SUBCOURSE
MM0750

EDITION
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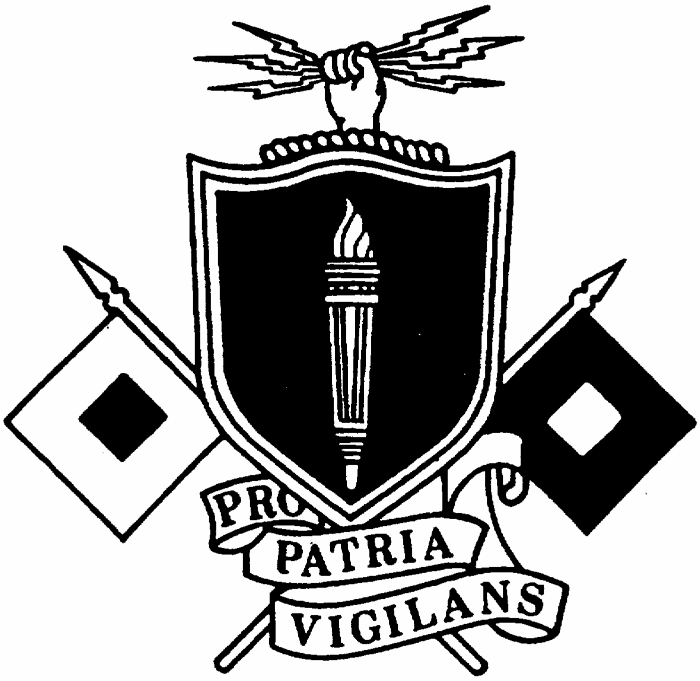
HIGH-FREQUENCY FIXED-STATION RADIO SYSTEMS



THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

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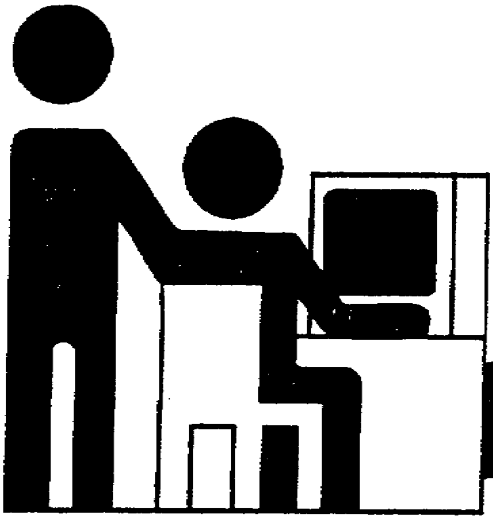

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VALIDATION INFORMATION

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SUBCOURSE 750

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SUBCOURSE 750

HIGH-FREQUENCY FIXED-STATION RADIO SYSTEMS

INTRODUCTION

To maintain efficient and effective fighting forces, a large volume of logistical and administrative data must be exchanged among the various command headquarters throughout the world.

The Defense Communications System is a worldwide point-to-point communications network designed for operations on a global scale. It provides data, teletypewriter, voice, and facsimile facilities. It is a system of interconnected fixed radio stations and leased or allocated long-distance wire channels. The system does not include local tactical and special-purpose communications circuits, but its facilities are available for use by all echelons of the Army, and long-distance circuits may be permanently or temporarily allocated to any approved user.

Although the Defense Communications System is controlled by the Department of Defense, portions of the system are operated by the three military departments. The Army portion is operated by the US Army Communications Command, one of the major commands of the US Army.

The purpose of this subcourse is to familiarize you with the principles involved in long-distance radio systems, the problems associated with establishing and maintaining these systems, the operational equipment used, and the duties of those individuals responsible for them.

This subcourse consists of seven lessons and an examination, as follows:

Lesson 1. Introduction to High-Frequency Radio Communications Systems

Lesson 2. Communications Circuit Quality

Lesson 3. Transmitting Equipment

Lesson 4. Receiving Equipment

Lesson 5. Antenna Systems

Lesson 6. Mobile Radio Stations

Lesson 7. Frequency Planning

Examination

Credit Hours: 16

You are urged to finish this subcourse without delay; however, there is no specific limitation on the time you may spend on any lesson or on the examination.

Texts and materials furnished:

Subcourse Booklet, which you may keep, and Examination.

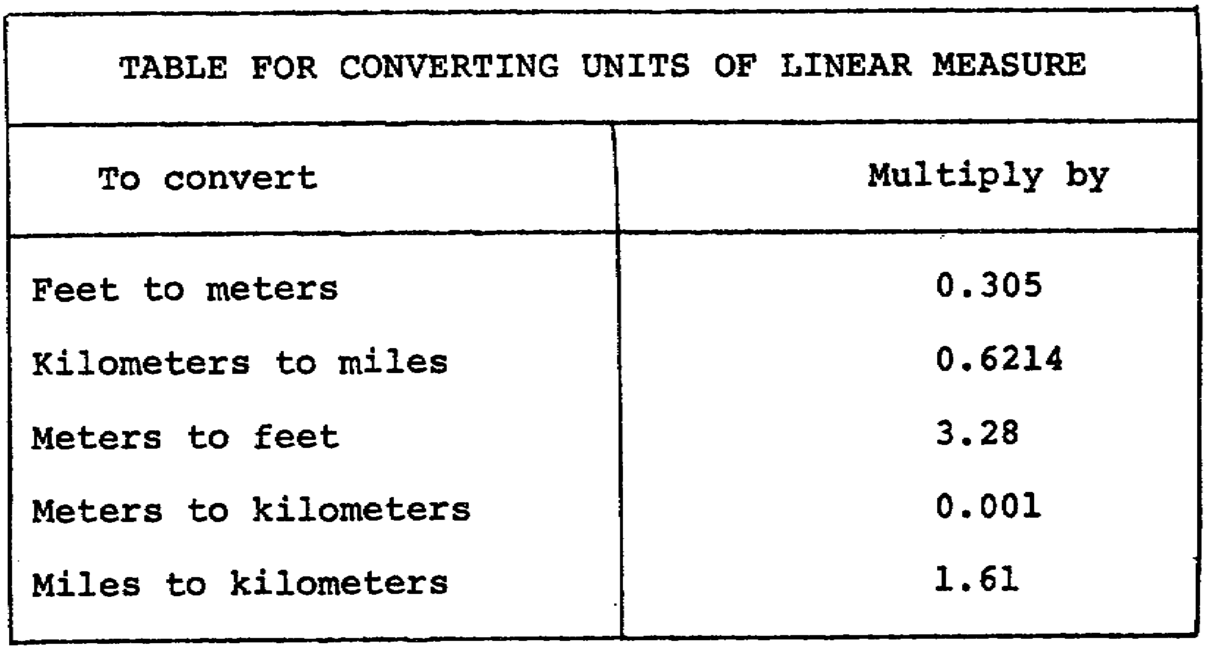


TABLE FOR CONVERTING UNITS OF LINEAR MEASURE

To convert	Multiply by
Feet to meters	0.305
Kilometers to miles	0.6214
Meters to feet	3.28
Meters to kilometers	0.001
Miles to kilometers	1.61

LESSON 1

INTRODUCTION TO

HIGH-FREQUENCY RADIO COMMUNICATIONS SYSTEMS

TRAINING OBJECTIVE:	Action:	Be able to list the functions of Defense Communications System and fixed station radio systems.
	Conditions:	Given SSO 750.
CREDIT HOURS:	2	

LESSON OBJECTIVES

When you have completed this lesson, you should know that:

1. The Defense Communications System is a global communications network operated by the Army, Navy and Air Force, but controlled by the Defense Communications Agency.

2. The use of single-sideband in high-frequency fixed-station makes possible the reduction of channel width and increases the efficiency of power utilization.

3. A single-sideband signal has better signal-to-noise ratio than a double-sideband signal because the receiver bandwidth may be reduced from the normal bandwidth required.

4. Physical separation of transmitter and receiver sites in a high-frequency long-distance radio station is required to minimize interference.

ATTACHED MEMORANDUM

1-1. DEFENSE COMMUNICATIONS SYSTEM.

a. Control by Defense Communications Agency. The communications system by which every theater and separate command maintains a contact with the Joint Chiefs of Staff is known as the Defense Communications System (DCS). This network, permanently established and permanently operating, is controlled by the Defense Communications Agency (DCA). It consists of radio circuits installed, operated, and maintained by the military departments; government-owned cables; and leased commercial cables and long-distance wire and radio circuits in the United States and overseas. The DCA controls the system through a series of communications control centers, and provides a means of integrating the communications systems formerly operated independently by the military departments.

b. A Worldwide System. The network is a global communications system that provides electrical communications facilities (teletypewriter, voice, data, facsimile, etc.) between military activities throughout the world. In addition, the system provides reliable communications for the Department of Defense, Presidential communications support, and various government agencies.

c. Deployment of Stations. The need for a communications station in any part of the world depends on the interest of a particular military service in that part of the world. For example, consider Hawaii as a typical example of representation by all services -- Aliamanu represents the Army, Wahiawa represents the Navy, and Hickam AFB represents the Air Force. In figure 1-1, these three military services are shown as the HON (Honolulu) subcomplex. And so it is throughout the world. Each oval in figure 1-1 represents one or more services, and each line represents the total system from one subcomplex to another. Thus, figure 1-1 represents the DCS, a giant system that can provide communications in peace or in war.

Figure 1-1. The Defense Communications System Complex.
(Located at back of subcourse booklet.)

d. Station Characteristics. Most radio stations in the DCS used for long-distance communications are rather large. Normally, large amounts of bulky equipment items are grouped together in a selected area for reasons of security, availability of power, and for efficiency of operation and maintenance. Moreover, since the antennas are in the high-frequency range, they cover large amounts of real estate. The combination of these characteristics dictates that the stations be emplaced in one location for long periods of time. Stations so emplaced are called fixed stations. However, mobile versions of these stations have been developed and may be transported to trouble spots around the world. In spite of differences in size and physical appearances, mobile and fixed stations must have compatibility of signal characteristics. Functionally, the equipments in these stations are designed for long-distance communications in the high-frequency range, and are variously known as long-haul and long-range.

e. Long-Haul Facilities. The facilities of the DCS consist of long-haul point-to-point radio, wire, and cable circuits used with diversified equipment, such as single-sideband (SSB), electronic time-division-multiplex, automatic and semiautomatic teletypewriter relay, and high-speed data terminals.

f. Major Links. Long-distance radio facilities furnish the major links or trunkline circuits between the stations in the DCS. Occasionally, short-distance radio facilities similar to those used for keying lines may be used to connect an outlying terminal station to its servicing relay station.

g. Circuit Assignments. Responsibility for providing communications facilities in a given area is assigned by DCA to the Army, Navy, or Air Force. Circuit assignments for traffic flow are designated by the DCS out of the facilities furnished by the selected service. The selected service also provides the personnel and command structure to implement the operation. The Army portion of the DCS is operated by the US Army Communications Command (USACC). The major traffic arteries of the DCS are shown in figure 1-1.

h. Full-Duplex Operation. Each of the DCS long-distance radio circuits includes two complete radio stations, one at each end of the circuit. The stations normally operate on a full-duplex basis and require an assigned radio frequency for each direction of transmission. The radio stations usually operate in space diversity; that is, two antennas are required to receive the radio signal. The arrangement is shown in block form in figure 1-2.

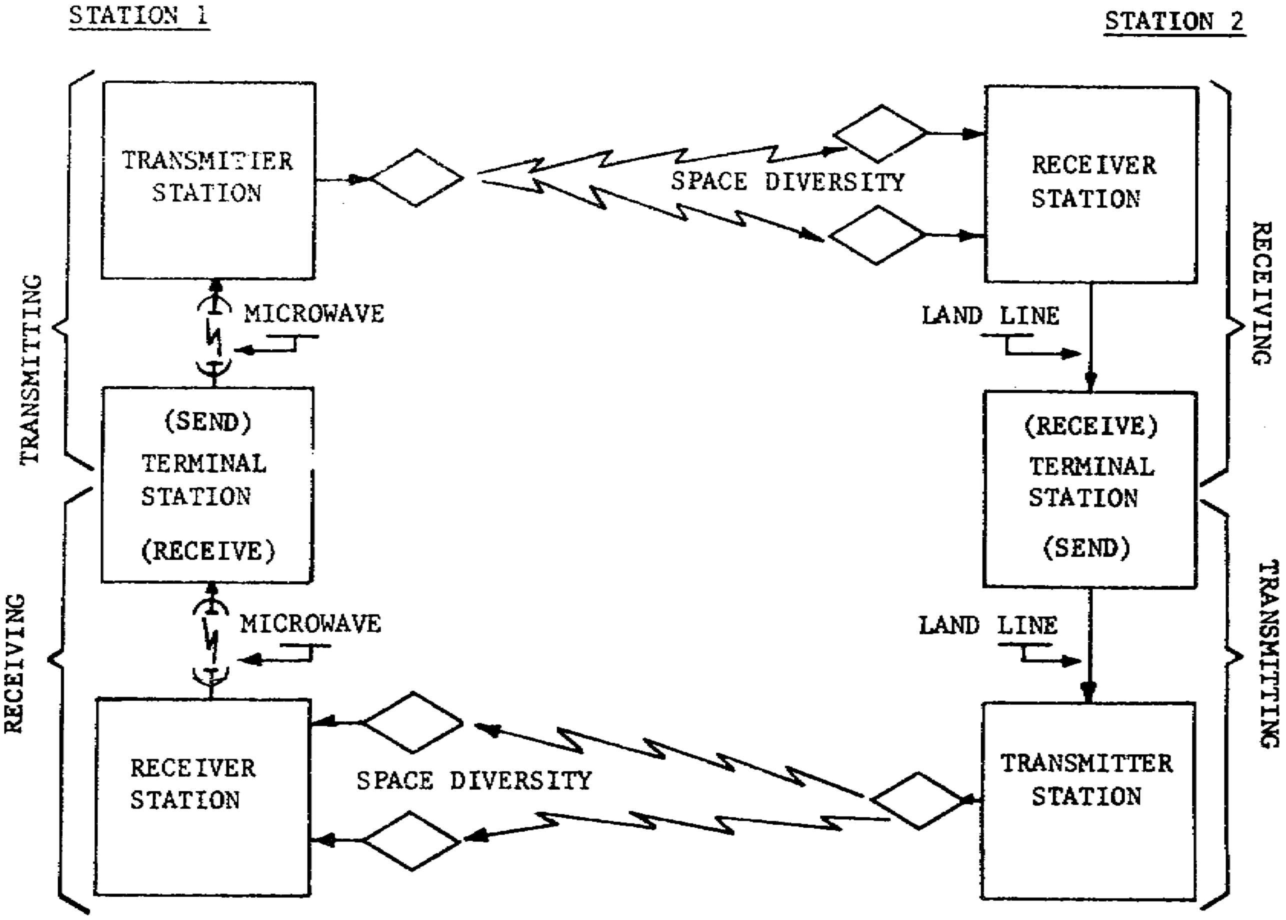


Figure 1-2. A full-duplex fixed radio station communication system.

i. Questions.

1-1a. What governmental agency is charged with controlling the Defense Communications System (DCS)?

a. Department of State.

b. Defense Communications Agency.

c. National Communications System.

d. Federal Communications Commission.

1-1b. The Army portion of the DCS is operated by the

a. US Army Electronics Command.

b. Defense Communications Agency.

c. US Army Satellite Communications Agency.

d. US Army Strategic Communications Command.

1-2. ORGANIZATION OF A FIXED RADIO STATION.

A military fixed radio station often is divided into three separate installations: a tape relay center combined with technical control at the terminal station, a radio transmitter station, and a radio receiver station (fig 1-3). Physical separation of the transmitter and the receiver sites is required to minimize interference.

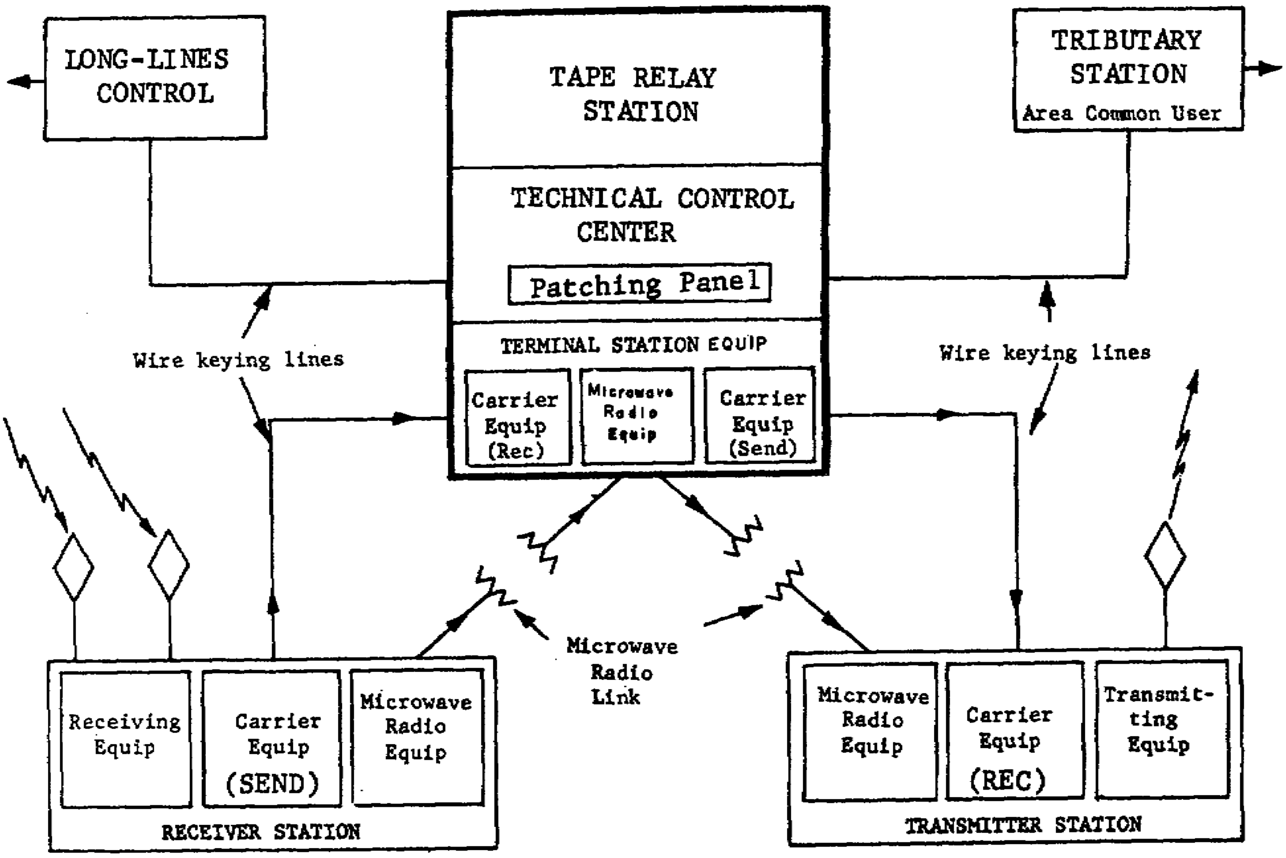


Figure 1-3. Organization of a fixed radio station.

a. Tape Relay and Associated Technical Control Center. For efficient operation, the technical control center usually is located adjacent to the tape relay station. It is desirable that both of them be located in the same building and separated by a glass panel so that operators in the technical control center can oversee the operations of the tape relay station.

(1) Tape relay station. The tape relay station receives and retransmits messages; that is, it relays written-record traffic between stations in the communications networks. The basic equipment consists of typing reperforators for recording incoming messages and transmitter-distributors for sending outgoing messages.

(2) Technical control center. The primary function of the technical control center is to control the written-record communications facilities in the area. Control people must always know the availability of equipment or circuits for immediate rerouting of the communications channels. Lines from every place of equipment in the associated tape relay station and area common-user terminal station, as well as all lines from the outlying installations, such as the transmitter and receiver stations, must appear on the patching panel in the control center. Technical control center equipment normally includes a main distributing frame, patching panels, line and circuit test equipment, monitoring devices, keying line and order-wire facilities, and radio receiving equipment capable of monitoring the associated long-distance radio transmitters.

(3) Terminal station. The terminal station equipment may include two different types of carrier telegraph terminals, depending on the systems used. One type multiplexes a number of individual teletypewriter channels for transmission between the terminal station and the local transmitter or receiver stations. A second type multiplexes 16 channels of teletypewriter communications for transmission over the long-distance SSB radio facilities. Signals from

the second type of terminal are not processed at either the radio transmitter or receiver station, but only at the terminal station. The terminal station also contains a set of microwave radio equipment.

b. <u>Radio Transmitting Station</u>. The radio transmitting station includes the antenna park and all equipment needed to transmit by radio the voice-frequency (VF) and direct-current (dc) signals received from the technical control center. This equipment includes the radio transmitters, keying line carrier terminals, and microwave radio link.

c. <u>Radio Receiving Station</u>. The radio receiving station includes the antenna park and all equipment required to translate received radio signals into VF or dc signals for retransmission to the technical control center. The equipment includes radio receiving, microwave link, and keying line carrier terminal.

d. <u>Tributary Station</u>. The tributary station receives, processes, transmits, delivers, or refiles written-record teletypewriter traffic originating and terminating at a major headquarters common-user service. This headquarters is the principal customer of the fixed radio station.

e. <u>Long-Lines Control Center</u>. The long-lines control center is used to control the long-distance circuits and facilities in the area under its jurisdiction. It is concerned primarily with telephone and teletypewriter communications over landline facilities to individual subscribers (dedicated service).

f. <u>Compatibility of Equipment</u>. Since identical signal types are transmitted between the technical control and transmitting and receiving stations, compatible terminal equipment must be used. The major difference between the transmitting and receiving stations lies in the types of radio equipment and antenna arrangements.

g. Questions.

1-2a. The two sections of a fixed radio station that are usually located close together are the

a. receiver and transmitter stations.

b. receiver station and terminal station.

c. tape relay station and technical control center.

d. transmitter station and technical control.

1-2b. The section of a fixed radio station that maintains information on the availability of equipment or circuits for immediate rerouting of communications channels is the

a. long-lines control center.

b. technical control center.

c. radio transmitting station.

d. teletypewriter terminal station.

1-2c. Teletypewriter signals sent over the single-side-band long-distance radio facilities are processed by the terminal equipment located in the

a. terminal station.

b. tributary station.

c. radio receiver station.

d. radio transmitter station.

1-2d. The sections of a fixed station in which microwave radio equipment normally will be found are the

a. tape relay station, long-lines control center, and radio transmitter station.

b. technical control center, tape relay station, and radio transmitter station.

c. radio transmitter station, radio receiver station, and carrier terminal section.

d. long-lines control center, technical control center, and carrier terminal section.

1-2e. Most fixed stations provide common-user and dedicated service. Dedicated service is furnished by the

a. tape relay station.

b. terminal station (tt).

c. long-lines control center.

d. technical control center.

1-3. FIXED RADIO STATION FACILITIES

a. Independent Sideband (ISB) Radio Facilities. ISB radio facilities are used extensively in fixed-station systems to provide multichannel telegraph, voice, data, and facsimile communications channels. In an ISB system the information carried in the upper sideband is different from the information carried in the lower sideband. One ISB radio system can provide various combinations of types of service, which can be individually distributed for use as either allocated or common-user communications channels. An ISB radio system provides four 3-kilohertz (kHz) VF channels of communications, each sideband containing two channels. Various combinations of terminal equipment can be incorporated in the system to give different quantities of teletypewriter channels.

b. Frequency-Shift-Keyed Radio Facilities. Frequency-shift-keyed (FSK) radio facilities are used in long-distance radio stations for one- to four-channel telegraph system or for single-channel facsimile systems. In an FSK system of transmission, the information is carried by shifting the frequency of the radio-frequency (RF) signal between two specified limits. In the high-frequency (HF) band the normal spread (difference between shifted frequencies) is 850 hertz (Hz). In telegraph transmission, the upper frequency indicates a marking pulse and the lower frequency indicates a spacing pulse.

(1) Single-channel system. Single-channel telegraph FSK radio systems (commonly called radio teletypewriter, or RATT) provide the least complex and most dependable automatic method of communications in long-distance radio networks.

(2) Multichannel system. Multichannel FSK radio teletypewriter systems operate in a manner similar to the single-channel system. The signals from two, three, or four teletypewriters are combined by a system of sequential timing. This system is known as time-division multiplex (TDM). The only additional requirement for radio and auxiliary equipment used in these circuits is that they must handle keying speeds several times faster than the equipment used for single-channel FSK systems.

(3) Facsimile service. Facsimile service is provided over FSK radio circuits by applying the signal in such a manner that the frequency is shifted in accordance with the signal. Different shades of gray in the picture produce different amounts of frequency shift within prescribed limits.

c. Intersite Radio Keying Facilities. Microwave radio link systems are used to connect the technical control center to the radio receiving and transmitting stations. They also can be used to provide short-distance (radio line-of-sight) communications facilities to outlying terminal stations or, in some cases, trunking channels to a nearby DCS radio link station. These radio link systems may be used as backup circuit facilities in the event of trouble with other types of communications systems terminating at the site.

(1) Very high frequency (VHF) and ultra high frequency (UHF) radio link systems operating in the frequency range of 30 to 1,500 megahertz (MHz) usually accommodate from four to twelve 3-kHz channels. Standard telephone carrier equipment can be applied over these systems.

(2) Microwave systems operating in the frequency range above 1,500 MHz can provide up to forty-five 3-kHz channels over a single path. Microwave is preferred to VHF-UHF because of its larger baseband capability.

d. Intersite Wire Keying Facilities. A wire-line system usually is provided for keying facilities to connect the technical control center and the radio transmitting and receiving stations. This system parallels the radio link system. Either multiple-pair cables or open-wire lines can be used to provide the necessary keying lines. Two general types of single must be passed by these wire lines, but must not be mixed in the same cable if mutual interference is to be avoided.

(1) Voice-frequency signals. These signals consist of keyed telegraph tones, speech (telephone), and facsimile.

(2) Direct-current signals. These signals consist of telegraph current pulses.

e. Telephone Facilities. Each terminal station is connected into a local telephone network. Thus, a local telephone user in a military establishment can be connected to any other telephone user in the worldwide network, no matter how distant. Of course, restrictions as to priority and importance must be imposed, and telephone circuits are restricted to passing urgent information that cannot be sent by a written message. Most military telephone equipment is designed to operate over a standard two-wire VF facility having 3 kHz bandwidth. However, the two-wire circuit is converted to four-wire during the transmission process. The equipment for making this conversion is normally installed in the terminal station.

f. Long-Distance Dc Telegraph Lines. Dc telegraph wire-line facilities may be installed and operated by military forces, or they may be leased from commercial agencies in the same manner as telephone facilities. Most circuits use neutral keying, although long-distance landline telegraph circuits may require polar keying to minimize the effect of telegraph distortion.

g. Carrier and Radio Terminal Facilities. Long-haul DCS facilities provide two types of channels: 3 kHz VF channels and telegraph channels. While only one voice or facsimile channel can be contained in a 3 kHz VF channel, up to 16 telegraph channels can be combined in one 3 kHz band. The process of combining a number of VF telegraph channels into one 3 kHz band is called frequency-division multiplexing. Although there are several types of multiplexing equipment, there are only two general methods of multiplexing telegraph signals.

(1) Time-division multiplexing. This method combines several telegraph signals by selecting first one signal and then another, in sequence. The combined selected signals are transmitted over a single path to the receiving equipment. Here they are selected and reformed into their original individual telegraph signals.

(2) Frequency-division multiplexing. This method divides a selected portion of the VF spectrum (usually 200 to 3,500 Hz) into the required number of frequency bands and assigns one band to each channel of telegragh communication. The dc telegraph signal assigned to each individual channel modulates or keys the VF tones within that discrete frequency band. The combined tones of all the channels are sent over a common transmission medium to the receiving end of the system. At the receiving end, these tones are separated into the various frequency bands and demodulated, and the dc signals from each individual channel become available again.

h. Patching Facilities. Complete flexibility of transmission facilities and equipment is necessary at each installation of the fixed station. This flexibility is provided by patchboards on which the input and output of each system component appear. Because of the different forms that a particular signal may take in its passage through the system, several separate patching facilities usually are required at each installation.

(1) Technical control center. Two separate patching facilities usually are required at this installation, one for dc signals and the other for VF signals. All channels and connecting circuits used by the communications center must appear on these patching panels. Both the input and output of all multiplexing or other auxiliary system terminal equipment must also appear on the patch panels at the technical control center.

(2) Radio transmitting station. At least three types of patch panels are needed at the radio transmitting station. In addition to separate dc and VF patch panels, an RF patching facility is needed to switch low-powered RF signals from one equipment to another within the transmitting station. In most stations, additional antenna switching facilities are required. Because of the high-power output of most transmitters, these antenna switching systems may be installed outside the actual transmitting building, but have remote controls inside the building.

(3) Radio receiving station. At least three separate patching facilities are required at the radio receiving station. These are similar to the patching facilities at the transmitting station, except that an outdoor patching or switching arrangement for RF antenna switching is not required. Since the received radio signals are low powered, they can be readily patched on an indoor RF patch panel.

i. Questions.

1-3a. Independent sideband radio facilities are used extensively in the DCS. If maximum use is made of an ISB radio circuit, a possible assignment of communications channels is

a. four teletypewriter channels.

b. 16 teletypewriter channels.

c. one VF (telephone) and 16 teletypewriter channels.

d. three VF (two telephone and one facsimile) and 16 teletypewriter channels.

1-3b. One difference between facsimile service and any one of the other types of frequency-shift transmission over long-distance radio systems is that with facsimile the radio-frequency signal shifts

a. varying amounts that depend on the different shades of gray in the image.

b. from one fixed limit to another in accordance with different shades of gray.

c. at a high repetition rate regardless of whether picture elements are being scanned.

d. only during the synchronizing intervals, not during picture element scanning.

1-3c. A primary use of microwave radio link systems in the DCS is to provide multichannel facilities between the

a. transmitter and receiver stations.

b. receiver station and long-line control center.

c. tape relay station and technical control center.

d. transmitter station and technical control center.

1-3d. The communications system that furnishes backup facilities in the event of trouble with circuits between the station sites makes use of the

a. wire keying lines.

b. microwave radio link.

c. area common-user circuits.

d. long-lines communications system.

1-3e. Long-distance dc telegraph lines are installed and maintained by the military forces or leased from commercial communications agencies. Polar keying is sometimes needed on long-lines to

a. utilize two wire circuits.

b. multiplex telegraph channels.

c. minimize telegraph distortion.

d. increase the number of telegraph carrier channels.

1-3f. To make the most efficient use of radio facilities, most DCS stations combine 16 teletypewriter VF channels into one 3 kHz signal. The process used to combine these signals is known as

a. VF patching.

b. frequency shift keying.

c. time division multiplexing.

d. frequency division multiplexing.

1-3g. Flexibility in the use of communications equipment of a fixed radio station is obtained by providing switching and patching facilities at the various sections. The section that may have to locate some of its patching facilities outside the building is the

a. radio transmitter station.

b. technical control center.

c. radio receiver center.

d. tape relay station.

1-4. TELETYPEWRITER OPERATION

a. General. The function of any teletypewriter communications system, whether radio or wire, is to reproduce precisely the same message (in the same content and form) at the receiving end of the system that was sent from the transmitting end. An understanding of how this is accomplished requires a familiarization with telegraph principles.

b. Telegraph Circuits. A teletypewriter is a mechanical telegraph device which automatically prints the message from a prearranged telegraph code. A telegraph circuit connects two or more teletypewriter machines in a communications network. All equipment, of whatever type, between the telegraph loop terminations become part of the telegraph circuit.

c. Teletypewriter Equipment. The teletypewriter consists of a transmitting keyboard and a receiving and printing mechanism. Depressing a key releases the transmitting mechanism which transmits a series of electrical impulses over a telegraph circuit to a receiving device. This device translates the impulses into a mechanical action, enabling the printer to select and print the proper character. Each key sends a different arrangement of pulses, and the message may be printed on a page form or on a tape, at a rate that may be as high as 100 words per minute (WPM). When a number of teletypewriters are installed on the same circuit, they are usually wired in series. Any machine in a circuit may be made to print any of the 26 letters of the alphabet and 24 different characters and numerals. Other functions performed include carriage return, line feed, letter shift, space, blank, signal bell, and motor stop. The motor stop, however, is not used in the DCS. Automatic transmission, which permits maximum use of the traffic-handling capability of the teletypewriter, can be accomplished by the use of tape that was previously perforated by an operator using a special keyboard. A transmitter-distributor (TD) interprets the message from the perforated tape and sends that information to teletypewriter receiving equipment.

d. Teletypewriter Code. The special binary signaling code used in teletypewriter transmission provides characters or signals of uniform length, each consisting of five unit intervals of time. The units are equal in length and are known as either marking or spacing impulses in the telegraph circuit. In the marking condition, current flows in the telegraph circuit, and the selector magnets in the receiving printers are operated. In the spacing condition, current does not flow in the telegragh circuit, and the selector magnets do not operate. Various combinations of marking and spacing impulses are used for different letters in the alphabet, for numerals, and for functions. Thus, each time the teletype-writer key is depressed, a distinctive code signal is sent, consisting of marking and spacing impulses.

(1) The first pulse transmitted is always a spacing pulse. It starts the mechanical operation of the printer. Then the five signal code pulses are transmitted, followed by a step pulse which is a marking pulse that is 1.42 times the length of any one of the six preceding equal-length pulses. The stop pulse synchronizes the receiving printer mechanical sequence with the received signal code sequence. This is a nonsynchronous (asynchronous) binary code system.

(2) In a synchronous binary code system the arrangement of pulses determines the synchronization. Since start and stop pulses are not required, the synchronous code system permits the transmissions of more information in a given time frame than the nonsynchronous system. The synchronous binary code system is not well

suited to use in the teletypewriter because it neither allows for nor corrects differences in the speed of the sending and receiving mechanisms; this is due to the absence of the start and stop pulses. The synchronous binary code system is best suited to electronic data transmission devices.

e. Telegraph Systems. A neutral telegraph system consists of telegraph circuits and equipment that operate on the basis of current flow during the marking impulse and the absence of current flow during the spacing impulse. A polar telegraph system employs similar facilities, except that the current flows in one direction during the marking impulse and reverses direction on the spacing impulse. The polar telegraph system is relatively free from the effects of telegraph distortion, so it can operate over greater lengths of dc telegraph circuits than is the case with neutral operation. However, because of the necessity of using polar relays to convert from neutral to polar signals and back again to neutral, the polar telegraph system requires more equipment and more careful installation and maintenance than the neutral telegraph system.

f. Question.

Assume that a synchronous dc teletypewriter signal is applied to a teletypewriter set designed to receive a nonsynchronous signal. What will be the result?

a. The synchronous signal pulses are too short to be of practical value.

b. Synchronization will be maintained by the code combination of the synchronous teletypewriter signal.

c. Synchronization of sending and receiving units cannot be maintained because the stop pulse is missing from the synchronous signal.

d. The synchronous signal must appear in the polar form, while the nonsynchronous signals can be used in either the neutral or polar form.

1-5. TRAFFIC DATA

Since various types of communications have different capacities, the type that is chosen for a particular application is the one that will meet the requirements and provide the greatest capacity. For example, a person talking rapidly and without pause can speak about 200 WPM over a telephone channel. The same telephone channel can be used to provide 16 teletypewriter channels, each capable of sending up to 100 WPM. When so used, the telephone channel can handle a transmission of about 1,600 WPM. Therefore the majority of communications over long-distance radio systems are handled by means of teletypewriter circuits. Manual telegraph, voice, facsimile, and data transmission circuits are also used when their specialized services are required. Most transmission is accomplished by transmitter-distributors because their constant speed of operation provides the most efficient use of teletypewriter circuits.

1-6. INTRODUCTION TO SINGLE SIDEBAND

a. The success of military operations often depends on the adequacy of radio communications. Two of the major problems in HF radio are the availability of transmission channels and the amount of power required to obtain a designated range. The number of channels available within the practical operating frequencies of radio sets is limited, so there are not enough channels to fulfill all of the requirements. Radios must be developed which will use a narrower channel width than at present so that more channels can be allocated. In addition, one of the primary factors that determine the range of a radio set is the power output of the transmitter. More efficient utilization of this power will provide for increased range of a reduction in the size of the individual set. An SSB system makes possible a reduction of channel width and an increase in the efficiency of power utilization.

b. Single-sideband transmission is a method of communications in which the frequencies produced by the process of modulation on one side of the carrier are transmitted, and those on the other side are suppressed. The carrier may be transmitted, suppressed, or eliminated.

1-7. SINGLE-SIDEBAND SIGNALS AND AMPLITUDE MODULATION

a. To review amplitude modulation (AM), assume that a 100 kHz carrier is amplitude modulated by a 1 kHz tone. Two new side frequencies will be produced as shown in figure 1-4. The upper side frequency is the sum of the 100 kHz carrier and the 1 kHz tone, or 101 kHz. The lower side frequency is the difference between the 100 kHz carrier and the 1 kHz tone, or 99 kHz.

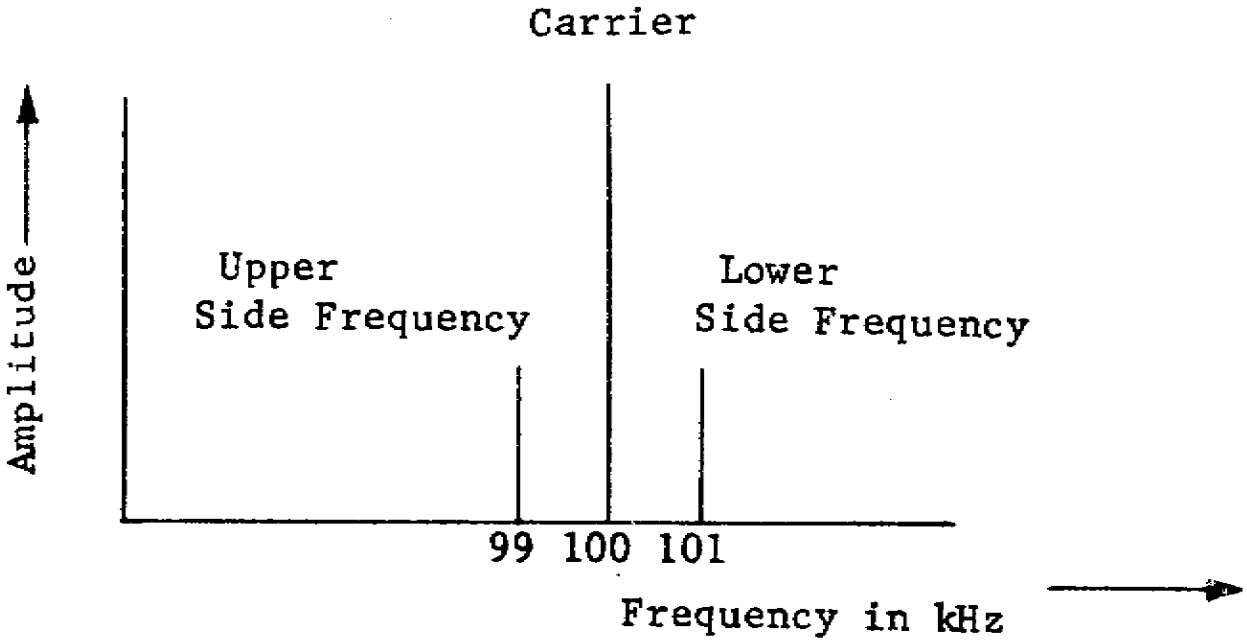


Figure 1-4. AM carrier and side frequencies.

b. Assume that the same 100 kHz carrier is amplitude-modulated by frequencies of 1 kHz, 3 kHz, and 5 kHz. A resultant upper and lower side frequency for each of the modulating frequencies will be produced. The upper side frequencies, the sum of the 100 kHz carrier and each of the modulating frequencies, will be 101 kHz, 103 kHz, and 105 kHz. The lower side frequencies, the difference between the carrier and each modulating frequency, will be 99 kHz, 97 kHz, and 95 kHz. The upper and lower side frequencies are shown in figure 1-5.

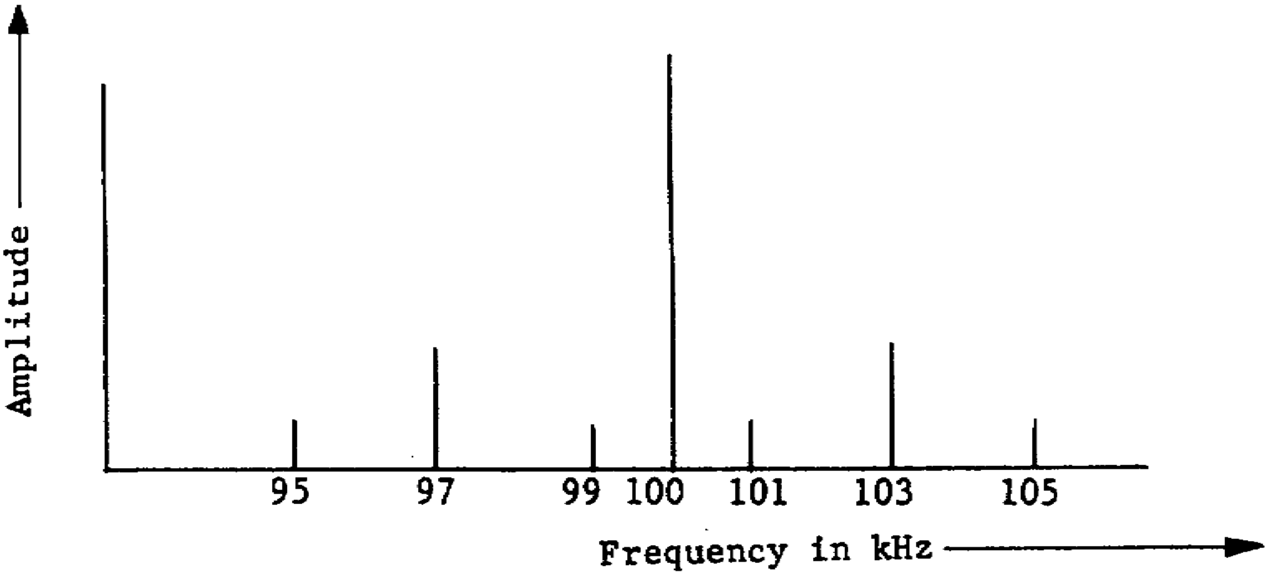


Figure 1-5. AM carrier with upper and lower side frequencies.

c. The three upper side frequencies make up a band of frequencies. This band is called a sideband. Since it is made up of the upper side frequencies, it is designated as the upper sideband. Similarly, the lower side frequencies are known as the lower sideband. The information, which was originally the modulating audio frequencies of 1 kHz, 3 kHz, and 5 kHz has now been converted into sidebands which are actually RF. Each of the sidebands contains the same information. To transmit all of the information, a bandwidth of 10 kHz must be passed. Since all of the information is contained in either sideband, let us remove one sideband. Then, it would be necessary to transmit only a bandwidth of 5 kHz. Furthermore, by eliminating one sideband the power applied to the antenna may be reduced by one-sixth. An even greater reduction in power applied to the antenna may be accomplished by eliminating the carrier, since all of the information is in the sidebands. The carrier alone accounts for two-thirds of the total power applied to the antenna. Therefore, it can be seen that besides cutting the bandwidth requirements in half, the SSB system can transmit the same signal in terms of effective sideband power with one-sixth of the power required by a double-sideband (DSB) system. Elimination of the carrier can reduce bandwidth requirements to less than half of that required for DSB operation. For example, if the modulating frequencies range from 500 to 1,200 Hz, the actual bandwidth of the radiated RF signal (with eliminated carrier) is 700 Hz.

However, whenever a pilot (suppressed) carrier is transmitted, the bandwidth of the radiated signal is equal to the highest modulating frequency. In the above example, the bandwidth of the SSB signal with carrier is 1,200 Hz.

d. Figure 1-6 shows how an SSB transmitter having 50 watts peak-envelope-power (PEP) output is equivalent in desired sideband power to an AM transmitter rated at 200 watts carrier power. A 200-watt AM transmitter 100-percent modulated will have a total antenna power of 300 watts (carrier plus sidebands). A comparison of the total power output of the two transmitter shows that the AM transmitter (B) requires six times the antenna power of the SSB transmitter (A) to transmit the same effective signal power.

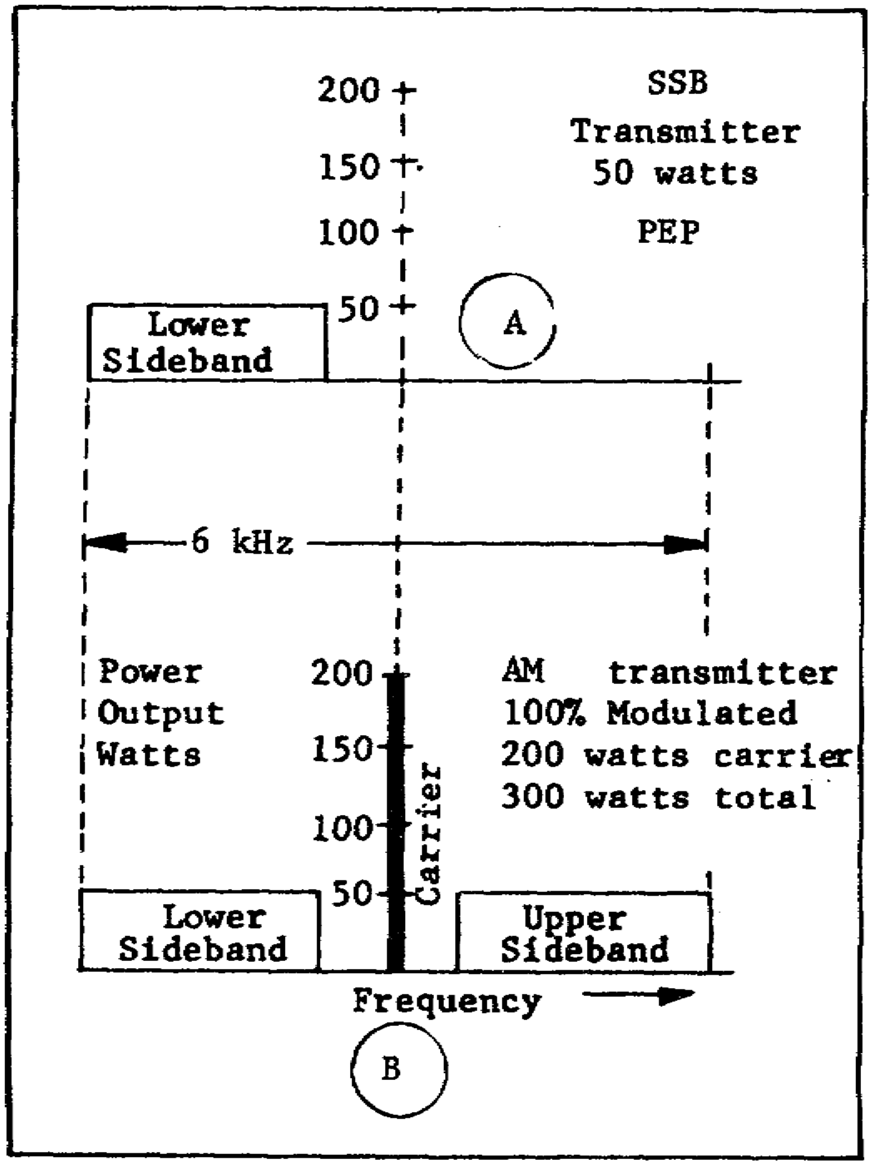


Figure 1-6. Comparison of power and bandwidth (AM and SSB).

e. Questions.

1-7a. Assume that an 800 kHz carrier is amplitude-modulated with a 4 kHz signal. All of the transmitted frequencies in a double-sideband AM system (neglecting spurious harmonics) are

a. 796 kHz, 800 kHz and 804 kHz.

b. 796 kHz and 804 kHz.

c. 796 kHz and 800 kHz.

d. 800 kHz and 804 kHz.

1-7b. When an 800 kHz carrier is amplitude-modulated with a band of audio frequencies ranging from 300 to 3,500 Hz, the bandwidth of the transmitted signal in a DSB AM system is

a. 3,200 Hz.

b. 3,500 Hz.

c. 6,400 Hz.

d. 7,000 Hz.

1-7c. In an eliminated-carrier single-sideband transmitter, a band of audio frequencies ranging from 300 to 3,500 Hz is used to modulate the 800 kHz carrier signal. The bandwidth of the transmitted signal is

a. 600 Hz.

b. 3,200 Hz.

c. 3,500 Hz.

d. 6,400 Hz.

1-7d. Assume that a commercial SSB transceiver (transmitter and receiver built as a single unit) has a peak-envelope-power (PEP) of 30 watts. The power that must be applied to the antenna from a standard DSB AM transmitter to provide equivalent effective signal power is

a. 60 watts.

b. 90 watts.

c. 120 watts.

d. 180 watts.

1-8. TYPES OF SINGLE-SIDEBAND TRANSMISSION

If the carrier is effectively eliminated, only the one group of sidebands is transmitted. However, the carrier must be reinserted in the receiver as a reference point to enable the demodulator (detector) to change the information back to its original form of audio signal. This step can be very critical, since the reinserted carrier must be exactly the same frequency as the eliminated carrier in order to reproduce the audio signal. Since the carrier need only be a reference frequency, the transmitter can radiate a small amount of carrier (pilot carrier) along with the one sideband. This small amount of carrier can be used as a guide or reference in the receiver to establish the correct reinserted carrier. This type of transmission is called suppressed carrier single-sideband transmission.

1-9. ADVANTAGES AND DISADVANTAGES OF SINGLE-SIDEBAND

a. Advantages. Several distinct advantages have been obtained with the development of SSB transmission. The primary advantage is that only one-half the bandwidth need be transmitted, thus using only half as much space in the frequency spectrum. Also, the total power is transmitted in one sideband. This provides for more effective power output with SSB transmission than can be obtained from DSB transmission under the same conditions. In addition, SSB provides a better signal-to-noise ratio because the receiver bandwidth may be reduced from the normal bandwidth required for DSB operation. Furthermore, SSB transmission produces less distortion in the presence of selective fading than DSB transmission. Another advantage is that an SSB transmitter consumes less power than a DSB transmitter of equivalent size and power output.

b. Disadvantages.

(1) The oscillator that develops the inserted carrier in the SSB receiver must have a high order of accuracy and stability. For example, if the oscillator frequency is slightly below the carrier frequency when the upper sideband is being received, the output audio is high pitched, as when a phonograph record is played too fast. Conversely, if the oscillator frequency is too high the audio is low pitched.

Oscillator accuracy and stability are improved by using frequency synthesizers. A frequency synthesizer produces a wide range of equally spaced frequencies, with the overall stability established by a highly stable master oscillator. The SSB receiver having a frequency synthesizer is tuned by selection of the correct synthesized frequency. A similar frequency synthesizer must be used in the radio transmitter to make the transmitter and receiver have compatible frequency selections.

(2) Not only is oscillator instability in an SSB receiver annoying to the listener, but it also tends to distort the VF FSK teletypewriter signals. Even a slight variation of oscillator frequency in the receiver makes passage of the VF FSK signals nearly impossible through the narrowband filters of the associated VF telegraph terminal. The result is garbled teletypewriter messages.

(3) SSB transmitters require the use of lowlevel modulation. Lowlevel modulation takes place in the transmitter at a point where the power is low compared with the power output of the transmitter. This type of modulation requires the use of linear amplifiers, usually operating class A or B. Moreover, linear amplifiers are difficult to adjust. The need for linear amplifiers precludes the use of the more efficient and more easily tuned class C amplifiers.

c. Question.

1-9a. Compared with DSB radio systems, SSB systems have the advantage of greater

a. signal-to-noise ratio and the ease with which the output amplifiers may be adjusted.

b. efficiency due to smaller input power requirements and less critical frequency stability.

c. efficiency due to the use of linear output amplifiers and the almost complete lack of selective fading.

d. effective output power using equal transmitter input power; and more economical use of the frequency spectrum.

LESSON 2

COMMUNICATIONS CIRCUIT QUALITY

TRAINING OBJECTIVE:	Action:	Be able to list the fundamentals of circuit quality control.
	Conditions:	Given SSO 750.
	Standard:	You must be able to successfully complete lesson exercises.

CREDIT HOURS: 2

LESSON OBJECTIVES

When you have completed this lesson, you should know that:

1. The quality of message reproduction is an indication of circuit quality.

2. The effect of noise on a signal is determined by observing the noise at the receiving device.

3. The signal-to-noise ratio in a high-frequency long-distance circuit can be improved by a number of techniques, most of which are applied to the radio receiving station.

4. Circuit conditioning involves processes of equalization, delay compensation, and frequency translation.

5. Emissions are classified and symbolized according to the type of modulation of the main carrier, type of transmission, and supplementary characteristics.

ATTACHED MEMORANDUM

2-1. QUALITY OF COMMUNICATIONS

Electrical communications is carried on by wire or radio, or by a combination of the two. The quality of communication by either wire or radio is affected by noise, interference, and distortion. The quality of communication is indicated by the presence or absence of these three factors. When none of the three are present, the circuit quality and the signals are said to be perfect. Although no communications circuit has perfect quality, every attempt is made by communicators to reduce the effect of noise, interference, and distortion.

a. Noise. There are two forms of noise: natural and manmade. Natural noise results from atmospherics, while manmade results from electrical appliances and devices.

b. Interference. Interference is the disturbance caused within a signal by extraneous signals. Interference in cables usually results from electromagnetic or electrostatic induction between wire pairs. Interference between radio stations is caused by careless operators or unstable radio transmitters.

c. Distortion. Distortion is the result of variation or change in the amplitude, phase, or frequency of an ac signal, or the change in length of dc signal pulses.

d. Total Effect. The total disturbing effect on a signal is the result of the cumulative effect of noise, interference, and distortion. Although these disturbances can be defined and discussed, they are difficult to extract from the signal once they have entered it. Prevention of these disturbances is therefore more important than is compensating for their effect.

2-2. EFFECT OF NOISE

The effect of noise on a signal is never known until the signal is demodulated. The effect of noise must therefore be observed at the receiving device.

a. General. Noise can occur on specific frequencies, or it can be a type that is spread equally over a wide part of the frequency spectrum. Impulse noise and ac hum usually are frequency selective--that is, they occur only on specific frequencies. Types of noise often present on radio circuits such as thermal noise, cosmic noise, atmospheric noise, etc., are generally broad and evenly distributed across a wide band.

b. Signal-to-Noise Ratio. The actual signal strength is not the most important factor in a communications circuit, since a weak signal can always be amplified. However, noise in the circuit is amplified at the same time. Also, additional amounts of noise are added at each amplifier. Therefore, the more times the signal is amplified in an overall system, the higher the noise level. If the noise level at the receiving device is far enough below the signal level so that the receiving mechanism can be adjusted to operate only on the desired signal and to ignore the lower amplitude noise, then the noise has no effect on the signal. The relationship between the amplitude of the signal and the amplitude of the noise is called the signal-to-noise ratio. This ratio is the limiting factor for reliable communications.

c. Questions

2-2a. Noise can occur on specific frequencies, or it can be spread over a wide part of the frequency spectrum. One type of noise that is frequency selective is

a. cosmic noise.

b. thermal noise.

c. impulse noise.

d. atmospheric noise.

2-2b. Reliability is the most important characteristic of a communications system. The limiting factor for reliable communications is the

a. signal strength.

c. number of amplifiers.

c. signal-to-noise ratio.

d. level of received noise.

2-3. SUPPRESSION OF MANMADE RADIO NOISE

a. An electric spark developed across relay contacts or electric motor brush contacts generates RF noise which, unless suppressed, can cause disruption of radio reception. Suppression of radio noise from sparking contacts can frequently be achieved by devices called suppressors, or spark killers. The common type of spark killer used with dc telegraph and teletypewriter relays or keying contacts consists of a resistor in series with a capacitor, connected across the contacts. The connecting leads must be kept as short as possible. Teletypewriter transmission measurement must be taken before and after installation of spark killers to detect any possible deterioration of waveshape that may in turn result in garbled or distorted signals (telegraph distortion). The commutators and sliprings of motors and generators require only the capacitor for adequate spark suppression.

b. To suppress noise caused by spark ignition systems, installation of standard suppressors without shielding gives considerable improvement at frequencies below 30 MHz, and some improvement at higher frequencies. Shielding of the device causing the noise may be necessary if suppression does not reduce the noise sufficiently. The criticalness of joints and materials in high-tension ignition shielding is greatly reduced by the use of suppressors. Army tactical vehicles, engine-driven equipment, and electrical and electronic equipment are normally suppressed from 0.15 to 1,000 MHz.

c. Radio noise may be "bottled up" within a well-shielded source by filters across all leads connected to the source. Typical bypass capacitors, even with very short leads, are effective up to only a few MHz, since they become less effective above their self-resonant frequencies. High quality feed-through suppression capacitors must be used where HF suppression is required, because they are effective up to 1,000 MHz.

d. When installing cables within the receiving station, it is advisable to separate conductors carrying RF signals from all other conductors. It is also advisable to pass voice and dc signals through separate cables to prevent crossfire of dc pulses into the voice signals. Such crossfire sounds like thumps or clicks in the voice signals.

e. The ground connection of a radio receiver often introduces noise into the receiver. The best remedy is to separate low-impedance grounds by providing short, direct, independent connections from the receiver and the noise source. Keep all receiver ground leads physically and electrically separated from the ground leads of any noise source.

f. Good bonding maintenance and practices are essential to obtain low-impedance ground connections between equipment or suppressors and vehicles or frames, thereby preventing generation or spread of radio noise. Connections should be direct, and contacting surfaces clean, bright, and firmly held together. Movable parts should be bonded to the stationary frame with flexible straps of tin-copper braid. Such straps should be kept as short as possible to reduce their inductance.

g. Good electrostatic shielding of a receiver (or any noise-producing equipment) can be insured by enclosing the receiver in a high-conductivity metallic shield, such as solid copper, aluminum shielding, or copper screening. All wires entering or leaving the equipment (except the antenna leads) should be properly bypassed or filtered. Necessary holes or cracks in a shielding should be kept as small as possible. Shielding can be improved by bonding the joints at closely spaced points. The lower the frequency, the thicker must be the shield. Because of the strong electromagnetic field that occurs at low frequencies, a soft iron shield may be more effective than one made of copper or aluminum.

h. Questions.

2-3a. Assume that you are monitoring a voice line in a radio station and you hear key clicks or thumps in the voice signal. The probable reason for this interference is that someone is sending

a. RF signals through a cable carrying dc pulses.

b. dc pulses through a cable carrying voice signals.

c. RF signals through a cable carrying voice signals.

d. facsimile pulse through a cable carrying RF signals.

2-3b. Sometimes it is necessary to inclose radio receivers with a metallic shield, such as copper screening. The purpose of this shield is to reduce

a. selective fading.

b. noise interference.

c. interference fading.

d. signal-to-noise ratio.

2-4. IMPROVING THE SIGNAL-TO-NOISE RATIO

Circuit reliability in long-distance radio operation depends to a large degree on the signal-to-noise ratio (S/N). The higher this ratio (large signal strength compared with noise level), the better are the chances for reliable communications.

a. Selection of Media. Wherever several transmission media are available, the technical controller should select the one which provides the best S/N for important message traffic.

(1) Radio propagation predictions help the technical controller to select the most reliable transmission frequencies. The predictions tell him in advance which frequencies will most likely provide him with reliable communications circuits. However, there is no guarantee that the predictions will always hold true. Sudden ionospheric disturbances always add elements of doubt to the success of HF long-distance radio communications. Of all the radio frequencies in the spectrum, only those in the HF range offer long-distance transmission at economical levels of transmitting output power without resorting to frequent relay stations. There are times when communications in the HF band becomes nearly impossible. For this reason the Department of Defense developed and installed a satellite communications system that does not depend upon the ionosphere.

(2) Experience has shown that satellite communications systems consistently provide the highest quality long-distance communications in spite of the relatively low power used in the ground terminal transmitters. This quality and reliability results from a combination of line-of-sight transmission paths, directional antennas, frequency modulation, and low-noise high-gain receivers. Primarily the greatest improvement in the signal is due to the line-of-sight transmission path. Moreover, frequencies used

are so high that they penetrate the ionosphere. Since the radio waves are neither reflected nor seriously refracted, they are relatively independent of the vagaries of the ionosphere.

b. Techniques. At the high frequencies used for long-distance communications, the S/N can be improved by a number of techniques, most of which are applied to the radio receiving station. The radio receiving station primarily determines the action to be taken and when that action should occur. The radio receiving operator is the first to know when that action should occur. The radio receiving operator is the first to know when the signal quality deteriorates to dangerous levels. He receives his warning by frequent fades and a rise in noise level. The radio receiver can do little about the noise that rides on the incoming signal. However, receiver design greatly reduces the amount of internally produced noise, especially the "front end" noise. Specially designed radio receivers include refrigerated RF preamplifier stages called parametric amplifiers. These high-gain low-noise amplifiers are to be found in satellite communications ground terminals and tropospheric scatter terminals. A list of techniques used to improve the S/N in HF long-distance radio communications follows.

(1) Radio transmission path.

(a) Directional antennas. A directional antenna at the transmitting station beams most of the radiated energy in the direction of the receiving station. A directional antenna at the receiving station limits the beamwidth of the received radio signal to the direction from which the radio signals arrive.

(b) Radio propagation predictions. Radio propagation predictions inform the technical controller and radio receiver operator which frequencies will most likely provide the strongest signal for the time of day and season of the year.

(2) Radio transmitter.

(a) Single-sideband transmission. Single-sideband transmission provides a stronger received signal than double-sideband transmission because most of the available power is concentrated in the information-bearing portion of the signal. Further, the absence of a strong carrier prevents heterodyning with adjacent signals, as well as minimizing distortion that occurs when the carrier fades during selective fading periods.

(b) Increase in power output. Although an increase in radiated output power does improve the S/N, the improvement is not spectacular. Moreover, when the fading conditions create an absence of signal at the receiving station, no increase in power can improve the S/N.

(c) Reduction of bandwidth. By reducing the signal bandwidth at the transmitter, the receiver bandwidth can be narrowed a like amount, improving the S/N by the numerical value of bandwidth decrease. In other words, if the signal bandwidth is reduced to one-half its former value, the S/N is improved by a factor of 2.

(d) Change of transmitter frequency. The change of transmitter frequency in line with radio propagation predictions is a very effective method of improving the S/N. The frequency-changing process is a completely coordinated activity under control of the two communicating technical controllers, who are alerted to the need for frequency change by the radio receiving operators.

(3) Radio receiver.

   (a) Circuit. A triple-conversion superheterodyne circuit is normally used in HF radio receivers to achieve the necessary selectivity and sensitivity.

   (b) AGC. Automatic gain control (AGC) helps the radio receiver to maintain a relatively constant output in the presence of fading. In SSB reception, the reduced pilot carrier normally furnishes the input signal for the AGC action.

   (c) AFC. Automatic frequency control (AFC) helps to keep the receiver tuned precisely to the received pilot carrier in SSB reception, thus minimizing the effects of transmitter frequency drift, as well as stabilizing the value of AGC voltage developed from the pilot carrier. When radio receivers and transmitters use compatible frequency synthesizers, the importance of AFC is minimal.

(4) Terminal equipment.

   (a) Narrowband filters. The bandpass of each filter in the terminal equipment is designed to pass only the signal components needed to convey the information desired, and to ignore other frequencies on either side of the bandpass.

   (b) Peak limiters. Peak limiters reduce the effect of noise on the signal by clipping off the noise peaks above the desired peak level of signal. However, peak limiters can be used only on signals that have a constant amplitude, such as frequency-modulated or frequency-shift-keyed. Peak limiters cannot be used on voice or AM signals because the clipping of peaks distorts the signal.

c. Meaning of S/N. The S/N is a ratio in which the signal should always exceed the noise.

(1) Since the human ear is not frequency sensitive, it hears all frequencies within its range. If you were to listen to the output of a wideband radio receiver with a pair of earphones, you would hear both signal and noise together. Your ear cannot separate signal from noise.

(2) To isolate the signal from background noise, frequency-selecting devices must be used, the simplest being a filter. In this way a communications channel using a narrowband input filter hears only that noise which passes through the filter along with the signal. The S/N in this case is the ratio of the desired signal level pining through the filter compared with the noise falling within the filter bandpass.

(3) There are times when it would appear to the receiving operator that the sound of the received signal is so badly smothered in noise that communications seems almost hopeless, yet the telegraph terminal may be producing perfect copy on the teletypewriters. A terminal can perform in this manner because of succession of narrowband filters and limiters in each channel circuit. The presence of these narrowband filters explains the superiority of VF telegraph channels for reliable communications as compared with telephone communications under noisy operating conditions.

(4) If the received signal is strong, the noise must likewise be strong to affect it. If the signal is weak, a weak noise can affect it. In other words, S/N expresses the relationship between the signal level and the noise level, and has nothing to do with the individual values of signal level and noise level.

d. Voice Communications. Voice communications is unreliable during high noise levels encountered on the long-distance transmission path when conditions are poor. The reason for this is that the voice channel uses a relatively wide input filter, and the ear is incapable of selecting the voice signal out of the noise across the voice band.

e. AM vs FM. The question may be asked, "if FM has an inherent noise-reduction feature, why not use FM on the HF band?" The answer lies not in the technology but in the number of users. The HF bands are so crowded that stations must conduct their communications in relatively narrow bands. This precludes the use of FM because each FM signal consumes relatively large segments of the spectrum. Conversely, the crowded conditions of the HF band assure the continuation of narrow-band AM on the HF band. On a comparative basis, an FM station consumes at least 50 kHz for one voice signal, while an independent sideband AM signal can carry four voice signals in no more than 12 kHz of spectrum.

f. Questions.

2-4a. The Department of Defense places great importance on the reliability of a satellite communications system. One of the system's characteristics that results in high reliability is

a. doppler shift has no effect.

b. ground terminal operates in the HF band.

c. radiated frequencies are so high they penetrate the ionosphere.

d. antennas used by the ground terminals radiate equally in all directions.

2-4b. One of the most effective means of improving the signal-to-noise ratio (S/N) when the signal develops deep fades on an HF long-distance radio system is to switch to an alternate frequency. The need for frequency change is first recognized at the

a. radio receiver.

b. radio transmitter.

c. telephone terminal.

d. technical control center.

2-4c. Peak limiting is an effective method for over-coming the effects of noise on a radio signal. It cannot be applied to an AM receiver because the limiter causes

a. delay distortion.

b. phase distortion.

c. frequency distortion.

d. amplitude distortion.

2-4d. The human ear is normally a poor judge of signal-to-noise ratio because the ear is

a. limited in sensitivity by the threshold of hearing.

b. unable to select the signal and disregard the noise.

c. insensitive to certain frequencies in the voice range.

d. unable to readily recognize the presence of distortion.

2-4e. Assume that a radio communications signal in the HF band is carrying four voice channels simultaneously. This indicates that the signal is a form of

a. frequency modulation.

b. amplitude modulation.

c. phase modulation.

d. pulse modulation.

2-5. INTERFERENCE

a. Radio Interference. The two most effective ways of overcoming interference on radio systems is to stabilize the radio transmitter output signals, and to train operators to respect frequency assignments.

(1) Recent advances in radio transmitter design feature frequency synthesizers. All frequencies produced by a frequency synthesizer are stabilized by a master oscillator, and therefore have comparable frequency stability.

(2) Radio operators must select and use only those frequencies that are assigned by higher authority. They must also operate their sets to

minimize transmission over greater distances than intended, by using specific antenna types and stated output power.

b. AM Signals. One annoying source of interference between conventional AM signals is caused by carrier heterodyne; that is, when the carriers to two adjacent AM signals heterodyne, the resulting audio beat frequency falls within the passband of the radio receiver input circuit. Single-sideband transmission largely eliminates this problem because little if any carrier power is transmitted.

c. FM Signals. When two FM signals interfere, the stronger of the two signals predominates, to the detriment of the weaker. When AFC is used, the receiver will detune to pick up the stronger of the two signals. Further, the limiters within the receiver will respond most readily to the stronger of two input signals.

d. Questions.

2-5a. Frequency synthesizers are used to stabilize the output of radio transmitters and to

a. conserve RF power.

b. overcome radio interference.

c. eliminate carrier heterodyne.

d. permit the use of FM on the AF band.

2-5b. One form of interference that does NOT develop during SSB reception is a squeal or howl caused by heterodyning. This does not occur in SSB reception because the

a. S/N is so high.

b. AGC keeps the receiver gain low.

c. full carrier power is not transmitted.

d. bandwidth of the sideband is so narrow.

2-6. DISTORTION

The amount of distortion appearing within the received signal is an indication of system linearity. A system could have a high S/N and, at the same time, be useless for communications because of high distortion levels. Moreover, when distortion exceeds minimum allowable levels, it becomes necessary to minimize it through a cooperative effort by system personnel under supervision of the technical controller. Further, the type of distortion and its effects are related to the type of signal being transmitted.

a. Hearing Distortion. The human ear is a poor indicator of distortion, since the ear hears everything within the signal. Moreover, the ability to discern the fact that distortion exists depends upon the person's training, experience, and hearing sensitivity. Electrical instruments are therefore necessary to measure the distortion. It is first measured at the transmitting end, and then the receiving end. The increase in measured distortion is the amount created by the transmission path and the receiving equipment.

b. Harmonics. Harmonics are multiples of the original frequencies and are caused mostly by overloaded amplifiers. The second harmonic is the strongest, the third is weaker, and the fourth is even smaller. The technique of determining harmonic content within the output signal is achieved by using filters to select the harmonics that are developed in the circuit. This procedure requires the use of a single-frequency sine-wave input signal. A wideband input signal consisting of many frequencies cannot be used, because the range of harmonics of such a signal is so great that isolation of the harmonics is very difficult.

c. Intermodulation Products. Intermodulation products are frequencies that are created by interaction of the distortion products in the presence of a nonlinear circuit element. The test for intermodulation products must therefore be performed by the use of two sine-wave signals differing in frequency but having identical amplitude. If a third frequency is created by this interaction, its level is a measure of the circuit nonlinearity. The ratio of the third frequency signal level to either one of the two equal level test tones is called the signal-to-distortion ratio (S/D). The frequency of the third signal is chosen to reflect the interaction between the second harmonic of one frequency with the fundamental of the other. This test is especially important for high-powered SSB radio transmitters.

Example: Two frequencies, 1,575 Hz and 1,000 Hz, are fed into the input of an SSB transmitter. If distortion is present, intermodulation will occur between all frequencies developed. Among these frequencies is the second harmonic of 1,000 Hz, which is 2,000 Hz. The difference between the 1,575 Hz and the 2,000 Hz harmonic is now 425 Hz. If we filter out the 425 Hz signal and measure its level, we will have an indication of how badly the input signals are distorted and intermixed.

d. Question.

2-6a. Two frequencies are sometimes fed into the input of an SSB radio transmitter during a maintenance period. These two frequencies are used in testing for the development of

a. harmonic frequencies.

b. intermodulation products.

c. thermonic noise within the circuits.

d. phase shift within the composite signal.

2-7. LONG-DISTANCE COMMUNICATIONS NETWORKS

a. Long-distance communications networks are combinations of long-lines cable and line-of-sight radio, together with long-distance radio systems. As an example, a message traveling from Washington, DC, to Vietnam may travel any one of a number of ways. During its travel the message must pass through a number of points where the systems join. These tures are generally called interfaces. Since each of the communications systems has a different set of characteristics, each circuit must be conditioned prior to interconnection. Failure to properly condition the circuit results in distorted and/or noisy signals. And once signals are distorted, nothing can be done to remove the distortion products; the only remedy is to compensate for their effects. Technical controllers have the task of directing the circuit conditioning procedures, and of checking distortion of signals during arrival and departure of these signals from interfaces under their control.

b. Question.

2-7a. Assume that a technical controller finds that signals received at an interface are distorted when they arrive. Before he can send the signals through the interface, he must

a. raise the signal level.

b. remove all equalization.

c. remove the distortion products.

d. compensate for the effects of distortion.

2-8. CIRCUIT CONDITIONING

When ac signals travel over a communications channel, they may be affected by variation in amplitude and phase. Circuit conditioning therefore is at attempt to return the received signal to as nearly its original condition as possible. Variation in the original frequency is not likely, but the amplitude may vary at different frequencies. Circuit conditioning involves processes of equalization, amplification, delay compensation, and frequency translation. The techniques of circuit conditioning nearly always involve the measurement of sound levels. This is usually accomplished by measuring the level with respect to a normal standard of 1 milliwatt (mw), designated 0 dBm on most decibel meters. Levels higher than 0 dBm carry a plus (+) sign, and levels lower carry a minus (-) sign.

a. Equalization. All telephone wires and cables have series inductance caused by magnetic fields around the wires and parallel capacitance between wires. The combination of series inductance and parallel capacitance causes the line to resemble a low-pass filter. Such a filter tends to pass the low frequencies readily but to attenuate the high frequencies. Correction of this condition is obtained by bridging circuit elements across the line so that they produce the exact opposite effect to the line constants. Inserting these circuit elements constitutes the process of equalization, which is always accomplished at the receiving end of the line. The result of equalizing is to attenuate the low frequencies and raise the high-frequency level. Technically, this is accomplished by equalizing the phase relationship between the current and voltage across the entire range of line frequencies. In other words, the phase relationship between the current and voltage is adjusted to a relatively constant value. The equalizing procedure always introduces some loss of signal power, so an amplifier normally follows each equalizer in the signal path. The amplifier raises the equalizer output signal to the level required by the terminal.

b. Delay Compensation. Theoretically, transfer of the current and voltage elements of a signal takes place instantaneously at the transmitting end of a circuit. Consequently there is no delay in power transfer. However, as the signal travels down the line, the constants of inductance and capacitance take their toll of signal quality by shifting current and voltage components of the signal. When the signal arrives at its destination, the phase relationship is different from when the signal was originally transmitted, and therefore the power within the signal is delayed in time. The result of this change is a variation of the signal's characteristics at different frequencies within the signal. The waveshape of the signal is therefore different when received from when transmitted. This distorted signal is corrected by bridging circuits containing inductance and capacitance across the line to offset the effect of line characteristics which caused the delay. This is the principle of delay compensation. Delay compensation techniques are analogous to equalization techniques, except that different testing devices are used. Delay has the greatest effect on digital signals because of the change in pulse waveshape occasioned by delay.

c. Transition Delay. In an ideal signal pulse, the change between two levels occurs instantaneously and the transition time between the two limits of the pulse is zero. When that ideal pulse travels through a device having inductance or capacitance, the phase shift causes a delay in recognition time of that pulse by the receiving device. The time delay from the start of the transition to the time the receiving device senses the change is called the transition delay. It should be apparent that if transition time of the received pulse is different from the transition time of the transmitted pulse, the pulse has changed length. Whenever transition delays are unequal, resulting in pulse length variation, the received message quality will suffer. These principles hold true for telegraph, data, pulse-code modulation, or any other form of pulse transmission. Moreover, the effect is related to the length of the pulses. The higher the speed of pulse transmission, the shorter are the pulses, and thus the greater is the effect a given transition delay has on signal quality. Transition delay is a characteristic of a circuit and is therefore an indication of circuit quality. Some form of delay equalization is then needed to correct for the distortion.

d. Frequency Translation. When a technical controller attempts to interface two communications circuits, he sometimes finds signals other than communications signals. Moreover, these special-duty signals sometimes occur at different frequencies. If such frequencies are not identical in the two circuits to be interfaced, frequency-translating devices will have to be incorporated in the interfacing facilities. These special-duty signals are used for signaling, ringing, switching, or testing.

e. Questions.

2-8a. Two similar techniques used in circuit conditioning are

a. equalization and delay compensation.

b. delay compensation and amplification.

c. amplification and frequency translation.

d. frequency translation and delay compensation.

2-8b. Phase delays in signal pulses may be caused by circuit constants in land lines. These phase delays are normally corrected by

a. changing the transmission rate.

b. switching to a secondary cable.

c. reducing resistance in the line.

d. bridging inductance and capacitance.

2-9. TELEGRAPH SIGNAL QUALITY

Unlike telephone distortion, which you can detect by poor sound quality, telegraph distortion does not make its presence known until it becomes so bad as to cause the teletypewriters to misprint. Because of this fact, one of the major duties of a technical controller is to periodically measure the distortion in the dc receive telegraph loops. Only in this way can he determine that signal quality is deteriorating. If he waits until misprinting occurs, he has delayed too long; the channel must be removed from service until the trouble is cleared. The technical controller must understand that when the circuit distorts the telegraph signals, little can be done to remove the distortion. Part of his job is to report the existence of the distorting and to compensate for its effect whenever he can. The task of finding and removing the source of distortion belongs to the equipment technician. Moreover, removing the cause of distortion is a far more useful operating technique than compensating for the effects.

a. Sources of Telegraph Distortion. Telegraph signal quality can be impaired anywhere along the communications system, from message transmission to message reception. The communications system may include cable circuits, radio circuits, and carrier channels, as well as the terminating teletypewriter sets. Telegraph signal quality can also be impaired by interfacing communications circuits that are not compatible.

(1) Teletypewriter sets. The driving motors of teletypewriter sets must rotate at the same speed to print good copy. Minor speed differences can be accommodated by the synchronizing scheme of the telegraph signals. Major differences in motor speed must be corrected before the system can be turned over to traffic. Moreover, the selecting mechanism within each printer must "see" and correctly interpret the information from the received signal pulses. If system analysis proves that motor speeds are correct and the teletypewriters are free of signal distortion, the remaining distortion in the system is created within the facilities that interconnect the teletypewriters.

(2) Information transfer. The telegraph signal code used for teletypewriter communications consists of a series of dc pulses in a prearranged code. As the pulses travel through a communications facility, the change in pulse waveshape causes the delays in transitions. Likewise, improper loop current and maladjustment of equipment items can cause variations in transition time. However, as long as enough of the pulse arrives to be recognized by the terminating device, the message will be printed correctly. Misprinting occurs when the transitions are displaced in time beyond the capability of the printer to interpret the code combinations correctly.

(3) Channel bandwidth of telegraph carrier terminal. When dc telegraph signals enter a channel of telegraph carrier equipment, the information contained within the telegraph pulse transitions is impressed on the carrier. The rate of occurrence of these transitions is related to the speed of transmission. Likewise, the expanse of sidebands developed in the modulation process are related to the speed of transmission. Since each channel contains a send filter to limit the expanse

of sidebands, the bandwidth of this filter limits the speed of transmission that the channel can carry. The higher the transmission speed, the wider must be the channel bandwidth. Increasing the transmission speed beyond the channel capability is almost certain to result in excessive telegraph distortion.

b. Data Transmission. The transmission of data signals is rapidly increasing in military communications. Since data pulses are much shorter than telegraph signal pulses, more pulses are used in the code and the keying rate is faster. Five methods that you can use to accommodate the data signals in a communications system are:

(1) Use telegraph carrier equipment having wideband channels.

(2) Use special equipment (serial-to-parallel converter) designed to pass data over existing telegraph carrier equipment.

(3) Slow down the rate of keying equivalent to the rate of telegraph transmission so that the signals may pass over a narrowband channel of existing terminal equipment.

(4) Replace existing telegraph carrier terminals with terminals having enlarged bandwidth capabilities.

(5) Bypass the telegraph carrier terminals entirely and place the data signals directly into the baseband input of a wideband radio transmitter.

c. Question.

2-9a. One of the duties of a technical controller is to determine the quality of telegraph signals and to report the facts to higher authority. He can tell that the signal quality is deteriorating by

a. waiting to see misprinting on the page copy.

b. inspecting the received perforated tape for errors.

c. measuring the amount of distortion in the dc send loops.

d. making periodic measurements of distortion in the receive dc loops.

2-10. INTERFACING TELEGRAPH CIRCUITS

Both VF and dc telegraph signals appear on loop circuits. Telegraph circuits always originate and terminate in dc loops. Telegraph terminals are interconnected by VF loops. Problems of interfacing (or joining) loops of compatible devices are different for VF and dc. The essential difference is that dc loops are normally sensitive to direction of current.

a. Voice-Frequency Interfacing. So long as compatible telegraph terminals are used at each end of a VF circuit the interface between two VF telegraph circuits can be accomplished readily (assuming minimum distortion) after levels are measured and adjusted.

b. Direct-Current Interfacing. When interfacing dc telegraph circuits, the technical controller must be certain of two factors:

(1) Current must be of the correct value.

(2) Current must be in the right direction. If the loop is turned over in the interfacing process, current flows in the wrong direction through the receiving telegraph device connected to the loop and causes misprints.

c. Question.

2-10a. A technical controller uses different techniques when interfacing VF loops than when he interfaces dc loops. When he interfaces VF loops he must assure himself of the

a. direction of current flow and the value of current.

b. proper signal levels and the direction of current flow.

c. compatibility of telegraph terminals and proper signal levels.

d. value of current flow and the compatibility of telegraph terminals.

2-11. TRANSMITTER OUTPUT WAVEFORMS IN TELEGRAPH TRANSMISSION

The characteristics of the transmitter output signal are determined mainly by the type of modulation used. The types of telegraph modulation most commonly used in long-distance radio systems are frequency-shift keying (FSK) and on-off tone. Both forms are illustrated in figure 2-1.

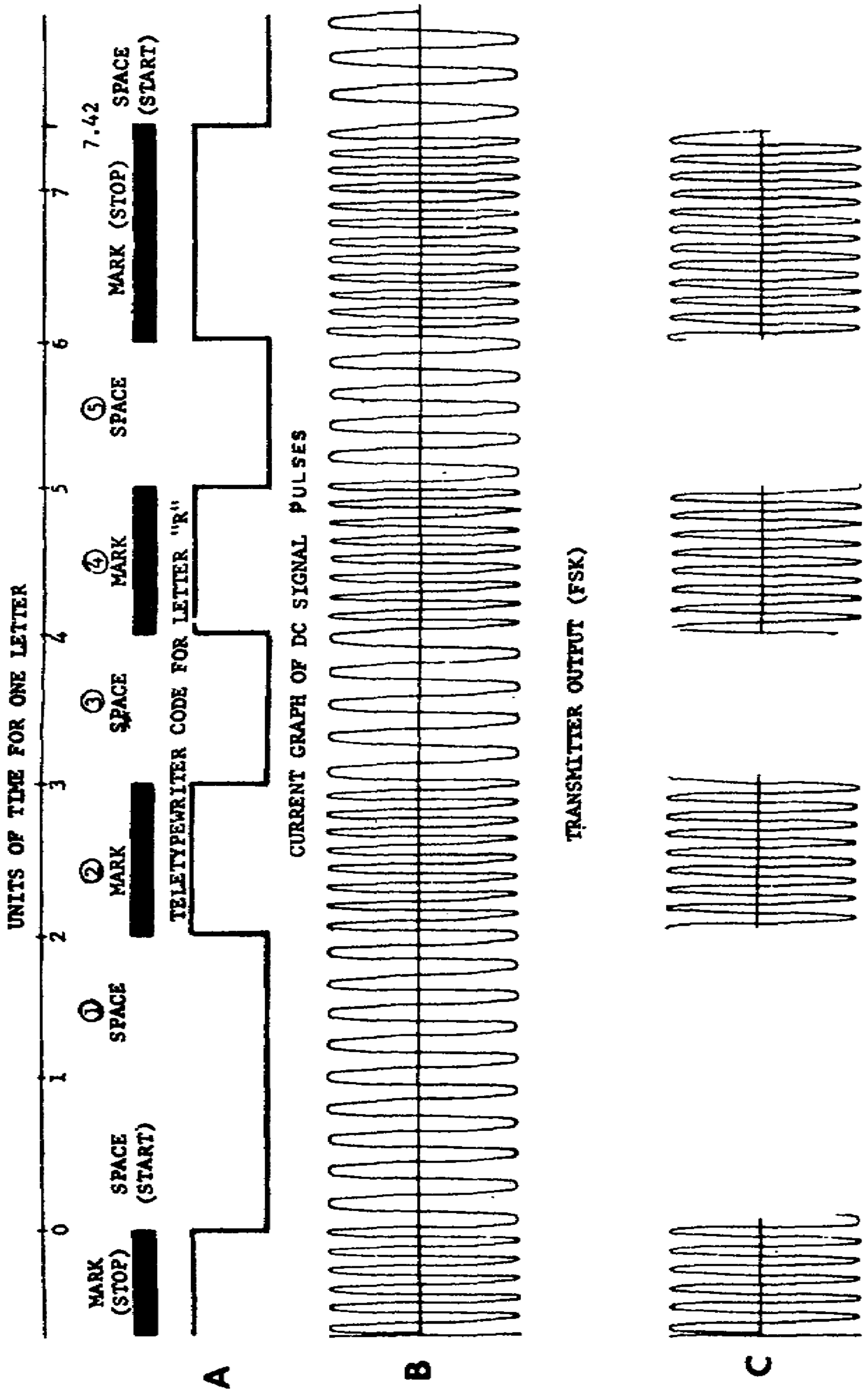


Figure 2-1. Teletypewriter code, keying signal, and output waveforms.

a. Fundamentals. Each letter combination in the teletypewriter code starts with a spacing pulse and stops with a marking pulse. Between the start and stop pulses are five mark or space information pulses equal in duration to the start pulse. However, the stop pulse is 1.42 times the length of a unit pulse at any selected speed of transmission. The longer stop pulse is needed to synchronize the receiving printer with the sending device. The number of transitions varies from 2 to 6, depending on the letter code combination. The higher the speed of transmission, the more frequent these transitions will occur, and the shorter will be the pulses. For example, the unit pulse length at 60 WPM is approximately 22 milliseconds (ms), while at 100 WPM the pulse length drops to approximately 13 ms.

b. Frequency-Shift Keying. FSK is generally used for teletypewriter operation over long-distance radio systems. It is achieved by shifting the radio carrier frequency slightly, one frequency being used for the mark signal and another for the space signal. The omitted signals usually shift upward 425 Hz from midband (assigned) frequency for mark, and 425 Hz downward from midband frequency for space, a total shift of 850 Hz. Since the teletypewriter signal is always in either the marking or spacing condition, the RF output of the transmitter is always either above or below the assigned frequency. The effect of noise picked up along the radio transmission path is greatly minimized by the constant-amplitude characteristic of the signal which permits peak limiting to be used in the radio receiving equipment.

c. Voice-Frequency FSK. FSK may also be produced by modulating a VF carrier. The nature of the signal is the same as that of an RF modulated FSK signal, except that the carrier is audio frequency, not radio frequency. This type of signal is used extensively in telegraph carrier over long lines and SSB radio transmission. A VF telegraph channel carrying up to 100-WPM traffic will have a total shift of 85 Hz, or 42.5 Hz either side of the carrier frequency for mark and space. On the other hand, a VF telegraph channel capable of carrying up to 400 WPM will have a total shift of 170 Hz, 85 Hz either side of the carrier frequency. The mark frequency is normally the higher of the two shifted frequencies. The constant-amplitude signal makes peak limiting possible in the VF telegraph channel, thus greatly minimizing the effect of noise on the signal.

d. On-Off Tone Keying. Whereas FSK is a form of frequency modulation, the on-off tone method of keying is a form of amplitude modulation. The on-off method is widely used in fixed radio stations for relatively short high-speed keying lines between the technical control center and the transmitting and receiving stations. Its chief features are simplicity and reliability, but noise tends to rise during the off-tone periods. The FSK method is far more reliable for long-distance radio transmission principally because of its noise reduction feature. Moreover, the on-off tone method introduces many transient frequencies that are transmitted over the air because the RF carrier is being switched on and off during the mark-to-space and space-to-mark transitions.

e. Length of Telegraph Loops. Telegraph loops using dc pulses must be relatively short because line constants (inductance and capacitance) easily distort the waveshapes. The same values of line constants have less distorting effect on VF keying. The usual practice, therefore, is to send VF signal pulse on long loops, while limiting dc keying to short local loops.

f. Questions.

2-11a. One similarity between the radio-frequency FSK system and the voice-frequency FSK system is that both normally use

a. an upward shift for mark.

b. a downward shift for mark.

c. the same amount of frequency shift.

d. an assigned frequency equal to the mark frequency.

2-11b. In long-distance radio systems there are recommended uses for VF FSK, VF on-off tone, and dc. The normal practice is to use

a. dc for long loops and VF FSK for long lines.

b. VF FSK for long lines and dc for short loops.

c. VF on-off tone for long lines and dc for long loops.

d. dc for short loops and VF on-off tone for long lines.

2-12. CLASSIFICATION OF RADIO SIGNALS

a. Types of Emission. Each radio station is authorized the transmission of a particular signal type or group of types. These signal types are classified according to the method of modulation, the information carried, and supplementary characteristics. The symbols used to indicate the type of emission are given below.

(1) Modulation method.

A - Amplitude

F - Frequency

P - Pulse

(2) Information.

0 - None (steady RF carrier)

1 - Radiotelegraphy

2 - Modulated radiotelegraphy

3 - Telephone

4 - Facsimile

5 - Television

9 - Composite, or not covered by the above

(3) Supplementary characteristics.

a - Single sideband, reduced carrier

b - Independent sideband, reduced carrier

c - Other emissions, reduced carrier

d - Pulse, amplitude modulated

e - Pulse, width modulated

f - Pulse, phase (or position) modulated

Example 1. A1 type of emission is the usual type of international Morse code transmission on short-wave radio with which you are probably familiar.

Example 2. The symbol for twin-sideband suppressed-carrier transmission that carries voice is A3b, because this form of transmission is amplitude modulated (A), radiotelephone (3) with separate information on each sideband (b). When either of the two independent sidebands carries carrier telegraph of facsimile signals, the signal falls into the classification of composite transmission and is designated A9b.

b. Bandwidth. Whenever the full designation on an emission is necessary, the symbol for that emission as given above shall be preceded by a number indicating in kilohertz the necessary bandwidth. The following is an example of necessary bandwidth and designation of emission.

12 A 9 b

Indicates bandwidth in kilohertz
Indicates type of modulation
Indicates type of information
Indicates supplementary characteristics

c. Question.

2-12a. Assume that the classification of a radio signal is F3d. This classification indicates an

a. FM signal carrying voice in the form of pulse-amplitude modulation.

b. AM signal carrying voice in the form of pulse-amplitude modulation.

c. FM signal carrying facsimile in the form of phase modulation.

d. AM signal carrying television with reduced carrier.

LESSON 3

TRANSMITTING EQUIPMENT

TRAINING OBJECTIVE:	Action:	Be able to list characteristics of fixed station transmitting equipment.
	Conditions:	Given SSO 750.
	Standard:	You must be able to successfully complete lesson exercises.

CREDIT HOURS: 2

LESSON OBJECTIVES

When you have completed this lesson, you-will:

1. Be able to identify radio transmitting equipment used in HF fixed station single-channel and multichannel frequency-shift-keyed radio teletypewriter communications.

2. Be able to identify radio transmitting equipment used in HF fixed station single-sideband and multichannel radio teletypewriter communications.

3. Be able to follow signal paths through block diagrams of HF radio transmitting systems.

4. Be able to explain the distribution of communications channels in a twin-sideband composite signal.

5. Know the basic principles and capabilities of a facsimile system.

ATTACHED MEMORANDUM

3-1. INTRODUCTION TO HIGH-FREQUENCY RADIO TRANSMISSION

a. Long-distance radio circuits furnish the basic facilities for communications among major headquarters throughout the world. They provide the trans-oceanic communications that may be required by a rapidly changing international situation. The basic facilities may be a radio teletypewriter circuit transmitting a single channel, a multiplex circuit carrying several teletypewriter channels, or an independent-sideband radio circuit that can carry a composite signal made up of any one of many possible arrangements of combined multichannel telegraph, voice communications, or facsimile channels.

b. The basic radio system consists of a transmitter and a receiver. For two-way communication, a transmitter and receiver are required at each end of a full-duplex circuit.

c. The transmitter station (figure 3-1) houses the equipment needed for transmitting the radio signals. This equipment consists of transmitters, exciters, power amplifiers, wire-line terminal equipment, and microwave radio link equipment associated with the transmitting process are also used at the technical control center where the traffic is first processed for transmission. For planning purposes, transmitters are divided into power classes (RF output power). Medium power is usually considered as less than 5 kilowatts (kW), high power as 5 to 20 kW, and very high power as above 20 kW. In practice, these terms are not defined as rigorously as this, but are usually given as a relative indication.

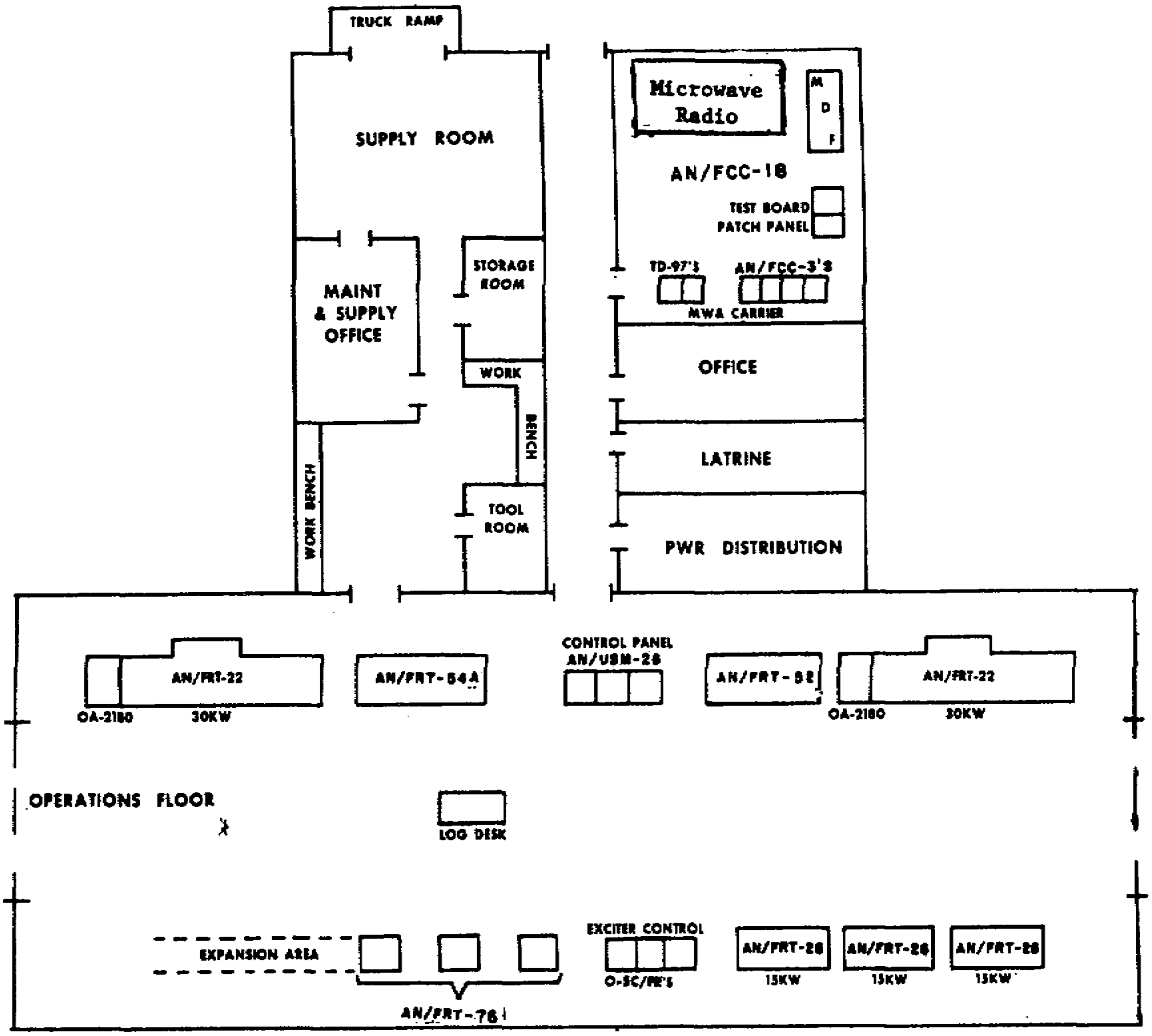


Figure 3-1. A type of equipment layout for a transmitting station.

d. Questions.

3-1a. The basic radio facilities that are most widely used in a long-distance radio station are

a. FSK RATT (single-channel), FSK RATT (multiplex), and double-sideband.

b. double-sideband, independent sideband, and FSK RATT (single-channel).

c. independent sideband, FSK RATT (single-channel), and FSK (multiplex).

d. FSK RATT (multiplex), double-sideband, and independent sideband.

3-1b. A radio transmitter with an RF output power of 15 kW is classified as a

a. low-power transmitter.

b. high-power transmitter.

c. medium-power transmitter.

d. very high-power transmitter.

3-2. TRANSMISSION OVER RADIO CIRCUITS

Most long-distance radio systems employ carrier equipments over some portions of the systems.

a. Single-Channel FSK Radio Teletypewriter System. FSK equipment in long-distance radio circuits use an RF signal that shifts between two frequencies corresponding to mark and space conditions of the keying signal. Figure 3-2 is a block diagram of a single-channel radio teletypewriter (RATT) system using a dc line from the transmitting teletypewriter to the technical control center. The length of the SEND LOOP will be determined primarily by the location of the teletypewriter. The dc line is connected to one channel of carrier equipment used for multiple channels between the technical control center and the transmitter station. Landline or radio link may be used as a transmission medium for this carrier system. At the transmitter station, the output of the carrier channel is again connected by a short dc line (REC LOOP) to the input of the FSK device of the radio transmitter.

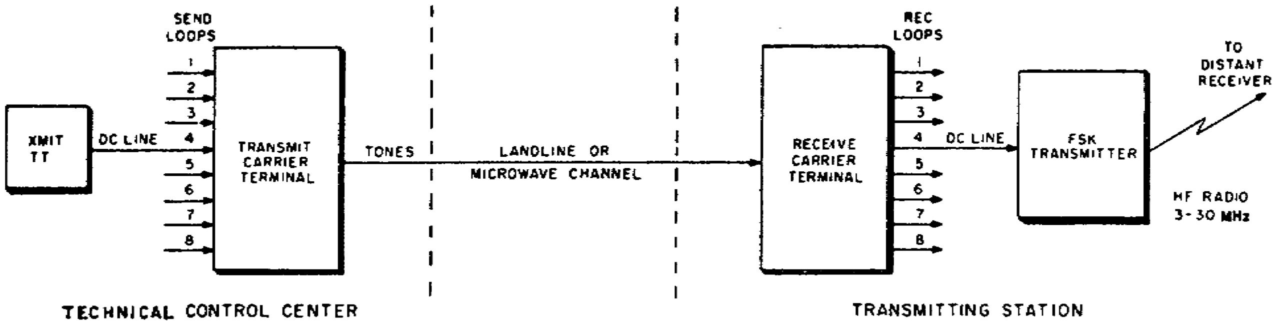


Figure 3-2. Typical single-channel FSK radio teletypewriter system, block diagram of transmitting facility.

b. Multichannel FSK Radio Teletypewriter System. Figure 3-3 shows a four-channel time-division-multiplex system using FSK radio as a means of transmission. Only one transmitting teletypewriter is shown in the block diagram, but the system is capable of providing four channels simultaneously. The transmitting teletypewriter is connected by a dc line to the SEND LOOP of one channel of the TDM equipment (Telegraph Terminal Set AN/FGC-5). The output of the TDM terminal, composed of time-division dc synchronous signals, is connected by a dc line within the technical control center to the SEND LOOP of a carrier channel. Because of its high keying rate, the TDM signal uses a wideband channel of Telegraph Carrier Terminal AN/FCC-3. The carrier equipment VF output is then transmitted over a landline or radio link circuit to the transmitter station. The output of the carrier channel at the transmitting station is connected by a short dc REC LOOP to the input of the FSK radio transmitter. The FSK output signal from the transmitter carries four-channel TDM telegraph information at a high keying rate.

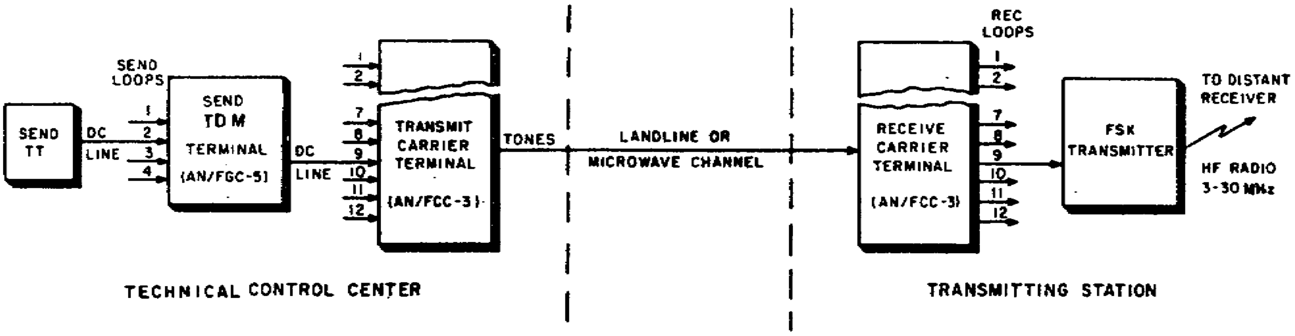


Figure 3-3. Typical multichannel FSK radio teletypewriter system, block diagram of transmitting facility.

c. Independent-Sideband Multichannel Radio System. In ISB equipment the radio signal contains two SSB's, each sideband carrying different information simultaneously. Each of the two independent SSB's provides a transmission capability of 6 kHz bandwidth, and each of the two 6 kHz bands may be broken down further into two 3 kHz channels. Each of the resulting four 3 kHz channels can be used to transmit audio information, such as facsimile, telephone, or VF multichannel teletypewriter. Figure 3-4 traces the path of one of the 16 teletypewriter channels placed on the HF ISB radio transmitting system. The transmitting teletypewriter is connected by a dc line to one SEND LOOP of Telegraph Terminal AN/FGC-29. The multiple-tone output of the AN/FGC-29 is sent to the transmitting station over a landline or radio relay circuit. These signals require a keying circuit capable of passing 3 kHz tones with little or no distortion. At the transmitter station, the tones are applied to one of the four 3 kHz channels of the ISB transmitting equipment. As shown in figure 3-4, the tones are applied to the A1 input channel of the transmitting equipment. These tones then are combined with whatever information is applied to the A2 input channel by a multiplexing unit at the transmitting station, and sent out over the HF radio transmitting circuit as one of the two 6 kHz sidebands of the radio signal.

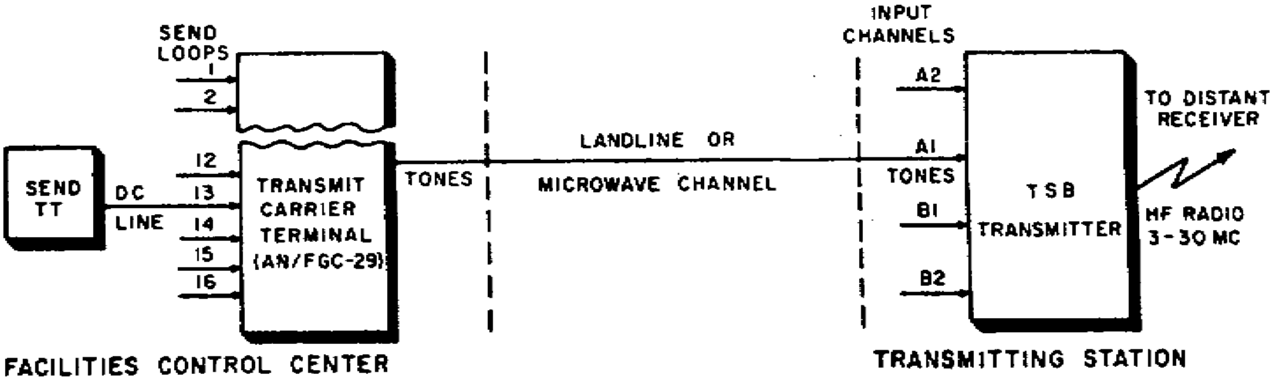


Figure 3-4. Typical multichannel operation over ISB radio system, block diagram of transmitting facility.

d. Radio Link. Microwave radio link equipment is installed at the technical control center and the transmitter station to provide auxiliary keying line facilities. This provides an adequate substitute for the wire keying lines during emergencies when the wire lines are out of operation or before the required wire lines are constructed. Certain tactical and strategic considerations may dictate the use of radio circuits as permanent keying lines. Because of the characteristics of microwave radio link equipment, the telephone carrier equipment is not necessary. For example, microwave radio link equipment such as Radio Telephone Terminal Set AN/FRC-35 provides 24 standard telephone channels. It may be used in place of a frequency-division telephone carrier system, but it does not replace the frequency-division telegraph carrier terminal. The keying lines from the technical control center are terminated on a terminal strip just inside the transmitter terminate these lines. After termination on the strip or frame, the keying lines are then connected to jacks on a keying line patching panel.

e. Question.

3-2a. The bandwidth of the ISB signal radiated from a system such as the one shown in figure 3-4 is

a. 3 kHz.
b. 4 kHz.
c. 6 kHz.
d. 12 kHz.

3-3. MULTIPLEXING METHODS

It is usually desirable to have more than one single independent information channel transmitted over a communications system. Methods used to achieve simultaneous transmission of different information streams over a single system are called multiplexing. The most important thing about multiplexing is that many messages can be sent at the same time, and they will not interfere with each other. Multiplexing can take many forms; however, multiplexing based on either frequency division or time division are the most common types.

a. Time Division. In time-division multiplexing, two or more signals are transmitted over a common path by using different time intervals for different signals. For example, four teletypewriter channels may be combined by equipment such as Telegraph Terminal Set AN/FGC-5 in association with FSK transmitting equipment such as Radio Transmitting Set AN/FRT-22 or Radio Transmitting Set AN/FRT-26.

b. Frequency Division. In frequency-division multiplexing, two or more signals are transmitted over a common path by using a different frequency band for each signal. For example, 16 FSK VF teletypewriter signals may be combined in a band from 375 Hz to 3,025 Hz, which can be transmitted over a standard telephone channel. These VF FSK teletypewriter signals are transmitted on separate channels, the center frequencies of which are spaced 170 Hz apart. Frequency division multiplexing of 16 teletypewriter channels in a 3-kHz VF channel may be achieved by equipment such as Telegraph Terminal AN/FGC-29. In an ISB multichannel radio system, two 3-kHz channels can be combined into one 6-kHz channel using Multiplexer TD-97/FGT-2 (part of the AN/FGC-29). This 6-kHz channel then becomes one of two sidebands of an ISB signal.

c. Question.

3-3a. Multiplexing is the method used to achieve simultaneous transmission of different information streams over a single system. The type of multiplexing associated with the AN/FGC-5 is

a. frequency space division.

b. time-division.

c. space-division.

d. frequency-division.

3-4. MULTIPLEXING EQUIPMENT

In HF fixed radio stations some types of multiplexing equipment are located at the technical control center, while other types are located at the transmitting and receiving stations. The multiplexing equipment (Multiplexer TD-97/FGT-2) shown in figure 3-5 is used to multiplex two 3-kHz signals into one 6-kHz signal, and is located at the transmitting station.

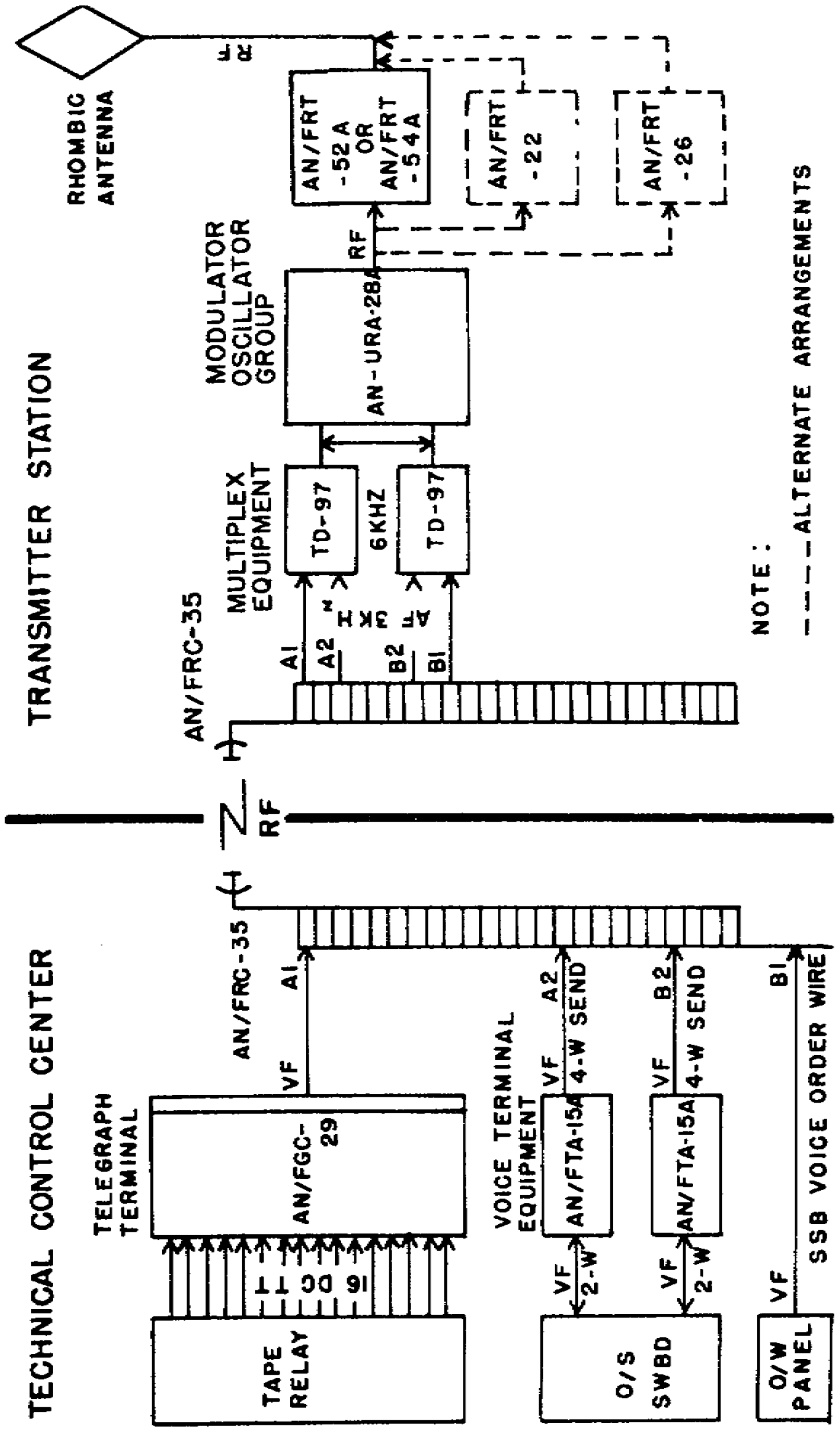


Figure 3-5. Independent sideband system, transmit side, with microwave keying facilities.

3-5. TELEGRAPH TERMINAL SET AN/FGC-5

a. Description. Telegraph Terminal Set AN/FGC-5 is a time-division-multiplexing set which provides four teletypewriter channels, full duplex. The terminal can normally be used with any single-channel teletypewriter system to provide multichannel operation. The number of channels which the set supplies for any particular teletypewriter circuit depends largely upon the circuit characteristics. Single-channel frequency-shift radio circuits and wideband VF carrier telegraph channels usually allow four channels to be operated if traffic load conditions warrant. Narrowband or circuits with excessive distortion may limit operation to three, or even two, multiplex channels. Generally, a circuit that operates single-channel teletypewriter with some margin will carry two-channel multiplex signals. When it is required to reduce channels, for example in a four-channel operation with channels A, B, C, and D, channel D is the first to be discontinued, then channel C, etc.

b. Technical Characteristics.

Number of channels	Four (60, 75, or 100 WPM per channel).
Signal type (loop)	Single-channel dc (neutral).
Signal type (line)	Multiplex dc (neutral).

c. Application. The AN/FGC-5 is normally installed at the technical control center and connected to the single-channel radio equipment at the transmitter and receiver stations by cable or microwave radio facilities. The only precaution in the application of the AN/FGC-5 to an existing single-channel radio system or the layout of a new system is the proper allowance for the higher keying speed of the multiplex signal. The multiplexed signal is similar to a teletypewriter signal keyed at speeds of 240 to 400 WPM.

d. Question.

3-5a. The multiplexed signal of the AN/FGC-5 is similar to a teletypewriter signal keyed at speeds of 240 to 400 WPM. What are the speeds (WPM) per channel of the four channels?

a. 60, 180 or 240.

b. 75, 150 or 300.

c. 60, 75 or 100.

d. 100, 200 or 400.

3-6. TELEGRAPH TERMINAL AN/FGC-29

a. Description. Telegraph Terminal AN/FGC-29 is a frequency-division-multiplex terminal that provides 16 channels of a teletypewriter over a long-distance radio system. The AN/FGC-29 is used with ISB radio equipment and provides fullduplex operation at speeds up to 100 WPM. Two of the six cabinets house the 16 transmit channels which convert the dc teletypewriter signals to individual tones. The remaining four cabinets contain 32 tone receivers which operate in pairs for diversity selection individually for each of the 16 teletypewriter channels.

b. Technical Characteristics.

Number of channels	16 (8 for dual diversity).
Operating speeds	100 WPM (maximum).
Channel frequencies	425 to 2,975 Hz.
Signal type (loop)	Dc neutral (20 or 60 ma).
Signal type (line)	VF tones (frequency-shift keyed).

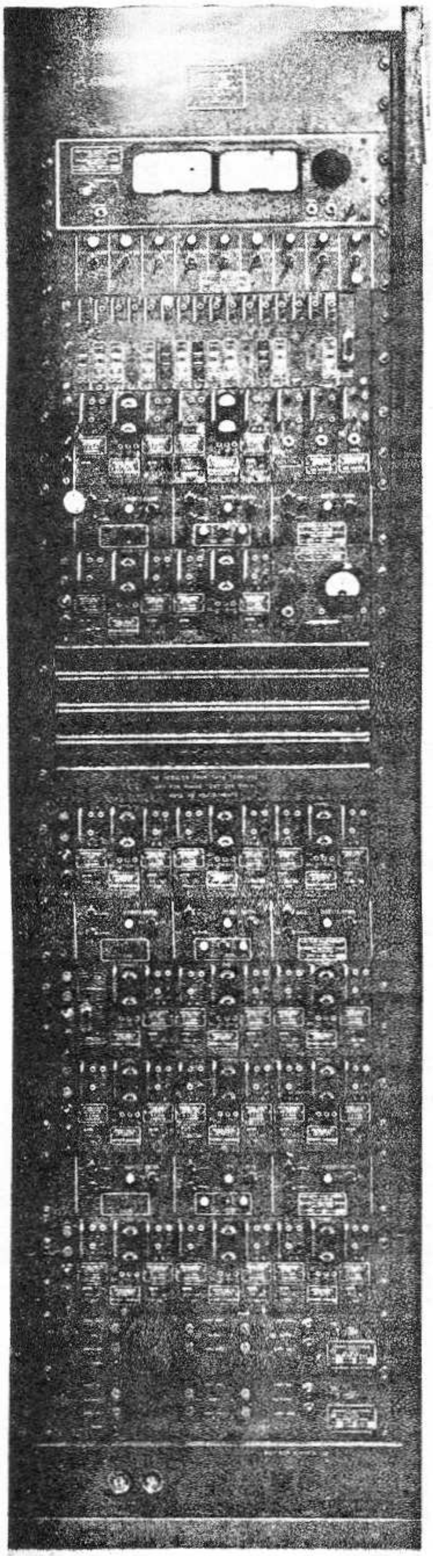


Figure 3-6. Telegraph Terminal AN/ FGC-61A.

c. Application. As shown in figure 3-5, the AN/FGC-29 is normally installed at the technical control center and is connected to the radio equipment at the transmitter and receiver stations by either cable or microwave radio equipment. One keying line channel is required to the transmitter station for the transmit tones, while two lines are needed from the receiver station to provide for diversity reception. As shown in figure 3-5, each Multiplexer TD-97/FGT-2 combines signals from two independent 3-kHz VF circuits into a 6 kHz signal for transmission over the associated radio system. Although TD-97/FGT-2 is part of the AN/FGC-29, it is often located at a remote transmitter station. On the receive side, Demultiplexer TD-98/FGR-3 separates the receive 6-kHz signal into two 3 kHz signals for transmission over cable or microwave to the technical control. This equipment is also a part of the AN/FGC-29, but is often located at the receiver station.

d. Questions.

3-6a. The units identified as "TD-97" at the transmitter site in figure 3-5 normally are components of the

a. telephone terminal equipment.

b. microwave radio link.

c. single-sideband transmitting equipment.

d. frequency-division-multiplex, teletypewriter terminal equipment.

3-6b. Each Multiplexer TD-97/FGT-2 in figure 3-5 can process the signals arriving at the transmitter station prior to the signals entering the ISB radio transmitter. Each such multiplexer can process the signals from

a. two lines or one channel of the AN/FRC-35.

b. two lines or two channels of the AN/FRC-35.

c. four lines or two channels of the AN/FRC-35.

d. four lines or four channels of the AN/FRC-35.

3-7. TELEGRAPH TERMINAL AN/FGC-61A (Figure 3-6)

a. Description. Telegraph Terminal AN/FGC-61A provides 16 channels of teletypewriter over ISB HF fixed-station radio systems. The AN/FGC-61A is a fully transistorized 16-channel transmit and dual-diversity receive frequency-division-multiplex terminal. All channels can be individually keyed at 60, 75, or 100 WPM. The AN/FGC-61A is housed in one cabinet and is compatible with Telegraph Terminal AN/FGC-29. The AN/FGC-61A and AN/FGC-29 are designed for operation on HF long-distance radio communications systems where fading is a problem. These two terminals contain special circuits designed to correct for phasing effects caused by the constantly changing altitude and density of the ionosphere. These special circuits compensate for the increase in pulse length caused by delay when normal and diversity tones are combined in the channel demodulators. The function of these circuits is to prevent the development of telegraph distortion in the presence of phase fading between signals received through the ionosphere.

b. Technical Characteristics. The technical characteristics of the AN/FGC-61A are the same as those given for the AN/FGC-29 (para 3-6b).

c. Application. The AN/FGC-61A is normally located at the technical control center and is connected to the single-sideband radio equipment at the transmitter and receiver stations by either 3 kHz bandpass cable or microwave radio facilities. This equipment is used in fixed-station and transportable applications.

d. Question.

3-7a. The telegraph terminal that is compatible with the AN/FGC-29 although it is transistorized, is the

a. AN/FCC-3.

b. AN/FGC-5.

c. AN/FCC-18.

d. AN/FGC-61A.

3-8. TELEGRAPH CARRIER TERMINAL AN/FCC-3

a. Description. Telegraph Carrier Terminal AN/FCC-3 is a 12-channel frequency-division-multiplex telegraph carrier terminal designed for use on wire lines or line-of-sight microwave radio circuits. Channels 1 through 8 are narrowband channels capable of passing signals with keying speeds up to 100 WPM. Channels 9 through 12 are wideband channels capable of passing signals with keying speeds up to 400 WPM. The AN/FCC-3 does not contain special circuits to compensate for fading, since fading is not a serious problem in wire line or line-of-sight radio systems.

b. Technical Characteristics.

Number of channels	12 (8 narrowband, 4 wideband).
Operating speeds	100 WPM (narrowband channels 1-8). 400 WPM (wideband channels 9-12).

Frequency range	300 to 3,400 Hz (nominal). 382.5 to 3,315 Hz (actual).
Signal type (loop)	20 or 60 ma neutral or 30 ma polar.
Signal type (line)	VF tones (frequency-shift keyed).

c. Application. The AN/FCC-3 provides a method of keying remote transmitter or teletypewriter equipment by means of an audio-frequency tone over a wire line or microwave radio channel. The narrowband channels will pass single-channel teletypewriter signals with keying speeds up to 100 WPM. The wideband channels will pass a four-channel multiplex signal such as the output signal of Telegraph Terminal Set AN/FGC-5. The AN/FCC-3 is used to key frequency-shift exciters at the transmitter station from the teletypewriter equipment at the communications center, and to key teletypewriter equipment at the communications center from the receiving equipment at the receiver station.

d. Question.

The AN/FCC-3 has narrow and wideband channels. How are the twelve channels divided between these two categories?

a. 6 narrow, 6 wide.

b. 4 narrow, 8 wide.

c. 8 narrow, 4 wide.

d. 10 narrow, 2 wide.

3-9. MULTIPLEXER SET AN/FCC-18 (Figure 3-7)

a. Description. Multiplexer Set AN/FCC-18 is a fully transistorized duplex frequency-division-multiplexer carrier system for use on line-of-sight, microwave radio, tropospheric scatter, or coaxial cable networks. The AN/FCC-18 employs single-sideband suppressed-carrier modulation. It can be packaged in 12, 60, 120, 240, or 600 voice channels. The

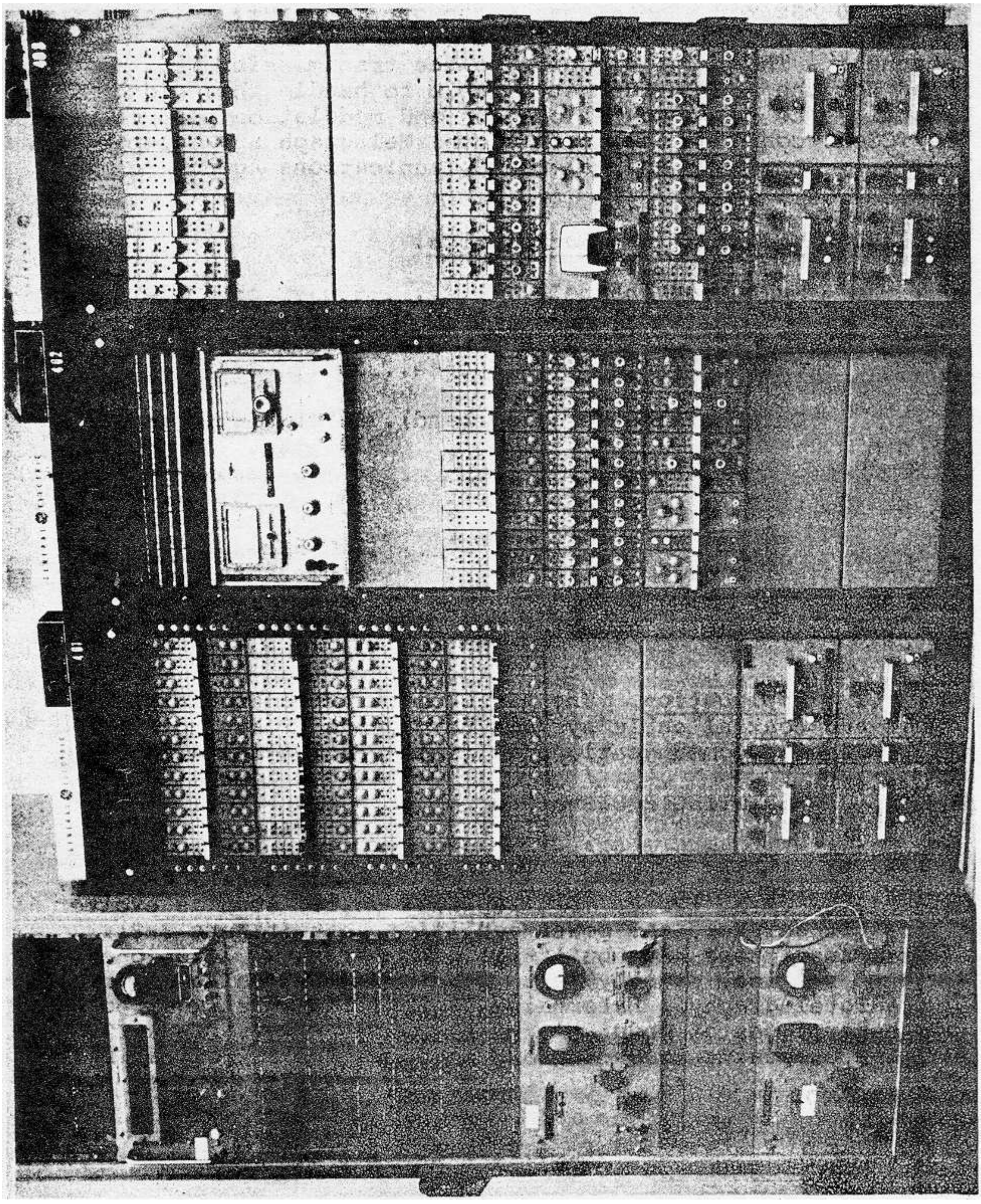


Figure 3-7. Multiplexer Set AN/FCC-18.

line signal of the AN/TCC-18 occupies the spectrum from 60 to 2,540 kHz for a total bandwidth of 2,480 kHz. Within this bandwidth is included space for 600 4-kHz voice channels. The input circuits to the transmission medium used for the AN/FCC-18 must be able to handle this wideband signal. The frequency allocation and modulation plan of the AN/TCC-18 conforms to International Telegraph and Telephonic Advisory Committee and Defense Communications Agency recommendations.

b. Technical Characteristics.

Number of channels	600 VF channels (maximum).
Channel frequency response	300 to 3,400 Hz.
Output frequency (baseband).	12 channels: 60 to 108 kHz. 60 channels: 60 to 300, or 312 to 552 kHz. 120 channels: 60 to 552 kHz. 240 channels: 60 to 1,052 kHz. 600 channels: 60 to 2,540 kHz.

c. Application. The AN/FCC-18 is used on microwave radio and coaxial cable systems to provide VF keying lines and intersite communications at fixed-station installations.

3-10. TRANSMITTING EQUIPMENT

High-frequency fixed-station radio transmitting equipment may consist of a single transmitting unit. More often, it is made up of two or more separate units, such as exciter unit, transmitter, and power amplifier unit (figure 3-8). Most transmitters have built-in exciters for at least one type of service, usually continuous wave (CW), also known as radiotelegraphy. External exciters often are required for other types of modulation or keying, such as FSK RATT, and ISB composite transmission. A power amplifier may be added to increase the amount of radiated power. The length of the radio transmission path and the predicted signal loss determine the required radiated power, and thereby influences the choice of radio transmitting equipment.

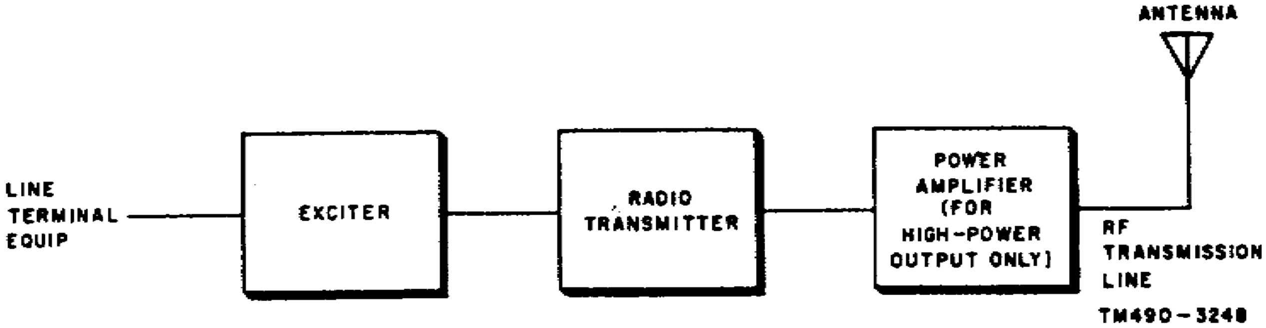


Figure 3-8. Typical fixed transmitting equipment, block diagram.

a. Questions.

3-10a. Assume that as NCOIC of a radio transmitting station you must select a transmitter for a new circuit. The required RF power output of the transmitter that you select will be influenced by the

a. type of RF exciter used.

b. type of multiplexing equipment used.

c. number of frequency multiplier stages used.

d. length of the transmission path and the predicted signal loss.

3-10b. Most transmitters have built-in exciters for at least one type of service, usually

a. time-division-multiplex (TDM).

b. frequency-shift-keying (FSK).

c. independent sideband (ISB).

d. radio telegraphy (CW).

3-11. RF EXCITER UNITS

Some long-distance radio transmitters have built-in exciters designed to provide the required types of service. Where the exciters are not part of the transmitters, external exciters can be used. External exciters are available for both FSK single-channel and ISB multichannel service. They are designed to replace the oscillators and low-power stages of the radio transmitters. Their normal power outputs range from about 0.10 to 5 watts.

a. Exciter Units 0-5B/FR and 0-5C/FR. Both of these units are crystal-controlled RF exciters to be used for single-channel or time-division-multiplex FSK excitation of any standard CW radio transmitter. Either unit can operate within a frequency range of 1.5 to 6 MHz and may be adjusted to produce narrowband frequency-modulated signals for operation of facsimile or voice radio circuits. The amplifying stages of the associated transmitting equipment are used as frequency multipliers where necessary to produce the assigned transmitting frequencies.

b. Modulator-Oscillator Group OA-2180/FRT-51. This exciter unit produces a complete composite ISB signal at the frequency of transmission. It provides a low-level amplitude-modulated wideband RF signal for the purpose of driving the linear amplifier stages to their rated output power. The exciter output frequency is variable from 1.7 to 30 MHz, the full frequency range of the associated linear-power amplifier in Radio Transmitting Set AN/FRT-51. The output frequency of the radio transmitter is identical with that of the exciter.

c. Modulator-Power Supply Group AN/URA-28A. This exciter unit is a twin-channel single-sideband suppressed carrier exciter. Two 6-kHz input channels are provided to derive the separate sidebands. The AN/URA-28A is crystal controlled and has provisions for mounting 10 crystals. The exciter has an RF power output of 1 watt and a frequency range of 2 to 32 MHz. The AN/URA-28A is located at the transmitter station.

d. Question.

3-11a. External exciters are available for both

a. time-division-multiplex and frequency-shift-keying service.

b. time-division-multiplex and independent-sideband service.

c. frequency-shift-keying and independent-sideband service.

d. radio telegraphy and time-division-multiplex service.

3-12. RADIO TRANSMITTER T-368/URT

a. Description. Radio Transmitter T-368/URT is a small, medium-powered, high-frequency transmitter designed for CW and double-sideband (DSB) AM voice transmission. By using an external FSK exciter, such as the O-5C/FR, the T-368/URT can be used in a medium-distance single-channel RATT circuit.

b. Technical Characteristics. The technical characteristics of Radio Transmitter T-368/URT are given below.

Frequency range	1.5 to 20 MHz.
Frequency control	Master oscillator or external exciter.
Stability	0.005 percent with master oscillator.

RF power output	CW 450 watts. AM and FSK 400 watts.
Output impedance	72 ohms.

c. Application. The transmitter is normally located at the fixed station and mobile transmitter station. The RF output is fed to a doublet-type antenna directly or to a rhombic antenna through an impedance-matching transformer. The transmitter is used as a self-contained unit for CW and AM operation. For FSK operation an exciter such as the 0-5C/FR is connected to furnish excitation.

3-13. RADIO TRANSMITTING SET AN/FRT-26 (Figure 3-9)

a. Description. Radio Transmitting Set AN/FRT-26 is a fixed-station, high-powered, high-frequency transmitting set designed for CW and FSK operation. The transmitter is a completely self-contained unit, with a built-in frequency-shift exciter that operates with either master oscillator or crystal frequency control. The set consists of Transmitter T-454/FRT-26 and Power Supply Assembly PP-1088/FRT-26, mounted in two metal cabinets bolted together to form a single unit. The power amplifier section of the transmitter may be used as a linear amplifier for increasing the power output of a medium-powered ISB transmitter. With modifications to the AN/FRT-26, Modulator-Oscillator Group OA-2180/FRT-51 or Modulator-Power Supply Group AN/URA-28A can be used to provide ISB excitation.

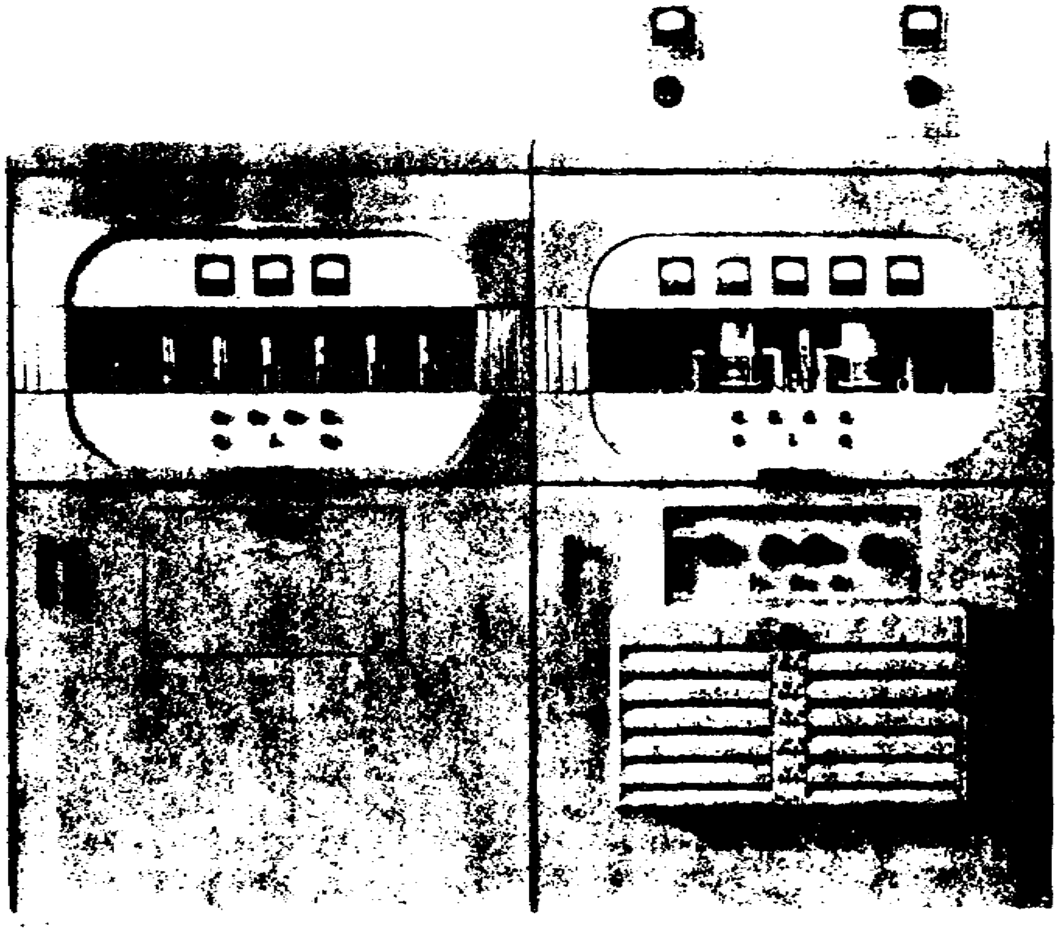


Figure 3-9. Radio Transmitting Set AN/FRT-26.

b. Technical Characteristics. The technical characteristics of the AN/FRT-26 are given below.

Frequency range	4 to 26.5 MHz.
Frequency control	Master oscillator or crystal.
Stability	0.001 percent.
Preset frequencies	10.
Type of emission	CW and FSK (ISB with external ISB excitation).

RF power output ....15 KW (8 KW with external SSB exciter).

Output impedance ....600 ohms.

c. Application. The transmitter is normally installed at the fixed-station transmitter site. For teletypewriter operation (figure 3-10) the signal from the technical control is connected to the transmitter's built-in frequency-shift exciter or to an external exciter such as the 0-5C/FR. The signal from the technical control is supplied over cable or microwave radio facilities. The AN/FRT-26 can be preset to the operating frequencies to provide for rapid frequency changes.

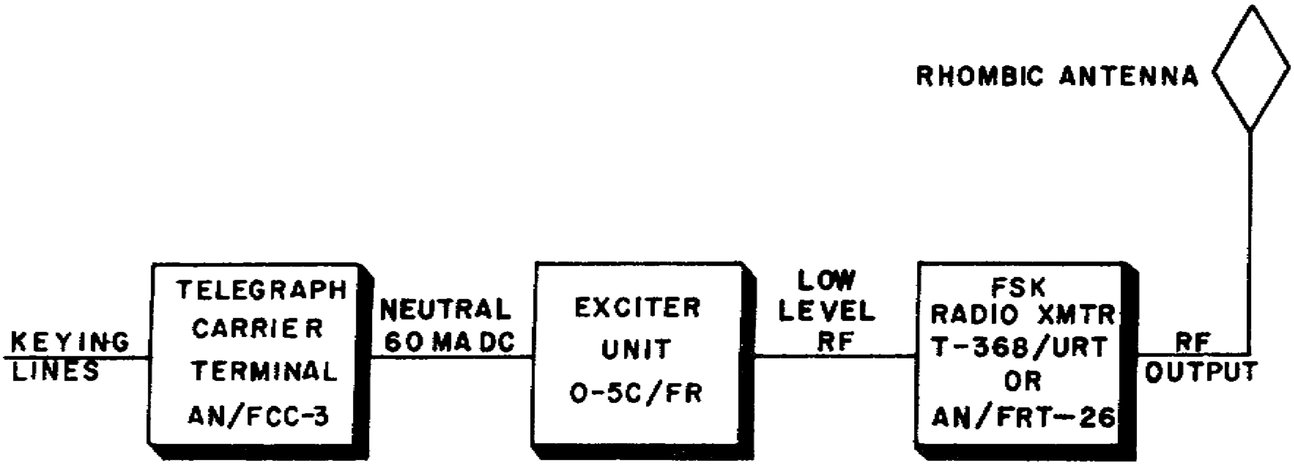


Figure 3-10. Transmitting station single-channel RATT FSK system, block diagram.

d. Questions.

3-13a. The maximum number of ISB circuits that can be operated simultaneously with the equipment available in figure 3-1 is

a.	two.	c.	five.
b.	four.	d.	seven.

3-13b. Assume that one of the transmitting circuits is arranged as in figure 3-10. The type of output signal from the radio transmitter is an

a. AM signal produced by modulating an RF carrier with a dc teletypewriter signal.

b. AM signal produced by modulating an RF carrier with a VF teletypewriter signal.

c. FSK produced by modulating an RF carrier with a dc teletypewriter signal.

d. FSK produced by modulating an RF carrier with a VF teletypewriter signal.

3-14. RADIO TRANSMITTING SET AN/FRT-22

a. Description. Radio Transmitting Set AN/FRT-22 is a fixed-station, very high powered, high-frequency unit designed for CW and FSK operation. The transmitter is a completely self-contained unit, with a built-in frequency-shift exciter operating from either crystal or master oscillator control. The set consists of the basic transmitter, AN/FRT-26, and RF Amplifier AM-738/FRT-22, Power Supply Assembly PP-1089/FRT-22, Power Control Unit C-589/FRT-22, and Power Transformer TF-197/FRT-22. The basic transmitter, amplifier, and power supply are housed in four metal cabinets bolted together to form a single unit. By using an external exciter unit such as the OA-2180/FRT-51, the AN/FRT-22, after modification, can provide very high powered ISB radio transmission. The final stages of the transmitter can also be used to amplify the output of medium and high-powered transmitters. The final states become linear amplifiers when used in this application.

b. Technical Characteristics. The technical characteristics of the AN/FRT-22 are the same as those given for the AN/FRT-26 (para 3-13), except for the RF power output which is 40 kW (30 kW with external SSB exciter).

c. Application. The transmitter is normally installed in the fixed-station transmitter station, and used on long-distance circuits where very high power output is required.

d. Question.

3-14a. The technical characteristics of the AN/FRT-22 differ from those of the AN/FRT-26 in one area.

a. Stability.

b. Emission.

c. Output impedance.

d. RF power output.

3-15. RADIO TRANSMITTING SET AN/FRT-52A (Figure 3-11)

a. Description. Radio Transmitting Set AN/FRT-52A provides multichannel long-range, high-frequency communications. The AN/FRT-52A provides independent sideband suppressed-carrier operation and is capable of transmitting four 3-kHz channels of information in a multiplexed communications system. The transmitter is manually tuned throughout. Any one of 10 preset crystal-controlled channel frequencies may be selected. The continuously variable oscillator may be used when other frequencies are required. The set contains its own ISB exciter, signal generators, spectrum analyzer, and monitor.

b. Technical Characteristics. The technical characteristics of the AN/FRT-52A are given below.

Frequency range	2 to 28 MHz.
Frequency control	Master oscillator or crystal.
Stability	0.0001 percent.
Preset frequencies	10.
Type of emission	CW, DSB AM-voice, and ISB.
RF power output	Sideband transmission: 10 kW PEP. CW or DSB AM-voice transmission: 5 kW.
Output impedance	Balanced: 600 ohms. Unbalanced: 50 ohms.

c. Application. The AN/FRT-52A is normally located at the fixed-station transmitter station. The output signal is usually fed into a rhombic-type antenna. The audio input signals for the two 6-kHz sideband channels are supplied over wire lines or microwave from the technical control, where the terminal equipment is located. To allow the use of 3-kHz line facilities between sites, the multiplexers are located at the transmitter station. Their function is to combine two 3-kHz bandwidth line signals into one 6-kHz signal for the transmitter audio input (figure 3-5).

d. Question.

3-15a. A new ISB circuit (high power requirement) must be established between two stations. The available frequency that is nearest the optimum traffic frequency is 25.2 MHz. The complete ISB transmitter that can be used in this circuit is

a. T-368/URT.

b. AN/FRT-22.

c. AN/FRT-26.

d. AN/FRT-52A.

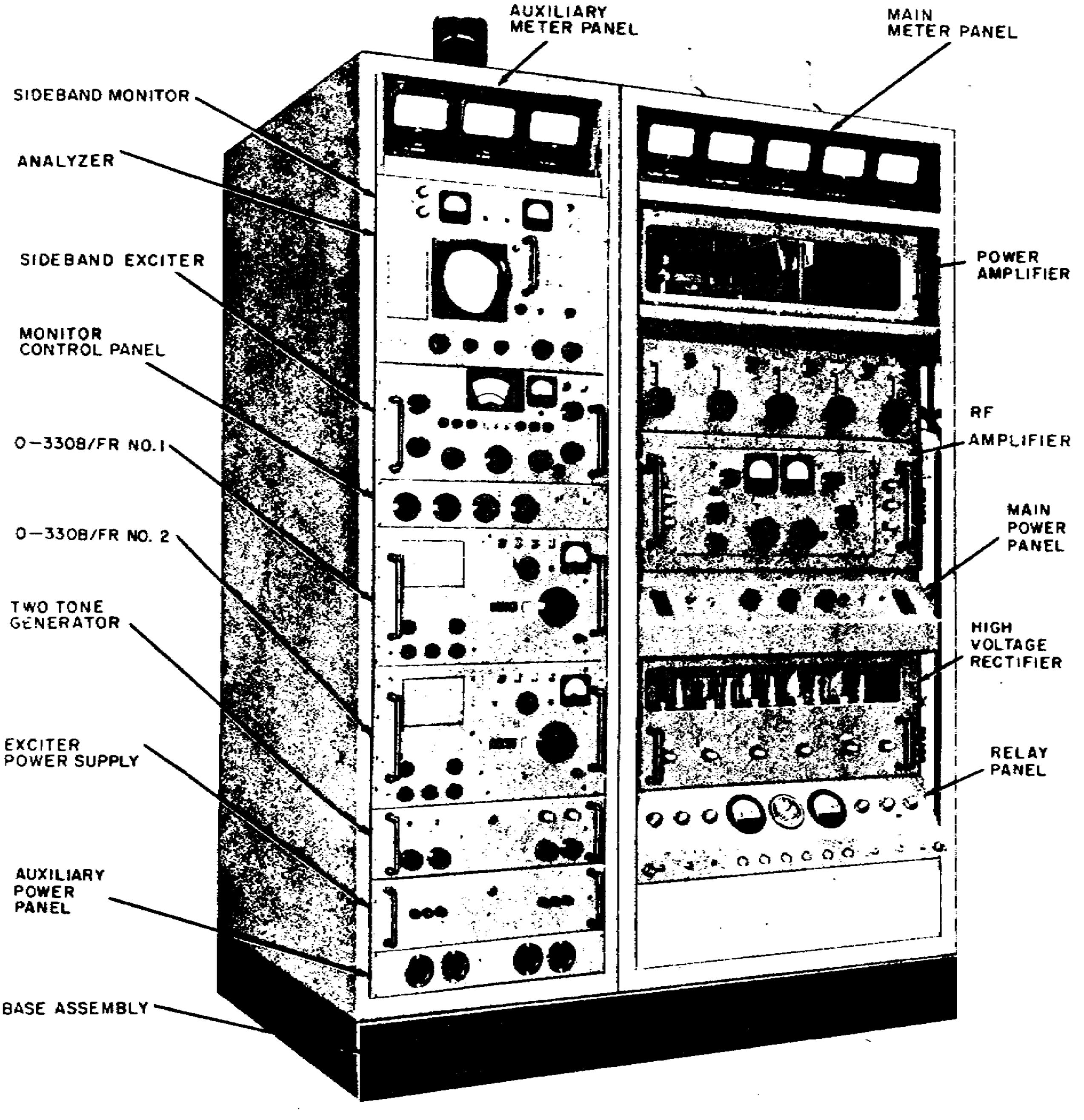


Figure 3-11. Radio Transmitting Set AN/FRT-52A.

3-16. RADIO TRANSMITTING SET AN/FRT-54A

a. Description. Radio Transmitting Set AN/FRT-54A is a fixed-station, very high powered, high-frequency unit designed for ISB suppressed-carrier operation. The transmitter is a completely self-contained unit, with a built-in sideband exciter operating from either crystal or master oscillator control. The set consists of the basic transmitter (AN/FRT-52A) and a 40,000-watt power amplifier and power supply. The components are housed in four metal cabinets bolted together to form a single unit.

b. Technical Characteristics. The technical characteristics of the AN/FRT-54A are the same as those given for the AN/FRT-52A (para 315), except for the RF power output which is 40 kW (20 kW on CW or DSB AM-voice).

c. Application. The AN/FRT-54A is normally installed at the fixed-station transmitter site and is used on long-distance circuits where very high RF power output is required.

d. Question.

3-16a. The AN/FRT-54 is a high powered, high frequency radio transmitting set designed for

a. FSK.

b. CW.

c. ISB.

d. TMD.

3-17. FACSIMILE TRANSCEIVER

a. Description. Facsimile Set AN/TXC-1 shown in figure 3-12 is an electromechanical-optical facsimile transceiver of the revolving-drum type for transmission and reception of page copy. Although it is designed for either transmission or reception, it operates in a one-way circuit only; that is, it can either send or receive, but performs only one function at a time. The AN/TXC-1 transmits maps, photographs, sketches, and printed or handwritten text over normal voice communications channels, either wire or radio. Colored copy may be transmitted, but the reproduction is always black and white and intermediate shades of gray. Received copy is recorded directly on chemically coated paper, or photographically reproduced in either negative or positive form. The output signal produced by the AN/TXC-1 is DSB AM, using a carrier frequency of 1,800 Hz.

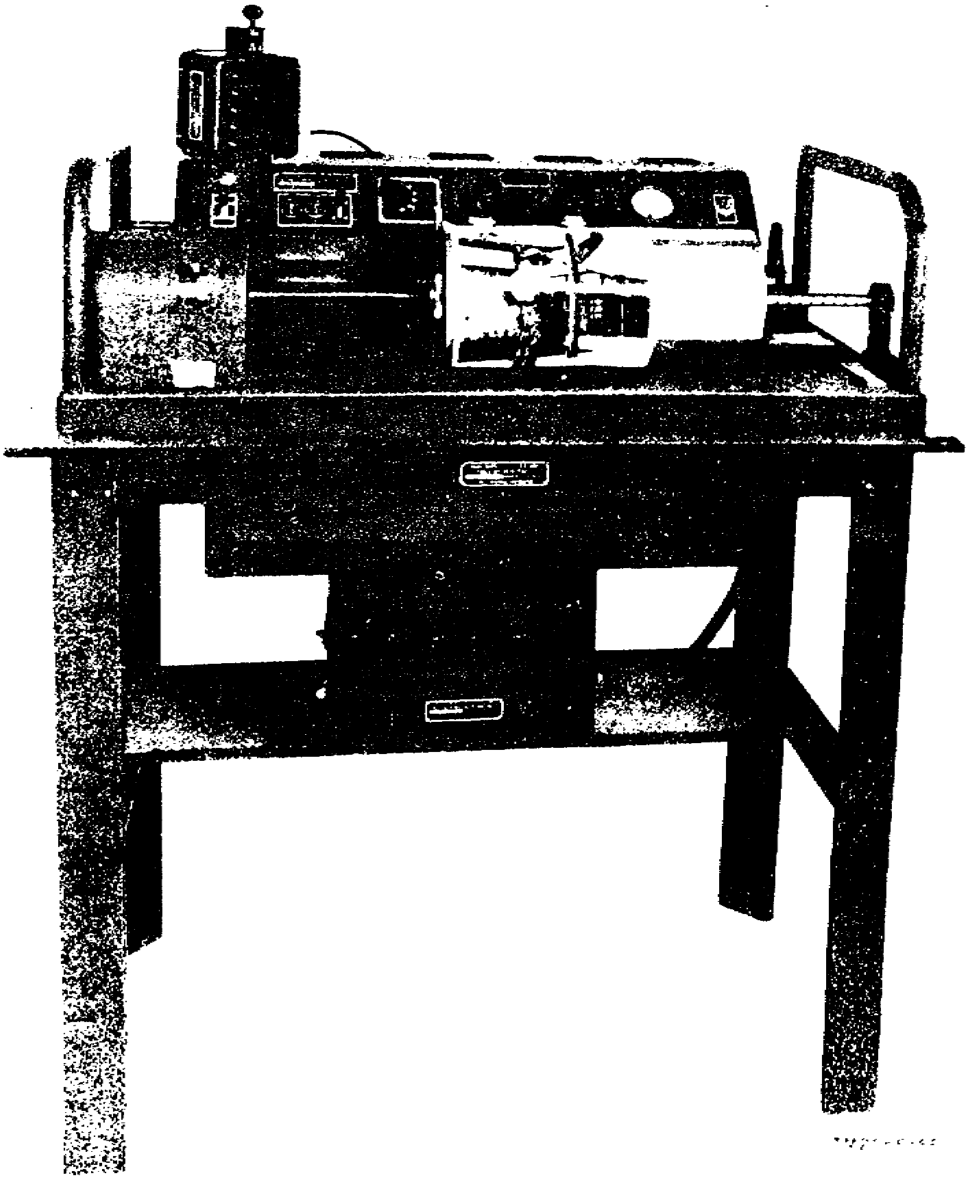


Figure 3-12. Facsimile Set AN/TXC-1.

b. Technical Characteristics.

Maximum size of copy ....Approximately 12 by 18 inches.

Size of scanning spot ....1/96 inch.

Rotational speed of drum	Choice of 30 or 60 RPM.
Lateral speed of drum	12 inches in 40 minutes at 30 RPM, or 12 inches in 20 minutes at 60 RPM.
Scanning lines per inch	96.
Audio carrier frequency	1,800 Hz.
Type of modulation	AM.
Frequency band limits	900 to 2,700 Hz.

c. Application. The AN/TXC-1 is normally installed at the communications center and is connected to the radio equipment at the transmitter and receiver stations by cable or microwave radio facilities.

d. Question.

3-17a. The picture elements within the image scanned by Facsimile Set AN/TXC-1 vary the components within the output signal. The output signal from AN/TXC-1 consists of

a. a VF signal with frequency variations.

b. an AM signal using a carrier frequency of 1,800 Hz.

c. direct current varying at the picture element rate.

d. an FM signal varying between the limits of 1,800 and 3,000 Hz.

3-18. TELEPHONE TERMINAL AN/FTA-15A

a. Description. Telephone Terminal AN/FTA-15A is a solid-state unit used in conjunction with a voice channel of an ISB radio system to connect a two-wire telephone line to the four-wire radio circuit. The telephone terminal provides two-wire to four-wire termination, automatic send and receive volume control, inband signaling for 20 Hz, and manual or dial operation.

b. Technical Characteristics.

Voice frequency range	300 to 3,000 Hz.
Transmitting level	0 dBm.
Receiving level	0 dBm.
Telephone signaling frequency	2,150 to 2,450 Hz.
Control frequency	1,310 to 1,225 Hz.

c. Application. Each of the two AN/FTA-15A's shown in figure 3-5 has a dual function. Its first function is to convert the two-wire switchboard line to a four-wire circuit during transmission, and to convert a four-wire circuit to a two-wire line during reception. Secondly, it controls the direction of signal flow by voice-switching techniques. By this switching feature it automatically reduces noise and suppresses echoes that are present in the received signal. An additional feature is in-band ringing; it converts 20-Hz telephone ringing to a VF tone for transmission over the radio circuit and, conversely, produces 20-Hz ringing voltage from the received VF signal.

(1) Operation. When the subscriber speaks into his microphone, his voice causes the circuit of the AN/FTA-15A to terminate (load) the output of the radio receiver. When he stops speaking, the circuit of the AN/FTA-15A terminates the transmitter input and opens the radio receiver output channel. He then hears the sound of the distant speaker in his telephone earpiece.

(2) Echo suppression. Echo suppression is used to prevent the speaker from hearing his own delayed voice. Echoes result from the sending voice signal feeding around the system and returning to the originating point. Echoes are difficult to prevent in long-distance radio systems because of the constantly changing level of the signal over

the long radio transmission path, together with the time delay in the signal's return over the long path. The most effective way to prevent echoes from interfering with telephone talkers is to switch the send and receive channels under voice control and to terminate the inactive path.

d. Question.

3-18a. Telephone Terminal AN/FTA-15A has several functions in an ISB radio communications system. One function is to

a. eliminate time delays.

b. suppress echoes by voice switching.

c. frequency-translate the input signal.

d. demodulate one of the two telephone channels.

LESSON 4

RECEIVING EQUIPMENT

TRAINING OBJECTIVE:	Action:	Be able to list characteristics of fixed-station receiving equipment.
	Conditions:	Given SSO 750.
	Standard:	You must be able to successfully complete lesson exercises.

CREDIT HOURS: 2

LESSON OBJECTIVES

When you have completed this lesson, you should:

1. Know the characteristics of radio receiving equipment for use in HF fixed-station radio communications.

2. Be able to identify radio receiving equipment used in HF fixed-station single-channel and multichannel frequency-shift-keyed radio teletypewriter communications.

3. Be able to identify radio receiving equipment used in HF fixed-station single-sideband multichannel radio teletypewriter communications.

4. Be able to explain the distribution of communications channels in the twin-sideband composite signal.

5. Be able to follow the signal path through block diagrams of HF fixed-station radio receiving systems.

ATTACHED MEMORANDUM

4-1. INTRODUCTION TO THE RECEIVING PROCESS

a. In the receiving process the incoming RF signal is selected and converted into its original form, which may be a telephone, teletypewriter, or facsimile signal. A receiving station usually contains receivers, FSK and SSB converters, multicouplers, wire-line terminals, and microwave radio link equipment. The receiving station is connected to the technical control center by wire lines or a radio link, or a combination of the two systems. The type of line terminal equipment in the receiving station is normally the same as that used in the transmitting station.

b. In long-distance HF radio communications systems, diversity techniques are used to provide more reliable reception. In space diversity, the most common type in fixed radio stations, two sets of antennas and receivers are used to take advantage of the fact that fading does not occur everywhere at the same time. When the receiving antennas are separated by several wavelengths, it is likely that the signal strength will be different at the two antennas. The receiving equipment will then compare the signals from the two antennas and select the stronger of the two. In most cases, this selection is made in the converter, which may be part of the radio receiver equipment.

c. When Multiplexer TD-97/FGT-2 is used in conjunction with ISB radio transmitters, the ISB radio receivers must use Demultiplexer TD-98/FGR-3 to maintain system compatibility. The two 6-kHz channels provided by the TD-97/FGT-2 are broken down into four 3-kHz channels by the TD-98/FGR-3. Each of the 3-kHz channels can carry telephone, facsimile, or VF teletypewriter signals. A third demultiplexer is needed in an ISB system to provide diversity tones when space diversity is employed. Transistorized items, Multiplexer TD-410/UGC and Demultiplexer TD-411/UGC, are electrically compatible with TD-97/FGT-2 and TD-98/FGR-3 although much smaller in size. One advantage of the new replacement items is that each one contains a level meter, eliminating the need for external test equipment.

d. Questions.

4-1a. Although the receiving process is the reverse of the transmitting process, the receiving station is similar to the transmitting station in that the same

a. types of line terminal equipment are used.

b. methods are used to lay out the transmitting and receiving equipment.

c. amount of space is required for installation of transmitting and receiving equipment.

d. number of receivers is used at the receiver station as transmitters at the transmitter station.

4-1b. When multiplexing equipment is used with the ISB transmitters at a distant transmitter station, compatible demultiplexing equipment is needed at the receiver station. In the receiver station shown in figure 4-3, the demultiplexing equipment is represented by the block labeled

a. AN/FGC-29.

c. CV-157.

b. AN/FRR-41.

d. TD-98.

4-2. ELECTRONIC COUNTERMEASURES

The reception of wanted radio signals may be prevented by the presence of unwanted interfering signals on the same operating frequency. Such interference may be intentional from unfriendly sources or unintentional from friendly or unfriendly sources. Intentional interference is called jamming.

a. Recognition of Jamming. Jamming signals may take any one of several forms. They may resemble some natural atmospheric or manmade noise, or some friendly transmitter operating normally; or the signal may be recognized as a special type of jamming.

b. Antijamming Procedures. Immediate recognition of intentional jamming is of prime importance. Prompt reporting of jamming to the direction finding organization for location and coordinated action against the source may discourage future jamming. When an operator recognizes that his receiver is being jammed he must immediately inform his supervisor. Under no condition will he cease operating. To provide maximum intelligibility of jammed signals the operator must adhere to the operational procedure established at his station for each type of operation, or refer to the antijamming instructions given in the manual covering the specific equipment being used. Steps that may be taken against jamming include:

(1) Receiver alignment. Properly aligned radio receivers are often capable of separating the wanted signal from the jamming.

(2) Antenna directivity. If the antenna is movable, changing its location of direction may cause discrimination between the wanted signal and the jamming.

(3) Additional power. More transmitter power may increase the signal strength at the receiver to the point where the wanted signal overrides the jamming.

(4) Frequency change. The use of another transmitter on a different frequency and changing call sign while still transmitting on the original frequency may give good results. If no additional transmitting equipment is available, changing frequency and call sign may give a usable wanted signal.

c. Question.

4-2a. Assume that you have been assigned as the station chief of a receiver station and are reviewing the station SOP on electronic countermeasures. The SOP should state that when an operator recognizes that a circuit is being jammed he should

a. stop operating immediately.

b. report it only after he can no longer operate.

c. inform his supervisor immediately and continue to operate.

d. hold all traffic and request the distant-end transmitter to reduce power.

4-3. FADING

a. Interference Fading. Incoming skywave signals are made up of many different incoming components, most of which travel over slightly different propagational paths and thus arrive at slightly different times. The small time differences create slight differences in phase of the many incoming signals. Effectively, the receiving antenna "sees" a composite signal, which is a sum of all the incoming signal components. Because each of these many signal components is constantly changing in accordance with the absorption and refraction properties of the atmosphere and ionosphere through which it passes, the sum is constantly varying to some degree. At times the signal components cancel each other to the point where the composite signal strength is reduced below usable limits. A great deal of this constant increase and decrease of the composite signal strength (called fade) is compensated for by automatic gain controls and other circuits within the receiving equipment. However, most long-distance radio facilities require such a high degree of reliability that other means must be used to overcome those variations that are beyond the capabilities of the receiving equipment. Therefore, most long-distance radio circuits are operated in space diversity.

b. Selective Fading. Fading may affect the entire received radio signal; that is, the carrier and all intelligence may be affected in the same manner. However, the incoming signal often is affected on selected narrow frequency bands. As this selective fading occurs in a random manner and in random amounts over portions of the frequency spectrum, it often affects only a small portion of the intelligence carried by the radio signal at any given instant. This type of fading often can be overcome by operating the radio circuits in frequency diversity.

c. Question.

4-3a. The function of the automatic gain control circuit in a receiver is to compensate for the effects of

a. change in receiver sensitivity.

b. bandwidth variation.

c. frequency drift.

d. fading.

4-4. SPACE-DIVERSITY RECEPTION

a. Antenna Separation. The variations, or fades, are not the same for every point in the field pattern of a receiving antenna. Therefore, by using two separate antennas and two separate receiving sets, most effects of fading can be overcome. While even two rhombic antennas with one support as a common side pole will give some diversity-reception improvement, it has been found that optimum diversity effect is obtained by separating the antennas by at least five wavelengths. Experience has shown that the space-diversity receiving method gives more reliable reception on long-distance radio circuits than any one of the several methods available.

b. Signal Selection. Several methods are used to combine or select the better received signal in diversity systems. ISB systems perform the combining or selecting process in the terminal equipment at technical control. Normally, FSK signals are detected and combined in converters located at the receiving station.

c. Switching Diversity. In switching-diversity systems, the signals from each receiver are compared, and only the better signal is selected--the other signal is totally rejected. The switching may be done either in the intermediate-frequency stages of the receivers, using common demodulators, or after demodulation has been accomplished by individual receivers.

d. Questions.

4-4a. Several methods are used to combine or select the better received signal in diversity systems. ISB signals are combined at the

a. receiver station.
b. transmitter station.
c. technical control station.
d. microwave and carrier station.

4-4b. There are several methods to combine or select the better received signal in a diversity system. The system that selects the better signal and rejects the other signals is

a. space diversity.
b. switching diversity.
c. audio-frequency diversity.
d. radio-frequency diversity.

4-5. FREQUENCY DIVERSITY

Frequency diversity is accomplished either by duplicating the entire transmission on another radio frequency (radio-frequency diversity) or by duplicating groups of audio intelligence signals within a single radio system (audio-frequency diversity).

NOTE: The term frequency diversity, through common usage, usually denotes audio-frequency diversity. The radio-frequency-diversity system is used only as an emergency expedient for short periods of time.

a. Radio-Frequency Diversity. In this system, two radio transmitters emit identical signals on two different radio frequencies. The signals are received on separate receivers and combined in the same manner as space-diversity signals. Because of the equipment and frequency requirements, this method is seldom used, except as an emergency measure during periods when propagational phenomena preclude normal operation.

b. Audio-Frequency Diversity. In long-distance systems, this type of diversity may be used over ISB systems carrying multiplexed telegraph signals. Terminal equipment for most ISB systems includes the necessary channel-combining equipment to provide audio-frequency diversity. The system carries identical telegraph information on two different audio frequencies.

c. Question.

4-5a. One diversity-receiving system uses two different VF signals to represent the same information. This system is known as

a. space diversity.

b. polarization diversity.

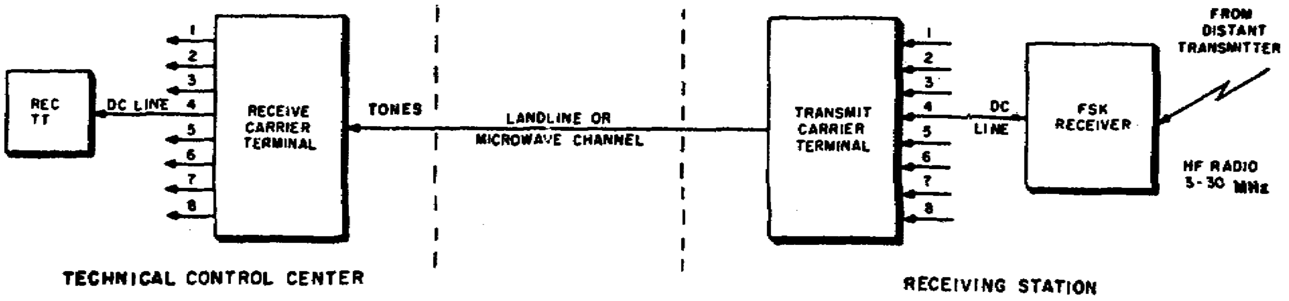
c. audio-frequency diversity.

d. radio-frequency diversity.

4-6. RECEPTION OF FSK RADIO SIGNALS

The mission of the receiving station is to receive and demodulate the radio signals. To assist in accomplishing this function, a receiving converter is always connected to the output of each radio receiver. This converter serves to change the form of the signal to one that is suitable for transmission over keying circuits connected to the technical control center. Here the final demodulation process takes place in terminating equipment such as telephone, teletypewriter, and facsimile devices.

a. Signal-Channel FSK Radio Teletypewriter System (fig 4-1). At the receiving station, the output of a frequency-shift converter is connected by a short dc loop to the input of a carrier system. This carrier system provides the necessary keying circuits between the radio receiving station and the technical control center. Landline or radio link systems may be used as a transmission medium for the carrier system VF tones. At the technical control center, the output of the carrier equipment is connected by a dc loop to the receiving teletypewriter.



<u>Figure 4-1. Typical single-channel FSK radio teletypewriter system, block diagram of receiving facility.</u>

b. <u>Multichannel FSK Radio Teletypewriter System</u> (fig 4-2). The output of the frequency-shift converter equipment is connected by a dc line to a wideband channel of a carrier system (Telegraph Carrier Terminal AN/FCC-3) and transmitted over a keying circuit to the technical control center. After channel separation in the receiving terminal of the carrier system, the signal is connected by a short dc line to the receiving terminal of the multiplexing equipment, where the four teletypewriter channels are separated and transmitted by separate dc lines to the receiving teletypewriters. Time-division-multiplexing equipment now in use can provide for two, three, or four channels of teletypewriter over one FSK radio circuit.

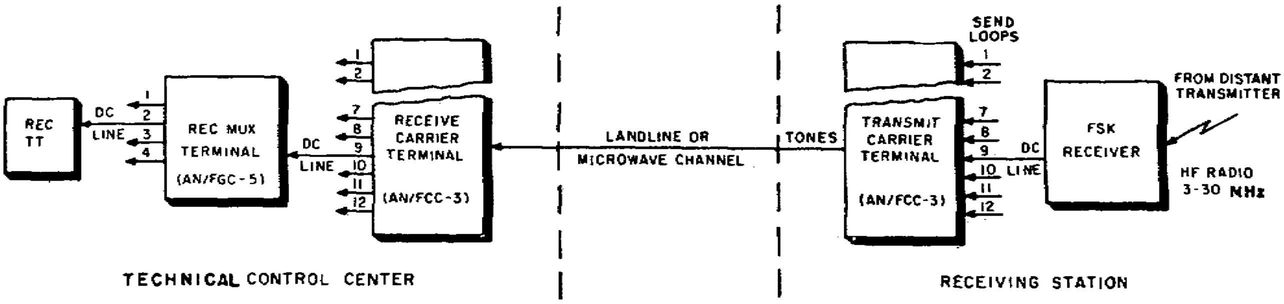


Figure 4-2. Typical multichannel FSK radio teletypewriter system, block diagram of receiving facility.

c. Question.

4-6a. The output of a frequency-shift converter is connected to the input of a carrier system at a receiving station by

a.	FSK longlines.	c.	FSK shortlines.
b.	dc long loops.	d.	dc short loops.

4-7. SINGLE-SIDEBAND RECEPTION

a. In conventional AM transmissions, the modulation information contained in the upper group of sidebands is also duplicated in the lower group of sidebands. For this reason, it is possible for a receiver to use just the carrier frequency and one group of sidebands to reproduce the transmitted information. The carrier frequency is used by the receiver only as a reference frequency in relation to the frequencies of the various sidebands. This carrier signal must be present because the receiver interprets the difference between the various sideband frequencies and the carrier (reference) frequency to reproduce the audio signals.

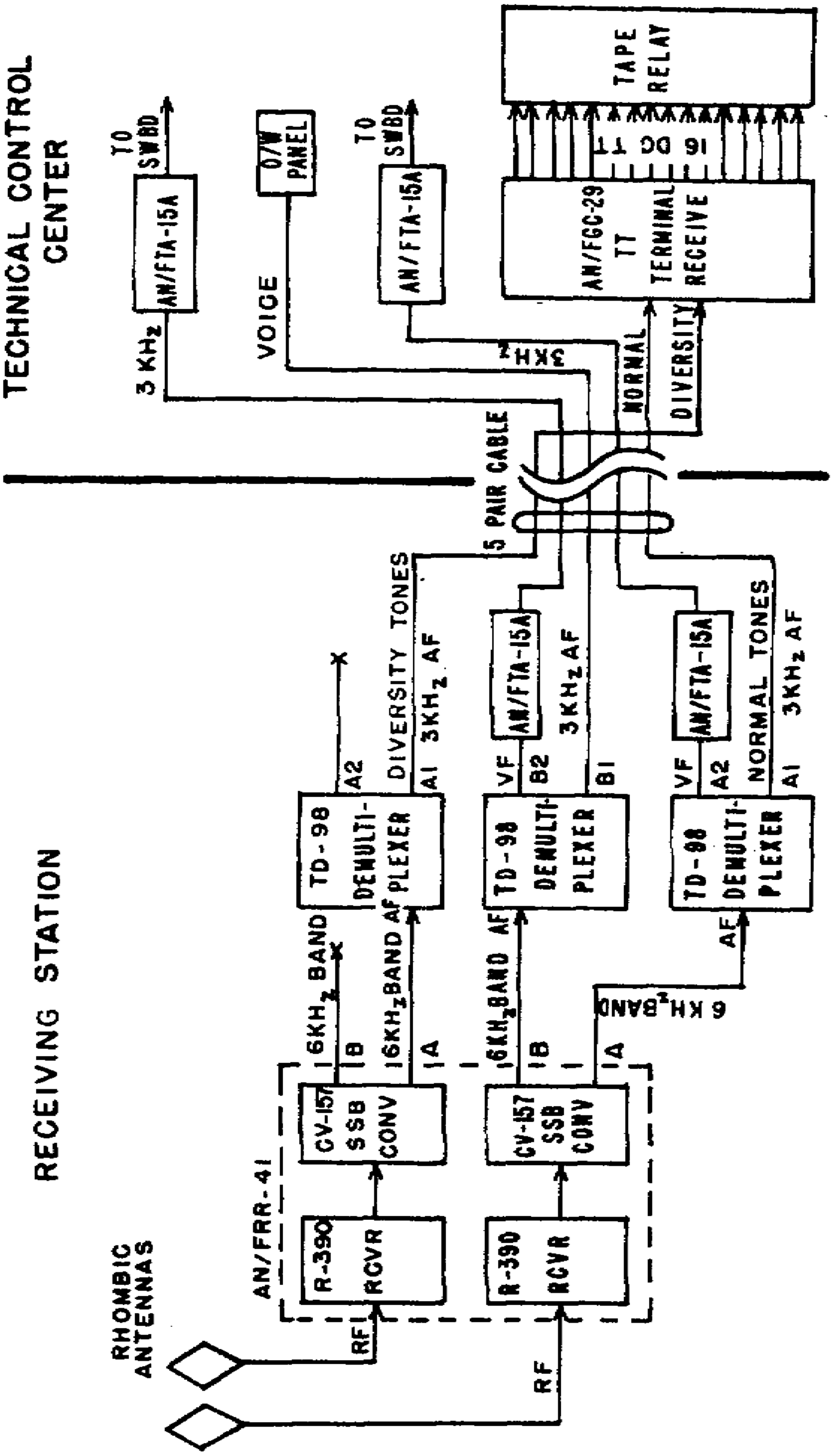


Figure 4-3. Independent sideband system, receive side, with cable keying facilities.

b. In true SSB transmission, only one sideband group is transmitted. The carrier frequency signal and the other group of sidebands are suppressed in order to conserve transmitter power and channel space in the radio-frequency spectrum. The suppression of the carrier signal at the transmitter will therefore require that an equivalent signal be generated and inserted at the receiver. The need for carrier reinsertion is the primary reason that the SSB receiver requires a few circuits that are different from those of the conventional AM receiver. When a pilot carrier is transmitted, it is used in the SSB receiver to control the frequency of the receiver carrier oscillator.

c. In ISB transmission, two 6-kHz SSB's (A and B) are developed, each sideband carrying entirely different information. At the receiving end of the system (fig 4-3), the 6-kHz sideband A is demultiplexed into its two 3-kHz components. The 3-kHz tone channel (A1) is transmitted to the technical control center over a keying circuit. At the technical control center, the 3-kHz tones are separated by the carrier terminal equipment into the several individual channel signals, demodulated, and then transmitted to the receiving teletypewriters over dc lines. The 3-kHz voice channel (A2) is used for voice communication. Similar treatment is given to the 6-kHz sideband B, except that different types of equipment (facsimile sets, voice terminal equipment, etc.) make up the end items.

d. <u>Question</u>.

4-7a. After studying block diagrams of two radio receivers you find that one is designed to receive SSB signals, while the other is limited to receiving DSB AM signals. One block you will see in the diagram for the SSB receiver that is missing in the AM receiver is marked

a. automatic gain control.

b. audio-frequency amplifier.

c. carrier reinsertion oscillator.

d. intermediate frequency amplifier.

4-8. SINGLE-SIDEBAND RECEIVER REQUIREMENTS

Various types of SSB receivers differ somewhat from one another because of the variety of circuits employed in the individual sets. However, there are generally four main features not normally found in AM receivers, which are usually incorporated in receivers designed for SSB reception. These features are a narrow bandpass, a very accurate tuning system, an oscillator for generating an equivalent carrier signal, and a means for obtaining good frequency stability.

a. Narrow Bandpass. Since the SSB signal occupies only half the frequency space of the AM signal, it requires only half as much receiver bandpass to provide a given audio bandwidth. The narrow bandpass is accomplished very simply by the design of the tuned circuits. One major advantage of the narrow bandpass is that of noise reduction. This is due to the fact that noise is proportional to the effective bandwidth of a system.

b. Accurate Tuning System. When a mechanical tuning system is used, it must be designed for a slow tuning rate. For example, an SSB receiver that covers from 20 kHz to 25 kHz per tuning knob revolution is easier to tune than one that covers from 100 kHz to 150 kHz per knob revolution. In addition to the tuning mechanism designed for easy tuning, a further refinement that may be used is a calibration circuit which enables the operator to zero-beat the receiver to assure accuracy of dial settings. Particular care in tuning is necessary because the receiver has to be set with great accuracy to receive the signal faithfully. To better understand why this is necessary, consider the following example: An SSB transmitter, operating on a frequency of 100 kHz and transmitting the upper group of sidebands, is modulated with a 1-kHz tone. Since the carrier frequency of 100 kHz is suppressed, the only signal transmitted in this case is the 101-kHz sideband. Because the receiver interprets the difference between the sideband frequencies and the carrier (reference) frequency, it must be accurately tuned so that the inserted carrier frequency in this example is exactly 100 kHz in order to obtain a 1-kHz output.

c. Oscillator for Inserting an Equivalent Carrier Signal. The suppression of the carrier signal at the transmitter makes it necessary that an oscillator be employed to generate and insert an equivalent carrier signal at the receiver. A signal of the carrier frequency may be inserted in the input of the receiver, or a signal of the intermediate frequency (IF) may be inserted in the IF section. At whichever point in the receiver this signal is inserted, it must be an accurate and stable frequency for the receiver to faithfully reproduce the transmitted information. It is also important that the amplitude of the inserted signal be several times as strong as the received sideband signals to prevent an undue amount of audio distortion.

d. Frequency Stability. For the receiver to continue operating with good results after it has been accurately tuned, a high degree of frequency stability must be maintained. If any part of the receiver drifts off frequency, the result is the same as detuning. The stability of the SSB receiver depends on both the local oscillator and the oscillator which generates the equivalent carrier signal. Any frequency drift in either of these oscillators will have adverse effect on the operation of the receiver. These oscillators are usually variable-frequency oscillators (VFO) that are tunable to cover the operating frequency range of the receiver. Often the receiver is designed to be operated on one of several preset frequency channels. In this case, the oscillators are converted to crystal oscillators by the throw of a switch. When crystal oscillators are not used, some form of automatic frequency control (AFC) must be employed to stabilize the operation of these circuits. The general types of frequency synthesizers, widely used in AM and FM radio equipment, are also adaptable for use in SSB receivers to accomplish frequency stability.

e. Questions.

4-8a. What is one of the major advantages of a narrow bandpass?

a. Reduction of fading.

b. Noise reduction.

c. Less equipment.

d. Frequency stability.

4-8b. In order to stabilize the operation of circuits, when a crystal oscillator is not used, what device is used?

a. Variable frequency oscillators.

b. Frequency lock switch.

c. Automatic frequency control.

d. Intermediate frequency control.

4-9. RF EQUIPMENT

a. RF Patching. The radio energy intercepted by an antenna is conducted to the desired receiver by an RF transmission line. Demands for space-diversity reception and the constantly varying characteristics of skywave transmission paths require flexible patching arrangements to select the necessary combinations of antennas and receivers. Antenna patching may be accomplished by means of a locally constructed patching system consisting of coaxial patch cords, jacks, and plugs.

b. Antenna Couplers. Multicouplers are wideband coupling devices designed to allow operation of two or more radio receivers from a single antenna without loading of the antenna or excessive interaction between the receivers. If multicoupler units (such as Antenna Coupler CU-168/FR) are installed, the desired flexibility may be obtained by mounting the multicouplers near the antenna patching panels. To complete the connection, the operator patches the antenna jacks to the multicoupler input jacks. The antenna multicoupler output jacks are then patched to the respective radio receiver input jacks. For space diversity, two antennas and two CU-168/FR's will permit the use of 10 different receivers for five different circuits.

c. Question.

4-9a. Using space diversity two CU-168/FR's and two antennas will allow the use of

a. 5 different receivers for 10 different circuits.

b. 10 different receivers for 5 different circuits.

c. 10 different receivers for 10 different circuits.

d. 5 different receivers for 5 different circuits.

4-10. CONVERTERS

Special converters are used in most long-distance radio receiving systems to translate the complex signal outputs of the radio receivers into a more usable form. These converters usually are built for a specific type of facility and cannot be used in other facilities.

a. ISB Converter. Single Sideband Converter CV-157/URR is used to translate the ISB IF output signals from a standard communications receiver into the two separate audio-frequency sidebands (A and B). It is designed primarily for use with Radio Receiver R-390/URR and, if it is used with a receiver having a different IF conversion sequence, the front panel identification of upper and lower sidebands may be reversed. Controls are provided for transposing the sidebands if necessary. When space diversity is used, one converter is used to separate the sidebands of the main receiver and a second converter separates the sidebands of the diversity receiver.

b. FSK Converters. Several types of RATT converters are available for converting FSK signals into dc pulse signals. These converters generally provide for diversity selection of signal outputs from two separate receivers. Some converters, such as Frequency Shift Converter CV-116/URR, use the intermediate frequencies from the receivers and must be connected to the receivers by coaxial cable. Other converters use audio-frequency outputs from the receivers, and connections can be made with standard two-wire lines.

4-11. LINE AND TERMINAL FACILITIES

a. Terminal facilities for receiver stations consist of wire lines and cable, short-distance radio or microwave link, and carrier terminal equipment. These are used to provide the required number of keying circuits between the receiver station and the technical control center. The use of carrier terminal equipment decreases the number of physical pairs required between the two terminals. Essentially the line and terminal equipment serves the same function in the receiving process as in the transmitting process; that is, it provides keying line facilities between the technical control center and the respective station (transmitter or receiver). The major difference in the use of the line terminal facilities is that the direction of communications in the receiving process is opposite that in the transmitting process.

b. The number of keying lines required between the receiver station and the technical control center may differ from the number required between the transmitter station and the control center. Ordinarily the same number of channels on any given type of communications is provided both to and from the technical control center even though the communications requirements may differ. However, when space-diversity operation is employed and Telegraph Terminal AN/FGC-61A, or its equivalent, is located at the technical control center, an additional line from the receiver will be required to handle the additional diversity tones (fig 4-3).

4-12. RADIO RECEIVING SETS

All receivers used for long-distance communications are of the super-heterodyne type and are designed for diversity operation. Some receivers are designed primarily for FSK operation, others for DSB and ISB operation. Most receivers used in ISB operation require conversion equipment when the full 6-kHz channel bandwidth is used. Usually the receivers are a part of receiving sets that consist of a converter and two receivers for diversity operation.

4-13. RADIO RECEIVING SET AN/FRR-38

a. Description. Radio Receiving Set AN/FRR-38 is a diversity set used primarily for the reception of high-frequency RATT signals. The set is composed of two Radio

Receivers R-390A/URR and one Frequency Shift Converter CV-116/URR mounted together in one cabinet.

b. Technical Characteristics.

Frequency range	0.5 to 32 MHz.
Frequency control	Variable oscillator with AFC.
Calibration	Built-in crystal standard.
Antenna input	Unbalanced 70 ohms, balanced 200 ohms.
Signal input	Frequency-shift keying.
Signal output	Dc teletypewriter.

c. Application. The AN/FRR-38 is used as the diversity-receiving equipment in a fixed-station point-to-point RATT communications system. The equipment is normally installed at the receiver station and uses two rhombic antennas. The design of the AN/FRR-38 is such that single-channel or time-division-multiplex signals can be accommodated without changes. The output signal from the teletypewriter or multiplexer is supplied to the teletypewriter or multiplex equipment at the technical control center through a channel of a telegraph carrier system over cable or microwave radio facilities.

d. Question.

4-13a. A receiving set that is designed to receive single-channel RATT or time-division-multiplex signals is the

a. AN/FRR-38.

b. AN/FRR-40.

c. AN/FRR-41.

d. AN/FRR-79.

4-14. RADIO RECEIVING SETS AN/FRR-40 AND AN/FRR-41 (fig 4-4)

a. Description. Radio Receiving Sets AN/FRR-40 and AN/FRR-41 are used primarily for the reception of high-frequency ISB signals. The basic components of these sets are Radio Receiver R-390A/URR and Single Sideband Converter CV-157/URR -- one each in the AN/FRR-40 and two each in the AN/FRR-41. The AN/FRR-40 is a single receiving set and the AN/FRR-41 is a space-diversity receiving set. Either receiving set can accommodate two independent 6-kHz (bandwidth) sidebands. These sidebands can carry teletypewriter, voice, and facsimile information simultaneously. The AN/FRR-40 and AN/FRR-41 require that carrier suppression be no greater than -20 decibels (dB) to provide sufficient pilot carrier to activate AFC circuits in the converters. However, for operation with frequency-stabilized transmitters where the carrier is fully suppressed, the receiving sets may be modified with Compensator, Frequency CN-1448/TSC-25.

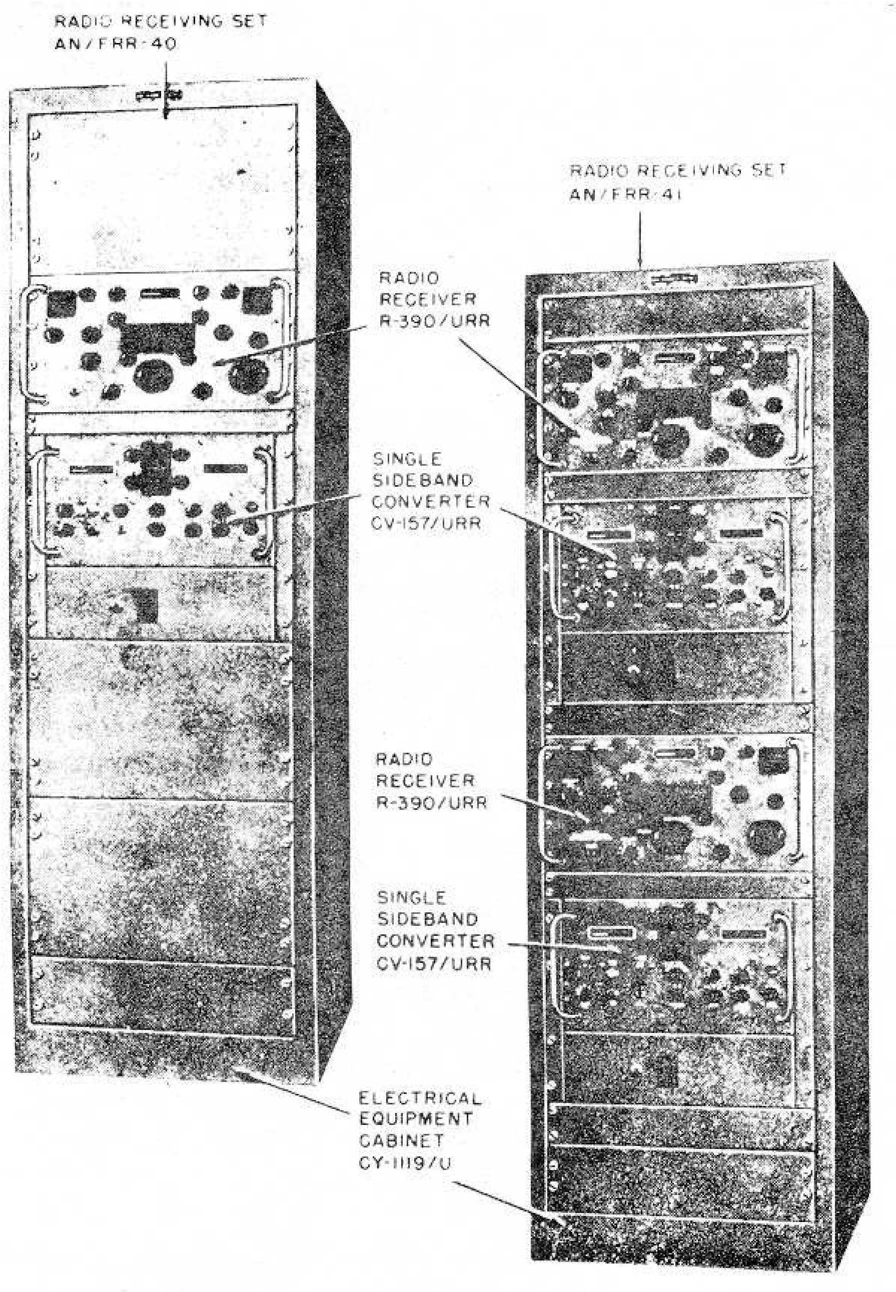


Figure 4-4. Radio Receiving Sets AN/FRR-40 and AN/FRR-41.

b. Technical Characteristics.

Frequency range..0.5 to 32 MHz.

Frequency control ....Unsynthesized – variable oscillator, with AFC.

	Synthesized – variable in 100-Hz steps and a frequency stability of 10-8 per 24-hour period.
Calibration	Built-in crystal standard.
Antenna input	Unbalanced 70 ohms, balanced 200 ohms.
Signal input	SSB, suppressed carrier.
Signal output	Audio frequency (two independent channels).

c. Application. The AN/FRR-40 and AN/FRR-41 are normally used as the receiving equipment at fixed-station installations that have a heavy flow of message traffic. As shown in figure 4-3, each of the two 6-kHz sidebands at the output of the receiving sets is broken down into 3-kHz channels and fed to the technical control center over cable facilities.

d. Question.

4-14a. Radio Receiving Set AN/FRR-41 contains two converters as well as two receivers. Two Single Sideband Converters CV-157/URR are required because

a. one converter is used, one is held as spare.

b. each converter changes two 6-kHz bands into four 3-kHz bands.

c. one converter combines the two upper sidebands and the other combines the two lower sidebands.

d. one converter separates the sidebands of one receiver and the other separates the sidebands of the second receiver.

LESSON 5

ANTENNA SYSTEMS

TRAINING OBJECTIVE:	Action:	Be able to list characteristics of antennas use in fixed-station radio communications.
	Condition:	Given SSO 750.
	Standard:	You must be able to successfully complete lesson exercises.
CREDIT HOURS:	2	

LESSON OBJECTIVES

When you have completed this lesson, you should:

1. Be able to identify various types of transmitting and receiving antennas used in fixed radio station installations.

2. Know the design features that contribute to efficiency of radiation in radio transmitting antennas.

3. Know that the same antennas can be used, for transmitting or receiving if designed for the dual function.

4. Know that the strength of the received signal is proportional to the antenna gain.

5. Know that the directional characteristics of the antenna establish the antenna gain.

ATTACHED MEMORANDUM

5-1. GENERAL

a. Antennas for high-frequency fixed-station communications are designed for maximum efficiency. Transmitting antennas are designed to achieve maximum power radiation, while comparable receiving antennas are designed to achieve maximum signal-to-noise ratio. As a general rule, good transmitting antennas make good receiving antennas, and both types usually have the same directional characteristics. The significant difference between the two types lies in the physical size of the components of the transmitting antennas to enable them to handle large amounts of RF power.

b. In fixed installations, the antennas are usually located considerable distances from the station sites. The RF energy is conducted to and from the transmitting and receiving antenna parks, respectively, by means of the nonresonant transmission lines. Nonresonant lines are preferred because of their relatively low loss.

c. Long-distance antenna assemblies are usually designed so that the nonresonant transmission lines terminate in equivalent impedance points on the antennas. This procedure is followed to match the transmission line and antenna impedances so as to minimize standing waves on the transmission lines.

5-2. CHARACTERISTICS OF RF TRANSMISSION LINES

The effect of characteristic impedance on radio signals being transmitted is similar to that on signals being received. However, to keep the explanation simple, reference will be made only to the effect which these characteristics have on the signals being transmitted.

a. Characteristic Impedance. Characteristic impedance is the opposition offered to the flow of RF current through a transmission line. The value of characteristic impedance depends on the distribution of resistance, capacitance, and inductance in the line. Since these distributed constants are different for each type of transmission line, the characteristic impedance will be different for each.

b. Attenuation and Losses. The ideal transmission line has no losses. Theoretically, it transfers all the energy available at the output of the transmitter to the antenna. Actual transmission lines, however, dissipate power in four ways:

(1) Radiation. The transmission line may radiate in a manner similar to that in an antenna. When this happens, surrounding objects near the transmission line may absorb some of the RF energy, and the antenna will receive that much less. If the antenna, transmission line, and radio transmitter are adjusted to reduce radiation from the transmission line, this loss of RF energy will be minimized.

(2) Heating. The resistance of the conductors in the transmission line dissipates a certain amount of power in the form of heat. The amount of heat rises in proportion to the rise in current. From this fact, it is apparent that, with given power output from the radio transmitter, heat loss will be high with a transmission line having a low impedance and, therefore, passing a high value of line current. In some fixed installations transmitting very large amounts of power, antenna terminating resistors sometimes are made of lengths of high-resistance transmission lines.

(3) Additional losses. Losses normally increase with an increase in frequency because the electrical charges tend to travel on the conductor surface at the higher RF frequencies (skin effect). An additional loss also results from leakage between the conductors (dielectric loss) and between the conductors and ground (leakage).

(4) Reflection. If the load impedance does not match the characteristic impedance of the transmission line, some of the RF energy is reflected back into the transmission line. This causes standing waves to develop, resulting in additional loss due to radiation absorption. Standing waves also prevent the load from absorbing maximum power from the line.

c. Question.

5-2a. Assume that a transmission line is connected to a mismatched load. The loss that results from this mismatch is caused by

a.	heating.	c.	dissipation.
b.	leakage.	d.	reflection.

5-3. TYPES OF NONRESONANT TRANSMISSION LINES

a. Open Two-Wire Line.

(1) The air between the two parallel wires in the open two-wire line is the dielectric between the two conductors. Because the conductors are maintained parallel to each other by the insulating spacers, as shown in (A) of figure 5-1, this type of transmission line is sometimes called a parallel-conductor line. The characteristic impedance of the line, if terminated in a load having a similar impedance, remains a constant value throughout its length. The usual practice is to use an open two-wire line having 600 ohms impedance.

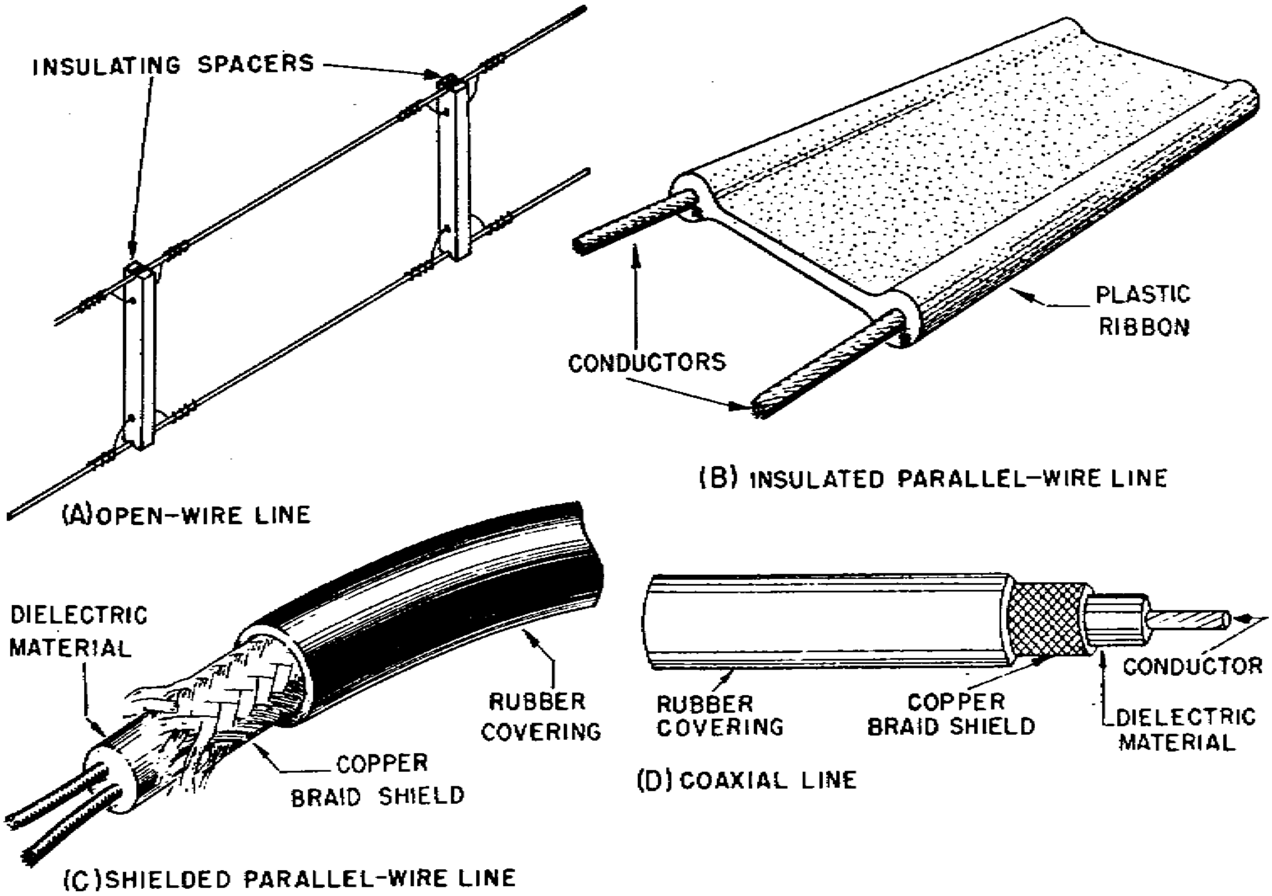


Figure 5-1. Four types of RF transmission lines.

(2) Currents flow through the two parallel conductors in opposite directions. If the currents are exactly 180° out of phase, the radiation fields nearly cancel one another and the radiation loss approaches zero. This loss, however, will increase with frequency. A practical upper limit to the use of an open two-wire line is about 200 MHz.

(3) The open two-wire line can be used with good results for either transmitting or receiving. However, it requires a large amount of material and considerable time to construct. For this reason, its use is usually limited to fixed radio stations or to special antennas used by mobile long-distance radio stations.

b. Insulated Two-Wire Line. The insulated parallel-wire line shown in (B) of figure 5-1 consists of two parallel wires with a plastic ribbon separator. This plastic ribbon serves two purposes: it is the dielectric between the wires, and it maintains the spacing between the wires. The dielectric losses are higher than in a comparable open-wire line, and the higher dielectric constant lowers the characteristic impedance. This type of line (sometimes called twin lead) is best suited for use with receiving antennas, and is widely used in TV and FM receiver installations.

c. Shielded Pair. A further development of the insulated two-wire line is the shielded pair shown in (C) of figure 5-1. The two parallel conductors are imbedded in a flexible dielectric. The insulated pair is then enclosed in a shield made of braided copper. The entire assembly is given a weatherproof coating. The principal advantage of the shielded pair over other types of two-wire lines is its low radiation loss. The loss is low because the shield provides a uniform ground for both conductors, resulting in a well-balanced line. Furthermore, the shield provides protection from stray pickup in the presence of external fields. This type of line finds its most useful application as lead-in from receiving antennas in areas where local electrical noise is a factor.

d. Twisted Pair. If two insulated wires are twisted together, a flexible transmission line is made without the use of spacers. This type is limited to short, untuned lines because of the high losses. Field telephone wire makes a fair substitute as a twisted-pair transmission line in emergencies. However, greater losses must be expected because of the steel wire placed in the conductors for added tensile strength.

e. Coaxial Lines. A coaxial transmission line has one conductor placed inside the other, as shown in (D) of figure 5-1. Coaxial transmission lines are probably the most widely used types for both sending and receiving in mobile radio sets. Coaxial cable is available in either flexible or solid form. Fixed installations can benefit most from the solid form, while the flexible form must be used with mobile radio sets. A coaxial transmission line confines radiation to the space inside the line. External objects therefore have no effect on transmission; consequently the loss is kept at a low figure. Also, because of the shielding effect of the grounded outer conductor, coaxial cable is well suited to conduct signals through electrically noisy areas.

f. Transmitter Patching. It is often necessary to change connections between transmitters and antennas. For example, standby transmitters may have to be substituted for normal transmitters during routine maintenance or repair of the normal transmitters. In other situations, high-power transmitters made up of a medium-power driver and power amplifier may be provided with a means of connecting the driver directly into the transmission line in case of failure of the power amplifier. Also, switching arrangements may be made for switching the output of a transmitter to either a regular or spare antenna.

> WARNING: Large amounts of RF power produced by fixed-station transmitters require strict observance of safety rules. Transmitters should be turned off before any attempt is made to change the connection between the transmitter and antenna, and unused feeder lines not in use must be grounded.

(1) Coaxial patching panels. Antenna switching is normally accomplished by means of a coaxial patching panel or an open-wire switching system. To provide complete flexibility on low-powered circuits (up to 3 kW), RF patching panels with flexible coaxial patching cords are available. Impedance-matching transformers called baluns must be used to match the low impedance of the coaxial cable to that of the open-wire line at the termination of the coaxial cable. Impedance matching is especially important at high power to minimize standing waves within the coaxial cable, which may cause arcs to develop between the inner and outer conductors.

(2) Open-wire switches. Although coaxial switching systems can be used for high-powered circuits, open-wire switching systems are much more economical. Open-wire switching systems usually consist of switches operated either manually or by means of relays.

g. Receiver Patching. Any receiving station handling large amounts of traffic generally requires several sets of antennas oriented in various directions. In addition, when space diversity is employed, two antennas must be provided for each direction of reception. Changeover from one set of antennas to another must be quick and easy.

(1) Patching panels. Since currents through receiving antennas are small, a different system from that used with transmitting antennas may be used for switching of receiving antenna feeders. Perhaps the simplest method is to terminate all antenna leads in RF jacks at a panel within the building. A set of leads from each receiver is terminated in an RF jack on the same panel. Changeover is made in seconds by the use of RF patching cords.

(2) Antenna couplers. Antenna couplers are used for operating several receivers from a single antenna. Additionally, antenna couplers isolate the individual receivers to prevent interaction between them.

h. Questions.

5-3a. Coaxial cable is widely used in receiving antenna installations because of its noise-reducing qualities. Coaxial cable is very effective in reducing the amount of interfering noise pickup because

a. the outer conductor is never grounded.

b. the outer conductor shields the inner conductor.

c. coaxial cable is always terminated in its characteristic impedance.

d. noise picked up in one conductor is cancelled out by an equal amount in the second conductor.

5-3b. The function of an antenna coupler is to

a. couple coaxial lines together.

b. operate several receivers from the same antenna.

c. switch receiving antennas to different receivers.

d. connect feed lines between radio transmitters and antennas.

5-4. RESONANT TYPES OF LONG-DISTANCE ANTENNAS

The most efficient type of resonant transmitting antenna is a half-wave dipole. However, it responds best to one particular frequency. Moreover, it suffers from dispersion of the radio wave in many directions. Most of the radiated energy is therefore lost, as far as the receiving antenna is concerned.

a. Double-Folded Dipole Antenna. The double-folded dipole antenna is a resonant type of transmitting antenna that can be fed directly by a nonresonant transmission line. The three wires making up the antenna increase the normal impedance of approximately 73 ohms at the center of a dipole to 600 ohms. Thus the two-wire transmission line can attach directly to the center of the antenna because the 600 ohms at the center of the dipole matches the 600-ohm characteristic impedance of the transmission line. An insulator separates the junction points of the transmission-line wires to the antenna. The bearing of the antenna indicates the directions of the maximum lobes of radiation. Since this is a resonant type of antenna, the length must be altered to accommodate each change of transmission frequency.

b. Delta-Matched Doublet. Another common high-frequency antenna is illustrated in figure 5-2. It consists of a single, horizontal wire of about one-half wavelength. The power from the station transmitter is transferred from a balanced 600-ohm transmission line to the antenna by means of a delta-matching section. The ends of the wires of the transmission line are fanned out and attached to the antenna at equal distances from the center. The purpose of the fanning is to increase the transmission line impedance from that of the line to the antenna so as to minimize standing waves on the line. The exact dimensions depend on the antenna height, ground conditions, frequency, and the effect of structures near the antenna, and are found by trial-and-error adjustments. This procedure is made necessary by the sharp frequency response of the antenna. The dimensions indicated in the drawing can be found from the following formulas:

$$A = \frac{467.4}{F} \qquad B = \frac{175}{F} \qquad C = \frac{147.6}{F}$$

NOTE: A, B, C are lengths in feet.
F is frequency in MHz.

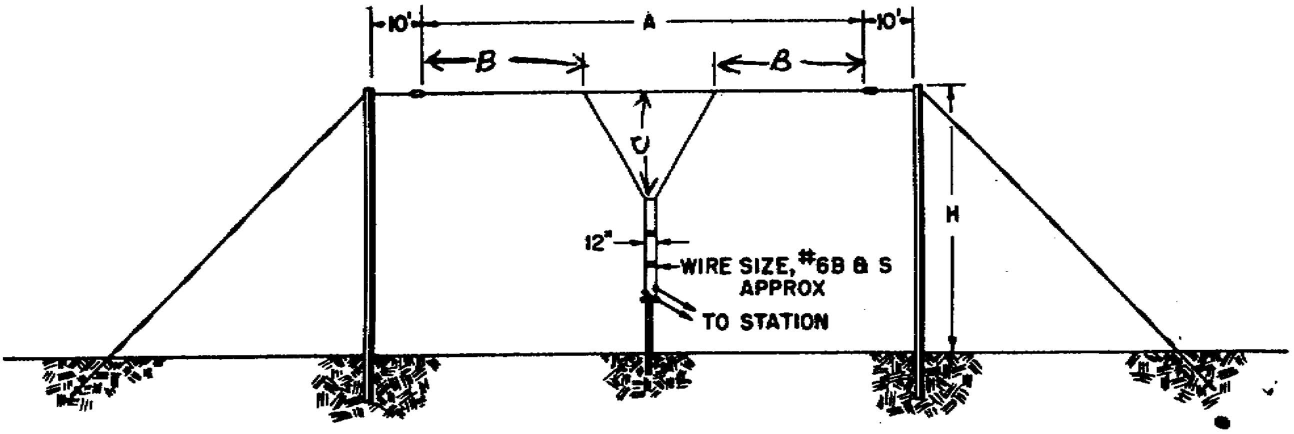
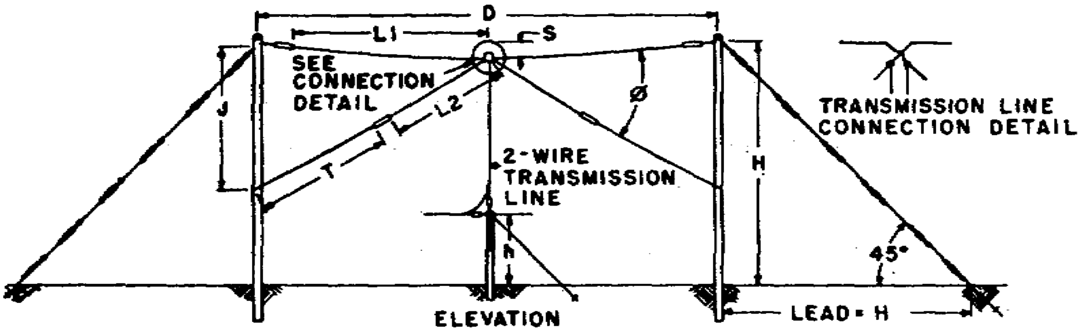


Figure 5-2. Delta-matched doublet antenna.

c. Double-Doublet Receiving Antenna. The double-doublet antenna is used extensively for reception of HF radio signals in both mobile and fixed long-distance radio systems. It works well as a receiving antenna because of its wide frequency response. Maximum response is broadside to the antenna, but the directivity pattern is by no means critical. The antenna should be located so that the stations to be received are more than 15° of either side of the direction toward which the antenna ends are pointing. A sample antenna (fig 5-3) is constructed of two separate half-wave doublets of different lengths installed at an angle to each other. The shorter doublet is cut to a half wavelength at the highest operating frequency, and the longer one is cut to the lowest operating frequency. The frequency-response curve shows a relatively even response throughout the spectrum between the two extreme operating frequencies used. Although the signal-to-noise ratio is good, it is not as good as if separate horizontal half-wave antennas were cut to each individual assigned frequency. Approximate dimensions of the standardized type A antenna are shown in figure 5-3.



LEGEND			
D	POLE SPACING BETWEEN CENTERS	J	ATTACHMENT SPACING
L1	ONE HALF UPPER ELEMENT	T	TIE WIRE (APPROX 45 FT)
L2	ONE HALF LOWER ELEMENT	Ø	30° APPROX
S	INITIAL DEFLECTION (DOWN LEAD	H	75 FT PREFERRED
	& LOWER ELEMENTS HANGING FREE)	h	12 FT PREFERRED

TABLE I
DOUBLE–DOUBLET REC ANTENNA DATA

TYPE	BAND RANGE (NOMINAL)	D	J	L1	L2	S
	(IN MEGAHERTZ	(IN FEET)				
A	2.5-20	130	37	60	30	3

TM486-515

Figure 5-3. Double-doublet receiving antenna.

5-5. NONRESONANT TYPES OF LONG-DISTANCE ANTENNAS

a. Nonresonant Antenna Principles. Neither of the two wires in an open-wire nonresonant transmission line will radiate as long as the same distance is maintained between them, even if standing waves do happen to appear on them. Whatever radiation takes place from one of the two wires is cancelled by radiation of an opposite-polarity signal from the other transmission line. However, radiation will take place from the lines if they are spread apart. This principle is used to advantage in the development of a nonresonant antenna. Assume, for example, that the ends of a nonresonant feeder line are spread out in the form of the letter V (A, fig 5-4). The individual lobes of radiation will reinforce themselves to develop a resultant pattern and directivity as indicated. This bidirectional V antenna can be made unidirectional by attaching the ends of the V to terminating resistors (B, fig 5-4). Power loss occurs in the terminating resistors, but the directivity gained by adding the resistors causes the signal picked up by the distant receiver to appear stronger than would be the case of a signal radiated from a half-wave dipole in free space. Thus it is common practice to say that a properly designed and terminated unidirectional nonresonant antenna has power gain.

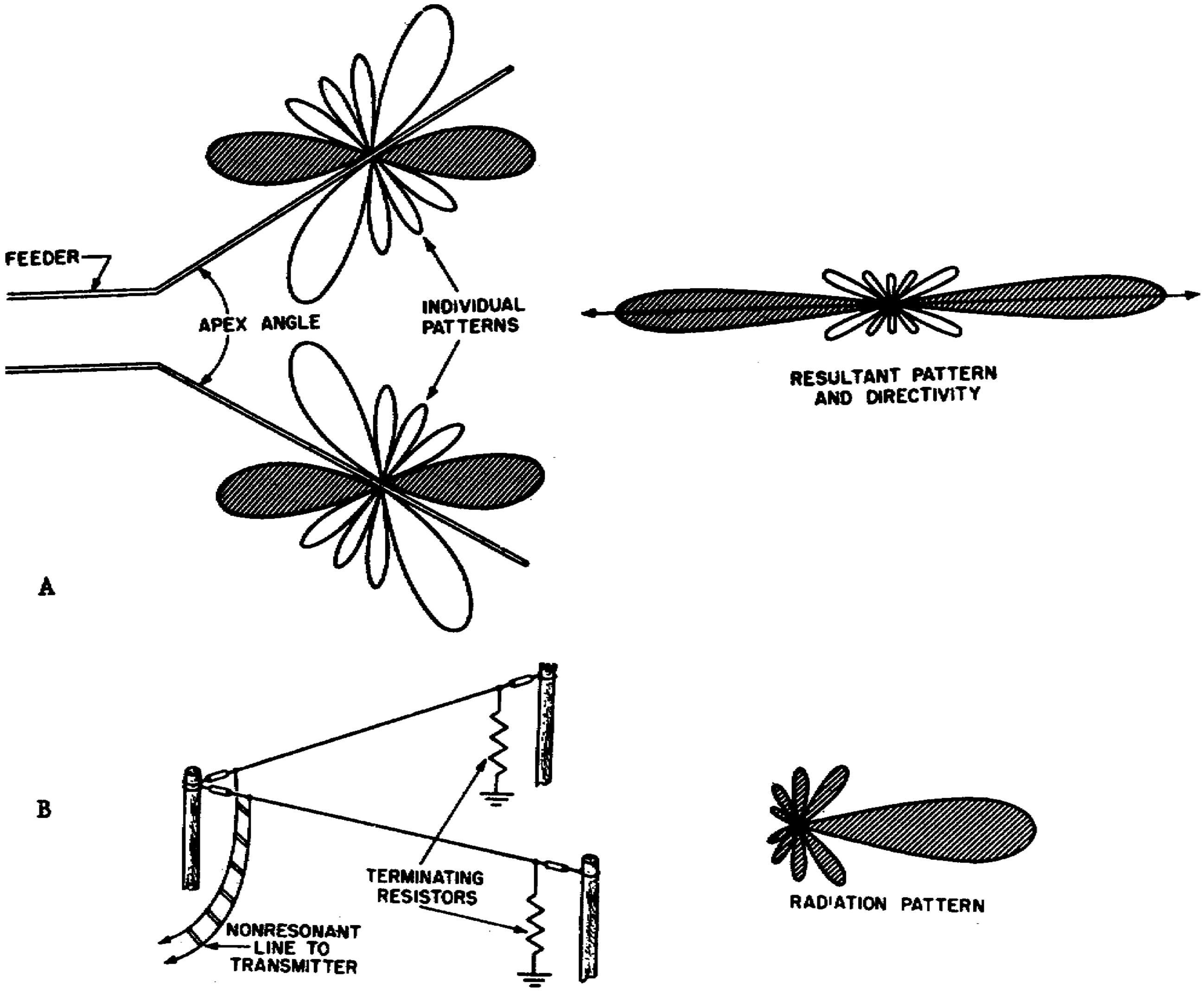


Figure 5-4. Development of a unidirectional nonresonant sloping-vee antenna.

b. Sloping-Vee Antenna. A practical example of a sloping-vee antenna is shown in figure 5-5. This is the type of antenna used with Communications Central AN/TSC-20, to be described in a later lesson. The transmitter output energy is conveyed through a coaxial cable to the coupler. The coupler serves to match the impedance of the two-wire transmission line to the coaxial cable. Insulated spacers maintain the separation of the wires in the vertical transmission line. The antenna legs are essentially extensions of the two-wire transmission line, and, because the distance between them is constantly changing, the impedance is constantly increasing, resulting in radiation. The combination of terminating resistors and counterpoise assemblies assists in the dissipation of the RF energy that is not radiated. In a properly designed antenna, these resistors must dissipate 50 percent of the energy fed into the antenna. The receiving antenna of this design is similar in most respects, except for wire size and dissipation capabilities of the termination resistors.

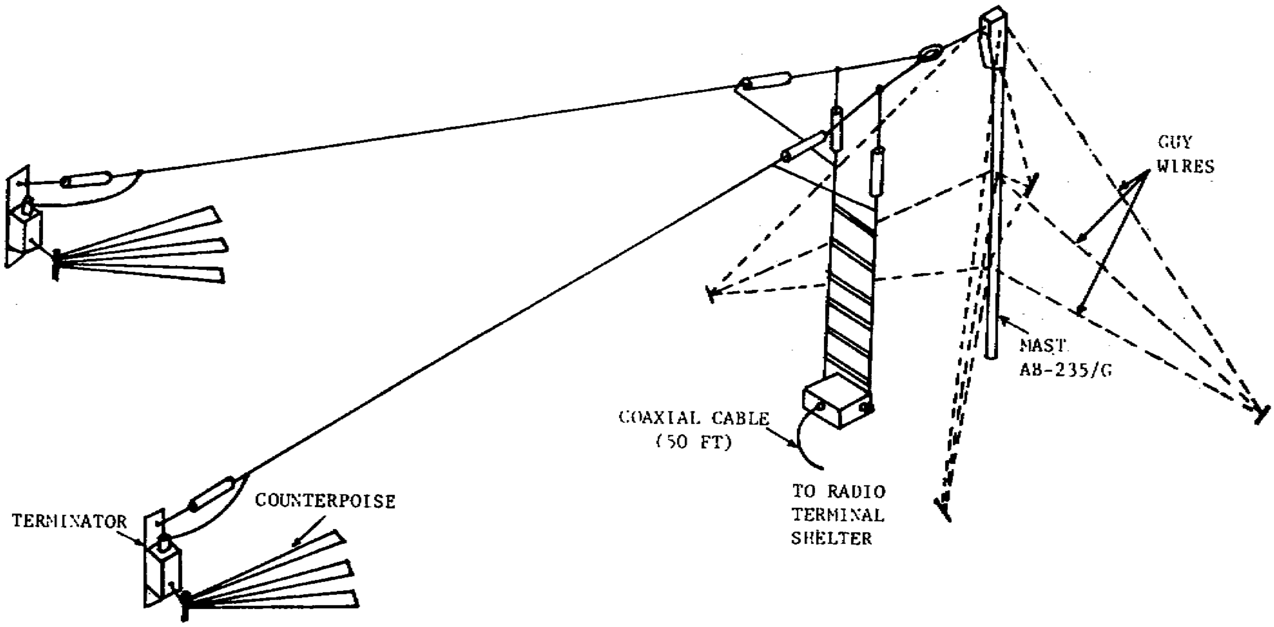


Figure 5-5. A sloping-vee transmitting antenna.

c. Transmitting Monopole Rhombic Antenna. The directional effects of a sloping-vee antenna can be increased by the addition of a second sloping-vee antenna (fig 5-6). Since only one supporting mast is necessary, construction and maintenance time is reduced from that required to erect a standard rhombic. It is called a rhombic antenna because it exhibits many of the characteristics of a rhombic antenna.

5-6. DESCRIPTION OF THE RHOMBIC ANTENNA

a. The basic rhombic antenna consists of four long-wire radiator elements arranged in the shape of a rhombus (fig 5-7), from which the antenna gets its name. This antenna is simple to erect, has high gain, is unidirectional, and provides good performance over a broad, continuous frequency range. The last characteristic is responsible for the wide use of the rhombic antenna, even though it takes more room than most antennas.

b. The maximum radiation lobe of the rhombic antenna lies along the major axis of the rhombus (fig 5-8). The radiation pattern is the effective sum of the individual radiation patterns of the four long-wire radiator elements. If the far end of the antenna is terminated in a resistance equal to the characteristic impedance, the antenna will be unidirectional and nonresonant. The nonresonant characteristic results in much lower RF voltages on the radiators than would be produced by the same input power on a resonant antenna. This is advantageous when the antenna is used with a high-powered transmitter or at high altitudes because there is less possibility of RF leakage across insulators.

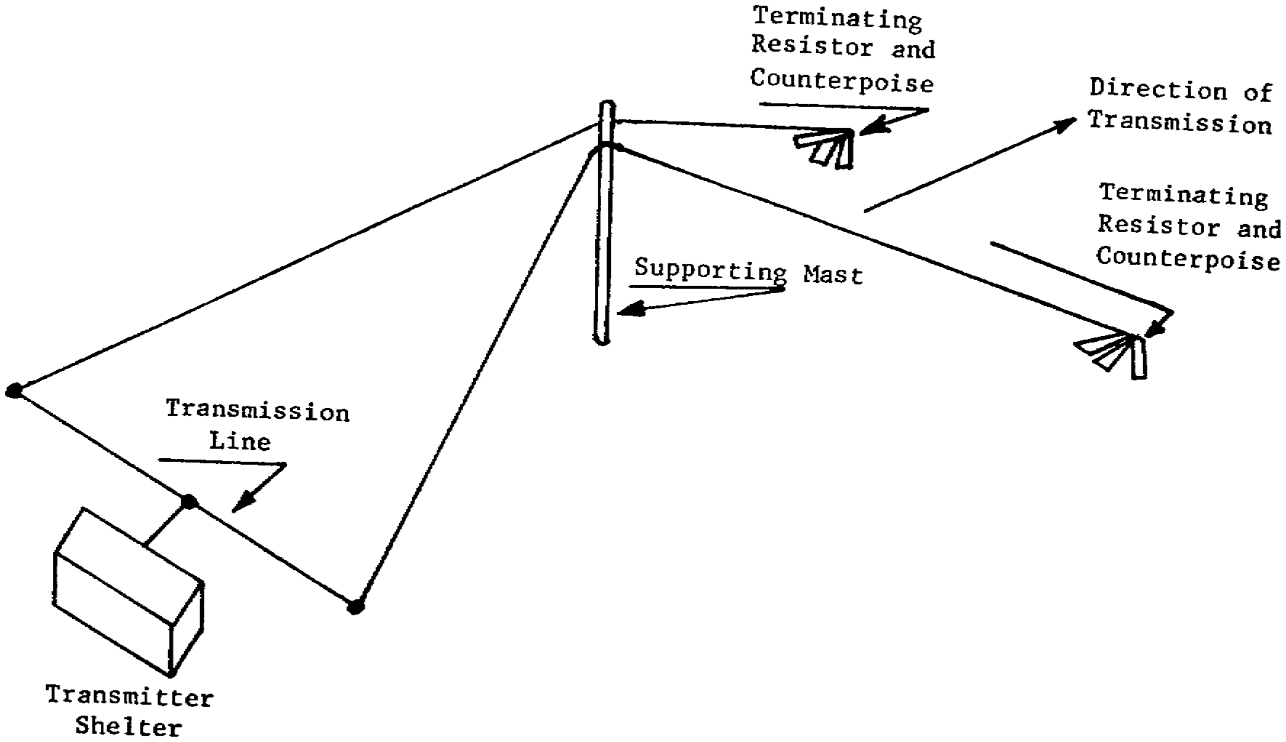


Figure 5-6. A transmitting monopole rhombic antenna.

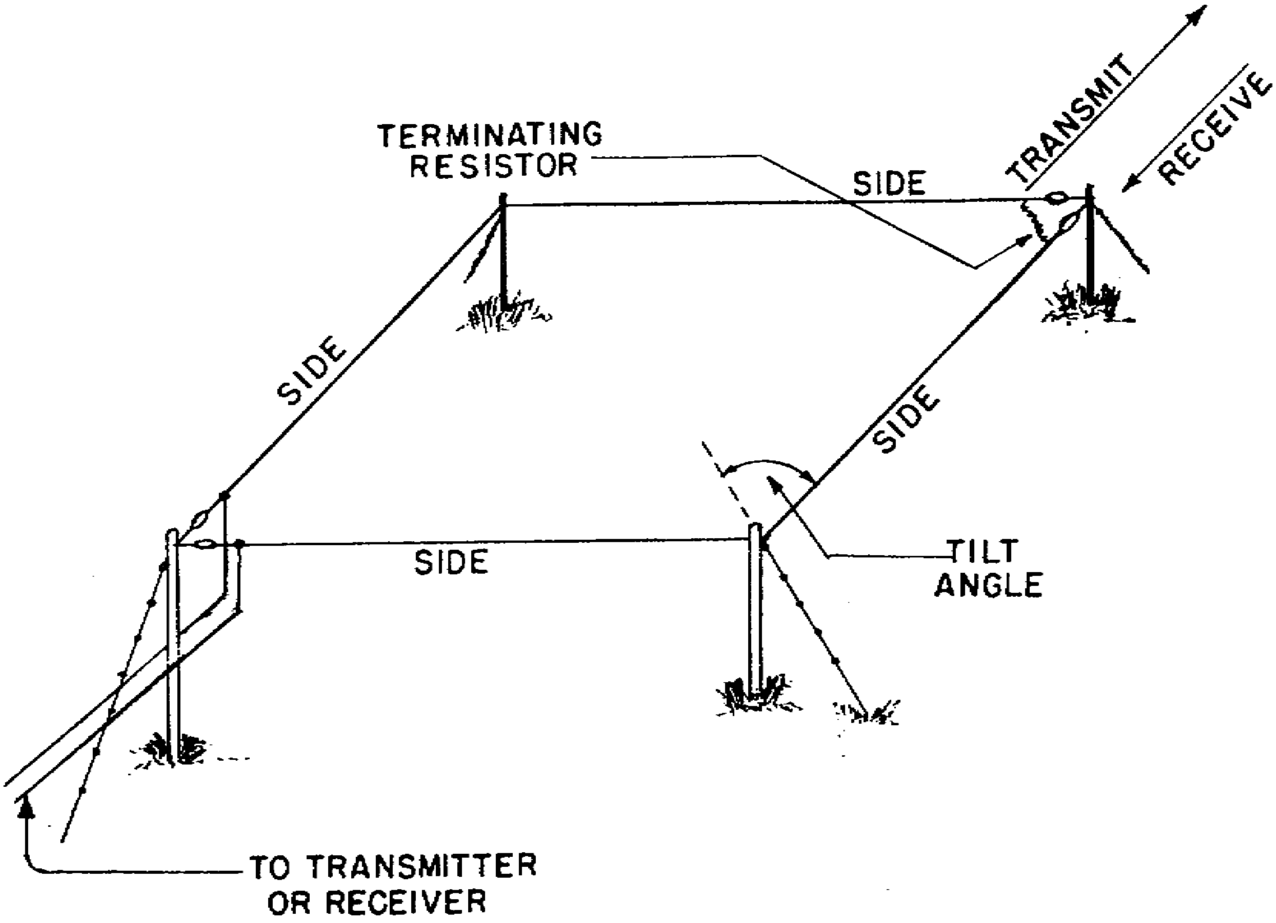
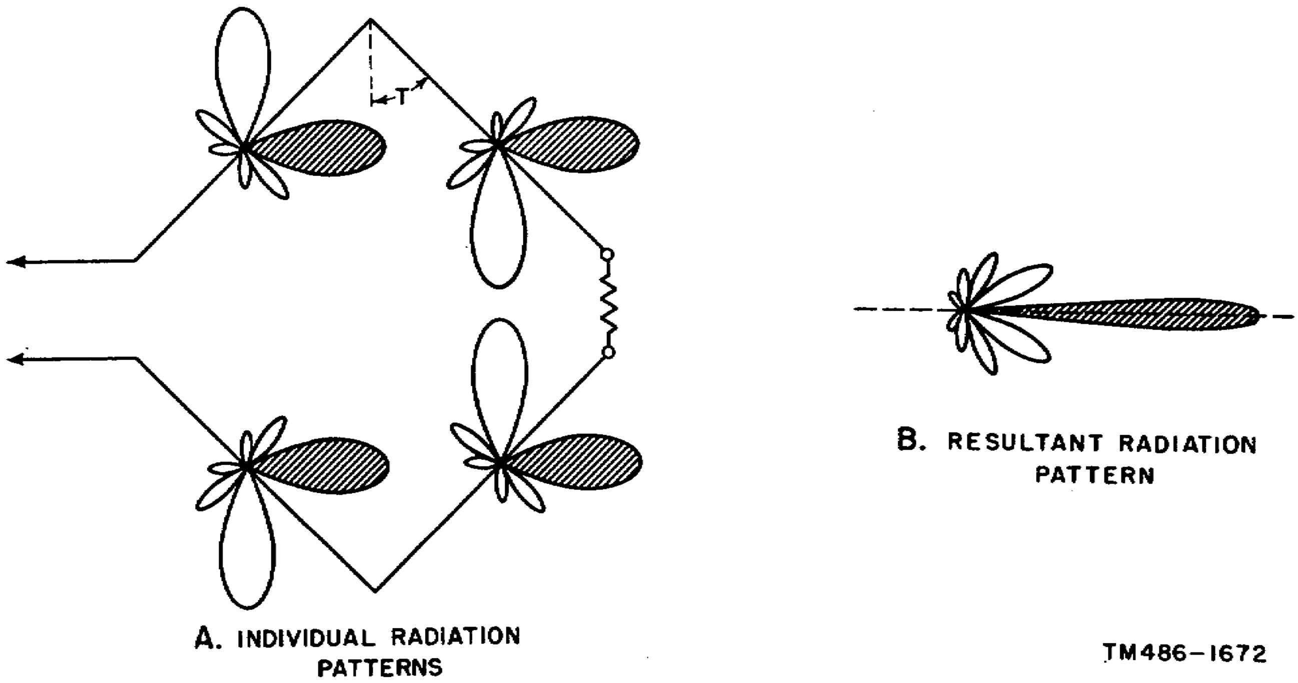


Figure 5-7. A basic rhombic antenna.



A. INDIVIDUAL RADIATION PATTERNS

B. RESULTANT RADIATION PATTERN

Figure 5-8. Radiation pattern of the rhombic antenna.

c. Questions.

5-6a. One advantage of a unidirectional nonresonant, antenna over a resonant type is that, when used with a powerful radio transmitter, the nonresonant type always has

a. one curtain.

b. no need for terminating resistors.

c. lower RF voltages on its radiators.

d. major lobes at both ends of the rhombus.

5-6b. All conditions being equal, a receiving antenna receives a stronger signal from a rhombic transmitting antenna than from a transmitting dipole because

a. the rhombic antenna is more directional than the dipole.

b. the rhombic antenna is a more efficient radiator than a dipole.

c. full power output of the transmitter is radiated by the rhombic.

d. resonant operation of the rhombic antenna reduces standing waves on the feeders.

5-7. POSITION AND POLARIZATION

The rhombic antenna may be used with its plane in either a vertical or horizontal position and it will respond, respectively, to vertically or horizontally polarized waves. Its application in the HF band has been in the horizontal rather than vertical position for the following reasons:

a. The supporting structure in the horizontal position is less expensive, since only four relatively short poles are required.

b. The inherent directive characteristics of horizontal antennas discriminate against ignition, power, and other noises originating near the ground.

c. The directivity of the rhombic antenna is sharpest in the plane of the antenna. Since the direction of wave propagation is more stable in the horizontal plane, it is desirable to have the plane of the antenna horizontal.

d. The directivity of the horizontal rhombic antenna can be aimed, to some extent, at the most desirable vertical angle.

e. The performance of the horizontal antenna is more stable with varying weather conditions, since horizontally polarized waves are less affected by varying ground constants than are vertically polarized waves.

f. Question.

5-7a. For long-distance radio communications, the rhombic antenna is constructed horizontally rather than vertically to provide the advantages of

a. higher gain, smaller wave angle, and larger tilt angle.

b. higher gain, simpler supporting structure, and smaller wave angle.

c. larger tilt angle, good noise discrimination, and better horizontal directivity.

d. better horizontal directivity, good noise discrimination, and simpler supporting structure.

5-8. CHARACTERISTICS AND DEFINITIONS

a. The characteristic impedance of the rhombic antenna is fairly constant over its length. Input impedances vary between 850 and 650 ohms for a single-wire antenna, and between 660 and 560 ohms for a three-wire curtain over a frequency range of 4 to 20 MHz.

b. The tilt angle is one-half the inside angle between the wires at the side poles of the antenna (fig 5-7).

c. The gain of a rhombic antenna is often quoted in terms of a half-wave dipole in the same plane and at the same height. For a rhombic antenna having dimensions of six wavelengths on a side and one wavelength above the ground, a power gain of 12 dB with respect to a similarly situated horizontal dipole is ordinarily obtained. This gain is relatively unaffected by the conductivity of the ground but is associated with a given vertical angel of propagation.

d. The side length, usually expressed in wavelengths, is the length of each one of the four sides of the rhombus.

e. The height, also expressed in wavelengths or fractions of a wave-length, is the distance between the plane of the antenna and the plane of the average ground level.

f. The wave angle is the angle of maximum radiation. It should coincide with the angle of radiation or arrival of the optimum propagational path for the circuit. The wave angle can be used to determine the three dimensions of the rhombic antenna--the side length, height above the ground, and the tilt angle. For any wave angle, there is one set of these dimensions that gives the maximum output at that particular angle.

g. Horizontal and vertical directivity patterns for typical rhombic antennas are shown in figure 5-9. They apply to either a transmitting or receiving antenna. The principal lobe is generally in a forward and upward direction--from the feeding point toward the terminating resistance. The radiation pattern depends on the length of each side of the antenna, the tilt angle, the frequency, and the height above ground. Since the angles required between sides do not vary appreciably with frequency changes, and since the circuit is nonresonant, a wide range of operating frequencies is possible.

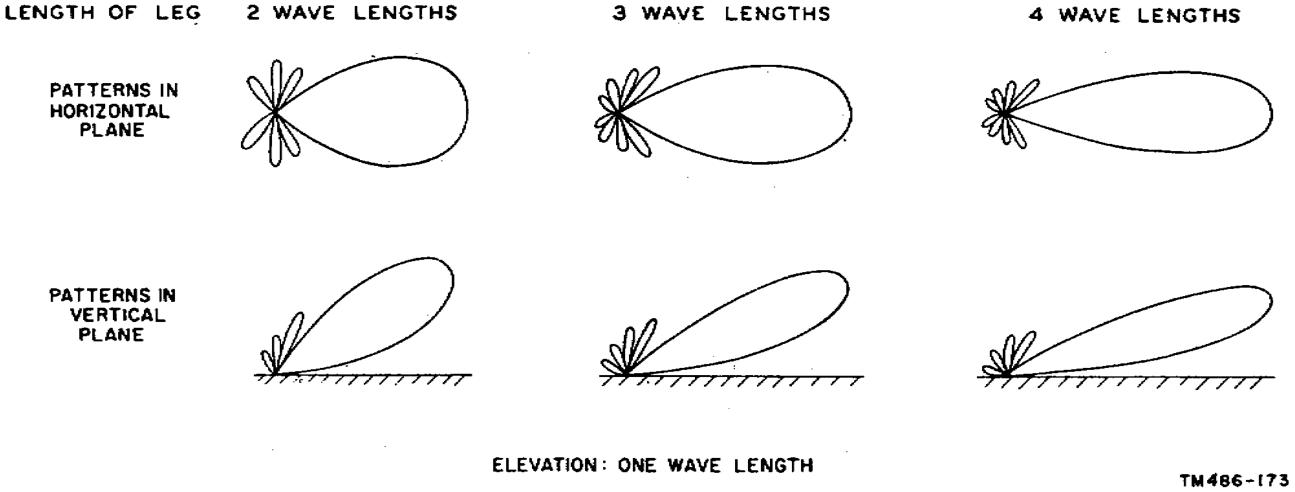


Figure 5-9. Relative patterns for horizontal rhombic antennas.

h. In general, a rhombic antenna is not a good radiator for large wave angels, because shortening the antenna (in wavelengths) to raise the angle of radiation also reduces the maximum length of the radiation field.

i. Question.

5-8a. In constructing a transmission line to feed a three-wire curtain rhombic antenna, you must make use of the fact that the input impedance of the antenna is approximately

a. 200 ohms.

c. 600 ohms.

b. 400 ohms.

d. 800 ohms.

5-9. PRACTICAL CONSTRUCTION OF RHOMBICS

a. The transmitting rhombic (fig 5-10) usually is constructed with more than one conductor on each side. The conductors are brought together at the front and rear apexes and are separated by several feet at the side poles, forming a curtain. This multiwire arrangement reduces the input impedance and provides a more uniform impedance over the frequency band.

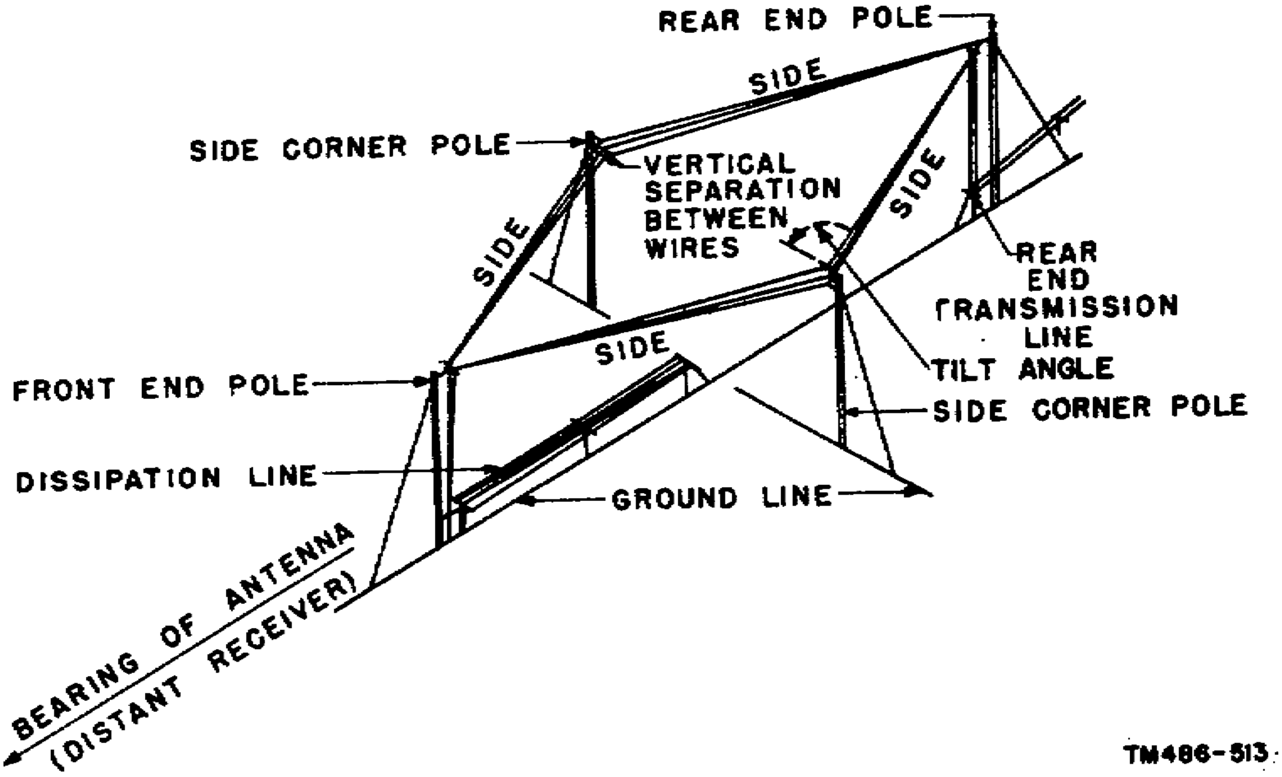


Figure 5-10. Transmitting rhombic antenna.

b. The single-wire rhombic, widely used in the past for receiving stations, is not as practical as the three-wire curtain, which as a flatter response curve and is effective in reducing precipitation static and some other types of radio noise. In new receiving installations the three-wire curtain rhombic antenna is generally used.

c. Rhombic antennas for installation at permanent sites are individually designed for the circuit in which they are to be used. The exact great-circle distance of the circuit and all operating frequencies assigned to that circuit are considered in the antenna design. The engineering of these antennas usually is performed on a project basis.

d. For interim installations or semipermanent sites not built under specific projects, one of a series of standard compromise rhombic antennas may be installed. The dimensions of the standard compromise horizontal rhombic antennas are listed in the chart below. The design for type A is for use at 3,000 miles or more. Type G is for use at about 400 miles, and others are for intermediate distances.

Rhombic antenna type	Range (mi)	Side length (ft)	Tilt angle* (deg)	Height (ft)	Length, end pole to end pole (ft)	Width, Side pole to side pole (ft)
A-----	Over 3,000	375	70	65	723	268
B-----	2,000 to 3,000	350	70	60	676	251
C-----	1,500 to 2,000	315	70	57	611	228
D-----	1,000 to 1,500	290	67.5	55	553	234
E-----	600 to 1,000	270	65	53	506	240
F-----	400 to 600	245	62.5	51	453	238
G-----	200 to 400	225	60	50	407	237

*The tilt angle is half the horizontal angle at the side pole. This is not wave tilt.

e. As the three-wire curtain is now standard for receiving rhombics, the major difference between receiving and transmitting rhombics is in their power-handling capabilities. The insulators used in the construction of a transmitting rhombic are larger than those used for a receiving rhombic. Termination resistors used with receiving rhombics are ordinarily small enough to be installed in small waterproof boxes at the top of the end pole of the antenna. The termination resistance required for a transmitting rhombic generally is in the form of a dissipation line. This dissipation line is required for all but the lower powered transmitters.

f. Questions.

5-9a. Assume that a new antenna is to be installed at a permanent receiving station. The recommended type of antenna for this application is the

a. single-wire rhombic antenna.

b. two-wire curtain rhombic antenna.

c. three-wire curtain rhombic antenna.

d. standard Army compromise rhombic antenna.

5-9b. Assume that you are required to establish a temporary two-way radio circuit between Puerto Rico and Panama, a distance of 1,835 km (1,140 miles). What number and kind of standard rhombic transmitting and receiving antennas should you requisition for the Puerto Rico station if space-diversity reception will be used?

a. Two type D.

b. Two type C.

c. Three type D.

d. Three type C.

5-10. EFFECTS OF ANTENNA PATTERN ON THE SIGNAL

The major purpose of using a directional rhombic antenna is to produce a radiation pattern that will minimize interference caused by multipath propagation. However, an antenna pattern that is too directive may be as unsatisfactory as one with insufficient directivity. Using random patterns, or patterns not expressly designed for the desired propagational path, can give poor results. Therefore, established design practices must be followed in the construction of new rhombic antennas.

a. The signal level at the receiver input terminals may be reduced considerably if the angle at which the radio wave arrives varies from the angle of the maximum lobe of the receiving antenna field pattern. The signal level may also be reduced by losses in the propagation path. The reduction in signal level by either of these two effects will appear as a fade at the receiver input terminals. When the two effects coincide, the signal level may drop below the noise level and produce an interval of nonintelligibility. This combination of the two effects sometimes causes fading that reduces the input signal to a level 100 dB or more below normal.

b. When two or more wave groups arrive in the vertical plane with different time delays along each of their arrival paths, the resulting phase difference causes selective fading. In addition--and more serious--the resulting phase difference also results in either elongation or shortening (distortion) of the received telegraph pulse. The delay is characteristically greater on multihop transmission since each wave traverses a longer path. The terminal equipment used on long-distance multihop radio transmission circuits is designed to compensate for telegraph distortion due to radio path delay. Examples of this design are found in Telegraph Terminals AN/FGC-29 and AN/FGC-61A.

c. Assuming that the transmitting and receiving antennas are of complementary design, the angle of departure of the radio wave from the transmitting antenna is approximately the same as the angle of arrival at the receiving antenna. Operating margins of a radio circuit using these antennas can be improved by transmitting more power. This procedure will improve the intelligibility of the received signal in the presence of noise or other interfering signals.

d. The improvement in the signal level resulting from the use of a rhombic antenna is usually measured in decibels.

The decibel figure relates the ratio of power in the signal received by a rhombic antenna to that received by a theoretical dipole in space. The gain of a rhombic results from the ability of the antenna to direct (or receive) the major lobe of radiation in the desired azimuth and elevation.

e. A simple power ratio and decibel scale is shown in figure 5-11. Assume that two separate antennas receive the same signal, and the very small power levels are read on sensitive recording devices. The gain of one antenna over the other is determined by comparing the power ratio of the two signals with the decibel scale. Decibel figures are always added to indicate gain, and subtracted to indicate loss.

Example 1. If the signal received by a rhombic antenna is 12 microwatts, while that received by a dipole is 3 microwatts, what is the gain of the rhombic antenna?

The power ratio is 12/3, or 4/1. Compare this power ratio with the decibel scale in the expanded circle. The antenna delivering the 12 microwatts of signal has a 6-dB gain over the antenna delivering 3 microwatts.

Example 2: If one signal is 80 times stronger than another, what is the decibel relationship of the two?

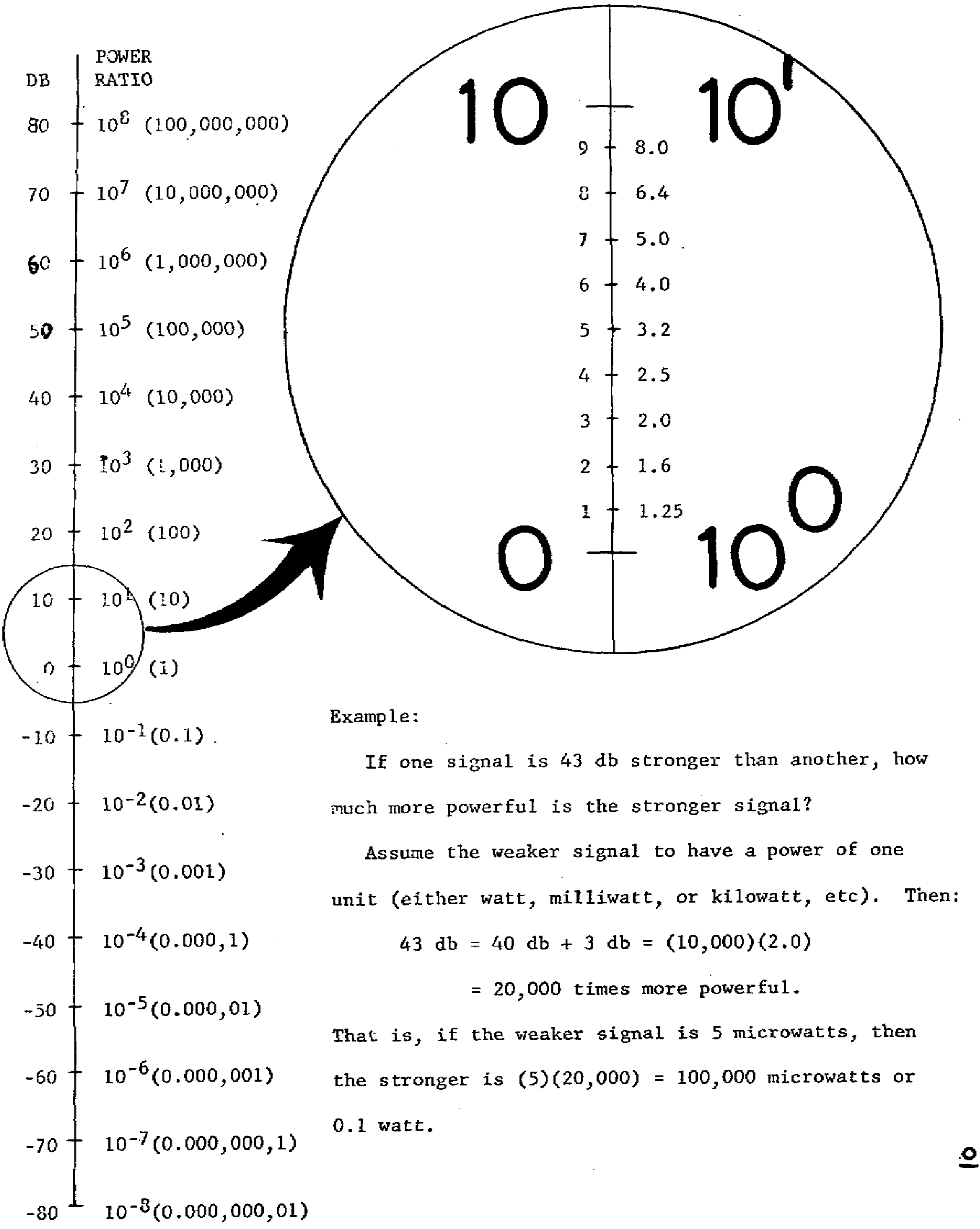
Find 8.0 on the circled power ratio scale. This corresponds to 9 dB on the decibel scale. Since 80 = 8.0 x 10, the decibel figure is obtained by adding 10 dB and 9 dB, for a total of 19 dB.

Example 3: If one signal is 43 dB stronger than another, how much more powerful is the stronger signal?

Assume the weaker signal to have a power of one unit (watt, milliwatt, or kilowatt, etc.). Then:

43 dB = 40 dB + 3 dB = (10,000) (2.0)
= 20,000 times more powerful.

That is, if the weaker signal is 5 microwatts, then the stronger is (5) (20,000) = 100,000 microwatts, or 0.1 watt.



Example:

If one signal is 43 db stronger than another, how much more powerful is the stronger signal?

Assume the weaker signal to have a power of one unit (either watt, milliwatt, or kilowatt, etc). Then:

43 db = 40 db + 3 db = (10,000)(2.0)

= 20,000 times more powerful.

That is, if the weaker signal is 5 microwatts, then the stronger is (5)(20,000) = 100,000 microwatts or 0.1 watt.

Figure 5-11. Chart Showing Relationship of dB to Power Ratio

f. Questions.

5-10a. Transmitting and receiving rhombic antennas having complementary design provide a strong received signal because the

a. propagation path losses are virtually eliminated.

b. time delays in arrival of radio waves are minimized.

c. azimuth and elevation of the major lobes vary inversely with the use in radiated frequency.

d. angle of departure from one antenna is approximately the same as the angle of arrival at the other.

5-10b. Assume that a rhombic and a double-doublet antenna are picking up the same signal simultaneously. If the output from the rhombic is 16 microwatts and the output from the double-doublet is 2 microwatts, the ratio of the rhombic power and the doublet power is

a. 8 dB.

b. 9 dB.

c. 12 dB.

d. 32 dB.

5-11. ANTENNA DESIGN

Three methods are used to design rhombic antennas for specified circuits.

a. Maximum Output Design. This method is based on the assumption that there are no restrictions on the physical size of the antenna. As the name implies, this method is used to design the antenna for the greatest output along a given angle of radiation, even though the lobe maximum may not exactly coincide with the desired angle of radiation. Selection of one rhombic antenna design over any other is dictated more by the radiation pattern than by any other antenna characteristic.

b. Alignment Design. This method is also based on the assumption that there are no restrictions on the physical size. In this method, the antenna is designed to radiate (or receive) with the lobe maximum exactly falling along the desired wave angle.

c. Adjusted Design. This method allows for variations in the design of an antenna in which one of the physical dimensions is limited. Thus, if one of the three major dimensions of the antenna is limited (side length, height, or tilt angle), the other dimensions can be adjusted to compensate for this limiting factor.

d. Questions.

5-11a. While planning for the construction of a rhombic antenna you have found that there is a limit on the distance that the antenna can be placed above the ground. The recommended design method to be used is the

a. adjusted design.
b. alignment design.
c. compromise design.
d. maximum output design.

5-11b. A well-constructed log-periodic antenna may have 13 dB gain. This is equivalent to a transmitter output power increase of

a. 10 times.
b. 12 times.
c. 20 times.
d. 22 times.

5-12. TERMINATION RESISTANCE

The unidirectional characteristics and the nonresonance of the rhombic antenna depend on termination in a proper resistance. An open terminating resistance causes the antenna to become bidirectional, thus allowing the antenna to pick up additional noise and interference from the back lobe. The value of resistance is important--it is approximately 800 ohms for a single-wire rhombic and 650 ohms for a three-wire curtain.

a. Receiving Antenna Termination.

(1) Accurately matched pairs of low-wattage carbon resistors are generally used for terminating receiving rhombics. When used with single-wire rhombics, each resistor in the pair has a value of approximately 800 ohms. Each resistor is installed in series with an antenna side, and the junction of the two resistors is connected to a common ground lead. The total value of the resistor network is not as critical as is the maintenance of absolute balance between the two sides.

(2) In single-wire rhombics, the impedance varies over wide limits as the frequency of operation is varied. The impedance will drop from approximately 850 ohms to 650 ohms as the frequency of operation increases from 5 to 20 MHz. with fixed values of terminating resistors, the impedance variation can cause the directivity characteristics of the antenna to change. This impedance variation can be kept to a minimum by using three curtains rather than a single wire.

b. Transmitting Antenna Termination Resistors. The type of terminating resistance is determined by the amount of RF power that will be fed to the antenna by the transmitter. The type selected must be capable of dissipating at least 50 percent of the transmitter output power. In low-powered systems (less than 3 kW), the terminating resistance usually consists of combinations of resistors capable of dissipating 1 kW each. Noninductive-type resistors are used in pairs, or they may be connected in series-parallel circuits of the proper resistance and wattage values to match the antenna and properly dissipate the power. High-power systems (above 3 kW) use very large dissipation resistors having resistance wire encased in the walls of glass tubing. Sometimes a fan helps dissipate the heat by driving air vertically through the hole in the tubing. Another type of high-power dissipation resistor is made of resistance wire strung between crossarms on telephone poles. In each instance, the network should be grounded at its electrical center.

c. Questions.

5-12a. If the termination resistors of a receiving rhombic are burned out by a lightening strike and replacement resistors are not readily available, the antenna operates, but with less satisfactory results because the

a. wave angle is doubled.

b. antenna gain is reduced by 50 percent.

c. standing waves are partially eliminated.

d. interference and noise pick-up are greater.

5-12b. A unidirection transmitting rhombic antenna can be distinguished from a unidirectional receiving rhombic antenna by the

a. size of the terminating resistance.

b. number of wires in the curtain.

c. length of the antenna legs.

d. value of the tilt angle.

5-12c. Assume that you are planning the construction of a wire-wound terminating resistor assembly for a rhombic antenna to serve a 2 kW output transmitter. What arrangement would you select?

a. A single 1 kW ungrounded noninductive resistor.

b. A single 1 kW inductive resistor grounded at one end.

c. Two 500 watt inductive resistors grounded at their electrical center.

d. Two 500 watt noninductive resistors grounded at their electrical center.

5-13. LOG-PERIODIC ANTENNA

The log-periodic antenna shown in figure 5-12 was designed to achieve a combination of unidirectional transmission, high-efficiency dipole radiation, and broadband capability for high-frequency fixed-station radio systems.

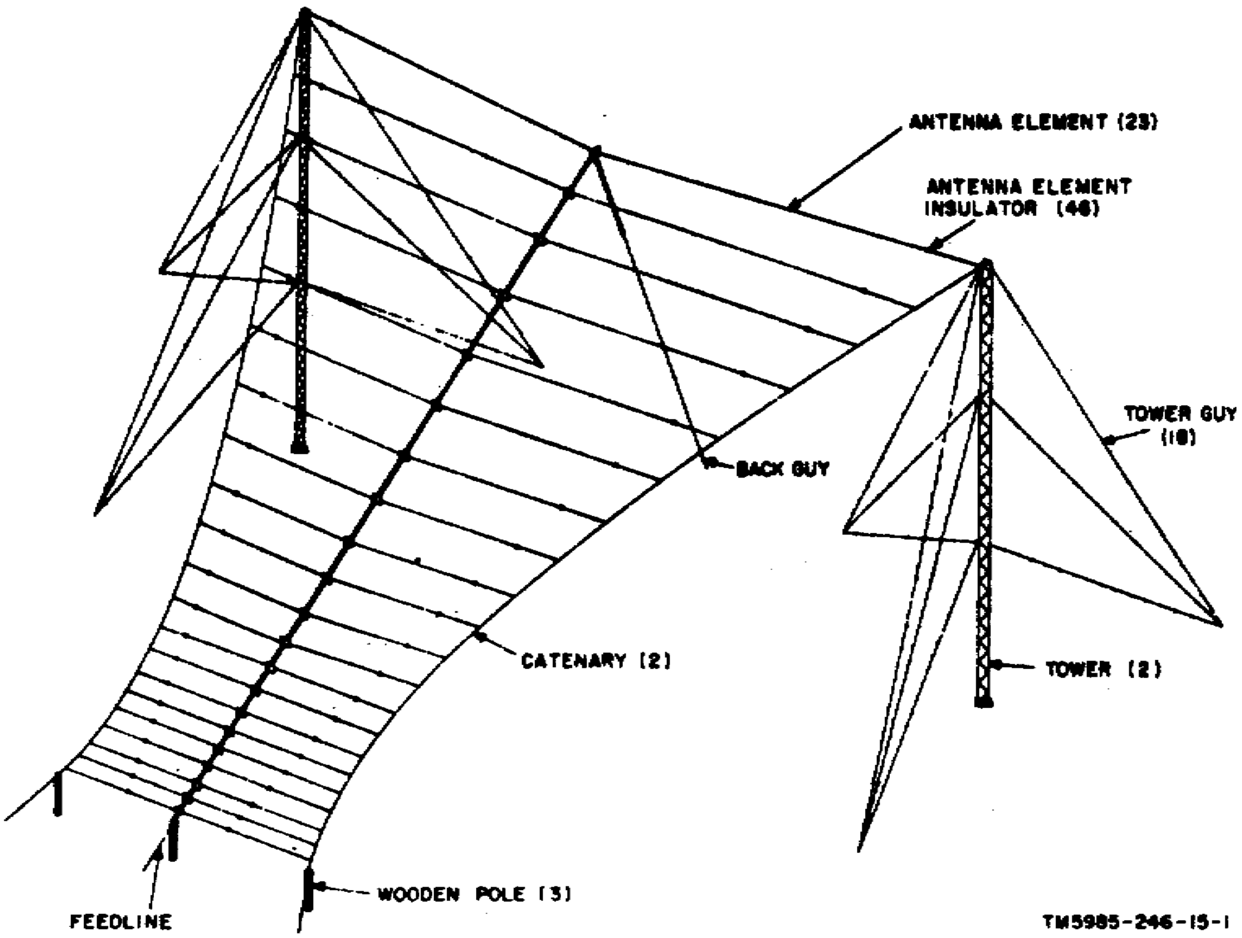


Figure 5-12. Fixed-station-type log-periodic antenna.

a. Purpose and Use. This log-periodic antenna is normally used for transmission. It is capable of approximately 13-dB gain within a frequency range of 4.0 to 30 MHz, and is suitable for high-frequency communications that require rapid changes in operating frequency. The impedance characteristic of the antenna feedline is essentially constant at 300 ohms throughout the operating range.

b. Construction. The antenna assembly shown in figure 5-12 is a series of half-wave dipoles which are cut to respond to selected frequencies in the HF band. Dipole spacing gives the desired horizontal radiation pattern, while slant of the dipole plane gives the desired elevation angle for the vertical radiation pattern. This arrangement eliminates the need of using several antenna structures to cover the range of frequencies in the HF band. The antenna assembly and its feedline are supported by two catenaries which are stretched between the towers and the wooden poles. Each dipole is stretched between the catenaries by insulators, rope, and hardware.

c. Supporting Towers. The two 140-foot supporting towers are constructed of seven 20-foot sections. Each tower is set on a concrete foundation and guyed at the 50-, 100-, and 140-foot levels. The guy wires are broken up with strain insulators to prevent guy wire radiation from affecting the performance of the antenna.

d. Space Requirements. The installation site requires approximately 4 acres. A favorable location is a flat, level area free from trees, large rocks, powerlines, or any long metallic objects. Metallic objects may themselves radiate and so disrupt the radiation pattern of the antenna.

e. Direction of Maximum Radiation. The direction of maximum radiation is broadside to the antenna elements, off the short-dipole end of the antenna assembly. The towers must be accurately positioned so that the short-dipole end of the antenna array is pointed toward the distant fixed radio station. Sometimes the log-periodic structure is mounted on top of a mast so that the antenna radiation pattern can be rotated for aiming toward distant mobile radio stations.

f. Questions.

5-13a. The maximum radiation of the log-periodic antenna shown in figure 5-12 is in the direction of the

a. feedline.

b. back guy.

c. left catenary.

d. right catenary.

5-13b. The design of a log-periodic antenna is a compromise to gain desired horizontal and vertical radiation. The horizontal pattern is varied by

a. selecting dipole spacing.

b. changing the slant of the dipole plane.

c. increasing the length of the catenaries.

d. enlarging the space between the dipole feedlines.

5-14. OPERATION OF LOG-PERIODIC ANTENNA

a. <u>Operating Principles</u>. The log-periodic design results in a directional antenna having characteristics which remain constant over an extremely wide band of frequencies. The radiation pattern and the input impedance are essentially independent of frequency.

(1) The signal travels along the feedline until it encounters a dipole that is one-half the wavelength of the input signal. These radiating dipoles are spaced so that there is a phase reinforcement of the signal in the desired direction.

(2) The low-frequency limit of the antenna is established by the longest dipole, and the high-frequency limit is determined by the shortest dipole.

(a) The transmission region is the portion of the antenna between the feed point and the dipole (half wave) that is resonant to the input frequency.

(b) The active region is the portion of the antenna between the resonant dipole and the dipole that is twice its length (full wavelength) of the resonant dipole.

(c) The unexcited region is the portion of the antenna between the 1-wavelength dipole (at the input frequency) and the back guy.

b. Radiation. Assume that a radio transmitter is driving the antenna at a specified frequency. The RF energy travels along the feeder lines through the transmission region to the active region of the antenna. Since the half-wavelength dipole resonates at the input frequency, it radiates most of the RF energy it receives from the feedline. Some of the radiated energy travels to the full-wavelength dipole, which acts as a parasitic reflector by reradiating the energy. The energy from the two dipoles is in phase in the forward direction and out of phase in the reverse direction. This causes reinforcement in the desired direction and cancellation in the back direction. This effect is achieved by the correct selection of dipole length and spacing, as well as the slope of the antenna plane.

c. Question.

5-14a. The high-frequency limit of a log-periodic antenna is determined by the length of

a. the longest dipole.

b. shortest dipole.

c. The feedline section.

d. transmission region.

LESSON 6

MOBILE RADIO STATIONS

TRAINING OBJECTIVE:	Action:	Be able to list characteristics of mobile radio stations.
	Conditions:	Given SSO 750.
	Standard:	You must be able to successfully complete lesson exercises.

CREDIT HOURS: 2

LESSON OBJECTIVES

When you have completed this lesson, you should:

1. Know that high-frequency independent-sideband mobile radio stations permit field commanders to enter the DCS from any part of the world.

2. Know that the composite signals transmitted between mobile and fixed radio stations must be completely compatible.

3. Know that equipment configurations are similar in all independent-sideband stations, whether mobile or fixed.

4. Know that mobile radio stations working into the Defense Communications System normally operate full duplex.

ATTACHED MEMORANDUM

6-1. NEED FOR LONG-DISTANCE MOBILE SSB RADIO STATIONS

The globe-girdling Defense Communications System (DCS) consists largely of a series of long-distance SSB radio stations at strategic locations. Mobile SSB radio stations enable field commanders to enter the DCS. These SSB sets have sufficient distance capability to communicate with the nearest strategically located fixed station in the DCS, and the signals sent and received by them are compatible with those used in the DCS. In addition to their mobility, these stations are air transportable and logistically selfsufficient for a sustained period of operation. A number of different types of SSB mobile radio stations have been constructed to satisfy the needs of the field commanders. Six types now available for field use are described in this lesson. They include Communications Systems AN/TSC-25 and AN/TSC-38B. These systems provide the necessary radio terminal facilities, but do not normally provide the ancillary telephone and teletypewriter sets to use the full traffic capabilities of the equipment. The ancillary items are normally furnished by the subscribers who communicate over the radio system. Although several different types of equipment items are in use for identical purposes, the equipment configurations of equipment in the shelters are similar.

a. Question.

Assume that you are assigned as NCOIC of an SSB mobile radio system capable of communicating with a DCS radio station. This capability is possible because your mobile radio system and the DCS radio station use

a. identical antennas.

b. identical transmitters.

c. compatible power units.

d. compatible send and receive signals.

6-2. APPLICATION OF MOBILE COMMUNICATION INDEPENDENT SIDEBAND SYSTEMS

The various mobile communication systems described in this lesson are different in their design, layout, and equipment lists. However, they all operate with a signal format that is compatible with DCS stations. Figure 61 is a block diagram of a threesite mobile ISB radio station. The principles illustrated in this diagram are exemplary of such radio stations. The system illustrated uses overland keying lines between the communications center and the radio receiving shelter. Only one station of a two-way communication system is shown.

a. Line Terminations.

(1) Multiplexer. The transmission of four circuits over the system is accomplished by two Multiplexers TD-97/FGT-2, or TD-410/UGC, which are used in conjunction with a twin-channel SSB radio transmitter. Each multiplexer combines two 3-kHz channels into one 6-kHz channel. The 6-kHz output from one multiplexer is applied to one of the 6-kHz sidebands of the transmitter. The 6-kHz output from the second multiplexer is applied to the second 6-kHz sideband of the transmitter.

(2) Demultiplexer. The reception of signals for four VF circuits is accomplished by twin-channel SSB radio receivers in conjunction with Demultiplexers TD-98/FGR-3, or TD-411/UGC. Each demultiplexer accepts signals from one of the 6-kHz sidebands of the radio receiver and divides the 6-kHz band into the two original 3-kHz channels. Three demultiplexers are required when two radio receivers are used for space-diversity reception.

(3) Audio Frequency Amplifier AM-911/FG. The AM-911/FG units are used whenever signals are transmitted over line facilities. They are installed at the terminating end of the transmission line (i.e., at the radio transmitting site for sending, and at the communications center for receiving) to provide equalization and gain. Each amplifier serves two separate line circuits.

b. Signal Format. Each Multiplexer TD-97/FGT-2 has two signal paths through it. The normal signal path passes 300 to 3,000 Hz. The translated path raises the VF signals contained in a band of 300 to 3,000 Hz up to a frequency band extending from 3,290 Hz to 5,990 Hz. Both bands pass through a 6 kHz sideband of the transmitter. Since the transmitter output signal is centered on the carrier frequency (C), the limits of the signal are C + 5,990 Hz and C - 5,990 Hz, as shown in figure 6-2. The opposite process is Demultiplexer TD-98/FGR-3 passes the normal band of frequencies and restores the translated frequencies back to normal. It is common practice to designate these two channels A1 and A2, or B1 and B2.

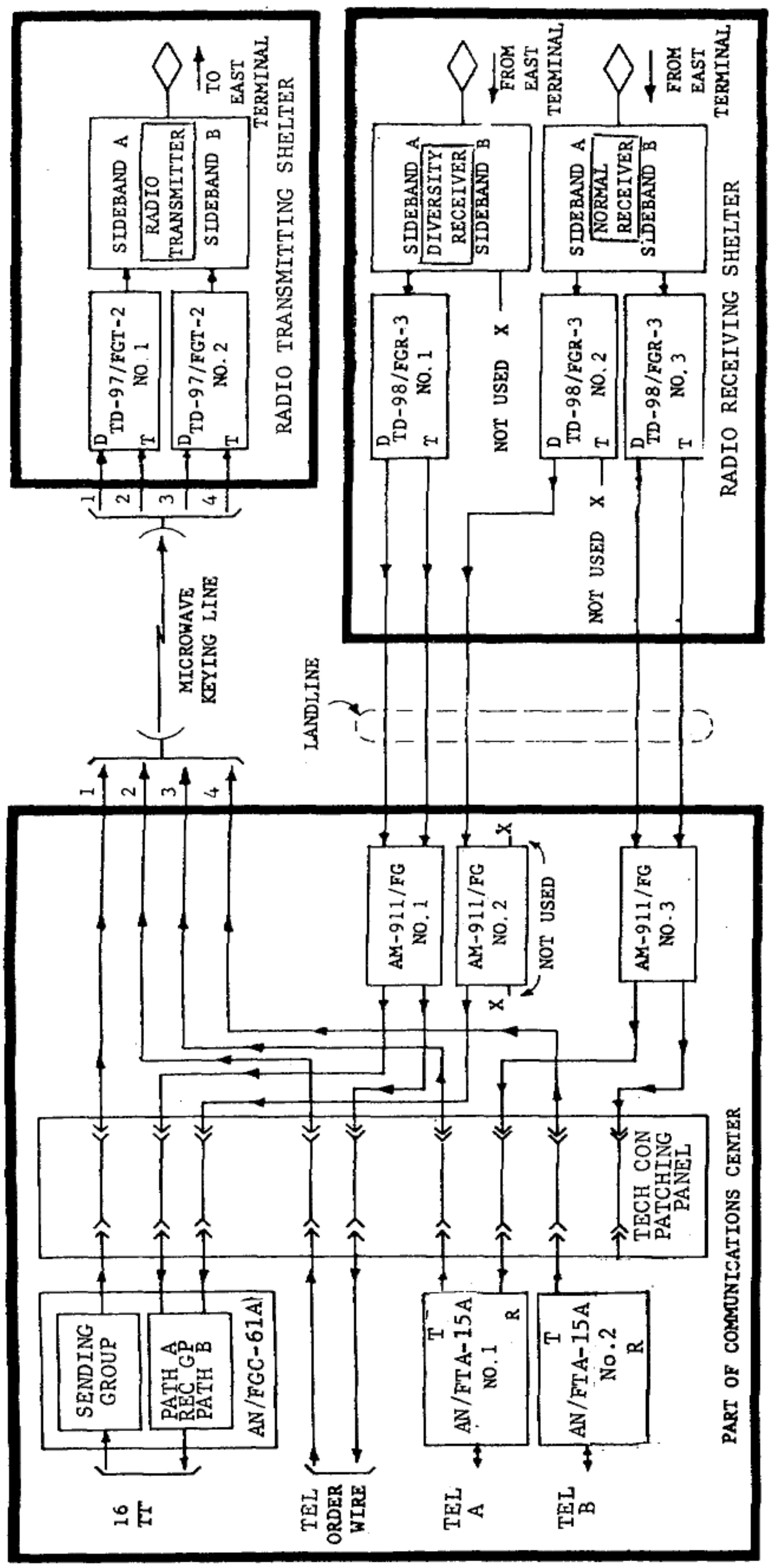


Figure 6-1. Application of mobile ISB radio communications system, block diagram.

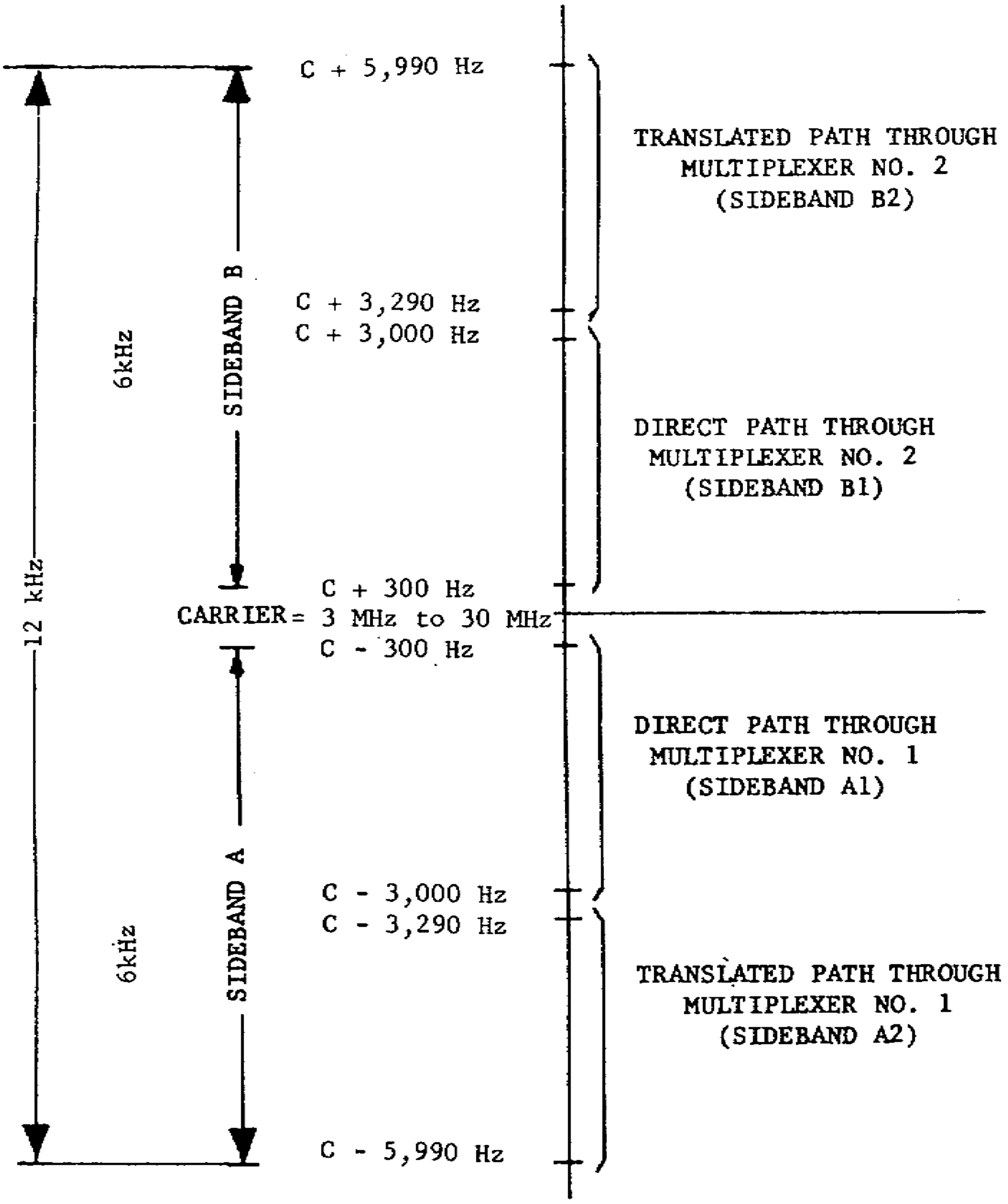


Figure 6-2. Frequency format of the ISB radio signal.

c. Questions.

6-2a. Multiplexer TD-97/FGT-2 contains two 3-kHz signal paths. The path that raises the VF signal to a frequency band extending from 3,290 to 5,990 Hz is the

a.	translated path.	c.	common path.
b.	direct path.	d.	normal path.

6-2b. An equalizing circuit is used at the line termination in the communications center to assure that the signal level of all received signals on that line are approximately equal. The equalizer is located at

a. Multiplexer TD-97/FGT-2.

b. Demultiplexer TD-98/FGR-3.

c. Radio Receiving Set AN/FRR-41.

d. Audio Frequency Amplifier AN-911/FG.

6-3. TRANSMITTING PATH

The output signals from the sending group of the AN/FGC-61A and the transmitting circuits of the two AN/FTA-15A's are applied to VF channels of the microwave radio set. The microwave link is used because the radio transmitting shelter is located as far as practicable from both the communications center and the radio receiving shelter to prevent interference. A high-frequency ISB radio transmitter transmits the combined telegraph and telephone signals to the distant (east) terminal.

a. Telegraph Path. The 3-kHz band of VF telegraph signals from the send group of the AN/PGC-61A is applied to channel 1 of the microwave link through the technical control patching panel. The output from channel 1 of the microwave link at the transmitting station is applied to the direct path (D) in TD-97/FGT-2 No. 1. The telegraph signal is then applied to sideband A1 of the radio transmitter.

b. Order-Wire Path. The transmitting wire pair of the telephone order-wire circuit is connected to channel 2 of the microwave link through the technical control patching panel. The output from channel 2 at the transmitting station is applied to the translated path (T) through TD-97/FGT-2 No. 1. The order-wire signal is then applied to sideband A2 of the radio transmitter.

c. Telephone A Path. The voice signals are applied to AN/FTA-15A No. 1 with a two-wire line. The transmitting section of the circuit converted to four-wire line (T) applies the voice signal to channel 3 of the microwave link transmitter through the technical control board patching panel. The output from channel 3 is applied to the direct path (D) through TD-97/FGT-2 No. 2, and then to sideband B1 of the radio transmitter.

d. Telephone B Path. The voice input signals to AN/FTA-15A No. 2 follow the same type of path through channel 4 of the microwave link transmitter to the translated path (T) through TD-97/FGT-2 No. 2, and then to sideband B2 of the radio transmitter.

e. Transmitting Circuit. The ISB radio transmitter at the local (west) station transmits to the distant (east) receiving station the four 3-kHz signals that are contained within the two ISB's. The distant (east) receiving station is equipped with two radio receivers that are arranged for space-diversity reception.

6-4. RECEIVING PATH

The signal that is received by one of the radio receivers in figure 6-1 is arbitrarily called the normal signal, while that received by the other radio receiver is called the diversity signal. Identical signals are received by both receivers, so it makes little difference which receiver is designated normal and which diversity. The radio receiving equipment at the east terminal is functionally identical with that at the west terminal, although it may be of a different type, size, and electrical characteristics. The important identity is compatibility with the ISB signal format.

a. Diversity Reception. The signals that are received by the normal and diversity receivers are identical, with the exception of their respective fading patterns. The receiving antennas are separated by about 620 meters (1,000 ft), so it is unlikely that the signals from the distant transmitter will fade simultaneously at both receiving antenna sites. The 6-kHz signals from sideband A of the diversity receiver are applied to Demultiplexer TD-98/FGR-3 No. 1, while the voice output from sideband B is terminated. It is not used because when two space-diversity speech channels are combined, the continual change of phase between the two makes the voice difficult to understand.

The signals from sideband A of the normal receiver are applied to TD-98/FGR-3 No. 2, and those from sideband B are applied to TD-98/FGR-3 NO. 3. Sideband B of the diversity receiver could be used just as well as sideband of the normal receiver, if desired. The purpose of terminating unused channels is to assure that the signal energy is dissipated in matched impedances, guaranteeing absence of reflection and freedom from circuit noise.

b. Telegraph Path. The 3-kHz band of telegraph signals which is contained in sideband A1 of the diversity receiver passes through the direct path (D) of TD-98/FGR-3 No. 1, and is applied through the technical control patching panel to the A path of the AN/FGC-61A receiving group. The 3-kHz band of telegraph signals contained in sideband A1 of the normal receiver passes through the direct path (D) of TD-98/FGR-3 No. 2, and is applied through the technical control board to the B path of the AN/FGC-61A. The identical (except for fading patterns) telegraph signals are combined in the receiving group of the AN/FGC-61A. After demodulation, the dc telegraph signals are sent to the teletypewriter receiving equipment in the communications center.

c. Order-Wire Path. The 3-kHz signal contained in sideband A2 of the diversity receiver is translated to the VF range in the translated-path circuits (T) of TD-98/FGR-3 No. 1. The order-wire signal then is applied through the technical control patching panel to the order-wire telephone. The sideband A2 signal from the normal receiver is not used in this application, so the translated output (T) from TD-98/FGR-3 No. 2 is terminated.

d. Telephone A Path. The output from sideband B of the normal receiver is applied to TD-98/FGR-3 No. 3. Sideband B of the diversity receiver could have been used just as well, but one or the other output must be terminated because space-diversity reception is not used with voice communications. Sideband B1 passes through the direct path (D) of TD-98/FGR-3 No. 3, and is applied through the technical control patching panel to the receiving circuit (R) of AN/FTA-15A No. 1. The voice-operated switching circuits in the AN/FTA-15A prevent feedback from the transmitting loop to the receiving loop at the user telephone equipment. When it is not prevented, this type of feedback causes an audio howl called singing to be present in the circuit. The AN/FTA-15A also helps to compensate for changes in voice level due to fading on the radio transmission path. The AN/FTA-15A sends the received telephone signal through the local switchboard (not shown in fig 6-1) to the user telephone TP A. Either two-wire or four-wire telephone terminating equipment can be used.

e. Telephone B Path. Sideband B2 from the normal receiver is translated to the VF band in the translated circuit (T) of TD-98/FGR-3 No. 3. The telephone signal is processed in the same manner as described in d above, except that it is applied to receiving circuit (R) of AN/FTA-15A No. 2. The output from this AN/FTA-15A can be applied to either a two-wire or four-wire telephone terminating equipment (TP B).

f. Questions.

6-4a. Reflection can be prevented in an ISB radio system by

a. reducing the transmit power.

b. using space-diversity reception.

c. terminating unused channels in matched impedances.

d. using three TD-98/FGR-3's instead of the normal two.

6-4b. Space diversity is normally used in ISB radio communications. The normal and diversity received signals are similar in that both

a. have similar levels.

b. have identical frequencies.

c. are received on the same antenna.

d. are demodulated in the same radio receiver.

6-4c. One sideband channel of an ISB radio receiver in space-diversity is not used because

a. speech signals combined in space-diversity cause phase distortion of the sounds.

b. space-diversity produces sounds in that channel which are entirely different from those in the corresponding channel of the second receiver.

c. the sounds produced are out-of-band and cannot pass through Demultiplexer TD-98/FGR-3.

d. VF tones occupy an entirely different set of frequencies and cannot be applied to Telegraph Terminals AN/FGC-61A.

6-5. COMMUNICATIONS CENTRAL AN/TSC-25A

a. Purpose. Communications Central AN/TSC-25A is a transportable ISB, medium-range radio communications facility that links field commanders at any point of the world with the nearest station of the DCS.

b. Employment. This equipment provides voice, teletypewriter, and/or facsimile communications to areas that lack strategic radio facilities or require additional equipment to augment existing networks.

c. Description. Communications Central AN/TSC-25 is a vehicular and air transportable, 1 kilowatt (uw), independent sideband (isb) radio teletypewriter facility capable of simultaneous transmission and reception of voice and teletypewriter signals in the 2.0 to 32.0 megaHertz (MHz) range.

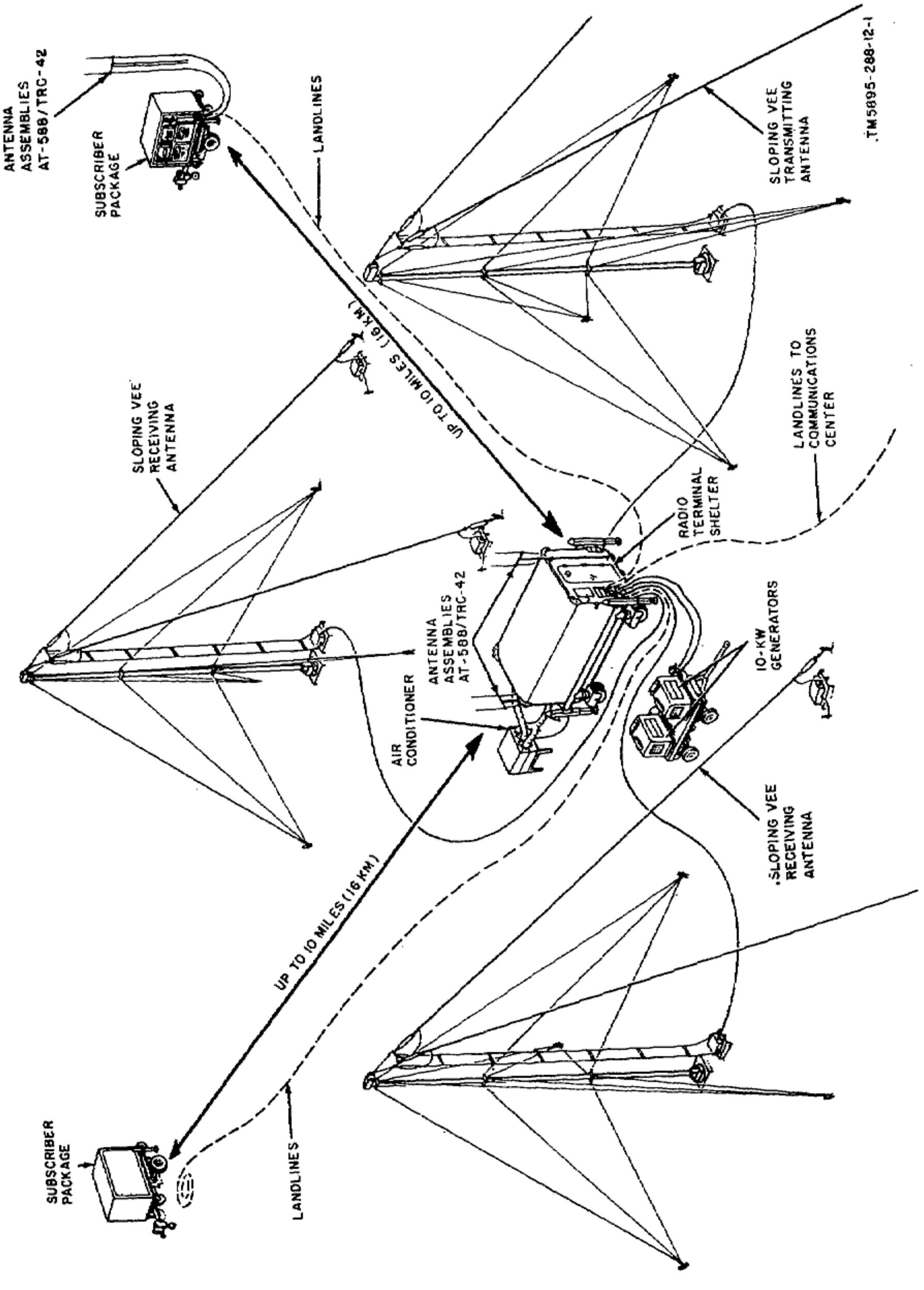


Figure 6-3. Communications Central AN/TSC-20.

d. <u>Characteristics</u>.

Power requirements	Two 10-kW gasoline generators.
Power output	1-kW PEP.
Distance range	2,500 miles (4,000 km).
Channels	3 voice and 8 teletypewriter.
Frequency range	1.6 tp 29.9999 MHz in 100 Hz steps.
Mode of operation	Suppressed-carrier ISB.
Flexibility	Air and ground transportable.
Compatibility	Army, Navy, Air Force, DCS.
Configuration	One shelter, two generator sets.
Antenna systems	Transmitting: sloping-vee; Receiving: two sloping-vee in space diversity.

e. Questions.

6-5a. What telegraph (teletypewriter) loop facilities are furnished by Communications Central AN/TSC-25?

a. 8 send and 8 receive 4-wire full-duplex dc loops.

b. 8 send and 8 receive 2-wire half-duplex VF loops.

c. 16 send and 16 receive 4-wire full-duplex dc loops.

d. 16 send and 16 receive 2-wire half-duplex VF loops.

6-5b. When the AN/TSC-25 combines space and frequency diversity, the number of teletypewriter channels in the telegraph terminal will be changed from 8 to

a. 2.

b. 4.

c. 12.

d. 16.

6-6. COMMUNICATIONS SYSTEM AN/TSC-38

a. Purpose. Communications System AN/TSC-38 is a transportable voice and data communications facility capable of transmitting and receiving on two independent SSB radio channels. It also has limited cryptographic and message center capabilities.

b. Employment. The primary function of the AN/TSC-38 is to link field commanders with the DCS by HF SSB radio. It provides voice and data communications from areas that lack fixed plant long-distance radio facilities. It can also be used to augment the traffic handling capability of an existing long-distance SSB radio station. It eventually will replace the AN/TSC-25 units.

c. Description. The AN/TSC-38 shown in figures 6-5 and 6-6 provides a primary and a secondary HF SSB radio circuit, each one capable of operating with distant stations independently. A 10kW SSB transmitter and two receivers in space diversity make up the primary radio facility. The secondary radio facility consists of a 1kW SSB transceiver wherein some stages of the set are common to both the transmitting and receiving processes.

(1) The system also provides service for 15 telephone subscribers over two-wire or four-wire

service. Limited remote control is available to frequency-shift-keying dial telephone subscribers. All 15 subscribers are served by an automatic switchboard and a manual dial service assistant position. Fourteen teletypewriter subscribers are served by a manual control position that utilizes full-duplex circuits.

(2) All operating facilities are mounted in a transportable Shelter S-141A/G. A separate auxiliary trailer is used to carry or store the antennas, test equipment, and the generators that provide primary or standby power.

(3) Test results have shown that the AN/TSC-38 represents a major improvement over previously developed transportable SSB long-distance radio communications systems. It incorporates many favorable characteristics, including compactness, surface and air transportability, comparative ease of siting and installation, modularized packaging, and automated operational features.

(4) The primary radio facility uses sloping-vee antennas. The secondary radio facility uses a shelter-mounted 32-foot whip antenna.

d. Characteristics.

(1) HF radio subsystem. This subsystem includes both the primary and secondary radio facilities. Both radio facilities tune automatically over the frequency range of 2.0 to 29.99 kHz in 0.l-kHz steps.

(2) Primary radio, full-duplex.

Power output	10-kW PEP.
Receivers	Two in space diversity.
Channelization	Four independent 3-kHz channels.

(3) Secondary radio, half-duplex.

Power output	1-kW PEP from the transmitting part of the transceiver combination.
Receiver	The single receiver is part of the transceiver combination.
Channelization	One to four 3-kHz independent voice channels.

(4) Antennas. The primary radio facility uses three sloping-vee antennas. One antenna is used for transmission and two are used for space-diversity reception. The secondary radio facility uses a 32foot shelter-mounted whip antenna to serve both transmitting and receiving functions. The

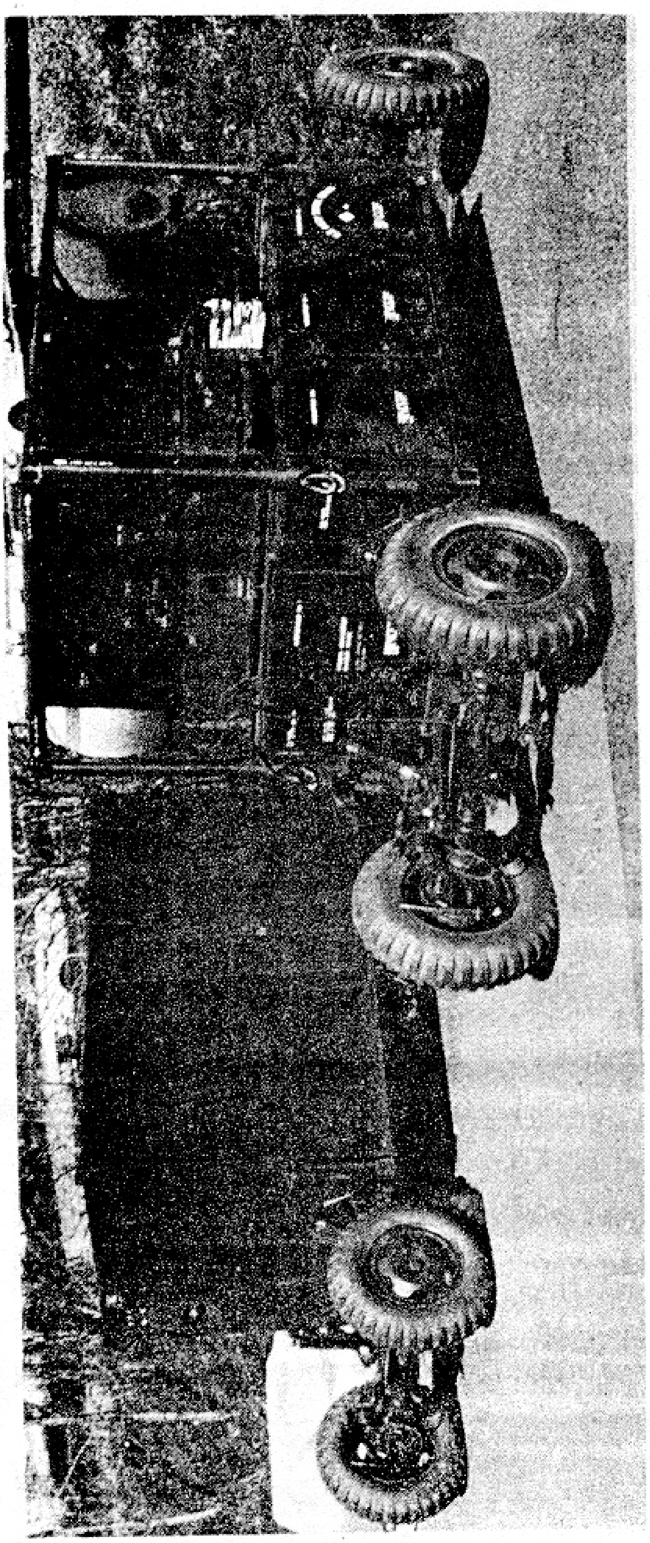


Figure 6-4. Communications System AN/TSC-38 shelters.

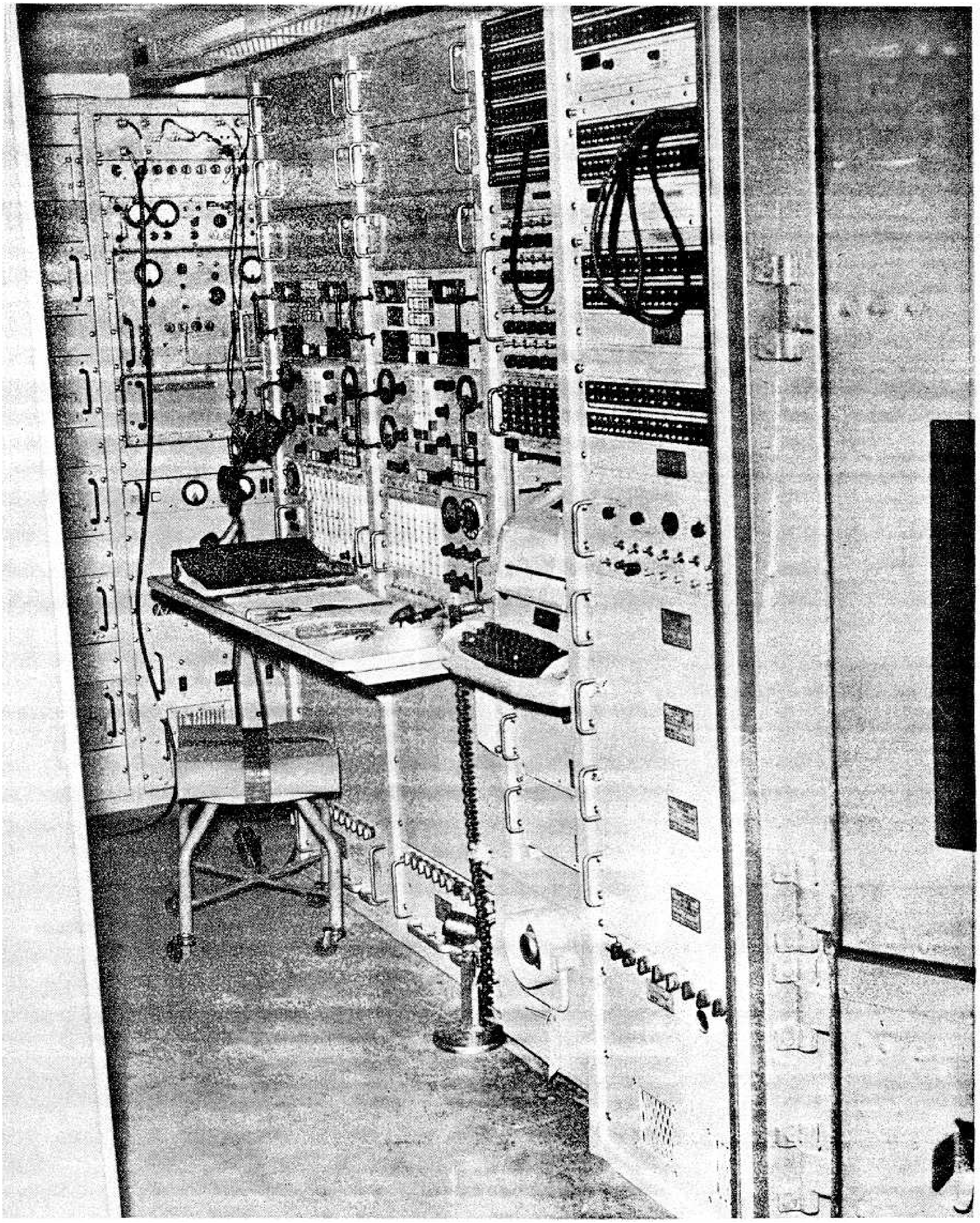


Figure 6-5. Inside view of AN/TSC-38 van.

secondary radio facility is equipped with electronic voice-operated control circuits to prevent the transmitter and receiver from operating simultaneously. When full-duplex operation of the secondary facility is desired, a 32-foot field-mounted whip antenna is used.

e. Questions.

6-6a. When first establishing communications with a distant station using Communications System AN/TSC-38, the operator employs the secondary radio facility. This facility consists of a

a. 1-kW transmitter and two receivers in space diversity.

b. transceiver with a transmitter circuit capable of 1-kW output.

c. transceiver with a transmitter circuit capable of 10-kW output.

d. 10-kW transmitter and one radio receiver using frequency diversity.

6-6b. Assume that you are to select an ISB communications system which provides automatic dialing telephone service. To satisfy this requirement, you would choose Communications System

a. AN/TSC-16.

b. AN/TSC-18.

c. AN/TSC-19.

d. AN/TSC-38.

6-6c. The number of full-duplex teletypewriter circuits that the AN/TSC-38 can provide is

a. 16.

b. 15.

c. 14.

d. 8.

6-6d. In the process of assembling Communications System AN/TSC-38 for operation, the technician fastens a 32-foot whip antenna to the top of the shelter. This antenna serves the

a. high-power transmitter.

b. primary radio facility.

c. Secondary radio facility.

d. space-diversity receivers.

LESSON 7

FREQUENCY PLANNING

TRAINING OBJECTIVE:	Action:	Be able to list the characteristics of frequency planning.
	Conditions:	Given SSO 750.
	Standard:	You must be able to successfully complete lesson exercises.
CREDIT HOURS:	2	

LESSON OBJECTIVES

When you have completed this lesson, you will:

1. Know that the problem of frequency assignment in the HF range is complicated by the number of requests in excess of the limited number of HF channels available.

2. Know that frequencies in the HF range allow efficient long-distance radio communications.

3. Be able to use long-term propagation predictions furnished by the US Army Strategic Communications Command, and short-term predictions from the National Bureau of Standards stations.

4. Know that fading on an HF radio circuit is due to changes in the density or the position of ionized layers surrounding the earth.

5. Be able to determine the maximum variation that is permitted from an assigned frequency.

ATTACHED MEMORANDUM

7-1. RADIO-FREQUENCY MANAGEMENT

In the last two decades the enormous demand for radio frequencies suitable for long-distance communications has resulted in extremely crowded conditions in portions of the radio-frequency spectrum. The bands most affected are those frequency bands up through the HF band. Since the frequency spectrum must be shared by all nations of the world, all radio stations must abide by national and international regulations governing its use.

a. International Frequency Control. The International Telecommunications Union (ITU) is a specialized control agency of the United Nations. It calls periodic international conferences to conclude treaties regulating the use of the radio-frequency spectrum, standardize methods and procedures, and to minimize interference. The International Frequency Registration Board (IFRB), a working group of the ITU, maintains a register of frequency assignments in the International Frequency List. It is this registration that insures international protection of frequency assignments. Frequency assignment disputes are handled by the IFRB and are normally resolved in favor of the earlier registration. All United States registrations are made through the Federal Communications Commission.

b. Frequency Management in the Department of the Army. As one of the major users of the radio-frequency spectrum, the Army has a vital interest in all facets of frequency management. The Army must share the spectrum with the other military services, government departments, and civil operations. The focal point for staff advice and coordination of all Army communications-electronics activities is the Chief of Communications-Electronics. This encompasses the assignment, allocation, and control of Army frequencies and the negotiations for new frequencies to meet ever-increasing requirements. Frequency management is more complicated in areas outside the United States. The frequency spectrum is a natural resource within the borders of any country exercising its sovereignty; therefore, it may be used only with the consent of that country. All commanders and communications-electronics personnel must be aware of the priority of host government communications-electronics operations. Strict operator discipline and effective control procedures are required to insure operation with the approved frequency, emission, and power. Any deviation could adversely affect negotiations with the host government.

c. Question.

7-1a. International frequency assignment disputes are resolved by the

a. Office of the Chief of Communications-Electronics.

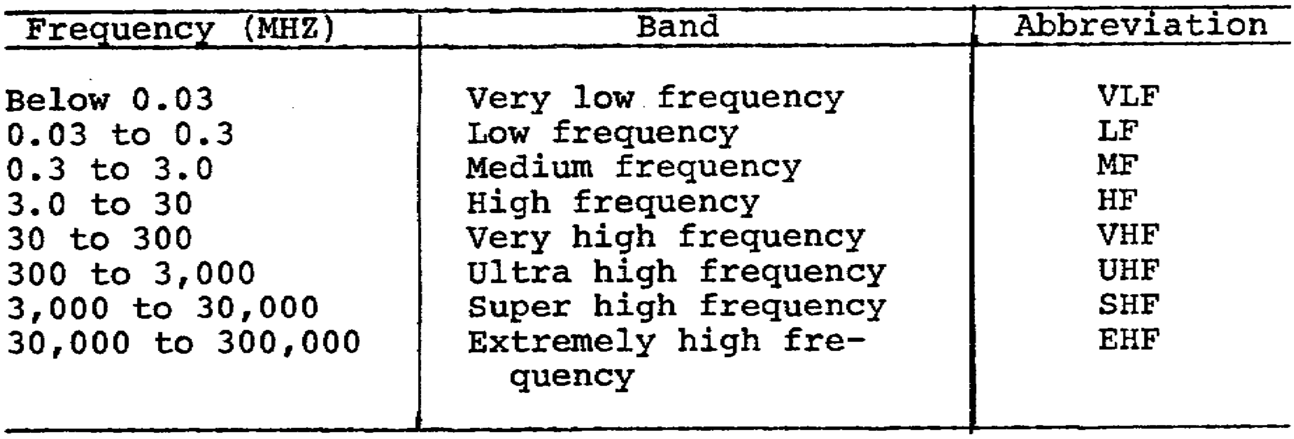
b. International Frequency Registration Board.

c. Federal Communications Commission.

d. Frequency Management Directorate.

7-2. OPERATING RADIO FREQUENCIES

a. Frequency Bands. The electromagnetic frequency spectrum has been arbitrarily divided into several bands as illustrated in the following chart. Because the transmission characteristics vary throughout these frequency bands, some frequencies cannot be used in long-distance radio systems.



Frequency (MHZ)	Band	Abbreviation
Below 0.03	Very low frequency	VLF
0.03 to 0.3	Low frequency	LF
0.3 to 3.0	Medium frequency	MF
3.0 to 30	High frequency	HF
30 to 300	Very high frequency	VHF
300 to 3,000	Ultra high frequency	UHF
3,000 to 30,000	Super high frequency	SHF
30,000 to 300,000	Extremely high frequency	EHF

b. Radio-Frequency Propagation. The propagation of electromagnetic energy from one point to another takes place via groundwaves, skywaves, and space waves, or a combination of these. Skywaves reach the receiver after refraction from the ionosphere, while ground waves and space waves reach the receiver through the earth's lower atmosphere (troposhere). The relationship between the types of propagation and the various frequency bands is as follows:

(1) In the EHF, SHF, UHF, and VHF bands, the circuits depend on groundwave and space-wave propagation, and the electromagnetic fields are rapidly attenuated beyond the horizon. The most suitable frequency bands for long-distance communications are the HF, LF, and, sometimes, the MF.

(2) In the HF band, propagation may be either by groundwaves or by skywaves, depending on the antenna construction and the distance between the transmitter and receiver. Groundwave propagation provides more reliable communications; however, groundwave distance coverage is limited. In contrast, skywave propagation in the HF band has virtually an unlimited distance coverage, depending primarily on frequency selection, antenna construction, the equipment used, and propagation conditions. As a result, skywave propagation is used extensively in long-distance radio circuits.

(3) In the LF and VLF bands, long-distance propagation is possible by groundwave with negligible fading. However, because of the high absorption rate of ground waves, LF and VLF propagation requires great power. Because of the limited number of frequencies available for allocation in these bands, the use of these frequencies by government agencies, including the military, is restricted to special circuits.

(4) Propagation using frequencies in the MF band is transitional in nature. It depends on ground waves at the lower end of the band and has limited skywave propagational capabilities at the higher end. In general, the MF band is used for short-distance tactical radio nets.

c. Allocation and Assignment of Operating Frequencies. The choice of a suitable operating frequency is restricted by frequency allocation and frequency assignment. Frequency allocation is the designation of a group of frequencies to be made available for a particular type of radio service. For example, the band from 540 kHz to 1,600 kHz is allocated for commercial AM broadcast service. Frequency assignment is the designation of a particular frequency for use on a specific net or circuit. For example, radio station WNBC in New York City is assigned an operating carrier frequency of 660 kHz.

d. Frequency Assignment. Each HF system is assigned a number of frequencies for use in each direction of transmission. This number is variable and depends primarily on long-term propagation predictions. Normally, a minimum of three frequencies for each circuit is required: one for daytime operation, one for nightime operation, and one for transitional periods. However, most circuits require more frequencies to cover long-term propagation path variations, short-term propagational phenomena, interference, etc.

e. Factors in the Choice of Operating Frequencies. The selection of a general frequency band for a specific circuit is determined by the transmission properties of the band, availability of frequencies in that band, and types of equipment available. Bands up to and including the HF band are crowded and subject to interference, thus complicating the choice of operating frequencies for long-distance communications. When an option exists on the choice of frequency band, consideration should be given to the traffic requirements, availability of equipment, circuit privacy, and reliability.

(1) Ionospheric conditions. Since long-distance communications in the HF band depends on ionospheric refraction, the choice of frequency is limited by conditions of the ionosphere. The highest frequency that may be used for point-to-point communications is determined by the degree of ionization and the distance between stations. The lowest frequency is determined chiefly by the amount of ionospheric noise and the technical characteristics of the equipment used.

(2) Groundwave propagation. At frequencies below about 30 MHz, large groundwave field strengths beyond the horizon can be received

and relatively long-distance coverage can be expected over earth of good conductivity. The groundwave signals become stronger (and the range becomes longer) when the conductivity of the earth is high and the transmission frequency is low. Propagation over sea water is particularly good because it possesses the best transmission characteristics, principally high conductivity. In many cases, long-distance communications is possible by means of LF groundwave propagation then ionospheric storms prevent reliable communications by means of HF skywave propagation. These ionospheric storms are caused chiefly by the auroral activities in the extreme northern and southern latitudes of the Arctic Antarctic zones.

(3) Reliability. Communications by means of sky-wave propagation depends primarily on ionospheric conditions, which are subject to hourly changes. Because of ionospheric variations, use of more than one operating frequency throughout a 24-hour period is usually necessary for reliable communications.

f. Pilot Circuits. When spare equipment is available at both ends of the radio circuit, it is advisable to establish a pilot circuit before the need arises for a frequency change. The pilot circuit is activated on the frequency that will probably be best after the anticipated frequency change. Transmitters on both frequencies are keyed with the same information. By tuning in both transmitted signals at the distant receiving station, time lost for frequency changes can be made negligible. With experienced operators at the receiving station and at the associated technical control center, frequency changes often can be performed with a loss of no more than one or two letters on each receiving teletypewriter. Personnel involved in this method of frequency change must be careful to specify in each instance exactly what frequency will be deactivated (by commonly assigned identification name or number). Maximum coordination is required between the receiving station personnel and the technical control personnel at the time of frequency changeover. Both received signals are fed to technical control from the receiver station, and the entire change is coordinated by technical control personnel.

g. Questions.

7-2a. The bands of frequencies that are most suitable for long-distance communications are

a. VHF, HF, and MF.

b. UHF, VHF, and HF.

c. SHF, VHF, and HF.

d. LF, MF, and HF.

7-2b. Skywave propagation is used in long-distance radio transmission. However, the range of skywave propagation is limited primarily by the

a. frequency selection, equipment employed, and antenna construction.

b. equipment employed, antenna construction, and amount of radiated power.

c. equipment employed, antenna construction, and line-of-sight distance between stations.

d. frequency selection, antenna construction, and line-of-sight distance between stations.

7-2c. At least three frequencies are required for each circuit in an HF long-distance radio station for use as follows:

a. two for day and one for night in summer.

b. one for day and two for night during changing of seasons.

c. one for day, one for night, and one for transitional periods.

d. one for day, one for night, and one for periods of excessive noise or interference.

7-2d. In the usual method of changing the operating frequency, the transmitting equipment must be shut down momentarily. Compared with this method, the use of a pilot circuit has the advantage of reducing the

a. time loss due to frequency changes.

b. transmitting equipment required.

c. receiving equipment required.

d. cost of operation.

7-3. CIRCUIT PREDICTION CHARTS

a. Origin. The Communications Engineering Department of the US Army Communications Command (USACC) publishes propagation information for distribution to DCS radio stations. Data taken from this information are used in the preparation of frequency curves. A completed sample graph showing these curves is illustrated in figure 7-1. The curves may show the predicted highest probable frequency (HPF), maximum usable frequency (MUF), or optimum traffic frequency (FOT).

(1) Generally the upper frequency limit is indicated by the FOT curve. Some stations desire, and can obtain by special request, the MUF or HPF curve. It will be furnished instead of, or in addition to, the normally furnished FOT curve.

(2) As a lower limit, the lowest useful frequency (LUF) curve is computed and plotted on the same chart. If any part of the great-circle propagation path of a particular circuit lies in either the northern or southern auroral zone, an additional curve is plotted to indicate the predicted frequencies for an adjusted lowest useful frequency (LUF-A).

(3) All of these curves are statistical predictions based on recorded activities of propagation conditions over many years as related to the

variations of sunspot numbers. The HPF, MUF, and FOT are measures of ionospheric support. Ionospheric support means that the density of ionization of the various ionospheric layers is such that the layers refract the actual MUF at any given instant. Frequencies above the actual MUF are not refracted back to earth, but penetrate the ionospheric layer and escape into space. (Frequency of escape, at vertical incidence, is called the critical frequency.)

(4) The LUF and LUF-A are indications of atmospheric absorption, giving the approximate frequency at which the atmosphere and ionosphere absorb so much energy from the radio waves that the signal becomes unusable.

b. Significance of the Curves.

(1) MUF curve. The MUF prediction curve is the expected monthly median value of the critical frequency at which the radio waves will not return to earth. This means that on 50 percent of the days of the month the actual measured MUF will exceed the frequency indicated by the curve and that on the other 50 percent of the days of the month the measured MUF will be less than the indicated predicted value.

(2) HPF curve. The HPF curve represents the frequency at which it is expected that only 10 percent of the days will show an actual measured MUF exceeding the predicted HPF. This HPF value is 15 percent above the predicted MUF .

(3) FOT curve. On 90 percent of the days of the month for which the prediction is made, the actual MUF is expected to exceed the predicted FOT. The FOT curve is 15 percent below the predicted MUF when the F-layers control the propagation. When the E-layer of the ionosphere controls the circuit, the FOT coincides with the MUF.

CIRCUIT DATA:

(1) Xmtr Output Power: 5 kw

(2) Xmtg Antenna: "B" Rhombic
Rcvg Antenna: "A" Rhombics in
dual diversity

(3) Service: RATT Channel

(4) Distance: 250 Miles

HIGHEST PROBABLE FREQUENCIES (HPF)
OPTIMUM TRAFFIC FREQUENCIES (FOT)
LOWEST USEFUL HIGH FREQUENCIES (LUF)

On disturbed days often accompanied by auroral phenomena, use the LUF-A curve instead of the LUF.

STATION X
Receiving
STATION Y

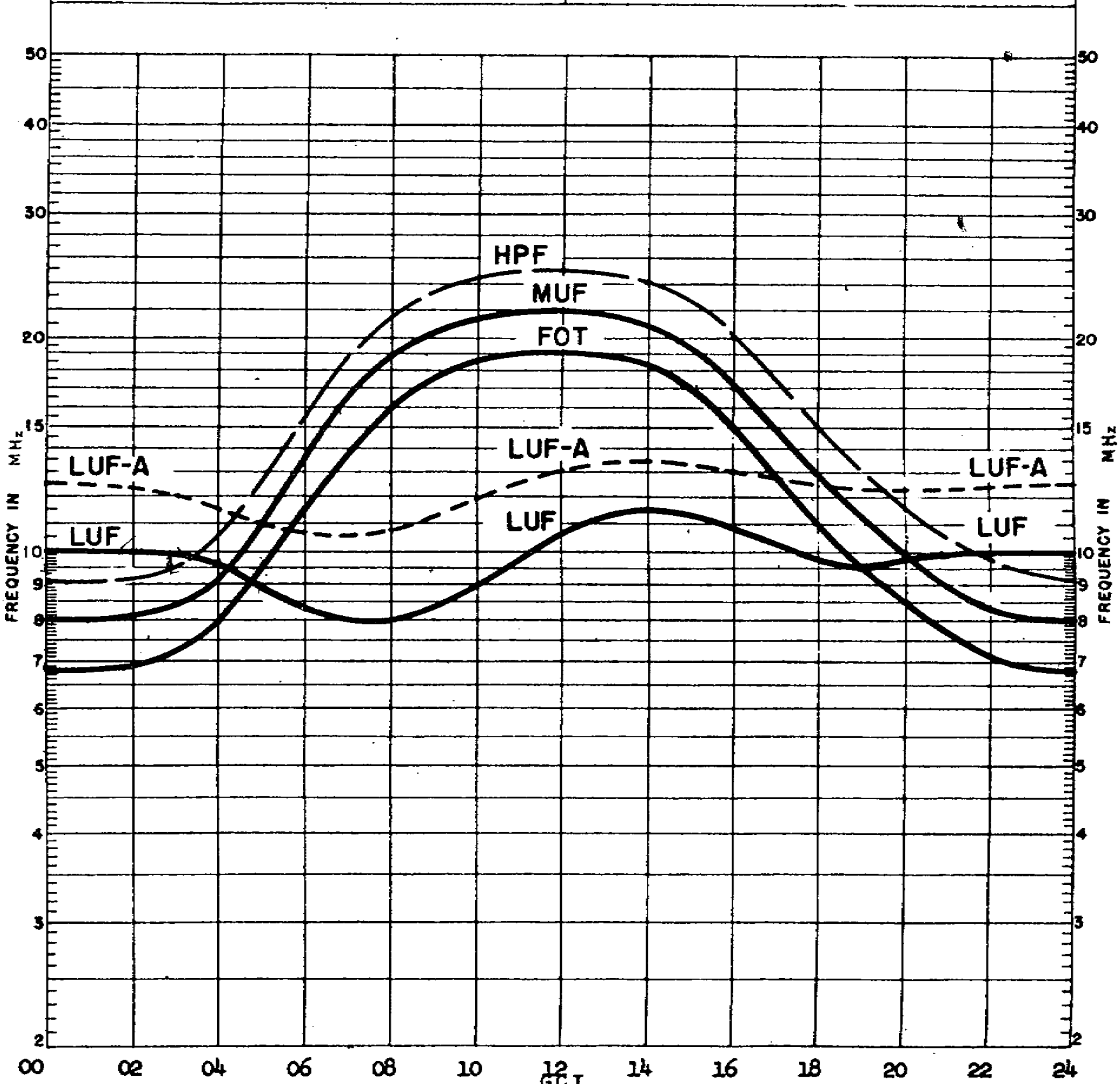


Figure 7-1. Sample frequency prediction chart.

(4) LUF curve. The LUF curve predicts the frequency below which the radio waves are expected to be weakened by absorption to the point where they no longer provide the minimum signal-to-noise ratio required for acceptable communications.

(5) LUF-A curve. The LUF-A curve represents an adjustment of the LUF prediction. It takes into account the additional absorption due to auroral disturbances. It is used only on disturbed days; on undisturbed days, the LUF curve is used.

c. Use of Circuit Prediction Charts. Frequencies assigned to the specific circuit should be indicated on the frequency prediction charts at the station. A horizontal line can be drawn in a contrasting color across the graph at the approximate level for each assigned frequency. The frequency most likely to afford reliable communications is indicated by the relative position of the prediction curves and the available frequency lines. The available frequency that lies nearest to the FOT prediction curve (or MUF curve if the FOT curve is not shown), and that also lies between the FOT (or MUF) and LUF curves is the frequency that should be selected. If this frequency proves unsatisfactory because of interference or other reasons, the next lower available frequency between the FOT (or MUF) and LUF curves should be tried. If after trying all frequencies between the FOT (or MUF) and the LUF, none of them provides satisfactory communications, then all other available frequencies should be tried. The actual MUF will be at some level below the predicted FOT on about 3 days of each calendar month.

d. Distribution. Propagation information is distributed to the transmitter, receiver, and technical control locations. This information is convenient to have in the transmitter and receiver locations, but it is essential in the technical control center.

e. LUF Above MUF. In the sample circuit prediction chart (fig 7-1), notice that from 1900 to 0500 hours the predicted FOT falls below the predicted LUF. During these hours, the prediction is that no frequency will afford satisfactory communications. However, because of the many variables involved in computing these prediction curves, it has been found that frequencies in or around the FOT, MUF, or HPF curves will often afford communications of some type. It may be necessary during these hours to substitute another type of service or to reduce the number of channels of communications in the system. Either of these expedients will, in effect, lower the LUF curve. In emergencies, a lower quality circuit may be provided during hours of poor circuit conditions with the expectation of individual message delays for the correction of errors introduced by the poor-quality circuit.

f. Special Prediction Charts. Special circuit predication charts can be obtained from the USASTRATCOM.

g. Question.

7-3a. One of the functions of the US Army Communications Command is to furnish circuit prediction information to DCS stations. On a completed frequency prediction chart the optimum traffic frequency is identified by the abbreviations

a. FOT.

b. HPF.

c. LUF.

d. MUF.

7-4. OVERCOMING THE EFFECTS OF ADVERSE PROPAGATION CONDITIONS

Some propagational disturbances or deteriorating effects can be overcome by proper operational action at the radio transmitting or receiving station.

a. Sudden Ionospheric Disturbances. Occasional magnetic storms and other phenomena may cause sudden ionospheric disturbances (SID). These disturbances usually are of short duration and may affect only a narrow band of frequencies, or they may affect all frequencies in the operating band at the time of occurrence. Furthermore, these SID's may cover only a small portion of the ionosphere, or they may cover such a large area that radio circuits in all directions of transmission are affected. The critical point is the actual area of ionospheric refraction. If the SID occurs in that geographical area, then all radio signals refracted by that portion of the ionosphere will be affected. Signals refracted from an undisturbed portion of the ionosphere will not be affected. SID's usually occur during daylight hours (at the ionospheric refraction area) and clear up within 30 minutes. With a pilot frequency in operation at the time of an SID, the receiving station should check for operational stability on that frequency. A quick changeover may be accomplished. In any case, the new frequency is one that is expected to provide better operating conditions within the next few hours than the one about to be vacated. No long-term predictions are available for SID's since they cannot be predicted more than a few hours or days in advance. Short-term predictions are broadcast periodically by radio stations of the National Bureau of Standards (NBS).

b. Band Fading. Except for SID's the average strength of the received signal changes gradually, and usually according to predictions. A reduction in the level of all signal components simultaneously is called band fading. This type of fading is an indication to the radio receiving personnel that the time is approaching for a change to another operating frequency. Operators should never wait until the signal fades below the noise level, because no technique will produce acceptable results under that condition. Although the order for the frequency change originates within technical control, the technical controller depends upon the advice of the receiving operators as to the deteriorating signal conditions. The most effective compensations for band fading are a combination of using two antennas in space-diversity, automatic gain control (AGC) in the receiver, and limiters in the terminal equipment.

c. Selective Fading. Whereas band fading affects all components in the composite signal simultaneously, selective fading occurs in a random manner and in random amounts over portions of the signal spectrum. It will often affect only a small portion of the information carried by the radio signal at any given instant. The effects of this type of fading often can be overcome by frequency diversity wherein two parallel channels operate through a common combiner unit, with the stronger of the two received signals assuming control of the circuit.

d. Combined Fading. Most of the time, the total effect of fading is a combination of band and selective fading. To help minimize the effect of signal distortion caused by fading, most long-distance HF radio systems use a combination of space-diversity and frequency-diversity.

7-5. RADIO PROPAGATION FORECASTS

A forecast of short-term propagation conditions is broadcast from radio stations WWV (Fort Collins, Colorado) and WWVH (Hawaii), both of which are operated by the NBS. The standard carrier frequencies for WWV are 2.5, 5, 10, 15, 20, and 25 MHz, while for WWVH they are 5, 10, and 15 MHz. The forecast announcement is sent only in international telegraphic code at approximately 19.5 and 49.5 minutes past each hour. It tells the users the condition of the ionosphere at the time the forecast is made, and how good or bad communications conditions are expected to be in the succeeding 6 or more hours.

a. Basis. These forecasts are based on data obtained from a worldwide network of geophysical and solar observatories, including radio soundings of the upper atmosphere, radio reception data, and similar information. Much of this information is obtained from the many ionospheric recording and field intensity recording stations operated by various governments.

b. Forecast Path Coverage. The forecasts from station WWV refer only to North Atlantic radio paths, while forecasts from station WWVH refer only to North Pacific radio paths. The forecasts apply only to HF skywave radio transmissions over paths that are near the auroral zone for a considerable part of their length. Ionospheric disturbances in these areas often accompany intense magnetic field variations and brilliant auroras. The resulting propagation effects range from severe fading to a complete break in communications.

c. Form of Forecast. The forecast is broadcast in the form of a letter and a digit. The letter portion indicates the quality of radio propagation at the time the forecast is made; letters N, U, and W signify, respectively, that radio conditions are normal, unsettled, or disturbed.

The digital portion of the broadcast is a forecast of the radio propagation quality over the typical transmission path (b above). This transmission path can be expected to deteriorate anytime after 6 hours from the time of the broadcast. Quality is graded in steps ranging from 1 (useless) to 9 (excellent) as shown in the following chart.

Disturbed grades (W)	Unsettled grades (U)	Normal grades (N)
1 - useless	5 - fair	6 - fair to good
2 - very poor		7 - good
3 - poor		8 - very good
4 - poor to fair		9 - Excellent

d. Form of Broadcast. The broadcast is, as mentioned previously, made in telegraphic code. It consists of the letter-digit combination sent at slow speed. For example, if the propagation conditions at the time of the broadcast are normal, but disturbing effects are expected in the next 6 or more hours which would reduce the conditions to poor, the signal N3 would be broadcast in international Morse code.

e. Questions.

7-5a. Assume that one of the operators at the receiver station asks you to explain to him the significance of the telegraphic code signal U9 which he heard when he tuned in radio station WWV. What is your explanation?

a. Propagation conditions are going to be useless in 9 hours on the South Atlantic radio transmission paths.

b. Propagation conditions are due to change from unsettled to excellent on the North Atlantic radio transmission paths.

c. Propagation conditions are due to change from excellent to unsettled on the South Pacific radio transmission paths.

d. Propagation conditions are so poor that 9 words a minute is the highest readable code speed on the North Atlantic radio transmission paths.

7-5b. Assume that the tape relay operator at San Francisco on the San Francisco-Anchorage radio circuit receives information at 1300 that the short-term propagation forecast is N2. This indicates to the operator that it will be advisable to move as much message traffic as possible before

a. 1900.

b. 2100.

c. 2400.

d. 0100.

7-6. SELECTION OF ASSIGNED FREQUENCY

Each HF long-distance fixed station is assigned several operating frequencies to assure reliability and flexibility of communications. The absolute minimum needs of any HF station are one frequency for daytime operation and one for night. At least two more are recommended when frequencies are available. The necessity for frequency change results from variation in height and density of the ionosphere.

a. Problems Involved in Making Frequency Changes.

(1) Under normal circumstances, experienced communicators rely heavily on experience as the basis for deciding when to change frequency, what channel to use, and what improvement in traffic-handling capacity can be expected from a frequency change. However, they cannot be certain that the desired improvement will be so obtained. They need a more scientific basis for judgment than experience alone can provide.

(2) When conditions are not normal (because of magnetic storms, SID's unusual interference, or jamming) the frequency selection problem is enormously increased. Under these conditions, the operator can no longer rely on his experience to guide him in corrective measures or to determine whether corrective measures are possible. In practice, the result of these unusual conditions is an increase in the backlog of message traffic.

(3) The amount of order-wire use required to coordinate a frequency change and reestablish message traffic flow creates communications outages. These outages may result in a decrease of as much as 8 to 15 percent in average circuit capacity. Furthermore, use of the order wire and the number of "repeats" required to correct message errors tends to needlessly waste valuable circuit time on the already overcrowded HF long-distance radio spectrum.

b. Improved Technique of Frequency Selection. In an effort to give the operators a working tool to solve their frequency selection problems, equipment designers and the military services are working together to perfect a system of oblique ionospheric sounding.

(1) The system depends for its operation on the transmission of very short pulses (similar to

radar) over the HF range on the frequency step basis. Starting at the lowest assigned radio frequency, the system transmits, in ascending sequence, a burst of RF energy on each of the higher assigned operating frequencies. These bursts, or pulses, of RF energy are transmitted and received over the existing antenna facilities at each end of the long-distance radio circuit.

The receiving equipment displays the results of the received signals on an oscilloscope, as shown in figure 7-2. Note that the horizontal and vertical scales compare frequencies of operation with range of communications. The white areas indicate the ion density in the ionosphere. Generally speaking, the greatest amount of refraction combined with minimum absorption occurs in the center of these areas of maximum ion density.

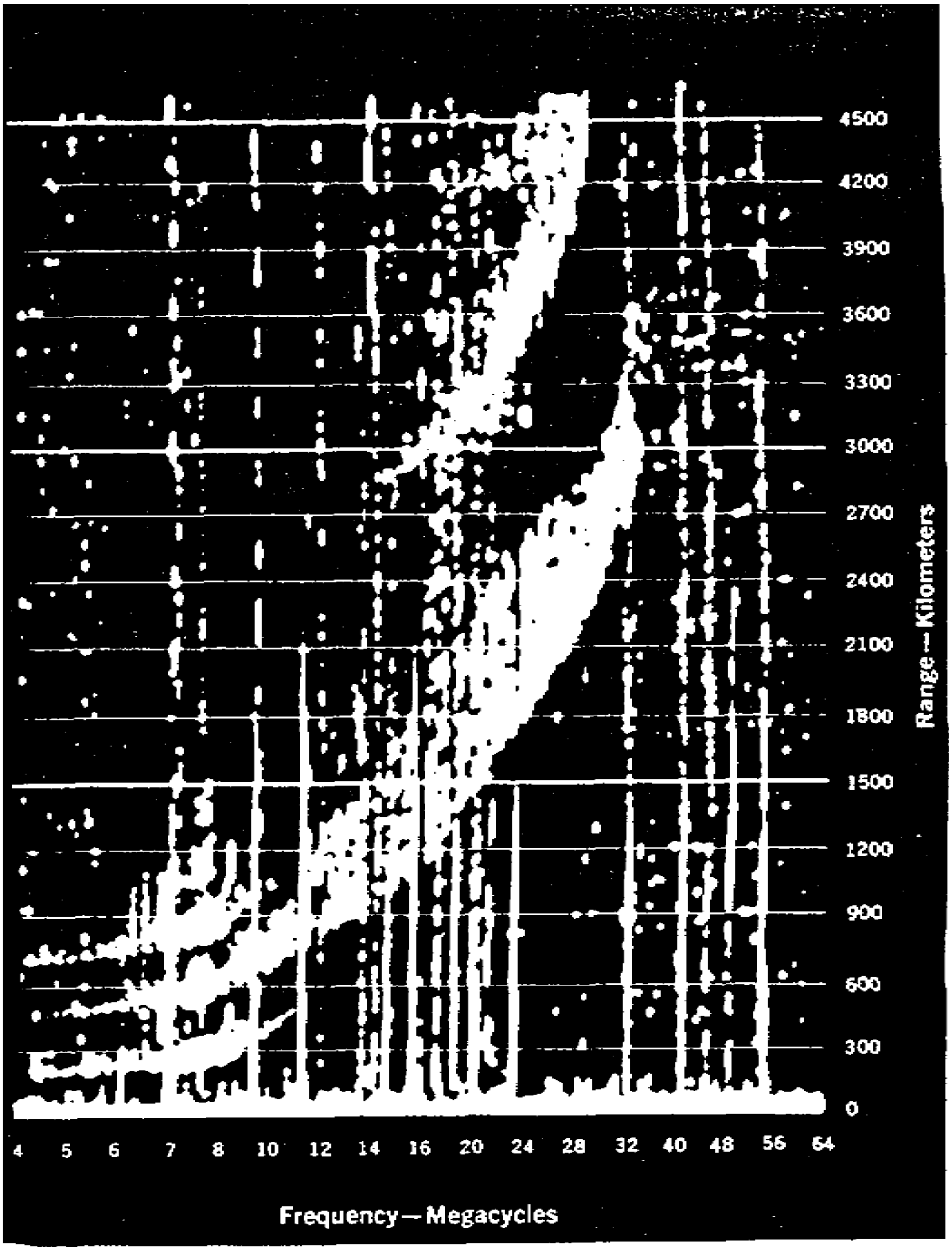


Figure 7-2. Typical oscilloscope record of ionospheric sounding.

(3) By interpreting the scale readings on the oscilloscope display the operator can see immediately which frequencies will give the most reliable communications. Since the time required to obtain the display is a matter of seconds, the operator can take a "picture" of the ionosphere layers at any time of the day or night.

(4) Further development of this idea will eventually bring about automatic switching of radio frequencies. When this system becomes available, completely unmanned stations can be deployed in any area, thus providing ready access everywhere to the worldwide Defense Communications System.

7-7. SUPERVISION OF RADIATED SIGNALS

Responsibility for monitoring and policing radio-frequency channels usually is part of the assigned mission of the receiver station officer in charge. As part of this responsibility, he must make sure that personnel assigned to this task have been properly trained and can perform their duties dependably.

a. Monitoring. The process of monitoring radio signals involves, among other duties, the measurement of carrier frequency. Two test sets suitable for measuring carrier frequencies are Frequency Calibration Set AN/URM-18 and Frequency Meter AN/USM-26. The AN/URM-18 is best suited for measuring the frequency of a constant radio-frequency carrier signal, while the AN/USM-26 can, in addition, measure small frequency changes (such as in FSK). Both sets are capable of measuring frequencies from 10 Hz to 100 MHz. In measuring the carrier frequency, the monitoring operator must determine two fundamental characteristics of the radiated signal.

(1) The carrier must be on the assigned radio frequency and within the maximum tolerance permitted by law for the type of signal under observation.

(2) The frequency variation (instability) caused by drift must not exceed the permissible tolerance.

Frequency (kHz)	Power output (watts)	Frequency Tolerance (percent)
10 to 50	Not specified	0.1
50 to 535	Not specified	0.02
1,605 to 4,000	Above 200	0.005
	Below 200	0.01
4,000 to 30,000	Above 500	0.003
	Below 500	0.01

b. Policing. Policing the various assigned frequencies is performed to make certain that the correct type of modulating signal is used for a specified carrier frequency and to assure compliance with regulations.

(1) When each frequency is assigned, the modulating signal is specified for that frequency. The fixed-station officer must assure himself that only the specified type of modulation is employed.

(2) The supervising officer must make sure that call-letter identifications required on circuits are sounded correctly.

(3) No transmitter should radiate a signal unless it serves a useful purpose. Local tests of a transmitter should always be made with a dummy load to keep the signal off the air.

(4) No profanity is to be used on the air at any time.

c. Frequency Measurement Log. A separate frequency measurement log is maintained by the station responsible for frequency measurements. Normally, this is the radio receiving station. This frequency measurement log records all measurements made by the designated site of all signals, both from distant station and the local transmitting station. All locally transmitted signals will be measured immediately after each frequency change, and periodically thereafter. Generally, each transmitted signal will be measured at least once during each working shift. Primary responsibility for correct frequency and shift of FSK signals is delegated to the frequency measuring station. Frequency, bandwidth, modulation, and harmonic tolerances must comply with regulations established by the Interdepartment Radio Advisory Committee (IRAC). These regulations and tolerances will be posted at the frequency measuring position. The log may be in any form, but it must contain the following information for each frequency measurement performed:

(1) Complete identification of circuit and transmitting station.

(2) Exact assigned frequency of the incoming or outgoing signal.

(3) Measured shift of FSK circuits.

(4) Exact measured center frequency of the signal. This is the carrier frequency in the case of ISB, DSB voice, CW, and similar modulation methods; or the mark frequency less one-half the measured shift of an FSK signal.

(5) Time of receipt of a request for measurement of a given frequency.

(6) Time of reporting frequency measurement results to the requesting installation.

(7) Initials or personal sign of the operator performing the frequency measurement.

(8) The reason for any delay in frequency measurement or failure to measure a requested frequency.

d. Questions.

7-7a. In a normal fixed radio station installation, the receiver station is equipped with an AN/URM-18 to measure incoming frequencies, while the transmitter station is equipped with an AN/USM-26 to measure the frequency the transmitted radio signals. The characteristic which is common to both of these sets is that they

a. consume the same amount of power.

b. are capable of covering the same overall frequency range.

c. can provide standard audio-frequency test frequencies from 0 to 5,000 Hz.

d. display the measurements in digital form by the eight-place panel indicating system.

7-7b. Assume that Radio Transmitting Set AN/FRT-52A is used for A1 (para 2-12a, Lesson 2) emission at an operating frequency of 17 MHz. Determine the minimum and maximum permissible frequencies.

a. 16,949 and 17,051 kHz.

b. 16,999.49 and 17,000.51 kHz.

c. 16,999.949 and 17,000.051 kHz.

d. 16,999.9745 and 17,000.0255 kHz.

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio Systems

LESSON 1 ....Introduction to High-Frequency Radio Communications Systems

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All references are to the attached memorandum.

1-1a. b--para 1-1a

1-1b. d--para 1-1g

1-2a. c--para 1-2a

1-2b. b--para 1-2a(2)

1-2c. a--para 1-2a(3)

1-2d. c--para 1-2a(3), b, c; fig 1-3

1-2e. c--para 1-2e

1-3a. d--para 1-3g

An ISB radio circuit can carry four 3-kHz channels. Each 3-kHz channel can accommodate 1 telephone, 1 facsimile, or 16 teletypewriter channels.

1-3b. a--para 1-3b(3)

1-3c. d--para 1-3c

1-3d. b--para 1-3c

1-3e. c--para 1-3f, 1-4e

1-3f. d--para 1-3g

1-3g. a--para 1-3h(2)

1-4a. c--para 1-4d(2)

1-7a. a--para 1-7b

In an AM system, the transmitted signals are the carrier and the sum and difference frequencies of the carrier and modulating signal. Therefore, the transmitted frequencies are the carrier, which is 800 kHz, the sum of the carrier and modulating signal, 800 + 4 = 804 kHz, and the difference between the carrier and modulating signal, 800 - 4 = 796 kHz.

1-7b. d--para 1-7c

The upper sideband consists of frequencies ranging from 800 + 0.3 = 800.3 kHz, to 800 + 3.5 kHz. The lower sideband consists of frequencies ranging from 800 - 3.5 = 796.5, to 800 - 0.3 = 799.7 kHz. Therefore, the total bandwidth of the transmitted signal is 803.5 - 796.5 = 7 kHz, or 7,000 Hz.

1-7c. b--para 1-7c

The bandwidth is the same whether the upper or lower sideband frequencies are transmitted. Therefore, using the upper sideband frequencies, the bandwidth of the eliminated carrier SSB signal is 803.5 - 800.3 = 3.2 kHz, or 3,200 Hz.

1-7d. d--para 1-7d

The DSB transmitter must have 30 watts in each sideband, or a total sideband power of 60 watts, to provide an equivalent signal. In addition, the carrier, which is twice the total sideband power, would be 2 x 60 = 120 watts. Therefore, the total power applied to the antenna from an equivalent DSB transmitter is 60 + 120 = 180 watts.

1-9a. d--para 1-9

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio Systems

LESSON 2 ....Communications Circuit Quality

All references are to the attached memorandum.

1. c--para 2-2a
2. c--para 2-2b
3. b--para 2-3d
4. b--para 2-3g
5. c--para 2-4a(2)
6. a--para 2-4b, b(2)(d)
7. d--para 2-4b(4)(b)
8. b--para 2-4c(1), d

The human ear is unable to select either signal or noise from the total sound. It is therefore impossible for the ear to determine the S/N.

9. b--para 2-4e
10. b--para 2-5
11. c--para 2-5b
12. b--para 2-6c
13. d--para 2-7
14. a--para 2-8b
15. d--para 2-8b
16. d--para 2-9
17. c--para 10a
18. a--para 2-11b, c
19. b--para 2-11c, d, e
20. a--para 2-12a

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio Systems

LESSON 3 ....Transmitting Equipment

All references are to the attached memorandum.

3-1a. c--para 3-1a
3-1b. b--para 3-1c
3-2a. d--para 3-2c
3-3a. b--para 3-3a
3-5a. c--para 3-5b
3-6a. d--para 3-6c
3-6b. b--para 3-6c
3-7a. d--para 3-7a
3-8a. c--para 3-8a, b, c
3-10a. d--para 3-10
3-10b. d--para 3-10
3-11a. c--para 3-11
3-13a. d--para 3-13 through 3-17
3-13b. c--para 3-13c
3-14a. d--para 3-14b
3-15a. d--para 3-15a
3-16a. c--para 3-16a
3-17a. b--para 3-17a
3-18a. b--para 3-18c

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio

LESSON 4 ....Receiving Equipment

All references are to the attached memorandum.

4-1a. a--para 4-1a

4-1b. d--para 4-1c

4-2a. c--para 4-1c

4-3a. d--para 4-3a

4-4a. c--para 4-4b

4-4b. b--para 4-4c

4-5a. c--para 4-5b

4-6a. d--para 4-6a

4-7a. c--para 4-7b

4-8a. b--para 4-8a

4-8b. c--para 4-8d

4-9a. b--para 4-9b

4-13a. a--para 4-13

4-14a. d--para 4-10a, 4-14

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio Systems

LESSON 5 ....Antenna Systems

All references are to the Attached Memorandum.

5-2a. d--para 5-2b(4)

5-3a. b--para 5-3e

5-3b. b--para 5-3g(2)

5-6a. c--para 5-6b

5-6b. a--para 5-4, 5-6a

5-7a. d--para 5-7

5-8a. c--para 5-8a

5-9a. c--para 5-9b

5-9b. c--para 5-9d

The chart of standard rhombic antennas shows that the type D antenna is selected to cover distances of 1,610 to 2,400 km (1,000 to 1,500 miles). At each station of the two-way radio circuit, one antenna is used for transmitting and two for receiving, because space diversity is specified.

5-10a. d--para 5-10c

5-10b. b--para 5-10e, fig 5-11

The power ratio of 16 to 2 microwatts is equivalent to a power ratio of 8 to 1. This power ratio is equivalent to 9 dB on the scale in figure 5-11.

5-11a. a--para 5-11c

5-11b. c--fig 5-11 13 dB = 10 dB + 3 dB = (10) (2.0) = 20 times apparent increase in power.

5-12a. d--para 5-12

5-12b. a--para 5-12a, b

5-12c. d--para 5-12b

Two 500-watt resistors will dissipate a total power of 1 kW, which is 50 percent of the transmitter output. The ground connection is made at their electrical center for balance. Noninductive resistors must be used.

5-13a. a--para 5-13e

5-13b. a--para 5-13b

5-14a. b--para 5-14a(2)

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio Systems

LESSON 6 ....Mobile Radio Stations

All references are to the Attached Memorandum.

6-1a. d--para 6-1

6-2a. a--para 6-2b

6-2b. d--para 6-2a(3); fig 6-1

6-4a. c--para 6-4a

6-4b. b--para 6-4a

6-4c. a--para 6-4a

6-5a. a--para 6-5c

6-5b. b--para 6-5c

6-6a. b--para 6-6c

6-6b. d--para 6-6c(1)

6-6c. c--para 6-6c(1)

6-6d. c--para 6-6d(4)

EXTENSION COURSE OF THE US ARMY SIGNAL SCHOOL

LESSON SOLUTIONS

SIGNAL SUBCOURSE 750 ....High-Frequency Fixed-Station Radio Systems

LESSON 7 ....Frequency Planning

All references are to the Attached Memorandum.

7-1a. b--para 7-1a

7-2a. d--para 7-2b(1)

7-2b. a--para 7-2b(2)

7-2c. c--para 7-2d

At least three frequencies will normally be assigned to every long-distance radio station for each direction of transmission. Additional frequencies may be assigned to accommodate greater traffic loads and to change frequencies in case of interference. However, the basic need for three frequencies is to provide one frequency for daytime operation, one for nighttime operation, and one to cover transitional periods.

7-2d. a--para 7-2f

7-3a. a--para 7-3a

7-5a. b--para 7-5c

7-5b. a--para 7-5c, d

The short-term propagation forecast refers to conditions of reception during the 6 hours or more after the forecast is issued. Since the digit of the letter-digit combination is 2, the indication is that the propagation condition on the San Francisco-Anchorage radio circuit will probably become very poor, decreasing from normal, starting 6 hours after the report time. Therefore, poor conditions can be expected at approximately 1900. The tape relay operator should therefore make every effort to move the message traffic over the radio circuit before 1900.

7-7a. b--para 7-7a

7-7b. b--para 7-7a(2), 3-15b

The maximum power output of Radio Transmitting Set AN/FRT-52A is listed at 5,000 watts for CW (AL emission). The chart in paragraph 7-7a(2) shows that the frequency tolerance for a radio signal having over 500 watts of power at 17,000 kHz (A1 MHz) is 0.003 of 1 percent. The minimum and maximum permissible frequencies are found as follows:

$$17{,}000 \text{ kHz} \times 0.003 \text{ percent} = 17{,}000 \text{ kHz} \times 3 \times 10^{-5}$$

$$= 0.51 \text{ kHz}$$

$$17{,}000 \text{ kHz} \pm 0.51 \text{ kHz} = 16{,}999.49 \text{ and } 17{,}000.51 \text{ kHz}$$

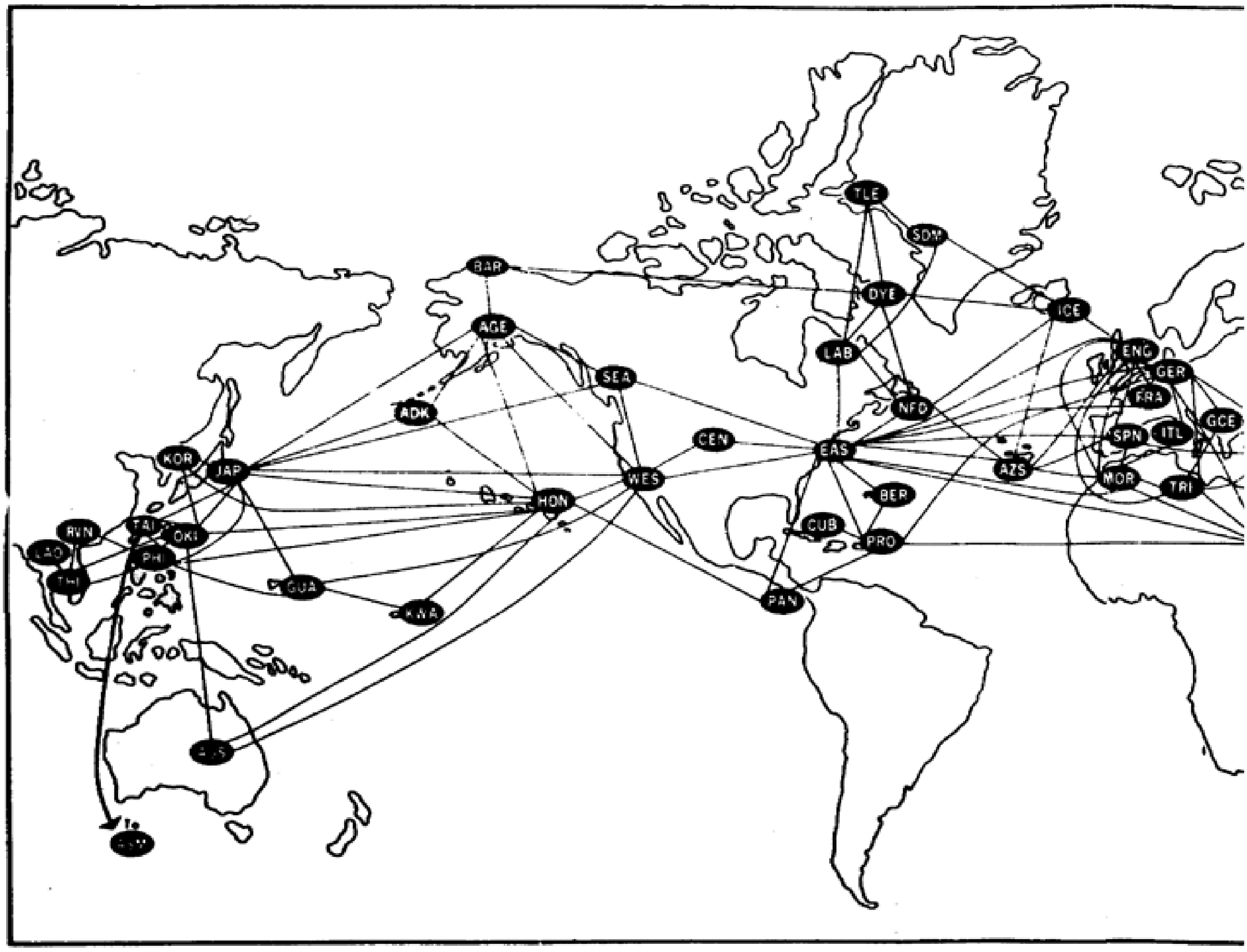
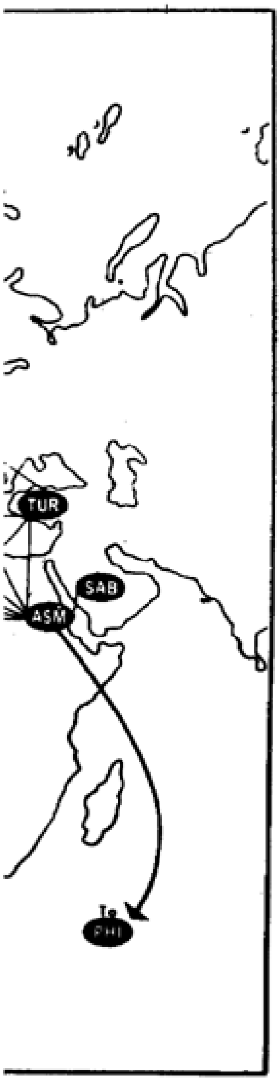


Figure 1-1. The Defense Communications System Complex.



LOCATION LEGEND

LEGEND	LOCATION	LEGEND	LOCATION	LEGEND	LOCATION
ADK	ADAK ISLAND	GUA	GUAM	PHI	PHILIPPINES
AGE	ANCHORAGE, ALASKA	HON	HONOLULU, HAWAII	PRO	PUERTO RICO
ASM	ASMARA, ERITREA	ICE	ICELAND	SAB	SAUDI ARABIA
AUS	AUSTRALIA	ITL	ITALY	SDM	SONDRESTROM, GREENLAND
AZS	AZORES	JAP	JAPAN	SEA	SEATTLE WASH.
BAR	PT. BARROW, ALASKA	KOR	KOREA	SPN	SPAIN
BER	BERMUDA	KWA	KWAJALEIN ISLAND	TAI	TAIWAN
CEN	CENTRAL U.S.	LAB	LABRADOR	THI	THAILAND
CUB	CUBA	LAO	LAOS	TLE	THULE, GREENLAND
DYE	CAPE DYER, BAFFIN ISLAND, CANADA	MOR	MOROCCO, AFRICA	TRI	TRIPOLI
EAS	EASTERN U.S.	NFD	NEWFOUNDLAND	TUR	TURKEY
ENG	ENGLAND	OKI	OKINAWA ISLAND		
FRA	FRANCE			RVN	VIETNAM
GCE	GREECE	PAN	PANAMA (SOUTHERN)	WES	WESTERN U.S.
GER	GERMANY				

Figure 1-1. The Defense Communications System Complex (continued).