APPENDIX I

The Station Instruction Book.

THE STATION INSTRUCTION BOOK

A. OUTLINE OF COMMUNICATION FACILITIES INSTRUCTION BOOK

Types of book required:

- Naval Communication Stations or Facilities.
  - Naval Radio Station (T).
  - Naval Radio Station (R).
  - Naval Communication Center.
  - Naval Radio Station (L).
- Communication Department Facilities.
  - Transmitter Component.
  - Receiver Component.
  - Administrative Communication Center.
  - Operations Radio.
  - Control Tower.
  - Fleet Air Wing Communications.
  - Fleet Tactical Base Radio.

PREFACE

The aim of this book is to provide between one set of covers a complete statement of what the station was built to do, why it was built the way it was, pointing out the operational and maintenance concepts employed. It is intended to be a concise analysis of the station as a system using a brief discussion of design, employment limitations, operation and maintenance plus reference to significant documents and detailed as built plans the latter being furnished by the Industrial Manager and to be maintained by station force.

1. GENERAL.

Refer to operational requirements which station was built to provide, inventory of prime and test equipment at commissioning, documents of understanding and agreement, copies of conditional and final letters of acceptance of the Commanding Officer.

2. DESIGN.

a. Plant design criteria employed.

Site requirements, developments, etc.

Building use and width, rows of equipment, cellular floor, wiring. Antenna arrangement, shadow angle, etc.

b. Plant design concepts, employment limitations and expansion capabilities.

Schematics of signal flow of the system.

Schematics of typical A.F., D.C., R.F., switching and mainframe circuit requirements.

Transmitter station; schematic of R.F. indoor-outdoor switching, console, safety features of power system.

Power, primary and emergency (from Public Works Officer).

Outside Plant, site arrangement, antennas, antenna separation, shadow angle, separation from sources of interference, transmission line, public works responsibility for structures, etc.

Ground system, use of.

3. OPERATION.

a. Patching—main frame, control center, transmitter console, A.F., R.F. distribution system, etc.

b. R.F. Switching—indoor, outdoor, status board, multicouplers.

c. Test facilities, employment of.

d. Operational spares, employment of.

e. Antennas, types to be used for various type of service.

4. MAINTENANCE.

a. Antennas—standing wave ratio standards; stubbing range of frequency use by adjustment of; termination lines and resistors, transmission lines, coaxial cable.

b. Maintenance instructions and spare parts lists for Industrial Manager manufactured and commercial items.

c. Reference to Electronic Supply Office spare parts allowance for commissioning allowance of equipment (see BUSHIPS INSTRUCTION 10550.34 ser 915-17 of 6 August 1954).

Format.

8″ x 10½″ sheets colitho or multilith.

Prints—ozalid.

Loose-leaf.

Copies to:	Quantity
Commanding Officer	determine locally
BUSHIPS	1
Management Bureau	1

B. OUTLINE OF INSTRUCTION BOOK FOR ELECTRONIC SEARCH, GUIDANCE OR INSTRUMENTATION FACILITY

1. TYPES OF BOOK REQUIRED:

a. Navigational Aid and Traffic Control Facilities, Naval Air Stations.

(1) Radar Air Traffic Control System.

(2) Air Surveillance Radar Installation, not part of (1) or (3).

(3) Ground Controlled Approach Installation.

(4) Instrument Landing System.

(5) Radio Range, 4-Course.

(6) Radio Range, Omnidirectional.

(7) Fan Marker Installation.

(8) Radar Beacon Installation.

(9) Compass Locator Station, L/MF and UHF.

(10) Aircraft Guidance Control.

b. Electronics Facilities for Training.

(1) CIC Training Facility.

(2) Air Defense Training Facility.

(3) Ground Controlled Intercept Training Facility.

(4) All Weather Training Facility.

(5) Airborne Early Warning Training Facility.

(6) Team Training Facility.

(7) Operator Training Facility.

(8) Maintenance Training Facility.

c. Electronic Equipment Test and Calibration Facility.

2. SUMMARY.

The book treats the station or facility as a system. Set forth are the requirements which brought the station into being, and the degree to which it is intended to fulfill the requirements, in light of design compromises due to environment and equipment and system limitations, which are also set forth. The book supplies only that technical installation and maintenance detail which is not contained in individual equipment instruction books. It references significant documents; and pertinent, detailed "as-installed" plans, which are furnished by the Industrial Manager and are to be maintained by station force.

3. CONTENTS.

a. General.

(1) Operational or training requirements established by appropriate authority, with references of official, promulgating action.

(2) List of approved allowances and on-board status, at time of commissioning, with references of official promulgating action, for the following:

(*a*) Major electronic equipment.

(*b*) Electronic test equipment.

(*c*) Essential ancillary equipment.

(3) Copies of documents of understanding and agreement.

(4) Copies of conditional and final letters of acceptance by the Commanding Officer or other operational or training authority.

b. Design.

(1) General area siting.

(*a*) Requirements.

(*b*) Criteria used.

(*c*) Compromises.

(2) Detail (pin-point) siting.

(*a*) Requirements.

(*b*) Criteria used.

(*c*) Compromises.

(*d*) Development.

(3) Plant Design.

(*a*) Requirements.

I. Initial operational load.

II. Provision for expansion of load.

III. Provision for expansion of facility.

IV. Protection against facility encroachment.

(*b*) Criteria used.

(*c*) System functional block diagrams, overall and by function (e.g., live radar, simulated radar, IFF, exterior communications, interior communications, data display).

(*d*) Functional layout plans, two-dimensional or isometric as required for optimum clarity.

(*e*) Provisions for flexibility of use.

I. Switching.

II. Patching.

III. Centralized terminations.

IV. Sectionalization of activated facilities.

(*f*) Provisions for flexibility of installation (changes or expansion).

I. Equipment foundation system.

II. Cabling system.

III. System of transmission line egress.

IV. Ground system.

V. Limits of switching system coordinates.

VI. Power system capacity and distribution system, regular and emergency circuits.

VII. Accessibility factors.

(*g*) Technical data for system elements not covered by equipment instruction books or other pertinent official publications.

(*h*) References to "as-installed" plans not covered by (*b*) through (*g*) above.

(*i*) Provisions for spare parts stowage.

(*j*) Designed extent of station maintenance and physical facilities provided.

c. Operation.

(1) Safety.

(*a*) General system precautions.

(*b*) Re-emphasis of important, specific safety provisions of equipment instruction books, other pertinent official publications, and technical data furnished under *b.*(3)(*g*) above.

(2) Operational capabilities and limitations of individual system elements.

(3) Instructions for use of system operational checks.

(4) Instructions for use of system elements not covered by equipment instruction books or other pertinent official publications.

d. Maintenance.

(1) Instructions for maintenance of system elements not covered by equipment instruction books or other pertinent official publications.

(2) Instructions for use of maintenance facilities.

(3) References to Electronic Supply Office spare parts allowance for commissioning allowance of equipment (see BUSHIPS INSTRUCTION 10550.34 ser 915-17 of 6 August 1954).

(4) Guide for obtaining assistance on maintenance work beyond capacity of station force.

4. FORMAT.

a. 8″ x 10½″ sheets—colitho or multilith.
Prints—ozalid.

b. Loose-leaf.

5. DISTRIBUTION.

Addressee	*No. of Copies*
Commanding Officer	Determine locally
Management Bureau	1
Training Agency (if other than Management Bureau)	1
Immediate Training Command	1
Bureau of Ships	1

APPENDIX II

Matching Doublet Antennas to Transmission Lines.

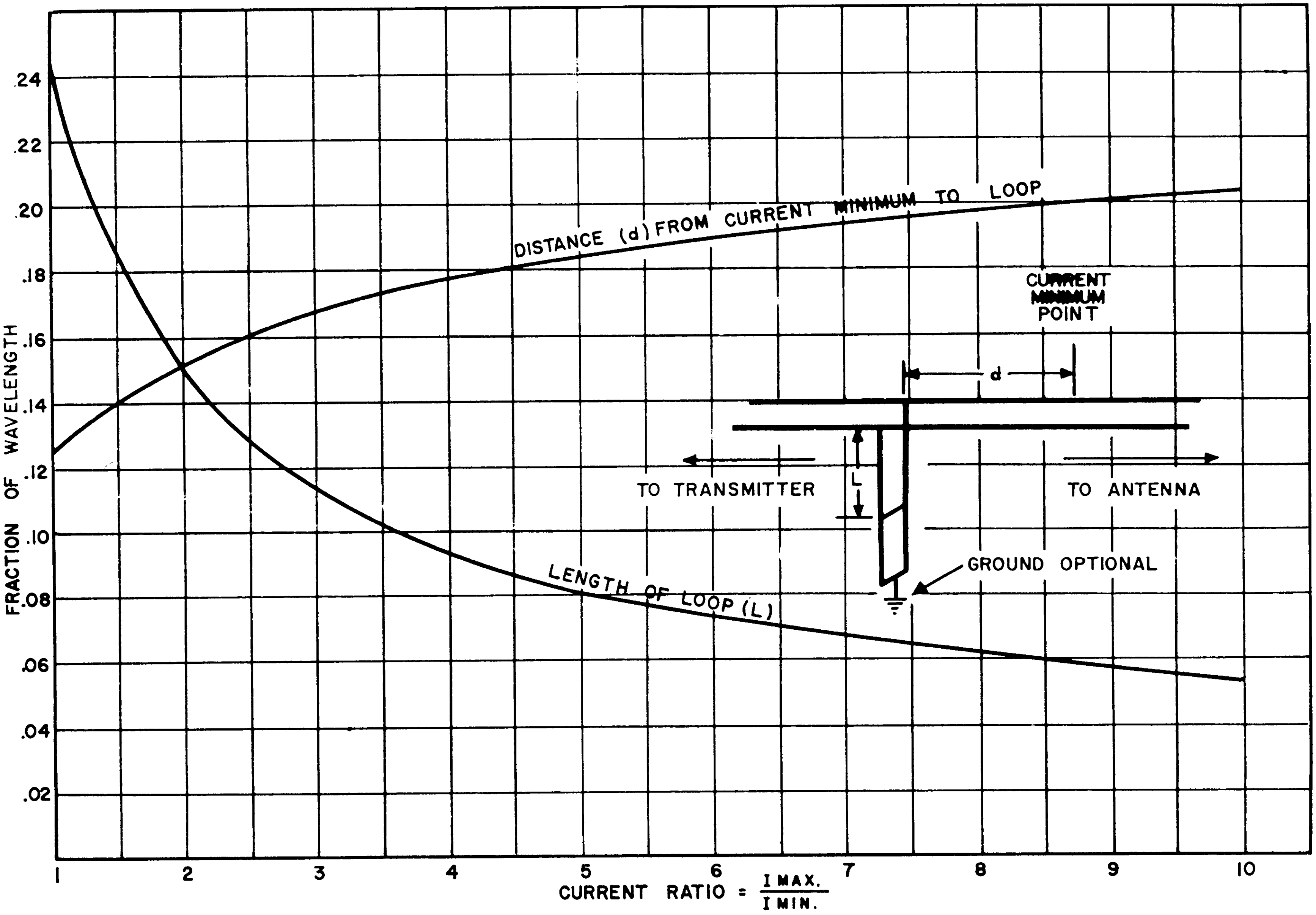


Figure II-1. Doublet Stubbing Chart

APPENDIX II

MATCHING DOUBLET ANTENNAS TO TRANSMISSION LINES

APPENDIX II

MATCHING AND TUNING DOUBLETS

A. MATCHING DOUBLET ANTENNAS TO TRANSMISSION LINES. (From BUSHIPS-INST 2920.1 of 16 March 1955.)

1. When a resonant two-wire doublet, or half-wave, antenna is connected to a 600-ohm transmission line, standing waves will exist along the transmission line between antenna and transmitter. These standing waves are objectionable for several reasons:

a. Standing waves cause radiation losses.

b. Standing waves make transmitters unstable or difficult to tune and neutralize.

c. Transmission lines radiate causing intermodulation problems.

2. The simplest way to minimize standing waves is to connect a short section of line, called a "stub," to the main transmission line at a predetermined point near the antenna. This stub is short-circuited at the correct distance from the main transmission line and then grounded for lightning protection.

3. Removal of standing waves with the stub is accomplished in two steps.

a. Determination of standing wave ratio on the unmatched transmission line, and location of minimum current point nearest to the antenna, to establish stub dimensions.

b. Attaching and adjusting the stub.

4. While an R.F. milliameter may be inductively coupled to the transmission line to determine the standing wave ratio, the use of such an instrument may lead to false readings in antenna fields where other nearby antennas induce strong currents into the line. Since most Navy shore installations have an AN/PRM-1 or equivalent receiver available, a shielded loop may be used with such an instrument for this type of measurement. Since the AN/PRM-1 is frequency discriminative, and the loop itself is shielded against extraneous pickup, relatively accurate readings may be obtained in fields of strong off-frequency R.F. Details of a shielded probe and pad to adapt the AN/PRM-1 for this service are shown in Figure II-2. The two disadvantages in determining standing wave ratio in this manner are (a) the somewhat cumbersome equipment to be carried in the field, and (b) the precautions which must be taken to keep meter readings on scale. The attenuator pad illustrated takes care of the latter problem and may be attached directly to the AN/PRM-1 input.

One type of trolley meter is shown in BuShips Drawing RE 10F 2181. This type was designed at the Annapolis Naval Radio Station and may normally be constructed of locally available materials. Such instruments may be pulled along the transmission line to detect I_{min} points for stub adjustments. It would also be possible to mount the shielded probe diagrammed in Figure II-2 on a similar trolley device.

In order to ascertain that correct null locations are found, measurements should be taken for several consecutive null points along the transmission line and the distances between null points physically measured. Nulls should be equi-spaced along the line.

5. The stub is prepared according to the graph. The stub dimensions being in fractions of a wave length requires (1) converting the frequency to wave length in meters and (2) converting meters to feet.

For example:

Meters = 300/mc., and meters × 3.28 = ft.
e.g.: 4 mc = (300/4) × 3.28 = 246 ft.
Assume VSWR = 8
then stub length = .063 × 246
or 15.5 ft.

The stub should be cut somewhat longer for adjustment purposes. The stub is then attached to the transmission line at the point indicated by the graph. After attaching the stub, mark for reference where the stub attaches to the line and where the short-circuiting wire is attached to the stub.

6. Next, the transmitter tuning is readjusted to compensate for attaching the stub to the line, and the new standing wave ratio is obtained and recorded.

7. To further reduce the standing wave ratio, readjustments are made in:

a. Position of short-circuiting wire, and

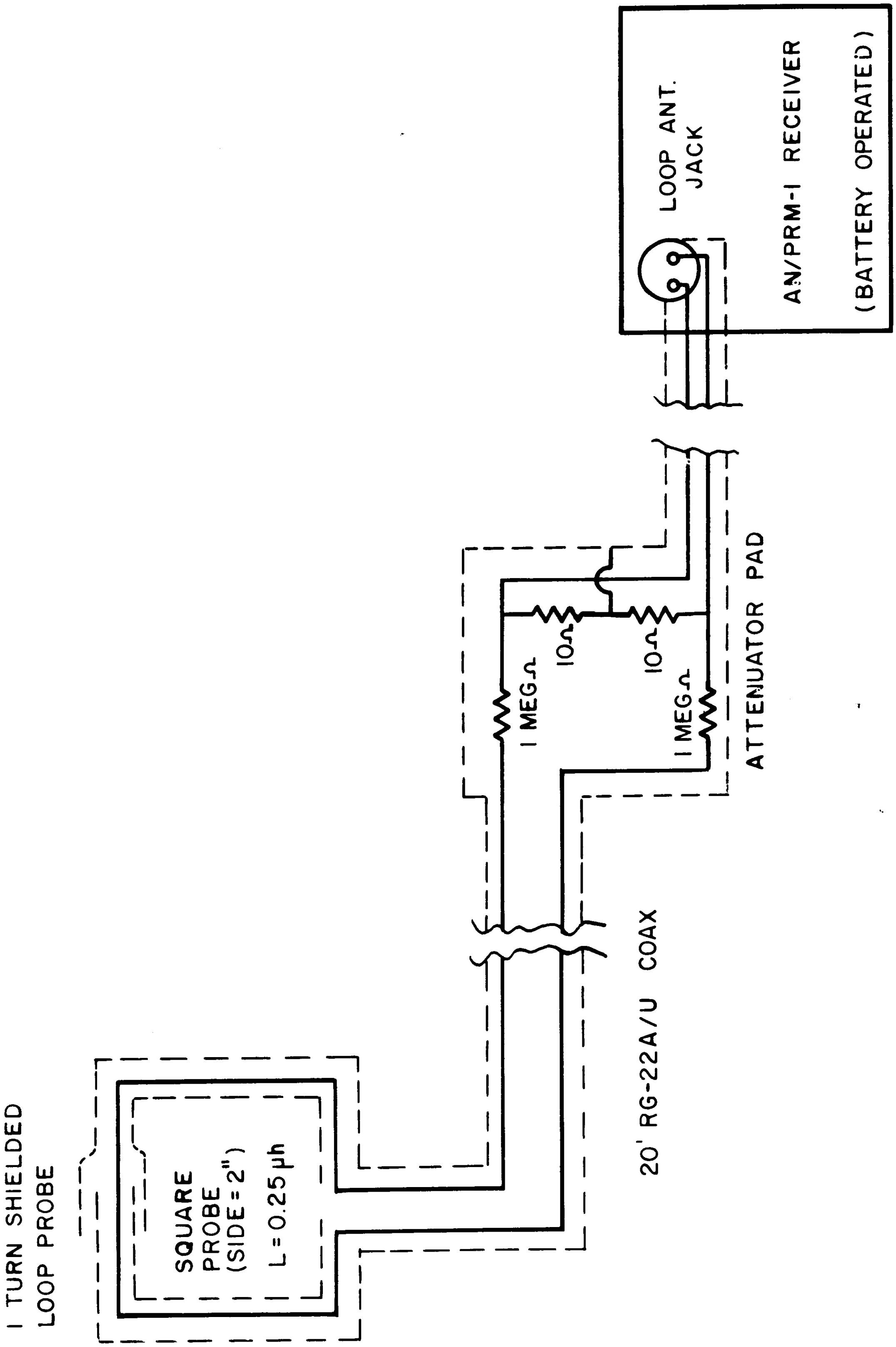


FIG. II-2 DETAILS OF SHIELDED PROBE AND PAD FOR AN/PRM-1 *b.* Position of the stub on the transmission line.

The position of short-circuiting wire and stub should be recorded for each readjustment, with the corresponding maximum and minimum line currents. The form below can be used:

Stub Pos.	Short Pos.	I Max.	I Min.	I Ratio
Start	Start	120	80	1.50
3" to Antenna	3" down	100	80	1.25
3" from Antenna	3" up	100	90	1.11

8. The recheck of standing wave ratio following each adjustment of the stub will indicate whether the change is made in the right direction. Adjustments should be continued in cut-and-try process until the standing wave ratio is a minimum (nearest 1:1).

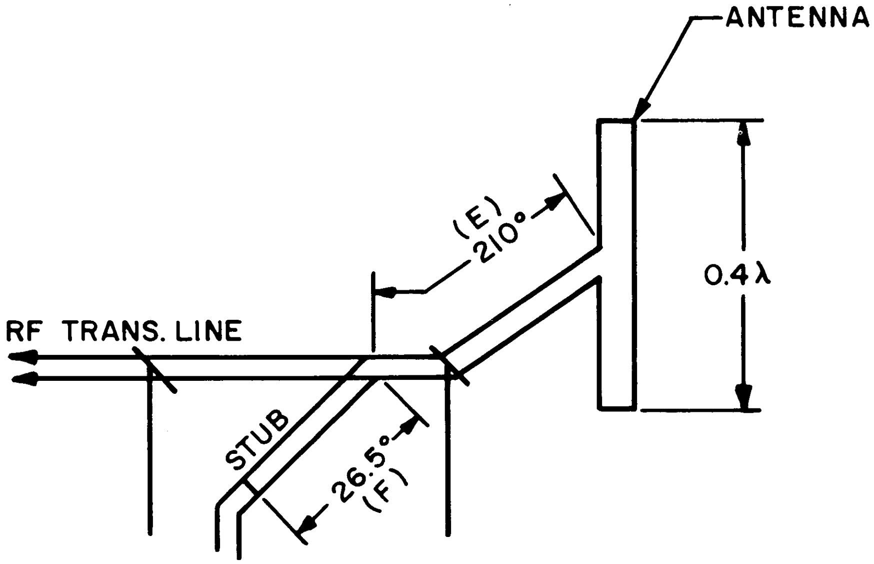
9. The cut-and-try process may be excessively long unless executed with guidance. The first adjustment should be to vary the position of the short-circuiting wire up or down to get equal line currents at 1/8 and at 3/8 wave-lengths positions away from the stub toward the transmitter. This resonates the antenna and the stub. Record the stub adjustment and the corresponding standing wave.

10. The next step is to change simultaneously the position of short-circuiting wire and the point of attachment of the stub to the transmission line. Take a series of readings moving the short-circuiting wire UP, and the stub connection AWAY from the antenna, by exactly the same amount—a few inches—and record the distances and current readings.

11. If the standing wave ratio becomes consistently higher, then return to the adjustment indicated in paragraph 9. Continue by moving the short-circuiting wire DOWN, and the stub TOWARD the antenna, by exactly the same amounts. Record data as before.

12. By roughly graphing the data in the field, the best position for the stub and short-circuiting wire will be indicated.

13. From the practical standpoint of planning and construction it may be desirable to have the construction agency perform as much of the antenna work



ADJUST STUB ATTACHMENT POINT & STUB SHORTING BAR FOR LOWEST S.W.R. (LENGTH & LOCATION SPECIFIED ARE THE MEDIAN VALUES FOR 19 ANTENNAS ADJUSTED AT NRS(T) KODIAK.)

FIG. II-3 APPROXIMATE METHOD

as possible. This should include furnishing materials for, and placing the tuning stub at a location that will be approximately correct. This location must be determined without actual measurement of the VSWR since it is very unlikely that a test transmitter could be set up for exciting the antenna during the construction period (particularly on new facility projects). The method just described can be relied upon for approximately 90% initial accuracy. Another method, Figure II-3, based on analysis of field data on 19 vertical doublets, showed that on the average, the stub can be placed 210 degrees from the antenna terminals. The average stub length can be made 26.5 degrees. With these values as general guides, it is possible to specify stub locations and lengths on the construction agency drawings that will result in a minimum of work to the field engineer in the final tuning operations of the antenna.

14. DOUBLE-STUB METHOD FOR MATCHING A FOLDED DOUBLET ANTENNA.

a. Although the single-stub method for matching a folded doublet antenna to its transmission line is extremely simple and effective, the length required for the matching stub becomes greater as the design frequency for the antenna is lowered. For doublet antennas in the frequency range 2 to 5 megacycles it is convenient to use two matching stubs, which reduces the effective length of stub required. Double stubs are also more convenient to adjust, since matching is accomplished by moving the location of the stub shorting bars without changing the point of stub attachment at the transmission line.

b. The double-stub impedance match may be considered to be a half-wave transformer extending from closed stub to closed stub. On a balanced system a current loop will exist in the shorting bar of each stub. The length of stub nearer the antenna may be adjusted to tune out antenna reactance while the other stub is adjusted to provide the transmission line "match." The two stubs cannot, however, be adjusted independently; when one stub is lengthened the other must be shortened to maintain an approximate half-wave length of transmission line between the two shorting bars.

c. Spacing between the two stubs, (E) in Figure II-4, determines the range of impedances which can be matched by the double-stub transformer. At a spacing (E) of 90 degrees (quarter wave-length) a 600-ohm transmission line can be matched to any antenna load in the range 600 ohms to infinity. With a spacing of 135 degrees (three-eighths wave-length), a 600-ohm line can be matched to any antenna load in the range 300 ohms to infinity. Half-wave (180 degree) spacing is not useful, since all transformer action is lost. A double-stub spacing of 135 electrical degrees (three-eighths wave-length) is therefore most useful in matching two-wire folded doublets to a 600-ohm transmission line.

d. Location of the first stub (F-), in relation to the standing wave pattern of the unstubbed transmission line, determines the amount of reactance which must be tuned out by the double-stub transformer. The best range of adjustment is obtained by attaching stub (F1) at a standing current minimum (voltage peak). Calculation of the stub length is greatly simplified for this stub location, because antenna reactance is zero at a current minimum.

e. The active lengths for double-stubs spaced three-eighths wave length apart and located in accordance with paragraph *d*, may be calculated from the formulas:

$$(1)\ \text{Cot F1} = 1 \pm \sqrt{\frac{2R-1}{R}}$$

$$(2)\ \text{Cot F2} = 1 \pm \sqrt{2R-1}$$

where F1 and F2 are the electrical length in degrees for stubs (F1) and (F2), and where R is the measured standing wave ratio of the unstubbed transmission line connected to its antenna. (Example: Measured VSWR is 2.0, Calculated stub lengths are 24 degrees and 20 degrees.) Feet per degree may be calculated by dividing the frequency (mcs) into 2.73.

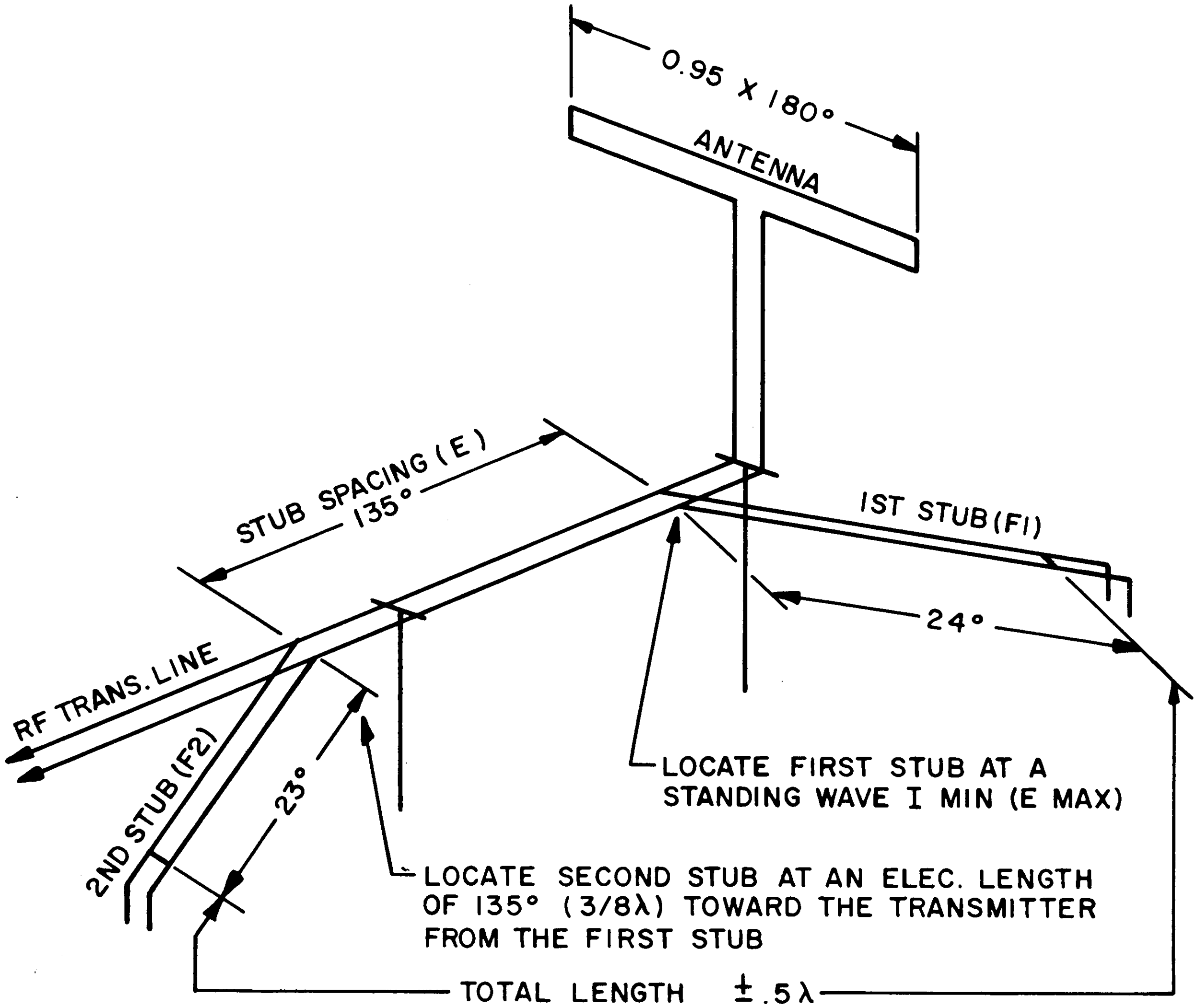
f. The active lengths for double-stubs spaced one-quarter wave length apart and located in accordance with paragraph *d*, may be calculated from formulas:

$$(1)\ \text{Cot F1} = \sqrt{\frac{R-1}{R}}$$

$$(2)\ \text{Cot F2} = \sqrt{R-1}$$

B. TUNING PROCEDURE FOR HIGH-FREQUENCY TWO ELEMENT VERTICAL DIRECTIONAL ANTENNA ARRAY.

1. As mentioned in paragraph 2-3*e*(4)(*g*), the vertical directional array, also known as a driven array or phased array, consists of two of the usual half-wave vertical doublets spaced at 90 degrees (see Figure II-5). The feeders to each doublet branch off the main transmission line at points 90 degrees (quarter wave) apart. Therefore, the current in the front doublet leads that of the rear doublet by 90 degrees. As the two doublets radiate, these currents add giving the array a 3 db gain over a single doublet in a cardioid pattern.



ADJUST THE STUB SHORTING BARS FOR LOWEST S.W.R. (STUB LENGTHS SPECIFIED ARE MEDIAN VALUES)

$$\text{LENGTH IN FEET} = \frac{2.73\,D}{\text{FREQ. IN MEGACYCLES}}$$

WHERE D = THE ELECTRICAL LENGTH IN DEGREES

DOUBLE STUB METHOD FOR 2-5.5 MC

HORIZONTAL AND TILTED FOLDED DOUBLETS

FIG. II-4 DOUBLE STUB METHOD

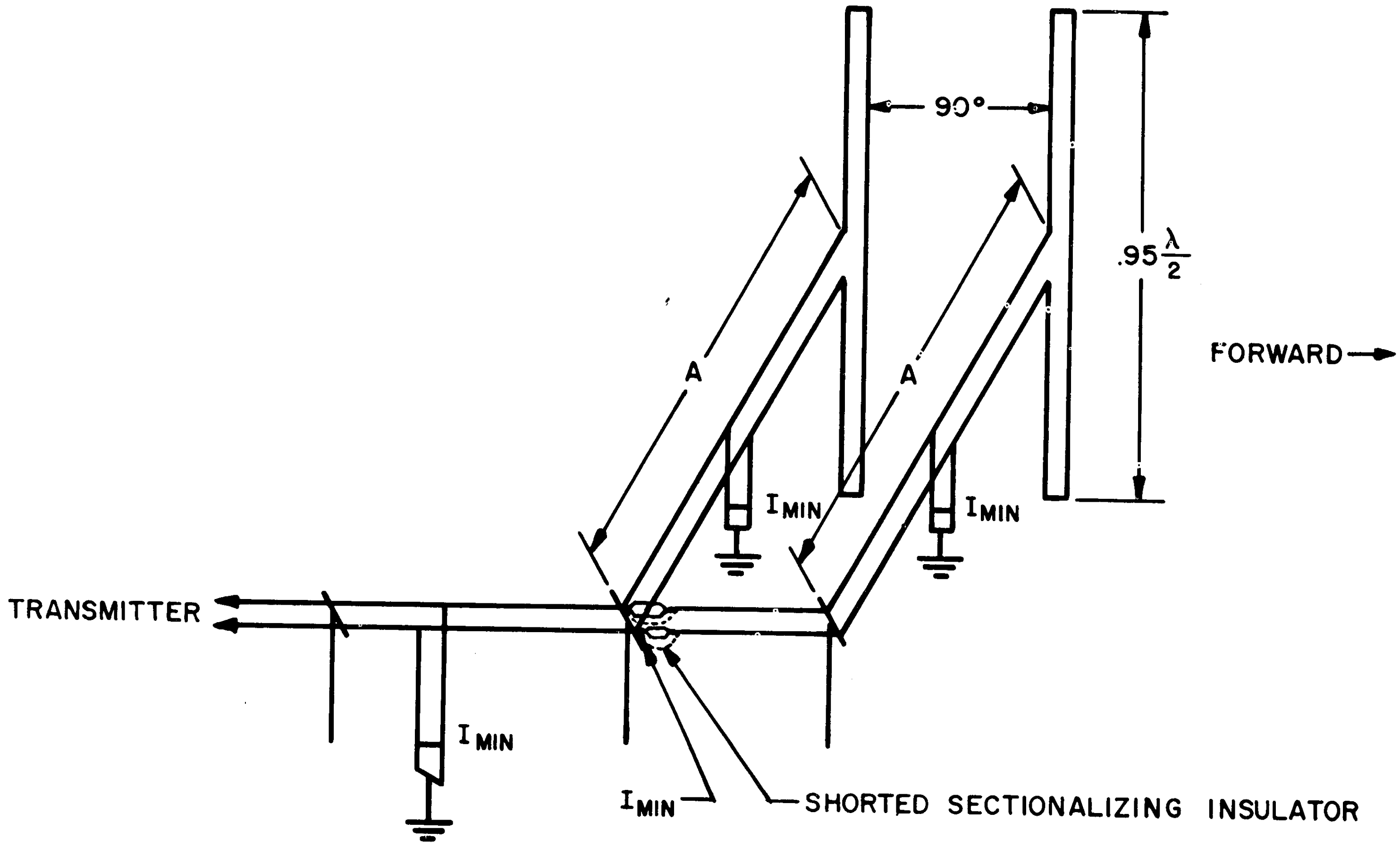


FIG. II-5 DRIVEN OR PHASED ARRAY

In order to bring about this 90-degree phase shift between the two doublets, a quarter wave point on the transmission line must be determined and the rear doublet feeders connected at this point. This is done as follows:

> (It should be noted that the branch feeders to the individual doublets must be electrically equal in length. Mechanical requirements might require one feeder to be physically longer than the other. The additional length, disregarding velocity factors, should be a multiple of a half wavelength.)

a. Disconnect both branch feeders from main transmission line and short end of main transmission line.

b. Feed main transmission line low power (50 to 100 watts) at the desired operating frequency.

c. Using an RF milliameter with loop, as described in paragraph A-4, inductively coupled to the line, locate current null (minimum reading) nearest antenna end of line.

d. Install a twelve-inch bar insulator (NT 61374 or equivalent) in series with each wire of the main transmission line so that the shackle nearest the transmitter end of the line will lie at minimum current point determined in *c.* above. Remove short at end of main transmission line.

e. The front doublet and its transmission line should be short-circuited at two or three points and grounded to prevent as far as possible inter-coupling with the rear doublet.

f. The feeders to the rear (away from desired direction of transmission) doublet can now be temporarily installed on the transmission line at the current minimum point determined in *c.* and *d.* above.

g. Following the stubbing methods outlined in paragraphs A1 through A12, Appendix II, stub rear doublet feeder and adjust for minimum VSWR.

h. Disconnect rear doublet feeders from main transmission line and short out rear doublet as described in paragraph *e.*

i. Permanently strap out insulator previously installed in transmission line by paralleling with No. 6 wire wrapped and secured at each end in accordance with standard installation practices.

j. Remove short circuits and grounds from front (in direction of desired transmission) doublet and permanently connect feeders to *end* of transmission line.

k. Match front doublet to transmission line with stub as was done with rear doublet in paragraph *g.*

l. Remove shorts and grounds from rear doublet and permanently connect to transmission line as previously connected in *f.*

2. EQUALIZING ANTENNA CURRENTS.

a. Measure from stub shorting bar of one of the antennas up stub and up feeder a few feet towards antenna, and mark point. Take identical measurement on other doublet feed line. These are *physical* measurements.

b. Apply power to array and calibrate two RF milliameters as described in paragraph A4. Place one meter at each marked point on the two branch feeders, and note readings. The front doublet current should initially read somewhat lower than that of the rear doublet. Therefore, it becomes necessary to equalize these currents.

c. Currents should be equalized by readjusting stubs to each antenna. In every case the matching stubs point of connection to the feed line and the position of its shorting bar are identically changed by measured distances, to keep the distance from stub shorting bar to the doublet always the same. Otherwise the system will be detuned and further adjustments will be complicated. It is recommended that currents be equalized by *decreasing* the load resistances; i.e., *raise* both shorting bars, and move both stubs *toward* main transmission line in small increments.

d. In all cases RF milliameters should not be moved on lines, otherwise their indications will be erroneous.

3. MATCHING COMBINED FEEDLINES TO MAIN TRANSMISSION LINE.

a. After completing the previous steps, standing wave ratios up to 4:1 may be expected on the main transmission line.

b. To remove or minimize these standing waves, consider the sectionalizing insulator point described in paragraph B1.*d* as the load. Follow normal stubbing procedure and place stub on main transmission line at nearest current minimum point towards transmitter and adjust for minimum VSWR.

C. ADJUSTMENT OF FOLDED DOUBLET WITH TUNED PARASITIC ELEMENT.

1. Two element directional parasitic arrays consist of a folded doublet driven element and a parasitic element, also a folded doublet. The latter is called either a reflector or director depending on the electrical length of the element.

2. With spacings between the two doublets of approximately 90 degrees (quarter wave), the parasitic element is preferably tuned as a reflector and the following tuning procedure applies. See Figure II-6.

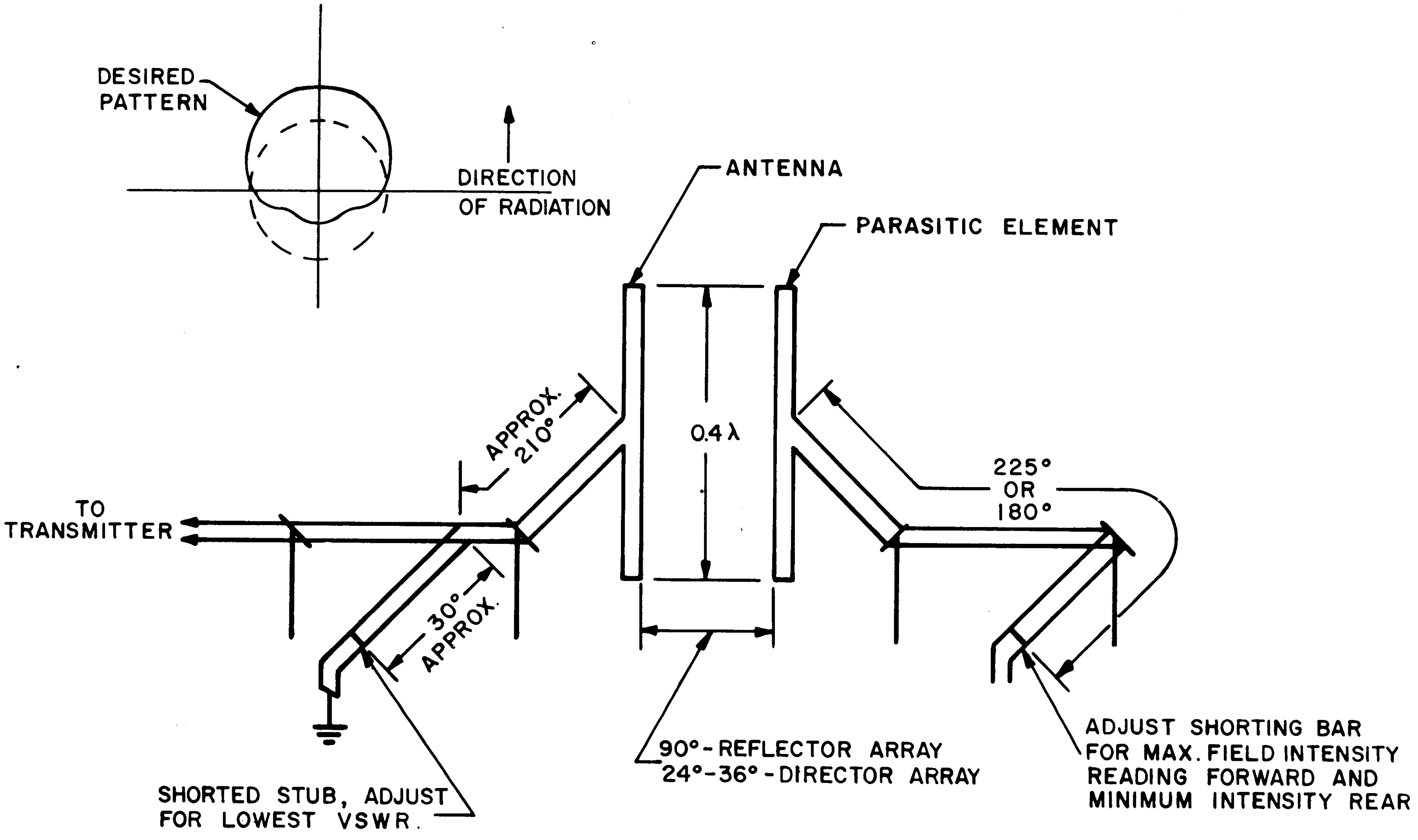


FIG. 11-6 STUBBING ADJUSTMENT OF PARASITIC ARRAYS

a. Set shorting bar on the parasitic element tuning line to approximately 225 degrees (five-eighths wavelength) from the parasitic doublet.

b. Follow the stubbing procedure given in paragraph B, Appendix II, to match driven element to transmission line with minimum VSWR. Since readjustment will later be necessary, this may be set roughly. A VSWR of approximately 2:1 is satisfactory at this point.

c. If two AN/PRM-1 or similar field intensity meters are available, set up one 500 feet or more in line with and in the forward direction of the array and the second a similar distance in the opposite direction. These positions should be well clear of other antennas and transmission lines in the field and, where possible, other antennas in the field should not be radiating. The loop antenna should be used with the AN/PRM-1 to insure direct bearing readings are obtained. If only one field intensity meter is available, the two positions should be staked and readings taken at both positions for each change in array adjustment.

d. Adjust the shorting bar on the parasitic element tuning line for a *minimum* reading in the back (parasitic element) direction and a *maximum* reading in the forward (driven element) direction. The final ratio of readings should be in the order of 3:1 or better.

e. Readjust stub on the driven element transmission line for minimum VSWR and recheck field strength. Some readjustment of shorting bar on parasitic tuning line may be required to reach an optimum pattern.

f. Field strength should next be checked in a radius around the array to roughly determine horizontal pattern. Some readjustment may be required if radiation lobe does not meet required sector coverage.

In some commercial applications, the only compromise required is between forward gain and front-to-back ratio. In Navy usage, uniform gain in a sector approximating 180 degrees with attenuated radiation to the rear is usually the most serviceable pattern. The pattern shown in Figure II-6 is typical of that normally desired. It is pointed out, however, that due to electrical obstructions in the field, difficulties in tuning arrays due to stray couplings, and compromises in measurement techniques, this ideal pattern may be difficult to achieve. Therefore, arrays should be tuned to best meet local service requirements.

3. In some cases it may be necessary from a clearance or physical location requirement to reduce the spacing between the driven element and the parasitic element. In this case, spacings of from .10 wavelength to .15 wavelength are recommended and the parasitic element may be tuned as a director, i.e., electrically short with respect to the driven element.

a. In using the parasitic element as a director, the distance to the initial position of the shorting bar on the tuning line should be set at approximately 180 degrees (half-wavelength) and tuning should then proceed as outlined above, except that field intensity readings should indicate maximum in the direction of the parasitic element and minimum in the direction of the driven element.

APPENDIX III

Sample Survey Report for Establishment of a Naval Shore Radio Transmitting Station

SAMPLE SURVEY REPORT FOR ESTABLISHMENT OF A NAVAL SHORE RADIO TRANSMITTING STATION

A. OUTLINE OF SURVEY REQUIREMENTS.—Data (as appropriate) obtained in the use of this check-off list may be used in site selection pertaining to: 1-22,*a,* The Radio Transmitting Station; *d,* Naval Air Station Radio Facilities; 2-3, Antenna and Transmission-Line System Engineering; and 2-8, Naval Air Station Communication Facilities.

Site 1.

Site 2.

Site 3.

For each proposed site area (i.e., 1, 2 and 3 above) show location, include approximate latitude and longitude, and enclose topographical map as Enclosure to this Survey.

1. *Fundamental Suitability for Radio Transmission.*

Site 1 Site 2 Site 3

a. Transmitting qualities of area.

b. Noise level at site (other than true atmospheric) (radio link considerations)

c. Ground Conductivity (state method used to measure).

d. Type of Soil.

e. Is soil uniform?

f. Is soil subject to variation? How?

g. What is mean water level?

h. Isolation from: (miles)

(1) Transmitting Stations.
(2) Are above transmitters beamed?
(3) Is site covered by beam?
(4) Receiving Stations.
(5) Air Fields.
(6) Glide Paths.
(7) Main Highways.
(8) High tension power lines (unburied).
(9) Habitable Areas.

i. Terrain.

j. Weather.

(1) Temperature extremes.
(2) Wind (average high hourly).
(3) Wind (Gust, peaks).
(4) Ice (Days freezing rain).
(5) Ice (500-1000 feet).
(6) Wind (500-1000 feet).

2. *Accessibility:*

Site 1 Site 2 Site 3

a. Distance from station's radio receivers.

b. Will link relays be required?

c. Are link paths subject to encroachment by tall buildings, etc.?

d. Are sites available for link relays?

e. Is right-of-way for control lines assured?

f. Are leased lines available?

g. Is electrical power available?

h. Is telephone service available?

B. PUBLIC WORKS—The following items are referred to Public Works for development:

1. *Accessibility of Utilities and Logistic Support.*

a. Distance from nearest:

Site 1 Site 2 Site 3

(1) Railroad station.
(2) Truck line terminal.
(3) Bus line.
(4) Other transportation.
(5) Naval Base.
(6) Other government base.
(7) Commercial markets.
(8) Schools.

b. Is water service available?

c. Is sewerage available?

d. Is garbage collection available?

e. Is fire protection available?

f. Are contractors available?

g. Is labor supply available?

h. Is site adaptable to defense against:

(1) Air attack.
(2) Gas attack.
(3) Bombardment.
(4) Sabotage.

i. Distance from nearest population center with:

(1) Movies.
(2) Shopping centers.
(3) Libraries.
(4) Beaches.
(5) Other cultural and amusement centers.
(6) Sports facilities.

Site 1 Site 2 Site 3

2. *Total Cost.*
   - *a.* Is site government owned?
   - *b.* Can restricted area be established by lease or agreement?
   - *c.* Is sufficient land available? Acreage?
   - *d.* Cost of land per acre.
   - *e.* How does cost compare with other land in area?
   - *f.* Cost of:
     - (1) Clearing.
     - (2) Grading.
     - (3) Draining.
     - (4) Protective improvement (seawalls, etc.).
   - *g.* Length and cost of roads:
     - (1) Outside station.
     - (2) Inside station.
   - *h.* Are any bridges required?
   - *i.* Cost of fencing.
   - *j.* If not fences, number of guards required.
   - *k.* Cost of:
     - (1) Operating building (Will special water resistant treatment of basement be required?).
     - (2) Barracks.
     - (3) Mess Hall.
     - (4) Quarters.
     - (5) Helix house.
     - (6) Store house.
     - (7) Sentry houses.
     - (8) Garage.
     - (9) Recreation building.
     - (10) Recreation facilities.
     - (11) Special buildings.
     - (12) Installation of electronic equipment.
     - (13) Landscaping.
     - (14) Antennas (complete with transmission line).
     - (15) Towers (if required).
     - (16) Fire protection system.
     - (17) Power supply (include emergency).
     - (18) Water supply (include emergency).
     - (19) Transportation system (equipment and buildings).
     - (20) Sewage system.
     - (21) Maintenance machinery (equipment and buildings).

Site 1 Site 2 Site 3

     - (22) Heating system.
     - (23) Air conditioning system.
     - (24) Other.
   - *l.* Annual maintenance cost:
     - (1) Repairs and painting due to normal depreciation.
     - (2) Fuel.
     - (3) Power.
     - (4) Water.
     - (5) Telephone.
     - (6) Transportation.
     - (7) Clearing brush.
     - (8) Road repairs.
     - (9) Other services.
   - *m.* Personnel required (No.).
     - (1) Naval (Rank or Rate).
     - (2) Civilian (Grades).

NOTE:—Do not include cost of electronic equipment or pay of Naval Personnel. Do not include pay of civilian personnel unless paid from maintenance funds.

C. PRE-CONSTRUCTION FIELD INTENSITY MEASUREMENTS AND DATA OUTLINE.—Included in the information required as a result of pre-construction field intensity measurements are a variety of factors not normally associated with such measurements. However, such factors are of vital importance in the construction and installation of new facilities in order to minimize electronic interference. For this reason, the data outlined herein are to be supplied in detail. If more than one site is under consideration, this information is to be supplied for each site.

1. Large scale map of area.
   - *a.* Proposed construction clearly marked.
   - *b.* Marked location of features listed herein.
   - *c.* Location where measurements were made.
2. Photographs of area and environment clearly referenced and oriented, showing existing features.
3. Description of fences in the area.
   - *a.* Distance from proposed construction.
   - *b.* Type.
   - *c.* Construction.
   - *d.* Materials.
   - *e.* Height.
   - *f.* Extent.
   - *g.* Ownership.
4. Description of aerial wires and cables in the area.
   - *a.* Distance from proposed construction.
   - *b.* Type of pole or other support.
   - *c.* Height.
   - *d.* Number of lines.
   - *e.* System or pole grounding.

f. Transformers and other accessory units.

g. Voltage on power lines.

h. Extent of lines.

i. Ownership.

5. Description of highways, roads, parking areas, aprons and ramps in the area.

a. Distance from site of proposed construction.

b. Number of traffic lanes or size.

c. Ownership or control.

d. Ownership of vehicles.

e. Estimate of traffic or activity.

6. Description of railroads near the area.

a. Distance from site of proposed construction.

b. Number of tracks.

c. Type of trains and locomotives using tracks.

d. Ownership or control of trains.

e. Estimate of traffic.

7. Description of buildings near the site.

a. Distance from proposed construction.

b. Type of construction.

c. Size.

d. Ownership or control.

e. Special features.

(1) Tin roofs.

(2) Ungrounded metal surfaces.

(3) Lightning rods and cable.

(4) Windmills.

(5) Rotating machinery.

(6) X-ray and diathermy equipment.

(7) Other equipment that might cause interference.

8. Description of pipe lines in or near the site.

a. Type of pipe.

b. Material carried by pipe lines.

c. Depth underground.

d. Distance from area.

e. Extent of pipe line.

f. Ownership or control.

9. Description of soil in the area.

a. Type of soil.

b. Water table.

(1) Depth.

(2) Seasonal variation.

(3) Extent under the area.

10. Time any and all measurements were made.

11. Meteorological conditions existing during any and all measurements.

12. Existing noise levels from 14 KC to 1000 MC with emphasis on the following:

a. 2 to 26 MC.

b. Crash or distress frequencies.

c. 120 to 160 MC.

d. 225 to 400 MC.

13. Navy transmitter interference and signal levels at the site.

a. Measured at following frequencies, where applicable:

(1) 2 to 26 MC.

(2) Crash or distress frequencies.

(3) 120 to 160 MC.

(4) 225 to 400 MC.

b. Measured as specified below with the concurrence and cooperation of the Communications Officer. Key all available transmitters simultaneously, using separate sources of frequency-shift and on-off keying, in order to produce maximum interference. The keying is to be done in a manner that will allow rapid identification of interference.

c. Measurements are to be made with normal transmitter operating frequencies only, unless known frequency combinations are to be studied further.

14. Received signal strengths.

a. Measured on following frequencies, where applicable:

(1) 2 to 26 MC.

(2) Crash or distress frequencies.

(3) 120 to 160 MC.

(4) 225 to 400 MC.

b. Signals to be measured are to cover a wide range in distance, time and azimuth.

c. Approximate bearings are to be given for all signals checked.

d. If more than one site is under consideration, these signal strengths are to be measured at each site, on the same frequencies, at approximately the same time of day, and under approximately the same conditions.

15. Abnormal atmospheric noise.

a. Measurement of any such noise encountered during the progress of work outlined herein.

16. Abnormal ionospheric disturbances.

a. Measurement of any such disturbances encountered during the progress of work outlined herein.

APPENDIX IV

Sample Survey Report for Establishment of a Naval Shore Radio Receiver Station

SAMPLE SURVEY REPORT FOR ESTABLISHMENT OF A NAVAL SHORE RADIO RECEIVER STATION

A. OUTLINE OF SURVEY REQUIREMENTS.—Data (as appropriated) obtained in the use of this check-off list may be used in site selection pertaining to: 1-20, *b,* The Radio Receiver Station; *d,* Naval Air Station Radio Facilities, *j,* H/F Radio D/F Facilities, and *k,* Control Link Facilities; 2-3, Antenna/Transmission Lines System Engineering; 2-4, *b,* The Radio Receiver Station, 2-6, Link Systems; 2-7, HF D/F Station; 2-8, Naval Air Station Communication Facilities.

Site 1.

Site 2.

Site 3.

For each proposed site area (i.e., 1, 2 and 3 above) show location, include approximate latitude and longitude, and enclose topographical map as enclosure to this survey.

1. *Fundamental Suitability for Radio Reception.*

Site 1 Site 2 Site 3

a. Receiving qualities of area (based on listening tests).

b. Noise level at site (other than true atmospheric).

c. Ground conductivity (state method used to measure).

d. Is soil uniform?

e. Is soil subject to variation? How?

f. What is mean water level?

g. Isolation from: ((miles)

(1) Transmitters (H.P.V.L.F.).

(2) Transmitters (other). Indicate power.

(3) Are above transmitters beamed?

(4) Is site covered by beam?

(5) Air fields.

(6) Glide paths.

(7) Communication Center (terminal building) location on the site.

(8) Are teletypes, etc. shielded?

(9) Main highways.

(10) High tension power lines (unburied).

(11) Habitable areas.

h. Terrain.

i. Weather.

Site 1 Site 2 Site 3

j. Is suitable area available for D/F site in accordance with NRL report 1938.

2. *Accessibility.*

a. Distance from station's radio transmitters.

b. Will link relays be required?

c. Are site available for link relays?

d. Is right-of-way for government owned control lines assured?

e. Are sites available for link relays?

f. Is electric power available?

g. Is telephone service available?

h. Is water service available?

i. Distance from nearest:

(1) Naval base.

(2) Other government base.

B. PUBLIC WORKS.—The following items are referred to Public Works for development:

1. *Accessibility of Utilities and Logistic Support.*

Site 1 Site 2 Site 3

a. Distance from nearest:

(1) Railroad station.

(2) Truck line terminal.

(3) Bus line.

(4) Other transportation.

(5) Commercial markets.

(6) Schools.

b. Is sewerage available?

c. Is garbage collection available?

d. Is fire protection available?

e. Are contractors available?

f. Is labor supply available?

g. Is site adaptable to defense against:

(1) Air attack.

(2) Gas attack.

(3) Bombardment.

(4) Sabotage.

h. Distance from nearest population center with:

(1) Movies.

(2) Shopping Centers.

(3) Libraries.

(4) Beaches.

(5) Other cultural and amusement centers.

Site 1 Site 2 Site 3

(6) Sports facilities.

2. *Total Cost.*

a. Is site government owned?

b. Can restricted area be established by lease or agreement?

c. Is sufficient land available? Acreage?

d. Cost of land per acre.

e. How does cost compare with other land in area?

f. Cost of:

(1) Clearing.
(2) Grading.
(3) Draining.
(4) Protective improvement (sea walls, etc.).

g. Length and cost of roads:

(1) Outside station.
(2) Inside station.

h. Are any bridges required?

i. Cost of fencing.

j. If not fences, number of guards required.

k. Cost of:

(1) Operating building. (Will special water resistant treatment of basement be required?)
(2) Barracks.
(3) Mess hall.
(4) Quarters.
(5) D/F building.
(6) Store house.
(7) Sentry house.
(8) Garage.
(9) Recreation building.
(10) Recreation facilities.
(11) Special buildings.
(12) Installation of electronic equipment.
(13) Landscaping.
(14) Antennas (complete with transmission line).
(15) Towers (if required).
(16) Fire protection system.
(17) Power supply (include emergency).
(18) Water supply (include emergency).
(19) Transportation system (equipment and buildings).
(20) Sewage system.
(21) Maintenance machinery (equipment and buildings).

Site 1 Site 2 Site 3

(22) Heating system.
(23) Air conditioning system.
(24) Other.

l. Annual maintenance cost:

(1) Repairs and painting due to normal depreciation.
(2) Fuel.
(3) Power.
(4) Water.
(5) Telephone.
(6) Transportation.
(7) Clearing brush.
(8) Road repairs.
(9) Other services.

m. Personnel required (No.).

(1) Naval (Rank or rate).
(2) Civilian (Grades).

NOTE: Do not include cost of electronic equipment or pay of Naval Personnel. Do not include pay of civilian personnel unless paid from maintenance funds.

C. PRE-CONSTRUCTION FIELD INTENSITY MEASUREMENTS AND DATA OUTLINE.—Included in the information required as a result of pre-construction field intensity measurements are a variety of factors not normally associated with such measurements. However, such factors are of vital importance in the construction and installation of new facilities in order to minimize electronic interference. For this reason, the data outlined herein are to be supplied in detail.

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c. Location where measurements were made.

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a. Distance from proposed construction.
b. Type.
c. Construction.
d. Materials.
e. Height.
f. Extent.
g. Ownership.

4. Description of aerial wires and cables in the area.

a. Distance from proposed construction.
b. Type of pole or other support.
c. Height.
d. Number of lines.
e. System or pole grounding.
f. Transformers and other accessory units.
g. Voltage on power lines.

h. Extent of lines.
i. Ownership.

5. Description of highways, roads, parking areas, aprons and ramps in the area.
a. Distance from site of proposed construction.
b. Number of traffic lanes or size.
c. Ownership or control.
d. Ownership of vehicles.
e. Estimate of traffic or activity.

6. Description of railroads near the area.
a. Distance from site of proposed construction.
b. Number of tracks.
c. Type of trains and locomotives using tracks.
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e. Estimate of traffic.

7. Description of buildings near the site.
a. Distance from proposed construction.
b. Type of construction.
c. Size.
d. Ownership or control.
e. Special features.
(1) Tin roofs.
(2) Ungrounded metal surfaces.
(3) Lightning rods and cable.
(4) Windmills.
(5) Rotating machinery.
(6) X-ray and diathermy equipment.
(7) Other equipment that might cause interference.

8. Description of pipe lines in or near the site.
a. Type of pipe.
b. Material carried by pipe line.
c. Depth underground.
d. Distance from area.
e. Extent of pipe line.
f. Ownership or control.

9. Description of soil in the area.
a. Type of soil.
b. Water table.
(1) Depth.
(2) Seasonal variation.
(3) Extent under the area.

10. Time any and all measurements were made.

11. Meteorological conditions existing during any and all measurements.

12. Existing noise levels from 14 KC to 1000 MC with emphasis on the following:
a. 2 to 26 MC.
b. Crash or distress frequencies.
c. 120 to 160 MC.
d. 225 to 400 MC.

13. Navy transmitter interference and signal levels at the site.

a. Measured at following frequencies, where applicable:
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c. Measurements are to be made with normal transmitter operating frequencies only, unless known frequency combinations are to be studied further.

14. Received signal strengths.

a. Measured at following frequencies, where applicable:
(1) 2 to 26 MC.
(2) Crash or distress frequencies.
(3) 120 to 160 MC.
(4) 225 to 400 MC.

b. Signals to be measured are to cover a wide range in distance, time and azimuth.

c. Approximate bearings are to be given for all signals checked.

d. If more than one site is under consideration, these signal strengths are to be measured at each site, on the same frequencies, at approximately the same time of day, and under approximately the same conditions.

15. Abnormal atmospheric noise.

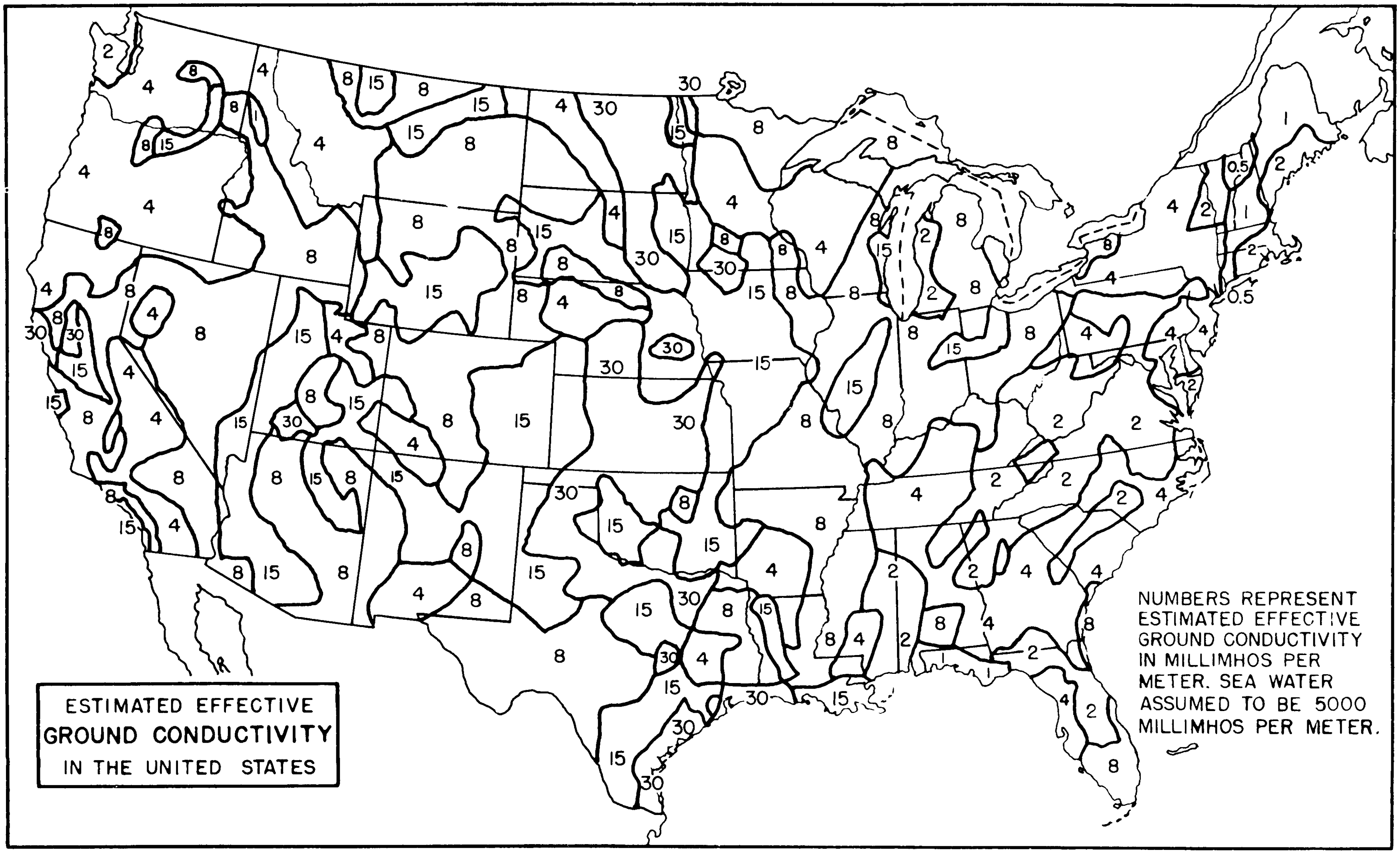
a. Measurement of any such noise encountered during the progress of work outlined herein.

16. Abnormal ionospheric disturbances.

a. Measurement of any such disturbance encountered during the progress of work outlined herein.

APPENDIX V

Ground Conductivity and Measurement



ESTIMATED EFFECTIVE
GROUND CONDUCTIVITY
IN THE UNITED STATES

NUMBERS REPRESENT ESTIMATED EFFECTIVE GROUND CONDUCTIVITY IN MILLIMHOS PER METER. SEA WATER ASSUMED TO BE 5000 MILLIMHOS PER METER.

Figure V-1. Ground Conductivity, United States

GROUND CONDUCTIVITY AND MEASUREMENT

GROUND CONDUCTIVITY AND MEASUREMENT.

The chart, figure V-1, is provided to show typical values of ground conductivity in the United States as determined by the Federal Communications Commission. Values shown are in millimhos per meter in accordance with the standard practice of that agency, with sea water assumed to be 5000 millimhos per meter. To convert from values of conductivity expressed in electromagnetic units, to values expressed in millimhos per meter, the emu figure is multiplied by 10^{14} which automatically converts absolute values to practical values and accounts for change in the unit of volume from centimeters to meters. Thus, a value of 3×10^{-13} emu becomes 30 millimhos per meter.

#The conductivity and dielectric constant of the earth vary greatly according to conditions. Typical values are given in the table. It is found that high values of dielectric constant tend to go with large conductivities, and vice versa, and that the highest conductivities are obtained with wet loam, while the poor conductivities and low dielectric constant are generally associated with dry, rocky, and sandy soil. Earth having a conductivity of the order of 5×10^{-14} to 10×10^{-14} emu is considered as average to better than average, values above 10×10^{-14} emu are very high, and conductivities of the order of 1.0×10^{-14} emu are considered as very low. Sea water has a conductivity many times that of earth, and also possesses a very high dielectric constant.

SOME TYPICAL GROUND CONSTANTS

Type of terrain	Dielectric Constant	Conductivity, emu
Fresh water	80	1×10^{-14}
Sea water, minimum attenuation	81	4.64×10^{-11}
Pastoral, low hills, rich soil, typical of Dallas, Tex., Lincoln, Neb., areas	20	3×10^{-13}
Pastoral, low hills, rich soil, typical of Ohio and Illinois	14	10^{-13}
Flat country, marshy, densely wooded, typical of Louisiana near Mississippi River	12	7.5×10^{-14}
Pastoral, medium hills and forestation, typical of Maryland, Pennsylvania, New York, exclusive of mountainous territory and seacoasts	13	6×10^{-14}
Pastoral, medium hills and forestation, heavy clay soil, typical of central Virginia	13	4×10^{-14}
Rocky soil, steep hills, typical of New England	14	2×10^{-14}
Sandy, dry, flat, typical of coastal country	10	2×10^{-14}
City, industrial areas, average attenuation	5	10^{-14}
City, industrial areas, maximum attenuation	3	10^{-15}

The effective conductivity of the earth tends to be reduced if the earth's surface is not level, as in the case of mountains or hilly regions. The effective conductivity also tends to be low in wooded areas, and in regions containing many buildings, particularly cities with large office buildings.

The value of conductivity and dielectric constant that is effective for radio waves represents the average value for a distance below the surface of the earth determined by the depth to which ground currents of appreciable amplitude exist. This depth of penetration depends upon the frequency, dielectric constant, and conductivity, and is commonly of the order of 5 to 10 feet at the frequencies used in short-wave communication, and 50 or more feet at broadcast and lower frequencies. As a result, the earth constants are not particularly sensitive to conditions existing at the very surface of the earth, as, for example, recent rainfall. The effective value of the earth constants tends to be substantially independent of frequency over a relatively wide frequency range.

The constants of the earth may be measured in a variety of ways and two methods are given in this handbook which have been used by the Bureau of Ships for the measurement of ground conductivity. Measurements by one method are made at radio frequencies as compared to measurements at 1000 cycles by the other method. Consequently, results obtained by using both methods in the same area might be widely divergent, but it must be borne in mind by the engineer making such measurements that the so-called "constants" measured are in fact "parameters" and it is likely that results differing in value are possible.

The two methods outlined therefore cannot be established as being without error in obtaining absolute conductivity. However, either or both methods may be used to make comparative measurements where more than one site is under consideration, and if procedures are carefully followed and recorded, the figures obtained may be used comparatively for future measurements on an established site.

In the first method, signal attenuation over ground is measured to determine ground losses and therefore conductivity. Calculations are based on an assumed dielectric constant of 15, which is considered a good average value for the type of terrain that is typical for consideration as suitable for a communication facility.

#By permission from Radio Engineers' Handbook, by Frederick E. Terman. Copyright 1943. McGraw-Hill Book Company, Inc.

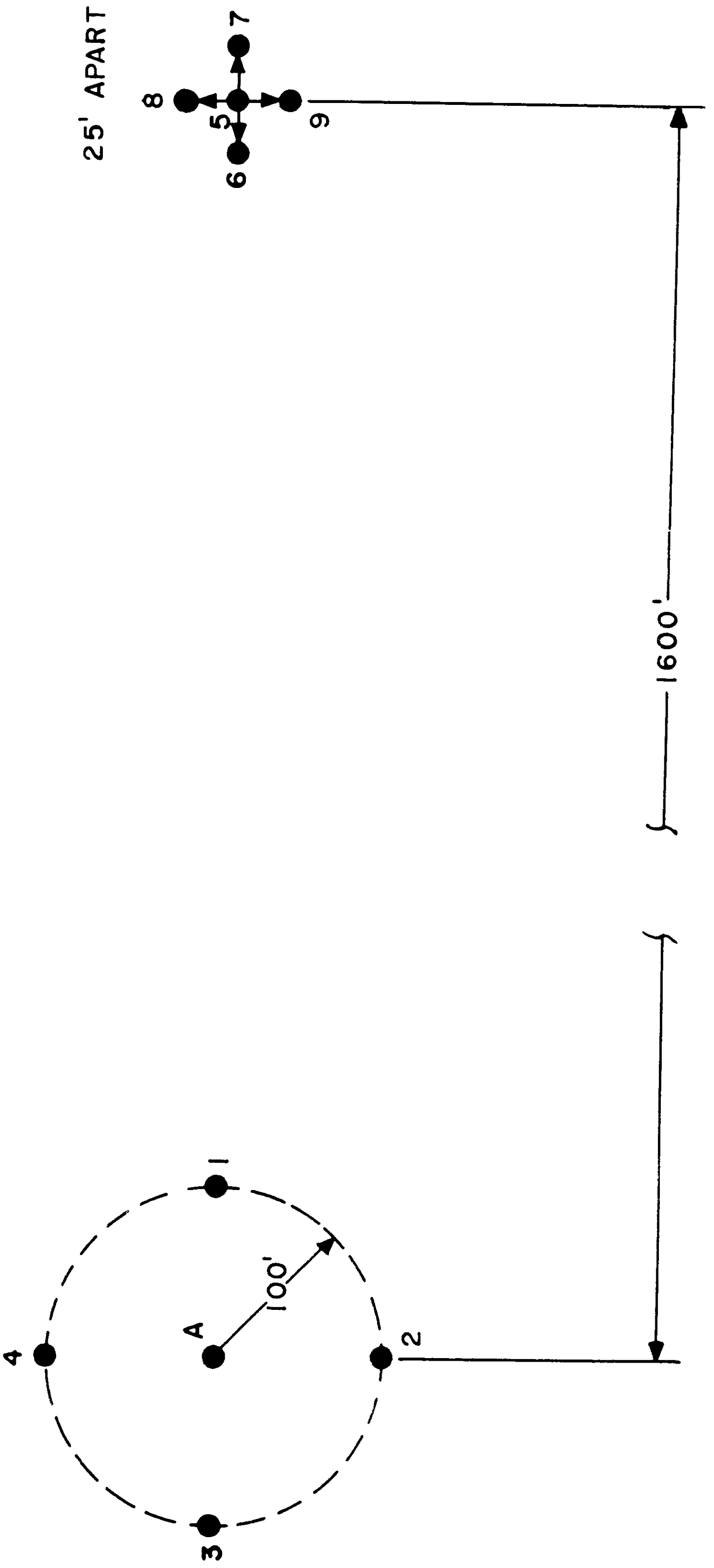


Figure V-2. Equipment Layout for Soil Conductivity Test

The second method determines ground resistance and provides a means for calculating ground conductivity.

Mathematical justification for each method is not made in this handbook, but may be obtained from the reports indicated, or in the referenced literature.

V-1. RATE OF ATTENUATION METHOD.

(From report of McIntosh and Inglis under contract NObsr 57049 to the Bureau of Ships.) The method consists of measuring the attenuation of a radiated signal between two points on a selected path. One point is close to the transmitter, and the other point a considerable distance away.

The equipment required for the measurement is as follows:

1 Portable (target type) transmitter capable of operating on 5, 10 and 15 mc.
1 Field intensity meter such as AN/PRM-1, calibrated in db.
1 Measuring tape.

A plot showing the equipment layout for the soil conductivity test is shown on figure V-2. The 1,600-foot distance was selected after considering the limited output of target transmitters, normal atmospheric noise levels, dimensions of sites, and probable attenuations due to frequency and conductivity.

The field intensity meter or transmitter, whichever is the least portable, is set up at point A. Equipment is tuned to the desired frequency, calibrated and field intensity in db above a reference level, is measured at points 1, 2, 3 and 4. These points are spaced approximately 90° apart on a 100 foot radius circle centered at point A. The field intensity is next measured in db above the same reference level at points 5, 6, 7, 8 and 9. The average values of field intensity at points 1, 2, 3 and 4 and at points 5, 6, 7, 8 and 9 are then computed, and the db difference in these averages can then be determined.

The transmitter must be equipped with an omnidirectional vertical radiator and its output maintained constant. If the transmitter is not equipped with an output indicating device, a check of the output can be made by remeasuring the 1,600-foot and a 100-foot point immediately after the series of measurements have been completed. Any decrease in the output during the tests would add to the measured attenuation, and results will not reflect the attenuation due to the soil constants alone.

If the field intensity meter is an AN/PRM-1 type equipment, measurements made with both the loop and rod antenna will serve to minimize observational errors.

As a comparative test for determining relative attenuation of a signal over several selected paths, the method is entirely satisfactory. Since the relative attenuation of the signal is also an indication of the relative desirability of a site for direction-finder or radio receiver installation, insofar as soil constants are concerned, this test provides the desired information.

The test does not provide results that allow determination of absolute values for both the conductivity and the dielectric constant. This is not necessarily a disadvantage, for it has been shown that there is a correlation between rate of attenuation and suitability of a site for direction-finder operation.

The Federal Communications Commission publication "Standards of Good Engineering Practice Concerning Standard Broadcast Stations" contains 20 graphs of conductivity versus distance, covering the frequency range between 540 and 1640 kc. The graphs are based on an assumed dielectric constant of 15 for land, and 81 for water, and were computed from figure 4 which is also included in the above publication.

In order to convert the measured attenuation to an approximate value of conductivity, it is required that a value for the dielectric constant be assumed.

The graph, figure V-3, has been prepared to include the necessary data to convert db attenuation to conductivity for frequencies 5, 10 and 15 megacycles. In these computations, a dielectric constant of 15 is assumed, and relates db attenuation to values of conductivity from 2 to 40 x 10^{-14} emu for 5, 10 and 15 megacycles.

In comparing the 100-foot and 1,600-foot readings, there will be a difference of 24 db (20 log 16/1) due to the inverse relationship of the unattenuated field intensity and distance. Any additional attenuation will be due to losses introduced by the soil constants of the measured path.

V-2. THREE POINT METHOD.

(From "A Special Report on a Three Point Method for Determining Ground Resistivity" submitted by U. S. Navy Yard, Mare Island, California, 24 February 1951.) Earth resistivity measurements by the three point method may be made utilizing an impedance bridge incorporating an energizing source of 60 or 1000 cycles. Since the voltage applied to any pair of electrodes will be small, rapid alternation of the applied potential is essential to minimize the effect of extraneous voltages caused by stray earth currents, or by galvanic potential differences.

The three electrodes used as test rods should be of low resistance material (copper) and about eight feet in length, since during the resistivity measurements, readings are taken normally at various depths of penetration up to six or seven feet. These rods are spaced 100 feet apart (for example) at the apices of an equilateral triangle, and initially driven two feet into the earth. The spacing of the electrodes is arbitrary and

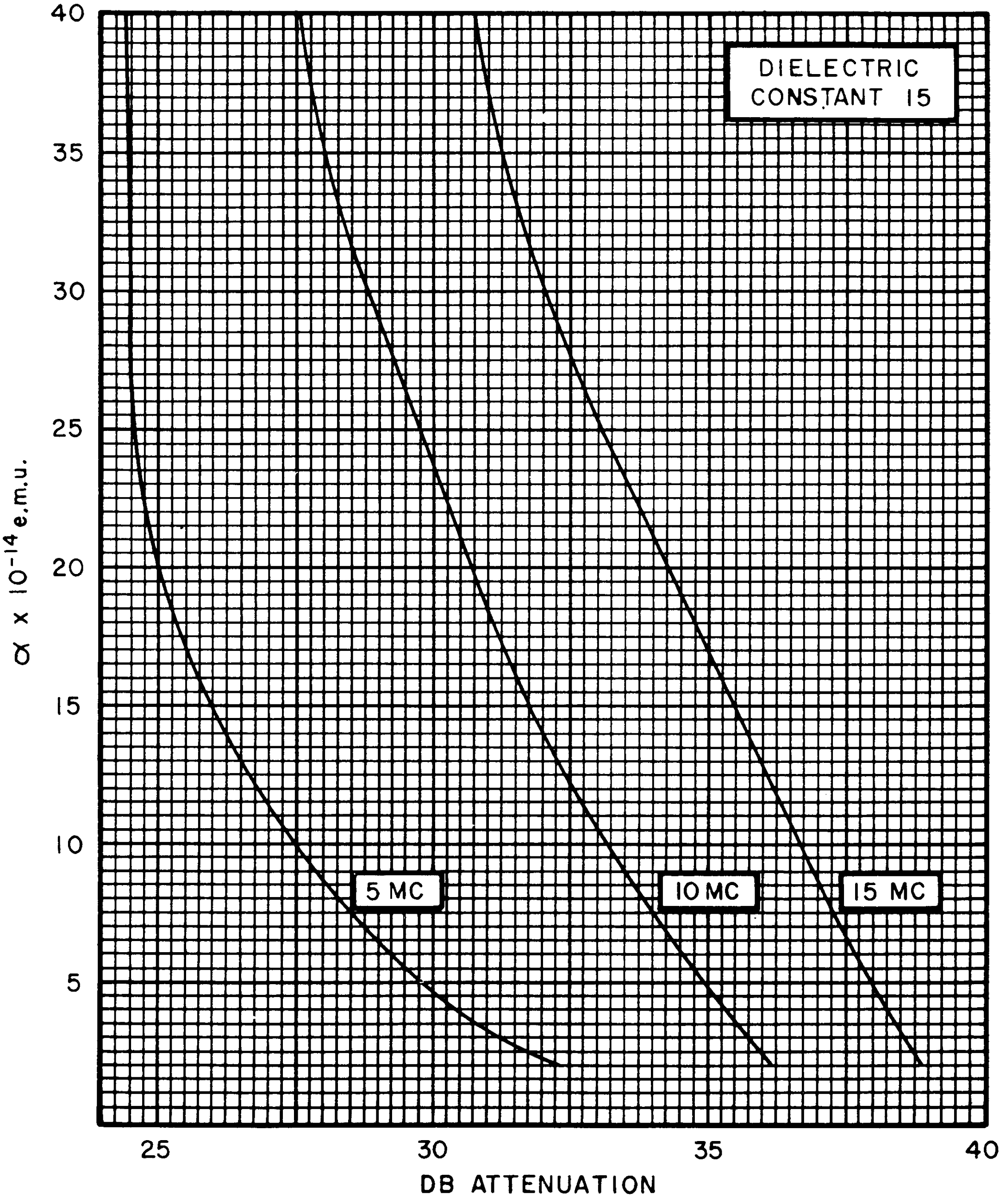


Figure V-3. Conductivity vs. DB Attenuation Between 100 ft. and 1600 ft.

may vary according to the nature of the problem involved, and the change in the earth's resistivity with spacing. Considerable fluctuation in the measurements with a change of electrode spacing necessitates continuation of the readings until the curve of resistivity versus spacing has flattened sufficiently to permit extrapolation of the resistivity for larger spacings.

Readings for penetrations of 2, 3, 5, and 7 feet are suggested, and an average of the readings taken at each pair of electrodes for any particular depth should be computed. In this manner, variations in resistivity with depth may be found. Terman states that the depth of penetration of radio waves, for example, is commonly in the order of 5-10 feet for short-wave communications frequencies; therefore, the above rod depths probably are quite satisfactory in this instance. Long periods of wet or dry seasons may affect the resistivity readings, but the earth constants are not particularly sensitive to relatively rapid changes in surface conditions due to the weather.

Suggested procedure is to drive two rods two feet into the earth and by means of the bridge, measure the resistance between them. The spacing of the rods is increased and re-measurements taken until the curve of resistance versus spacing has flattened out considerably. The third rod is then driven into the earth to form an equilateral triangle with the spacing between rods 1 and 2 as one side of the triangle.

Resistance measurement is made between rods 1-2, 2-3, and 1-3, giving values of resistance indicated as, R_{1-2}, R_{2-3}, and R_{1-3} respectively.

The "self-resistance" of each rod, R_{11}, R_{22}, and R_{33} can then be computed by means of the formulae:

$$R_{11} = \tfrac{1}{2}(R_{1-2} + R_{1-3} - R_{2-3})$$
$$R_{22} = \tfrac{1}{2}(R_{1-2} + R_{2-3} - R_{1-3})$$
$$R_{33} = \tfrac{1}{2}(R_{1-3} + R_{2-3} - R_{1-2})$$

The above three values are then averaged to obtain the average ground resistance of the area, R.

The resistivity per CM^3 is then obtained from the formula

$$\rho = \frac{2\ \ mR}{\log \dfrac{4m}{d}}$$

Where: ρ = ohms per CM^3
R = average ground resistance
m = depth of penetration (CM)
d = diameter of rod (CM)

To convert to conductivity in electromagnetic units, σ (emu), take the reciprocal of $\rho \times 10^9$.

Example: Let it be assumed that the electrodes in question have been placed in the configuration outlined, and that the depth of penetration has been fixed at, say, five feet. The diameter of each electrode is ¾ inch. Using an impedance bridge capable of supplying a reasonable voltage at 1000 cycles, further assume that the resistance measured between electrodes 1 and 2 is 60 ohms; between 2 and 3, 57.5 ohms; and between 3 and 1, 59 ohms. From these data, the resultant self-resistances, R_{11}, R_{22}, and R_{33}, are found to be 30.75, 29.25, and 28.25 ohms, respectively, for an average ground resistance of 29.75 ohms.

Substitution of the physical and electrical quantities of the field data into equation results in

$$\rho = \frac{2 \times 152.4 \times 29.75}{\log \dfrac{4 \times 152.4}{1.905}} \qquad \begin{aligned} m &= 5' = 152.4 \text{ CM.} \\ d &= \tfrac{3}{4}'' = 1.905 \text{ CM.} \end{aligned}$$

from which

$$\rho = 4935 \text{ ohms/CM}^3$$

Conductivity is then

$$\sigma = \frac{1}{4.935 \times 10^3 \times 10^9} = 2 \times 10^{-13} \text{ emu (approx.)}$$

APPENDIX VI

Microwave Link Systems.

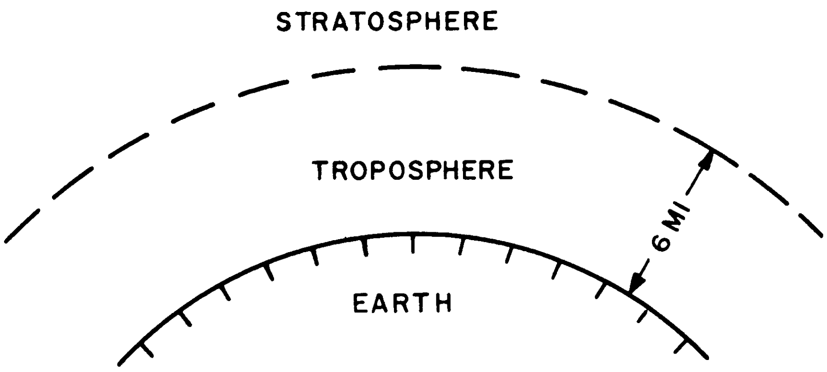


Figure VI-1. The Troposphere

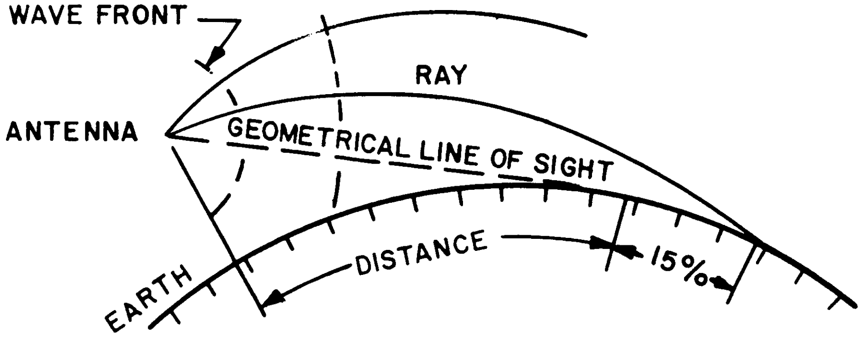


Figure VI-2. Refraction

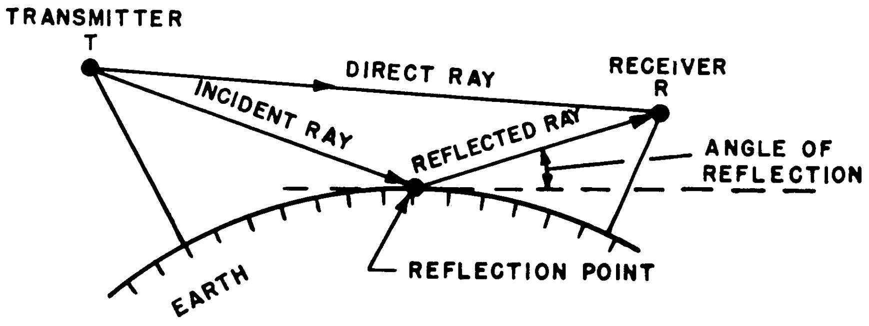


Figure VI-3. Reflection

MICROWAVE LINK SYSTEMS

This appendix is provided to aid systems engineering in siting and operation of microwave link systems. The following outline of siting presents the problem of site selection with details discussed in the paragraphs following:

VI-1. SITING.

a. Use line-of-sight paths with clearances as determined by methods indicated in the detailed discussion.

b. Repeater sites should be located close to motor roads and power lines if possible. Terminals are integrated in communication center, transmitter, and receiver station sites; radar link terminals are located at the radar site and as appropriate for remote PPI application.

c. Make a preliminary reconnaissance of proposed sites to determine path obstacles.

d. Select path locations remote from cities and areas of potential building construction and reforestation if possible. Building easements should be obtained if feasible.

e. Obtain true profiles of proposed paths and add factor of safety with clearance for forestation and buildings.

f. Plot required clearances at all high contours.

g. Re-examination of the proposed path in detail by the appropriate Public Works office is indicated.

h. Base all plans on using towers sufficiently high to provide the required path clearances.

VI-2. WAVE PROPAGATION PHENOMENA.

a. GENERAL.—The frequencies used for microwave radio relay systems are so high that radio transmission in this spectrum behaves very much like light waves. The radio waves travel in approximately straight lines and can be reflected and refracted. Radio waves traveling along the ground are greatly attenuated. Waves traveling upward are not reflected by the ionosphere as in the case of lower frequencies. These waves, however, may be reflected by discontinuities caused by unusual conditions of temperature and humidity in the lower atmosphere, or they may be reflected when striking the surface of a body of water or a flat conducting earth. In addition to reflection, the waves are bent or refracted by gradual changes in pressure and humidity in the atmosphere. Because of these factors, it is very important to locate radio relay antennas where a good line-of-sight path is available. The amount of clearance required and the techniques for overcoming various propagation difficulties are included in the paragraphs which follow.

Several factors must be considered in choosing a site which is suitable from supply and radio path standpoints. The important factor pertains to the site selection from a strictly radio propagation viewpoint. The operating frequencies of microwave radio relay equipment make it imperative that the radio path between the two stations of a radio link be free of any obstacles. A clear path is known as a line-of-sight path. A line-of-sight path which just clears obstacles is known as a grazing path. On level ground, the distance between two sites for a grazing path is limited by the height of the transmitter and receiver antennas above ground. This limitation is due to the curvature of the earth.

Path distances between sites should be limited to approximately 30 miles. Longer hops without repeaters should be avoided generally, because of the practical factors discussed under VI-3, FADING.

b. THE TROPOSPHERE.—The troposphere which is the transmission medium for microwaves is the layer of atmosphere directly adjacent to the earth's surface. It extends upward approximately six miles. The temperature normally decreases about 10° C. per mile with increasing altitude to a value at the upper boundary of about minus 50° C. (figure VI-1). Above this is the stratosphere in which the temperature remains relatively constant at approximately minus 50° C.

c. REFRACTION.—Propagation of radio waves in the troposphere is materially influenced by the distributions of temperature, pressure, and water vapor. The variation of these quantities with height is expressed conveniently by the index of refraction which decreases linearly with height in a so-called standard atmosphere. The condition most nearly approximated in the temperate zone has been accepted as the standard atmosphere. The radio energy emitted from a transmitter antenna is a wave spreading out in three dimensions which may be represented by a series of concentric spherical wave fronts or by a system of lines called rays (figure VI-2). Since the index of refraction normally decreases with height, the upper portions of these wave fronts move with higher velocities, relative to the earth, than the lower portions, and the wave paths may be represented by rays curved slightly downward toward the earth. As a result, the distance to the radio horizon is 15 percent greater than the geometrical line-of-sight distance from the transmitter to the horizon. This curvature of the rays by the atmosphere is called refraction.

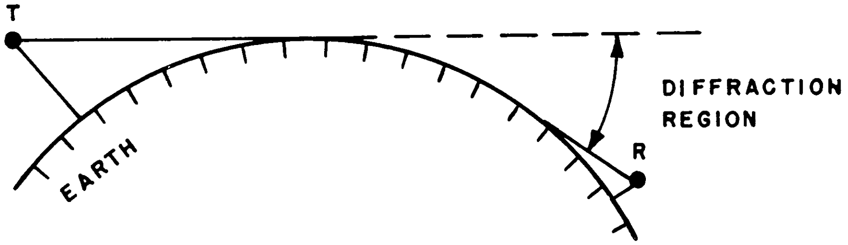


Figure VI-4. Diffraction Region

The standard atmosphere is used to simplify calculations. This is accomplished by using an equivalent earth radius which is 4/3 the true earth radius, and making all calculations and drawings with straight line transmission paths.

d. REFLECTION.—Over a line-of-sight path, the radio wave at the receiver R is the vector sum of the radiations arriving by way of both the direct and reflected ray paths (figure VI-3). The contribution from the reflected ray path depends primarily on the manner in which the earth or sea acts as a reflecting body. Over water and salt flats for instance, the reflection is essentially 100 percent. Over land areas with gentle rolling country with some vegetation, the reflection is only approximately 10 percent complete. Since the angle of reflection to be taken into consideration in radio relay siting is very small, consideration need not be given to polarization effects, that is, whether the antenna is horizontally or vertically polarized. For the same reason, the phase lag of the reflected wave with respect to the incident wave at the point of reflection is for all practical purposes 180°.

e. DIFFRACTION.—The mechanism by which radio waves curve around edges and penetrate into the shadow region behind an opaque obstacle is called diffraction. This effect is of importance because it allows a limited extension of the line-of-sight path length (figure VI-4).

f. HEIGHT-GAIN CURVE.—As the receiving antenna is elevated (figure VI-4) from ground level, the received signal strength due to diffraction rises rapidly until line-of-sight is reached (figure VI-5). Above line-of-sight, the direct and reflected waves interfere and result in a Fresnel pattern containing maxima and minima. The first maximum occurs when the difference in path length between the direct and reflected wave is one-half wavelength, since, as indicated in paragraph *d,* the reflected signal undergoes a 180° phase reversal at the reflecting point. The succeeding maxima are odd multiples of half wavelengths. The magnitude of the first maximum and minimum fields with relation to the free space field is dependent on the magnitude of the reflection coefficient. The height required to obtain the first maximum clearance at microwave frequencies is much less than that required at VHF, since the wavelength at microwaves is measured in inches and at VHF, it is measured in feet. It should be noted that in the diffraction region, the signal strength for microwave frequencies falls more rapidly than for VHF.

g. PATH ATTENUATION.—Energy radiated from a transmitting antenna does not travel in a line or in a beam to the receiving antenna, but spreads out (figure VI-6) so that the amount of power received at the receiving antenna is a small portion of the transmitted energy. The difference between radiated power and received power is termed the attenuation of the path.

In microwave radio relay siting (part VI-4), the transmitting and receiving antennas are elevated above ground to such a height that the free space field strength is received. If the antennas are parallel to each other and in the same plane, that is, both antennas are either horizontally or vertically polarized, then the amount of power P_R received by a dipole antenna from a dipole antenna, radiating a power P_T, is $\frac{P_T}{P_R} = \frac{(8\pi d)^2}{(3\lambda)}$ where λ is the wavelength and d is the distance between the antennas. The wavelength

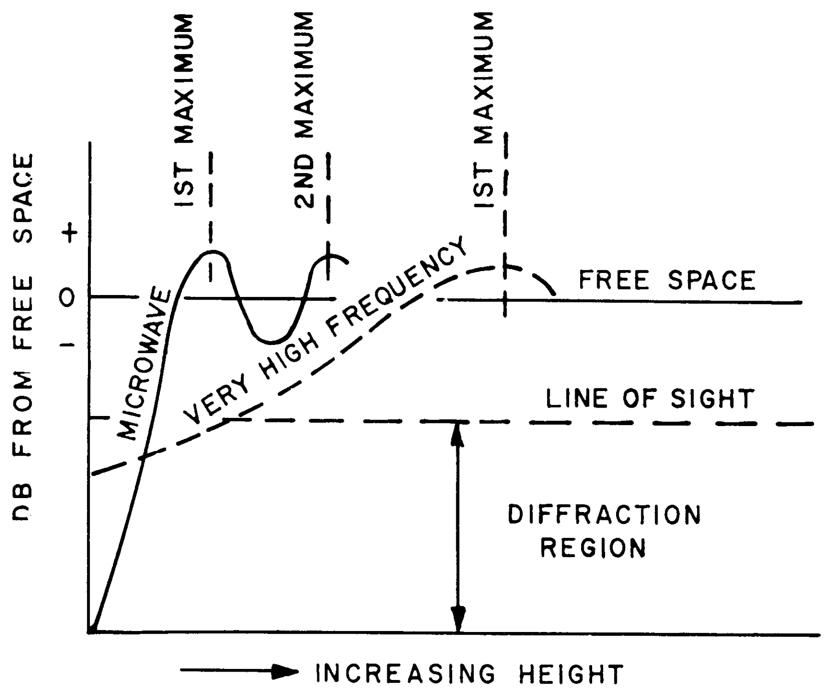


Figure VI-5. Height — Gain Curves

and the distance must be measured in the same units. The attenuation, expressed in DB (decibels) for convenience, is

$$A = 33 + 20 \log d + 20 \log f,$$

where d is in miles and f in mc.

A nomograph which permits the rapid determination of attenuation at a frequency of f between dipoles spaced a distance D (miles) is shown in figure VI-7. As an example of the use of this chart, assume that the dipole antennas are elevated to such a height that the path has normal clearance, and,

$$f = 2000 \text{ mc.}$$
$$D = 28 \text{ miles.}$$

Draw a line as shown in the chart between these values on the f and D scales and read the attenuation directly in decibels on the A scale. This reading of 128 DB is the path attenuation.

An auxiliary use of this nomograph is the direct conversion of wavelength in centimeters to frequency in mc, and the conversion of distance in kilometers to miles.

Another important factor in path attenuation is the effect of rainfall, fog, snow and sleet on radio propagation. The effects at frequencies below 6000 mc are so slight as to be negligible but above that frequency, where the size of the raindrops may become appreciable with respect to wavelength, attenuation by absorption and scattering will materially affect propagation. In planning for the installation of facili-

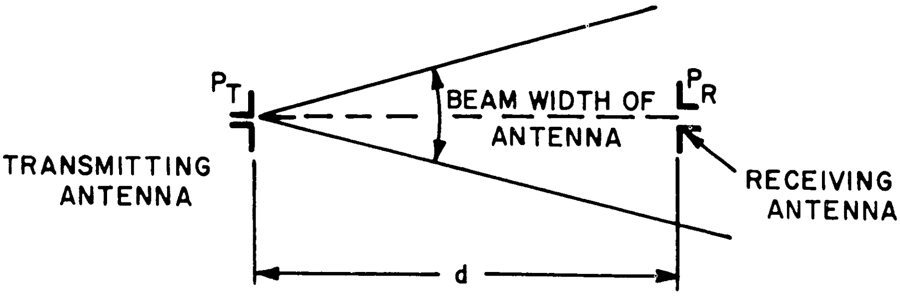


Figure VI-6. Path Attenuation

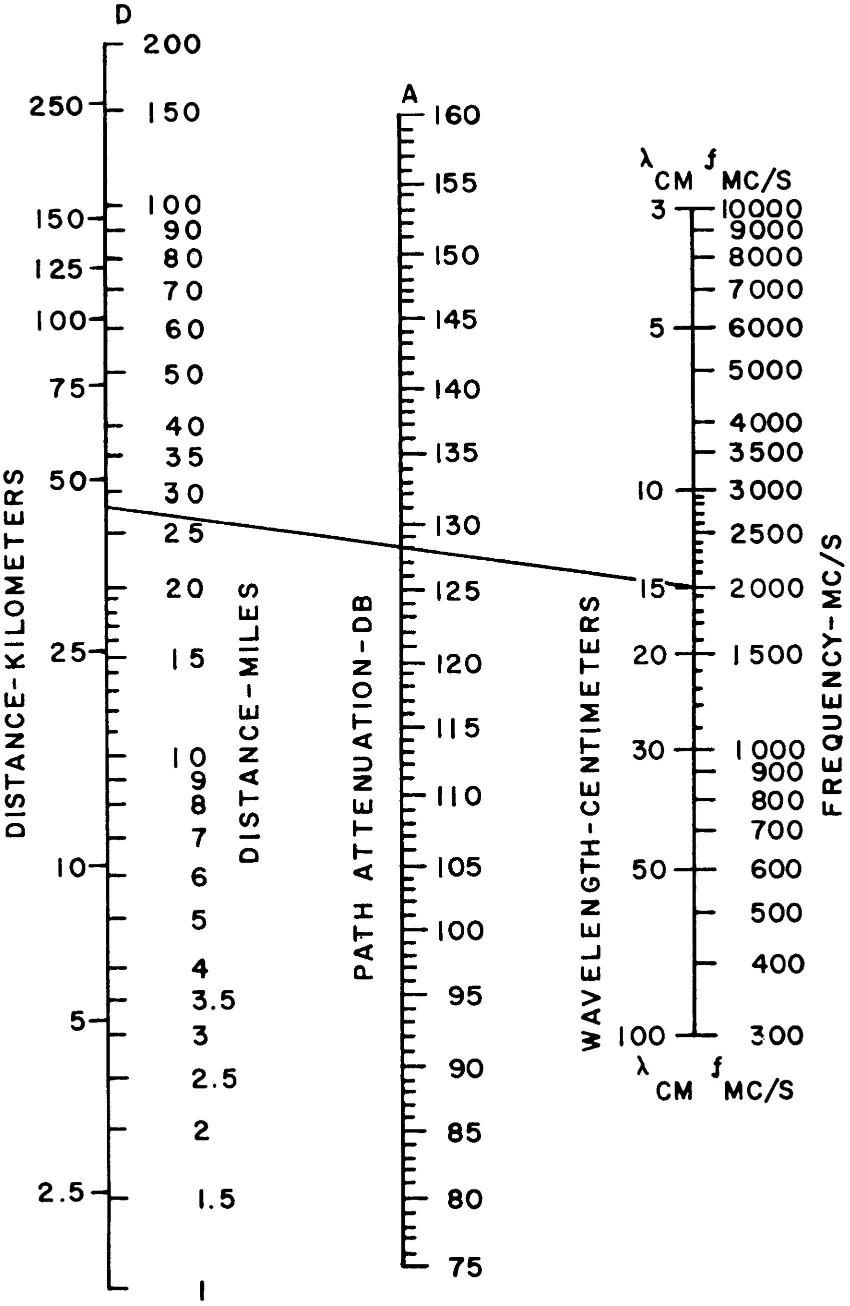


Figure VI-7. Path Attenuation for Free-Spac Propagation Betw en Dipole Antennas ties such as a radar link using frequencies above 6000 mc in areas where considerable precipitation is common, consideration must be given to this in the determination of link path length and attenuation tolerances.

The nomogram, figure VI-8, provides a means to measure DB attenuation in terms of path length, inches of rainfall and frequency. This nomogram is based on a uniform rate of precipitation along the total path length. If the maximum rate of rainfall is used in conjunction with the nomogram, the computed attenuation will be at a maximum. A figure of 75% of the attenuation, as given by this nomogram will usually be a safe value for any path length over 25 miles.

Scattering due to snow is difficult to compute, owing to the irregularities of the flakes, and while information on the attenuating effect of snow is limited, it is probable that attenuation from snow is less than from rain falling at an equal rate. This is borne out by the fact that the density of rain is eight times the density of snow. Information on fog, hail and sleet is likewise meager but can account for appreciable attenuation in path lengths approaching the maximum.

VI-3. FADING.

a. TYPES OF FADING.—The troposphere is continually undergoing changes in dielectric constant which affect the field strength of the received signal. The fading range ordinarily increases with increase in distance since the effects of atmospheric refraction are more pronounced at greater distances. Changes in atmospheric refraction appear to change the transmission path curvature. Drawn on 4/3 earth profile paper, the earth may appear to bulge in a more convex curve (equivalent earth radius) (factor K less than 4/3) or may appear to be less convex (K greater than 4/3). In most localities the earth's radius factor K is rarely less than 0.8 or greater than 3. As an example of the effect of change in equivalent earth curvature, table I has been prepared to show required antenna heights for various values of K and distances to the horizon. The signals received on twin antennas separated vertically (space diversity) under these conditions are affected alike.

TABLE I. REQUIRED ANTENNA HEIGHT IN FEET.

Earth radius factor K	Horizon distance 15 miles	30 miles	50 miles
0.8	180	800	2,300
1	150	620	1,800
4/3	120	480	1,300
2	75	300	950
3	50	200	600

Another common cause of fading, called multiple-path transmission, is one in which two, three, or more signal components are found to arrive at the receiving station at various angles in the vertical plane. The extent of this type of fading is dependent on the relative amplitudes and delays of each of the components. This fading, which has a fine structure (rapid fade), can be thought of as being superimposed on the fading described above. The signals received on two antennas separated vertically under these conditions are affected differently.

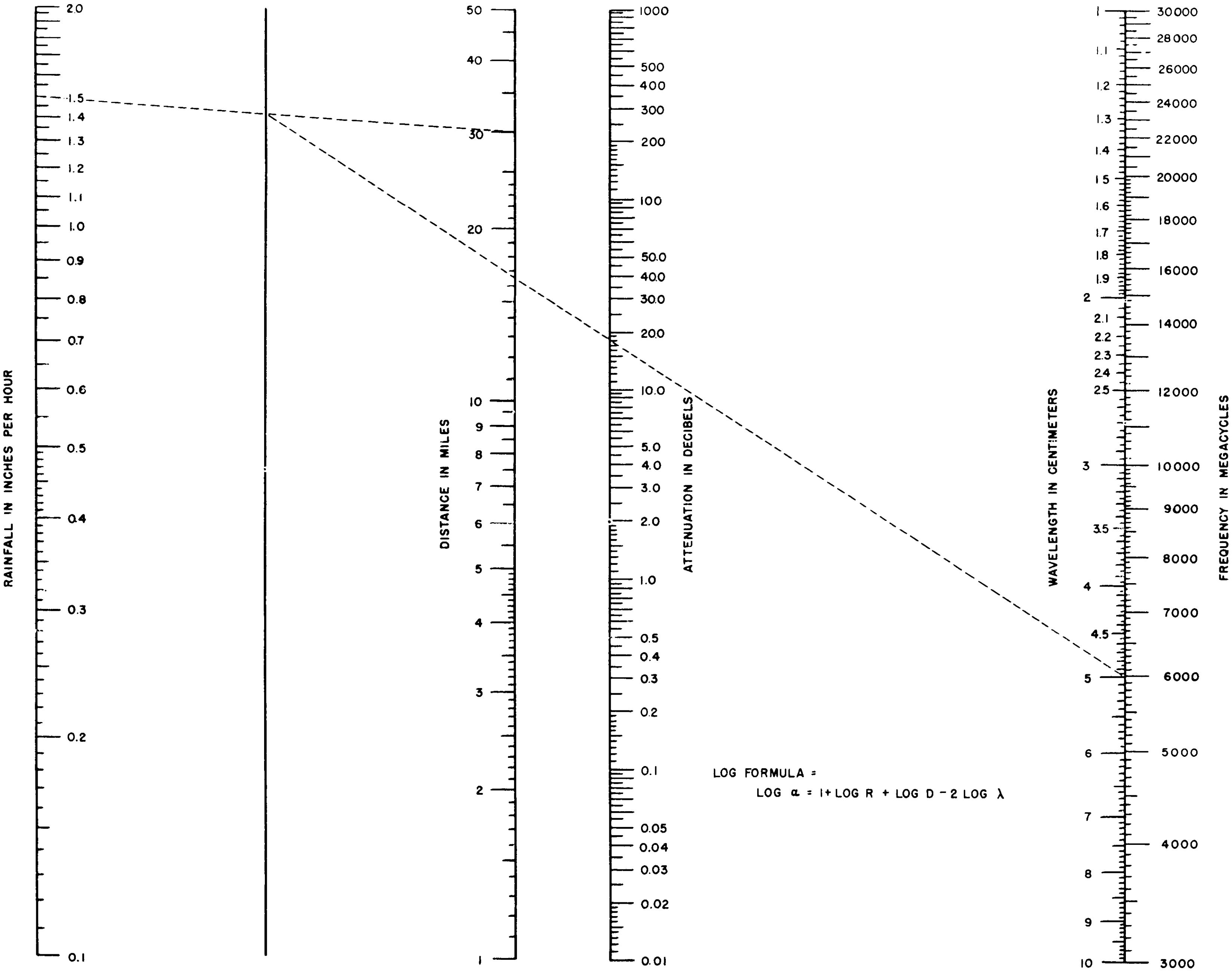
b. PATH DISTANCES.—In table I, the columns marked 15, 30, and 50 miles correspond to path lengths of 30, 60, and 100 miles. The variation in height around the 4/3 earth radius can be thought of as the variation of the clearance of an engineered path. Table II shows this midpath clearance variation normalized on a 4/3 earth radius factor. The minus sign in this table indicates the extent to which the signal is in the shadow region. It will be noted that a 30-mile path is clear over the entire range of K factors which normally can be expected. A 60-mile path on the other hand may appear to be in the shadow region or may appear as a path which has excessive heights. At 100 miles, this variation is even more marked. During the time when the field strength appears to be in the shadow region, diversity is not useful, since the signal strength on both of the diversity antennas will fade simultaneously.

TABLE II. MIDPATH CLEARANCE VARIATION IN FEET NORMALIZED ON K = 4/3, f = 2000 MC.

K	Midpath clearance in feet 30 miles	60 miles	100 miles
0.8	20	—206	—852
1	50	—26	—352
4/3	80	114	148
2	125	294	498
3	150	394	848

These wide variations which occur on long path lengths are taken into account in radio relay systems engineering by limiting the path lengths to approximately 30 miles. Longer path lengths, 40 to 50 miles, may be used in areas where the climate is dry and propagation fading is not influenced greatly by changes in humidity. Again path lengths longer than 30 miles may be engineered by increasing the fade margin (by use of larger antenna dishes and/or amplifiers) or by accepting less reliability than that described in the following paragraph.

c. RELIABILITY OF TRANSMISSION.—Sites engineered to path lengths of 30 miles, and provided with the free space clearance called for in paragraphs VI-4 and VI-5 should result in a propagation reliability, for most operations, in which the depth of fade that can be expected a certain percentage of the time, and its



LOG FORMULA =

$$\text{LOG } \alpha = 1 + \text{LOG } R + \text{LOG } D - 2 \text{ LOG } \lambda$$

Figure VI-8. Attenuation Due to Rainfall

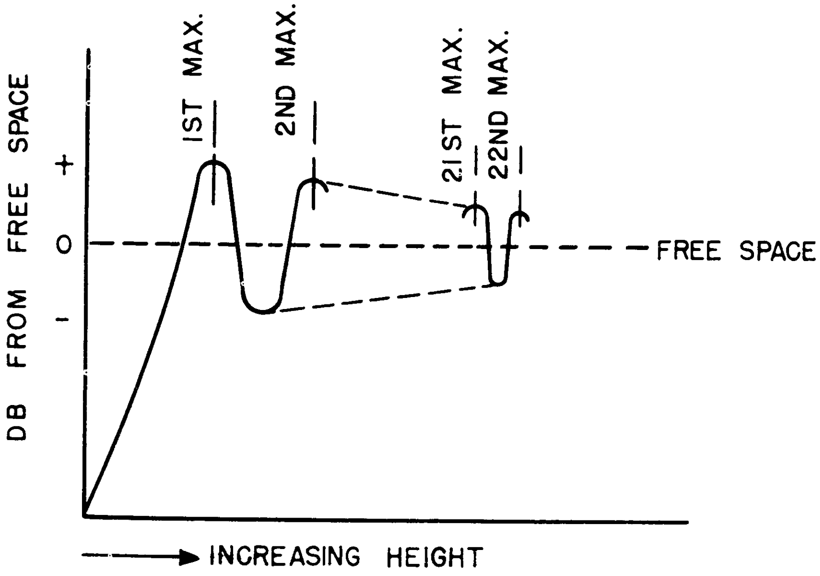


Figure VI-9. Maxima Pattern Spacing

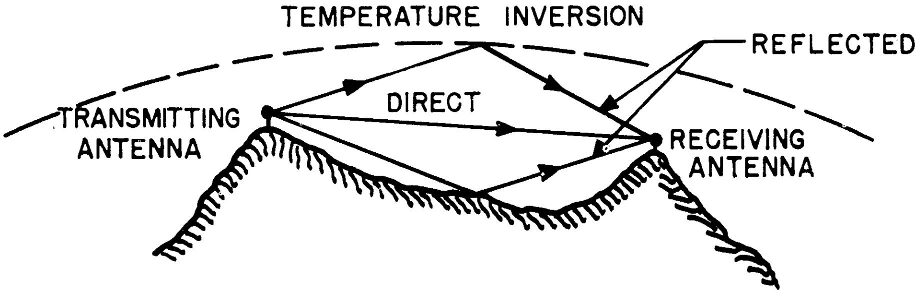


Figure VI-10. Reflection from Inversion Within Receiving Antenna Beam Width

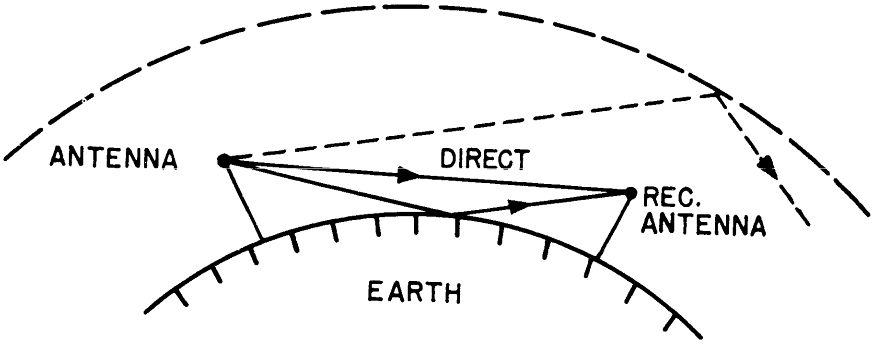


Figure VI-11. Reflection from Inversion Outside Receiving Antenna Beam Width corresponding percentage of reliability, is approximately as follows:

Fade in db	Percent of the time	% reliability
10	10	90
20	1	99
30	0.1	99.9
40	0.01	99.99

It is unusual for signals over two or more paths to experience the same depth of fade simultaneously. Therefore, the system reliability of a number of paths in tandem is the combined reliability of each path taken separately. This results in a system reliability which is less than that of the individual path. This means that the fade in DB which can be expected in a system will be present for a greater percent of the time than is shown in the chart above. For example: When using a 10-jump system, each of these fade ranges may be increased approximately 6 to 9 DB without incurring any corresponding change in the percentage of the time. For further discussion as applied to system evaluating see paragraph VI-6.*c*.

d. SMOOTH TERRAIN.—Where the intervening earth is smooth (coefficient of reflection more than 1/10), such as salt flats or overwater paths, changes in the atmospheric refraction, and therefore, equivalent earth's radius factor, may cause the direct and reflected components to cancel each other. Since multiple transmission is involved, it is necessary to use diversity to obtain maximum reliability. Where possible, as mentioned in paragraph VI-5, these paths should be avoided or use should be made of the high-low techniques. As a second alternate, a screened path as defined in figure VI-16 may be used.

e. HIGHLY ELEVATED PATH.—Transmission paths which have an Nth Fresnel clearance or excessive lobing, such as may be encountered in going from one mountain top to another, are generally to be avoided. Where the intervening terrain has a coefficient of reflection of less than 1/10, the signal strength will fluctuate between the maxima and minima of the Fresnel pattern, but the variation will be small; resulting in reliable transmission. If the coefficient of reflection is more than 1/10, such as overwater paths and salt flats, the maxima and minima of the Fresnel pattern are widely separated in amplitude and the reliability is decreased. Diversity is not a cure-all for such paths but it does reduce the percent of the time deep fades occur. The reason diversity may still result in deep fades is that the atmosphere is not homogeneous. The lobes are therefore caused to move in random fashion in front of the antenna. These lobes are relatively close together at higher elevations, since the spacing between successive maxima decreases with increasing height. For example, at 2,000 mc with a path difference of 30 miles, the spacing between the first and second maxima is approximately 200 feet and the spacing between the twenty-first and twenty-second maxima is approximately 45 feet, if the transmitting antenna remains fixed and the receiving antenna is the variable (figure VI-9). Excessive heights also may result in fading due to reflections caused by temperature inversions which are generally present at around 7,000 feet above the earth's surface (figure VI-10). At lower heights with ranges of approximately 30 miles, the inversion is usually outside the beamwidth of the receiving antenna (figure VI-11).

f. METEOROLOGY.—The correlation between received field strengths and meteorological conditions is as yet in its infancy; reliable results, however, can be obtained. The statistical information which relates depth of fading to percentages of the time takes into account the fact that at various times throughout the day, month, and year, the atmospheric conditions may be such as to form low-level ducts, high-level ducts, substandard refraction, super refraction, temperature inversions, and other meteorological effects. In locations where one or more of these meteorological effects are pronounced, appreciable fades may be expected during these conditions. Restricted path lengths may be necessary in such locations but apparently conditions of this type are the exception rather than the rule.

VI-4. SITING FROM PROFILE MAPS.

a. ROUTE ENGINEERING.—The selection of sites suitable for stations of a radio relay system may be made from contour maps or stereoscopic photographs.

Choose several alternate locations for each site, if possible, so that after profiling, factors other than path clearance, which then become important, may be taken into consideration. The choice of the most suitable sites may be influenced by:

Accessibility to the site from installation, operational, and maintenance standpoints.

Proximity to roads and utilities.

Contour maps generally lack information regarding trees, buildings and other obstacles. Facilities such as power lines and smaller roads may not appear on the map. Also, the contour map may be in serious error. It is well, therefore, to make a preliminary survey of proposed paths, noting the foregoing information on the contour map. This survey can be made by air reconnaissance or vehicle.

b. PROFILE ANALYSIS.—Path profiles should be obtained from the appropriate Public Works office, and studied to determine the following points:

Is the path, including available tower heights, clear of objects? If not, another path perhaps of shorter length must be plotted.

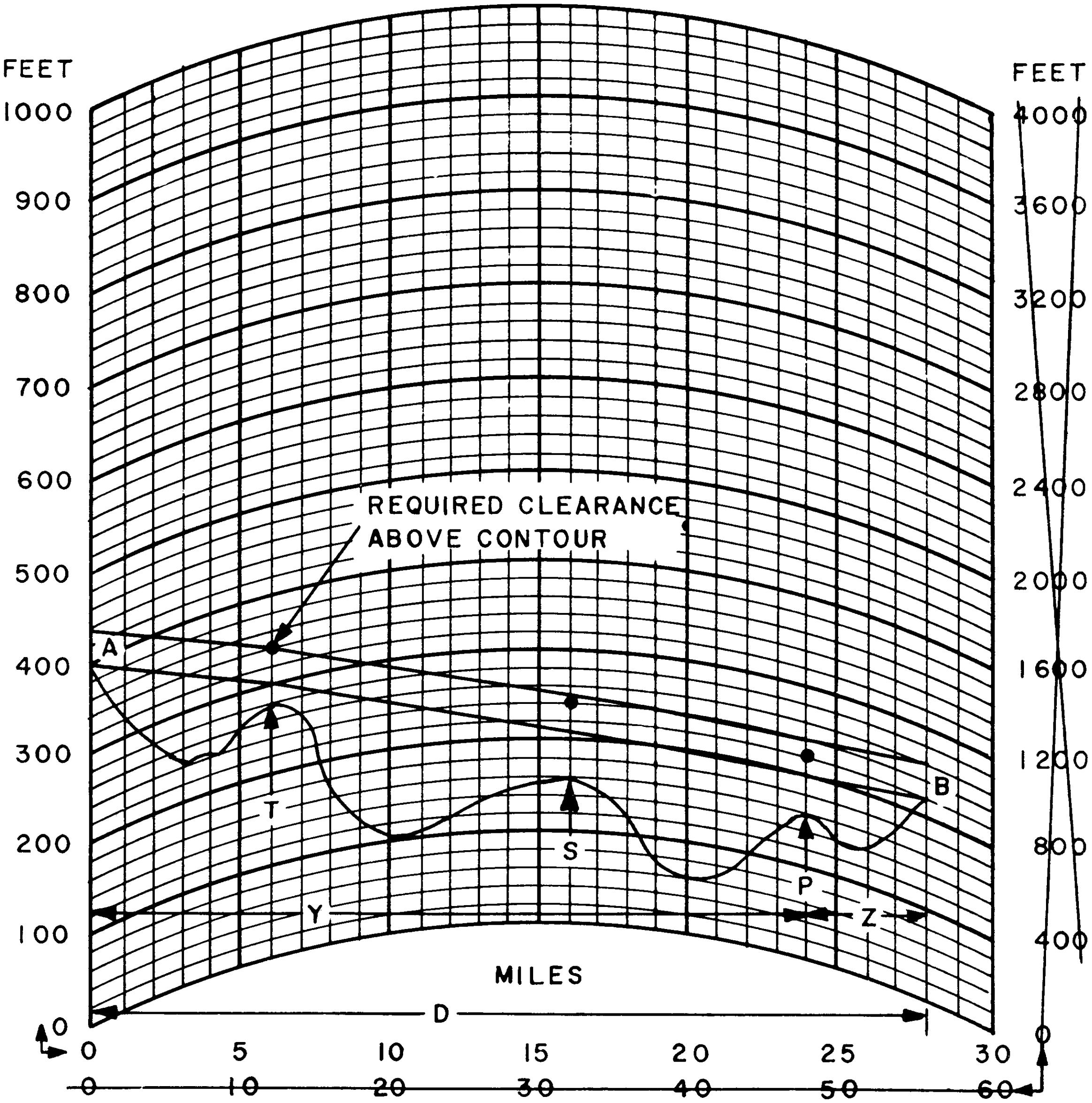


Figure VI-12. Plotting Profiles on 4/3 Earth Profile Paper

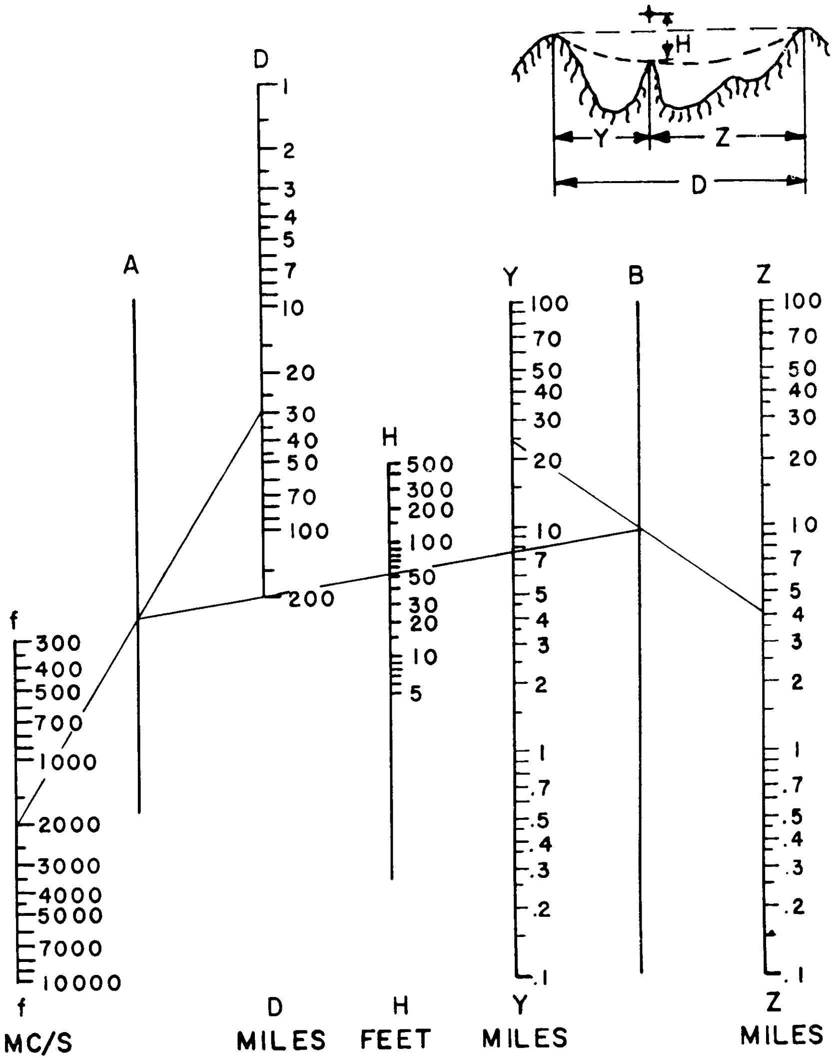


Figure VI-13. Nomograph for Determining Free Space Path Clearance

If the path is clear, by how many feet does the line drawn between the sites clear high contours? The determination of this clearance must include the height of trees and other objects. The free space clearance should also be maintained in all directions relative to the line drawn between the sites. The procedure to be used in determining whether a path has the required clearance and what the required tower heights must be is given in the following example.

Example: Assume equipment is used with a radio carrier frequency f = 2000 mc and a path as in figure VI-12 in which the path distance is D = 28 miles between proposed sites. The high contour at point P is, Y = 24 miles from A and is, Z = 4 miles from B. Referring to figure VI-13, proceed as follows:

(1) Set a straightedge across the f and D scales and draw a line from f = 2000 mc to D = 28 miles.

(2) Set a straightedge across the Y and Z scales and draw a line from Y = 24 miles and Z = 4 miles.

(3) Set a straightedge across the A and B scales and draw a line from the points intersected on the A and B scales by the two operations above.

(4) Read the H scale. This reading, which is the required clearance above point P, is H = 55 feet.

This procedure is followed for other high contours such as point S on figure VI-12. It will be noted that the line drawn between the f and D scales for a particular profile remains the same for all high contours under investigation. Point S is Y= 16 miles from A and is Z = 12 miles from B and requires a clearance of 78.5 feet. Point T is Y = 6 miles from A and is Z = 22 miles from B and requires a clearance of 65 feet. The required clearance above the high contours is indicated on figure VI-12 by large dots.

After determining the clearance above high contours, it is necessary to determine the tower heights required at the sites. The following considerations should be noted.

(1) If a line drawn on the profile paper between the sites is below a required clearance point, as in figure VI-12, towers must be provided to clear this point. On figure VI-12, the required tower height is 40 feet. If the required tower height is excessive, new sites must be surveyed.

(2) If the line just passes above required clearance, then a tower height of six to eight feet may be used at each site. If the site in the direction of transmission is not clear of trees, use tower heights which provide the necessary clearance above the tree tops.

(3) If the line between sites is well above required clearance, i.e., two or more times the required midpath clearance, then sites providing less clearance should be chosen.

c. RECONNAISSANCE.—The profile of the proposed paths is now available and is ready for use on location checking. Aerial reconnaissance by helicopter, liaison plane, or vehicle along the propagation path should be made to determine the reliability of the information on the profile. During flight, the propagation path should be viewed for obstructions, such as trees, buildings, and other land marks which were not shown on the profile. At the sites, observe whether the land is cleared and is accessible by vehicle. It is desirable to have commercial power available at the sites so that power units are not required. In terrain where there is considerable visibility, visual exploration at one site may determine the line-of-sight properties to the other site. For nighttime observation of the line-of-sight properties of selected sites, searchlights may be used.

VI-5. TRANSMISSION PATHS.

a. OVERLAND.—Irregular terrain, such as is encountered in rolling countryside, is generally suitable from a propagation standpoint. Smooth terrain, such as salt flats, should be avoided, if possible. If it becomes expedient to use such paths, however, a high-low type of siting should be employed. This technique uses one site highly elevated so as to provide the required clearance at midpath and the other site located six to eight feet above ground level (figure VI-14).

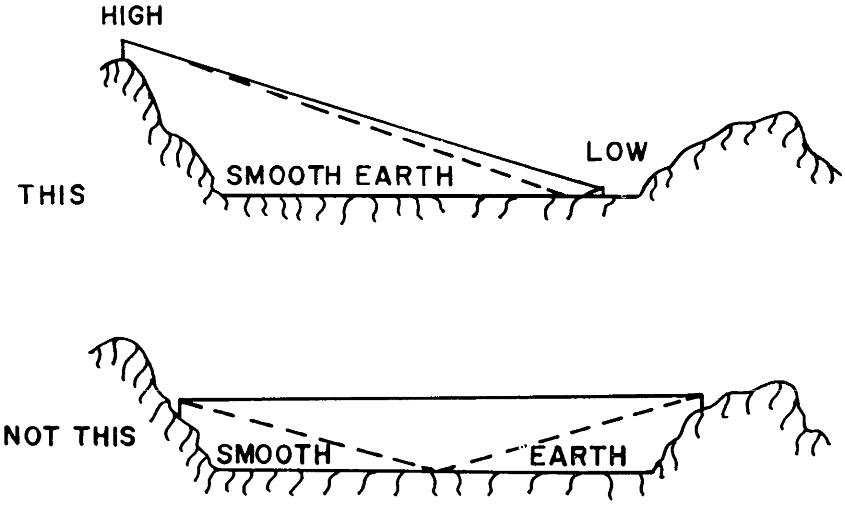


Figure VI-14. High-Low Technique Overland, Smooth Earth Siting

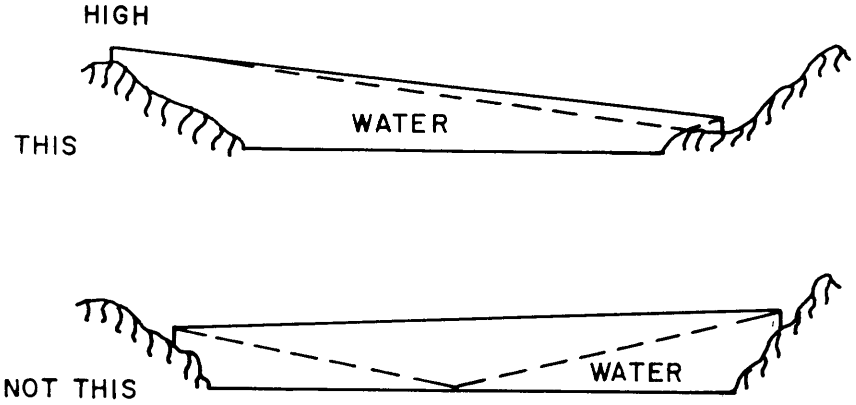


Figure VI-15. High-low Technique, Overwater Siting.

b. OVERWATER. — Overwater paths should be avoided, if possible. If such a path must be used, the high-low technique again may be applicable. Again, one site is highly elevated and the other site is located a few feet above ground level so that the reflection point occurs overland (figure VI-15). Path clearances at midpath are as indicated in the previous section on siting. This type of siting should, in many locations, provide reliable communications, but space diversity may be required. Where the overwater path is such that the high-low technique cannot be applied, it may be possible to use the screening technique (figure VI-16). The high contour which serves as the screen must still have the required clearance called for in the previous part. Space diversity may still be required in the event of severe fading. Where the overwater paths are such that neither of these techniques can be applied, a more desirable path should be chosen.

c. HIGHLY ELEVATED PATHS.—A highly elevated path, that is, one in which the path clearance is many times the required clearance H, is generally to be avoided. One method of avoiding this type of path is to provide a repeater station near the midpath. Another method is the high-low technique described above. Still another alternative is to select sites at lower elevations which may still result in path lengths

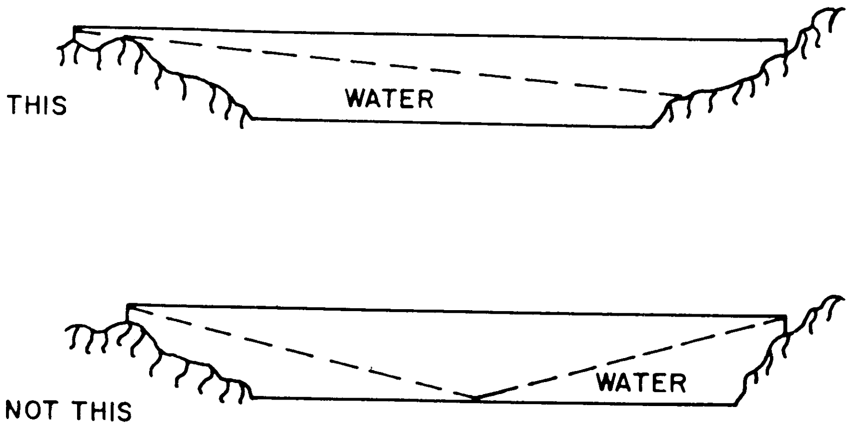


Figure VI-16. Screening Technique, Overwater Siting.

of approximately 30 miles. In the event that these alternates are not possible, these highly elevated paths may require space diversity.

d. OVERLAND - OVERWATER. — Selected sites which contain partially overland and overwater paths are satisfactory if the reflection point is on the land portions of the path. If the reflection point is overwater, it is advisable to move one of the sites. This is generally accomplished by moving one site a relatively short distance.

e. SPACE DIVERSITY.—Where the fading conditions of the path are such as to require space diversity, the vertical distance between the receiving antennas is determined as follows:

All high contours should be investigated to determine which one results in the smallest required midpath height. This high contour is therefore the path clearance determining point. Referring to figure VI-17, the line AB connects the two sites. The distance E = 1040 feet is the extent to which the direct path AB clears the high contour T. The required midpath clearance h is this clearance divided by the path clearance determining factor C which may be obtained from figure VI-18. The point T is X = 3 miles from midpath, therefore $\frac{X}{D} = \frac{3}{28} = 0.107$ which, from figure VI-18, corresponds to a C factor equal to 0.97. The midpath clearance h feet is therefore $\frac{E}{C} = \frac{1040}{0.97}$ = 1072 feet. A similar calculation for the high contour S will result in a midpath clearance which is larger than the one for T. Therefore, the point T is the path clearance determining point.

Example: For convenience, the frequency and path length is assumed as being the same as the example given in paragraph VI-4, *b.* Find the clearance H, at midpath from figure VI-13 and the method discussed in paragraph VI-4, *b,* using Y = 14, Z = 28 and f = 2000. H will be found to be 79 feet. Then $\frac{h}{H} = \frac{1072}{0.79} = 13.6$. Referring to figure VI-19, this corresponds to a diversity antenna spacing factor N = 0.21. The required vertical spacing between antennas is N × X = 0.21 × 79 = 17 feet.

Where the spacing is larger than a reasonable tower height required by transmission without space diversity, the second antenna should be located close to the base of the tower, provided clearance above nearby trees, etc., is obtained.

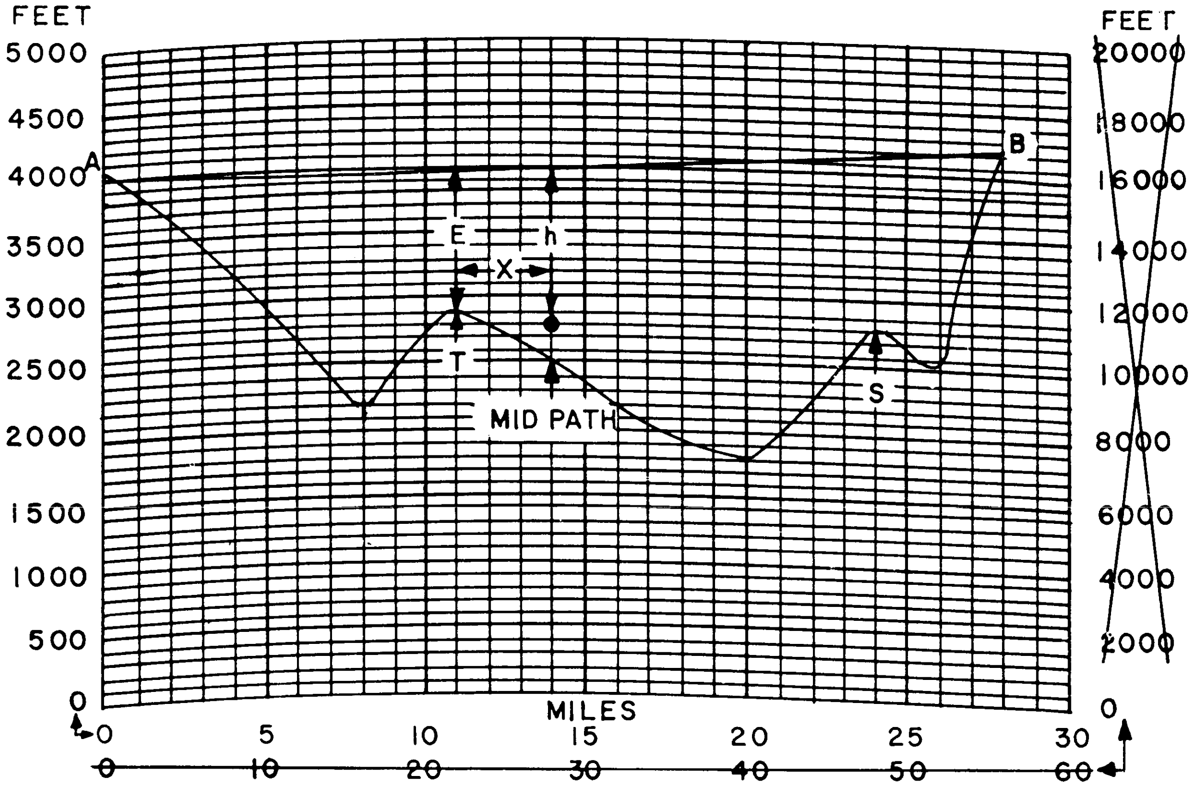


Figure VI-17. Large Clearance Path, 4/3 Earth Profile Paper

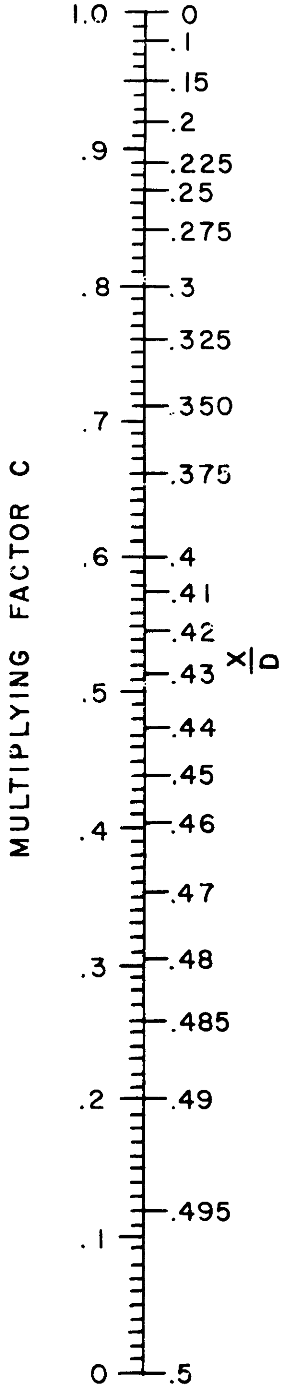


Figure VI-18. Path Clearance Determining Factor

VI-6. SYSTEM EVALUATION.

a. GENERAL.—A microwave radio relay link, in order to operate satisfactorily, must have an overall system gain which exceeds the system attenuation by an amount which accounts for the fading and results in a reliability of transmission as indicated in paragraph VI-3.*c*. Elements which contribute to the overall system gain are the transmitter power, the transmitting antenna gain, the receiving antenna gain, and the wideband gain. Elements that contribute to the overall system attenuation are the antenna line loss, the free space path attenuation for the given distance between stations, and the frequency used. The system evaluation extends from the audio or broadband terminals of the modulator in the transmitter to the audio or broadband terminals of the demodulator in the receiver.

Commercial, and some military, radio relay systems operate with multichannel telephone carrier equipment. Power levels in telephone terminology are expressed in DBM (decibels above or below 1 milliwatt). For this reason power levels for radio links will likewise be expressed in DBM.

b. TYPICAL PROBLEM.—Obtain, from the equipment instruction book, the system gain and the antenna gain. From the equation in paragraph VI-2.*g*. or the nomograph of figure VI-7, obtain the path attenuation. Obtain attenuation per 100 feet of desired coaxial transmission line, and use required tower heights to determine transmission line losses. Assuming, for this problem, f = 2000 mc, d = 28 miles, antenna gain = 32 DB, system gain = 113 DB, transmitting tower height = 300 feet, receiving tower height = 200 feet, transmission line loss = 1.5 DB/100 feet, we have:

	gain DB	*loss DB*
System	113	
Receiving Antenna	32	
Transmitting Antenna	32	
Total Gain	177	
Path Attenuation		128
Receiving transmission line loss		3
Transmitting transmission line loss		4.5
System degradation		6.0
Total Loss		141.5

Fade Margin = Total gain — Total loss
= 177 DB — 141.5 DB
= 35.5 DB

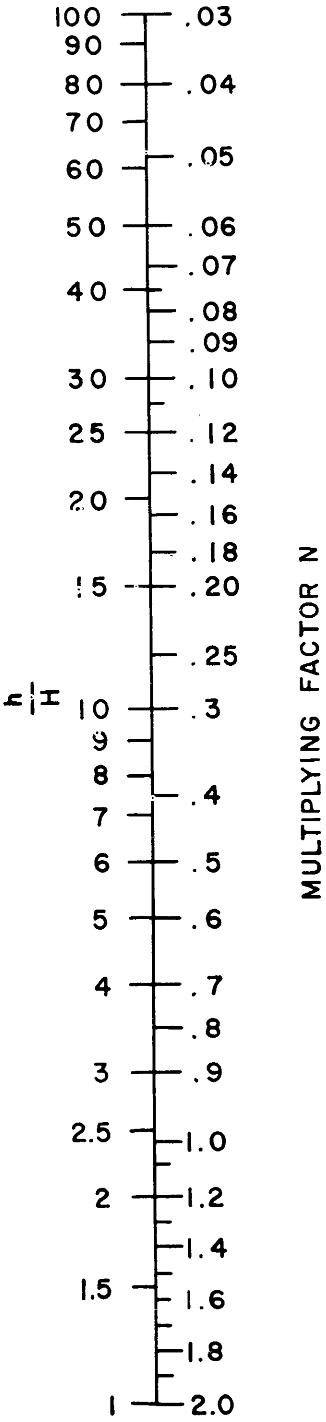


Figure VI-19. Diversity Antenna Spacing Factor

From the chart in paragraph VI-3.*c*, expected reliability is greater than 99.9.

From the nomogram, figure VI-20, expected reliability is approximately 99.96.

c. MULTIPLE-HOP SYSTEM EVALUATION.—In evaluating a multiple-hop system, additional factors must be taken into consideration. The audio noise level of a multiple-hop system is higher than for a single-hop system, therefore, the AF signal-to-noise ratio will be smaller. Also in a multiple-hop system the reliability from a propagation viewpoint is reduced.

Consider a multiple-hop system in which, for convenience, the path distances for each hop is the same and the path clearances are as outlined in paragraph VI-4; that is, free space clearance. Assume also for this discussion that no propagation fading is taking place. The single-hop RF and AF signal-to-noise ratios can then be calculated as in paragraph *b.*

(1) The RF and audio signal level, receiver noise level, and threshold level will remain the same at each repeater receiver and at the terminal receiver.

(2) The audio noise level will rise in each successive receiver starting at the receiver nearest the terminal transmitter and will be a maximum level at the terminal receiver. The amount of increase in noise level is dependent on the number of jumps. The conversion scale (figure VI-21) shows the increase in audio noise level for a system of a given number of hops.

If in the illustrative example of paragraph *b.* the audio signal-to-noise ratio is 65 DB S/N, and a multiple-hop system of eight jumps is assumed, then from figure VI-21 a rise in noise level of 9 DB will result in an AF signal-to-noise ratio of 56 DB.

The other factor which must be taken into account in system evaluation is the system reliability from a wave propagation standpoint. As described in paragraph VI-3.*c*, the multiple-hop reliability compared to single-hop reliability is lower and the system reliability of a number of paths in tandem is the combined reliability of each path taken separately. The nomograph of figure VI-20 shows how the system reliability due to propagation is affected by multiple-hop systems. This chart assumes all paths approximately 30 miles long and provided with free-space clearance. Thus, continuing the illustrative example, a fade of 32 DB occurs approximately 0.1 percent of the time or from figure VI-22 a path with a fade margin of 32 DB has a reliability of 99.93 percent.

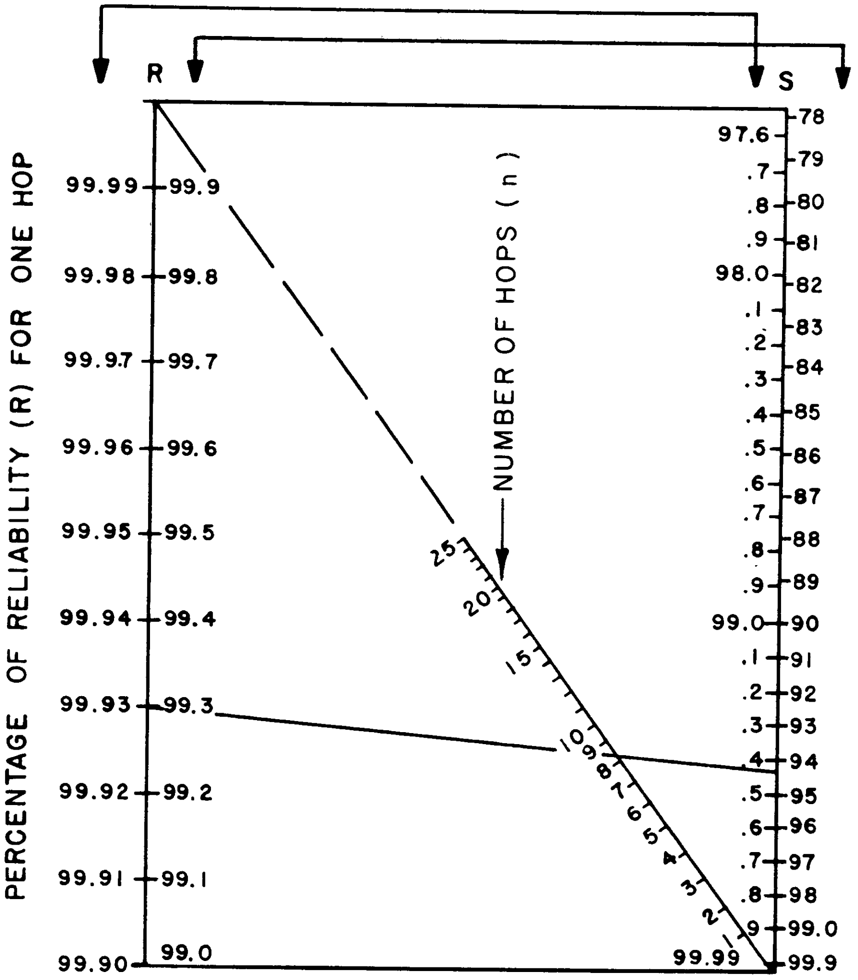


Figure VI-20. System Reliability

For an eight-jump system using the nomograph of figure VI-20, draw a line between R = 99.93 and n = 8. Read the value where the line crosses the S scale or S = 99.4. This is the system reliability due to propagation.

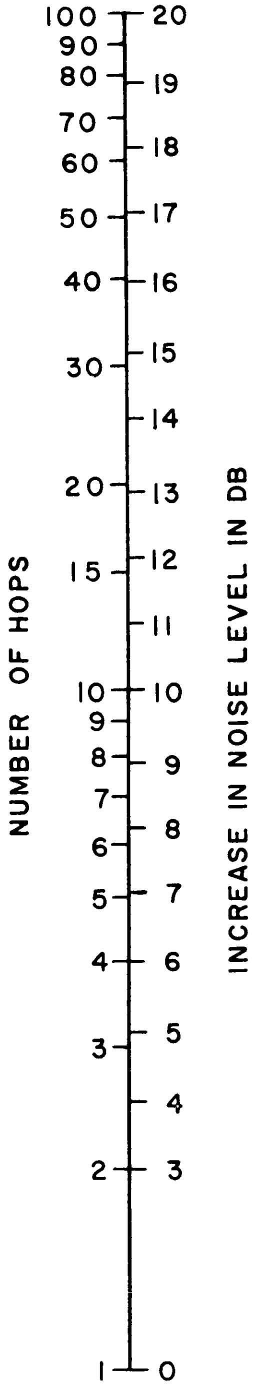


Figure VI-21. Noise Level Increase for Multiple Hop

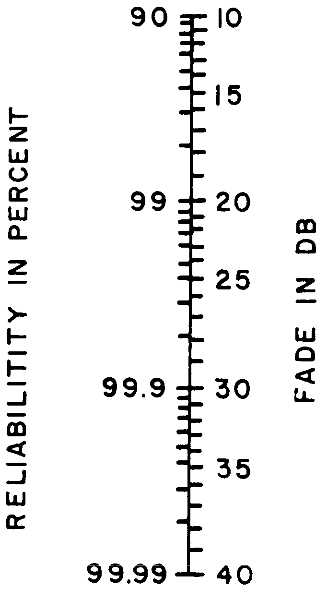


Figure VI-22. Fading Reliability

d. INTERFERENCE.—Another factor affecting siting is the problem of mutual interference between equipments. Mutual interference problems may be encountered when a number of equipments are installed at a terminal or repeater station for parallel operation, or when systems cross each other.

The amount of mutual interference is a problem of the individual installation. Since this discussion does not deal with individual equipments, it is the intention here to list some factors which will generally help reduce interference.

(1) Select frequencies separated sufficiently so as to eliminate interference.

(2) Cross-polarize the antennas, that is, use horizontally-polarized antennas on one system and vertically-polarized antennas on the other nearest system.

(3) The use of larger paraboloidal dishes will reduce the antenna beamwidth and discriminate against signals arriving in a direction within the beamwidth of a smaller antenna.

(4) For nonparallel systems, select sites away from the common site which are outside the beamwidth of the mutually-interfering antennas.

VI-7. REFLECTORS.

The following technical data may be used in the design of mirror and passive repeaters:

Compute path margin for path D_3. Subtract desired fade margin. Let the excess path margin be R, and solve:

$$40 \log a = 79.4 - R + \log \left(\frac{\lambda D_1 D_2}{D_3}\right)$$

The width of the mirror is:

$$b = \frac{a}{\sin \phi}$$

Where: a, b, and λ are in feet,
D_1, D_2, and D_3 are in miles.

The mirror must be flat within:

$$\pm \Delta = \frac{\lambda}{10 \sin \phi}$$

For a passive repeater:

Compute path margin for path $D_1 + D_2$. Subtract desired fade margin. Let the excess path margin be R. Then solve:

$$2G = 74.9 - R$$

Where G is the gain of each dish used in the passive repeater. If the cable connecting the two dishes must be quite long, the gain of the dishes must be increased accordingly.

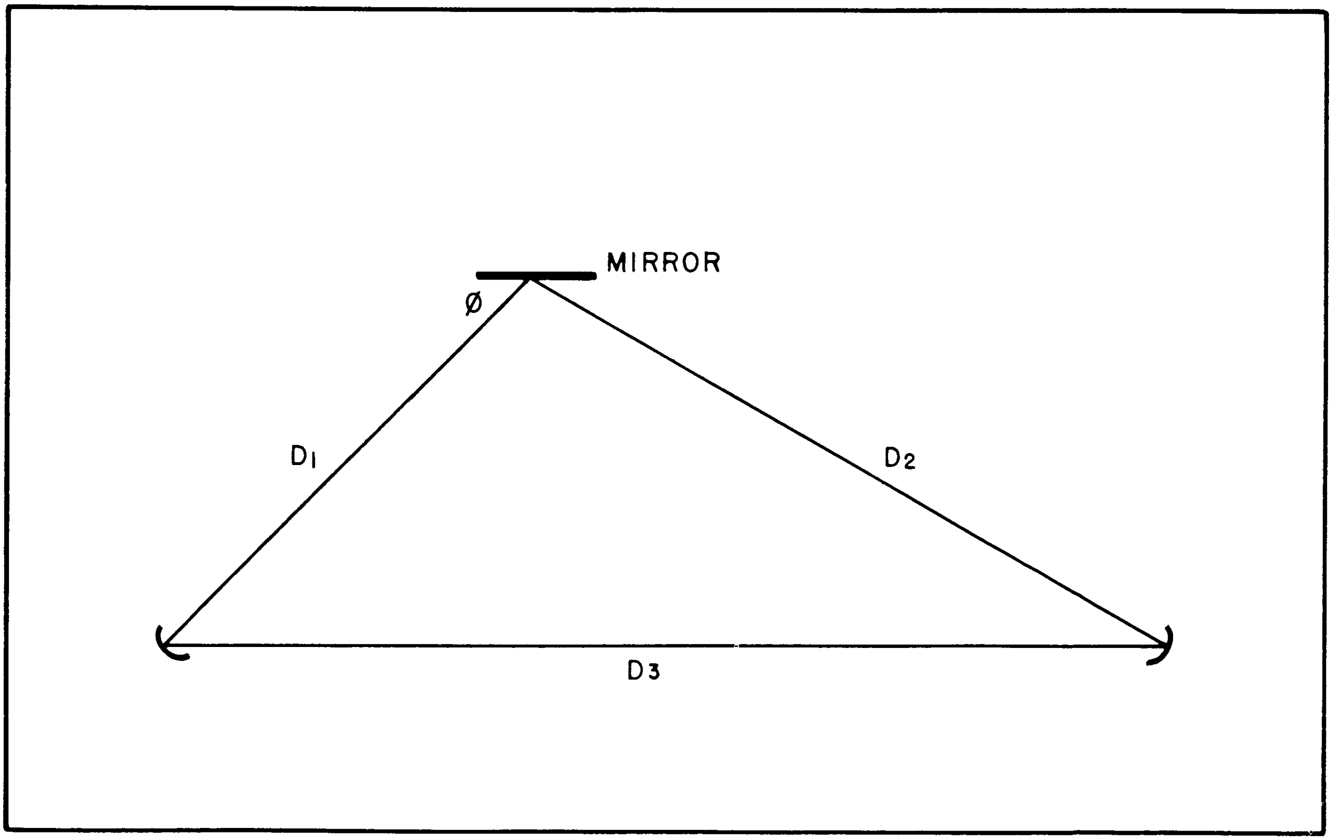


Figure VI-23. Mirror Repeater

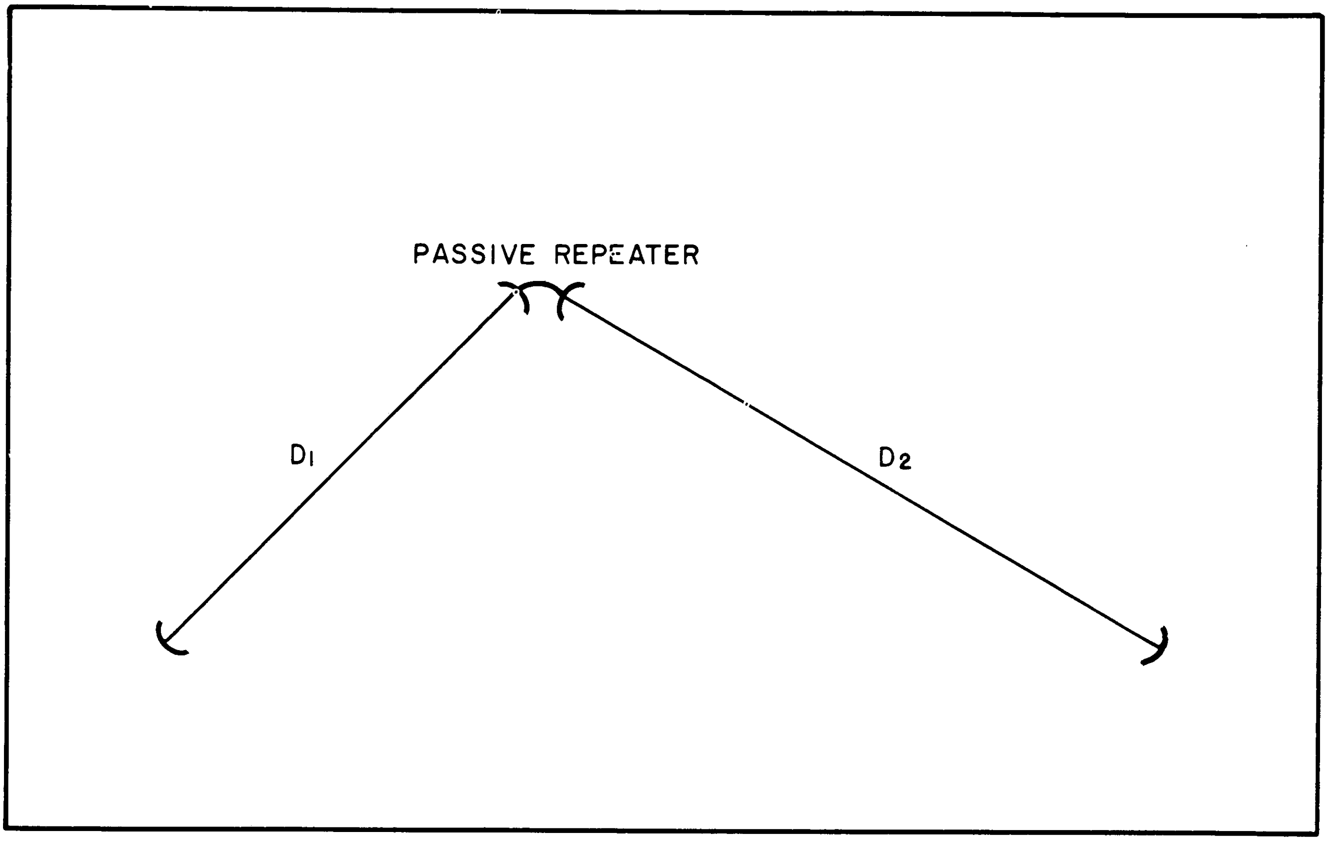


Figure VI-24. Passive Repeater

APPENDIX VII

Broadband Sleeve Antenna.

REPORT 478

Broadband Sleeve Antenna for Omnidirectional Shore Station Use

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U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA
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BROADBAND SLEEVE ANTENNA

The following is from Report 478, Broadband Sleeve Antenna for Omnidirectional Shore Station Use, by W. E. Gustafson, T. E. Devaney, and N. H. Balli, Electromagnetics Division of the U. S. Navy Electronics Laboratory, San Diego, California (Bureau of Ships Laboratory).

introduction

Where the need is for vertical polarization, and omnidirectional coverage, it has been common shore station practice to use vertical wire antennas directly over the transmitter or receiver building. When the number of antennas were few and their lengths widely different, this type of antenna system was both simple and effective. But at the modern station, with its multiplicity of antennas, it results in reduced efficiency and unwanted directivity due to intercoupling between antennas. To eliminate these effects, the wire antennas are sometimes moved some distance from the building and fed through rather long transmission lines. When this is done, efficient operation can only be obtained over a narrow frequency range without retuning at the antenna base. As a result many antennas are necessary to achieve flexibility.

To reduce intercoupling without this multiplicity of antennas, the Bureau of Ships requested the Navy Electronics Laboratory to develop a broadband, non-directional antenna for short station use. This antenna was to be designed primarily for transmitting over the frequency range 2.5 Mc to 7.5 Mc, although its modification for use at higher frequencies and for receiving was also to be considered. It was to match a 75-ohm transmission line within a VSWR of 3 to 1 over its operating range. A simple structure, such as one which could be built about a single long pole, was desired. Furthermore, the base diameter was to be kept as small as practicable.

design considerations

Recently several types of broadband antennas have been extensively investigated.[1-2-3] Of these the sleeve antenna seems to be the most attractive from the standpoint of size, ease of construction, and pattern characteristics. This type of antenna consists of two parts, a grounded base section or pedestal, and an upper ungrounded section which is generally of greater length and smaller cross section than the base section. It is fed at the junction of the upper and lower sections, an air-line transformer often being used to improve the impedance characteristics. Normally its over-all height is slightly less than one-quarter wavelength at the lowest operating frequency.

Using models built from cylindrical sections, NRL[1] made an extensive investigation of the way in which the properties of these antennas vary with the length and diameter of the two sections. Utilizing these data, they proposed various optimum designs based on assumed size limitations of the base diameter. In the case of the 2.5-to-7.5 Mc sleeve an-

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[1] A. W. Walters and L. C. Huffman *Experimentally Determined Characteristics of Cylindrical Sleeve Antennas* (Naval Research Laboratory, Report R-3354) 13 September 1948.

[2] R. L. Linton, Jr. *The Folded Fan as a Broad-Band Antenna* (California. University. Antenna Laboratory, Report 169) 15 April 1950.

[3] A. G. Kandoian "Three New Antenna Types and Their Applications" *Institute of Radio Engineers. Proceedings* vol. 34, no. 2, February 1946, pp. 70W-75W.

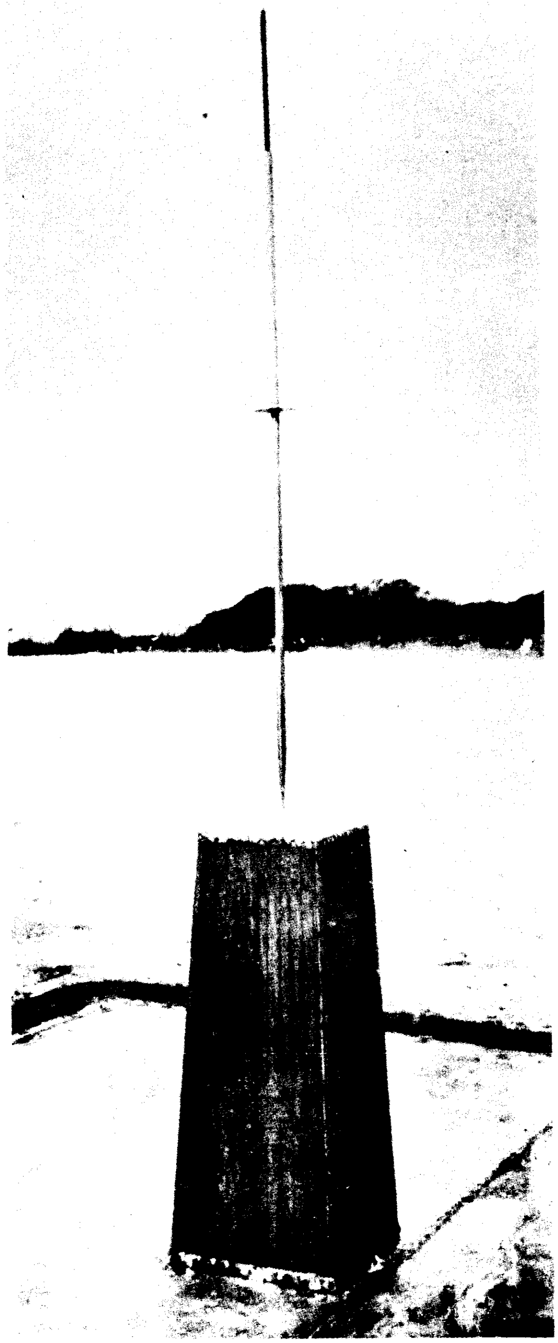
tenna, it was felt the base diameter should not be much greater than 10 feet. Applying this restriction, the NRL analysis led to a structure 90 feet high, the upper section being 60 feet long and the lower section 30 feet long. The base section would be 12 feet in diameter and the upper section 1.5 feet. Tests on a model of these proportions had indicated a VSWR of about 3.5 to 1 with respect to a 52-ohm line over a frequency range of 3 to 1. These values were close enough to the needs of this problem to make it seem probable that the sleeve antenna could be adapted to the design requirements.

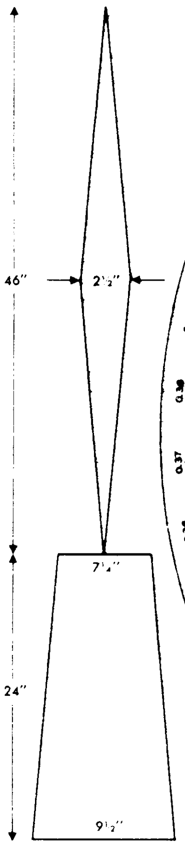
design details

Scale models (1 to 15) of a 2.5-to-7.5 Mc sleeve antenna were constructed. The early models differed from the NRL design in that the base section was square and tapered from bottom to top rather than being cylindrical. This was done to simulate a standard steel tower, which it was felt might make an excellent lower section for the full-scale antenna. Impedance studies on these first models were disappointing. With the use of an air-line transformer, a VSWR of 3 to 1 could be obtained over a frequency range of only about 2 to 1. A number of variations in the relative proportions of the base and upper section were then tested. They indicated that the optimum proportions were close to those proposed by NRL. In working with these data, it became apparent that wider frequency coverage would be obtained if the base capacitance of the upper section were reduced. Accordingly, a variety of tapered upper sections were constructed. The feedpoint input impedance of the model sleeve antenna was obtained using each of these upper sections. The characteristics of the air-line transformer which would give optimum match to a 75-ohm line was then found. Finally, for each upper section, the input impedance which would be presented to a 75-ohm line was calculated.

When these data were studied, the best type of upper section was found to be a double-tapered cone having its maximum diameter at the midpoint of the upper section and tapering to a point at either end. The model antenna with this upper section is pictured in figure 1. Its impedance at the feed-point

Figure 1. Final model of sleeve antenna showing upper section which yielded optimum impedance characteristics.





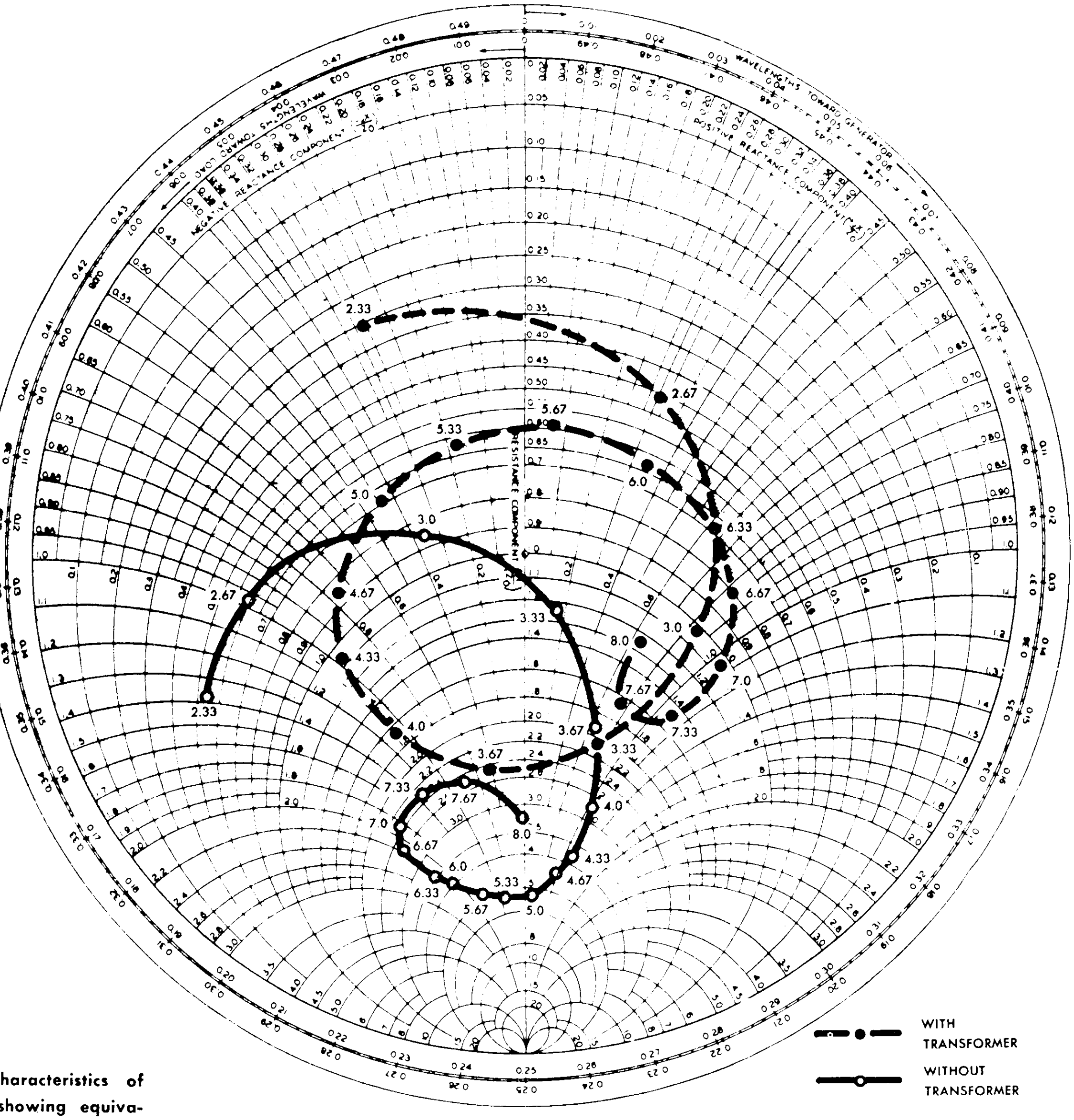


Figure 2. Impedance characteristics of model sleeve antenna, showing equivalent full scale frequencies.

and at the input to the line transformer is shown in figure 2. All impedance values are normalized to 75 ohms. The full scale equivalent of the line transformer would be 41 feet of 138-ohm line. It is apparent that the VSWR is within 3 to 1 over a frequency range somewhat in excess of 3 to 1. A similar balanced, 1/100 scale model was built and vertical patterns obtained using a free space mount. These patterns are given in figures 3 through 8. They agree quite closely with the vertical patterns obtained by NRL[1] for their cylindrical-sleeve antennas.

The upper sections used in the models were formed from 6 wires built around a center support. This type of construction was used because it would be easy to duplicate in the full-scale design either by a trussed-whip style of construction, or by hanging the wire cage from a pole-mounted yard arm.

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[1] A. W. Walters and L. C. Huffman *Vertical Patterns of Cylindrical Sleeve Antennas* (Naval Research Laboratory, Report R-3411) 2 February 1949.

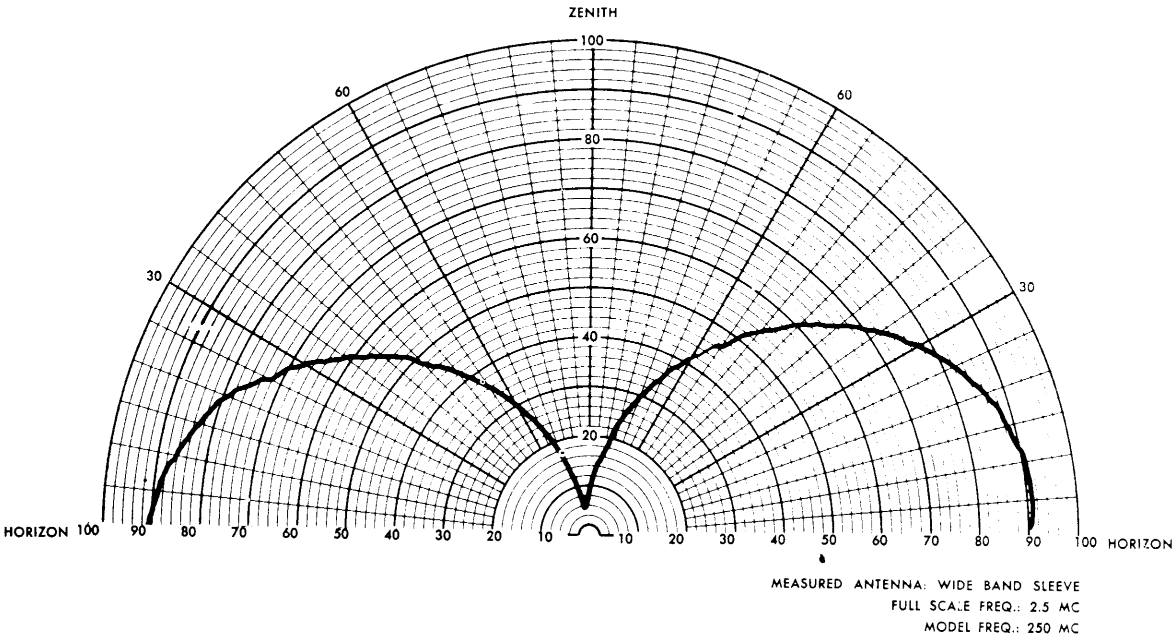
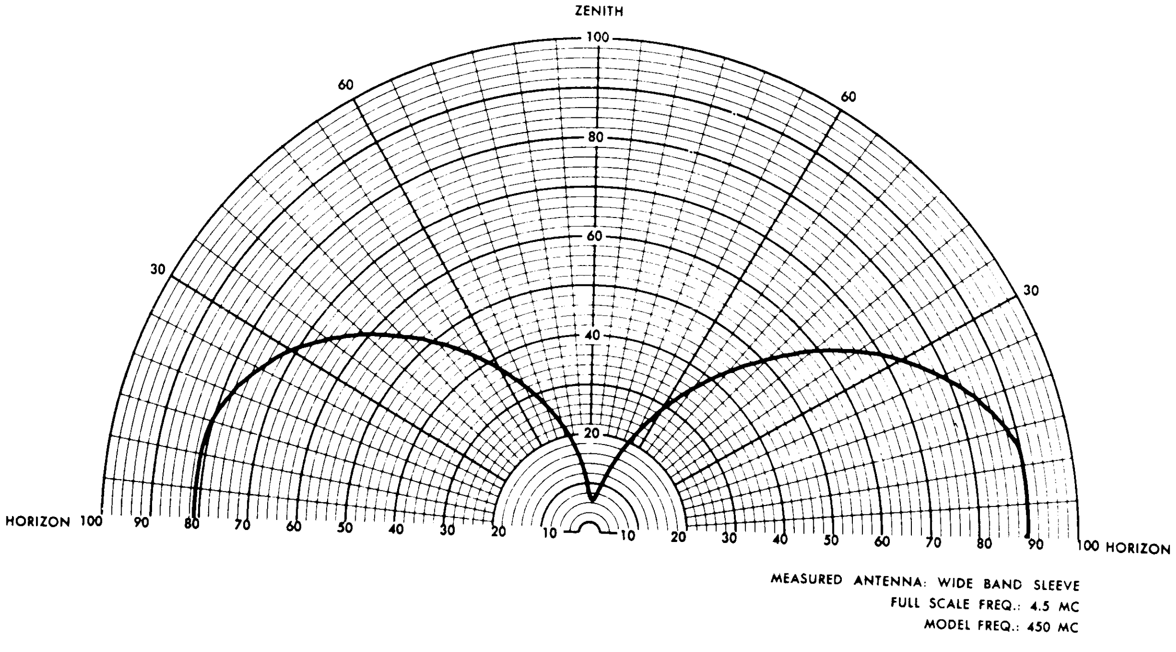
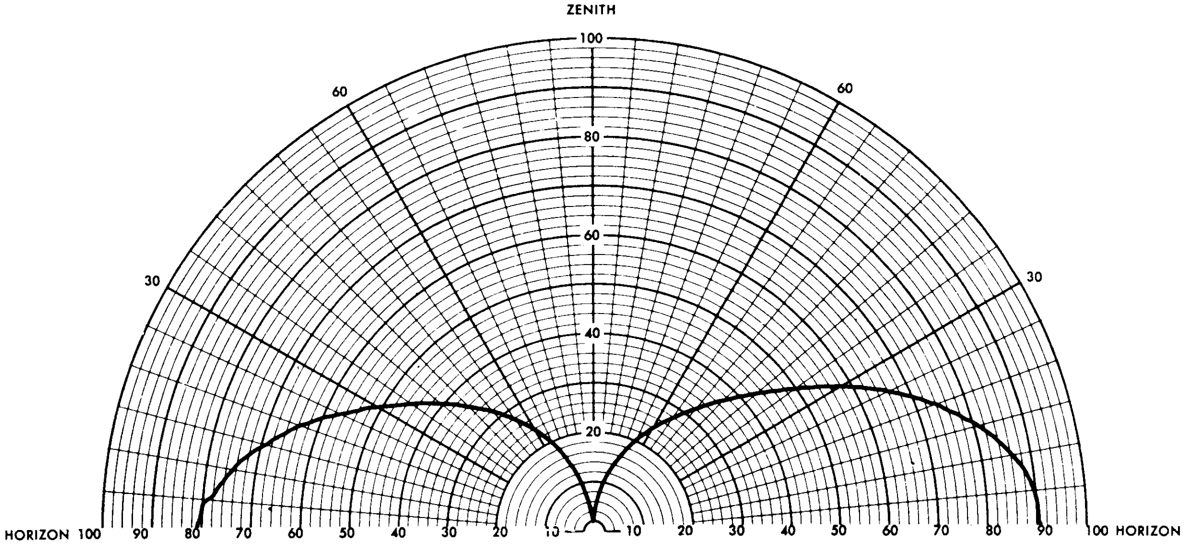


Figure 3. Vertical pattern of 1/100 scale model of experimental antenna at equivalent full scale frequency of 2.5 Mc.

Figure 4. Vertical pattern of 1/100 scale model of experimental antenna at equivalent full scale frequency of 4.5 Mc.

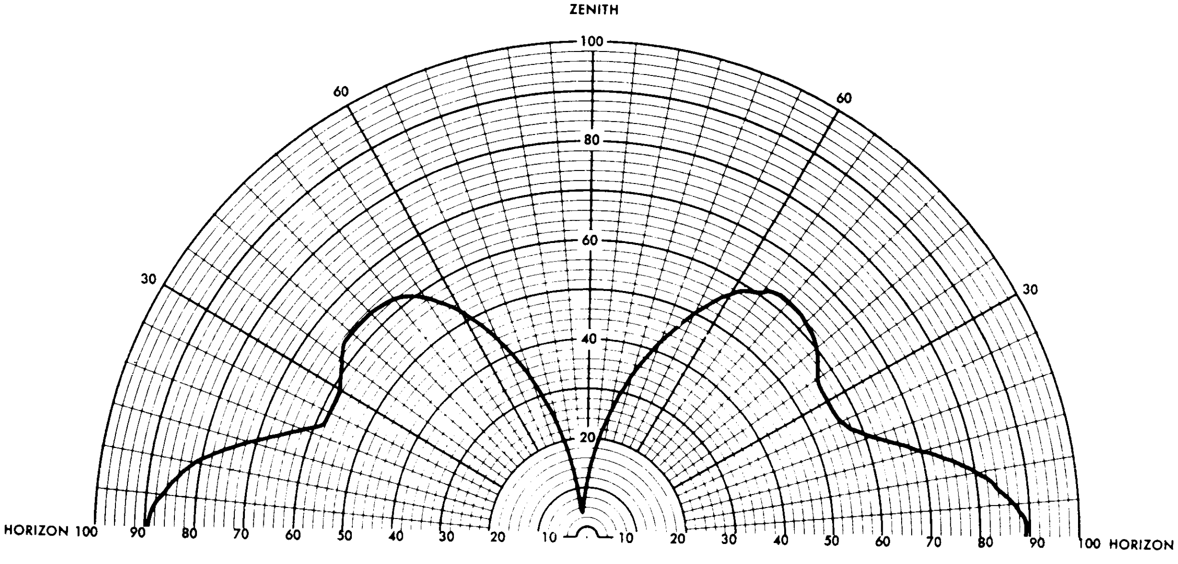




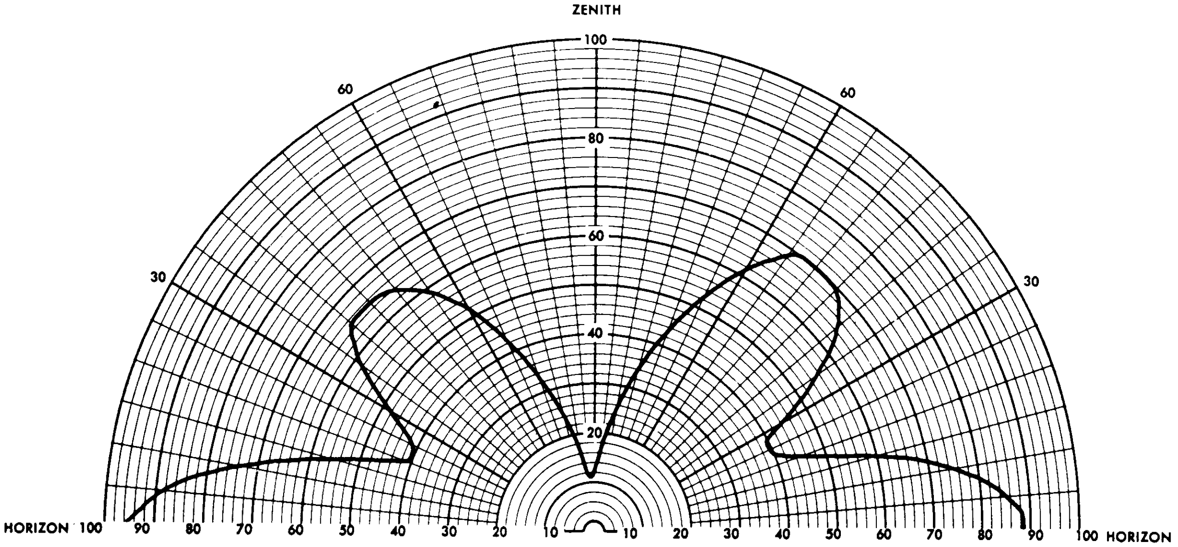
MEASURED ANTENNA: WIDE BAND SLEEVE
FULL SCALE FREQ.: 6.5 MC
MODEL FREQ.: 650 MC

Figure 5. Vertical pattern of 1/100 scale model of experimental antenna at equivalent full scale frequency of 6.5 Mc.

Figure 6. Vertical pattern of 1/100 scale model of experimental antenna at equivalent full scale frequency at 7.5 Mc.



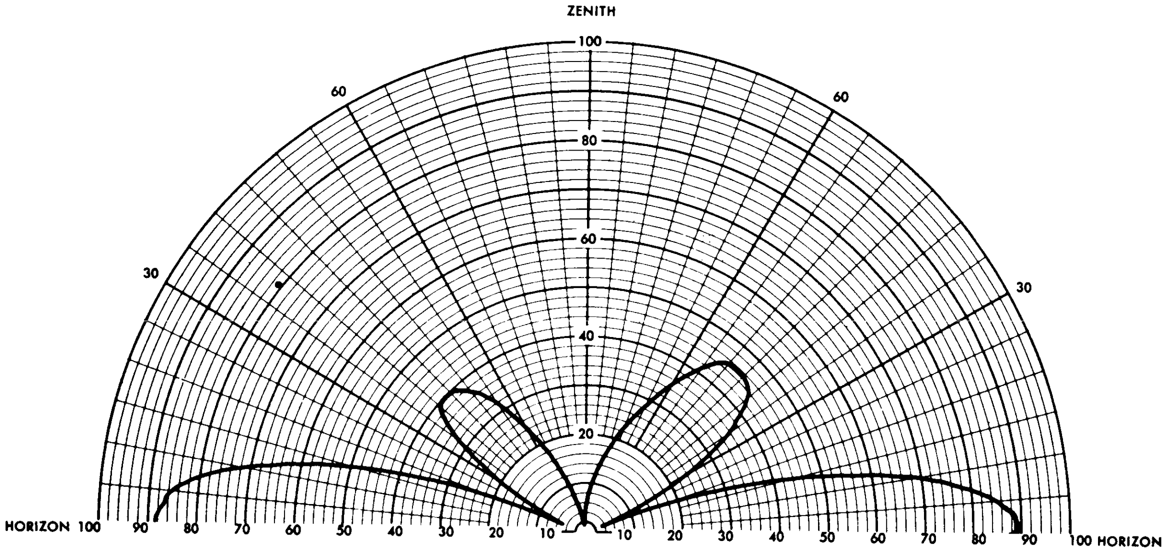
MEASURED ANTENNA: WIDE BAND SLEEVE
FULL SCALE FREQ.: 7.5 MC
MODEL FREQ.: 750 MC



MEASURED ANTENNA: WIDE BAND SLEEVE
FULL SCALE FREQ.: 8.5 MC
MODEL FREQ.: 850 MC

Figure 7. Vertical pattern of 1/100 scale model f experimental antenna at equivalent full scale frequency f 8.5 Mc.

Figure 8. Vertical pattern of 1/100 scale model of experimental antenna at equivalent full scale frequency of 9.5 Mc.



MEASURED ANTENNA: WIDE BAND SLEEVE
FULL SCALE FREQ.: 9.5 MC
MODEL FREQ.: 950 MC

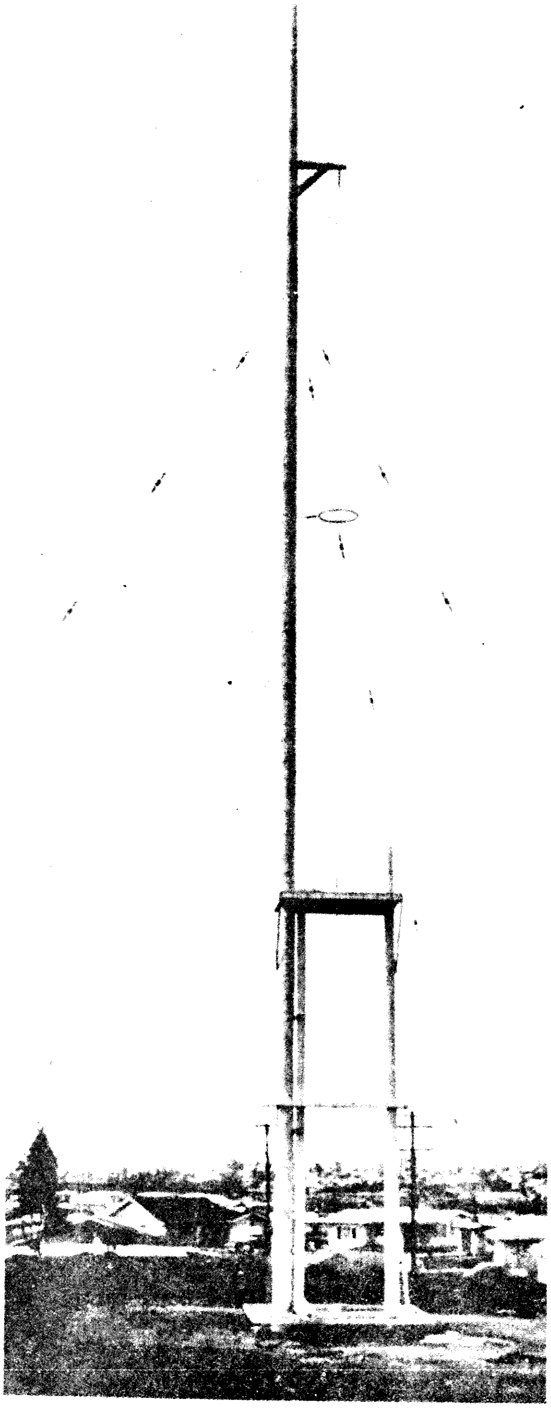


Figure 9. 2.5-to-7.5 Mc sleeve antenna at Chollas Heights Radio Station.

During the course of the development, the plan to use a standard steel tower as the base section was abandoned. It was determined that a wooden structure with parallel wires covering the sides from top to bottom would be far cheaper and equally as good electrically. Tests were made to find the minimum number of wires per side needed to simulate a solid-base structure. Ten wires per side proved to be sufficient.

description of experimental antenna

In order to test the practicability of the design, the Bureau of Ships requested that an experimental model of the 2.5-to-7.5 Mc antenna be constructed at a shore station in the San Diego area. Using sketches furnished by NEL, engineers from the Assistant Industrial Manager's Office, located at the U. S. Naval Station in San Diego, worked out the detailed mechanical design. This design is contained in five Asst Ind Man drawings numbers RJ-6F-2406, RJ-6F-2408, RJ-6C-2409, RJ-6C-2410, and RJ-6C-2415.

The 2.5-to-7.5 Mc antenna is shown in figure 9. The bottom sleeve section is 12 feet square at the base, 9 feet square at the top and is 30 feet high. The "radiator" section is 56 feet 6 inches long. It is 3 feet in diameter at the center and is tapered to a point at each end. A single long pole supports the top of the "radiator" and together with another short pole supports the sleeve section. The sleeve section is of open-frame construction with 10 wires per side forming the electrical circuit from the feed-point at its top to ground. The transmission-line transformer is a 38-foot section of 8-by-8 inch square trunk with a ⅞-inch OD center conductor supported on pedestal insulators. The top end of the trunk connects to the antenna at the "radiator" base and the bottom end connects to the RG-85/U transmission line which is fed from the transmitter.

The experimental model has a 36-foot-square ground-system of galvanized hardware cloth. Since its construction, the Bureau of Ships has recommended using a ground system of 120 radial wires extending outward from the antenna a distance equal to the height of the antenna. If these wires are insulated and lying on the surface of the ground, they should be terminated with 2-foot ground rods. This is an interim ground system, as more detailed study is required to determine the optimum.

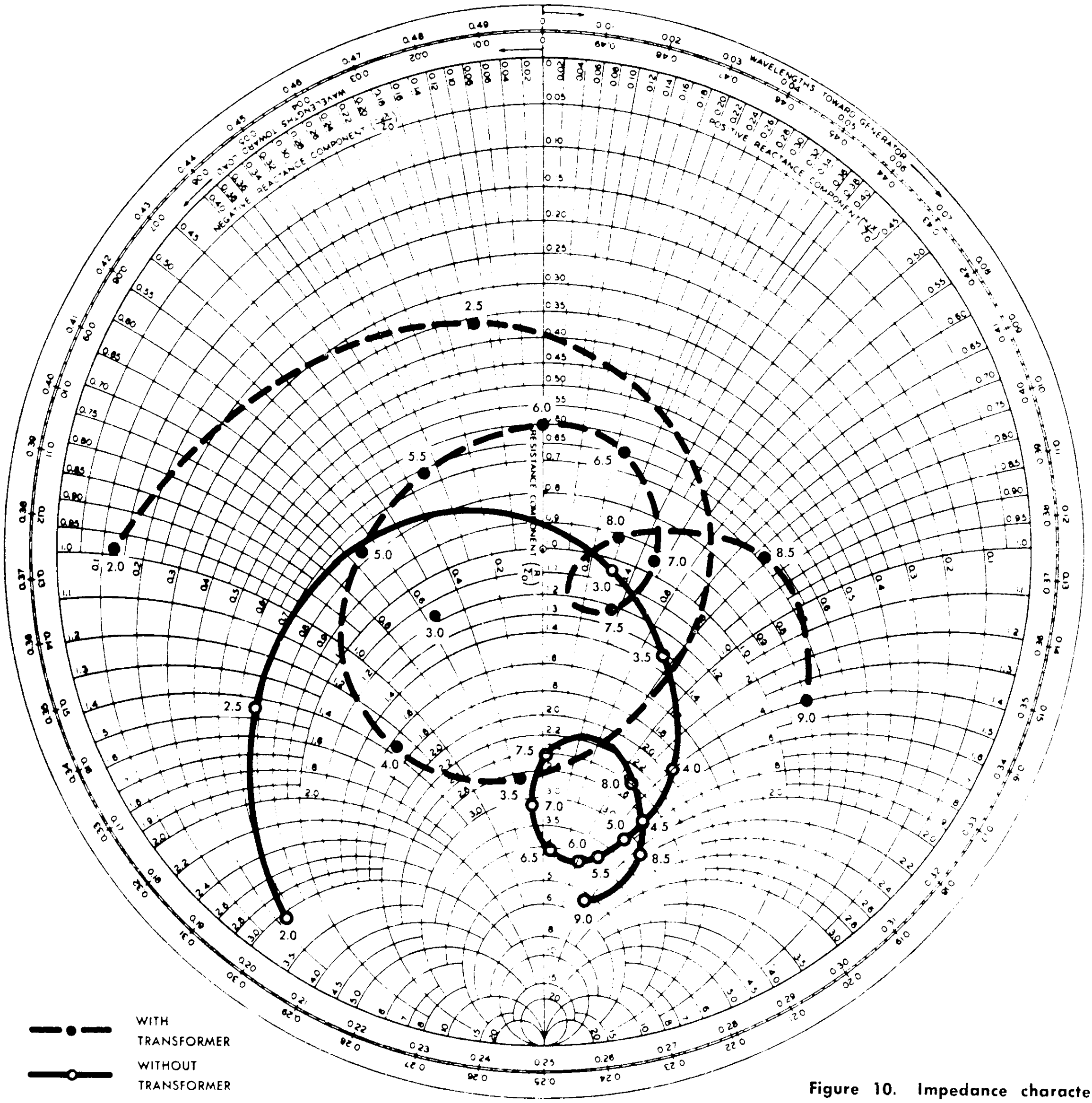


Figure 10. Impedance characteristics of full-scale prototype sleeve antenna.

The experimental model was constructed at USN Communications Station (T), Chollas Heights, California. An RG-85/U transmission line approximately 1000 feet long connects the antenna to a Navy Type TDH Transmitter.

test results on experimental antenna

Impedance measurements made on the full-scale experimental antenna and normalized to 75 ohms are plotted in figure 10. The dashed line shows the input impedance presented to the RG-85/U transmission line, while the solid line shows the impedance at the base of the "radiator." Since the ground dropped away sharply on two sides of the experimental antenna, only fair agreement could be expected between its impedance and that of the model antenna. A comparison of figures 2 and 10 shows this to be the case. Furthermore, a careful study of the impedance differences has indicated that they

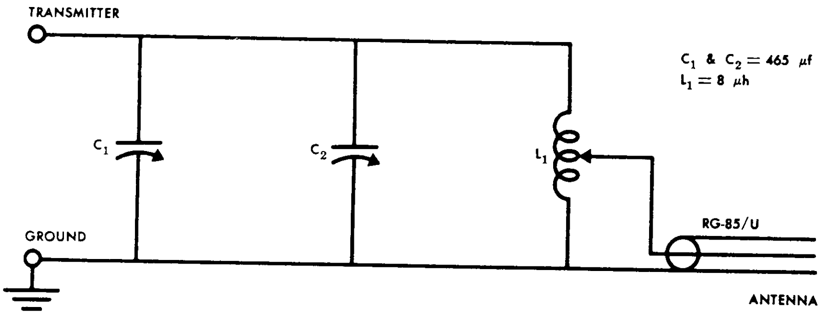


Figure 11. Schematic of modified coupling unit, Navy Type 50153.

are of the kind to be expected from the non-ideal location of the experimental antenna. In spite of these impedance differences, the VSWR of the experimental antenna as seen by the feed line is 3 to 1 or less from just below 2.5 to 8.5 Mc.

A complete study of the transformer section was not possible because of limited availability. However, the measurements which were made indicated that the supporting insulators had lowered the characteristic impedance from 137 ohms to 125 ohms, and reduced the velocity of propagation to 0.9 that of free space. This reduction in the velocity of propagation gave the transformer section an electrical length of about 42 feet.

The experimental antenna was fed by a TDH transmitter. In order to bring the antenna impedance within the normal range of the transmitter, a Navy Type 50153 Coupling Unit was inserted between the transmitter and the RG-85/U cable feeding the antenna. This coupling unit was modified as shown in figure 11 and then was mounted directly on the transmitter so as to keep the lead lengths as short as possible. With capacitors C_1 and C_2 set at capacitance minimum, and with the movable tap on coil L_1 set at the midpoint, the transmitter tuned normally throughout the 2.5-to-7.5 Mc range.

A test was made to compare the radiated field from the sleeve antenna to that from one of the station's regular antennas, a 56-foot vertical wire running upward from the top of the transmitter building. Since the sleeve antenna was designed for low VSWR, it had been located well in the clear by using the long transmission line. The vertical wire, on the other hand, was in the main cluster of antennas near the transmitter building. It was expected that the field from the sleeve antenna would be more uniform and of greater strength because of the high degree of coupling between the vertical wire and other antennas near it.

During the test, each antenna was connected in turn to the transmitter and a constant input power to the transmitter was maintained. Because of rough topography and residential construction in the vicinity of the station, it was necessary to measure the radiated field at a considerable distance. Measurements were taken at several azimuth angles at distances of 5 to 11 miles. Table 1 gives the comparative field intensities at several frequencies. The gain in the ground-wave intensity produced by the sleeve antenna averaged about 7 db as compared to that from the vertical wire antenna. Some of this gain may have been due to radiation at higher angles from the wire antenna (because of its coupling to other antennas); but it is probable that most of the difference resulted from losses in the wire antenna caused by the large induced currents flowing in the surrounding antennas and their respective transmitter load coils. These unwanted currents produce actual power losses as well as lower antenna radiation resistance.

Owing to the varying ground constants and rough topography, it was impossible to obtain true radiation patterns. However, the comparative measurements between the two antennas indicate that a horizontal plane directivity of 6 to 10 db was present.

TABLE 1. Ratio of rms values of ground-wave field intensities from prototype sleeve antenna and presently used 56-foot vertical-wire antenna.

Frequency (kc)	Field Intensity Ratio
2370	3.92
3310	2.91
4010	2.23
5870	1.70
7500	1.10

There appeared to be little difference in the magnitude of pattern variations of the two antennas, although the actual pattern shapes were different. This large variation in pattern was not expected for the sleeve antenna since it was located approximately 500 feet from the nearest of the three 600-volt vlf towers. Calculations were then made to determine the amount of directivity that would be possible, and these calculations showed that a directivity of 8 db might occur. This comparatively large amount of directivity is caused by the unusually large parasitic elements formed by the towers, and by the large number of parasitic elements in the vicinity.

design for other frequency ranges and receiving applications

After tests on the experimental model were completed, the Bureau of Ships requested that the transmitting sleeve antenna be designed also for two additional frequency ranges: 5.0 to 15.0 Mc and 7.3 to 22.0 Mc. Also it was requested that receiving sleeve antennas for all three frequency ranges be designed.

NEL sketches SK 722 E 140 and SK 722 E 141 contain the transmitting antenna designs for the two additional frequency ranges. For receiving antennas, the construction can be simplified by replacing the matching section of trunk line by a section of RG-63B/U cable. Table 2 lists the dimensional requirements of the various components of both the transmitting and receiving antennas. For other frequency ranges, the dimensions should be scaled as indicated in the table. Departures of 5 per cent from specified values will result in only minor changes in characteristics.

It was earlier recommended to BuShips that the length of the RG-63B/U used with each receiving antenna be made equal to the length of trunk line used for the corresponding transmitting antenna. Since then, tests have indicated that a cable which is 90 per cent the length of the corresponding trunk line will result in better impedance characteristics. These reduced lengths are accordingly recommended in table 2. The change is, however, only of minor importance, since the reduction in reflection loss coefficient is at most only a few tenths of one db.

TABLE 2. Dimensional requirements of sleeve antennas for three ranges in the high frequency band.

Frequency Range (Mc) and Antenna Type	Sleeve Top Width (ft)	Sleeve Bottom Width (ft)	Sleeve Height (ft)	Radiator Height (ft) (above sleeve)	Radiator Center Diameter (ft)	Transformer Length (ft) (center conductor)	Transformer Type	Ground Radial Length (ft)	Maximum Power from Transmitter (kw)
2.5-7.5 Transmitting	9.0	12.0	30.00	57.50	3.0	38.0	8 x 8 in trunk	175.0	8.0
5.0-15.0 Transmitting	4.5	6.0	15.00	28.75	2.0	19.0	8 x 8 in trunk	85.0	5.5
7.3-22.0 Transmitting	3.0	4.0	10.33	19.66	1.0	13.0	8 x 8 in trunk	60.0	4.5
2.5-7.5 Receiving	9.0	12.0	30.00	57.50	3.0	34.0	RG-63B/U	175.0	—
5.0-15.0 Receiving	4.5	6.0	15.00	28.75	2.0	17.0	RG-63B/U	85.0	—
7.3-22.0 Receiving	3.0	4.0	10.33	19.66	1.0	11.5	RG-63B/U	60.0	—

conclusions

1. The sleeve type antenna is well suited to broadband operation needs. Broadband-sleeve antenna operation is especially helpful in reducing the total number of antennas required as compared to conventional, resonant, narrowband antennas with long transmission-line runs. The sleeve antenna can be placed at distances up to 1000 feet from operating buildings, with small losses. It is also well suited to areas of restricted size, as it makes possible the use of multicouplers connecting one antenna to several receivers or transmitters on widely separated frequencies. By reducing undesired antenna intercoupling, broadband antennas can considerably increase the reliability of stations where many antennas are erected in a small area.

2. Operation with transmitters of a power output of 4.5 to 8.0 kw, depending on operating frequency, is possible with the present design. However, if higher power transmitters are to be used, or if several 3-kw transmitters are to be coupled to one antenna, it will be necessary to design a new feed system. The present power handling capacity of solid-dielectric transmission lines is the limiting factor.

3. Antennas such as the broadband sleeve have the same advantages over vertical wire antennas when used for receiving as when used for transmitting. However, they should not necessarily be substituted for horizontal-wire receiving antennas. In certain areas of high ambient noise, horizontal receiving antennas have inherently better signal-to-noise ratios.

4. Directivity is severe in locations where many very large parasitic elements are present, even when large separations from the elements are possible. This is true for any type of vertically polarized antenna.

recommendations

It is recommended that (1) broadband antennas, such as the sleeve antenna, be used to reduce the number of antennas required; (2) broadband antennas be used to increase efficiency by avoiding clustering of many antennas around a central point; (3) where possible, vlf antennas with very large structures be located apart from mf and hf transmitting stations; (4) development be initiated on a means of increasing the power-handling capability of broadband, unbalanced types of antennas; and (5) development be initiated to adapt the broadband, unbalanced antenna to directional uses.

APPENDIX VIII

Direction Finder Siting.

DIRECTION FINDER SITING

VIII-1. GENERAL.

Most of the factors affecting wave propagation may be directly applied to the needs of a direction finder site. For example, a resonant conductor will reradiate; its field, when added to the direct field, will cause a change in apparent bearing as well as the signal strength of the received signal. A slender conductor will be sharply resonant, so the effects will be apparent at one frequency, whereas a wide conductor, will be broadly resonant and the effects will be apparent over a rather wide range of frequencies. It is necessary to locate a D/F antenna sufficiently distant from a possible reradiator to reduce these effects to an acceptable level. Similar reasoning will, for the most part, provide criteria for optimum siting of any D/F array. The criteria set forth below are based upon such considerations and upon actual measurements, and will provide a guide for the siting of a D/F facility with minimum bearing errors. The total bearing error in the low and medium frequency ranges is the algebraic sum of the individual errors, but in the HF range, the r.m.s. value will give correct data since the phases are random. In the VHF/UHF range, a study of the individual site is required to determine the total bearing error. The individual error caused by each of the criterion listed below will be less than one degree.

VIII-2. SPECIFIC SITE CRITERIA.

a. ALL FREQUENCIES.

(1) SOIL CONDITIONS.—The soil should be homogeneous and have a conductivity of 10^{-13} emu. Poorer soil will result in greater horizontal polarized signal strengths with attendant swinging and blurring of the bearing indication; resulting in decreased accuracy.

(2) The site tilt must be less than 30 minutes. Sites with a uniform downward slope of less than two degrees in all directions will usually be good. For the purpose of this section, the site is considered to extend 600 feet in all directions from the antenna.

(3) ELEVATED HORIZONTAL CONDUCTORS.—An elevated horizontal conductor must not subtend a vertical angle greater than three degrees at the base of the direction finder antenna. If conducting towers are used, or if the elevated horizontal conductor is a receiving antenna, the tower or transmission lines will be of greater significance and siting must be accomplished for vertical conductors (see VIII-2.*b.*(1), *c.*(1), or *d.*(1)), except that the distance must be doubled due to the loading effect of the horizontal conductor.

(4) INCLINED CONDUCTORS.—See vertical conductors (VIII-2.*b.*(1), *c.*(1), or *d.*(1)).

(5) Railroads must be at least one-fourth mile from the antenna.

(6) Rivers and streams generally do not have any effect.

b. LOW AND MEDIUM FREQUENCIES (DAH, DAK AND SIMILAR).

(1) VERTICAL CONDUCTORS.—Any vertical conductor less than one-tenth wavelength long at the highest frequency of the direction finder must subtend a vertical angle of less than ten degrees at the base of the antenna. If the conductor is resonant within the band, it should be at least seven wavelengths (at the resonant frequency) from the antenna.

(2) BURIED HORIZONTAL CONDUCTORS.—Horizontal cables should be buried to a minimum depth of five feet when within 300 feet, three feet when between 300 and 600 feet, and two feet when beyond 600 feet of the D/F antenna. Good conductivity soil (VIII-2.*a.*(1)) is assumed. Depths must be increased for poorer soil. ($D = d\sqrt{\sigma \times 10^{-13}}$).

(3) WIRE FENCES.—For well grounded fences, distance to antenna should be at least 300 feet.

(4) LARGE CONDUCTING SURFACES.—See Buildings (VIII-2.*b.*(8)).

(5) TREES AND WOODS.—Distance from any antenna element to a single large tree must be 150 feet; to woods must be 1200 feet.

(6) HILLS AND MOUNTAINS.—Isolated hills should be at least 20 times their height from antenna. Mountainous country is not suitable.

(7) COASTLINES.—Minimum distance should be two wavelengths. For shorter distances, errors due to refraction up to four degrees may be expected for signals at grazing incidence.

(8) BUILDINGS.—Large metal buildings must be at least one mile from the direction finder antenna. Small metal buildings (emergency power, tool sheds, etc.) or metal objects (wiring, plumbing, ducts, equipment cabinets, etc.) in wooden buildings shall not sub-

tend an angle greater than two degrees at the base of the antenna.

(9) ROADS.—No effects, except see applicable section for elevated conductors, wire fences, and interference.

(10) RUNWAYS (reinforced concrete).—Minimum distance from edge of runway to direction finder antenna is 150 feet. Audio noise must be considered for operators efficiency. See also interference (VIII-3.*c.*).

(11) DITCHES.—No effects.

c. HIGH FREQUENCIES. (AN/GRD-6, DAJ AND SIMILAR.)

(1) VERTICAL CONDUCTORS.—Vertical conductors must not subtend an angle greater than three degrees at the D/F antenna.

(2) BURIED HORIZONTAL CONDUCTORS. —(VIII-2.*b.*(2)).

(3) WIRE FENCES.—Wire fences should not subtend an angle greater than one degree. In addition they should be bonded and grounded every five feet.

(4) LARGE CONDUCTING SURFACES.—A flat surface, one wavelength long and one wavelength high, should be 25 wavelengths or more from the direction finder antenna. The distance is directly proportional to the area.

(5) TREES AND WOODS.—A single tree should be 500 feet or more and a woods should be at least one-half mile from the D/F antenna.

(6) HILLS AND MOUNTAINS.—See section VIII-2.*b.*(6).

(7) COASTLINES.—Refraction is not an important factor.

(8) BUILDINGS.—For metallic buildings, see section VIII-2.*c.*(4). Metallic objects, including wiring, plumbing, ducts, and reinforcing steel, in wooden, masonry, or concrete buildings must not subtend a vertical angle greater than one degree at the base of the antenna.

(9) ROADS.—No effects. See buried conductors if reinforced or pipelines under road exist. See elevated horizontal conductors if telephone, telegraph, or power lines parallel road. Also see interference.

(10) RUNWAYS.—Minimum distance of one wavelength to edge should be maintained. Reradiation interference and audio noise caused by aircraft must be individually studied.

(11) DITCHES.—No effects.

d. VHF AND UHF (AN/URD-2, AN/URD-4, AND SIMILAR).

(1) VERTICAL CONDUCTORS.—Vertical conductors should not subtend an angle greater than one and one-half degrees at the D/F antenna.

(2) BURIED HORIZONTAL CONDUCTORS. —No significant effect.

(3) WIRE FENCES.—Single wire fences should be no closer than 600 feet. Wire mesh fences should be avoided; if required, they should be well bonded and grounded and treated as VIII-2.*d.*(4).

(4) LARGE CONDUCTING SURFACES.—A flat surface, one wavelength long and one wavelength high should be at least 50 wavelengths from the direction finder antenna. The distance is directly proportional to the area.

(5) TREES AND WOODS.—Single trees should be 500 feet and woods should be 1200 feet from the base of the antenna.

(6) HILLS AND MOUNTAINS.—Errors may be caused by reflections. Treat as in VIII-2.*d.*(4).

(7) COASTLINES.—No effect.

(8) BUILDINGS.—Treat as in VIII-2.*d.*(4).

(9) ROADS.—Minimum of five wavelengths distant at lower frequencies. See section VIII-3.*c.*

(10) RUNWAYS.—See section VIII-2-*c.*(10).

(11) DITCHES.—Shallow, irregular ditches may be 300 feet distant, whereas deep, straight ditches should be 500 feet distance.

VIII-3.

In addition to the considerations given to terrain features and man-made structures which create bearing errors, the following criteria must be adhered to for the prevention of man-made noise:

a. RADIO TRANSMITTER STATIONS.—Major transmitter stations should be no closer than five miles, and minor or emergency stations no closer than one mile.

b. HOUSING.—The widespread use of household electrical appliances requires that housing areas be no closer than 1500 feet to the D/F site.

c. INTERFERENCE.—Ambient interference level should be less than three microvolts per meter throughout the desired frequency range.

VIII-4

The criteria above must not be abrogated by encroachment after the site has been selected. Regular inspections must be made to insure this.

APPENDIX IX

SOURCE MATERIAL

APPENDIX IX

Multiple VHF/UHF Communication Systems

The following paragraphs of interest to the system planner of multiple VHF/UHF communication systems have been extracted from Reference 44, Appendix XII.

Although the referenced report deals primarily with details concerning shipboard installation, many similar problems confront the system planner for RATCC and control tower facilities where space limitations and multichannel operation impose planning problems. The full report should be consulted for factors which must be considered in order to obtain optimum equipment performance.

INTRODUCTION (from the referenced report)

The performance of a UHF communication system depends on many variables, only some of which are under the partial control of the systems planner. There are two general classes of these variables: those that govern the performance of a single channel, and those that become important when several channels are operated simultaneously from a limited area. Most of the variables affecting the performance of a single channel are well recognized and allowance is made for their effect in the systems design. Those that become important when several individual channels are integrated into a coordinated system are not always considered, and the over-all systems performance may fail to meet expectations. An understanding of these latter variables is urgently needed, because the simultaneous operation of a comparatively large number of channels from a platform of limited size is of vital importance to the Navy.

Three major factors influence the engineering of a UHF communication system: the frequency plan, the antenna system layout, and the communication equipment characteristics. It is necessary to keep constantly in mind that these three factors are closely interrelated and that each influences the others. The improvement possible by consideration of any of the factors individually, without coordination with the others, is insufficient to produce a satisfactory system.

From a study of the methods of utilization and interference characteristics of present communication equipments, the isolation required in the antenna system to avoid various types of interference can be determined. It will be shown that with practical antenna systems some of the isolation requirements can be met and others cannot. This still leaves some types of interferences and interactions; these can be dealt with only by carefully designed and controlled frequency plans.

SCOPE OF REPORT

This report shows how to establish a number of coordinated frequency plans, each of which contains a maximum number of frequencies that can be used simultaneously on one ship (station) or in one task group without interference, and all of which can be used simultaneously in a task force with minimum mutual interference. These frequency plans are based upon experimentally determined interference and performance characteristics of currently used communication equipments. The emphasis is on the best methods of utilizing presently available communication equipments, with their existent shortcomings, rather than on methods for future improvement of the equipments.

In this report, only the UHF communication band of 225 to 400 megacycles is considered in detail, and only data applicable to this frequency band are presented. However, most of the same basic problems also apply to the high frequency communication band and the same methods of analysis can be used; of course, somewhat different electrical characteristics and physical arrangements of antennas and equipments would be found.

In addition to showing how to establish coordinated frequency plans, this report attempts to supply the basic information needed to establish rules for best frequency assignment. It analyzes the types of interference encountered and the physical situations in which they exist, as well as supplying experimental data on the characteristics of equipments in current use.

For given communication equipment combinations and antenna system arrangements, experimental data are given which lead to conclusions as to the minimum frequency separation between channels required to control those interferences and interactions which primarily depend on the minimum channel separation. The experimental data show also how to determine those additional interferences which depend, not on the minimum channel separation, but on the discrete frequency relationships between channels, and which cause certain noncontiguous channels to be unusable.

Probably, a completely interference-free communication system of adequate capacity cannot yet be realized. The demand for channel assignments is so great and the potential types of interference are so many, that insufficient interference-free channels exist to permit an adequate number of non-interfering frequency plans for simultaneous operation in one area. A compromise has to be made in which some of the less frequently used channels occasionally are subjected to some of the less objectionable forms of interference.

Although the system planner for a naval shore facility may have little control of the frequency plan to be employed in a given system, the planner must take into consideration equipment arrangement and operation so as to obtain optimum performance under a prescribed frequency plan.

CONTROLLABLE FACTORS IN COMMUNICATION SYSTEMS PERFORMANCE

Once the decision is made as to the transmitters and receivers for a communication system, only a few additional variables remain under the control of the planner. The most important are the antenna arrangement, whether and in what manner antenna multicouplers are to be used, and the frequency plan for channel utilization.

The antenna arrangement is important in that it determines both the antenna radiation pattern distortion and the mutual coupling between antennas and, hence, between equipments operating on the same ship (station). As will be shown later in the report, mutual coupling between equipments produces many undesirable effects: transmitter intermodulation, transmitter and receiver cross-modulation, detuning of transmitters, energy dissipation, receiver intermodulation, and receiver desensitization. Desirable antenna arrangements will be considered in considerable detail.

The choice and manner of application of antenna couplers are important. When couplers are applied to reduce the number of antennas in a system, by permitting the operation of two or more equipments simultaneously on one antenna, the coupler selectivity replaces the electrical isolation between equipments normally obtained by antenna separation. However, couplers also may be useful in supplementing the somewhat limited radio frequency selectivity normally available in transmitters and receivers, even in situations where no strong incentive exists to reduce the number of antennas. When so applied couplers function essentially as filters and may do much to increase the number of interference-free channels obtainable in a system. The advantages of using couplers greatly exceeds the disadvantage of the small loss in power incurred by their proper application. The importance of the frequency plan for channel utilization has, of course, already been discussed.

TRANSMITTER INTERMODULATION

When two or more transmitters operate simultaneously in a situation where appreciable coupling exists between their outputs, spurious radiations called intermodulation products may be produced by the mixer or modulator action due to nonlinearity of the final power amplifier. Two voltages are present in the plate circuit of the final power amplifier, one due to the desired transmitter and of channel frequency, and the second due to coupled energy from the interfering transmitter and of a nearby frequency. The spurious radiations occur at frequencies related to the sum-and-difference frequencies of the two signals, and multiples thereof. The sum frequencies fall outside the communication band and do not interfere directly with communication equipments, unless out-of-band spurious receiver responses exist. The radiations related to the difference frequencies produce a series centered about the desired carrier frequency and spaced by multiples of the difference frequency. Harmonic frequencies of each of the carriers are also produced but, in general, fall outside the UHF communication band.

The final result of intermodulation is a number of groups of spurious radiations, each group consisting of frequencies centered about the center frequency and separated from it by small multiples of the difference between that center frequency and the frequency of every other transmitter that might be used simultaneously. Where the separation in transmitter frequencies is small, the amplitude of the spurious radiations tends to be large; as the separation increases, the amplitude tends to be smaller and finally becomes inconsequential.

When more than three transmitters operate simultaneously, as in many actual situations, the calculation of spurious radiations due to intermodulation becomes cumbersome. A later section of this report, on the calculation of frequency plans, describes a more convenient technique to use for a large number of channels.

The degree of coupling between transmitters needed to produce the spurious radiations due to intermodulation usually exists only between transmitters on the same ship (*station*). The magnitude of the coupling depends on the antenna placement and on whether antenna couplers are used. Due to the selectivity in the antenna tuning and output circuits of the transmitters, and in the couplers if used, the effective coupling decreases rapidly with increasing frequency separation between the channels. When frequency separation is small, the spurious radiations near the carrier frequency may be only 20 or 25 db below the carrier level.

It will be shown that spurious radiations of such magnitude make any channels upon which they fall completely unusable in the whole communication area.

RECEIVER INTERMODULATION

When two strong signals on different frequencies simultaneously reach the input terminals of a receiver, an effect very similar to transmitter intermodulation may be produced by lack of sufficient receiver selectivity and nonlinear action of the mixer tube. The simultaneous presence of the two signals at the mixer circuit produces sum-and-difference frequencies and multiples thereof. These receiver intermodulation products are of the same nature and on the same frequencies as the transmitter intermodulation products just discussed. If the receiver is tuned to the frequency of any of these intermodulation products, they are converted to the receiver intermediate frequency by heterodyne action in the usual manner, and a receiver response results. Similar responses may result when three or even more strong signals exist simultaneously at the receiver input.

Extensive precautions to avoid receiver intermodulation effects do not appear to be essential at the present time in Naval UHF communication systems. The transmitter intermodulation effect produces interference upon the same channel frequencies as does receiver intermodulation and usually at such amplitude levels as to make those channels unusable. Since control measures available for the reduction of the effects of transmitter intermodulation are insufficient to clear the channels for normal use, the receiver intermodulation effect would fall upon channels already subject to interference and therefore better left unassigned.

Receiver intermodulation effects are reduced by any measures, preceding the mixer tube of the receiver, that increase the selectivity or discrimination against off-channel signals. Antenna couplers assist in providing such selectivity and, hence, in reducing receiver intermodulation. Increase of the physical separation or electrical isolation between the receiving antenna and nearby transmitting antennas is also helpful.

Limited receiver intermodulation tests were attempted exposing AN/URR-13A and AN/URR-35 receivers to two strong signals. No receiver intermodulation products were detected.

RECEIVER DESENSITIZATION

When a receiver operates in close electrical proximity to a transmitter, but on a somewhat different frequency, receiver desensitization may occur. The transmitter may feed sufficient off-channel energy into the receiver input terminals to alter the operating point or bias of the radio frequency amplifier and mixer tubes. This shift reduces the receiver gain on the desired signal frequency and may seriously impair the reception of a weak signal. The effect may be overlooked completely by the average operator, particularly if the strong interfering signal should be unkeyed and unmodulated. The receiver whose sensitivity is reduced may operate normally in every other respect.

Receiver desensitization is a function of the amplitude of the portion of the strong interfering radiation reaching the radio frequency amplifier or mixer tubes. It can be controlled by selectivity preceding the radio frequency portion of the receiver, or by space attenuation of the interfering radiation. Increased frequency separation of adjacent channels or the use of antenna couplers increases the selectivity. Increased spacing between receiving and transmitting antennas increases the space attenuation.

Figures 17A to 17F show the results of desensitization measurements on three receivers of different types of different frequencies. The receivers were adjusted to standard sensitivity, and the receiver response to a desired signal of amplitude sufficient to give standard output with no interfering signal present was determined. An interfering signal, separated by a small frequency increment from the desired signal, was introduced and increased in amplitude until the receiver response to the desired signal decreased by a predetermined amount between 0.5 db and 6 db, thus showing a reduction in effective receiver sensitivity. The interfering signal level plotted is with respect to the level of the desired signal. Correction factors converting the values to decibels below one watt are included. To control receiver desensitization, sufficient attenuation or selectivity must exist between the interfering signal source and the receiver input terminals to reduce the interfering signal to the indicated dbw level.

Figure 17 shows that, on the average, the receivers provide discrimination against strong signal desensitization of approximately 90 to 110 db, depending upon the receiver type and the frequency separation between the interfering and the desired signal. The AN/URR-13A receiver displays the least discrimination against desensitization while the R-278B/GR receiver displays the most, although the difference is not great.

The tolerable interfering signal levels at the receiver input terminals are approximately - 15 dbw to - 45 dbw. Since a 100-watt transmitter has a power output level of 20 dbw, a total of 35 db to 65 db attenuation must be provided between the transmitter output terminals and the receiver input terminals, if receiver desensitization is to be eliminated.

RESULTS OF STUDY

From this study it is concluded that:

1. There are many potential sources of interference between transmitters and receivers operated simultaneously on a number of channels in a limited area.

2. These potential interferences are of great importance to the Navy because of its frequent and almost unique need to operate many channels simultaneously from a very limited area, a single ship (or station).

3. Many of these potential interferences are of such magnitude under average conditions that they render certain channels completely unusable.

4. Careful antenna system design to reduce coupling between antennas on the same ship (station) can ameliorate interference conditions but cannot eliminate them entirely.

5. The application of antenna couplers to an antenna system in order to reduce the number of antennas may result in an increase or a decrease in the interference between circuits.

6. The energy losses and consequent reduction in range with well-designed couplers properly used is very small.

7. The selectivity of presently available types of couplers varies greatly. High selectivity in a coupler results in a considerable reduction in interference effects and increases the number of channels that may be used simultaneously.

8. Presently available types of transmitters and receivers vary considerably in their interference producing characteristic.

9. The intermixture into one system of types of transmitters and receivers having different basic design characteristics, results in a considerable increase in the number of interferences and a reduction in the number of usable channels.

10. The frequencies subject to interference can be calculated by relatively simple relationships.

11. The magnitude of the interferences can be estimated from laboratory data on equipment characteristics.

12. A random selection of channel frequencies without consideration of system and equipment characteristics is almost certain to result in intolerable interference on a number of channels.

13. After all available techniques for interference reduction have been considered, it is essential that a careful selection of frequencies be made to render innocuous interferences that cannot be eliminated.

RECOMMENDATIONS

It is recommended that:

1. Antenna systems be designed so as to realize the maximum possible isolation between antennas located on the same ship (station). Vertical collinear separations of approximately five feet center-to-center or horizontal separations of 20 feet provide isolations of approximately 35 db. An increase in vertical separation provides some increase in isolation but for horizontal separations a 20 foot separation represents the point of rapidly diminishing returns.

2. Antennas be assigned to equipments in such a manner as to maximize the isolation obtained between transmitters and receivers, keeping the transmitters in one group and the receivers in a second group.

3. If an AN/GRC-27 radio set be included in the system, then the T-217 A/GR transmitter be assigned to the antenna having the greatest isolation from adjacent antennas.

4. Efforts be made, if feasible, to restrict the use of the Model TED transmitter and the AN/URR-13A receiver to situations where a maximum number of interference-free channels are not required. The AN/URR-35 receiver and the AN/GRC-27 equipments have superior selectivity and interference characteristics.

5. The circuits carrying the heaviest traffic loads be assigned to the lower frequencies where both selectivity and efficiency are generally higher.

6. Frequency plans be studied carefully to minimize interference and to maximize the number of usable channels. This will require a knowledge of equipment characteristics and the conditions under which they are used. Seldom will the number of usable channels exceed 20 per cent of the gross number of channels available for assignment.

7. Every effort be made to use antenna couplers of the latest available design having superior selectivity.

8. Serious consideration be given to the application of antenna couplers to conform to antenna system Arrangement D, which separates transmitters and receivers as explained in this (*referenced*) report. The use of this arrangement increased the number of usable channels in a frequency plan from 11 to 18, a substantial increase.

9. As demand for channels increases, consideration be given to the design and use of tunable resonator or filter circuits as preselectors preceding receiver input circuits to supplement the radio frequency selectivity of receivers, and following transmitter output terminals to reduce spurious radiations and intermodulation product production, for use in situations where reduction in the number of antennas is not a requirement.

PERTINENT DATA CONCERNING SYSTEM TESTS AND PERFORMANCE STANDARDS

a. SAMPLE MAINTENANCE CHECK CHARTS FOR THE NAVY UQ MICROWAVE SYSTEM.—The following check-out sheets are used in maintenance at one Navy activity provided with microwave link facilities. The procedures follow those prescribed in the instruction book, with several additional items for check-out which experience has found to be useful.

NAVY U Q
Daily Maintenance Check Chart

Page 1.

STATION "A" RF Bay# ________ Week Beginning ________________

DAY	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
Transmitter A							
Frequency ________ Div							
Power - Div							
Transmitter B							
Frequency ________ Div							
Power - Div							
Receiver A							
Frequency ________ Div							
AVC - Div							
Receiver B							
Frequency ________ Div							
AVC—Div (if applicable)							
Combined Receiver							
AVC—Div (if applicable)							
Temperature & Ventilation							
Power Circuit Lamps-Lighted							

NOTE:

Record transmitter frequency then reset if 3 divisions or more off
Set transmitter power at 25 divisions with new tubes. Replace tube
when power drops to 50 percent.

NAVY U Q
Daily Checks

Page 2.

LINE PRESSURE ON WAVE GUIDE (Lbs.)

STATION B RECEIVER	STATION B TRANSM'TR	STATION C RECEIVER	STATION C TRANSM'TR	CN - 259/U		DATE
				REG. #1	REG. #2	

NAVY U Q
Weekly Maintenance Check Chart

Date_______________

1. Check all knobs.

2. Meter readings in RF equipment

TRANSMITTER NUS-1429	BAY #1		BAY #2	
	XMTR A	XMTR B	XMTR A	XMTR B
Signal input				
1st amp cathode current				
2nd amp cathode current				
Modulator current				
Wavemeter				
Power output				

RECEIVER NUS-1415	BAY #1		BAY #2	
	RCVR A	RCVR B	RCVR A	RCVR B
Osc. grid current				
Osc cathode current				
Wavemeter				
Xtal current				
AVC Volts				
I F current				

POWER SUPPLY NUS-1417	BAY #1		BAY #2	
	P.S. A	P.S. B	P.S. A	P.S. B
Line volts (115V)				
Low volts (220V)				
High volts (1000V)				
DC current				

3. Inspect all transmitter blower air filters for cleanliness.

4. Check 250 v.b+; on all mods & demods.

5. Check all pulse trains: (The oscilloscope, OS-38/FRC is set up for examination of the pulse train output of the modulator, OA/FRC. Examination is made at test point number 5, E 508, and will show the marker pulses and all channel pulse outputs. Pulses should be uniformly spaced and have equal amplitude. If not, it can be determined which channels require re-alignment of the pulse position and if corrective maintenance procedures are necessary. Minor alignment can be made to individual channels as necessary. The techniques as prescribed in Vol 1, Sect. 5, paragraph 7b(6) apply particularly.

NAVY U Q
Monthly Maintenance Check Chart
NAVSHIPS 91845 - Vol. 1, Table 5-8)

Date ____________

1. Clean cabinet interiors.

MOD BAY			DEMOD BAY			RF BAY		PATCH BAY	
1	2	3	1	2	3	1	2	1	2

2. Check all terminal boards and connectors. ____________

3. Check emergency power. ____________

4. Check primary source voltage.
Line #1 ________ Volts Line #2 ________ Volts

Record regulated voltage.
Regulator #1 ________ Volts Regulator #2 ________ Volts

5. Check tube life records. (NO NORMAL SERVICE PERIODS ARE AVAILABLE AT PRESENT.)

6. D-C Voltages NUS-1419 #250 Volts.

MOD BAY #1	________ Volts	DEMOD BAY #1	________ Volts
#2	________ Volts	#2	________ Volts
#3	________ Volts	#3	________ Volts

7. Receiver pulse train output.

RF BAY #1		RF BAY #2	
RCVR A	________ Volts	RCVR A	________ Volts
RCVR B	________ Volts	RCVR B	________ Volts

8., 9., and 11., see page 2.

10. See pages 3 and 4.

11. Record any noise greater than -53DBM (60 DB S/N)

DEMOD BAY #	PULSE #	NOISE	DEMOD BAY #	PULSE #	NOISE
		DBM			DBM
		DBM			DBM

Noise corrected by ________________________
(Tube replaced, TX repaired, etc).

12. Record any distortion greater than -19DBM (26 DB S/Dist. -5%).

DEMOD BAY #	PULSE #	DISTORTION	DEMOD BAY #	PULSE #	DISTORTION
		DBM			DBM

13. Alarms.

MOD ALARM	TX STANDBY ALARM	DEMOD ALARM
1. ______	1. ______	1. ______
2. ______	2. ______	2. ______

14. Fade Margin and Receiver Adjustment. (see note 1, page 9)

NAVY U Q
Monthly Maintenance Check Chart

Page 5.

8., 9., and 11.

	MOD BAY						DEMOD. BAY		
	PULSE POSITION			MODULATION			PWM		
BAY #*	-0.1 usec			-15DBM for 2.0 usec			Hump below baseline		
PULSE #	1	2	3	1	2	3	1	2	3
*1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									

RECORD THEN REPAIR

NAVY U Q
Monthly Maintenance Check Chart

10. Waveforms.
(See NAVSHIPS 91845 Volume 1, Figures 5-14 through 5-38)

		VOLTS	WIDTH
5-14	Transmitter NUS-1429, Video INPUT AT E204		
	RF BAY #1 - XMTR A		
	- XMTR B		
	RF BAY #2 - XMTR A		
	- XMTR B		
5-15	Transmitter NUS-1429, VIDEO OUTPUT AT E205		
	RF BAY #1 - XMTR A		
	- XMTR B		
	RF BAY #2 - XMTR A		
	- XMTR B		
5-17	Delay line pulse generator NUS-1422B DELAY LINE INPUT AT TP1 (E104)		
	MOD BAY #1		
	#2		
	#3		
5-18	Delay line pulse generator NUS-1422B DELAY LINE OUTPUT AT TP2 (E105)		
	MOD BAY #1		
	#2		
	#3		
5-21	Three KC modulator NUS-1424B, PULSE OUTPUT E202 on NUS-1420B.		
	MOD BAY #1 Smallest Pulse (Should be at least		
	#2 Smallest Pulse 50% of largest pulse)		
	#3 Smallest Pulse		
5-25	Marker pulse generator and mixer line amplifier NUS-1423C-CHANNEL PULSE INPUTS AT TP1, TP2, and TP3 (E504, E505 and E506)		
	MOD BAY #1 Smallest Pulse		
	#2 Smallest Pulse		
	#3 Smallest Pulse		
5-26	Same as 5-25, MARKER PULSE AT TP4 (F507)		
	MOD BAY #1		
	#2		
	#3		

NAVY U Q
Monthly Maintenance Check Chart

10. Waveforms. (continued)

			VOLTS	WIDTH
5-27	Same as 5-25, PULSE TRAIN OUTPUT AT TP5 (E508)			
	MOD BAY #1			
	#2			
	#3			
5-28	Demod, mounting Chassis NUS-1421 (E602)			
	INPUT TO DEMOD			
	DEMOD BAY #1	(Check each of the three E602's in each bay. They should be the same).		
	#2			
	#3			
5-29	Marker separator and pulse generator NUS-1426E			
	DELAY LINE INPUT AT TP2 (E904)			
	DEMOD BAY #1			
	#2			
	#3			
5-30	Same as 5-29			
	DELAY LINE OUTPUT AT TP3 (E905)			
	DEMOD BAY #1			
	#2			
	#3			

NAVY U Q
Monthly S/D and S/N Check
MOD and DEMOD are in SPARE CONDITION

CHANNEL	STATION B MOD & DEMOD		STATION C MOD AND DEMOD		SPARE MOD AND DEMOD	
	S/N	S/D	S/N	S/D	S/N	S/D
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
	(SEE NOTE 2, Page 9.)					

NAVY U Q
Monthly Maintenance Check Chart

NOTE 1. (See Page 4)

(14. Fade Margin and Receiver Adjustment)

Ref. Sect. 3, Para. 6aa, UQ INSTRUCTION BOOK.

This check can be made without disabling active equipment by performing check on a receiver in "standby" condition.

Disconnect the video output of the receiver from the system and terminate into a 68 ohm resistance load. (130 ohms if receivers are used in diversity.)

Connect OS-38/FRC oscilloscope across output of receiver.

Adjust oscilloscope gain for amplitude of 2 blocks. Input to the receiver is a signal from the transmitter normally associated with this microwave link.

Insert sufficient RG-21 lossy line input to reduce output to 50% (one block on the oscilloscope).

The amount of lossy line added should total 35 DB or more for a normally operating receiver - less than this amount indicates a requirement for corrective maintenance.

Adjustments made while the receiver is in this condition are:

Oscillator (maximum output);
Mixer (maximum output and maximum AVC as read on the
  monitor meter in AVC position);
Tube replacement in IF strip.

NOTE 2. (See Page 8)

The extra lines are used for checking S/N on active multiplex channels after first being checked under "standby" condition. Channel numbers checked are those channels in critical condition, or any unmodulated channel available.

NAVY U Q

Microwave QUARTERLY Maintenance Check Chart

Date

CABINET BLOWER MOTOR	INSPECT RECORD OF TIMES OF PREVIOUS LUBRICATION	
ALL BLOWER MOTORS	INSPECT IMPELLERS FOR DIRT	

Microwave SEMI-ANNUAL Maintenance Check Chart

Date

ANTENNA	CHECK FOR LOOSENESS OF MOUNTING AND OTHER MECHANICAL FAULTS	
R-F TRANSMISSION LINES	CHECK FOR LOOSENESS OF SUPPORTS AND COUPLINGS SHARP BENDS AND BREAKS	
RELAYS	CHECK MOVEMENT & CONTACTS	
OSCILLATOR TUNING SHAFTS & WORM GEARS IN XMTRS & RCVRS.	CHECK FOR FREE MOVEMENT	

Microwave ANNUAL Maintenance Check Chart

Date

ADJUSTMENT OF DIPLEXER STUBS	SEE PARAGRAPH 3h(3)	
CROSSTALK	CHECK CROSSTALK BETWEEN CHANNELS AT ALL STATIONS HAVING MULTIPLEX EQUIPMENT (INCLUDING REPEATERS WITH DROP AND INSERT). SEE PARAGRAPH 31.	

b. SINGLE SIDE BAND OPERATION.

SSB OPERATION

The following extract from OPNAVINST 2300.2 dated 23 December 1953, is quoted for guidance in SSB operation:

"Discussion and Criteria for operation of Carrier Suppression and Carrier Suppression Compensation Circuits in the Single Side Band (SSB) Suppressed Carrier Multi-Channel Communication System"

SUBJECT: SSB - Carrier Suppression and Carrier Suppression Compensation

1. Before going into a discussion on Carrier Suppression at the Transmitter Station and Carrier Suppression Compensation at the Receiver Station it is necessary to mention the available power level measuring equipment at the three points of the SSB system.

(a) Transmitter (TEF, T-265/FRC) Station:

At this point in the SSB system there is available one W. E. Volume Indicator for measuring the power level input to either channel "A" or channel "B". This unit reads directly in "dbm" (0 dbm may be defined as a power level of ONE milliwatt (0.001 watt) across a 600-ohm load). This unit may be used to measure "Transmitter Input" levels without interruption to service on either channel "A" or channel "B" at the "TRANS IN" jacks.

(b) Receiver (REA, LR-D1) Station:

At this point of the SSB system the REA receiver (or its newer model counterpart) is provided with a power level output meter calibrated in "db6m" (0 db6m may be defined as a power level of SIX milliwatts (0.006 watt) across a 600-ohm load). The scale of this meter is from minus 10 db6m to plus 6 db6m. By means of a switch this meter may be used to measure either the output of channel "A" or channel "B" without interrupting service. The Radio Control SSB technician must always remember to use the term "dbm" when transmitter levels are being considered, and "db6m" when the receiver output levels are being considered. Always be on the safe side and check the receiver report as to whether the receiver man means so many "dbm" or so many "db6m". The following table gives most used power levels in the SSB system in "dbm" and their equivalent values in "db6m".

	dbm				db6m	
plus	8	dbm	equals		0	db6m
"	7	"	"	minus	1.0	"
"	6	"	"	"	2.0	"
"	5	"	"	"	3.0	"
"	3	"	"	"	5.0	"
"	2	"	"	"	6.0	"
"	1	"	"	"	7.0	"
"	0	"	"	"	8.0	"

From the above table the technician may easily determine the conversion factor. For example, to convert "db6m" values simply add a "plus 8" to the "db6m" value, and the result will be a "dbm" value.

(c) Control (UP, FCC) Station:

At this point of the SSB system the only method available to measure power levels is the W.E. type 13-A transmission measuring set. This unit is calibrated in "dbm" values. However, in all cases service will be interrupted on the circuit or circuits where level measurements are being made in the Model UP or FCC terminal equipment. Therefore, the technician must exercise caution before taking level measurements if the system is in service.

2. Carrier suppression is effected at the Transmitter (TEF, T-265/FRC) Station. Before taking up this subject let us consider WHY the carrier frequency is suppressed at the transmitter? Briefly, the answer is to permit the maximum utilization of the available transmitter power on the side band that conveys the intelligence. Remember that on double side band transmission, such as a broadcast transmitter, two-thirds of the available transmitter energy is in the carrier and yet the carrier conveys no intelligence. Thus, in the SSB transmitter, by suppressing the carrier to a small fraction of the available transmitter power, more power is available for the side band conveying the intelligence. Normal carrier suppression for the SSB transmitters is 20db (this means that the suppressed carrier power is one-hundredth of the sideband power). In some cases 10db is used (suppressed carrier power is equal to one-tenth of the sideband power).

Briefly, carrier suppression at the transmitter is accomplished as follows:

(a) Carrier Suppression control is turned to extreme counter-clockwise position, so no carrier gets into the transmitter. This control is R-21, bias control for the "Carrier Resupply Amplifier", which cuts off plate current in this stage when in the extreme counterclockwise position.

(b) The transmitter is then tuned with channel "A" fed by a 1000-cycle test tone whose level is such as to provide full power output at the transmitter.

(c) An output meter indicator is provided in the transmitter. Some RF is picked up in the output tank circuit of the last power stage, then rectified with a diode tube. The cathode current passes through this output meter indicator. The transmitter operator, after tuning the transmitter as per para (b) above, notes the reading on this output meter. Let us assume it is desired to set up with 20db suppression, and the output meter (current device) reads 9 (this is merely a relative value).

(d) The transmitter channel "A" test tone is now turned off. Next the carrier resupply control is turned slowly clockwise and the output indicator indication is noted. When a value equal to one-tenth of that mentioned in para (c) is reached, or 0.9, then the transmitter is ready for operation with 20db carrier suppression. In case 10db suppression is desired the value on the output indicator would be adjusted to one-third of 9.0, or for an indication of 3.0.

3. An experienced Navy transmitter operator can, under normal conditions, shift the SSB transmitter frequency and set up carrier suppression within three (3) minutes. More time is required when a power amplifier such as the TPA or TEC is employed. AT&T and/or RCAC tune up exciter and amplifier complete in less than 3 minutes (reduced time due to their correct placement of exciter and amplifier units facing each other, requiring only one man to change frequency).

4. The Control Station technician should obtain, from his transmitter station, the following information when a frequency shift is made:

(a) Carrier Suppression set-up.
(b) Channel "A" (TTY tones) input level, and channel "B" (voice peaks) input level, in "dbm".

The above information should preferably be obtained via order-wire printer. When the SSB circuit is up to the other end this information should be passed to the distant receiver end via the voice channel and also entered into the daily operating log. The Control Station on the distant end should pass this information to his Receiver (REA, LR-D1) Station. The distant station should provide this end with the same information when he shifts frequency on his transmitter. The control station technician at this end should then pass this information via the order-wire printer to his receiver station. In addition, he should enter same into his daily operating log plus, of course, the send and receive frequencies. Without the above information it is very difficult, if not impossible, to analyze SSB circuit outages

5. Before taking up carrier suppression compensation (CSC) at the receiver station, it is well to review the reasons WHY the SSB receiver required a suppressed carrier. The SSB receiver required a suppressed carrier:

(a) For use as a pilot frequency to operate the "Automatic Tuning Control" (ATC) circuits.
(b) To generate "Automatic Volume Control (AVC)" voltages to various receiver stages, thus providing correct channel output levels, during fading of signal.
(c) To generate the demodulating frequency voltage for the third demodulators (detectors) in channel "A" and "B" branches, when so desired. Otherwise, "LOCAR" (Local Carrier) may be used for this purpose.

6. Let us now consider the carrier branch of the SSB receiver. The suppressed carrier frequency is picked up by the directional receiver antennae (usually a twin-rhombic) and amplified by the HFA (RF amplifier stage), then demodulated by the first detector to the first intermediate-frequency which is 2900 kcs. It is then fed through an amplifier into the second demodulator where it is demodulated to the second (and last) intermediate-frequency which is 100 kcs. It is then amplified by two stages before entering an extremely sharp crystal bandpass filter. The characteristics of this bandpass filter are: "midfrequency 100 kcs, bandpass plus or minus 20 cycles." Thus, for all practical purposes, only the carrier frequency may pass through this filter. From the filter output the carrier goes to the CSC amplifier. It is in this stage of the receiver that compensation is made for carrier suppression at the transmitter. This is accomplished by a potentiometer R-10 front panel control, designated as "CSC". This control varies the grid bias on the CSC amplifier stages thus varying the gain. Now, assume the carrier at the transmitter is suppressed 20db (carrier power low). At the receiver, in this case, the CSC control is set at the 20db calibrated point. This point is such that the negative grid bias voltage on the CSC amplifier will be relatively low, thus providing high gain through this stage which in turn supplies the correct output level into the AVC rectifier stage V-4, which in turn will provide the correct value of AVC voltages to the various receiver stages thus maintaining correct receiver channel output level. In addition, the CSC amplifier also supplies the correct level of 100 kcs carrier to the "Automatic Tuning Control" circuits.

7. Now let us assume that the carrier is suppressed 10db (more carrier power than at 20db suppression) at the transmitter. At the receiver the CSC control is set to the 10db calibrated point, this point is such that the negative grid bias voltage on the CSC amplifier is not increased in relation to the example above where it was set on the 20db calibrated point. Thus, now we have a stronger carrier from the transmitter and the receiver has set the CSC control on the 10db calibrated point (less gain than with 20db setting). Thus, in the output of the CSC amplifier there is the same output level feeding the AVC rectifier stage V-4. This in turn again provides correct AVC control voltage to the various receiver stages and therefore the receiver channel outputs are again maintained at the correct levels. In addition, the "Automatic Tuning Control" circuits are supplied with the correct value of 100 kcs carrier by the CSC amplifier.

8. From the above examples the control technician should realize the importance of knowing the value of suppression being used on the SSB circuit also why the receiver station must be told the value of suppression employed by the distant transmitter end.

9. Let us now review some of the more important operational points of the CSC circuit:

(a) As the CSC control R-10 is increased in setting (clock-wise) the compensation increases.
(b) The negative grid bias on the CSC amplifier decreases.
(c) The gain of the CSC amplifier increases.
(d) This would provide more AVC voltage to the various receiver stages if the 100 kcs carrier voltage remained constant. Also, it provides more voltage to drive the ATC circuits.
(e) More AVC voltage to the receiver stages would cause the channel outputs to be reduced in level.

10. Now consider the overall SSB circuit. The SSB circuit from one transmitting end to the other receiving end is essentially what is known as "ZERO LOSS CIRCUIT". By this term it is meant that under normal operating conditions, if a tone level of plus 3dbm is fed into channel "A" of the transmitter, the receiver at the other end of the circuit would provide a plus 3dbm output meter would indicate minus 5 db6m). Thus, there is no gain and no loss over the system.

11. On the SSB REA receiver there is a milliammeter "0 to 2ma." scale, connected in series with the plate load of the AVC rectifier stage V-4. This meter indicates a value of approximately 1.0 ma. when the receiver is:

(a) Properly tuned to the incoming carrier frequency.
(b) CSC control is correctly set.

This meter will also dip and rise as the incoming signal fades and rises beyond the limits of the AVC characteristic of the receiver. When the SSB receiver is correctly adjusted the AVC action is such that THE OUTPUTS WILL NOT VARY MORE THAN 4db OVER A 70db VARIATION OF RECEIVER INPUT VOLTAGE. In other words, the signal could fade 70db and the channel output would fade not more than 4db. However, to meet this requirement the receiver must meet the manufacturer's requirements for ALL line-up tests listed in the instruction manual.

NOTE: In the newer model of SSB receiver (LR-D1) some of the I.F. frequencies mentioned will vary from the old REA and the EF range coverage is also different.

12 In conclusion, remember that in case levels at the receiver outputs are running high (above normal) they can be reduced at the receiver by increasing the CSC setting, provided of course, that we are certain that the levels into the transmitter at the other end are normal. If the distant end complains of high channel output levels remember to first find out from your transmitter what the input levels are. If they are below or above normal have them corrected (IN ANY CASE, REGARDLESS OF DEMAND OF DISTANT END, NEVER EXCEED SPECIFICATIONS FOR TRANSMITTER TONE INPUT LEVELS).

If the complaint continues request the other end to notify his receiver to increase the CSC setting to reduce his levels to normal.

If the complaints still continue, have your transmitter shift to 10db carrier suppression (assuming it has been on 20db). This will permit the distant receiver end to have more range over which he can increase his receiver CSC setting. This procedure is not the best engineering practice, however, as the indications are that the SSB system is not operating correctly. However, it is worth trying in order to reduce circuit outages. It is better to perform the above than trying to reduce receiver output levels by decreasing transmitter input levels below normal requirements. In certain cases receiver output levels run high (above normal) because of low AVC voltage to the receiver stages which, in turn, may be caused by a weak incoming carrier, improper CSC setting, actual carrier suppression at transmitter not what it should be, or the selection of a wrong operating frequency.

c. SAMPLE SSB RECEIVER CHECK-OFF.

Ref: A. Maintenance procedure dtd 16 Nov. 1953
B. W.E. Inst. Bulletin 982
C. OpNav Inst. 2300.2

Subj: Maintenance procedure to be followed by all technicians servicing REA-1 receivers. Deviation from adopted procedure is prohibited; however, constructive criticism is invited.

A. WEEKLY MAINTENANCE:

1. Log receiver down with supervisor, check for load plugs on AF board, set tuning dials for 250, antenna plug out, gain at 0, CSC at 100, AVC off. RF band switches set opposite each other.

2. POWER SUPPLY VOLTAGE MEASUREMENT AND ADJUSTMENTS.
   - (a) Take maximum and minimum reading of each power supply.
   - (b) Set power supplies as follows 135V, 135V, 135V, 95V, 400V, 400V plus or minus one volt max. tolerance.
   - (c) Minimum for No. 1-4 not less than 80V, for 5 & 6 not less than 300V.
   - (d) If these requirements are not met test tubes of rectifiers.

3. MEASUREMENT OF VACUUM TUBE PLATE, SCREEN, AND GRID CURRENTS.
   - (a) Read value of tube currents at meter positions groups 1 & 2.
   - (b) Set gain to 100 at Ip HF range 1, and then reduce to 0 at carrier rectifier plate current in order of readings.
   - (c) Record meter readings, compare with tolerances of previous normal readings.

4. DRIVE TO SECOND DEMOD:
   - (a) De-energize power supply No. 1 (pull power plug) set meter switch 1 to D2.
   - (b) Check space current of D2, replace plug. Space current value greater than 5 indicates unbalance of demod tubes.
   - (c) Rebalance by substituting tubes.
   - (d) Set drive to D2 at a meter reading of 45 above space current using R1 in BO-2 unit.

5. SPACE CURRENT OF CARRIER RECTIFIERS:
   - (a) Set carrier rectifier space current to a reading of .3 on carrier rectifier meter using R14 in carrier rectifier unit.

6. ADJUSTMENT OF ATC UNIT:
   - (a) Carrier oscillator plate switch off.
   - (b) Set space currents of ATC mods 1,2,3, and 4 to 10 micro amps using potentiometers R47, R48, R49, and R50 respectively.
   - (c) Turn carrier osc. switch on and set reading of mods 3 & 4 to an average of 35 micro amps. Not to exceed 5 micro amps on either side by means of R16.
   - (d) Repeat for Mods 1 & 2 to same limits by using R12.
   - ( ) Set up 7 meg. signal at 100 micro volts on LP signal generator and inject into receiver at RF amplifier input.
   - (f) Tun and peak receiver set manual gain for a reading of .75 n carrier rectifier meter

(g) Throw carrier osc. switch off, set reading of mods 1 & 2 to an averag of 35 micro amps using R3 and keeping signal on peak as indicated by carrier rectifier meter by varying ATC control. Ten (10) micro amps difference not applicable

(h) Repeat for mods 3 & 4 using R8. Throw carrier osc. on, observe action of ATC. Mods as indicated by slow swing of meter needle.

7. ADJUSTMENT OF CHANNEL AMPLIFIERS:

(a) Set manual gain for a reading of 1 mil on carrier rectifier meter.

(b) Throw metering switch 2 to AD3 position. Set carrier supply switch (local-recon-off) on channel "A" to off. Observe space current reading.

(c) Set carrier supply switch to Recon position. Adjust R19 in channel "A".amplifier for a reading of 45 above value obtained in step sub.(b).

(d) Repeat above sub steps a, b, and c for channel "B" with the m ter switch at BD3 position and using R19 in channel "B" amplifier.

(e) Set manual gain to 0 meter switch to AD3 position, carrier supply switch (Channel "A" anpl.) to local position. Adjust R21 in ATC unit for a reading of 45 above space current value observed in b above.

(f) Repeat above step c for channel "B" with meter switch in position BD3 and using R26 in ATC unit.

8. ADJUSTMENT OF VOICE OUTPUT LEVELS:

(a) Inject 7 mcs signal into receiver at 100 micro volts from LP signal generator (50 microvolts input.) Re-adjust BO-1 tuning until an audio note of approximately 1000 cycles is hear in "B" channel output.

(b) Throw carrier supply switch, channel "B" to off position, put group 2 meter switch to BD3 position AVC off and manual gain to 0 Advance MVC control for a small increase in current on BD3 meter. Peak with fine frequency and HF tuning controls.

(c) Remove signal generator input and observe space current reading on meter. Replace signal generator input and adjust MVC for a meter reading of 40 above space current value.

(d) Reduce input from LP signal generator to 6.4 micro volts and throw channel "B" carrier supply switch to Local.

(e) Observe reading on out meter, output indicator switch to "B" position set to a reading of -3db using S2 in channel B amplifier.

(f) Repeat a thru e for channel "A" using channel "A" carrier supply switch group 2 meter switch to AD3 position, output indicator switch to "A" position and adjust with S2 in channel "A" amplifi r.

9. CHECK RECEIVER DIAL CALIBRATION.

(a) Check receiver calibration with LR signal generator and correct posted calibrations to within 2 dial divisions.

B <u>QUARTERLY</u> <u>MAINTENANCE</u>:

1. CALIBRATION OF CARRIER SUPPRESSION COMPENSATION CONTROL:

After completing a weekly maintenanc procedures, inject a 7 mc signal at 50 micro volts (allow for any attenuation of signal at the HF input jack and tune BO-1 off for a 1000 cycle note in channel "A". With AVC off, CSC to 0; carrier supply switch to off, group two metering switch to AD3 advance the MVC for an increase on the group two meter to midscale.

Peak signal with HF amp tuning and fine tuning controls. Turn output meter switch to B (normal reverse switch in reverse position in order to tune in the 1000 cycle note in channel A). Look at the A level with 3.2 micro input which is 6.4 micro volts from LP signal generator. Increase the manual volume control until this reads 0 db6m on the output meter. Do not move the MVC hereafter. It has been set for a 0 db6m level. Now increase the CSC control to 100 and tune the 7 mc signal in properly (a peak on the carrier rectifier meter) and peak with HF tuning and fine tuning controls; reducing the CSC setting as necessary. In order to keep the carrier rectifier meter approx. midscale. Now with the input attenuator at 0 as it has been throughout all maintenance adjust the CSC control for a reading of .75 on the carrier rectifier meter. This corresponds to 0 db6m suppression. Move the attenuator to the 10 position and again bring the carrier rectifier meter to a reading of .75. This corresponds to 10db suppression. Continue the same for 20 and 30 db. Interpulate for 5, 15, and 25.

2. SENSITIVITY MEASUREMENTS OF RECEIVER:

(a) Connect signal generator output to receiver input, adjust signal generator for 7 mcs.
(b) Adjust LP signal generator for 50 micro volts.
(c) Set AVC on and tune receiver for peak on signal from signal generator.
(d) With AVC off and MVC to 0 check that reading of carrier rectifier meter is .3. Correct with R14.
(e) Turn carrier suppression compensator dial to position corresponding to 20 db suppression as per calibration.
(f) Turn MVC adjustment dial to 40 and adjust signal voltage input to receiver until the carrier rectifier meter reads 1 milliamp.
(g) Record input signal voltage.
(h) Turn MVC gain adjustment to 70 and repeat steps f and g.
(i) Turn carrier supply switch on channel A to local position and adjust BO-1 tuning dial for an audio signal of approximately 1000 cycles in channel A peak signal.
(j) Turn MVC adjustment dial to 40 and throw output indicator dial to position A.
(k) Adjust signal voltage input to receiver until output meter reads 0db.
(l) Record input signal voltage.
(m) Turn MVC gain adjustment dial to 70 and repeat above steps k and l.
(n) Repeat above steps with signal generator frequency adjusted to 16 mcs.
(p) The signal input voltages should not exceed the following voltages.
Note: Voltages input to receiver is one half the value shown on LP dial when using dummy antenna unit.

Frequency	MVC Dial Setting	Carrier Branch. (Setps g&h)	Chan.Branch (Steps l&m)
7 mcs	40	120 microvolts	1100 microvolts
7 mcs	70	.75 "	6.9 "
16 mcs	40	570 "	5350 "
16 mcs	70	5.6 "	33 "

(q) Ratios of signal voltages at dial settings of 40 and 70. The ratio obtained for carrier branch and channel branch should not differ by more than -30% and +10%. Corresponding values of receiver sensitivity for the two HF channels shall not differ by more than plus or minus 10%.

3. MEASUREMENT OF AUTOMATIC VOLUME CONTROL ACTION:

(a) With the receiver in normal operating condition and HF attenuation dial turned to 0 connect the output of the signal generator to the input of the receiver.

(b) Turn on and adjust the signal generator to 7 mcs.

(c) Set CSC for 20db suppression as determined in test 3.15.

(d) Adjust the output of the signal generator so as to provide 5,000 micro volts at the receiver input.

(e) Adjust signal generator for internal modulation (400 cycles) at 10 percent. NOTE: This provides a ratio of signal generator carrier to sideband of 20db.

(f) Tune the receiver so that the signal generator carrier passes through one of the channel filters, and the signal generator sideband through the receiver carrier filter branch.

NOTE: This simulates a single sideband signal the carrier of which is suppressed 20db in relation to the sideband. At the receiver input now there is 5000 microvolts of sideband and 500 microvolts of sideband and 500 microvolts of carrier amplitude.

(g) Throw the output indicator dial to the position corresponding to the channel through with the signal generator carrier is being received in step (f). Observe and record the output meter indication.

(h) Place the HF attenuation dial to 10db position.

NOTE: Signal now is decreased 10db from value in step (g)

(i) Observe and record the output meter indication.

(j) Place the HF attenuation dial to 20db position.

NOTE: Signal now is decreased 20db from value in step (g).

(k) Observe and record the output meter indication.

(l) Place the HF attenuation dial to 30db position.

NOTE: Signal now is decreased 30db from value in step (g).

(m) Observe and record the output meter indication.

(n) Place the HF attenuation dial to 0 position and reduce the signal generator output from 5000 microvolts to 50 microvolts.

NOTE: Signal now is decreased 40db from value in step (g).

(o) Observe and record the output meter indications.

(p) Place the HF attenuation dial to 10db position.

NOTE: Signal now is decreased 50db from value in step (g).

(q) Observe and record the output meter indication.

(r) Place HF attenuation dial to 20db position.

NOTE: Signal now is decreased 60db from value in step (g)

(s) Observe and record the output meter indication.

(t) Place HF attenuation dial to 30db position.

NOTE: Signal now is decreased 70db from value in step (g)

(u) Observe and record the output meter indication.

REQUIREMENT: The output should not vary more than 4db over the whole (70db) range of input voltages.

(v) Repeat this test for the other channel branch.

4. POWER SUPPLY RIPPLE:

(a) View output of power supplies on calibrated scope at grid cap of control tube.

(b) Any visible 60 cycle ripple should be corrected at once.

5. 100E AMPLIFIER:
   - (a) Check all tubes for shorts, gas, and etc.
   - (b) Thoroughly clean cabinet and check wiring.
   - (c) Check pot and switch and interlock.

6 COMPLETE FREQUENCY CALIBRATION:
   - (a) Calibrate all REA-1 SSB receivers with a combination of a LR and LP frequency meter and signal generator. The frequency calibration chart in W.E. inst. 982 should be used to be sure REA-1 are not calibrated on a harmonic frequency, etc.
   - (b) All SSB Frequencys used at the present time are available from the supervisor; these are all to be calibrated.

C. <u>YEARLY MAINTENANCE</u>:

1. ADJUSTMENT OF CARRIER OSCILLATOR FREQUENCY:
   - (a) Connect signal generator into receiver and inject signal of 7 mcs at 50 microvolts. Tune and peak receiver.
   - (b) Disconnect signal generator and set AVC to off position and MVC dial to 100.
   - (c) Observe direction and rate of drift of ATC motor in terms of ATC dial divisions per minute. This drift should not exceed 0.2 dial divisions per minute over and interval of at least 5 minutes.
   - (d) If this requirement is not met remove mat and from shield of carrier osc. panel and locate capacitor S8 in this unit.
   - (e) If drift is toward black dial divisions increase value of C8 (by adding capacitance) until corrected, (not to exceed a value of 30,000 mmf.) should more capacitance be indicated additional inductance must be inserted in this circuit.
   - (f) If drift is toward red dial divisions value of C8 must be reduced until corrected.

2 ADJUSTMENT OF TRANSFORMERS AND FIRST INTERMEDIATE FREQUENCY FILTER:
   - (a) The adjustment described under this subdivision should be made only when they are required as determined on trouble location.
   - (b) With the receiver in normal operating condition and HF attenuation dial turned to 0 connect signal generator output to receiver input.
   - (c) Adjust signal generator frequency to approximately 16 mcs.
   - (d) Turn on and adjust output of signal generator so that the input to the receiver is 100 microvolts.
   - ( ) Turn CSC dial to position corresponding to 20db suppression as determined in test 3.15.
   - (f) Line up receiver on signal from signal generator.
   - (g) With the MVC gain adjustment dial turned to 0 turn AVC dial to off position.
   - (h) Turn MVC gain adjustment dial sufficiently to provide carrier rectifier meter reading of 0.5 milliampere.
   - (i) Remove the dust cover on the back of the HF amplifier and first detector panel.
   - (j) By means of the screwdriver, tune the adjustment on the back of transformer T-2 for a maximum deflection on the carrier rectifier meter.
   - (k) Readjust signal generator frequency to approximately 7 mcs.
   - (l) Repeat steps 3 to 7 inclusive.

(m) By means of the screwdriver tune the adjustment on the back of transformer T-3 for a maximum deflection on the carrier rectifier meter.
(n) Replace dust cover on back of HF amplifier panel.
(o) Remove dust cover on the back of the first intermediate amplifier and second detector panel.
(p) By means of the screwdriver tune the adjustments on the transformer T-1 and T-2 and the filter adjustment labeled "CB" for maximum deflection on the carrier rectifier meter.
CAUTION: Do not disturb the adjustment labeled "CA" do not disturb.
(q) Replace dust cover on back of the first intermediate amplifier and second detector panel.

3. ADJUSTMENT OF FREQUENCY OF BO-2:
(a) Tune LM frequency meter to 2900 kcs and attach output to grid of one tube in D2 (IF amp unit) thru a capacitor.
(b) Turn off calibrator on LM.
(c) Adjust frequency; adjust on BO-2 for zero beat in phones in LM.

4. CLEANING:
(a) Clean all units inside and out with soap, water, crocus cloth (contacts) carbon tet and anything else available.
(b) Check all wiring and correct deficiencies noted.

d. SAMPLE GCA CHECK-OFF SHEET.

CHECK SHEET FOR GCA UNIT 35

Week of ____________________

DAILY INSPECTION-CPM 4 MANUAL									ADDITIONAL WORK
Angle volt. gen	Para 5-714								
AZ-EL Ind. disp	5-716								
Comm. cont unit	5-730								
DC supply voltages	Check								
DF bearing	5-735								
MTI receiver	5-748								
Precision converter	5-752								
Prec. trans-mod	5-758								
Search converter	5-767								
Search ind. display	5-771								
Search syncro system	5-771								
Search trans mod	5-774								
Voltage reg.	5-784								

WEEKLY INSPECTION CPM 4					
Ant. compt safety sw.	CHECK				
Batteries	5-720				
Blanker switches	5-723				
DC voltage supplies	5-677				
HV pwr supply ovld	5-775				
Precision antenna	5-755				
10 KV pwr supply	5-781				
TR tubes recovery time	5-217				

MONTHLY INSPECTION CPM 4		
Angle volt gen.	5-715	
Angle cplg. cap.	5-721	
Batt.jnctn.box	5-736	
Fire extinguisher	Check	
Heater and Vent	5-747	
Remoting eqipmt.	5-765	

CHECK SHEET FOR CGA UNIT 35

Date_______________ _____

SEMI-ANNUAL INSPECTION CPN 4

Air Ducts	5-712	☐
Blower racks and duct	5-725	☐
Comm. antennas	5-726	☐
Electronic units	5-792	☐
Prec. trans. line	5-761	☐
Vent. fan and bracket	5-787	☐

ANNUAL INSPECTION CPN 4

Indicator duct	5-749	☐
Prec. trans line	5-761	☐
Trans duct	5-784	☐
Voltage regulator	5-790	☐

Check greasing and oiling chart ☐

DAILY INSPECTION FPN 28

Distribution cabinet	☐	☐	☐	☐	☐	☐	☐
Search indicator 2 steps	☐	☐	☐	☐	☐	☐	☐
Search ant. pedestal	☐	☐	☐	☐	☐	☐	☐
Search trans. 3 steps	☐	☐	☐	☐	☐	☐	☐
Search stalo 2 steps	☐	☐	☐	☐	☐	☐	☐
Mod. search norm. recvr.	☐	☐	☐	☐	☐	☐	☐
STC operation	☐	☐	☐	☐	☐	☐	☐
MTI - normal video baseln.	☐	☐	☐	☐	☐	☐	☐
Normal search video level	☐	☐	☐	☐	☐	☐	☐
Noise output of normal if	☐	☐	☐	☐	☐	☐	☐
Coherence	☐	☐	☐	☐	☐	☐	☐
Cancellation	☐	☐	☐	☐	☐	☐	☐
Search afc amplifier	☐	☐	☐	☐	☐	☐	☐
Line compensator	☐	☐	☐	☐	☐	☐	☐
Standby radar unit	☐	☐	☐	☐	☐	☐	☐

WEEKLY INSPECTION FPN 28

Search indicator	☐	☐	☐	☐	☐
Cont.sys.pwr.supply	☐	☐	☐	☐	☐
Search ant. pedestal	☐	☐	☐	☐	☐
Search trans.	☐	☐	☐	☐	☐
Search trans. stalo	☐	☐	☐	☐	☐
Mod. search trans.	☐	☐	☐	☐	☐

MONTHLY INSPECTION FPN 28

Search indicator 3 steps	☐
Search ant. pedestal	☐
Search trans.pwr supply 2	☐
Search stalo	☐
Mod. search receiver	☐
Mod.Search MTI rcvr 2 step	☐
Search AFC amplifier	☐

See chart for oil & grease.

BI-WEEKLY INSPECTION FPN28

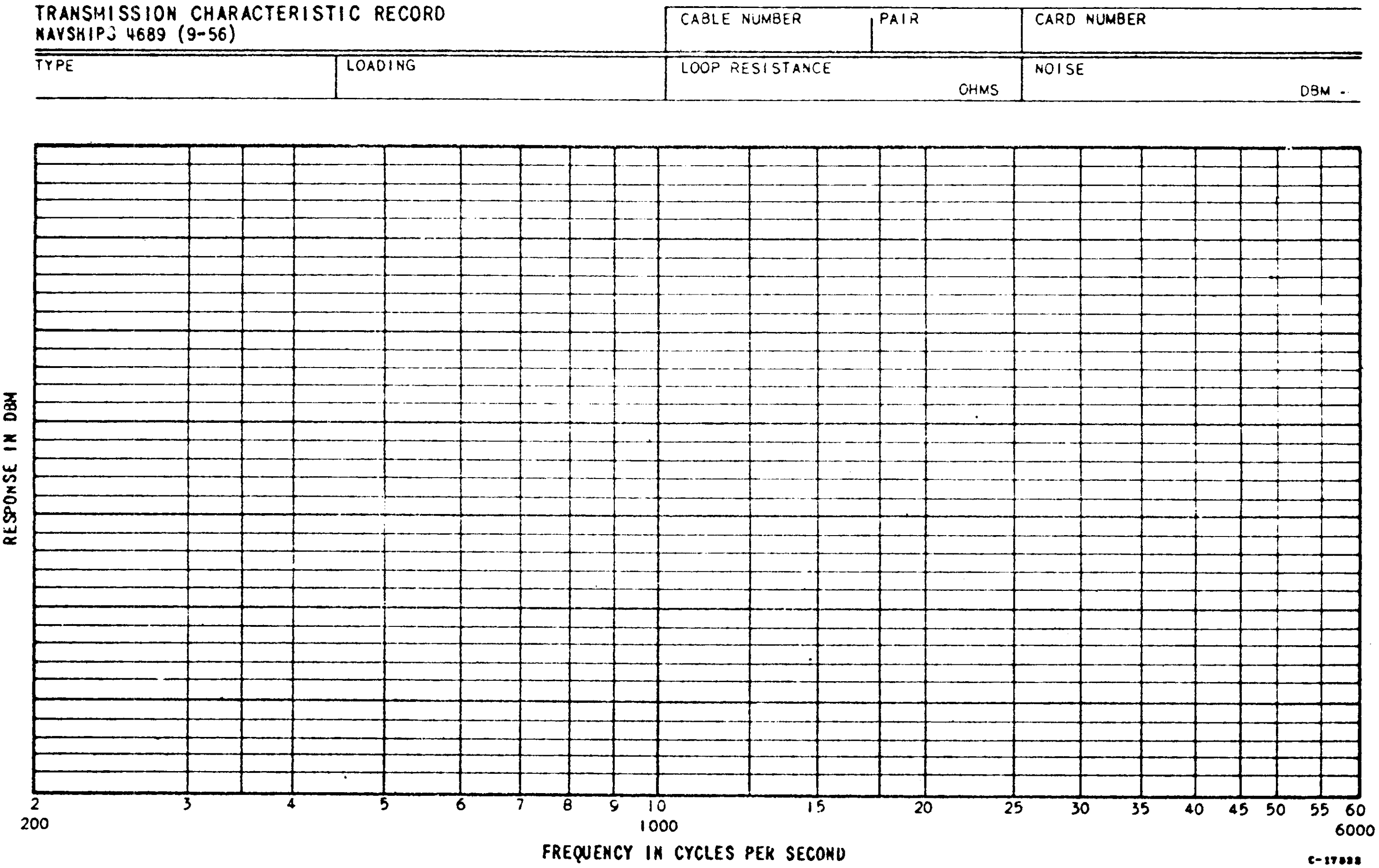
Search transmitter	☐	☐	☐	☐	☐
MTI driver output level	☐	☐	☐	☐	☐

SEMI-ANNUAL INSP FPN 28

General

Interlock circuits	☐ ☐

Technician
1. Smith
2. Jones
3. Goldfarb
4. O'Flaherty
5. Dumbrowski
6. Fernando
7. Swenson
8. Martinelli
9. Kraut
10. ____________
11. ____________
12. ____________



TRANSMISSION CHARACTERISTIC RECORD
NAVSHIPS 4689 (9-56)

		CABLE NUMBER	PAIR	CARD NUMBER
TYPE	LOADING	LOOP RESISTANCE OHMS		NOISE DBM -

e. SAMPLE TRANSMISSION CHARACTERISTIC RECORD, NAVSHIPS 4689 (9-56).

FUNDAMENTALS OF TELEGRAPH SIGNAL DISTORTIO

By RICHARD A. DAY, RCA Field Engineer

TELEGRAPH SIGNAL DISTORTION

It is essential that all controllers and maintenance personnel concerned with telegraph systems learn to interpret the system performance through distortion measurement. We cannot afford either the time or the money to transmit repeatedly the same message just to ascertain that the message is being received correctly. Consider the "on-line" (encrypted) transmission. What other means is there for such a systems operating and maintenance personnel to check system performance except possibly at the distant receiving station?

It has been a common practice among teletype maintenance and operating personnel to adjust the teleprinter "range" scale to the optimum point for the circuit and equipment. This practice has usually acted as a camouflage for existing circuit difficulties. *HOW* well the signal prints on a particular printer is unimportant when considering a complete system. It is more important to know the fidelity of the signal being passed to line at any point in the system. Signals transmitted to line should be printable on any properly adjusted receiving telegraph equipment. Therefore, the *fidelity* of the receive signal must be given prime consideration.

There are four fundamental types of distortion which adversely affect the fidelity of telegraph signals.

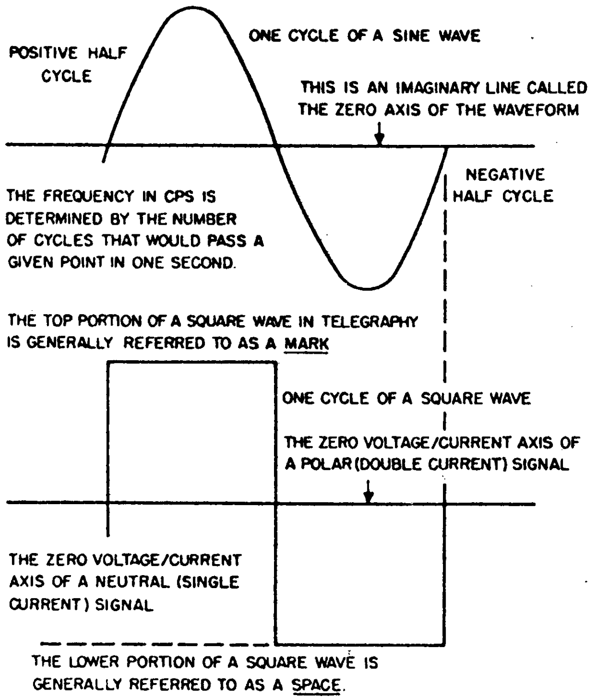
a. *Bias distortion.* The uniform lengthening or shortening of the mark or space elements, one at the expense of the other. (See figure 2.)

b. *Fortuitous distortion.* The random displacement, splitting, and/or breaking up of the mark and space elements. (See figures 3A and 3B.)

c. *End distortion.* The uniform displacement of the mark to space signal transitions with no significant effect on the space to mark transitions.

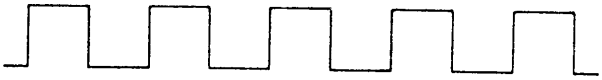
d. *Characteristic distortion.* The repetitive displacement or disruption peculiar to specific portions of a signal. (See figures 3A, 3B, and 3C.)

The total of these four forms of signal distortion is known as the cumulative distortion of the signal. A signal having mark bias in one link of a telegraph



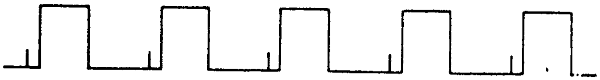
Note that the time for a half cycle is equal to a mark or space as the case may be. To avoid confusion, however, we have telegraph terms to refer to a square wave. The *DOT CYCLE* or the *BAUD.* The dot cycle is equal to one mark and one space. The baud is equal to a mark or a space. Notice that the ratio between the length of the mark and the length of the space are equal as drawn here. The dot cycle assumes an equal mark:space ratio. The baud does not assume anything about the mark:space ratio; it means that the shortest element mark or space is equal to one second divided by the number of baud. For a system to pass a square wave it must pass a minimum number of harmonics. A square wave is made up of the fundamental sine wave plus a certain number of ODD harmonics, the more perfect the square wave the more odd harmonics present. It is for this reason we have the term dot cycle or baud to warn us that we are dealing with a square wave.

Figure 1—Sine Wave and Square Wave Signals



This waveform in telegraph work is generally called AC reversals or just reversals. It may also sometimes be referred to as DOTS, REVS, 1:1 (ones) or 2:2 (twos). 2:2 are actually one half the speed of 1:1 but they have the same waveform. This waveform shows zero BIAS or END distortion. Notice that every mark is the same length as every other mark. Every space is the same length as every other space. The mark:space ratio is 1:1. This means that the mark length is equal to the space length.

AC reversals showing 20% MARK BIAS distortion. Notice the length of the mark is 20% longer than a normal mark. Every mark-space transition is 20% late while each space-mark transition takes place at the proper time. End distortion could produce a similar pattern with the added possibility that the Space-Mark transitions might also be displaced. This fact allows one to identify End distortion as a separate entity from Bias distortion.



AC reversals showing 20% SPACE BIAS distortion. The same condition applies to space bias as mark bias except that this time the space to mark transitions are late.

Figure 2—AC Reversals showing Mark Bias and Space Bias Distortion

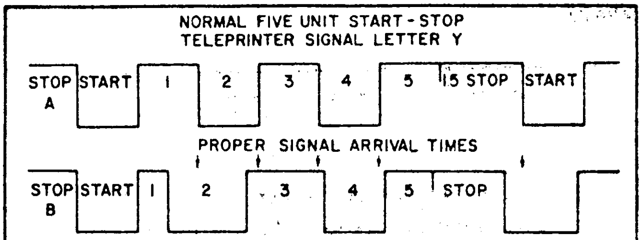
system and space bias in another portion of the system could actually have less cumulative distortion at the distant receiving point than at test points along the system due to the cancellation effects of bias distortion. It is mandatory that the reader realize that Characteristic distortion cannot change anywhere in the system itself unless the signal is regenerated in some manner; that the effects of End distortion in one link in the system can be offset by Bias distortion in another portion of the system, but the Fortuitous distortion components will continue to rise as the number of links away from the sending point is increased unless signal regeneration takes place. It should be obvious to the reader that if one can easily separate these various forms of distortion into separate entities it will simplify the job of finding the trouble, and improving the fidelity of the signal.

For many years the rule of thumb for acceptable distortion for start-stop telegraphy has been thirty-five percent (35%) distortion. The *kind* of distortion has not been specified. A well-maintained 45.5 Baud teleprinter will readily accept thirty-five percent (35%) Bias or End distortion either marking or spacing. However, only twenty percent (20%) Fortuitous distortion will produce an entirely different effect on the receiving equipment. (See figures 5A and B.) Suppose a teleprinter is caused to wait thirty percent (30%) due to Fortuitous distortion during the start impulse. The next element received may have practically no distortion. Then the next element may be thirty percent (30%) early due to Fortuitous distortion. Under these conditions the second code element would be printed incorrectly due to the fact that the receiving equipment is showing this element as either sixty percent (60%) late or forty percent (40%) early in selection time. Telegraph signal distortion causes the elements to occur either earlier or later than that of a perfect signal and the total distortion present is the cumulative effect of the earliest arrivals to that of the latest arrivals.

In start-stop telegraph signalling Fortuitous distortion is much more detrimental to the receiving equipment than other types of distortion. With start-stop signalling any displacement of the stop to start time will be reflected throughout the entire character being selected, and as the distortion occurs at random it may aid some code elements but damage others.

For this reason with start-stop telegraph systems we can only regenerate or detect with any degree of reliability, Fortuitous distortion that is *one quarter or less* the total range of the receiving device. For the average 45.5 Baud mechanical receiving device eighteen percent (18%) early and eighteen percent (18%) late are the maximum acceptable Fortuitous distortion figures. In general, electronic stop-start selecting devices can cope with up to twenty-four percent (24%) Fortuitous distortion for reliable printing.

Synchronous systems have a marked advantage over start-stop systems in that the detection capabilities of synchronous systems are primarily determined by the accuracy of the synchronizing devices, and the width of the pulse selecting the line signal condition (Mark or Space). (See figure 5.) If the selecting pulse is one percent (1%) of the total signal pulse width then the receiving device will detect Fortuitous distortion



This signal is suffering from high Fortuitous distortion. Some elements are losing portions of their allotted period of time others are gaining.

Code element #2 Mark to space transition is approx. 50% early.

Code element #3 Space to mark transition is approx. 20% early.

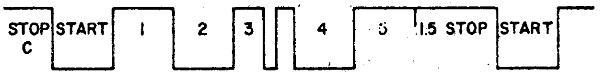
Code element #4 Mark to space transition is approx. 22% late.

Code element #5 Space to mark transition is approx. 20% late.

The Stop element has been shortened by approx. 25%.

The Fortuitous distortion figure for this signal is then the total of the highest early and highest late percentages.

50% early plus 22% late, is a total of 72% Fortuitous distortion for this signal



This signal is suffering from a split element on the 3rd code element. If this happens repetitively it should be classed as Characteristic Distortion. If it happens only once over an extended period it would be Fortuitious distortion. Actually the signal has been drawn to show zero bias and zero Fortuitous distortion on all other elements so it is reasonable to decide if the third element repeatedly splits that the transmitting equipment is faulty. On suitable distortion measuring equipment this would be displayed as two transitions in this element. One approx. 50% late and another about 65% late.

IF WE RESOLVE THE DISTORTION BY CLASSES WE CAN THEN LOCATE SCIENTIFICALLY THE TROUBLE. WE CANNOT LUMP ALL THE FORMS OF DISTORTION INTO ONE GRAND TOTAL. THE DISTORTION SHOWN ON WAVEFORM C IS 65%, BUT ONLY ON ONE SPECIFIC CODE ELEMENT, THEREFORE THE TRANSMISSION PATH OR RADIO CONDITIONS COULD NOT CAUSE THIS PARTICULAR ELEMENT TO DISTORT REPETITIOUSLY.

Figure 3—**Normal 5 Unit Start-Stop Teleprinter Signal Letter Y with high Fortuitous and Split Element Distortion**

correctly up to forty-nine and a half percent (49½%) early or late. This then would be a total Fortuitous distortion component of ninety-nine percent (99%). In actual fact there are presently working systems capable of accomplishing this under controlled laboratory conditions. However, when the fortuitous component on a working circuit rises to a figure as high as this the circuit for all practical purposes is useless because the system has been degraded to almost one hundred percent (100%) Fortuitous distortion. Failures will appear in the traffic each time the Fortuitous distortion exceeds forty-nine and a half percent (49½%) early or late.

It should be kept in mind that any system that exceeds its normal Fortuitous distortion figure is cause for alarm. Fortuitous distortion is practically uncontrollable in nature, therefore, it must be minimized even if it means rerouting and/or reengineering the system. If a telegraph system is made up of groups of equipment and links, such as radio and landline facilities, a percentage breakdown of all distortion figures for each link and each piece of equipment on the circuit should be known.

There is no way for maintenance personnel on any telegraph system to evaluate the performance of a working telegraph system except through distortion figures. Assuming that a VF carrier link from point A to point B has a Bias distortion figure assigned that says, "You will not exceed two percent (2%) mark or space bias, the Fortuitous distortion figure is not to exceed three percent (3%)." It is of course assumed that these figures have been proven within the capabilities of the particular working system. If the traffic passing on this system is shown to be outside these limits it should be the standard practice of the sending end of the "VF link" in question to measure the signal being introduced into the system. If the distortion of the signal being introduced into the system is normal but the receiving end of the link is receiving traffic with a distortion figure which exceeds the total of the input signal distortion plus the inherent link distortion then there is cause for alarm and corrective action must be taken immediately. If the signal being introduced into the system has a high distortion figure then there is cause for investigation of the signal being introduced into the FV system.

Notice how pointless it would be to place printing monitoring equipment on such a channel if the traffic was anything but clear text. And even if it was clear text, suppose there was high Bias distortion in the particular monitor in use, the monitor might, with its range scale, indicate that there was a lowered operating margin. Now as the monitor can't indicate whether its Bias, Fortuitous, End, Characteristic or Speed distortion the maintenance man is no better off than before. All he knows is that he has a lowered operating margin but as what to do with it he really hasn't a clue, except time-honored trial and error methods that take great pains to produce a questionable answer and cost dearly in channel traffic time. If the maintenance personnel used distortion measurements on working circuits they would know at all times exactly how well the systems are working.

CAUSES AND EFFECTS OF FORTUITOUS DISTORTION

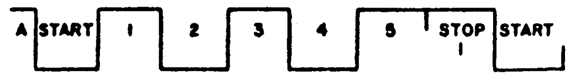
Fortuitous distortion is caused by cross talk between two or more circuits, atmospheric noise, power line induction, poorly soldered joints, lightning storms, dirty keying contacts and similar such disturbances. It must be emphasized that Fortuitous distortion means RANDOM disturbances.

AC power line interference can have a very definite relationship to the signalling speed in use but due to the fact that the signalling will normally have random keying rather than reversals on the circuit the effect of the interfering AC will be Fortuitous in nature. (See figures 3 and 5.)

CAUSES AND EFFECTS OF BIAS DISTORTION

It is most important that the reader realize that bias is a uniform lengthening and shortening of the length of the mark or space element, one at the expense of the other. (See figures 1 and 2.) This means that the total time allocated to one mark and one space never changes, only the length of the mark or space element changes. If the mark is lengthened then the space will be shortened by the amount that the mark is lengthened. If the above described distortion of the mark or space elements is not uniform and repetitive then some other form of distortion is taking place.

Bias distortion can change from one hour to the next or with one adjustment of the equipment to another. Bearing the definition for bias in mind it should be quite obvious that there are few places in a telegraph system for producing bias. A maladjusted relay causing the armature to hold longer on the space or mark contact will cause Bias. A receiver detuned causing the beat note being fed to the discriminator of an FSK converter will produce either marking or spacing bias depending on whether or not the beat note is predominately on the marking or spacing side of the discriminator response slope. It should be noted



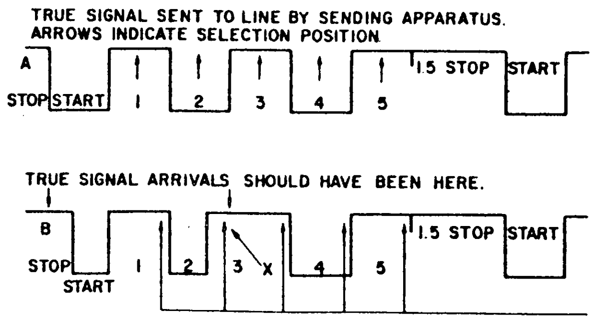
The stop element starts here in time but we see no transition because the last code element =5 was a mark.
Teleprinter letter Y in five unit start-stop teleprinter code. The stop is shown for waveform A as a UNIT stop (stop the same length as the start and code elements).

The stop in this waveform is 142% the length of the Start or code element length. This waveform is sometimes referred to as 7.42 unit code.

The stop in this waveform is 150% the length of the Start or Code element length. Most European teleprinter equipment uses this teleprinter character formation.

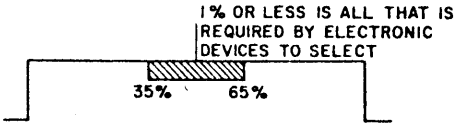
The stop in this waveform is 200% the length of the start or Code element length.
NOTE THAT YOU CAN ALWAYS WORK FROM A SYSTEM WITH A LONGER STOP INTO A SYSTEM WITH A SHORTER STOP BUT NOT FROM A SYSTEM WITH A SHORTER STOP INTO A SYSTEM WITH A LONGER STOP.
The character length can be determined by the length of the stop element and/or by changing the speed (length) of the individual signal element. If we send each mark and space element twice as fast we would double the speed of the signal. WE WILL NOT CHANGE THE LENGTH OF THE STOP TIME WITH RELATIONSHIP TO THE START AND CODE ELEMENTS BY SIMPLY CHANGING THE SIGNALING SPEED. THE STOP ELEMENT IS DETERMINED EITHER BY A CAM IN MECHANICAL SENDING DEVICES OR CIRCUITRY IN ELECTRONIC DEVICES.

Figure 4—Variations in Stop Elements



Due to 30% Fortuitous distortion the arrival of the Stop-Start transition was delayed. This means that the receiving start-stop device will now be 30% late in all code elements with regard to the true signal arrivals.

Notice that the second code element will be selected as a mark rather than a space because the distortion present on this element is effectively 60%. This is because the receiving device was delayed 30% and the S/M #2 transition is 30% early. It is for this reason that in start-stop telegraphy the distortion figures must present the early or late arrivals as a total. An example would be ten percent early and twenty-five percent late arrivals would be a 35% distorted signal.



Mechanical devices as a general rule require approx. 30% of the pulse width to select. A further important point is that mechanical devices begin to require more and more of the pulse width as the speed is raised. When the pulse width becomes under 10 milleseconds in length the mechanical device competing with electronic devices loses ground fast.

Figure 5—Effect of Fortuitous Distortion on True Signal

that any drift in the transmitter or receiver frequency control equipment will cause migration on the discriminator response slope, thus producing Bias.

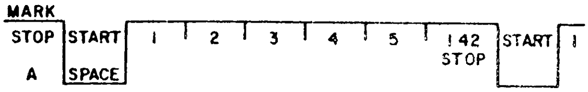
Changes in speed of the sending equipment *cannot* produce Bias distortion even though certain types of distortion measuring equipment will display a speed change as Bias. It is for this reason that one must be very sure whether bias or speed is the cause for the distortion present. (Note: If the transmission speed increased or decreased the mark-space elements would be changed equitably in length, therefore, the bias could be zero but the total time for one mark and one space would be longer or shorter than that required for the particular signalling in use.)

Probably the number one cause for concern over high Bias distortion is that it produces the same effect as raising the signalling speed. (See figures 1 and 6.) The fundamental bandwidth occupied by any signal is determined to a great extent by the rate of signalling. The faster the signalling the greater the bandwidth. The greater the bandwidth the more improvement you have to make in your signal and the faster the signal the less tolerance for distortion. A system has to be designed to pass the fastest signal elements. Therefore, if a system is designed for 22 millesecond mark or space pulses as the shortest (fastest) elements and if we should mark bias the signal fifty percent (50%), all the single mark elements will now be 33 milleseconds while all the single space elements would only be 11 milleseconds. With a Bias condition we have now developed signals that are twice as fast as the system is really designed for and any signal that is received from the system under these conditions is probably suffering from Fortuitous distortion as well as bias distortion. It is axiomatic that if we exceed the bandwidth of the system with the signal in use that we will distort the signal and if we exceed the bandwidth excessively we will destroy the signal beyond use.

There are several ways of calculating Bias distortion. (See figure 2.) The method most often encountered today is the ratio between the normal mark or space element and the amount the mark or space has been lengthened. This means if the mark element is half again as long as it should be it would be considered a fifty percent (50%) mark bias. Note that at this same moment the space element would be shortened fifty percent (50%). It has been the practice in the past to calculate the mark-space ratio by comparing the length of the mark against the space. This is possibly a bit more difficult to do and while effectively the same result is produced it is suggested that the first method is easier to understand and more commonly used.

CAUSES AND EFECTS OF END DISTORTION

End distortion is often confused with Bias distortion but it is very different in nature. It normally effects the mark to space change-overs in the signal more significantly than the space to mark change-over. We can have both End distortion and Bias distortion present on a particular signal. For the purpose of this discussion we will consider that the mark element is considered in U.S. military systems as be-



A five unit start-stop teleprinter signal sending the letters shift. The most important thing to know in order to determine the minimum allowable bandwidth is the length of the shortest elements. In the above waveform the start element is the shortest element shown. In the above waveform there is nothing to indicate the speed (length of the elements) of transmission. The waveform does indicate that all elements are the same length except the stop element which is 142% longer than the start or code elements. If one is told that the start or code elements are 20 milleseconds long then it is immediately possible to determine the bandwidth requirements for the signal.

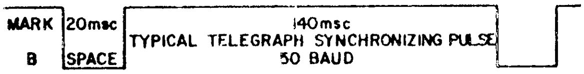
Step #1—divide one second by the 20 milleseconds.

$$\frac{1}{.02} = 50 \text{ BAUD}$$

Step #2—multiply the Baud speed × 3 to get a satisfactory signal bandwidth.

50 × 3 = 150 cycles bandwidth required

The term Baud has been used for many years in telegraph work and a thorough understanding of its meaning is mandatory for personnel engaged in the process of handling square wave information such as computer, teleprinter, dial, exchange, time and frequency division multiplexing equipment and similar related fields. In the United States a term has been used called the Dot Cycle. Essentially a Baud is Half a Dot Cycle with one rather definite advantage. The Dot cycle assumes a Mark-Space ratio of 1:1. The Baud means the length of the fastest elements is X units of time that the signal is square wave in nature and it is probably a nonrepetitive waveform in its information bearing condition. The Dot Cycle states that the time for *one mark and one space* is X units of time that the signal is square wave in nature and it is probably nonrepetitive in its information bearing condition.



Take the case of waveform B in accordance with the definition of the Baud the keying speed of waveform B is 50 Baud

$$\frac{1}{.02 \text{ seconds}} \quad 50$$

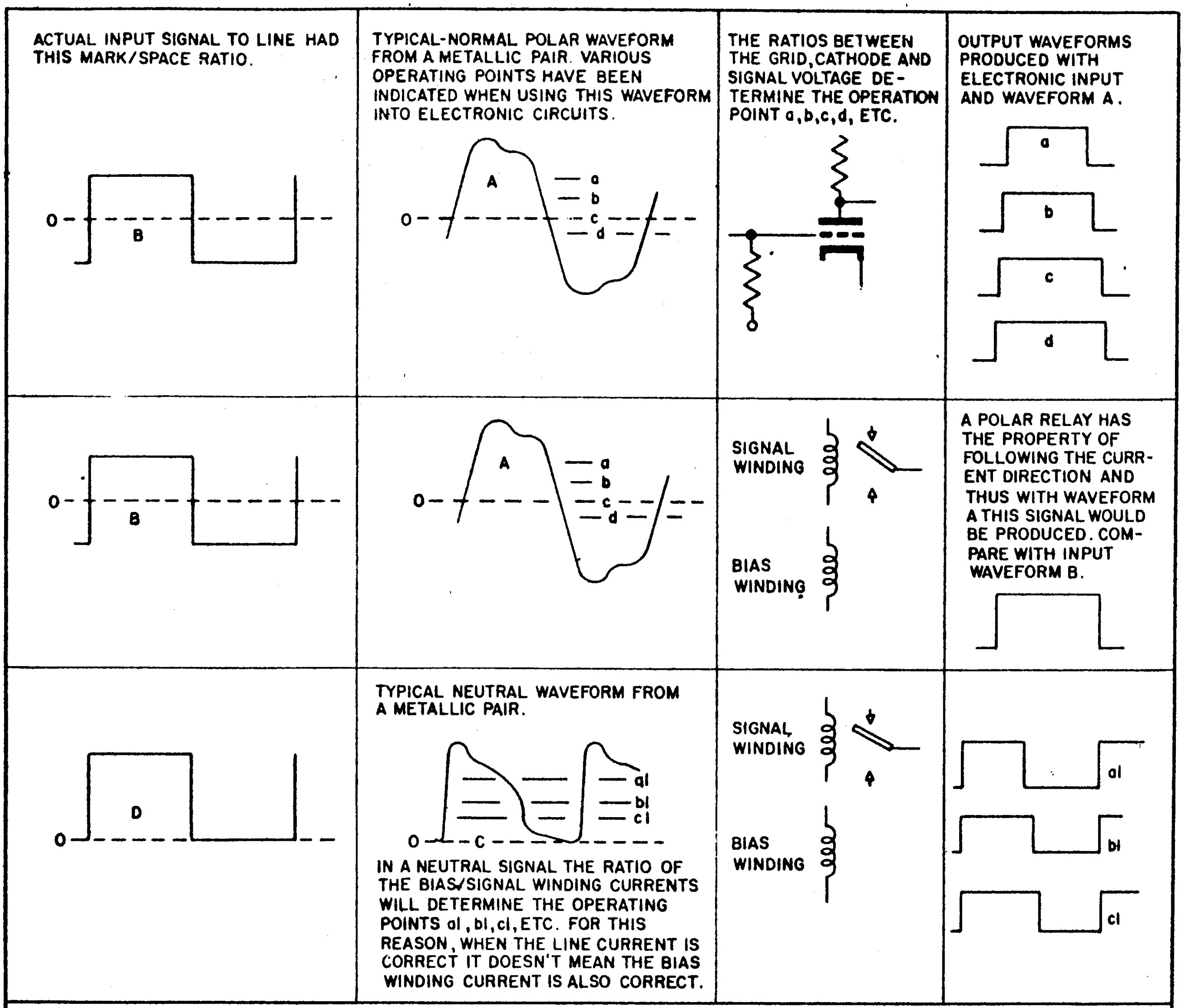
Suppose one calculated waveform B using Dot cycle and assumed the 1:1 mark-space ratio. The total time for one mark and one space is 160 milleseconds.

Dividing:

$$\frac{1}{.16} = 6.25 \text{ Dot Cycles}$$

When one is using Dot Cycles we multiply by 6 to get bandwidth requirements. Therefore 6.25 × 6 = 37.5 cycles. Yet in the calculations for waveform A we showed that a 20 millesecond pulse requires 150 cycles bandwidth. It is suggested that use of Dot Cycle rather than Baud is a matter of choice but let the user BEWARE!!

Figure 6—Hints on how to arrive at an acceptable bandwidth for the keying in use



ACTUAL INPUT SIGNAL TO LINE HAD THIS MARK/SPACE RATIO.

TYPICAL-NORMAL POLAR WAVEFORM FROM A METALLIC PAIR. VARIOUS OPERATING POINTS HAVE BEEN INDICATED WHEN USING THIS WAVEFORM INTO ELECTRONIC CIRCUITS.

THE RATIOS BETWEEN THE GRID, CATHODE AND SIGNAL VOLTAGE DETERMINE THE OPERATION POINT a, b, c, d, ETC.

OUTPUT WAVEFORMS PRODUCED WITH ELECTRONIC INPUT AND WAVEFORM A.

A POLAR RELAY HAS THE PROPERTY OF FOLLOWING THE CURRENT DIRECTION AND THUS WITH WAVEFORM A THIS SIGNAL WOULD BE PRODUCED. COMPARE WITH INPUT WAVEFORM B.

TYPICAL NEUTRAL WAVEFORM FROM A METALLIC PAIR.

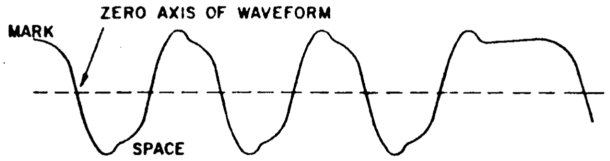
IN A NEUTRAL SIGNAL THE RATIO OF THE BIAS/SIGNAL WINDING CURRENTS WILL DETERMINE THE OPERATING POINTS al, bl, cl, ETC. FOR THIS REASON, WHEN THE LINE CURRENT IS CORRECT IT DOESN'T MEAN THE BIAS WINDING CURRENT IS ALSO CORRECT.

1. While a relay or electronic device may reshape a distorted waveform it doesn't hold that the space/mark or mark/space transitions are any longer correctly spaced.
2. If the distorted waveform is polar and being fed to a properly adjusted relay then the signals will be reshaped and the mark/space and space/mark transitions will be in their proper relationship to each other.
3. If the polar waveform is fed into electronic circuitry only by arranging the zero axis of the waveform as the space/mark and mark/space transition point will we arrive at a minimum distortion of the signal transitions.
4. A relay operated in a neutral circuit will have the same limitations as the electronic device.

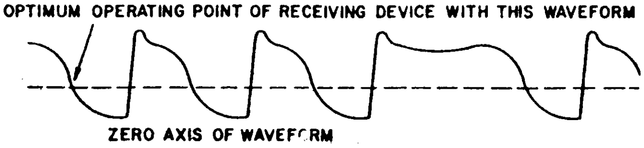
IT IS ABSOLUTELY MANDATORY. THAT THE DEVICE BEING KEYED BY ANY WAVEFORM BE ADJUSTED TO THE POINT THAT CAUSES MINIMUM DISTORTION TO S/M AND M/S TRANSITION.

Figure 7—Effect of electronic and mechanical devices on polar and neutral signals

ing a current or voltage or both on the line and the absence of same as being a space element. (The reason for separation of the current and voltage even though both are actually present is to make sure that both voltage and current keying conditions are considered.) *Due to the different rise-fall time of the voltage in neutral (single current) circuits the effect on the mark to space voltage waveform is different*



TYPICAL LINE SIGNAL FOR THE LETTER Y USING 1.5 STOP. KEYING A POLAR RELAY THIS WAVEFORM WOULD PRODUCE AN EXCELLENT SIGNAL WITH LESS THAN 3% FORTUITOUS DISTORTION.



TYPICAL NEUTRAL SIGNAL RECEIVED FROM A METALLIC LINE. LETTER Y USING 1.5 STOP. THIS WAVEFORM SHOULD PRODUCE AN EXCELLENT SIGNAL IF THE OPERATING POINT IS CAREFULLY PICKED. It would be difficult in a practical case to keep the Fortuitous distortion under 5% using this waveform. Note that the space signal barely has time to approach the zero voltage axis prior to the next signal arrival. This indicates that not much increase in signalling speed can be achieved on this circuit without resorting to polar keying conditions. The performance figures on AC reversals on a signal with this waveform on reversals would give no more than 1% Fortuitous distortion. It is for this reason that one should be cautious in using reversals as a performance check of a circuit.

Figure 8—Typical Line and Neutral Signals

from the space to mark waveform rise time. (See figures 2, 7, and 8.)

In a DC telegraph circuit we have resistance, capacitance, and inductance present. The effect of the resistance is to limit the current flow and over a rather wide range this may be overcome by the use of higher line battery voltages but the effect of capacitance and inductance cannot be so easily overcome in neutral signalling. It should be emphasized that the capacitance and inductance is not lumped in one unit but distributed along the length of the cable. For this reason it is not easy to cancel out the effect of one with the other.

The biggest offender in most neutral DC systems is the capacitance. The capacitance will cause the voltage decay slope of the mark to space transition to be lessened. Consequently the voltage present, as much as forty percent (40%) after the actual start of a mark-space change-over can be sufficient to hold a relay marking or a tube conducting. In a neutral signal the effect of the capacitance on the space to mark change-over is generally insignificant and thus the relay or vacuum tube operates at essentially the proper time. A neutral circuit in the mark condition at the sending terminal is terminated in a low impedance while in a space condition it is open circuit. (See figures 7 and 8.) End distortion can have an effect on a TTY signal that is most frustrating if one is not alert to the possibility of it existing; i.e., a test transmission can have all but perhaps two particular characters correct and repeatedly garble these characters only at the distant end. The result is that the receiving stations assume it is a poor test transmission. While in actual fact the circuit is marginal due to END distortion and any slight deterioration will cause seriously mutilated traffic.

End distortion is revealed as mark bias on distortion measuring sets because it produces an effect similar to bias but as it is not actually bias we must identify it by a separate and distinct term. The most reliable and effective way to eliminate End distortion is to operate the circuit with polar (double current) signalling. (See figure 8.) The utilization of polar signals accomplishes two things. One, it causes the line to be terminated in a low impedance at all times except during the transit time of the keying device. This means that the rise-fall time of the transitions is much sharper and symmetrical. Secondly, a polar relay has the property of only changing from one contact to the other under the influence of the direction of the signal current. The polar relay can be adjusted to operate at approximately the zero axis of the waveform, with the result that whatever amount is taken from the signal in time on the space-mark change-over is added to the signal on the next mark-space change-over.

When working into a vacuum tube the operating voltages can be adjusted to the zero voltage axis of the polar signal which will normally be the steepest portion on the rise-fall time and thereby minimize the effect of End distortion. A vacuum tube doesn't really have that valuable property that a polar relay does of following the current direction. The vacuum tube also converts the received polar signal to a neutral signal as far as the circuit operated by the vacuum tube is concerned.

CAUSES AND EFFECTS OF CHARACTERISTIC DISTORTION

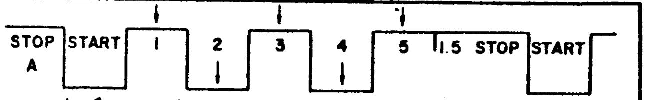
This term is the least understood and most misapplied of all the forms of telegraph distortion. Probably the best definition for Characteristic distortion is this:—"The repetitive displacement or disruption peculiar to specific portions of a signal." It is normally caused by maladjusted or dirty contacts of the sending equipment. An example would be the repeated splitting of the third code element of a TTY signal. (See figure 3.)

It is most important that we be able to separate Characteristic distortion from the other forms of distortion. If we are able to establish that only a certain portion or portions of the signal is disrupted we can immediately eliminate the entire system between the sender and receiver and say that the sending equipment is the cause of the distortion. (Note: If there is any regeneration equipment in the system we have to make sure that we don't blame the circuit prior to the regeneration equipment.)

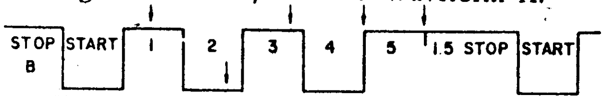
As an example, suppose we have less than three percent (3%) bias, less than one percent (1%) speed variation, less than three percent (3%) Fortuitous distortion and forty percent (40%) Characteristic distortion of the second code element on a thousand mile telegraph system with the added complication that the signalling is "on-line" (encrypted). Now if the distortion measuring gear will resolve these facts as separate entities, anyone working on the system can immediately determine that the sending equipment is the cause for the high distortion and that the system itself is in first class operating condition.

The fact that a line has a Characteristic waveform that is inductive or capacitive should not be interpreted as Characteristic distortion. Nor should the fact that a VF carrier telegraph system has a distortion figure that is characteristic of the particular system be interpreted as Characteristic distortion. Characteristic distortion can only be introduced into a system at the sending point, a regeneration point, or a point where the signals are converted from one code to another. An example of changing codes would be feeding a start-stop TTY signal into a time division multiplex system.

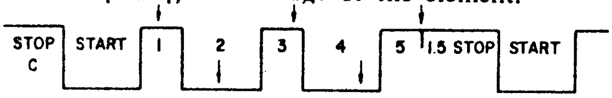
A system itself, can only introduce Bias distortion, End distortion or Fortuitous distortion. Therefore, when we speak of a system's performance we should make very clear how much of each form of distortion is present, and not try to lump the distortion of the whole system under Characteristic distortion.



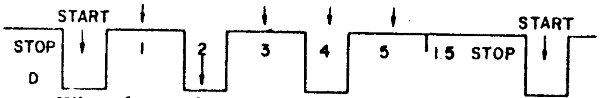
A five unit start-stop teleprinter signal with a 1.5 Stop sending the letter Y. The selection positions have been indicated with the arrows. For this discussion we will assume the receiving device is adjusted for Waveform A.



Waveform B is the same type of signal as waveform A but approx. 9% faster. Notice how the selection position has moved very late in the elements 3, 4, and 5. The signal would not be satisfactory for traffic use as element 5 would be selected either marking or spacing at the edge of the element.



Waveform C is the same as B except we now have added 30% Space Bias. Notice that we have significantly improved the operating margin on the S/M transitions, but the Mark elements have been significantly shortened (increased their speed) and the M/S transitions have not been effected.



Waveform D is the same as B except we now have 30% Mark Bias. Notice that we have improved our operating margin on the M/S transitions but the S/M transitions are unaffected. The Space elements are significantly shortened (increased their speed).

The main objective of the above waveforms is to show how Bias distortion may help to camouflage SPEED difficulties. We must resolve the amount of Bias and any Speed difference present if we are to intelligently operate any telegraph system.

Notice that by misadjusting the selection position from the center of the element that we tend to compensate for speed difficulties but we do not cure the off-speed operation or enhance our signal. Any adjustment that moves the selection position from the center of the signal element is lowering the operating margin of a working system. No adjustment should ever be made that in any way actually lowers the system performance. We must, therefore, locate the difficulty at the source.

Figure 9—How bias Distortion may help camouflage speed difficulties

CAUSES AND EFFECTS OF SPEED PROBLEMS

In start-stop telegraphy we are continuously faced with the problem of synchronizing the speed of our receiving equipment with the speed of the sending equipment. It is for this reason that the teleprinter stops at the end of each character sent and restarts before sending or receiving the next character. Mechanical receiving devices working start-stop have a better capability of working with shortened character lengths than some electronic devices. Therefore, we must be alert to the actual speed and length of each character that is being sent, because we never know what particular equipment may be actually used on the transmission system.

Mechanical and electronic systems such as time-division multiplex are also very conscious of the number of bits of information handled in a given time and if by simple maladjustment of the sending equipment the length of the stop element is shortened we find that we can now send more bits of information in a given period of time than before. Most time division multiplex systems supply a limited amount of storage for this and other reasons, but if we exceed the limited storage capacity even slightly, the time division system will add up these extra bits of information and when they are approximately equal to the length of one character a character will be eliminated. (See figure 4.) This unintentional elimination of a character destroys any enciphered signalling that may depend on the number of character arrivals to maintain its synchronism. It is mandatory, therefore, to know at any distortion check what the actual speed of the signal is.

One of the great problems in measuring distortion is to avoid lumping the four forms of distortion into one or at best two forms. It will be found that meter type displays will read speed problems as Bias distortion, and as shown above, the causes of Bias and Speed distortion are two very different entities. If a signal is caused to send faster or slower this does not mean that the signal will be biased. It means, that the total time for one mark and one space will be shorter or longer but their mark-space ratio will remain unchanged. Speed of teleprinter signals can be varied in several ways. The most common one is that the motor governor fails or is maladjusted. Speed variations can also be caused by slipping clutches on mechanical devices or in the case of electronic distributors the oscillator frequency varying. The effect of off-speed operation in start-stop telegraphy is to cause the later elements in the signal to be much more distorted than the earlier portion of the signal. (See figure 9.)

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INDEX