SECTION 2
SYSTEM ENGINEERING CRITERIA

2-1. GENERAL.

Section 2 of this handbook has been prepared to aid the electronics engineer in exercising technical control of the design, installation, and provision for maintenance of the electronic material which goes into the electronic facilities of a Naval shore activity. The aim of this handbook is to establish criteria which will promote standardization, simplification and optimum performance in the electronic components of the Shore Establishment within the continental United States and for fixed stations on a world-wide basis. Deviations may be expected in systems engineering of facilities of the Naval Reserve whereby the mission, site availability, fiscal, and other limitations make it impracticable to provide and maintain the electronic equipment strictly in accordance with the criteria as established in this handbook. Deviation will, however, be kept to a minimum insofar as possible. Criteria for advanced base electronic installations are under the cognizance of the Bureau of Ships, Code 945.

Systems engineering to provide "optimum performance" includes design and operational techniques of equipment and facilities which will obtain performance which is best, most favorable, or most conducive to a given end; especially under fixed conditions.

a. DEFINITIONS.

(1) ELECTRONIC SYSTEM.—The integration of various electronic components which together perform a specific electronic function, is termed an *electronic system.* This definition follows that of Chapter 67, Bureau of Ships Manual, which states: "A system consists of two or more sets or major units located at two or more points with interdependence and interrelated operations for the accomplishment of a specific objective." Under this definition a complete transmitting system would consist of all the facilities required to handle the message (or any other form of intelligence) from the time the first readable copy was presented for transmission by the "sender," until the radio signals were radiated from the transmitting antenna. For the purpose of this handbook a transmitting system at a radio transmitting station also would include those components of the complete system which are required to take the message as received by landline or link and convert it to radiated energy. Similarly, a complete receiving system would consist of all the facilities necessary to deliver a readable copy of the message to the addressee as the result of radio signals picked up by the receiving antenna. However, those components of the complete system located within the boundaries of a radio receiver station in themselves constitute a system capable of delivering a message to the connecting landline or link for ultimate delivery to the addressee; normally through the facilities of a communication center.

(2) FACILITY.—The term "electronic facility" in this handbook is used to describe the grouping of electronic components, or electronic systems with the necessary housing and utilities which ar established to meet an operational requirement. The use of the word "facility" is not limited to the above definition, however, and the dictionary definition applies where it is employed otherwise. When it is used in connection with the title of an activity located outside the continental United States, the word is capitalized.

(3) SYSTEMS ENGINEERING.—This includes the art and science of converting a stated operational requirement into an electronic facility of maximum practicable effectiveness. The electronics ngineering process includes site selection, development of equipment allowances, operating structures design requirements, antenna and antenna field designs, architectural and engineering development guidance and approval, electronics installation design, installation, performance criteria and maintenance procedures.

b. OBJECTIVE.—The objective of systems engineering is the application of best engineering techniqu s in order to obtain maximum performance out of the components which comprise a syst m or facility. In its larger scope, systems engineering considers many points which are not truly electronic. These include structural requirements, human engineering, and fiscal considerations such as first cost versus long range cost. While the electronics engineers are not primarily responsible for these factors, they have a sincere and responsible interest in them. Without this interest and consideration the completed electronic installation probably would be deficient in overall performance. The responsibility of the Bureau of Ships maintenance authority for these non-electronic matters is in advising the cognizant authority of the electronic requirements for that feature, without telling them how to do it.

Factors of systems engineering at shore establishments are under the cognizance of the local Bureau of Ships maintenance authority, whose duties and responsibilities are specified by the Bureau of Ships in Chapter 67 of Bureau of Ships Manual.

All electronic equipment and systems under the technical control of the Bureau of Ships shall be maintained in satisfactory operating condition, and shall be capable of rendering the required services and fulfilling the standards of operation established by the Chief of Naval Operations. The local Bureau of Ships maintenance authority is charged with the responsibility of seeing that these conditions are met. This is best accomplished through the medium of initial and final acceptance tests, approval of plans, and through annual inspections as outlined in Chapter 67 of the Bureau of Ships Manual. Close cooperation and maintenance of friendly relations with the commanding officers will enhance and expedite accomplishment of electronic planning, installation, and maintenance work. Provision of competent engineering services and accomplishment of the actual work within a reasonable period of time, and at the lowest possible cost, is of paramount importance in furthering this objective.

c. SITE SELECTION AND ALLOWANCE FOR GROWTH.—In planning a new facility or a major addition to an existing facility, systems engineering is required to plan intelligently, farseeingly, and generously. Experience indicates that if an electronic installation is to exist, it grows; that is, the demands upon it increase. More circuits, more words per circuit, more personnel (operators or students), more equipment, more antennas, more flexibility of choice and often more space, (land and housing) invariably result.

Where a choice of sites is limited, and even though the original funds for equipment and facilities may be limited to that necessary to meet immediate needs, with no allowance for expansion in case of normal growth and/or mobilization plans, much can be accomplished by careful long-range engineering planning. Utilize the space and other facilities by arranging the on-hand (or allowed) equipment in such a manner that additional equipment can be added with a minimum disturbance of the then existing installation. In other words, allow a space for additional equipments. Do not sacrifice the possibility of making expansion logically for the sake of "compactness" of the original installation.

This factor applies particularly well in the case of cables, cable ducts, and patching or switching facilities. If not actually installed, plan as if the additional facilities were to be installed immediately and then when the expansion does come, install according to plan; not on the spur-of-the-moment. The magnitude of the provision which should be made for normal growth and expansion, emergency growth and expansion, and for mobilization is always a debated subject. There are many factors which must be known before a realistic estimate can be made. Most of these factors vary from case to case. The percentage allowance which can be included in any project will depend on the provisions of the specific military construction appropriation and the adequacy of the line items of the appropriation to meet existing operational requirements at the time of commissioning.

2-2. SYSTEM DESIGN.

a. GENERAL DESIGN PROCEDURES.

(1) DESIGN STANDARDS.—In setting standards for electronics shore work, the requirements to make the solution as nearly ideal as possible will be presented. In some instances the ideal must be compromised. The greater the compromise, the less satisfactory the end result will be; until finally the compromised solution becomes unacceptable. In many instances there is more than one solution which will give a satisfactory result. Even good authorities do not always agree as to which is the best. Therefore, if more than one good solution or method is known, they will be presented so that under the prevailing circumstances the most satisfactory solution may be selected. A "preferred" solution may be indicated when appropriate.

A "temporary" installation should be well engineered and carefully installed. "Temporary" installations often become "temporarily permanent," and all too often become permanent by default. As long as the nominally temporary and poorly executed installation remains, it is subject to more frequent failures, will not do the job as well, and in the long run will be more costly. In areas where standards have not been established herein, after careful consideration the project engineer should decide upon a "standard" method of doing something and maintain that standard at least for that locality. Do not deviate! *If a superior method is later discovered or developed, change all similar units at that locality or do not use the "superior" method at all. Preferably, all similar units should be the same throughout the system.*

(2) OPERATIONAL REQUIREMENTS.—Before any constructive engineering study can be made, the operational requirements first must be determined. These operational requirements for an electronic in-

stallation are usually specified or approved by the Chief of Naval Operations.

In studying the operational requirements, it should be determined how permanent the installation is considered. Does its geographical location materially affect its strategic utility? Should it be protected from gunfire or bombing? Should it be designed to operate attended or unattended? Attended operation implies that a facility requires continuous supervision and adjustment by personnel constantly in attendance. Complete unattended operation requires only the periodic attention required for maintenance, and applies to such facilities, for example, as a radio beacon operating on a fixed frequency.

In considering the relative long-time costs versus short-time costs, the first-cost is only one consideration. Other considerations are (a) cost of maintenance parts and installation labor, and (b) relative cost of attended versus unattended operation. Industry spends large sums of money to reduce maintenance costs, not only by keeping maintenance parts consumption to a minimum, but also to save the labor costs to install them. The opportunity to reduce maintenance costs and possibly providing for unattended operation is a subject which no wide-awake project engineer should overlook.

When the operational requirements have been fully determined, the project engineer must determine whether or not the project will, or should, require an entirely new facility. He must also determine whether an existing facility should be so modified or expanded so as to accomplish the new mission without impairing the functioning of the existing facility, or the well-being of the system as a whole.

If the task requires a new facility, it becomes a complete engineering-design problem which can proceed with somewhat less regard to existing conditions. The engineer has a good opportunity to utilize all the latest techniques and know-how on a system-wide basis.

If the task must, and is capable of being accomplished by modification or expansion of existing facilities, the project engineer must proceed along somewhat different lines. To preserve any semblance of systems engineering, the "new" work must operate consistently with the "old," or the "old" must be modified to operate with the "new."

(3) SYSTEM REQUIREMENTS.—Once the overall operational requirement has been interpreted, the detailed system requirements must be determined. This involves such details as, (a) scope and configuration of the electronic systems required, (b) proposed major and test equipment allowance, and (c) electronic specifications for architectural and engineering development including utility requirements.

Miscellaneous factors which must be included in system planning and arrangement are as follows:

(*a*) SHOP AND STORAGE.—Whenever possible, allow and provide ample ready storage space in the original planning. There is a tendency to ignore its importance in favor of operating space, depending on acts of expediency to meet the needs. Shop space must be provided to meet maintenance requirements. Spare parts stowage as determined by the operating command should be provided, but its location should be near operating spaces but not in them.

(*b*) HUMAN ENGINEERING.—Human engineering, for the purposes of this handbook, may be defined as the consideration of the factors which affect the well-being and actions of an individual and his associates. "The Human Engineering Guide for Equipment Designers" by Wesley E. Woodson of the Navy Electronics Laboratory staff is recommended for reference. Copies have been distributed to various Bureau of Ships field activities. Additional copies may be obtained from the University of California Press, Berkeley, Los Angeles, California.

The electronics engineer's interest in human engineering is to enable an electronic installation to perform its mission in the most efficient manner by consideration of these factors. Any installation of electronic equipment which is not wholly automatic, requires human assistance to perform its mission. Therefore, the well being of the individual who is to render the human assistance is of considerable importance.

It has been proven that if an individual is reasonably comfortable, he can perform more and better work for longer periods than if he is uncomfortable. In this sense comfort does not mean luxury, nor ease which would promote laziness or inattention.

Four factors which contribute to the COMFORT of the individual are: (a) sufficient clean AIR, free from objectionable odors, and having humidity and temperature levels which are consistent with his duties; (b) sufficient non-glaring LIGHT so placed as to properly illuminate his work without requiring him to look into lights beyond; (c) reasonably QUIET surroundings; and (d) working conditions which cause MINIMUM CONFUSION.

Other important factors are:

APPEARANCE.—It has been shown that if the original installation is pleasing in appearance it will work better. There is a definite tendency for maintenance and operating personnel to take pride in keeping the installation good looking. At the same time they give it better technical maintenance, which in turn tends to keep the equipment in better operating condition.

CONVENIENCE.—Another important factor

in human engineering is CONVENIENCE. It has at least three beneficial effects: (a) it promotes accomplishment of things which might otherwise be neglected; (b) it enables one to do better work in less time; and (c) by the careful placement of equipment many needless steps can be saved thus conserving personal energy and time.

Care and thought should be given to the arrangement of meters, test equipment, jack fields, indicating lights, etc. to assure they are at proper eye level for the use of the people who are to use them.

SAVING STEPS.—In arranging equipment, consider whether the proposed arrangement will save the maximum number of unnecessary steps for the operator and/or supervisor, commensurate with possible other disadvantages.

ROUTINE OPERATIONS.—Relieve the operators and/or supervisor of the necessity of puzzling over what is the difference between the control of different but similar units (such as transmitters keyed from wire, radio or multi-channel, or the output circuits of single-channel or multi-channel radio receivers) by making all similar operations appear similar. This is important, particularly while working under stress or emergency conditions when the operators are busy thinking of other things.

COMPATIBILITY. — Another problem in the human engineering field is that of joint tenancy or joint use of sites, buildings, structures, or even electronic equipment or facilities. It is necessary or desirable to subdivide a facility into subunits of varying degrees of physical isolation because of their function, or the security classification of the work carried on therein. Examples are manual circuits functionally requiring low ambient noise and high concentration, message centers as distinct from relay functions, or crypto spaces.

(4) SYSTEM PLANS.—Drawings may take the form of: (a) engineering sketches and engineering specification notes, (b) detailed design drawings and specifications, and (c) finished or final manufacture and/or installation drawings and plans.

The types of drawing required for a particular task solution will vary within wide limits. Among the types frequently required are: (a) vicinity plan, (b) site plot plan, (c) sub-surface facility plans, (d) antenna farm layout, (e) functional block diagrams or signal flow charts, (f) building layout plan, (g) equipment layout within building plan, (h) schematic wiring diagram(s), (i) inter-unit cabling drawings and/or lists, (j) "type" or guidance plans of standard equipments, (k) "type" drawings of special equipments (such as patch panels, frequency measurement equipment, control panels and/or operating positions), (l) cross-connection lists, and (m) installation materials list.

(5) SYSTEM INTEGRATION.

(*a*) PHYSICAL.—Although this may not particularly apply to communication equipment, in determining the best arrangement of certain electronic equipment for a proposed new installation, or a rearrangement of an existing one, it is an excellent policy to make three-dimension model layouts for all installations, using blocks to represent the individual equipments. The scale for these models is one inch to the foot.

The use of three-dimension models will enable the operating personnel to better visualize what the completed installation should look like, and how it should operate. Photographs of alternate arrangements can be made for comparative purposes. These photographs can be forwarded to those interested, especially those for whom it is impossible or impracticable to view the actual model.

(*b*) ELECTRICAL.—Standard installation practices shall be adhered to where electrical integration of units of a system, or integration of systems is involved. Six hundred-ohm open-wire transmission lines or special 70-ohm coaxial cable is used for the transfer of high power RF energy such as is encountered in HF transmissions and lower frequencies. For VHF-UHF applications, 50-ohm coax is used. The standard RF transmission line impedance for receivers is 70-ohm coaxial cable. Audio signals are carried on standard shielded twisted pairs, engineered to maintain 600 ohms input and output impedances, and balanced for isolation from noise or other unwanted signal energy.

In order to integrate multiple systems, standard control facilities are prescribed for communication installations whereby systems can be controlled by means of standard patch cord and switch panels. Permanently installed monitoring devices are also a part of these facilities. Coaxial antenna patching arrangements to provide maximum flexibility shall be planned for, and installed at receiving facilities. A system of outdoor and indoor switches for 600-ohm open-wire lines is provided at transmitter stations, supplemented by coaxial patching of certain antennas which are so connected. The use of antenna multicouplers at Naval Air Stations and Radio Stations (R) conserves vital antenna space, in addition to the economy of having less antennas to provide.

(*c*) SPURIOUS EMISSIONS, RESPONSES, AND CROSSTALK.—Although the equipment itself may be designed to meet specification limits pertaining to spurious emissions, responses, harmonic generation or crosstalk, care must be exercised as to the arrangement of equipment and external connections so that such undesirable effects are minimized. This requires careful engineering of such factors as shielding, bonding, and circuit isolation as well as provision for the maintenance of proper signal levels and assurance that equipment will be properly operated. Precautionary measures are especially vital at receiver stations where circuit sensitivity, as a ratio of signal to noise level, limits receiving capabilities. Proper operation of transmitters also is essential, because an over-modulated or improperly adjusted transmitter is a potential source of interference to other stations.

Sources of interference are sometimes difficult to locate and suppress. A good look at all the prolific sources of interference as listed in para 2-15*e* of this handbook will assist systems engineering in the development of environmental conditions which will provide optimum performance of a facility.

b. SUMMARY.—To assist the project engineer in making his investigation of the electronics considerations for shore electronic installation, new or old, the following check-off list is provided. Criteria for each item may be obtained by consulting the index of this publication, or in correspondence pertaining to the establishment of the electronic facility.

(1) Operational requirements of project or task.
(2) System-engineering concepts.
(3) Radio circuit requirements (operational).
(4) Electronic equipment selection.
(5) Site or location considerations.
(6) Station area layout.
(7) Antenna requirements.
(8) Tower height and aircraft clearance.
(9) Azimuth coverage of radar installations.
(10) Antenna transmission lines.
(11) Antenna terminations.
(12) Antenna switching.
(13) Analysis of radio path and propagation.
(14) Building and structures (physical, type of construction, etc.).
(15) Building and structures (electronic, operational features required).
(16) Ground systems.
(17) Electronics spaces required (number and size).
(18) Communication and control radio links.
(19) Communication and control cables.
(20) Test equipment.
(21) Special purpose electronic equipment.
(22) Equipment arrangement.
(23) Human engineering.
(24) Cable and RF link terminations.
(25) Power switching and distribution.
(26) Wire and cable distribution.
(27) Circuit control and switching.
(28) RF lines switching and distribution.
(29) Electronics power requirements.
(30) Heat liberated by electronic equipment.
(31) Air conditioning of electronics spaces.
(32) Lighting of electronics spaces.
(33) Hardstand requirements.
(34) Station services: water, gas, etc.
(35) Roads and parking areas.

2-3. ANTENNA AND TRANSMISSION-LINE SYSTEM ENGINEERING.

a. GENERAL*.—There are three basic aspects of antenna engineering. The first pertains to radiation characteristics and includes all matters incident to the distribution of radiant energy in space around an antenna system, as well as the current distribution that produces the radiation pattern. The second pertains to antenna circuitry and involves such matters as self- and mutual impedances, currents, potentials, insulation, and feeder systems that will yield the desired current distributions. Third, there is structural engineering which has to do with all the mechanical details of support, rigging, materials, strengths, weights, hardware, assembly, adjustability, stability, and maintenance. While each aspect must be separately developed, the final design must be an integration of the three, with a minimum of compromise and within reasonable economic limits.

The purpose of a transmitting antenna is to project radiant energy over a given wave path in the most effective and economical manner. The purpose of a receiving antenna is to absorb a maximum power from a passing wave field, with the maximum exclusion of noise and interfering signals. The transit of a wave field between the two depends upon the physics of wave propagation. The antenna engineer must be familiar with wave propagation to be able to design antenna systems of maximum effectiveness. Wave propagation is a vast and complicated statistical subject, and for that reason this book is limited to the barest essentials.

The engineer recognizes rather large overlaps in the bands of frequencies into which antenna design techniques are classified. They blend gradually from one into the other; the amount and the extreme ranges varying with the state of the ionosphere and ground characteristics, as shown in the following table.

TABLE 2-1, ANTENNA DESIGN-FREQUENCY GROUPING*

Term	Abbreviation	Approximate Band	Most Useful Propagation
Low Frequency (long wave)	LF	Up to 500 kilocycles	Ground waves and sky waves
Medium Frequency (medium wave)	MF	200 to 5000 kilocycles	Highest usable ground waves and sky waves
High Frequency (short wave)	HF	3 to 40 megacycles	Sky waves propagated by way of ionosphere

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The three overlapping frequency groupings roughly define the three different classes of techniques which apply to antenna design, with specific types for each class discussed in paragraphs which follow. To a certain extent, high-frequency design techniques may also be applied to antennas used for optical propagation, but antennas for the frequencies propagated optically become still another class of techniques. They are discussed under VHF/UHF APPLICATIONS with further discussion under RADAR EQUIPMENT INSTALLATIONS.

For clarification, the following standard table of frequency designations is provided.

TABLE 2-2, STANDARD FREQUENCY DESIGNATIONS

VLF	– under 30 kc
LF	– 30–300 kc
MF	– 300–3000 kc
HF	– 3–30 mc
VHF	– 30–300 mc
UHF	– 300–3000 mc
SHF	– 3000–30,000 mc
EHF	– 30,000–300,000 mc

Radio frequency waves at frequencies above 300 mc are commonly called "microwaves."

Antenna installation at shore activities involve all types, with frequency ranges from 14 kilocycles to and including microwaves. Requirements to be met vary from broadcast and point-to-point circuits of several thousand miles, to those for control tower/landing-strip coverage at Naval Air Stations. Power handling capabilities range from microwatts to megawatts.

b. INTERPRETATION OF ANTENNA REQUIREMENTS.—The requirements for an efficient transmitting antenna at a given frequency are the same as for an efficient receiving antenna. Therefore, the following discussion on antenna systems will generally pertain to both transmitting and receiving systems.

In the interpretation of the antenna requirements for a given facility, each circuit must be considered separately and the design of the antenna should be such as to most effectively meet the requirements of that circuit. When all circuits have been considered, the total antenna requirements will require integration into a system with consideration given to antenna impedance, gain, radiation patterns and frequency ranges, separation of antennas and feeders, switching and/or patching for flexibility, relative cost, and optimum system performance.

In general, antenna fields are arranged such as to keep transmission line losses and antenna interaction to a minimum, coaxially fed antennas and higher frequency antennas being near the transmitter or receiver buildings and the point-to-point antennas, usually rhombics, are placed near the periphery. Each antenna for point-to-point service is precisely located and constructed with optimum vertical and azimuthal directivity to take advantage of most favorable ionospheric conditions.

In fulfilling the Navy requirements for antenna systems, a number of factors quite aside from purely electromagnetic aspects must be considered before the relative merits of possible configurations can be established. These factors arise because the antenna is an element of a communications system and as such must be integrated into the system requirements. If the system is complex, consideration must be given to the multiplicity of operational requirements. Specifically, the following items should be examined as an aid in making a choice of a particular antenna to satisfy a given set of requirements.

Polarization.
- Horizontal
- Vertical
- Circular
- Elliptical

Radiation Pattern Requirements.
- Azimuthal Coverage
- Vertical Coverage

Impedance.
- Broadband
- Narrowband
- VSWR

Feed System.
- Balanced
- Unbalanced
- Combination

Efficiency.

Structural Complexity and Physical Size.

Cost.

The polarization of the propagated wave is determined initially by the type and arrangement of the transmitting antenna. As a rule, a vertical conductor radiates a vertically polarized wave, and a horizontal conductor radiates a horizontally polarized wave. A receiving antenna is oriented to take advantage of the polarization of the received wave. More complex forms, such as circular and elliptical polarization, in which the direction of maximum voltage rotates in space at the frequency of transmission, are also possible. These types are generated by certain special antennas or may be developed unintentionally when simple polarized waves pass through nonuniform media. The wave polarization in free space is always in a plane perpendicular to the direction of propagation.

As a consequence of the random polarization of medium and high frequency ionospheric waves due to changes in transit, the polarization of the transmitting antenna need not be dictated by the characteristics of the remote receiving antennas. There are, however, several factors which must be considered when making the choice between a vertically or a horizontally polarized radiator. Figure 2-1 is provided to show the attenuation of horizontally and vertically polarized waves over sea water, and over ground of poor and good conductivity. Where circuit requirements are for ground wave propagation, vertical polarization provides maximum area coverage.

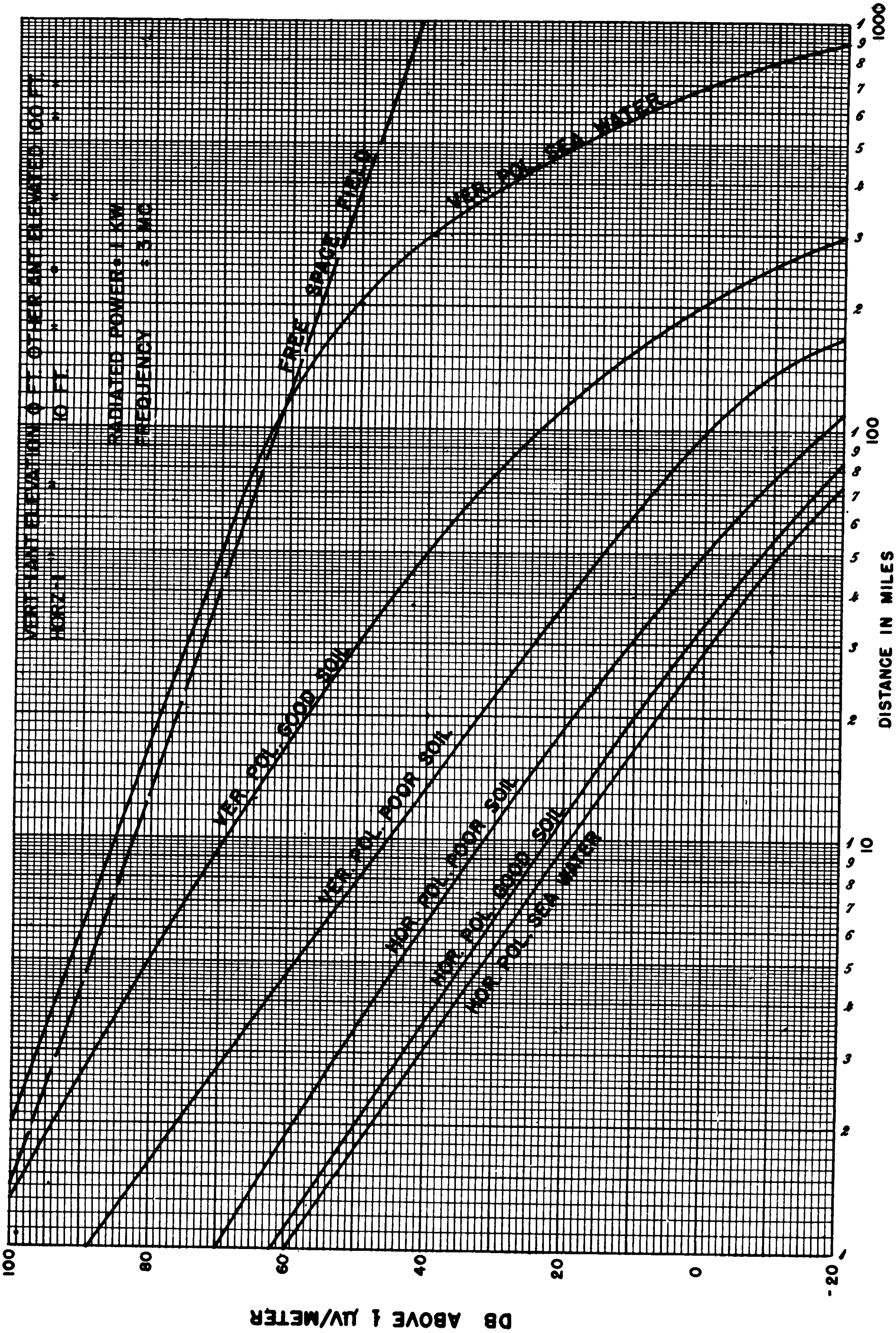
In the determination of the antenna design requirement, the first factor to be considered pertaining to polarization is the manner in which the radiation pattern characteristic is related to antenna configuration. A second factor to be considered is that of achieving short-range coverage (within several hundred miles) by the effective utilization of ground-wave propagation. Over sea water, which has the best conductivity afforded by nature, substantial distances can be covered with frequencies up to five mc. This factor has often been utilized for inter-island communication and for short-distance ship-to-shore communication, particularly in harbors and estuaries. In such applications, vertical polarization gives best results, and the station sites should be located near the shore to avoid excessive attenuation over land.

The principal difference between antennas utilized for broadcast and those used for point-to-point service lies in the required radiation pattern characteristics. While the gain of 10 to 20 DB that can be achieved through the use of directive arrays in point-to-point service does not overcome the vagaries of the ionosphere in its effect on signal transmission, it may often mean the difference between reliable and marginal communications. In broadcast and ship-to-shore applications, where the receiving stations are randomly disposed in azimuth and range, such antenna gains are not feasible. However, by utilizing "sector coverage," an antenna gain up to six DB can be realized.

The radiation pattern characteristics of a particular antenna configuration are variable with frequency. This imposes certain limitations on the bandwidth over which the antenna should normally be used. Rhombic antennas, for example, have impedance characteristics that are very constant over an 8:1 range in frequency, and yet variations in the vertical radiation pattern suggest its use be restricted to bandwidths on the order of 2:1 for optimum operation. Although the bandwidth characteristics of the rhombic are recognized, antenna park space and construction cost considerations will usually mitigate against provision of an optimum design for each assigned frequency. In general, two rhombic designs are provided.

The versatility of broadband antennas at radio stations having a large number of operating equipments and frequencies hardly needs emphasis. The use of these antennas, together with a well-engineered switching system, permits high equipment utilization and flexibility of station operations. It is unfortunate that to a certain extent the structural complexity and the cost of high frequency antennas is directly related to their bandwidth. Simple doublets are inherently highly efficient; they are, however, virtually single-frequency radiators. Broadband radiators represent a much larger investment in effort and cost than their narrowband counterparts. The increased operational efficiency, versatility, and generally reduced antenna park space requirements made possible by their use, however, will usually outweigh the factor on increased cost. With larger and larger traffic volumes to be handled, the compromises employed for economic expediency may no longer be tolerable in the future.

Antennas for ship-to-shore and broadcast circuits in the high frequency band usually consist of half-wave doublet antennas, both vertical and horizontal, or of simple arrays of such doublets, depending on the area coverage requirements. These antennas are normally matched to the transmission line by closed stubs placed across the transmission line near the antenna and grounded at the shorting bar end. The antenna and matching device have a narrow frequency band characteristic. Such antenna systems can therefore be used only at frequencies close to the design frequency without re-stubbing, but stubbing techniques extend the useful frequency range of the antenna from 0.36 wavelength to 0.6 wavelength. Antennas, for example, such as stubbed horizontal, vertical, or tilted doublets can be used to effectively cover bands of frequencies as



Figur 2-1. Dipol Propagation, V rtical and Horizontal Polarizati n

follows:

Design	4.8. mc	8 mc	12 mc	16 mc	20 mc
Coverage	3.5- 5.8	5.8- 9.6	8.6- 14.4	11.5- 19.2	14.4- 24.0

It will be seen from the foregoing that complete spectral coverage can be provided by stubbing for all nominal frequency assignments. Since these services normally, or under mobilization, require simultaneous keying on five high frequencies, doublet antennas provide frequency assignments at the lowest cost. On broadcasts, one low or very low frequency also may be keyed to cover an area extending from the transmitter location out to distances on the order of several thousand miles. Ordinarily, it is not possible for any of these frequencies to cover the full range of distances. At the lower frequencies, except for high power stations, ionospheric absorption and atmospheric noise combine to limit the transmissions to relatively short distances. However, in order to provide coverage for submerged reception and to provide reliable communications in high latitudes, high power VLF and LF transmissions are required.

At the highest frequencies, the skip distance limits useful communications to the longer distances, in the daytime, and completely rules out their use at night. The range of vertical angles to be used depends on the height of the reflecting layers, on the distances to be covered, and on the frequency being used.

For frequencies near four mc, ground-wave propagation normally can be relied upon to provide usable signals out to distances of about 250 miles over sea water. At that frequency and at a distance of 250 miles, the surface wave may be expected to be about 16 DB below the free-space value. On a day of rather high ionospheric absorption, the ionospheric wave also will be reduced about 16 DB below the free-space value at a distance of approximately 250 miles. Hence, in such a case, little is gained when high angles are included in an attempt to obtain sky-wave transmission at distances less than about 250 miles. For the reflection at the highest F2-layer which is normally encountered, vertical takeoff angles of 55 degrees to 60 degrees are required in order for the sky-wave to return to earth at 250 miles. During much of the time, frequencies near four mc will be reflected by the E-layer and much lower angles would suffice. Because of greater absorption at four mc, signal strength at eight mc frequently may be greater at distances immediately beyond 250 miles. Hence, antennas for eight mc should likewise radiate at angles up to 55 or 60 degrees. At some times during the year or sunspot cycle, eight mc also may be called upon to cover the full range of distances out to 2500 miles and beyond. As a result, the eight mc antenna should include radiation down to angles in the vicinity of 10 degrees.

At the highest frequencies in the broadcast group (i.e. greater than 20 mc), rather well-determined limits also may be set on required vertical angles. Because of rapid attenuation, the ground wave is unimportant at these frequencies. In addition, the F-layer critical frequency at vertical incidence does not often range to frequencies higher than 7-10 MC. This corresponds to skip distances of about 1200 miles at 20 mc. Thus, these transmissions would usually be limited to distances greater than 1200 miles. At 1200 miles the one-hop mode would be used, and at 2500 miles the two-hop mode would prevail.

Frequencies near 12 and 16 mc normally would be used to cover somewhat shorter distances than the higher frequencies and, in addition, will be useful for distances out to 2500 miles, or greater, at night.

Certain conclusions may be drawn regarding favorable vertical pattern requirements with emphasis on providing complete coverage from close range, to distances in excess of several thousand miles. These conclusions must of necessity include all anticipated conditions of the ionosphere, accounting for epoch of the sunspot cycle, time of year, and time of day. In summary, frequencies of approximately four mc, usable for ground wave coverage out to distances of approximately 250 miles, should cover a vertical sector of 0 to 60 degrees; frequencies between four and eight mc, used mainly for sky-wave coverage from a few hundred out to several thousand miles, should cover a vertical sector from 10 to 60 degrees; frequencies between eight and 12 mc, mainly sky-wave coverage from several hundred to several thousand miles, desired vertical sector 9 to 50 degrees; frequencies between 12 and 16 mc, mainly sky-wave coverage from approximately 700 to 2500 miles or greater should have a vertical sector of 8 to 45 degrees; frequencies above 20 mc, mainly sky-wave coverage from approximately 1200 to 2500 miles or greater, desired vertical sector 8 to 30 degrees.

The coverage requirements in the vertical directions at the various frequencies can, of course, not be met exactly without going to entirely uneconomical antenna structures. In general, vertical radiators approximately a half-wavelength or less, provide good patterns for the launching of ground waves, and they give adequate coverage at all angles of elevation up to about 60 degrees from the horizontal. Such antennas are especially useful at LF, MF, and HF for broadcast operation where omni-directional antennas are required.

Some control of the radiation patterns of horizontal and vertical antennas can be achieved by varying the height above ground at which the antennas are suspended. A horizontal doublet elevated by one half-wavelength provides good vertical coverage from about 10 to 40 degrees. Increased gain at particular angles can be obtained by varying the doublet height. This is achieved, however, at the expense of the breakup of the pattern into sharp lobes. A height of one half-wavelength above ground, is therefore the best possible compromise for omni-directivity.

High frequency point-to-point circuits operate between fixed transmitting stations and fixed receiving sites. High frequencies are used for all transmissions long enough to permit sky-wave propagation. The ionosphere dictates the choice of frequency, the power rating of the transmitters, and the antenna radiation pattern characteristic required.

One of the main distinctions between the point-to-point circuits and the broadcast or ship-to-shore circuits is the fact that the fixed location of transmitters and receivers in the former permits the use of highly directional antenna systems. Many designs for such antennas have been developed in the past; the most widely used type at the present time is the rhombic. It has excellent gain and directivity when used over a relatively narrow band of frequencies around the desired optimum. The design of the antenna should not be such that the radiation pattern is too sharp to allow for normal variations in arrival angles in either the horizontal or vertical planes.

Admittedly, ionospheric propagation is extremely complex and generalities are not reliable. Ionospheric turbulence, wave trapping, magnetic storms, refractions and reflections, and scattering in space and at reflection points on the earth all contribute to unpredictability. However, it can be said that there is a sufficient amount of successful engineering experience available to justify the specification of desired vertical sectors, and to further stipulate that the radiation patterns within these sectors should be reasonable uniform and free of deep nulls.

c. ANTENNA GAIN–

(1) Antenna Gain may be defined as a measurement of radiated power in a given direction. It is also the ratio of power radiated in a given direction to power radiated in a like direction by a standard reference antenna, keeping input power to the two constant.

Since most radio communications over any great distance use sky wave transmission, i.e., radio waves are transmitted at an angle upwards to be reflected by the ionosphere, it is evident that the given direction cited in the above definition must also include that above a horizontal plane. This direction is angularly defined and is called the vertical angle of radiation.

Although power radiated from an antenna at a known angle is of interest in practical application, gain ratings are derived from measurements taken at the maximum power lobe regardless of the angular relationship between this and the reference antenna's maximum radiation power angle. In selecting an antenna for transmitting over a given sky path, radiated power at the optimum take-off angle would be of prime importance.

(2) In order to establish a point of reference for the purpose of comparing antenna types, a theoretically perfect antenna is used as a standard. This primary standard is called an Isotropic Radiator. The chart in Figure 2-2 compares it to several secondary standards which can be set up as practical radiators for model range work and for field comparison with other antenna types.

(3) In practical application the quarter wave vertical serves well as a secondary standard for comparisons of unbalanced antenna types. Half wave dipoles are a logical choice for balanced types. Of course other types of antennas may be used as well, providing their characteristics reference to the primary standard are known.

(4) A further comparison of standard reference antennas to include vertical radiation patterns is shown in Figure 2-2a. This graph is based on unattenuated field strength in millivolts per meter at one mile with a radiated power of one kilowatt. This is a standard value to which antenna engineering calculations may be referenced mathematically and is particularly useful in propagation path calculations. (Attention is called to Paragraph 2-3*b* for a discussion of radiation patterns and their influence on antenna selection.) An example of the use of such a chart (Figure 2-2a) follows, using a model range for empirical measurements.

(*a*) It is desired to make preliminary tests on a new conical monopole design. The design data is scaled down to an electrical size set arbitrarily at a quarter wave length at 940 mc. Scale models may be readily used due to the fact that there is a fixed relationship between antennas of identical electrical dimensions. The antenna is set up on a model range. Among other measurements, field strength measurements are made of its radiated power at various frequencies and elevation angles. These results are plotted against quarter wave vertical radiators cut to the exact frequencies and operating under the same conditions as the conical monopole. Input power to both antennas are the same. A plot of relative voltages is laid out in a polar graph as shown in Figure 2-2b. It is important to note that the actual voltages need not be known as long as they are plotted to each other.

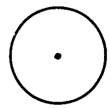
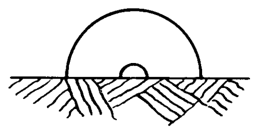
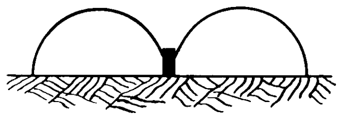
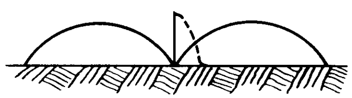
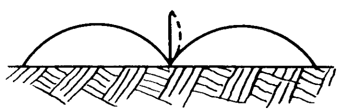
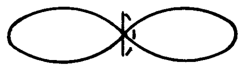
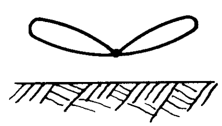
TYPE OF ANT.	VERTICAL PATTERN	MV/M AT 1 MILE 1 KW	POWER GAIN	db GAIN
ISOTROPIC		107.6	1	0
HEMISPHERICAL		152.1	2	3.01
VERTICAL CURRENT ELEMENT		186.3	3	4.771
1/4 λ VERTICAL		194.9	3.282	5.161
1/2 λ VERTICAL		236.2	4.822	6.832
1/2 λ FREE SPACE		137.8	1.641	2.151
1/2 λ HORIZONTAL 1/2 λ ABOVE EARTH		278.0	6.56	8.17

FIG. 2-2 SUMMARY OF STANDARD REFERENCE RADIATION PATTERNS

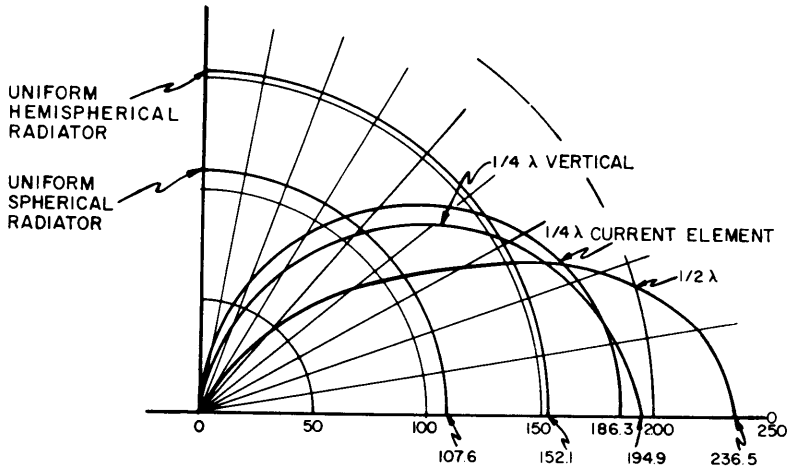


FIG. 2-2a UNATTENUATED FIELD STRENGTH IN MILLIVOLTS PER METER AT ONE MILE, RADIATED POWER ONE K.W.

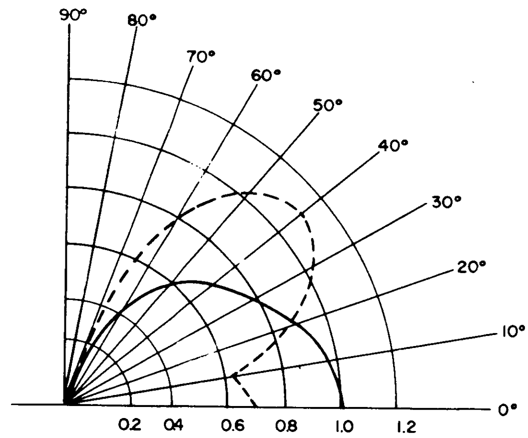


FIG. 2-2b PLOT OF RELATIVE VOLTAGES, CONICAL MONOPOLE VS QUARTER-WAVE VERTICAL RADIATOR

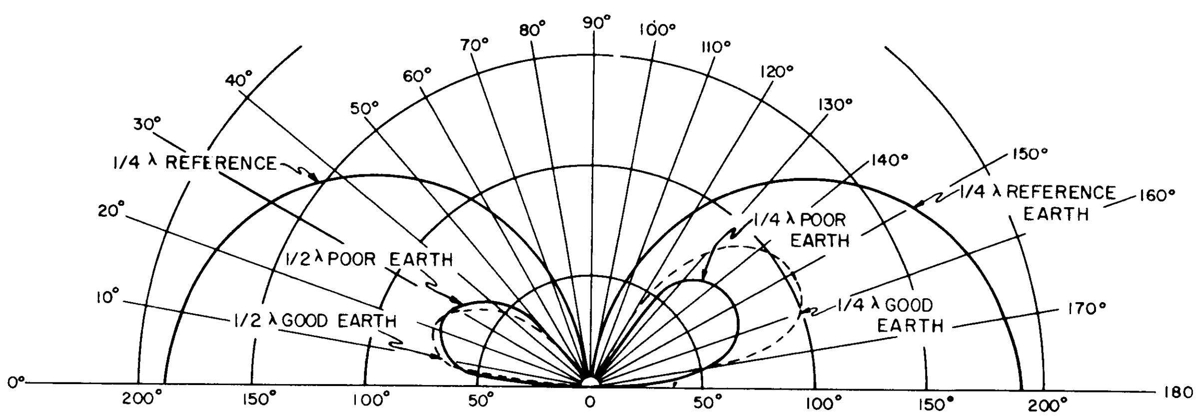


FIGURE 2-2c COMPARISON OF A QUARTER WAVE VERTICAL RADIATOR OVER PERFECT EARTH, GOOD EARTH, AND POOR EARTH. ALSO A HALF WAVE RADIATOR AGAINST THE STANDARD REFERENCE.

(*b*) Since these are RELATIVE VOLTAGES, then

$$db = 20 \log 10 \frac{E_1}{E_2}$$

At 10 deg 20 log .9/.62 = 3.22 db gain of vertical over conical monople

At 20 deg 20 log .84/.84 = 0 db (both antennas are equal)

At 30 deg 20 log 1.02/.79 = 2.28 db gain of conical monopole over vertical

At 40 deg 20 log 1.06/.65 = 4.24 db gain of conical monopole over vertical

(*c*) By referring back to Figure 2-2, it is found that a quarter wave vertical has a db gain of 5.161 over the primary reference, the Isotropic antenna. The following may therefore be listed as the db gain of the conical monopole over an Isotropic at *one particular frequency* as evaluated on the model range.

10 deg	1.94 db
20 deg	5.16 db
30 deg	7.44 db
40 deg	9.40 db

(*d*) It should be remembered that model range antenna evaluations are usually conducted at ultra high frequencies under ideal earth or free space conditions. While they are a useful tool in judging the merits of antenna types prior to the construction of full scale models, additional measurements must be made on full scale models before evaluation may be considered complete.

A discussion of earth conditions appearing in Paragraph 2-3*b*. indicates that significant differences in results under field conditions may be expected. In addition, full scale antennas may act somewhat differently from models due to conductor losses, coupling between elements, structural changes which may have been made to overcome mechanical problems, etc. Therefore, a discretionary attitude should be maintained in using model range evaluations as a guide in antenna selection. Some of the differences in radiation patterns which occur follow:

1. Comparison of a quarter wave vertical radiator over perfect earth, good earth, and poor earth. Also a comparison of a half wave radiator over good earth and poor earth against the standard reference. See Figure 2-2c.

2. Figure 2-2d compares a 2.5 mc sleeve and a 2.5 mc discone antenna under simulated poor earth conditions referenced to a quarter wave vertical over perfect earth, all other conditions being equal. The graphs point out the change in vertical patterns as the frequency approaches upper limits of design.

The foregoing has dealt principally with vertically polarized antennas and their radiation aspects, because of the greater effects of ground constants on the radiation patterns of vertically polarized, as compared to horizontally polarized antennas. With the latter, variation in height above ground and the addition of elements are the controlling factors determining the vertical pattern and ground conductivity is of minor impact. Results to be expected from horizontally polarized systems can readily be predicted. In the case of vertical polarization, ground conditions are one of the primary interests in the consideration of antennas designed for this orientation.

Constant effort is being expended in attempts to improve antenna evaluation techniques in order to obtain more efficient designs and to more accurately predict the field results which may be expected from some of the more complex antenna structures under development at present.

d. ANTENNA SEPARATION.—At shore activities where multiple antenna installations are involved, the question of antenna separation, area requirements, and area availability are factors which must be considered. VLF high power transmitting antennas require individual engineering and a VLF station is usually set up at a separation from other antennas as determined by individual engineering study. Other antennas which are discussed in detail in the following paragraphs require separation from each other and from other types as indicated in Table 2-3.

TABLE 2-3, ANTENNA SEPARATION

Doublets	One wavelength
Rhombics	250 feet (see Note 1)
Vee	250 feet
Sleeves	Transmitting, four times tower height; Receiving, three times tower height. (see Note 2)
90 degree corner reflector	See Note 2
180 degree sector	See Note 2
Conical monopole	1 wavelength (see Note 3)
Discone, grounded cone	1 wavelength (see Note 3)
Discone, regular	2 wavelengths
Log periodic	1 wavelength (see Note 3)
Yagis	1 wavelength
Top-loaded tower	1000 feet

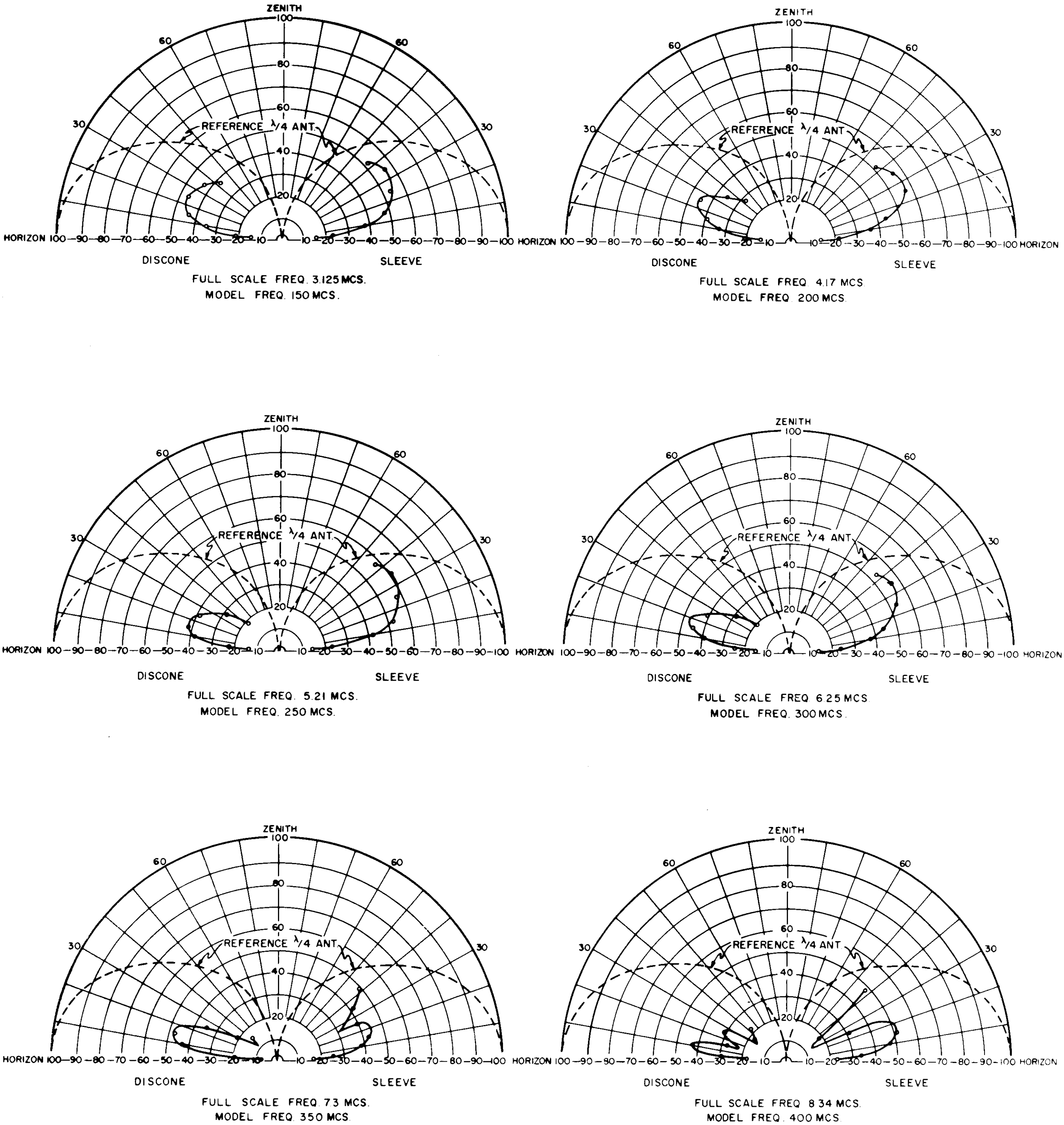


FIG. 2-2d VERTICAL PATTERNS, SLEEVE VS DISCONE, 2.5 MC.

Note 1: Rhombics should not be laid out to "fire through" one another. 250 foot separation has been established and is based on coupling not to exceed minus 40 DB. Using closer spacing will result in greater coupling and increased side lobe levels. In the use of two receiving rhombics for a given circuit, the smaller rhombic symmetrically located inside the larger is recommended. A study is being made of like possibilities for transmitter rhombics. In order to further utilize the large area of land required for a rhombic, vertical radiators may be erected inside the rhombic if sufficient clearance from rhombic curtain and dissipation line is maintained. Use of this area for horizontally polarized antennas, however, is not recommended.

Note 2: The coupling between corner antennas and other structures is quite complex and depends on a number of factors. The following general criteria apply:

(a) Antennas of small obstruction such as sleeves located in line with the corner beam should be spaced at least one wavelength and preferably two wavelengths at their lowest design frequency.

(b) At the present time, it is assumed that rhombic antennas will not adversely affect the corner antenna patterns providing the vertical down-leads of the rhombic antennas are at least 250 feet from the beam center.

(c) An object in the direct beam such as a metal tank or building should be at least 1000 feet from the corner reflector. If there are several buildings, the spacing should be doubled. If the objects are removed from the beam by 90 degrees, the spacings can be reduced by half. Buildings containing noise sources should not be placed in the beam of the antennas or immediately adjacent to them. (The reflector is not a perfect shield but gives an estimated 10 DB of noise isolation.)

Note 3: Pending further study.

e. ANTENNA TYPES.

(1) VLF ANTENNAS.—This requirement involves high power transmitter applications which are resolved as special cases to meet specialized requirements. Multiple tower construction is usually indicated in order to obtain maximum effective radiation. At receiver stations, long wire or loop antennas are used with poles for support.

(2) LOW FREQUENCY ANTENNAS.—In the lower frequency range, antenna engineering is principally a problem in circuit design and involves obtaining maximum efficiency from an electrically short antenna. Where the need for high power exists, the resulting large antenna currents and voltages call for special design techniques. Since the cost of the antenna and ground system may exceed, by several times, the cost of the equipment, it is important that the increase in performance and gain of the system be balanced against the increase in cost. The objective of the design engineer, then, is to obtain an antenna that is electrically as long as possible with the funds available.

The radiation fields of low-frequency antennas are vertically polarized. The usual antenna configurations for operation in this frequency range are towers, vertical wires, and top-loaded wires or towers. Figure 2-3 shows a low frequency radiator with table indicating height recommended for various transmitter power ratings. A vertical unbalanced antenna working against poor ground system may induce high losses in the soil. Top loading at these frequencies improve the efficiency in the radiating system.

Where space and economic factors permit, vertically polarized antennas should preferably be separated at least one wavelength.

(3) HIGH FREQUENCY MARCONI ANTENNAS.—An end-fed slant or vertical conductor of arbitrary length is commonly referred to as a Marconi antenna. Since the antenna radiates throughout its length, i.e., from the transmitter cabinet on, the result is a cluster of antennas in and out of the transmitter building. Serious intercoupling usually results. The effects of intercoupling manifest themselves by interaction in the tuning of the transmitters, generation of spurious signals, and reduced antenna radiation efficiency.

No pattern control is possible with the Marconi antennas since they may be used at nearly any frequency, irrespective of physical length. Furthermore, unless they are used with good ground systems, ground losses are high. For the above reasons, this antenna is no longer approved for general use. The sleeve, doublet, and other types have replaced it at medium and high frequencies.

(4) DOUBLET ANTENNAS.

(*a*) SINGLE WIRE DOUBLET.—A center-fed half-wave doublet has a driving point impedance which is nominally 70 ohms, and may vary from 60 to 100 ohms depending upon the height above ground. The fundamental bandwidth may be defined as the band of frequencies in which the magnitude of reactance does not exceed the resistance. It is more convenient, however, to define the bandwidth as the range of fre-

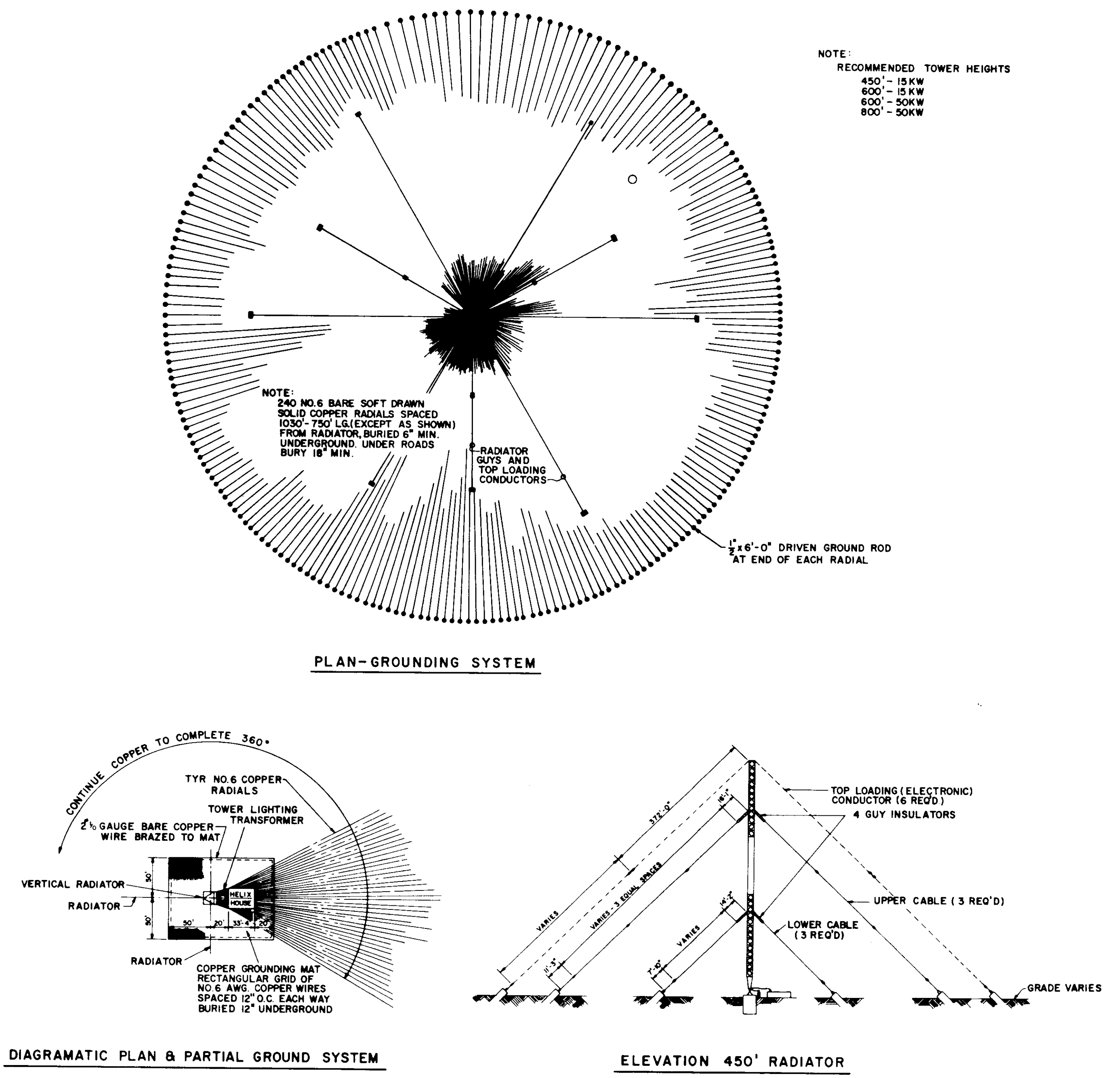


FIG. 2-3 TOP-LOADED TOWER - 450 FOOT RADIATOR

quencies in which VSWR does not exceed the value of 1.5 to 1. The selectivity is greatly affected by the conductor size, or more precisely by the ratio of length to diameter of the conductors forming the ant nna. As a typical example, the use of No. 6 wire for a half-wave doublet will give a bandwidth of approximately 5% at four mc. Such an antenna therefore could be used without retuning, only at frequencies within 200 kc of this design frequency.

Because of the advantages of the folded doublets outlined below, the single wire doublet is not approved for future installations.

(*b*) TWO- AND THREE-WIRE FOLDED DOUBLETS.—One limitation inherent in the single-wire radiators is that of the power handling capability. In general, the power handling capability is increased by the same methods that are used to increase bandwidth, i.e., either increased conductor size or the use of multiple conductor configurations. Since power limitations are established by corona potentials, any reduction in potential gradients through the use of thicker elements and in greater numbers, permits increased power input. The major advantages of the two-wire folded doublet over the single-wire doublet is the higher power handling capability of the two-wire antenna, and a slightly greater natural bandwidth. For these reasons, the use of the two-wire folded doublet is recommended in lieu of the single-wire antenna.

The driving point impedance of a folded doublet is controllable over a relatively wide range by the appropriate selection of the number, spacing, and radii of the conductors. The two most common configurations are the simple two-wire and three-wire doublets. Number six wire and spacings in the order of 12 inches between elements for frequencies below 16 mc, and spacings in the order of six inches above 16 mc, are normally used. The two-wire version has a driving point impedance of approximately 300 ohms, while the three-wire doublet has an impedance near 600 ohms. These impedances also vary with height above ground in a manner similar to a single-wire doublet.

A direct match to the standard 600-ohm transmission line is possible in the three-wire doublet and by judicious selection of stub length and distance, this antenna may be stubbed to cover a frequency range of approximately 1.22 to 1 with VSWR not exceeding 1.5 to 1. This permits sharing circuits when needed within this frequency range.

Bureau of Ships Drawings RE 66F 2034, RE 66F 2036, RE 66F 2037, RE 66F 2048, and RE 66F 2077 show detailed electronic requirement drawings of the transmitting and receiving versions of the two- and three-wire folded doublet antennas.

(*c*) TILTED DOUBLET.—Due to the height of poles required, it is normally not practicable to build a vertical doublet for use much below five mc. For this reason, the tilted doublet is sometimes used in an effort to improve low-angle coverage off the ends of the antenna. Refer to Bureau of Ships Drawings RE 66F 2045 and RE 66F 2051 for details of the tilted transmitting and receiving antennas.

(*d*) STUBBING DOUBLET ANTENNAS.—Stubbing of transmission lines is a technique used to match the impedance of the transmission line to that of the antenna. This insures low transmission line VSWR, facilitates antenna tuning for frequency reassignment, and affords a convenient means of lightning protection. The parallel stub line method of stubbing consists of connecting a short section of shorted transmission line to the main transmission line at a point near the antenna, adjusting and grounding the stub.

Detailed step-by-step procedures for the stubbing of any doublet antenna may be found in Appendix IIA.

(*e*) TERMINATED FOLDED DOUBLET.—A further variation of the folded doublet is the terminated folded doublet. In this form a terminating resistance equal to the characteristic impedance of the feeder is employed so that the radiating elements carry traveling waves and not standing waves. The efficiency of this antenna varies between 20 and 60 percent and a VSWR which varies between 1 and 3.5 to 1 when used between 4 and 26 mc. The horizontal and vertical radiation patterns are made up of many lobes. However, it is an antenna into which one transmitter can be loaded without switching, and this one feature is believed to justify the compromised impedance and pattern characteristic. It is recommended for use as a spare or casualty antenna only.

The Bureau of Ships is constantly striving, by continued research, to improve the efficiency of antenna systems and hopes to replace this antenna in the future with one having equivalent power capacity, a higher efficiency, and better radiation characteristics over this wide range of frequencies.

(*f*) APPLICATION FOR GENERAL COVERAGE REQUIREMENTS.—A final important consideration, and one that is common to all balanced half-wave horizontally-polarized doublets, is that of the radiation pattern characteristics. Since the vertical-plane radiation characteristics of a horizontal half-wave doublet are greatly influenced by the height above ground, it is important that this dimension be optimized for each installation. The ground constants have some influence on the pattern and field strength, but for these antennas with heights greater than 0.2 wavelength, the effects are of second order. For all requirements except those in which very low angle radiation is desired, a distance of one half-wave length above ground is optimum. When wave angles of five degrees are important, the height may be increased to 0.6 to 0.7 wavelength. However, serious departure from omni-directivity is coupled with low-angle radiation from this type of antenna. At wave angles of 15 degrees or less, very little radiation takes place in horizontal sectors off either end of the doublet. Figure 2-4 shows the vertical-plane radiation patterns of a vertical half-wave antenna and Figures 2-4a and 2-4b show the patterns for a horizontal half-wave antenna at different heights above a perfectly conducting ground.

(*g*) DOUBLET ARRAYS.—Doublet arrays, both horizontal and vertical, are used for broadcast and ship-to-shore circuits where sector coverage is desired. The use of such arrays reduces radiation in undesired directions and provides a small amount of forward gain. Some of the advantages of antenna arrays are:

1. More efficient use of transmitter power by concentrating the energy in the desired sector. This results in greater transmission distances with no increase in power.

2. Less interference to other services by the reduction or elimination of radiated power in unwanted directions, and a larger signal-to-noise ratio at the receiver.

3. More energy extracted from the passing field by such a receiving antenna.

4. Several DB improvement in signal-to-noise ratio at the receiver. With external random noise coming in from all directions, larger improvements in signal-to-interference may be possible when the interfering signal is arriving from other than the direction of the incoming signal.

There are two types of horizontal and vertical doublet arrays presently being employed at shore communication stations, the parasitic and the driven arrays. Both types consist of two identical folded doublets. Parasitic elements can be used to form, with driven antennas, quite effective directive systems and are easier to adjust than the driven array. Bureau of Ships Drawing No. RE 66F 2032 shows the parasitic array. One type of driven array presently in operation at major transmitting stations for broadcast purposes is based on two identical vertical doublets spaced 90 degrees on a great circle bearing toward the desired service area. Both doublets are fed with equal currents with the currents with the current in the front doublet having a positive 90-degree phase angle. These parameters produce a typical cardioid radiation pattern covering approximately 180 degrees in the forward direction with a three DB gain over a single-element antenna. Most of the radiation in the vertical plane is below 40 degrees, increasing as the angle approaches the horizontal. Folded doublets are used in the design to obtain high input impedance and to facilitate impedance matching.

These antennas are tunable over the same range of frequencies as the doublet antennas previously described. While the element spacing in terms of wave-length may vary appreciably, acceptable front to back ratios can be maintained.

The centers of the doublets should be as near one-quarter wavelength above ground as possible. In consideration of personnel safety, however, the lower metallic end of each doublet is kept eight feet above the ground level. To avoid unstable line currents, radiation pattern deviation and wind damage, the doublet wires are held taut by the use of appropriate weights on the bottom of each doublet. The feed lines should be brought to the doublets as nearly at right angles as practicable (not less than 60 degrees) to minimize inductive coupling from lines to doublets. The lowest frequency for which this antenna may be employed is dependent on practical pole-splicing limitation permitted by local wind, ice loading, and other structural considerations.

The step-by-step tuning procedure for this type array will be found in Appendix IIB.

(5) HF SLEEVE ANTENNAS.

(*a*) OMNI-DIRECTIONAL.—Appendix VII consists of a copy of Report 478 of the NEL entitled "Broadband Sleeve Antenna for Omni-Directional Shore Station Use," by W. E. Gustafson, T. E. Devaney, and N. H. Balli, of 15 March 1954. The sleeve antenna has been the "work horse" of broadband antennas for Navy use. It covers a 3:1 frequency range presenting 3:1 or less VSWR based on 75 ohms. Sleeves for a number of frequency ranges were developed and standards issued as BuShips Drawings RE 66F 2073 and RE 66F 2075. RE 66F 2173 are the complete manufacturing drawings for aluminum kit type sleeves. The sleeve as well as being one of the first and readily available broadband antennas has two inherent advantages. First, it is fed above ground level, lessening snow accumulation problems and R. F. hazards to personnel and livestock in the area. Second, it presents a relatively small electrical obstruction, i.e., its influence on other antennas in the antenna field is not as severe as with some other types. As with all of the broadband antennas in this section, the sleeve is

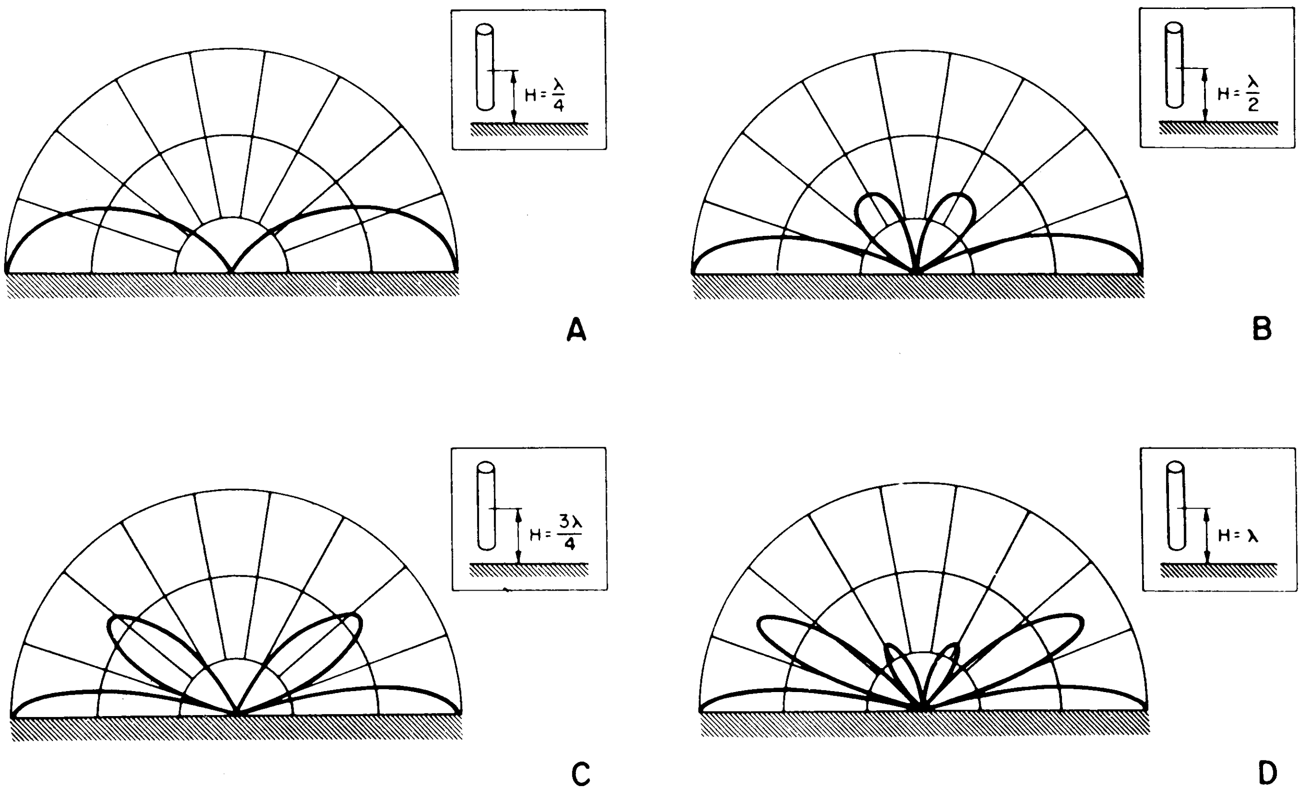


FIG. 2-4 VERTICAL PLANE RADIATION
VERTICAL DOUBLET

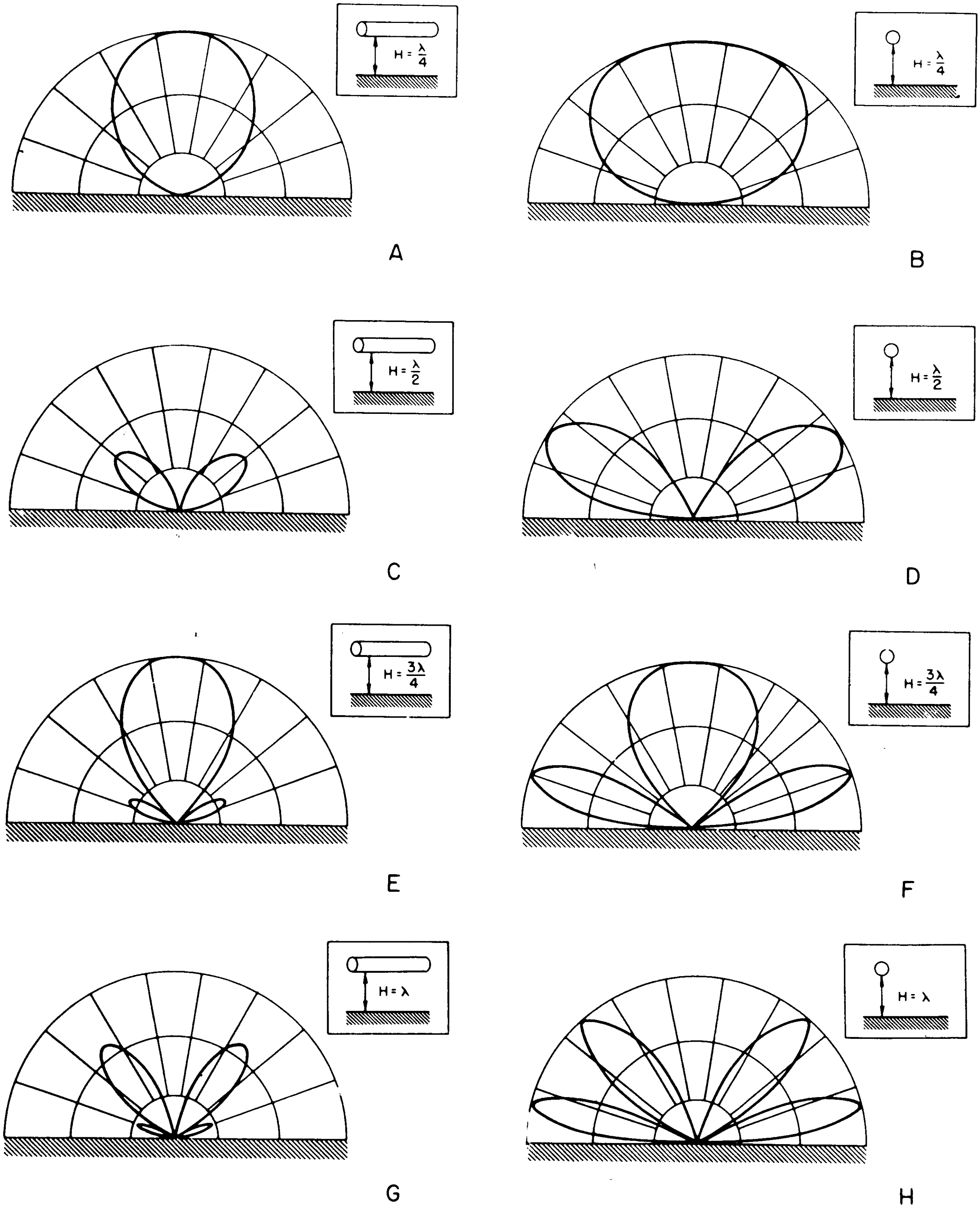
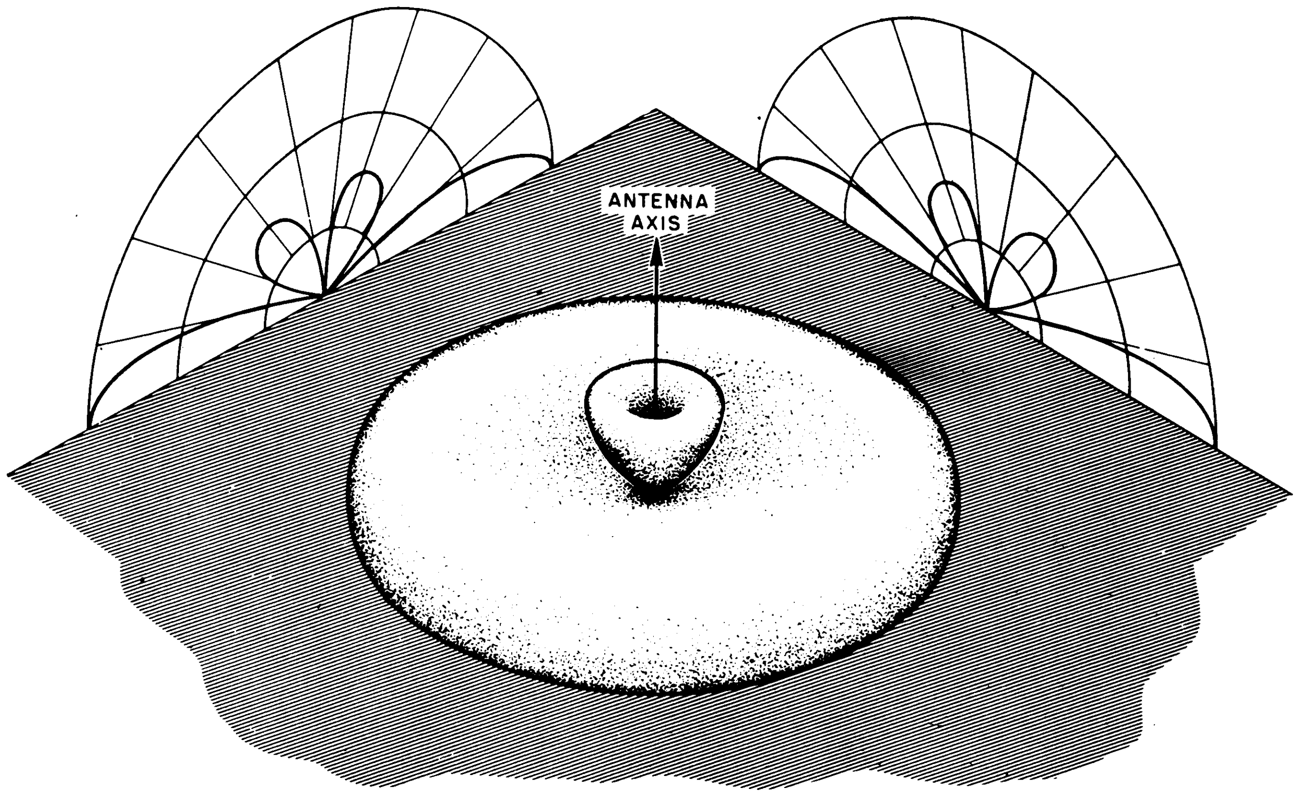
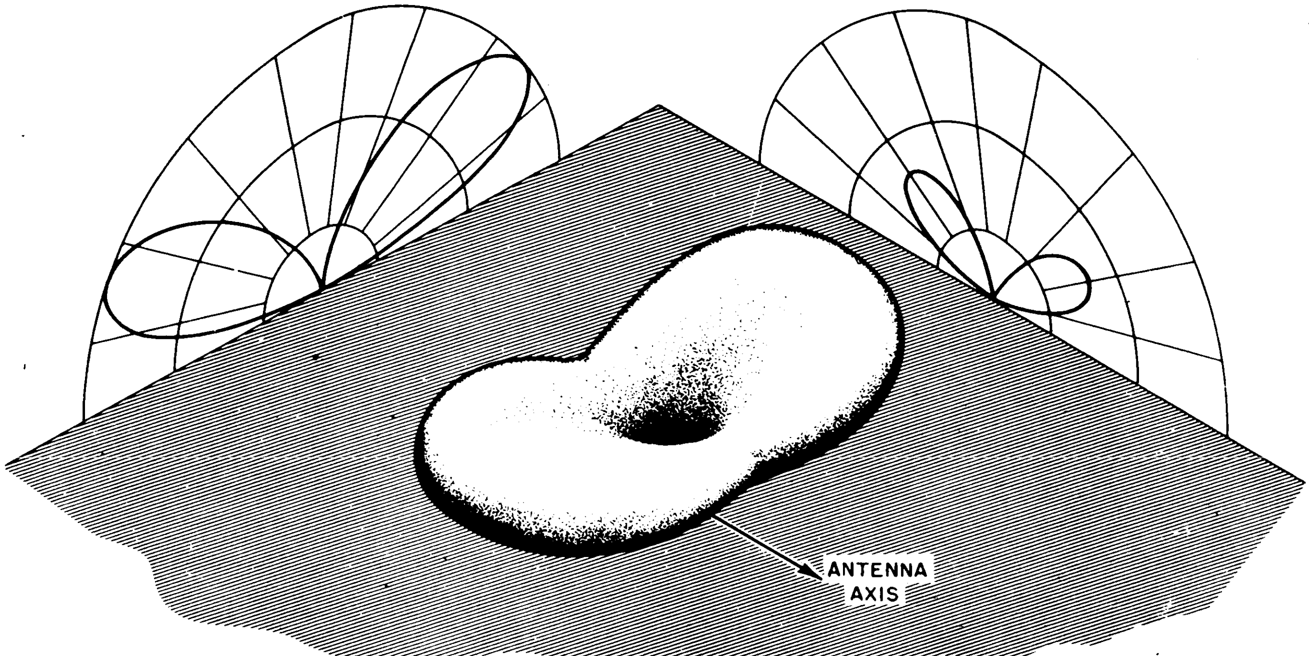


FIG. 2-4a VERTICAL PLANE RADIATION
HORIZONTAL DOUBLET



Solid pattern produced by vertical half-wave antenna located a half-wavelength above ground.



Solid pattern produced by horizontal half-wave antenna located a half-wavelength above ground.

FIG. 2-4b SOLID PATTERNS OF VERTICAL & HORIZONTAL DOUBLET ANTENNAS

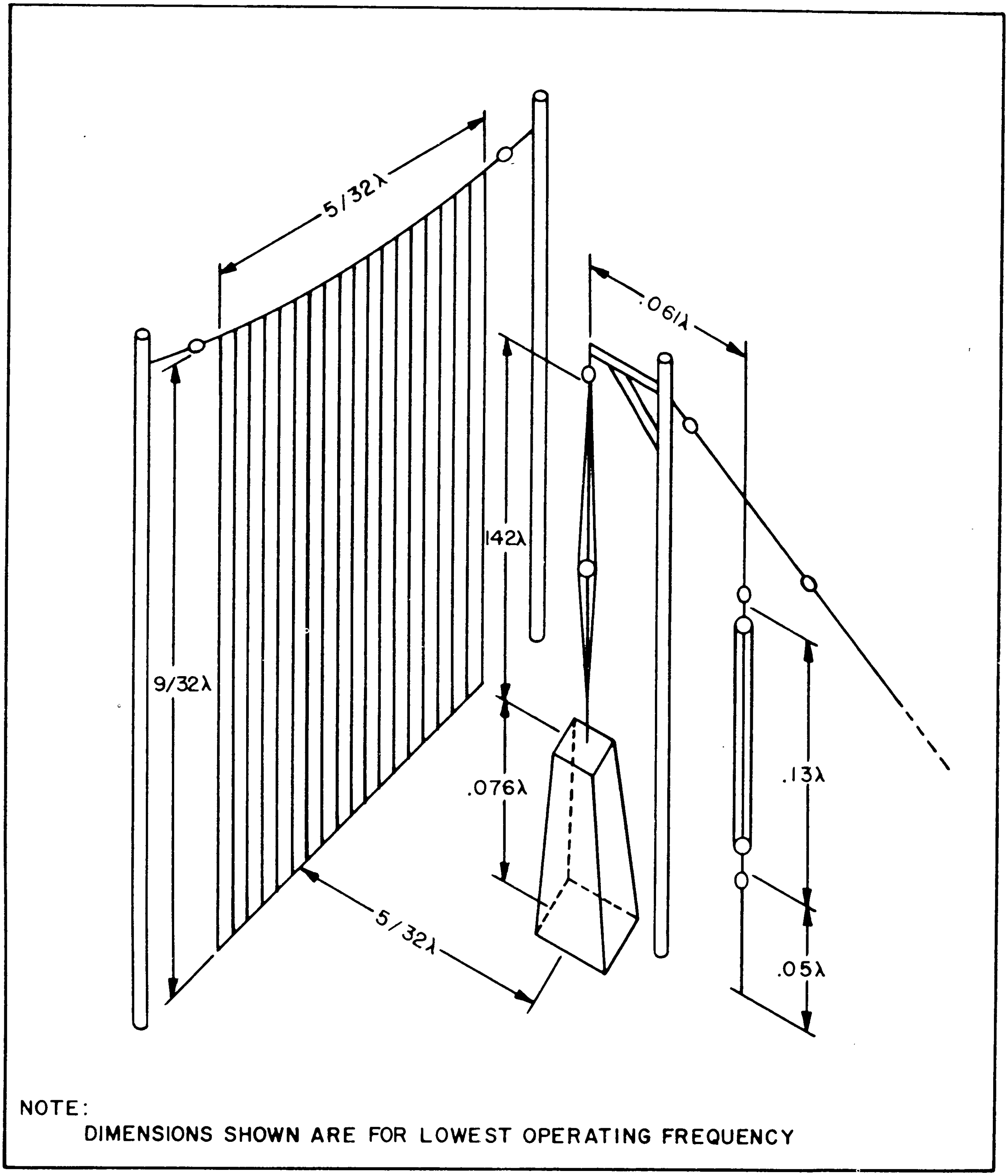


FIG. 2-5 BROADBAND 180 DEGREE SECTOR ANTENNA

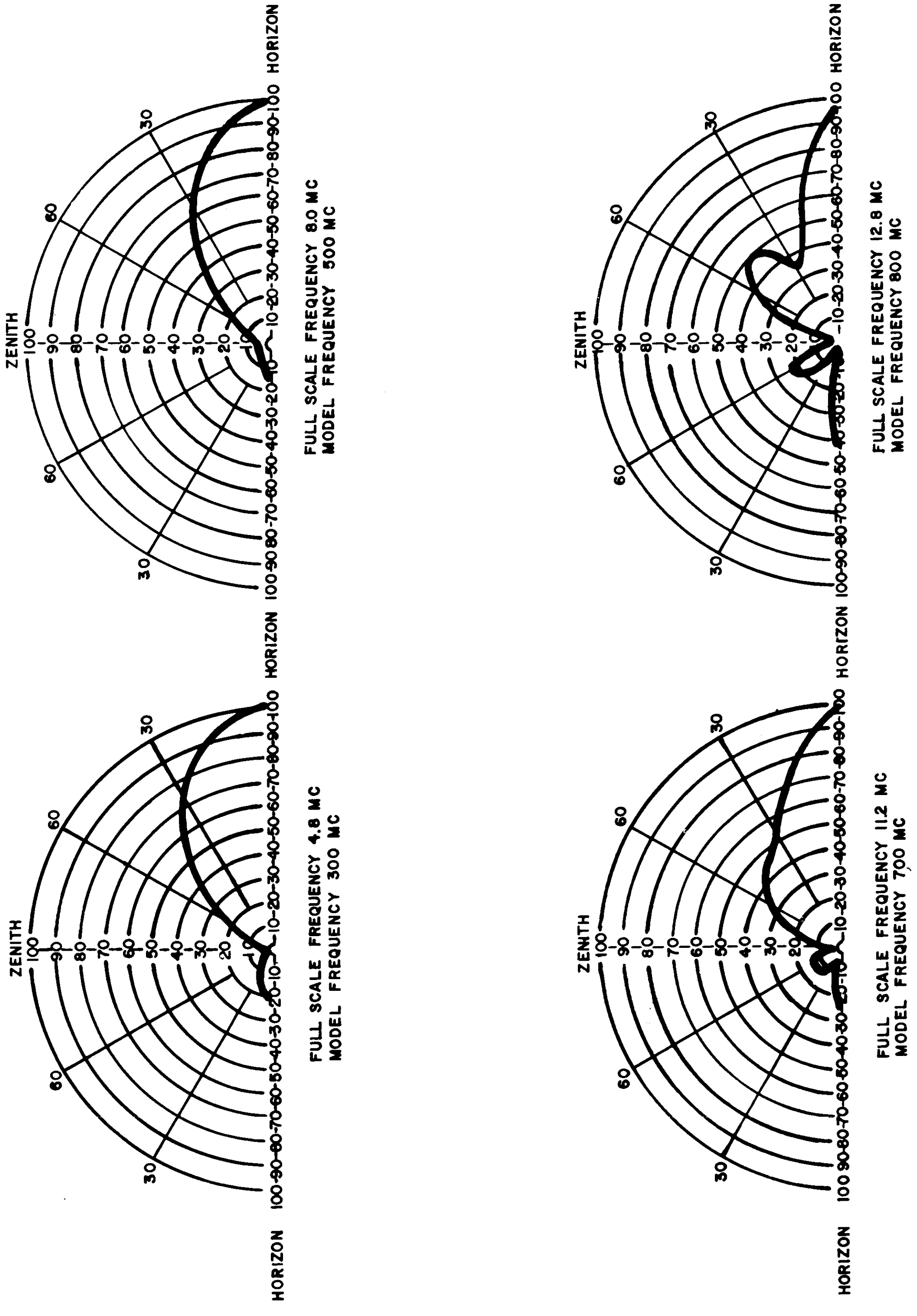
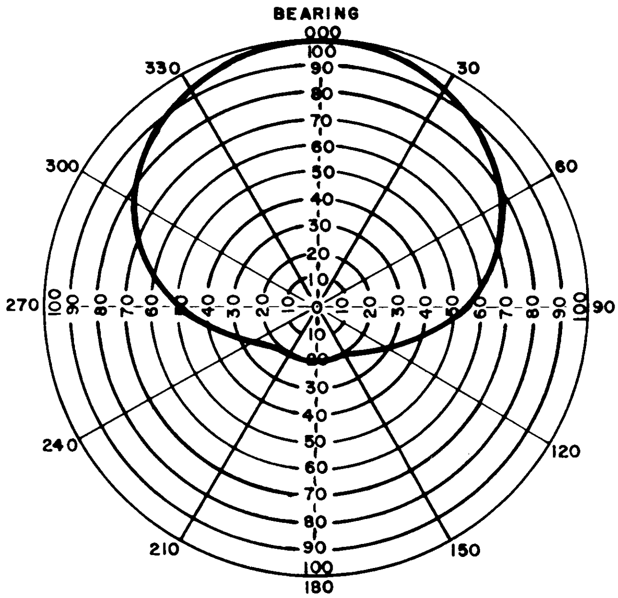
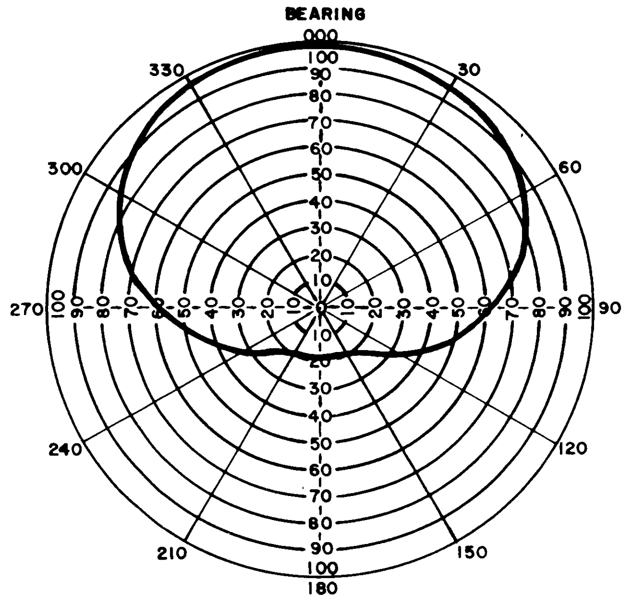


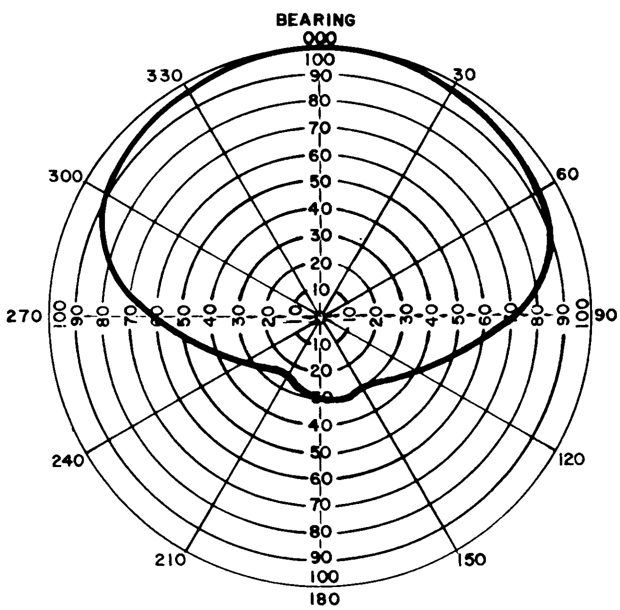
FIG. 2-5 a VERTICAL PATTERNS BROADBAND 180 DEGREE SECTOR ANTENNA



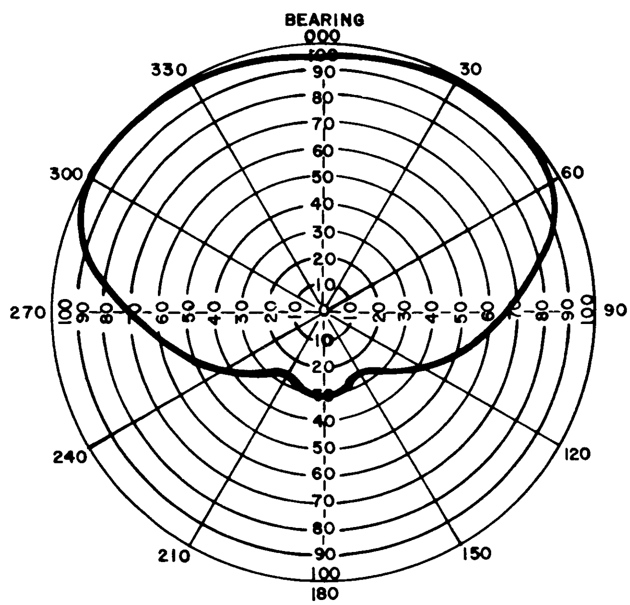
MODEL FREQUENCY 120 MC
BEAMWIDTH 148 DEGREES
FULL SCALE FREQUENCY 4.0 MC



MODEL FREQUENCY, 220 MC
BEAMWIDTH 165 DEGREES
FULL SCALE FREQUENCY 7.34 MC



MODEL FREQUENCY 340 MC
BEAMWIDTH 176 DEGREES
FULL SCALE FREQUENCY 11.3 MC



MODEL FREQUENCY 380 MC
BEAMWIDTH 180 DEGREES
FULL SCALE FREQUENCY 12.7 MC

FIG. 2-5b AZIMUTHAL PATTERNS BROADBAND 180 DEGREE SECTOR ANTENNA

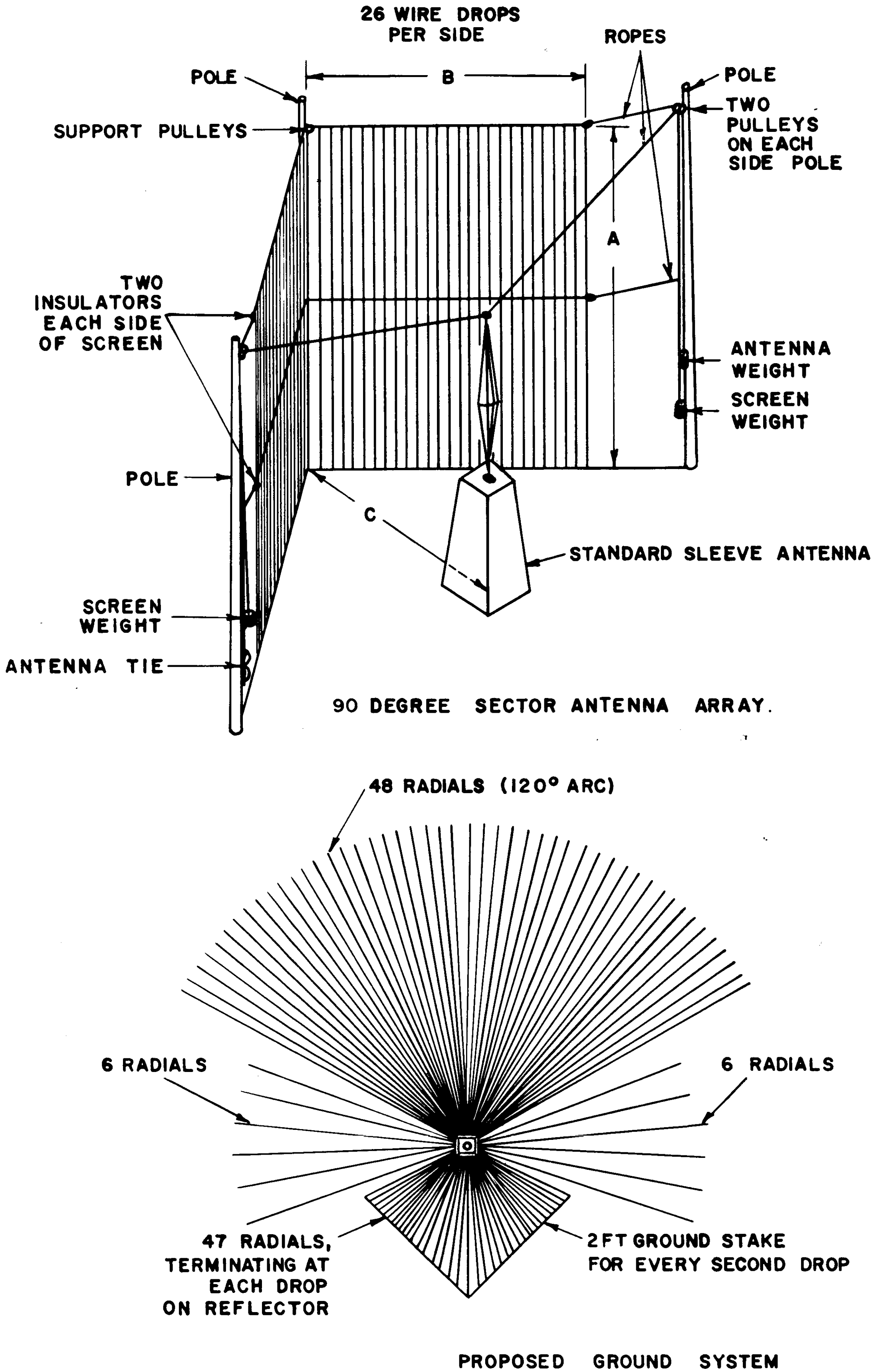
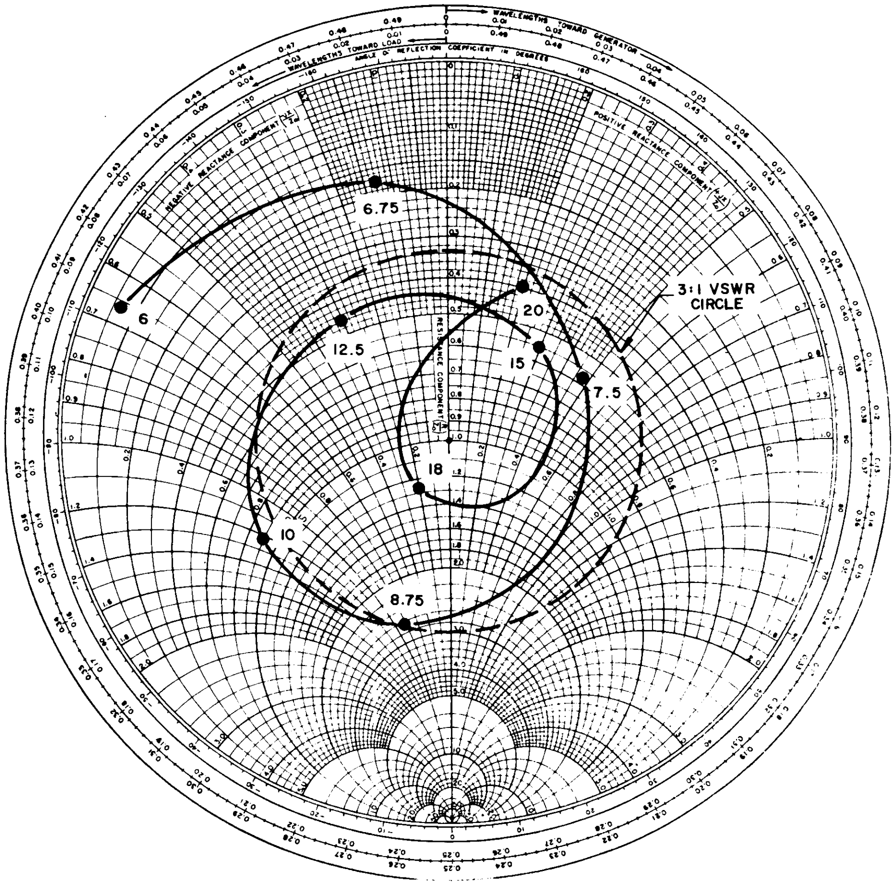


FIG. 2-5c CORNER REFLECTOR, 90 DEGREE SECTOR ANTENNA ARRAY

ANTENNA TYPE	ARRAY FREQ. RANGE (Mc)	ANT. BASE FREQ. (Mc)	SLEEVE			RADIATOR		TRANSFORMER		SERIES CAPACITOR (uuf)	REFLECTOR			GROUND	
			TOP WIDTH (ft)	BOTTOM WIDTH (ft)	HEIGHT (ft)	LENGTH (ft)	CENTER DIAM. (ft)	CENTER CONDUCTOR LENGTH (ft)	TYPE		A HGT. (ft)	B SIDE LG. (ft)	C SPACE TO SLV. CTR. (ft)	FWD. 120 ARC LG. (ft)	SIDES LG. (ft)
TRANSMITTING	4-11	3.66	6.15	8.2	20.5	39.3	2.05	26.0	8 x 8-IN.	750	76	67	63	600	128
	6-16.5	5.5	4.08	5.45	13.6	26.1	1.36	17.3	TRUNK	500	50	45	42	400	85
	10-27.5	9.16	2.46	3.28	8.2	15.7	.82	10.4		300	30	27	25	240	51
RECEIVING	4-11	3.66	6.15	8.2	20.5	39.3	2.05	23.2	RG-63B/U	750	76	67	63	600	128
	6-16.5	5.5	4.08	5.45	13.6	26.1	1.36	15.4		500	50	45	42	400	85
	10-27.5	9.16	2.46	3.28	8.2	15.7	.82	9.3		300	30	27	25	240	51

FIG. 2-5d DIMENSIONAL REQUIREMENTS OF 90-DEGREE-CORNER ANTENNA



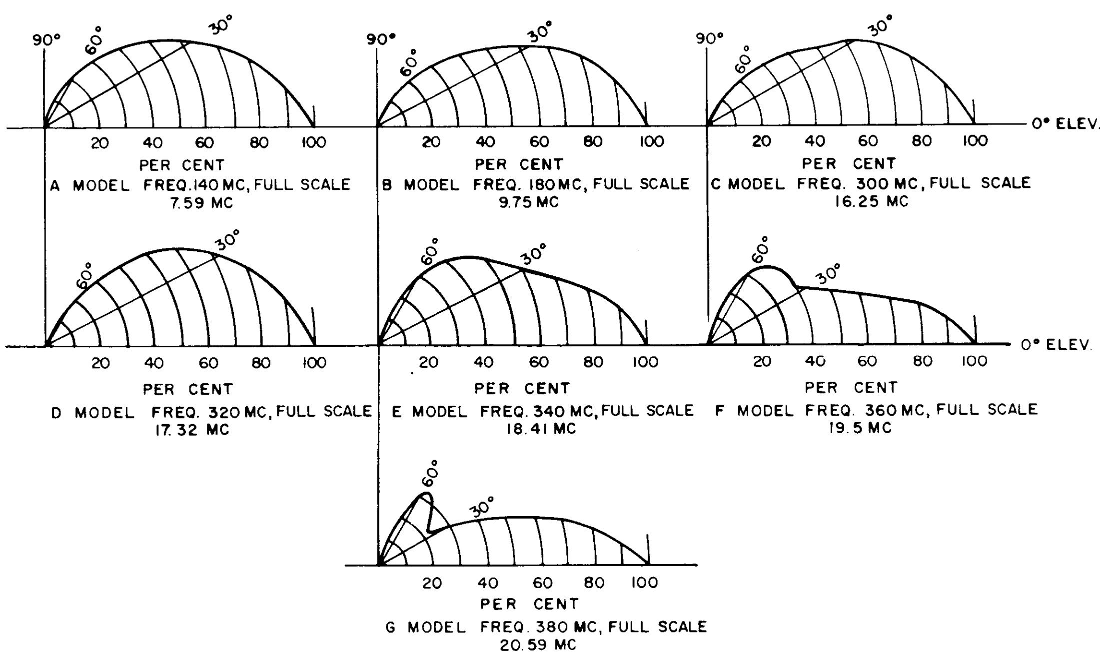
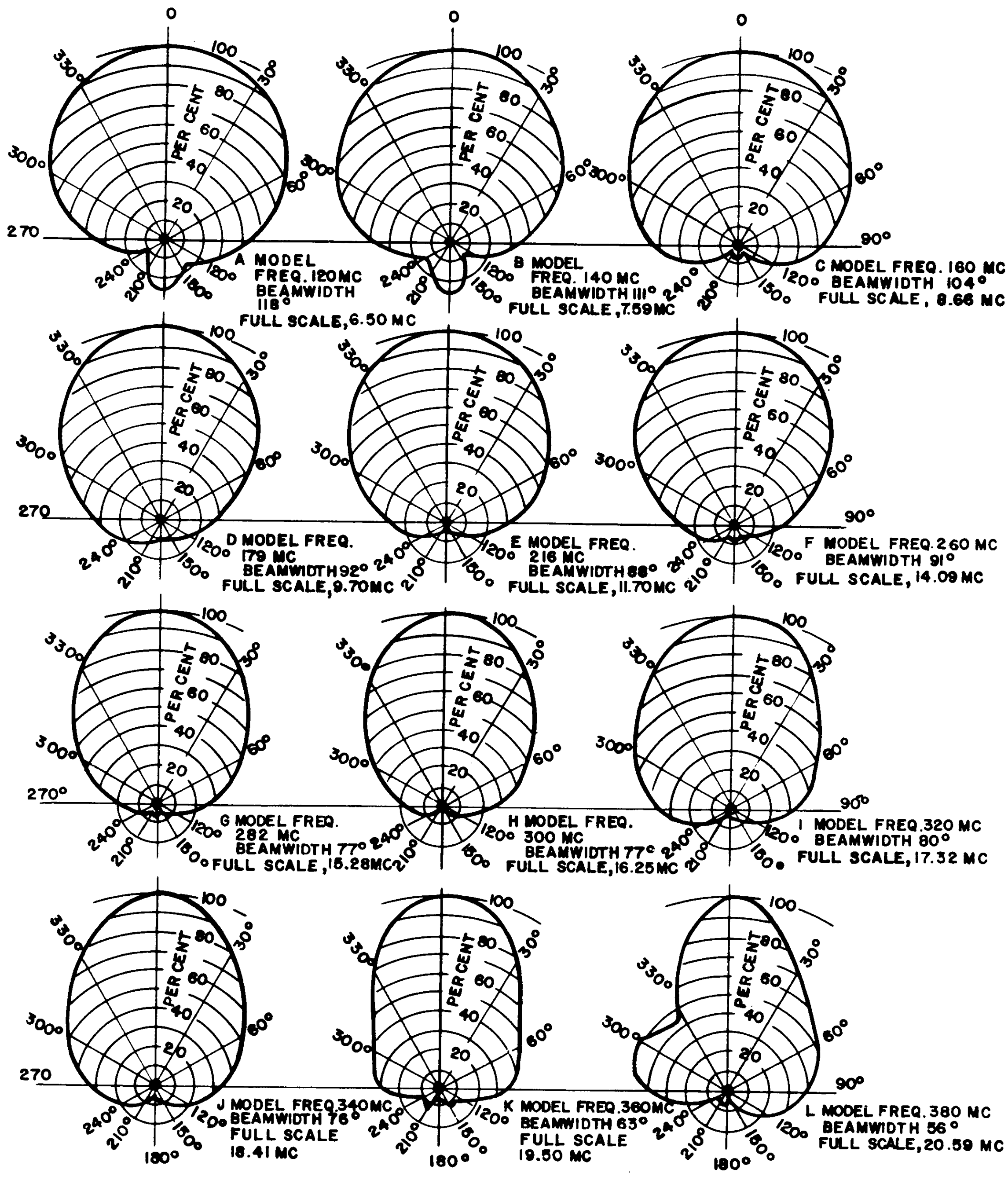


FIG 2-5e VERTICAL PATTERNS AND REACTANCE CHART, 90 DEGREE CORNER REFLECTOR



MODEL HORIZONTAL DIRECTIVITY PATTERNS OF 90-DEGREE-CORNER ANTENNA. AZIMUTHAL VOLTAGE PLOT. SPACING 15/64 WAVELENGTH, SIDE WIDTH 1 1/4 WAVELENGTH, HEIGHT 9/32 WAVELENGTH, ALL AT SLEEVE BASE FREQUENCY OF 120 MC. 26 WIRE DROPS PER SIDE.

FIG. 2-5f AZIMUTHAL PATTERNS, 90 DEGREE CORNER REFLECTOR fed with coax. In siting, care should be taken to keep the transmission lines short.

BuShips Drawing RE 66D 160 shows sleeve antenna obstruction lighting details.

(*b*) 180 DEGREE COVERAGE.—The sleeve antenna is also suitable for use in directive arrays. Figure 2-5 shows dimensions of a broadband sector array. It may be operated over a 3:1 frequency range with a VSWR based on 75 ohms of approximately 3:1. Figure 2-5a and 2-5b shows vertical and azimuthal model range patterns. The array provides 2 to 3 DB gain over that obtained by an omni-directional sleeve. Sector antennas built to date have covered the 4/12 mc and 9/27 mc frequency range. Additional information may be obtained from NEL Report 578, "Broadband 180 Degree Sector Antenna" and BuShips Drawings No. RE 66F 2115 and RE 66F 2116.

(*c*) CORNER REFLECTOR.—A further adaptation of the sleeve is in the Broadband 90-Degree Corner Reflector Antenna (Figures 2-5C and 2-5d), NEL Report 691. Figures 2-5e and 2-5f shows impedance curves with vertical and azimuthal model range patterns. A gain of approximately 5 DB over an omni-directional sleeve is obtained. Recommended arrangements to obtain 90, 180, 270, and 360-degree coverage from two frequency range antennas, 4-11 mc and 10-27 mc, follows.

1. 360 DEGREE, 4-27 MC.—Four 90-degree, 4-11 mc corner arrays should be grouped in a rosette arrangement, the reflector sides being common for the four antennas. The 10-27 mc antennas should consist of two 180-degree arrays placed on opposite sides of the 4-11 mc rosette. None of the higher frequency antennas will then be pointed toward the lower frequency rosette. The best patterns are obtained when the higher frequency arrays are placed in line with the lower frequency array reflecting screens such that the centers of the lower frequency beams do not illuminate the smaller sectors. A minimum spacing of 270 feet is recommended with greater spacings desirable. Greater spacings may require longer transmission lines, therefore necessitating compromises in the majority of installations.

2. 270 DEGREES, 4-27 MC.—One rosette for lower frequency coverage and one rosette for high frequency coverage is recommended. The small rosette should be placed in line with the center of the middle sector of the large rosette and oriented such that its unused sector points directly toward the large rosette. Recommended minimum spacing is 480 feet between the closest portion of the rosettes.

3. 180 DEGREES, 4-27 MC.—Two arrays, each consisting of two 90-degree corner antennas with a common screen should be used. The smaller array should be placed in front of the larger and in line with the common reflecting screen. The recommended minimum spacing is 270 feet with 400 feet preferred.

4. 90 DEGREES, 4-27 MC.—For 90-degree coverage, the higher frequency antenna may be placed in front of the lower frequency one at a minimum of 400 feet. Alternatively, it may be placed 45 degrees off the lower frequency beam center at a minimum of 270 feet. If side by side arrangement is used, the minimum spacing should be 400 feet.

5. GROUND SYSTEM.—Since the corner reflector arrays are relatively costly and are used only where the requirements of gain and/or front-to-back ratios are mandatory, extended ground radial systems, i.e. 2-1/2 wavelength radials, are most always incorporated. If the corner antennas are sited as herein indicated, overlapping ground radials will result. If the soil conductivity is poor and considerable signal strengths are present, interference may be generated by the nonlinear points of crossing ground radials. This interference potential is being further studied. Assuming that it is desired to keep the radials from touching, several solutions are suggested:

(a) Use a ground mat such as that used for HF DF ground systems in lieu of radials in the areas of overlapping ground systems.

(b) Use insulated wire such as standard Navy Stock No. N-16-W-3740-1, conforming to MIL-W-17211.

(c) Bury the radials at different depths, the higher frequency antenna radials nearer the surface (the radials need not be buried except for mechanical reasons).

Installation of the grounds need not be perfectly flat. Estimated limits on ground plane contour are 10%, i.e., five feet elevation in 50-feet length, in the area of the antenna out to approximately twice the antenna height. Beyond that point a 20% slope could be tolerated. Slight variations in the 3-degree spacing of radials is also tolerable. If a stump, rock or other radial obstruction exists, the radial could be "run around" the object.

The recommended ground system for this type of antenna consists of radials 2.5 wavelengths long, spaced at 3 degrees. In areas where reduction in the recommended ground radial length is required, the following general reductions in low angle radiation can be expected:

(a) 5/4 wavelength 3 db.

(b) 1/4 wavelength 6 db.

It is not expected that impedance characteristics will be effected by the change in radial lengths.

6. TOLERANCES.

(a) The width of the reflecting screen is relatively critical.

(b) A 10% sag in the reflector catenary may be tolerated. The shortest wire in the screen, i.e., the bottom of the catenary, should be used for screen height determination.

(c) The variation of the sleeve base line height with respect to the screen base line may be plus or minus 10%.

(d) The distance between the sleeve and the screen may vary plus or minus 5% of that specified as optimum.

(e) The dimensions of the sleeve itself should be held to within plus or minus 2-1/2%.

(6) CONICAL MONOPOLE ANTENNA.

Some of the objections to the sleeve antenna were its height and difficulty in obstruction lighting. The conical monopole was developed to overcome these difficulties. See Figure 2-6. Figure 2-6a shows its dimensions; Figure 2-6b sample model range vertical patterns; and Figure 2-6c impedance. Additional information may be obtained from NRL Memorandum Report 871 of 8 November 1958 by M. L. Leppert, Supplement No. 1 of 10 December 1959, and Bureau of Ships Drawings RE 66F 2121. Although the impedance excursions permit 6:1 bandwidth operation, for station design purposes 4:1 based on pattern has been established. The antenna is suitable for powers up to 50 kw. Aluminum kits have been developed. Figure 2-6 shows such an antenna. As standard plans become available, they will be promulgated. Figure 2-6b shows vertical patterns relative to a quarter wave monopole.

(7) DISCONE.

There are several versions of HF discones including grounded cone discones, inverted discones, elevated discones, etc. Figures 2-7, 2-7a, and 2-7b show general dimensions and types. The discone element presents an exceptionally flat impedance over a wide frequency range (2:1 VSWR over 10:1 frequency range) and as such is useful especially as a spare antenna. A further advantage of the discone of Figure 2-7a is that it requires no ground radial system. The vertical pattern, however, is questionable above a 3:1 bandwidth. In addition, separation between antennas of about twice that required for sleeves or conical monopoles is required.

An adaption of the basic discone is the grounded cone discone. It has a radial ground system but is considerably smaller than other discones. It was developed mainly for air station application, its main advantages being its low height, ease of obstruction lighting and wide "impedance bandwidth." BuShips Drawing No. RE 66F 2118 shows construction details.

(8) YAGI ANTENNAS.

Parasitic rotatable beam antennas furnish considerable gain in a small amount of space. They are inherently single frequency devices, however, and as such do not find broad Navy use.

(9) LOG PERIODIC.

Log Periodic Antennas (LPA) have impedance characteristics of 2:1 VSWR or less over a 10:1 frequency range. Their real estate requirements appear moderate and although their gain is not great, by proper design vertical patterns may be established and controlled over the full frequency range. Horizontally and vertically polarized LPA's as well as rotatable LPA's have been developed. It should be pointed out that the compactness of the rotatable version is gained only at the expense of compromising vertical pattern. Figure 2-8 shows typical vertical patterns obtained with a rotatable LPA. A 60-degree azimuthal beam width is average. The Bureau of Ships is developing a design handbook for LPA antennas so that their features may best be adapted to given point to point or sector coverage requirements. The book will be promulgated upon completion.

(10) RHOMBIC ANTENNAS.

Rhombic antennas consist of straight wires arranged in the form of a rhombus. For most HF applications, the antenna is suspended horizontally from four poles at a height determined by the desired vertical angle for maximum radiation. The sides are usually long, compared to a wavelength, and one of the acute ends of the rhombic is terminated in a resistance equal to its surge impedance. The transmission line is connected to the opposite apex.

The most important characteristics of an antenna are its impedance and its radiation pattern. A correctly terminated rhombic antenna presents an essentially constant impedance at its input terminals. Measurements in the frequency range from 7 to 20 mc on a single-wire rhombic antenna terminated in an 815-ohm resistor, show variations in the resistive component of the input impedance from a minimum of 660 ohms to a maximum of 830 ohms. This antenna would provide an adequate match for a 600-ohm transmission line over this frequency range; the maximum VSWR being about 1.5 to 1.

When determining the location of rhombic antennas, the sites must be chosen so that the transmission paths are not obstructed vertically in excess of five degrees in the required direction. Some of the

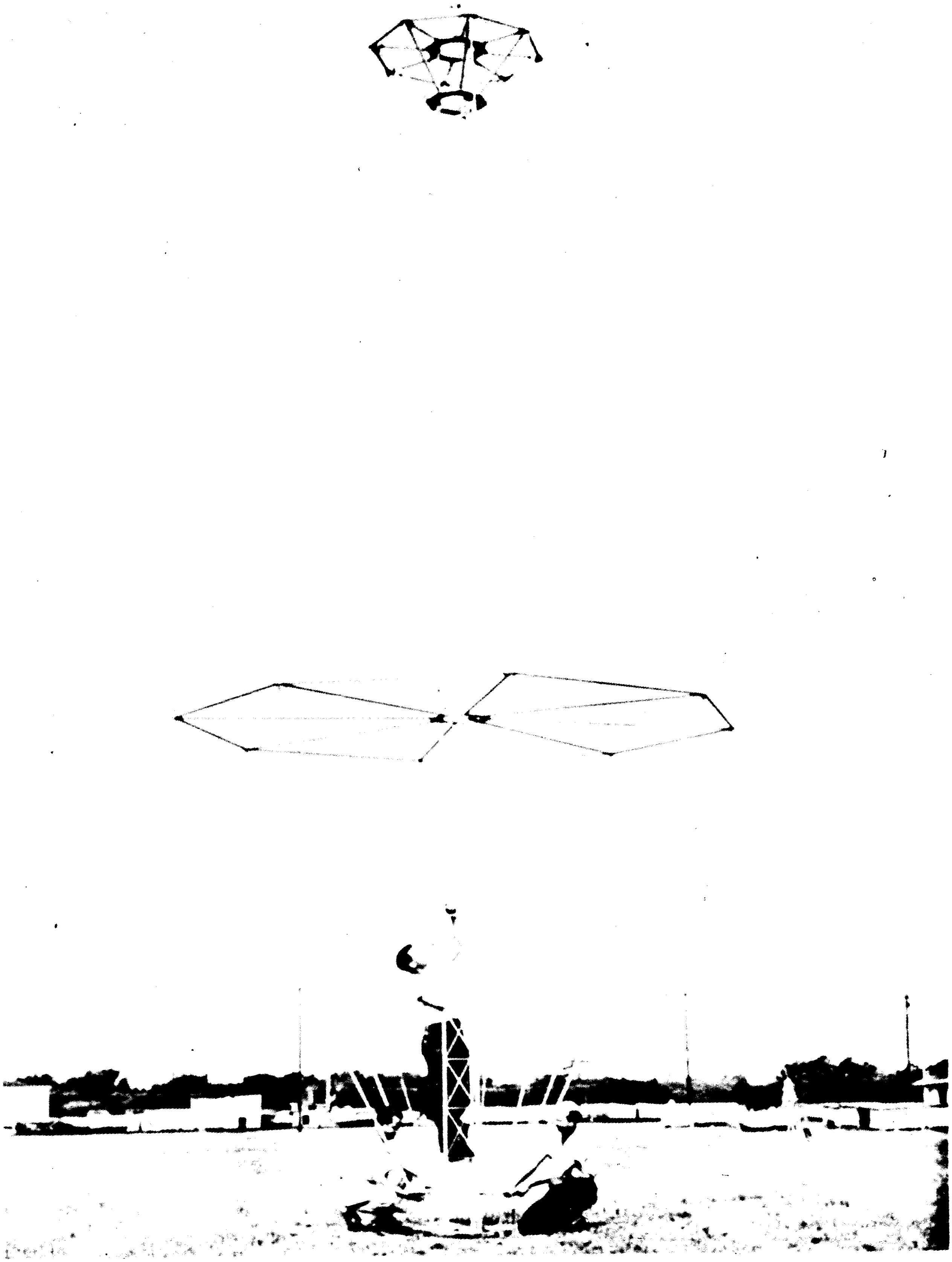
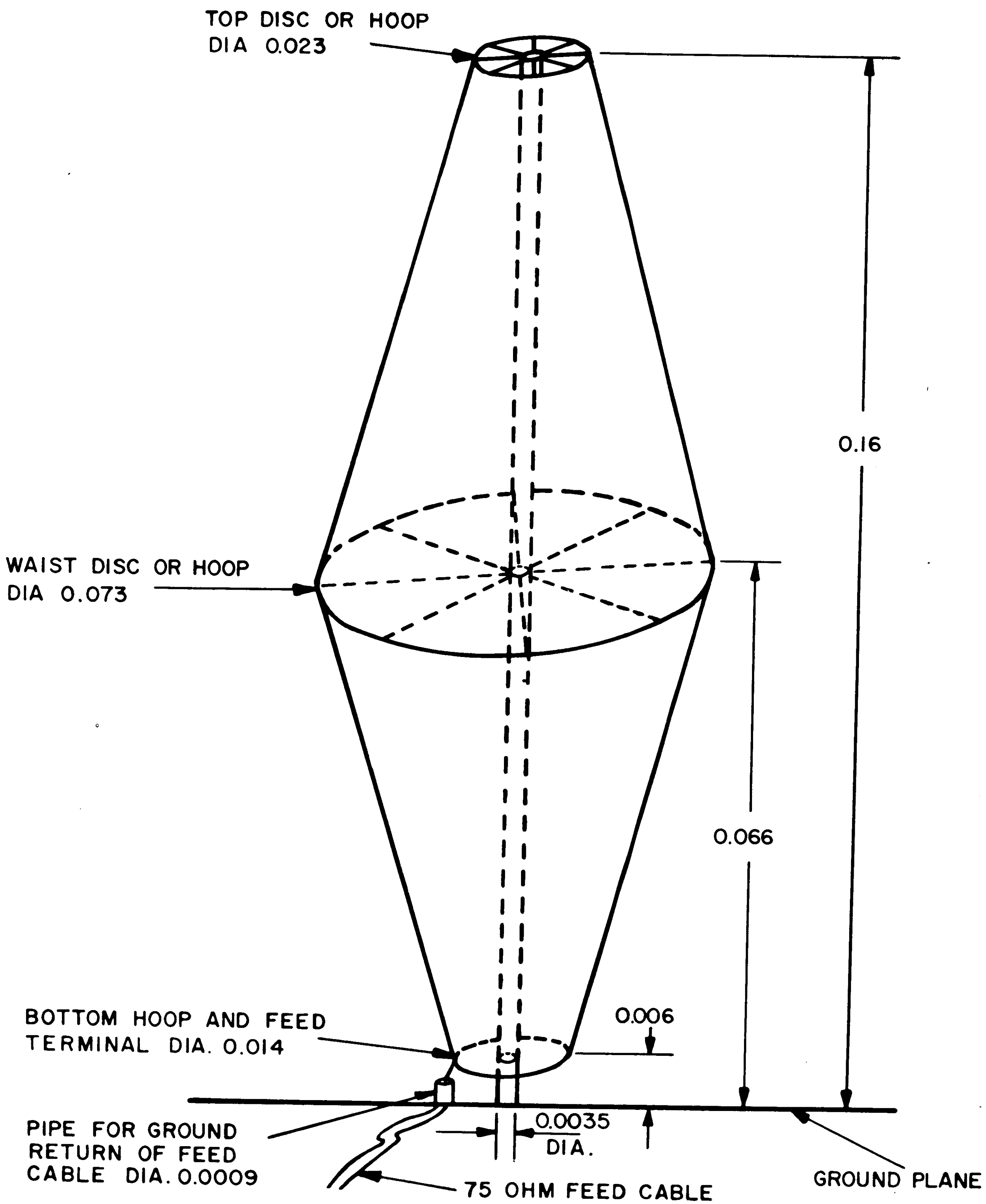
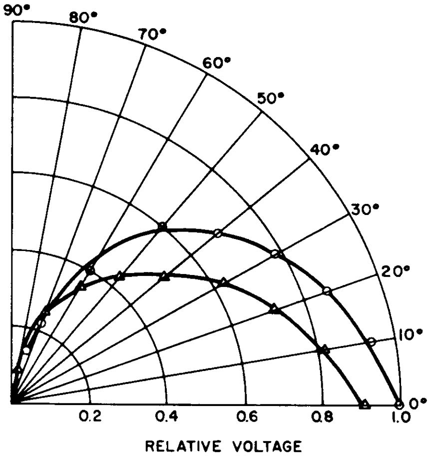


FIG 2-6 CONICAL MONOPOLE ANTENNA



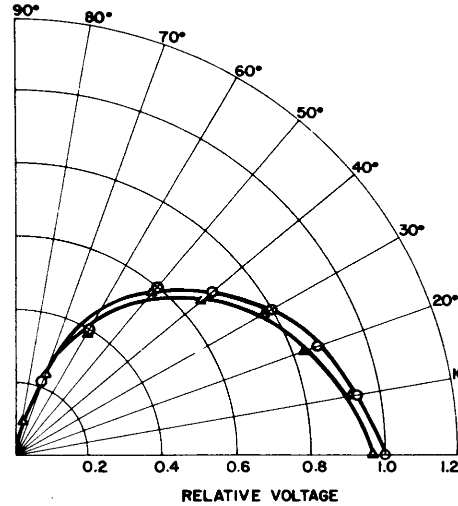
(DIMENSIONS IN WAVELENGTHS AT LOWEST OPERATING FREQUENCY)

FIG. 2-6a CONICAL MONOPOLE DIMENSIONS



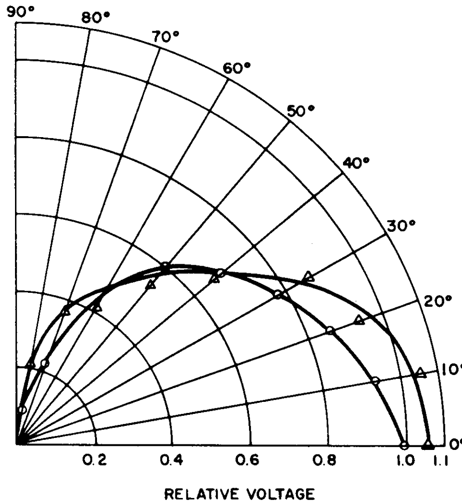
O = QUARTER-WAVE MONOPOLE, L/D = 25

Δ = CONICAL MONOPOLE, AT 0.16λ, RELATIVE TO QUARTER-WAVE MONOPOLE



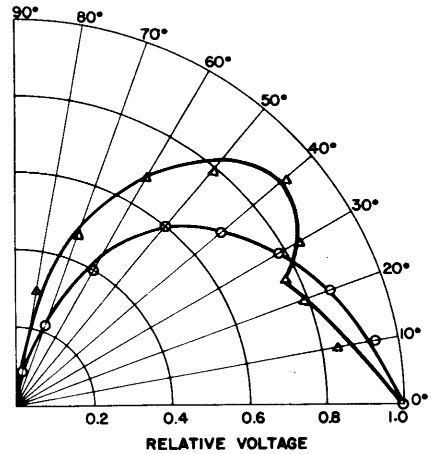
O = QUARTER-WAVE MONOPOLE, L/D = 25

Δ = CONICAL MONOPOLE, AT 0.25λ, RELATIVE TO QUARTER-WAVE MONOPOLE



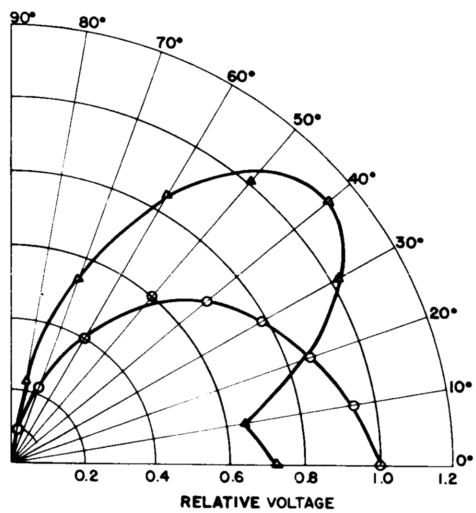
O = QUARTER-WAVE MONOPOLE, L/D = 25

Δ = CONICAL MONOPOLE, AT 0.50λ, RELATIVE TO QUARTER-WAVE MONOPOLE



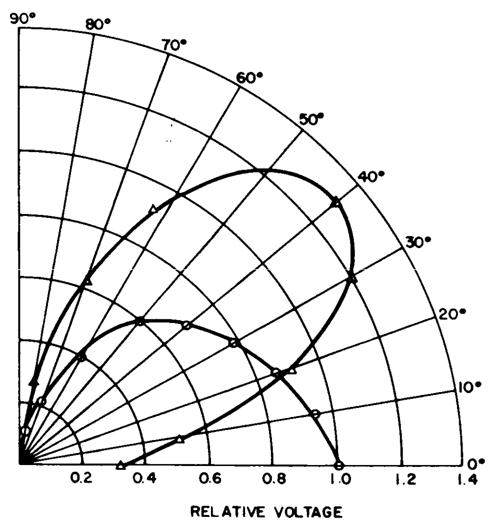
O = QUARTER-WAVE MONOPOLE, L/D = 25

Δ = CONICAL MONOPOLE AT 0.58λ, RELATIVE TO QUARTER-WAVE MONOPOLE



O = QUARTER-WAVE MONOPOLE, L/D = 25

Δ = CONICAL MONOPOLE, AT 0.64λ, RELATIVE TO QUARTER-WAVE MONOPOLE



O = QUARTER-WAVE MONOPOLE, L/D = 25

Δ = CONICAL MONOPOLE, AT 0.72λ, RELATIVE TO QUARTER-WAVE MONOPOLE

FIG. 2-6b RADIATION PATTERNS, CONICAL MONOPOLE VS QUARTER-WAVE RADIATOR

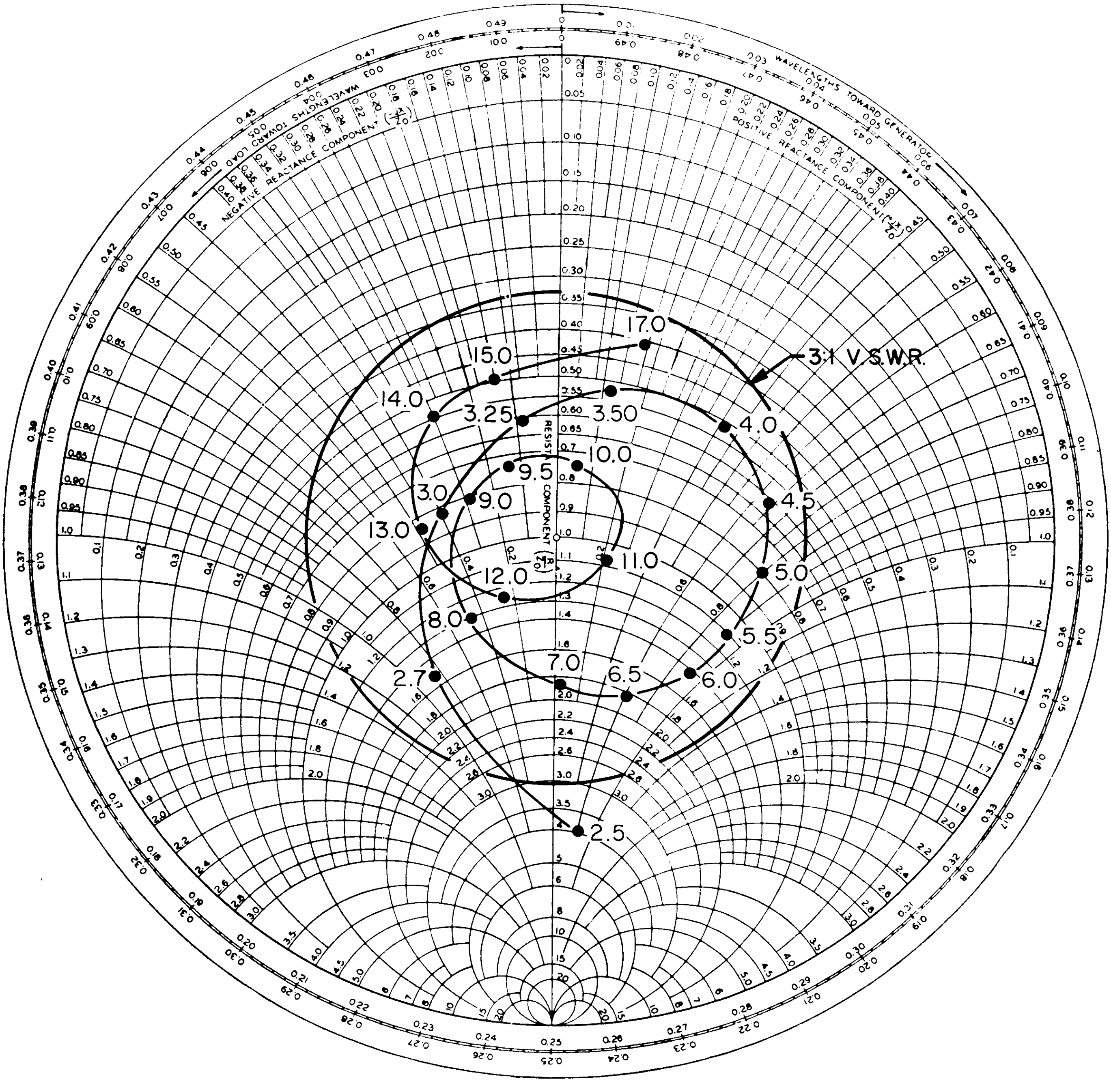
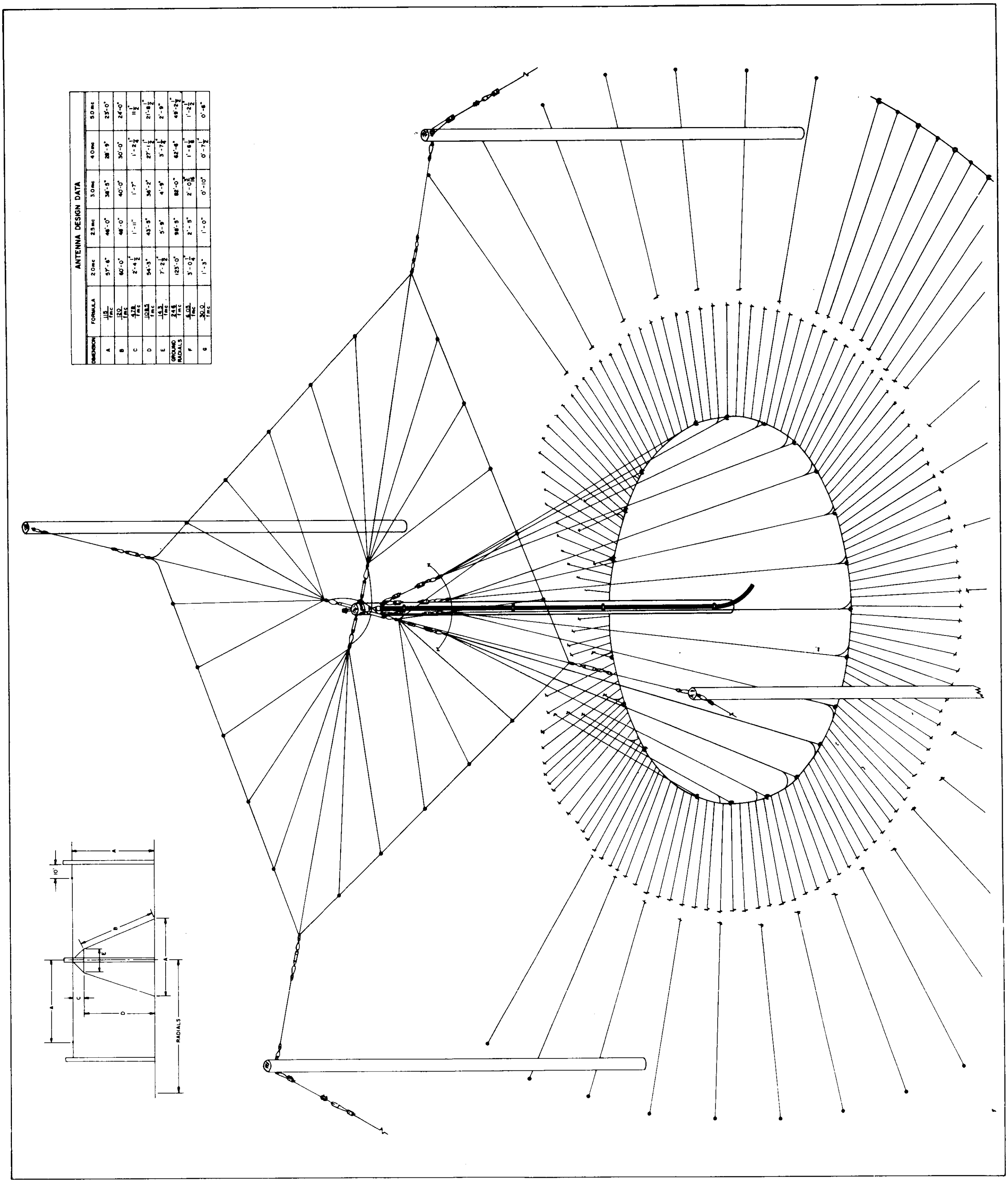


Fig. 2-6c Conical Monopole Antenna Impedance Relative to 70 Ohms



ANTENNA DESIGN DATA						
DIMENSION	FORMULA	2.0 mc	2.5 mc	3.0 mc	4.0 mc	5.0 mc
A	115/fmc	57'-6"	46'-0"	38'-5"	28'-9"	23'-0"
B	120/fmc	60'-0"	48'-0"	40'-0"	30'-0"	24'-0"
C	47.8/fmc	2'-4 1/2"	1'-11"	1'-7"	1'-2 1/4"	11 1/2"
D	108.5/fmc	54'-3"	43'-5"	36'-2"	27'-1 1/2"	21'-8 1/2"
E	14.3/fmc	7'-2 1/2"	5'-9"	4'-9"	3'-7 1/4"	2'-9"
GROUND RADIALS	246/fmc	123'-0"	98'-5"	82'-0"	62'-6"	49'-2 1/2"
F	6.05/fmc	3'-0 1/4"	2'-5"	2'-0 3/16"	1'-6 1/8"	1'-2 1/2"
G	30.0/fmc	1'-3"	1'-0"	0'-10"	0'-7 1/2"	0'-6"

FIG. 2-7 GROUND CONE DISCONE ANTENNA

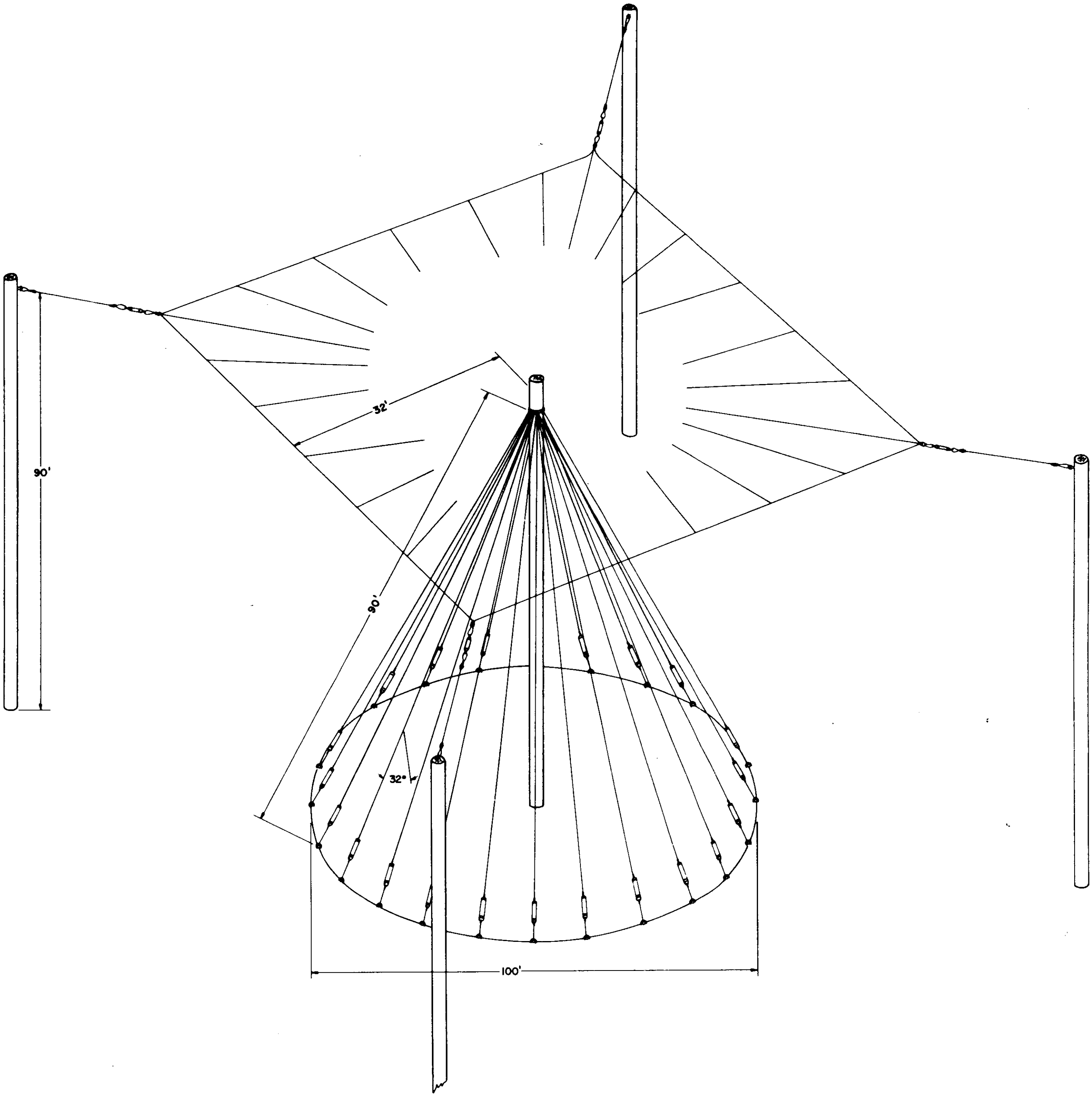
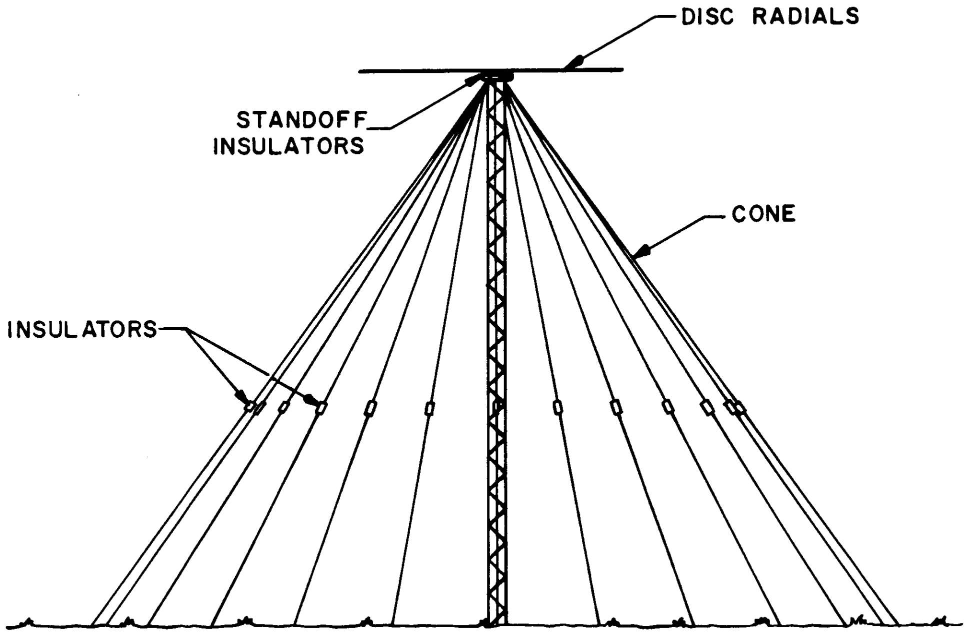


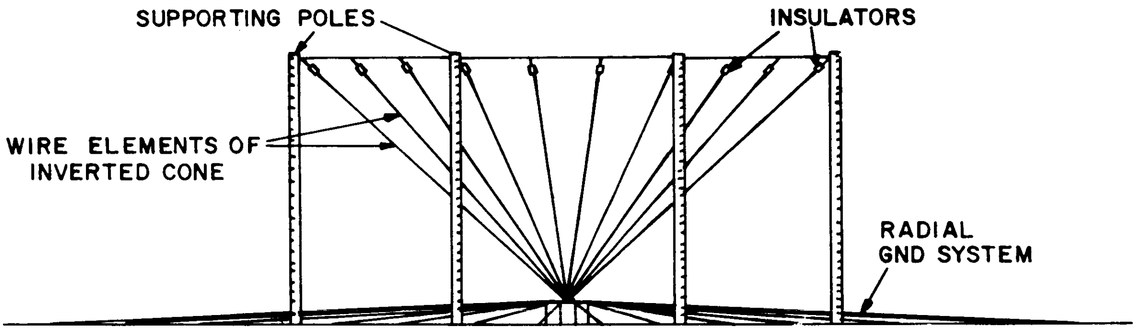
FIG. 2-7a 2.5-20 MC DISCONE



ELEVATION VIEW

ELEVATED DISCONE ANTENNA

PLAN VIEW



ELEVATION VIEW

INVERTED DISCONE ANTENNA

FIG. 2-7b DISCONE ANTENNAS

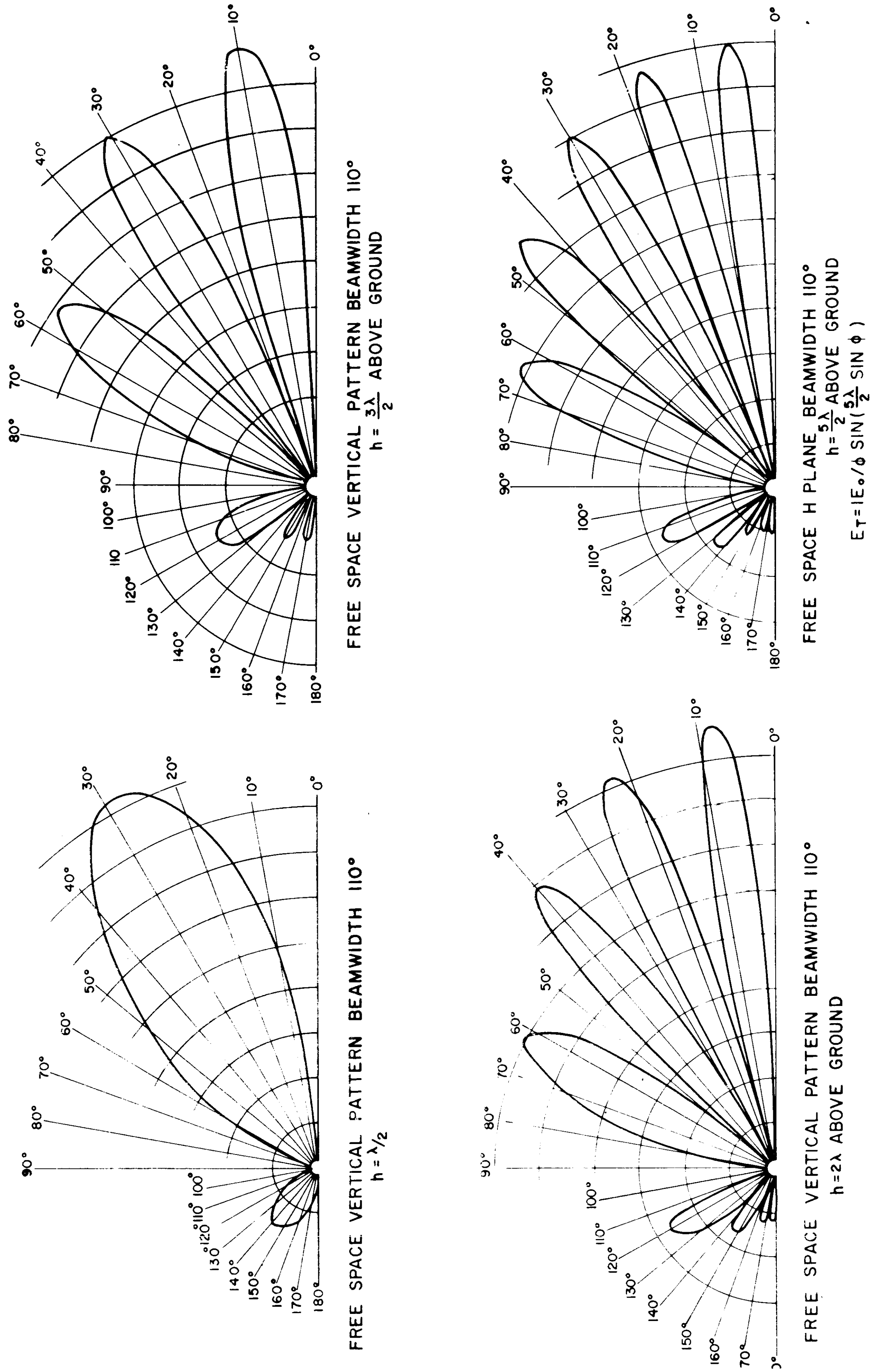


FIG. 2-8 VERTICAL RADIATIONS PATTERN, LOG PERIODIC ANTENNA

advantages are simplicity of construction, ease of maintenance, favorable impedance characteristics over a large range of frequencies, and the relatively high gain which can be achieved over a reasonable band of frequencies.

Another important advantage is the ability to simultaneously receive two signals, separated in azimuth by 180 degrees, and still retain its unidirectional characteristics for reception in either direction. When used in this manner, separate coaxial transmission lines must be run from each end of the antenna, and both ends of the antenna must be correctly terminated to its transmission line through antenna matching transformer NT 471138. It is particularly important in order to maintain unidirectivity that the transmission lines from the antenna be terminated in a multicoupler at the receiver building, such as the CU 656/U or the CU 168/FRR to continuously provide a termination of the transmission line in its characteristic impedance. These multicouplers are designed to have a nominally constant input impedance of 75 ohms regardless of receiver inputs and is, therefore, a satisfactory terminating impedance for the cable when matched by the transformers for either end of the rhombic. The cable alone cannot be considered as a "far end" terminating impedance as the attenuation of approximately 5000 feet of open-ended RG-85A/U at two mc is only 4.77 DB. Computation would indicate a probable VSWR of two to one. Similarly, the attenuation of 2000 feet at ten mc gives a VSWR of two to one. Therefore, even an extremely long cable is something less than an "infinite line."

A nominal forward gain can be simultaneously maintained from both ends of a double-ended rhombic and the useful frequency range of the rhombic is not impaired. Also, in the case of transmitting, the direction of transmission may be reversed by installing the necessary switching devices between the antenna, the dissipation line, and the transmission line. Care must be exercised in designing the rhombic in either case to insure the best compromise of desired vertical pattern for both ends. Some of the disadvantages of the rhombic antenna are the large amount of space required for construction, power dissipated in the terminating resistance, variation of the radiation pattern with changes in frequency, and the large number of secondary lobes.

Instead of using a single wire rhombic, a better match to a 600-ohm transmission line is obtained by making each leg of the rhombus consist of two or more wires connected in parallel, the spacing between wires being larger at the corners than at the apex. The characteristic impedance is thereby lowered while it is, at the same time, kept more uniform along the length of the antenna. It has also been determined that the use of the multiple-wire rhombic, when used for receiving reduces the noise caused by precipitation static, thereby improving the signal-to-noise ratio of the system when these conditions exist. An estimated 6 DB improvement in signal-to-noise ratio can be expected. Because of the advantages listed above for the three-wire rhombic, it is the only type rhombic presently recommended for installation at transmitting or receiving stations.

The terminating impedance of rhombic antennas is usually resistive. Receiving rhombics are normally terminated in a 600-ohm non-inductive resistor. With transmitting rhombics for average powers of 3 kw and below a lumped dissipator is recommended. For greater powers dissipation lines and dissipation lines combined with lumped dissipators are recommended. BuShips Drawing RE 66F 2079 shows recommended terminations.

Ferromagnetic stainless steel wire is used in the construction of dissipation lines. A more than sixfold increase in attenuation is obtainable when using ferromagnetic wire instead of non-ferromagnetic wire. The use of AISI type 446 stainless steel #10 AWG wire is recommended for use in the construction of dissipation lines. To insure that the correct terminating impedance is being used, newly constructed rhombic antennas or terminations should be checked by measuring the VSWR on the transmission line over the entire frequency range for which the antenna is to be used. Adjustments of the terminating load may be required in order to obtain the best possible impedance match over the range.

It is not difficult in practice to match a rhombic antenna to a 600-ohm transmission line, within a VSWR of better than 1.5 to 1 over a six to one range in frequency. From this point of view alone, such an antenna is a broadband radiator. When the radiation pattern is considered, however, the useful frequency range over which a given rhombic antenna can operate is considerably smaller. The angle of elevation above the horizontal of a rhombic antenna and, therefore, the power gain in the direction of the principal lobe varies as a function of the frequency. Depending on the frequency of transmission, the main lobe of the radiation pattern may be several degrees above or below the required angle. While the gain in the direction of the principal beam remains fairly constant, the gain of the rhombic in the required directions may be very small indeed. The performance of a rhombic antenna in many cases may be very much worse than that of a horizontal doublet antenna cut for the required frequency and suspended at the proper height above ground. In general, the radiation pattern in the vertical plane limits the useful frequency range of rhombic antennas to about 2 to 1. This fact is often overlooked in the actual use of such antennas.

Satisfactory communications are sometimes obtained by the use of rhombic antennas over a frequency range of as much as six or more to one, but it is accomplished, at least part of the time, because of the following reasons:

(*a*) One of the numerous secondary lobes of the antenna pattern may launch a signal over transmission paths involving an increased number of hops. Such paths, however, usually offer higher attenuation than those using a smaller number of hops. These secondary lobes are often a source of interference at offbearing locations.

(*b*) The RF power available from the transmitter may be sufficient to make up for the decrease in antenna gain, provided the pattern has not been shifted to a complete null in the desired direction.

A considerable share of circuit outage must, however, be attributed to this type of usage of rhombic antennas. In order to decrease the occurrence of circuit outages it is recommended, when practicable, that the rhombic antennas be used over a more restricted range of frequencies than is the current practice. It is realized that non-availability of land, in some cases, will not permit the construction of sufficient rhombic antennas for such operation. The practical application of this recommendation to the rhombic antennas will be discussed below.

Rhombic antennas are more directive in the horizontal plane than in the vertical plane. Therefore, they should not normally be used for transmissions deviating by more than three to five degrees from the direction of the major axis of the rhombus. Figure 2-9 is a typical example of the behavior of the radiation pattern in the horizontal plane. The curves show the gain of the rhombic in off-course directions relative to the gain in the forward direction, as a function of the length of one of the legs of the antenna. The leg length is given in wavelengths so that this scale is proportional to frequency. At a frequency corresponding to a leg length of 5.5 wavelengths, there is a null in the radiation pattern at ten degrees from the main axis of the antenna. For angles 20 degrees removed from the major axis of the rhombic, the null occurs at a lower frequency, corresponding to a leg length of 3.5 wavelengths. The apparent gain in the directions off the side for leg lengths above about seven wavelengths is due to the fact that the main lobe in the forward direction splits into two parts at the corresponding frequencies. A rhombic antenna should, of course, never be used at the frequencies where this takes place. Figure 2-10 is presented as an illustration only. Details of the curves depend on the tilt angle of the antenna and on the vertical elevation of the principal lobe. In general, the horizontal beam width decreases with increasing frequency. This should be borne in mind when making use of rhombic antennas for transmissions in directions other than that of the major axis.

The question of how far apart rhombic antennas must be placed in order to produce negligible mutual coupling is an important one. Little quantitative information is available as to the minimum allowable spacing between antennas. Until such time as more information is available, one wavelength at four mc or a minimum of 250' is required. Placing one rhombic antenna directly in the main beam of another should be avoided.

Bureau of Ships Drawings RE 66F 2017 and RE 66F 2019 show details of three-wire receiving and transmitting rhombics, respectively. For design information on rhombic antennas see NAVSHIPS 92564.

A final word should be added about the terminating impedance of rhombic antennas. The radiation pattern in the forward direction is very little affected by the presence or absence of the termination. Radiation in the backward direction, on the other hand, is directly dependent on whether or not power is being absorbed at the forward end of the antenna. In the absence of a termination, with the apex either open- or short-circuited, a reflected wave is set up on the antenna which radiates in the backward direction. To a first approximation, about half of the power is in the forward traveling wave and half in the backward traveling wave, when no termination is used. A resistive termination absorbs power for the backward traveling wave and therefore reduces the radiation in the backward direction only. Suppression of the back lobe is desirable, however, since signals from a high-power RF source over a high-gain antenna may cause interference many thousands of miles away from the transmitting station. The chances for mutual effects between antennas on the site are also greatly increased. For these reasons, as well as for proper matching of the transmission lines, rhombic antennas should be carefully terminated, and so maintained.

(11) VEE ANTENNAS.

Two wires combined to form a V, at such an angle that the main lobes reinforce along the line bisecting the V, make an effective directional antenna. If the two sides of the V are excited 180 degrees out of phase, by connecting the two-wire feed line to the

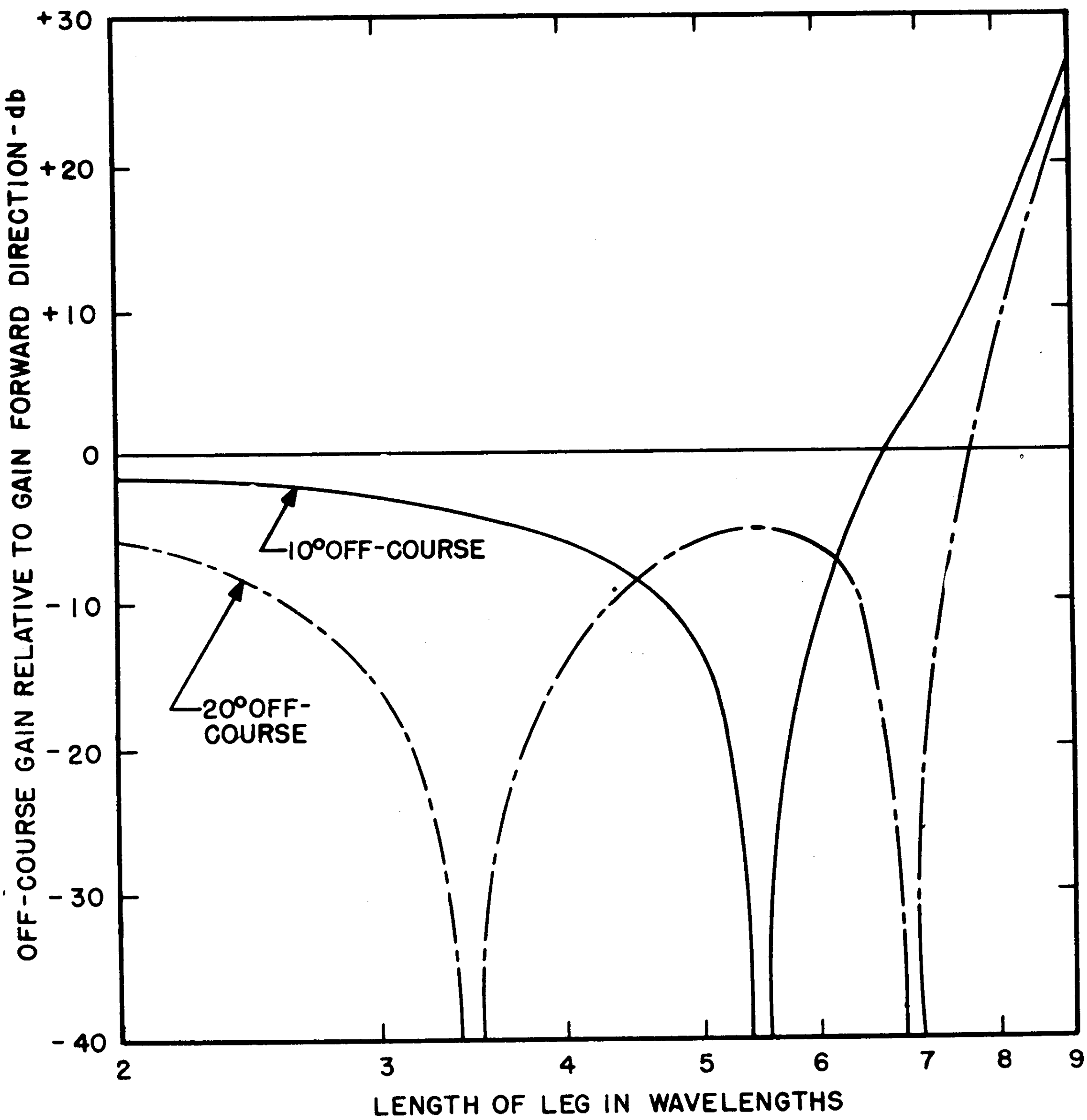
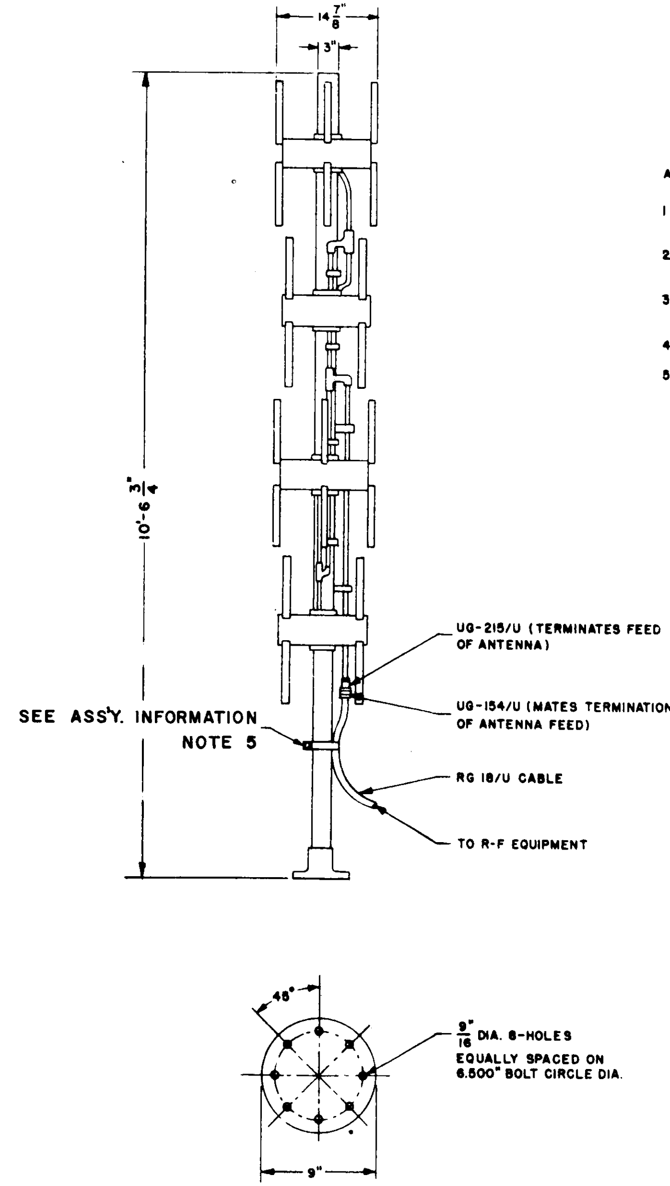


FIG. 2-9 RHOMBIC ANTENNA GAIN IN HORIZONTAL PLANE



ASSEMBLY INFORMATION:

1. MOUNT ANTENNA FLANGE USING STAINLESS STEEL HARDWARE AS REQUIRED (NOT SUPPLIED BY MFG.).
2. ASSEMBLE UG-154/U CONNECTOR TO RG-18/U CABLE (CONNECTOR SUPPLIED; CABLE NOT SUPPLIED).
3. CONNECT UG-154/U CONNECTOR ONTO UG-215/U WHICH TERMINATES THE ANTENNA FEED.
4. BE SURE ALL CONNECTIONS ARE TIGHT.
5. RG-18/U CABLE TO BE SECURELY FASTENED TO MAST APPROX. 10 INCHES BELOW 154/U CONNECTOR.

NOTES:

1. WEIGHT 275 LBS. CRATED, 120 LBS. UNCRATED
2. DIMENSIONS CRATED-11' LONG, 21" HIGH, 21" WIDE
3. VOLUME OF CRATE - 33.7 CU. FT.

FIG. 2-10 AS-768/GR ANTENNA, OUTLINE AND MOUNTING DIMENSIONS apex of the V, the lobes add up along the line of the bisector and tend to cancel in other directions. The V antenna is essentially a bi-directional system when unterminated. When terminated, it provides a practically unidirectional radiation pattern in the direction of the terminated ends. The gain of the V antenna depends upon the length (in wavelengths) of the wires in each leg. The V is a simple antenna to build and operate, provided that the necessary space is available, and can be operated satisfactorily over a frequency range of approximately three to one, although it is optimum for only one frequency. Nevertheless, it will show considerable gain over a wide frequency range; the gain increasing as the frequency increases. The longer the V, the less will be the departure from optimum angle as the frequency is varied. Its principal advantage over the rhombic is the smaller amount of space required and can be used in place of the rhombic where gain may be sacrificed in order to conserve space. Its disadvantage lies in higher side lobe levels.

The open ends of the V antenna should be terminated to ground through noninductive resistors having a value that may be varied from about 400 to 800 ohms. The resistors should be adjusted for minimum standing waves on the feeders and the performance should be checked on several frequencies throughout the band. Terminating each leg of the antenna to ground provides lighting protection and static drain. The terminating resistors, in the case of transmitting antennas, should be capable of dissipating approximately half of the power delivered to the antenna. The terminated V antenna is fed by a 600-ohm transmission line when used for transmitting. For receiving, RG-85A/U coaxial cable in conjunction with antenna matching transformer type NT 471138 is used.

Bureau of Ships Drawings RE 66F 2028 and RE 66F 2055 give details of the electronic requirements of the transmitting and receiving V antennas.

f. VHF/UHF APPLICATIONS.

(1) GENERAL.—Frequencies covered under this subhead are VHF (30-300 mc) and the lower portion of the UHF range (300 to approximately 400 mc). A discussion of the upper portion of the UHF range will be found under the section devoted to "RADIO LINK SYSTEMS."

Because of the "line-of-sight" behavior of radio waves in the VHF/UHF range of frequencies, site and antenna selection depend upon the type of service to be provided.

If application is for omni-directional ground communications such as local harbor circuits, engineering is concerned with obtaining elevation for maximum line-of-sight coverage and the selection of an appropriate omni-directional antenna. Where a choice of sites is possible, it is better to choose a site which will provide the maximum propagation path over water. This is because propagation even for short distances over land attenuates the signals much more than an equivalent distance over sea water. Where sector coverage is required, each case will be considered separately and specifically engineered where considered justified. Special consideration must be given to ground-to-air communications at these frequencies and this is discussed under AIR/GROUND COMMUNICATIONS.

The following discussion on antenna siting concerns principally point-to-point communications at these frequencies and is pointed toward site and antenna selection for this type of service. However, many of the principles apply to ship, shore, and mobile installations.

(2) ANTENNA SITING.—The choice of an antenna site will depend largely on the nature of the local and intervening terrain. The longer circuits, especially those over difficult terrain, will require better siting at each end than a circuit which is to operate over a more favorable path. Similarly, multichannel circuits require better antenna siting than single-channel circuits for a given distance between stations. For these reasons, planning of circuits and the selection of sites should always be preceded by a careful study of terrain maps and, wherever possible, detailed information concerning the nature of the terrain and the accessibility of desirable sites. This is particularly important when the proposed circuit requires the installation of intermediate relay stations in isolated areas. Although terrain characteristics and their effect on radio transmission vary, careful consideration of the factors summarized below should enable personnel to select suitable antenna sites.

(*a*) WOODS AND JUNGLE.—The following rules apply regardless of topography:

1. Avoid dense woods, particularly when using the higher frequencies. If possible, locate antennas in sizeable clearings.

2. When in proximity to woods or scattered trees, if vertical polarization is to be used, try several sites a short distance apart and select the one which gives the best results. If available, mobile test transmitters and receivers may be used to help select the best locations.

3. In jungles, support antennas on masts extending above the jungle growth, or locate in clearings at least 100 yards in diameter and use the highest mast available. Transmission over open paths

across a river or along open river valleys is recommended, where feasible.

(*b*) FLAT TERRAIN.–

1. Place the antennas well in the clear, and with sufficient height to allow for a good line-of-sight path if possible.

2. Avoid depressions. Select any slight rise of terrain in the vicinity.

(*c*) HILLY OR MOUNTAINOUS TERRAIN.–

1. Hilltop installations providing line-of-sight paths between terminals usually provide the best results. One site highly elevated and the other site located near the base of an opposite hill may give better results when the transmission is over smooth earth or salt flats.

2. Barren hills are preferable to wooded areas. It is essential that the antenna be located above surrounding trees.

3. Try different locations at the same site and with different antenna heights. Wide variations in signal strength may exist within small areas due to reflection from surrounding objects.

4. Objects in the vicinity of either the transmitting or receiving antenna may distort its radition pattern. Experiment with the orientation of either or both antennas to obtain maximum signal at the receiver.

5. If line-of sight locations are not available choose antenna sites at each end so that the least bending of the radio wave is involved in clearing an obstructing hill. Avoid sites at the base of high intervening hills.

6. The presence of river valleys and gaps between mountains should not be overlooked as a means of obtaining transmission paths devoid of high intervening hills.

(*d*) SEA WATER.–The field strength of a vertically polarized wave at 30 mc is practically constant from zero height up to heights of approximately 300 feet, and increases very little more at 75 mc. Therefore, there is little advantage when operating below approximately 90 mc in increasing the height, unless it is possible to raise the antenna elevation above this level. There is an advantage in increasing the height of vertical antennas when operating over land. Vertical polarization is especially useful for communication with ships at these frequencies where antenna heights may be limited. Above approximately 100 mc where the antenna height is at least several wavelengths, and the distance between stations is much greater than the heights of the antennas, there is very little difference in the field strengths of vertically and horizontally polarized waves.

(3) POLARIZATION.–In all cases, the orientation of the receiving antenna should be the same as that of the transmitting antenna. The simple vertical doublet or ground-wave antenna is nondirectional in a horizontal plane. This feature is advantageous when good communication is desired in all directions from the transmitting station.

Vertical polarization is decidedly better than horizontal where antenna elevations are limited to very low heights, such as shipboard installations. This results in a field strength at the receiver much greater than that obtained with horizontal polarization, using antennas at the same heights. This difference in received signal strength is greater in the lower portion of the VHF band, and gradually decreases as the frequency is increased and the antenna heights reach several wavelengths. At higher frequencies there is little if any difference when the antennas are at least several wavelengths in height. Vertically polarized antennas are presently used for all ship-to-shore and air-ground VHF/UHF communications.

In link circuits, the inherent directivity of a simple horizontal doublet is sometimes of advantage as a means of minimizing interference, and is less apt to pick up man-made interference which may be predominately vertically polarized.

(4) ANTENNA TYPES.–A complete discussion of all the various types of VHF and UHF antennas is beyond the scope of this book. Normally point-to-point or link circuits, consist of directional arrays. Ship-to-shore and air-ground circuits are omni-directional, except where sector coverage is desired. One very important characteristic of VHF and UHF signals is their polarization, in that both transmitting and receiving antennas must be similarly polarized for best results. Since the physical size of antennas in this range of frequencies, especially in the higher portion of the band, are small, they are relatively easy to install. If carefully constructed and adjusted, they are highly efficient.

(*a*) GROUND PLANE.–The ground plane antenna consists of a quarter-wave vertical radiator working against a rod structure simulating a ground plane. The ground plane serves to establish a stable antenna impedance characteristic by effectively completing the antenna circuit.

Navy types 66015 and 66091 are typical examples of ground plane antennas. NT 66015 consists of a 42-inch vertical radiator which is suitable for the frequency range of 60 to 80 mc. NT 66091 has a telescopic vertical radiator, variable from 18 inches to approximately 24-1/2 inches, and covers the band of

115 to 156 mc. Both types have four horizontal rods spaced 90 degrees acting as the ground plane.

(*b*) DIPOLE.—The AT 150/SRC is a broadband coaxial dipole type of antenna and is used for transmitting and receiving vertically polarized waves at frequencies within the range of 220 to 400 mc. It is balanced with respect to ground and has a nominal input impedance of 50 ohms. The AS 390/SRC is a broadband coaxial stub antenna used for both transmitting and receiving vertically polarized waves, and covers the same range of frequencies as the AT 150/SRC. It has a nominal input impedance of 50 ohms and is unbalanced to ground. Both antennas have radiation patterns similar to that of a conventional dipole. The Navy type 66095 is a broadband dipole similar to the AT 150/SRC but covering the frequency range of 115 to 156 mc.

(*c*) COLLINEAR ARRAY.—The AS 768/GR antenna is a four-element collinear array possessing a vertical radiation pattern width of 15 degrees at the half power point. The point of maximum radiation occurs at four degrees above the radio horizon. This four degree electrical tilt tends to suppress the low elevation angle of radiation, which decreases the depths of the nulls in the vertical propagation pattern compared to that of the AT 150/SRC and AS 390/SRC antennas. This coupled with the inherent array gain increases the range of solid UHF communication. The horizontal separation of these antennas should be 40 feet, and the average height 35 feet above ground. Figure 2-10 shows outline and mounting dimensions of this antenna, while Figure 2-10a shows the vertical radiation pattern at 400 mc.

(*d*) CORNER REFLECTOR ANTENNAS.—This type of antenna system is particularly well-suited for link service in the VHF and UHF frequency ranges. It consists of two plane surfaces set at an angle of 90 degrees, with the antenna assembly consisting of a driven dipole set on a line bisecting the angle. The use of this type of antenna is considered to be a special case and the Bureau of Ships is prepared to furnish design for 130-150 coverage where more gain is required than is provided by the Navy type 66157 plane reflector type.

(*e*) PLANE REFLECTOR ANTENNAS.—Navy type 66157 is similar in operation and is used for the same kind of service as the corner reflector antenna but has a plane reflector instead of a corner reflector. It is a broadband conical type dipole antenna capable of operation over the frequency range of 132 to 156 mc. The antenna consists of two colinear cones each 16 inches long with their apexes connected to either side of a coaxial feed line through a series resonant circuit. This line is made up of a 5/8-inch tubular inner conductor mounted in a large rectangular outer conductor which serves to secure the antenna elements to the reflector. The reflector is 40 by 40 inches square. The antenna may be used for vertical or horizontal polarization, and has a gain of approximately six db over that of a single dipole antenna.

(5) AIR/GROUND COMMUNICATIONS.

(*a*) ANTENNA HEIGHT.—There is an optimum ground station antenna height for use in typical air-to-ground communication systems. When antennas lower than this optimum are used, the maximum distance range is reduced at all aircraft altitudes. When antennas higher than this optimum are used, the interference between the direct and ground-reflected waves causes gaps to occur in the coverage at the higher aircrafts altitudes. The minimum altitude at which the gap in coverage occurs decreases with increasing frequency and with increasing ground station antenna height. The optimum antenna height decreases with increasing frequency and this, in turn, reduces the maximum distance range for satisfactory communication as the frequency increases.

Figure 2-11 is provided to show the maximum ground station antenna height, h_{1m}, for gapless over land air-to-ground communications up to the aircraft altitude, H_m. These curves are based on compiled data contained in a report of the Department of Commerce concerning "Gapless Coverage in Air-to-Ground Communications at Frequencies Above 50 MC" (CRPL-6-4, 28 March 1951).

In the use of this graph, it is assumed that six DB communication system attenuation which includes that caused by the length of the propagation path and within the confines of the "radio horizon," will provide satisfactory communications. Calculations are also made for 12 DB attenuation. From the graph it can be determined that at 200 mc, the maximum tower height for gapless coverage within the range of normal 12 DB attenuation is approximately 30 feet for altitudes up to 40,000 feet . At 300 mc, to obtain the same coverage a tower height of 15 feet or less is indicated.

Considering the fact that solid coverage at the shorter ranges is usually more important operationally than an increase in the maximum distance range, calculations have been made of the maximum ground station antenna height, h_{1m}, which will insure gapless communications out to the maximum distance range at all altitudes less than a specified value, H_m. The value H_m is determined by operational considerations and, in this publication, calculations have been made for the illustrative values of H_m = 10,000 feet;

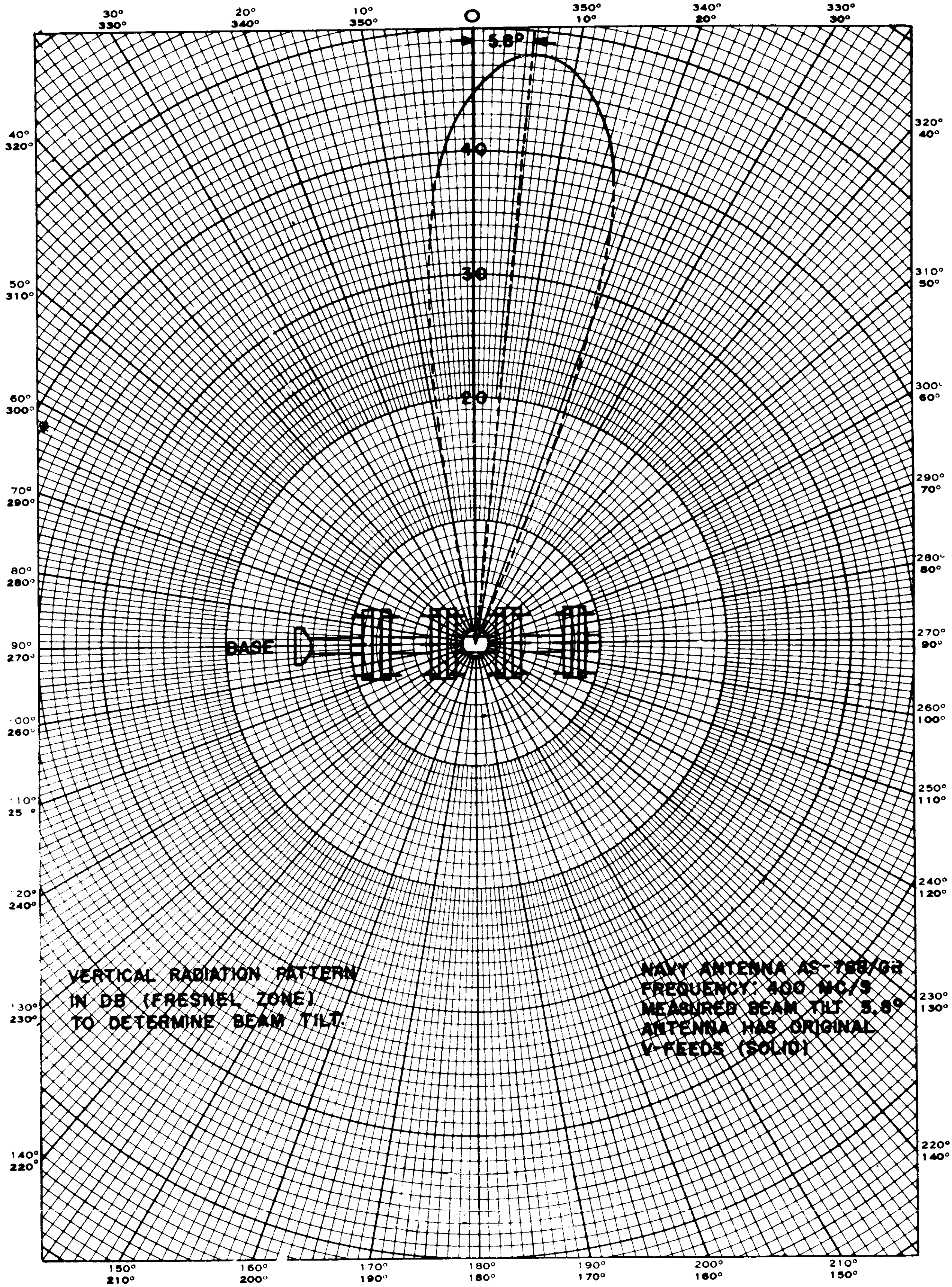


FIG. 2-10a AS-768/GR ANTENNA VERTICAL RADIATION PATTERN

CALCULATED FOR A SMOOTH SPHERICAL EARTH & THE AVERAGE ATMOSPHERE AT WASHINGTON, D.C.
AIRCRAFT TRANSMITTER POWER 6 WATTS; GROUND STATION RECEIVER SENSITIVITY 0.18$\mu\mu$ WATTS; AIRCRAFT & GROUND STATION ANTENNAS HALF-WAVE VERTICAL DIPOLES

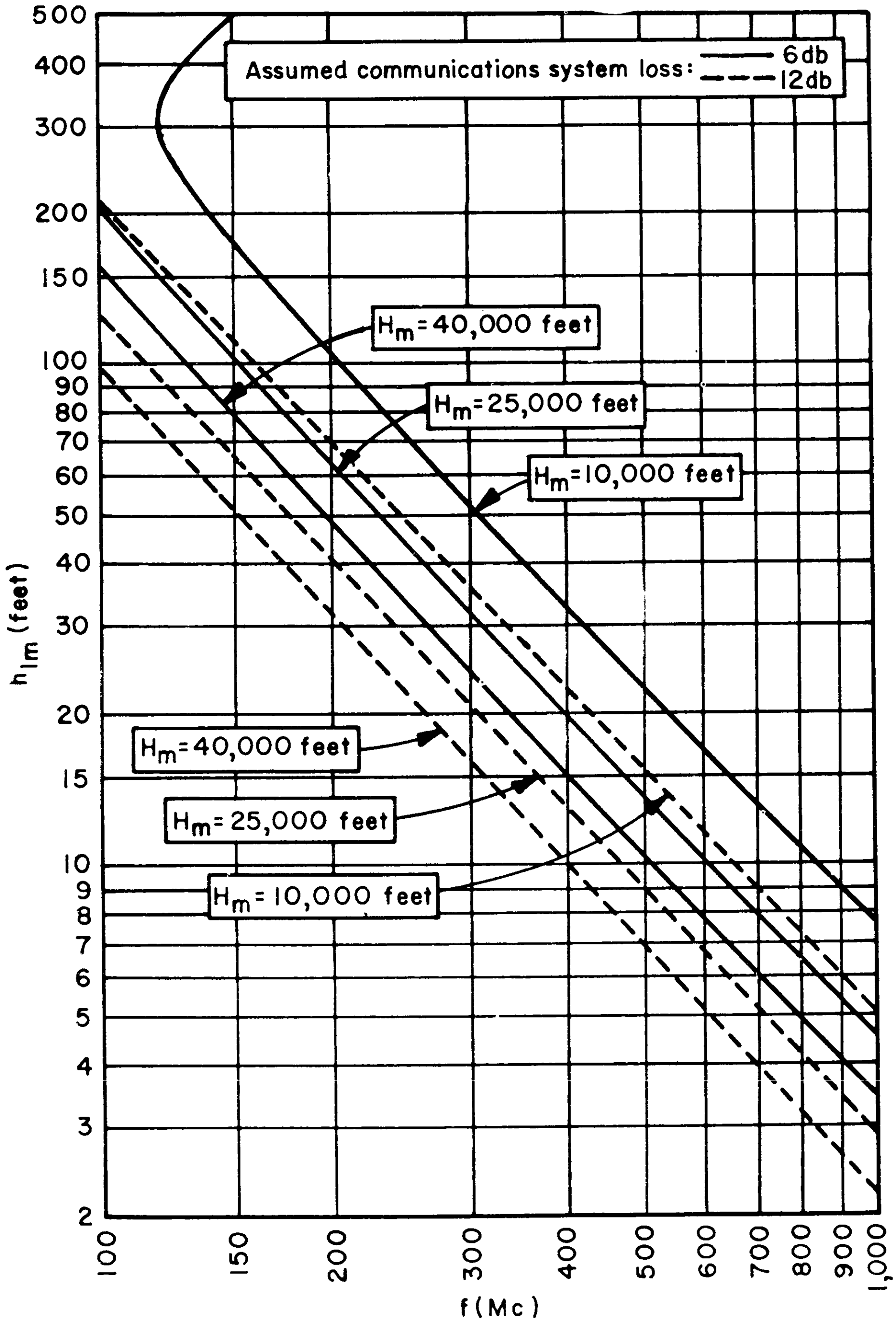


FIG. 2-11 ANTENNA HEIGHT AIR/GROUND PROPAGATION

25,000 feet, and 40,000 feet. Figure 2-11 shows these values of h_{1m} as a function of the radio frequency throughout the range from 100 to 1000 mc. It is interesting to note that there should be no gaps in communications at altitudes below H_m = 10,000 feet with a six DB communications system loss on frequencies below 118 mc, regardless of the height of the ground station antenna.

Additional information on this subject may be obtained by referring to Proceedings of the I.R.E., May 1952, concerning "Service Range for Air-to-Ground and Air-to-Air Communications at Frequencies above 50 MC," by R. S. Kirby, J. W. Herbstreit, and K. A. Norton.

The criteria for UHF installations at Air Stations (including RATCC) and Special Purpose activities such as Fleet Air Defense Training, Ground Control Intercept, and Combat Information Center Schools, etc., are to establish a vertical pattern lobe structure and achieve maximum gapless coverage suitable for AIR/GROUND Communications. A compromise height for the antenna has been established at 35 feet above average ground level. These installation criteria apply to receiving as well as transmitting antennas; both roof-top and pole mounting. The height of VHF antennas above average ground level should not exceed 90 feet.

The antenna types normally used at the above locations include the AT 150/SRC, AS 390/SRC, AS 768/GR, and the 66095 (VHF).

(6) MULTICHANNEL OPERATION.—Reference 44, Appendix XII, a part of which is quoted in Appendix IX, contains an excellent discussion of antenna arrangement and factors affecting equipment performance for multichannel operation in the 200-440 mc range.

(*a*) ANTENNA MULTICOUPLERS.—As pointed out in the referenced NEL report, the use of multicouplers for both receivers and transmitters is mandatory in multichannel operation at shore installations such as for tower and RATCC control of aircraft. The following description of one type of multicoupler is furnished as an example:

Antenna Coupler CU-691/U provides isolation between four transmitter and/or receiver combinations operating simultaneously into a common antenna. Isolation is achieved with four highly selective tandem filters and a combining network. The high selectivity reduces intermodulation interference, cross modulation interference, and spurious responses. Harmonic radiation from the transmitter(s) is also attenuated.

Inside the coupler are eight silver-plated aluminum tunable cavities. When properly tuned, each cavity is a 1/4-wavelength shorted coaxial element. The cavities are aperture coupled in groups of two, forming four dual-cavity tunable tandem filters. Adjustable tuning slugs in the cavity side walls permit compensation for minor irregularities in the cavity resonance curve. The outputs of the four filters are coupled to a common junction at the input of a combining network. The output of the combining network is the output connector for the antenna transmission line.

(*b*) MONITORING.—Shore station system test facilities are augmented in the CU-691/U by having a monitor coupler assembly inserted in each input transmission line between the input type N coaxial connector and the input to the tandem filter. The coupler assembly develops direct-current (d-c) voltages proportional to the forward and reflected wave components existing on each line. The d-c voltages are supplied to the meter circuit via the function selector switch. Calibrating resistors, selected by the switch, derive meter readings from the developed d-c voltages which show forward power and standing-wave ratio (swr). The meter readings are useful for tuning the filters and for monitoring line conditions during operation.

(*c*) SEPARATION.—(In preparation). This paragraph will provide criteria pertaining to frequency and antenna separation in the VHF/UHF bands so as to minimize interference caused by intermodulation products and other factors related to multichannel operation.

g. SUMMARY OF ANTENNA TYPES.

The following tabulation is included for planning purposes and gives antenna types currently installed at Shore Activities.

TABLE 2-4, ANTENNA TYPES

Designation	Frequency Band	Transmitting	Receiving
VLF	Below 30 kcs	Special designs.	Marconi, long wire, barrage, loop
LF	30—300 kcs	Vertical Radiator (vertical wire or tower with top loading).	Marconi, long wire, loop.
MF	300—500 kcs	Vertical Radiator (vertical wire or tower with top loading), conical monopole, Discones.	Marconi, long wire
MF	2—3 mcs	Vertical, Tilted and Horizontal Doublets, Sleeve.	Same as Transmitting

HF 3—30 mc Omni-directional	Sleeve, Vertical Doublet, Tilted Doublet, Discones, Conical Monopole.	Same as Transmitting
Sector Coverage	Sleeve Array, Vertical and Horizontal Array, Corner Reflector Array, Log Periodic	Same as Transmitting
Point-to-Point	Rhombic, Vee, Doublet, Sleeve Array, Corner Reflector, Discones Conical Monopole, Log Periodic, Doublet Arrays.	Same as Transmitting
VHF 30—300 mc Omni-directional	Vertical Monopole with Ground Plane, Vertical Dipole, Stacked Vertical Array.	Same as Transmitting
Point-to-Point	Horizontal Doublet, Doublet Array, Corner Reflector.	Same as Transmitting
UHF 300—3000 mc	Same as VHF except no horizontal polarization. Parabolic Reflector types.	Same as Transmitting
SHF 3000—30,000 mc	To meet Requirements.	To meet Requirements

b. RADIO-FREQUENCY TRANSMISSION LINES AND MATCHING.

(1) GENERAL.–Since antennas are physically removed from the transmitter or receivers by distances ranging from a fraction of a wavelength to many wavelengths, some form of low-loss transmission line must be utilized for the feeder system. This line will be an aperiodic system only when it is correctly terminated in its characteristic impedance. Thus, if the antenna impedance at the feed point differs from the characteristic impedance of the line, standing waves occur with resulting high losses and high potential points on the line. Furthermore, the input impedance to the line seen from the transmitter will no longer be the line impedance but will be a function of the mismatch between the antenna and the line. If this mismatch is such that a 2:1 voltage standing wave ratio (VSWR) appears on a 600-ohm line, then the transmitter must be capable of matching from 300 to 1200 ohms of impedance, including the reactance and resistance which is associated with such a load. Good engineering practice dictates operation with minimum VSWR at all times. Due to practical limitations, a VSWR of 1.5 to 1 or less is designated as a reasonable standard.

While it is possible to achieve a wide range of characteristic impedances in both balanced and unbalanced transmission lines, it is usually at the expense of having to choose complex multiple wire configurations. The advantage of the inherent simplicity of coaxial lines and two-wire open lines usually outweighs the disadvantage of the restricted impedance ranges they afford. The two-wire open parallel line is relatively simple to construct and install. It provides a reasonably good balance and a constant characteristic impedance. The coaxial line is easily installed but the chief value is that it minimizes radiation losses and problems due to coupling between lines. Nominal characteristic impedances of 50 and 75 ohms are Navy standard for coaxial cable, while 600 ohms is Navy standard for two-conductor open-wire balanced lines.

The maximum intrinsic bandwidth and efficiency of a system involving an antenna and feeder usually occurs when the respective impedances are equal and therefore self-matching. In some cases it is possible to design the antenna for an impedance that will fit a particular feeder impedance. When this cannot be fully achieved, as in the case of doublet antennas, the Bureau of Ships recommends the use of the parallel stub line method of matching as outlined in Appendix IIA.

Although not generally recommended, it is possible to obtain terminal impedance matching by a number of other methods. The most common are:

(*a*) Tapered transmission lines.

(*b*) Lumped reactance networks.

(*c*) Coupled line sections.

(*d*) Series line sections of proper characteristic impedance (used in matching a sleeve antenna to 75-ohm coaxial cable).

(*e*) Antenna feed point adjustment.

While there are numerous methods of accomplishing a balance-to-unbalance transformation in a feeder line, most of them introduce frequency selectivity. The obvious advantage of keeping the number of frequency-selective elements to a minimum leads to a natural selection of balanced feeders for balanced antennas, and an unbalanced line for unbalanced antennas, whenever possible. Broadband techniques are being pursued.

Standardization has resulted in most shore station transmitters being designed to work into open-wire 600-ohm transmission lines, with matching arrangements to the antenna provided, as required. Exceptions are those applications where 75-ohm coaxial cable is used and in VHF/UHF where 50-ohm coaxial cable is standard. Receivers (except VHF/UHF) are normally designed for 75-ohm input impedance with provision for 75-ohm coaxial transmission line feeders from the antenna. Standard practice for receiving antennas is to terminate the

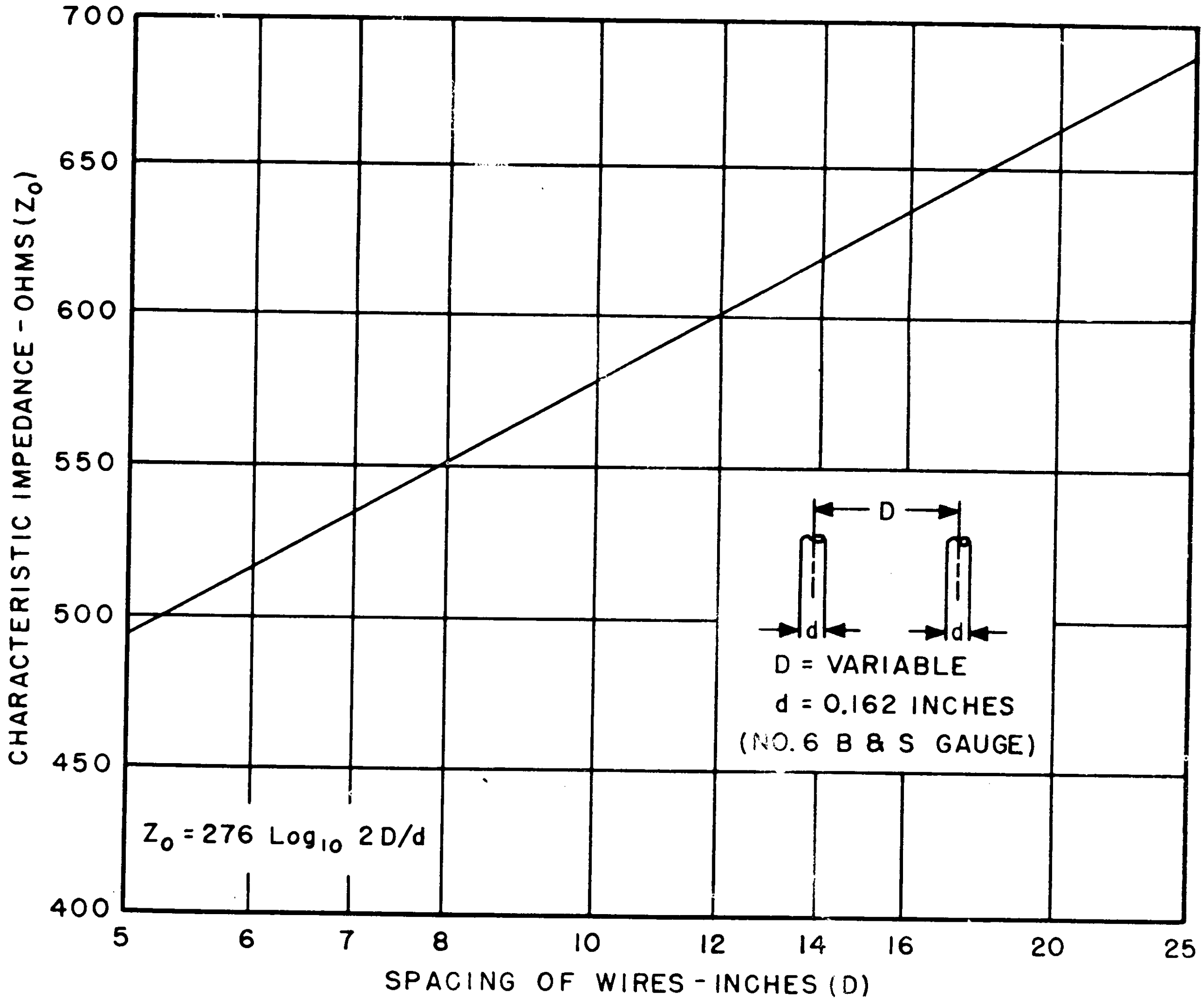


Figure 2-12. Characteristic Impedance of Parallel Wire Line

antenna in a suitable matching transformer NT 471138 located at the antenna, and to transfer the RF energy by means of a buried coaxial transmission line to the receiver building.

(2) OPEN WIRE LINES.

(*a*) APPLICATION.–Transmission lines consisting of two parallel conductors of No. 6 gauge copper wire spaced 12 inches apart have a characteristic impedance of 600 ohms. Considerable variations in spacing between conductors can be tolerated without seriously affecting the VSWR on the line. This is illustrated in Figure 2-12 which shows the characteristic impedance of a two-wire line made of No. 6 wire. If, for example, the spacing between the conductors of a matched 600-ohm line were suddenly reduced from 12 inches to six inches, beginning at some point along the line, the VSWR on the six inch line would be changed from unity to only 1.16:1. It should be noted that the characteristic impedance depends on the ratio between wire size and spacing. In this case, if the wire size had been reduced to No. 8, the 600-ohm impedance would have been maintained. Some Naval shore stations utilize No. 8 wire at a 6-inch spacing for interior runs to minimize proximity coupling between lines, tapering out to a No. 6 wire at 12-inch spacing outside the building, because of the lower attenuation and greater tensile strength of the larger diameter wire. This compromise can be tolerated where necessary providing transition is made with care. Sudden changes in line spacing can produce possible points of corona formation, as well as power losses in the form of radiation, and should therefore be avoided whenever possible.

Of more importance, because it is overlooked more often, is the requirement of keeping the total length of the two wires in the balanced feeder system exactly equal. This especially should be watched for sections of feeder passing from the transmitters to the outside of the building, in the switches, and at bends or turns in the line.

Some of the power delivered to the feeder by the transmitter is dissipated in the form of ohmic losses in the wire and insulator leakage. Radiation losses are usually negligible. The attenuation of two-wire copper line less insulator and radiation losses is given by:

$$a = \frac{14.4\sqrt{f}\ \text{db}/1000\ \text{ft}}{dZo}$$

where a = attenuation in db per 1000 feet of two-wire line
f = frequency in mc
d = diameter of conductors in inches
Zo = characteristic impedance of line in ohms

The attenuation of the 600-ohm line using No. 6 conductors is plotted as a function of frequency in Figure 2-13. It will be noted that such a line is highly efficient, so that relatively long runs may be tolerated when this is required for proper spacing of the antennas. It is obvious, of course, that the feeders should not be made longer than strictly required. A feeder length of more than 2500 feet is not recommended except in unusual circumstances. If the line is mismatched at the antenna end, additional losses are introduced. For properly terminated rhombic antennas this additional loss is negligible. The curve of Figure 2-13 may be taken to represent the losses introduced by the feeder system. Ground losses may be neglected if the transmission line is suspended at a height greater than ten times the line spacing.

In large installations, it is inevitable that several feeders must run parallel to each other over considerable distances. Close spacing of lines not only produces coupling between adjacent circuits but also unbalances the feeder systems.

To prevent coupling between circuits, they should be spaced apart horizontally by at least nine times the horizontal spacing between conductors of a single pair of lines, and have a vertical separation of a minimum of ten feet. Greater vertical separation is desirable but impracticable. This still permits the use of a single pole and two cross-arm construction to support up to four pairs of lines. From a maintenance aspect, four is considered the maximum that should be supported by one pole.

(*b*) PHYSICAL PROPERTIES AND INSTALLATION.–Some of the factors that must be considered when designing transmission line connected to transmitters are:

1. Power handling capabilities.
2. Voltage breakdown.
3. Losses.

Pouer – The amount of power that can be handled is determined by the size and number of wires used.

Voltage Breakdoun – The maximum RF voltage that can be safely used on open-wire line depends on the spacing of the wires, the type, size, and condition of the insulators, the heights above sea level, the temperature, and the humidity. Outdoor weathering and deterioration also have an effect on the voltage breakdown of open-wire transmission lines. Balanced lines composed of more than two conductors will have higher breakdown or corona voltages than

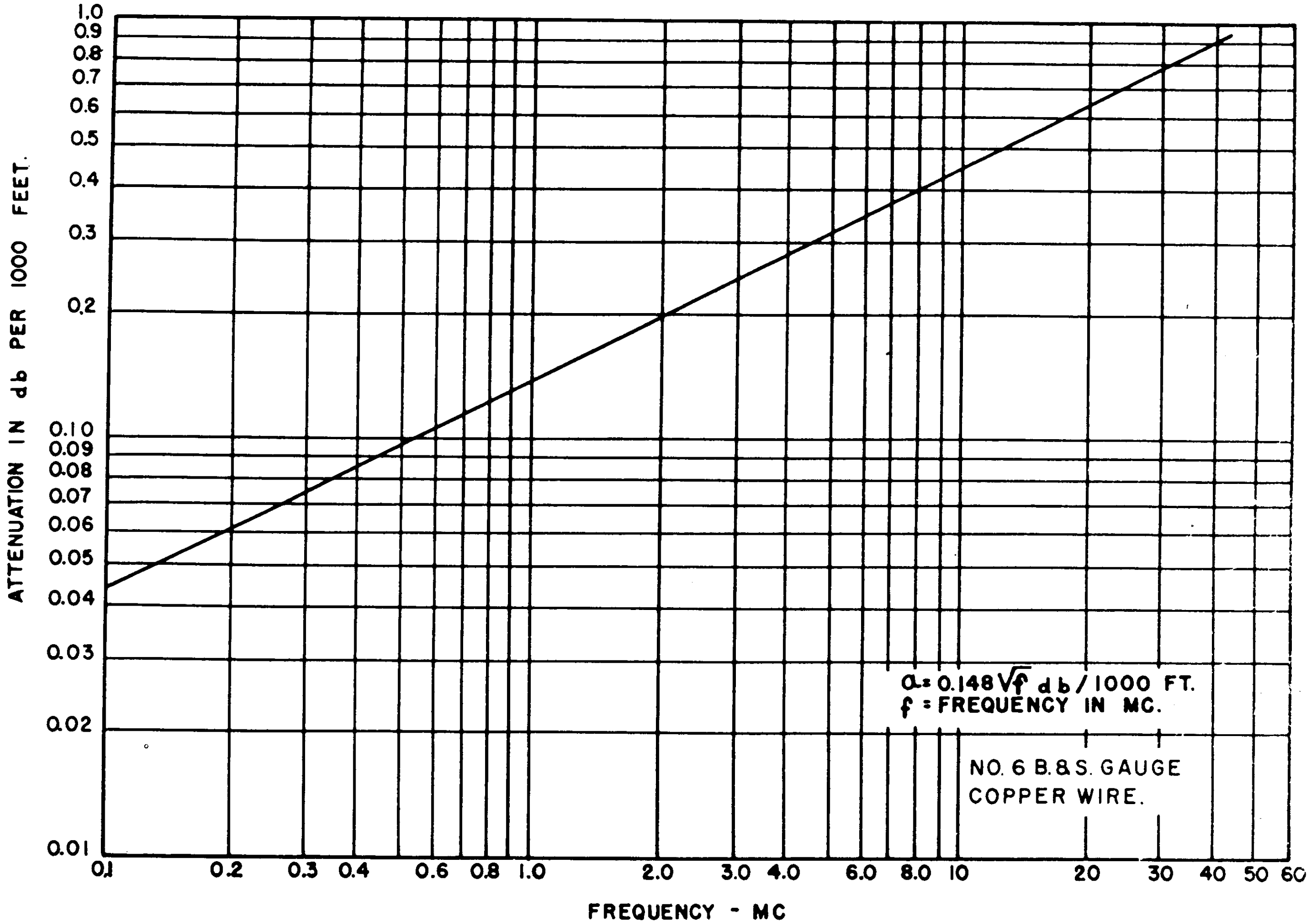


Figure 2-13. Attenuation of 600-Ohm Parallel Wire Line

will two-wire lines using the same size conductors. Four-wire lines have a breakdown voltage of approximately 1.44 times that of the two-wire lines. In general, however, multiwire lines containing more than four conductors do not divide the line currents equally among the conductors. This unequal current division results in higher gradients in some of the line conductors than others, and thus reduces to some extent the voltage breakdown capability. At present maximum powers of 50 kw, two-wire transmission lines provide approximately 300% safety factor, which is quite adequate. Therefore, the simple two-wire 12-inch No. 6 Copperweld line has been designated as the Navy standard for open-wire lines.

Losses – Losses in a balanced transmission line include direct radiation from the line, copper losses, and insulation losses. Direct radiation losses from a well-designed line can usually be neglected provided line is terminated at or near its characteristic impedance. However, if radiation is present on a transmission line, it may seriously affect the radiation pattern of a directional antenna. Copper losses are determined by the size of the wire used. Insulation losses are determined to a great extent by the configuration, the material used, and the care used in the construction of the line. These losses will also vary with conditions such as icing and the condition of the insulators. Insulation losses from a long line used at high frequencies may range from approximately 20 percent to 70 percent of that of the copper losses.

(*c*) CONSTRUCTION.–Some of the factors to be considered when constructing open-wire transmission lines are:

1. Two-wire 600-ohm transmission lines delineated in Bureau of Ships Drawing RE 10F 2143 are Bureau standard for open-wire transmission lines up to 24 mc.

2. Transmission lines should be spaced horizontally by at least nine times the horizontal spacing between conductors of a single pair of lines, have a vertical separation of at least ten feet, and be at least ten feet above the ground. These factors become important where conductors may swing in the wind or become coated with ice. Mechanical strength and current carrying capacity are the most important factors in selecting the gage of wire for open-wire RF lines. No. 6 AWG Copperweld wire is used for open-wire lines because of its high tensile strength. Losses at these frequencies are comparable to those of copper wire. The voltage breakdown of such a line is well in excess of that required for 50 kw transmitter power.

3. The electrical lengths of the two sides of the lines should be kept identical. Sharp turns should be avoided wherever possible. A necessary sharp turn should be made with jumpers that take a gradually curving path. The jumpers on opposite sides of the line must be identical in length and have the same spacing throughout their curve as the transmission line. These length and spacing requirements are most conveniently met by twisting the transmission line to a vertical position just ahead of the turn, and returning it to a horizontal position after the turn has been completed. The twist in the line must be gradual. After twisting the transmission line to a vertical position to make a bend, it is advisable to twist the line again in the opposite direction and for the same distance. This equalizes the capacitive unbalance introduced by the first twist, which placed one conductor closer to the ground than the other. Bureau of Ships Drawing RE 10F 2143 indicates standard turns.

4. All wire connections should be well served and soldered. All connections should be either pour or dip soldered, to prevent the uneven solder lumps and points that form when a soldering iron is used. Such points may go into corona far below the breakdown voltage rating of the line. Nicopress sleeves may be used for line splices.

5. Special attention should be given to building entrance arrangements. Line spacing at point of entry to the building should be as shown on Bureau of Ships Drawing RE 10F 2143. Lightning protection should be designed and installed so that both wires of the line have identical circuits through the protective device. Electrical conductors must be prevented from grounding through the building walls in wet weather.

6. No connections to the line should be made that would result in an unbalance. Each connection or tie wire on one side of the line should be duplicated in an identical manner and at exactly the same electrical point on the other side of the line.

7. "Candle Stick" insulators used in transmission line construction shown in Drawing RE 10F 2143 provide lowest loss and least capacitance to ground under current availability. They must be so installed that minimum vertical or horizontal strain is exerted by the wire. Individual insulators can be in strain by nonvertical mounting on the cross-arm roof, or by mounting of the insulator on the cross-arm in such a manner that the wire binds in the slot and exacts a twisting strain. The maximum tension recommended by the manufacturer shall not be exceeded during installation. This insulator may be structurally weak for areas of heavy icing and/or wind loading and such cases should be referred to the

Bureau of Ships. Where required, Type 747-270 insulators, manufactured by the Wind Turbine Company, may be used in place of the Candle Stick type.

(3) COAXIAL TRANSMISSION LINES.

(*a*) APPLICATION.–As long as the VSWR is kept within reasonable limits and the coupling network of the transmitter and antenna is compatible, coaxial lines may be used. The losses are low in high quality coaxial transmission lines, but they are approximately three times as large, in the case of RG-85A/U, as those of the two-wire balanced feeders due to a higher attenuation factor. The antennas fed by coaxial cables should therefore be kept as close to the transmitters as is practicable while maintaining the required separation between antenna systems. Since line losses increase as the frequency increases, the higher frequency antennas should be placed nearest the transmitter building. The VSWR should be less than 3:1 for safe, continuous operation. In spite of the higher losses encountered in carrying RF energy on coaxial cables as compared to open wire transmission lines, nearly all transmission lines serving receivers are coaxial cable. This is because greater loss can generally be tolerated in the case of received RF, and the coaxial cable is far superior in maintaining signal-to-noise integrity.

The two MIL-stds for coaxial cable have been set at 50 and 75 ohms. As previously mentioned, for shore applications the Navy has chosen 50 ohms for VHF/UHF and 75 ohms for high frequency. (The use of 75 ohm vice 50 ohm allows greater flexibility in HF broadband antenna design.) For receiving stations, RG 85A/U is recommended for direct burial installation. When the losses due to operating frequency and cable length becomes excessive, jacketed 1-5/8" semi-flexible cable is recommended instead of RG 85A/U.

(*b*) RATING OF COAXIAL CABLES.

1. Coaxial cable is normally rated in terms of the amount of power the cable can handle, called the AVERAGE POWER RATING, and the voltage breakdown limitations, called the PEAK POWER RATING. In communications service and at the frequencies involved in these activities, the peak power rating exceeds usage to the extent that it may be disregarded.

The average power rating is based on the allowable heating effect within the cable. This, in turn, is based on the temperature of the center conductor as compared to ambient (outside) temperature. Average power rating may also be defined as the level of input power which will produce a maximum safe center conductor temperature under steady state conditions when cable is terminated in a matched load. A survey of the industry indicates a standard ambient temperature of 40 degrees C. (104 degrees F) and a maximum center conductor temperature of 75 degrees C. Therefore, under practical conditions, only the center conductor temperature need be considered.

2. Factors which modify the power rating as defined above include (a) Standing wave ratio, (b) Modulation, (c) Duty cycle, (d) Frequency, and (e) Installation deficiencies.

Standing wave ratio. Since standing waves on a transmission line of some length include reflected currents, at a given frequency and at a given point on the line the reflected current and the forward current will be in phase and additive, creating a hot spot on the line. For this reason, the ratio between forward current and reflected current may be divided directly into the power rating of the cable to modify the rating accordingly.

$$\frac{P_{av}}{VSWR} = P_{av} \text{ modified by standing wave ratio.}$$

Modulation. Amplitude modulation of the transmitter enters into the power rating of the cable due to the fact that sideband power is added to initial carrier power. For a sinusoidally modulated waveform, power in each sideband equals one fourth carrier power. Total power at 100 percent modulation would therefore equal 1.5 times carrier power. The following would apply:

$$\frac{P_{av}}{1.5} = P_{av} \text{ modified by 100\% sinewave modulation.}$$

Voice modulation only reaches 100% level at instantaneous peaks, averaging out at some level between zero and 100%. Industry standards arbitrarily set this level at 30%. Due to compression and peak limiting in military communication systems, a level of 40% seems more logical. Hence a practical safe factor to use here would be:

$$\frac{P_{av}}{1.2} = P_{av} \text{ modified by average amplitude modulation power.}$$

Duty Cycle. Duty cycle refers to on-off time of operation and on-off time of modulation. No mathematical factor is applied here. Since it was originally pointed out that the initial base rating applied to a steady state condition, a minor upgrading in cable power rating may be applied where transmitters are only intermittently on the air or where modulation is only occasionally applied.

In a typical air station installation, voice modulated transmitters might be operated for five minutes out of an hour, or thirty minutes on and two or three hours off between transmissions. In such cases, the heat rise in the cable would not reach maximum and would not be progressive. A reasonable increase in cable power rating might therefore be allowable.

Frequency. Dielectric absorption (thus dielectric heating) increases with an increase in frequency. This effect makes frequency a definite factor in the rating of coaxial cable, the power rating decreasing at a log-log rate as frequency increases. This curve has the same slope for all solid dielectric cables, so if the rating for one frequency is known, the approximate rating for a different frequency may be obtained by interpolation on any coaxial cable power versus frequency graph.

Installation Deficiencies. Any discontinuity in coaxial transmission lines may affect power rating by effectively lumping resistance or reactance at a given point causing an increase in current and thereby an increase in center conductor temperature at that point. Included would be sharp bends, improperly made splices, improperly installed connectors and end seals, etc. Caution should be especially observed in installation regarding bends. Manufacturers' specifications should not be exceeded. If a known specification is not available, a reasonable rule of thumb is:

$$\text{Radius}_{(\text{bend})} = 10 \times \text{Diameter of cable plus.}$$

An example of field rating of coaxial cable follows:

A sample of RG 85A/U was tested by calorimetric means resulting in a P_{av} rating of 12 kw. To be determined is the maximum transmitter power which this cable may be expected to handle under given field conditions.

Assuming the cable is to be buried in a temperate zone, the ambient temperature condition may be disregarded and the established 12 kw rating used as a base figure.

Frequency of operation assigned to this circuit is 15 megacycles. A bridge measurement of the antenna load shows the antenna input impedance to be 225 ohms at the frequency. Since RG 85A/U is listed as having a characteristic impedance of 75 ohms, a VSWR of 3:1 is anticipated.

Using the formula

$$\frac{P_{av}}{\text{VSWR}} = P_{av} \text{ modified}$$

$$\frac{12}{3} = 4 \text{ KW}$$

4 KW would be a safe C.W. rating under these conditions.

Transmitter is to be voice modulated.

Using the formula

$$\frac{P_{av}}{1.2} = P_{av} \text{ modified}$$

$$\frac{4}{1.2} = 3.33 \text{ KW}$$

3.3 kw would be a safe A.M. rating under these conditions.

It is decided to shift frequency up to 30 megacycles, all other conditions remaining the same. Consulting a coaxial cable catalog, a family of curves is found. Among these curves, RG 17/U, a similar cable, is rated at 5 kw at 15 mc and 3.8 kw at 30 megacycles. Following the same slope line as this similar cable, an interpolation shows a new power rating for RG 85A/U of 2.53 kw. Since 2.53 kw is beyond prescribed safe limits, in order to meet requirements transmitter power must be reduced, and adjustment of load made to reduce VSWR, a lower frequency selected, or intermittent operation employed.

RG 85A/U as used in the foregoing example is a common cable type in many Naval Air Station transmitter installations where transmission line runs are reasonably short. It will be noted that with a 3 kw amplitude modulated transmitter the safety factor appears marginal. Due to the fact that in most cases the duty cycle is light and also due to the fact that frequencies used are in the 3 to 20 megacycle spectrum, the operation is acceptable. Caution should definitely be observed in any changes which might increase power in cable. Powers exceeding 3 kw amplitude modulated output are not recommended. Engineering for future installations where anticipated power will be higher should specify larger cable. Due to the unpredictability of future employment of antennas and transmitter powers, the following Navy Standards are set up as recommended average power limits for 75-ohm coaxial cable:

RG 85 U	Up to	3 kw maximum
1⅝" coaxial cable	3 to	5 kw maximum
3⅛" coaxial cable	5 to	50 kw maximum
6⅛" coaxial cable	over	50 kw

The parameters are based on average output power of transmitters and make allowances for a maximum VSWR of 3:1.

It is hoped that the above will demonstrate some of the calculations used to determine safe levels of power in using coaxial cable rating charts, and to emphasize the caution required in selection of cable by power ratings due to the variables involved.

(*c*) BALANCED CABLES.—Balanced transmission cables are available in various forms. One variety consists of two insulated wires twisted together or paralleled and held together with a weatherproof material such as impregnated braid or vinyl insulation. Another type of balanced cable consists of two parallel conductors embedded in a common insulating medium; with or without metallic sheath. These cables generally have characteristic impedances ranging from 50 to 300 ohms. Balanced cables find their greatest use in direction finder systems.

(4) MONITORING.—A continuous check should be kept on the operation of the feeder systems used with transmitters. Monitoring devices used at the present time are RF ammeters inserted in series with the transmission lines. By using one such meter in each leg of the two-wire lines, the transmitters can be adjusted for balanced current input to the feeder system. These should be sensitive meters, of small current range, so that the readings fall around the more sensitive part of the scale. A continuous check of the VSWR and power input to the coaxial cables is essential to prevent overloading and breakdown. Existing trolley meters are adequate for monitoring VSWR and power input to balanced transmission lines, and in-circuit directional couplers are available for monitoring coaxial lines.

i. SITE SELECTION.

The primary consideration that applies in site selection for the antenna park of a communication activity is "suitability for the conduct of communications," as herein defined. Other factors which affect site selection are suitability for construction and support at reasonable cost, tactical factors, treaty rights, land costs, results of real estate surveys, etc. These factors may seem of secondary importance but they do influence selection and sometimes result in engineering compromises. Emphasis, however, should remain on site selection criteria which result in optimum communication performance. Bureau maintenance activities should press for the optimum sites which may be obtained under the above premises. (See Section 1-4.*d.*) Final approval of sites will be made at departmental level. Site selection for any one communication activity also shall take into consideration site selection for related communication facilities with which it will be integrated in order that provision can be made for link circuits as required.

(1) REQUIREMENTS.—The requirements for the location of an antenna park determines the site for a transmitting or receiving facility. Included are topography, ground constants, space availability and site environmental factors which are discussed in the following paragraphs. For additional antenna siting criteria applying to VHF/UHF and microwave, see 2-3*f*(2) VHF/UHF APPLICATIONS and Appendix VI MICROWAVE LINK SYSTEMS.

(*a*) TOPOGRAPHY.—An antenna park should be located on flat or only slightly rolling ground in order to permit construction of antennas engineered for maximum performance. Areas of rock outcroppings should be avoided not only from the standpoint of the complicated construction problems involved, but to avoid the likelihood of encountering inhomogeneity in the ground area and resultant nonuniformity of ground constants. Wooded and jungle areas may be cleared but at considerable expense which must be considered where a choice of sites is possible.

(*b*) GROUND CONSTANTS.—Conductivity and dielectric constant are the two ground characteristics which are most important in the conduct of radio communications. Both are used in calculations concerning wave propagation and are particularly influential in determining vertical antenna wave patterns. Conductivity is the most important characteristic from the standpoint of wave propagation when signal attenuation is caused by loss of energy in the ground; also, it must be considered in the establishment of an effective power grounding system. Specification limit of ground conductivity for radio receiving and transmitting antenna park areas is that conductivity be not less than 5×10^{-14} emu.

A further discussion of ground constants and two procedures for the measurement of ground conductivity are contained in Appendix V.

(*c*) SPACE AVAILABILITY.—Space requirements for an antenna park will depend on the number, type, and separation of antennas to be provided, with consideration given to station building requirements, isolation requirements, and provision for expansion. Generous provision should be made for space, if possible and within fiscal limitations, not only to provide for future expansion or mobilization requirements, but so as to provide adequate corridor space between antennas and utility buildings and clearance from power lines, roads, fences, etc.

(*d*) SITE ENVIRONMENTAL FACTORS.—The surrounding terrain should be as free as possible from mountains, hills, or other obstructions which tend to shield or deflect the most important low-angle electromagnetic waves used in the conduct of communications. Specification limits for unobstructed wave path is 3 degrees above the horizon for some applications, such as direction finder stations, with 5 degrees being tolerated in some communication activities.

Sites must be so related to one another that link communications may be established and maintained between the various components at reasonable costs. Paths over densely populated areas should be avoided as new construction and noise may severely handicap such communications.

Sites for short range ship-shore communications involving low power ground wave propagation on medium frequencies, VHF and UHF, should normally be located as close as possible to the harbor areas to be covered. In many cases these facilities are not components of a remote Naval Communication Station, but are installed at a Naval Base or Naval Station serving the ships.

Environmental interference to the conduct of radio communications results from the generation of radio-frequency energy by sources in the vicinity of a site which may not be controllable. It consists of radio waves, harmonics, and spurious frequencies from broadcast, amateur, and other transmitters in the area, in addition to the noises generated by residential, and vehicular sources. All this must be carefully measured and evaluated in the determination of site suitability.

A permanent communications facility should have a useful life of 20 to 30 years. The secret of receiver site selection is to stay away from the possible growth areas by using natural obstructions such as swamps, rivers, ocean, etc. Establishment should be where roads to other centers of population are not apt to be built, and above all enough land should be procured to keep highways and power lines from being constructed close enough to constitute major noise hazards.

(2) SITE SURVEYS.—In the initial planning for a new facility, drawings should be made showing relative antenna positions, possible building sites with provision for ample separation between antennas, corridor space around antennas and transmission lines, and indicating minimum separation requirements from other facilities. The drawing should be scaled to fit over topographical maps of the area to be surveyed. Several sites should be considered in this manner taking into consideration surrounding terrain, logistics, and other factors which will influence site selection with the minimum of engineering compromises before starting the survey.

(*a*) GENERAL PROCEDURES.—The planning engineer should visit the sites under consideration during the time that test borings are being made by the Public Works Officer to obtain first-hand knowledge of soil characteristics. This information combined with measurements will facilitate engineering decisions concerning site suitability.

The contour and profile charts prepared by the Public Works Office are to be studied from the electronic viewpoint to determine antenna and transmission line arrangement and control link routes. Engineering sketches are made.

(*b*) FIELD STRENGTH MEASUREMENTS.

1. SIGNALS.—Whether a survey is being conducted for a transmitting facility or radio receiving facility, a determination of the radio reception from a number of fixed stations over wide ranges of distance, azimuth, frequency, and time should be made. When reception is good at a particular area it can be assumed that transmission from that area will also be good. Frequencies to be covered are from 10 kc to 300 mc with emphasis on frequencies that will normally be employed at the facility.

A complete study can be made by arranging for simultaneous measurements taken at two or more sites on transmissions from the same fixed stations so that comparisons can be made for each site against every other site under consideration. This requires considerable coordination and arrangement but will result in accurate determination of the relative merits of all proposed sites from the recorded data obtained.

2. INTERFERENCE.—Sources of interference including harmonic and spurious radiations from other transmitters, as well as ignition and other industrial noises such as power line noise radiation, shall be investigated. This is more important where a receiving site is under consideration, but it is also important where a transmitting station is concerned due to possible effect on control line and emergency receiving applications.

For a receiving facility, the signal level from a non-Navy station shall not exceed ten millivolts per meter, with harmonic or spurious radiations not to exceed five microvolts per meter. (It is assumed here that this type of interference will be confined to narrow bands of frequencies and is not to be confused with wide band, random, man-made interference.)

The noise level (man-made interference and not atmospheric or random galactic disturbances) of a desirable site should not exceed two microvolts per meter in the 10 kc to 140 mc range.

(*c*) PRESENTATION OF DATA.—Appendices III and IV contain report forms for the submission of data on site surveys for transmitting and receiving facilities, respectively.

2-4. COMMUNICATION SYSTEM ENGINEERING.

A shore communication activity is designed to serve the Navy on a service-wide basis in accordance with the Basic Armed Forces Communication Plan (BAFCOM). Provision is made for communication channels,

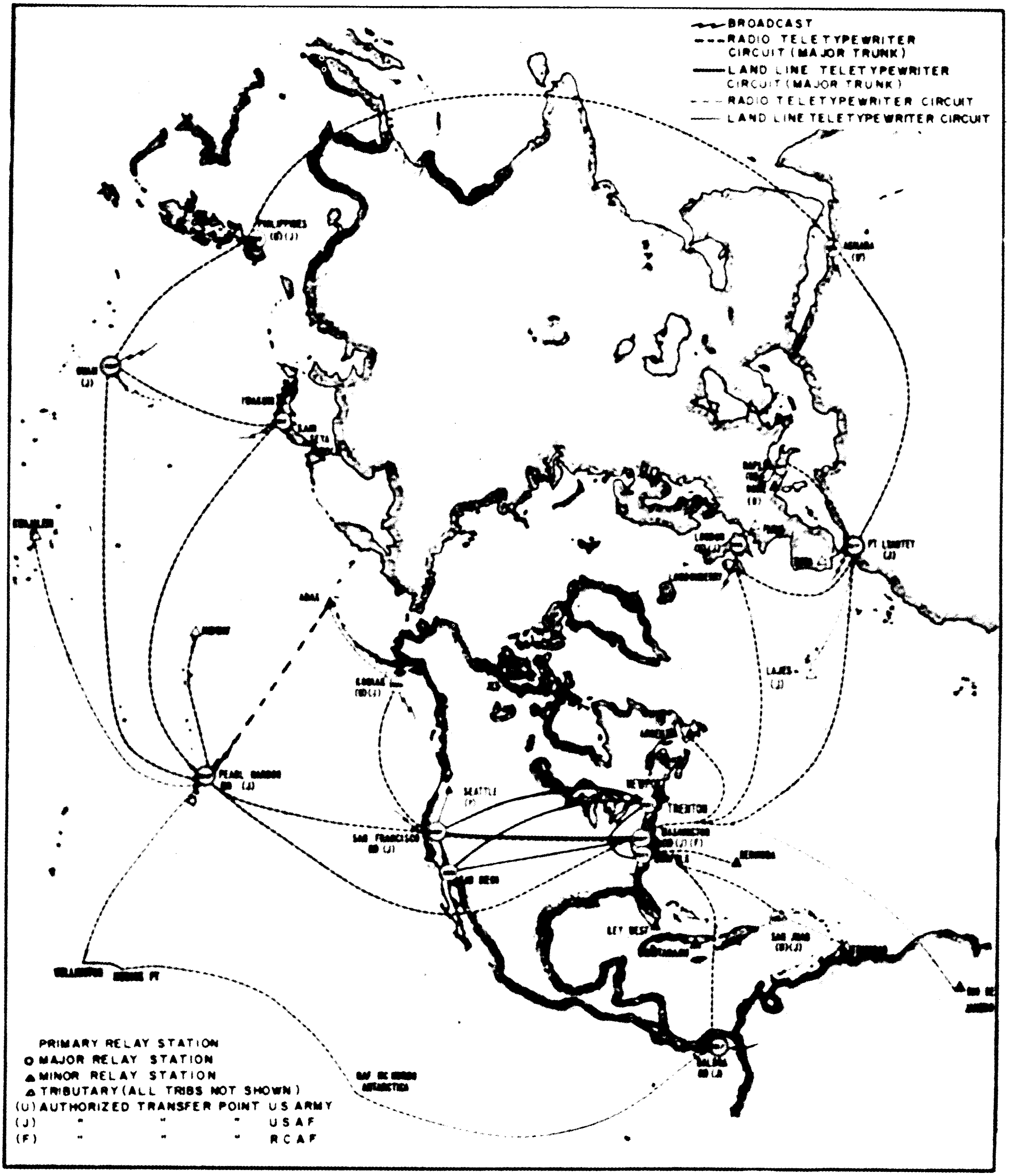


FIG 2-14 U S NAVAL COMMUNICATION SYSTEM

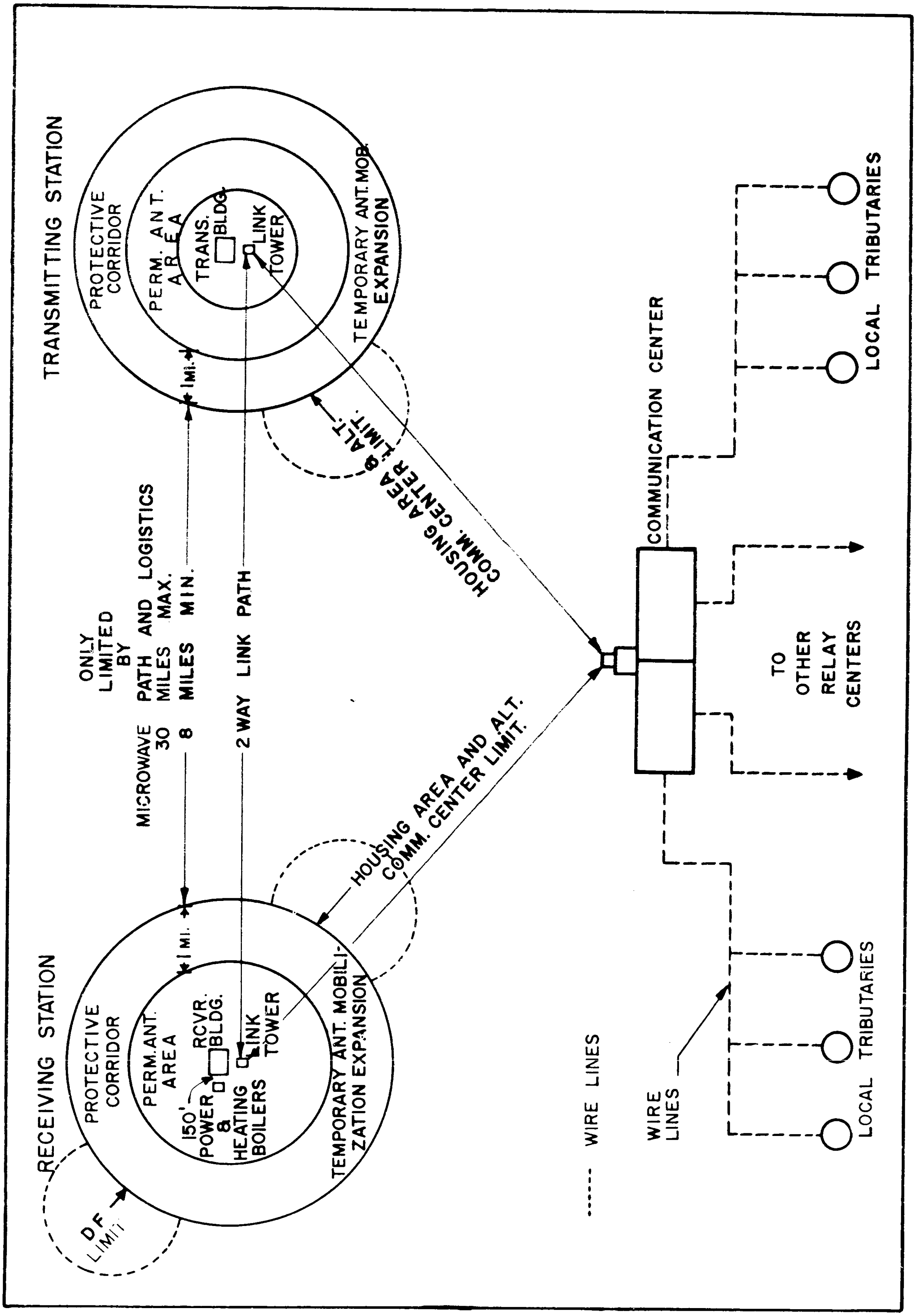
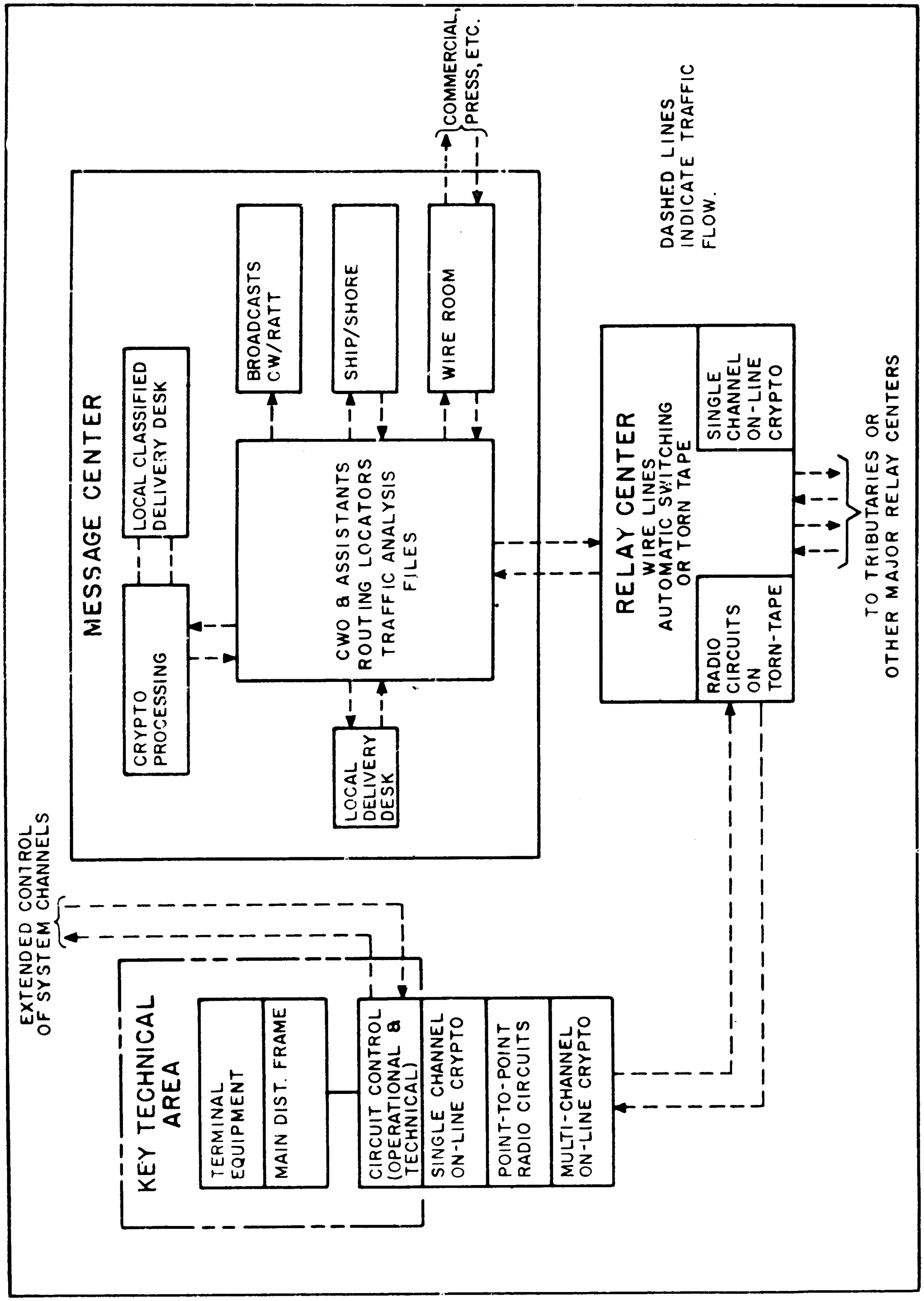


Figure 2-15. Major Communication Station



Figur 2-16. Communication C nt r

circuits, and nets based on the operational requirements of the Naval Establishment as determined and prescribed by the Chief of Naval Operations (DNC). Figure 2-14 depicts the schematic network of the Naval Communication System consisting of Naval Communication Stations and Facilities.

a. THE NAVAL COMMUNICATION STATION.—Communication system engineering involves construction and integration of radio transmitting stations, radio receiving stations, link systems, and communication centers which will provide rapid and reliable radio communications between units of the Fleet and shore, with aircraft, and between shore activities. The complete facility, Naval Communication Station (NAVCOMSTA) or Naval Communication Facility (NAVCOMFAC), is composed of the three component facilities: Transmitting Station, Receiver Station, and Communication Center, which are integrated by control lines or radio links to provide complete communication service to the Fleet in the area of the shore establishment in which it is situated. Figure 2-15 is a block diagram of a typical Naval communication station with its supporting facilities.

The simultaneous operation of multiple communication channels requires careful planning and engineering. Establishment of a new facility, or modification of an existing one, requires careful study of the requirements in order to facilitate the proper selection of components, site selection, and plant development. Total operational requirements of a facility are based on the integration of individual circuit requirements. Individual circuit requirements are determined by the Chief of Naval Operations on the basis of the following:

(1) Type of circuit and terminals.

(2) Frequency(ies) or desired frequency band in mc.

(3) Emission.

(4) Maximum power (for broadcast, the desired coverage).

(5) Hours of operation.

(6) Method of operation based on anticipated traffic load, e.g., Simplex, Manual, DURATT, SSB.

(7) Personnel requirements.

(8) Equipment requirements.

(9) Cryptographic systems and ancillary equipment, if required, dependent upon intended on- or off-line operation.

Each circuit has system requirements which must be analyzed separately from the engineering standpoint covering all pertinent items in the foregoing tabulation, and all systems integrated so as to obtain maximum over-all performance.

b. THE COMMUNICATION CENTER.

(1) FUNCTIONAL COMPONENTS.—The Communication Center is the control activity for the component facilities of the Naval Communication Station. The functional components of the Communication Center are outlined in Figure 2-16 and are defined as follows:

(*a*) MESSAGE CENTER.—The message center is the hub of operations. Here the ship locators and routing information is currently maintained for proper routing of traffic in the system. Traffic originating locally, or for local delivery, or interchanged between ship-shore and the relay system, is routed via the message center for checking and routing. Radio broadcast and ship-shore circuits, both RATT and C.W., wire line teletype circuits, other than tape relay, and crypto processing are considered an integral part of the message center operations, and are conveniently located to facilitate the passing of messages.

(*b*) TECHNICAL CONTROL CENTER.—The technical control center provides for technical control of the circuits in the communication center. Patchboards terminate lines to remote transmitters and from remote receivers as well as drops to the equipment located within the center. This provides flexibility so the control supervisor can make substitutions, by patching, in case of circuit outage, to restore service, and maintain operation. Due to the relationship to the on-line crypto equipment in operations, OPNAV has directed that this facility be located in the on-line crypto spaces. CSPM 1, 1-34 (REV) 1 November 1959 must be complied with.

(*c*) RELAY CENTER.—The relay center exchanges teletype traffic between other relay centers, its tributaries, and all the elements comprising the communication center. This process utilizes perforated tape for receiving and re-transmitting. "Hard copies" are not required except as monitor copies on receive point-to-point radio circuits as a circuit supervisory device. The relay functions may be accomplished by the use of automatic switching equipment, in which the traffic is routed automatically according to the routing indicators, or by torn-tape equipment in which all traffic must be processed manually for re-transmission. Equipment and maintenance services for the automatic switching system will normally be leased, with the Navy furnishing operating personnel. Provisions are to be made in the relay center for the future installations of single channel on-line cryptographic equipment on individual channels.

(*d*) SUPPORT FACILITIES.—Support facilities are required to maintain the operating facilities.

These include administrative, technical repair, supply, and storage.

(2) OPERATIONAL REQUIREMENTS.–Operational requirements are established by Chief of Naval Operations for the communication station as a whole. Minor additions may be made necessary by local command requirements. The total requirements are then converted into technical requirements for each facility comprising the communication station. The communication center must be of sufficient size to accommodate equipment, control facilities, and personnel to fulfill the mission of the communication station. In planning a new communication center the following factors must be considered in order to insure the ability to meet the mission.

(*a*) SITE SELECTION.–The selection of a site is governed by several considerations: removal from target area, housing, logistic support, and proximity to transmitting and receiving facilities with consideration given to establishment of link systems if required.

(*b*) EQUIPMENT AND SYSTEMS.–Most equipment requirements at a communication center consist of terminal equipment with criteria for its selection and installation discussed under Paragraph 2-5, TERMINAL SYSTEMS. Distributing frames and patching facilities are discussed in Paragraph 2-15, INSTALLATION PRACTICES. A block diagram of a typical send-receive system is shown in Figure 2-17 with a detailed description given in Paragraph 2-5, TERMINAL SYSTEMS. A standard distribution frame is shown as Figure 2-18. Other equipment such as receivers and transmitters for emergency use are selected and installed to meet local requirements.

(*c*) BUILDING REQUIREMENTS.–Figure 2-19 is provided to assist the project engineer in advance planning toward development of a communication center. No fixed plans could be conceived that would fit all requirements and each project must be engineered to meet local conditions. Building features which are common to all communication centers are included in the following:

Construction. The building is windowless, of concrete or masonry, with a full basement, one story unless a Security Activity is included when a second story will be provided. Operating spaces should be free of support columns to provide maximum flexibility in equipment installation. It has been determined that a 32-foot width, free of columns is the minimum acceptable to accommodate equipment layout in the Communication Center spaces.

Partitions. Permanent wall construction is permissible in administrative and utility spaces but partitions within operating spaces should be designed for easy rearrangement and free of electrical or heat control wiring.

Flooring. Cellular flooring should be used in all equipment spaces with access to raceways, cable trenches, and wiring passageways, except floors laid on the ground below grade. If, however, no alternative is possible, cable trenches below grade must have waterproof membranes between the slab and earth, and be provided with sumps and automatic pumps.

Main Frame. All control wiring terminates in the "Main Frame." This includes exterior control lines (link), patch panels, equipment, and operators' positions wiring.

Air Conditioning. Air conditioning equipment is installed in the basement or suitable space adjacent to the building as determined by local factors, with provision for adequate ventilation.

Power. Equipment power requirements with consideration of heat dissipation will be furnished to Public Works so that total power requirements can be provided. Emergency power must be available and is generally provided for in an adjacent building with diesel operated equipment. Terminal equipment will operate satisfactorily from a 120/208 V ±10%, three-phase, 60 cycle ±2%, four-wire distribution system. Requirements for power factor, panel locations, and circuit capacities will be furnished. Where use of on-line crypto devices are required the following criteria shall govern selection of "No-Break" power units:

No-Break Power. Purpose: The use of communications transmission devices requires an A.C. power supply that can never fail for more than one cycle and the voltage can never drop to less than 80% of normal.

The no-break power shall not allow an interruption of the A.C. power for longer than one cycle. An interruption, for purposes of this paper, is defined as any abnormality on any or all phases of the input power. An overvoltage of 10% or an under voltage of 20% is to be considered as an abnormality. A short circuit on one or all phases or an open circuit on one or all phases or any combination of the above will be considered as an interruption.

The no-break power unit shall be rated 120/208 volts, 60 cps, three phase, four wire. Frequency regulation shall be plus or minus 0.5 cycles per second. Voltage regulation of plus or minus 2%. The voltage shall return to the regulated value in 5 seconds or less. Voltage shall never drop to less than 80% of nominal. The frequency shall not drop to less than 58 cps during transition and must return to 60 cps

NOTES:

1 LONG DASH LINES DEFINE ROOM OR BUILDING

2 CLR = CLEAR LANGUAGE

3 ENC = ENCRYPTED LANGUAGE

4 MF = MAIN DISTRIBUTING FRAME.

5. IDF = INTERMEDIATE DISTRIBUTING FRAME

6 C-IDF = CLASSIFIED INTERMEDIATE DISTRIBUTING FRAME

7. PRI TST = PRIMARY TEST BOARD

8. SINGLE CHANNEL EQUIPMENT SHOWN IS TO BE FUTURE INSTALLATION

9. L/L = LAND LINE

10. MAY BE LAND LINE OR LINK.

11. NUMBERING SYSTEM FOR IDENTIFICATION AND LOCATION IN CORRESPONDENCE OR OTHER REFERENCES.

12. 16 CHANNEL AND SINGLE CHANNEL RELAYS ARE INTERIM MEASURE ONLY WILL REQUIRE SPECIFIC APPROVAL OF BU SHIPS AND CNO OPNAV NOTICE 02221 OF 15 DEC 1959 APPLIES

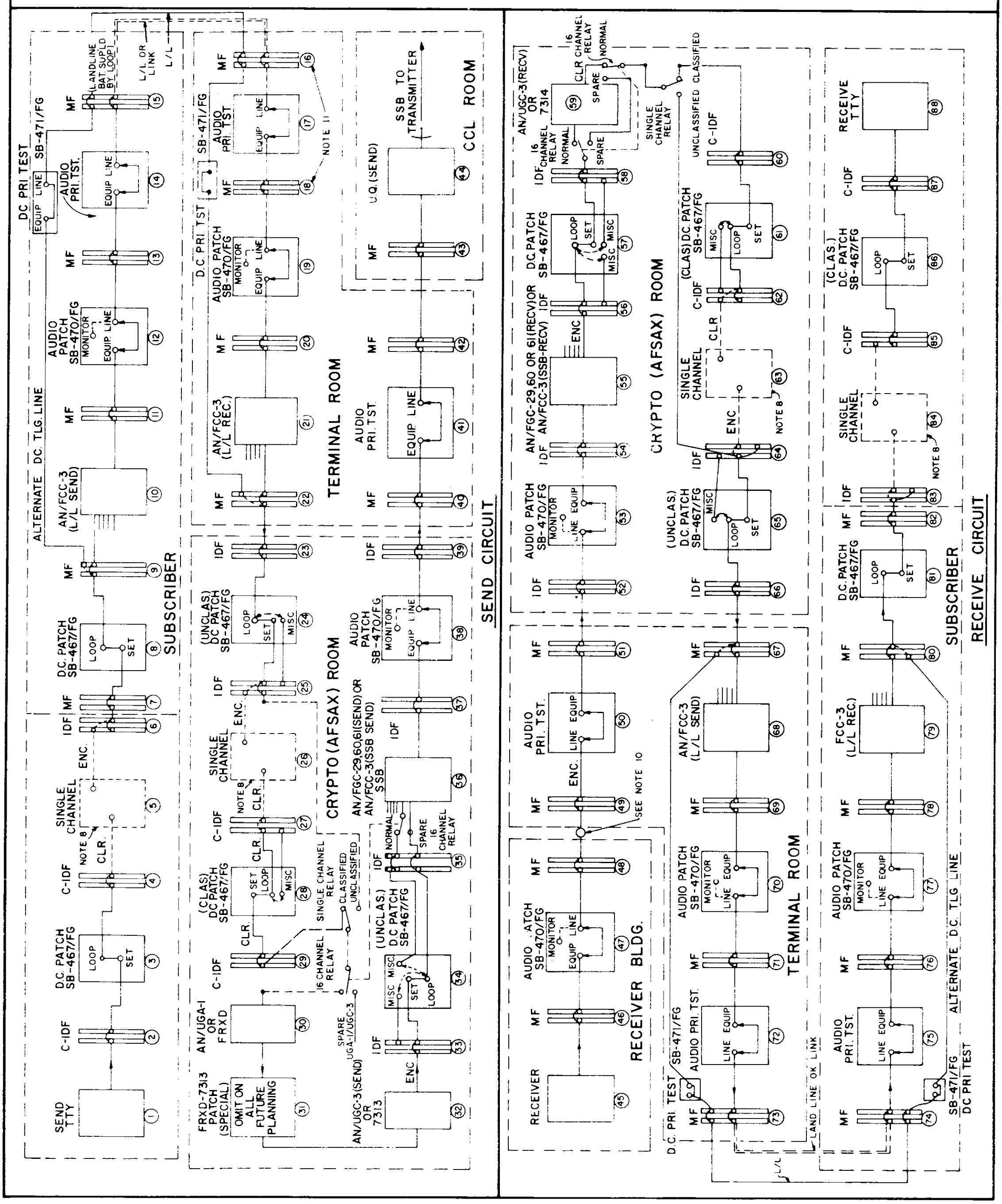
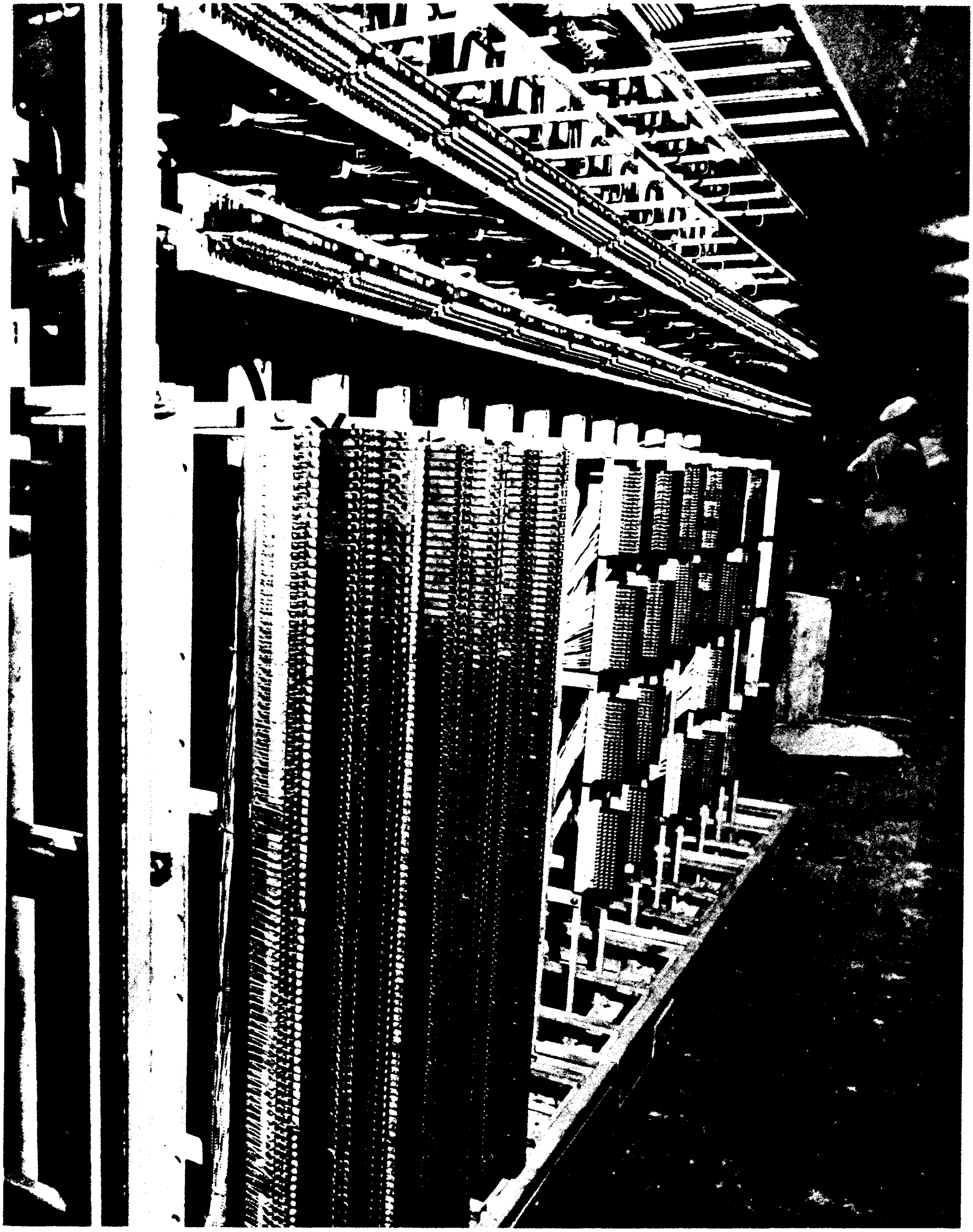
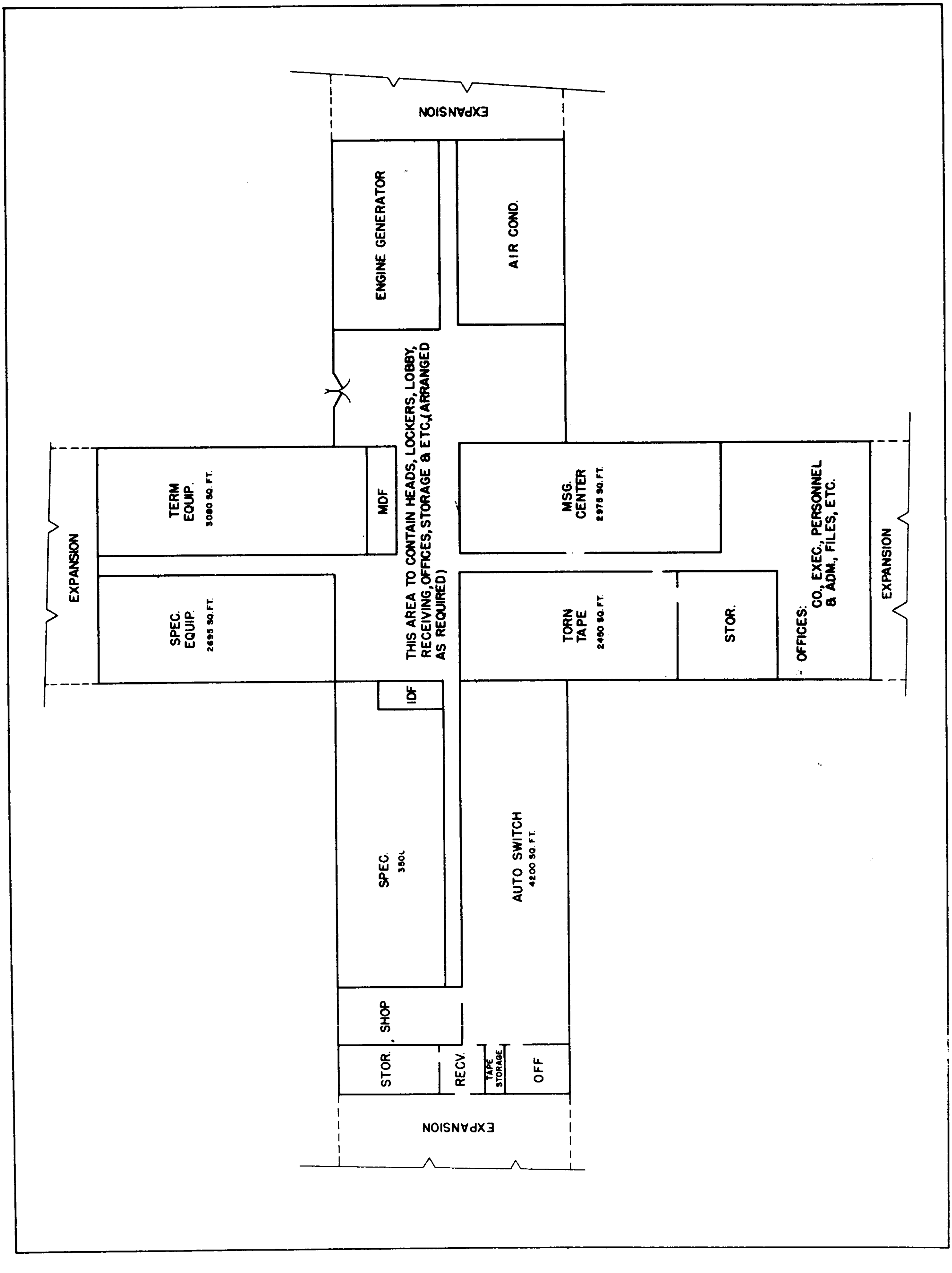


FIG. 2-17 TYPICAL COMMUNICATION SYSTEM, BLOCK DIAGRAM





Figur 2-19. Proposed Typical Layout f r Communication C nter

in 15 seconds or less.

Electronic Repair. Facilities are to be provided for equipment maintenance and repair. Standard teletype maintenance equipment, signal generators, oscilloscopes, and measuring devices used in receiver and control line maintenance, power and hand tools, along with work benches as required, and maintenance parts stowage are included in the maintenance facilities. The quantity of maintenance equipment will be determined from the equipment requirements and a recommended allowance submitted in accordance with current directives.

(*d*) BUILDING LAYOUT.–Obviously, a single building design or layout will not satisfy the requirements of all communication centers. The arrangement must then be determined by individual requirements, but following typical plans as closely as possible. It is the responsibility of the operating authorities to plan the arrangement by laying out the spaces previously discussed, according to the traffic flow. The technical authorities will plan the electronic equipment layout, following type plans and other available criteria, and by mutual cooperation develop the final arrangement plans for submission.

(*e*) ANTENNAS AND ANTENNA ARRANGEMENT.–Local requirements will determine what antennas are required and what antenna arrangements are best suited for installation at the communication center. Transmitters and receivers within the center are generally for emergency operation but may have application for local harbor circuits. VHF/UHF antennas may be mounted on the roof or on a tower or poles.

(*f*) CONTROL LINES AND LINK EQUIPMENT.–Transmitter and receiver controls are required as functional facilities to fulfill the operational requirements of the Communication Center. Lines or links performing these functions are defined as the communication channels and circuits which supply intelligence between the communication centers and transmitting-receiving facilities, as well as providing for control of frequency and other operating variables of transmitters and receivers. Provision for such control lines, for entry into the building, for main frame connection, for distribution, and for operational and maintenance equipment requires serious consideration under system engineering. Criteria are contained in 2-5, TERMINAL SYSTEMS. Where radio links are to be provided, tower and building construction may be required as discussed in 2-6, RADIO LINK SYSTEMS, with criteria for engineering of the link route contained in Appendix VI.

c. THE TRANSMITTING STATION.

(1) OPERATIONAL REQUIREMENTS.–Once the proposed construction of a new transmitting facility or alteration of an existing facility has been firmly established as a project to meet an operational requirement, engineering to meet the requirement is started by the Bureau of Ships. A transmitting station must provide all the facilities needed for the transmission of radio signals over the circuits that have been prescribed by the Assistant Chief of Naval Operations (DNC). Circuit requirements are listed by circuit number and frequency in the current edition of Janap 195, or are described in an "operational requirement" letter by ACNO (DNC). The first step in plant development is the interpretation of the operational requirements in terms of the number and type of transmitting systems required and provision for the integration of all systems into a properly functioning facility.

(2) PLANT DEVELOPMENT.

(*a*) SELECTION OF EQUIPMENT AND SYSTEMS.–Equipment selection to meet the system requirements of a transmitting facility is made by the Bureau of Ships which provides a recommended list of equipment with its estimated cost to the Management Bureau of the facility to be established. Installation costs are also estimated by the Bureau of Ships for preliminary planning with final cost estimates being provided by the cognizant Industrial Manager. Equipment lists will include transmitters, keyers, and other modulating or control units which are not integrally part of the transmitter, test and monitoring equipment, transmitter control patching units, main frame, telegraph terminals, and equipment required for switching or patching the transmitters to various antennas, as well as antenna tuning equipment to be installed in the remote "helix house(s)." Link equipment may be included separately in a list of microwave system requirements. Standard practice dictates that an extra transmitter of each type be installed for every five operating units; the extra unit to be used in rotational maintenance. An exception to this may be in multichannel or other equipment having limited application where duplicate installations are made. Table 2-5 lists standard power designations for transmitters.

TABLE 2-5. STANDARD TRANSMITTER POWER DESIGNATIONS

Power	*Designation*	*Range*
Low	LP	Under 1 KW
Medium	MP	1–5 KW
Medium high	MHP	5–20 KW
High	HP	20–50 KW
Very high	VHP	Above 50 KW

(*b*) SITE SELECTION.–Of the factors discussed in Section 1 of a site for a radio transmitting station, system engineering is principally concerned with the "fundamental suitability of the site for radio transmission." A sample survey report form is contained in Appendix III. This will enable the project engineers to determine factors pertaining to fundamental suitability and to make engineering decisions regarding site selection, bearing in mind the overwhelming importance of antenna construction and environmental factors affecting their performance. After the over-all land area requirements are determined by methods outlined below, topographic maps of the area are used to determine several sites which appear to be relatively flat, sparsely inhabited, large enough, and with intervening terrain suitable for microwave connections to the receiver station and communication center. See Figure 2-15.

(*c*) ANTENNAS AND ANTENNA ARRANGEMENT.–First consideration in the development of a transmitter site must be given to antennas. Preliminary engineering includes the selection of a type of antenna most suitable for each operating circuit, preparation of an antenna layout which takes into account antenna orientation, proximity to other antennas, and the "foreground," particularly for beam antennas. Consideration must be given to the location of antennas in relation to the transmitter building, so as to keep feedlines short. Open wire transmission lines should not exceed 2000 feet in length and buried coaxial cables should not exceed 1000 feet. The final arrangement will result in an antenna layout in a rosette pattern with the transmitter building in the center, rhombic antennas on the periphery, and omnidirectional antennas inside the rhombic circle. Figure 2-20 shows the layout of a typical transmitter station.

It is customary to consider first all circuits for which there are requirements for rhombic antennas. Consideration of frequency range and power handling capability as well as orientation is necessary to achieve maximum effective radiation from the rhombic antennas. Sketches and scale models will assist the engineer in preparing an antenna layout.

Other high frequency antennas of the omnidirectional types (doublets, sleeves, conical monopoles, etc.) can be arranged between rhombics and inside the rhombic circle. Erection of three or four 300-foot self-supporting towers around the transmitter building will provide support for medium power MF and LF antennas. Each high-power low-frequency transmitter will require a 800-foot vertical radiator with radial ground system 2000 feet in diameter. The Bureau of Yards and Docks has the responsibility for structural design and construction of all buildings and antennas to conform to electronic engineering requirements of the Bureau of Ships.

(*d*) TRANSMISSION LINES AND MATCHING.–The radio-frequency energy supplied by transmitters to the radiators is normally carried on overhead 600-ohm standard transmission lines or buried 75-ohm coaxial cable. When the point of feed to an antenna type differs from 75 or 600 ohms, matching arrangements must be designed to minimize standing waves along the lines. In HF applications this is usually accomplished with matching stubs at the antenna end of 600-ohm transmission lines, tuned couplers or "line flatteners" in coaxial systems, or other arrangements as discussed in Paragraph 2-3*b*.

Low frequency transmissions are carried on a standard 600-ohm line with matching at the antenna accomplished in the "helix house" by means of a coupling arrangement to balance out reactance. The helix house components are provided as part of the transmitter contract and are described in detail in the technical manual which accompanies the low frequency transmitter.

(*e*) ANTENNA SWITCHING.–A well-engineered transmission line switching system is an important requisite in transmitting stations, if best utilization of equipment and antennas is to be achieved. The frequent changes in working frequency over a given circuit during the day, together with changes in traffic capacities, place demands of versatility on the installations. In general, the degree of complexity of the switching system increases rapidly with increased flexibility; therefore, the goal should be one of limited flexibility which is tailored to meet operational requirements. Other important considerations which add to the general complexity of switching schemes include the requirements for maintenance of regularity in characteristic impedances of the lines, retaining balance of lines to ground, and preventing any dead-end sections of line from appearing across active circuits.

Although the stacked-boom switch presently being used suffers certain limitations, such as the inability to switch one circuit while others are active without danger to personnel and equipment, it also has many advantages: it is electrically sound, it is mechanically simple and rugged, a large number of different combinations of transmitters and antennas is possible, and, most important, adequate spacing of lines can be maintained throughout to prevent coupling between equipments.

Bureau of Ships Drawing RE 24 F 185 shows a Mare Island indoor type antenna selector

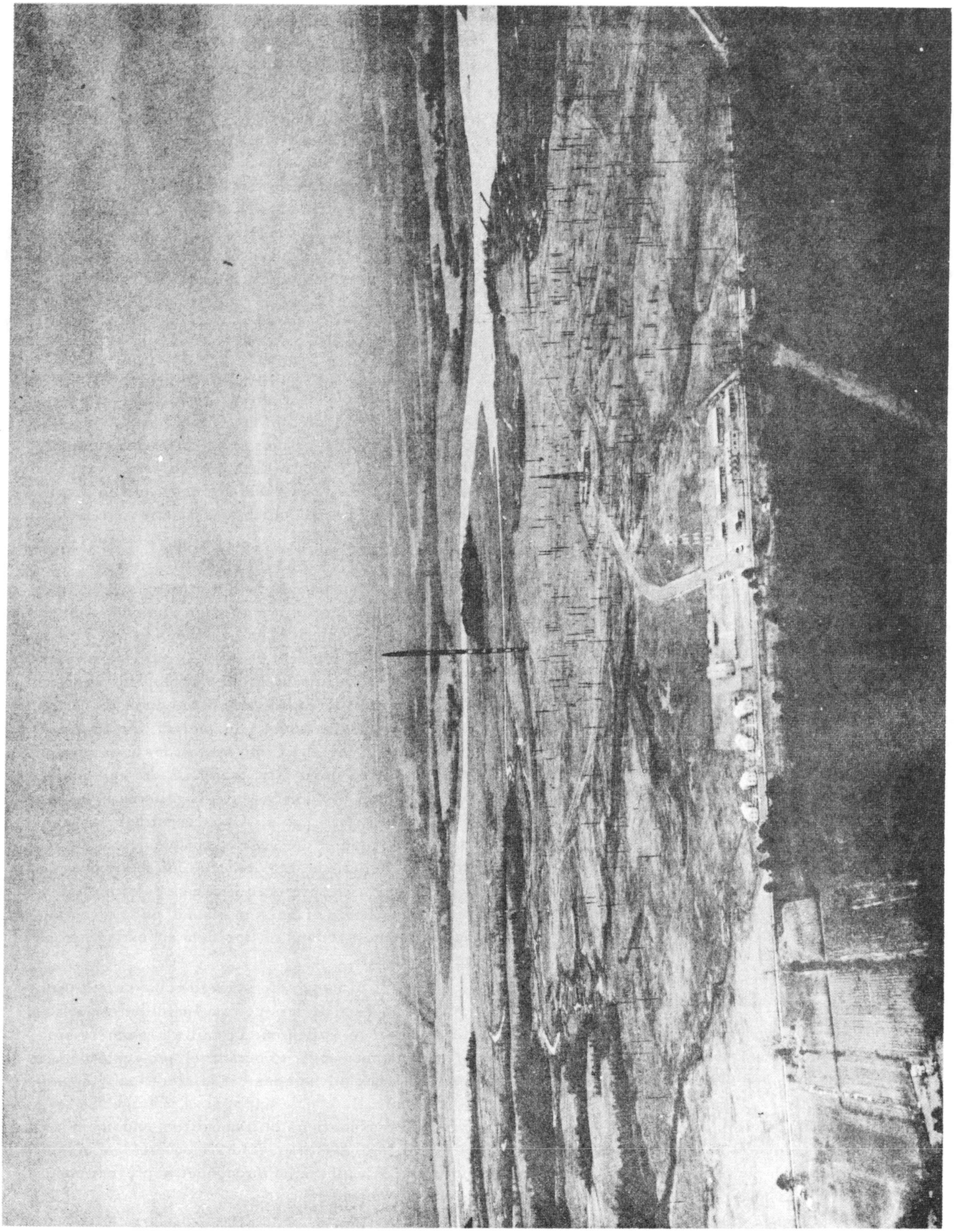


Figure 2-20. *Radio Transmitting Station*

switch for a 600-ohm balanced transmission line. Drawing RE 24 F 2005 shows the stacked boom type outdoor switching station which can accommodate transmission lines from six different transmitters. A typical outside switching arrangement is shown in Figure 1-2.

In systems using 75-ohm coaxial feed to antennas a number of switching systems, both automatic and manual, have been devised. One of these is a manual system consisting of physical patching with "U" shaped patch links and allows patching any transmitter to any antenna in a 7 by 7 system, maintaining a 75-ohm system impedance. For applications of frequent circuit change, automatic switching systems may be employed. Both systems are free of stubs or line discontinuities and present negligible insertion loss.

(*f*) BUILDING REQUIREMENTS.–The transmitter building is normally located in the center of the antenna field. The construction site should be so chosen and the building so oriented as to allow the maximum number of transmission line entrances to the building with the shortest length of antenna transmission line runs.

The general design of transmitter buildings has been standardized over the years to a structure of windowless reinforced concrete, rectangular or "T" shaped in outline. The transmitter room of the standard transmitter building is 50 feet in width and its length is comprised of 20-foot sections, each providing 1000 square feet of floor space, to a maximum length of 200 feet (20,000 square feet). In the event that more than 20,000 square feet of transmitter floor space is required to meet operational requirements the building design may be changed to a "T" shape by the addition of a third wing 50 feet in width and 100 feet (maximum) in length. The T shaped building is not suited to an orderly arrangement of open wire (600-ohm) antenna transmission lines, but may be used to advantage when part of the antenna distribution is by coaxial cable. Consideration should be given to the construction of two separate rectangular transmitter buildings instead of one large "T" shaped building to utilize more effectively the available land areas for antenna fields.

It must be kept in mind that transmitter building construction costs vary from a low of approximately $27.00 per square foot for continental construction, to $34.00 or more for overseas construction. Therefore, building space must be allotted to electronic equipment and ancillary apparatus only. The inclusion of large administrative areas or recreational spaces is not to be condoned. If these facilities are required, they should be provided by other buildings on the station where, due to a different type of construction, cost per square foot is lower.

Transmitter building space will consist of the transmitter equipment floor area, a full basement, and a "head house." The "head house" will house terminal equipment, link facilities, electronics repair shop, electronics parts stowage, and a small administrative office. The purpose of the head house is to isolate the terminal equipment and link equipment from any local radio-frequency fields in the transmitter room, provide a repair shop and small parts stowage close at hand for equipment maintenance and provide a modest area of administrative office space. The basement area of the head house will generally be used for the heating, air conditioning, and dehumidification equipment.

A loading platform and large double doors should be installed in each end of the main equipment room to provide a means of bringing in transmitters or large maintenance parts. The basement area under the main transmitter floor will contain the power and control cable trays suspended from the overhead and hangers for the distribution of coaxial antenna cables. The depth of the basement should be such as to allow a six-foot, two-inch clearance between the basement floor and the bottom of the lowest overhead cable tray. Basement areas may be used for equipment stowage as well as for the installation of heavy transmitter components such as plate transformers, voltage regulators, etc.

Provision must be made for a basement opening to facilitate the unloading of large equipment items. Ramp construction to accommodate large trucks or a suitable crane arrangement for handling heavy components may be utilized for this purpose.

Temperature and Humidity Control. Air conditioning will be required to suit climatic conditions of the applicable weather zone. The air conditioning system must be capable of handling the complete transmitter building with all equipment in operation. It should be designed to maintain a temperature not higher than 80 degrees F. at a constant relative humidity of not more than 50% at the air intakes to the transmitting equipment. Its design should employ recirculation of the building air with a provision for discharging approximately 20% to the outside with 20% intake of of outdoor air. The outdoor air intake must be well filtered to remove dust.

The capacity of the system will be determined by the above criteria and the total amount of heat dissipated in the building. Heat dissipation of the transmitting equipment may be calculated by subtracting the sum of transmitter power outputs in kilowatts from the total building power load.

In the temperate as well as frigid zones of the world, a heating system will generally be required. Although transmitting equipment while in operation liberates large quantities of heat, some areas will require an extensive heating system to maintain a minimum room temperature of 60 degrees F. within the equipment spaces. The detailed design of a heating and cooling system is a responsibility of the Bureau of Yards and Docks.

Wiring and Cabling. Power and control cables between transmitters and associated equipment are carried in cable trays suspended from the basement overhead. The trays are of expanded-metal construction and are arranged in two tiers with one tray used to carry power cabling, and the second to carry control cables. The cable trays run the length of the building in four rows under the rows of transmitting equipment. The first floor slab is pierced with four rows of 6-inch sleeves on two-foot centers. Each sleeve is fitted with a temporary wood filler covered with cement grouting and is provided as part of the building construction. To use the sleeves, the grouting is chipped out, the wood knock-out is removed, and cables are passed through the sleeve opening between cable trays and transmitters.

A main distribution frame (MDF) for control circuits is required in each transmitter station. The MDF should preferably be located in the head house area, should be placed out of the way of other equipment, and sufficient space should be allowed to gain easy access to all sides of the frame.

The construction of the main distribution frame is based upon the telephone system concept wherein the frame is open construction with all incoming cables entering on lug and lug vertical terminal blocks with protector block heat coil protection assemblies in the circuits from outside cable plant. For microwave link circuits, protector block assemblies are not required. In general, external cables are terminated on vertical blocks on one side of the frame, with interior "house" cable pairs terminated on the opposite side, which may use either horizontal or vertical blocks depending on the type of frame used.

All equipment control pairs, inputs and outputs must terminate on the frame via house cable with interconnections made by cross-connecting done at the frame. The MDF concept will require an expanded cable system in the transmitter plant over the type of system which does not use a frame. However, use of an MDF prevents deterioration of the plant wire system over the years due to discouraging the use of temporary hookups between equipment. Standard procedure is to make all wire changes at the main frame. Records are simply maintained.

Bonding and Grounding. Provision is made for equipment grounding for personnel protection and to reduce strong radio-frequency fields. (See Paragraph 2-16.) As a part of the standard transmitter building construction (by BUDOCKS) a grounded copper mesh is placed on or embedded in the first floor slab and is connected to earth through driven ground rods on 20-foot centers around the building perimeter. The intent is to provide a low impedance ground plane and Faraday screen immediately beneath the transmitting equipment so that the cabinets of operating transmitters will not be "hot" with radio frequency voltages. (See GROUNDING CRITERIA, 2-16.)

Lighting. Fluorescent lighting with grounded shielding. Determined by the Bureau of Yards and Docks.

(*g*) EQUIPMENT LAYOUT.–The following items are not rigid specification requirements, as each facility must be engineered to meet local conditions.

1. TRANSMITTERS.–Each facility is engineered to provide a specific number of transmitting systems. Each system includes an antenna which is located in a precise position with respect to the building to most effectively serve the system. The transmitter serving that system should therefore be located so that its feeder (transmission line) will reach the antenna with the shortest path possible consistent with patching flexibility and with a minimum of crisscrossing of transmission lines of other systems. This requires careful engineering and must be included in the original antenna plot planning as well as the system selection of equipment. It also precludes the location of all transmitters of each type in one locality because adjacent systems may have widely divergent power and frequency requirements. Consideration must also be given to alternate and maintenance standby equipment where change-over can be effected with the minimum disruption of system utility. Equipment is generally spaced three feet apart as a standard spacing based on studies of space required for operation and maintenance.

2. ANTENNA SWITCHING.–Antenna switching arrangements within the building should be engineered for maximum flexibility with a minimum of transmission line crossings.

3. TRANSMITTER CONTROL.–A central control area is provided for operating control of all transmitters. It contains a control console and patch panels with monitoring and measuring devices conveniently installed. Indicating lights which show on-off and keying indication are provided for all transmitters.

RF pick-up arrangements are available for frequency measurement with audio output at the transmitter. An audio signal generator and oscilloscope provide facilities for frequency shift adjustment or other uses as required. Teletype equipment is provided for monitoring purposes and order wire between Transmitters and Communication Center. Service telephones to the Receiver Station and Communication Center are additional facilities provided to augment transmitter control.

4. MAIN FRAME.–All control wiring goes to the "Main Frame" with a "Frame Room" generally provided in the "Head House." This wiring includes that to the equipment, control console, and CCL or outside control lines to other facilities. At larger transmitting stations this means that the main frame becomes quite large, but standard design has made it possible for rapid changes in control arrangements to be effected with a minimum of effort, which assists the station to maintain the plant wire system in the most efficient manner.

5. POWER DISTRIBUTION.–In general, power to the equipment at many stations now in operation is supplied from a central power panel where switches and circuit breakers for all equipment are located. Power is brought into the building from a sub-station located outside the building area with provision for separate supply for equipment.

(*h*) POWER REQUIREMENTS.–The project electronic engineer furnishes Public Works with total equipment power requirements for operation and heat dissipation in order that total power requirements including utilities can be computed and the power provided. The construction agency provides primary, alternate, and emergency power as described in 1-5, Section 1.

(*i*) MAINTENANCE AND TEST FACILITIES.–A repair shop must be provided and equipped with work benches, power, and hand tools in sufficient quantity to effect routine maintenance and repair. Standard test equipment is to be included in the allow-

This replaces Paragraph 2-16, GROUNDING CRITERIA.

2-16 GROUNDING CRITERIA.

a. General.

(1) Safety

(2) Interference

(3) Propagation

ance list. Standard bin storage is arranged for "parts peculiar" and "parts common," and a plant account system set up, normally contiguous to shop space.

(*j*) PLANS AND SPECIFICATIONS.—The development and construction of a transmitting facility requires plans, drawings, and specifications as outlined in 2-2.*a.*(4), SYSTEM PLANS. Broad building requirements and details of construction to fit equipment layout are provided by the Bureau of Ships in letter form along with line drawings to enable local electronics authorities in collaboration with Public Works to prepare details which will result in detailed design drawings and specification blueprints. Experience has shown that firm plans that will hold for the duration of construction and installation are the exception because of the time lapse between conception and ultimate turnover of a facility to Management. However, careful planning will minimize changes and result in the most economical facility development.

d. THE RADIO RECEIVER STATION.

(1) OPERATIONAL REQUIREMENTS. — Construction of a new radio receiver station, or the alteration of an existing station, is a result of the operational requirement which prescribes the establishment of facilities for the reception of radio signals on a number of circuits and channels. Each circuit or channel will require a radio receiving system consisting of all necessary components including antennas, receivers, link, and terminal equipment to insure delivery of messages to addressees. The first step in plant development therefore consists of the interpretation of the operational requirements in terms of the number and type of systems required and provision for the integration of all systems into a properly functioning facility.

(2) PLANT DEVELOPMENT.

(*a*) SELECTION OF EQUIPMENT AND SYSTEMS.—Equipment selection to meet system requirements of a receiving facility is accomplished by the Bureau of Ships which also indicates unit and total cost of such equipment to the management bureau of the facility to be established. Installation costs may be estimated by this Bureau or by the office of the Industrial Manager who exercises technical control of the electronic equipment. Equipment will include receivers, frequency shift converters, multicouplers, operating tables, monitoring equipment, major test units, and control equipment including AF/RF distribution panels. Link equipment cannot be overlooked in receiver station planning but may be included separately in a list of microwave system requirements. Standard practice dictates that an extra unit of each major component be installed for every five operating units; the extra unit to be used for operational maintenance.

System selection is an engineering problem which consists of the proper arrangement of equipments into systems which will provide optimum accomplishment of the operational requirement. A block diagram of a typical receiving system, which includes terminal equipment, is shown in figure 2-17. Similar block diagrams shall be made for each system to enable all systems to be integrated and total equipment requirements to be established.

(*b*) SITE SELECTION.—Of the factors discussed in Section 1 of a site for a radio receiver station, systems engineering is principally concerned with the "fundamental suitability of the site for radio reception." A sample survey report form is contained in Appendix IV which will enable the project engineer to determine factors pertaining to fundamental suitability, and to make engineering decisions regarding site selection. See site selection under 2-3, ANTENNA/TRANSMISSION LINES, for further details.

Radio receivers and measuring equipment must be provided at the various sites under consideration, and this survey conducted as thoroughly as time permits.

Once a site has been determined as being suitable for the reception of signals, other factors including antenna and building space requirements, logistic factors, and proximity to other facilities with which it will be integrated (communication center and transmitters), as well as isolation from sources of interference, will be determined so that engineering development can proceed.

As shown in figure 2-15, the area requirements and facility arrangement will provide a receiver building in the center of the area with permanent antennas arranged in a circle surrounding this building. A protective corridor is prescribed outside of the antenna park with housing, utilities and administrative facilities located on or near the outer boundary of this corridor. When a HF/DF facility is present, its location should also be on this circle but on the opposite side from utilities, so as to provide proper isolation.

Of major importance in site selection is to give consideration to the link paths which are required to connect this facility with transmitters and communication centers. (See criteria under 2-6, LINK SYSTEMS, and Appendix VI.)

(*c*) BUILDING REQUIREMENTS.—The receiver building is the heart of a receiving facility, located in the center of the antenna park and remote from all other buildings included in the activity. The receiver building is usually a two-level structure unless a Supplementary Activity is to be served. Provision is then made for a third level (second floor) to furnish

NOTES:

1. ALL PARTITIONS (EXCEPT THOSE AROUND HEADS, DUCTS, FRAME, ROOMS, STAIRWELLS & CABLE PASSAGEWAYS) ARE TO BE OF A MOVABLE TYPE.
2. CONTROL CABLES # 1 & 2 TO BE SUITABLY TERMINATED IN LOCKED CABLE TERMINATION BOX AS SHOWN. CONTROL CABLE # 3 TO BE SUITABLY TERMINATED IN LOCKED & SHIELDED BOX AS SHOWN.
3. BINS IN BOTH REPAIR PARTS READY STORAGE TO BE PROVIDED IN ACCORDANCE WITH BUSHIPS INSTRUCTIONS 10550.30 DATED 15 APRIL 1954 & BUSHIPS DWG. RE CF 22:9.

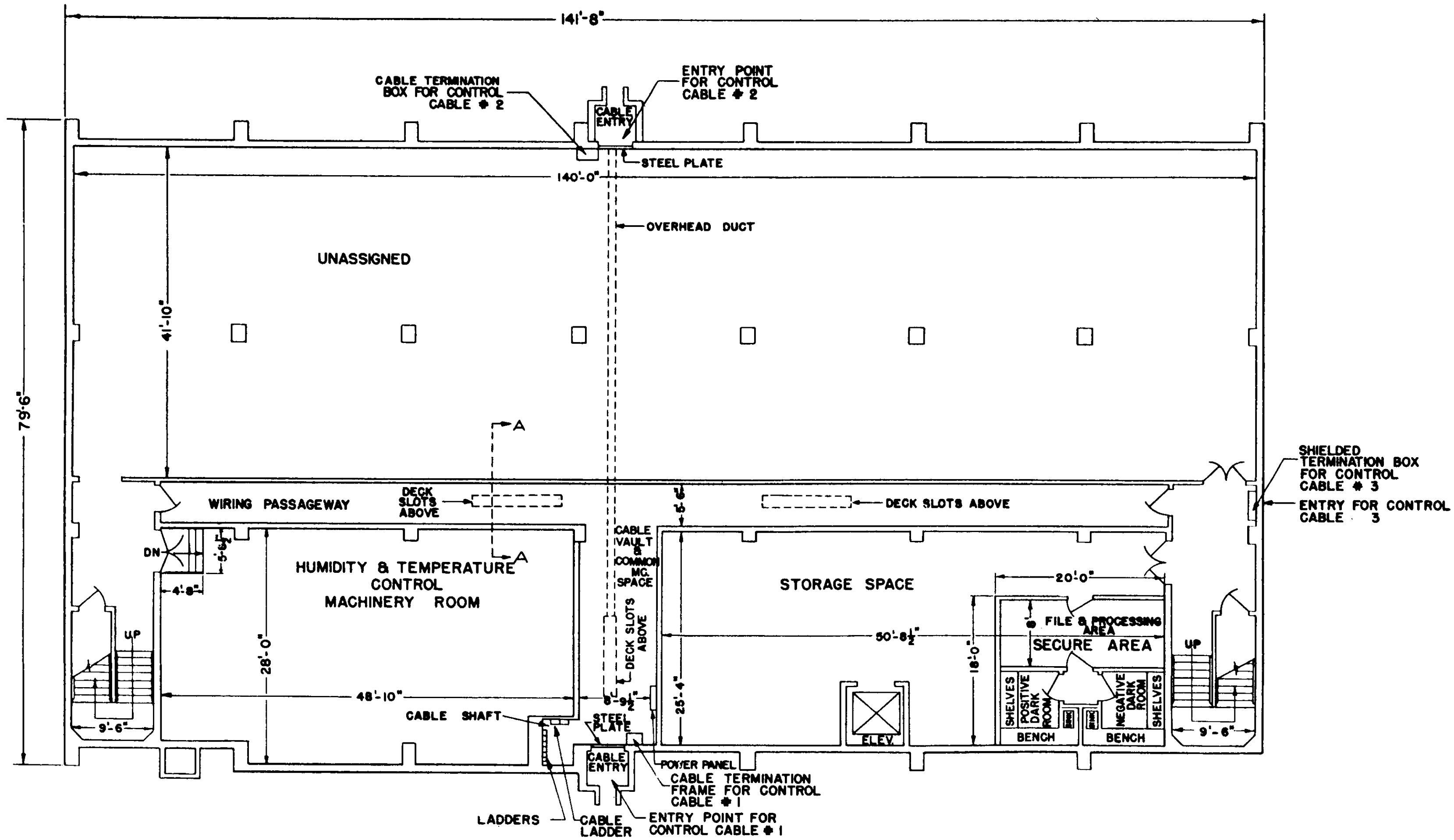
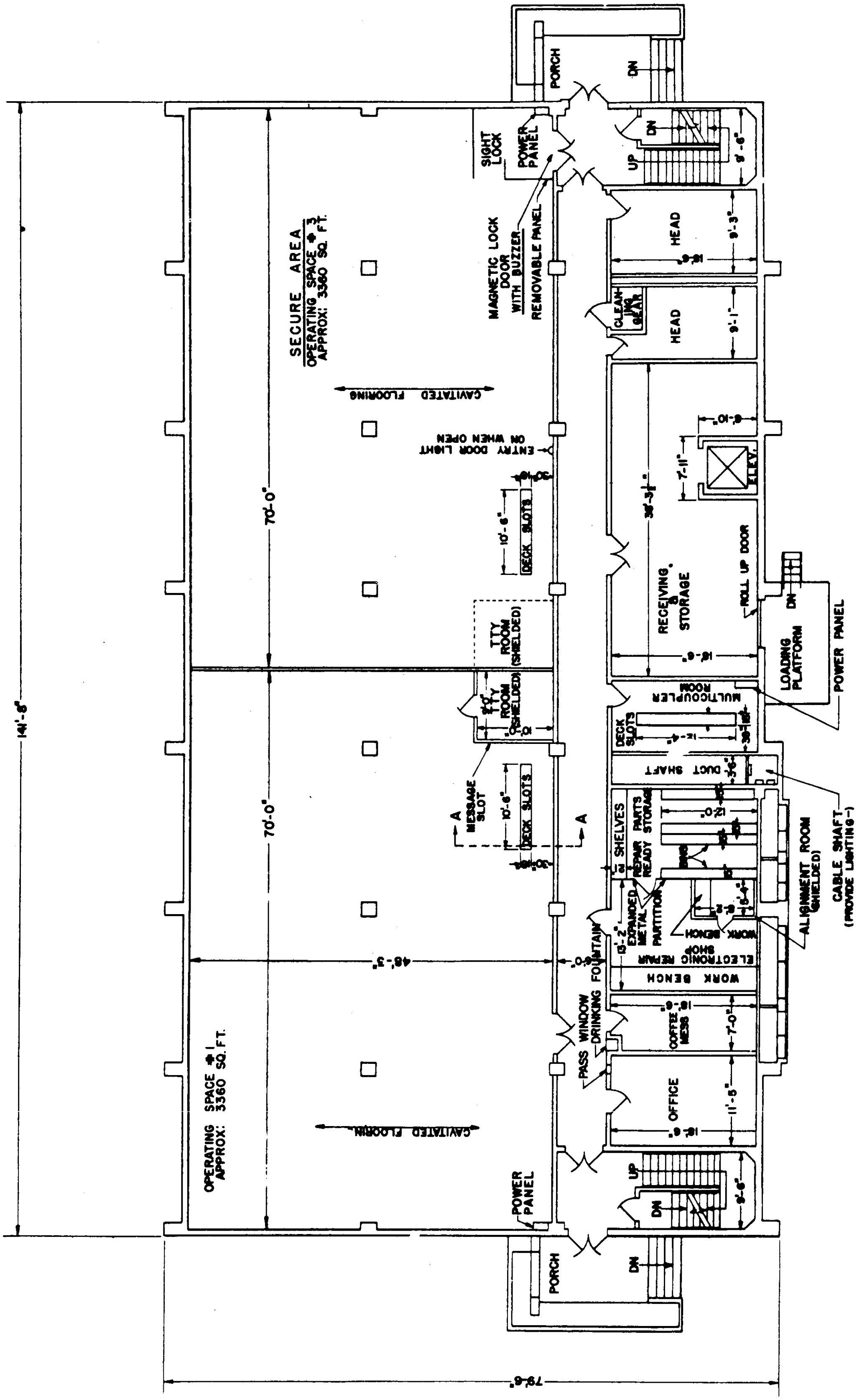


Figure 2-22. Typical Receiver Building, Basem nt Floor Plan



Figur 2-23. Typical R c iver Building, First Floor Plan

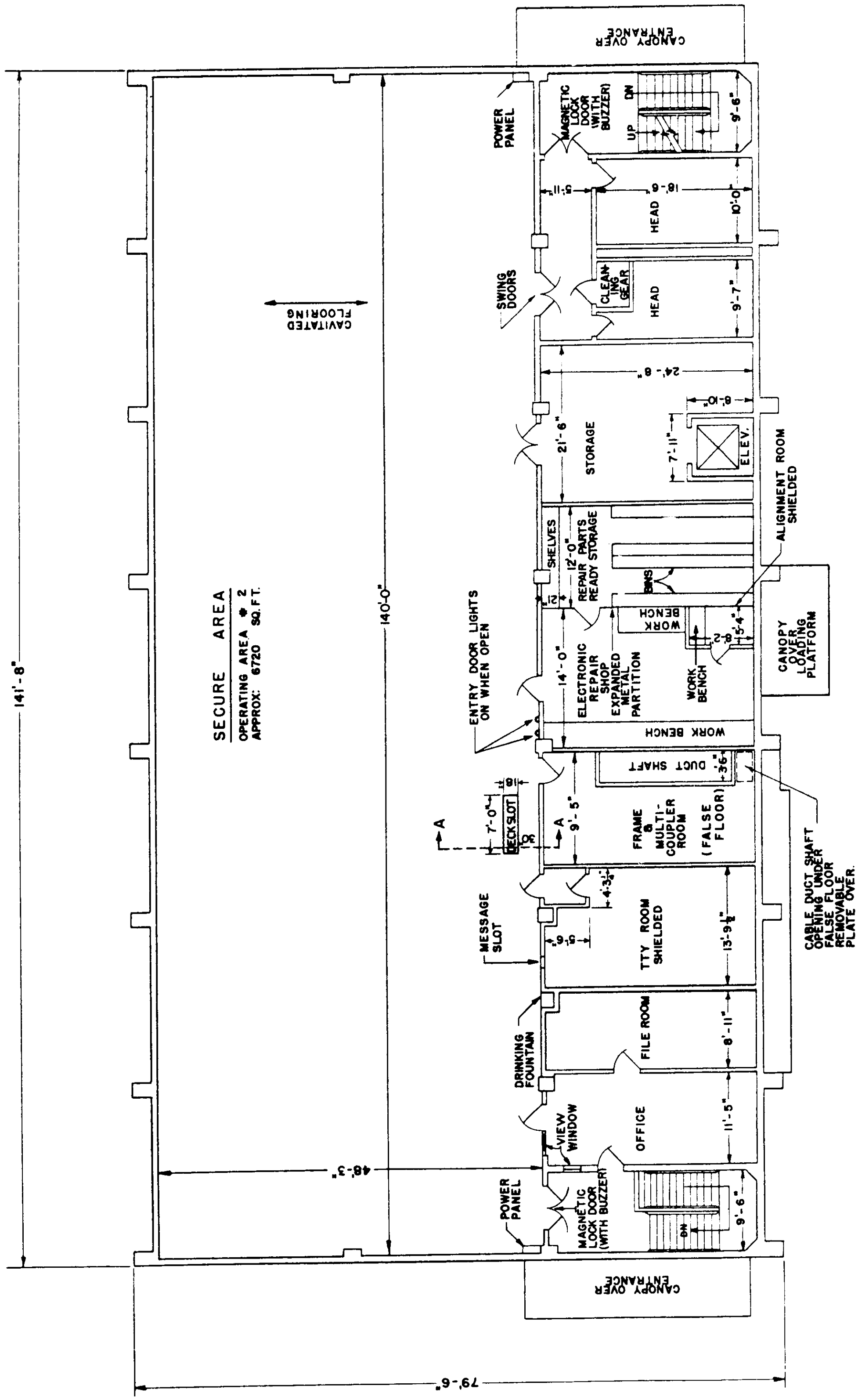


Figure 2-24. Typical Receiver Building, S cond Floor Plan

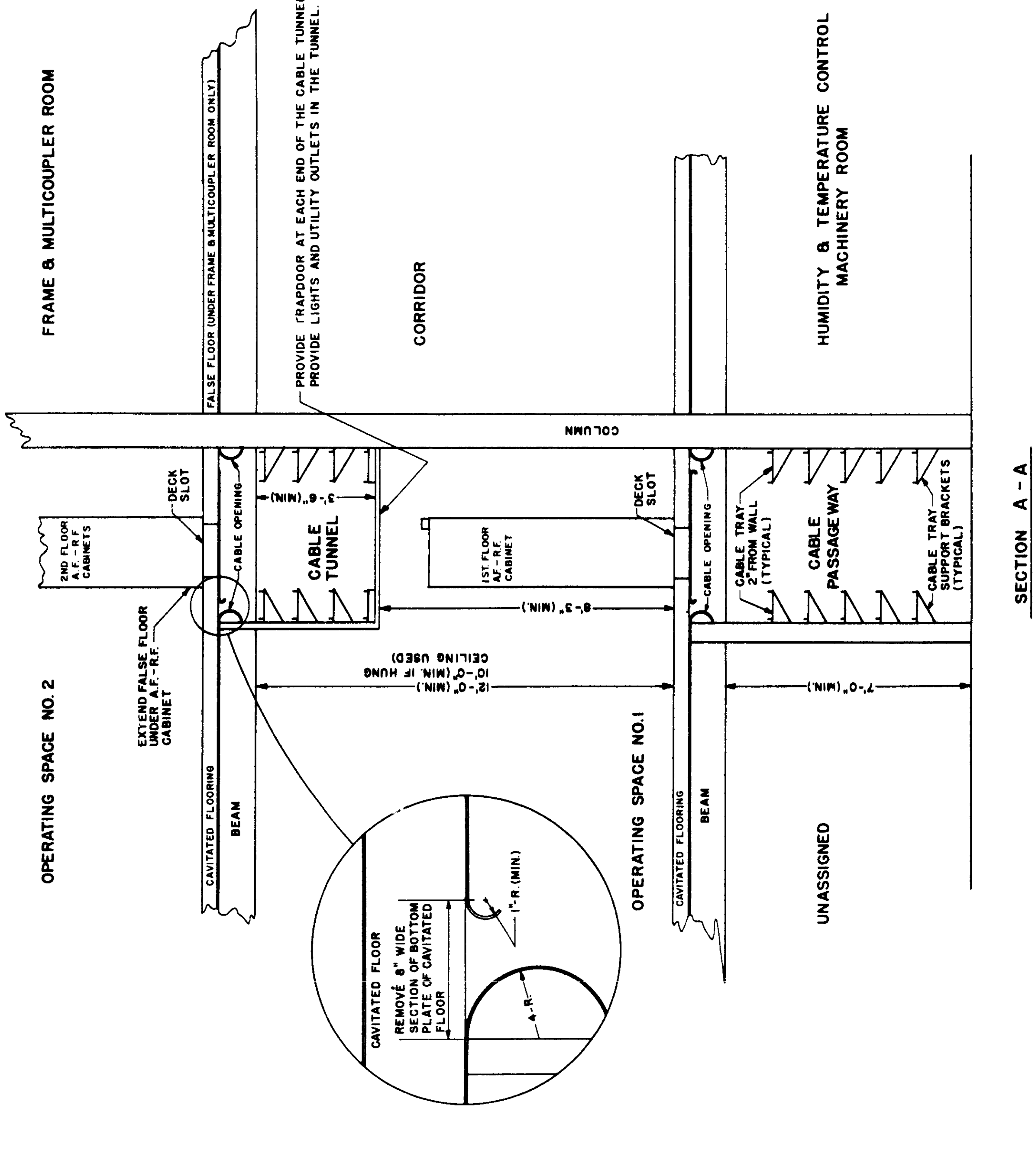


Figure 2-25. Typical Receiver Building Cross Section

receiving facilities for that activity; the basement thereunder being layed out for joint occupancy.

A typical receiver building layout is shown in figures 2-22, 2-23, 2-24, and 2-25. They have been prepared to be used as a guide in future planning but cannot be established as the ideal building arrangement nor as a basis for rigid building specifications. Each facility will have special problems which must be resolved locally. An undesirable feature of the building shown is the presence of building support columns in the operating spaces of the first floor. This presents problems of equipment installation and, where possible, such support columns should be eliminated from operating spaces. A standard room width of 48 feet for operating spaces is prescribed.

The building is usually rectangular, of masonry or concrete, fireproof, and architecturally in harmony with other buildings in the area. The size of the receiver building will depend primarily upon equipment space requirements, with additional space requirements which include space for administrative, storage, utility and maintenance purposes. It is the responsibility of the electronics engineer to determine operating space requirements by interpretation of the operational requirements in terms of system requirements providing adequate space for all equipments, thus collaborating with Public Works in this phase of A & E development of a project.

Exterior walls are windowless so as to provide maximum wall space for flexibility in equipment arrangement. Interior walls will also be arranged for maximum free wall space with supporting columns outside of operating spaces. Partitions are constructed of accoustical material, non-load bearing, and capable of being relocated if required for future alterations.

Building features which require engineering collaboration include:

Temperature and Humidity Control. Provision for adequate ventilation and heat dissipation of equipment.

Wiring Passageway and Cable Vault. Consideration given to cable entries, racks, "through-floor" fittings, cable trays, terminating frames and blocks.

Shielded Enclosures. Double shielded cellular type shielding not structurally integrated with the building, with provisions for passageway and message handling without destroying shielding integrity. Applicable specifications: MIL-E-4957A or MIL-E-18639.

Electronics Repair Shops. Work bench and storage bin requirements are to be specified, with provision made for maintenance as described in 1-13.

Bonding and Grounding. NAVSHIPS 900,-000, Electronics Maintenance Book, Section 10-20 contains criteria for grounding systems and for ground mat construction.

Power for Electronic Equipment. Estimates made of power requirements for each operating space, antenna multicoupler space, and electronics repair shop to provide 80 percent power factor, 120-volt, single phase, 60-cycle power. Initial requirements are provided as described in 1-5, Section 1. Standard 208/120, four wire installation is acceptable with appropriate regulations (voltage ± 10%, 60 cycles ± 2%).

Floors. To provide cellular flooring and cable ways, with suitable entry and exit facilities.

Lighting. Incandescent lighting used and candlepower requirements for adequate illumination in operating, office and other spaces specified.

Radio Interference Suppression. Shielding and filtering to be provided on equipment which is not inherently free of radio interference generation. The requirements for suppression should be determined on the basis of interference to receivers in their operational environment.

(*d*) EQUIPMENT LAYOUT.—The layout of equipment shall conform in all respects with operational dictates, with emphasis being employed on the most direct traffic flow, least amount of personnel travel, centralized supervision, and complete accessibility for maintenance.

For layout standardization purposes, whereby the operating or maintenance personnel may become thoroughly familiar with the engineering practices employed, the basic layouts for all stations must be identical. However, the operational requirements vary from station to station thereby creating problems of rearrangement, additions and/or deletions of certain equipments to a point where the interior of one station no longer resembles the first. The necessity for this rearrangement and continued growth precludes the promulgation of rigid installation plans.

Figure 2-26 shows typical equipment arrangement in a radio receiver building.

The following items of equipment and systems will come under consideration in planning equipment layout:

1. AF/RF SYSTEM.—The AF/RF Signal Distribution System will be designed to meet local requirements, with standard components if possible. Front panel spacing of equipment and accessories will be in compliance with standard requirements. Use NAVSHIPS 91047 RF and AF Signal Distribution Unit as guide.

2. MANUAL OPERATORS DESK.—Manual operators desks are of metal construction with design features as follows:

a. Desks are adapted to cellular floor wiring

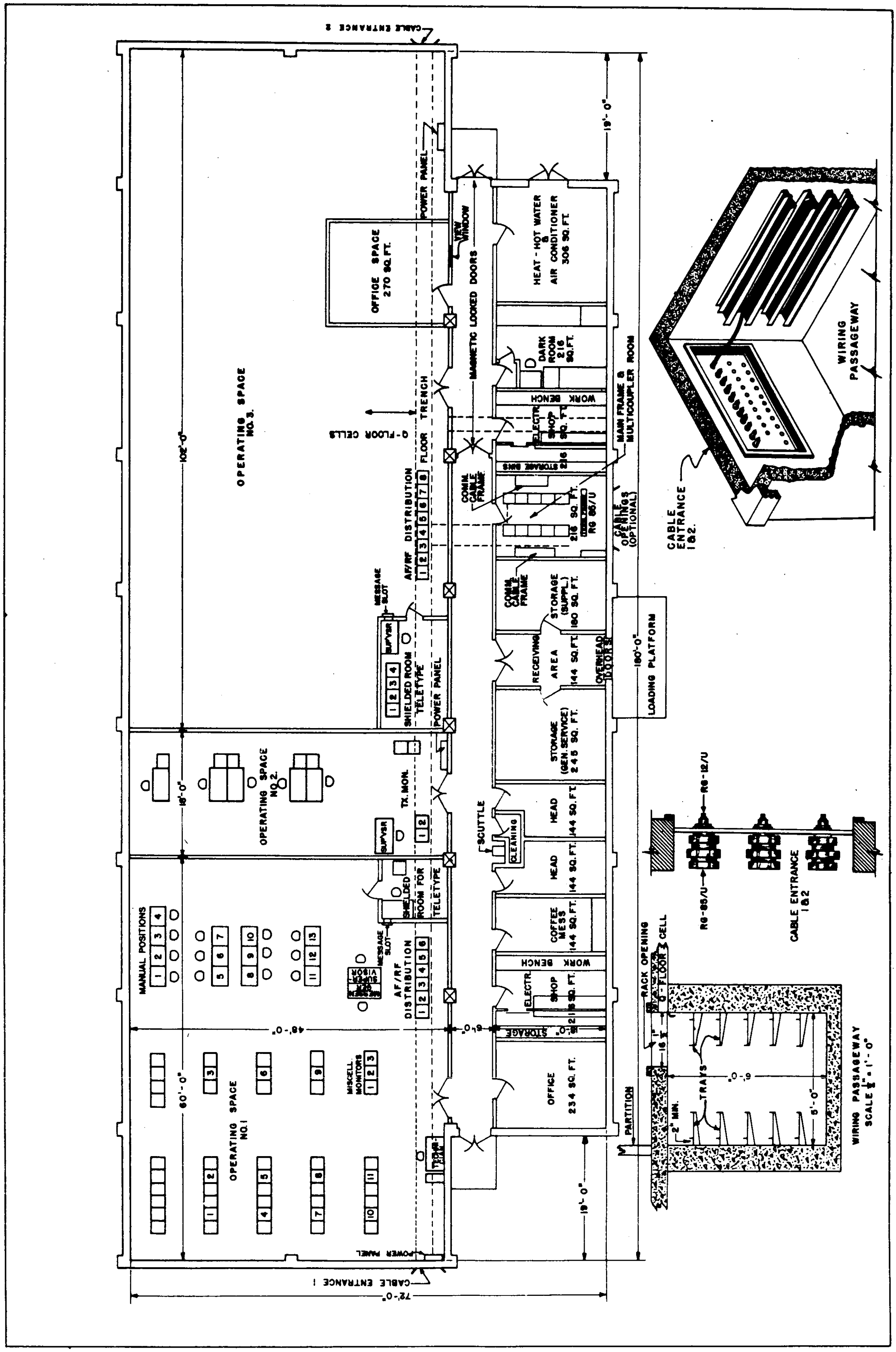


Figure 2-26. Typical R c iv r Building, Equipm nt Layout

or square D duct wall wiring. The panel below the back of the desk may be installed at any point along back of desk to take advantage of all floor cells without the necessity of "staggering" desks in rows.

b. AC power wiring, fuses, line switch, and convenience outlet are built into desks.

c. Desks may be mounted back to back or against walls. Access to all cables to be available below the front of the desk.

d. Desks have low shelf height to permit operators' ease of tuning receivers.

e. Two receivers may be operated on each desk and, by stacking one receiver on another, four receivers may be operated.

f. Two typewriters may be operated on each desk if required. For example, one for keeping the log and one for copying traffic.

g. The desk is provided with covering in conformance with grade II of MIL-T-1717A(Ships) of 23 October 1952 which is equal to "Formica" and is cigarette and stain proof.

3. OPERATORS CHAIRS. — All operators chairs should be swivel steno chairs, GSSO Stock No. 26-C-11450, or equal.

4. AUDIO OUTPUTS OF RECEIVERS.—The audio outputs of all radio receivers at manual operating positions are connected to an audio control box mounted in each operator desk. In addition, the output of each receiver is terminated in an audio jack on the AF/RF Distribution Unit provided for the Supervisor.

5. CELLULAR FLOOR CONNECTION BOX.—A cellular floor connection box manufactured in accordance with Bureau of Ships drawing RE6F2254A is employed below all manual operating desks to provide terminations for all cabling (i.e. RF, AF, AC and keying) to each position. This box is intended for installation along the back of the desk.

6. FRAME ROOM.—All multicouplers and the Model AN/FRA-3 equipment are installed in a Common Frame Room. The AN/FRA-3 equipment will be patched to the Supplementary Activity, the Security Activity, and General Service Activity as required. Antenna patching facilities within the frame room should permit, as far as practicable, the patching of any antenna to any activity within the Receiver Building either direct or through any multicoupler at the option of the operational personnel.

7. SUPERVISORS' FACILITIES.—The following facilities are normally required at or near the supervisors' desks, (if the receiver station accommodates both General Service and a Supplementary Activity, facilities described will be located to meet individual requirements):

a. AF/RF Distribution System, including transmitter control.

b. Two-way inter-communication facilities (voice) between the supervisors' positions and each manual operator's desk and subsection operating position that is more than 25 feet away.

c. Access to one output of the AN/FRA-3 antenna selector. This may be included as a part of a nearby operator's desk.

d. Master station inter-communication control.

e. Monitor receiver and frequency meter.

f. Station telephone.

g. Buzzer and control for magnetic release of entrance door to supplementary space.

h. Station fire alarm push button.

i. Emergency power indicator lights or meters, as appropriate.

j. Office desk and typewriter stand.

k. Traffic handling facilities.

8. SHIELDED ROOMS.

a. For teletype, a shielded room is provided in new construction projects for receiver buildings to permit operation of a limited number of teletype equipments in the receiver building without interfering with radio receiving conditions. This space shall be double shielded and the power input to this room is filtered and/or provided with electrostatic shielding. Signal lines are RG-108/U cable or equal.

b. Where the AN/FRM-3 equipment is employed by the Security Activity, a similar shielded room is provided for this equipment and the monitor teletype equipment used with the AN/FRM-3.

c. All shielded rooms must be provided with adequate ventilation or be air-conditioned.

9. MONITOR TELETYPE EQUIPMENT.—The only teletype equipment that should be permitted in a radio receiver building is that located in a shielded room provided for that purpose, or monitor teletypes that have been rendered interference free. Monitor teletype must be kept to a minimum and are normally mounted on wheels to permit their being utilized at various operating positions. The Model 28 series of teletypes have been found to meet interference requirements, but other teletypes may meet these requirements if provided with adequate shielding and filters and grounded to the power or "Q" cell ground. Teletype equipment located in a receiver building should never be connected directly to the electronics ground. It is well to bear in mind in system engineering, that even though equipment is rendered interference free at time of installation, it may not remain so in operation and could conceivably cause excessive interference.

10. MISCELLANEOUS.—Other items which

will come under system engineering include radio printing and radio photo facilities and ink and voice recording facilities; location of such devices to be subject to local requirements and as specified by the Management Bureau. Remote control of receivers must also come under consideration. Where this requirement exists, control lines for this service shall be included in patching and distribution.

(*e*) ANTENNAS.—Antennas of all types will come under consideration including rhombics, sleeves, doublets (horizontal and vertical) as well as long wire antennas for frequencies below 500 kc. Total antenna requirements will result in an antenna park with a rosette arrangement and, in order to provide the shortest possible transmission lines (coax) to the receivers, the receiver building will of necessity be constructed in the center of the park. As shown in figure 2-27, antennas occupy concentric circles around the receiver building with rhombics on the outer circle at distances between 1000 and 1500 feet to near pole. Omni-directional and sector coverage antennas are placed on the inner circles with highest frequencies nearest the building.

Not shown in figure 2-27, but where the requirement exists, poles are erected to accomodate long wire antennas for low frequency applications. In addition, the use of sleeve antennas replacing a considerable number of the doublets shown, is recommended in new construction.

VHF, UHF, and SHF receivers are provided with individual antennas. Coaxial cable runs should be short and modified patching arrangements provided where a limited amount of patching for spare receivers is made available.

System engineering also requires that provision be made for antennas in space diversity and result in additional space requirements for adequate circuit coverage. Space diversity is used to combat natural fading experienced in ionospheric propagation. Experience has shown that two receiving systems with antennas spaced about 600 feet apart will provide optimum performance. Spacing may be in any direction with respect to the direction of the incoming signal. In point-to-point service where antenna gain is important, two rhombics pointed in the proper direction and spaced properly will be provided. In other applications where signal level is sufficient, any combination of two antennas with adequate spacing will provide satisfactory performance.

At the higher frequencies where space diversity is less effective, polarization diversity may be used. By providing sufficient horizontal and vertical dipoles, combinations of these antennas can be used in diversity for greater reliability in circuit coverage.

Recommended procedure for determination of the total number of antennas is to determine and list frequency requirements for each circuit. Receiving doublets are useable over ± 5% frequency spread. Assign up to five receivers for an antenna through multicouplers where frequencies or antenna patterns are compatible. An integrated rhombic rosette, with consideration given to frequencies and vertical angles, will provide overlapping coverage. Determine bearings of all point-to-point circuits and provide optimum and skip range design for these circuits. Then orient rhombics ever 7.2 degrees providing best compromise for point-to-point bearings. Additional flexibility may be obtained by "double-ending"' the rhombic antennas as described under 2-3, ANTENNAS.

(*f*) TRANSMISSION LINES.—Standard practice is to carry all receiver RF signals on 70-ohm coaxial lines, and standardization has resulted in all Navy receiving apparatus being designed with an input terminal impedance of 70 ohms. The RG-85/U coaxial cable has been designed for outdoor use and is used almost exclusively for transferring RF energy from the antennas into the receiver building. The cables are buried in the ground with firm connection of the outer conductor to the electronic ground system. Standard fittings are available for cable entry into the building either through a cable vault which is sometimes underground, or above ground, whichever is best to meet local conditions.

The use of 70-ohm cable requires impedance matching to the antenna, which is accomplished by means of the NT 471138 matching transformer. This transformer has been designed to provide coupling of the 70-ohm coax to a 600- or 270-ohm antenna as well as static leakage, lightning protection, and watertight integrity. The antenna is terminated in the transformer which is normally mounted on one of the antenna support poles or on a pole provided for the purpose.

(*g*) PATCHING AND DISTRIBUTION.—Three types of patching and distribution must be considered at a receiving facility; the first being "radio frequency" distribution which provides the receivers with input signals permitting one or more receivers to obtain signal excitation from one antenna or, each receiver with a choice of antennas from which signal energy is obtained. The second type of distribution is "audio frequency," whereby the output of the receivers can be terminated in headphones, monitored and/or patched through to other measuring or terminating devices. The third type of distribution is a telegraph (DC) patchboard for transmitter keying and control, local teletype, etc.

NAVSHIPS 91047, RF and AF Signal Distribu-

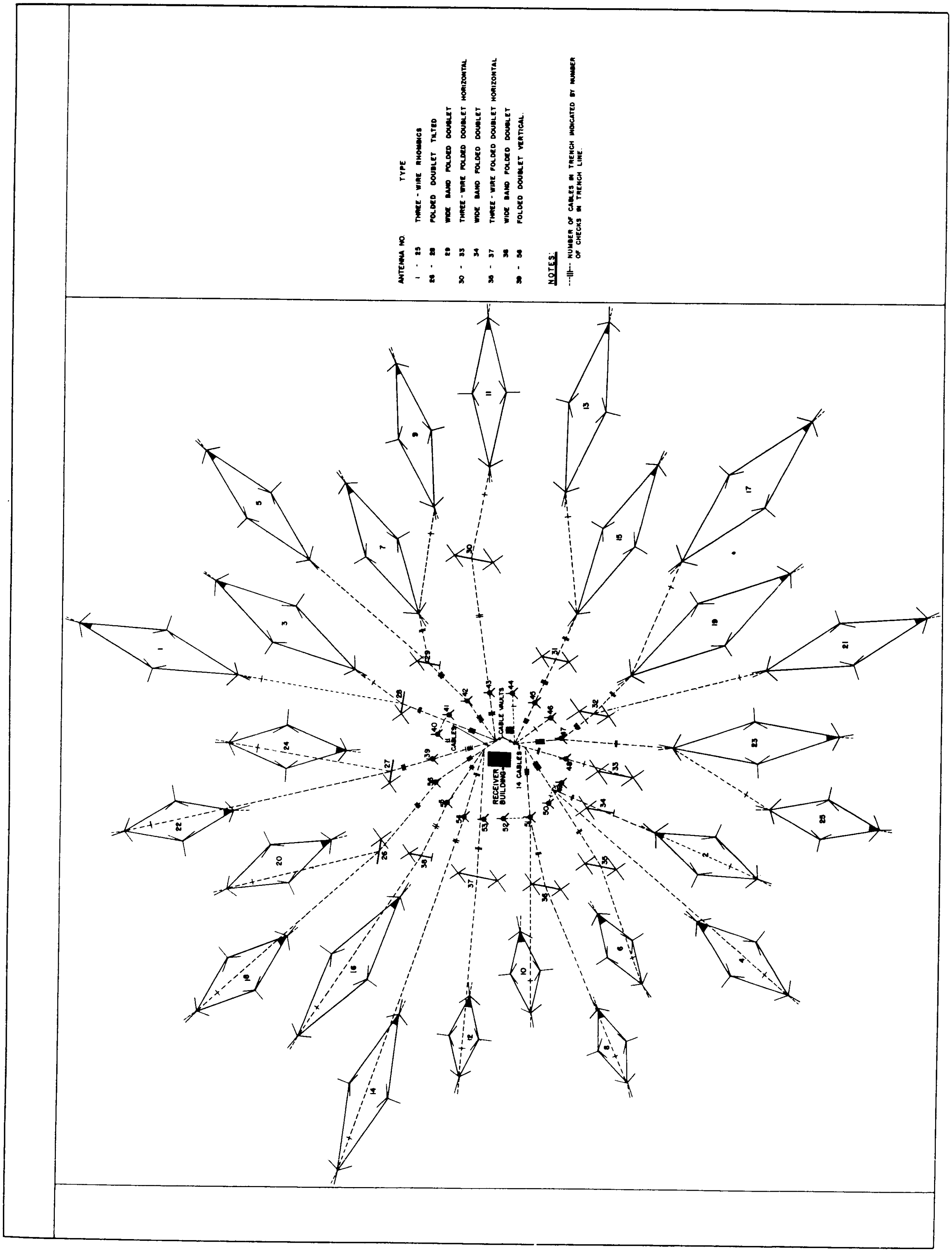
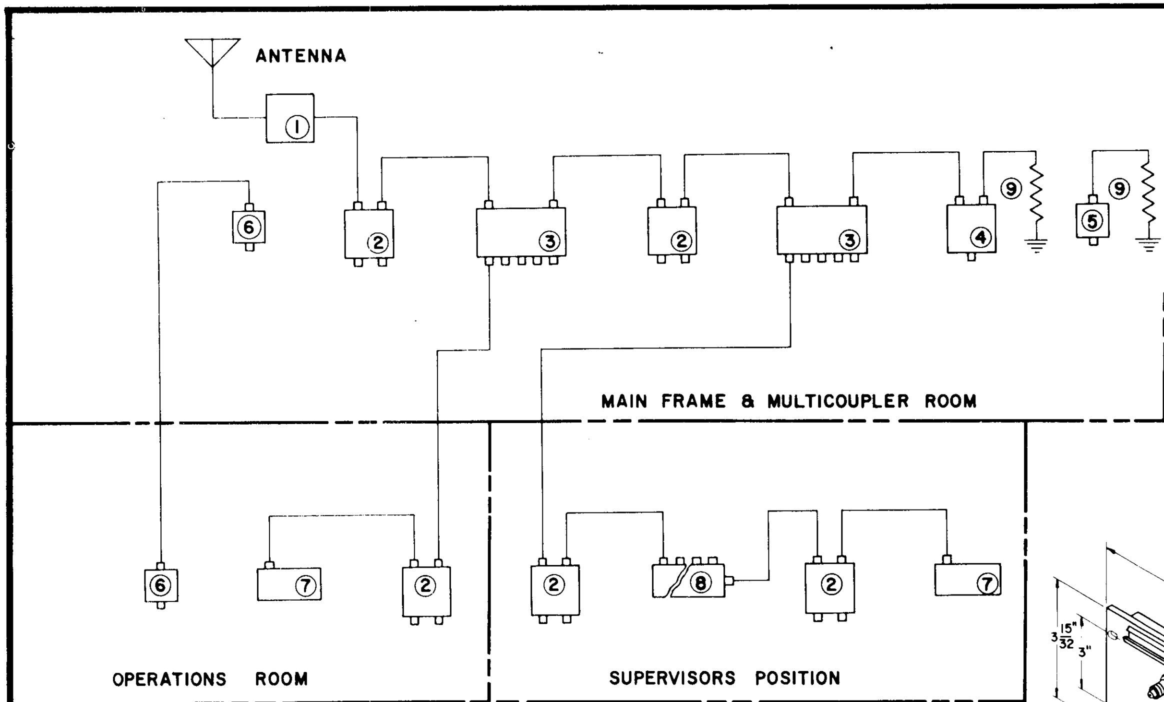
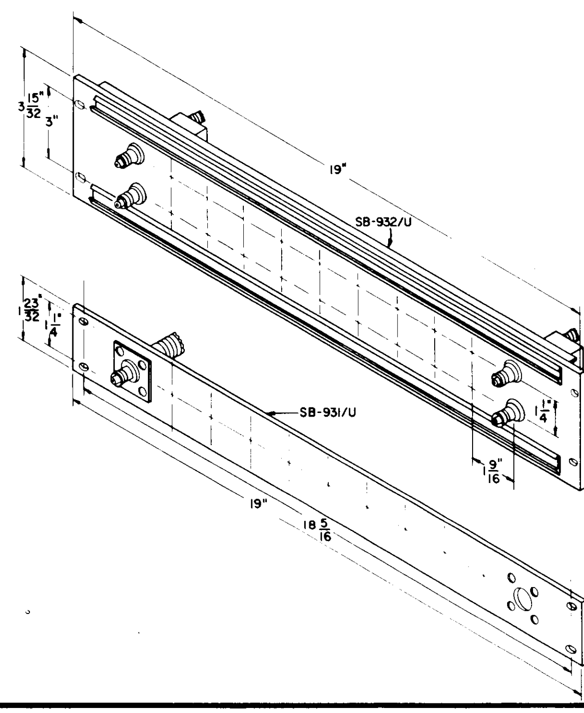


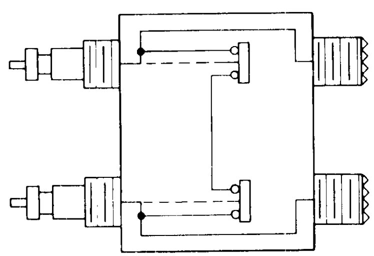
Figure 2-27. Receiv r Station Ant nna Layout



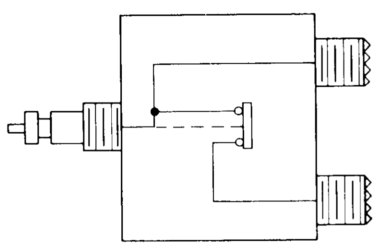
LIST OF EQUIPMENT				
NO.	DESCRIPTION	TYPE	REF. DWG.	REMARKS
1	END SEAL ADAPTER	NT-491625		
2	R.F. SWITCHING JACK	PART OF SB-932/U		SEE NOTE 1
3	MULTICOUPLER	CU-168/URR		
4	R.F. SWITCHING JACK	SA-598/U		SEE NOTE 2
5	RECEPTACLE	UG-1180/U		
6	QDS TO UHF ADAPTER	PART OF SB-931/U		
7	RADIO RECEIVER			
8	ANTENNA SWITCH	SW-138/U		
9	RESISTOR, 68 OHM, 2W	N16-R-49499-171		
10	PATCH CORD			SEE NOTE 3

NOTES:
1. SEE DETAIL NO. 1
2. SEE DETAIL NO. 2
3. RG-11/U WITH UG-968B/U EACH END (NOT SHOWN)
4. UG-968/U AND UG-968A/U NOT TO BE USED WITH ITEM NO 2, 4, & 6.





DETAIL NO. 1
PART OF SB-932/U



DETAIL NO. 2
SA-598/U

FIG. 2-27a RECEIVING ANTENNA DISTRIBUTION SYSTEM

tion Unit, will provide guidance and component specification parts of standard distribution facilities. The three types of distribution are discussed in the following paragraphs.

1. RF DISTRIBUTION.—Standard practice is to bring all RF signal energy into the building on standard coaxial cable (RG-85/U). Cabling within the building is normally RG-11/U. First transition from the outside, RG-85/U, cable to the inside, RG-11/U, shall be at the point of cable entry by means of the Navy type 491652 standard connector-adapters. This transition shall be in a cable vault or in the RF Frame Room where first distribution begins. (The exceptions to this are VHF/UHF/SHF applications where receivers are grouped and a local patching facility provided to permit patching spare equipment to the several antennas. Also excepted are LF applications where long-wire antennas are brought into the building wall through a standard entering insulator and distributed in operating spaces with a RG-162/U coaxial trunk provided with receptacles containing 300-ohm decoupling resistors for attaching each receiver.)

The frame room contains initial patching facilities, multicouplers, and AN/FRA-3 equipment (if authorized). RF cabling is run between the frame room and the standard patch panels provided in the Signal Distribution Unit; terminating in standard jack panels where, by means of patch cords and the antenna selector switch(es) (SA-136/G, 137/G, 138/G), antenna selection, monitoring, frequency measuring, and testing can be accomplished. Jack panels are normally arranged for "normal-through" operation whereby each receiver is connected without patch cords to the antenna or multicoupler to which it is assigned.

2. AF DISTRIBUTION.—The output of each receiver is carried on a shielded twisted pair for distribution within the receiver building. All audio signals leaving the station via cable or link shall pass through power limiting AM413 series amplifiers unless this function is incorporated in the signal generating equipment. Input audio signals levels shall not exceed ϕ DBM (1 milliwatt). Standard practice carries the receiver outputs through the main frame cross connect located in the frame room, with permanent interconnection to the Signal Distribution Unit, where temporary patching may be accomplished. Operation is usually "normal-through," from receiver to terminal equipment with provision at jack panels to patch other equipment in parallel if necessary. Patching should be kept to a minimum, however, and where permanent changes in distribution are made, re-wiring of the main frame to eliminate patching should be accomplished.

3. TELEGRAPH (D.C.) DISTRIBUTION.—Local teletype, order wires, and transmitter keying and control circuits require distribution. Control and keying lines to the radio transmitting station and communication center either by cable, telegraph carrier, and radio link are wired through the main frame cross connect and brought to the panel for distribution without patching. Operation of control lines are "normal-through" for casualty or maintenance substitution. Complete SB467/FG switchboards or jack fields thereof shall be employed for this service. This is discussed in detail under TERMINAL EQUIPMENT and INSTALLATION PRACTICES.

4. SUMMARY.—A careful engineering analysis and interpretation of the operational requirements at a communication receiving activity are required to provide maximum utility and flexibility in signal distribution. Circuit requirements consist of manual and automatic channels, all capable of simultaneous 24-hour service. Ship-to-shore circuits are normally manually operated but patching facilities and equipment must be provided so that RATT, FAX, etc., may be utilized if required. High frequency point-to-point service calls for diversity arrangements and multi-channel automatic operation. Provision must be made for patching spare equipment where required. Expansion of facilities and changes in operational requirements require generous initial provision for additional equipment and connecting cables if required. Amplifiers and attenuators must be provided to maintain proper signal levels and extreme care must be exercised in order that the proper signal to noise ratio is maintained. Cellular flooring and adequate cable racks permit flexibility and facilitate grounding and bonding of signal carrying cables. All of the above factors require careful engineering in order to provide facilities for optimum reception of signals and rapid delivery of traffic by the Management Bureau operating the facility.

(*h*) POWER REQUIREMENTS.—The project electronics engineer furnishes Public Works with total equipment power requirements for operation and heat dissipation in order that total power requirements including utilities can be computed and the power provided. Initial provision by the construction agency is as described in 1-5, Section 1, with 208V/120V, four wire, instantaneous regulation ± 10% (voltage), 60 cycles ± 2%.

(*i*) MAINTENANCE AND TEST FACILITIES.—Maintenance of equipment and test facilities are provided in the receiver building where space is made available for work benches and bin storage. A maintenance parts system requires installation of standard bin storage units for "parts peculiar" and "parts common" which are normally carried on board, and for setting up of a standard plant account system in accordance with current directives. Equipment maintenance and repair are accomplished in the space provided, with appropriate power tools made available. Test equipment such as signal generators, output meters, and oscilloscopes are provided in addition to that test equipment permanently installed in the Signal Distribution Unit.

NAVSHIPS 92326 contains plans for a typical work bench installation.

(*j*) PLANS AND SPECIFICATIONS.—The development and construction of a receiving facility requires plans, drawings, and specifications as outlined in 2-2.*a.*(4), SYSTEM PLANS. Broad building requirements and details of construction to fit equipment layout are provided by the Bureau of Ships in letter form along with line drawings to enable local electronics authorities, in collaboration with Public Works, to prepare details which will result in detailed design drawings and specification blueprints. Experience has shown that firm plans that will hold for the duration of construction and installation are the exception because of the time lapse between conception and ultimate turn-over of a facility to management. However, careful planning will minimize changes and result in the most economical facility development.

2-5. TERMINAL SYSTEMS.

a. GENERAL. — Military Communication System Technical Standards, MIL-STD-188, dated 13 July 1955, were prepared to insure compatibility between equipment of the several military services in the event interoperation became necessary. The terms and definitions given therein will be used in ensuing discussions in this publication, and shall be required in future transactions between the Bureau and its field representatives. There are, however, certain areas not covered in MIL-STD-188, and some terms or definitions following are considered as being peculiar to the Naval Service and will be adopted as such.

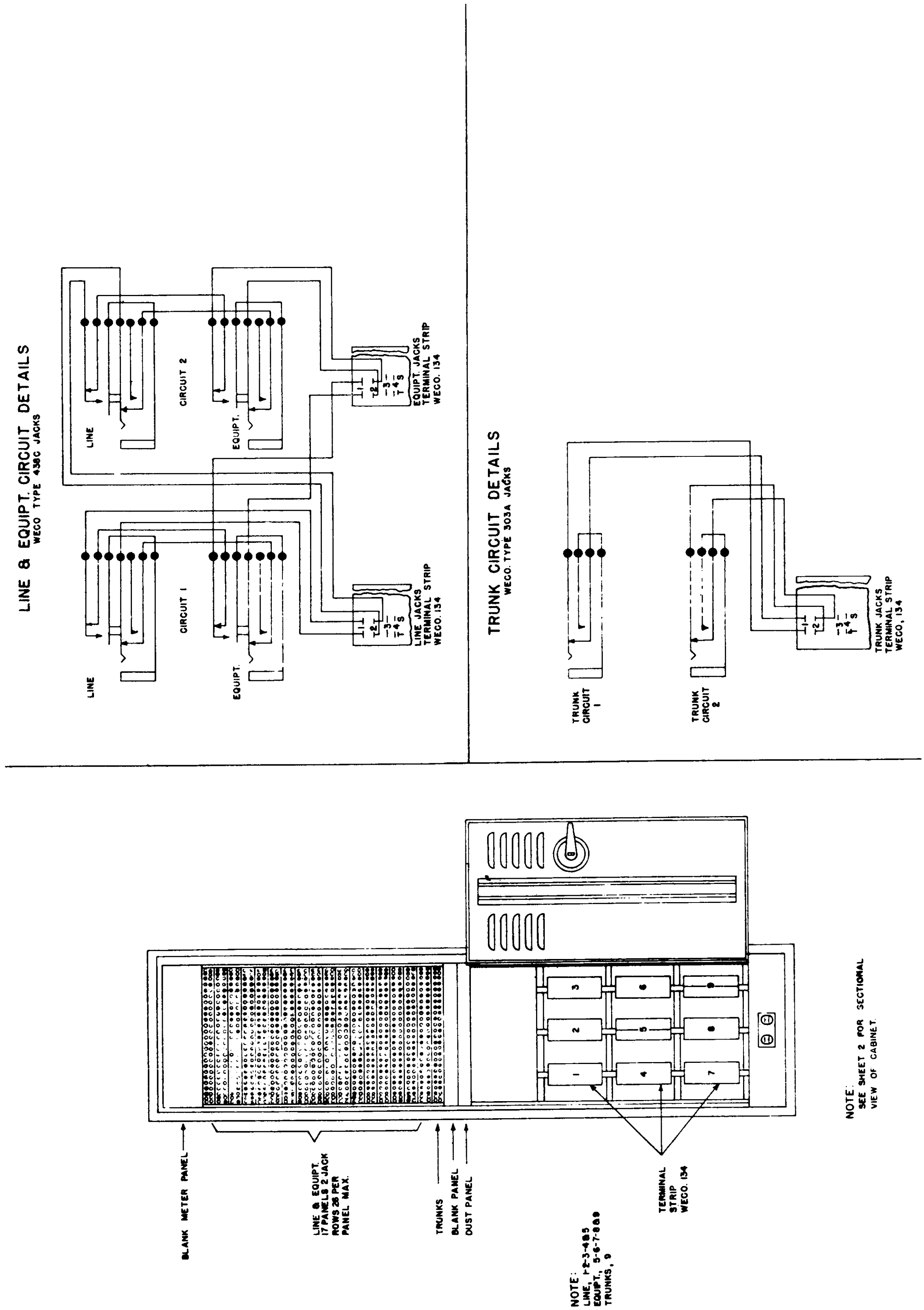
For example, "Terminal Equipment" as applied to Naval Shore Communications includes end instruments, (defined in MIL-STD-188 as devices connected to one end of a loop and capable of converting usable intelligence into electrical signals and vice-versa), telegraph carrier terminals, switchboard repeaters, amplifiers, and all other equipment necessary for the translation, control, and distribution of signals in a communications center or terminal area.

Terminal systems engineering then, is the process of converting the operational requirements of a facility into quantities and types of terminal equipment to be provided, planning the circuitry to unite the equipment into an efficient system, planning the equipment layout to provide operational efficiency and facility for the user, and the preparation of the necessary data for use by the cognizant Public Works Officer in developing space, power, air conditioning, and other utility requirements. In no other place could the principles of human engineering discussed at the beginning of this section be put to more advantageous use than in planning the layout of terminal equipment.

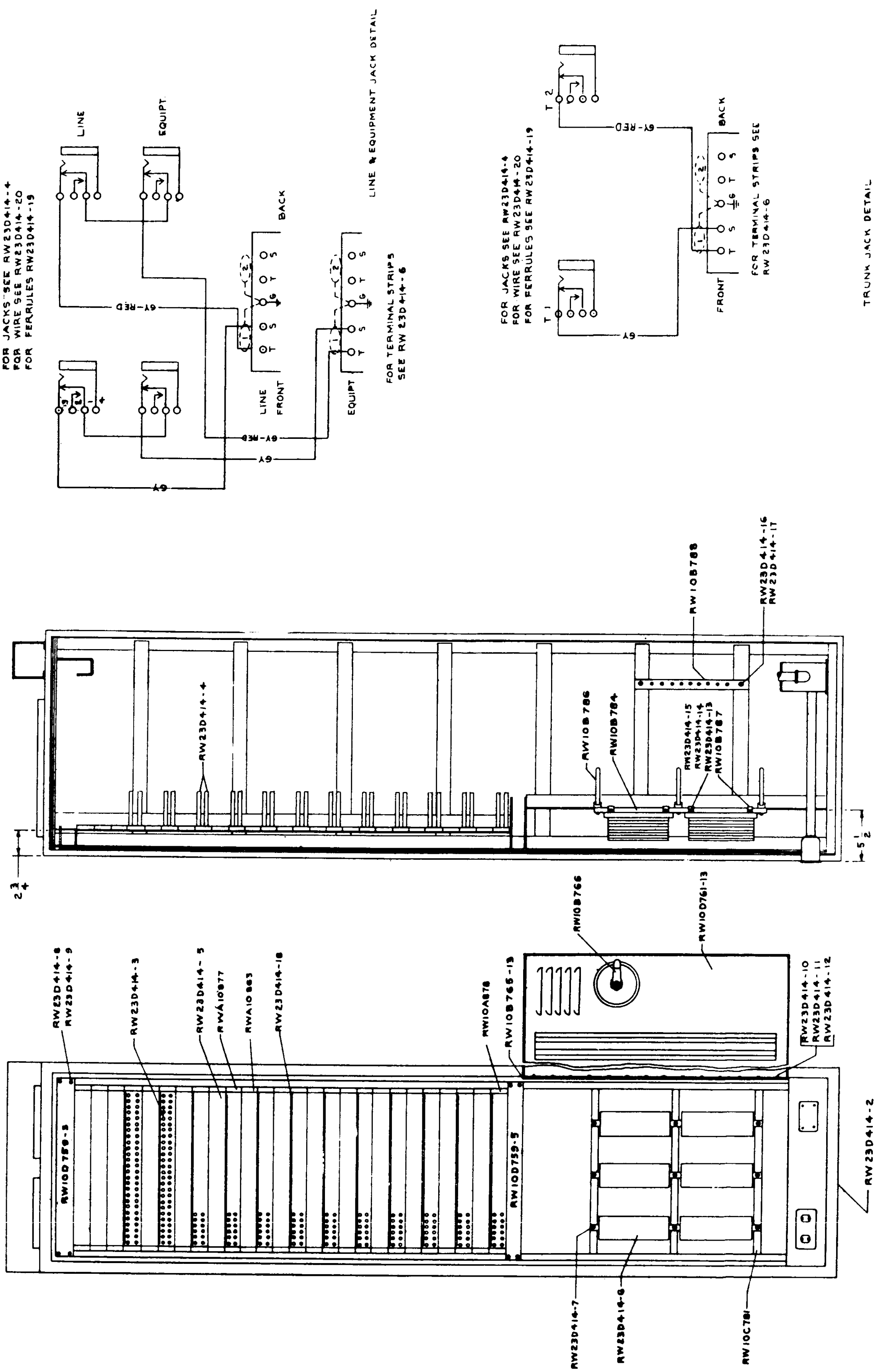
In communication centers, it is especially important that system standards and practices be adhered to. The reason for this is that here the supporting remote facilities are joined together to form an efficient machine for the sole purpose of moving a high volume of traffic with a minimum of delay. It is obvious that the physical arrangement of the message center components should permit an even flow of traffic from receipt to departure. It is equally obvious that the electrical channels carrying the traffic intelligence be engineered for the convenience of operating personnel for circuit control, as well as for the convenience of the technical personnel in maintaining and servicing. System standards and practices have been developed as criteria and promulgated by the Bureau of Ships in the form of standard plans or Bureau Instructions or Notices pertaining to specific items or areas of interest. In those cases not treated by specific criteria, it has been presumed by the Bureau that commercial standards and practices would be followed by field engineers. It might be stated in all frankness that most of the Navy standards are but commercial ones modified to meet the special military requirements. A further requirement for standardization is due to the military practice of transferring personnel from station to station. If physical arrangement and electrical circuitry follow established patterns, the "in training" time of a new arrival is reduced, the full benefit of his services is realized more quickly, and operating efficiency is maintained.

Section 2-4.*b.* discussed the functional components of the communication center. Figure 2-17, copied from Bureau of Ships drawing RE 6D 2269, was developed as a block diagram of a typical communications system with on-line cryptographic equipment. A casual examination would leave an impression that installation of the system is made unnecessarily complicated by the number of appearances required per circuit on the distributing frames and patching facilities. However, a detailed examination should be made to understand the reasoning behind this system planning.

The system shown is based upon the premise that the subscriber is located some distance from the com-



Figur 2-28. D.C. Primary T st Board, Navy Typ SB-471/FG



Figur 2-29. Audio Primary Test Board

munication center and that there are sufficient circuits between the two to justify multichannel terminal equipment over landlines or links. Under most conditions, as described in section 2-4.*b.*, the subscriber will be extended on a full duplex d-c telegraph circuit, therefore the system will be somewhat simplified by the elimination of the telegraph terminal equipment and associated facilities, between symbols (7) and (22) as well as (67) and (82), on figure 2-17. The circuitry for a d-c telegraph circuit only is shown by dotted lines between (9) and (22), and incorporates d-c primary test board SB-471/FG (figure 2-28).

b. SYSTEM DESIGN.—The following general rules apply to the system design: (Numbers refer to symbols in figure 2-17.)

(1) All landlines or incoming control lines shall first terminate on the main distributing frame, (16).

(2) A *Primary Testboard* (17) (figure 2-29) shall be provided as the first jack appearance of the incoming lines. This testboard shall be used (a) for clearing or terminating the line while clearing faults or testing; (b) to drop a faulty line and substitute an alternative one to maintain service. The lines terminated on the *line* jacks will be cross-connected on the main frame to appear in a systematic or sequential order according to the commercial circuit number or other identification. The *equipment* jacks are normalled to the *line* jacks and shall terminate the circuit looking toward the equipment within the facility.

(3) An *Audio Patchboard* (19) (figure 2-30) shall be provided for technical maintenance. The *line* jacks terminate the lines to the primary testboard; the equipment jacks terminate at the equipment. The *equipment* jacks shall be cross-connected on the main distributing frame (M.F.) to make the equipment grouping appear sequentially. (While only one AN/FCC-3 is shown, additional equipment will be connected in like manner.)

(4) The two frames shown, (22) and (23), are connected by tie cables. This is a requirement because the two equipment spaces are physically separated.

(5) The d-c outputs of the AN/FCC-3 equipment terminate on the *looping* jacks on the *d-c patchboard,* SB-467/FG (24) (figure 2-31). Battery is supplied by the AN/FCC-3 with the *tip* of the looping jacks always of negative polarity. There are 26 circuits per group in the SB-467/FG and, since the AN/FCC-3 is a 12 channel equipment, it has been determined that, to obtain symmetry, circuits 1 to 12, beginning at the left side of the board contain the first equipment; circuits 13 to 24 the second, and circuits 25 and 26 are not used. This sequence is repeated on the jack groups below and on additional patchboards if required. The unused circuits may be assigned for dummy loops or test circuits if desired.

(6) The *set* jacks of the patchboard (24) are terminated on the IDF (25). A tie cable to the Classified Intermediate Distribution Frame (C-IDF) is the only connection permitted between classified and unclassified frames for security reasons. It will be noted that provision is made for the future installation of single channel crypto equipment. With the installation of that equipment there will be complete isolation of clear and encrypted circuits in the system.

(7) The classified d-c patchboard (28) terminates the FRXD equipment on the *SET* jacks. This portion of the system shall be grouped to accomodate a 16 channel system. (Although the AN/FCC-3 is shown as the single sideband terminal equipment (36), this will eventually be replaced by the AN/FGC-29, a 16 channel system.) In order to obtain the optimum system grouping with minimum loss of circuit capacity, the jack field of the patchboard shall be arranged as follows: circuits 1 through 8, and 27 through 34 shall be assigned for the send side of the first 16 channel system; circuits 9 through 16, and 35 through 42, the second system; and circuits 17 through 24, and 43 through 50, the third system. Circuits 25, 26, 51, and 52 will be unassigned. Since the capacity of the SB-467/FG is for 104 circuits, the associated receive channels will be grouped in the same manner. Thus, circuits 53 through 60, and 79 through 86 will contain the 16 channels of the receive system associated with the send system immediately above; circuits 61 through 68, and 87 through 94, the second system; and circuits 69 through 76, and 95 through 102, the third system. Circuits 77, 78, 103, and 104 will also be unassigned. Additional patchboards as required will be placed adjacent to the first; thus, the system grouping shall progress in the same order toward the right.

(8) The unclassified d-c patchboard (34) will also be grouped for 16 channel system operation as described above. By virtue of the system application it will be possible here to maintain the same sequential order of the single sideband terminal (36) on the *looping* jacks that is established for the system terminating on the *set* jacks.

c. SUMMARY.—The foregoing discussion should be sufficient to have established the procedures to be followed in this and similar portions of any system. Additional criteria pertaining to the subscriber circuit follows:

In the subscriber circuit terminal, the send teletype equipment (1) is shown terminated on the *set* jacks of a d-c patchboard (3). This patchboard is provided in torn-tape relay centers and message centers to permit substitution of equipment primarily for maintenance,

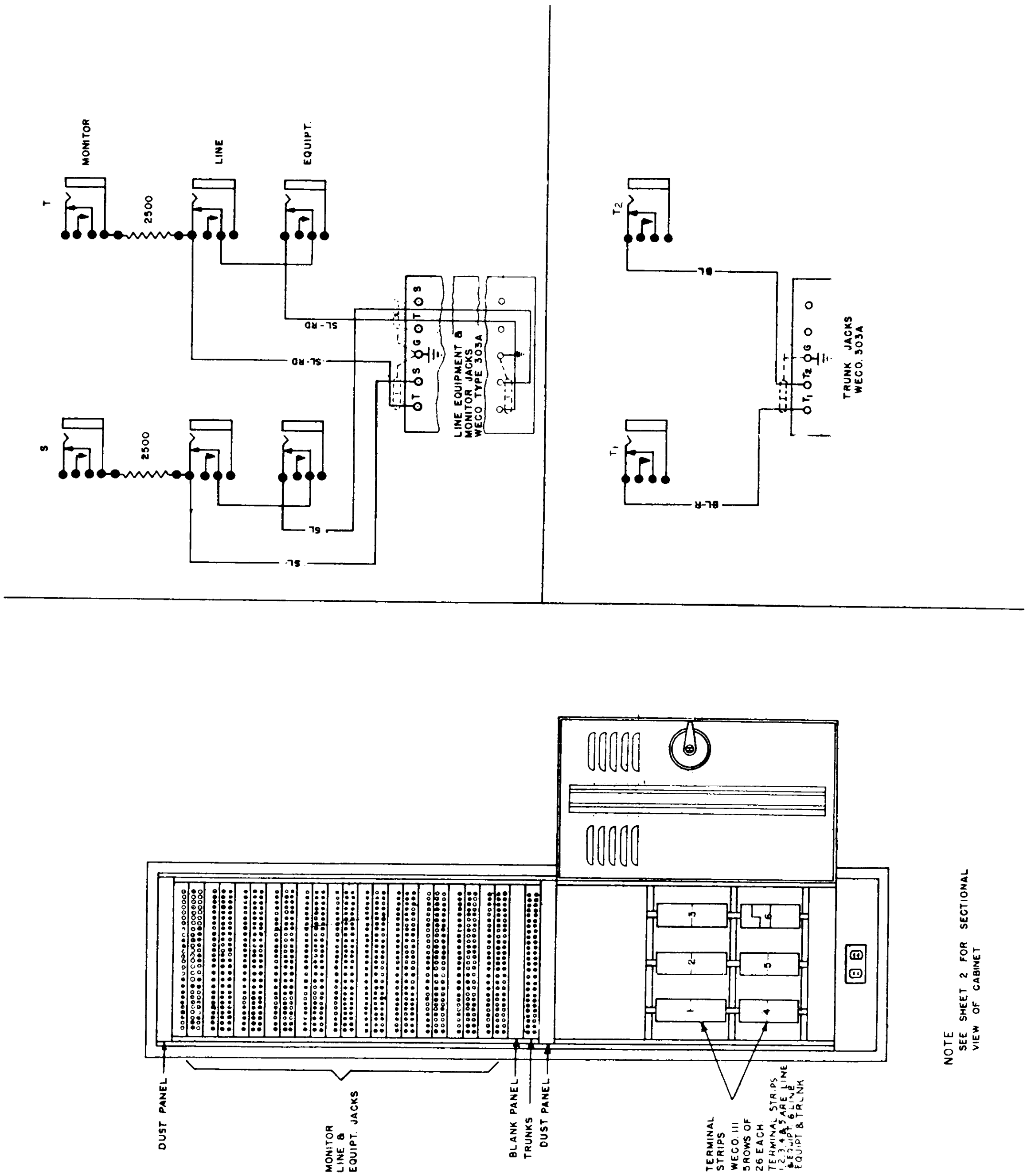


Figure 2-30. Audio Patchboard, Navy Typ SB-470/FG

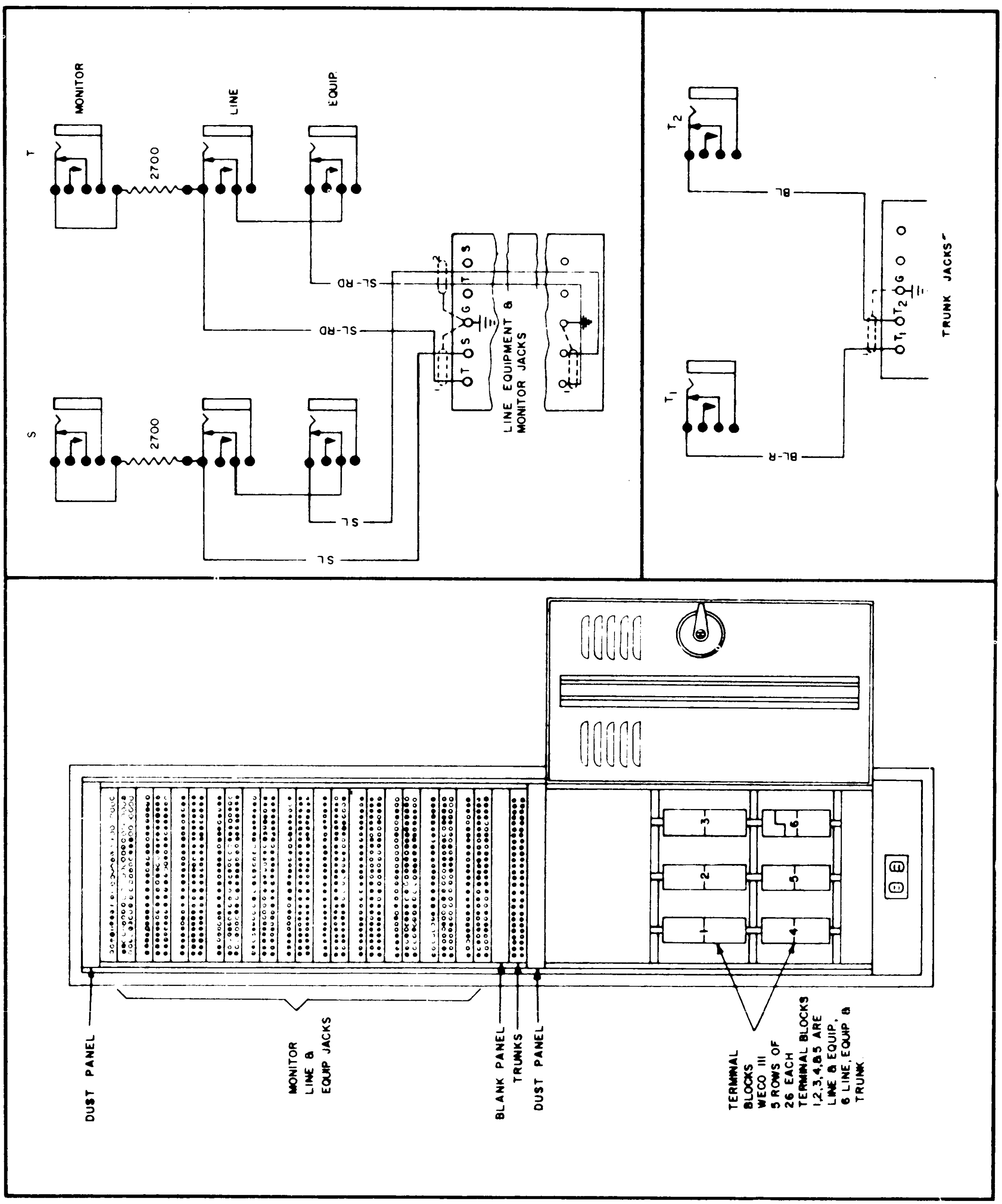


FIG. 2-30 AUDIO PATCHBOARD NAVY TYPE SB-470/FG

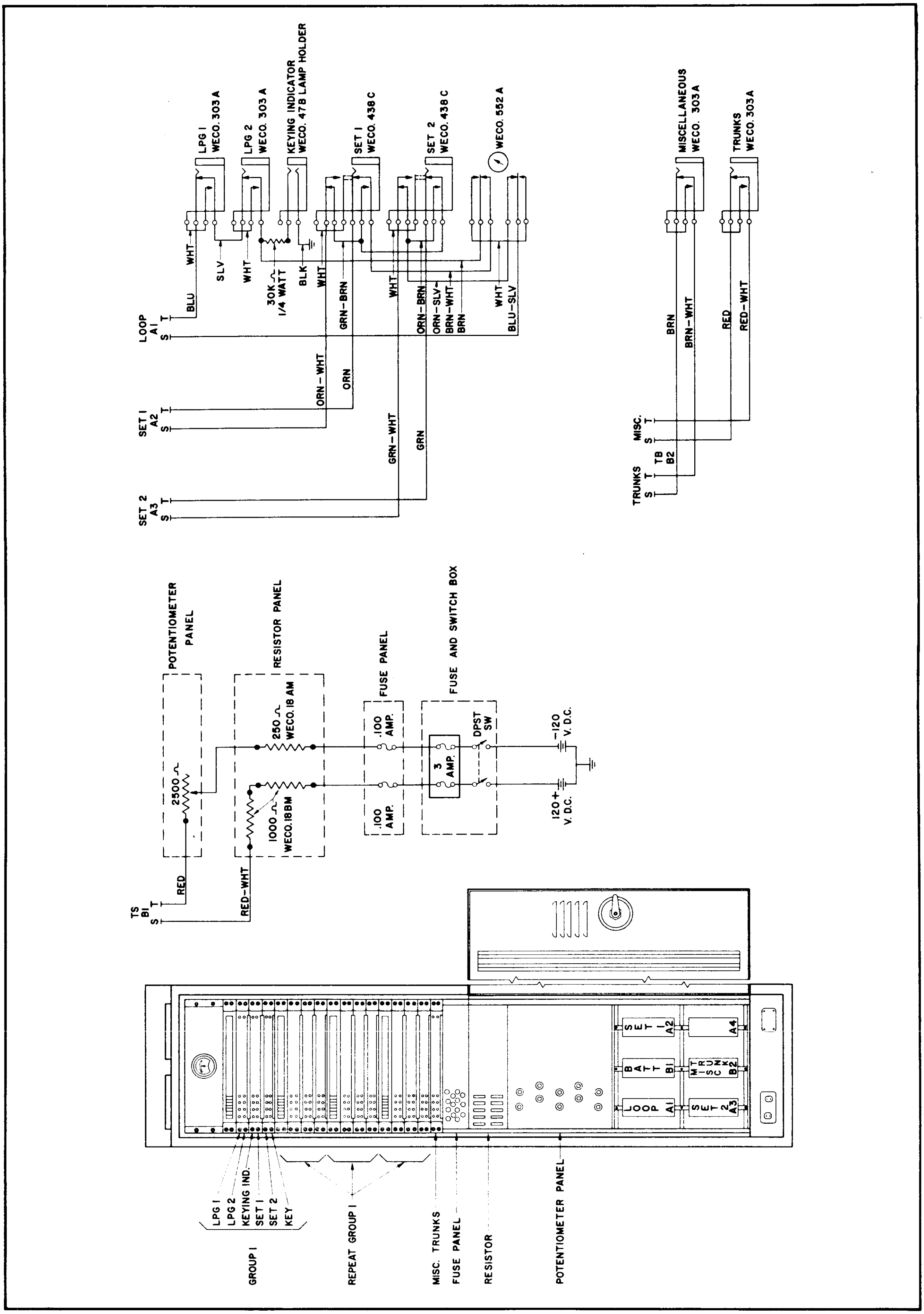


FIG. 2-31 TELETYPE PATCHBOARD, NAVY TYPE SB-467/FG

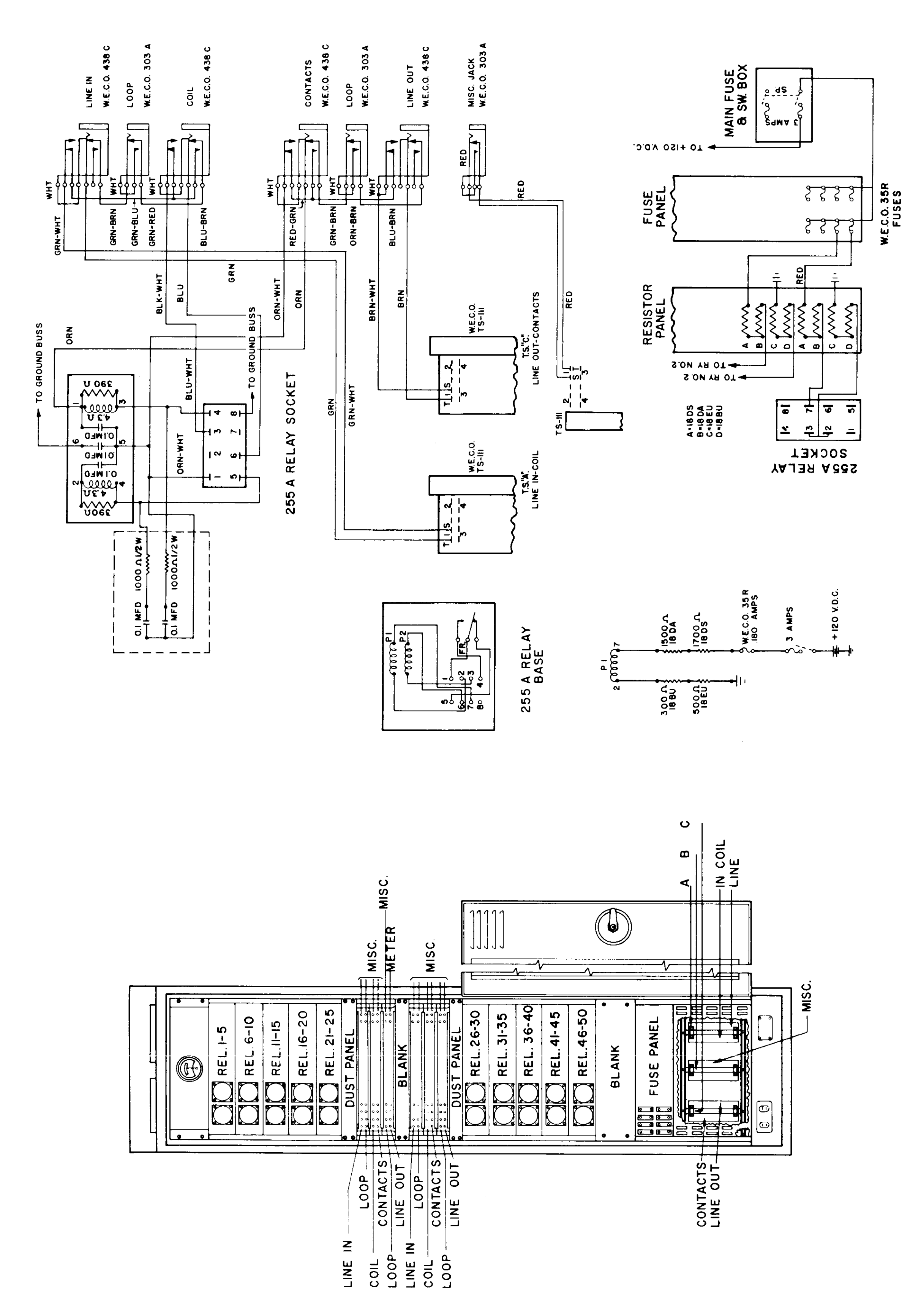
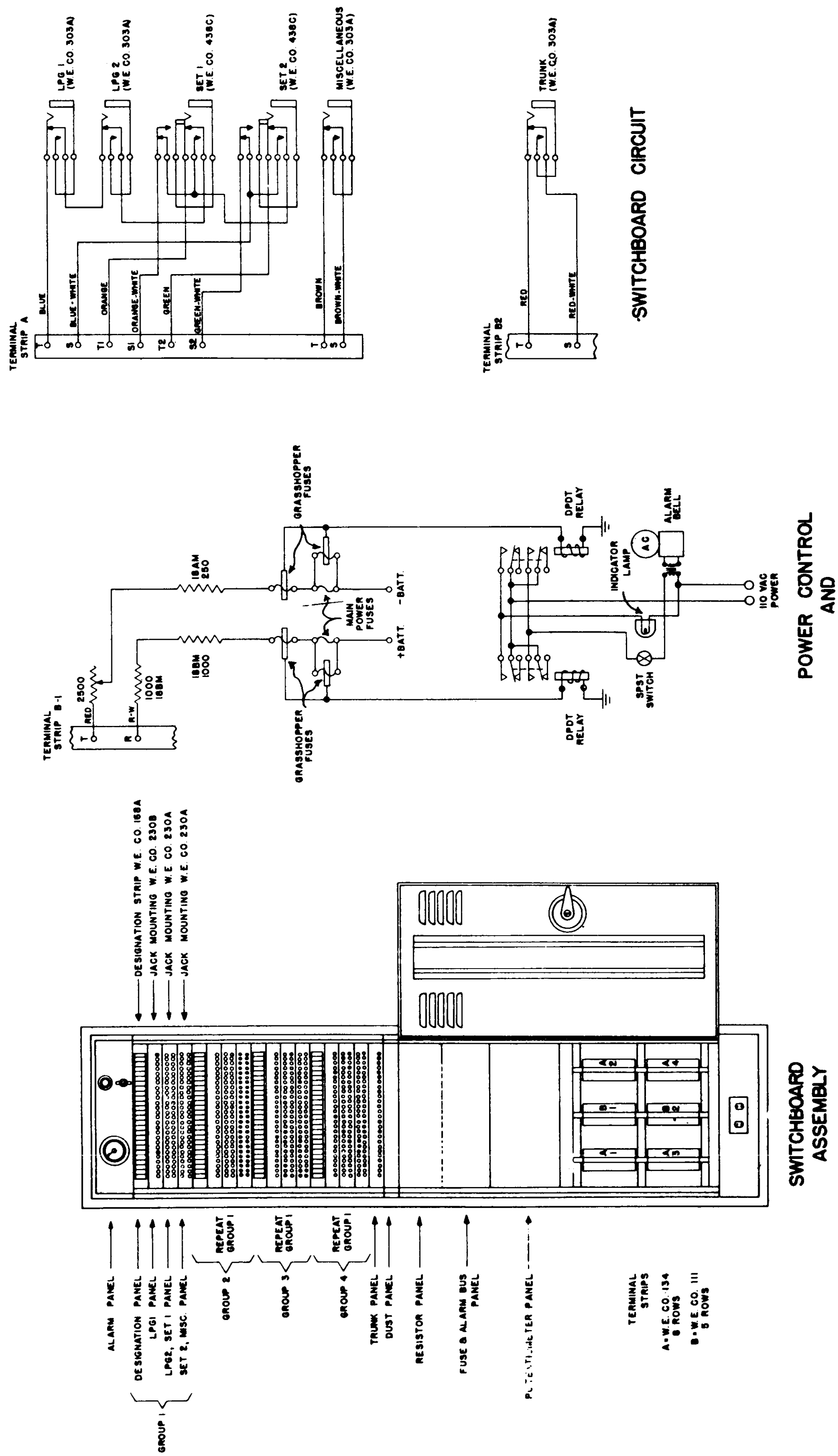


FIG. 2-31a RELAY PANEL



Figur 2-31. T l typ Patchboard, Navy Type SB-467/FG

although it may be used infrequently for operational purposes. On this board the *set* jacks shall be arranged in a sequential order since quick location of a local machine is of greater importance. The *looping* jacks do not necessarily terminate in the same order as the AN/FCC-3 equipment on the SB-467/FG (8) since the channel assignment for the AN/FCC-3 equipment may be changed from time to time for technical reasons. The remainder of the subscriber terminal circuits follows the previously described system design.

NAVSHIPS 92326 should be referred to for detailed circuit connections. Additional information will also be promulgated by the Bureau as indicated in the Foreword. Further discussion concerning distribution frames and patching facilities is contained in 2-15, INSTALLATION PRACTICES.

2-6. RADIO LINK SYSTEMS.

a. PURPOSE OF RADIO LINKS.—Radio links as employed by the Navy are wide-band systems which, as complete systems, or with external voice-band carrier equipment, provide several voice-band channels over a single radio-frequency channel. Operation is in the VHF, UHF or microwave portions of the radio spectrum and therefore requires line-of-sight transmission paths. The wide-band feature permits voice channels to be system engineered to support telegraph carrier equipment permitting a multitude of high-quality telegraph channels on each radio-frequency system, or may be engineered for wide-band applications such as for radar data transmission.

The primary purpose of the Navy multi-channel communication link installations is to provide keying of transmitters by the circuit terminal equipment and receiver output keying of circuit terminal equipment at a communication activity. Remote control functions required by certain standard Navy transmitters and remote control of receivers may also be effected by these channels. Channels are also allocated for order wire, link system control, and where required for telephone service. Presently installed communication control links (CCL) are mostly in the VHF range but most of this equipment is being replaced by equipment operating in the 1700 to 2400 mc range of the microwave region. The terminal ends of these link circuits are provided with both transmitters and receivers for simultaneous multi-channel operation and includes appropriate standby equipment. Where the link terminals are separated more than thirty miles or, because of terrain, a deviation from a straight line is required, one or mort link repeater stations or passive reflectors must be provided. The repeater station will contain two active transmitters and receivers to facilitate simultaneous two-way communication.

Radar link systems provide means whereby radar data is supplied for operation of remote indicators and application is at localities where installation of the radar is at a distance which precludes use of video cables. The frequencies used for this service in presently available equipment is in the 7000-7500 mc portion of the microwave region and thus requires special microwave techniques for installation as described in Appendix VI.

b. COMMUNICATION CONTROL EQUIPMENT.—The Navy Model UQ Radio Relay Link Equipment is standard for this type of installation at present, and detailed discussion of operation, installation, and maintenance is contained in the instruction books provided.

A typical installation wiring diagram is shown in figure 2-32 with a brief description of the items of equipment as follows:

(1) ANTENNA.—The antenna, used for both receiving and transmitting, has either a six-foot or a ten-foot parabolic bowl reflector and is mounted on an appropriate tower.

(2) RADIO TERMINAL GROUP, OA-501/FRC.—In two-way terminals, the minimum amount of RF equipment required for operation is a receiver, a transmitter, antenna equipment and a power supply. To enable one antenna to be used for both transmission and reception, a diplexing filter must be added. This group is designed to provide 100 percent standby equipment, so several other units are added. These are a receiver, a transmitter, a power supply, and automatic switch-over equipment (including coaxial switches). For convenience in making certain connections, a termination and convenience outlet panel is included.

(3) VIDEO PATCH, SB-325/FRC.—This Radio Signal Distribution Panel includes three rows of four connector-adapters each, which are provided so that, where both active and standby multiplex equipment is supplied, video connection between active and standby RF equipment and normal or spare modulator and demodulator equipment can be changed easily and quickly.

(4) DEMODULATOR GROUP, OA/504 FRC.—This group includes components needed to re-create each audio signal from a pulse train applied to the multiplex equipment by the receiver and to present each separate signal to its proper output.

(5) MODULATOR GROUP, OA/502 FRC.—This group contains equipment needed to receive speech and/or signalling information from as many as 23 different sources at the same time, to prepare and insert this information into a pulse train, and

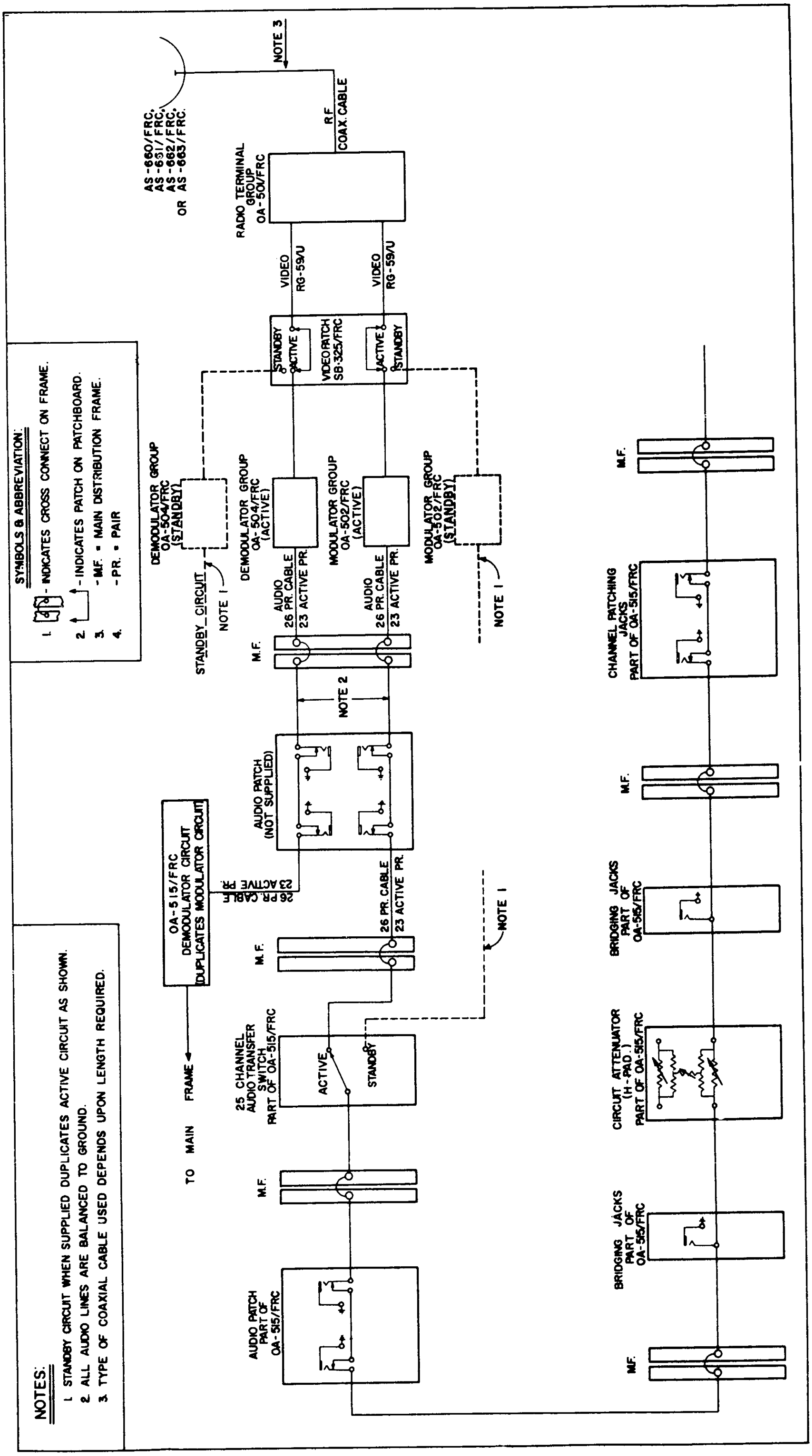


Figure 2-32. Microwave R lay System, Block Diagram

to apply the pulse train to the transmitter. The equipment is used at terminal stations.

(6) MAIN FRAME.—Following standard installation practice, all control equipment is wired through the main frame in order that wiring changes may be effected and new equipment added without affecting existing equipment wiring.

(7) PATCH PANELS AND TEST GROUPS, OA-515/FRC.—Patch groups are required for use with each basic multiplex equipment. Therefore, 23-channel, two-way terminal stations have two patch groups, one for use with the modulator equipment, the other for use with the demodulator equipment.

c. RADAR RELAY EQUIPMENT.—In order to provide remote radar display for radar air traffic control, and other applications where a radar site is too remote for practical video cabling, microwave radar link equipment may be prescribed. A block diagram of a typical system is shown as figure 2-33 with a brief functional description as follows:

(1) PURPOSE.—The Mototola MRR-3A Microwave Radar Relay system provides a microwave carrier for transmitting azimuth information, radar video, trigger pulses, and range marks from a radar location to a remote plan position indicator. Normally, this information is transmitted from the radar equipment to the PPI by means of a cable. By substituting the cable with the MRR-3A system, it is possible to provide PPI presentation of radar information at a location many miles from the radar site. Separation distances of 15 to 30 miles are accomplished between the microwave transmitting terminal at the radar site and the microwave receiving terminal at the PPI location, as long as a "line-of-sight" path is maintained. Greater terminal separation is possible by using as many microwave repeater stations as are necessary.

(2) DESCRIPTION.—The Microwave Radar Relay is primarily designed for use with intermediate and early warning radar systems. It is capable of relaying the following radar information: three radar video signals, trigger pulses, range marks, and azimuth information.

At the transmitting terminal the radar information from the radar set is fed into the video transmitting equipment which applies it as modulation to two microwave carriers in the 7125 mc to 7425 mc band. Azimuth information from the radar set is converted by the azimuth transmitting equipment into three voltages whose relative phase is determined by antenna position. These voltages modulate three subcarrier transmitters. Radar video 1, trigger pulses, and the subcarriers containing azimuth information are combined as a composite signal and applied as modulation to the microwave transmitting klystron operating on channel A. Range marks, radar video 2, and radar video 3 are combined as a composite signal and applied as modulation to the microwave transmitting klystron operating on channel B.

A single antenna is used for the simultaneous, continuous transmission of the two microwave channels. The basic antenna structure consists of a waveguide horn feeding a paraboloid antenna.

In most installations a tower is essential to obtain the necessary "line-of-sight" condition between transmitting and receiving stations. In typical installations the antenna is mounted at the base of the tower and is directed upward toward a 45-degree passive reflector placed at the top of the tower. The reflector, when properly adjusted, deflects the beam in the desired direction.

No reflector is required at locations where "line-of-sight" conditions prevail without using a tower. In such locations, the antenna is mounted vertically on the RF housing, and direct horizontal propagation is obtained without reflectors.

At the receiving terminal both channels are received on one antenna and waveguide system. Preselector cavities in the waveguide system separate the two channels and feed them to two receivers. The output signals from the receivers are fed to video separators. The signals from the channel A receiver go into a video separator as a composite video signal and is separated into three signals: radar video 1, trigger pulses, and three subcarrier signals. Subcarrier receivers demodulate the subcarrier signals into three voltages whose phase relationship contains the azimuth information. A servo amplifier and gear train unit convert these phase-shifted voltages into azimuth signals suitable for driving the PPI servo system. The channel B signal is separated in another video separator into radar video 2, radar video 3, and range marks.

These six output signals (three radar videos, trigger pulses, range marks, and azimuth information) provide the necessary inputs for normal operation of a remote PPI.

d. OPERATIONAL REQUIREMENTS.—In the development of a new facility or in modification of an existing one by providing microwave link facilities, a careful interpretation must be made of the operational requirements of the stations to be linked. The 23 channels provided by the standard microwave communication link equipment used in this discussion would normally be sufficient to supply the needs of most stations especially where it is realized that each channel can be engineered for multi-circuit operation by the use of tone channels. The project engineer will, however, make a thorough investigation of the requirements in order to provide sufficient equipment

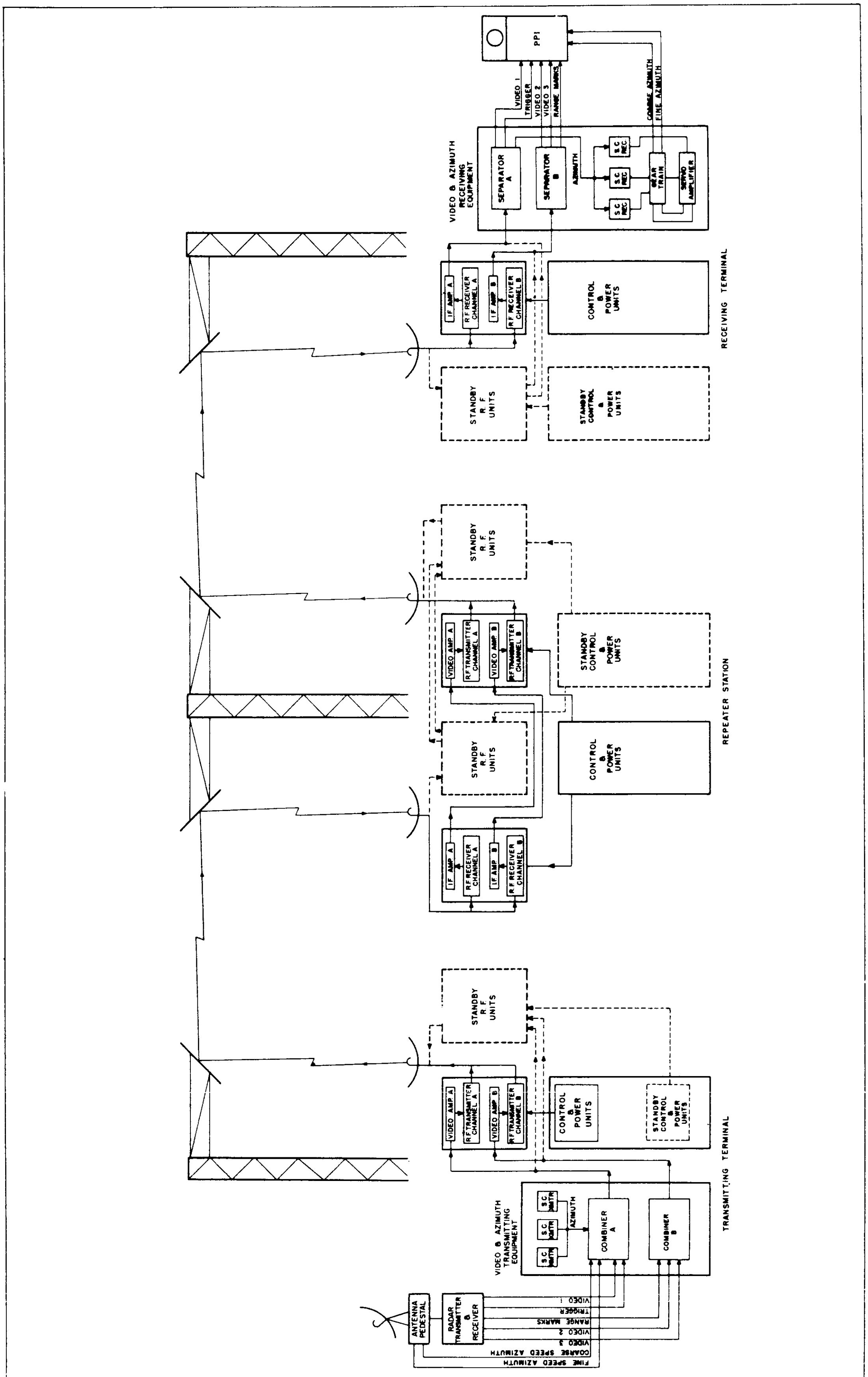


Figure 2-33. MRR3-A Radar Relay Syst m, Block Diagram

to meet existing requirements and to provide for expansion of facilities when required. Due consideration must also be given to standby equipment and facilities for rapid change-over in order to provide 100% uninterrupted service if possible.

In planning a new facility, the Bureau of Ships provides the Management Bureau with a list of the equipment requirements and their cost; final installation costs being determined by the Industrial Manager or other Bureau of Ships representative. Criteria for project construction and collaboration with Public Works and Management is outlined in Section 1 of this handbook.

e. SITE CONSIDERATIONS.—The most important use for microwave link facilities by the Navy is in the provision for control links between the component stations of a communication activity. These stations are normally situated so as to form a triangle with link paths forming the sides of the triangle. Site selection for each component, the transmitter station, the receiver station, and communication center, is not only made with due regard for maximum utility of the station itself, but with consideration for interconnection with the other component stations by means of the microwave link circuits. The discussion, contained in Appendix VI, concerns the general engineering problems associated with site selection so as to provide microwave link facilities and with provision for relay stations if required. Final consideration will rest with the Bureau of Ships, where facilities available to this Bureau will be used to investigate meteorological and terrain conditions which will affect microwave transmissions along any particular path under consideration. From these observations, final criteria for the establishment of a link facility can be determined.

f. TOWERS AND ANTENNAS.—Antennas used in the microwave region are usually of the paraboloidal reflector type which have a very narrow beam. For that reason, supporting structures must be rigidly constructed to prevent twisting or flexing to such a degree that the beam is deflected away from normal during high winds or for other causes. Deflection limit for antennas is in the order of a few degrees and for a passive reflector as shown schematically in figure 2-33, less than one degree. The exact limitations are usually given in the applicable instruction books. Tower height requirements depend on terrain and are specified in Appendix VI. In specifications for initial construction of towers for link service, space should be provided for additional antennas if required for expansion of service or for use in diversity.

g. REFLECTORS.—Passive reflectors may be used in place of repeaters in some applications such as where the direct beam path is over an intervening hill. This requires careful engineering, taking into consideration additional path attenuation and the reflection losses that will be present.

Two types of passive reflectors are used, depending on the terrain. They are (1) plane reflectors, and (2) passive repeaters. If the repeater stations are so located that the signal can be bounced off a plane reflector to the receiving station, then the plane type will suffice. However, where a high ridge intercepts the beam, or a situation exists where a plane reflector cannot be made to reflect the signal toward the receiver, the passive repeater is used. This type consists of two parabolic antennas, one facing each repeater station, and connected together by means of a wave guide or coaxial cable. Considerable attenuation takes place in either application; more so in the passive repeater with its additional transmission line loss, and for this reason can be used only on short hops. Both have practical application where terrain makes maintenance and inspection of a repeater station difficult. Technical data concerning reflectors contained in Appendix [illegible]

2-7. HF DIRECTION FINDER STATIONS.

a. OPERATIONAL REQUIREMENTS. — In the establishment of a Direction Finder Station to meet an operational requirement, systems engineering is primarily concerned with criteria for the following:

Site selection so as to provide the best available site for direction finder operation;

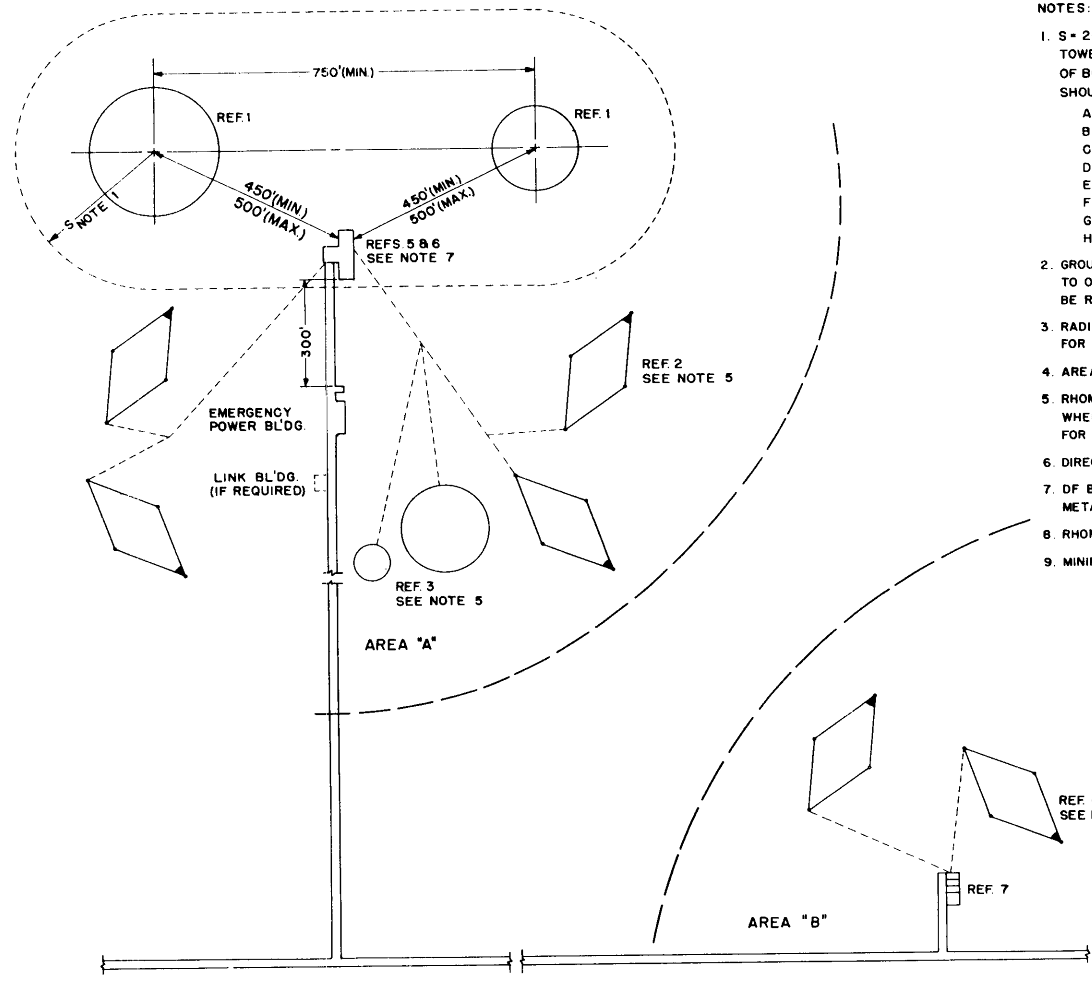
Equipment and antenna arrangement including provision for clearance which will provide optimum performance; and

Provision for communication facilities so that the station can be integrated with other direction finder and communication activities within the area that is to be served.

b. SITE CONSIDERATIONS.—Selection of the proper site is most important for the use of any known D/F methods. All factors, such as instrumental, technical, and environmental, must be carefully judged. The proper choice of site can reduce adverse effects to a tolerable value (from two to three degrees bearing error). Otherwise, the accuracy and reliability of results will be seriously threatened. Siting criteria as described in Appendix VIII shall be rigidly followed.

c. RECEIVING QUALITIES.—A D/F site must have excellent receiving qualities. Poor reception limits the range of D/F equipment and may introduce considerable bearing error, particularly if poor reception is caused by an unsymmetrical absorbing area. Preliminary determination of the reception must be made from a number of fixed stations over wide ranges of distance, azimuth, and frequency.

Field strength measurements should be made on local



NOTES:

1. S = 20 TIMES THE HEIGHT OR LENGTH OF ANY OBSTRUCTION (TREES, HILLS, TOWERS, ETC.) IN ADDITION. THE MINIMUM DISTANCE BETWEEN THE CENTER OF BOTH DIRECTION FINDER ANTENNA ARRAYS AND SPECIFIC OBSTRUCTIONS SHOULD BE MAINTAINED AS FOLLOWS:
   - A. HIGH TENSION POWER TRANSMISSION LINES (100' TOWERS OR GREATER) — 6000 FT.
   - B. TRANSMITTING ANTENNAS — 6000 FT.
   - C. METALLIC BUILDINGS (LARGE SINGLE OR CLUSTERS OF SMALL) — 5000 FT.
   - D. NON-METALLIC BUILDINGS (LARGE SINGLE OR CLUSTER OF SMALL) — 1500 FT.
   - E. RAILWAY LINES, RIVERS ETC. — 2500 FT.
   - F. AIRCRAFT DISPERSAL - POINTS, PARKING AREAS, ETC. — 1250 FT.
   - G. SHORELINES (1200 FT. DESIRABLE) — 600 FT.
   - H. MAN-PROOF STEEL FENCE — 500 FT.
2. GROUND CONDUCTIVITY WITHIN DIRECTION FINDER SITE BOUNDARY MUST BE EQUAL TO OR GREATER THAN 10×10^{-14} EMU AT 10 MCS. VALUES LESS THAN THIS MUST BE REFERRED TO THE BUREAU.
3. RADIO INTERFERENCE FROM 1.5 TO 30.0 MCS. SHOULD BE LESS THAN 10 MV/M FOR FUNDAMENTAL SIGNALS AND 5MV/M FOR SPURIOUS OR HARMONIC SIGNALS.
4. AREA MUST BE ESSENTIALLY FLAT AND LEVEL.
5. RHOMBIC AND SLEEVE ANTENNAS AS WELL AS TRANSMITTING EQUIPMENT REQUIRED WHERE NOT OTHERWISE AVAILABLE. TRANSMITTING ANTENNAS SHOWN AS RHOMBICS FOR PLANNING PURPOSES.
6. DIRECTION FINDER BUILDING AND EMERGENCY POWER BUILDINGS TO BE SIMILAR TO REF. 6
7. DF BUILDING SPECIFICATIONS SAME AS REFERENCES 5 AND 6 EXCEPT THAT NO LARGE METALLIC OBJECTS MORE THAN 8 FT. ABOVE FLOOR NOR 11 FT. ABOVE GRADE.
8. RHOMBIC ANTENNAS NOT DRAWN TO SCALE.
9. MINIMUM DISTANCE BETWEEN AREA "A" AND "B" IS ONE MILE.

REFERENCES		
NO.	TITLE	DRAWING NO.
1	AN/GRD-6 DIRECTION FINDER	RE 36 F 2042-46
2	ANTENNA DETAILS RADIO REC. RHOMBICS	RE 66 F 2017
3	RECEIVING SLEEVE ANTENNA	RE 66 F 2075
4	ANTENNA 3-WIRE TRANS. RHOMBIC	RE 66 F 2019
5	TYPICAL LAYOUT AND SPECS. NAVAL SHORE DIRECTION FINDER STATION	RE 6 F 2055
6	OPERATION BUILDING DETAIL	BUDOCKS 508242-43-44-45-57-60-62-64
7	TRANS, UTIL, BARRACKS DETAILS	BUDOCKS 508247-48 THRU 59 & 63

Figure 2-34. Typical Plot Plan for AN/GRD-6, HF Direction Finder

and distant transmissions and the noise level at the site determined. A survey of sites under consideration, conducted in the manner prescribed for a communication receiver station, and using the form (Appendix IV) will be of assistance to the project engineer in making engineering decisions pertaining to site selection.

d. FACILITY ARRANGEMENT.—Figure 2-34 is provided to show the typical layout of a D/F station. As indicated on the drawing, receiving and transmitting facilities are required only when they are not available locally. Control cable or radio link facilities are provided as required for communications.

Building requirements are outlined in Section 1 of this manual, with information on buildings, antenna construction, and equipment layout available in the referenced drawings on figure 2-34.

Cables other than those associated directly with the D/F equipment must be kept as far from the center of the arrays as possible. They should be buried under good conductivity soil to the following depths:

Minimum depth	*Distance to center of array*
5 feet	300 feet
3 feet	300-600 feet
2 feet	beyond 600 feet

The depth of burial should be increased with decreasingly poor soil.

e. ADCOCK ANTENNAS.*—Direction finders presently in use at HF D/F stations employ Adcock antenna arrangements.

The Adcock antenna in its simplest form consists of two spaced vertical antennas. The action of this arrangement, as far as vertically polarized waves are concerned, is identical with a loop since the resultant current in the output coil of such an Adcock system is proportional to the vector difference of the voltages induced in the two vertical members, exactly as in the case of the loop. Horizontally polarized downcoming waves do not affect the Adcock antenna, however, since the voltages induced in the two horizontal members which connect the two vertical members to the feeder, are of the same magnitude and phase, and so cancel out as the result of the circuit arrangement.

The effective height of an Adcock antenna is the same as that of a one-turn loop of corresponding dimensions. A loop is not limited to a single turn, and generally consists of several turns with the resultant signal the sum of those induced in each turn. Since the Adcock is basically one turn, a larger physical structure must be used to obtain comparable response. This is one of the chief limitations of the Adcock antenna.

* By permission from Radio Engineers' Handbook by Frederick Emmons Terman, Sc.D. Copyright 1943. By the McGraw-Hill Book Co., Inc.

The value of the Adcock antenna system is the greatly reduced susceptibility to polarization errors. Adcock systems are hence especially valuable at short waves, and at ultra-high frequencies, where loops perform least well.

A perfectly symmetrical Adcock antenna system would have zero polarization errors if operated in free space remote from all other objects. However, when the antenna system is in the vicinity of the earth as it must be in a practical installation, polarization errors are present to a greater or lesser extent. These errors, however, may be reduced by using an extensive ground mat.

The sensitivity of the Adcock system to neighboring objects, and particularly the earth, has resulted in the employment of two pairs of Adcock antennas at right angles to each other in a goniometer system, which is the system presently employed at a HF D/F station.

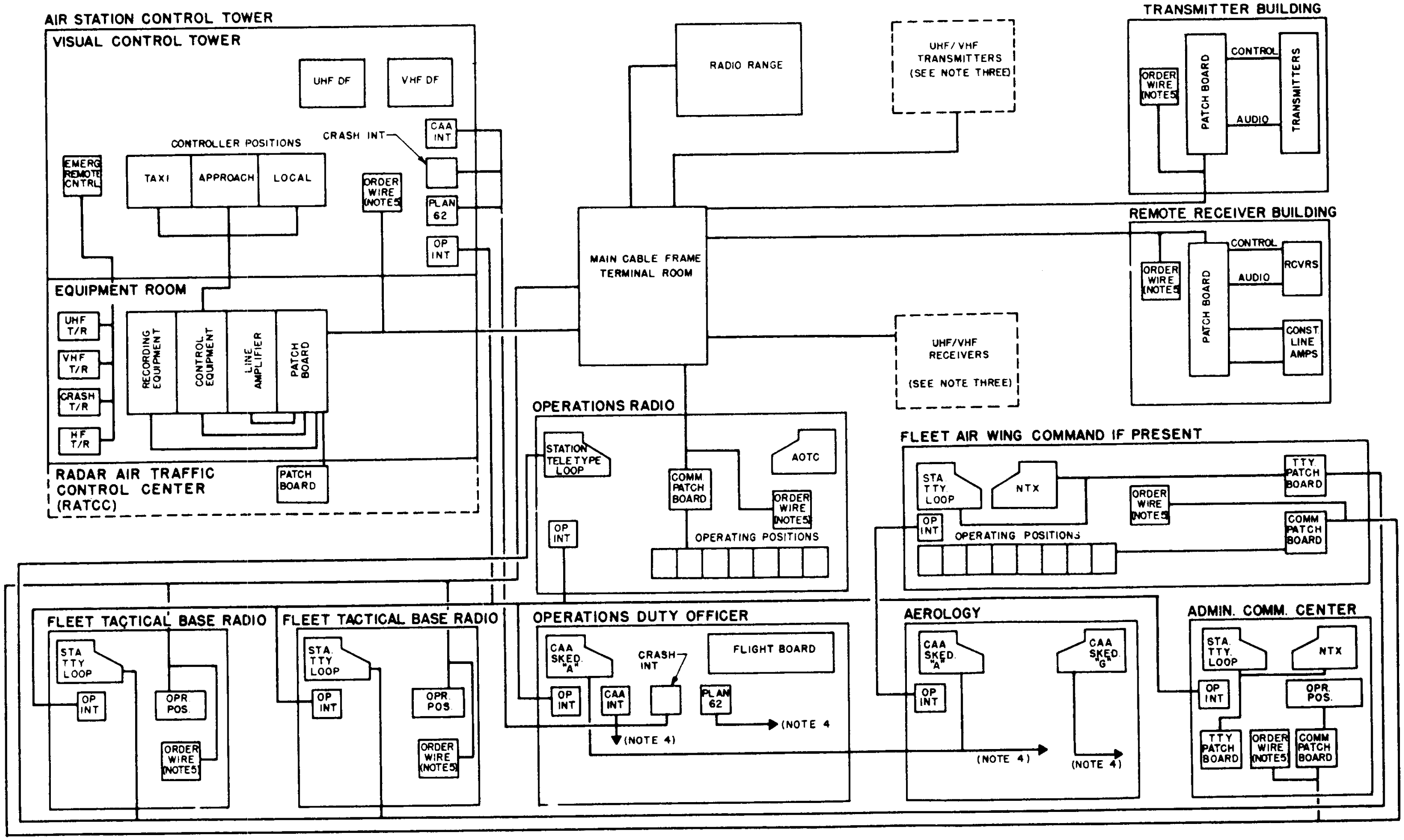
Adcock antenna systems are subject to vertical antenna pickup just as are loop systems. With Adcock arrangements, antenna effect arises from failure to maintain symmetry between the various vertical antennas and their associated leads and coupling coils. Electrostatic shielding of horizontal members and also the use of electrostatic shields in the coupling coils helps reduce unbalances.

In order to minimize errors in performance, it is imperative that precise location and exact installation specifications be followed in system engineering of a D/F station. This includes the use of a properly designed and installed ground mat which serves to minimize ground effects. The mat stabilizes local ground electrical constants and results in decreased polarization errors and antenna effect.

f. EQUIPMENT REQUIREMENTS. — Equipment selection to meet the requirements is accomplished by the Bureau of Ships which provides the Management Bureau with a list of equipment to fill the operational needs of the individual activity. Final equipment installation costs are determined by the Industrial Manager or other Bureau of Ships representative. Criteria for project construction and collaboration with Public Works and Management is outlined in Section 1 of this handbook.

2.8. NAVAL AIR STATION COMMUNICATION FACILITIES.

a. OPERATIONAL REQUIREMENTS. — Radio communications at a Naval Air Station include facilities for ground-to-air communication with tactical and transient aircraft, for control of aircraft departures and landings, and for communication with other air stations and connection to the N.C.S. Systems engineering is concerned in the development of such facilities



1 NUMBER OF TRANSMITTERS TO BE IN ACCORDANCE WITH THE ALLOWANCE LIST
2 TRANSMITTERS MAY BE COMBINED WITH A NAVAL RADIO STATION (T) OR NAVAL RADIO FACILITIES (T) WITH ADEQUATE CONTROL LINES TO MEET ALL AERONAUTICAL REQUIREMENTS
3 WHERE HF TRANSMITTER AND RECEIVER BUILDINGS ARE SO LOCATED THAT LINE OF SIGHT COVERAGE TO RUNWAYS AND TAXI AREAS CAN NOT BE OBTAINED, UHF/VHF FACILITIES MUST BE PROVIDED TO MEET THESE CONDITIONS.
4 RENTED SERVICE.
5 ORDER WIRE UTILIZING COMMON BATTERY TELEPHONE INSTRUMENTS TO BE PROVIDED BETWEEN ALL COMMUNICATION CONTROL SPACES AND TRANSMITTER-RECEIVER FACILITIES. ORDER WIRE IS TO BE INDEPENDENT OF THE OPERATIONS INTERPHONE AND STANDARD PBX TELEPHONE SYSTEM.
6 ONLY TRANSMITTER AND RECEIVER CONTROL AND ORDER WIRE MAY BE INCLUDED IN THE COMMUNICATION CONTROL CABLE.
7 FLEET AIR WING AND OPERATIONS RADIO MAY BE INTEGRATED IF OPERATIONALLY DESIRABLE.

Figure 2-35. Naval Air Station Communication Faciliti s by prescribing the equipment and establishing communication systems which will most effectively meet the operational requirements as established by the Chief of Naval Operations (DNC) for the Naval Air Station. Installation of such equipment under the technical control of the Bureau of Ships through the local Industrial Manager or other representative, shall be in accordance with criteria as outlined in 1-22*d*, NAVAL AIR STATION RADIO FACILITIES. General requirements are as shown in figure 2-35.

b. DEVELOPMENT.

(1) CONTROL TOWER FACILITIES.—The tower, which under standard specifications is five stories high, provides space for the installation of electronic equipment, in the first, third, and fourth floors in addition to facilities for control and operation of the equipment in the Control Cab. Standard cellular floor construction provides space for cable runs and permits standard installation practices. Equipment is provided for tape recording of air traffic control communications. Air Stations and Auxiliary Air Stations are furnished with a standard Control Monitor Group, located in the visual control cab, which provides three operators stands or positions, for control of radio communication equipment. Normal equipment allowances generally prescribe five UHF, four VHF, and three HF channels under control of tower operators. The present standard communication control system for air traffic control towers is the AN/FRA-11 Control Monitor Group. A brief functional description follows:

(*a*) CONTROL MONITOR INDICATORS.

1. Three operating position control indicators, C-1443/FRA-11, designated "A," "B," and "C," are furnished. Each is identical in design, both physically and electrically, and are installed in the Control Cab.

2. The control indicator provides switches for control of 16 transmitting channels, with lamps to indicate a channel in "ready" condition and another to indicate it in "use."

3. It provides control of 16 receiving channels; control to consist of one switch in the loudspeaker circuit, one switch controlling the signal into the operator's headset, and an indicator lamp to identify the channel on which signal is being received.

4. A jack is provided for a Western Electric 52C headset or equal, with attenuator pad for adjusting level in the headset receiver.

5. Arrangement of controls is such that additional circuits may be added without removal of the console from the tower.

6. Panels on which switches and components are mounted are in accordance with Bureau of Ships drawing RE 23F 225D.

7. The compartment enclosing the components, terminal strips, etc., has a sloping top with a 20 degree rise; panels are mounted to permit access from the top. The compartment has sufficient height to accomodate components, wiring, and external connections; yet the top panel is not too high for operator comfort, in reaching and manipulating the controls while seated, and the bottom arranged to permit freedom of movement of limbs while operating a foot switch.

(*b*) CONTROL EQUIPMENT.

1. Four equipment cabinets which contain the AN/FRA-11 amplifiers, power supplies, etc., are located in the electronics equipment room directly beneath the control tower. The cabinets are mounted side by side and with a minimum clearance of 30 inches for servicing at the front and rear. This clearance is required to accommodate DB meters and signal generators used frequently in operational maintenance. The equipment racks contain the following AN/FRA-11 components and accessories:

a. Sixteen Relay Assemblies, RE-166/FRA-11.
b. Three Amplifiers, Audio Frequency, AM-1043/FRA-11 or AM-413/G.
c. Four Amplifiers, Audio Frequency, AM-1042/FRA-11.
d. Two Amplifier Assemblies, AM-1044/FRA-11.
e. Three Power Supplies, PP-1143/FRA-11.
f. One Panel, Signal Distribution, Radio, SB-390/FRA-11.
g. Two Power Supplies, PP-1142/FRA-11.
h. One Panel, Power Distribution, SB-389/FRA-11.
i. Six Patch Panels.
j. One Patchcord Storage Panel, MX-814/G
k. One Patchcord Retainer Pulley Assembly, MX-813/G.

(*c*) RECEIVE, TRANSMIT, AND POWER SYSTEMS.

1. The receiving system of the control monitor group is designed to receive, amplify, and distribute the audio outputs from any combination of 16 radio receivers.

Special features of the receiving system are squelch circuits which reject undesirable receiver and line noises, and mixer amplifiers which eliminate the need of individual speakers for each channel. The received signals may be switched to overhead speakers, pull-down speakers, or to headphones at the discretion of the operator.

The receiver lines are routed via a jack panel to provide rapid switching between receiver outputs and the 16 control monitor group channels. Additional jacks provide patching between receiver outputs and voice recorders.

Indicator lamps provide visual indication for each received channel.

2. The transmitting system of the control monitor group can be considered as two separate systems: an audio signal distribution system for transmitter modulation, and a control system for transmitter keying.

The transmitter audio distribution system is designed to use either carbon or dynamic microphone inputs. The microphone outputs are amplified to produce ϕ DBM audio level into a control line connected to the remote transmitter and are switched to the desired transmitter, or transmitters, by use of the 16 channel selector switches. Each channel of transmitter audio is routed via jack panel to provide rapid switching between transmitter audio inputs and the 16 control monitor group channels.

The transmitter control system utilizes a network of d-c relays and provides keying of any combination of transmitters. Transmitter selection is accomplished by the same channel selector switches as are used for the above audio switching; the channel selector switches being common to the audio and control circuits. The keying lines are also routed via jack panels to provide for rapid switching of channels. Interlocking relays prevent an operator keying a transmitter that is already in use.

2. The AN/FRA-11 is designed to operate from a 115 V., 60 cycle, 1 phase, a-c source. Self-contained power supplies furnish the required D. C. voltages.

(*d*) ADDITIONAL CONTROL FACILITIES. —VHF/UHF direction finder indicators are located adjacent to the third operator stand or as directed by local authorities; with D/F antennas on the tower roof or poles as required to meet local requirements. Antennas should be elevated above all other structures and for optimum performance; criteria for siting as described in Appendix VIII apply, and should be followed insofar as practicable.

Radio facilities are provided for communication with and control of crash vehicles as prescribed for "crash operation" communications. (See para. (10).)

Other facilities include aerological instruments, telephone, inter-communication circuits, and field lighting as required by cognizant authority.

(2) RATCC.—On stations designated Radar Air Traffic Control Centers, the requirement for a complete and rapid changeover between radar and manual traffic control, without compromising flight safety, dictates a need for the utmost reliability of communications between air controllers and pilots. It is therefore required that in addition to the control tower equipment which can be operated jointly by the Control Cab and RATCC, standby electronic communication equipment required in the tower area for Radar Air Traffic Control Centers' use will be as prescribed by current directive and connected to permit selected operation from either the primary or emergency power source.

The location of the Radar Air Traffic Control Center is in the operations building with provision for accessibility to tower communication facilities. The equipment layout showing communication consoles and radar display are shown in figure 2-36 and are discussed further under "Navigational Aid and Traffic Control Facilities."

(3) OPERATIONS BUILDING. — Communication facilities provided in the Operations Building (which may or may not be attached to the control tower structure) include the Operations or Base Radio, and Fleet Air Wing Command, if required. Systems engineering will provide teletype equipment; operating positions, and patching facilities as required to meet the local operational requirements as indicated in the Basic Schematic Diagram, figure 2-35. Aerology is established within the operations building with equipment installed for reception of weather and for facsimile weather map service from commercial sources.

(4) ADMINISTRATIVE COMMUNICATION CENTER.—Located in the administrative spaces of the Naval Air Station, the Communication Center is equipped to handle the administrative traffic of the station. Teletype equipment normal for NTX operation, as well as minor relay facilities, are provided as required for local use. Total equipment requirements will be based on the overall communication requirements of the station, with consideration given to local teletype drops as well as relay facilities to other activities. Cryptographic facilities may be installed in either the operations or administration building by local option.

(5) TRANSMITTER HOUSE. — Location and general description are contained in Section 1. Systems engineering is concerned with selection of equipment to meet the operational requirements of the station. In this respect, the size of the transmitter building will be determined by the total number of transmitters, plus a 25% expansion factor, required to fulfill a given operational requirement. The total number of transmitters will govern which of the five standard building sizes to use.

The standard building as shown in figure 2-37, has

NO	UNIT	WIDTH	DEPTH	HEIGHT	WEIGHT	HEAT DISSIPATION
1	PPI IP-310/FPN-28	33 INS.	34 INS	42 INS.	400 LBS	850 WATTS
2	COMMUNICATIONS CONTROL PANEL					
3	PPI S.R. IP-309/FPN-28	33 INS.	34 INS.	42 INS.	350 LBS.	400 WATTS
4	STRIP BOARD					
5	PPI M.R. AN/UPA-35	26 INS.	35 INS.	42 INS.	575 LBS.	500 WATTS
6	DF					
7	TELEPHONE COMMUNICATIONS PANEL					
8	M.R. SITUATION DISPLAY	36 INS.	36 INS.	42 INS.	400 LBS.	700 WATTS
9	OA-827/FPN-28	39-3/4 INS.	25-3/4 INS.	88-1/2 INS.	525 LBS. 563 LBS.V.P.	250 WATTS
10	DESK					
11	OA-741/FPN-28	26-1/4 INS.	27-1/4 INS.	36-1/4 INS.	200 LBS.	350 WATTS
12	M.T.I.	34-3/8 INS	27 INS.	60-3/4 INS.	550 LBS.	
13	VIDEO DISTR.	24 INS.	29 INS.	63-9/16 INS.	570 LBS.	
14	POWER DISTR.	25 INS.	32 INS.	61-1/2 INS.	760 LBS.	
15	POWER CONTROL BOX	22 INS.	20 INS.	62 INS.	276 LBS.	
16*	(1) AN/UPX-1A (3) KY-80/UPA-24	54 INS.	24 INS.	RACK MOUNTED		
17	AN/UPM-4A (DOLLY MTD.)	36 INS	24 INS	50 INS.	300 LBS.	APPROX. 10 K.W.
18	PPI (DOLLY MTD.)	36 INS	24 INS	36 INS	500 LBS	
19	ANTENNA CONTROL	10-7/8 INS.	13-1/2 INS	37 INS	100 LBS.EST.	
20	RANGE INDICATOR (DOLLY MTD.)	19 INS.	32-3/8 INS.	52 INS.	203 LBS.	
21	MOD P/S	30 INS.	28 INS.	56 INS	1160 LBS.	
22	MOD	24 INS.	26-1/2 INS.	55-1/2 INS.	578 LBS.	
23	TRANSMITTER	32 INS.	24 INS.	57-1/2 INS.	680 LBS.	
24	RECEIVER	33-1/8 INS.	27 INS.	50-1/2 INS.	477 LBS.	
25	OA-826/FPN-28	28 INS.	25 INS	88-1/2 INS.	600 LBS	900 WATTS
26	PP-1269/FPN-28	26-3/4 INS.	19-1/4 INS.	53 INS.	380 LBS	900 WATTS
27	PP-1270/FPN-28	26-3/4 INS	19-1/4 INS.	53 INS.	350 LBS	1500 WATTS
28	CY-1555/FPN-28					
29	AMPLIDYNE	49-1/8 INS.	21 INS.			
30	S.R. SITUATION DISPLAY	36 INS.	36 INS.	42 INS.	400 LBS	700 WATTS

* PLUS OTHER ITEMS IF REMOTE

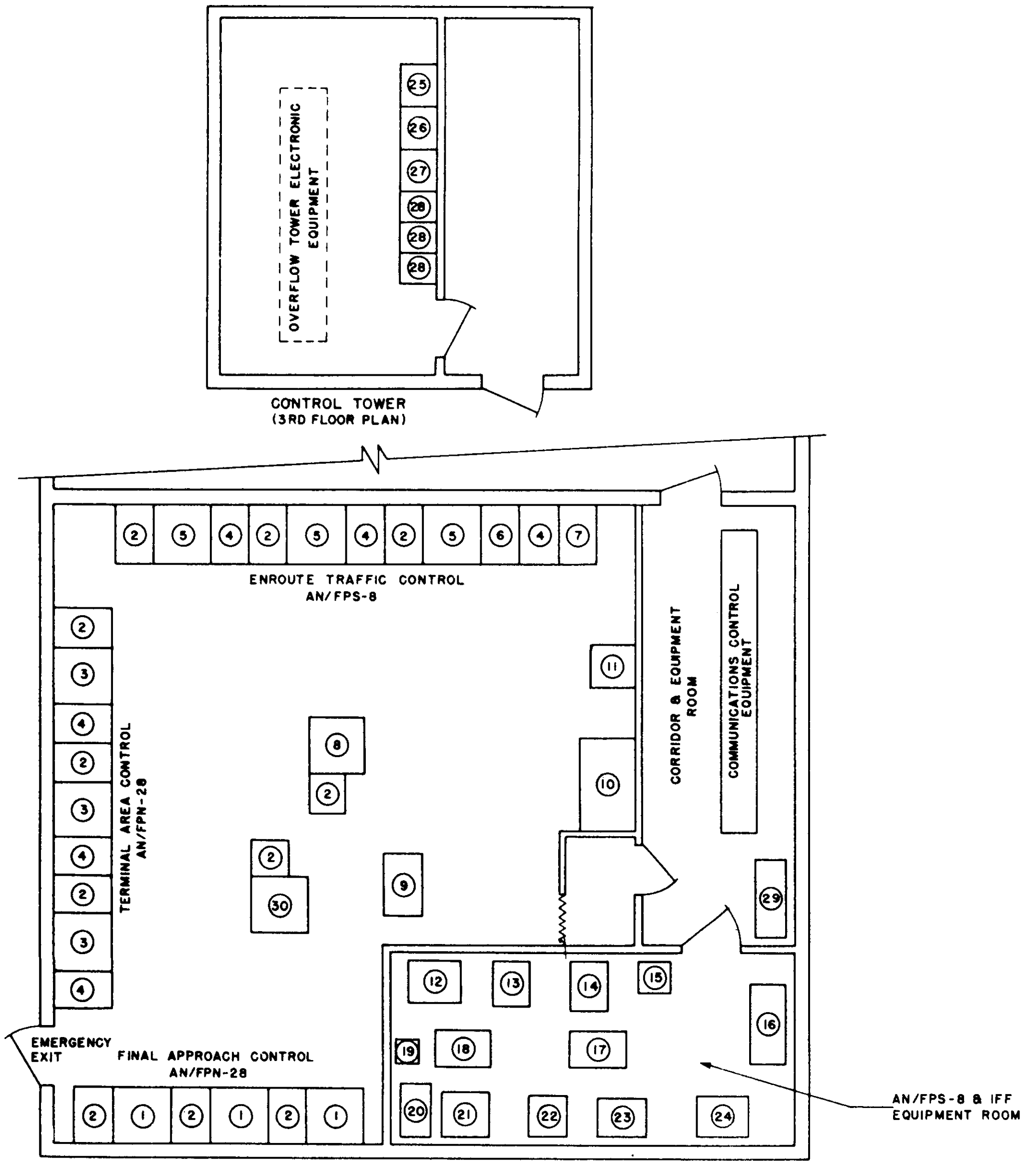
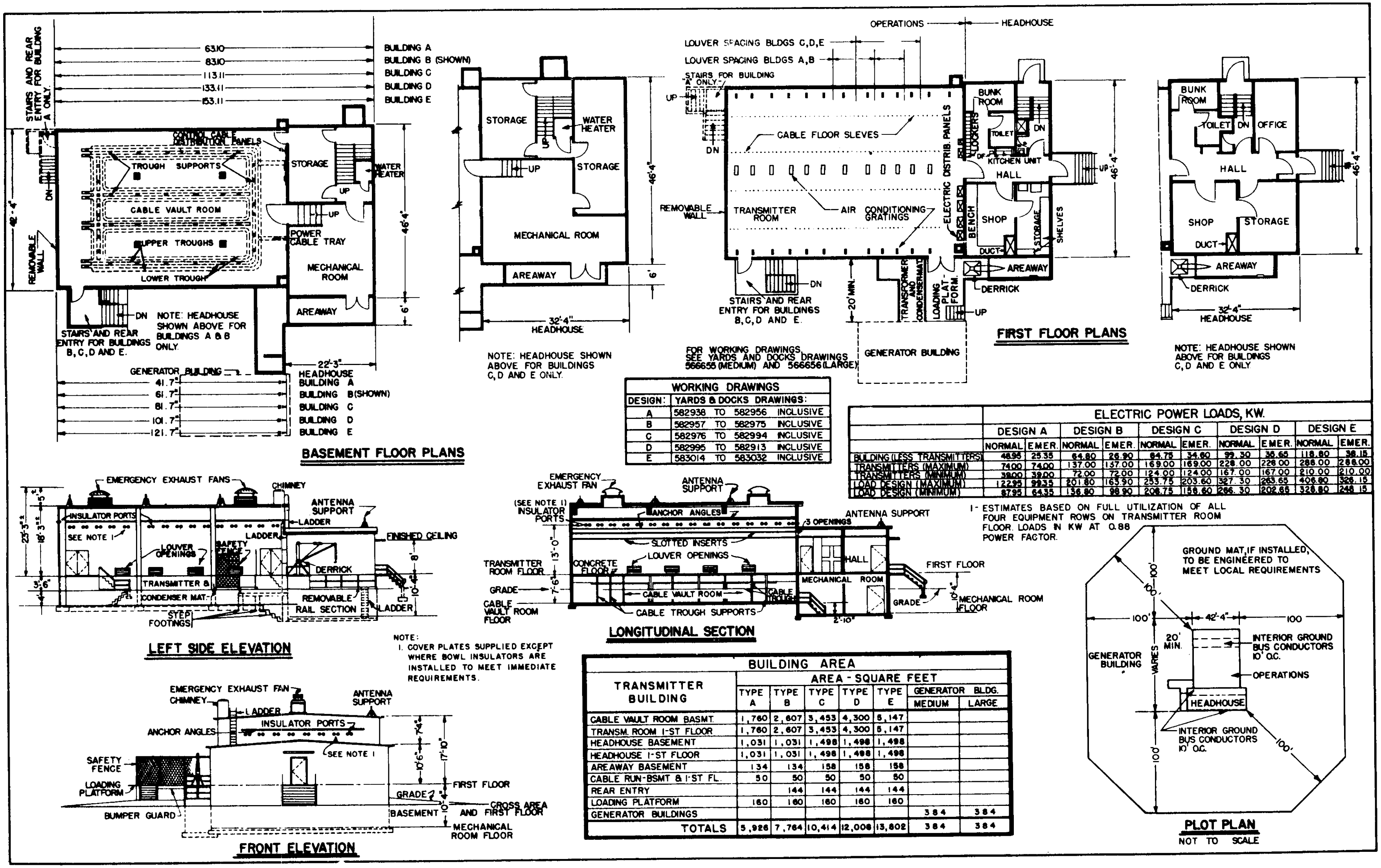


Figure 2-36. RATCC—Equipment Layout



WORKING DRAWINGS	
DESIGN:	YARDS & DOCKS DRAWINGS:
A	582938 TO 582956 INCLUSIVE
B	582957 TO 582975 INCLUSIVE
C	582976 TO 582994 INCLUSIVE
D	582995 TO 582913 INCLUSIVE
E	583014 TO 583032 INCLUSIVE

	ELECTRIC POWER LOADS, KW.									
	DESIGN A		DESIGN B		DESIGN C		DESIGN D		DESIGN E	
	NORMAL	EMER.	NORMAL	EMER.	NORMAL	EMER.	NORMAL	EMER.	NORMAL	EMER.
BUILDING (LESS TRANSMITTERS)	4895	25.35	64.80	26.90	64.75	34.60	99.30	35.65	118.80	38.15
TRANSMITTERS (MAXIMUM)	7400	74.00	137.00	137.00	169.00	169.00	228.00	228.00	288.00	288.00
TRANSMITTERS (MINIMUM)	3900	39.00	72.00	72.00	124.00	124.00	167.00	167.00	210.00	210.00
LOAD DESIGN (MAXIMUM)	12295	9935	201.80	163.90	253.75	203.60	327.30	263.65	406.80	326.15
LOAD DESIGN (MINIMUM)	8795	6435	136.80	98.90	208.75	158.60	266.30	202.65	328.80	248.15

1- ESTIMATES BASED ON FULL UTILIZATION OF ALL FOUR EQUIPMENT ROWS ON TRANSMITTER ROOM FLOOR. LOADS IN KW AT 0.88 POWER FACTOR.

TRANSMITTER BUILDING	BUILDING AREA						
	AREA - SQUARE FEET						
	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	GENERATOR BLDG. MEDIUM	GENERATOR BLDG. LARGE
CABLE VAULT ROOM BASMT.	1,760	2,607	3,453	4,300	5,147		
TRANSM. ROOM 1-ST FLOOR	1,760	2,607	3,453	4,300	5,147		
HEADHOUSE BASEMENT	1,031	1,031	1,498	1,498	1,498		
HEADHOUSE 1-ST FLOOR	1,031	1,031	1,498	1,498	1,498		
AREAWAY BASEMENT	134	134	158	158	158		
CABLE RUN-BSMT & 1-ST FL.	50	50	50	50	50		
REAR ENTRY		144	144	144	144		
LOADING PLATFORM	160	160	160	160	160		
GENERATOR BUILDINGS						384	384
TOTALS	5,926	7,764	10,414	12,008	13,802	384	384

Figur 2-37. Standard Remore Transmitter Building, NAS

been designed to provide an optimum amount of installation space consistent with operations and maintenance requirements, and to most effectively utilize an orderly antenna entrance plan. As transmitters of an excess of 3 kw are seldom required for air communications, building size has been reduced accordingly.

In general, equipment location parallels that of Naval Radio Station practices, where equipment is installed in four rows with transmitters spaced three feet apart and equipment facing each other in two rows.

A transmitter control and monitor facility is generally provided, and is placed in such a position as to allow a clear line-of-sight to as many transmitters as possible.

A main frame must be incorporated as part of the system. It may be in a form that is enclosed in a CY-597/G cabinet, mounted next to the monitor and control facility in the smaller stations; or in a very large station, may be open frame construction.

In most new constructions, sleeve type antennas are used almost exclusively. This allows the use of a coaxial cable patch board to interchange transmitters and antennas. The coaxial patch panel should be mounted in an area that will allow the shortest runs of cable between the transmitters and the board. It should also be placed to allow easy access to, and be within sight of, the maximum amount of equipment. Its preferred location is in the vicinity of the console.

In cases where a Naval Communication Station is within 2 to 30 miles from the Air Station, the first thing to consider is incorporation of air requirements into the N.C.S. In many cases this will provide high quality communications of a superior nature at a great savings in construction costs, and continuing maintenance support. The advantages to be gained by use of this concept, cannot be too highly stressed. Therefore, preliminary planning must first consider use of available facilities, before continuing on a basis of NAS transmitter building construction.

(6) REMOTE RECEIVER BUILDING.—Location and description are contained in Section 1. Systems engineering is concerned with selection of equipment to meet the operational requirements of the station, and arrangement of the equipment and antennas to provide maximum utility. Criteria for the engineering of a receiving facility at a Naval Air Station follows the same concepts as outlined under "2-4.*d.*, RADIO RECEIVING STATIONS," Section 2 of this Handbook. The standard Air Station receiver building is shown as figure 2-38.

The size of the building is determined by the number and types of electronics equipments with associated monitoring, patching and, where necessary, supervisory positions required to perform the mission as dictated by the authorized operational requirements. At least 25% expansion area should be considered in initial planning to offset change in mission during construction cycle. Initial installation shall be such as to permit expansion without disturbing original installation of equipment and/or cable.

In new construction, sleeve type antennas are recommended in order to reduce antenna requirements and promote flexibility. Older installations employ terminated folded doublets, long wire, or other antenna types as have been required to meet local needs. The standard receiver building is designed for roof-mounted HF and VHF/UHF antenna construction.

Equipment layout shall be such as to permit operation of the complete complex with the least amount of internal building travel, maximum flexibility, easy access for maintenance, and presenting neat and uniform appearance. When the facility expands to a point where supervisory billets must be made available, supervisory positions shall be centrally located with respect to patching and monitoring facilities and to the operating terminals. This will enable operating personnel to quickly restore abnormal conditions and accelerate necessary frequency changes; keeping outage time to a minimum.

Cabling and wiring shall be in accordance with standard practice based on best known engineering practices. Standard practices are intended to simplify installation planning, maintenance, and training.

Bonding, shielding, and grounding shall be in accordance with Bureau criteria for the preservation of communication integrity.

Where the Receiver Building is located in such a position as to provide line-of-sight operation to runways, VHF/UHF receivers may also be installed, in addition to the normal HF receiving equipment.

(7) VHF/UHF TRANSMITTER AND RECEIVER BUILDINGS.—Their location and description are contained in Section 1.

There should be 1500-foot separation between the transmitter and receiver buildings with provision for a common emergency power supply housed in a building in between.

Equipment requirements will be based on the operational requirements of the activity to be served.

(8) SITING OF COMPONENTS.—Although not always obtainable, the following component separations are highly desirable minima: (Note separation of the transmitter and receiving facilities as shown in figure 1-10.)

(*a*) Remote transmitter building (HF) to:

1. Operations building and control tower, 1 mile.

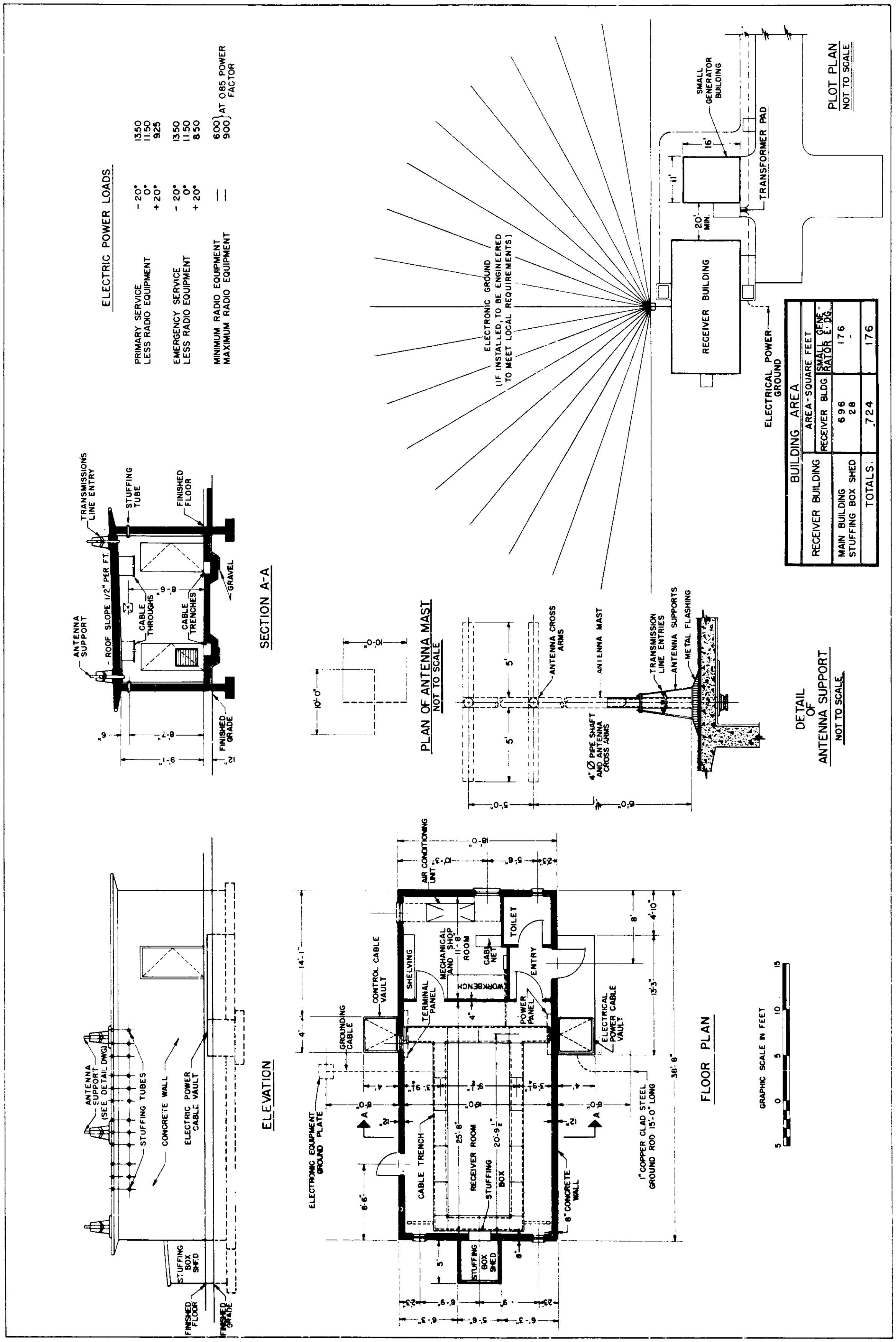


Figure 2-38. Standard Remote Receiver Building, NAS

2. Remote receiver building (HF), 3 miles.

3. Remote VHF/UHF receiver building, 1500 feet.

(*b*) Remote receiver building (HF) to:

1. Operations building and control tower, 1 mile.

2. Radar installations (depending on type), 1500 feet.

3. Highways and industrial and housing areas, 1 mile.

4. Open-wire powerlines and station roadways, 1000 feet.

(*c*) Remote VHF/UHF transmitter building to:

1. Operations building and control tower, 1000 feet.

2. Remote VHF/UHF receiver building, 1500 feet.

(*d*) Remote VHF/UHF receiver building to:

1. VHF/UHF transmitters, 1500 feet.

2. Highways, industrial and housing areas, 1000 feet.

3. Radar installations, 1500 feet.

(9) SYSTEM INTEGRATION.—In planning a new facility, or in the modification of an existing one, systems engineering is concerned with integration of the complete communication facilities of figure 2-35. Equipment control cabling must be provided between Operations and remote receivers and transmitters, and between control tower and remote components of the system. This involves considerable underground cabling with cable ducts provided for transmitter and receiver control as well as provision for expansion of facilities, and for exclusive applications independent of telephone wiring where control of "on-station" equipment is involved.

Based on economic and terrain factors, radio links may be required in lieu of cables and should be given consideration in overall systems engineering. See 1-22,*k* for policy for the establishment of radio links. Installation shall be in accordance with criteria contained in 2-6.

(10) "CRASH OPERATION" COMMUNICATIONS.—As directed by effective Bureau of Aeronautics directives, systems engineering includes provision for the installation of FM equipment operating in the 40-mc band for crash communications. Basic ground station allowances to selected activities consist of two base stations; one for operation and the other for standby. Three remote control units for use with the base station will be furnished; one for installation in the control tower for "on field" crash operations. The other two are for installation at strategic locations, as determined by the local operations officer, for control of "off landing field" and "off station" crash operations.

(11) MOBILE FACILITIES.—Total equipment requirements at a Naval Air Activity includes that equipment mounted in vehicles and helicopters assigned to "crash operations." This is FM equipment and when the need arises a crash communication net is established under operational control of the appropriate remote control unit.

A variable quantity of mobile units, based on a basic allowance as established by the Chief of the Bureau of Aeronautics and as required for the minimum communication requirements for "crash operations" is prescribed.

In addition, three portable VHF (FM) transmitter-receivers and two MAY UHF (AM) portable transmitter-receivers are a part of the prescribed allowance. The total equipment allowance will be sufficient to permit the implementation of an effective crash communication circuit.

Portable GCA installations contain communication equipment in addition to other electronics facilities, and is discussed further under "Navigational Aid and Traffic Control Facilities." Other mobile equipment suitable for Naval Air Station installation is described in 2-14., MOBILE INSTALLATIONS, together with criteria for equipment mounting on vehicles.

2-9. AIR NAVIGATIONAL AIDS AND TRAFFIC CONTROL

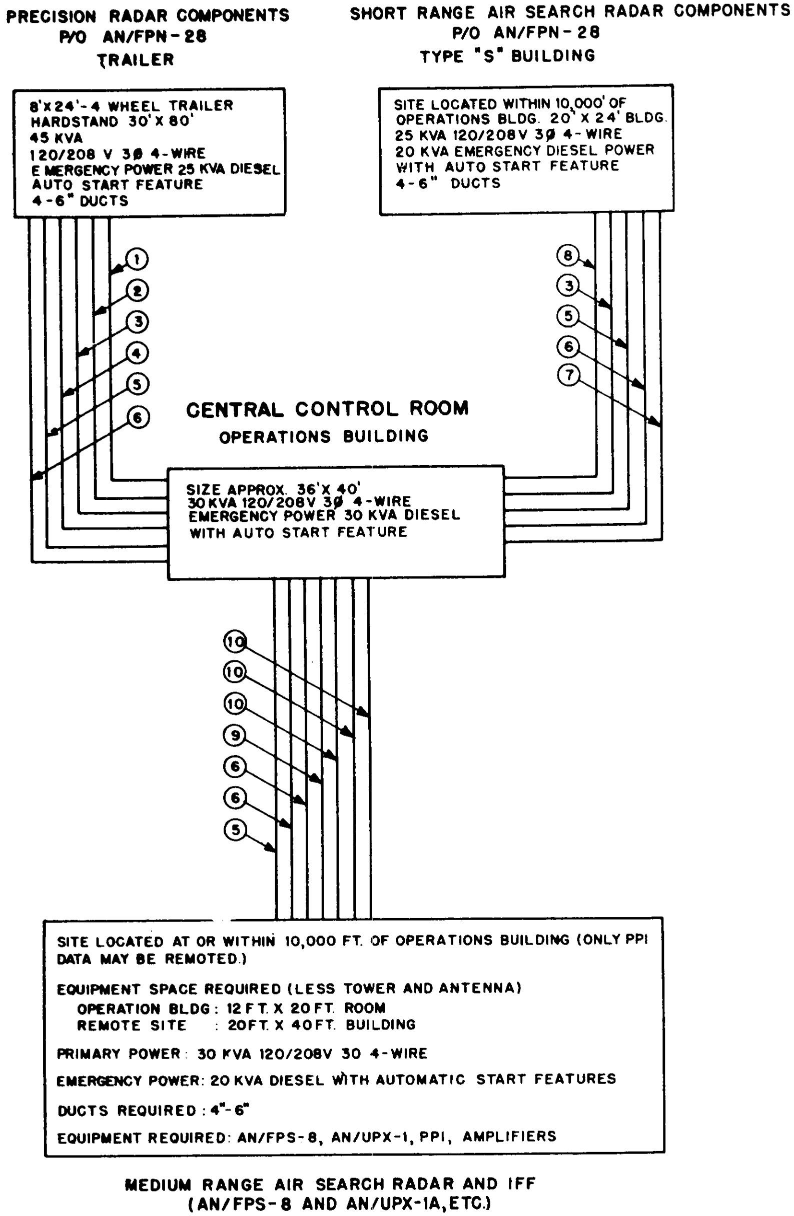
a. OPERATIONAL REQUIREMENTS.—In addition to the electronic communication requirements for air establishments ashore as discussed under "2-8. NAS COMMUNICATION FACILITIES," certain navigational aids and traffic control facilities are prescribed by the Chief of Naval Operations. Systems engineering is concerned with the selection and installation of this equipment to most effectively meet the operational requirements.

The Bureau of Ships prescribes the equipment. A list of equipment and its cost is furnished, and in collaboration with Public Works, who accomplishes the construction, Bureau of Ships exercises technical guidance for installation of the electronic equipment through the local Industrial Manager or equivalent Bureau of Ships representative. Step by step procedures are outlined in Section 1 of this handbook.

Systems engineering pertaining to specific navigational aid and traffic control facilities is discussed in the following paragraphs.

b. RATCC.—The components of a Radar Air Traffic Control Center as described in Section 1 of this handbook consist of the following:

Medium range air search radar.
Short range air search radar.
Precision approach radar.



NOTES:

1. RADAR* CONTROL CABLE; MFD LGTH. 2500 FT., 80 CONDUCTOR CABLE NO.18 AWG 7 STRANDS, PULLING LENGTH 1000 FT. USE DATA; TRAILER TO OP. BLDG., 27 1/2 PAIRS USED.
2. RADAR CONTROL CABLE; MFD. LGTH. 2500 FT., 19 TWISTED PAIRS NO.18 AWG 7 STRANDS, PULLING LENGTH 1200 FT., SHIELDED PAIRS. USED DATA; TRAILER TO OP. BLDG., 14 PAIRS USED
3. RADAR POWER CABLE; MFD. LGTH. 1000 FT., 7 CONDUCTORS (5 NO.3 AWG 7 STRANDS & 2 NO.8 AWG 7 STRANDS), PULLING LENGTH 1000 FT. USE DATA; TRAILER TO OP BLDG., 2 NO.3 AWG 7 STRANDS & 2 NO.8 AWG 7 STRANDS USED. OP. BLDG., "S" BLDG. 4 NO.3 AWG 7 STRANDS & 2 NO.8 AWG 7 STRANDS USED.
4. RADAR LOW CAPACITANCE CABLE; MULTI-COAXIAL CABLE C/O 11 COAXIAL CABLES IDENTICAL TO RG-12/U LESS ARMOR & JACKET. MFD. LGTH. 1500 FT., PULLING LGTH. 1500 FT. USE DATA; TRAILER TO OP. BLDG., 9 OF 11 COAXIAL CABLES USED.
5. RADAR TELEPHONE; MFD. LGTH. 2500 FT., 12 PAIRS NO.18 AWG 7 STRANDS, PULLING LGTH. 1450 FT USE DATA; TRAILER TO OP. BLDG., 10 PAIRS USED. MRASR (IF REMOTE) TO OP. BLDG., 10 PAIRS USED
6. RADAR COAXIAL VIDEO CABLE; MULTI-CONDUCTOR COAXIAL C/O 4 COAXIAL CABLES IDENTICAL TO RG-12/U LESS ARMOR, MFD LGTH. 2500 FT. USE DATA; TRAILER TO OP. BLDG., 3 OF 4 CO-AXIAL CABLES USED. OP. BLDG TO "S" BLDG., 3 OF 4 COAXIAL CABLES USED. MRASR (RADAR) TO OP. BLDG., 3 OF 4 COAXIAL CABLES USED. MRASR (IFF) TO OP. BLDG., 3 OF 4 COAXIAL CABLES USED. PULLING LENGTH 1200 FT.
7. RADAR CONTROL CABLE; MFD. LGHT. 2500 FT., 40 CONDUCTORS NO.18 AWG 7 STRANDS, PULLING LGTH. 1100 FT. USE DATA; OP. BLDG. TO "S" BLDG., 24 CONDUCTORS USED.
8. RADAR SHIELDED CABLE; MFD LGHT. 2500 FT., 3 NO.12 AWG 7 STRANDS SHIELDED CONDUCTORS & 6 TWISTED SHIELDED PAIR NO.18 AWG 7 STRANDS. PULLING LGTH. 1400 FT. USE DATA; OP. BLDG. TO "S" BLDG., 4 PAIRS NO.18 AWG 7 STRANDS AND 2 NO.12 AWG 7 STRANDS USED.
9. 20W NO.16 (4 SPARES)
10. MSCA-30 (12 SPARES)

Figure 2-39. RATCC System—Cabling

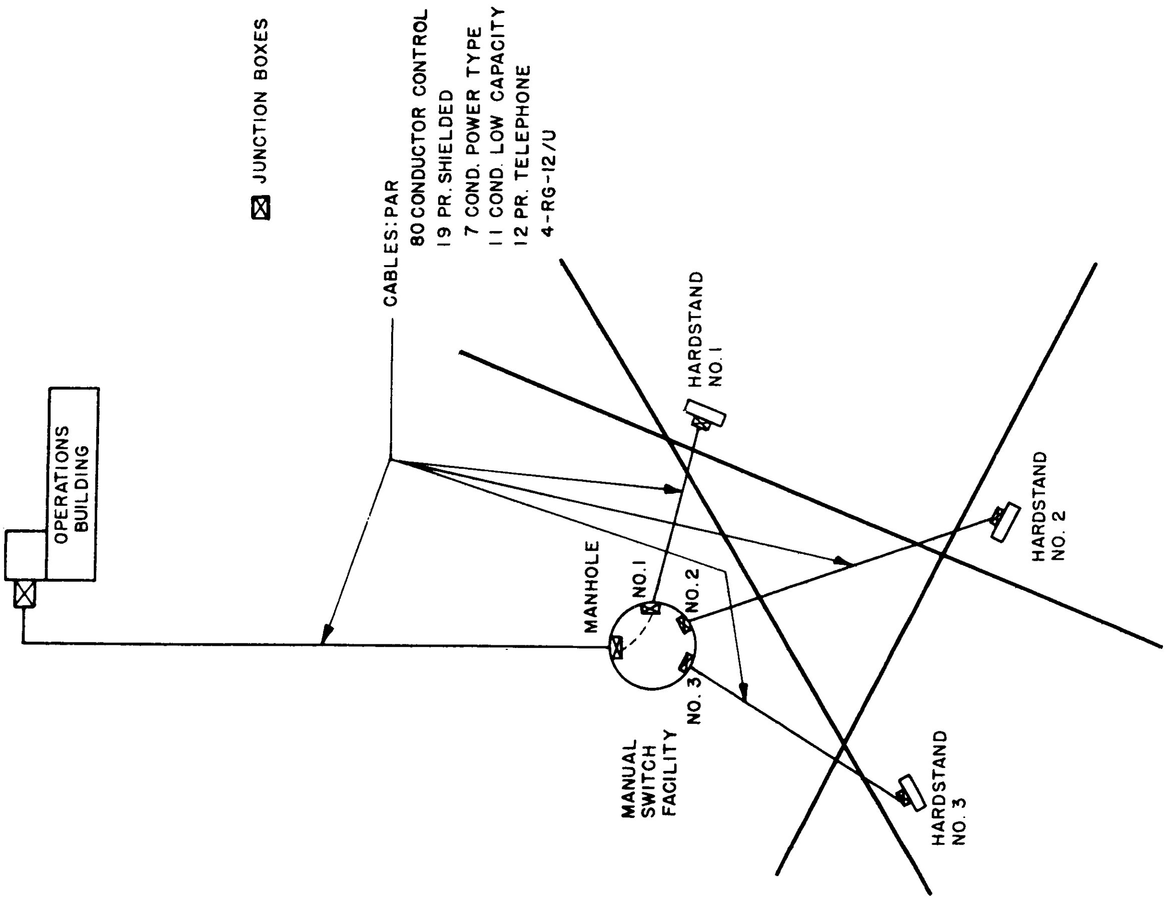


Figure 2-40. RATCC—Multiple Hardstand Cabling

Instrument control room—situation display.

Systems engineering is concerned with the selection and installation of equipment which make up these facilities, and with system integration which provides effective air traffic control and ground controlled approach at a designated Naval air establishment. Figures 2-36, 2-39, and 2-40 are provided to show location and utility requirements by the Bureau of Ships to aid Public Works in the determination of cabling ducts, building sizes, and power requirements.

(1) MEDIUM RANGE AIR SEARCH.—This component may be located on the station or remotely at another activity, and is not generally operated by the Navy. Information on "enroute" aircraft obtainable by this radar is made available to the Control Center either directly, by means of remote indicating devices located in the Control Center, or indirectly, on communication channels between radar and Control Center. If the radar is located on the station, the transfer of video information to remote indicators in the Control Center is no great engineering problem and is highly desirable operationally. Where considerable separation exists, the problem is more complex and if direct information is required, video transmission by means of radio links or other means must be provided. Systems engineering is therefore confronted with the problem of providing this information to the Control Center by whatever method is applicable to meet local requirements.

(2) SHORT RANGE AIR SEARCH.—This facility is permanently housed and located on the station, capable of line-of-sight ranges of approximately 20 to 50 miles at altitudes of 10,000 to 15,000 feet, and located so as to have an unobstructed view of the touchdown point of all runways to be served. Figure 2-39 shows typical cabling which will provide remote control and display at the Control Center.

(3) PRECISION APPROACH RADAR.—This equipment is housed in a trailer along with other equipment and trailers necessary for approach and landing control. The trailer is located precisely, and on the hardstand provided, adjacent to the runway to be served. Figure 2-39 outlines the requirements for integration with other components, and figure 2-40 shows a typical cable layout for stations requiring more than one hardstand. Criteria for hardstand construction and positioning are discussed under "2-9.*d.* MOBILE GCA." The hardstand requirements for PAR are not precisely the same as for mobile GCA, but similar arrangements exist, and it is recommended that where new PAR hardstand construction is involved, mobile specifications be followed to permit replacement of the PAR by mobile CGA if required.

Instruction books provided with the equipment contain specific instructions for location and operational criteria.

(4) INSTRUMENT CONTROL ROOM.—Figure 1-5 shows the location (Air Traffic Control), and figure 2-36 outlines a typical control room equipment layout. This layout may be used as a guide but equipment arrangement will vary from station to station, and systems engineering of a facility must be governed by local operational requirements as defined by the Operations Officer. Radar display facilities are arranged to most effectively meet the needs of the control operators. Refinements may be engineered into the equipment which include "video mapping" and arrangements whereby visual indication of target bearing, obtained by radio direction finder, may be displayed along with the radar information.

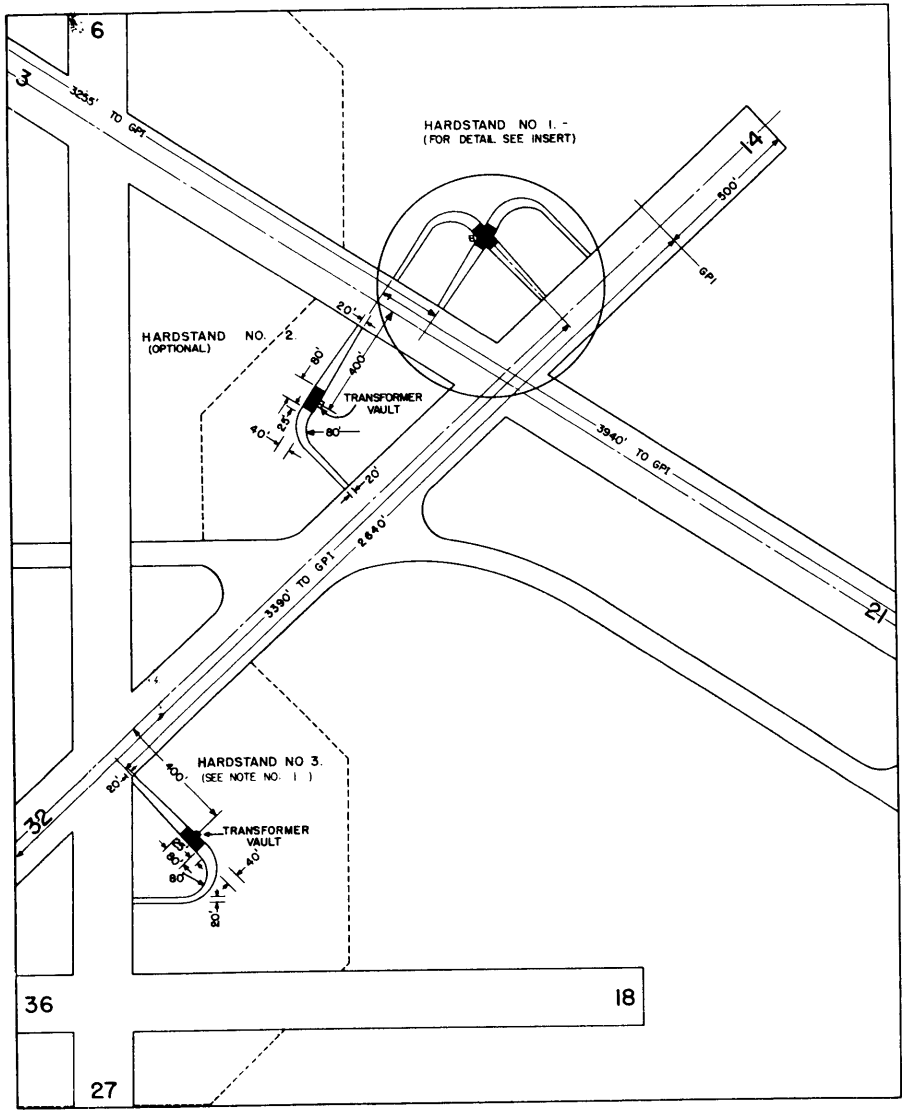
Of special importance is to provide generous air conditioning and dehumidification facilities at the control center. There is considerable concentration of heat-producing equipment in a small area, and with the number of personnel required to operate this equipment, it is imperative that the proper environment be provided. This is important not only from the human engineering point of view, but to assure that equipment will operate satisfactorily.

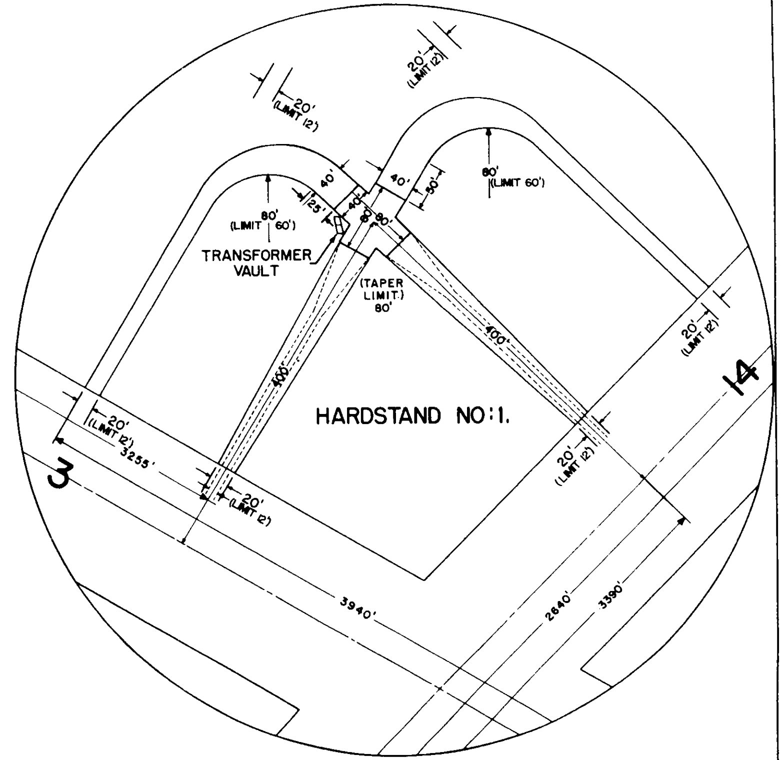
As indicated in figure 2-36 the equipment requirements for traffic control include control of communication equipment as well as radar display. Provision must be made for rapid changeover from tower to radar control, and for coordination of the two facilities for most efficient operation.

The cables connecting the remote radar equipment and the tower indicators will be laid in ducts across the air station, usually a distance of several thousand feet. During wet seasons, it will be found that water rises in the cable ducts and manholes and that the cables and splices will be underwater. Utmost precaution must be exercised during splicing operations to assure that the splices are waterproof, because a single drop of water entering the cables through a leak will lower the insulation resistance and impair both the operation of the radar equipment and the tower indicators. Wherever it is practicable, the manholes should be built up above grade a foot or two and the splices racked in this top part to prevent immersion during wet seasons.

Parallel runs of power cables and radar control cables should be avoided. If this is not possible, minimum separation of at least one hundred feet should be maintained. Necessary cable crossings should be made at right angles to one another.

c. FIXED GCA.—At an air establishment ashore where the facilities of a medium range radar is not available or required, systems engineering of a fixed





NOTES:

1. HARDSTAND NO 1 IS PRIMARILY DESIGNED AND LOCATED TO SERVICE RUNWAY 3 AND 32 WITH NORMAL APPROACHES. THIS HARDSTAND IS ALSO DESIGNED TO SATISFACTORILY SERVICE RUNWAY 21 WITH A BACKHAND APPROACH.

2. HARDSTAND NO 2 (OPTIONAL) IS LOCATED TO SERVICE RUNWAY 21 WITH A NORMAL APPROACH.

3. HARDSTAND NO 3 DESIGNED & LOCATED TO SERVICE RUNWAY 14 WITH NORMAL APPROACHES. (IT IS IMPOSSIBLE TO LOCATE THIS HARDSTAND TO SERVICE BOTH RUNWAYS 14 & 32 DUE TO THE LENGTH OF THE RUNWAY & THE LOCATION OF THE INTERSECTION OF RUNWAYS 18-36, 6-27, AND 32-14.)

4. ALL HARDSTANDS & DRIVEROADS ARE TO BE CONSTRUCTED AS SHOWN AND TO THE DIMENSIONS INDICATED. THE HARDSTANDS WILL BE CONSTRUCTED OF CONCRETE & DESIGNED TO SUPPORT A LOAD OF 9,000 LBS. PER WHEEL. THE DRIVEROADS WILL BE CONSTRUCTED OF MACADAM & DESIGNED TO SUPPORT A LOAD OF 9,000 LBS. PER WHEEL.

5. EACH HARDSTAND WILL BE SUPPLIED WITH AN UNDERGROUND TRANSFORMER VAULT CONTAINING 3 15 KVA SUBWAY TYPE TRANSFORMERS FOR SUPPLYING 3 Ø 4 WIRE 115/208 VOLTAGE.

6. PROVISIONS WILL ALSO BE MADE FOR TELEPHONE COMMUNICATIONS WITH EACH HARDSTAND.

Figure 2-41. Typical GCA Hardstand Layout

GCA installation is accomplished in the same manner as prescribed for the complete RATCC, but omitting equipment and arrangements which pertain to the medium range radar.

d. MOBILE GCA.—The equipment, which is contained in three vans as described in Section 1 of this Handbook, requires precise location for its establishment.

In planning a new air facility ashore, or in the modification of an existing one, hardstands are constructed for the use of mobile GCA. Figure 2-41 shows the GCA hardstand locations at a typical airfield with notes which indicate provisions that are made to meet operational requirements.

General siting criteria for mobile GCA hardstand construction and positioning are as follows:

(1) One or more hardstands 40 feet by 80 feet are constructed with the long dimension perpendicular to instrument runway or runways to be served.

(2) Hardstand to be a minimum of 2500 feet from end of runway touchdown point (3000 feet or more is preferable), and a minimum distance of 350 feet (400 feet or more preferable) from runway centerline.

(3) Hardstand should be positioned on the left side of the runway as viewed from the aircraft making an approach to the instrument runway. "Right hand" positioning is acceptable in cases where the same hardstand can be used to serve more than one runway, or for other reasons where "left hand" positioning is impracticable.

(4) Shown in figure 2-41 are the hardstand details which have been submitted to the Bureau of Ships for approval, and were drawn for a particular airfield. Specifications prescribe that access (drive) roads to the hardstand should be a minimum of 12 feet wide, with turning radius, when required, of not less than 60 feet. The taper from the end of the hardstand to the 12-foot width should extend for at least 80 feet to permit alignment of the equipment on the hardstand.

(5) Hardstand should withstand trailer wheel loads of a minimum 9000 pounds per wheel.

(6) Each hardstand will be supplied with 45 KVA three phase four wire 120/208 V commercial/station power. Transformer(s) are usually housed in an underground vault.

(7) The instrument runway hardstand is furnished with a standard 26 pair communication cable terminating in the control tower. Other hardstands are supplied with similar facilities in order that complete inter-communication between tower and all hardstands is provided. Although the foregoing hardstand specifications apply particularly to mobile GCA, the same hardstand can be used for the PAR component of RATCC if provision is made for cable ducts and integration with the control center. The positioning for PAR units with respect to the runways is similar to mobile GCA, and systems engineering of new construction, where the initial requirement is for mobile GCA, should include consideration for future expansion and possible RATCC installation. This will involve construction of cable ducts under runways, laid out in the direction of the tower (or site of the RATCC control center), and which can be used for remote display and control purposes.

e. VHF/UHF DIRECTION FINDERS.—As described in Section 1, VHF/UHF direction finder installations at air activities are engineered for use at the control tower and/or control center, and are standard components of mobile GCA. For convenience, D/F antennas are generally mounted on the roof of the control tower and operated in conjunction with other control cab facilities. The usual precautions must be exercised in the D/F loop installation to avoid factors which affect bearing accuracy. Criteria for siting as described in Appendix VIII apply, and should be followed insofar as practicable.

Systems engineering will give future consideration to remote operation of VHF/UHF direction finders. In order to secure maximum gapless coverage, the same factors which are considered under VHF/UHF AIR/-GROUND COMMUNICATIONS are applicable to D/F operation at these frequencies.

f. LF/MF FOUR-COURSE RADIO RANGE.—No special systems engineering requirements are indicated for this navigational aid of which there are several existing installations, but which are now considered obsolescent. No future installations are anticipated.

g. VHF OMNIDIRECTIONAL RANGE.—The location of this facility (AN/FRN-12A) is off the end of the instrument runway at a distance of five to eight miles as described in Section 1 of this Handbook.

NAVSHIPS 92326, Bureau of Ships Shore Electronic Equipment Installations Plans, contains Electronics Drawing No. RE 6A 2203 which provides siting criteria for this facility.

Mobile installations (AN/URN-9) require a hardstand or suitable substitute to withstand minimum load of 5000 rounds per wheel, with power requirements as specified in Section 1.

h. RADAR BEACONS.—A brief description of this facility is contained in Section 1. Detailed information on siting and systems engineering is contained in the instruction books on the equipment currently employed for this navigational aid.

i. UHF RANGE.

(1) TACAN.—The expression TACAN is a code

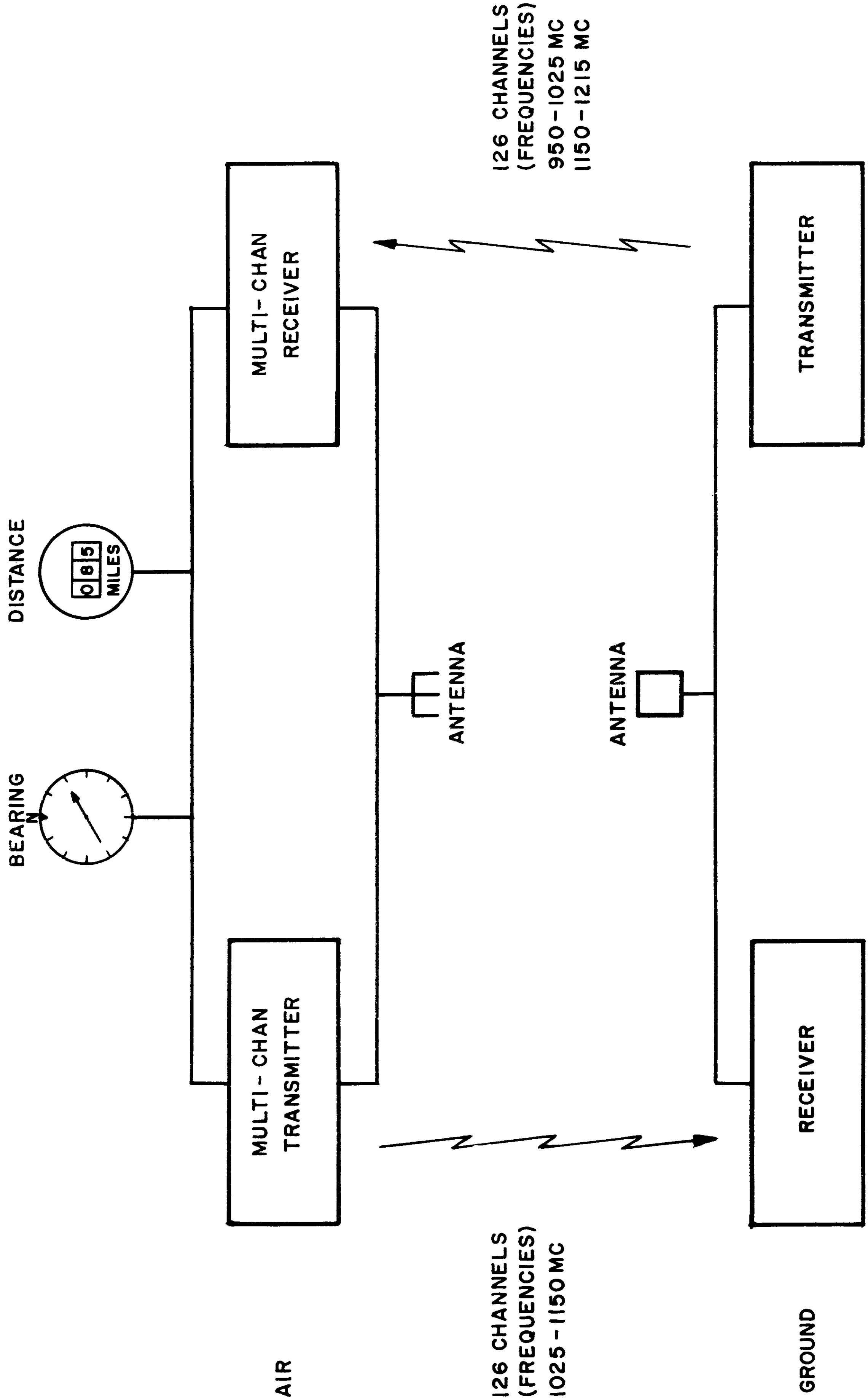


Figure 2-42. El ments of TACAN Syst m

word for "tactical air control air navigation" and nomenclature for the equipment is AN/ARN-21 (airborne portion) and AN/URN-3 (ground portion). The system is shown schematically in figure 2-42.

TACAN is a system of radio navigation which provides an aircraft with accurate distance and bearing information with respect to a selected ground station. Both functions are transmitted over the same channel, the bearing information being amplitude modulated upon the output of a constant duty-cycle DME (distance measuring equipment) pulse transponder. This system has 126 crystal-controlled two-way operating channels available for assignment. The frequencies are spaced 1 mc apart. For ground-to-air transmissions(serving both bearing and distance functions), there are 63 frequencies in the band 960 to 1925 mc, plus 63 frequencies in the band 1150 to 1215 mc.

(2) INSTALLATION.—Because of the frequencies involved, TACAN performance is influenced in the same manner as communications discussed under AIR/GROUND COMMUNICATIONS. Location and antenna height must therefore be specified on a case basis and is a compromise among the following factors:

(*a*) Line-of-sight coverage.
(*b*) Obstruction and terrain clearance.
(*c*) Gaps in solid coverage.
(*d*) Cost and installation difficulty.
(*e*) Reliability and maintenance.
(f) Antenna height limits for locations near runways.

It has been determined that coverage and performance of the AN/URN-3 antenna at a height of 100 feet is better than that of the antenna at 15 feet upon consideration of factors (*a*), (*b*) and (*c*). In general, the economic and safety factors (*d*), (*e*) and (*f*), favor antenna heights including down to eight feet from runway level.

j. MISCELLANEOUS AIR NAVIGATION AND GUIDANCE FACILITIES.—The following are described briefly in Section 1 of this Handbook:

(1) VHF Fan Marker Beacons.
(2) "H" Facility.
(3) Instrument Landing System (ILS).
(4) Aircraft Guidance Central.

The Bureau of Ships prescribes equipment for these facilities at Naval Air Activities where applicable in accordance with operational requirements. Instruction books on the equipment contain siting and engineering criteria for their establishment.

2-10. RADAR EQUIPMENT INSTALLATIONS.

a. OPERATIONAL REQUIREMENTS. — Systems engineering of a radar facility at a shore activity consists of adapting a radar system to the operational requirement for a particular locality. The design of radar equipment is such that all the components of a radar system have been systems engineered to work together as a unit. Transmitter, receiver, and antenna, along with various indicators, are designed for a specific function. Systems engineering is therefore required to provide the proper environment and utilities to obtain satisfactory operation.

Equipment to meet an operational requirement is prescribed by the Bureau of Ships. The environment for satisfactory operation includes siting, housing, and antenna elevation, which will provide the required line-of-sight coverage. Utility requirements include power for normal as well as emergency operation.

Systems engineering will give consideration to operation and maintenance of the equipment, logistics, personnel requirements, and to details of attended versus unattended operation. Remote control and/or display may be indicated in the operational requirement.

Surface search radars used in harbor defense require particular location and integration with other components of harbor defense. Systems engineering of such facilities will be governed by local requirements.

Other radar applications ashore include those installed at training facilities. These consist of installations used in maintenance and operational training, as well as for specific utility, such as "Ground Controlled Intercept." Fire control radar installations have application in training and are under cognizance of the Bureau of Ordnance. Where INDMAN personnel are concerned with such installations, advance planning should include technical assistance by Bureau of Ordnance engineers, so that most efficient results can be obtained from this equipment when "turn-over" to Management is effected.

Most operational radars under technical control of the Bureau of Ships are used in air surveillance applications. These radars, as described in Section 1, are used at Naval air stations as components of radar air traffic control, or for general utility, and search and rescue operations normal to aircraft operation.

b. SITING CRITERIA.—Most radars operate in the microwave portion of the radio spectrum with propagation in the troposphere, and therefore require antenna elevation above surrounding obstructions for line-of-sight operation. The same principles apply that govern link paths, as discussed in Appendix VI, MICROWAVE LINK SYSTEMS, except that coverage is usually extended to 360° for most applications. The first consideration in site selection therefore, is to select a site to give the desired area or sector coverage for line-of-sight operation.

Because of terrain, or other factors where location of the facility is remote, whether on or off a station, consideration must be given to several other factors which influence site selection. A remote site may be selected which is ideal from a propagation point of view but provision for power and utilities, as well as road building and other construction, may increase the cost so as to be prohibitive. In remote operation, the problem of maintenance must be considered; unattended operation being impracticable. Total personnel requirements for remote operation are greatly increased over operation of any facility near the center of activity.

A medium range air surveillance facility may be installed on or off a station, and may or may not be operated by the Navy. When an operational requirement specifies that the Navy install such equipment at an air activity, it is highly desirable that installation be made on the station, and if possible, at the site of the control center.

Where a remote radar installation is serving a station for medium range operation, provision is made for communications and remote display if required. Communication between the control tower and radar sites, or between a control center and radar sites, may be by telephone, intercomm, or radio channels. Where remote display is required at the control center, the engineering is more complex. Video lines may be used to supply information to the control center indicators if the distance is less than 10,000 feet, and terrain and other factors permit. At greater distances microwave radar relay service is indicated, and equipment can be provided which will furnish this service; engineering of such facility being guided by principles discussed under LINK SYSTEMS.

In siting for a short range facility as used as a component of GCA, an unobstructed view of the instrument runway touchdown point(s) is mandatory, and highly desirable for touchdown points of other runways to be serviced. Operating characteristics of the equipment require a separation of about one-half mile between radar and touchdown points. In these applications, cable runs must be provided for remote control and display at the control center. Remote operation is normal for this facility but equipment requirements should include local indicators for maintenance and emergency use.

Mobile radar sets have application for harbor defense, and for mobile ASR and PAR service at air stations. These radars are self-contained units; van-mounted; and are provided with their own power supply and communication facilities. Siting will depend on local terrain and requirements. These air surveillance radars provide short range radar facilities for traffic control where permanent installation is not feasible. This facility finds greatest application at seaplane bases where it is necessary to control seaplane traffic from a point ashore close to takeoff and landing areas. Hardstand and commercial power may be provided as required for semi-permanent application of this mobile equipment.

c. ANTENNA CONSIDERATIONS.—The establishment of a radar system at a shore establishment as a result of an operational requirement involves a choice of radar sets to meet the requirement. Design has brought about various types of radars to meet specific requirements, and it is customary to design the antenna along with other components of the system to provide optimum performance. Because microwaves are employed in radar, optical principles may be used to design the antenna to obtain the desired beam pattern. The following brief discussion of various types of antennas, and resultant beam patterns, is provided.

(1) ANTENNAS FOR TOROIDAL BEAMS.—The least directive beam is the "toroidal beam," which is uniform in azimuth but directive in elevation. Such a beam is desirable as a marker for an airfield because it can be detected from all directions. A toroidal beam may be produced by an isolated half-wave antenna. This is a useful antenna over a large frequency range, the limit being set by the mechanical problems of supporting the antenna, and achieving the required isolation. The beam thus produced, however, is too broad in elevation for many purposes.

(2) PENCIL BEAM ANTENNAS.—The most directive type of antenna gives a "pencil beam," in which the major portion of the energy is confined to a small cone of nearly circular cross section. With the high directivity of this beam goes a very high gain, often as great as 1000. Such a beam may be used like a searchlight beam in determining the angular position of a target, and finds application in the PAR used as a component of GCA.

Although the pencil beam is useful for precise determination of radar target positions, it is difficult to use in locating random targets. For the latter purpose it is better to use a "fanned beam," which extends through a greater angle in one plane than it does in a plane perpendicular to that plane. The greater part of the energy is then directed into a cone of roughly elliptical cross section, with the long axis, for example, vertical. By sweeping this beam in azimuth, one can scan the sky more rapidly than with a pencil beam, thereby decreasing the time during which a target may go undetected. Such a fanned beam still permits precise location of targets in azimuth, at the expense of loss of information concerning target elevation.

(3) SHAPED-BEAM APPLICATIONS. — The

highly directive beams attainable with microwave antennas have been utilized to achieve large antenna gain, precision direction finding, and a high degree of resolution of complex targets. The exploration of a wide angular region with such sharp beams requires an involved scanning operation in which the scanning time becomes a limiting factor. This problem is much simplified if the required scanning can be reduced to only one direction, the coverage of the angular region being completed by fanning the beam broadly. For many applications, however, the characteristic shape of the fanned beam obtained by simply reducing the corresponding dimension of the aperture is unsatisfactory; it may be wasteful of the limited microwave power, or it may result in a very unequal illumination of targets in different directions. To overcome these limitations, it is necessary to impose on the beam, by special design techniques, some shape not characteristic of the normal diffraction lobe. These beams are referred to as *shaped beams,* and the antennas that produce them as *shaped-beam antennas.* This type of beam-shaping has application in the radars associated with air surveillance and other operational radars used at shore activities.

For use in search for aircraft, an antenna on the ground or on a ship is required to produce a beam sharp in azimuth, but shaped in elevation. The azimuth coverage is obtained by scanning. The elevation shape of the beam must provide coverage on aircraft up to a certain altitude and angle of elevation, and out to the maximum range of the system. This is to be accomplished without wasteful use of available power. The antenna beam need not meet the coverage requirement very accurately, since conservation of power and a relatively constant signal on a plane at a fixed altitude are the only objectives.

In order to maintain a fixed minimum of illumination on the aircraft at various points along the upper contour of the coverage diagram, it is necessary that the amplitude of the antenna pattern be proportional to the distance r from the antenna to the aircraft on that contour. In other words, the coverage contour can be taken to be the amplitude pattern of the antenna. Since $r = h \csc \theta$, the amplitude pattern must be proportional to $\csc \theta$, or the power pattern must be proportional to $\csc^2 \theta$. The proportionality must hold over the region from a minimum angle arc sin h/r_{max}, to the maximum elevation angle for which coverage is required.

(4) ANTENNA HOUSING.—Where radar installation is to be made in areas subject to severe weather conditions, two types of protective systems are available for protection of the antenna. One is an air supported shelter system (rubber radome cover). This cover is flexible and is supported by a blower system with automatic features which pressurizes the inside. Another system is a rigid shelter system constructed of prefabricated, panelized sections, which does not require auxiliary power or integral equipment. Preference is given to the rigid shelter system.

d. TOWER HEIGHT.—Several factors may influence tower height. In an attempt to obtain maximum line-of-sight coverage, consideration must be given to aircraft clearance at air activities. Criteria for this is laid out by the Bureau of Aeronautics' "Planning Standards."

One of the factors which comes under consideration in radar applications at shore activities is the subject of imperfect radar performance due to "self-interference." This phenomena is caused by ground reflections which can produce nulls in coverage in the same manner as discussed under VHF/UHF AIR/GROUND COMMUNICATIONS and produce undesirable false echoes, double echoes, or flutter effects similar in nature to the propagation difficulties experienced in microwave link systems as discussed in Appendix VI. These effects may be especially important in areas where the ground is perfectly flat and has good conductivity, as may be expected over sea areas. There is undoubtedly an optimum tower height that, for a given beam pattern such as the $\csc^2$ pattern as employed in medium range air search radars, these adverse effects may be minimized. There is also some evidence that there is an optimum tower height for MTI operation. Precise information, however, is lacking on these subjects.

In practice, the tower height is specified to be no higher than necessary to obtain line-of-sight coverage. As discussed in connection with radar installations at Naval air stations, in order to minimize transmission line (waveguide) losses, tower heights of 100 to 125 feet are prescribed as the limit. When greater tower heights come under consideration, installation of equipment in the tower to shorten the waveguide is not recommended where this requires access to the equipment house by means of long ladders. A better method is penthouse construction of equipment housing on existing buildings. This permits greater accessibility which is an important factor in maintenance.

e. INTERFERENCE.—Systems engineering is also concerned with radio interference at shore activities where both radar and communication radio facilities are installed, as radars sometimes produce interference to communication equipment. Radar interference at the output of communication receivers can usually be attributed to one or both of the following phenomena: (a) shock excitation of the receiver tuned circuits due to the reception of the steep wavefronts associated with the high-power pulse that modulates the magnetron. This energy is radiated from the metallic parts of the radar set, including the antenna reflector and interconnecting cables, and is picked up by the receiving antenna. (b) Receiver case penetration of the radiated radar energy which becomes rectified inside the receiver, and reverts to frequency components within the acceptance band of the equipment.

Modern radar sets which have met the current interference design specifications can be placed in very close proximity to receiving antennas without causing the first type of interference. Older radars, however, should be located so that a separation of approximately 1500 feet is maintained between the LF-MF and HF receiving antennas and any portion of the radar set including above-ground power lines to the radar. The second type of interference is a function of the shielding integrity of the receiver cabinets. In all cases, an effort should be made to locate the radar antenna so that the receivers are not immersed in a strong radiated field. Where such location becomes a problem because of operational requirements, consideration should be given to which facility has operational priority. In the usual case, operation of communication equipment in the radar propagation path is only for emergency purposes, and consideration can then be given to radar shutdown or limited scanning. This problem can usually be resolved to meet local requirements in a satisfactory manner.

c. Where multiple radar systems are installed at a shore establishment, radar-to-radar interference may become a problem. This type of interference can be eliminated in currently available equipment by the introduction of a suitable blanking pulse into the provided blanking circuit which renders the radar receiver inoperative during the instant the interfering signal is being received.

d. IFF.—Operational requirements at shore activities may prescribe the installation of IFF equipment. When this occurs, applicable SERIS (Shore Electronic Recognition and Identification System) diagrams are obtained from the Bureau of Ships, and provision made for this equipment in the overall systems engineering.

2-11. HARBOR DEFENSE FACILITIES ENGINEERING.

NAVSHIPS 900,166A, Technical Information for Harbor Defense Planning, and NAVSHIPS 250-770-1, Harbor Defense, are issued for use and guidance by Naval personnel and others who have the responsibility for planning harbor defenses with currently available equipment and material. All phases of harbor defense are covered in the two publications, which includes systems engineering of all lectronic equipment.

2-12. TRAINING FACILITIES.

Systems engineering of electronic installations at training activities involves consideration of the purpose of each installation on its own merits. No set of rules could be set up that would apply to all installations, and any training project which requires electronic equipment must be engineered for maximum utility of the equipment for training in operation and maintenance as required. New building construction to house electronic equipment should follow the general pattern applying to transmitter or receiver station buildings, with provision for cellular floor construction and power availability. Standard shore installation practices should be followed wherever possible, and where standard shipboard or air-borne equipment is installed, applicable equipment arrangements simulating normal environment will facilitate maximum training utility.

2-13. RADIAC REPAIR FACILITIES.

NAVSHIPS 92326 contains Bureau of Ships drawing RE 10 D2121, Radiac Repair Facilities Layout, and other drawings which will assist electronics engineering in the development of a radiac facility, if required. Because of personnel hazard and other factors involved, radiac repair facilities are only authorized for establishment at specific locations as indicated in current Bureau of Ships directives.

2-14. MOBILE INSTALLATIONS.

a. EQUIPMENT.—Most of the mobile electronic equipment presently in use by the Navy is used for internal security operations and for emergency communications at air stations. Some of the other types available include electronic equipment installed in jeeps and small trucks which are compact and highly maneuverable. These small units may be used for such purposes as anti-aircraft and anti-tank warnings, fire control and fire direction nets, control nets for base stations, ground-air liaison, and for short-range communication in the field. The frequency range and type of equipment installed in such vehicles depends on the intended operation.

The Navy also has available large communication vans that may be used to set up a complete communications center, including coding and radio teletype facilities. These may consist of separate receiving vans, separate transmitting vans, separate coding vans, all with their own power supply units. They may consist of VHF/UHF relay vans complete with terminal equipment, or complete teletype transmitting and receiving vans. These mobile communication vans may be used to set up an advanced base communication center, or for various types of emergency communications.

There are also several types of mobile D/F, radar, GCA, radar beacons for navigational aids, GCI fighter direction, surface and air defense, and IFF vans; all designed and built for specific purposes. No attempt will be made to describe all the various types of mobile electronic equipment in use by the Navy. Information on these systems may be found in NAVSHIPS 900,123, and the instruction manuals furnished with the vans.

b. RADIO INTERFERENCE REDUCTION.—Most mobile units are procured by the Bureau of Yards and Docks from the Army Ordnance Corps. Normally, the interference reduction requirements applied to these procurements are those outlined in MIL-S-10379A. Of the interference sources on the engine, those associated with the high-voltage system are likely to be the most troublesome. The most practical methods of reducing the effect of ignition noise are the use of noise limiters in receiving equipment, and the installation of shielded ignition systems, resistor-type spark plugs, external suppressors, or resistance-type high-voltage ignition wires.

The low-voltage sources of interference include the generator and the voltage regulator. Generator hash is caused by sparking at the commutator. The pitch of the noise varies with the speed of the engine. The normal solution to this problem is to use a capacitor (0.1 to 0.25 mfd) in the armature circuit mounted on the generator frame as close to the commutator as possible. Interference from a voltage regulator may be reduced by installing a capacitor (0.1 to 0.25 mfd) at the battery and generator terminals of the regulator. A 0.002 mfd mica capacitor and a 4-ohm resistor in series, connected from the field terminal of the regulator to ground, will result in further reduction. Extreme cases may require the insulation of the regulator from the car metal, and shielded wire from the regulator to the generator. Ref. NAVDOCKS P-278.

Two minor types of interference which are sometimes encountered are wheel static and tire static.

Wheel static shows up as a steady popping in the receiver at speeds over about 15 mph on smooth dry streets. Front-wheel static collectors are available to eliminate this variety of interference. They fit inside the dust cap and bear on the end of the axle, effectively grounding the wheel at all times. Rear-wheel collectors have a brush that bears against the inside of the brake drum. It may be necessary to order these through a car dealer. Tire static sometimes sounds like a leaky power line and can be very troublesome even on the broadcast band. It can be remedied by injecting an antistatic powder into the inner tubes through the valve stem. The powder is available at car dealers.

2-15. INSTALLATION PRACTICES.

a. OBJECTIVE.—The objective of the following paragraphs is to provide notes and references on standard installation practices which will assist in the systems engineering of a facility to obtain maximum performance, to provide flexibility, and to operate with a minimum of interference with respect to other installations.

As discussed elsewhere in this Handbook, consideration is given first to selection and arrangement of the equipment. This includes such items as antennas, matching and transmission-line arrangement for a transmitting or receiving facility, site selection, housing, power, and optimum antenna height for installations where this is an important factor. Also included is equipment arrangement so as to provide adequate working space needed in operation and maintenance, provision for flexibility in use, and consideration for alteration and future expansion of facilities. Systems engineering proceeds with preparation for installation of such components by the compilation of installation requirements after equipment arrangement has been established.

b. INSTALLATION PROCEDURES.—To enable systems engineering to follow proper procedures of installation, NAVSHIPS 900,171, Electronic Installation Practices Manual has been prepared. This manual is intended for the use of the electronics installation worker, and although application is aimed primarily at shipboard installations, much information contained in various chapters of the manual is usable for shore electronics work. It may be used as a reference book on installation practices or in training beginners in Naval electronic installation work. Where a conflict may exist between installation practices as described in NAVSHIPS 900,171 and those contained herein, the concepts contained in this publication (NAVSHIPS 92675) will prevail.

A brief description of the contents and/or intent of each chapter of NAVSHIPS 900,171 follows:

Chapter 1, Safety and First Aid.

The safety precautions outlined in this chapter are not intended to supersede information given in instruction books or other applicable instructions for the installation of electronic equipment. They are intended to doubly impress upon personnel the hazards involved in working with or around high-voltage electronic equipment, and the precautions to observe in the performance of such duties.

Special precautions are required for electronic equipment because power supply voltages up to 40,000 volts and even higher radio frequency voltages are used. Special precautions are also necessary because of the effect of electrical fields existing in the vicinity of antennas and antenna leads which may introduce fire hazards, especially where explosive vapors are present.

Additional precautions are needed for personnel working aloft to prevent injuries due to falls, often complicated by possible shock.

Chapter 2, Extinguishing Electrical Fires.

All personnel working with or around electronic equipment should know exactly what to do if an electrical fire starts. Such knowledge is essential along with familiarity with local fire regulations. Personnel will locate and determine the type of portable extinguisher available in the vicinity of any new working quarters. Valuable time must not be lost trying to remember the location of a fire extinguisher or by becoming panic stricken. Lives of many people—important electronic equipment—even a ship—may be saved by knowing how to extinguish an electrical fire.

Chapter 3, Hand Tools.

The hand tools illustrated in this chapter are those most likely to be used in electronic installation work, and include special-made electronic tools. Since the same tool may vary slightly in appearance, depending upon the manufacturer, or late improvements, these illustrations are general in detail. Instructions are given for the proper use and maintenance of these tools.

Standard Navy stock numbers of tools discussed are listed in Section 3-3 of NAVSHIPS 900,171.

Chapter 4, Test Equipment.

The purpose of electronic test equipment is to measure accurately the value and to determine the nature of unknown quantities in circuits of electronic and electrical equipment. Once the measurements are made, they are used to determine the operating condition of the equipment under test.

Some of the fundamental measurements that are made in electronic testing are as follows:

Voltage, measured in volts or microvolts.

Current, measured in amperes, milliamperes or microamperes.

Resistance, measured in ohms or megohms.

Each of these measurements is used to determine the operating condition of electronic or electrical equipment. The accuracy with which these measurements are made depends on the type of instrument used, its sensitivity, its rated accuracy, and its useful range.

Chapter 5, Electrical Wire Connectors.

This chapter discusses, in order, the three major groups of electrical connections as used in electronic installations. In these three groups, wire termination is a presistent electrical problem. No matter what the form of application, the quality of wire terminations must be excellent. These three major groups are as follows:

1. SOLDER TERMINALS.

Solder terminals are widely used in electronic work. When properly made they are strong, permanent connections. However, there is always the danger of a "cold solder joint" and of corrosion from soldering fluxes unless care is used. Acid fluxes should never be used.

Soldering to various types of terminals is discussed in Section 5-2 of NAVSHIPS 900,171.

2. SOLDERLESS TERMINALS.

For some applications in electronic work, the use of an approved solderless terminal has been authorized. Some of the considerations that make up a good solderless connection are as follows: identical and uniform connections, insulation support, low resistance, radio noise interference-free, and corrosion proofings. Solderless terminals are discussed in Section 5-3 of NAVSHIPS 900,171.

3. "AN" CONNECTORS.

"AN" connectors are sometimes used for power, indicating, and control circuits of shipboard electronic equipment. They provide means of making dependable connections in water-proof, moisture-proof, flame-proof, vibration-proof, and pressure-proof applications. A complete "AN" connector is made up of two mating units: a plug assembly, and a receptacle assembly.

The "AN" prefix in connector part numbers indicates that design, materials, and construction conform to the military specification MIL-C-5015. "AN" connectors are discussed in Section 5-4 of NAVSHIPS 900,171.

Chapter 6, Insulating and Water-proofing.

This chapter is written to provide the installation worker with concise and factual information concerning the electrical characteristics of insulating and water-proofing materials, as well as the techniques used in the application of these materials to electronics work.

All insulating materials are classified in five categories; each one of which exhibits varying degrees of reaction to temperature, moisture, etc.

Section 1 defines these classes of insulation, lists their properties (resistance, dielectric strength, etc.), and the factors affecting their properties. In addition, fabricated insulating materials which may be obtained from shop supplies are included, together with pertinent information intended to familiarize the worker with a general background of the subject matter.

In Section 2, the approved methods of storing, maintaining, using insulating and water-proofing materials are presented.

However, when a detail specification for insulating and water-proofing is given on installation specifications, requirements and/or drawings, the specification should be used.

Chapter 7, (unavailable).

Chapter 8, Stuffing Tubes and Kickpipes.

Material discussed concerns shipboard installations mainly, but may have application in shore installations such as harbor defense, where shipboard practices may be indicated.

Chapter 9, Cabling.

This chapter concerns cable types and applications, including procedures for installation of certain cables needed for electronics installation. However, few of the cables commonly used in shore communications installations are described.

Chapter 10, Flexible RF Transmission Lines and Fittings.

Contains general description, installation handling, splices, and testing of solid dielectric cables.

Chapter 11, Rigid RF Transmission Lines.

Rigid RF transmission lines include waveguides (rigid and flexible), bead-supported coax (Teflon and Steatite), stub-supported coax, and Pyrotenax cable.

Chapter 12, Batteries.

Contains information pertaining to the construction and installation practices which concern storage batteries and dry batteries.

Chapter 13, Equipment.

This chapter discusses electronic equipments which are installed aboard Naval vessels, insofar as the installation worker is affected.

Shipboard electronic equipment includes the following categories: Radar, Radio, Sonar, Radiac, Teletype and Facsimile, invisible light (infrared and ultra violet), television, IFF, telemeter systems, and electronic test equipment.

The descriptive material and illustrations contained herein cover methods of uncrating, carrying, hoisting and installing electronic equipment.

Chapter 14, (unavailable).

Chapter 15, Motors, Generators and Amplidynes.

The primary purpose of this chapter is to provide electronic installation personnel with information and procedures necessary for the proper installation and care of motors, generators, and amplidynes.

Chapter 16, (unavailable).

Chapter 17, Tubes.

This chapter covers transmitting and receiving tubes in some detail, as well as special receiving devices. Figure 17-1 illustrates various receiving tube styles. The chapter also covers some of the less frequent applications to which tubes may be used.

Chapter 18, Tables.

The purpose of this chapter is to provide the electronic installation worker and electronic engineer with tables, scales, conversion charts, equations, and reference material prepared especially for application to electronic equipment. In addition, the tables, scales, conversion charts, etc., adapted for general use are included.

This special material includes, for example, cabling, tables, JAN nomenclature, fundamental antenna formulas, the formula for determining the characteristic impedance of coaxial or concentric cable lines, stuffing tube information, standard Navy color codes, and CG, RG and UG type designations with available Navy stock numbers.

Chapter 18 is thus prepared to assist the electronic installation worker in his daily duties and the electronic engineer in his daily calculations. Both should be cautioned, however, that the information listed is to be used only in the absence of a more specific data. Reference data, especially item lists, must be revised to keep pace with electronic equipment and methods of use.

Chapters 19, 20, (unavailable).

Chapter 21, Filters.

It is the purpose of this chapter to present a general knowledge of filters, their limitations, and proper installation methods.

Grounding and shielding techniques are discussed only as they affect the performance of the filters.

c. FLEXIBILITY.—Electronic installations at shore activities have been standardized by building specifications which require cavitated cell or trenched flooring where multiple equipment installations are involved. Flexibility with regard to future alteration or expansion involves consideration of space requirements and the initial installation of sufficient spare cabling.

d. DISTRIBUTING FRAMES AND PATCHING FACILITIES.—Where multiple equipments are involved such as those at transmitter, receiver, and communication center activities, the components which are designed to provide flexibility in use with provision for expansion and alteration are "Main Frames." Standard Installation Practices require that all equipment controls, patching, and monitoring facilities be wired through the main frame. The purpose is to eliminate "permanent" patches so that under normal operating conditions, no patching is required; patching facilities being used only in unusual circumstances such as in emergency, or in the performance of test, temporary monitoring, and maintenance operations.

(1) DEFINITIONS.—The following definitions apply:

Main Distributing Frame (MDF).—Terminates outside lines entering the building and equipment lines inside.

Outside lines may be terminated on protected or unprotected terminals, depending upon local conditions. Protected terminals are used for protecting personnel and inside equipment against excessive voltages originating outside. When heat-coils or fuses are used, both outside cables and inside equipment are protected against excessive currents, regardless of the source.

Intermediate Distribution Frame (IDF).—Is used for tie-points or inter-connecting between equipment, or equipment spaces within the building.

Combined Distributing Frame (CDF).—When the functions of the MDF and IDF are combined, the frame is designated CDF.

Classified Intermediate Distributing Frame (C-IDF).—This frame is peculiar to the Naval service and is so designated to indicate the nature of the circuits terminated. Circuits carrying classified information in plain language cannot be terminated on the same distributing frame with those carrying unclassified traffic. In fact, classified and unclassified frames must be separated spatially a minimum of six feet to minimize inadvertent cross-connecting of circuits and the jeopardizing of security.

(2) GENERAL.—The main distribution frame is the division point between the outside and inside of the station. All trunk circuits to and from the station are terminated at the main frame. Normally, all incoming and outgoing cable pairs, and all wiring within the station, except interbay, terminate on the main frame in order to facilitate trouble shooting, and provide flexibility in arrangement of circuits. Localization of trouble, if not determined by checks at patchboards, is facilitated by final line checks at the main frame. All wiring to the patch panels is terminated on a distribution frame. By proper cross-connection at the frame, any jack on the patch panels can be connected to any keying line or facility. By these cross-connections, the patch panel jacks are arranged so that operators can conveniently switch equipment and keying lines, as required.

The location of the main frame depends mainly on the location of the terminal equipment within the building. It is general practice, where space permits, to bring the outside cables into a vault. From there they may be routed up through the floor and terminated on the main frame. Where a cable vault is provided, the main frame should be located where it requires a minimum number of bends in the duct system, and as close to patch panels as practicable. This is usually done by having the frame in line with the entrance ducts lengthwise to the cable vault, and in the immediate vicinity of the associated patchboard.

The frames are composed of built-up units of steel framework used for the mounting of terminal boards. The number of frames depends on the number of lines to be served. In all cases, consideration should be given to the possible future growth of the station and of the main frame. Enlargement of the main frame should not interfere with other equipment, nor should other equipment lie in the path of the ultimate growth of the main frame. Framework may extend from deck to overhead, but the installation worker should not have to lie down to solder connections.

Distributing frames may be constructed to have:

(*a*) Vertical terminals on one side, and horizontal on the other side.

(*b*) All vertically mounted terminals on one side only, or

(*c*) Both vertical and horizontal terminals on one side.

In a large installation, the use of (*a*) is recommended because of the advantage in having more clear space for running cross-connect jumpers.

There are two types of main frames: wall, and floor. The floor-type frame is generally preferred. The permanent end of the floor-type frame should be placed at least three feet from the wall. A minimum clearance of three feet is required on both the vertical and horizontal sides. This space is necessary for proper operation and maintenance of the frame. Wall-type frames need not be placed more than one foot from the wall, since the jumpers are usually run from the front.

A typical floor-mounted MDF, with horizontal and vertical terminals, and cable protectors, is shown in figure 2-18.

(3) PATCH PANELS.—All communication installations must have patch panels to provide for flexibility, and integration of the communication system. The patch panel is normally located in the control center of the station, and is specifically designed to facilitate the restoring of defective circuits and equipments to an operating condition in the minimum amount of time by the operating personnel. Patching facilities enable the restoration of services by substitution whenever the fault cannot be readily corrected. A patch panel consists of a jack field mounted on a rack structure. It generally has facilities for testing and monitoring. Lines from every piece of local equipment, as well as all lines from the outlying installations, such as the transmitter and receiver stations, must appear on the patch panel in the control center.

The control center equipment includes patch panels for connecting circuits to terminating equipment, to the tape relay station, to the communication center, to associated terminal station, to carrier equipment generally associated with specific radio transmission systems, and other specialized equipment such as monitoring teletypewriters and test equipment.

The jacks for lines and equipment carrying tone or AF keying and the jacks for d-c keying circuits should be located in separate patchboards. Jacks used for like equipments are grouped together to facilitate operational control.

Equipment which produces or receives keying signals that may require monitoring or testing, while the circuit is in operation, should have additional jacks assigned for this purpose. These monitor jacks are connected so that a monitor teletypewriter, or some type of transmitter-measuring device, can be patched into the circuit without disturbing normal circuit operation.

All jacks in the patch panel are the normal-through type. When all circuits are operating normally and unmonitored, and the keying signals are passing through their normally assigned keying lines, there are no patch cords on the board.

The location of the control patch panels is determined by the location of the main control room in the building.

(4) GROUNDING.—All equipment and frames must be grounded to reduce the noise created by potential differences, and to safeguard personnel from shock. The ground should have as low a resistance as can be obtained. The equipment itself also requires protection from lightning, or other currents, that may be conducted to the office over outside lines. Protectors, as stated before, act as a safeguard by providing a discharge path to ground for high potential and long-continued excess currents. The effectiveness of the protectors depends on a good ground connection. Fuse protectors required for terminating outside cables should be mounted on the main frame, but may be mounted on the wall nearest the cable entrance, if the frame is not designed for mounting them. A wall frame or rack used for mounting fuse protectors should extend approximately one foot from the wall.

(5) CABLING.—To prevent high-level audio signals from being picked up and amplified in low-level circuits, separate cables should be used for carrying high-level and low-level audio signals. D.C. telegraph and control circuits should not be run in audio cables, but separate cables provided for this service.

In new construction, cellular flooring with trench or header duct is being provided for use as cable raceways. However, overhead racks should be used when cable runs are below grade level.

The establishment of criteria for the utilization of r-f cable is difficult because of the number of variables associated with any given installation. The type of cable, the utilization of the cable and the environment of the cable all play an important role. The first aspect of the problem to be considered would be the question of coaxial or armored coaxial cable. It can be shown that a theoretical improvement of 25 to 40 DB in leakage (signal to noise ratio) can be obtained by the use of armored cable rather than unarmored. As an illustration, consider for a moment two cables, Type RG-8/U, running in the cableway so that they are touching for a distance of 50 feet. If one of these cables had on it an RF level of 0.1 volts, it can be shown that the voltage induced on the inner conductor of the second cable is 2 microvolts. Under an identical situation the use of a double shielded or armored cable (RG-9A/U or RG-10/U) would result in an approximate reduction in induced signal of 80 DB. In the event that these two cables are in receiver circuits, no serious trouble could be expected to result. However, if one of the cables is of a different type and connected to a transmitter, such as might occur in an emergency installation, the output voltage on the transmitter cable would be considerably higher than 0.1 volt and the resulting signal induced in the second cable would be proportionately increased. The mechanical aspects of the cable problem should not be overlooked. Armored cable or double shielded cable in certain atmospheric environment will deteriorate over a period of time and will, therefore, become less effective. In addition, cutting or marring the armor during installation will further reduce the effectiveness of the cable.

e. INTERFERENCE.—One of the most important factors for consideration under systems engineering pertains to the installation of equipment in such manner as to minimize the effects of interference. This applies to the generation of radio interference as well as provision against interference to operation of equipment by causes which cannot be eliminated at the source.

As outlined in NAVSHIPS 900,000, Electronics Maintenance Book, the following is a representative listing of the most prolific sources of radio interference which systems engineering will take into consideration in all cases where electronic installation is to be accomplished:

(1) Overhead unshielded power lines located within approximately one mile or less of a receiving antenna.

(2) Vehicles and internal combustion engines having unshielded spark ignition systems and operated within 1,000 feet of a receiving antenna.

(3) Unfiltered motors and generators.

(4) Fluorescent lighting.

(5) Poor grounding systems.

(6) Defective shielding and bonding.

(7) Link trainers operated in proximity to a receiving activity. Radio interference is created by the turbo-compressors and the type NSF-11 Bodine motor located in the link trainer.

(8) Inert gas shielded arc welders, diathermy apparatus and induction heating equipment.

(9) TXC facsimile recorders.

(10) Unfiltered and unshielded oil burner ignition systems.

(11) Universal ac-dc electric motors in photographic laboratories such as are used in the PDX-30 photo developing equipment.

(12) Painted insulators on antenna systems.

(13) Taxiway lighting systems at Naval Air Stations.

(14) Proximity of radar and transmitter installations to receiving activities.

(15) Teletypewriters using gaseous rectifier power supplies and/or series motors.

(16) Electromatic typewriters, electric coding machines, electric adding machines and other miscellaneous electric office equipment.

(17) Flashing signs and thermostats.

(18) Electric razors and electric erasers.

(19) Rotary converters used for battery charging or as a source of direct current.

(20) Electric drills, vacuum cleaners and floor waxing machines.

(21) Power supplies using gaseous rectifiers.

(22) Leaky lightning arrestors on power distribution poles.

(23) Dirty, painted, or cracked insulators on power distribution poles.

(24) VRF-1 film recorders.

(25) Dry disc rectifier power supplies built by Raytheon Manufacturing Company under the trade name "Rectifilter" Catalogue 1082, Specification Number W-2529A.

Radio interference investigations have disclosed the following as representative of poor installation and maintenance procedures in connection with shielded systems:

(1) A general lack of proper cable and equipment bonding.

(2) Shielded cables found depending on loose clamps for bonding.

(3) Cable securing clamps having friction tape between the securing clamps and the flexible cable.

(4) Bonding straps of excessive length, constituting possible radiation loops.

(5) Securing clamps having surfaces painted at points of contact with the shielded cable.

(6) Bonding jumpers terminating to poor grounding surfaces.

(7) One bonding jumper used to ground a quantity of shielded cables.

(8) Breaks in cable shielding and loose couplings.

(9) Corroded bonding and joint mating surfaces, creating a point of high radio-frequency impedance.

Poor installation and maintenance practice in connection with receiving activities has also been found responsible for the existence of high levels of radio interference even though the activity itself was not originally located in an area of high radio interference levels. This condition is caused by the subsequent installation and operation of radio interference sources in proximity to a receiving activity, without taking corrective action towards rendering these sources ineffective, by means of shielding, bonding, and/or filtering. The radio interference investigations conducted to date have disclosed a general lack of proper and periodic maintenance procedures. This lack of maintenance is manifested by broken or corroded shielding, ineffective grounds, bonding straps excessively long or not properly terminated, and insulators painted.

2-16. GROUNDING CRITERIA.

a. GENERAL.–An important factor in the design of a shore electronic facility is the establishment of an adequate ground. Adequate electronic grounding requires that the impedance of the ground system, at all frequencies of interest, be low compared to the impedance of the network to which it connects.

The establishment of an adequate ground at power frequencies, where the length of the ground leads is very short compared to a wavelength, only requires the use of simple d-c analysis. However, for adequate grounding at radio frequencies, where the length of the ground leads is long compared to a wavelength, transmission line techniques and consideration of the distributed parameters (primarily the stray capacitance) are required in the analysis.

There are three factors to consider for an adequate ground system. In many respects the function of the ground system for one factor will overlap the function of the ground system for another factor, allowing one ground system, which provides adequate grounding, to meet all specifications. These three factors are (1) safety, (2) interference, and (3) propagation.

(1) SAFETY.–Grounding for the safety of personnel and the protection of the building is effective only when the impedance of the ground system is low compared to the impedance of the human body. Grounding for this factor follows long-established engineering practices for power systems that are grounded by driving rods of the necessary length into the ground at strategic places. Personnel hazards and lightning protection are considerations which determine the extent of this grounding system. These power grounding techniques are applied as part of the establishment of the "building ground" at shore electronic installations. The building ground as well as the equipment case ground comes under this category and is essential where electronic equipment is installed.

(2) INTERFERENCE.–Interference in shore electronic facilities can come from numerous sources. Studies have been made to eliminate or lower the interference and bring about a higher signal-to-noise ratio.

Most receivers at Navy Shore Receiving Facilities are connected to their antennas via coaxial cable which is usually run underground from the antenna into the building. Inside the building the coaxial cable is armored, single-shield cable, such as RG-12A/U, and may be several hundred feet in length before termination. The length of cable "above ground," plus ineffective receiver case grounding, can lower the signal-to-noise ratio unless care is exercised in grounding techniques.

A transmission line is formed between the outer conductor (armor braid) of the antenna cable and ground, which is terminated in a very low resistance by virtue of the cable being buried in earth. The impedance looking from the receiver will fluctuate from an extremely high to an extremely low value, as will the impedance of any improperly terminated transmission line. Thus, at some frequencies the shield will constitute a good ground and carry most of the noise to ground, while at other frequencies it will not, since other paths will be more effective.

The fluctuation in the impedance to ground may be minimized by correcting the distributed constants of this transmission line, to provide a better ground at all frequencies of interest. Analysis has revealed that a lower impedance to earth can be obtained by bonding the equipment to a large conducting surface beneath the equipment.[49] As the width of the conducting surface increases, the stray capacitance increases, the unit length inductance decreases, and the characteristic impedance decreases even further. This effect is shown in Figure 2-43.

Use of the large conducting surface will also help in other ways.

(*a*) Any noise on a cable or conductor coming to the receiver through or along the conducting surface will have its field contained between the conductor and the surface. This noise field can easily be "shorted out" by filters and bond straps because the distance between the transmission line conductors is very small. If the surface were not there, the field would exist between the conductor and earth, and a short is impossible for such a transmission line. Shorting out the noise field has the desirable effect of keeping noise currents from flowing over the receiver case and along the antenna input cable.

(*b*) Filters at the output terminals of equipment can operate more effectively when both terminals of their equivalent transmission line are available. As in (*a*), a large conducting surface makes it possible to contain the field carried by the offending conductor, in such a way that it can be prevented from traveling further.

(*c*) The presence of a large conducting surface to which receivers are bonded will tend to lower any noise voltage between the receiver chassis and earth. This will also reduce the possibility of noise currents being induced into the input transformer in a path back to earth through the antenna-earth capacitance as shown in Figure 2-44. When a receiver is connected to its antenna, a voltage source from chassis to earth can cause current to flow in a far more sensitive path, as shown in Figure 2-44. E_n is a voltage applied between receiver chassis and earth by the power cord or other receiver cables. This causes a current to flow through the primary winding of the input transformer and back to earth through the antenna-earth capacitance. The current flow along the antenna input cable may be reduced by running the cable underground.[50]

(*d*) A large conducting surface will tend to shield any roof-top antennas from cable runs below it.

(3) PROPAGATION.—The ground itself is a part of the propagating mechanism, particularly for unbalanced antennas which require the establishment of an efficient radiation field between the above-ground portion of the radiator and the earth. Two factors are considered in the design of this counterpoise, ground mat, or radial ground system. These factors relate to (a) the power consumed because of heavy current flow in the ground, and (b) the effect of ground on the radiation pattern. Power losses in the ground due to low conductivity result in lower available radiated energy. The extent of the ground system with respect to the vertical radiator greatly affects the radiation pattern. In general, the longer the ground radials the more efficient the low angle radiation. Engineering of such a radial ground system should be based on operating requirements and ground conductivity. Lengths of 1/4 wavelength radials are generally specified. For low angle requirements and low soil conductivity, radial lengths up to 2-1/2 wavelengths are recommended. For take-off angles of the order of 10 degrees and low soil conductivity, a gain of approximately 3 db may be expected when using one wavelength and 6 db when using 2-1/2 wavelength as compared to 1/4 wavelength radials. Additional radial length contributes very little. LF and VLF ground systems are considered on a "case" basis.

b. STANDARD GROUNDING PRACTICES.

(1) GROUND RODS.—To provide an earth connection for a ground system, ground rods are driven into the earth and connected by straps to the remainder of the ground system. To meet the National Electric Code specification for ground rod installation, a minimum depth of eight feet is recommended for a three-quarter inch single rod into the earth. Multiple rod connection to earth or greater depth is generally required to obtain a ground connection approaching the recommended value of three ohms. Test measurements are required as outlined in Appendix V. Figure 2-45 shows graphs of typical values of ground resistance obtainable with variation in depth and for multiple rod application.

A ground connection, regardless of its application, must meet certain well-defined specifications.[77] The relation between the conductance of a group or rods spread over a given area to the conductance of a single rod is shown in Figure 2-45. A ground mat which uses driven ground rods effectively will be constructed at such a spacing that the ground rods act as individual grounds, with relatively little over-lapping of current paths, and the conductors connecting them are different fractions of wavelengths at radio frequencies.

Criteria for construction under cognizance of the Bureau of Yards and Docks which concern Electrical Apparatus Distributing Systems and Wiring, is set forth in NAVDOCKS Specification 9YG, Paragraphs 2.11, 2.11.1, 2.11.1.1, 2.11.1.2, and 2.11.2.

Table 2-6 lists the maximum allowable ground resistance for electrical distribution systems and equipment. Resistance measurements must be taken (see Appendix V) at each ground rod (or group, when multiple rod connections are used) to assure the resistance listed is not exceeded.

TABLE 2-6, MAXIMUM ALLOWABLE GROUND RESISTANCE FOR ELECTRICAL DISTRIBUTION SYSTEMS AND EQUIPMENT

	OHMS
For grounding generating stations	1
For grounding main substations, distribution substations, and switching stations on primary distributing system	3
For grounding metal enclosures and cable sheaths enclosing electrically operated equipment and connecting cables	3
For grounding systems to which portable electrical utilization equipment of appliances are connected	3
For grounding secondary distribution systems (neutral), noncurrent carrying metal parts associated with distribution systems, and enclosures of electrical equipment not normally within reach of others than authorized and qualified electrical operating and maintenance personnel	10
For individual transformer and lightning arrester grounds on distribution systems	10
For equipment not covered	10

(2) EQUIPMENT AND CABLE GROUND.—Equip-

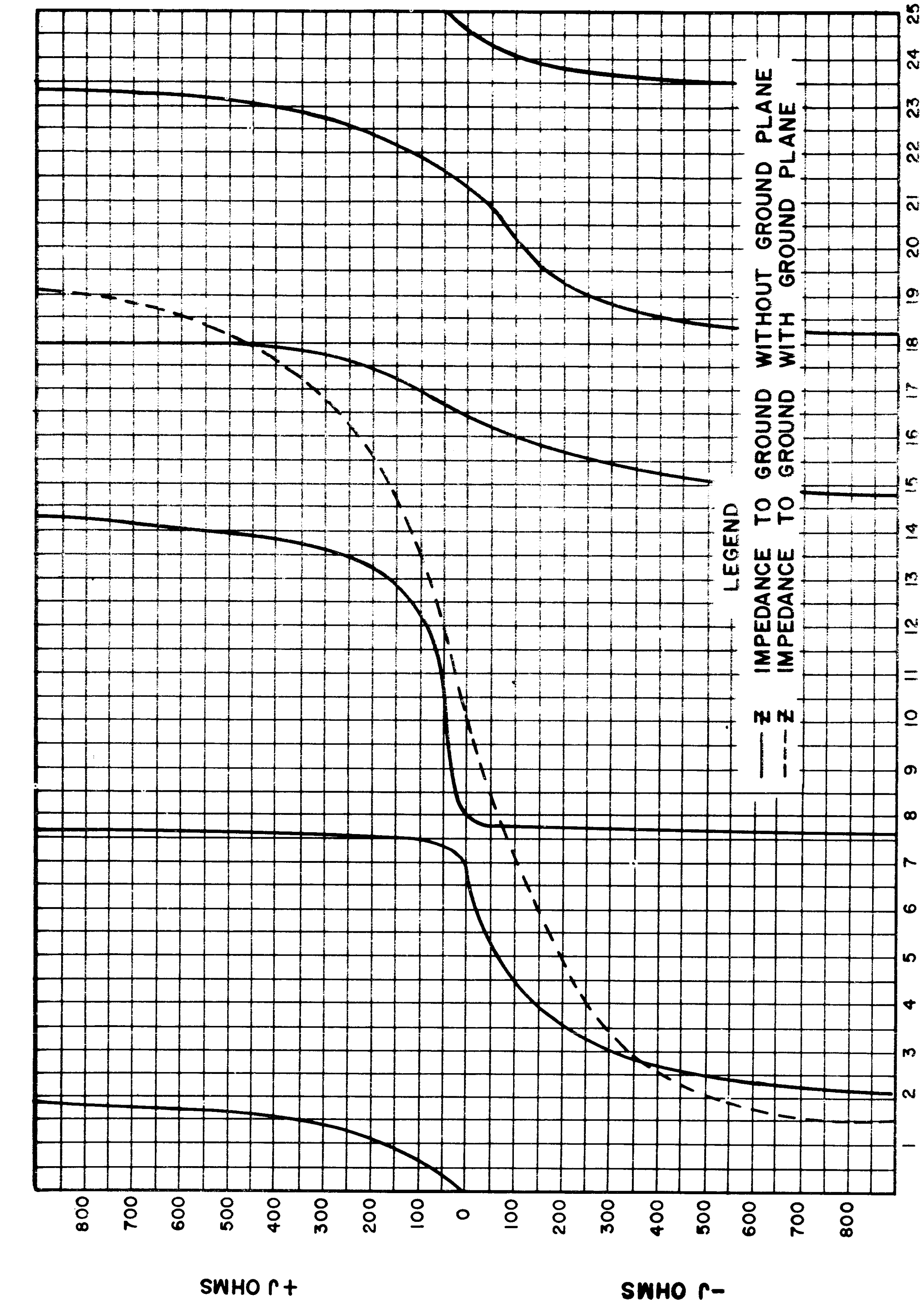


FIG. 2-43 CURVES SHOWING IMPEDIANCE TO GROUND WITH AND WITHOUT THE LARGE CONDUCTING SURFACE AS A GROUND PLANE

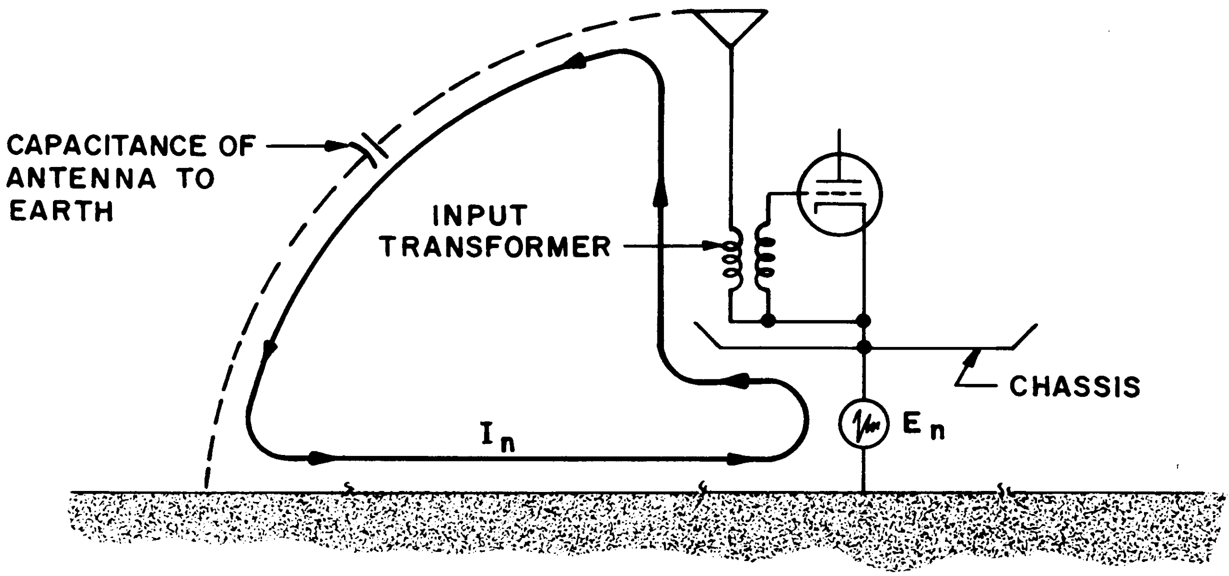


FIG. 2-44 NOISE VOLTAGE THROUGH INPUT TRANSFORMER AND BACK TO EARTH THROUGH ANTENNA-EARTH CAPACITY

ment and cable armor are bonded to the building ground system by means of bonding straps. The bonding strap should meet the specifications set forth in MIL-I-16910B. The ratio of 1 to 5 given in this specification may be unrealistic in some cases; if so, common three-quarter inch strap material may be used for such ground connections. Firm electrical connections to paint-free metal surfaces are mandatory.

Properly installed, the coupling nut of the standard connector, together with a grounding ferrule, provides a ground connection for cable armor. Grounding is to be accomplished at the cable vault rack and in the standard r-f distribution panel within the building. The cable armor should also be grounded where entry into the conducting surface (Q-cell flooring, copper-weld grid, or a metallic subfloor of copper screen or sprayed copper mesh) is made by means of a standard conduit entry assembly.

Where video coaxial cables are brought into a building, they will be bonded together and provided with a separate grounding rod. This will reduce cross talk between the signals in the video cables and the signals in the audio and control cables.

(3) TRANSMITTER BUILDING.—As a part of the standard transmitter building construction (by BUDOCKS) a grounded copper-weld grid, copper wire mesh, or sprayed copper mesh is placed on or embedded in the concrete floor and bonded to a #2/0 stranded copper perimeter ground cable around the outer building wall. Reinforcing steel and structural metal parts are electrically bonded together and to the perimeter cable by #6 copper wires. Earth connections for the perimeter cable are made by driving a 3/4 inch copper-weld ground rod to a depth at which the d-c resistance is 0.5 ohm, or to refusal, at each building corner and at intervals of not less than 20 feet around the building perimeter. Each ground rod is electrically connected to the perimeter cable by means of two #6 wires.

Standard transmitter building construction includes knockout cable sleeves through the floor to the cable trays suspended on hangers in the basement space underneath. Building construction will provide a stranded #O AWG copper wire approximately 5 feet in length that is welded (brazed) to the grounding grid and coiled within each sleeve during building construction. See Figure 2-46. When equipment is installed, one ground wire will be pulled through the cable sleeve and lugged to ground equipment by bolting into its frame. Wires unused for transmitters will be used for grounding cable trays and cable armor. It is standard practice to provide the cable sleeves and #O AWG ground wires on two foot centers beneath each row of transmitters.

In the small transmitter building which may be constructed without basement, a similar copper

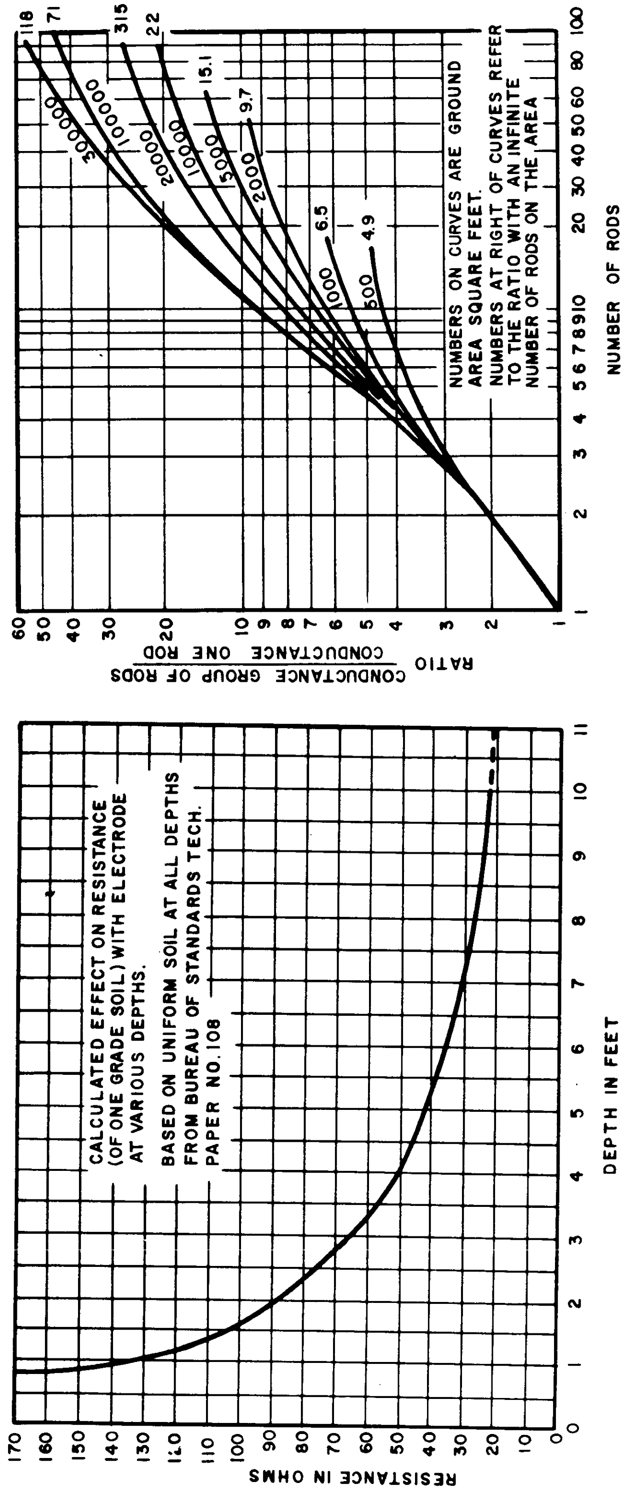


FIG. 2-45 GROUND RESISTANCE OBTAINABLE WITH VARIATION IN DEPTHS AND FOR MULTIPLE ROD APPLICATION

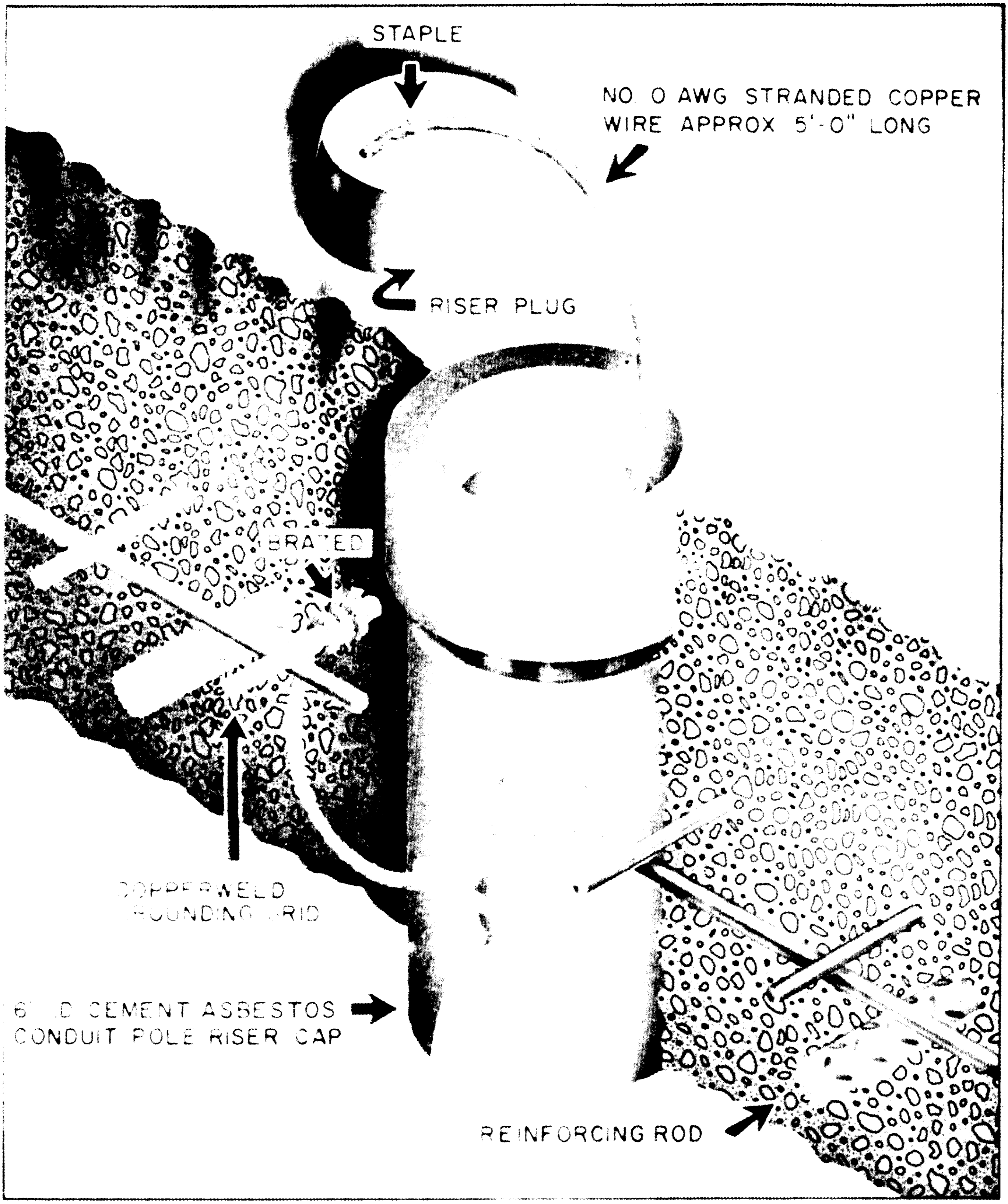


FIG 2-46 CABLE SLEEVE OF STANDARD TRANSMITTER BUILDING FLOOR

ground mesh will be provided in the ground floor and bonded to a perimeter cable. Buildings of this type will have cable trenches with a copper grounding strap running along the upper edge of the cable trench and #O AWG ground wires brazed to the strap at two-foot intervals. These will provide a convenient means for equipment and cable grounding. The copper grid, together with the grounding rods, forms a low impedance path to earth for both power supply and radio frequency currents.

It is standard construction practice to bond and weld all structural reinforcing steel within the floors and walls of the transmitter building to form an electrically connected and grounded system. Bonding the copper-weld floor grid to the structural steel at two-foot intervals is accomplished during building construction.

(4) RECEIVER BUILDING.—The building ground system of the standard receiver building is similar to that of the foregoing transmitter building, except Q-cell flooring is used on all floor levels above the basement. The Q-cell flooring will function as the large conducting surface discussed previously. A copper bus, 3/16" x1", connects the Q-cell flooring to each driven ground rod. Grounding of equipment fixtures, cabinets, cable armor, and cable fittings is accomplished with minimum ground strap length, to any portion of the Q-cell floor where positive connection can be made.

To provide equipment ground connections into the Q-cell steel, a hole is drilled through the concrete floor and through the steel to the ceiling below. A half inch flanged steel rod is run through the hole and welded to the Q-cell steel. The other end of the rod is provided with a screw connection to which a lugged ground strap may be connected.

This building ground system will provide a low impedance to ground for both power and radio frequency potentials. External ground mat or radial systems are only required when this type of ground is an integral part of the wave propagating mechanism. Marconi (long wire) antennas for receiving should be provided with such a separate ground, installed a considerable distance from the receiver building, and the antenna coaxial cable run under ground into the receiver building. Thus, the antenna is isolated from noise sources in and around the receiver building and the receiver is protected against such noise by the shielded cable and grounding techniques as previously described. Other unbalanced antenna types, such as sleeve antennas, also require ground radials.

(5) VHF-UHF BUILDING (NAVAL AIR STATIONS).—The standard building is specified for remote VHF-UHF receiver installations, but may be used for VHF-UHF transmitters. A copper-weld grid is embedded in the ground floor and connected to earth by means of driven ground rods. Cable trenches are provided as for the transmitter building. An external ground mat is usually not necessary.

(6) OPERATIONS BUILDING AND CONTROL TOWERS.—An adequate building ground for this type of building will have a ground embedded in the floor, Q-cell or similar flooring in equipment spaces, and connected to earth with driven ground rods.

Where communications are mainly in the VHF and UHF ranges, ground mat installation is not necessary.

(7) D-F STATIONS.—The building ground of the D-F building is similar to that of the standard receiving building and equipment and cable grounding will conform with standard practices as set forth in Paragraph 2-16, *b* (2).

(8) RADAR INSTALLATIONS.—A building ground similar to that of the standard transmitter or receiver building is required. Equipment and cable grounding will conform to standard practices as set forth in Paragraph 2-16, *b* (2).

(9) CRYPTO FACILITIES.—Grounding criteria concerning crypto facilities is promulgated by N.S.A. under "Criteria for Secure Wire Distribution System for Crypto Systems."

c. BUILDING PLANS.—Standard plans for building construction will incorporate grounding facilities as described in the preceding paragraphs. Where such standard plans are not presently available, new construction or alterations will incorporate the foregoing features of grounding into building construction to provide environment for the most efficient electronic system performance.