CHAPTER 1

VLF, LF, AND MF COMMUNICATIONS

The very-low, low, and medium frequencies occupy that portion of the frequency spectrum which lies between 3 to 3000 kilohertz (VLF, 3 - 30 kHz; LF, 30 - 300 kHz; MF, 300 - 3000 kHz). The VLF and LF frequencies have been principally used in long-range, shore-to-ship circuits and for land based communications in the arctic as backup to high-frequency circuits which are subject to numerous outages from auroral and polar disturbances. The VLF frequency range has received considerable emphasis in the field of navigational aids because of the long-range, high-reliability ground wave signal propagation characteristics.

1.1 VLF COMMUNICATION

The pace of progress and world developments -- political, geographical, technological, and military -- have broadened the Navy's commitments to communications to cover the face of the earth. New sea frontiers to the north have opened a four-million square mile ice-covered ocean of strategic importance. The requirement for positive control of U.S. Navy forces operating in new and expanded areas has dictated an urgent need for additional communication capacity, range, and reliability for the Navy's Command Responsibilities. This need has been confirmed through fleet exercises. The need has been particularly great in the North Atlantic, and the newly opened Arctic Ocean. The auroral effect in these northern latitudes prevented reliable communications from previously existing U.S. Naval Radio Stations. VLF (very low frequency) transmissions provide a highly reliable path for communications in these northern latitudes, as well as over and under all the oceans and seas of the world. The sea water attentuation is approximately 1 dB/foot of depth at 20 kHz and attenuation increases greatly as frequency is increased. VLF traffic reached a peak in the early twenties when it was the only means of long distance wireless communications.

After this period, many commercial VLF stations were abandoned in favor of high frequency (HF), due partly to the lower cost of HF equipment. At present, practically all VLF transmitters are used for fleet communications or navigation. In this connection, the U.S. Navy has been using VLF for general broadcasting to ships at sea for many decades. The dependability of reception is such that no confirmation of the received message is normally required.

Recent history has shown an increase of all radio traffic, and this is especially true of VLF. Such an increase may be expected again, not only for naval communications, but also for communications to large numbers of satellites and as a backup to short-wave communications blacked out by nuclear activity. The use of VLF for precise navigation, missile guidance, and satellite control over enemy territory might meet with vigorous and clever use of jamming, but the effectiveness of jamming VLF is largely determined by relative power and geographical distance. The strong reliance placed on VLF by the world's navies for crucial communications is good evidence of VLF reliability during hostilities.

Additional uses of the VLF communication system includes long range navigation and time and frequency broadcasts.

The cesium beam is the present basis for precise time measurement. Experiments over the last few years have shown the benefits of VLF for the broadcast of standard time and frequency signals with more than adequate precision for the operation of synchronous crypto devices, decoding devices and single sideband transmissions. The predictable low time-delay plus the phase-stability of the VLF signal contribute to this precision.

Use of a highly accurate time and frequency source (four cesium-beam standards) with the inherent stability of the phase characteristics of the VLF transmission over thousands of miles is the concept on which the radio navigation system OMEGA is based. Upon completion, it will provide worldwide navigation fix accuracies of 1 or 2 nautical miles (or greater, depending on receive equipment used) to aircraft aloft, surface ships at sea, and submerged submarines.

1.1.1 Operational Requirements and Message Handling Procedures

The principal use of the Navy VLF Communication System is for fleet broadcasts to the submarine fleet and associated ships and activities throughout the world. Transmission of messages to ship and shore facilities usually originates with the Operation Commander (or are directed to him for permission and priority of transmission). The communications office at the headquarters of the operation commander determines the location of each boat or subscriber under its command or where it should be. (Thus, if the operation commander has a message for a particular boat, it will first receive a precedence rating to determine its relative importance with respect to other communications sent to the fleet.) The communications office then forwards the message, precedence and subscriber location to the Broadcast Control Authority (BCA), which has control responsibility for all message traffic through one or more transmitter stations. The BCA determines which transmitter will send the message and according to its precedence will schedule the actual transmission. The complete message-schedule is forwarded to the individual transmitter Facility Control. Technical control of the transmission, including monitoring the signal quality, is the responsibility of the Facility Control, which normally has the final control of the signal input to the transmitter via a continuous direct patch. The Transmitter Facility receives the message data via direct wire, microwave, satellite, or a combination thereof. If the message-date is arriving from only one source, then the transmitter facility will have the continuous direct patch from the Facility Control to the transmitter input circuit, but if due to its remote location there is a possible second source of input data, the transmitter facility will be required to operate a second Facility Control operation.

The VLF transmission is normally considered a broadcast, one way transmission, no reply required. The VLF transmitter presently transmits single channel teletype via FSK (frequency shift keying) but the transmitter has the capability and occasionally transmits interrupted continuous wave for test or emergency transmissions. A security broadcast consists of a key stream of digital transmissions and is crypto covered. The signal is continuous around the clock, with message repetition at set times, with as many repeats of particular messages as determined by the BCA. The broadcasts are segmented so that critical messages are repeated often and less critical, less often. Delay in transmission of a particular message is dependent on its precedence. The delay may be seconds, minutes, or hours. The type of information transmitted to the fleet will vary from operational instructions, general or informational, news items of interest to the fleet, and even special personal messages. The non-operational messages, used as "filler," are sent as time permits. If the volume of operational information is low, due to the small number of units assigned to receive the transmission, a large volume of "filler" messages will be transmitted. When transmitter coverage area is large and/or the number of operational units in the area is large, non-operational messages are kept to a minimum.

The extent and location of the area to be covered has a strong bearing on the decision for the transmitter location and power output. For worldwide coverage the Navy has installed seven VLF transmitters:

	Transmitter Designation	Transmitter Location	Sign	Rated Transmitter Output Power	Frequency
Atlantic Fleet	AN/FRT-31	Cutler, Maine	NAA	2 MW	17.8 kHz
	AN/FRT-87	Annapolis, Md.	NSS	1 MW	21.4 kHz
	AN/FRT-73	Summit, Canal Zone	NBA	1 MW	24.0 kHz
	AN/FRT-3	Jim Creek, Wash.	NLK	1 MW	18.6 kHz
Pacific Fleet	AN/FRT-64	Lualualei, Hawaii	NPM	1 MW	23.4 kHz
		Yosami, Japan	NDT	0.25 MW 0.5 MW (1 CW only)	17.4 kHz
	AN/FRT-67	North West Cape, Australia	NWC	2 MW	22.3 kHz

Though their signals may overlap, each transmitter services only its designated area. The VLF system reliability requirement is 99.9%. To accomplish this high reliability, replacement parts are built-in by providing redundant subsystems which may be rapidly switched into operation while the defective circuit is removed for repair. Therefore, Navy VLF communication transmitters contain approximately double the number of components required for normal operation.

High reliability with redundant subsystems is only one of the factors which influence the cost of VLF transmitter facilities. The high power output required (0.25 to 2.0 megawatts) is extremely expensive to attain. The electronic and mechanical components used, as detailed in chapter 4, are physically large and with the high operating voltages and high power radiated, the transmitter facility requires enormous space for proper operation and human safety. The cost of real estate and buildings and their maintenance also adds significantly to the overall price of a VLF transmitter facility.

The environment of the transmitter facility location also has an important affect on the cost. The electronic equipment requires a large cooling system for proper operation. In hot and humid areas, additional air conditioners and dehumidifiers are used. In cold areas, heating is needed, and addition of 60 Hz may also be required for deicing the antennas. It may be necessary to employ dual antennas and antenna controls, so that as one antenna continues in operation, the other may be deiced. To perform this type of deicing requires several megawatts of 60 Hz power in addition to the normal power required to operate the station.

The primary function of a VLF Communication System is to accurately transfer teletype (TTY) information encoded in the form of binary digits (bits) between the originator and user. However, communication channels are usually characterized by certain imperfections that may degrade the transmitted information. To minimize this degradation at the receiving terminal, a form of error control is often incorporated in the data channel. Naval Research has revealed that channel disturbances (impulse noise, fades, drop outs, man-made interference, etc.) have an effect on VLF transmission. The effect that it may have does not warrant (at present) installation of error-control equipment, as is required for communication systems operating at higher frequencies. The maximum character error rate required for the Navy VLF communication system, and realized within standard operation, is a maximum of 10^{-3}, or one bit error per 1000 bit transmission. It has been determined that normal repetition of messages is adequate for overcoming the few infrequent communication imperfections encountered.

1.1.2 System Utilization

The prime purpose of the Navy VLF communication system, as has been previously stated, is for the transmission of fleet broadcasts. In an emergency, the transmitters may be switched from standard teletype-FSK mode to ICW mode of transmission. This operation, on command, generally must be accomplished within 2 minutes, but may require as little as 30 seconds at some sites, including the time required for fine tuning of the transmitter-antenna circuits. Reversing the operation, ICW to FSK mode, must be accomplished within 8 minutes.

Secondary applications of the VLF range, include the worldwide transmission of standard frequency and time signals. The requirement for the distribution of standard frequency and time signals with the highest accuracy over long distances has become increasingly important in many fields of science. It is essential for the tracking of space vehicles, worldwide clock synchronization and oscillator calibration, international comparisons of atomic frequency standards, radio navigational aids, astronomy, national standardizing laboratories, and some communication systems. Methods used for propagation of time and frequency information include use of high-frequency (HF), low-frequency (LF), and VLF radio transmissions, portable clocks, satellites carrying a clock or a transponder, and RF cables and lines.

VLF PTTI transmissions have proven to be dependable for accurate distribution of standard time/frequency information over large areas of the world. VLF transmissions have been widely used for this purpose only during the last ten years.

VLF transmissions have been used by several countries to intercompare atomic frequency standards since the standards first became available. As a result of greater understanding of VLF propagation and the improvements in the accuracy of atomic standards and VLF receiving equipment, frequency comparisons over long distances with precisions better than one part in 10^{11} are now possible.

The purpose of the Navy's VLF precise time and time interval information systems is to provide a worldwide means of standardizing the measurement of frequency and time that is traceable to the U.S. Naval Observatory. The time information system operates in conjunction with the Navy VLF communication system on a time sharing basis with resolution greater than 20 μsec. The frequency information is broadcast continuously, as all Navy standard VLF stations are controlled by cesium beam atomic oscillators, highly stable VLF transmitter signals are received with a monitor antenna and phase-tracking receiver at the transmitter site. The output of the receiver is a direct current proportional to the relative phase difference between the received VLF carrier and the local reference oscillator. Any phase changes or variations within the system can be recorded as a change in the phase of a coherent frequency from the local reference oscillator. When this condition exists, the phase error may be nulled out by changing the frequency of the reference oscillator either manually or automatically by the amount of the error. The system error or degree of uncertainty is less than 1 part in 10^{10} in frequency and 1 to 2 μsec in time.

Studies have shown that the time of a VLF signal transmission over thousands of miles is predictable within a maximum error of 2 to 5 microseconds. Taking advantage of the high phase-stability and low attentuation-rates of VLF radio transmissions, these signals can also provide global position-fixing of good accuracy and high reliability. Such a system can be used by ships, aircraft, and submarines to moderate depths. A radio navigation system based on this concept is OMEGA.

OMEGA utilizes the reliability of VLF transmission predictions and the known location of each transmitter, to develop accurate phase-difference Lines of Position (LOP's). By employing eight widely separated transmitter stations, each transmitting on synchronized frequencies such as 10.2, 13.6, 11.33 kHz, in sequence, a unique family of hyperbolic LOP's is generated at each frequency, by phase-difference measurements between two stations of a synchronized pair. All signals of all frequencies are phase-locked, thus guaranteeing a fixed relationship between each set of LOP's. Therefore, when the system is completely installed and operating, the LOP's will embrace the earth in a permanent network of identifiable grid lines. Position of a receiver will be established by intersection of hyperbolic contours defined by the eight stations. The stations will have average separations of about 5000 nautical miles. With minor exceptions, caused by high attenuation in transmission over the polar ice-caps and permafrost, all eight stations will be observable at any receiving point; five or six of the stations will ordinarily supply signals fully satisfying the system standards of fix accuracy and reliability.

A similar capability exists with the Navy high power radio stations since their keying will be timed by the stations' atomic clocks, thereby allowing not only differential phase/time measurements as used up to now, but in addition giving a "Lane" resolution capability which is compatible with the OMEGA technique.

Time signals, as emitted over VLF radio every few hours, will then only be needed to identify the seconds, minutes, etc., in case the local clock has stopped. The new FSK time signal format (together with "bit" timing) allows a resolution of better than 50 μsec. This is sufficient to identify a carrier cycle ("Lane" resolution). Schedules of VLF and HF time signals should be requested from the USNO.

The navigator can determine a line of position generated by any convenient pair of these stations, and can cross it with one or more other lines derived from another pair or pairs. Thus the navigator will choose position lines by OMEGA much as he chooses celestial lines of position -- for good accuracy and for large crossing angles -- and there is a satisfactory degree of redundancy to protect him in case of failure of one of several OMEGA transmitters. He may make readings on four or five lines of position, but usually he will choose the two pairs that jointly give the greatest precision at his location.

The navigational accuracy of OMEGA is wholly dependent on rigid frequency and phase control. To accomplish this, each station is controlled by the frequency of one of four cesium beam standards, but adjustable over at least a few parts in 10^{11}. All needed frequencies are derived from this single source, and are internally checked and maintained to achieve very high reliability of phase. The precision of frequency is such that phase can be maintained within approximately one microsecond per day. This frequency source is used to provide all radiated signals and timing sequences with the stability required to enable OMEGA to operate as a precise navigation system, and in addition, as a worldwide source of standard frequencies. The Naval Observatory, early in 1967, cited OMEGA as an accredited source of standard frequencies.

OMEGA is particularly useful for ships because positions can be fixed to within one mile during the day and two at night. For station-keeping or rendezvous, the relative accuracy will be about one-quarter mile. Submarines can obtain the same fix accuracies for antenna depths as great as 40 to 50 feet.

Presently, four limited-capacity transmitting stations are operating and providing navigational coverage from 0° to 90° North and 0° to 150° West. These stations are located in Norway, Trinidad (West Indies), Haiku (Hawaii), and LaMoure (North Dakota) (replacing the Forestport, New York facility). The U.S. is currently negotiating and finalizing international agreements with potential partner-nations for the establishment of the remaining four transmitting stations. The anticipated locations of these stations are in Argentina, Japan, La Reunion (near Madagascar), and Australia. Current plans call for completion of the system by 1974.

1.1.3 System Mode of Operation

Communication system bandwidth requirements are determined by data rates, signal encoding, and the type of modulation employed. Overall communication performance is greatly influenced by the type of signal encoding and decoding used prior to modulation and subsequent to demodulation. Until recently VLF transmitters used only simple on-off modulation of the carrier, which is referred to as ICW keying or simply CW keying, with data rates ranging from 15 to 50 words per minute (wpm). The high speed broadcasts were copied on magnetic tape and played back at slower speeds. Emergency and test transmissions are ICW modulated, but the normal VLF modulation method is frequency shift keying (FSK), by which two signal levels are translated into discrete frequencies (the modulating signal shifts the output frequency between predetermined values). As a result of the need for higher data rates and automatic operation, radio teletype signaling with FSK modulation has been developed to the status of highly reliable data rates in the order of approximately 71.42 wpm at VLF.

The bandwidth required depends upon the keying rate, type of modulation and signal encoding used, and the output data rate and waveform fidelity required. The keying rate for a given output data rate is a function of the type of signaling system employed. The three types of codes used for teletype (TTY) are 5-unit and 7-unit start-stop codes and the new U.S. Department of Defense 8-unit code known as ASCII (American Standard Code for Information Interchange); existing equipment in the Navy uses the 5-unit TTY system, although with the start and stop pulses it is known as the 7.0 code and is crypto covered. The three codes are similar in format, in that they all have a start pulse, followed by the character pulses and a stop pulse in sequence (figure 1-1). The 5-unit code provides 32 character/control signals, while the 7-unit and 8-unit codes allow up to 128 character/control signals to be transmitted. The 5-unit TTY code, including the various pulse interval times and unit codes used, is presented in detail in figure 3-7 of NAVELEX 0101,102, Naval Communication Station Design Handbook; the teleprinter-code alphabets for all three systems are presented in chapter 30 of Reference Data for Radio Engineers, fifth edition.

The 5-unit code system used by the Navy VLF Communication System has a keying element unit intervals of 20 milliseconds (ms) and a code of 7.0, which is equivalent to 50 baud. These numbers are related as all unit intervals for the start character and stop pulses are equal in length (20 ms), for VLF systems but other codes may have a longer stop pulse. By adding the individual intervals, the result is the character interval of 140 ms. The character interval (140 ms) divided by the unit interval (20 ms) equals the total number of pulses per character. The unit code may be used to convert between applicable data rates, wpm, and baud.

$$\frac{\text{wpm x unit code}}{10} = \text{baud} \qquad (1\text{-}1)$$

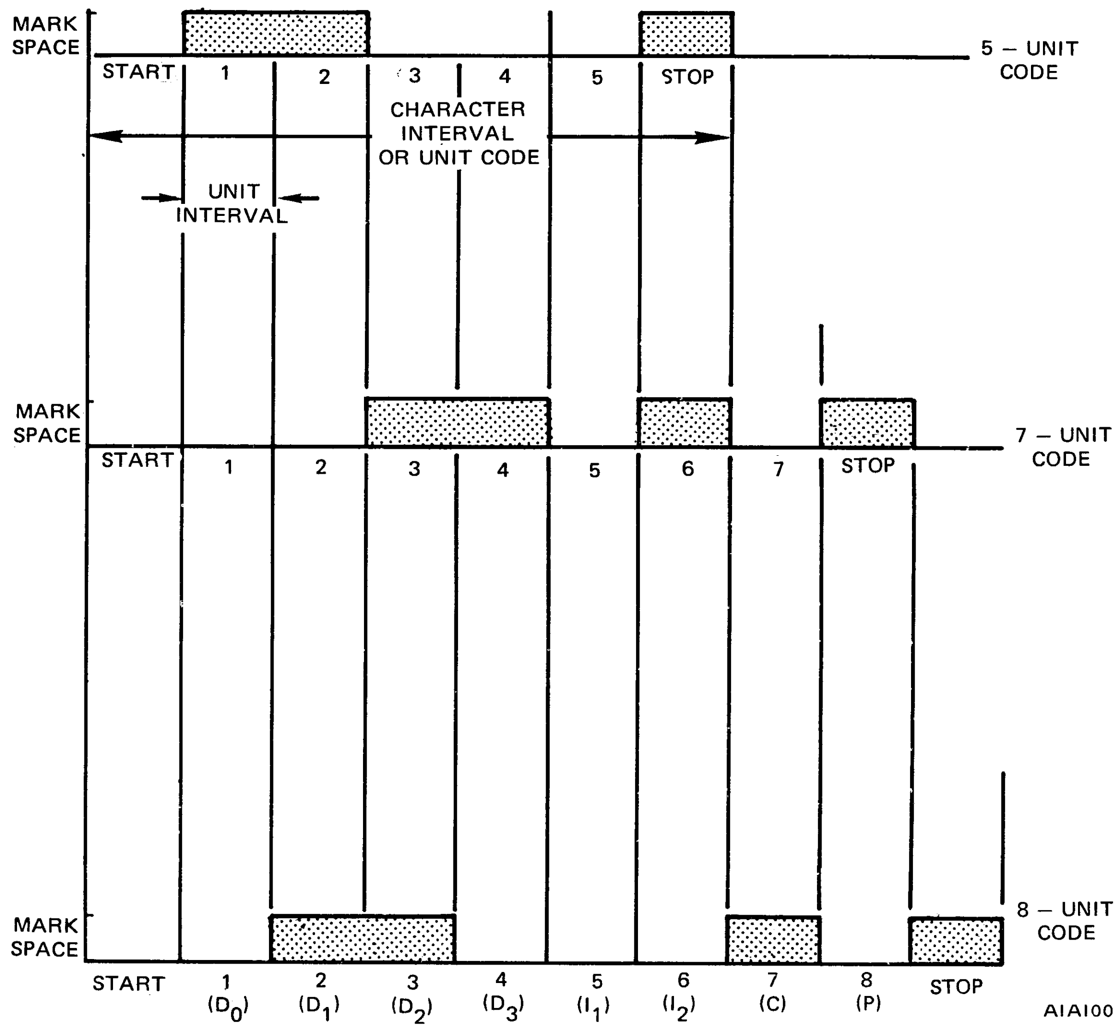

Figure 1-1. Comparison of Transmission Format of Letter A Using 5-, 7-, and 8- Unit Code Systems

The term baud is the unit of modulation rate. One baud corresponds to a rate of one unit interval per second. Baud was first used to indicate telegraph signaling speed, derived from the shortest signaling pulse; a telegraphic speed of one baud is one pulse per second. Therefore, for continuous telegraphy the modulation rate is expressed as the reciprocal of the duration in seconds of the unit interval. For example, if the duration of the unit interval is 20 ms, the modulation rate is 50 bauds. But other TTY circuits require the addition of start-stop codes, thus the unit code or total number of pulses per character is significant in the calculation of the modulation rate baud. In simplified terms, the TTY modulation rate is equal to the keying rate times the unit code.

$$\text{Keying Rate x Unit Code} = \text{Modulation Rate} \tag{1-2}$$

Where the keying rate is equal to the product of the message rate (wpm) and the number of characters per word.

$$\frac{\text{Words}}{\text{Minute}} \times \frac{\text{Characters}}{\text{Word}} \times \frac{\text{Minutes}}{\text{Second}} \times \frac{\text{Pulses}}{\text{Char.}} = \frac{\text{Pulses}}{\text{Second}} = \text{Baud} \tag{1-3}$$

In TTY transmission the average number characters per word is six (6). Therefore the equation reduces as follows:

$$\text{wpm x 6 x 1/60 x unit code} = \text{Baud} \tag{1-4}$$

Further reduction results in the original equation,

$$\frac{\text{wpm x unit code}}{10} = \text{Baud}$$

Therefore, Navy VLF transmitters operating with a modulation rate of 50 baud and a unit code of 7.0 (pulse unit interval = 20 ms), are transmitting messages at a rate of 71.42 words per minute.

$$\text{wpm} = \frac{\text{10 x 50 bauds}}{7.0} = 71.42 \tag{1-5}$$

The bandwidth required to attain reliable FSK transmission (the 3 dB bandwidth) has been equated for a single tuned antenna of 3 to 6 dB bandwidth ratio of 0.58, as follows:

$$b_{3\ dB} = 1.16kR_w\ (m + \tau b_6) \tag{1-6}$$

where

R_w = words/min message rate

k = keying rate constant for code type used

m = modulation index ($\Delta f/f_r$)

τb_6 = keying element bandwidth product

Using the value of 71.42 words/min for R_w, the value of $k = 0.25$ as tabulated (Table 6.5.1 in VLF Radio Engineering, A.D. Watt) for 5-unit TTY code, modulation index of 1, and a keying element bandwidth product of 1.45, would result in a minimum bandwidth requirement as calculated,

$$b_{3\ dB} = 1.16 \times 0.25 \times 71.42 \times (1 + 1.45) \cong 50 \text{ Hz}$$

The Navy FSK-TTY transmission system would require thus a minimum bandwidth of approximately 50 Hz for a 50-baud modulation rate, although 50-baud FSK is generally used at frequencies for which greater bandwidths are available.

1.1.4 System Configuration

The Navy VLF Communication System normally transmits a single-channel TTY broadcast. Though most of these transmissions are capable of encompassing a major portion of the earth, each transmitter provides coverage over a limited geographic area. The basic components of the VLF communication system are presented in figure 1-2; details of the component equipments are presented in chapter 4.

The input message is translated into a frequency shift keyed electrical signal using a teletypewriter, with the 5 unit start-stop code. Transmission of the electrical signal to the transmitting facility is via microwave links, landline cable, and/or satellite. Terminal equipment reforms the FSK signal to modulate the VLF carrier. Power amplification of the modulated carrier occurs in the transmitter which feeds into a matching network and finally into the antenna.

Transmitter antenna designs vary due to the amount and type of land available, signal coverage area bandwidth requirements, etc. Changes to antenna designs are also dependent on the economic advantages of using extensive portions of existing systems in the improved design. All of the Navy VLF antennas utilized top-hat capacitive loading with one or more vertical radiating elements. The antenna may include a vertical tower which is insulated from ground, or a supported vertical wire as shown in figure 1-3. The supported wire is also referred to as the download of the antenna array, and the top-hat may take many shapes. A portion of the matching network consists of a tunable coil in series with the antenna. This coil, the transmitter termination, and the antenna termination are all located in the helix house building. The transmission system between the transmitter and the helix house depends on the location and number of antenna feeds and/or downleads required. The simplest configuration can be used when the antenna and transmitter are in close proximity, and the helix house is adjacent to the transmitter building. Other configurations involve a helix house located a distance from the transmitter building or even two antennas separated from each other connected in a dual operating configuration. The latter arrangement at Cutler, Maine involves an underground transmission-line with over a half mile of tunnels connecting the antennas to the transmitter building. Details of these system components are presented in later chapters.

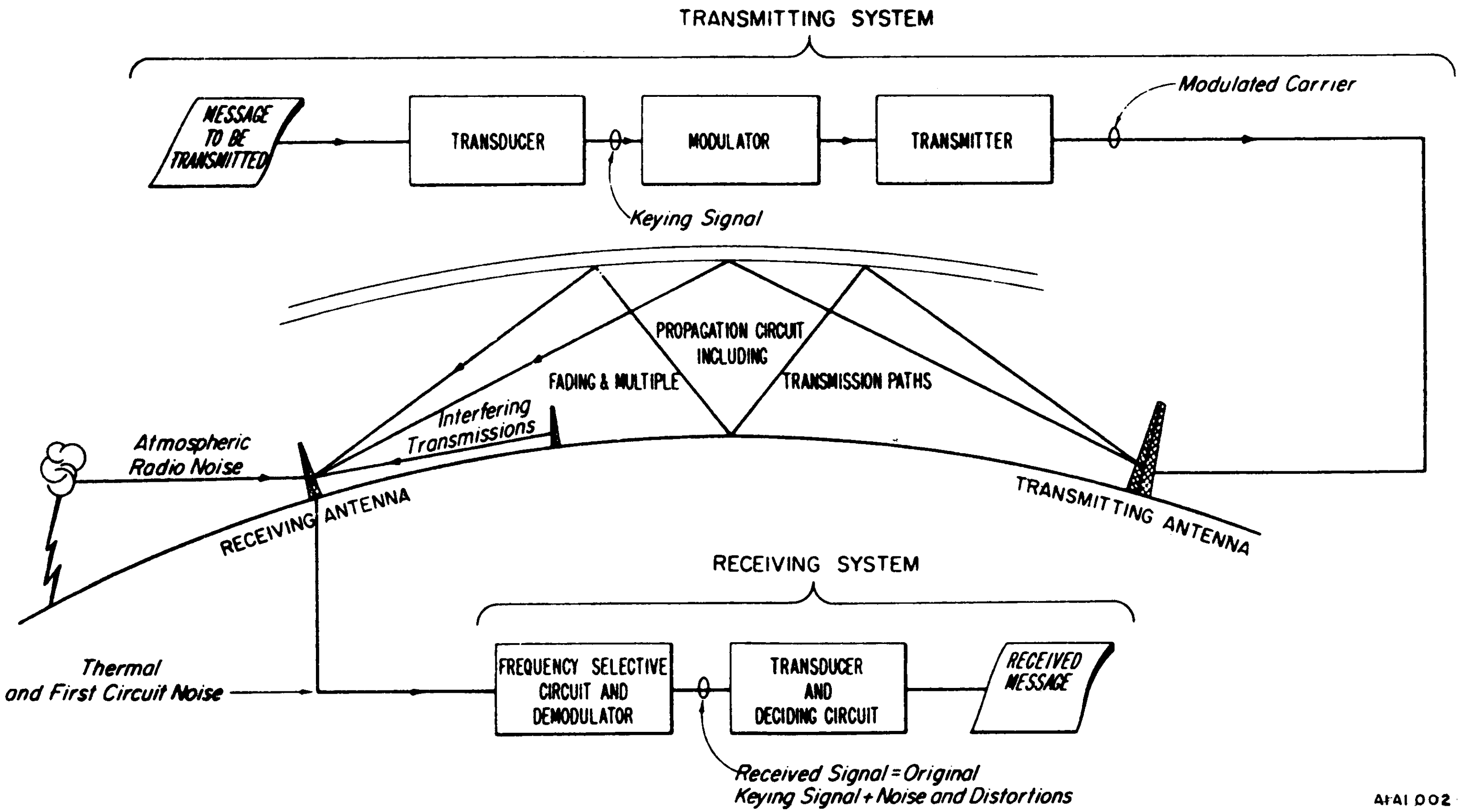

Figure 1-2. Diagram of a Typical Radio Communication System

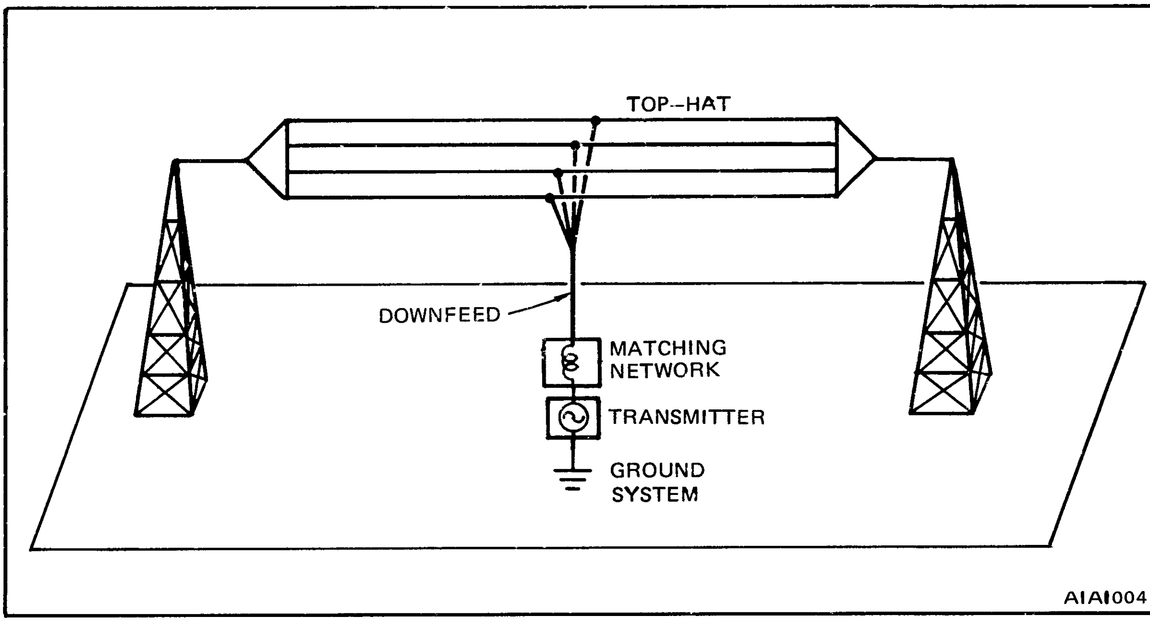

Figure 1-3. Simplified VLF Transmitting Antenna

Primary power is usually obtained locally, but in a few cases it is generated on the station. U.S. Naval Radio Station (T) Cutler, Maine, has its own 12-megawatt generating plant and needs no power from commercial sources. Deicing circuits capable of melting three inches of radial ice from the entire 26-tower antenna-array, tower lighting, and all base utility needs are provided energy by this power station.

The VLF receiving installation on board a submarine or surface ship basically consists of an antenna, receiver, and terminal equipment such as decoders, pointers, and teletypewriters. The types of antennas available for use with the system include a loop antenna whip and long wire, 50-ohm output impedance systems. The receiver covers the frequency range of 14 to 30 kHz and is capable of receiving both ICW and FSK transmission. The receiver has an output to a headphone jack for audio monitoring of ICW signal, or to a keying circuit to supply a teleprinter drive output when receiving FSK signals. Normally the FSK signal is a coded transmission, therefore, the receiver output passes to a crypto-decoder to provide clear-text output fo the printer.

1.2 LF COMMUNICATION

The low-frequency band occupies only a very small part of the radio frequency spectrum. Nevertheless, this small band of frequencies has been used for communication since the advent of radio. Although the historical significance of the low-frequency band is well known, the great extent of present usage of this band is not generally appreciated.

In the history of radio communication, the low-frequency transmitting installations of the pioneering era were characterized by their large physical size and by their high construction and maintenance costs. Moreover, then, as now, signal reception at low frequencies was seriously hampered by atmospheric noise, particularly at low geographical latitudes. In addition the increasing demand for radio communications soon resulted in serious congestion of transmissions within the then available spectrum. Thus, with the development of the high-frequency "beamed" systems about 1924, it was found that the high frequencies offered an attractive solution to many long-distance communication problems, and the use of the low frequencies became considered as outmoded. Nevertheless, propagation factors peculiar to the low-frequency band have resulted in their continued use for radio communication. In particular, the reception of low-frequency waves is not so seriously affected during periods of ionospheric disturbance when communication at the high frequencies is disrupted. Because of this, there is a particular interest in the application of low frequencies at high geomagnetic latitudes. Since the initial use of radio for communication purposes, considerable advances have been made in improving both the efficiency and the quality of communication by the application of communication theory, radio wave propagation studies, and new techniques.

The Navy requirement to provide the best possible communications to the fleet requires it to operate on all frequency bands and engage in constant research to improve its existing capabilities and utilize new systems and developments as they become operationally reliable (proven systems).

In the past the Fleet Broadcast System has provided the ships at sea with low frequency (LF) communications via CW telegraph transmissions. As the state of the art advanced, the system was converted to single channel radio teletype transmissions. Today LF communication also operates as a segment of the Fleet Multichannel Broadcast (MULCAST) System providing eight channels of Frequency Division Multiplex teletype traffic on each transmission.

The low frequency band is also utilized for the Long Range Navigation System (LORAN) which will be supplemented by the OMEGA system which operates in the Very Low Frequency (VLF) Band. The transition from LORAN to OMEGA is being accomplished to increase the coverage and reliability with fewer stations.

1.2.1 System Utilization

The Low Frequency (LF) Communication System which is operated as a part of the Fleet Multichannel Broadcast System is divided into two subsystems which are the shore based subsystem and the shipboard subsystem. The shore based portion performs three basic functions, signal processing, signal transmission, and quality control monitoring. The shipboard portion performs the functions of signal reception and signal processing.

The functions of message processing, etc., are handled by the communication station (COMMSTA). The COMMSTA is made up of a transmitter site, a receiver site and a communication center. The transmitter and receiver sites are generally located approximately 5 to 50 miles from the communication center, but in some instances the receivers and communication center are colocated. The receiver and transmitter sites are separated from each other by several miles. Landlines and microwave links are used for routing communications between the communication center and the transmitter and receiver sites (see NAVELEX 0101, 102).

The LF transmission provides radioteletype message traffic which is covered by on-line encryption, applied to a voice frequency carrier terminal (VFCT) which converts the signals from DC to audio frequency tone shift (AFTS) signals. The signals are then multiplexed and sent by either landline or microwave to the transmitter site where the signals are used to modulate the transmitter. The system will handle eight message channels of teletype traffic on a single voice channel. Each teletypewriter will print up to 100 words per minute.

The Fleet Multichannel Broadcast (MULCAST) System is a communication system designed to enhance the command and control of Naval operating forces by providing a secure and flexible means of delivering shore-to-ship teletypewriter traffic. The MULCAST System consists of area-oriented networks of communication stations so configured as to furnish, to the greatest extent possible, communication coverage to all ocean areas of the world.

A low frequency communications system provides in comparison with the HF band a highly reliable medium range communication system. The LF band transmission provides a good ground wave signal out to about 500 to 1000 km and is not as subject to the anomalies of sky wave propagation. The LF spectrum is freer of intermodulation and harmonic distortion for reception aboard ships.

The LF boardcast is, however, limited in range and traffic capacity. The range of the LF broadcast will depend on atmospheric noise levels which vary with geographical location, time of year, and time of day, but presently is primary out to approximately 500-600 nautical miles from the transmit site.

The initial cost of a low frequency transmitting station is usually a function of the rated output power of the transmitter. Low frequency higher power transmitters presently cost approximately three dollars per watt to build and install. This cost estimate does not include the construction and design of the low frequency antenna system and its matching network.

The helix house is a copper lined building which houses the antenna tuning and loading coils and other components used to match the output impedance of the transmitter to the antenna impedance.

The basic standard LF antenna is the top loaded vertical monopole supported on an insulated base and with tower height of between 400 and 1200 feet. The optimum antenna height is determined by the operating frequencies of the station. The cost for the single guyed tower is presently $1000 per foot. This cost includes the construction of the ground plane, top loading radial umbrella and the helix house.

Low frequency systems require only sufficient land to accommodate the antenna system and the helix house. The antenna utilizes an extremely large area since it requires an extensive ground mat with radials approximately the height of the tower, and requires a circular area having its diameter equal to twice the tower height. The helix house is usually located at the base of the LF transmitting antenna. The transmitter building may be located next to the helix house or a distance away.

1.2.2 System Mode of Operation

The low frequency communication system as a segment of the Fleet Multichannel Broadcast System utilizes the single sideband suppressed carrier (SSB) mode of transmission. Single sideband suppressed carrier radio transmissions offer a considerable advantage over conventional amplitude modulation (AM). Greater power efficiency results when transmitting only the desired signal rather than two identical sidebands plus the carrier. This narrowing of bandwidth (as compared to operational AM) allows bandpass reduction at the receiver which results in an improved signal-to-noise ratio and better rejection of adjacent channel interference. Transmission of only the required signal is also beneficial to all users of the overcrowded radio frequency spectrum in that one half the AM bandwidth is required.

Low frequency transmissions are capable of supporting eight one-hundred-word-per-minute information channels on Frequency Division Multiplex when operated with the multichannel broadcast system. The higher frequency bands are capable of supporting sixteen information tone channels but are presently configured so that transmission of information requires the pairing of two tone channels for frequency diversity.

1.2.3 System Configuration

The general practice is to generate a Base Electronic System Engineering Plan (BESEP) which provides information needed to document and justify the need for a new electronic system or site. This document defines both system and equipment requirements including the presentation of necessary supporting data such as; site surveys, the evaluation of potential interference problems and definition of installation and maintenance responsibilities.

The design of a low frequency transmitting station is closely controlled and coordinated by the use of NAVELEX Standard Plans. These documents define the equipment layouts, interface wiring, power requirements and other engineering and installation criteria. The intent of system standardization is to provide uniformity of equipment and facilities. These two factors will also reduce logistic problems and amount of retraining or station orientation for personnel.

The LF receiving system is used only as a quality monitor system of the radiated signal since no shipboard generated traffic is received ashore on the LF band.

1.3 MF COMMUNICATION

The medium-frequency band covers the part of the radio spectrum from 300 kHz to 3 MHz. Included in this range is the International Distress frequency 500 kHz (to monitor) and approximately 484 kHz to respond from shore station (Coast Guard).

Every ship has a receiver and a transmitter set for these emergency frequencies; when at sea, the receiver is continuously monitored and the transmitter is usually in the standby position. Ashore, the receiver and transmitter configuration is usually affiliated with search and rescue organizations, which are generally located near the coast.

There are occasions when the 500 kHz frequency is used for calling another station. Since all Navy and Merchant ships must monitor this frequency, it is sometimes convenient (when the sender does not know what other frequency the receiver is monitoring) to send a short message stating what frequency the receiver should tune to for further communications. The only restriction is that no call-up transmissions are permitted during the periods 15-18 minutes and 45-48 minutes past the hour, every hour of the day. This period of time is required by law to permit the channel to be clear of all but emergency communication.

1.3.1 System Mode of Configuration

There are three transmitters used by the Navy for MF transmission, though neither unit was designed specifically for the MF band. The AN/FRT-19 (obsolescent) is an LF transmitter, normally operating between 30 and 300 kHz with an output of 15 kW. But, if operated at reduced power, 3 kW, the system is capable of extending its range to 600 kHz. The AN/FRT-39 normally operates in the HF band, 2-28 MHz, with an average output of 5 kW. This system, when operated with a Low Frequency Adapter is capable of transmitting in the low frequency range and when so modified is known as the ART/FRT-74. The TAB-7 is an obsolescent transmitter that is still used in certain installations.

The MF receiving system is capable of receiving on-off-keying (ICW) transmission, and it utilizes receivers which are capable of operating in the VFL through MF range.