency use only.

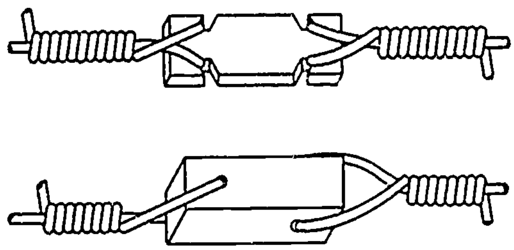


Fig 4-22. Improvised wooden insulators.

b. Vertical antennas. A vertical antenna may consist of a piece of wire supported by a tree or wooden pole (fig 4-23A). If the mast is not long enough to support the antenna, the connection at the top of the antenna may be modified (as in fig 4-23B) to form an inverted-L antenna. Figures 4-23C and D show additional methods of supporting vertical antennas.

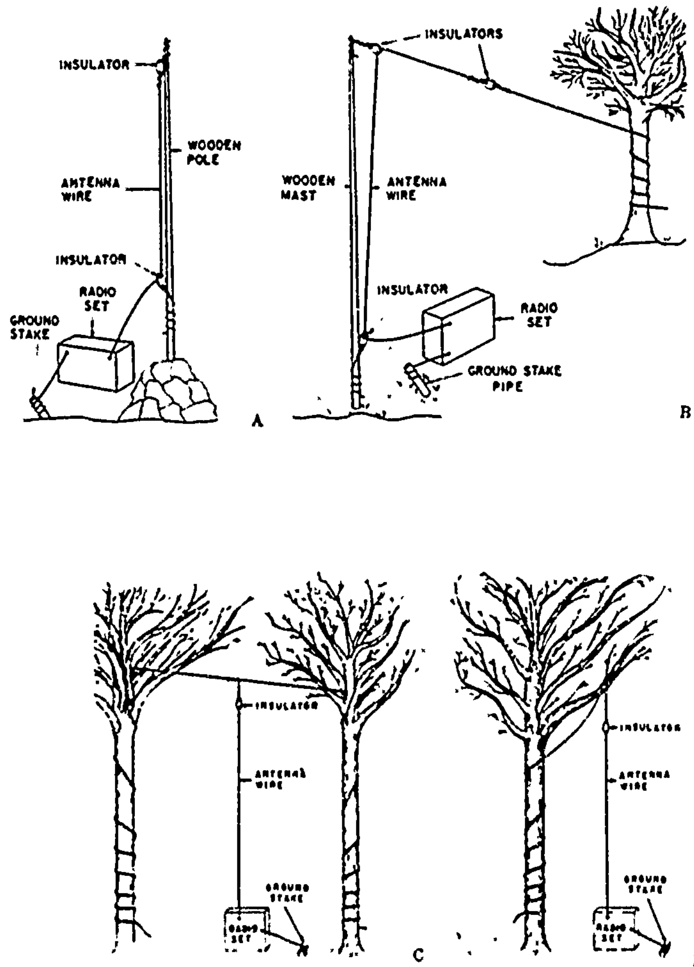


Fig 4-23. Improvised vertical antennas.

c. Half-wave antennas. An improvised antenna of this type can be constructed with wire and rope as shown in figure 4-24. An insulator is placed at the exact center of the antenna. A 2-wire transmission line is used, with one wire connected to one side of the antenna and the second wire connected to the other side. Antenna length is important; therefore, the two wires should be cut as closely as possible to the correct length.

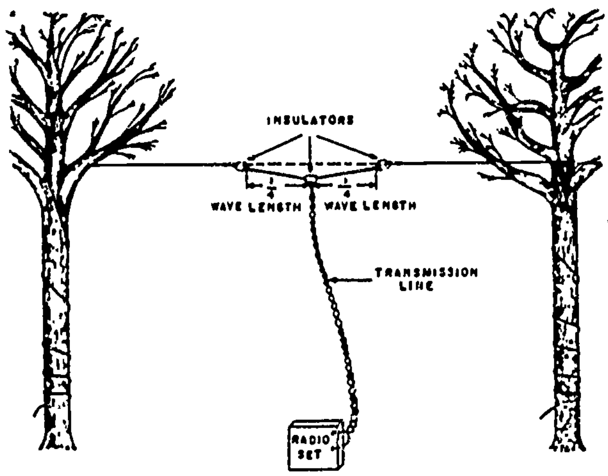


Fig 4-24. Improvised half-wave antenna.

(1) Short half-wave antennas can be supported by uprights of wood, as in figure 4-25. A horizontal half-wave antenna is illustrated in figure 4-25A. A vertical antenna of this type is shown in figure 4-25B. These antennas can be turned in any position for maximum efficiency.

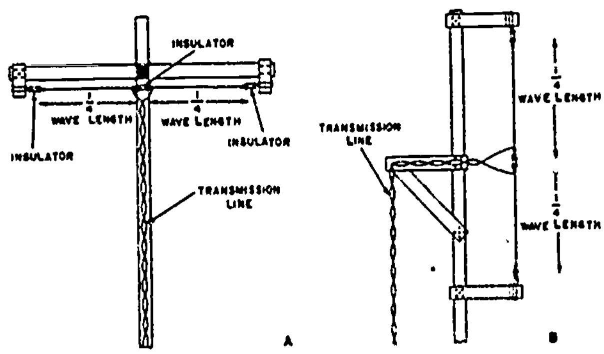


Fig 4-25. Improvised vertical and horizontal half-wave antennas.

(2) Another method for constructing a short half-wave antenna is pictured in figure 4-26. The ends of this antenna are connected to a length of dry wood such as bamboo. The bend in the pole holds the antenna straight. The mast is made of a pole or bundle of poles.

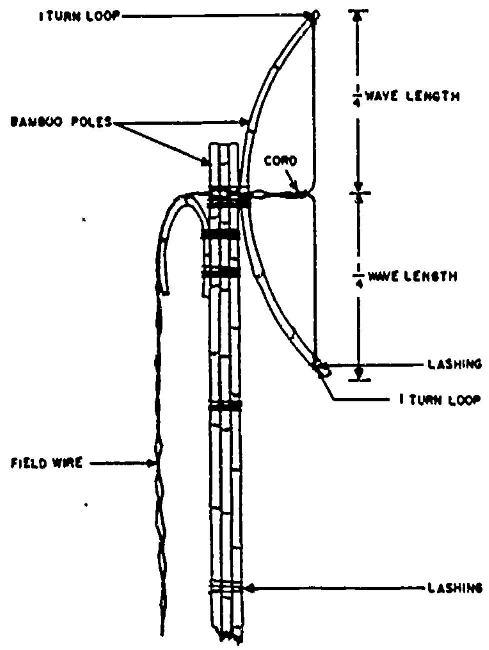


Fig 4-26. Improvised method of supporting a vertical half-wave antenna.

d. Directional antennas. These will normally increase the range of FM sets. They are directional and will transmit and receive in the direction of the terminated end. The terminating resistor should be capable of handling one-half of the transmitter power output, and should have a value of 400 to 700 ohms. If the transmitter loads poorly, add to or subtract from the length of the antenna. Figures 4-27 and 4-28 illustrate two types of field expedient directional antennas.

NOTE: If these antennas are left in place during strong winds, the tree may rub through the insulation and cause a ground on the antenna.

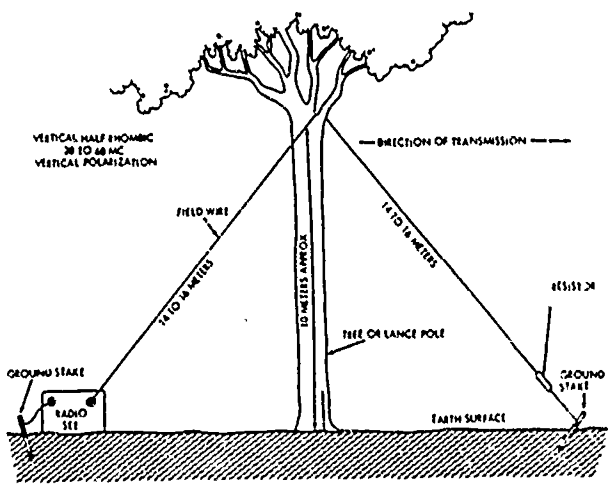


Fig 4-27. Improvised half-rhombic antenna.

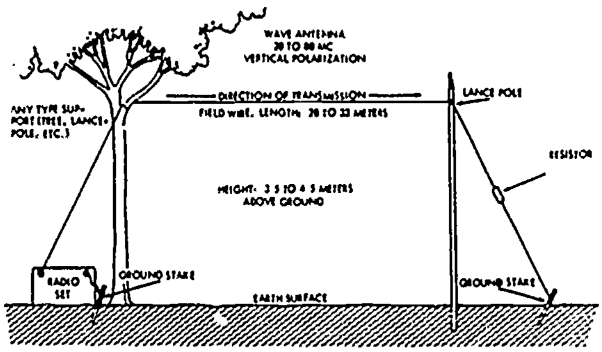


Fig 4-28. Improvised wave antenna.

e. Ground plane antenna. The AN/PRC-25 antenna can easily be modified to construct a ground plane antenna (fig 4-29). By cutting three wires of the same length as the AT-271/PRC and strapping them to a 20- to 30-foot pole along with the AB-591/PRC, the antenna can easily be assembled. Use a 2-wire transmission line. One wire is connected to the AB-591/PRC and wrapped around the outside of the radio set's auxiliary-antenna jack. The other wire is connected to the AT-271/PRC and inserted in the center of the auxiliary-antenna jack.

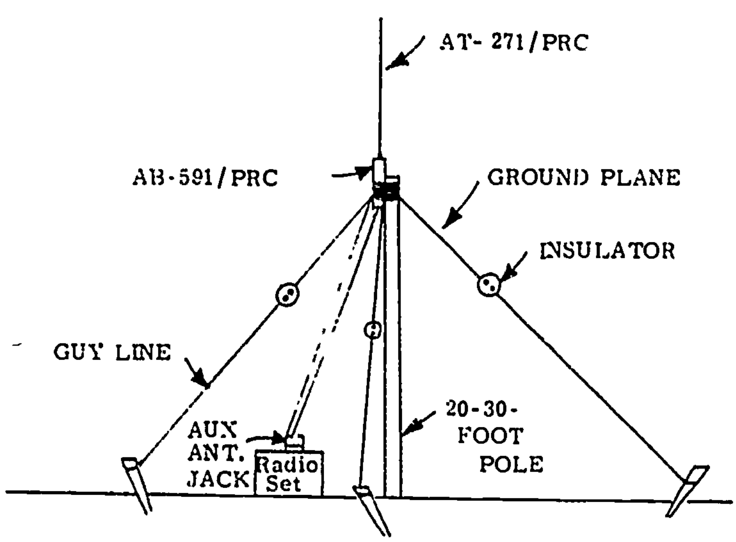


Fig 4-29. Ground plane antenna improvised by using the AN/PRC-25 antenna.

Chapter 5

RADIO WAVE PROPAGATION

Section I. PROPAGATION FACTORS

5-1. GENERAL

When a radio wave leaves the transmitting antenna, it travels to the distant receiving antenna by either ground wave or sky wave propagation. The path actually taken depends on many factors. This section will cover such factors.

5-2. FREQUENCY SPECTRUM

The effect of the atmosphere on radio wave propagation depends on the frequency of the transmitted radio wave. The characteristics of low-frequency propagation are different from those of high-frequency operation. For ready identification, these frequencies have been arbitrarily divided into different classes as shown in table 5-1.

Table 5-1. Frequency Spectrum

Frequency (MHz)	Description	Abbreviation
Below .03	Very low frequency	vlf
.03 to .3	Low frequency	lf
.3 to 3.0	Medium frequency	mf
3.0 to 30	High frequency	hf
30 to 300	Very high frequency	vhf
300 to 3,000	Ultrahigh frequency	uhf
3,000 to 30,000	Superhigh frequency	shf
30,000 to 300,000	Extremely high frequency	ehf

5-3. THE ATMOSPHERE

For the purpose of radio wave propagation, the earth's atmosphere is divided into three regions: the troposphere, the stratosphere, and the ionosphere. Their relative heights are illustrated in figure 5-1.

a. The troposphere is the portion of the earth's atmosphere extending from the surface to a height of approximately 7 miles. The temperature in this region varies appreciably with altitude.

b. The stratosphere is between the troposphere and the ionosphere. It is also known as the isothermal region, since its temperature is almost constant. It reaches an altitude of approximately 18 miles.

c. The ionosphere is composed of several layers (fig 5-1) that represent different levels and intensities of ionization. The properties and effects of these layers will be discussed in relation to sky wave propagation (para 5-10).

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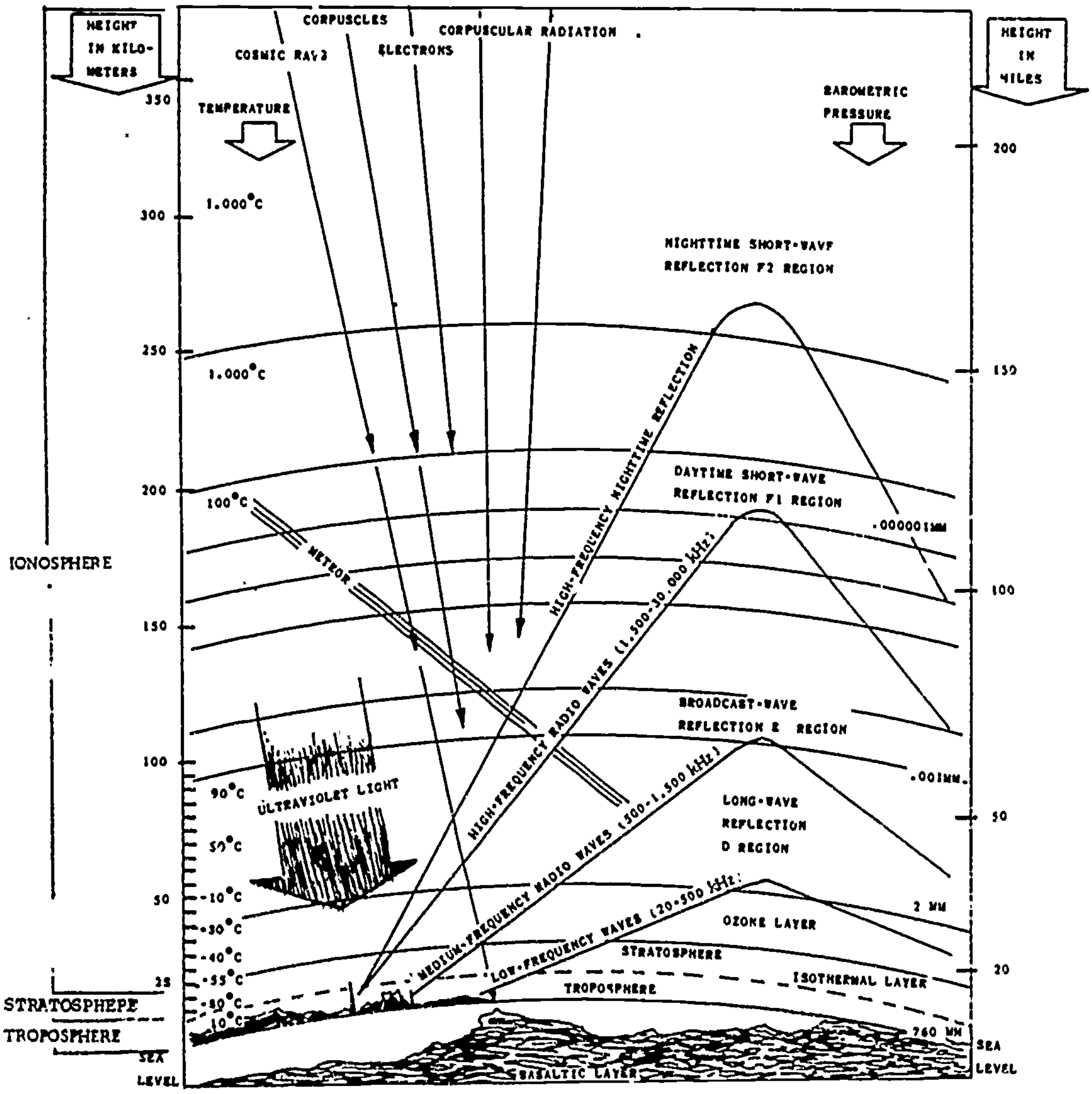

Fig 5-1. The earth's atmosphere.

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5-4. WAVE BENDING

A radio wave may travel to a distant receiving antenna in a straight line, or the wave path may be altered through reflection, refraction, or diffraction.

a. Reflection. The reflection of a radio wave is identical to that of any other type wave. For example, when a ray of light falls on the surface of a mirror, nearly all of it is turned back or reflected. The efficiency at which the reflection of radio waves occurs depends on the surface of the reflecting material. Large, smooth metal surfaces of good electrical conductivity, such as copper, are very good reflectors. The earth's surface is also a good reflector.

Figure 5-2 shows a radio wave reflected from a smooth surface. (Remember that the angle of incidence always equals the angle of reflection.) However, the incident wave front, A-A1, is reversed by the reflecting surface and appears at B-B1 180° out of phase. The reason is that point X of the incident wave reaches the reflecting surface before point Y. It is reflected to point X1 during the time it takes point Y to move to the point of reflection, Y1. The parallel arrows indicate the phase reversal.

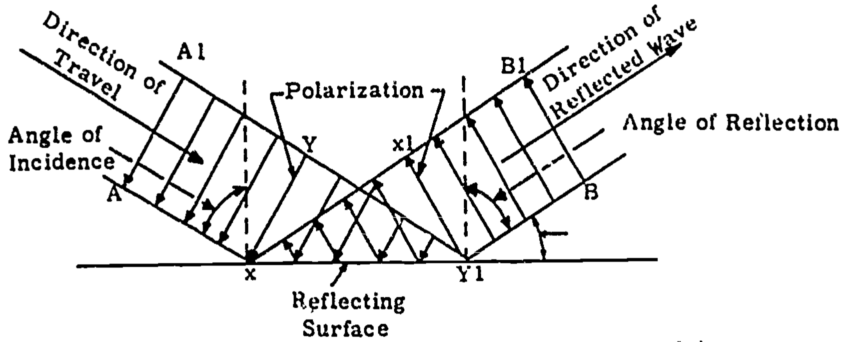

Fig 5-2. Reflection of a radio wave.

b. Refraction. If a beam of light strikes a smooth surface such as water, part of the beam will be reflected and a portion will penetrate the water's surface. This penetration results in refraction. For example, if a spoon is immersed in a glass of water and viewed from an angle, it appears to be bent at the point where it enters the surface of the water. The reason is that light waves travel faster through air than through water. Figure 5-3 illustrates this phenomenon.

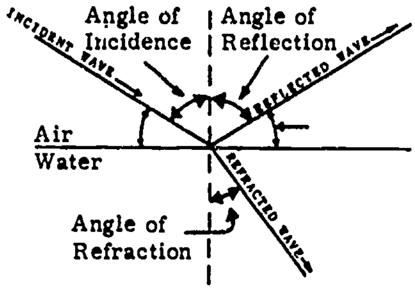

Fig 5-3. Reflection and refraction.

Figure 5-4 illustrates how the change of direction occurs. Consider the wave front, A-A1. Since the speed of light is less in water than in air, point A will travel distance d1 in a given period of time, but point A1 will travel a greater distance (d2) in the same amount of time because it is still passing through a faster medium. Thus, the wave front will travel in a new direction. Refraction occurs only when the wave nears the new medium in an oblique direction.

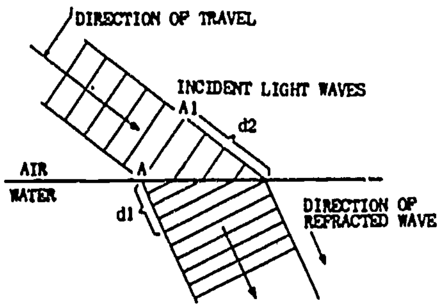

Fig 5-4. Refraction.

If the wave front arrives perpendicular to the surface of the new medium, its velocity will be slowed and no bending will occur.

The amount any wave is refracted as it passes from one medium to another is known as the <u>refractive index.</u> It is a ratio of the velocity of the electromagnetic wave through a vacuum compared with its velocity through the medium (water, the earth's atmosphere, etc.).

c. <u>Diffraction.</u> Diffraction is the bending of waves around the edge of a solid object. The lower the frequency of the wave, the greater amount of bending occurs. For example, if a beam of light in an otherwise blacked-out room shines on the edge of an opaque object, it will be seen that the object will not cast a perfect shadow. The reason is that the light rays are bent around the edge of the object and decrease the area of total shadow. Figure 5-5 A and B illustrate diffraction and show why radio waves can be received on the far side of a hill or other obstruction.

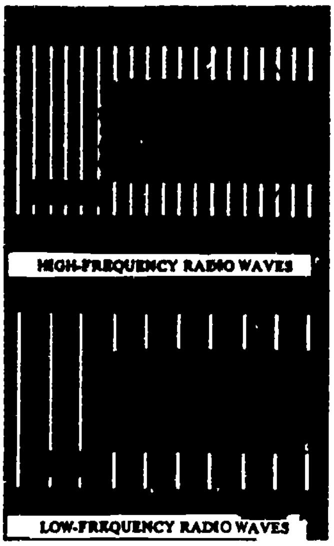

Fig 5-5. Diffraction of high- and low-frequency radio waves.

Section II. GROUND WAVE PROPAGATION

5-5. GENERAL

This type of propagation does not make use of reflections from the ionosphere. The field intensity of the ground wave depends on these factors. characteristics of transmitting the radio wave, its diffraction around the earth's curvature, electrical properties of the terrain, nature of the transmission path, and climatic conditions.

Since the earth acts as a semiconductor, some of the radiated energy is absorbed and dissipated in the form of heat. Thus, ground wave transmission is limited to moderate-distance communications (up to several hundred miles) due to the inherent losses. There are some exceptions at low frequencies and special high-frequency applications.

5-6. COMPOSITION

Figure 5-6 shows the paths taken by the ground wave in its travel. It may be conducted by the earth's surface, refracted in the troposphere, take a direct route, or be reflected. Thus the ground wave is considered to be made up of the following: direct wave, ground-reflected wave, surface wave, and tropospheric wave.

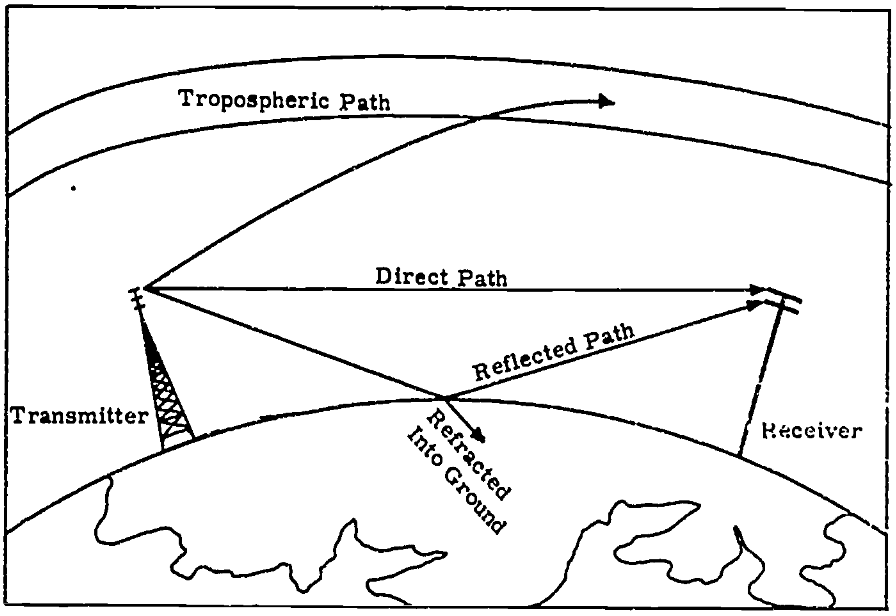

Fig 5-6. Ground wave paths.

a. Direct wave. This component of the wave travels straight from the transmitting antenna to the receiving antenna. It is limited only by the line of sight from the transmitter plus the small distance added by atmospheric diffraction of the wave around the curvature of the earth. It is also subject to refraction in the troposphere, but is not affected by the earth's surface.

b. Ground-reflected wave. This component reaches the receiver after being reflected. Upon reflection it has a phase reversal of 180°.

Figure 5-7 illustrates a comparison between the reflected and the direct wave, with the two waves in phase up to the point of reflection. After reflection, they are 180° out of phase, plus the small amount of phase displacement due to time lag. The reflected wave arrives at the receiving antenna slightly more than 180° out of phase with the direct wave. As a result there is cancellation of signal energy at the receiving antenna. The cancellation effect can be reduced by increasing the height of either antenna. This decreases the phase difference between the direct and the ground-reflected wave, thus reducing the degree of signal cancellation.

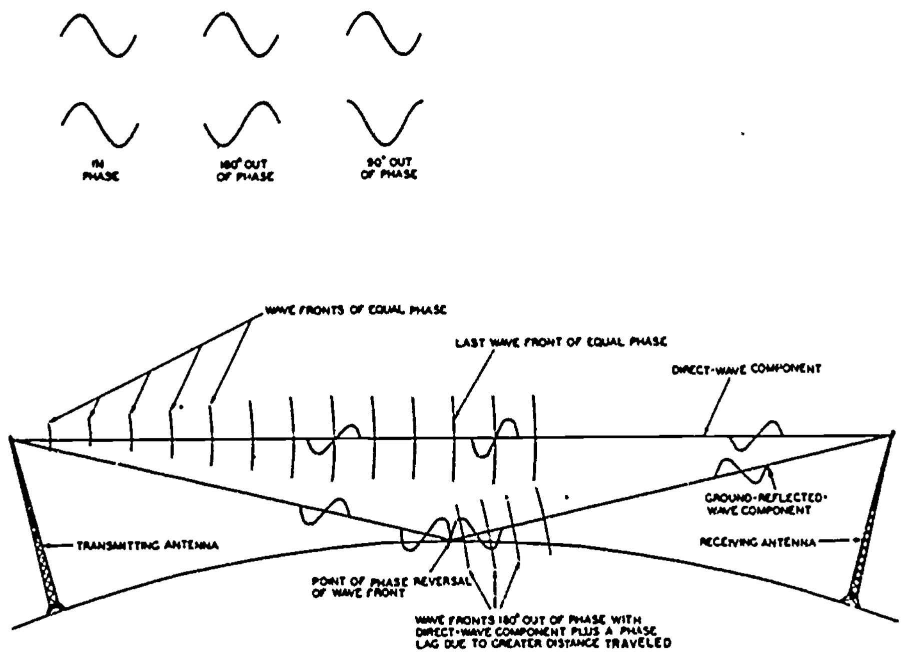

Fig 5-7. Comparison of the direct and the ground-reflected wave.

c. Surface wave. This component follows the curvature of the earth. Although it is primarily affected by the electrical characteristics of the local terrain, it is not limited to traveling along the earth's surface, but extends upward to considerable heights. Its field strength decreases as the height increases.

Since part of the energy of the surface wave is absorbed by the earth, this wave is attenuated at a much greater rate than the direct wave. The amount of attenuation depends on the conductivity of the local terrain (see table 5-2).

Table 5-2. Conductivity of Various Types of 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	-----

The surface wave is generally transmitted as a vertically polarized wave. This method is chosen because the ground has a short-circuiting effect on a horizontally polarized wave. The electric field of the vertically polarized wave is not short circuited by the earth. Actually, energy is restored by the ground currents.

Since no surface is a perfect conductor, losses are present. They tend to make the wave bend forward in the direction of travel. Thus, the earth's surface acts as a waveguide.

d. Tropospheric wave. This component is refracted in the lower atmosphere, due to rapid changes in atmospheric humidity, density, or temperature. At altitudes of a few thousand feet to 1 mile, there are large masses of warm and cold air, and consequent abrupt changes in temperature and density. The reflection and refraction of the tropospheric wave enable it to travel far greater distances than normally covered by the ordinary ground wave.

Figure 5-8, A, illustrates the downward bending of a wave which enters a layer of air whose moisture content decreases as altitude increases. Figure 5-8, B, shows the upward refraction of the same wave for opposite conditions.

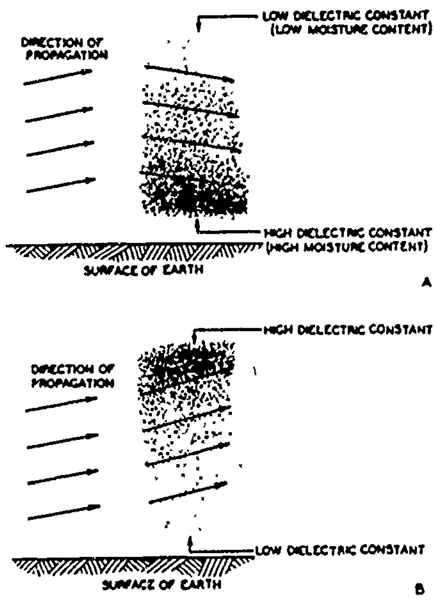

Fig 5-8. Tropospheric refraction.

5-7. CHARACTERISTICS

a. Frequency. The frequency characteristics of the ground wave determine which one of its components will predominate. When the wave frequency is below 30 MHz (Megahertz) and the conductivity of the earth is high, the surface wave will be the primary means of communication, except in air-to-ground or air-to-air transmission that uses the ground-reflected wave. At frequencies above 30 MHz, the losses suffered by the surface wave are excessive. Thus, the means of transmission is the direct wave. For frequencies at which the ground wave field intensity is largely determined by the surface wave, vertical polarization is superior to horizontal, except in heavily wooded or jungle areas. Because most foliage grows vertically and absorbs vertically polarized radiation, horizontal polarization provides better gain, even at frequencies and distances where the surface-wave component normally would be predominant. Above 30 MHz, if the direct wave is the prevailing factor, the difference between horizontal and vertical polarization is negligible.

b. Points to remember:

(1) The lf band is used for moderate-distance surface-wave communication. In this band, ground losses of a vertically polarized wave are minimum, and the wave is able to follow the curvature of the earth for several hundred miles.

(2) The mf band is used for moderate-distance communication over land and long-distance communication over water up to 1,000 miles.

(3) The hf band is used for short-distance communication.

(4) The dielectric constant of the earth decreases the field intensity of the surface wave, and is a prime factor in causing attenuation in the vhf band. Therefore, the vhf band is used for line-of-sight communication. At these frequencies, the direct wave is the important component.

5-8. TROPOSPHERIC PROPAGATION

a. Weather duct. Characteristics of the troposphere vary with weather conditions. In the tropics and over large bodies of water, temperature inversions are continuously present at altitudes up to 3,000 feet, particularly from 100 to 500 feet. When the area of temperature inversion is relatively narrow, waves traveling horizontally or at low angles of elevation become trapped by the refracting layer of air and are bent back toward the earth. The line of temperature inversion and the earth form a duct through which the wave travels. This condition is shown in figure 5-9.

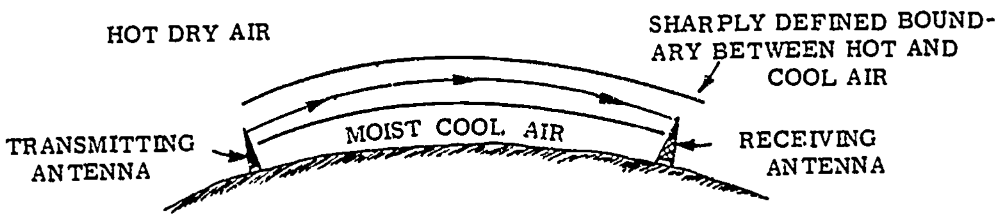

Fig 5-9. Transmission using the tropospheric duct.

Since there is minimum attenuation in the tropospheric duct, field intensity does not decrease inversely as the square of the distance. Thus, waves can follow the curvature of the earth at distances far beyond the optical horizon of the transmitter. In some locations, this distance may reach many thousands of miles.

Tropospheric ducts can also be formed by two layers of air with sharply defined temperature inversions. The height of the duct determines the minimum frequency. At extremely low altitudes, communication may be possible only at uhf or shf (ultrahigh, superhigh frequencies). Occasionally, the characteristics of the duct are suitable for vhf transmission.

There are two necessary features for tropospheric duct transmission. The first is that the angle of approach of the incident wave must be approximately half a degree or less, in order that the wave be trapped. The second factor is that both transmitting and receiving antennas must be inside the duct. If either antenna is above or below the duct, there will be no communication by means of the tropospheric duct, even though line-of-sight conditions may be present.

b. Troposcatter. A recent development in the field of radio wave propagation is the use of the scattering effect of the troposphere. Although this effect had been known to science earlier, much research was needed before it could be applied to the propagation of radio waves.

This phenomenon seems to be a result of variations in the refraction index of the troposphere, caused by fluctuations in temperature and water vapor content or turbulence. Such variations tend to scatter the signal in all directions, resulting in communications at distances not covered by short-range uhf or long-range lf stations.

Figure 5-10 illustrates this scattering effect. The solid lines denote conventional transmissions by ionospheric bending. The dashed lines represent the scattering of radio waves by the troposphere.

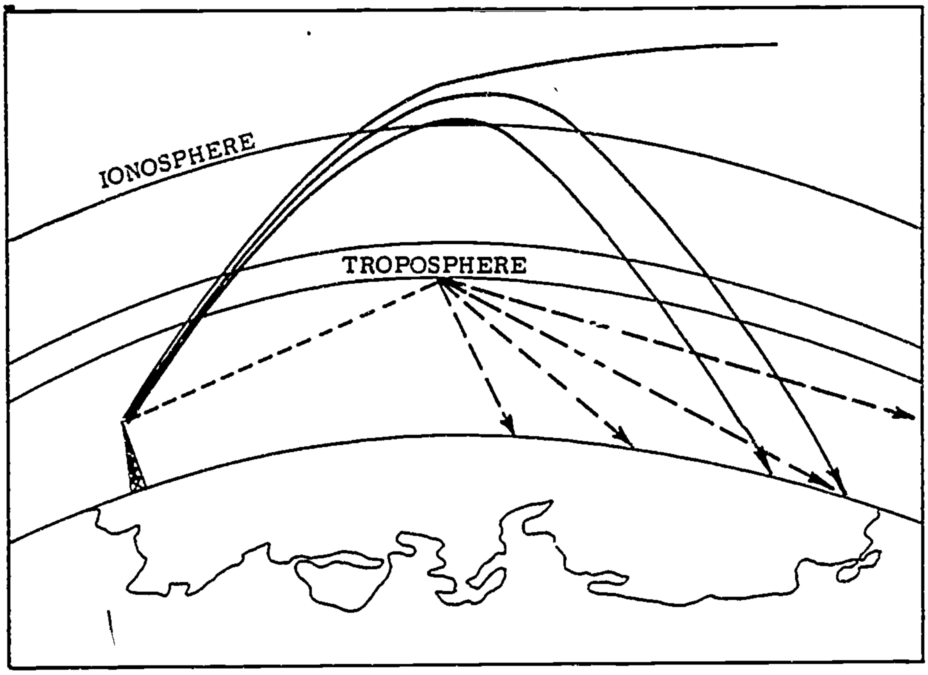

Fig 5-10. Scattering effect of the troposphere.

Troposcatter is used primarily for microwave transmission in the uhf or shf range, to provide moderate-distance communication up to 600 miles.

Section III. SKY WAVE PROPAGATION

5-9. GENERAL

Sky wave propagation uses ionospheric reflections to provide signal paths between transmitters and receivers. It is the primary means for long-distance communication. To understand the principles involved in sky wave propagation, you must first know about the ionosphere and its effect on radio waves.

5-10. THE IONOSPHERE

a. General. As illustrated in figure 5-1, the earth's atmosphere extends to an altitude of approximately 250 miles. Above this altitude, the density of the gases that make up the atmosphere decreases, so that air particles are practically nonexistent. The atmosphere is constantly bombarded by the sun's radiation and cosmic rays (their source is still in doubt). This radiation includes light rays, infrared rays, ultraviolet rays, and particle showers composed of positrons and electrons moving at almost the speed of light. As the different forms of radiation approach the earth's atmosphere, they pass through areas where the gases are of such density as to be particularly susceptible to ionization. In these areas, ionized layers are formed.

b. Ionospheric layers. The four distinct layers in the ionosphere are called (in order of increasing altitude and intensity) the D, E, F1, and F2 layers. As shown in figure 5-11, all four are present during daytime. At night, the F1 and F2 layers seem to combine to form a single F layer, and the D and E layers fade, due to recombination of the ions composing them. Actually the number of layers, their height, and intensity vary constantly.

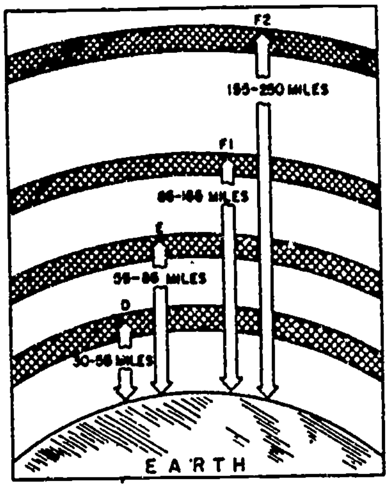

Fig 5-11. Ionospheric layers.

(1) D layer. The D layer ranges from an altitude of 30-55 miles above the earth's surface. In comparison with the other layers, the amount of ionization in the D layer has little effect on the bending of radio waves. The major effects of the ionization in this region are to attenuate the field intensity of the high-frequency radio waves and to completely absorb low- and medium-frequency radio waves. The D layer exists only during daylight. Ionization is most dense at noon and fades out shortly after sunset. It is responsible for the fact that the intensity of a received high-frequency wave is lower during daylight than during darkness.

(2) E layer. Between the altitudes of 55 and 85 miles lies the E layer (also called Kennelly-Heaviside region, after the men who discovered it). Its ionization intensity follows the sun's variations closely, being maximum about noon and diminishing during darkness to a level practically useless as an aid to high-frequency communications. This layer can refract frequencies up to 20 Megahertz. Thus, the E layer is important for communication over distances up to approximately 1, 500 miles. At greater distances, better transmission can be obtained with the F, F1, and F2 layers.

(3) F layer. At altitudes of 85-250 miles, there is another level of ionization, the F layer, which is present at all times. It is usually two well-defined layers during daytime: they combine to form one at night. Sufficient ionization remains at night so that high-frequency radio waves are refracted back to earth.

(4) F1 and F2 layers. During daylight, the F layer is divided into two distinct layers. The F1 layer ranges from an altitude of 85 miles up to 155-220 miles, depending on the season and time of day. The F2 layer is the most highly ionized layer. Its intensity has an appreciable day-to-day variation (in comparison with the other layer); it reaches maximum during the afternoon and gradually decreases during the night. It is the most useful layer for long-distance communications.

(5) Sporadic E layer. An unusual condition that affects radio communications is the sporadic E layer. It consists of intensely ionized clouds lying within the E layer. It is more prevalent during early spring months in northern latitudes. Its greatest effect is to permit vhf transmissions up to 1, 500 miles, by means of refraction from abnormally highly ionized clouds.

5-11. IONOSPHERIC CHARACTERISTICS

a. General. The principal ionospheric characteristic affecting long-distance communication is the ionization density of each layer. The higher the frequency of the radio wave, the greater the ionization density required to reflect the waves back to earth. Thus, at any given time, for each layer there is a value of highest frequency at which waves sent vertically upward are reflected back to earth. This value is called the critical frequency.

b. Critical frequency. Waves of lower frequency than the critical frequency are reflected to earth, whereas waves of higher frequency pass through to outer space. Figure 5-12 illustrates waves of different frequencies radiated vertically into the ionosphere. Two of them are returned to earth, and the third passes through both layers into outer space.
The value of the critical frequency is determined by beaming an RF signal vertically into the ionosphere and timing its return. As the frequency is increased, the effective altitude changes until the critical frequency is reached. A graph of these measurements is shown in figure 5-13. The dotted curve, plotted for a summer day, shows that at approximately 4 MHz there is a sharp increase in layer height. As the frequency is increased to 5.5 MHz, there is a break in the curve, indicating reflection from a higher layer. At approximately 7.2 MHz, the wave no longer returns to earth. Thus, as the frequency of a wave is increased, the signal will be returned to earth from successively higher layers until the F2 layer is reached. Once it has penetrated the F2 layer, the wave will no longer return to earth, regardless of frequency.

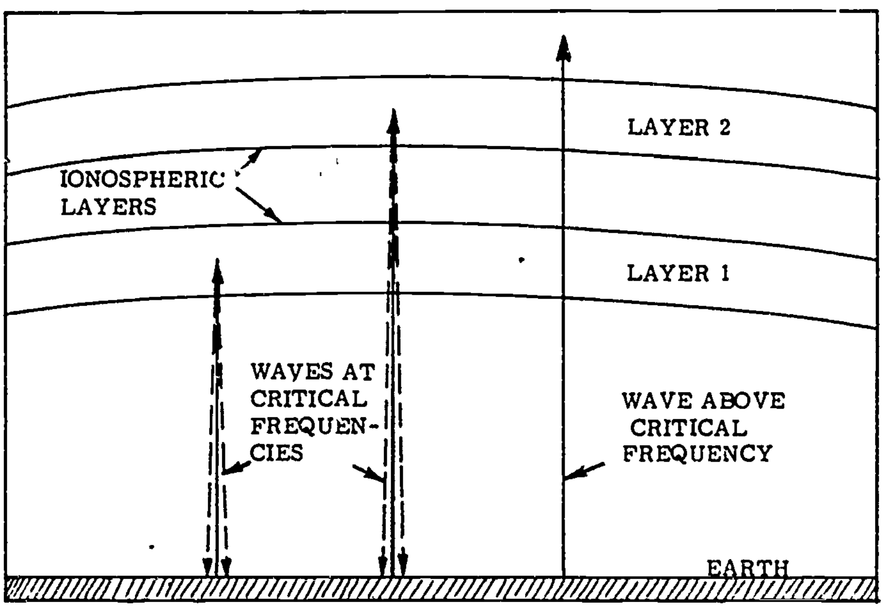

Fig 5-12. Critical frequencies in relation to waves.

Radio waves generally enter the ionosphere at some oblique angle. They may or may not be returned to earth. Obviously, frequencies at or below the critical frequency will be returned to earth, but those above the critical frequency will also return if propagated at certain angles of incidence.

Note: The angle of incidence is between the direction of the incident wave and a line drawn perpendicular to the boundary of the ionosphere.

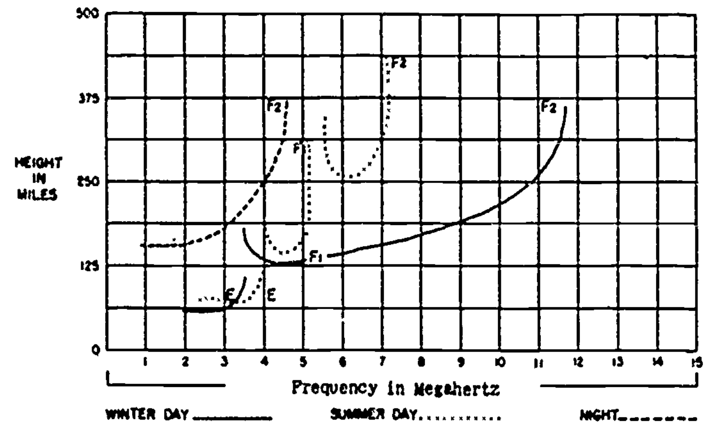

Fig 5-13. Determination of critical frequencies.

The possibility of the return of frequencies above the critical frequency can be understood by considering the example in figure 5-14. If a beam of light passes from a dense medium (water) to one of less density (air) at right angles (angle of incidence of 0°), the beam is only slightly reflected back into the water, most of the light being refracted into the air. The amount of bending increases as the angle increases, but at a given angle, which is the critical angle, no light is refracted by the air. All of it is reflected back into the water. At angles of incidence larger than the critical angle, the light beam is reflected back at greater distances from the light source.

Note: This phenomenon cannot be strictly applied to radio waves, since the boundaries between layers of the ionsphere are not sharply defined.

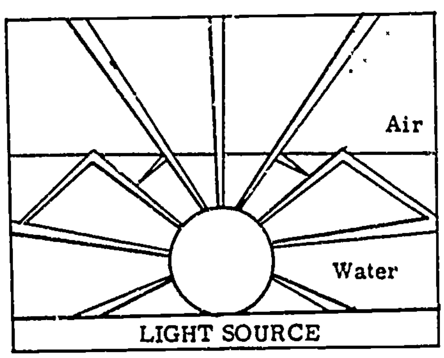

Fig 5-14. Critical angle.

c. Ionospheric variations. Since the existence of the ionosphere depends on the sun's radiation, changes in the sun's activity will result in variations of the ionosphere that are regular and can be predicted, and irregular variations resulting from abnormal behavior of the sun.

(1) Regular variations. These are broken down into four classes: diurnal or daily, seasonal, 11-year, and 27-day. See table 5-3.

(2) Irregular variations. In addition to the regular variations of the ionosphere, a number of singular effects, though unpredictable, have important bearing on propagation. Some of the more prevalent effects are the sporadic E, sudden ionospheric disturbances (SID's), ionospheric storms, and scattered reflections. These variations are listed in table 5-4 with their effects on the ionosphere and communications, and suggested methods of compensation.

Table 5-3. Regular Variations of the Ionosphere

Type of variation	Effect on ionosphere	Effect on communications	Method of compensation
Diurnal (variation with hour of day)	F layer: Height and density decrease at night, increase after dawn. During day, layer splits into—(1) F1 layer: Density follows vertical angle of sun; (2) F2 layer: Height increases until midday, density increases until later in day. E layer: Height approximately constant, density follows vertical angle of sun. Practically nonexistent at night. D layer: Appears after dawn, density follows vertical angle of sun; disappears at night.	Skip distance varies in 1- to 30-MHz range. Absorption increases during day.	Use higher frequencies during day, lower frequencies at night.
Seasonal- - - - -	F2 layer: Effective heights increase greatly in summer, decrease in winter. Ionization density peaks earlier and reaches higher value in winter. Minimum predawn density reaches lower value in winter. F1, E, and D layers: Reach lower maximum densities in winter months.	MUF's (maximum usable frequencies) (para 5-13b) generally reach higher midday values in winter but maintain high values later into afternoon in summer. Predawn dip in MUF's reaches lower value in winter. Less absorption encountered in winter.	Provide greater spread between nighttime and daytime operating frequencies in winter than in summer.
11-year sunspot cycle- - - - - -	Layer density increases and decreases in accord with sunspot activity.	Higher critical frequencies during years of maximum sunspot activity. MUF variation: Sunspot max: 8-42 MHz, sunspot min: 4-22 MHz.	Provide for higher operating frequencies to be used during periods of sunspot maximum and lower frequencies for use during minimum.
27-day(sunspot)-	Recurrence of SID's (sudden ionospheric disturbances) and ionospheric storms at 27-day intervals. Disturbed conditions frequently may be identified with particularly active sunspots whose radiations are directed toward the earth every 27 days as the sun rotates.	See effects of SID's and ionospheric storms in table 5-4.	See compensation for SID's and ionospheric storms in table 5-4.

Table 5-4. Irregular Variations of the Ionosphere

Type of variation	Effect on ionosphere	Effect on communications	Method of compensation
Sporadic E layer- -	Clouds of abnormal ionization occurring in the E layer or slightly above for a large portion of time each month result in abnormally high critical frequencies. Usually spotty in geographic extent and time.	Excellent transmission within normal skip distance. Occasionally, long-distance communications on frequencies of 60-MHz or higher are possible.	Frequency may have to be lowered to maintain shortskip communications. At times, long-distance communications on abnormally high frequencies are possible.
Sudden ionospheric disturbance (SID)	Unusual amount of ultraviolet radiation from solar flare results in abnormally high ionization in all layers. Ionization increase occurs with great suddenness throughout daylight portion of earth.	Normal frequencies above 1 or 1.5 MHz are rendered useless because of high absorption in the abnormally ionized D layer. Frequencies considerably higher than normal will survive this absorption for short hops Low frequencies may not penetrate the D layer and thus may be transmitted for long distances.	Raise working frequency above normal for short-hop transmission. Lower frequency below normal for long-hop transmission.
Ionospheric storm-	Usually accompanies magnetic disturbance occurring about 18 hours after SID's. Probably both are due to abnormal particle radiation. Upper ionosphere expands and diffuses; critical frequencies below normal, effective heights above normal. Severest effects toward equator. Few minutes to several hours in duration; effects disappear gradually in few days.	Limits number of usable high frequencies.	Use frequencies lower than normal, particularly in high-latitude circuits.
Scattered reflections- - - - - -	The ionospheric layers are not smooth. Irregularities in density and in height are normal.	Because of irregularities in the ionosphere, the electric field at a receiver consists of several fields arriving from slightly different directions with varying phase relationships. The result is fading of the signal resulting from cancellation and reinforcement.	Fading of short duration. No compensation required.

5-12. TRANSMISSION PATHS

Figure 5-15 illustrates the many possible paths of radio waves. Note that some of the components of the entire wave front, which are assumed to be of too high a frequency to be reflected by the ionosphere, are lost in space. Other components, which are assumed to be the correct frequency, are returned to earth. These components provide communications. Note also that skip distance is that distance from the transmitter at which the ion density will just support reflection.

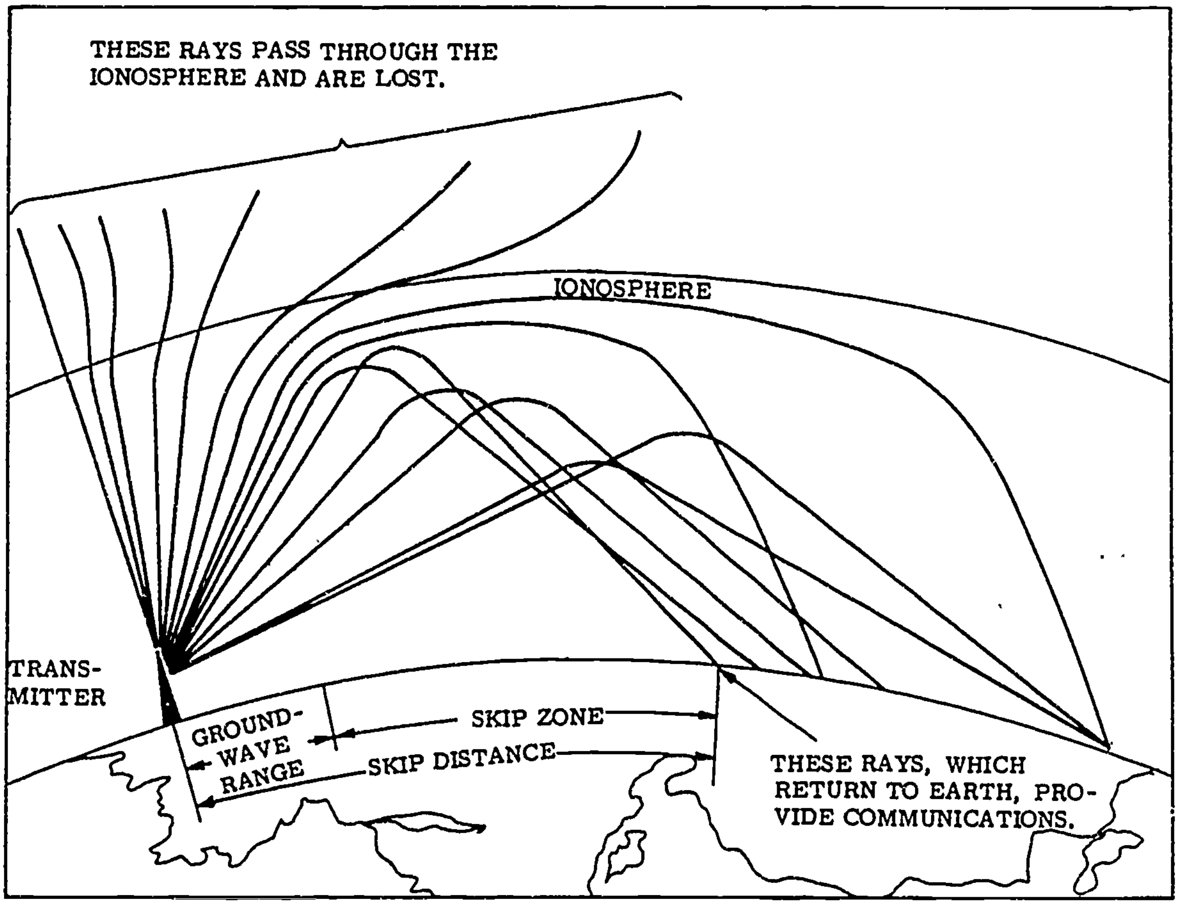

Fig 5-15. Sky wave transmission paths.

Figure 5-16 shows the skip zone and its relation to the ground wave. When the skip distance becomes less than the inner limits of the skip zone, both sky wave and ground wave may have the same field intensity but a random relative phase. When this occurs, the field of the sky wave successively reinforces and cancels that of the ground wave, resulting in severe fading of the signal. Note the distinction between the terms skip distance and skip zone. Skip distance depends only on the frequency of the radio wave and the state of ionization of the ionosphere. Skip zone depends on the extent of the ground wave range, and disappears entirely if the ground wave range equals or exceeds the skip distance.

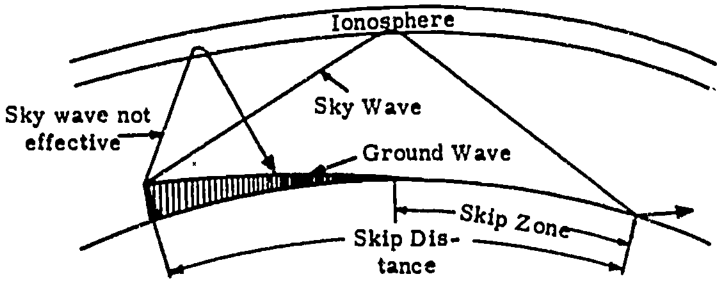

Fig 5-16. Skip distance and skip zone.

a. Sky wave modes. The distance at which the wave returns to earth depends on the height of the ionized layer and the amount of bending required to refract the wave back to earth. Upon returning to the earth's surface, some of the energy is dissipated by the earth, but part is reflected into the ionosphere, where it may be reflected downward at still greater distance from the transmitter. This means of travel in hops, by alternate reflections from the ionosphere and from the surface of the earth, may continue; and it enables transmission over great distance. Figures 5-17 illustrates this means for paths involving one or more reflections from the ionosphere (single- and multiple-hop modes, respectively).

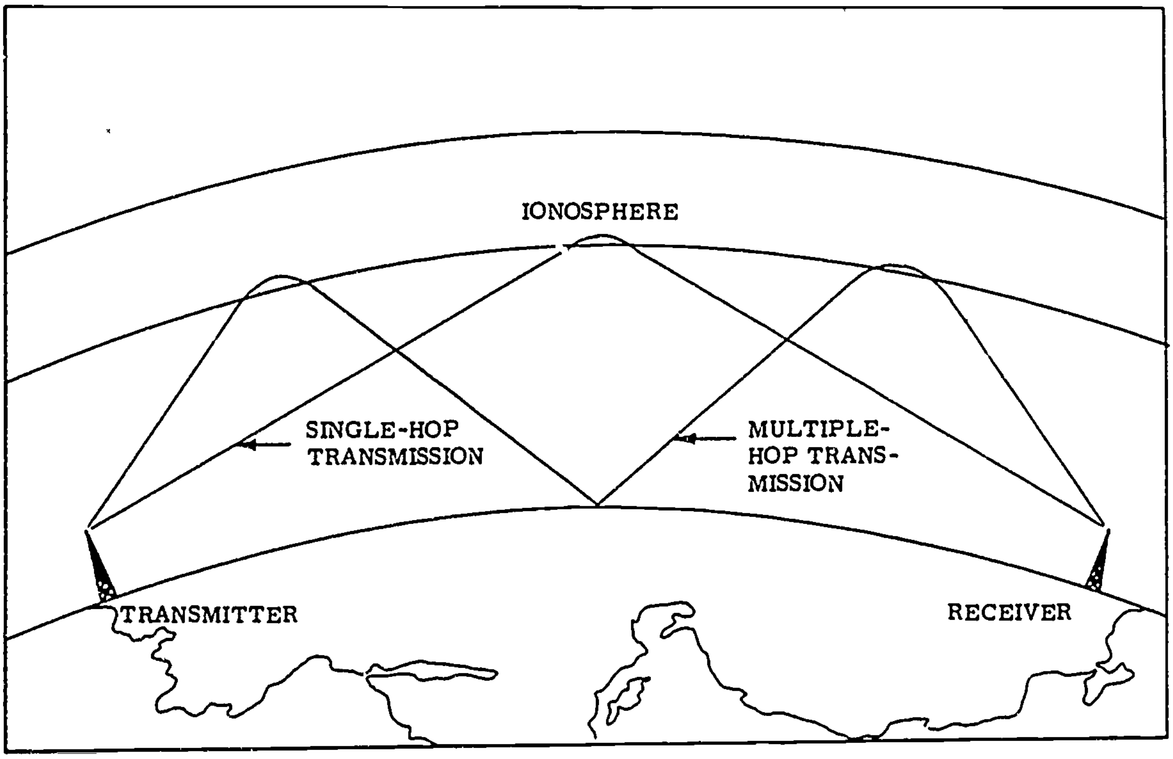

Fig 5-17. Single- and multiple-hop modes.

b. Great-circle paths. The paths on which radio waves normally travel from transmitter to receiver lie in the plane passing through the center of the earth and the transmission and reception points. This type of path is generally called the great-circle path. Frequently, however, radio waves do not follow the path confined to this plane, and such deviation is called the nongreat-circle path. Waves can follow either the major arc or minor arc of the great-circle path. For instance, radio waves emanated from New York City might travel cross-country westward to San Francisco, which would be along the minor arc. However, they could travel eastward, almost around the world to the same destination, which would be along the major arc. These two types of transmission are called short-path and long-path transmission, respectively.

c. Incident angles. For a radio wave of particular frequency and an ionized layer of certain density of ionization, there is an angle called the critical angle of incidence, at which the wave is reflected and returns to earth near its skip or minimum distance. Note that the critical angle is sometimes defined as the angle at which the wave is horizontally propagated within the ionospheric layer, and thus does not return to earth. Note further that these two definitions are the same, since the angle at which the first wave returns and the angle at which it does not return are the same. To avoid confusion, when reference is made to the angle of radiation from the source (transmitter), the angle of departure is used to define the critical angle. The angle of departure is formed between the direction of the wave and the earth (considered as a horizontal plane surface). When reference is made to wave entry into the ionosphere, then the angle of incidence is used to define the critical angle.

Figure 5-18 shows a given wave at various angles of departure and the resultant reflection of each wave in the ionosphere. Note that at angles of departure larger than the critical angle, the wave is not sufficiently refracted in the ionosphere, so it escapes into space. As the angle of departure decreases below the critical angle, the wave returns to earth at decreasing distances from the transmitter until a point of minimum distance (the skip distance) is reached. As the angle of departure continues to decrease, the distance between the transmitter and the point at which the wave returns increases and continues to increase for smaller and smaller angles of departure. Any high-angle wave which returns beyond the skip distance is attenuated greatly, and the skip distance remains as the point at which the wave first returned in strength to the earth.

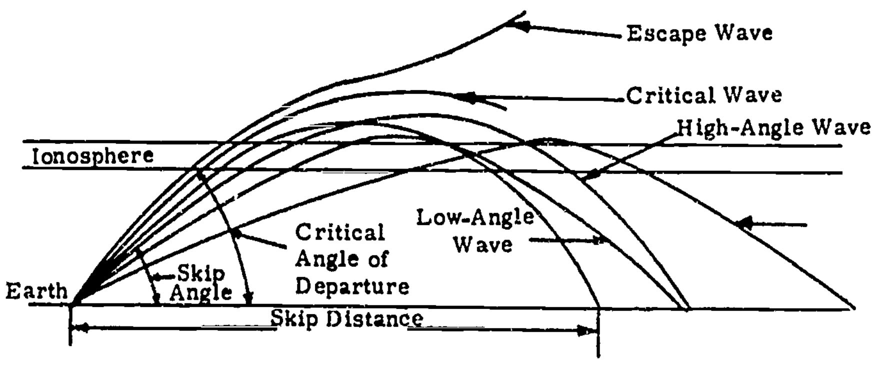

Fig 5-18. Departure wave paths.

This irregular variation of the return distance with regular variation of the departure angle results from the fact that the ionosphere acts principally as a refracting medium for the larger angles of departure. If the angle of departure of the transmitted radio wave can be controlled, the smaller angles result in communication over greater distances. Figure 5-19 shows sky waves of a fixed frequency propagated at the critical angle of departure and at various smaller angles. Note that the smaller the angle, the greater the distance at which the wave returns to earth.

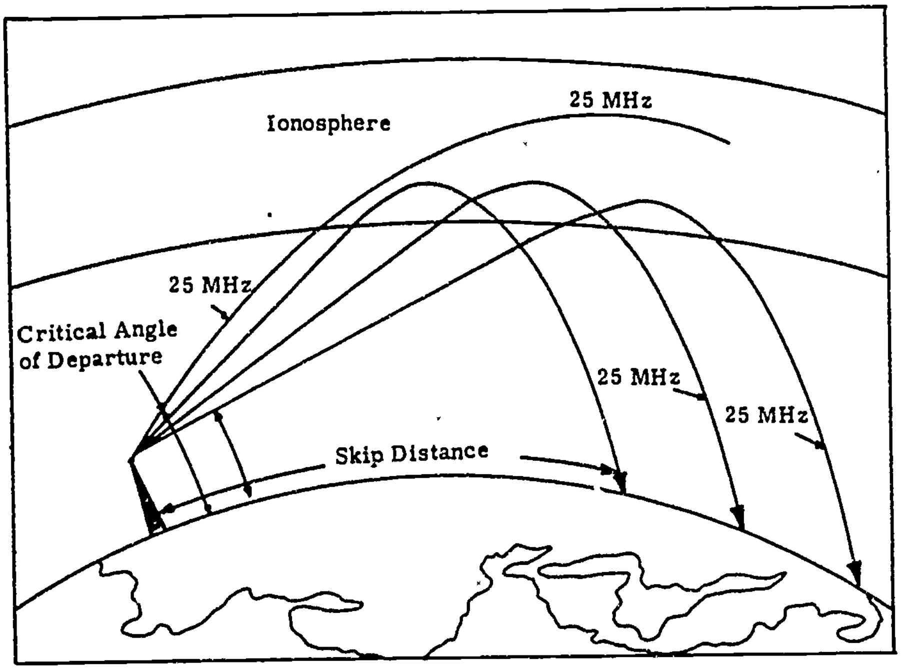

Fig 5-19. High-frequency wave at various angles of departure.

5-13. FREQUENCY PREDICTION

a. General. Sky waves reach the receiver after refraction from the ionosphere. Since the ionosphere is affected by the sun's radiation that varies according to season and the 11-year sunspot cycle both of which can be predicted, frequencies can also be predicted. These frequencies are categorized as follows:

Maximum Usable Frequency (MUF),
Lowest Useful Frequency (LUF), and
Optimum Working Frequency (FOT).

b. Maximum usable frequency (MUF). For any given ionized layer of fixed height and ion density, and for a transmitting antenna with a fixed angle of radiation (departure), there is a frequency (higher than any other) that will return to earth for a given distance. This frequency is the maximum usable frequency for that distance. It is always a frequency higher than the critical frequency because the angle of departure is less than the vertical angle. Thus, for any given great-circle distance along the earth, there is a maximum usable frequency (MUF). This is the highest frequency that will be reflected from a given layer of the ionosphere and that will return to earth at the great-circle distance. If the distance between transmitter and receiver increases, the maximum usable frequency increases.

In selecting the proper operating frequency for sky waves which travel along a fixed path, the MUF is perhaps the most important factor to be considered. If the operating frequency is above the maximum usable frequency, the wave will pass through the ionosphere and escape into space. If the operating frequency is lower than the maximum usable frequency, the wave becomes increasingly attenuated, due to ionospheric absorption. Thus, it is desirable to operate as close to the MUF as possible. A direct relationship exists between the maximum usable frequency, the condition of the ionosphere, time, and the angle of departure as shown in figure 5-20. Thus, it is possible to predict mean values of maximum usable frequency for propagation over any path for the future.

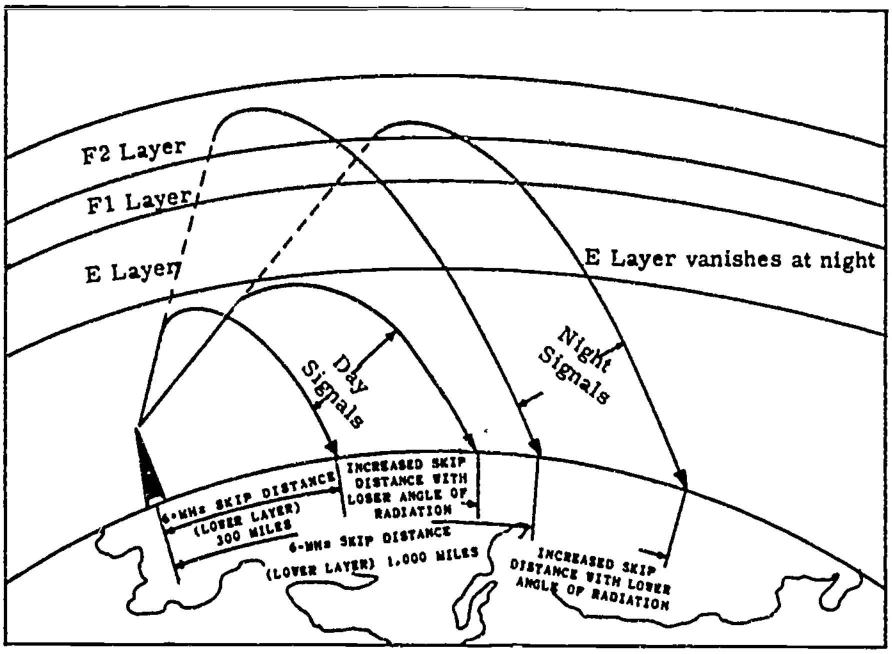

Fig 5-20. Relationship between distance, time, angle, and frequency.

c. Lowest useful frequency (LUF). At certain frequencies, radio waves penetrating into the ionosphere, primarily in the D and lower portion of the E layers, lose some of their energy by absorption. Generally, the higher the frequency used (up to the limit of the MUF), the less will be the total absorption; and more satisfactory communications will result. Absorption is maximum for frequencies of 500 kilohertz to 2 Megahertz in daytime, and decreases for both higher and lower frequencies at night. Thus, for frequencies above 1 Megahertz, the strength of the received sky waves will, in daytime, increase with frequency. Finally, a frequency will be reached for any given sky wave path if the strength of the received signal just overrides the noise level. This frequency is called the LUF. Frequencies lower than the LUF are absorbed to such an extent as to render them too weak for useful communication. Note that the LUF depends on both the power of the transmitter and the distance involved. At night, the noise level increases with decreasing frequency so that as the frequency is lowered, the signals become weaker with respect to noise and the LUF is eventually reached.

d. Optimum working frequency (FOT). The actual upper limiting frequency must be selected at a value which will insure against the probability of the operating frequency becoming greater than the MUF for any particular day. For the F2 layer, the optimum working frequency thus is selected at approximately 85% of the MUF for that particular transmission path. The FOT for the combined E-E1 layer may be taken as the MUF, since day-to-day variations in an E layer ionization are small. Of course, if the LUF is nearly equal to the MUF for a given transmission path, the operating frequency must be selected at a value consistent with both.

Note: For an up-to-date prediction chart consult the current edition of NTP-6 SUPP-1( ).