NAVSHIPS 0967-177-3010 *(Non–Registered)*

SHIPBOARD ANTENNA SYSTEMS

VOLUME 1

COMMUNICATIONS ANTENNA FUNDAMENTALS

SUPERSEDES CHAPTER 1 NAVSHIPS 900, 121(A)

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DEPARTMENT OF THE NAVY

NAVAL SHIP SYSTEMS COMMAND

SEPTEMBER 1972

LIST OF EFFECTIVE PAGES

SECTION NUMBERS	CHANGE IN EFFECT	PAGE NUMBERS
Title Page	ORIGINAL	i
Front Matter	ORIGINAL	iii through viii
1	ORIGINAL	1-1 through 1-12
2	ORIGINAL	2-1 through 2-32
3	ORIGINAL	3-1 through 3-12
4	ORIGINAL	4-1 through 4-2
5	ORIGINAL	5-1 through 5-6
6	ORIGINAL	6-1 through 6-4
Appendix A	ORIGINAL	A-1
Appendix B	ORIGINAL	B-1 through B-10
Appendix C	ORIGINAL	C-1 through C-6
Alphabetical Index	ORIGINAL	Index 1 through Index 4

TABLE OF CONTENTS

SECTION 1 -- INTRODUCTION

SECTION 2 -- ANTENNA TYPES

TABLE OF CONTENTS (Continued)

SECTION 3 -- ANTENNA CHARACTERISTICS

SECTION 4 -- ANTENNA ENVIRONS AND PROPAGATION

SECTION 5 -- ANTENNA TRANSMISSION LINES

SECTION 6 -- ANTENNA SYSTEM MAINTENANCE

TABLE OF CONTENTS (Continued)

APPENDICES

LIST OF ILLUSTRATIONS

List of Illustrations (Continued)

SECTION 1

INTRODUCTION

1.1 PURPOSE.

This publication is Volume 1 of a series published by the Navy concerning elements of Shipboard Antenna Systems. The purpose of this volume is to describe the individual types of communications antennas in use onboard ship and to outline their employment in the various systems. The unique problems encountered in the design, installation, and maintenance of shipboard antennas are included in this volume. Although the emphasis is directed primarily toward antennas, peripheral and ancillary components and equipments are discussed insofar as their integration into the antenna systems is concerned. Radar, fire control and navigational antennas are not covered except to present their influence on the communications antennas.

This volume is intended for use by electronics and communication personnel afloat who have responsibility for the operation and maintenance of the ship's communications system, and by design and installation personnel engaged in topside integration engineering and installation.

1.2 GENERAL.

1.2.1 IMPORTANCE OF THE ANTENNA.

The radio frequency energy that is generated by the transmitter serves a useful purpose only when it is radiated into space in the form of electromagnetic energy. The antenna, as the interface between the transmitter and free space, is required to convert the power from the transmitter into electromagnetic energy as efficiently as possible and to direct this energy where it will be useful. The degree to which the input power is converted to useful radiated energy is the figure of merit or efficiency of the antenna. Since antennas are used both for transmitting and receiving, the various properties of individual antennas apply to both modes of operation. Thus it is apparent that the antenna is a major element of the transmitting/receiving communications system.

1.2.2 CONSTRAINTS

The design and installation of communications antennas onboard ship must take into consideration the constraints presented by the following factors.

ENVIRONS. The environment and space allocated to communications antennas.

SERVICE PERFORMANCE AND FLEXIBILITY. The service performance and flexibility as required by the operational requirements of the specific ship.

EMI. The electromagnetic interference with other systems such as radar and fire control directors.

EMC. The electromagnetic compatibility between the communications antennas and other systems.

ARC OF FIRE. The restrictions placed on the installation of communications antennas in the vicinity of the firing arc of gun mounts and missile launchers.

AIRCRAFT OPERATING AREAS. The restrictions placed on the installation of communications antennas in the vicinity of the aircraft operating areas.

REPLENISHMENT AT SEA STATIONS. The restrictions placed on the installation of communications antennas in the vicinity of replenishment at sea stations.

ADDITIONAL AREAS. The restrictions placed on the installation of communications antennas in the vicinity of stacks, exhausts, navigational areas and other ships structures.

1.3 UNIQUE ENVIRONS PROBLEM.

1.3.1 SPACE AVAILABILITY.

A ship, regardless of class or relative size, presents a very restrictive platform for the installation of communications antennas. It's dimensions fore and aft and across the beam are fixed. The only space relatively free for varying is in the vertical plane and this dimension is generally constrained by such features as the above deck configuration, international height limitations and ship stability. There is considerable competition for space in this area from other requirements, e.g. flag halyards, radar antennas and navigational aids antennas. The firing arcs of the ordnance system restrict the installation of antennas in the vicinity of gun mounts and missile launchers. The increased use of rotary wing aircraft for operational missions and vertical replenishment services imposes severe restrictions on the location and size of antennas in the vicinity of the helicopter approach and landing areas. The net result of these restrictions is to limit the space available for communications antennas to a narrow strip approximately one third of the length and two thirds of the beam width of the ship. In the case of a DDG this area is roughly 135 feet by 30 feet. Additional space is gained by mounting types of whip antennas on gun mounts and other structures outside the arc of fire restrictions.

The design, installation and maintenance of shipboard communications antennas to adequately fulfill the operational requirements present many difficult problems. The methods used to resolve these problems are not always the best possible since they have been arrived at by a series of improvisations and compromises to meet expanded fleet requirements. Topside arrangements require close cooperation between all concerned with design and installation in the area to insure the best approach to satisfy the requirements of the various systems. The individual sections of this volume will further expand the methods and designs employed to furnish the best system within the constraints of the ship.

1.3.2 ANTENNA DESIGN SIZE LIMITATIONS.

A naval ship is not only a gun or missile firing platform or an aircraft landing site; it is also a large radar station, a direction finder station, an electronic navigational aid station, and a transmitter-receiver communication site. Some ships combine all these features and most ships have the majority of these systems. If all communication services required onboard ship were located on shore the surface area required by the antennas would be many hundreds of times the space actually available onboard ship. The equipments would be widely separated into a number of groups to avoid mutual interference.

The availability of space for antennas at shore based facilities generally permits the use of large antennas designed to satisfy specific frequency, directivity, and impedance parameters. But, in the shipboard case, because the limited space generally available for antennas is amidships and covers a length of only 200 to 300 feet on the larger ships, design of the 2-30 MHz (MF-HF) portion of the communication suit must take into account that this area is about one-half wavelength at 2 MHz. Spacing from major ship structures that act as parasitic radiators is very small and this results in major coupling problems forcing compromises in physical size and a reduction in the total number of antennas as compared to a shore station with similar operational requirements. This situation has necessitated the development of a family of broadband antennas for use in the MF/HF (2-30 MHz) portion of the spectrum, e.g., fans, discones, discages and trussed whips. In general these antennas are capable of operating with a VSWR not greater than 3:1 over a 3:1 frequency range. Broadband antennas are also capable of being used with multicouplers to permit the use of more than one transmitter or receiver with a single antenna. Whip antennas are used for transmitting and receiving, usually with a single equipment. Whips are installed on many areas of the ships structure such as the stacks, bridge wings, masts and platforms. Special probe type antennas are used for receiving in the LF/MF/HF bands. Probe antennas are relatively small and are usually equipped with a remotely controlled tuner that is an integral part of the antenna mount. These antennas are installed on yardarms, radar platforms, stacks, and masts.

Though VHF and UHF antennas are physically smaller they also present location problems with regard to other systems. VHF and UHF are line-of-sight systems and therefore require siting in a clear area at an optimum height on the ships structure or mast. Unfortunately this area is also needed for radar, UHF direction finder and navigational aid systems. VHF and UHF antennas are usually installed on stub masts above the foremast and below the UHF direction finder. UHF antennas are often located on the outboard ends of yardarms and other structures that offer a clear area.

1.3.3 SIMULTANEOUS RECEIVE/TRANSMIT CONSTRAINT.

The preceding sections outlined the problems relative to constraints placed on communications antennas by restricted space and physical size. The requirement to transmit and receive simultaneously presents additional restrictions on the location of transmitting and receiving antennas. When transmitting and receiving antennas are located in close proximity the voltage induced in the receiving antenna may be sufficient to interfere with or damage the receiver. The ratio of the interfering power radiated by the transmitting antenna to the amount delivered to the receiver is defined as the isolation. In general, the particular value of isolation depends on the antenna configuration, impedance, and the spacing between antennas. Ideally, antennas should be as widely separated as physically possible to provide a high degree of isolation. The possibility of damage to the receiver from excessive induced voltage increases directly as the transmitter and receiver frequencies approach each other. Levels of 100 volts can be expected and must be allowed for in protecting the receiving system from burn-out and other degrading phenomena such as: overload desensitization, resulting from the receiver being driven into a non-linear region by interfering signals; cross-modulation, caused by transferring modulation from the interfering signal to a signal on the receiver frequency; intermodulation, caused by two interfering signals mixing in receiver non-linearities; spurious and image responses that are the results of specific relationship between the frequency of the external signal and signals from oscillators inside the receiver necessary for superheterodyne operation. In each case the degree of degradation is dependent on the isolation between antennas.

The physical isolation of receiving and transmitting antennas onboard ship is limited due to lack of space. Common practice is to install receiving antennas on gun mounts, bridge wings and other structures at the extreme boundaries of the available antenna space as far from transmitting antenna as possible. Transmitting antennas are usually located between the masts or in the center of the available antenna space. On some of the larger ships transmitting antennas are located on the bow to provide isolation from the antennas amidships. In a well designed system that provides maximum physical separation between the transmitting and receiving antennas additional isolation is accomplished by the use of the filtering in transmitting and receiving multicouplers. The minimum frequency separation between transmitting and receiving frequencies for simultaneous operation is dependent on the isolation between the antennas and the passbands of the filters.

1.4 SERVICE PERFORMANCE AND FLEXIBILITY.

1.4.1 GRADE-OF-SERVICE COMPROMISES.

The mission of naval shipboard communications is to provide and maintain reliable, secure, and rapid communications based on combat requirements and the needs of naval command and administration. To accomplish this mission it is necessary to operate shipboard transmitting equipment within the frequency range of 300 kHz to 400 MHz and receiving equipment from 14 kHz to 400 MHz. The range of coverage extends to 2000 miles. The number of circuits and individual frequencies in use at any specific point in time is based on the operational employment of the ship. A typical operation might require the use of VHF/UHF transmitting and receiving for ship-to-ship and ship-to-air, HF transmitting and receiving for ship-to-ship and ship-to-shore, and ship-to-shore receiving on VLF/LF/MF and HF. Modes of operation include AM, FM, SSB, AFSK RATT, FSK RATT, FAX and CW. In the worst case all circuits may be operating simultaneously. The ship's navigational and air radars, fire control radars, and electronic aids to navigation equipments may also be in operation at the same time as the communication systems. Under these conditions it is highly probable that there will be interference within and between systems due to the limited area available for antennas onboard ship. The level of interference will be dictated by the mutual coupling between antennas, spurious radiation, operational frequencies, and transmitting power in use. The interference will create various conditions such as cross modulation, intermodulation products, and desensitization of receivers.

Maximum operating efficiency can be expected only if the interference can be eliminated or controlled by the proper selection of antennas, frequencies, and power levels. System tuning and alignment must be done with care to take advantage of the filtering circuitry in the transmitters, receivers, and multicouplers. It may be necessary, in extreme cases, to assign priorities and secure individual circuits to overcome interference. Operating personnel should be aware of the sources of interference that exist under certain combinations of equipment operations. Conditions that repeatedly create difficulties should be avoided through judicious selection of frequencies, power levels, and operating periods to obtain best possible operations.

1.4.2 TRANSMISSION AND RECEIVING TRAFFIC DELAYS.

Transmission and receiving traffic delays may be encountered in communication systems due to the ships antenna system configuration. The availability of antennas is fixed both in number and, in the case of broadband types, in frequency coverage. The total number of circuits required to be operational at a specific time is dependent on the mission of the ship. The frequencies required to furnish circuit coverage are dictated by the area in which the ship is operating and the point of access into the ship-to-shore system. The use of multicouplers, both for receiving and transmitting, has increased the number of available circuits. However, due to the limitations imposed by shipboard antenna locations, interaction between transmitting and receiving antennas, and the required adjacent frequency separation in the multicoupler, certain frequencies may be unavailable when required. In this situation it may be necessary to assign priorities to individual circuits. Operating personnel must be skilled in selecting the best antenna-coupler combinations to decrease interference between circuits, and in choosing the correct antennas for the MUF and LUF during any specific time period. It would also be helpful to be aware of any peculiarities in the directional characteristics of the ship's antennas.

1.5 ANTENNA ELECTROMAGNETIC INTERFERENCE (EMI).

1.5.1 INTRACOMMUNICATIONS SYSTEM EMI.

Electromagnetic interference can result in annoying or impossible operating conditions. This problem is becoming especially serious because of the continual increase in the number of electronic equipments operating within given space and frequency boundaries, the high power levels of transmitting equip-equipment, and the increased sensitivity of receiving equipment. In considering the sources of electromagnetic energy two basic categories have been established. The first category consists of sources specifically designed to generate radio frequency energy. Examples are oscillators, communications transmitters, and radar transmitters. The second category consists of natural and manmade sources that are not specifically designed for the purpose of generating radio frequency energy. A number of electrical devices fall in this category. Examples include DC generators, motors, switches, and relays. Natural interference sources include thunderstorms, snowstorms, cosmic sources, and the sun.

All of these sources create EMI problems onboard ships. The possibility of EMI is further increased by the concentration of the possible sources in a relatively small area. Shipboard antennas, particularly broadband antennas in the HF region, are compromises to satisfy space, frequency, impedance, and bandwidth requirements. As such they are more susceptible to non-linear interference than are the narrow band types.

Equipments such as communication and radar receivers present EMI problems because they respond to relatively low-level signals. However, other equipments such as control units, computers, telemetry and test equipment, audio amplifiers and electroexplosive devices are equally susceptible.

The reduction of generated EMI at the source can be controlled by restricting non-linearities in the transmitter output and antenna system, limiting bandwidth, and by filtering and equipment shielding.

Radiated EMI during transmission can be controlled by physical separation of the transmitting and receiving antennas, the use of directional antennas and limiting antenna bandwidth. A degree of control of receiving equipment susceptability to EMI is possible by increasing selectivity, restricting non-linearities, filtering and shielding.

The physical constraints created by the minimal area available for antennas aboard ship limit the separation between transmitting and receiving antennas necessary to obtain adequate isolation. The use of directional antennas in the HF bands is impractical also due to lack of space. Ideally shipboard antennas should be as omnidirectional as possible to insure coverage independent of the position of the ship.

The limited number of antennas available onboard ship has necessitated the use of broadband types to satisfy the demand for operational frequencies. Therefore, the use of narrowband antennas to reduce EMI is not practical.

The most probable victim of interference from communication transmitting antennas is navigational aids. Loran receivers, MF and HF direction finders operate within the fundamental frequency range of the transmitting equipment and as such are susceptible to high signal level interference. Since the interfering signals are high level, RFI reduction is difficult due to the proximity of the transmitting antenna to the receiving antenna. Severe cases will necessitate priority assignment and possible shutdown of the communication transmitter. Interference to TACAN is somewhat remote due to operating frequencies and low power levels of possible communication interference sources. However, all systems are susceptible to RFI if non-linearities are present in any system.

Ship's entertainment, announcing, and telephone systems are susceptible to RFI from communication transmitters due to non-linearities in the equipment, poor shielding and grounding and locations near to high level radiation.

Broadband antennas make the use of multicouplers practical in covering a much wider band of frequencies in comparison with narrow band antennas. The multicouplers provide filtering in both transmitting and receiving antenna systems to assist in reducing EMI. The degree of filtering is dependent on frequency separation, the selectivity of the filter tuned sections and filter losses.

Selectivity and filter losses are determined by the basic equipment; therefore, frequency separation is the most critical. With current transmitter performance, about 8% separation between transmitting and receiving frequencies is needed. A 5% minimum separation between transmitting frequencies used simultaneously is also required.

1.5.2 INTERCOMMUNICATIONS AND ELECTRONICS SYSTEMS EMI.

EMI problems are usually a two-way street. Communications systems are subject to interference from radar, fire control directors, navigational aids, etc. Conversely communication transmitters cause interference to these systems. Interference to radar systems from communications transmitters may exist when harmonics of the transmitter output frequency fall within the IF passband of the radar receiver. If the communication transmitter is properly adjusted, the possibility of this type of interference is somewhat remote. Fire control directors use highly directional antennas and operate on frequencies far removed from any harmonic relationship of sufficient power from the communication transmitter to cause interference.

1.6 ANTENNA ELECTROMAGNETIC COMPATIBILITY (EMC).

1.6.1 GENERAL

Electromagnetic Compatibility (EMC) is an all inclusive term used to describe the ability of communications equipments to operate in their intended environment without suffering or causing unacceptable degradation because of unintentional electromagnetic radiation or response. Electromagnetic compatibility and electromagnetic interference are closely related; however, in an equipment or system test the terms take on a slightly different meaning. In this case EMC is considered on a system level, while EMI is considered on an individual equipment level.

When all methods of EMI reduction have been employed to decrease interference between all systems the lower limit of EMC level in which the ship must operate has been established.

1.6.2 COMMUNICATIONS ANTENNA EFFECTS.

The prime antenna factor affecting EMC within the communications system and between other electronic systems onboard ship is the close spacing of the antennas for the various systems. Control of EMC at shore stations, where adequate space is available to permit antenna separation, is considerably easier than in the restricted shipboard environment. Space availability at shore stations usually permits a one antenna - one equipment operation. Moreover directional antennas are used to provide transmission path gain in the desired direction permitting orientation away from possible sources of incompatibility and toward areas that will minimize interference to other systems. The number of communication circuits required by the operational commitments of the ship generally exceeds the number of available antennas on a one-to-one basis. To overcome this deficiency broadband antennas and multicouplers are used. Broadband antennas are inherently susceptible to harmonic radiation. Transmitter harmonics that fall within the passband of the communication receivers are possible sources of system degradation due to various types of RFI. This in turn limits the full use of the receiver's sensitivity characteristics. Directional antennas, with the exception of satellite and other specialized types, are not used on ships because of the requirement to have maximum omnidirectional coverage independent of the ship's position.

The degree of compatibility between shipboard communications transmitting and receiving systems is dependent on the same criteria required for the reduction of RFI.

Compatability with other electronic systems is determined by the antenna proximity, frequencies employed, types of emission and equipment characteristics. Surface search and fire control radars do not ordinarily present compatibility problems due to the directional characteristics of the radar antennas and the radar frequencies. The VHF/UHF communications receiving systems are subject to incompatability with low frequency, (215 MHz), high power air search radars due to antenna and frequency proximity. If the problem exists solely due to proximity, the condition may be alleviated by relocation of the VHF/UHF antennas. However, prior to relocating any antenna a review of the effect of the relocation on the entire system should be made to insure that no adverse compatibility conditions are created. The quickest and most effective method of determining the effects of antenna relocation is the measurement of all desired parameters on a suitably prepared scaled model.

The communications antenna receiving system is susceptible to compatibility problems from the ship's electrical systems. These problems are related to the inherent electromagnetic noise from generators, motors and switching devices.

1.7 ARC OF FIRE RESTRICTIONS

1.7.1 ESTABLISHMENT OF ARC OF FIRE.

The arc of fire areas of the various ordnance systems of a ship are determined by the ship's structure in the vicinity of the guns, missiles, or sub-surface weapons. The weapons are prevented from firing beyond their assigned arcs of fire by mechanical stops at the weapons and electrical cut-outs in the fire control equipment.

1.7.2 ANTENNA INSTALLATION RESTRICTIONS.

The arc of fire limitations in the area of the weapons severely reduces space available for antennas, especially in the area above weapons. This is because of the requirement for the weapons to operate at, or near, zenith. Antennas installed near the boundaries of arcs of fire are subject to damage from over-pressure during firing and must be designed to physically withstand these pressures.

1.8 AIRCRAFT OPERATING AREA RESTRICTIONS.

1.8.1 ESTABLISHMENT OF AIRCRAFT OPERATING AREA.

The helicopter landing area on combatant ships other than CV, LHA, LPD and LPH types is normally located on the stern. Service force ships have additional areas assigned for helicopter operations. The size of the helicopter landing area or obstruction envelope is determined by the type of aircraft employed. Helicopter landing clearance criteria is contained in Section 3, Para. 3.7 of NAVSHIPS 0967-177-3020 SHIPBOARD ANTENNA SYSTEMS, Volume 2, ANTENNA INSTALLATION DETAILS. The restrictions for vertical replenishment areas is also covered in this section.

The operating area for both rotary and fixed wing aircraft on ships specifically designed for aircraft operations are clear of structural interferences and communications antenna installations are limited to locations on the island and flight deck edges.

1.8.2 ANTENNA INSTALLATION RESTRICTIONS.

The limitations imposed by the helicopter landing area requirements preclude the use of the after section of the ship, on other than CV, LHA, LPH and LPD types, for the installation of antennas except for whip antennas using tilting or lowering mechanisms to reduce vertical heights to prescribed limits. Any wire-type antenna installed in this area must be fitted with releasing devices to allow removal during helicopter operations. Antennas installed along flight deck edges on CV, LHA, LPD and LPH types must be equipped with tilting devices to lower the antennas to horizontal during flight operations. A degradation in efficiency due to the lowering of the antenna can be expected and these antennas should be assigned to low priority circuits during flight operations.

1.9 REPLENISHMENT AT SEA STATIONS RESTRICTIONS.

1.9.1 ESTABLISHMENT OF REPLENISHMENT AT SEA STATIONS.

Replenishment at sea stations are located port and starboard in the vicinity of the forward and after ends of the deckhouse. Amidship stations, either centerline or port and starboard, are used for ordnance replenishment. Fueling stations are also located in proximity to the RAS stations. Additional stations are also required in the vicinity of the missile launcher for missile replenishment.

1.9.2 ANTENNA INSTALLATION RESTRICTIONS.

Each replenishment or fueling station is required to have a working range of 30° forward to 30° aft of a transverse plane perpendicular to the center line of the ship and horizontal to 30° below horizontal. The working area limits the installation of whips within the area. Wire antennas cannot be terminated within the area unless provisions are made for their temporary removal during RAS operations. In some instances RAS kingposts are used for mounting small whips and terminating wire antennas.

1.10 COMMUNICATION TRANSMITTING ANTENNA RADIATION HAZARDS.

1.10.1 PERSONNEL HAZARDS.

The use of high power communication transmitting systems has increased the possibility of injury to personnel in the vicinity of the antennas. The handling of metallic cargo lines, lifelines, guy wires and other metallic items when the transmitter is radiating can cause rf burns due to induced currents flowing through the body area in contact with an rf voltage source. The degree of burn that occurs is the result of the heat produced by the current flow through the resistance of the skin at the point of contact. The effect of the heat on an individual ranges from warmth to painful burns. This type of rf burn should not be confused with the rf RADIATION HAZARDS (RADHAZ) related to microwave energy.

The specific level at which contact with rf voltages should be classified as an rf burn hazard is not distinct. The variations in the impedance of individuals presented to the rf source makes the establishment of an exact level impractical. Any rf voltage that will cause a person pain, visible skin damage, or cause involuntary reaction should be considered hazardous.

Warning signs are used in the vicinity of transmitting antennas to warn personnel that hazardous conditions exist. If ship's force are required to work in hazardous areas it will be necessary to restrict the use of the antenna. The reduction in possible sources and levels of induced voltages can be accomplished by bonding and grounding metallic objects in the vicinity of the antennas.

1.10.2 FUELING HAZARDS.

Laboratory tests have indicated that the ignition of volatile fuel vapor is possible at distances as great as one-half wavelength from a transmitter antenna with a power output of 100 watts or less in the frequency range of 2 to 13 MHz. Shipboard tests employing worst case antenna configurations have proved that ignition is possible in the region of 200 MHz. However, the effort necessary to obtain ignition under test conditions shows that the probability of ignition during normal fueling procedures is somewhat remote.

The major effort to reduce the possibility of ignition has been directed towards eliminating all conditions conducive to arcing when fuel is being handled. The use of less volatile fuels has also decreased the possibility of ignition.

To preclude the possibility of ignition from rf sources volatile fuels should not be stored in the vicinity of transmitting antennas. Transmitting equipment should be secured if the possibility of ignition exists during fuel handling operations.

1.10.3 ORDNANCE HAZARDS (HERO)

The Hazards of Electromagnetic Radiation to Ordnance (HERO) problem has existed since the introduction of electro-exploxive devices. The use of these devices is increasing steadily and some weapons now contain more than 75 such devices. Development efforts in these systems has been toward reducing weight and space, lowering power requirements and increasing sensitivity and reliability. At the same time the power of communications transmitting equipment is being increased and the frequency spectrum broadened. This produces an incompatible situation since transmitters have only one purpose - to radiate energy, and the ordnance devices need only to be supplied with the proper amount of energy for an explosion to take place. RF energy may enter a weapon through a hole or discontinuity in the weapon skin, or be conducted into the weapon by firing leads and other wires that penetrate the weapon enclosure. The exact probabilities of electroexplosive device actuation are unpredictable and are dependent on frequency, field strength, orientation of the transmitting antenna and weapon, environment, and metallic or personnel contact with the weapon. It would be difficult to attempt to outline the requirements, restrictions and procedures for determining HERO levels in this volume. The detailed information relative to the intelligent assessment of possible hazard is contained in Radio Frequency Hazards Manual NAVORD OP 3565 16-1-629.

1.11 ADDITIONAL AREAS.

1.11.1 EXHAUST AND STACK GASES.

Whereas stack gases from oil fired steam generating equipment contain corrosive compounds that cause deterioration of antennas and antenna fittings, the increased use of gas turbines for main propulsion and auxiliary generators has introduced a potential source of EMI to antennas installed in the immediate vicinity of their exhausts. The exhausts from a gas turbine consists of large volumes of hot gases and minute particles of unburned hydrocarbons. The collision of the hot gases and exhaust particles with the antenna generates static electrical charges on the antenna resulting in broadband noise in the receiving equipment.

The residue formed by deposits of soot and salt spray on antenna elements and insulators form non-linear junctions that are sources of electromagnetic noise when excited by strong rf fields. In addition these deposits form low impedance paths to ground thus decreasing the efficiency of the antenna.

1.11.2 ANTENNA INSTALLATION RESTRICTIONS.

Whip antennas should not be installed in the immediate vicinity of gas turbine exhausts. Sufficient separation between the exhausts and the antenna should be provided to prevent high velocity exhaust gases from contact with the antenna.

The lack of topside space for antennas makes it impossible to locate antennas in areas that are not subject to contamination from stack gas and soot discharges. However, care should be taken not to locate antennas in the immediate discharge areas of stacks and macks. Antennas that are subject to deterioration from high heat should not be installed in these areas.

1.12 ANTENNA MODEL STUDIES.

1.12.1 ANTENNA MODEL AND RANGE.

The most useful tool in determining the design and operational characteristics of communications antenna systems or for a specific antenna in a shipboard environment is a scaled model study. A scaled model study requires building a scale model of the ship, usually from brass or aluminum, with a complete topside configuration. This includes all communications antennas, fire control directors, ordnance, structures and other equipment that might influence the antenna patterns. The model is installed on an antenna model range with a metallic surface simulating the sea. The range is clear of any horizontal and vertical interferences or obtructions for many wavelengths of the scaled frequencies to be used with the model. The model may be rotated from 0 to 360 degrees in azimuth in the horizontal plane, in reference to the location of the recording equipment, and provisions are made to record patterns from 0° to zenith in the vertical plane.

1.12.2 MODEL STUDIES

After all physical requirements for the model have been satisfied, each antenna is excited from an external source and patterns recorded in azimuth and elevation. During the study, combinations of simultaneous transmitting and receiving operations are investigated to determine sources of EMI and EMC within the system. The analysis of the patterns and data recorded provides a basis for determining the degree to which the design will satisfy the requirements of the ship. If the basic design does not meet the requirements modifications are made to the antennas, their locations, and surrounding structures, and further tests performed. When the best possible antenna operating characteristics in accordance with the communications systems requirements, the requirements of other systems, and economic feasibility, have been achieved, the design is considered to be satisfactory for installation onboard ship. Model studies are used extensively in antenna development and to determine the effects of any changes to installed systems.

Indiscriminate antenna changes should not be made to installed systems since the effects within and outside the system cannot be adequately determined without a model study.

The Navy maintains an antenna scale model range at the Naval Electronic Laboratory Center at San Diego, California.

SECTION 2

ANTENNA TYPES

2.1 GENERAL

Ship antenna pattern and impedance characteristics are the result of current and voltage component distributions along antenna elements including the ships structure. The distribution for a single quarter-wave element on a flat ground plane is shown in Figure 2-1. Multiple element array distribution is basically the same as the single element; however, the addition of elements broadens the impedance over the design bandwidth.

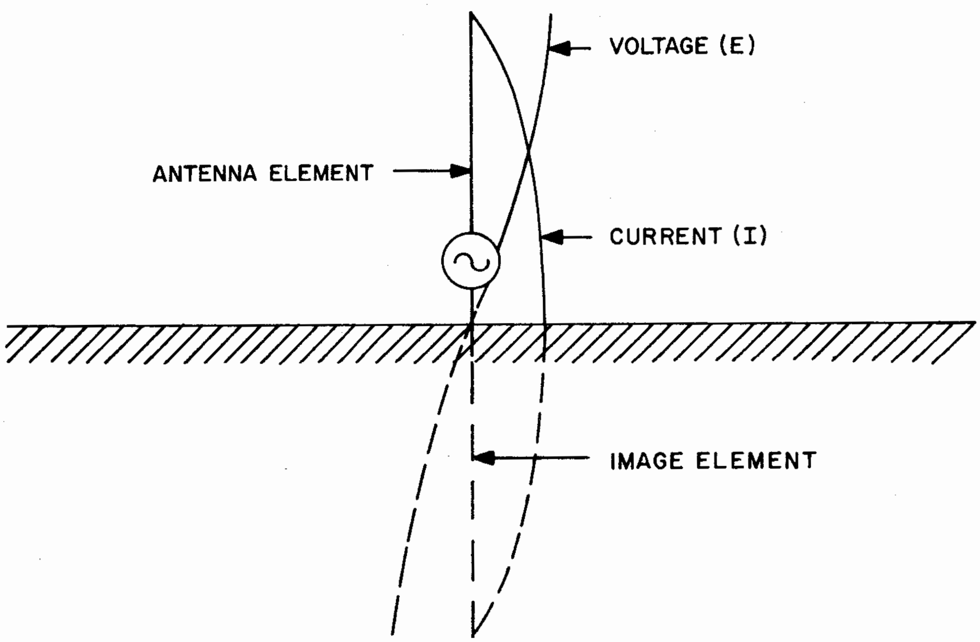


FIGURE 2-1 CURRENT AND VOLTAGE DISTRIBUTION FOR QUARTER WAVE ANTENNA ELEMENT

The optimum antenna is one that has pattern characteristics compatible with the radio path signal propagation parameters as determined by the mode of signal propagation. The mode frequencies most commonly used are 2 to 6 MHz for surface, 5 to 30 MHz for sky, and 30 to 500 MHz for line-of-sight signal transmissions.

Surface mode of operation is used for ship to ship and ship to shore communications in the LF range over short and medium distances, up to 600 miles. VLF frequencies are used by shore stations for fleet broadcasts. The shore stations transmit at very high power levels to provide coverage greater than the distances stated above.

The principal angle of arrival and departure for surface mode signal transmission is approximately zero degrees. Figure 2-2 illustrates the relative field strength as a function of angle of elevation for vertical single element antennas of different height-to-wavelength ratios. Note that no significant benefit can be obtained at zero angle of elevation for any increase in height and size of antennas considered for shipboard installations.

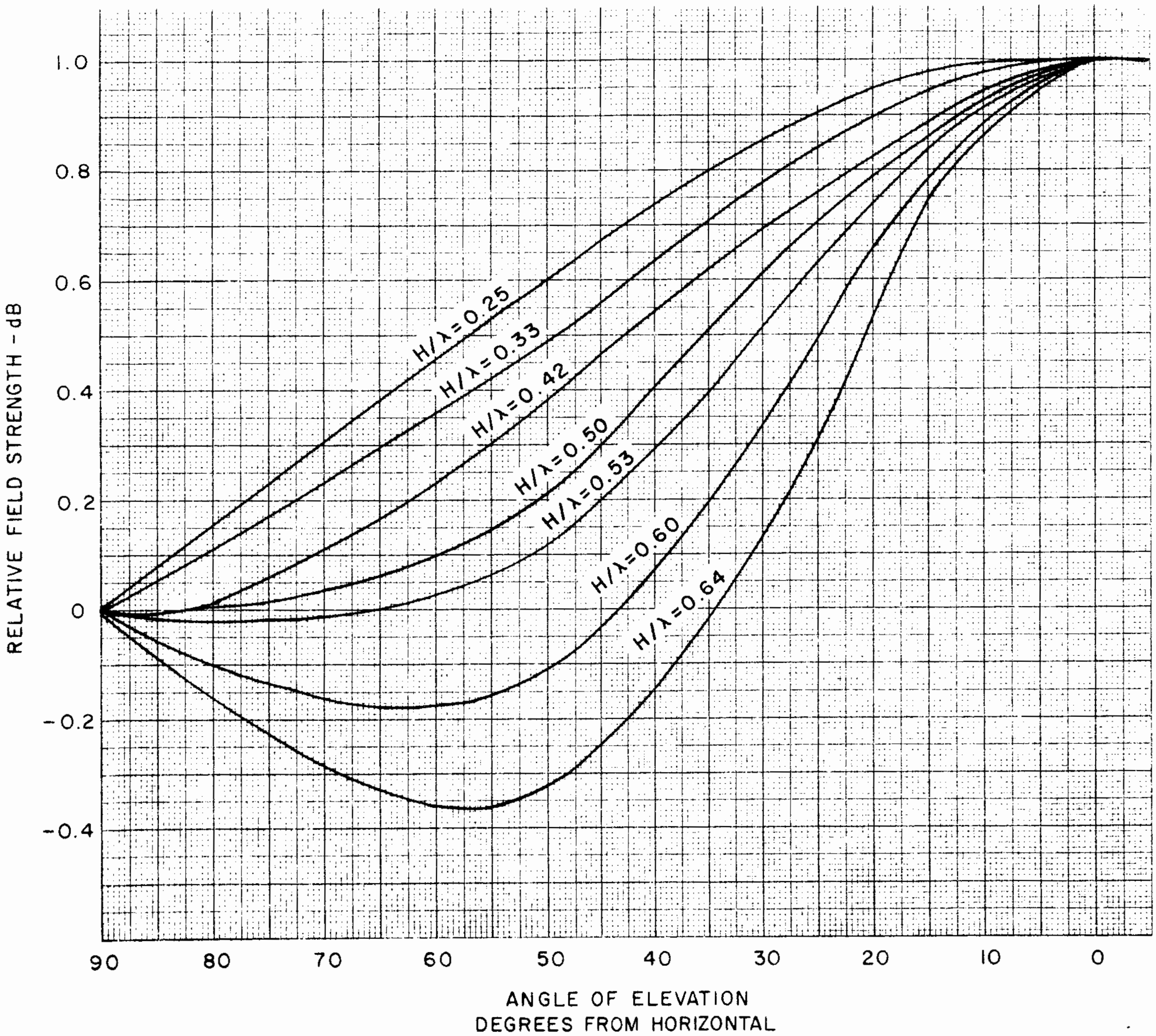


FIGURE 2-2 VERTICAL ANTENNA FIELD STRENGTH AS A FUNCTION OF ANGLE OF ELEVATION FOR DIFFERENT H/λ RATIOS

ANTENNA TYPES

Sky mode of operation is used for ship-to-ship and ship-to-shore communications in the HF frequency bands. This mode is used to transmit and receive signals over distances greater than 150 km - usually to very distant points up to several thousand kilometers away by one or more "hops" (reflections off the ionosphere and earth's surface).

The angle of elevation for sky mode receiving and transmission of signals via the radio path media varies from 5 to 30 degrees. Figure 2-3 illustrates the great circle distance in nautical miles as a function of angles of elevation. Figure 2-2 illustrates the various height-to-wavelength ratios that comply with the needs of the radio path parameter angles of elevation shown in Figure 2-3. Antenna selection designs with these ratios are practicable for shipboard installations.

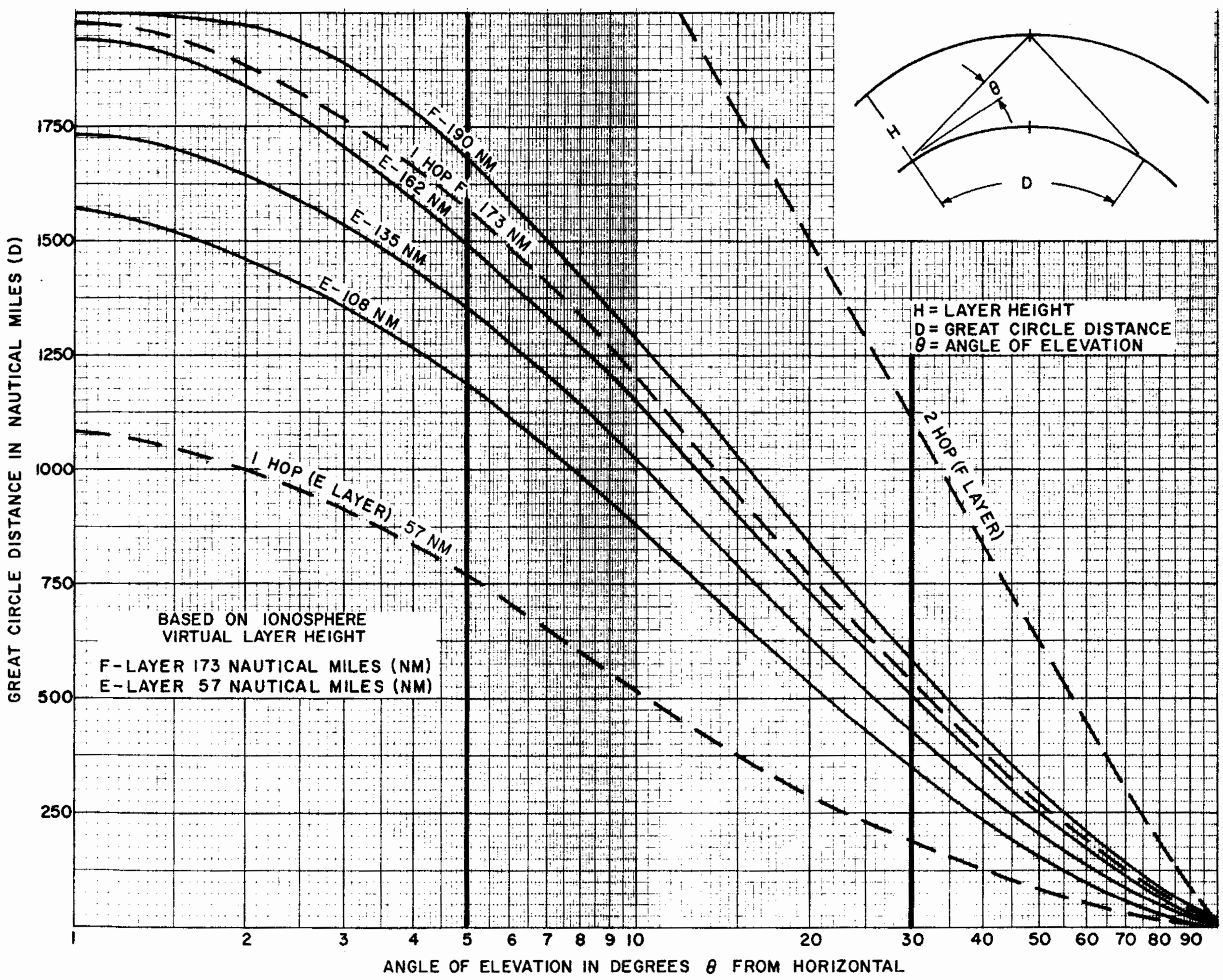


FIGURE 2-3 ANGLE OF ELEVATION VERSUS GREAT CIRCLE DISTANCE

The line-of-sight mode is used for signal transmission for communications between surface to surface points (ship-to-ship and ship-to-shore) and ship-to-space points (ship-to-aircraft and ship-to-satellite). Illustration of the UHF (225 to 400 MHz) radiation pattern contour levels which are typical for signal transmission between ship-to-ship and ship-to-aircraft are shown in Figure 2-4 and indicates the reason fading occurs (peaks and nulls) between ship-to-air. The information from this figure may be used to predict areas of low signal for communications paths between ship and aircraft.

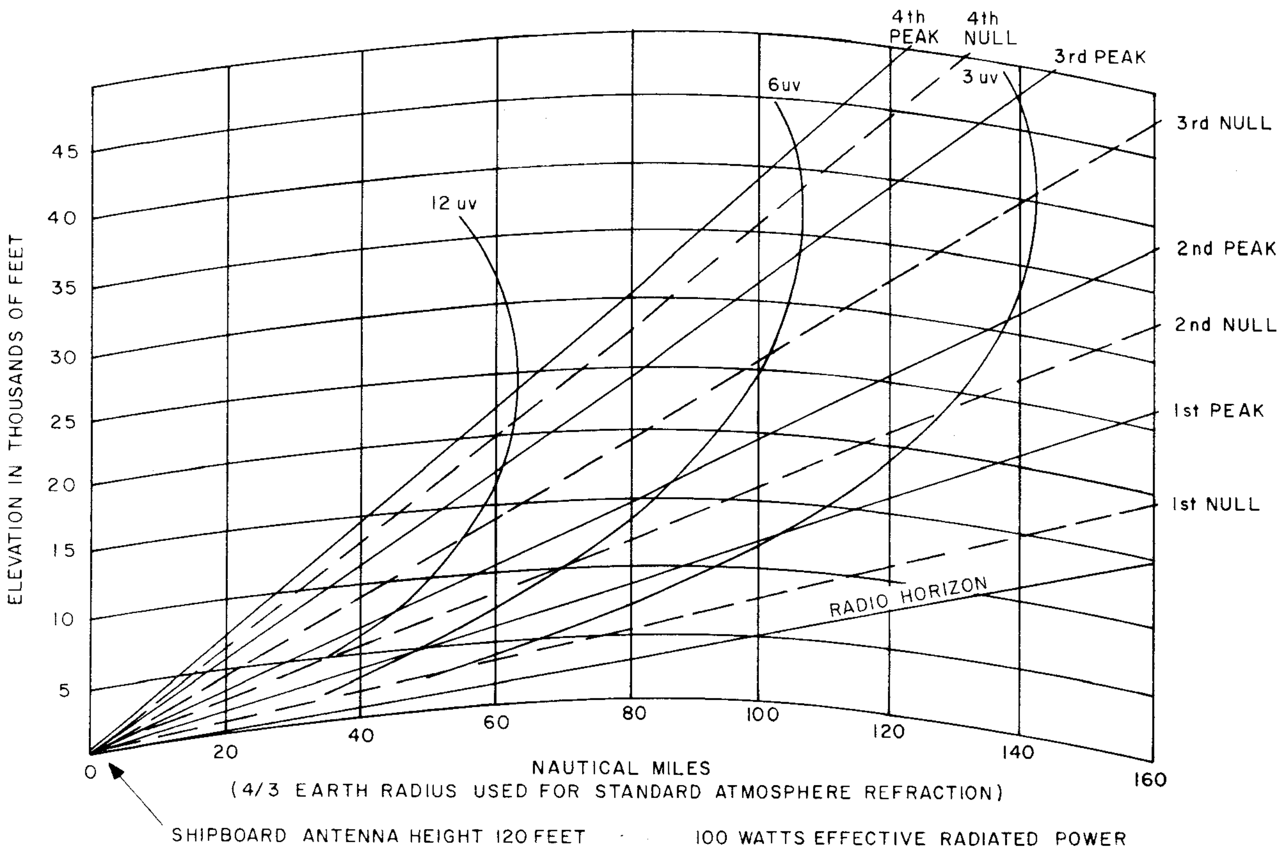


FIGURE 2-4 TYPICAL UHF RADIATED PATTERN CONTOUR LEVELS FOR SURFACE-TO-AIR COMMUNICATIONS OVER SEA WATER

The ship-to-ship and ship-to-air are considered low altitude line-of-sight operations whereas ship-to-satellite is high altitude line-of-sight.

The earth's surface radius coverage of a synchronous satellite is a function of altitude that the satellite is above the earth's surface from the zenith point. Figure 2-5 illustrates the earth's surface radius coverage for satellites ranging in altitude from 5,000 to 25,000 nautical miles above the earth's surface.

For example, assuming the satellite is 23,000 miles above the earth at the zenith point, the earth's radius coverage for this altitude will be

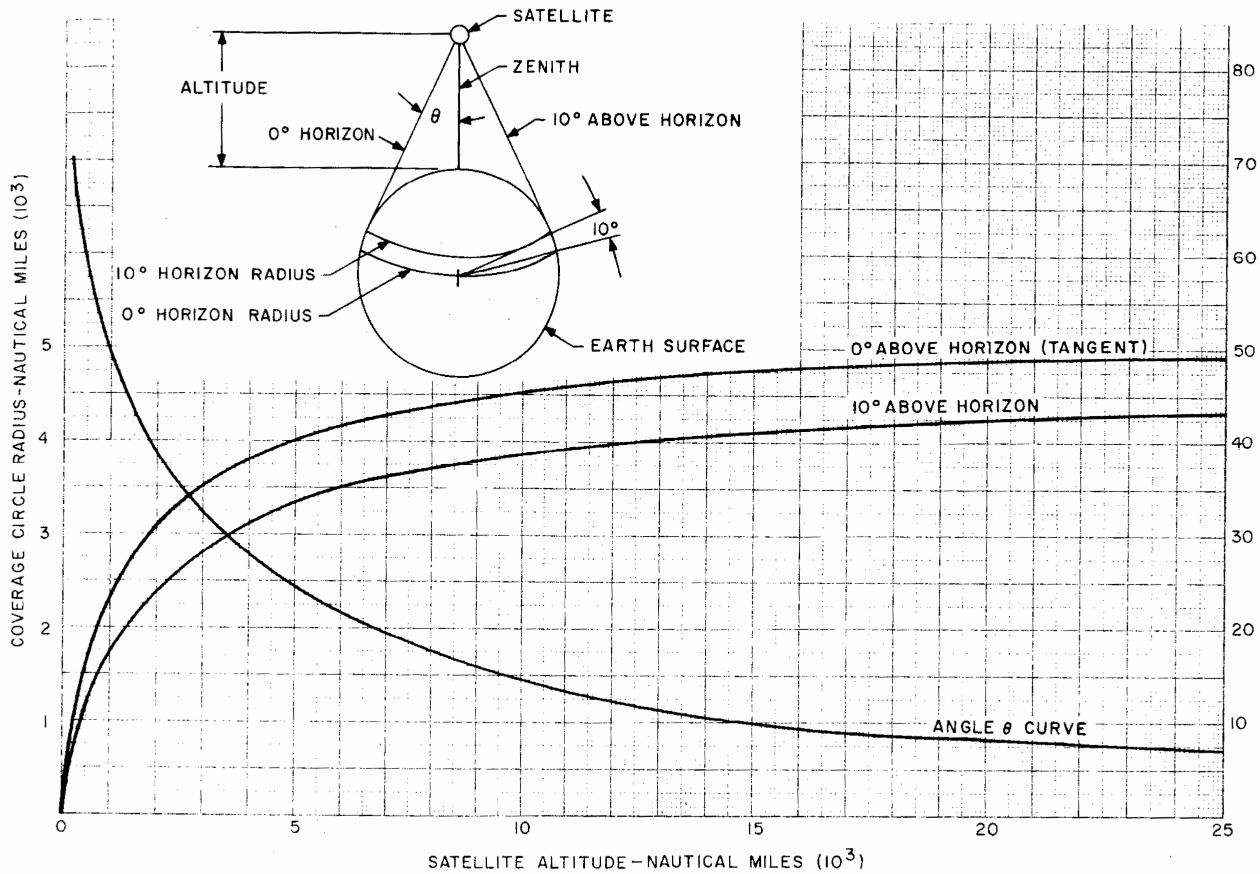


FIGURE 2-5 SATELLITE TO EARTH COVERAGE

approximately 4750 nautical miles for 0 angle of elevation of the ship's satellite antenna. Thus, this is the initial point that the ship can expect to be within line-of-sight of the satellite radio path.

The most desirable pattern for a shipboard antenna other than satellite is one that radiates equally in all directions (omni-directional). The optimum antenna impedance match is one that is compatible with the impedance of the system transmission line and equipment and preferably does not exceed a three to one (3:1) standing wave ratio (SWR).

The impedance characteristics of antennas will vary widely in confined areas as presented in shipboard antenna installations. Isolation of antennas to minimize mutual coupling is a function of antenna spacing. Figure 2-6 illustrates the mutual impedance between two parallel quarter wave ($\lambda/4$) thin wire antennas. The resistance (R_m) and reactance (X_m) components shown in the figure illustrate the magnitude of the effect on the inherent characteristic impedance of antennas as the separation is increased from 0 to over one wavelength. Ideally, that is if no mutual coupling existed, the values of impedance and reactance would lie on the zero line. From the figure it will be noted that the values vary widely with respect to wavelength separation and as the separation is increased the mutual coupling decreases allowing the antennas to approach their characteristic impedance.

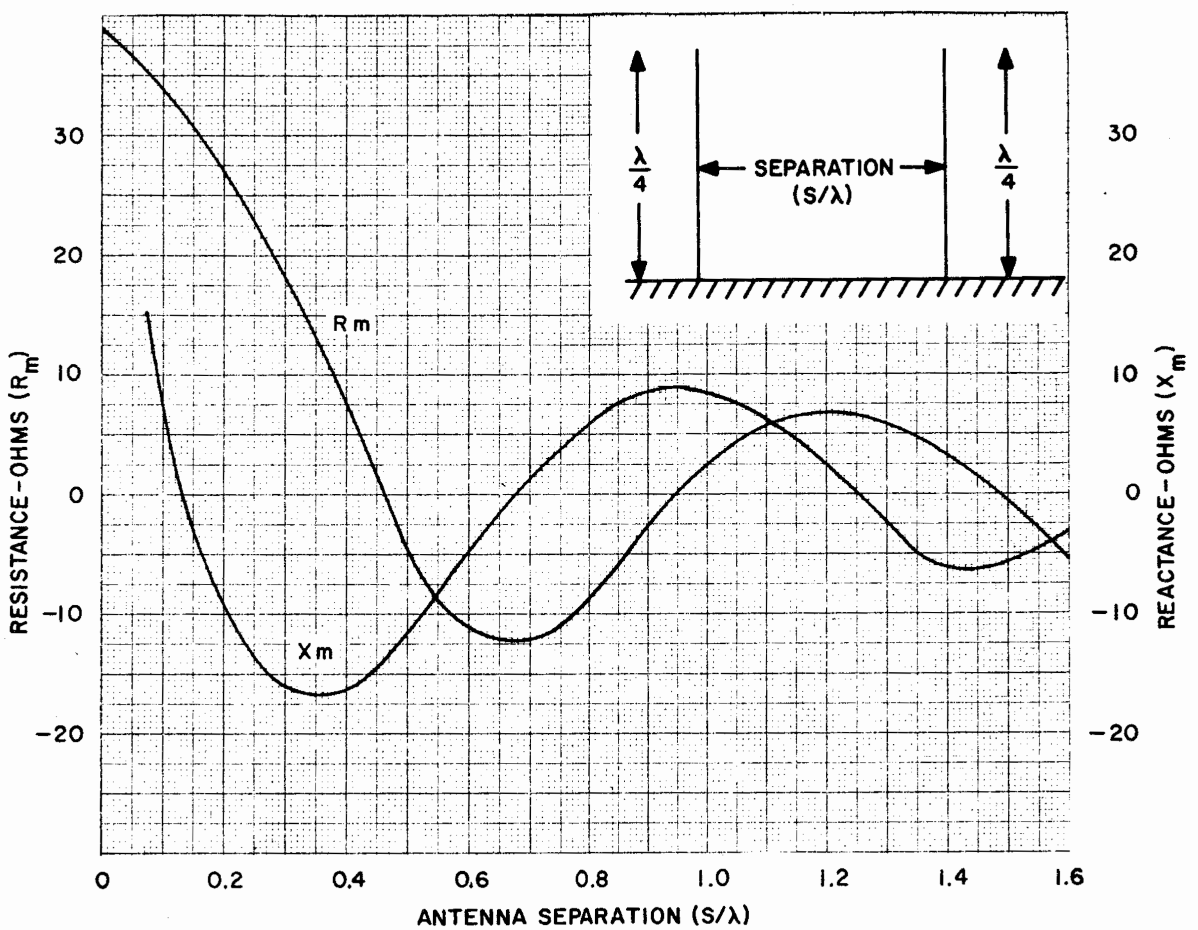


FIGURE 2-6 MUTUAL IMPEDANCE BETWEEN TWO PARALLEL QUARTER WAVE ANTENNAS

Figures 2-7 and 2-8 show the relationship between the electric and magnetic fields that exists between parallel and orthogonal antennas. The degree of separation will vary the amount of coupling between the fields, and, consequently, the impedance effects shown in Figure 2-6. The installation of random antennas within the wavelength distances shown will affect the degree of mutual coupling between the system antennas. This will result in antenna pattern changes that may invalidate the data supplied by the antenna scaled model study.

2.2 WHIP ANTENNAS

Whip antennas are used for LF, MF and HF communications transmitting and receiving systems. The type most commonly used is the single element 35 foot whip. The single element whip is simple and economical to construct, install, and maintain. Whip antennas used for transmitting purposes are generally equipped with base tuning units to provide optimum impedance matching, and thus maximum power transfer between the antenna and transmission lines.

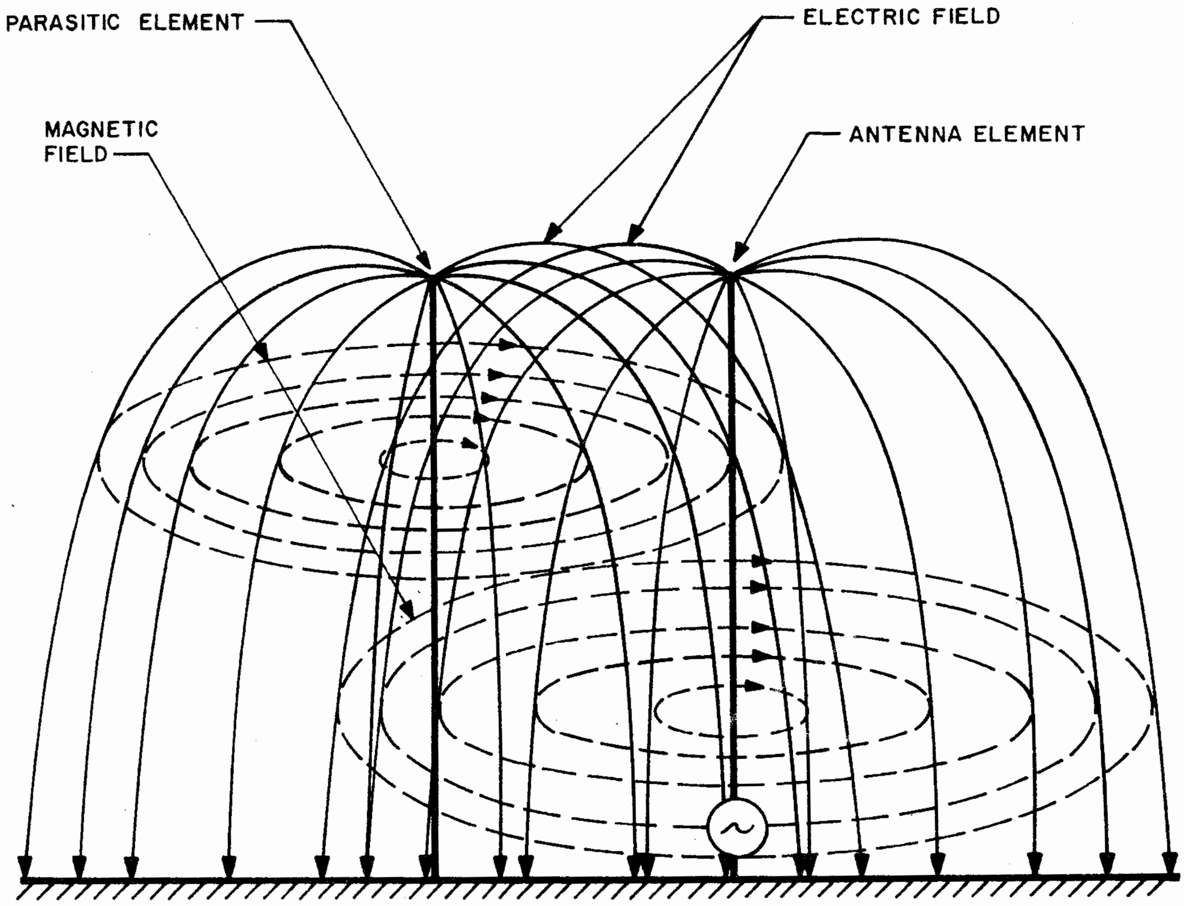


FIGURE 2-7 MUTUAL COUPLING BETWEEN EQUALLY POLARIZED ANTENNAS

2.2.1 OPERATIONAL CONSTRAINTS

The main disadvantage of the tuned whip antenna is the limited number of equivalent designed antennas that can be installed onboard ship with sufficient space separation necessary to prevent serious pattern distortion and excessive mutual coupling between the antennas. This type of antenna is not broadband and therefore is not generally used with a multicoupler in the transmitting mode. Pattern distortion is caused by mutual coupling effects and beam masking from other antennas or ship's metal structures. Vertical structures such as masts, stacks, radar towers, bridge structures, and, in the case of carriers, island structures, are examples.

2.2.2 DESIGN CONSTRAINTS

The resistance component of a whip terminal impedance of less than 1/10 wavelength is very low as shown in Figure 2-9. Regardless of L/D (length-to-diameters) ratios, the radiation resistance is less than 10 ohms at element length of $\lambda/10$. Figure 2-10 indicates that a 35 foot whip approaches $\lambda/100$ at 300 kHz. The radiation resistance for an antenna of this length is approximately 0.04 ohms.

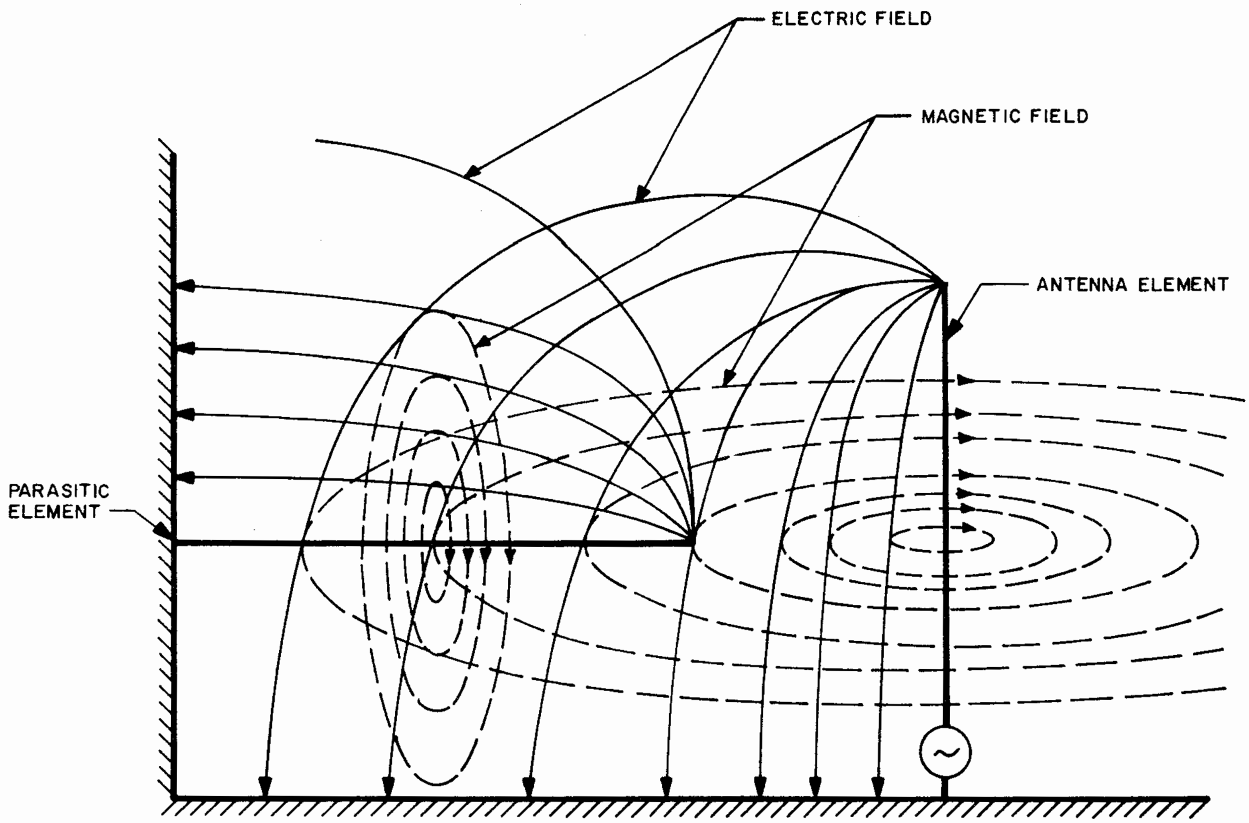


FIGURE 2-8 MUTUAL COUPLING BETWEEN UNEQUALLY POLARIZED ANTENNAS

The use of a tuning device to effect an impedance match between the antenna and transmission line only transfers the loss to the tuning device. Tuning devices prevent excessive standing wave ratios at the transmitter.

The efficiency of single element antennas matched to 50 ohms is improved as the length is increased above 35 feet because the antenna impedance approaches the impedance of the transmission line. The closer the antenna is matched to the line the less the amount of reactance required in the matching device. The losses in the matching device are reduced as the match is improved and consequently the amount of power transferred to the antenna is increased. Figure 2-9 shows that a vertical antenna with an L/D ratio of 5 with wavelengths from 0.15 to 0.40 can be matched to a 50 ohm transmission line with small reactance components in the matching device.

2.2.3 INSTALLATION CONSTRAINTS

Locating whip antennas far from other antennas and metal structures having multiple wavelengths of the tuned frequency will reduce mutual coupling and improve the pattern of the whip antennas. Objects that have lengths approaching electrical resonance tend to act as either directors or reflectors thus altering the radiation pattern of the antenna. It is important to locate receiving antennas as far as possible from transmitting

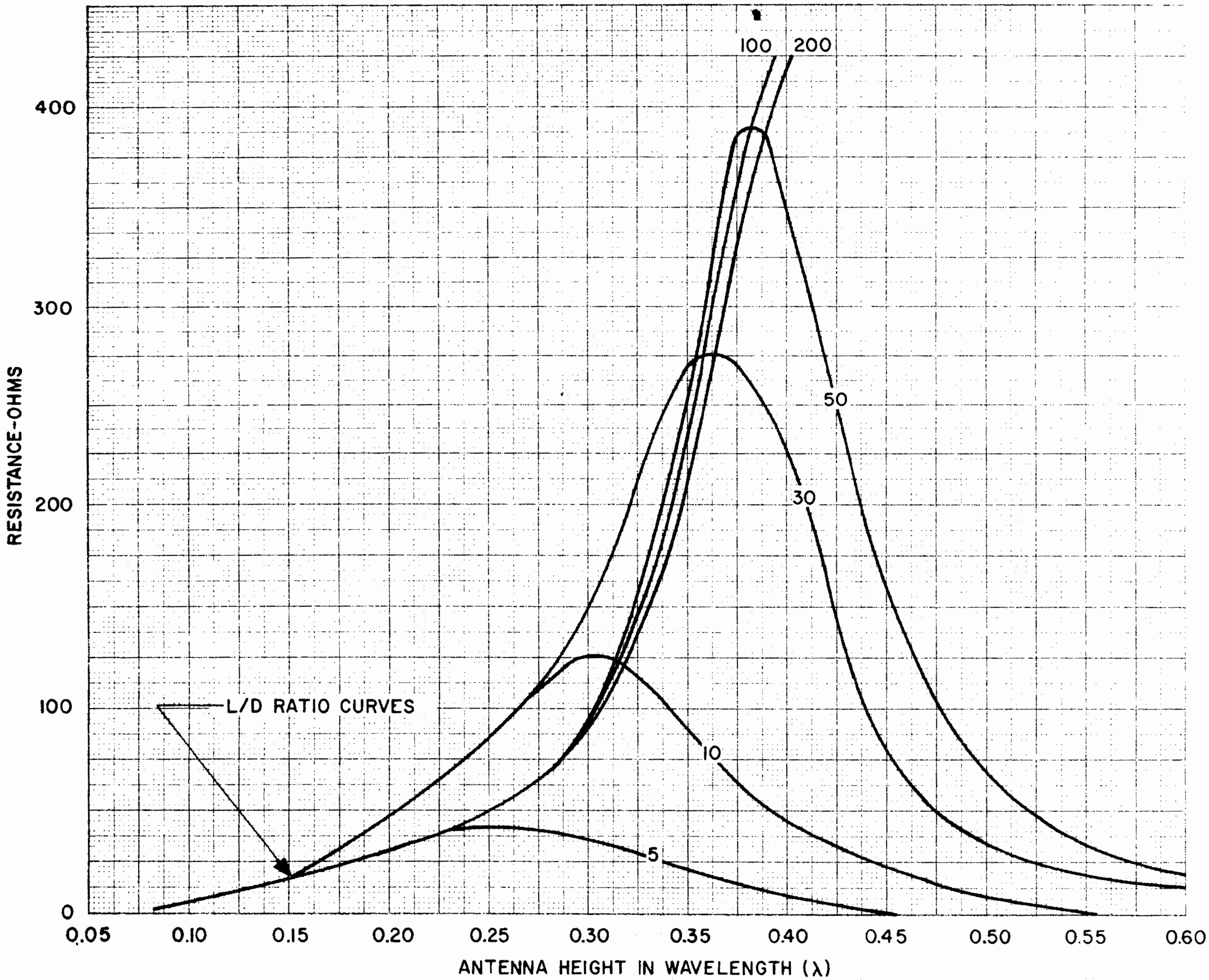


FIGURE 2-9 RESISTANCE CURVES FOR VERTICAL ANTENNAS OF DIFFERENT LENGTH (L) TO DIAMETER (D) RATIOS

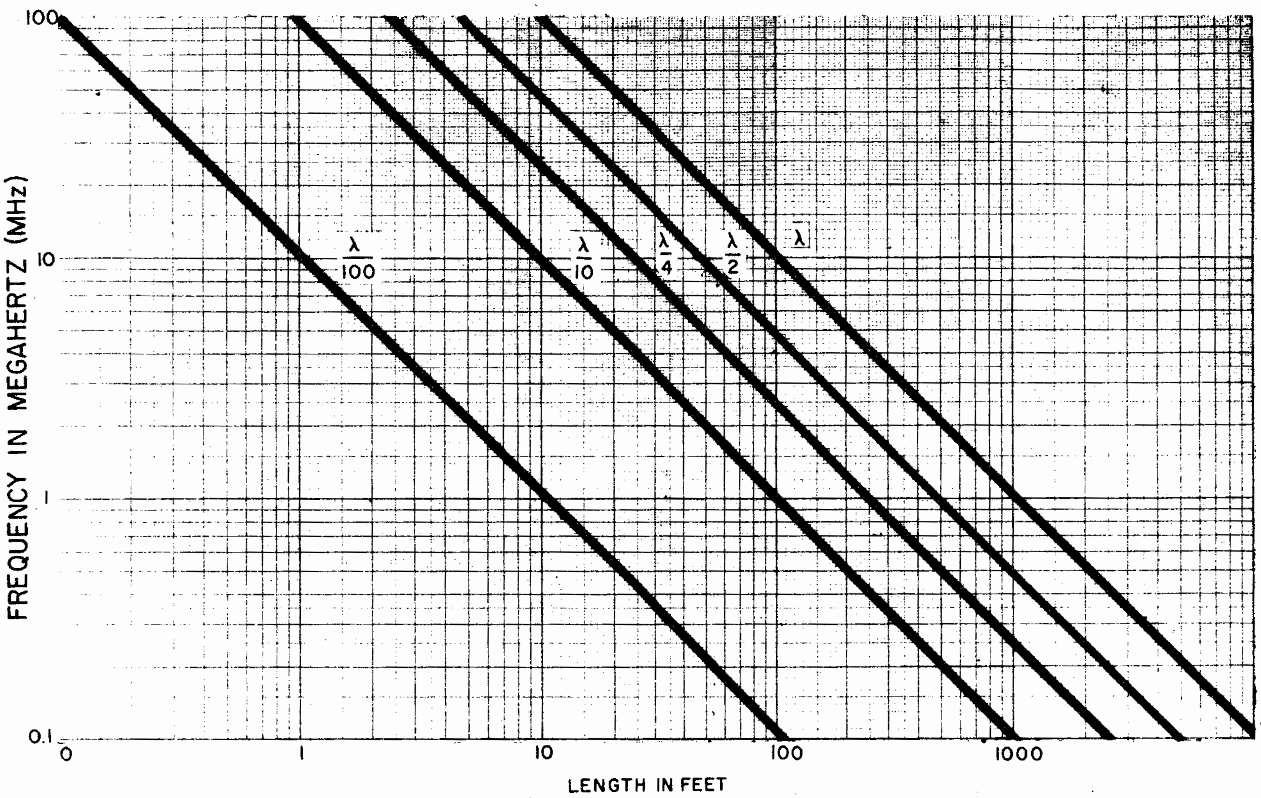


FIGURE 2-10 MULTIPLE WAVELENGTH CONVERSION FROM FREQUENCY TO FEET

antennas in order to reduce interference to the receiving circuits as explained in Section 1. Additional isolation between transmitting and receiving antennas is possible by locating the antennas so that their pattern peaks are not beamed toward each other. The information necessary to determine antenna siting can be best obtained from scale model studies and careful control of topside configuration in the area of the antennas. Figures 2-11 and 2-12 are computed radiation patterns at selected elevation angles for 35 foot vertical whips on a flat perfect conducting ground at 8 and 16 MHz. Figures 2-13 and 2-14 are radiation patterns for the same antenna and same frequencies recorded from a scaled model antenna mounted on a modeled ship. It will be noted that the patterns become distorted due to mutual coupling with the ships structure. The degree of distortion will be predicated on the proximity and geometry of the surrounding structures. Inspection of Figure 2-13 indicates that there is satisfactory omnidirectional coverage at angles of 0 and 23 degrees above the horizontal. Deep nulls are located at 330° and 170° thus disturbing the omnidirectional characteristics at an angle of 15°. Figure 2-14 indicates that satisfactory omnidirectional operation may be expected from the antenna on 16 MHz at all angles. The curves shown in Figures 2-13 and 2-14 are valid only for the frequencies indicated. Any change of operating frequency will result in variations in the curves. After completion of the model study and all trade-offs have been resolved to provide best possible design, the location of the antenna and surrounding structures should not be altered. Any change of significant magnitude will result in pattern change.

ANTENNA TYPES

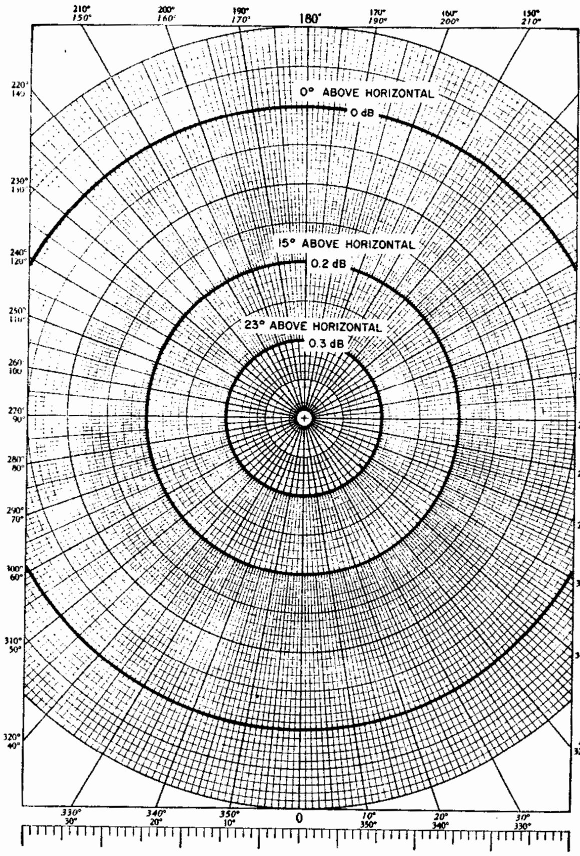


FIGURE 2-11 COMPUTED 8 MHz ANTENNA PATTERN FOR A 35 FOOT WHIP ANTENNA AT SELECTED ELEVATION ANGLES

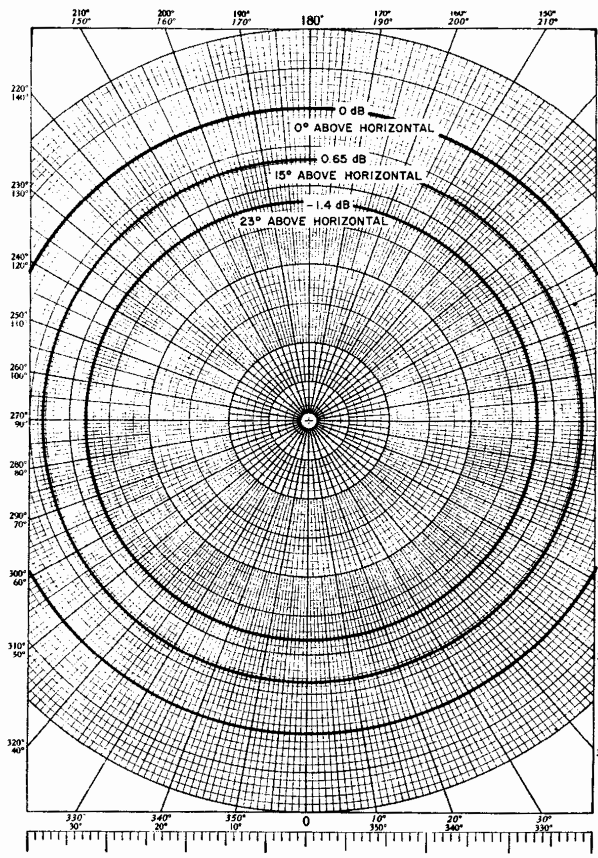


FIGURE 2-12 COMPUTED 16 MHz ANTENNA PATTERN FOR A 35 FOOT WHIP ANTENNA AT SELECTED ELEVATION ANGLES

The scale models used for antenna studies are retained at the range for use on a recurring basis to assist in solving problems associated with communications antennas.

2.3 BROADBAND ANTENNAS

The number of communications circuits required to satisfy the operational commitments of shipboard communications systems have increased to a degree that it is not possible to install tuned antennas for each circuit. This is due primarily to lack of shipboard space, and, secondly, the effects of the interaction between closely spaced antennas that tend to degrade their efficiency. Broadband antennas are capable of operation with multicouplers and several circuits may be operated with a single antenna. Therefore the total number of antennas for an individual system is reduced, and the possibility of pattern distortion and mutual coupling impedance effects are diminished due to the greater separation possible with fewer antennas.

Typical broadband antennas used for shipboard installations are: multiple element (trussed) whips, discone/cages, and fans. Rotating log

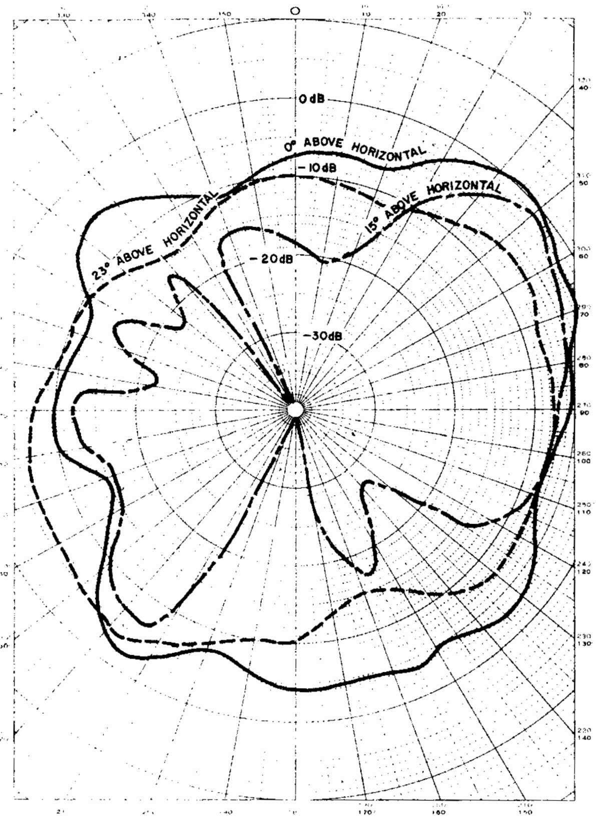


FIGURE 2-13 MODELED 8 MHz ANTENNA PATTERN FOR A 35 FOOT WHIP AT SELECTED ELEVATION ANGLES

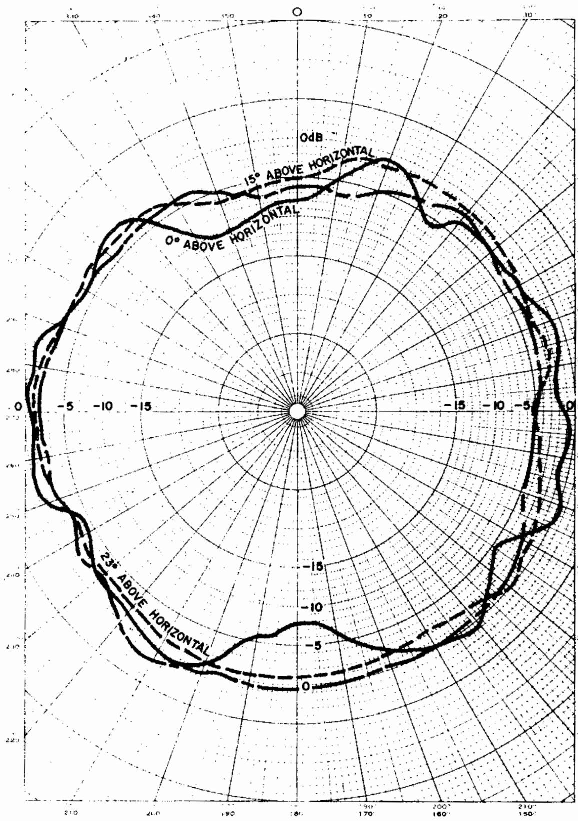


FIGURE 2-14 MODELED 16 MHz ANTENNA PATTERN FOR A 35 FOOT WHIP ANTENNA AT SELECTED ELEVATION ANGLES

periodic antennas are used on specialized duty type ships, but generally not on combatant type ships. Broadband transmitting antennas are normally designed to cover a 3:1 frequency bandwidth with a maximum of 3:1 standing wave ratio over the band.

The 3:1 limitation for VSWR is required to permit the transmitting equipment to operate within the linear portion of its output circuit parameters. Operation outside the linear area causes inefficient operation and possible damage to the equipment; nonlinear operation also increases the possibility of the development of harmonics and other EMI products.

The installation of HF antennas for shipboard communication requirements has become an increasingly difficult problem as the topside space becomes more limited by the demands for other shipboard subsystems. This condition has made it necessary to have a continuous development effort for HF antennas that may be located in the topside space available on various classes of ships. The presently developed HF broadband antennas include the

ANTENNA TYPES

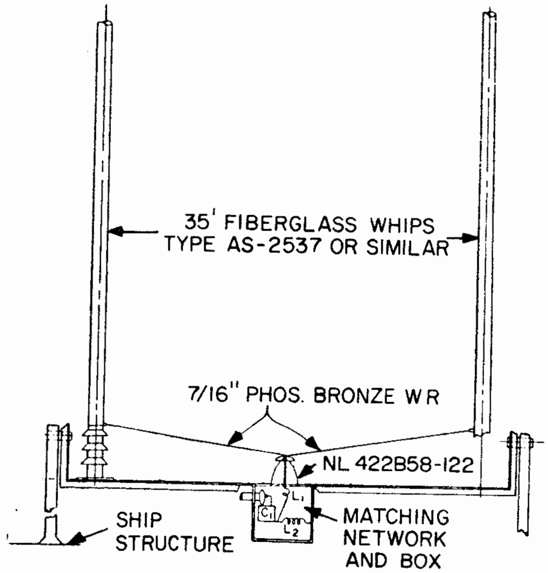


FIGURE 2-15 35 FOOT TWIN-WHIP FIBERGLASS ANTENNA, PHYSICAL OUTLINE

the following designs: 35 foot twin and trussed whips shown in Figures 2-15 and 2-16, half cone antenna shown in Figure 2-17, cage antenna shown in Figure 2-18, and a variety of fans shown in Figures 2-19 thru 2-22.

The antenna installation for VHF/UHF communication operation is not as difficult a problem as for the HF antennas. Being smaller, these antennas can be accomodated in the ship topside with more ease. The installation of VHF/UHF antennas is made so as to minimize the masking and mutual coupling effects of other antennas and shipboard metal structures, and are placed as

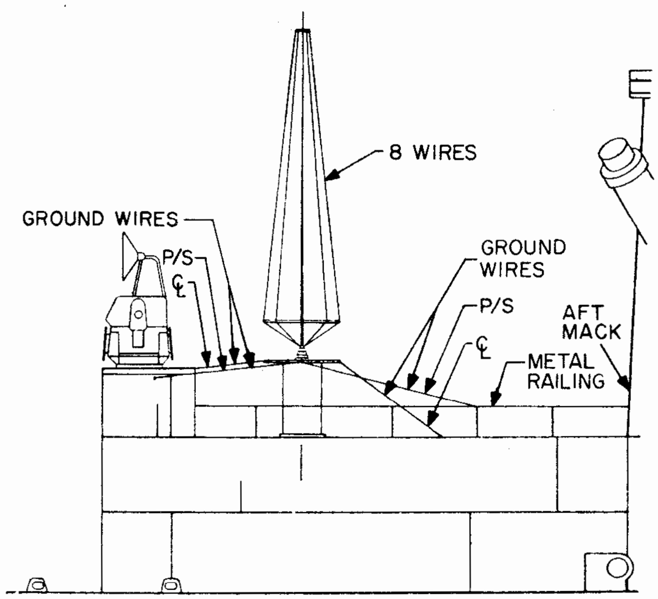


FIGURE 2-16 35 FOOT TRUSSED WHIP, PHYSICAL OUTLINE

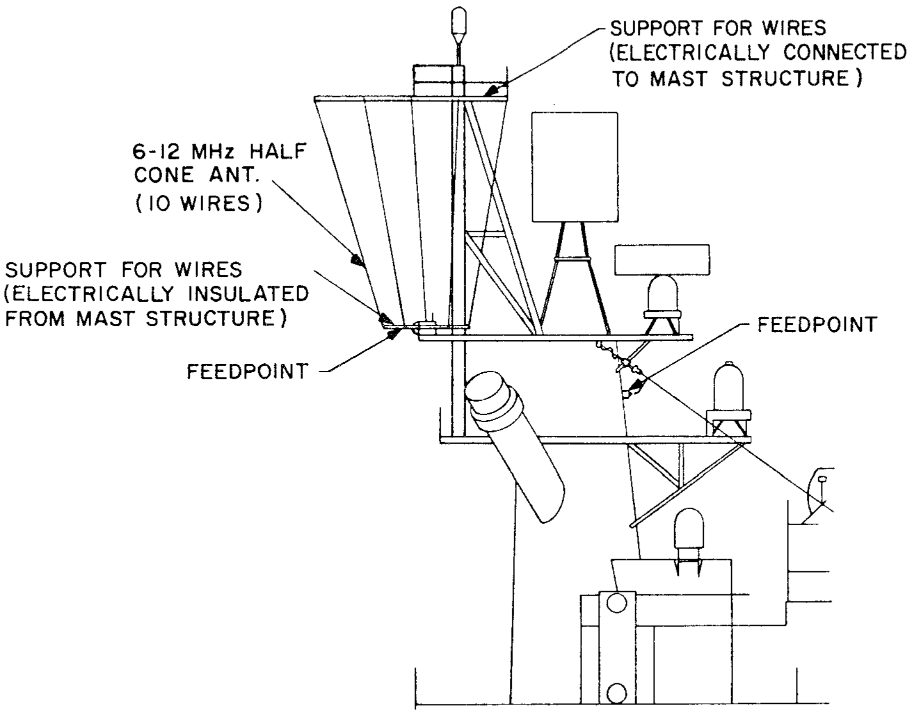


FIGURE 2-17 HALF CONE ANTENNA PHYSICAL OUTLINE

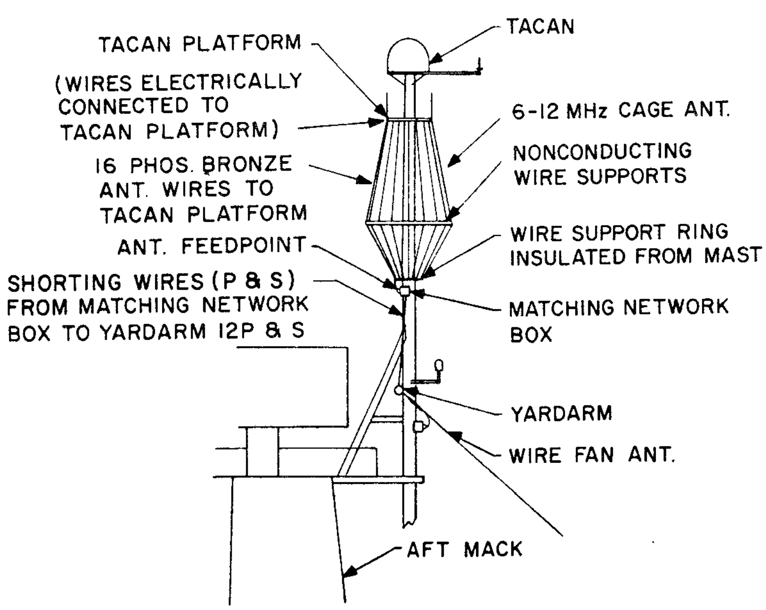


FIGURE 2-18 CAGE ANTENNA, PHYSICAL OUTLINE

PLAN VIEW

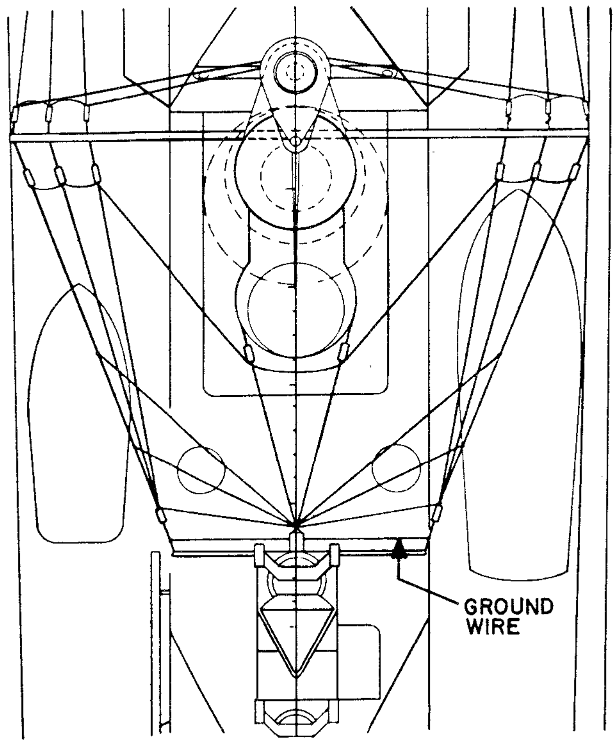


FIGURE 2-19. WIRE FAN ANTENNA, PHYSICAL OUTLINE TOP VIEW PLAN

high as possible on the ships structure, usually on a stub mast above the radar platforms. This type of installation places the antennas at the same level, and in relative proximity to each other. To prevent receiver burn-out problems care must be exercised in the selection and spacing of operating frequencies.

PLAN VIEW

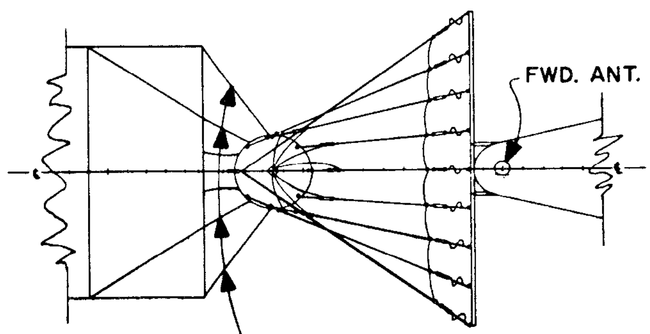


FIGURE 2-20. WIRE FAN ANTENNA, PHYSICAL OUTLINE, TOP VIEW PLAN

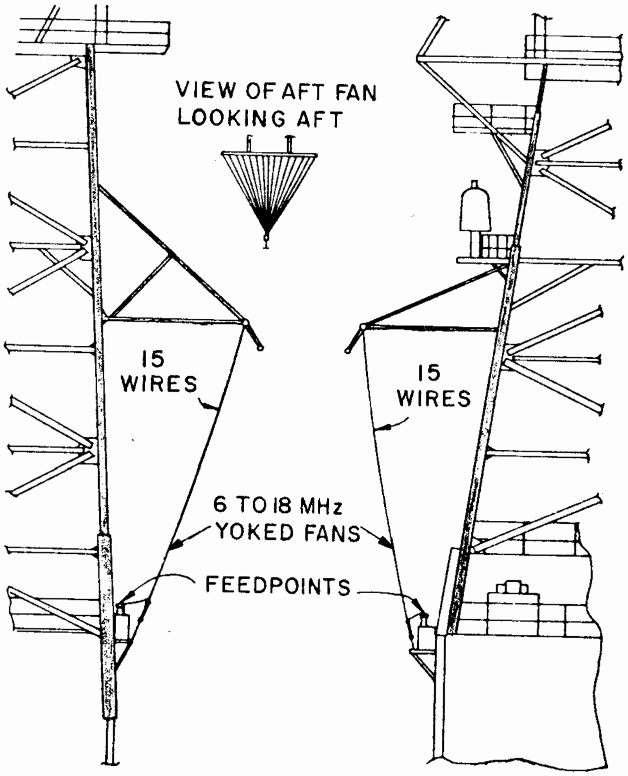


FIGURE 2-21 YOKED FOLDED WIRE FAN ANTENNA, PHYSICAL OUTLINE

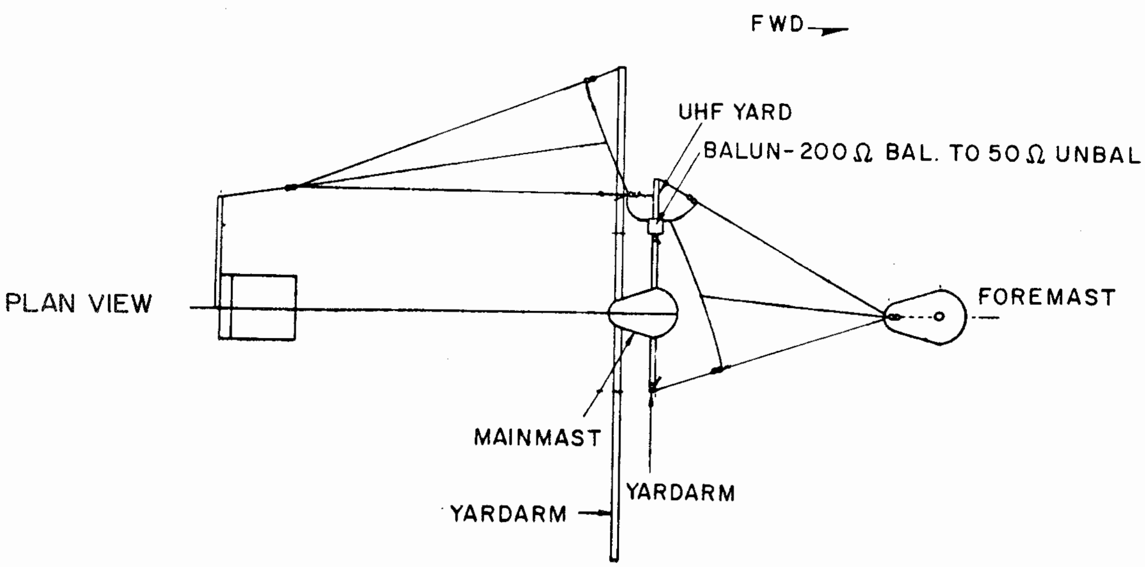


FIGURE 2-22 BALANCED DIPOLE FAN ANTENNA, PHYSICAL OUTLINE

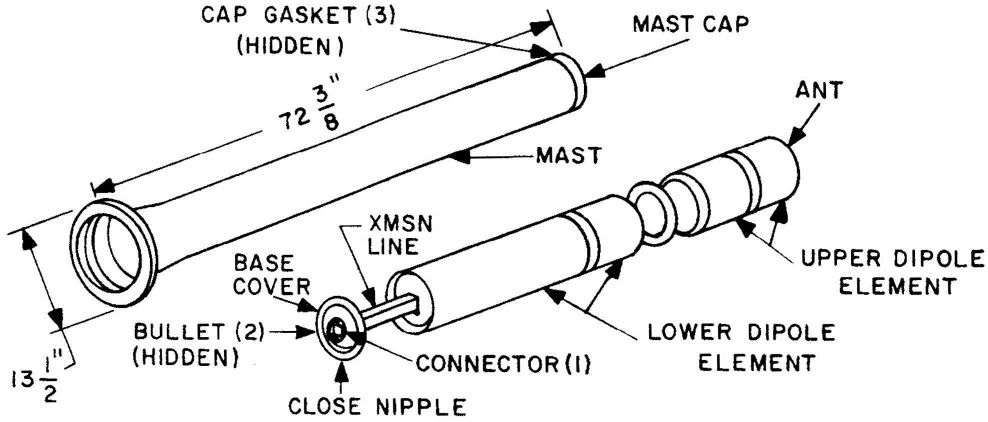


FIGURE 2-23 AS-1018/URC VHF/UHF ANTENNA, PHYSICAL OUTLINE

Broadband antenna characteristics allow these antennas a flexible choice of frequencies to overcome pattern distortion and mutual coupling effects from other non-communication antennas and topside structures. Illustration of the antenna designs most commonly used for VHF/UHF communications are shown in Figures 2-23 thru 2-25.

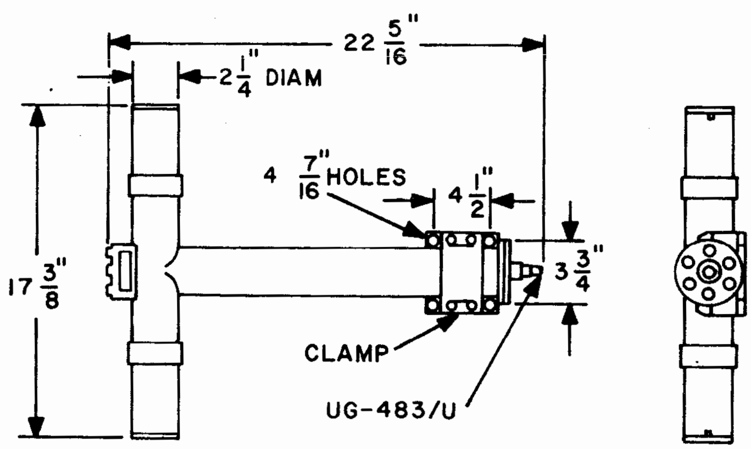


FIGURE 2-24 AT-150/SRC VHF/UHF ANTENNA, PHYSICAL OUTLINE

The antenna shown in Figure 2-26 is used for TACSATCOM operations. The antenna is used for both transmit and receive functions. An unobstructed path is required between the ship and satellite for reliable operation. Two antennas are normally installed on-board ship to provide 360 azimuthal and 0 to 90 vertical coverage without beam masking from ships structures and other antennas.

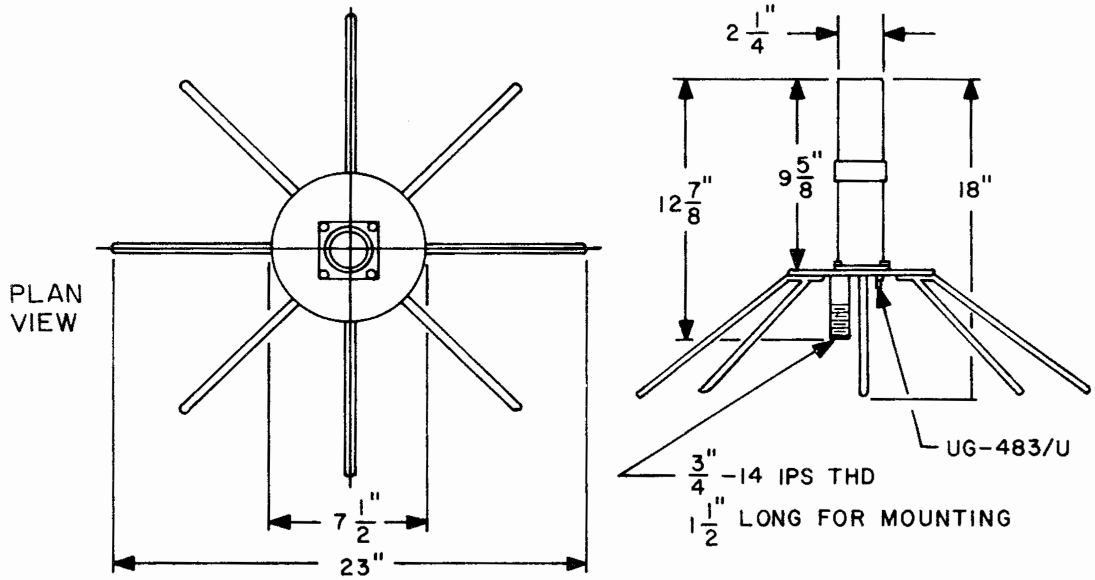


FIGURE 2-25 AS-390/SRC VHF/UHF ANTENNA, PHYSICAL OUTLINE

The AS-2410/WSC-1 antenna used for UHF satellite communications is designed with a beam of 40 degrees steerable over a 360 degree horizontal sector and from zero to 90 degrees in the vertical plane from the antenna horizontal plane. The antenna polarization sense is right-hand circular-beamed for receive and transmit operations. The minimum pattern gain is approximately 11 dB with respect to an isotropic radiator across a frequency band from 290 to 315 MHz. The voltage standing wave ratio measured at the antenna terminals is 1.2:1 or less across the frequency band.

The AS-2815/SSR-1 FLEETBROADCAST receiving antenna has a fixed 360 degrees horizontal pattern with a maximum gain of 4 dB at 90 degrees from the antenna horizontal plane. The maximum loss in the antenna vertical pattern sector is 2 dB. The voltage standing wave ratio is less than 1.5:1 referenced to a 50 ohm level over a 4 MHz bandwidth. The antenna shown in Figure 2-27 is used to receive fleet braodcasts from a satellite. The antennas should be located to prevent interference and possible front end burnout from radar and UHF transmitters.

UHF frequencies should be spaced to prevent TACSATCOM front end burn-out and mutual interference.

2.3.1 OPERATIONAL CONSTRAINTS

Broadband HF transmitting antennas are designed to operate efficiently over a frequency bandwidth of 3:1 with standing wave ratios not to exceed 3:1 referenced to 50 ohms.

Broadband HF receiving antennas systems will tolerate a VSWR of 15:1 over the 2 to 30 MHz bandwidth.VHF/UHF transmitting and receiving antennas are designed to operate over a bandwidth of 2:1 with a VSWR of 1.5:1 referenced to 50 ohms.

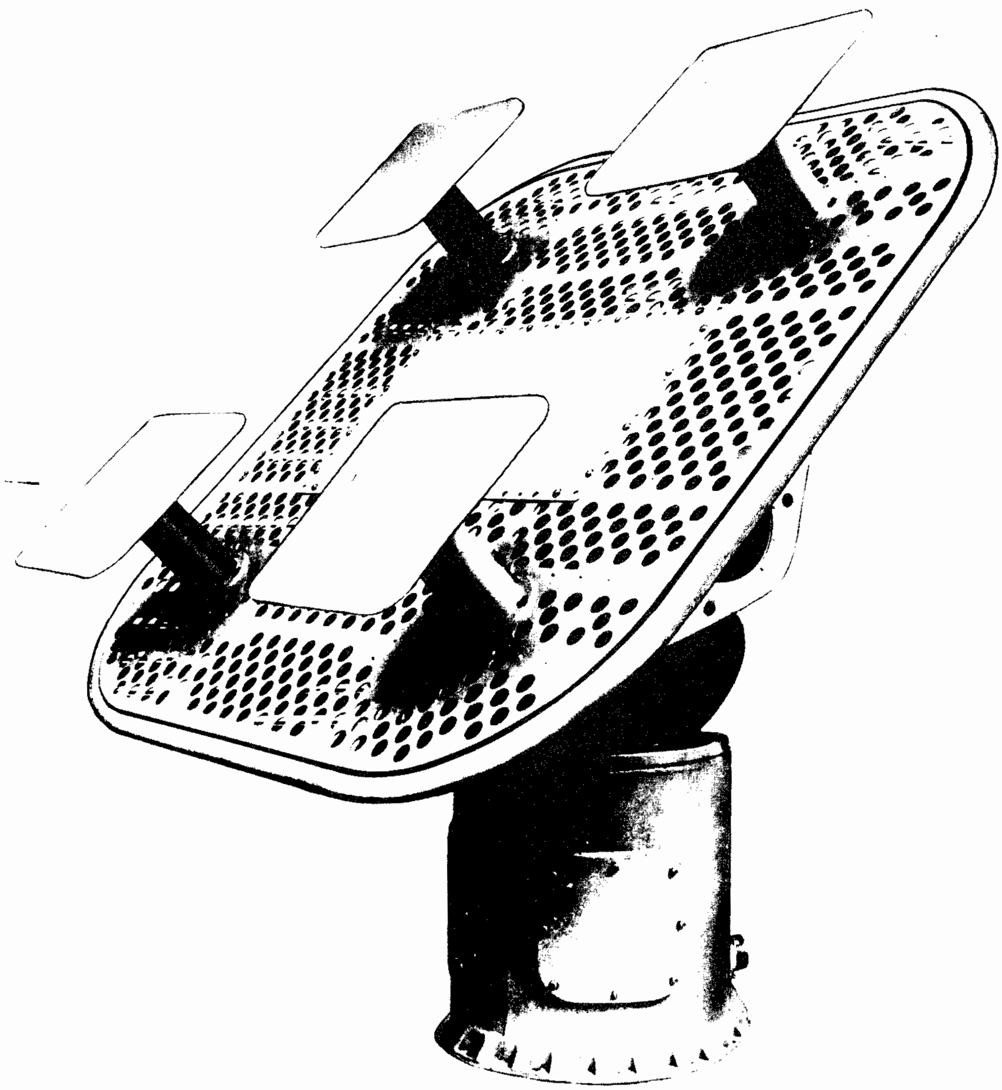


FIGURE 2-26 AS-2410/WSC TACSATCOM ANTENNA, PHYSICAL OUTLINE

The number of channels that may be operated simultaneously on a specific broadband antenna is dependent on the number of channels available in the multicoupler and, in the case of transmitting channels, the frequency separation between the individual channels.

Ideally shipboard communication antennas should be omnidirectional. However due to interferences from ships structures and other objects in the vicinity of the antennas, pattern distortion and impedance mutual coupling problems may be experienced on specific frequencies and azimuths. Degradation in system operating efficiency can be expected on any frequency or azimuth that is subject to these conditions.

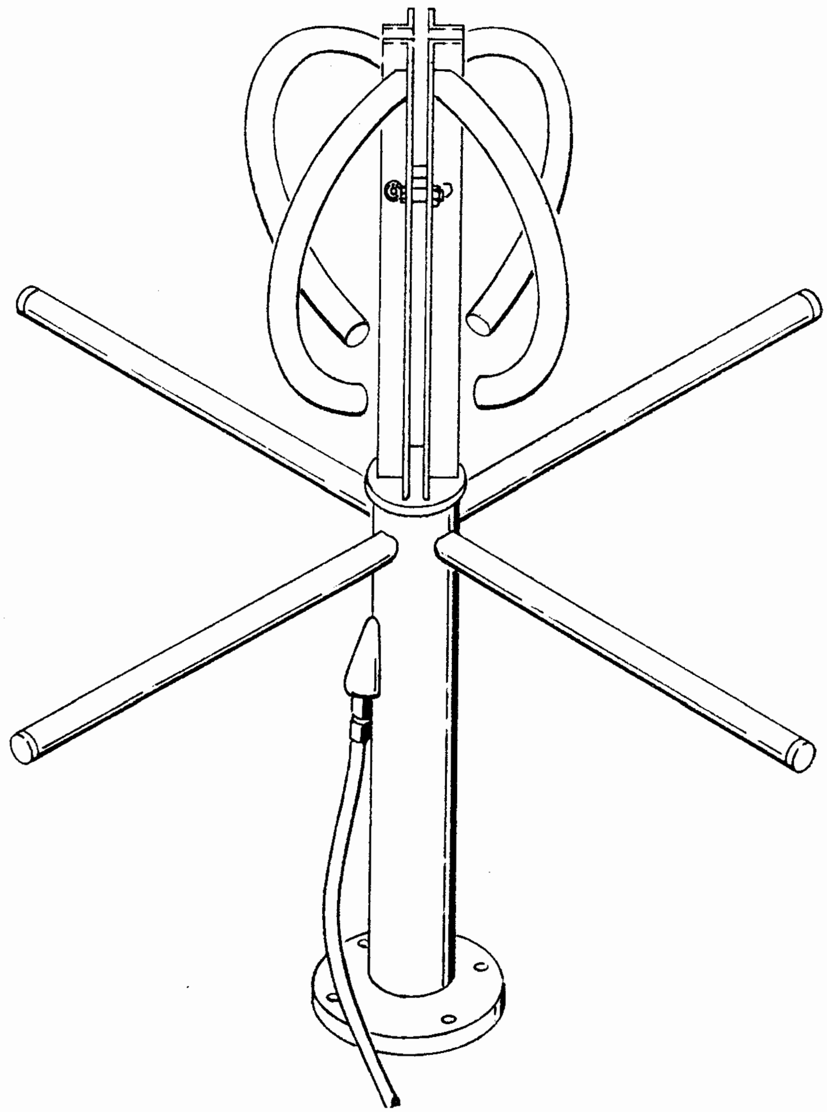


FIGURE 2-27 AS-2815/SSR-1 VHF/UHF SATCOM ANTENNA PHYSICAL OUTLINE

HF ship to ship and ship to shore communications paths use sky wave mode for long distance communications. The transmission path for this mode is affected by the antenna pattern and ionospheric conditions. The correct antenna must be selected to support the conditions of the path taking into consideration the LUF and MUF. The antenna pattern will determine azimuthal and vertical path deficiencies and antennas with vertical take-off angles in excess of 30 on specific frequencies should not be used due to the possible increase of multipath interference at the receiving terminal.

VHF/UHF ship to air communications paths are limited to line-of-sight. At times greater distances are experienced when atmospheric conditions support the signal propagation between the ship and the aircraft. VHF/UHF ship to ship paths are normally line-of-sight limited by the curvature of the earth's surface. Additional coverage beyond the horizon may exist periodically due to climatic conditions. This situation is the result of temperature inversions which form sharply defined boundaries or layers in the atmosphere. When these boundaries exist radio waves become "trapped" between two refracting layers of air or between a layer of air and the earth. In many cases this duct is only a few feet high and only VHF/UHF waves are confined. Operating personnel should be aware of the possiblity that VHF/UHF transmissions may be propagated beyond line-of-sight and affect security measures.

2.3.2 DESIGN CONSTRAINTS

Antenna patterns and impedance characteristics are functions of the bandwidth, electrical length, and the number of antenna elements. Because the antenna is the instrument required for transfer of power between the communication system and the radio transmission path the antenna impedance is designed for minimum interface power transfer losses. Broadening the antenna impedance is accomplished by physically "fattening" the antenna, i.e. increasing the effective diameter. Whip diameters may be made larger by arranging them in parallel (twin) as shown in Figure 2-15 where the diameter has been effectively increased from 3" (single whip) to 2 1/2 feet (twin whip); other methods of increasing the effective diameter are by designing cones, cages, trussed whips and wire fans as illustrated in Figure 2-16 thru 2-22.

The impedance levels for antenna types specified on Figures 2-28 through 2-31 are typical values that may be expected from antennas of similar design when exposed to a shipboard environment. The data given for each design is based on ship scale model testing. The impedance deviations for any ship installation should not exceed the encircled boundary limits.

Matching networks are installed between the transmission line and the antenna terminals to bring the impedance values exceeding specified limits to within the boundary.

Antenna reactance coordinates, R and X, for each frequency can be obtained directly from the Smith Chart associated with each antenna type in Figure 2-28 through 2-31. For example, from Figure 2-28 for the twin-whip at 4 MHz R is 30 ohms and Xc is 70 ohms. Fundamentals of the Smith Chart are given in Appendix C. The location of the values of R and X on the chart are helpful in determining if the impedance of the antennas at specific frequencies falls within the 3:1 VSWR limitations specified for linear operation of the transmitters.

Long range HF communications depends on good omnidirectional antenna patterns especially in the vertical plane between 5 and 30 degrees. Antenna pattern nulls should be limited to values of less than 10 dB from the maximum in this area.

The HF antenna patterns shown in Figures 2-32 and 2-33 are typical pattern characteristics based on ship model testing and may be expected from similar designs when installed in shipboard environment. The angle of elevation from the antenna horizontal plane is expressed by the symbol ψ and the azimuthal vector by the symbol ϕ.

Some of the most commonly used antennas for ship to aircraft VHF/UHF communication operations include the AS-1735/SRC, AT-150/SRC, AS-390/SRC, AS-1018/UR and the AS-2493/SRA-62. The voltage standing wave ratios for these designs are less than 2:1 referenced to a 50 ohm level over the frequency

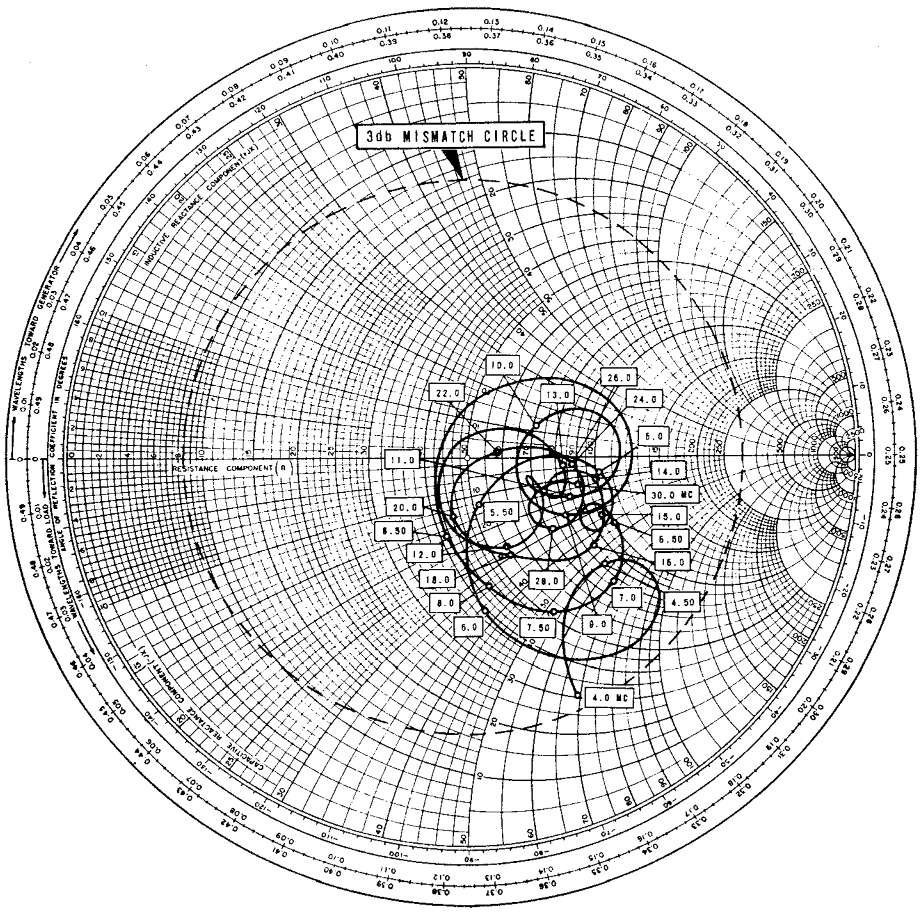


FIGURE 2-28   TWIN WHIP ANTENNA, IMPEDANCE AT SELECTED FREQUENCIES

range from 225 to 400 MHz. Pattern characteristics for an AS-1018/UR antenna on specific frequencies shown in Figure 2-34. These patterns are typical for aircraft carrier installations at heights of not less than 120 feet above the water line. These antennas are located on stub masts above the superstructure. The nulls are generally the result of masking by mast structures and other interferences.

2.3.3 INSTALLATION CONSTRAINTS

The main purpose for using broadband antennas on ship installations is to reduce the number of antennas and thereby pattern distortion, alteration of antenna feedpoint impedance, and the transfer of RF energy among antennas installed on ships. These effects have been described in previous paragraphs and their mention in the following paragraphs will be to describe the procedures used to minimize the effects in the shipboard environment.

In general, HF cage-type antennas are mounted away from king posts or mast structures by a distance equal to at least the height of the cage antenna. Cage antennas mounted on pedestals or similar structures require pedestals

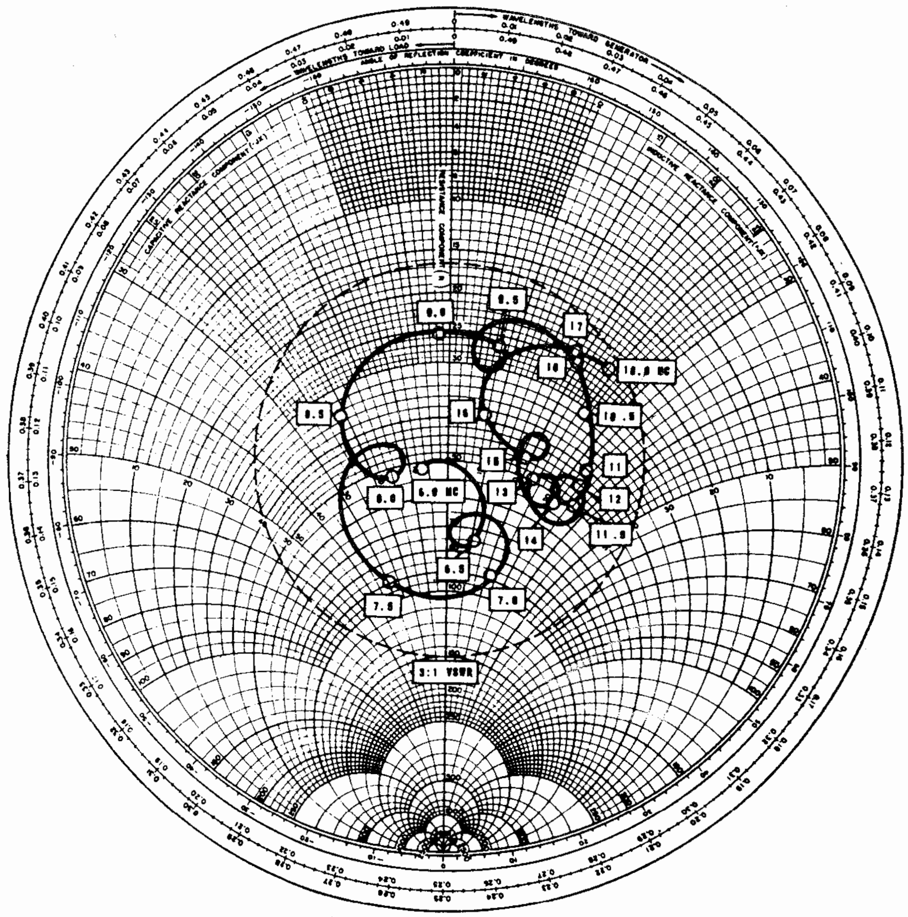


FIGURE 2-29 CAGE ANTENNA, IMPEDANCE AT SELECTED FREQUENCIES

of equal diameters as the cage base. If the pedestal is more than 20 percent of the height of the cage and small in diameter, a ground plane is constructed which extends radially from the antenna base. If the cage is installed on the bow of a ship and the pedestal is too tall or small in diameter the antenna impedance can be considerably improved by extending 6 to 9 evenly spaced wires from the top of the pedestal outward and down to the ship's deck.

Broadband fan antenna design makes use of the ship's superstructure to obtain pattern and impedance characteristics. The 2 to 6 mHz broadband fan antennas are fed from the top of the ship's mast superstructure. The minimum height of the yardarm above the main deck is 50 to 70 feet from the ground plane (waterline). The mast or tower may be taller than the yardarm but the feed point of the fan input terminals should not be less than the heights given. This requirement is necessary to realize the impedance characteristics for efficient power transfer.

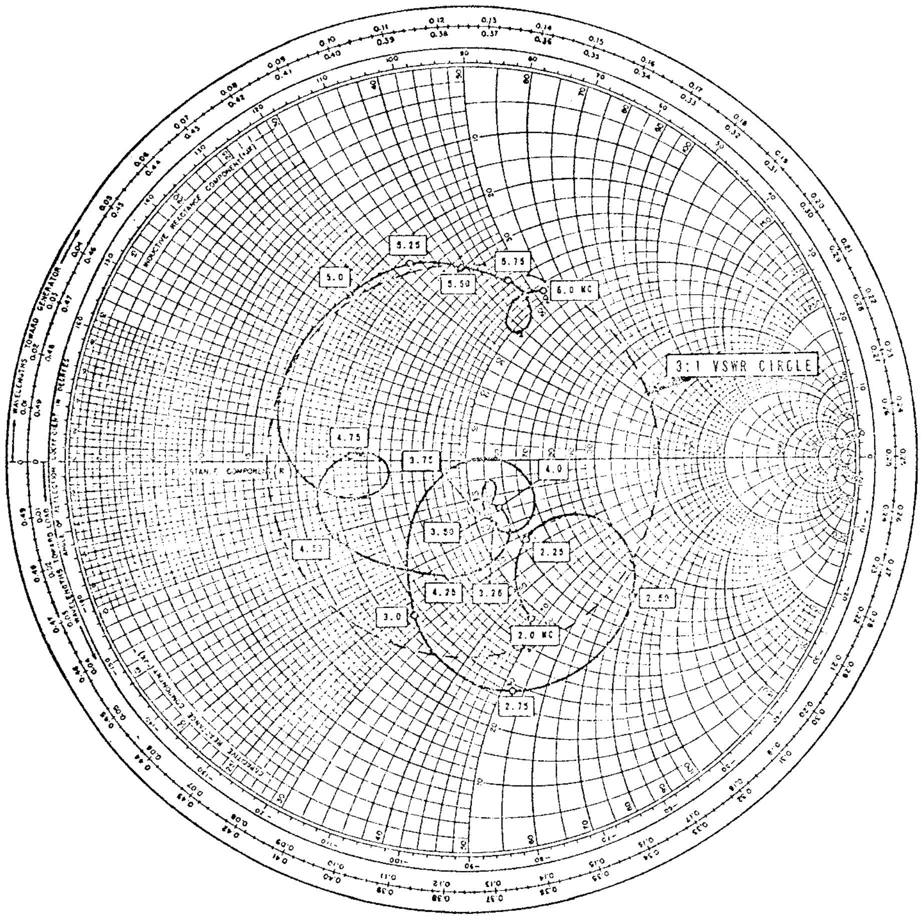
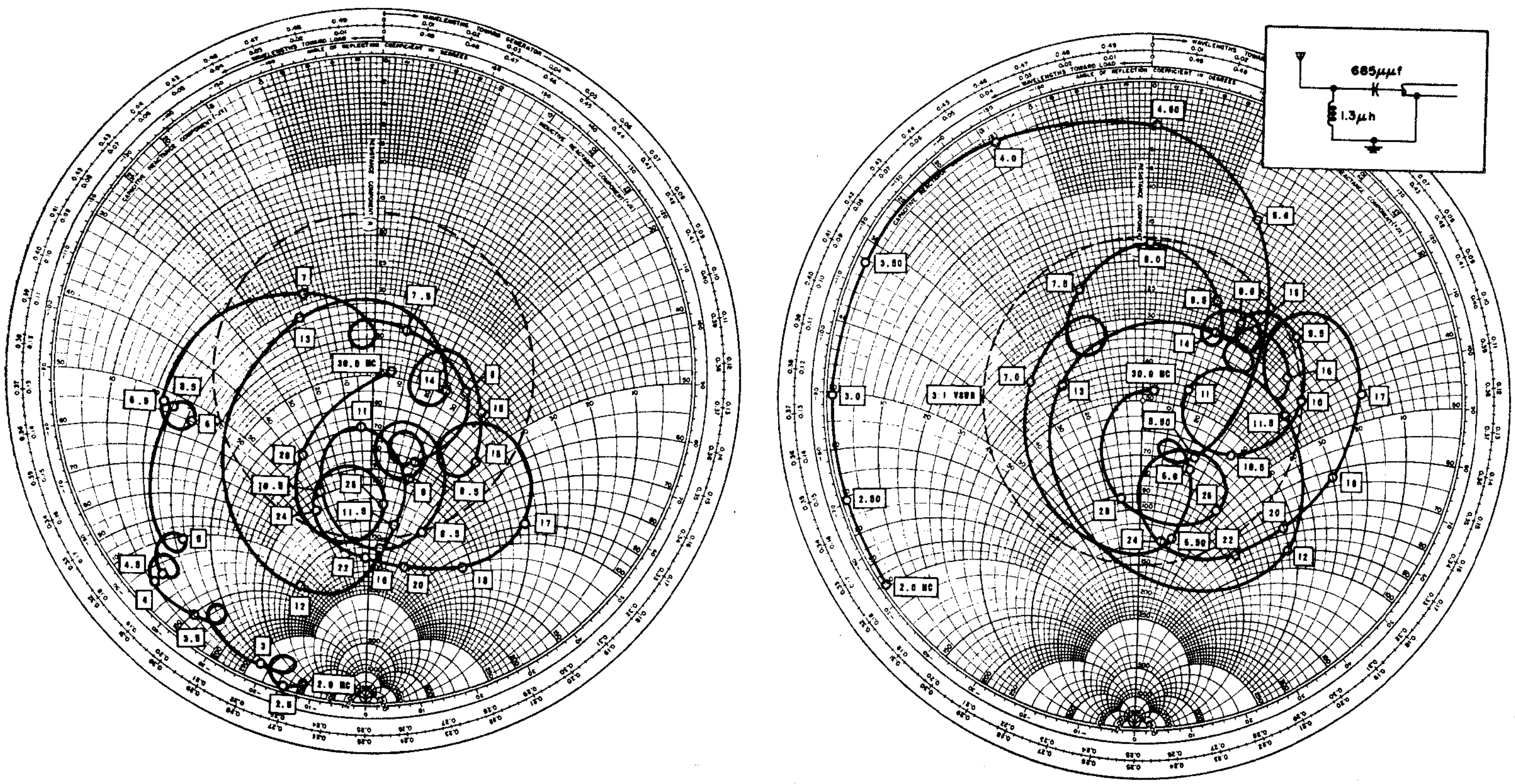


FIGURE 2-30 DOUBLE FAN ANTENNA IMPEDANCE AT SELECTED FREQUENCIES

Another factor related to the fan impedance characteristic is the antenna element length. The antenna length is primarily determined by the mast structure height. The fan antenna designs make use of the ship's structure as part of the antenna to realize the desired impedance over the bandwidth. The coupling of single or twin fans to excite the mast, that is, top feeding the antenna, is not a difficult problem. Multiple wire feeds as shown in Figure 2-35 for top-feed antennas frequently offer considerable improvement in impedance compared to a single wire feed. Base fed antenna fans may be secured directly to the ship structure at the top or coupled to the structure through capacitors. This method is typical for antennas designed to operate at frequencies above 4 MHz. The grounded and bottom fed antenna must have a circumference of approximately half-wave at the lowest frequency of the antenna in order to obtain an acceptable impedance in the presence of the ship environmental effects.



Unmatched Antenna

Antenna and Matching Device

FIGURE 2-31 BASE FAN ANTENNA IMPEDANCE AT SELECTED FREQUENCIES, MATCHED AND UNMATCHED

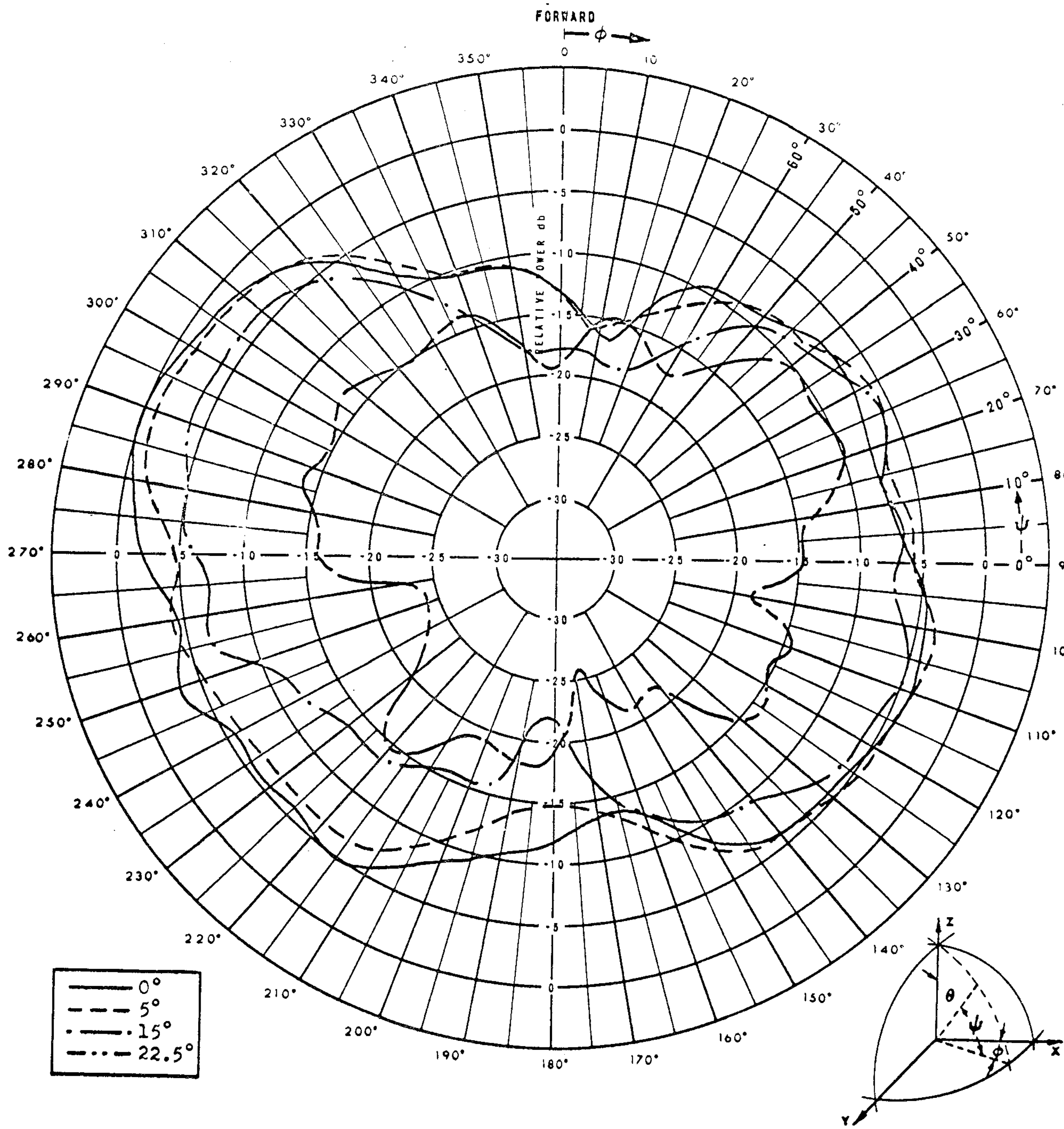


Figure 2-32 TWIN WHIP ANTENNA 8 MHz AZIMUTH AND VERTICAL PATTERNS

ANTENNA TYPES

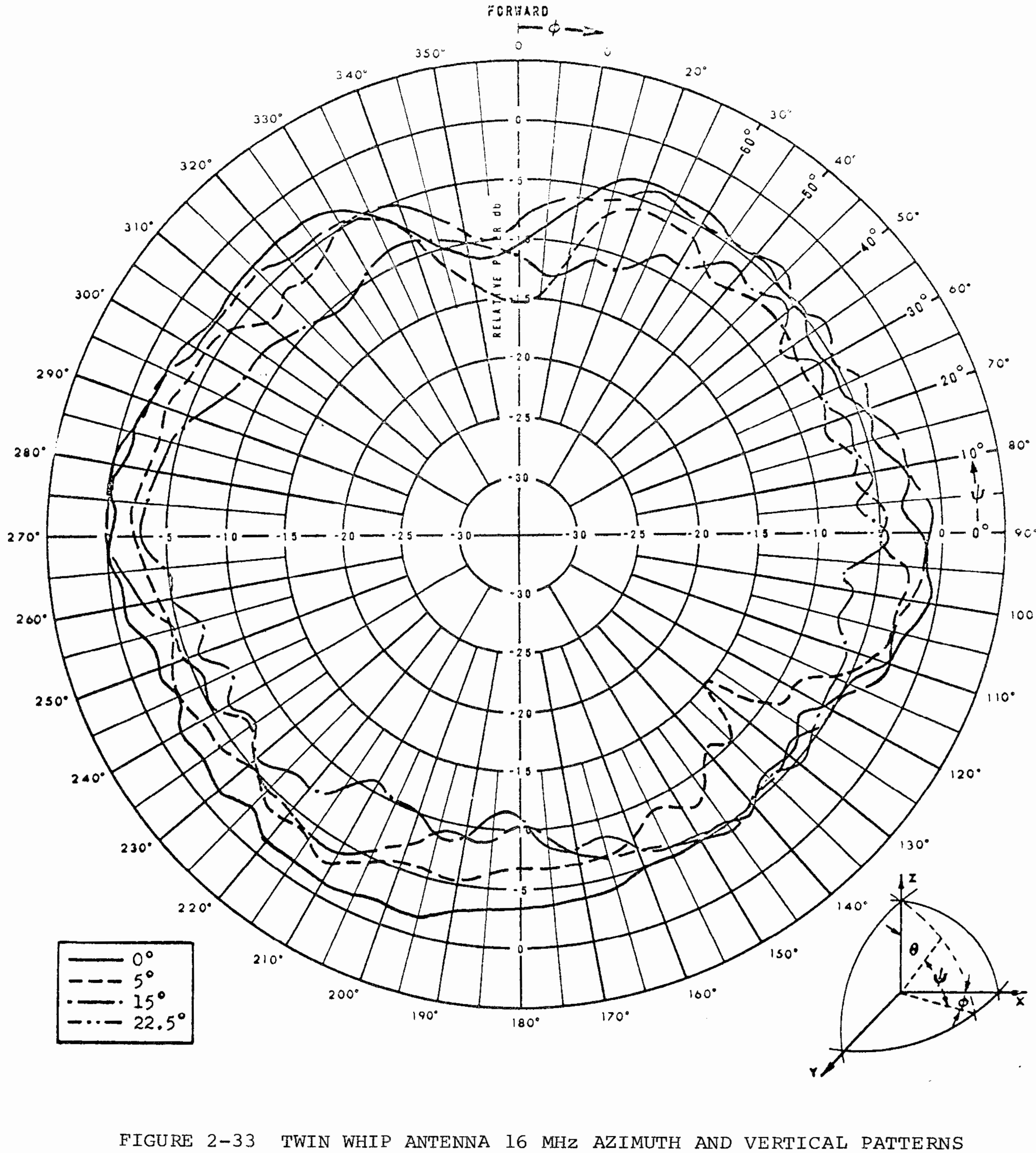


FIGURE 2-33 TWIN WHIP ANTENNA 16 MHz AZIMUTH AND VERTICAL PATTERNS

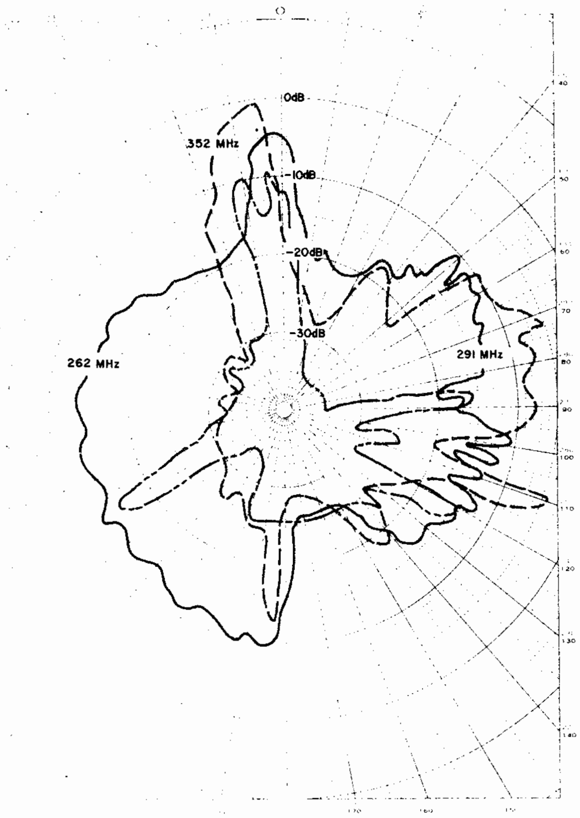


FIGURE 2-34 AS-1018/UR ANTENNA PATTERN AT SELECTED FREQUENCIES

In general, antennas designed to operate below 6 MHz should be long in order to obtain reasonable impedances over the design bandwidth. This requirement can be accomplished by using shorter elements and elevating the feed point from the antenna base when installed on the ship's deck. This type of feed arrangement has the advantage of reducing the ship's structure tendency to distort the antenna impedance and pattern characteristics. Use of such ship structures as masts or towers to support the antenna element not only makes the structure part of the antenna, but also eliminates one potential parasitic element thus reducing antenna pattern nulling. The fan antenna impedance can be improved by using shorting wires to change the shape of the ship structure affecting the impedance or by multi-wire feeds. These techniques are illustrated in Figures 2-19 and 2-20. Coaxial cable termination at the feed points or matching networks requires the cable outer conductor to be grounded at its end with short and large diameter, solid, low conducting ground wire.

Typical shipboard installations for twin-whip antennas are shown in Figure 2-36 for a vertical installation on the forward edge of the pilot house and Figure 2-37 for a 45 degree slanted installation on the forward edge of the pilot house. As an example these types of installations allow the pattern nulls to be less than 10 dB from the pattern maximum in the horizontal and vertical planes in the sector from zero to 30 degrees in elevation for approximately 87 percent of two-masted DLG type ships.

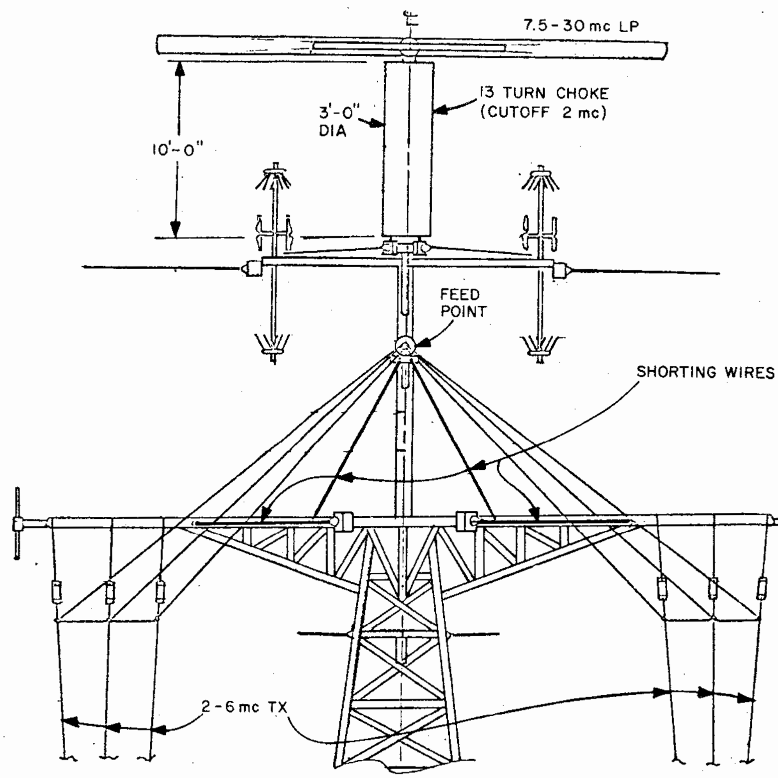


FIGURE 2-35 MULTIPLE WIRE TOP FED ANTENNA, FEED POINT LOCATION

The optimum antenna height as a function of frequency for VHF/UHF communications is shown in Figure 2-38 for shipboard antenna installations (sea water curve). Installation of antennas at optimum heights for VHF/UHF ship to air omnidirectional communications is not always possible because of interference from the ship's structure and other shipboard antennas. The AN/SRA-62 systems are not generally susceptible to masking since they are installed in clear areas on carrier islands. Ideal patterns would only be realized from these systems if the antennas are installed at the indicated optimum heights. The pattern relationship is depicted in Figure 2-4; however, the relationship to the radio path field strength coverage for distance points from the ship is discussed in Section 3.

The installation of shipboard satellite antennas must be free from masking caused by the ship structure and other shipboard antennas. Specifically, the antenna installation should be made to prevent interference to and from other communications and electronic subsystems operating in adjacent frequency channels during the receiving and transmitting modes of the satellite equipment.

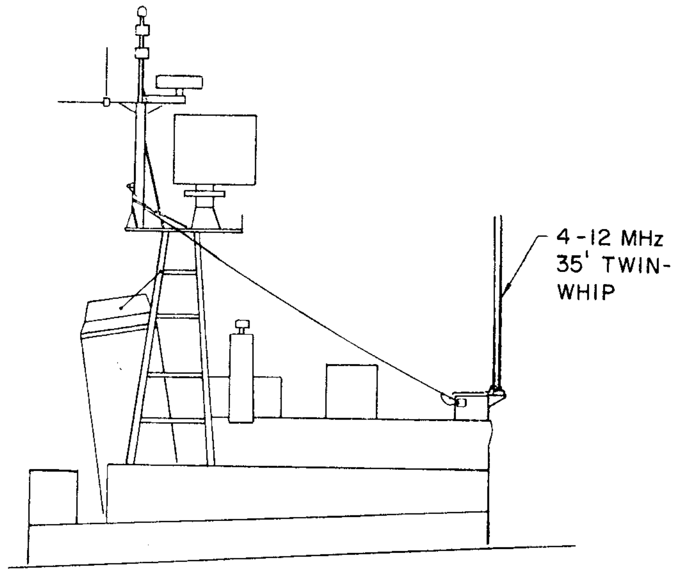


FIGURE 2-36 TWIN WHIP VERTICAL INSTALLATION ON PILOT HOUSE

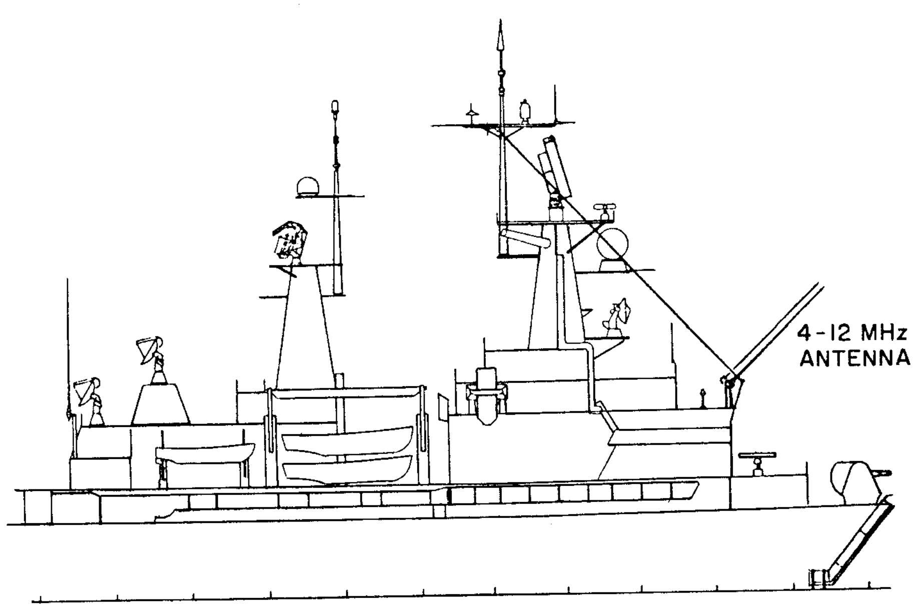


FIGURE 2-37 TWIN WHIP 45° SLANT INSTALLATION ON PILOT HOUSE

ANTENNA TYPES

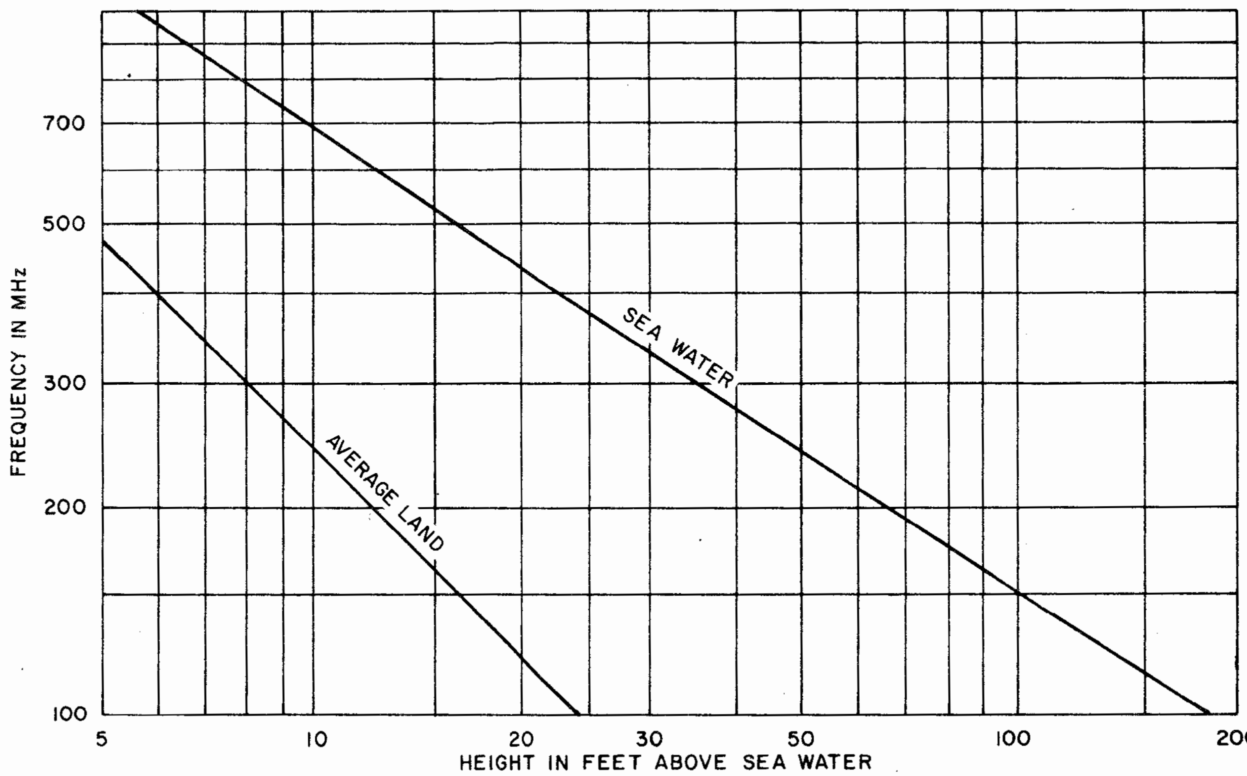


FIGURE 2-38 OPTIMUM SHIPBOARD ANTENNA HEIGHTS FOR MAXIMUM VHF/UHF COVERAGE

SECTION 3

ANTENNA CHARACTERISTICS

3.1 GENERAL

Section 2 discussed the operational, design and installation constraints of the typical antennas installed on ships for LF, MF, HF, VHF/UHF and satellite communication operations. The information did not relate the basic antenna characteristics that warranted their adoption for shipboard use. It is the purpose of this section to disclose the basic design characteristics which are essential to cope with antenna pattern and impedance distortion caused by antennas and metal structures associated with shipboard environments.

The factors that affect antenna design include impedance, radiation patterns, gain, bandwidth, polarization, and input power. These factors are inter-related and often include other by-products, such as, electromagnetic interference, electromagnetic compatibility, harmonics and signal-to-noise ratio.

Basically, antennas used for shipboard installations are divided into either narrow band or wideband. The narrow band types include the 35 foot single element antenna tapering from 3 inches at the base to one inch at the top. Shorter heights are used and are also considered to be in the narrow band category. The wideband class includes cages, twin-whips, trussed whips, discone/cages, wire fans, log periodics, VHF/UHF shipboard antennas used for ship to aircraft communication operations, and shipboard satellite antennas.

Figure 2-10 will be of aid in simplifying conversion from frequency to feet for the most commonly used multiples of wavelengths ($\lambda/100$, $\lambda/10$, $\lambda/4$, λ) as related to antenna length. This figure is especially useful for the discussions in the following paragraphs of the design factors for shipboard antennas.

3.2 IMPEDANCE

The impedance consists of the resistance and reactance components. The components as applied to antenna design are functions of antenna element dimensions and the configuration of elements in multiple element designs.

3.2.1 DIMENSIONAL PARAMETERS

Figure 3-1 illustrates the radiation resistance values that can be expected from short cylindrical elements of infinitely thin (dotted line) and finite (solid line) diameter. This figure reveals that for a 35 foot vertical whip no more than one ohm of radiation resistance can be expected for a frequency of 300 kHz based on the length conversion derived from Figure 2-11. The reactance for the same frequency and L/D ratio as above will be capacitive with a value of approximately 400 ohms. Figure 3-2 illustrates the reactance component values in ohms that can be expected for antenna wavelengths from 0.05 to 0.06 and for L/D ratios from 5 to 200. As the length to wavelength ratio is increased a considerable improvement can be realized particularly when the length to diameter ratio of the element is decreased. The improvement in resistance is shown in Figure 2-9 for (L) from 0.05 to 0.60 element wavelengths.

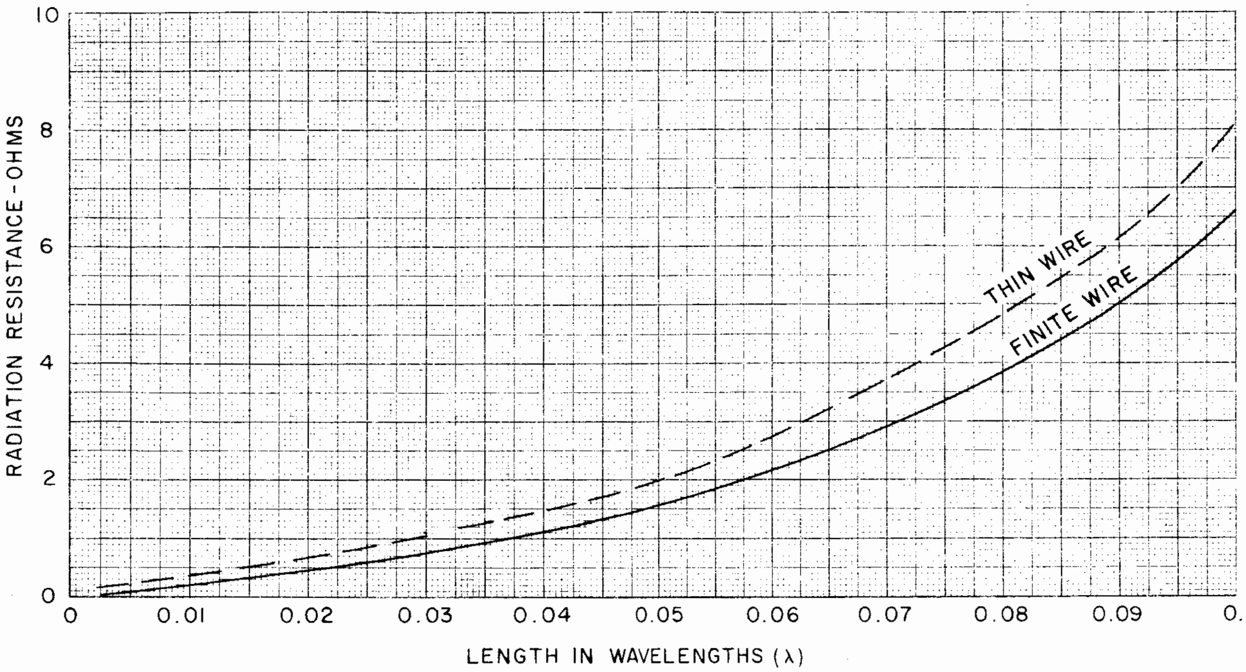


FIGURE 3-1 RADIATION RESISTANCE OF SHORT ANTENNAS

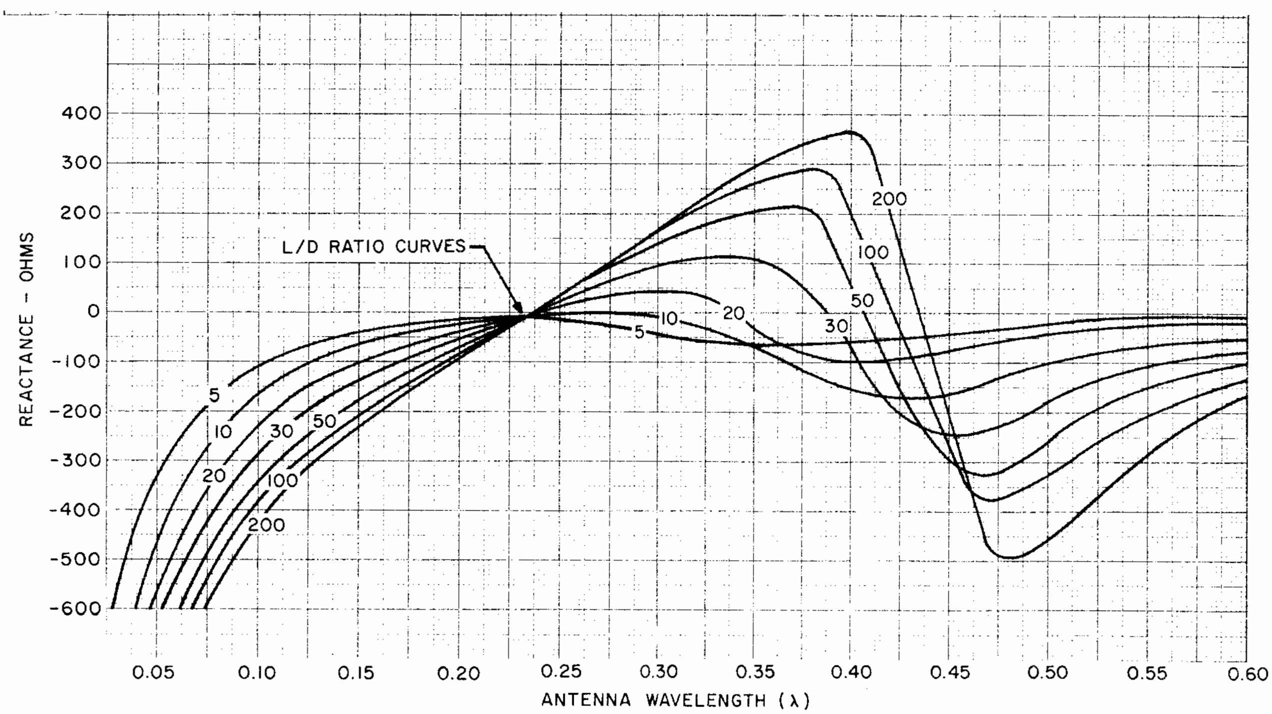


FIGURE 3-2 REACTANCE CURVES FOR VERTICAL ANTENNAS OF DIFFERENT LENGTH (L) TO DIAMETER (D) RATIOS

From the above, as related to short element antennas, the radiation resistance, and, therefore the efficiency of the antenna system, can be determined. The efficiency depends on the amount of power transferred from the transmission line to the antenna. When the impedances are equal or matched there will be maximum power transfer or efficiency. The degree of efficiency will decrease in porportion to any mismatch. As the resistance of the antenna approaches the impedance of the line the better the match and consequently the better the efficiency of the system.

The objective of a transmitting antenna is to radiate strong fields to distant points while that of the receiving antenna is to respond as efficiently as possible to externally impressed fields. From the resistance characteristics of short antennas of less than 1/10 wavelength it can be concluded that the power delivered to the antenna terminal will be largely dissipated in heat due to low radiation resistance. As the length of the antenna increases, to $\lambda/4$ (or multiple thereof) the radiation efficiency increases and the power transfer improves.

The twin-whip antenna, shown on Figure 2-15, consists of two elements connected together at their bases by 7/16" phosphor bronze wire, and the midpoint of this interconnection is connected to the transmission line matching network. Each element is 35 feet in height with a length to effective diameter ratio of approximately 140 and is arranged so that a maximum omnidirectional pattern is realized.

The antenna impedance components of each element, as seen by Figures 2-9 and 3-2 for an L/D ratio of 140, are optimum for a twin-whip antenna design which spans a frequency band from 4 to 12 MHz (0.1 to 0.25 wavelength multiples of L).

The trussed-whips have similar impedance characteristics; however, the length to diameter ratio is lower than the twin-whip. The trussed-whip L/D ratio is approximately 6. The frequency band for this design is approximately 4 to 12 MHz.

The twin-whip, trussed whip, and the cage antennas belong to the family of thick or fattend monopole design. Although the cage element length is not as long as that used for twin-whip and trussed antenna designs, the diameter of the cage is large; therefore, the impedance characteristics can be expected to allow broadband operations from 6 to 12 MHz.

It is difficult to satisfy impedance design criteria for wire fan antenna installations where the ship structure is made part of the antenna. Impedance design is further complicated by the variation in ship topside structures and by the variations in space made available for large size antenna installations. The best method for determining impedance component values is by performing model tests. Figures 3-3 and 3-4 indicate resistance and reactance components that may be expected for double fan and base fed fan antennas.

3.3 PATTERN

The pattern characteristics of any antenna are dependent on element dimensions and arrangement. To be effective, the pattern shape in the vertical and horizontal planes must be compatible with the mode used for the signal propagation.

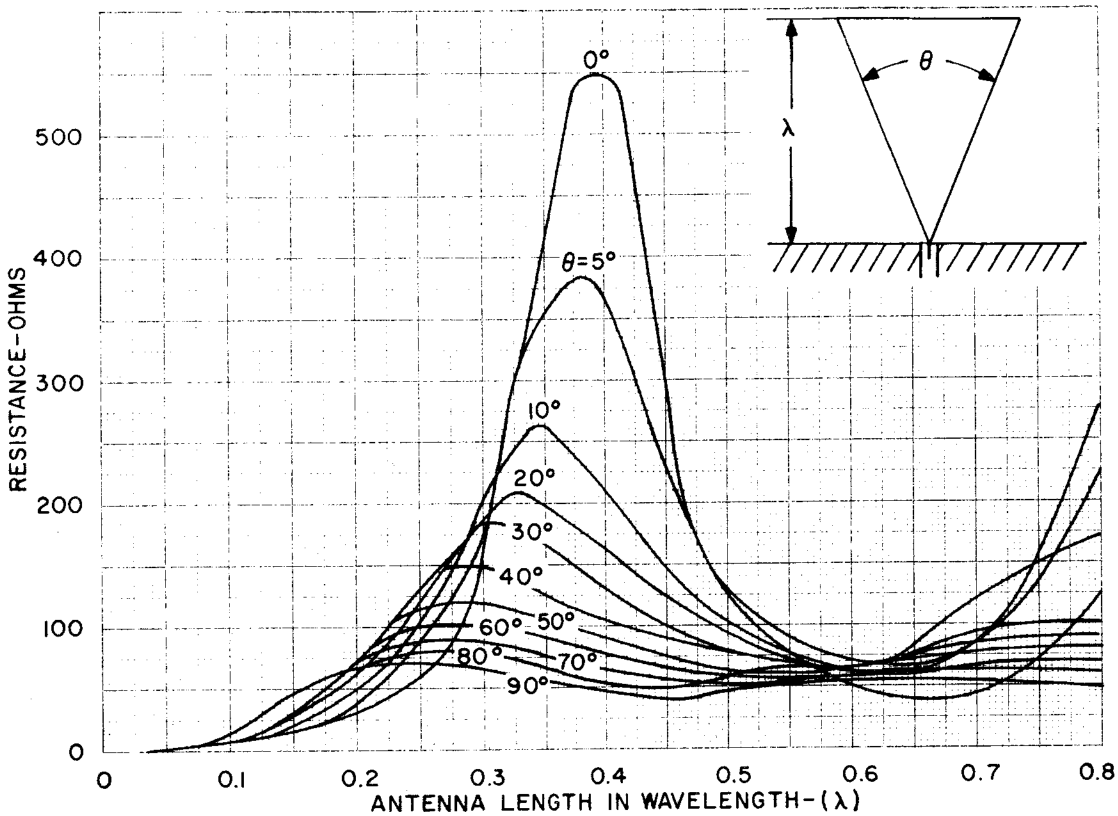


FIGURE 3-3 RESISTANCE CURVES OF CONICAL UNIPOLE ANTENNAS VERSUS LENGTH IN WAVELENGTH FOR VARIOUS FLARE ANGLES

3.3.1 PATTERN CHARACTERISTICS

Each mode of signal propagation places a different demand on the antenna pattern characteristics in the horizontal and vertical planes. These demands are related to the antenna arrangements on shipboard that restrict the installation area and location, resulting in pattern distortion and reduction in efficiency.

The installations for operating frequencies below 2 MHz make use of the surface mode of signal propagation where pattern distortion is negligible because most top side structures and other shipboard antenna elements are less than the multiples of frequencies below 2 MHz. Signal attenuation over sea water is much less than over land, and with antenna element heights of more than 1/10 wavelength excellent distance coverage can be realized.

The sky wave mode is used in the HF region for long distance communications and makes use of the ionosphere to support the signal path. The height of the various ionosphere layers that reflect the sky signal for great circle distances from zero to 1750 nautical miles are shown in Figure 2-3. The most effective layers are the 1 hop E and 1 hop F. The one hop E layer ranges in height from 57 to 162 nautical miles from the earth surface and the one hop F layer from 173 to 250 nautical miles. Based on these figures the optimum angle of arrival or departure span is from 5 to 30 degrees, for great

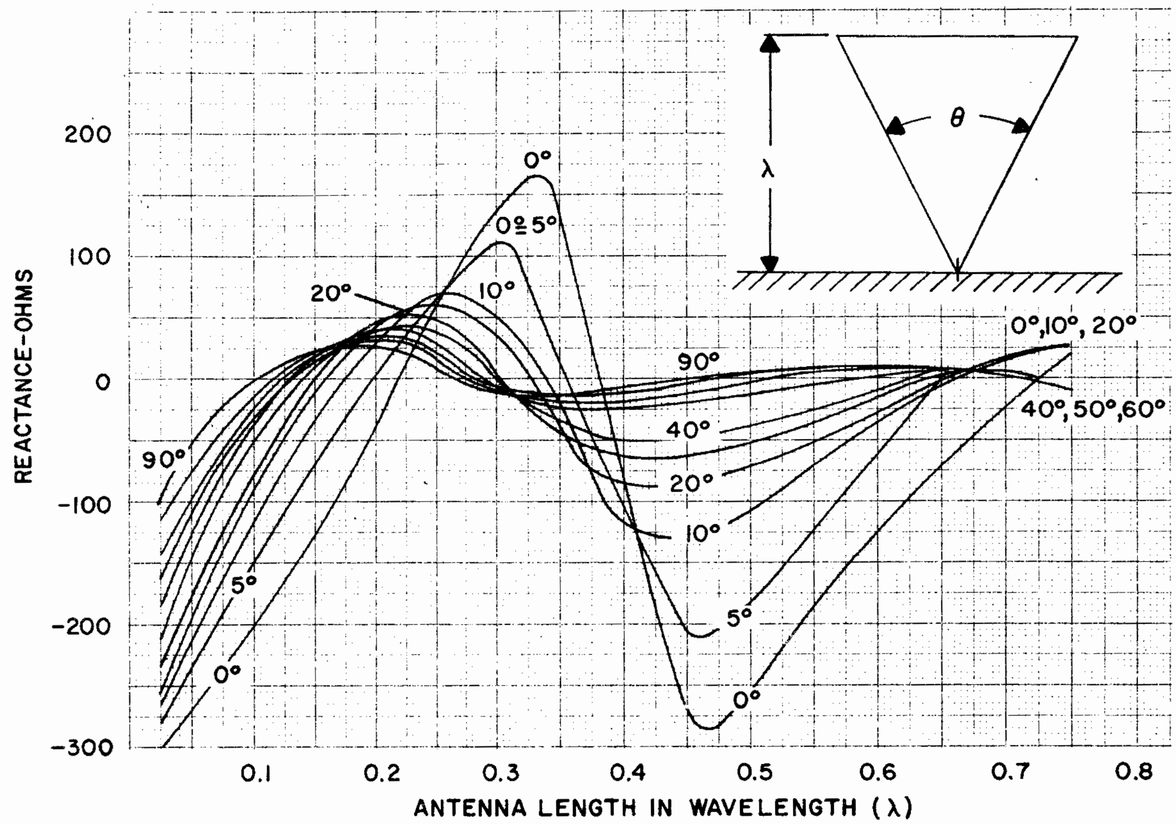


FIGURE 3-4 REACTANCE CURVES OF CONICAL UNIPOLE ANTENNAS VERSUS LENGTH IN WAVELENGTH FOR VARIOUS FLARE ANGLES

circle distances of 175 to 1750 nautical miles. Antennas designed for sky wave HF communication operations should incorporate this capability in their design.

Antenna patterns derived from element lengths exceeding 1/10 wavelength have excellent characteristics that are conducive to sky wave signal propagation over long distances. This is supported in Figure 2-2 which illustrates the relative field strength that can be expected from antennas with height (H) to wavelength (λ) ratios from 0.25 to 0.64 for angles of elevation ranging from zero to 90 degrees from the horizontal plane of the antenna.

Pattern distortion and impedance characteristics for sky wave communication operations are difficult to determine without scaled model test performance data. This data is also required to determine the impact of any modifications or additions to the antenna system. The magnitude of these effects were illustrated and discussed in Section 2.

HF ship to ship and ship to shore communications paths use sky wave mode for long distance communications. The transmission path for this mode is affected by the antenna pattern and ionospheric conditions. When sky wave propagation is used the electromagnetic wave from the antenna is transmitted toward an ionic layer at an oblique angle. The incident wave is then reflected, at the same oblique angle from the ionic layer back toward the receiving antenna. Figure 3-5 shows sky wave propagation paths which can be used. Actually the wave is not reflected; although this term is commonly used for convenience, the wave is bent back toward the earth by refraction, just as a prism refracts light. The figure shows only a one hop E and one hop F layer path; however, greater distances may be possible with multihop paths. The angle of incidence at the ionic layer is determined by the carrier frequency and the take off angle of the antenna. The correct antenna must be selected to support the conditions of the path taking into consideration the LUF and MUF. The antenna pattern will determine azimuthal and vertical path deficiencies and antennas with vertical take off angles in excess of 30° on specific frequencies should not be used due to the possible increase of multipath interference at the receiving terminal.

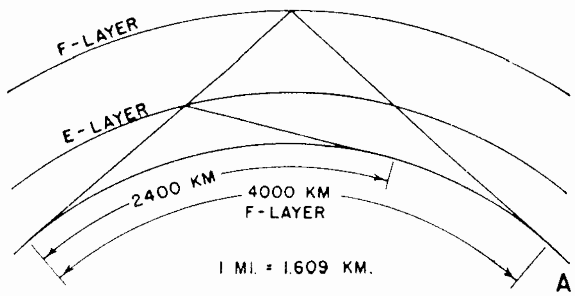


FIGURE 3-5 E AND F LAYER IONOSPHERIC TRANSMISSION

The optimum pattern for VHF/UHF ship to aircraft communications is one that gives full coverage for aircraft heights varying from the radio horizon to the maximum operational height of the aircraft. This coverage is not possible except for distances that are within the receiving equipment sensitivity of the ship and aircraft installations. There are areas above the radio horizon which exceed the solid coverage contour distance range. This characteristic is shown in Figure 3-6. These areas consist of peaks and nulls varying in height and distance from the ship location. The peaks have the equivalent level of the solid coverage contour signal magnitudes. The formation of the peaks and nulls from the ship antenna radiations at distant points and elevations are the result of the phase relationships of the direct and reflected radio paths. Path arrivals of equal phase add and form the peak areas and paths 180 degrees out of phase cancel out and form the null areas. The radio paths establishing the pattern characteristic at distant points for the direct and reflected rays emanating from the ship antenna are shown graphically in Figure 3-7. The configuration of peaks and nulls is a function of the ship antenna height above ground level (sea water). Any change in height affects the direct and the reflected rays since the angles of incidence and refraction are changed. This in turn affects the positioning of the peak and null areas with respect to the ship's position. Any distortion that may be experienced in the VHF/UHF region is generally traceable to structural interferences and from other antennas operating at or near the antennas operating frequency. Optimum heights for VHF/UHF antenna installations as a function of frequency versus height above sea water are shown in Figure 2-38.

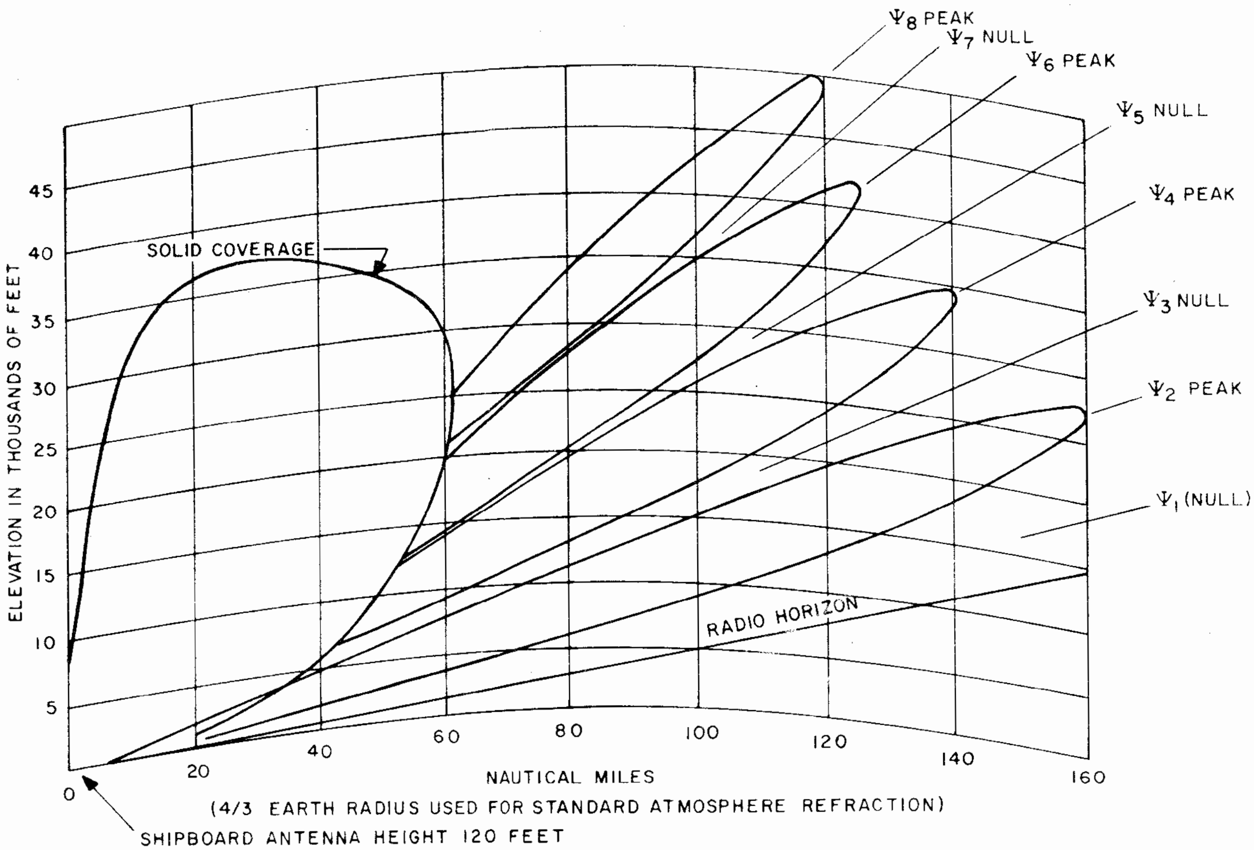


FIGURE 3-6 SOLID COVERAGE CONTOUR FORMATION-VHF/UHF ANTENNAS

VHF/UHF ship antenna pattern distortion is greater for operations on the higher frequencies of the 225-400 MHz band. This is observed in Figure 2-34 derived from ship model tests. This distortion is attributed to ship structure masking and coupling.

The AS-2410/WSC-1 antenna has a 40 degree beam measured at the half power points. The gain is at least 12 dB with respect to an isotropic radiator measured at 305 MHz. The AS-2815/SSR-1 receiving antenna has a fixed 360 degrees horizontal pattern with a maximum gain of 4 dB at 90 degrees from the antenna horizontal plane. The maximum loss in the antenna vertical pattern sector is 2 dB.

3.4 BANDWIDTH

Unlike impedance and pattern characteristics, the bandwidth of an antenna does not have a unique definition. The bandwidth may be limited by one of the following factors: change of pattern shape or direction, increase in side lobe level, loss in gain, change of polarization characteristics or deterioration of impedance characteristics. For antennas where all factors mentioned are important, one, such as gain or impedance, will determine the low-frequency limit while another, such as change of pattern shape, will determine the high

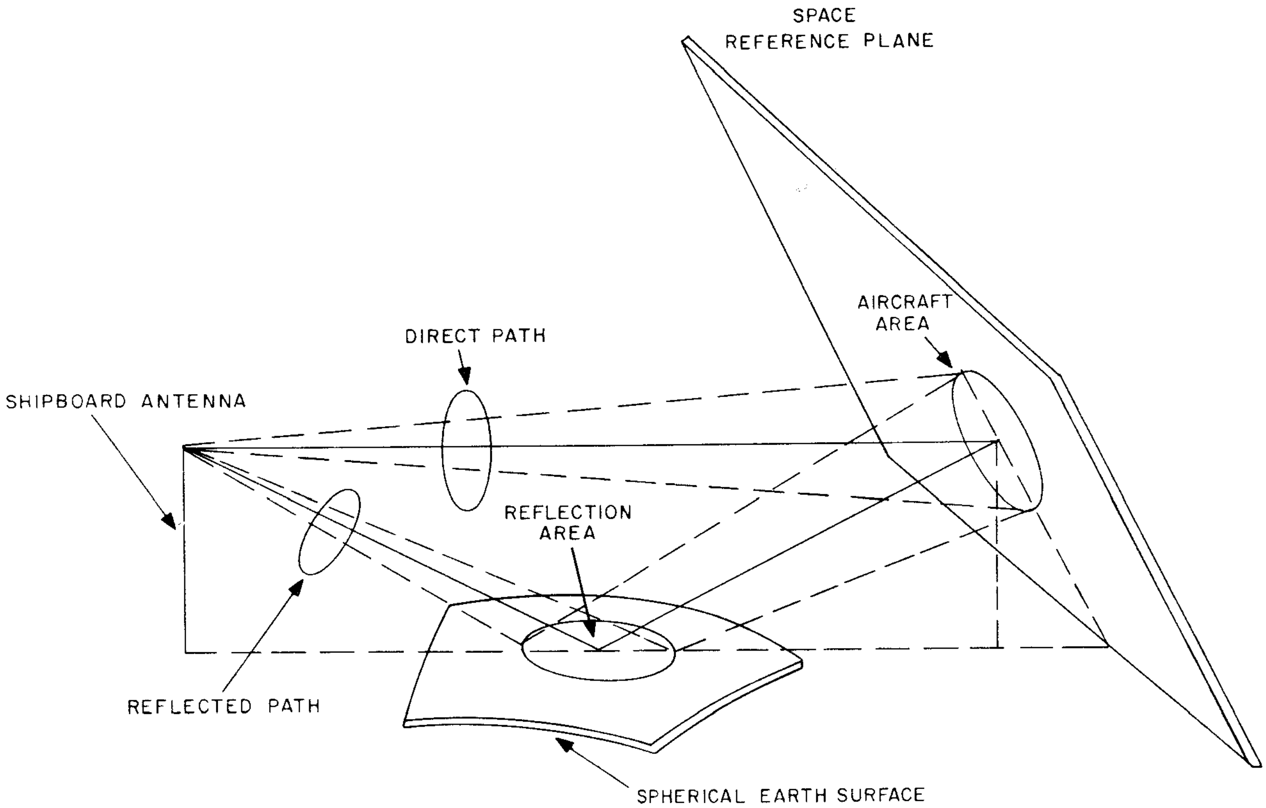


FIGURE 3-7 DIRECT AND REFLECTED SHIP TO AIR VHF/UHF RADIO PATHS

frequency limit. The most important factor limiting bandwidth for shipboard antennas is impedance. This is because of the relatively small dimensions, less than $\lambda/2$, and low radiation resistance of the antennas. In general the only appropriate definition for the bandwidth of an individual antenna is the band within which the antenna meets a given set of specifications.

3.4.1 BANDWIDTH CHARACTERISTICS

The 35 foot thin element whip antenna is one of the most versatile antennas used for shipboard installations. These antennas are not bulky, hence installation can be accommodated in less space that required for other designs. The main disadvantage is its bandwidth limitation. Figure 3-8 illustrates the resistance and reactance values of a 35 foot whip. Instructions for interpreting Smith Charts are shown in Appendix C. Satisfactory operation may be expected of antennas when the parameters fall with the 3:1 bandwidth and VSWR requirements. These impedance component characteristics were derived from ship model tests. The ship model test information has good correlation with the design criteria of Figures 2-9 and 3-2. When excessive voltage standing wave ratios are experienced, matching networks are required to reduce the impedance mismatch to permit communications equipment operation within design limitations. Because the antenna for these modes of operation will be inefficient, most of the power transfer will be lost in heat in the matching device. Trade off decisions shuld be made to determine if the loss incurred by the network introduced in the antenna system is warranted compared to the matching improvement.

ANTENNA CHARACTERISTICS

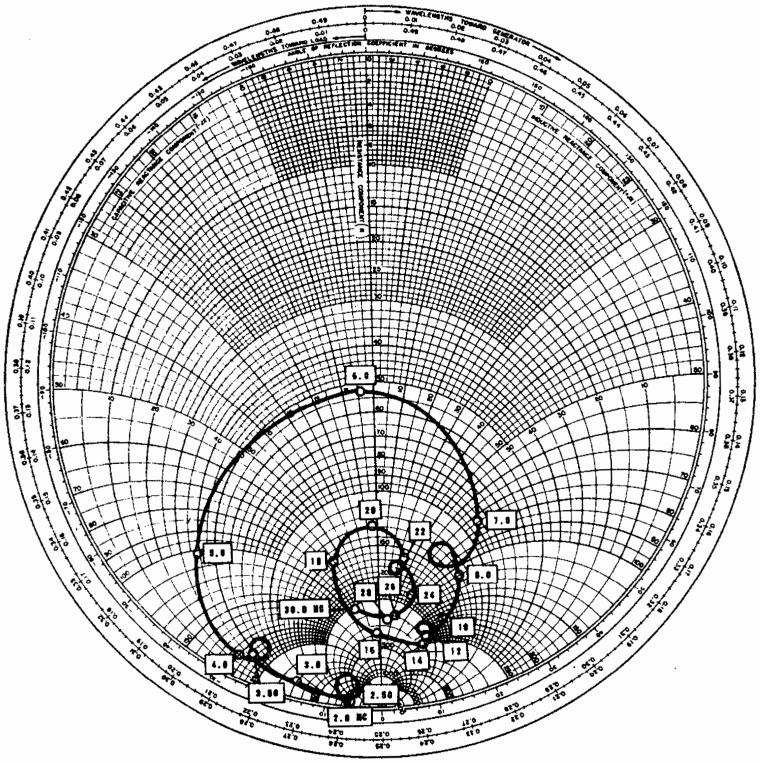


FIGURE 3-8   35 FOOT WHIP ANTENNA, IMPEDANCE PLOT

The wire fan antenna uses the ship's structure to obtain the impedance characteristics which will keep the antenna and transmission line interface loss at a minimum over the frequency bandwidth. Unique antenna feeds are also used to minimize the undesirable ship effects from being coupled into the antenna system. The ship model test impedances shown in Figures 2-30 and 2-31 indicate that it is possible to obtain 3:1 frequency bandwidths with a 3:1 voltage standing wave ratio for a 50 ohms transmission line match. The goal is to obtain a 3:1 VSWR over as wide a bandwidth as possible so that a specific antenna may be used for as great a number of frequencies as possible. This requirement and the complexity of the ships antenna environment make it difficult to match the antenna input impedance to the transmission line over the entire band. Since mismatch causes standing waves on the line which reduces the efficiency of the system, various types of lumped L-C matching networks are used to match the antenna to the line and keep the VSWR within the 3:1 limits.

The VHF/UHF antennas used on board ship are designed with adequate bandwidth to span the entire spectrum with a 1.5:1 VSWR. There is little affect on bandwidth from structures and other shipboard antennas as experienced at the lower frequencies.

The AS-2410/SSR-1 satellite antenna is designed with a bandwidth capable of providing a minimum of 11 dB gain with respect to an isotropic radiator over the specified frequency range. The AS-2815/SSR-1 is designed with a minimum bandwidth of 4 MHz measured at the 1 dB points at the preamplifier.

3.5 ANTENNA POLARIZATION

Signals from surface, sky, line-of-sight and satellite modes of electromagnetic wave propagation received and transmitted from shipboard communication installations are more efficiently processed with polarized antennas.

3.5.1 TYPES OF ANTENNA POLARIZATION

The majority of shipboard communication antennas are vertically polarized. This type of polarization allows the antenna configuration to be more easily accomodated in the limited space allocated to shipboard communication installations. Vertical antenna installations often make use of the ship top side structure to support the antenna elements and in some cases act as part of the antenna to obtain the required impedance match between antenna base terminal and transmission line.

VHF/UHF antennas used for ship to aircraft communications employ both vertical and circular polarization. Installation required for either type is small. Circularly polarized shipboard antennas frequently offer considerable signal improvement over vertically polarized antennas during aircraft maneuvers causing cross polarization effects.

Circular-polarized antennas are also used for ship to satellite communication operations, offering the same improvement as given for the VHF/UHF ship to aircraft communications operations. Except for higher altitudes, satellite antenna problems are similar to those experienced with aircraft antenna operations.

3.6 INPUT POWER

Surface, sky, line-of-sight and satellite modes of electromagnetic wave attenuation differ in level for each mode. As a tradeoff, and sometimes as a necessity, an increase in input power to the antenna assists in improving the signal-to-noise ratio for radio communications. However the power increase may have an affect on the operations of other ship subsystems by increasing electromagnetic interference thus limiting their capabilities. Moreover, the power increase may in some instances induce potentials on shipboard metal structure that prove hazardous to shipboard personnel.

3.6.1 INCREASED POWER EFFECT

High frequency band operations, because of their use for long distance communications, at times require an improvement in signal-to-noise ratio to override the signal attenuation effect. This is normally accomplished by increasing the transmitter power applied to the antennas. If the power increase causes local interference with the receiving antenna system the interference may be reduced by physical separation of the receive and transmit antennas or by increasing the frequency separation between the receive and transmit frequencies. It is difficult to isolate the ship metal structure from induced fields of high power antennas; in fact there are many cases where ship structure is also made part of the antenna. Induction field voltages are greater and more effective in the 2 to 12 MHz band. (Refer to chapter 1 for discussion of effects of mutual coupling.)

VHF/UHF ship to aircraft communications and ship to satellite communications use approximately the same band (225-400). The transmitter power level used by two modes for signal propagation will not interfere when ample frequency separation is used between adjacent channel operation (normally 5 percent).

ANTENNA CHARACTERISTICS

An increase of transmitter output power may create signal levels at the ship's receiver input terminals of sufficient magnitude to cause receiver desensitization and possible front end burnout. The susceptibility of receivers to intermodulation and crossmodulation products is increased with an increase in transmitter output power. In a shipboard environment where EMI and EMC problems are of major concern due to the lack of area for transmitting and receiving antenna separation any increase in transmitter power output can only result in some degree of degradation in the receiving system.

SECTION 4

ANTENNA ENVIRONS AND PROPAGATION

4.1 GENERAL

Radio wave propagation refers to the radiated energy from a transmitting antenna during transmission through the radio path to the received energy at the receiving antenna. This includes the properties of both antennas, such as pattern, gain, directivity, and polarization, the free path attenuation of the wave and such factors as refraction, reflection, interference, and scattering effects. Propagation is also dependent on frequency and is subject to variation from diurnal, seasonal, geographical and solar cycle effects. These effects have great influence on the quality of signals required for reliable communications. The increased use of digital type signals has placed additional requirements on the grade of service available from the antenna system. The effects of the shipboard antenna environment and the influence of the transmission path characteristics on radio wave propagation are discussed in the following paragraphs.

4.2 RADIATION PATTERNS

The radiation pattern of an individual shipboard antenna is dependent primarily on its environment. The influence of the ship's structure and other interferences in close proximity to the antenna produce pattern distortion resulting in nulls. The location and depth of the nulls in a particular pattern is determined by the carrier frequency in use and the distance between the antenna and obstructions in relation to the wavelength. Pattern distortion may vary in either or both horizontal and vertical planes. Distortion in the horizontal plane has most affect on surface mode operation with decreased azimuthal coverage. Antenna pattern distortion for a 35 foot whip antenna at selected frequencies in a scale model shipboard environment is shown in Figure 2-13. Inspection of the figure will reveal that the antenna will not provide reliable omnidirectional coverage over a path requiring a vertical take off angle of 15° above the horizontal. It will be noted that adequate coverage may be expected at 0° and 23° above the horizontal.

Pattern distortion in the line of sight mode is the result of masking from structures and obstructions in the antenna near field. To reduce the possibility of path distortion and reduced coverage, line of sight antennas should be located in areas as clear as possible of any obstructions that might affect the pattern.

Satellite antennas are steerable types and as such may be directed from possible sources of pattern distortion. However, care must be exercised in their installation to avoid locations that will cause masking.

Antenna patterns are derived from scaled model studies and radio range patterns. A knowledge of the antenna patterns and their deficiencies is valuable to the ship's communications system operating personnel for selecting the best antenna for the frequency and mode required to provide reliable communications.

4.3 PROPAGATION PATH ATTENUATION

For LF/MF mode of operation the reflective wave is attenuated to a greater degree than the ground wave. This is expecially true on frequencies below 2 MHz. However, when the strength of the reflected wave is sufficiently strong and arrives at the receiver out of phase with the ground wave, fading or complete signal loss may be experienced. This situation may be rectified by space diversity reception; however, the lack of available space for the separation of antennas required onboard ship does not make this type of diversity feasible. Propagation losses using the sky wave mode in the 3 to 30 MHz band result from diurnal, seasonal, geographical, solar cycle, ionospheric distortion, and multipath effects. Of all the effects only multipath can be reduced sucessfully with an antenna designed to provide a pattern 5 to 30 degrees from the horizontal plane. (Figure 2-3 shows that the most useful angles of arrival and departure for sky wave propagation of great circle radio paths ranging from 175 to 1750 nautical miles span an elevation sector from 5° to 30°.)

There is no appreciable absorption due to the presence of moisture in the atmosphere for signal transmission using frequencies below UHF (225 to 1100 MHz). A full treatment of path loss due to atmpsphere absorption is beyond the scope of this manual. The reader is referred to references 4 and 7 in the Bibilography for a detailed discussion.

SECTION 5

ANTENNA TRANSMISSION LINES

5.1 GENERAL.

Transmission lines are used to electrically connect the antenna to its terminal equipment.

There are many types of transmission lines; however, the peculiar requirements for shipboard installations generally dictate the use of coaxial types for communications systems. Certain specific installations such as SATCOM systems may require the use of waveguides due to the frequencies and signal levels involved.

The selection of the proper type of cable to satisfy the system operating parameters is dependent on the attenuation, impedance and power handling capabilities of the individual cable. The physical construction of the cable is important to insure that it is compatible with the ship's environment. A list of preferred transmission lines by impedance and physical properties is contained in Appendix A to NAVSHIPS 0967-177-3020 SHIPBOARD ANTENNA SYSTEMS, ANTENNA INSTALLATION DETAILS.

5.2 COAXIAL CABLES.

5.2.1 FLEXIBLE CABLES.

Flexible coaxial line using a solid or stranded inner conductor, a solid plastic dielectric support and a braided outer shield or conductor with a plastic outer jacket is the most commonly used type for shipboard installations. Flexibility is required because of the routing of the cable through ship compartments and the inherent vibration of the ship. The transmission loss in this type cable is relatively high as compared to air dielectric because of dielectric loss. However, the requirements for flexibility outweigh this factor in applications where some loss is tolerable.

5.2.2 SEMIFLEXIBLE CABLES.

Semiflexible coaxial cables are characterized by a helical or foamed dielectric support for a copper center conductor. The outer conductor may be an aluminum or corrugated copper tube. This type of cable has a limited bending radius and exhibits transmission losses only slightly greater than air dielectric lines. Exterior types are covered with a plastic jacket for weather protection.

Semiflexible coaxial types are used for relatively straight runs such as on masts and other exterior portions of the ships structure.

5.2.3 RIGID LINES.

This type of coaxial line consists of a rigid pipe-like outer conductor with insulating spacers at intervals to support the solid or tubular inner conductor. Rigid lines provide the lowest transmission losses and highest power ratings for a given diameter coaxial cable. Rigid lines are used in communications systems where high RF power handling capabilities and low attenuation are required; however, this type is not ordinarily used on shipboard.

5.3 LINE ATTENUATION.

5.3.1 SOURCES OF ATTENUATION

The ideal transmission line has no losses. It transfers all the energy available at the transmitter to the antenna. Actual transmission lines, however, dissipate power in three ways.

(1) RADIATION - The transmission line tends to act like an antenna. This condition is more prevalent in open wire lines than in coaxial types and is not generally a factor in shipboard systems.

(2) HEATING - The resistance of the conductors dissipates a certain amount of power in the form of heat (I^2R loss). At the higher frequencies, an appreciable amount of heat loss can result from skin effect. Dielectric loss or leakage between the conductors also creates I^2R losses. Heat loss increases with lines having a lower characteristic impedance because of the higher currents permitted to flow.

The length of the cable between the energy source and the load will determine the amount of I^2R loss that will be introduced between the two points. Attenuation at the VHF/UHF frequencies increases critically with length and frequency. It also depends on the physical configuration of the individual cable. For long runs it may be necessary to use a larger size cable to reduce attenuation.

(3) REFLECTIONS - If a transmission line is not properly terminated, that is, if terminated in any load other than the characteristic impedance, energy will be reflected back along the line. This will result in standing waves and a power loss. In practice, these reflections are measured by a voltage standing wave ratio (VSWR) meter. The magnitude of this loss will depend on the degree of mismatch. Therefore, the VSWR is a measure of the efficiency of the line and load as a system.

Reflections may also be the result of discontinuities in the dielectric such as fluctuations in diameter, ellipticity of the core, or centering of the inner conductor and connectors along the line. In critical installations it may be necessary to have individual cables measured by frequency scanning techniques over the specified operating band.

5.3.2 COAXIAL CABLES - FLEXIBLE AND SEMIFLEXIBLE TYPES.

The amount of attenuation presented by a specific type of line at a specific frequency is dependent on the physical properties and electrical characteristics of the cable. Attenuation in this sense is not referenced to power handling capabilities.

The construction of coaxial cables determines the nominal impedance and capacitance of the cable. The composition determines the value of dielectric loss that may be expected under given operating conditions.

At frequencies in the VLF and HF ranges the flexible and semiflexible cable appearing on list of Navy approved types do not present attenuation problems. However, at frequencies in the VHF and UHF portions of the spectrum severe attenuation is experienced due to the shunting effects between the inner and outer conductors of the cable. Additionally, the rf at these frequencies tends to follow the skin of the conductor. Stranded or solid conductors tend to limit the surface area. The solid dielectric types are most susceptible to attenuation due to losses in the dielectric material. The larger types of solid dielectric cables manufactured for high power usage have lower losses due to the size and composition of the dielectric material and the size of the inner conductor. The semiflexible types are manufactured with cellular or helix dielectrics with very low loss characteristics. This type is superior to the solid types for use on the VHF/UHF frequencies.

5.3.3 RIGID LINES.

Rigid lines are constructed with the inner conductor supported by ceramic or plastic spacers. The major dielectric is air. The greatest source of dielectric leakage is, therefore, across the spacers. The materials selected for these spacers usually exhibit extremely low loss in order to keep the overall loss as close as possible to air. The inner conductor is generally tubing which increases the surface area available as compared to a solid conductor of the same diameter. Rigid lines may be pressurized with dry air or nitrogen to further stabilize dielectric leakage. Rigid lines have the lowest attenuation characteristics of all coaxial lines and are used in VHF/UHF systems to reduce attenuation and on lower frequencies for high power.

5.4 LINE CAPACITANCE.

5.4.1 DETERMINATION OF LINE CAPACITANCE.

The capacitance of coaxial cable is determined by the ratio of the diameter of the inner surface of the outer conductor to the diameter of the outer surface of the inner conductor. The electrical characteristic (dielectric constant) of the material chosen as the dielectric determines the amount of leakage in this capacitor under signal conditions. Coaxial cables are manufactured to established values of impedance in the interest of standardization and simplicity. The majority of the coaxial cables used in shipboard communication systems have a nominal impedance of 50 ohms and a nominal capacitance of 29.5 picofarads per foot.

5.4.2 COAXIAL CABLES - FLEXIBLE AND SEMIFLEXIBLE TYPES.

All coaxial cables present a shunt capacitance to the signal source. The value of this capacitance is determined by the product of the nominal capacitance value of the cable and the length of the cable. For example a 50 ohm cable with a nominal capacitance of 29.5 picofarads per foot, 100 feet long will have a capacitance of 2950 picofarads. In an ideal system in which the output impedance of the generator is equal to the impedance of the load and the transmission line, i.e. perfectly matched, (VSWR 1:1) there will be no power losses. To accomplish this, the tuning elements of the system, either transmitting or receiving, must be able to compensate for the capacitance in the line as well as matching the input and load impedance. As the frequency in use increases, the capacitance becomes a significant factor in contributing to overall system loss. In addition to the nominal capacitance of the cable, irregularities due to manufacturing or installation procedures produce varying amounts of capacitance of this line. Although the value of these capacitances is relatively small, possibly a few tenths of a picofarad, the combined reactances become low enough to affect the operation of the line at VHF/UHF frequencies.

5.4.3 RIGID LINES.

The operating characteristics of rigid type lines are dependent on the same constants as the flexible types. The air dielectric, coupled with low loss spacers, extends the upper frequency operating range compared to an equivalent solid dielectric type. The material and the design of the inner conductor supporting spacers has a definite affect on the capacitance as the frequency varies. At the higher frequencies where the spacer dimensions approach a wavelength, the distance between the inner and outer conductors must be changed in order that the nominal capacitance remain constant. This is accomplished by cutting a slot in the inner surface of the outer conductor or the outer surface of the inner conductor at the location of the spacers. Rigid lines are also susceptible to capacitance changes due to discontinuities caused by dents and other deformities of the outer conductor.

5.5 LINE MAXIMUM POWER CAPABILITY.

5.5.1 DETERMINATION OF LINE POWER CAPABILITY.

Coaxial cable, as does any other electrical conductor, resists the flow of electrical energy. Some of the impressed energy is therefore expended in the form of heat in overcoming the cable's resistance. In a coaxial cable most energy losses occur in the conductors and the dielectric between the conductors. The majority of the losses occur along the surface of the inner conductor which becomes the warmest part of the cable. Since this is a difficult place from which to remove heat, the inner conductor temperature becomes a limiting factor in establishing the power handling capabilities of a coaxial cable. The maximum voltage that should be applied to a coaxial transmission is a voltage some value less than that causes corona. If the voltage reaches a sufficient peak it will cause ionization of the dielectric resulting first in corona and, finally, an arc between the two conductors. The voltage at which corona occurs in an air dielectric is determined by local stress concentration such as those caused by metallic burrs on the conductor, a sharp corner at a connection, or surface irregularity on a bead or spacer. In solid dielectric cables, small air voids exist within the dielectric and around the conductors. Electrical discharges occur within the gaseous voids when the peak voltage reaches a critical value. The critical value, or corona level, does not vary substantially in a gas from very low frequencies to several hundred megahertz. The maximum radio frequency power that may be safely transmitted on a coaxial line is limited either by the voltage introduced due to peak power or the thermal heating due to the average power.

5.5.2 COAXIAL CABLES - FLEXIBLE AND SEMIFLEXIBLE TYPES.

Solid dielectric materials used in flexible type coaxial cable will withstand higher voltages than air dielectric types before corona occurs. The maximum peak voltage at any point on the line will generally differ from the input voltage when the line is not properly terminated. The value of this voltage will depend on the degree of mismatch, the electrical length, and the attenuation of the line.

The attenuation on the line will also determine the amount of heat that will be generated internally at the inner conductor, within the dielectric, and at the outer conductor in direct proportion to their individual attenuation. The limiting factor in power handling capability of a solid dielectric coaxial cable is usually controlled by the melting point of the dielectric. The rate of heat dissipation from the line is dependent on the diameter, dielectric material and the ambient temperature. Excessive temperatures can result in conductor shifting due to the softening of dielectric, mechanical damage due to different rates of expansion, and chemical deterioration. A mismatched load will also cause heating.

ANTENNA TRANSMISSION LINES

Some semi-rigid coaxial cables using polyethelene tubes or polystyrene tape dielectrics have a lower maximum operating voltage then equivalent solid dielectric types. Since the inner conductor of these cables is not entirely within the dielectric they are less susceptible to heating.

5.5.3 RIGID LINES.

Since the major dielectric in rigid coaxial lines is air, the power limiting factor is the voltage necessary to break-down air, causing corona and eventual arcing within the cable. Again this value is less than an equivalent solid dielectric type. Also, heating of the inner conductor is not as great a limiting factor since the inner conductor is suspended in air with a large surface area. Increased power rating can be obtained by pressurizing the cable and by the use of gases having a dielectric strength greater than air.

SECTION 6

ANTENNA SYSTEM MAINTENANCE

6.1 GENERAL.

The best receiver or transmitter cannot give optimum performance if its associated antenna is not physically and electrically in good operating condition. These conditions are interdependent and physical damage generally results in changes in electrical characteristics.

The antenna for an individual system consists of all items from the outboard antenna, be it a whip, cage, or wire, insulators, coaxial cables, antenna patching systems, multicouplers and tuning units. In general the information in this section will be limited to the antenna and its associated coaxial feed lines. Maintenance and testing requirements of multicoupler, tuning units, transmitters, and receivers, are covered in their respective technical manuals.

All antenna systems have a set of standard operating conditions. This data is developed from information accumulated during initial system tune-up and from actual system operations. These conditions form a basis against which to evaluate system performance and any variations from these values can be expected to degrade the system's operational capabilities. The individual conditions most important in determining system operating performance are VSWR and power output levels.

The testing required for preventative and corrective maintenance will involve physical inspection and the use of instrumentation to ensure that the standards are maintained at operational level.

The instrumentation required to perform electrical testing is, in part, available from built-in equipment in the transmitter, multicouplers, and tuners. This instrumentation consists of VSWR indicators and power output meters. The majority of transmitters and antenna coupling devices installed on board ship are equipped with these instruments for adjustment and monitoring purposes. Additional test equipment is required to perform electrical resistance and impedance measurements. Complete procedures for testing antenna systems is available in NAVSHIPS 0967-177-3040 SHIPBOARD ANTENNA SYSTEMS, VOLUME 4, TESTING ANTENNA SYSTEMS.

The test equipment configuration required will depend on the type of test required and may involve VSWR, impedance, and DC resistance (continuity) measurements.

The frequency of the routine testing to maintain maximum operational capability should be established based on the ship's mission, amount of time at sea, and area of operation. Tests should be performed immediately when any degradation of service occurs. This is extremely important in high power transmitting systems to prevent damage to the antenna systems and the associated equipment. Improperly operating and defective antennas systems are possible sources of EMI due to arcing, excessive harmonic radiation and out of band operation.

6.2 ELECTRICAL TEST MEASUREMENTS

6.2.1 TEST TYPES AND METHODS

Electrical test measurements are divided into two categories: First, tests that may be performed with instrumentation available in the transmitting or receiving system, and, secondly, tests requiring outboard or separate instrumentation.

Built-in testing in transmitting systems is limited to determining VSWR and power levels. VSWR readings are the most readily available source of performance levels since VSWR measurements are made during each frequency change or tune-up.

Certain transmitting equipments automatically measure VSWR and continuously adjust loading and transmitter tuning to maintain the VSWR within prescribed limits. The system is automatically shutdown if the VSWR exceeds a specified level. During the initial adjustment of the system a chart of VSWR and power levels versus operating frequencies should be prepared as a standard. Power levels are especially important in low power and VHF/UHF systems, since these systems must be operating at peak efficiency to provide maximum coverage.

Receiving systems, with the exception of the AN/SRA-17 Antenna Group, are not equipped with built-in test equipment. Receivers equipped with a carrier meter or input level meter furnish an indication of relative operating efficiency level of the receiving system. However, unless these values have been averaged over a period of time on specific signals the readings are subject to variables such as fading. As such these levels are not determinate standard values. Dependence is placed on operator evaluation of signal levels to assess the condition of the antenna system. The AN/SRA-17 is equipped with a diode noise generator for system adjustment. This generator checks only the tuner and the coaxial cable between the tuner and associated receiver.

The condition of transmitting and receiving antennas are checked electrically by use of an ohmmeter and a megger. The ohmmeter is used to check the continuity of the coaxial cable, and the megger to determine the leakage in the dielectric of the cable and the insulation values of the antenna insulators. To perform conductivity checks it is necessary to disconnect the various elements of the system and check for continuity by shorting the inner and outer conductors of the transmission line. Ideally this resistance should be less than one ohm depending on the cross section of the inner conductor and cable length. To test for transmission line leakage connect the megger across the center and outer conductor. The readings should be a minimum of 40 megohms. If values are not within these limits, the cable connectors should be inspected as possible sources of trouble.

Many shipboard antennas are designed to operate at DC ground potential. In this case, resistance and megger readings are not valid tests for the overall condition of the antenna. The insulating spreaders, standoffs, and separators, used in these antennas should be inspected individually if their insulation qualities are suspect.

Whip and wire antennas insulated from ground are tested by connecting a megger across the input terminal and ground. This test establishes the leakage value across the insulators. A resistance above 100 megohms to ground indicates that the antenna is in good condition as far as insulator leakage is concerned. A resistance of 35 to 100 megohms to ground indicates that the insulators need cleaning, and a resistance below 35 megohms indicates a defective insulator.

Impedance measurements are conducted on shipboard antennas to determine frequency bandwidth versus VSWR. These measurements are used to establish the bandwidth of the antenna within the 3.1 VSWR points. This value is required to ensure that the transmitter is operating in the linear portion of its output circuit. Operation outside the linear portion tends to generate spurious emissions with possible RFI to other systems. If major structural changes are made to the areas in the vicinity of the antennas, impedance measurements should be made to determine any variations in bandwidth due to mutual coupling between the antennas and surrounding structures. Instrumentation to perform impedance measurements requires the use of an rf bridge, rf signal generator, and a communications receiver. RF bridges are not normally carried on the shipboard test equipment allowance list so impedance measurements are usually accomplished by shore establishment personnel. Results are supplied in tabulated form and curves drawn on a Smith Chart. This information is furnished to the ship and should be made available to operating personnel as an aid in determining the limitations in bandwidth of the antenna. It also establishes a performance level for VSWR versus frequency that can be used to monitor the condition of the antenna.

6.2.2 FREQUENCY OF TESTS

Electrical tests should be scheduled on a regular basis. The period between tests should be based on the mission of the ship, operating periods, and the climatic condition in which the ship operates. The mission of the ship establishes the degree of readiness, the operating period indicates the use factor, and climatic conditions determine the possibility of failure due to moisture. Electrical tests should be conducted at least quarterly. If the ship is scheduled for long term deployment, tests should be made prior to departure to insure maximum operational readiness.

6.2.3 TIME DOMAIN REFLECTOMETER TESTING

The time domain reflectometer is used to locate coaxial cable faults such as shorts, opens, defective connectors, mismatched terminations and physical damage. The TDR employs a type of closed loop radar system in which the transmitted signal is a very rapid step voltage and the reflected signal is measured with a high speed sampling oscilloscope. A time profile is obtained revealing the characteristics of each point along the cable. The information presented on the oscilloscope discloses both the location and the nature of each discontinuity. Each type of discontinuity presents a specific characteristic pattern on the CRT. The CRT is calibrated directly in distance for air and solid dielectric cables. The instrument can test polyethelene cables up to 600 feet in length.

This equipment is used by Naval Shipyards during check out of antenna systems.

6.3 PHYSICAL TESTING

6.3.1 INSPECTION OF TRANSMISSION LINES

Ship's engineering personnel maintain a record of the routing of all types of piping throughout the ship. This information is used for maintenance and damage control. Shipboard piping is marked and identified as to the type of liquid or air in the pipe. Identification is in accordance with standard markings and at specified intervals. Coaxial transmission lines may be considered as a piping system for rf from the antenna to the transmitting or receiving systems. Transmission lines are also marked with standard identification as to type and system. Communications personnel should be familiar with the routing of all coaxial transmission lines in the ship's communications antenna system. Familiarity with transmission line routing will assist in performing routine and emergency physical inspection. Physical inspection requires viewing the cable over its entire length including connectors and terminations. Common sources of difficulties include damage from physical abrasions and cuts, excessive pressure at watertight fittings, cable sag caused by hanging objects on the cable, excessive heat in the vicinity of the cable and loose connectors and end seals. Close inspection should be made of all connectors for indications of moisture, corrosion and proper connection of the inner and outer conductors.

6.3.2 INSPECTION OF INSULATORS.

Insulators should be inspected for cleanliness, surface damage or cracks in the porcelain, and bonding across mechanical joints. If the insulators are dirty with encrustations of soot or salt crystals they should be washed with a dishwashing compounding in a solution of hot fresh water until all surface dirt has been removed. A thin coat of Dow-Corning Compound No. 4 should be applied to the surface of the insulator. This compound forms a film which sheds water and reduces the formation of salt water deposits and the accumulation of dirt. Cracks and chips in the porcelain indicate possible failure and are depositories for dirt. The bonding across metallic antenna fittings is especially important since they are a source of wideband noise generated by arcing in a high energy electromagnetic field. Whip antenna base insulators should be inspected for cleanliness and treated in the same manner as strain insulators.

6.3.3 INSPECTION OF ANTENNAS.

Wire rope antennas should be inspected for indications of fraying, corrosion, and loose connections. Frayed wire with broken strands should be replaced because of reduction in the overall tensile strength and tendency to cause RFI problems due to arcing and corona discharge; wire antennas are constructed with patented terminating devices that depend on mechanical compression for strength. Each such fitting should be inspected for tightness and worn pins.

Particular attention should be given to the dress of wire antennas. An antenna that is stressed too tightly is subject to damage from ship movement. Excessive slack can introduce sufficient variations in the capacitance of the antenna to detune the system. This condition is especially undesireable during ships motion in a seaway.

VHF and UHF antennas require cleaning of their insulating surfaces. These antennas are very susceptible to water leakage and moisture entrapment. If moisture has been detected within the antenna, dismantling is required. The antenna must be thoroughly cleaned and any corrosion removed. After cleaning, the antenna is reassembled with proper gasketing to prevent future leakage.

Discone and discage antennas should be inspected for corrosion, clean insulators, and tight joints.

6.3.4 FREQUENCY OF INSPECTION.

Physical inspections of antenna transmission lines, insulators and antennas should be scheduled on a quarterly basis. Physical inspections should coincide with the electrical tests except for inspection for dirty insulators and antenna dress. Wire antenna dress observation is important if the ship has experienced periods of heavy weather. A careful physical inspection should be made and any discrepancies corrected prior to deployment.

APPENDIX A

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APPENDIX B

GLOSSARY OF TERMS

-A-

AMPLIFICATION - A general term used to denote an increase of magnitude in transmission from one point to another. It may be expressed as a ratio or by extension of the term in decibels.

ANGLE OF DEPARTURE - The angle made between the surface of the earth and the line of propagation of a radio wave from a transmitting antenna.

ANGLE OF INCIDENCE - The angle between the perpendicular to a reflecting surface at a point at which an electromagnetic wave strikes a surface and the direction from which the wave approaches the surface.

ANGLE OF RADIATION - The angle between the surface of the earth and the center of the beam of energy radiated upward into the sky from a transmitting antenna.

ANTENNA - A device for radiating electromagnetic waves into space, or for receiving these waves.

ANTENNA, BASELOADED - A vertical antenna, having an impedance in series at the base, for loading the antenna to secure a desired electrical length.

ANTENNA, DIPOLE - An antenna comprising a straight conductor, having an overall length of one-half wavelength or less, connections to which are made at the center.

ANTENNA, GROUND PLANE - A vertical antenna combined with a turnstile element to lower the angle of radiation, and having a concentric base support and center conductor that together serve to place the antenna at ground potential even though it may be located several wavelengths above ground.

ANTENNA HALF-WAVE - An antenna whose electrical length is approximately equal to one-half the wavelength being transmitted or received.

ANTENNA HEIGHT, EFFECTIVE - The effective height of an antenna is the height of its center of radiation above the effective ground level.

ANTENNA LENGTH, EFFECTIVE - The length which, when multiplied by the current at the point of maximum current, will give the same product as the length and uniform current of an elementary electric dipole at the same location, giving the same radio field intensity in the direction of maximum radiation.

ANTENNA, LOADED - An antenna provided with additional inductance or capacitance in order to change its electrical length.

ANTENNA, LOG PERIODIC - A broadband multielement antenna whose frequency response characteristics are repeated at frequencies equally spaced with a period equal to the logarithm of the ratio which determines length and spacing of the antenna elements.

ANTENNA, OMNIDIRECTIONAL - An antenna having an essentially nondirectional pattern in azimuth and a directional pattern in elevation.

ANTENNA, QUARTER-WAVE - An antenna which has an electrical length equal to one-fourth the wavelength of the signal to be transmitted or received.

ANTENNA, TUNED - An antenna designed to provide resonsance at the desired operating frequency by means of its own inductance and capacitance.

ATMOSPHERIC DUCT - An almost horizontal layer in the troposphere in which the downward curvature of a radio ray exceeds the curvature of the earth.

ATTENUATION - A general term used to denote a decrease in magnitude of current, voltage, or power of a signal in transmission from one point to another.

ATTENUATION, PRECIPITATION - The loss of radio energy due to the passage through a volume of the atmosphere containing precipitation.

ATTENUATION, RADIO - For one-way propagation, it is the ratio of the power delivered by the transmitter to the transmission line connecting it with the transmitting antenna to the power delivered to the receiver by the transmission line connecting it with the receiving antenna.

ATTENUATION, SPACE - The loss of energy, expressed in decibels, of a signal in free air, caused by such factors as absorption, reflection, scattering, and dispersion.

-B-

BALANCED - Electrically symmetrical with respect to ground.

BANDWIDTH, RADIO FREQUENCY - The difference between the highest and the lowest emission frequencies of a transmitter, in the region of the carrier or principal carrier frequency.

BEAMWIDTH - The angle between the directions, on either side of the axis, at which the intensity of the radio frequency field drops to one-half the value it has on the axis.

-C-

CABLE - An assembly of one or more conductors, usually within an enveloping protective sheath. The structural arrangement of the individual conductors permits their use separately or in groups.

CIRCUIT - An electronic path between two or more points capable of providing a route for a number of channels of communication.

COMMUNICATIONS SYSTEM - A collection of individual communications networks, transmission systems, relay stations, and tributary stations capable of interconnections and interoperations designed to form an integral whole. To form a system, these individual components must serve a common purpose, be technically compatible, employ common procedures, respond to some form of control, and in general, operate in unison.

COUNTERPOISE - A system of wires or other conductors, elevated above and insulated from the ground, forming the lower system of conductors of an antenna.

COUPLER, DIRECTIONAL - A transmission coupling device for separately sampling (through a known coupling loss for measuring purposes) either the forward (incident) or the backward (reflected) wave in a transmission line.

COUPLING, DIRECT - The association of two or more circuits by means of a self-inductance, capacitance, resistance, or a combination of these which is common to the circuits.

COUPLING, INDUCTIVE - The magnetic coupling between two circuits due to flux linkage, resulting in mutual inductance.

-D-

DECIBEL (dB) - The decibel, commonly used for expressing transmission gains, losses, levels, and similar quantities, is a division of the logarithmic scale such that the number of decibels is equal to 10 times the logarithm to the base 10 of the power ratio. $dB = 10 \log_{10} P1/P2$.

DIRECTIVITY - That characteristic of an antenna which enables it to radiate or receive more energy in some directions than in others.

DISTORTION - Distortion is an undesired change in wave form. The principal sources of distortion are: a nonlinear relation between input and output at a given frequency; nonuniform transmission at different frequencies; and phase shift not proportional to frequency.

DISTRUBANCE, IONOSPHERIC - A variation in the state of ionization of the ionosphere beyond the normally observed random day-to-day variation from average values for the location, date, and time of day under consideration.

-E-

EFFICIENCY - The ratio of the useful output to the input (energy, power, quantity of electricity, etc.). Unless specifically stated otherwise, the term "efficiency" means effectiveness with respect to power.

EFFICIENCY, RADIATION - The ratio of the power radiated by an antenna to the total power supplied to the antenna at a given frequency.

ELECTROMAGNETIC COMPATIBILITY (EMC) - The ability of communications-electronics (C-E) equipment, subsystems, and systems to operate in their intended operational environments without suffering or causing unacceptable degradation because of unintentional electromagnetic radiation or response.

ELEMENT, RADIATING - In antenna practice, it is a basic subdivision of an antenna which itself is capable of radiating or receiving radio frequency energy.

EMC - See ELECTROMAGNETIC COMPATIBILITY.

EMI - See INTERFERENCE, ELECTROMAGNETIC.

-F-

FADING - The fluctuation in intensity and relative phase of any or all frequency components of a received radio signal due to changes in the characteristics of the propagation path.

FIELD INTENSITY, RADIO - The electric or magnetic field intensity at a given location associated with the passage of radio waves.

FIELD STRENGTH - Radio field strength refers to the magnitude of the electric or magnetic field vector (E or H) at a given location resulting from the passage of radio waves.

FILTER - A combination of resistances, inductances, and capacitances, or any one or two of these, which permits the comparatively free flow of certain frequencies or of direct current, while blocking the passage of other frequencies.

FREE SPACE - The empty space with no free electrons or ions present. It has approximately the electrical constants of air. It usually refers to a condition where the radiation pattern of an antenna is not affected by surrounding objects such as earth, buildings, trees, etc.

FREQUENCY - The number of complete cycles per unit of time. When the unit of time is one second, the measurement unit is given in hertz (cycles per second).

FREQUENCY, LOWEST USABLE (LUF) - The lower limit of the frequencies that can be used at a specified time for radio transmissions between two points and involving propagation by reflection from the regular ionized layers of the ionosphere.

FREQUENCY, MAXIMUM USABLE (MUF) - The upper limit of the frequencies that can be used at a specified time for radio transmission between two points and involving propagation by reflection from the regular ionized layers of the ionosphere.

FREQUENCY SPECTRUM DESIGNATION -

	KHz	MHz	GHz
VLF (very low frequency)	3-30		
LF (low frequency)	30-300	.03-0.3	
MF (medium frequency)	300-3,000	0.3-3	
HF (high frequency)	3,000-30,000	3-30	
VHF (very high frequency)		30-300	.03-0.3
UHF (ultra high frequency)		300-3,000	0.3-3

-G-

GAIN ANTENNA - Antenna gain is commonly defined as the ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction from a reference antenna with the same power input.

GROUND - A ground is a conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent, which serves in place of the earth.

-H-

HARMONIC - A sinusoidal quantity having a frequency which is an integral multiple of the fundamental frequency of a periodic quantity to which it is related. For example, a wave the frequency of which is twice the fundamental frequency is called a second harmonic.

HERO - An acronym meaning Hazards of Electromagnetic Radiation to Ordnance.

HERTZ (Hz) - A measure of frequency in units of cycles per second.

HOP - An excursion of a radio wave from the earth to the ionosphere and back to earth, in traveling from one point to another. It is usually used in expressions such as single-hop, double-hop, and multi-hop. The number of hops is called the order of reflection.

HORIZON, RADIO - The line at which direct rays from a transmitting antenna become tangent to the earth's surface. Its distance from the transmitting antenna is greater than that frequency.

HORIZONTAL ANGLE OF DEVIATION - In the propagation of radio waves from transmitter to receiver, it is the horizontal angle between the great-circle path and the direction of departure or arrival along the line of propagation.

-I-

IMAGE EFFECT - The effect produced on the field of an antenna due to the presence of the earth. Electromagnetic waves are reflected from the earth's surface and these reflections often are accounted for by an image antenna at an equal distance below the earth's surface.

IMPEDANCE - The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

INTERFACE - A concept involving the specification of the interconnection between two equipments or systems. The specification includes the type, quantity, and function of the interconnection circuits and the type and form of signals to be interchanged via those circuits.

INTERFERENCE - Interference in a signal transmission path is either extraneous power which tends to interfere with the reception of the desired signals or the distrubance of signals which result.

INTERFERENCE, ELECTROMAGNETIC (EMI) - An electromagnetic phenomena which, directly or indirectly, can contribute to a degradation in performance of an electronic receiver or system.

INTERFERENCE, MUTUAL - The manmade interference from two or more electrical or electronic systems which affect these systems on a reciprocal basis.

IONOSPHERE - That part of the earth's outer atmosphere where ions and free electrons are normally present in quantities sufficient to affect the propagation of radio waves. It is divided into several regions or layers which can absorb or reflect electromagnetic radiation.

-L-

LAYER, E - One of the regular ionospheric layers with an average height of about 100 kilometers. This layer occurs during daylight hours and its ionization is dependent on the sun's angle. The principal layer corresponds roughly to what was formerly called the Kennelly-Heaviside layer. In addition, areas of abnormal intense ionization occur which are called sporadic E.

LAYER F - A layer in the F region of the ionosphere existing in the night hemisphere and in the weakly-illuminated portion of the day hemisphere.

LAYER, F1 - The lower of the two ionized layers normally existing in the F region in the day hemisphere.

LAYER, F2 - The highest of the two layers normally existing in the F region in the day hemisphere, and the continuation of that layer in the night hemisphere. Most useful of the ionospheric layers for radio propagation.

LEAKAGE - The electrical loss resulting from poor insulation.

LEVEL, POWER - The power level at any point in a transmission system is the ratio of the power at that point to some arbitrary amount of power chosen as a reference. This ratio is usually expressed, either in decibels referred to one milliwatt, abbreviated dBm, or in decibels referred to one watt, abbreviated dBw.

LINEAR - The relationship of two related quantities such that a change in one will result in the exact proportional change in the other. A system in which the output varies in direct proportion to the input.

LINE-OF-SIGHT (LOS) - The straight line distance from transmitter to the horizon. Represents the radio and radar VHF and UHF transmission range limits under normal operating conditions.

LINE, TRANSMISSION, BALANCED - A transmission line utilizing two identical conductors having equal conductor resistances per unit length and equal impedances from each conductor to earth and to other electrical circuits.

LINE, TRANSMISSION, MATCHED - A transmission line terminated with a load equivalent to its characteristic impedance. A transmission line is said to be matched at any transverse section if there is no wave reflection at that section.

LINK, SATELLITE - A communications path formed between two ground stations transmitting and receiving radio communications traffic via a satellite.

LOBE - One of the three-dimensional sections of the radiation pattern of a directional antenna bounded by one or two cones of nulls.

LOBE, MAJOR - The antenna lobe containing the direction of maximum radiation or reception.

LOBE, MINOR - Any lobe of an antenna radiation pattern except the major lobe.

LOSS - A general term used to denote a decrease in signal power in transmission from one point to another. Loss is usually expressed in decibels.

LUF - See FREQUENCY, LOWEST USABLE

-M-

MATCHING - The connecting of two circuits or parts together with a coupling device in such a way that the impedance of either circuit will be equal to the impedance existing between the coupling terminals to which that circuit is connected.

MATCHING, IMPEDANCE - A method of minimizing the adverse effects of junctions between dissimilar transmission lines or connections between equipment with different impedances so that there is the maximum transfer of power and the minimum of reflective power.

MISMATCH - A condition in which the impedance of a load does not match the impedance of the source to which it is connected.

MUF - See FREQUENCY, MAXIMUM USABLE

-N-

NETWORK - An organization of stations capable of intercommunications but not necessarily on the same channel.

NOISE - Any electromagnetic disturbance within a useful frequency band, such as undesired electromagnetic waves in a transmission channel or device. When caused by natural electrical discharges in the atmosphere such as lightning, noise may be called static.

NOISE, ATMOSPHERIC - Noise or static that is due to natural causes. It is due mainly to electrical storm activity.

NOISE, ELECTRICAL - Noise generated by electrical devices, such as motors, engine ignition, power lines, etc., and propagated to the receiving antenna direct from the noise source.

NOISE LEVEL - The value of noise integrated over a specified frequency range with a specified frequency weighting and integration time. It is expressed in decibels relative to a specified reference.

NONLINEAR - The relationship of two related quantities such that a change in one does not result in the exact proportional change in the other. A system in which the output does not vary in direct proportion to the input.

-P-

POWER, ANTENNA - The square of the antenna current of a transmitter multiplied by the antenna resistance at the point where the current is measured.

POWER, EFFECTIVE RADIATED - The power supplied to the antenna multiplied by the relative gain of the antenna in a given direction expressed in watts.

POWER GAIN, RELATIVE - The relative power gain of one transmitting or receiving antenna over another is the measured ratio of the signal power one produces at the receiver input terminals to that produced by the other, the transmitting power level remaining fixed.

PROPAGATION - In electrical practice, propagation is the travel of waves through or along a medium or transmission path.

-R-

RADIATION - In radio communication, it is the emission of energy in the form of electromagnetic waves.

REFLECTION - A phenomenon causing a wave which strikes a medium of different characteristics to be returned into the original medium with the angle of incidence and of reflection equal and lying in the same plane.

RESISTANCE, ANTENNA - It is equal to the power supplied to the entire antenna circuit, divided by the square of the effective antenna current at a specified point.

RESISTANCE, RADIATION - It is equal to the power radiated by an antenna divided by the square of the effective antenna current referred to a specified point.

-S-

SATELLITE, COMMUNICATIONS, ACTIVE - A satellite equipped with electronic devices which receives, amplifies, and retransmits signals between ground stations.

SELECTIVITY - That characteristic of a radio receiver which determines the extent and degree to which the receiver is capable of differentiating between the desired signal and signals or interference at other frequencies.

SENSITIVITY - The minimum input signal required in a radio receiver to produce a specified output signal having a specified signal-to-noise ratio. The signal input may be expressed as power or as voltage, with input network impedance stipulated.

SHIELD - A housing, screen, or other object, usually conducting, which substantially reduces the effect of electric or magnetic fields on one side thereof, upon devices or circuits on the other side.

SIGNAL STRENGTH - The strength of the signal produced by a radio transmitter at a particular location, usually expressed as millivolts per meter of effective height of the receiving antenna employed.

SIGNAL-TO-NOISE RATIO - The ratio of the magnitude of the signal to that of noise. This ratio is often expressed in decibels. It may also be expressed in terms of peak values in the case of impulse noise and in terms of root-mean-square values in the case of random noise, the signal being assumed sinusoidal.

SKIN EFFECT - The tendency of alternating current to flow near the surface of a conductor, thus being restricted to a small part of the total cross-sectional area. This effect increases the resistance and becomes more marked as the frequency rises.

SKIP DISTANCE - The minimum separation for which radio waves of a specified frequency can be transmitted at a specified time between two points on the earth by reflection from the regular ionized layers of the ionosphere.

STANDING-WAVE RATIO (SWR) - 1. The ratio of current (or voltage) at a loop (maximum) in a transmission line to the value at a (minimum) node. It is equal to the ratio of the characteristic impedance of the line to the impedance of the load connected to the output end of the line. 2. The ratio of the amplitude of a standing wave at an antinode to the amplitude at a node.

STATIC, PRECIPITATION - A type of interference xperienced in a receiver during snowstorms, rainstorms, and duststorms.

-T-

TOP LOADED VERTICAL ANTENNA - A vertical antenna that is larger at the top resulting in a modified current distribution which gives a more desirable vertical radiation pattern.

-U-

UNBALANCED - Electrically unsymmetrical with respect to ground.

-V-

VOLTAGE STANDING-WAVE RATIO (VSWR) - The ratio of the amplitude of the electric field or voltage at a voltage minimum to that at an adjacent maximum in a stationary-wave system, as in a waveguide, coaxial cable, or other transmission line.

-W-

WAVE, GROUND - Any radio wave that is propagated along the earth except ionospheric and tropospheric waves.

WAVELENGTH - The distance in meters traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

APPENDIX C

Instructions for the use of Smith Chart

Appendix C contains examples with instructions on the use of a Smith chart for determining phase angle, SWR and impedance coordinates (R and X).

Smith Chart. The Smith chart provides a method for computing with reasonable accuracy solutions to problems related to attenuation, admittance, impedance and standing wave ratio.

Configuration. The chart inner grid consists of a group of arcs with intercept points which represent resistance and reactance coordinates for impedance or as conductance and susceptance coordinates for admittance. The inner perimeter circle represents the angle of reflection coefficient in degrees ±180° from zero. The scales shown below each chart are used for measuring the scaled parameters from the Smith chart when scaled from the chart center (point 1.0) radially to any point on the grid or circles. Scales are given for reflection parameters measured in units of voltage and power coefficients. Scales are also shown for measurement of standing wave ratio in units of voltage or decibels.

Example 1 is used for determining phase angle and SWR. Example 2 is used for determining impedance coordinates (R and X) and SWR.

Example 1

Given: Coordinates R = 75 ohms and X_L = 105 ohms.
Characteristic Impedance (Z_O) = 50 ohms.

Determine: Phase angle (θ) and SWR where

Step 1 R = 75 ohms and X_L = 105 ohms in formula $Z = R \pm jX$ ($Z = 75 + j105$).

Step 2 Normalize step 1 formula components by dividing each by Z_O

$$\frac{Z}{Z_O} = \frac{75}{50} + j\frac{105}{50} = 1.5 + j2.1$$

Step 3 Plot step 2 formula normalized components on a Smith chart. Since X_L is an inductance component, the component value is plotted on the positive side of the Smith chart, $+j\frac{X}{Z_O}$, see chart C-1.

Step 4 Draw a line from the Smith chart resistance component line $\frac{R}{Z_O}$ point 1.0 to the coordinates point plotted in step 3. Project the line to the outer perimeter of the chart as shown in chart C-1. The intersection of the line with angle of reflection coefficient circle denotes the phase angle (θ) of the impedance Z.

Step 5 The length of the line from the chart C-1 point 1.0 to the coordinates point is equal to E_r or ρ. Scale the length of E_r line upon the parameter reflection coefficient scale of the Smith chart C-1. The scale value of ρ is equal to 0.66.

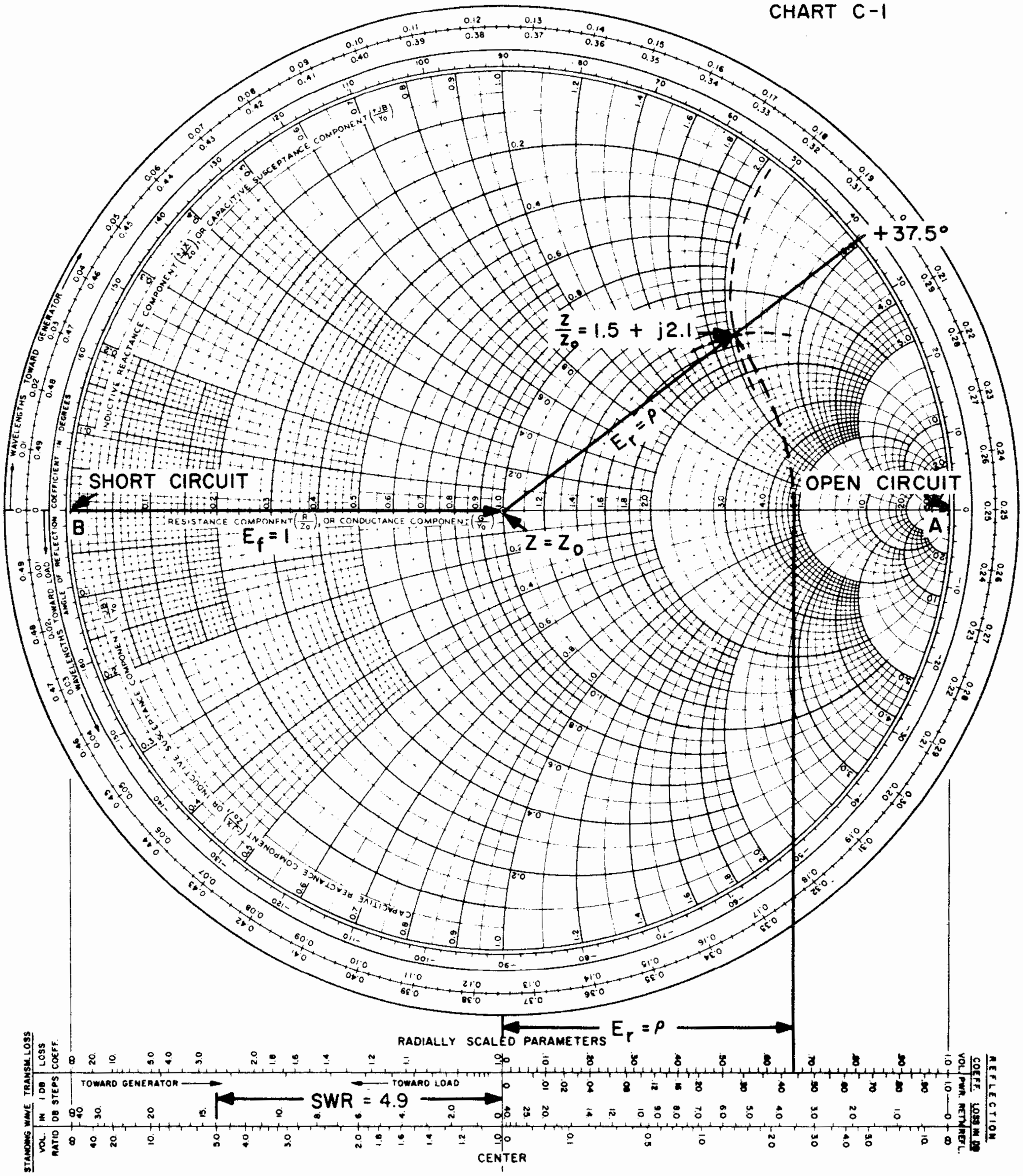
Step 6 SWR can be determined by scaling the length of the ρ upon the SWR parameter scale of chart C-1 or by the formula:

$$SWR = \frac{E_f + E_r}{E_f - E_r} = \frac{1 + \rho}{1 - \rho}$$

Step 7 Using either method of step 6 the SWR value determined is equal to 4.9.

IMPEDANCE OR ADMITTANCE COORDINATES

CHART C-1



Example 2

Given: E_r or ρ = 0.52 and phase angle θ = +100°.
Characteristic impedance (Z_o) = 50 ohms.

Determine: Impedance Z coordinates R and X and SWR.

Step 1 Plot a line with its origin on a Smith chart resistance component line $\frac{R}{Z_o}$ point 1.0 to the angle of reflection coefficient circle +60° point. Scale the 0.52 value of E_r or ρ on the line starting from the 1.0 point of the $\frac{R}{Z_o}$ line.

Step 2 The intersection of the scaled E_r or ρ point with the chart R and $+j\frac{X}{Z_o}$ components circle of the Smith chart are the impedance values required (see chart C-2). The values are R = 0.5 and X_L = 0.7. The normalized impedance is equal to Z = 0.5 + j 0.7. The impedance can also be given in polar form e.g., $Z = \rho \angle \pm\theta = 0.52 \angle +100°$.

Step 3 SWR can be determined by scaling the length of ρ upon the SWR parameter scale of chart C-2 or by the formula:

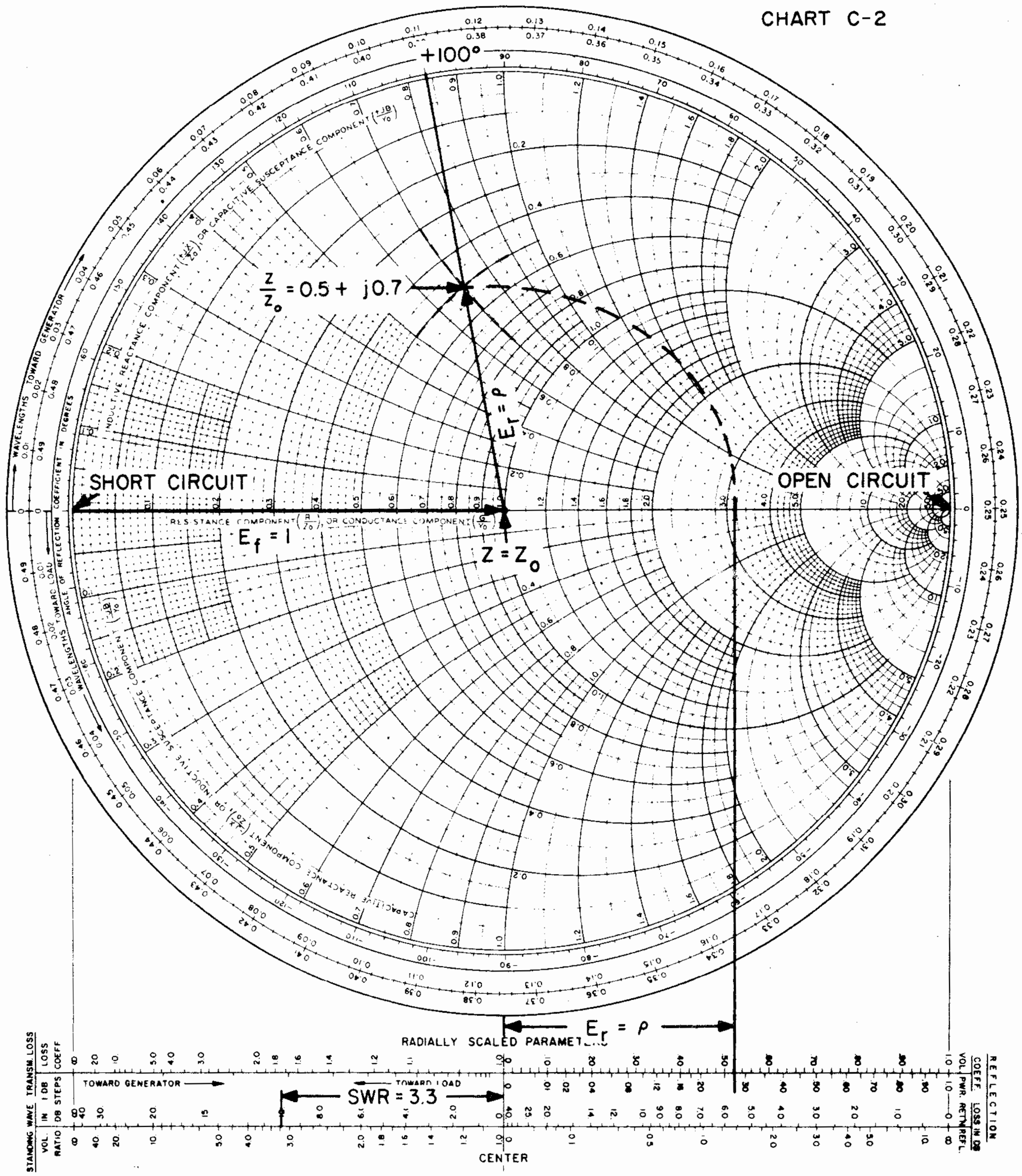
$$SWR = \frac{E_f + E_r}{E_f - E_r} = \frac{1+\rho}{1-\rho}$$

Step 4 Using either method of step 3 the SWR value determined is equal to 3.3.

SMITH CHART

IMPEDANCE OR ADMITTANCE COORDINATES

CHART C-2



INDEX

ALPHABETICAL INDEX

INDEX (Continued)

INDEX (Continued)