CHAPTER 5

COMMUNICATIONS THEORY AND EQUIPMENT

The word "radio" can be defined briefly as the transmission of signals through space by means of electromagnetic waves. Usually the term is used when referring to the transmission of intelligence code and sound signals, although television and radar also depend on electromagnetic waves.

Radio equipment can be divided into three broad categories: transmitting equipment, receiving equipment, and terminal equipment. The transmitting equipment provides a means for generation, amplification, and modulation of the transmitted signal. The receiving equipment provides a means for receiving a radio wave and converting it into the modulation signal (i.e., some form of the original intelligence). The terminal equipment converts the modulation into the original intelligence. Terminal equipment is used primarily where coded transmissions are employed to convert the modulated signal into the original intelligence.

A basic radio communication system may consist of only a transmitter and a receiver, which are connected by the medium through which the electromagnetic waves travel (fig. 5-1). The transmitter consists of an oscillator (which generates a basic radio frequency), radio frequency (rf) amplifiers, and the stages (if any) required to place the audio intelligence on the rf signal (modulator).

The electromagnetic variations are propagated through the medium (space) from the transmitting antenna to the receiving antenna.

The receiving antenna converts that portion of the transmitted electromagnetic energy received by the antenna into a flow of alternating radio frequency currents. The receiver converts these current changes into the intelligence that is contained in the transmission during voice communications or provides these current changes to terminal equipment, such as teletype or facsimile, for conversion to original intelligence. A detailed discussion of teletype and facsimile equipment is found in Chapter Six.

The portion of the overall frequency spectrum used for communications is shown in figure 5-2. The frequency bands in the lower end of the spectrum are defined in Table 5-1. These are the frequencies used for communications at the present time. A few of the general characteristics are described in the following paragraphs.

The vlf and lf bands require great power and long antennas for efficient transmission; therefore, the Navy normally uses these bands for transmissions emanating from shore. (The antenna length varies inversely with the frequency.)

Because the commercial broadcast band extends from about 550 kHz to 1700 kHz, only the

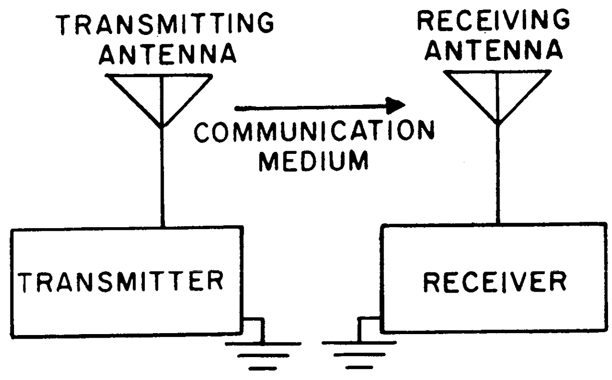

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Figure 5-1.—Basic radio communication system.

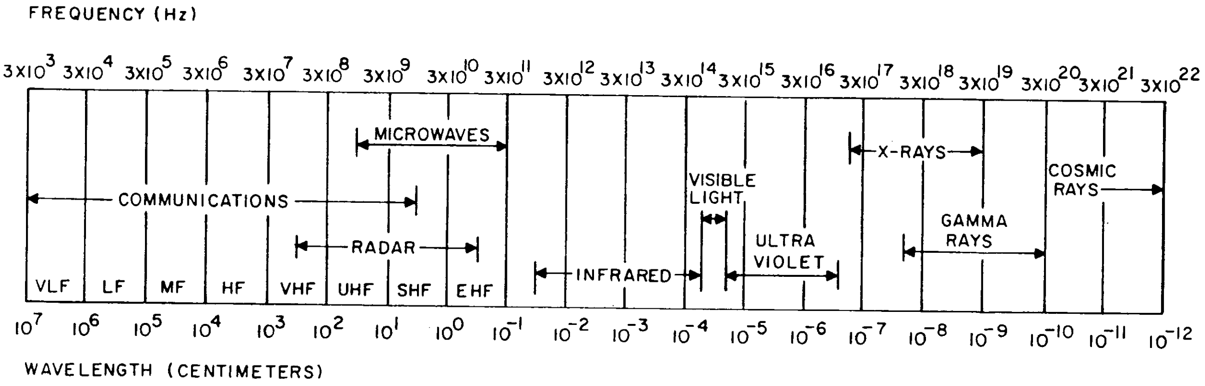

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Figure 5-2.—Frequency spectrum.

Table 5-1.—Frequency bands

ABBREVIATIONS	FREQUENCY BAND	APPLICATION
VLF	VERY LOW FREQUENCY	SHORE BASED COMMUNICATIONS, EXPERIMENTAL
LF	LOW FREQUENCY	SHORE BASED COMMUNICATIONS, NAVIGATION
MF	MEDIUM FREQUENCY	COMMERCIAL BROADCAST BAND, 550 kHz TO 1700 kHz. COMMUNICATIONS ON EITHER SIDE OF BROADCAST BAND.
HF	HIGH FREQUENCY	SHIP AND SHORE LONG RANGE COMMUNICATIONS.
VHF	VERY HIGH FREQUENCY	COMMUNICATIONS, NAVIGATION
UHF	ULTRA HIGH FREQUENCY	LINE OF SIGHT COMMUNICATIONS TO 400 MHz. ABOVE THIS FREQUENCY, RADAR AND SPECIAL EQUIPMENTS.
SHF	SUPER HIGH FREQUENCY	RADAR AND SPECIAL EQUIPMENTS
EHF	EXTREMELY HIGH FREQUENCY	RADAR AND SPECIAL EQUIPMENTS.

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upper and lower ends of the mf band have naval use.

As most long-range shipboard radio communications are conducted in the hf band, a large percentage of shipboard transmitters and receivers are designed to operate in this band.

A large portion of the lower end of the vhf band is assigned to the commercial television industry and is used by the Navy in amphibious operations and in special instances. The upper portion of vhf band (225 MHz to 300 MHz) and the lower portion of uhf band (300 MHz to 400 MHz) are used extensively by the Navy for short range and aircraft communications. The frequencies above 400 MHz in the uhf band through the shf and ehf bands are normally used for radar and special equipment.

CONTINUOUS WAVE

Continuous wave (cw) is one of the oldest and least complicated forms of radio communications. The system consists of little more than a transmitter and a receiver connected to facilitate their control from a central location.

CW TRANSMITTER

The cw transmitter is turned on and off (keyed) to produce long or short radio frequency (rf) pulses which correspond to the dots and dashes of the Morse Code characters. The transmitter (fig. 5-3) has four essential components: (1) a generator of rf oscillations, (2) a means of amplifying and, if necessary, multiplying the frequencies of these oscillations, (3) a method of keying the rf output in accordance with the code to be transmitted, and (4) a power supply to provide the operating voltage to the various electron tubes and transistors. Although not physically a part of the transmitter, an antenna is required to radiate the keyed output radio wave of the transmitter.

MODULATION

The cw transmitter must be manually turned on and off at specified intervals to produce Morse code keying. This method of transmitting intelligence is very slow and inefficient by present-day standards; therefore, the Navy relies on modulation of the carrier frequency (rf output of the transmitter) for communications.

Modulation is the process of varying some characteristic of a periodic wave with an external signal. The voice frequencies (about 15-3,000 Hz) are contained in the audio frequency spectrum 15-20,000 Hz. In naval communications, the terms "voice communications" and "audio communications" are sometimes used interchangeably. The audio signal is impressed upon the radio frequency carrier because it is impractical to transmit frequencies in the audio range. This is due in part to the excessive wavelength. As you can see in figure 5-2, the wavelength at 3000 Hz is 10,000,000 cm. The physical size of circuit components at these frequencies is too large to be practical.

There are three characteristics of the carrier wave that may be varied at an external signal rate: amplitude, frequency, and phase.

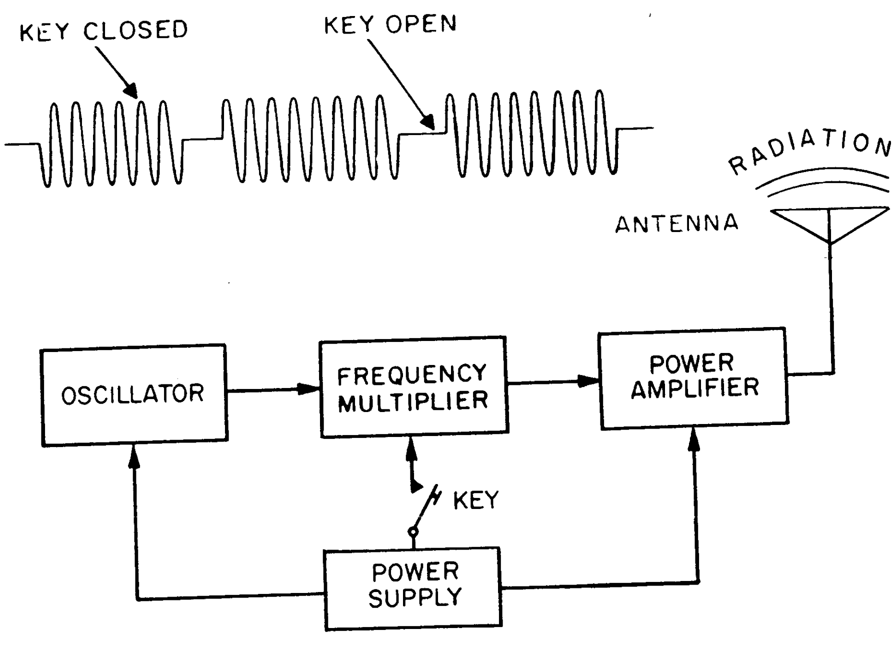

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Figure 5-3.—Continuous-wave transmitter.

AMPLITUDE MODULATION

Amplitude modulation (AM) is the process of combining audio frequency and radio frequency signals in a manner which causes the amplitude of the radio frequency waves to vary at an audio frequency rate. This process can be accomplished by removing the key and modifying the continuous-wave transmitter (fig. 5-3) so that the audio output from a microphone (and necessary amplifiers) is impressed on the carrier frequency. The required changes are incorporated in the block diagram of a basic AM radiotelephone transmitter, as shown in figure 5-4. The top row of blocks produces and amplifies the rf carrier frequency; the lower row produces and amplifies the audio frequency. The speech amplifier, driver, and modulator stages provide the voltage and power amplification required in the modulation process.

Assume that the modulating audio signal is of constant frequency (e.g., 1 kHz tone). The audio voltage is fed into the rf power amplifier stage so that it alternately adds to and subtracts from the d.c. plate supply voltage in the amplifier. An increase in voltage in the power amplifier increases the rf power output. Conversely, a decrease in voltage decreases the rf power. The presence of the audio voltage in series with the supply voltage causes the overall amplitude of the rf signal to increase gradually during the time of audio voltage increase (from 1 to 2 on the waveforms of figure 5-4). A decrease in rf signal amplitude also occurs during the time the audio output is decreasing (from 2 to 3 on the waveforms of figure 5-4). These rf signal amplitude changes in turn govern the instantaneous levels of the electromagnetic field radiated from the antenna.

Variations in rf power output similar to the compression and rarefaction of sound occur throughout each audio cycle. The waveform at the antenna thus contains three major frequencies: (1) the carrier frequency, (2) the carrier frequency plus the audio frequency (sum frequency), and (3) the carrier frequency

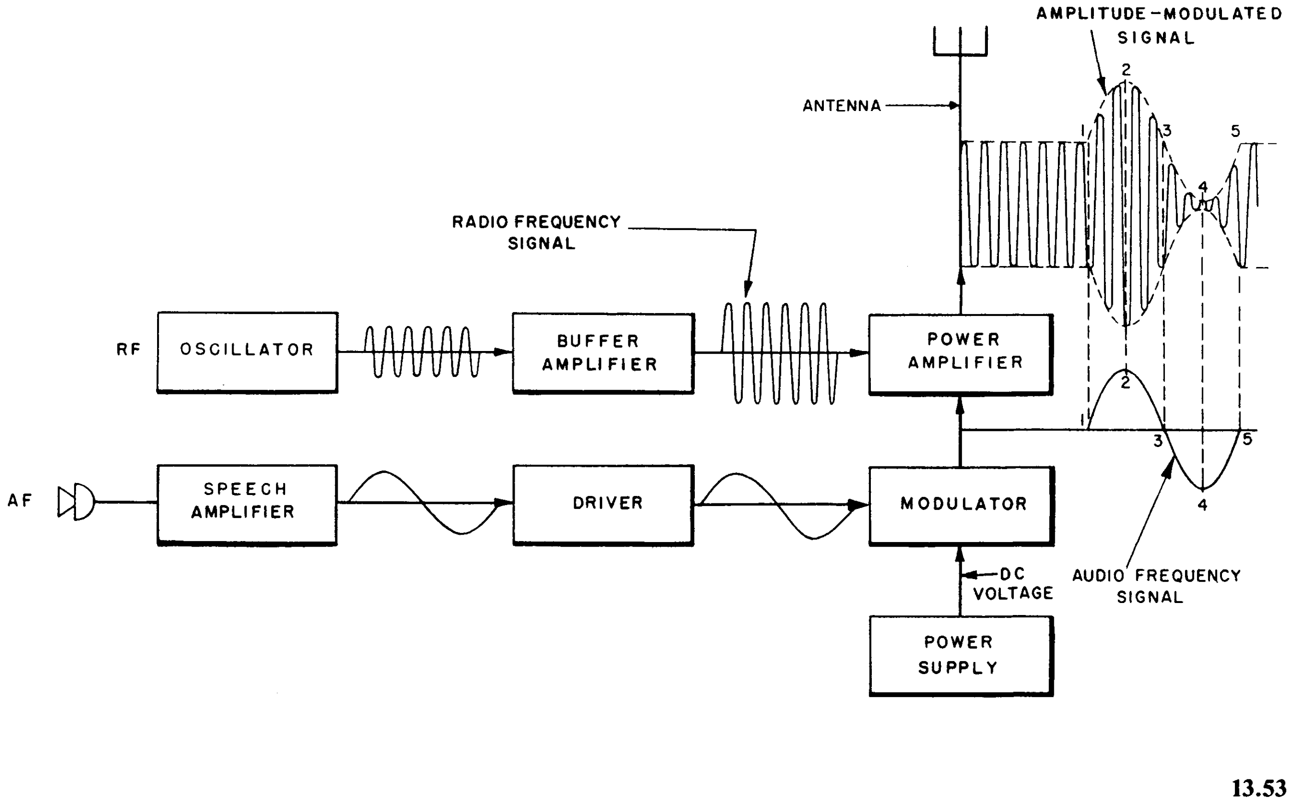

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Figure 5-4.—An AM radiotelephone transmitter.

minus the audio frequency (difference frequency). The sum frequency is called the upper sideband; the difference frequency, the lower sideband. The sideband frequencies are always related to the carrier frequency by the sum and difference of the modulation frequency.

The relationship of the carrier, audio, and sideband frequencies is illustrated in figure 5-5. Assume that the carrier frequency is 1000 kHz and that the audio-modulating frequency is a single 1-kHz tone. Then each of the sidebands is displaced 1000 hertz from the carrier frequency. The lower sideband is 1,000,000 hertz − 1000 hertz = 999,000 hertz (or 999 kHz). The upper sideband is 1,000,000 hertz + 1000 hertz = 1,001,000 Hz (or 1001 kHz).

Note that the amplitude of each of the three frequencies is constant when considered alone. But because these frequencies appear simultaneously at the output, they add to form one composite envelope (signal). This envelope is in the shape of the output waveform shown in figure 5-4.

During modulation, the peak voltages and currents on the rf power amplifier stage are greater than values that occur when the stage is not modulated. To prevent damage to the equipment, a transmitter, designed to transmit both cw and radiotelephone signals, is provided with controls that reduce the power output for radiotelephone operation.

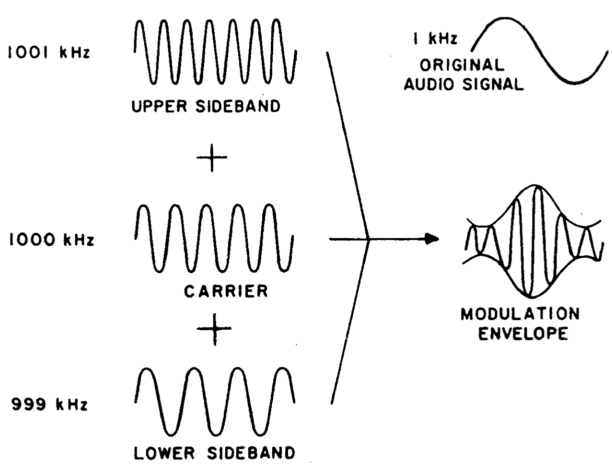

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Figure 5-5.—Formation of the modulation envelope.

FREQUENCY AND PHASE MODULATION

Frequency modulation (FM) is the process of combining audio and carrier signals in a manner which causes the frequency of the carrier waves to vary at an audio rate while the amplitude of the carrier waves remains essentially constant. The carrier frequency can be varied a small amount on either side of its average or assigned frequency by means of the audio frequency (af) modulating signal.

The relationship between the audio modulating signal and the FM signal is shown in figure 5-6. The horizontal axis represents a linear time base, and the vertical axis represents relative amplitude. During T_0 in figure 5-6A, there is no audio modulation and the FM signal is at the carrier or rest frequency. As the audio modulating signal goes in the positive direction during T_1 , it causes a change in the FM signal. The amplitude of the audio modulating signal determines the amount of change (increase) in the frequency of the FM signal. The greater the audio signal amplitude (i.e., the louder the sound in voice modulation), the greater the increase in frequency of the FM signal. To show this, the audio signal in figure 5-6A, is increased in amplitude to form the audio signal shown in figure 5-6B. A comparison of the FM signals in figures 5-6A and 5-6B shows a discernable change in frequency of the FM signal.

During T_2 in figure 5-6A, the audio signal passes through zero amplitude, and the FM signal returns to the carrier frequency (rest frequency). At T_3 the audio signal swings in the negative direction, causing a change (decrease) in the FM carrier frequency. Again the amplitude of the audio signal determines the amount of change in the FM signal frequency (i.e., the louder the sound in voice modulation, the greater the change in frequency of the FM signal).

In figure 5-6, this relationship is shown with a time base reference. Since time is inversely proportional to frequency ($T = \frac{1}{f}$); time for a complete cycle is decreased as frequency is increased. For example, at T_0 in figure 5-6A, the FM signal is at the carrier frequency and the time for a complete cycle (point A to point B) is a certain

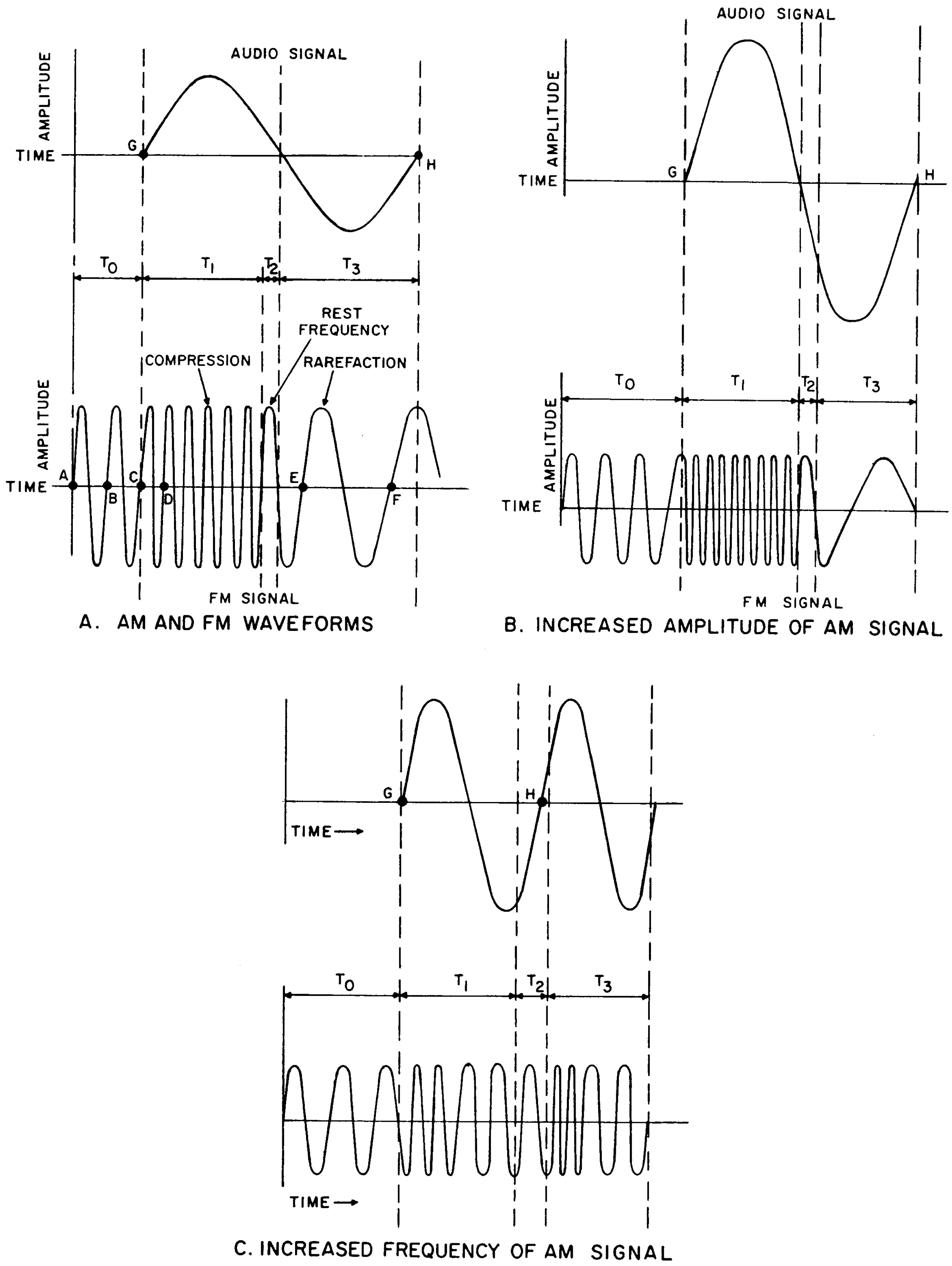

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Figure 5-6.—FM waveform compared to an audio modulating signal.

amount of time. During T_1 the amplitude of the audio signal increases, causing the frequency of the FM signal to increase and the time (point C to point D) of a complete cycle to decrease when compared to time AB. At time T_3 the amplitude of the audio signal is decreased, causing the frequency of the FM signal to decrease and the time for a complete cycle (point E to point F) to increase when compared to time AB. In other words, the FM signal is compressed during T_1 and rarefied during T_3.

The time required for a complete audio cycle is represented by points G and H along the time axis in figure 5-6B. When the frequency of the audio signal is doubled, as shown by points G and H along the time axis of figure 5-6C, a comparison of the modulated signals of figures 5-6B and 5-6C shows that the shift from compression to rarefaction is correspondingly reduced in time. As a result, the rate at which variations in the assigned carrier (or resting) frequency occur, has increased.

It may now be stated that the amount of variation from the carrier frequency depends on the magnitude of the modulating signal, and the rate of variations in carrier frequency depends on the frequency of the modulating signal.

Frequency modulation and phase modulation (PM) are essentially the same. The difference lies in the physical method of accomplishing the frequency shift in the transmitter. Both FM and PM can be received on FM receivers, and both are commonly referred to as FM.

A block diagram of a representative FM transmitter, in which frequency modulation is accomplished by a phase-shift system, is shown in figure 5-7. The transmitter oscillator is maintained at a constant frequency by means of a quartz crystal. This constant-frequency signal passes through an amplifier that increases the amplitude of the rf subcarrier. The audio signal is applied to this carrier phase-shift network in such a manner that it causes the frequency of the carrier to shift according to the variations of the audio signal. The FM output of the phase-shift network is fed into a series of frequency multipliers that raise the signal to the desired output frequency. Then the signal is amplified in the power amplifier and coupled to the antenna for radiation.

RECEIVERS

An AM receiver processes amplitude modulated signals received by its antenna, and delivers as an output a reproduction of the

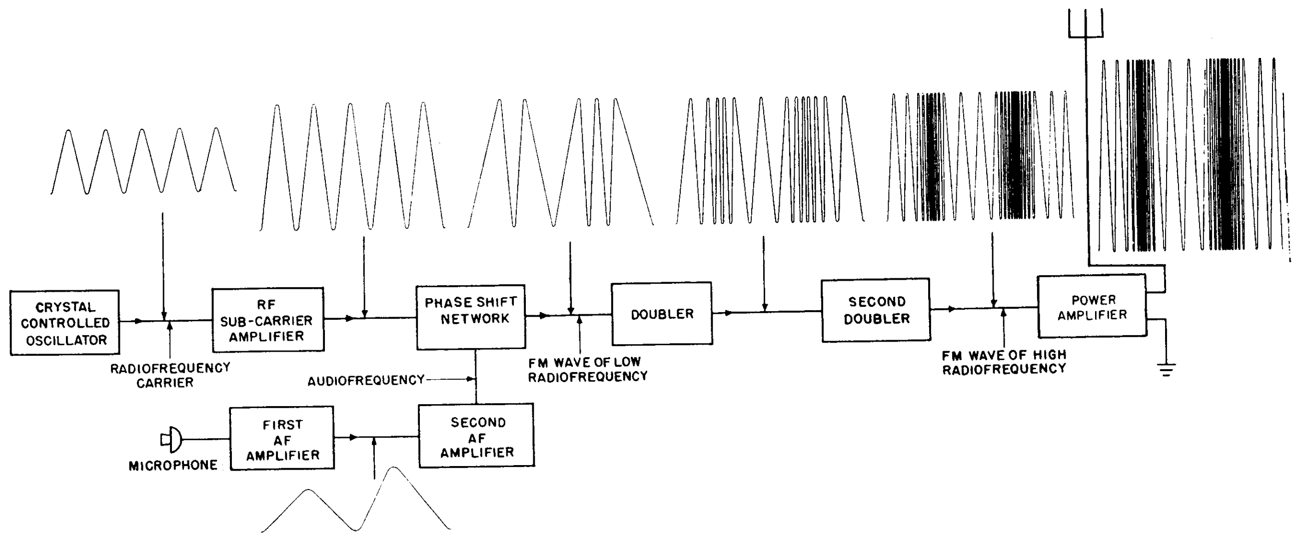

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Figure 5-7.—Block diagram of an FM transmitter and waveforms.

original signal that modulated the rf carrier at the transmitter. The signal can then be applied to some reproducing device such as a loudspeaker, or a terminal device such as a teletypewriter. Actual AM receivers vary widely in complexity. Some are very simple; others contain a relatively large number of complex circuits.

Whatever its degree of sophistication, a receiver must perform certain basic functions in order to be useful. These functions, in order of their performance, are: reception, selection, detection, and reproduction.

RECEPTION—Reception occurs when a transmitted electromagnetic wave passes through the receiver antenna in such a manner as to induce a voltage in the antenna.

SELECTION—Selection is the ability to select a particular station's frequency from all other station frequencies appearing at the receiver's antenna.

DETECTION—Detection is the action of separating the low (audio) frequency intelligence from the high (radio) frequency carrier and is accomplished in a detector circuit.

REPRODUCTION—Reproduction is the action of converting the electrical signals to sound waves which can then be interpreted by the ear as speech, music, and the like.

RECEIVER CHARACTERISTICS

Receiver characteristic measurements are useful in determining operational conditions and as an aid for comparison to other units. Important receiver characteristics are sensitivity, noise, selectivity, and fidelity.

Sensitivity

The ability of a receiver to reproduce very weak signals is a function of the receiver's sensitivity. The weaker a signal can be applied to a receiver and still produce a certain value of signal output, the better that receiver's sensitivity rating. Sensitivity of a receiver is measured under standardized conditions and is expressed in terms of the signal voltage, usually in the microvolts that must be applied to the antenna input terminals to give an established level of the output. The output may be an a.c. or d.c. voltage measured at the detector output, or a power measurement at the loudspeaker or headphone terminals.

Noise

All receivers generate a certain amount of noise which must be taken into account. Noise is a limiting factor on the minimum usable signal that the receiver can process and still deliver a usable output. Therefore, the measurement is made by determining the amplitude of the signal at the receiver input required to give a signal-plus-noise output at a predetermined ratio above the static noise output of the receiver.

Selectivity

Selectivity is the degree of distinction made by the receiver between the desired signal and unwanted signals. The better the receiver's ability to exclude unwanted signals, the better its selectivity. The degree of selection is determined by the sharpness of resonance to which the frequency-determining circuits have been engineered and tuned. Measurement of selectivity is usually by a series of sensitivity readings in which the input signal is stepped along a band of frequencies above and below resonance of the receiver's circuit (e.g., 100 kHz below to 100 kHz above tuned frequency). As the frequency to which the receiver is tuned is approached, the input level required to maintain a given output level will fall. As the tuned frequency is passed, the required input level will rise. Input voltage levels are then plotted against frequency. The steepness of the curve at the tuned frequency indicates the selectivity of the receiver.

Fidelity

The fidelity of a receiver is its ability to accurately reproduce, in its output, the signal that appears at its input. In general, the broader the band passed by frequency selection circuits, the greater the fidelity. It may be measured by modulating an input frequency with a series of audio frequencies; then plotting the output measurements at each step against the audio input frequencies. The resulting curve will show the limits of reproduction.

It may be remembered that good SELECTIVITY requires that a receiver pass a narrow frequency band. Good FIDELITY, on the other hand, requires that the receiver pass a broader band in order to amplify the outermost frequencies of the sidebands. Therefore, receivers in general use are a compromise between good selectivity and high fidelity.

SUPERHETERODYNE (AM) RECEIVER

The superheterodyne receiver was developed to overcome the disadvantages of earlier types of receivers. The essential difference is in the amplifier stages preceding the detector (fig. 5-8). The IF amplifier in the superheterodyne receiver is pre-tuned to one fixed frequency, called the intermediate frequency (IF). The rf amplifier and local oscillator are variable frequency dependent upon the selected frequency.

The intermediate frequency is obtained through the principle of frequency conversion by heterodyning a signal generated in a local oscillator of the receiver with the incoming signal in a mixer stage. Thus, an incoming signal is converted to the fixed intermediate frequency, and the IF amplifier operates with uniform selectivity and sensitivity over the entire tuning range of the receiver.

A block diagram of a representative superheterodyne receiver is shown in figure 5-8. A superheterodyne receiver may have more than one frequency-converting stage and as many amplifiers as needed to obtain the desired power output. (The additional amplifiers are not shown in the figure.)

Heterodyning

The intermediate frequency is developed by a process called heterodyning. This action takes place in the mixer stage (sometimes called a converter or first detector). Heterodyning may be described as the combining of the incoming signal with the local oscillator signal. This action

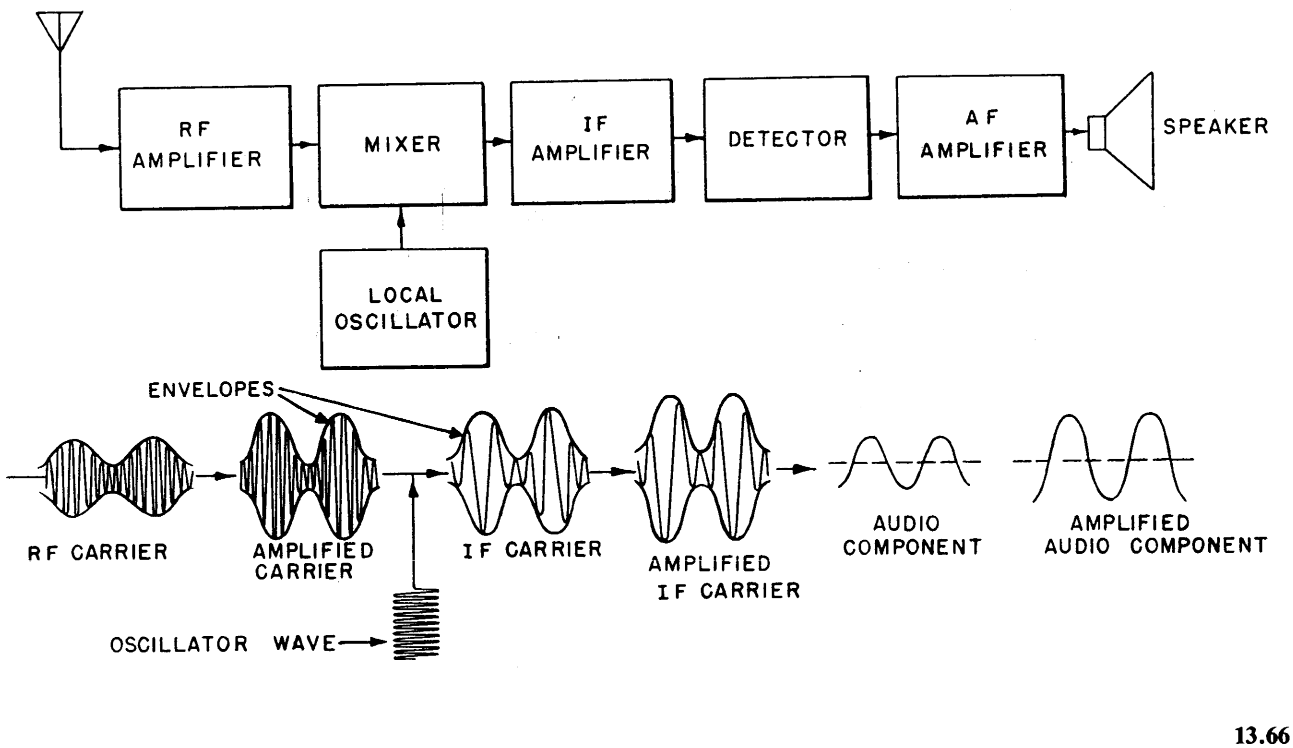

Figure 5-8.—AM superheterodyne receiver and waveforms.

alters the input signal from its rf carrier frequency to an intermediate frequency (IF) which is more suitable for purposes of extracting intelligence from the transmitted signal. The local oscillator signal is of a constant amplitude and does not alter that intelligence.

The local oscillator is set to track with the tuning of the incoming signal so that it produces a frequency higher or lower than the frequency of the incoming signal by the exact amount of the fixed IF frequency. By heterodyning the incoming signal and locally produced signal in the mixer stage, four frequencies appear at the mixer output. They are (1) the incoming rf signal, (2) the local oscillator signal, (3) the sum of the incoming rf signal and the local oscillator signal, (4) the difference in these frequencies. Although the sum frequency is present, it is the difference frequency to which the IF amplifier is tuned. A typical intermediate frequency for AM communication receivers is 455 kHz.

Detection

Once the IF stages have amplified the intermediate frequency to a sufficient level, it is fed to the detector (or second detector, if referring to the mixer as first detector) to extract the modulating audio signal. The detector stage consists of a rectifying device and filter which respond only to the amplitude variations of the IF signal to develop an output voltage varying at an audio frequency rate. The output from the detector is further amplified in the audio amplifier and used to drive a speaker or earphones.

SUPERHETERODYNE (FM) RECEIVER

The function of a frequency modulated (FM) receiver is the same as the AM superheterodyne receiver. There are certain important differences in component construction and circuit design because of differences in the modulating technique. The comparison of block diagrams (figures 5-8 and 5-9) shows that in both AM and FM receivers the amplitude of the incoming signal is increased in the rf stages. The mixer combines the incoming rf with the local oscillator rf signals to produce the intermediate frequency, which is then amplified by one or more IF amplifier stages. Note that the FM

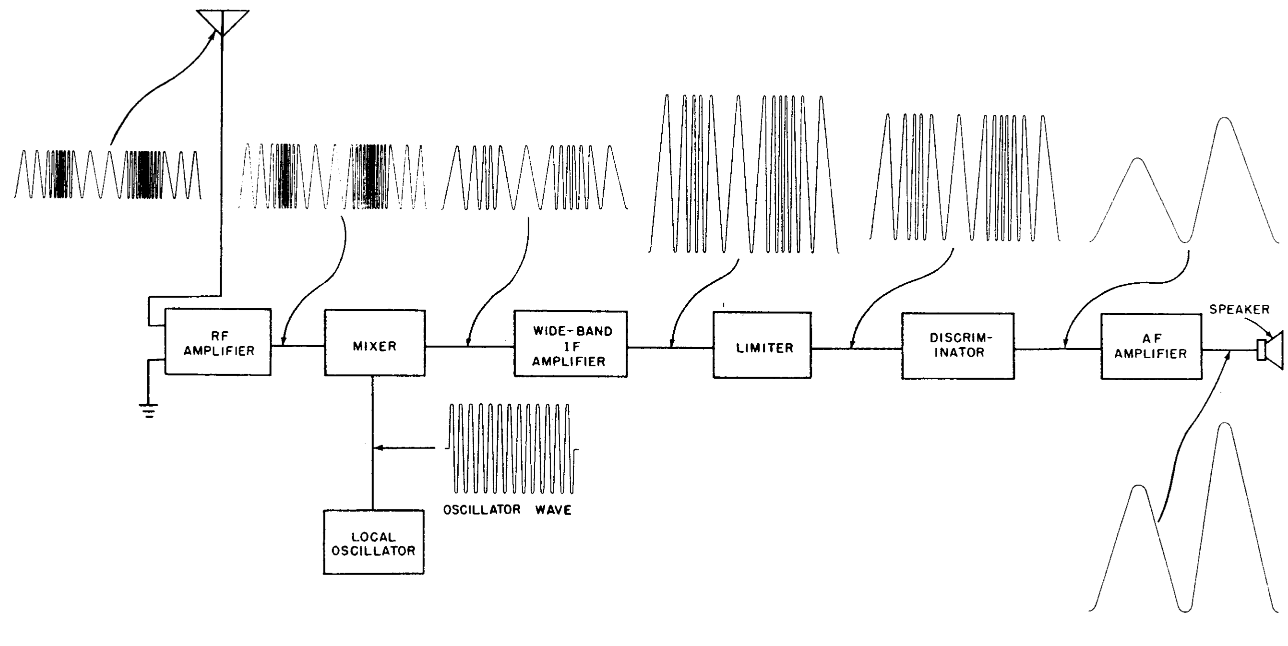

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Figure 5-9.—Block diagram of an FM receiver and waveforms.

receiver has a wide-band IF amplifier. Since the band-width for any type of modulation must be wide enough to receive and pass all the side-frequency components of the modulated signal without distortion, the IF amplifier in an FM receiver must have a broader passband than an AM receiver.

Sidebands created by FM and phase-modulated (PM) systems differ from the AM system. They occur at integral multiples of the modulating frequency on either side of the carrier wave. Recall that the AM system consists of a single set of side frequencies for each radio frequency signal that is modulated. An FM or phase-modulated signal inherently occupies a wider band than AM, and the number of these extra sidebands that occur in FM transmission is related to the amplitude and frequency of the audio signal.

Beyond the IF stage there is a marked difference between the two receivers (figures 5-8 and 5-9). While AM demodulation involves the detection of variations in the amplitude of the signal, FM demodulation is the process of detecting variations in the frequency of the signal. In FM receivers, a "discriminator" is designed to respond to frequency shift variations. A discriminator is preceded by a limiter, which limits all signals to the same amplitude level to minimize noise interference. The audio frequency component is then extracted by the discriminator, amplified in the AF amplifier and used to drive the speaker.

Electrically, there are only two fundamental sections of the FM receiver which are different from the AM receiver: the discriminator (detector) and the accompanying limiter.

Some Advantages of FM Receivers

In normal reception, FM signals are totally absent of static while AM signals are subject to cracking noises and whistles. FM followed AM in development and had the advantage of operating at the higher frequency where there is a greater amount of spectrum. FM signals provide a much more realistic reproduction of sound because of an increased number of sidebands.

The major disadvantage of FM is the wide bandpass required to transmit the FM signals. Each station must be assigned a wide band in the frequency spectrum. During FM transmissions, the number of significant sidebands which must be transmitted in order to obtain the desired fidelity is equal to the deviation (change in carrier frequency) divided by the highest audio frequency to be used. Thus, if the deviation is 40 kHz and the highest audio frequency is 10 kHz, the number of significant sidebands is

$$\frac{40 \text{ kHZ}}{10 \text{ kHZ}} = 4$$

This number of sidebands exists on both sides of the rest frequency; therefore, there are eight significant sidebands. Because the audio frequency is 10 kHZ, and there are eight sidebands, band-width must accommodate an 80 kHz signal. This is considerably wider than the 10- to 15-kHz bandpass for AM transmitting stations.

Frequency Conversion

Frequency conversion is accomplished by employing the heterodyne principle of beating two frequencies together to get an intermediate frequency. So far only single conversion has been discussed, however some receivers use double or triple conversion, sometimes referred to as double or triple heterodyning. These receivers are most selective since they suppress image signals in order to yield sharp signal discrimination. (The image frequency is an undesired modulated carrier frequency that differs from the frequency to which a superheterodyne receiver is tuned by twice the intermediate frequency.) Double and triple conversion receivers also have better adjacent channel selectivity than can be realized in single conversion sets.

It should be noted that the sacrifice of fidelity to gain improved selectivity is permissible in communications receivers, since intelligence (voice, teletypewriter) can be carried on a fairly narrow band of frequencies. Entertainment receivers, on the other hand, must reproduce a wider band of frequencies to include the musical subtlety of a variety of instruments and arrangements.

SINGLE-SIDEBAND COMMUNICATIONS

The intelligence of an AM signal is contained in the sidebands, and for normal operation the information in both sidebands is the same. It is possible to transmit only one sideband, eliminating the carrier and other sideband, and still retain the information transmitted. This method of transmission is called single side band (ssb).

Figure 5-10 illustrates the transmitted signal for both AM and ssb. There are several advantages to ssb communications. By eliminating the carrier and one sideband, all of the transmitted power can be concentrated into a single sideband. Also, an ssb signal occupies a small portion of the frequency spectrum in comparison to the AM signal. This results in two advantages, narrower receiver bandpass and the ability to place more signals in a small portion of the frequency spectrum.

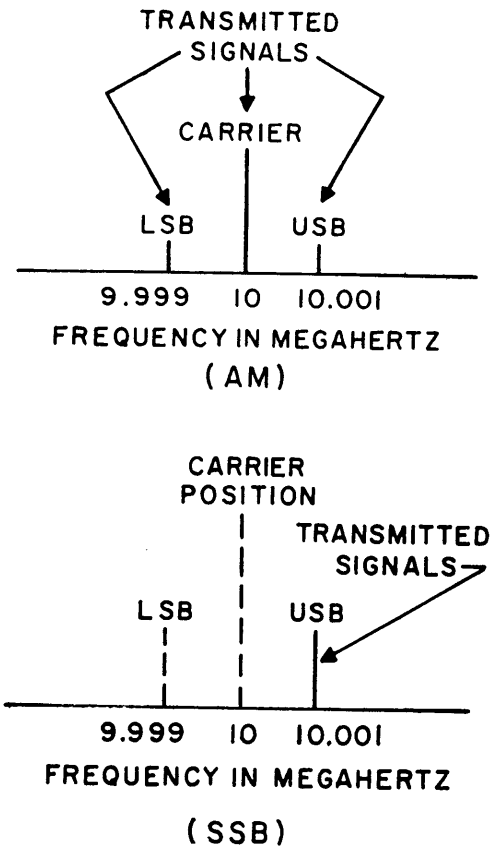

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Figure 5-10.—Comparison of AM and ssb transmitted signals.

Ssb communication systems have some disadvantages. The process of producing an ssb signal is somewhat more complicated than simple amplitude modulation, and frequency stability is much more critical in ssb communication. While there is not the annoyance of heterodyning from adjacent signals, a weak ssb signal may be completely masked or hidden from the receiving station by a stronger signal. Also, a carrier of proper frequency and amplitude must be reinserted at the receiver because of the direct relationship between the carrier and sidebands.

Ssb Receivers

Figure 5-11 illustrates the block diagram of a basic ssb receiver. It is not significantly different from a conventional superheterodyne AM receiver. However, a special type of detector and a carrier reinsertion oscillator must be used. The carrier reinsertion oscillator must furnish a carrier to the detector circuit at a frequency which corresponds almost exactly to the position of the carrier in producing the original signal.

The filters used in the rf amplifier section of the ssb receivers serve several purposes. As previously stated, many ssb signals may exist in a small portion of the frequency spectrum. Therefore, filters supply the selectivity necessary to adequately receive only one of the many signals which may be present. They may also select upper sideband (usb) or lower sideband (lsb) operation when desired, as well as reject noise and other interference.

The oscillators in an ssb receiver must be extremely stable. In some types of ssb data transmission, a frequency stability of plus or minus 2 hertz is required. For simple voice communication, a deviation of plus or minus 50 hertz may be tolerable.

Ssb receivers may employ additional circuits which enhance frequency stability, improve image rejection, or provide automatic gain control (agc). However, the circuits contained in the basic receiver of figure 5-11 will be found in all single sideband receivers.

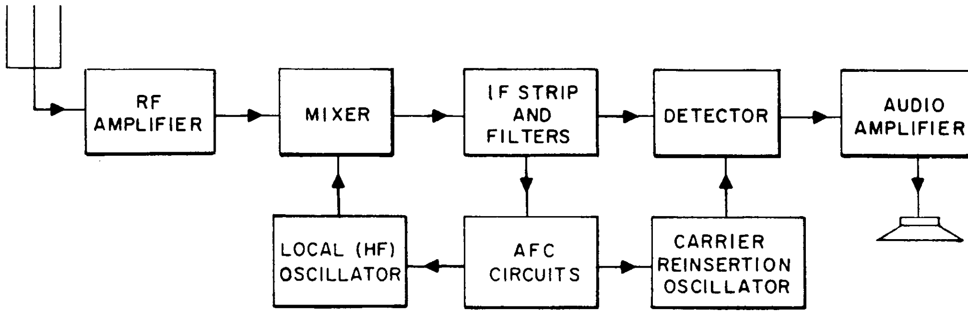

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Figure 5-11.—Basic ssb receiver.

CARRIER REINSERTION.—The need for extreme frequency stability may be understood if one considers that a small deviation from the correct value in local oscillator frequency will cause the IF produced by the mixer to be displaced from its correct value. In AM reception this is not too damaging, since the carrier and sidebands are all present and will all be displaced an equal amount. Therefore, the relative positions of carrier and sidebands will be retained. However, in ssb reception there is no carrier, and only one sideband is present in the incoming signal.

The carrier reinsertion oscillator frequency will be set to the IF frequency that would have resulted had the carrier been present. For example, assume that a transmitter, with a suppressed carrier frequency of 3 MHz, is radiating a usb signal. Also assume that the intelligence consists of a 1-kHz tone. The transmitted sideband frequency will be 3,001 kHz. If the receiver has a 500 kHz IF, the correct local oscillator frequency should be 3,500 kHz. The output of the mixer to the IF stages will be the difference frequency 499 kHZ which is in the IF passband. The missing carrier would have been based on an IF frequency of 500 kHz. Therefore, the carrier reinsertion oscillator frequency should be 500 kHz in order to preserve the frequency relationship of carrier to sideband at 1 kHz.

Recall that 1 kHz is the modulating signal. If the local oscillator frequency should drift to 3500.5 kHz, the IF output of the mixer will become 499.5 kHz. The carrier reinsertion oscillator, however, will still be operating at 500 kHz. This will result in an incorrect audio output of .5 kHz rather than the original 1-kHz tone. If the intelligence transmitted were a complex signal, such as speech, it would be unintelligible due to the displacement of the side frequencies caused by the local oscillator deviation. It is, therefore, very important that the local oscillator and carrier reinsertion oscillator be extremely stable.

MULTIPLEXING

The number of communications networks in operation per unit of time throughout any given area is constantly increasing. As a result, all areas of the rf spectrum have become highly congested.

To a great extent, the maximum permissible number of intelligible transmissions taking place in the radio spectrum per unit of time is being increased through the use of multiplexing. Multiplexing involves the simultaneous transmission of a number of intelligible signals using only a single transmitting path. Either of two methods of multiplexing may be used. These are time-division and frequency-division multiplexing.

TIME-DIVISION MULTIPLEXING

With AM voice and tone communications, it is desired to transmit and receive the full 360° of each sine wave. However, an audio signal may be transmitted and received satisfactorily by periodically sampling the signal. The result of the sampling process yields a received signal such as that shown in figure 5-12. Although there is no limit to the maximum number of samples that may be made, an approximate minimum of two samples per cycle of audio will give satisfactory results. In practical systems, 2.4 samples per cycle are usually taken. This concept of sampling forms the basis for time-division multiplex operation.

Figure 5-13A illustrates, in a highly simplifed form, the basic principle of time-division multiplexing. Assume that a 3,000-Hz tone is applied to each of the six channels in the transmitter. Assume also that the rotating switch turns fast enough to sample, in turn, each of the six channels 2.4 times during each cycle of the 3,000-Hz tone. The speed of rotation of the switch must then be 2.4 × 3,000 or 7,200 rotations per second for the optimum sampling ratio of 2.4 to 1.

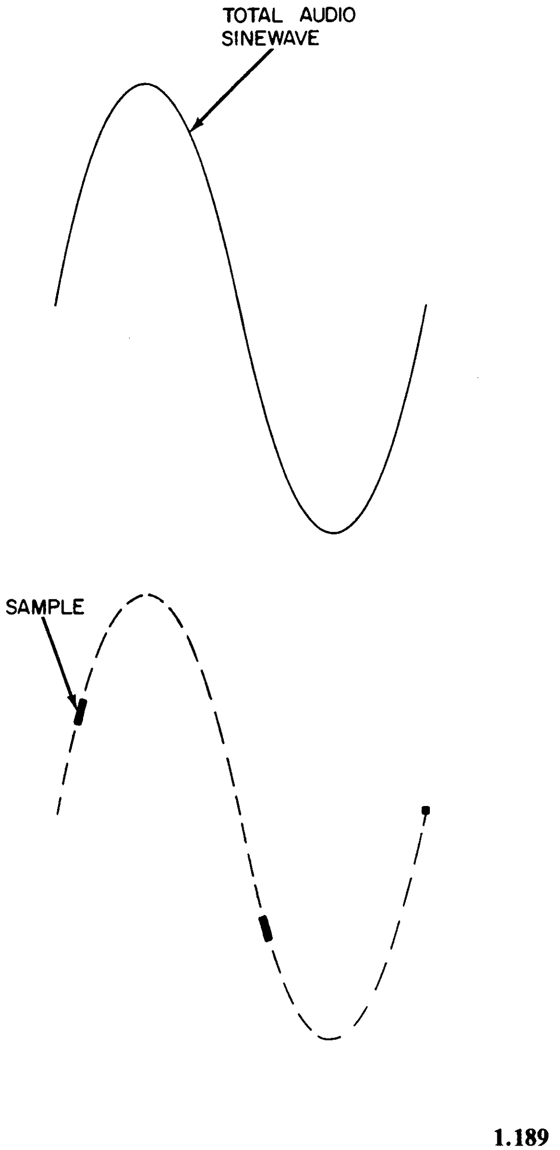

Figure 5-12.—Components of a sine wave.

If the transmitter and receiver switches are synchronized, the signals will be fed in the proper sequence to the receiver channels. The transmitted samples from transmitter channel 1 will be fed to receiver channel 1. Thus, in the time-division method multiplexing, many channels of audio are combined (with time spacing between components of the separate channels) to form a single output (multiplexed) chain. The chain is transmitted (via wire or radio path) to distant demultiplexing receivers. Each receiving channel functions to select and reconstruct only the information included in the originally transmitted channel.

In most present day applications an electronic switching tube is used as the sampling component; however, electromechanical sampling is employed in certain installations where size, weight and power are prime considerations. The main advantage to electronic sampling is the longer life of the electronic switch with respect to the electromechanical switch. For simplicity, a mechanical system is shown in figure 5-13.

A sine wave sampled four times for each channel is illustrated in figure 5-13B. In an actual transmission, segments from the waveforms in all of the channels will be interspaced with these four segments on a time-sharing basis. In other words, only one segment can be transmitted at a time, and the segments are taken in sequence from the waveforms existing in the six channels.

More than six channels (perhaps 24 or more) may be used. However, as the number of channels is increased, the width of each sample segment must be proportionately reduced. The great disadvantage in reducing the width of the pulse is that the bandwidth necessary for transmission is greatly increased. Decreasing the pulse width will decrease the minimum required rise time of the sampling pulse and increase the

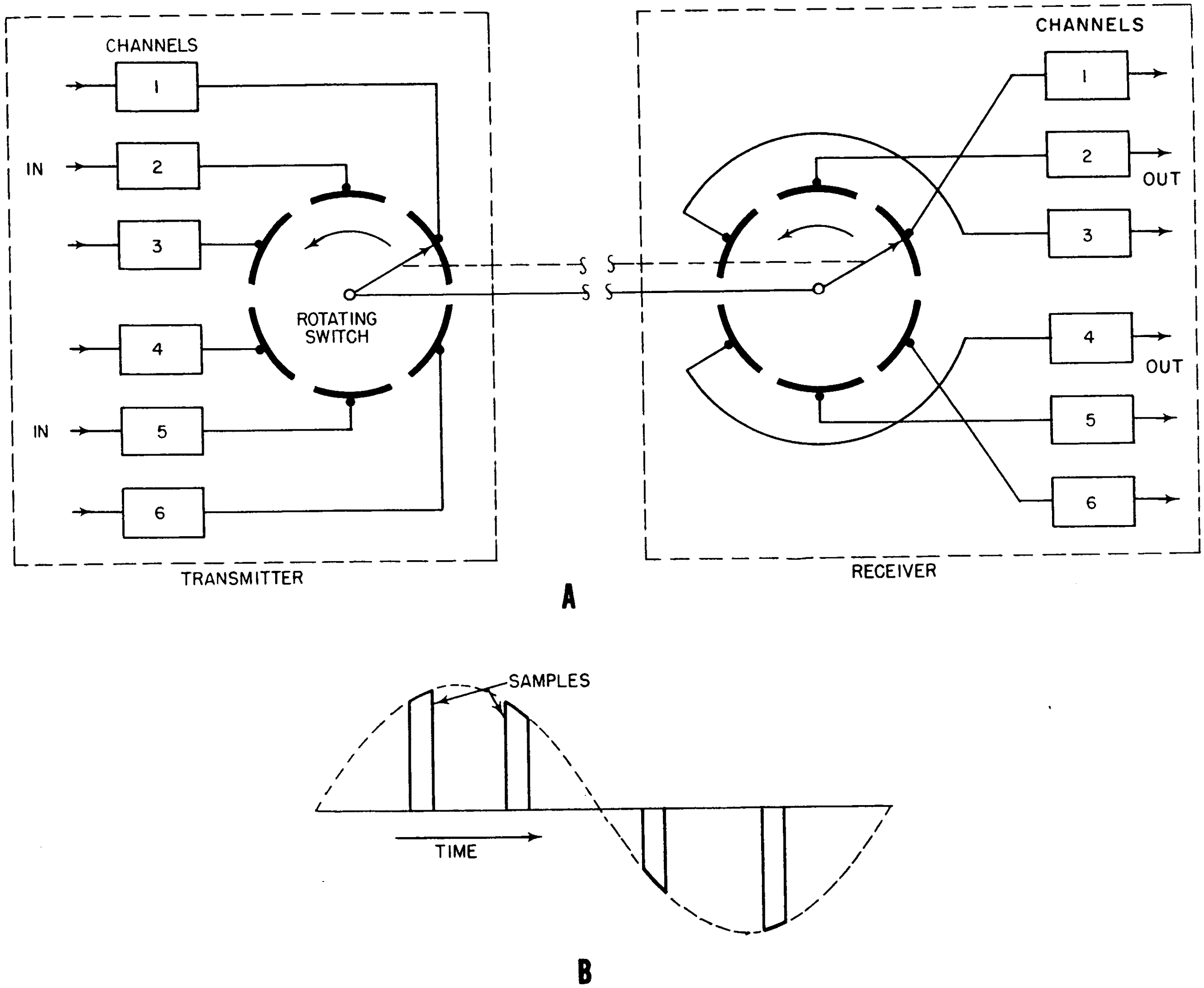

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Figure 5-13.—Basic principle of time-division multiplexing.

required bandwidth. Hence, an increase in the number of channels ultimately increases bandwidth. The bandwidth is also affected by the shape of the sampling pulse and the method of varying the pulse to carry the modulation.

Commonly used methods of time division multiplexing include pulse amplitude modulation (pam), pulse width or pulse duration modulation (pwm) or (pdm), pulse position modulation (ppm), and pulse code modulation (pcm). Pulse amplitude modulation is shown in figure 5-13.

In time-division multiplexing, to use time in the most efficient manner, the bandwidth necessary to transmit n channels would be only slightly wider than n times that necessary for one channel. To prevent crosstalk, however, the minimum bandwidth is not generally utilized.

FREQUENCY DIVISION MULTIPLEXING

Frequency division multiplexing (fdm), unlike time division multiplexing, transmits and receives the full 360° of a sine wave. Fdm used presently by the Navy may be divided into two categories, one being used for voice communications and the other for teletype communications.

The normal voice speaking range is from .1 to 3.5 kHz. During single channel AM voice communications the audio or voice frequency is used to amplitude modulate a single radio frequency (carrier frequency). However, in voice frequency division multiplexing, each voice frequency is used to modulate a separate frequency lower than the carrier frequency (subcarrier frequency). If these subcarrier frequencies are separated by 3.5 kHz or more, they may be combined on a composite signal to modulate the carrier frequency without causing excessive interference with each other.

For example, in figure 5-14, the output of channel 1 is the voice frequency range (.1 - 3.5 kHz). The output of channel 2 is the combination of a different voice frequency with a subcarrier frequency of 4 kHz giving an output frequency range of 4.1 - 7.5 kHz. Similarly the output of channel 3 is another voice frequency combined with a subcarrier frequency of 8 kHz giving an output frequency range of 8.1 - 11.5 kHz. The overall bandwidth for the composite modulation package shown in figure 5-14 is therefore .1 to 15.5 or 15.4 kHz with each separate channel occupying its own band of frequencies. This composite signal is then used to modulate the carrier frequency of the transmitter.

Multichannel broadcasts and ship/shore terminations utilize teletype frequency division multiplexing, whereby each channel of the composite tone package of the broadcast or termination is assigned an audio frequency. An advantage in multiplexing teletypewriter circuits is that up to sixteen teletypewriter circuits may be carried in any one of the 3-kHz multiplexed channels described above. The two types of multiplexing should not be confused. In the first case, 3-kHz audio channels have been combined; in the second case, a number of d.c. teletypewriter circuits are converted to tone keying and combined in a single 3-kHz audio channel. Figure 5-15 illustrates a 16-channel teletypewriter multiplexing system in which the output of the d.c. pulsed circuits is converted to audio keying. Each channel has a separate audio center frequency. Channel frequencies range from 425 Hz for the lowest channel to 2975 Hz for the highest channel. A mark in an individual teletypewriter loop will key an audio tone 42.5 Hz below the center frequency and a space in the input signal will key an audio tone 42.5 Hz above the center frequency. Referring to figure 5-15, the mark and space frequencies for channel one, for example, may be calculated as 382.5 Hz and 467.5 Hz respectively (425 ± 42.5). Combining these keyed tones into a composite signal results in a tone package within a standard 3-kHz bandwidth. By occupying no more than 3 kHz of the audio spectrum,

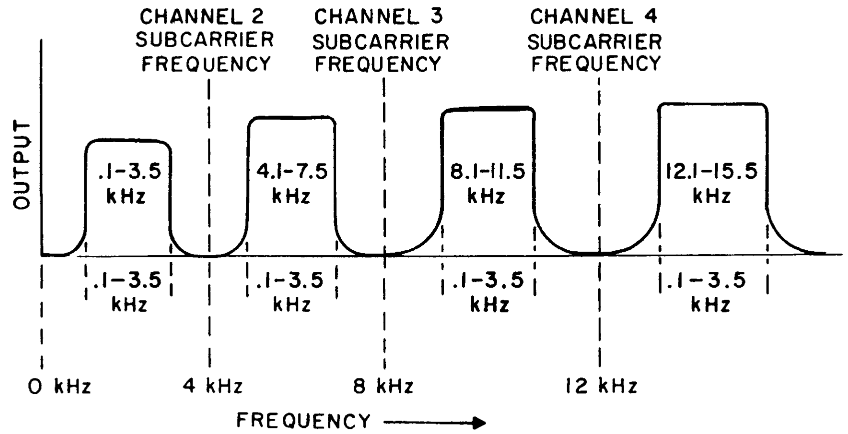

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Figure 5-14.—Block diagram of a frequency-division multiplexing system.

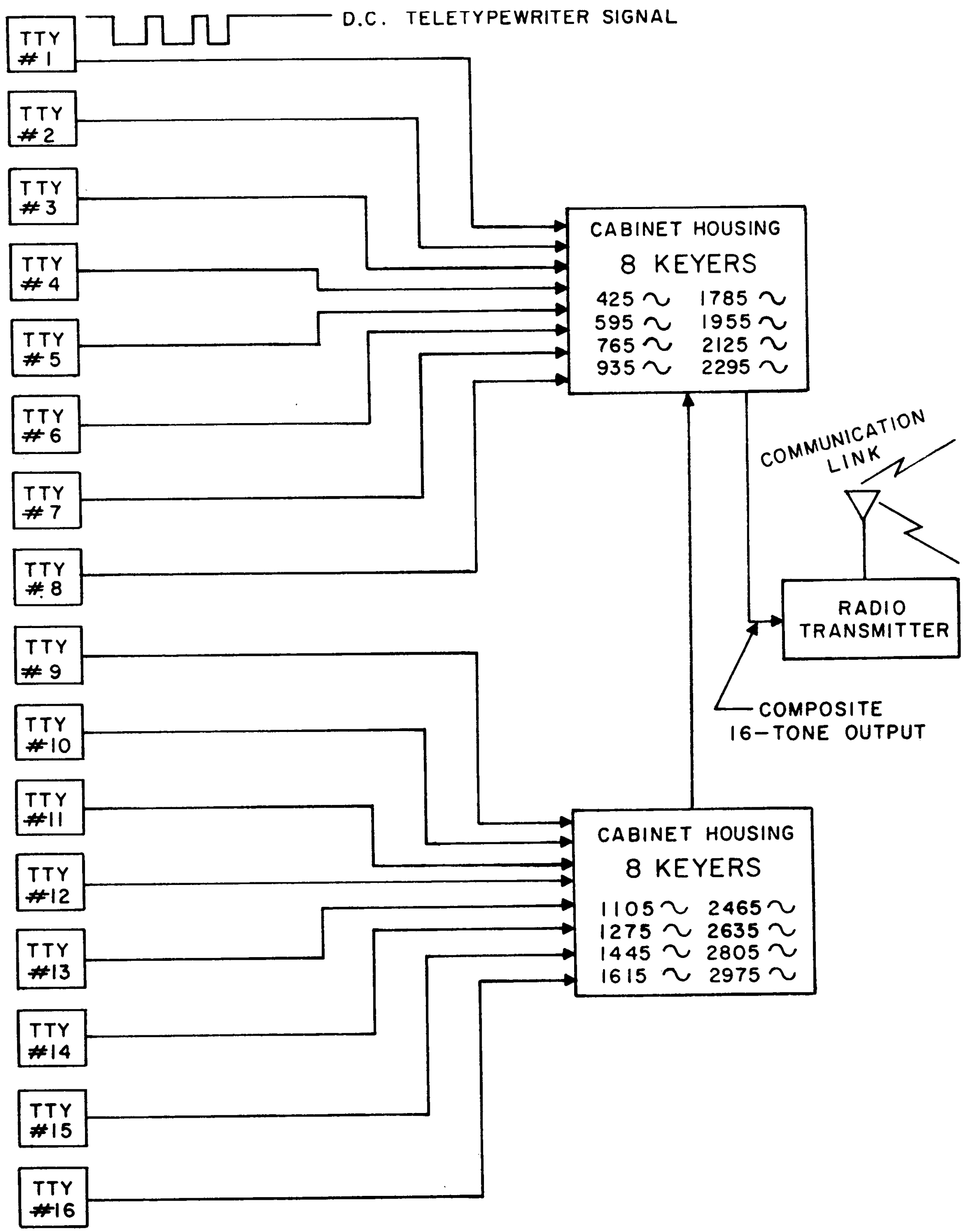

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Figure 5-15.—Block diagram of modulator units.

Table 5-2.—Emission designations

Emission	Type
Modulation Types	
Amplitude	A
Frequency	F
Pulse	P
Modulation (Transmission Mode)	
None	0
Telegraphy (Keyed RF carrier)	1
Telegraphy (Tone)	2
Telephony	3
Facsimile	4
Television	5
Four Channel Duplex Telegraphy	6
Multichannel Voice Frequency Telegraphy	7
Cases not covered above	9
Supplemental Characteristics	
Double Sideband	NONE
Single Sideband	
—reduced carrier	A
—full carrier	H
—suppressed carrier	J
Two independent Sidebands	
—suppressed carriers	B
Vestigial Sideband	
—amplitude modulated	D
—width modulated	E
—phase modulated	F
—code modulated	G

the output signal is suitable for transmission via radio or landline.

DESIGNATION OF MODULATION CLASSES

As communication systems grew more complex, an international designation system was needed to describe the characteristics of the type of modulation being transmitted. This international system is shown in table 5-2. It designates the rf emissions by type, mode, and supplementary characteristics. For example, A3B denotes telephony, two independent sidebands, suppressed carriers. A number preceding this designation, such as 6A3B, indicates the bandwidth in kilohertz. Table 5-2 is the international system and is used throughout the Navy.

ANTENNAS AND PROPAGATION

An antenna is a conductor or system of conductors that radiates and/or intercepts energy in the form of electromagnetic waves. In its elementary form, an antenna may be simply a length of elevated wire. For communication and radar work, however, other considerations make the design of an antenna system a more complex problem. For instance, the height of the radiator above ground, the conductivity of the earth below the radiator, and the shape and dimensions of an antenna are a few factors affecting the field pattern in space.

When rf currents flow through a transmitting antenna, they produce electromagnetic waves. Radio waves are radiated in a manner analogous to waves on the surface of a pond in which a rock is thrown. However, electromagnetic waves may be either parallel to the surface of the earth (horizontally polarized) or perpendicular to the surface of the earth (vertically polarized).

Figure 5-16 illustrates a transmitting and receiving antenna and the associated electromagnetic waves. The electromagnetic waves are divided into three components according to propagation characteristics: groundwaves, skywaves, and spacewaves.

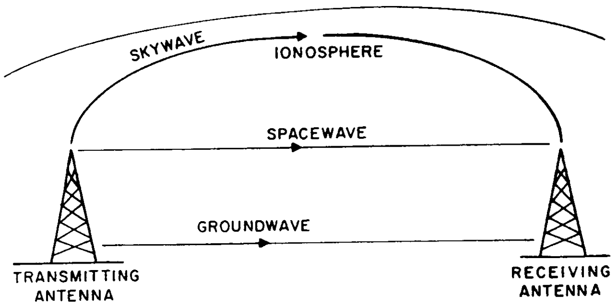

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Figure 5-16.—Divisions of the transmitted electromagnetic wave.

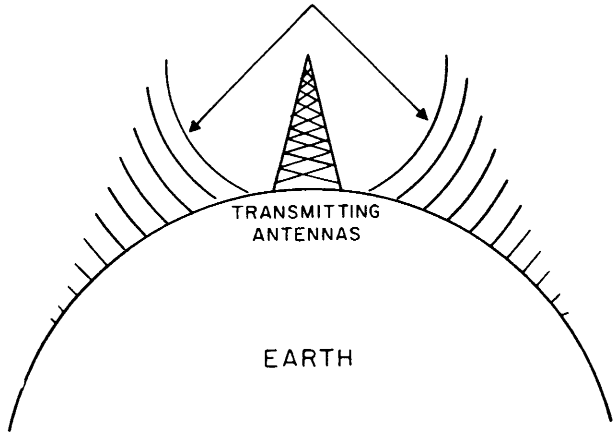

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Figure 5-17.—Groundwave component of the transmitted electromagnetic wave.

GROUNDWAVE PROPAGATION

The groundwave (fig. 5-17) is the portion of the radiated wave that moves along the surface of the earth. The field strength of the groundwave diminishes with distance much more rapidly than the waves that move through free space. There are many complex factors contributing to this, several of which are briefly described here.

Absorption by the earth increases with an increase in frequency, so long distance communications by groundwaves are limited to low frequencies at very high power. Daytime reception of the Standard Broadcast Band is an example. The type of soil near the antenna site will also be a factor in attenuation of the groundwave. Clay or loam will attenuate the signal less than sand or rock. However, salt water will propagate the signal better than either type of soil. The horizontally polarized wave is short-circuited by the earth and is attenuated much more rapidly than the vertically polarized wave. Thus, to gain maximum advantage, the groundwave must be transmitted and received using vertically polarized antennas. Despite these limiting factors, the groundwave remains the most reliable means of radio communications because most restricting factors are of constant nature and do not vary with time of day or weather conditions.

SKYWAVE PROPAGATION

The skywave (fig. 5-18) is the portion of the electromagnetic signal radiated upward which may or may not be refracted back to earth by the ionosphere (the upper atmosphere beginning 40 to 50 miles above the earth). Skywave propagation is not as reliable as groundwave propagation; however, much greater distances may be covered by this means because the radiated electromagnetic field is directed toward the ionosphere and is refracted back at distances of hundreds or even thousands of miles. Refraction is a bending of the electromagnetic energy caused by the energy passing from a more dense medium to a less dense medium. Refraction of electromagnetic energy at radio frequencies is much like refraction at the high frequencies of light. Viewed from the surface, an underwater object appears to be foreshortened, or displaced, because of light refraction. This phenomenon is explained by differences in density of the media through which the light travels. Similarly, density differences in the ionosphere account for the refraction, or bending, of radio waves.

Electromagnetic energy is refracted (or bent) back toward earth when passing through the layers of the ionosphere. The angle at which the energy is refracted is dependent upon many variables; the major ones being frequency, angle of radiation, height, and density of ionospheric layers. There is an angle at which the

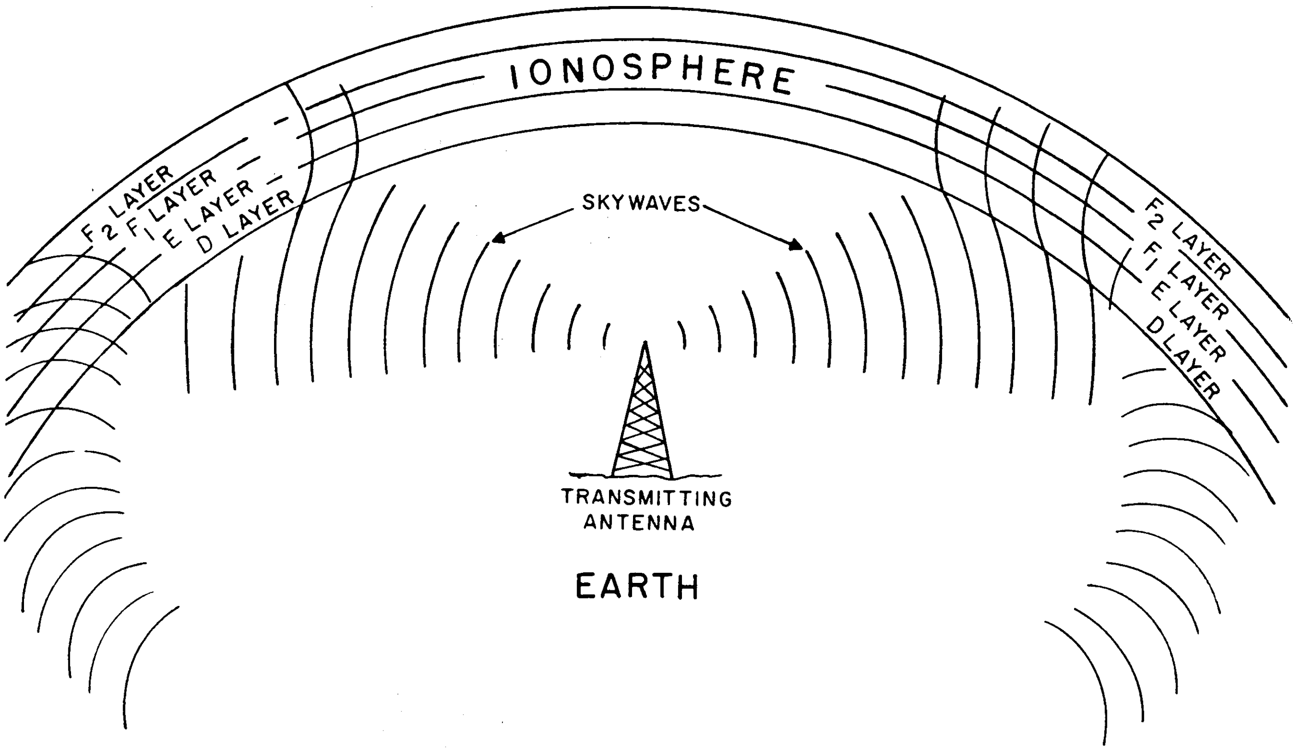

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Figure 5-18.—Refraction of the skywave component during daylight hours.

electromagnetic waves enter the ionosphere, which will cause the energy to be refracted but not enough to return to earth. This angle is referred to as the critical angle. Any transmitted energy entering the ionosphere beyond this angle continues into free space.

The ionosphere differs from other atmospheric layers because it contains a much higher number of positive and negative ions. The negative ions are believed to be ions in which energy levels have been raised to a high level by solar bombardment of ultraviolet and particle radiation. Extending from about 30 miles to 250 miles in the ionosphere there are four layers of ionization: D, E, F_1 and F_2 , as shown in figure 5-18. Although ionization appears in distinguishable layers, the intensity and height of ionized layers in any given region depends on many factors including season, sunspot cycle and, most readily apparent, the time of day. The D layer is present only during daylight and has little effect on refraction but is a factor in absorbing energy from the electromagnetic fields that pass through it. The E layer is much stronger during the day than at night and can refract frequencies up to approximately 20 MHz during the daylight hours. The F layers have the most effect on the refraction of electromagnetic energy. During the night the D layer fades, the E layer becomes much weaker, and the F_1 and F_2 layers combine into a single F layer. The reduction in absorption losses due to the fading of the D and E layers can cause the electromagnetic energy to cover greater distances at night, by permitting the combined F_1 and F_2 layers to reflect higher energy level signals at greater angles.

Long distance radio communications may be accomplished by using multihop transmissions. During these transmissions, a sequence of refractions in the ionosphere and reflections from the earth occur, causing the electromagnetic energy to "bounce" several times over the distance covered.

The complete effects of all the variables on skywave propagation are not fully understood. Researchers are continuously searching for means to improve the reliability of long distance skywave communications.

SPACEWAVE PROPAGATION

The spacewave (fig. 5-19), sometimes referred to as the direct ground wave, is that part of the total wavefront that travels directly, or is reflected by the earth from the transmitting antenna to the receiving antenna. The spacewave is limited to line-of-sight distances plus the additional small distance created by the bending of the wave (by atmospheric diffraction) a slight amount around the curvature of the earth. This total limiting distance can be calculated by assuming an earth radius 4/3 times its actual radius. Such an assumed earth size would have a larger circumference and, hence, a longer transmission distance to the horizon. Naturally, line-of-sight distance can be increased by

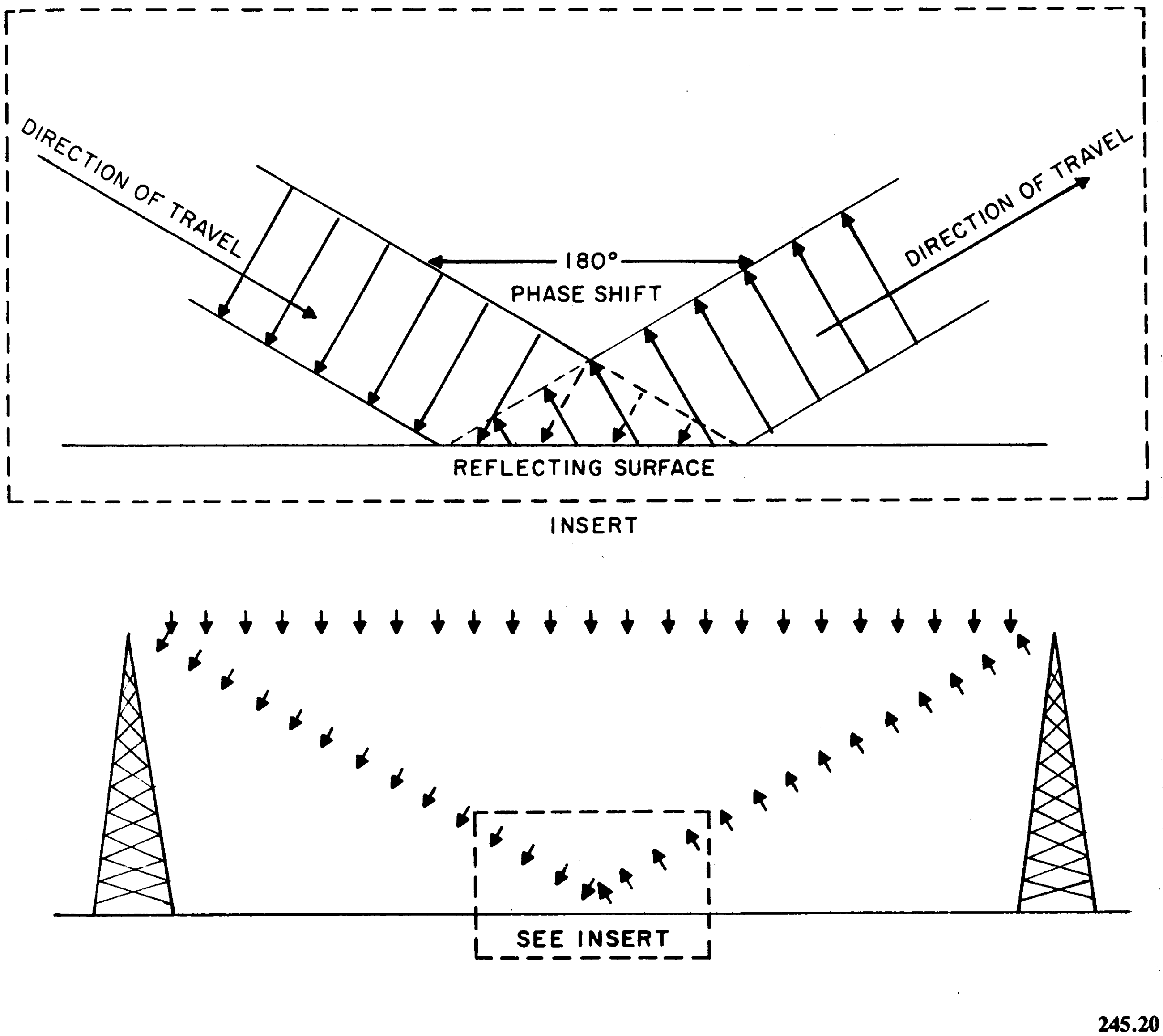

Figure 5-19.—Spacewave component of the transmitted electromagnetic wave.

increasing either or both of the heights of the transmitting and receiving antennas.

The reflected spacewave is reflected by the earth at some distance between the transmitting and receiving antennas. When the transmitted wave strikes the surface of the earth, a part of the energy is lost in the form of heat dissipation, and the balance is reflected at the same angle at which it arrived. When the wave is reflected from the surface of the earth, it undergoes a phase reversal of 180 degrees. (See insert, fig. 5-19.) In addition, the reflected spacewave, traveling a longer route, arrives at the point of reception later in time than the direct line-of-sight space-wave. These two factors are important considerations, since the 180-degree phase shift plus its longer route may cause the reflected spacewave to be out of phase with the direct wave at the point of reception. In other words, the two waves may have a tendency to cancel at the receiving antenna.

SATELLITE COMMUNICATIONS

Experience with satellite communications has demonstrated that such systems can satisfy many military requirements for reliable, high capacity, secure, and cost effective telecommunications.

Satellites are the ideal, if not the only, solution to problems of communicating with highly mobile forces deployed worldwide.

Satellites, if properly used, provide an independent alternative to large, fixed ground installations.

For the past 50 years, the Navy has used high frequency (hf) transmission as its principal method of sending messages. In the 1970's, an era when the hf spectrum was overcrowded, when "free" frequencies were at a premium, and when hf jamming techniques were highly sophisticated, the need for new and advanced long-range transmission methods became readily apparent.

Communications via satellite is a natural outgrowth of modern technology and the continuing demand for greater capacity and higher quality communications.

Although the communications facilities of the various military departments have generally been able to support their requirements in the past, predictable requirements indicate that large-scale improvements will have to be made to satisfy future needs of the Department of Defense. The usage rate of both commercial and military systems has increased steadily in recent years, and there appears to be general agreement that this trend will continue at an accelerated rate. Centralized control of military operations, with its accompanying reliability and security requirements, has generated demands for communications with greater capacity and for long-range communications to previously inaccessible areas. Some of these requirements can be met only by the sophisticated modulation techniques and narrowband, long-distance communications made possible by the use of satellites.

A BASIC SATELLITE COMMUNICATION SYSTEM

A satellite communication system is one that uses earth-orbiting vehicles or satellites to relay radio transmissions between earth terminals. There are two types of communication satellites: active and passive. A passive satellite merely reflects radio signals back to earth. An active satellite, on the other hand, acts as a repeater; it amplifies signals received and then retransmits them back to earth. This amplification results in a stronger signal at the receiving terminal than would be possible from a passive satellite.

A typical operational link involves an active satellite and two earth terminals. One station transmits to the satellite on a frequency called the up-link frequency, the satellite amplifies the signal, translates it to the down-link frequency, and then transmits it back to earth where the signal is picked up by the receiving terminal. This basic concept is illustrated by figure 5-20 which shows several types of earth terminals.

The basic design of a satellite communication system depends to a great degree upon the parameters of the satellite's orbit. In general terms an orbit is either elliptical or circular and its inclination is classified as inclined, polar, or equatorial. A special type of orbit is a synchronous orbit, one in which the period of the orbit is the same as that of the earth's.

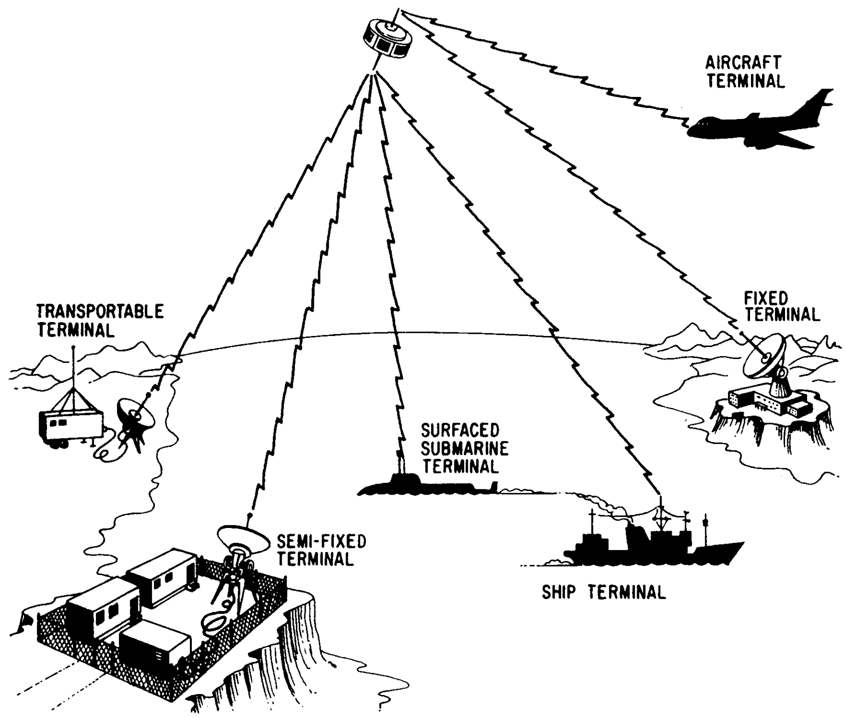

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Figure 5-20.—Satellite communication system.

The essential basic system components of an operational communication satellite system are (1) an orbiting vehicle with a communication receiver and transmitter installed and (2) two earth terminals equipped to transmit and receive signals to and from the satellite. The design of the overall system determines the complexity of the various components and the manner in which the system operates.

FLEET SATELLITE COMMUNICATIONS

The Fleet Satellite Communication (FLTSATCOM) System provides communications links, via satellite, between designated mobile units and shore sites. The area of coverage for these communications links is world-wide, between the latitudes of 70° N and 70° S. Four satellites in synchronous orbit are located at 23° W, 72° E, 172° E, and 100° W longitude. The system includes rf terminals, subscriber subsystems, training, documentation, and logistic support. Within each satellite, the rf channels available for use have been distributed between the Navy and the Air Force.

The impact of the FLTSATCOM System upon naval communications may be understood when it is realized that equipment in support of this system is being placed on ships, submarines, aircraft, and shore stations. These equipment installations vary in size and complexity, depending on the communication requirements at each installation. Furthermore, with the exception of voice communications, the system applies the technology of processor (computer) controlled rf links and employs the assistance of processors in message traffic preparation and handling.

Although any part of the FLTSATCOM System may be operated as a separate module, the system integration provides connections for message traffic and voice communications to DOD communication networks. Backup capability that can be used in the event of an outage is provided between shore stations. This capability is built in as part of the system design, and is limited to selected FLTSATCOM subsystems and by the ability of shore stations to access various satellites.

The FLTSATCOM System represents a composite of information exchange subsystems that use the satellites as a relay for communications. Each subsystem has been designed to address a selected area of naval communications. The following subsystems comprise the Navy's portion of the FLTSATCOM system.

Fleet Satellite Broadcast (FSB) Subsystem. This subsystem is an expansion of Fleet Broadcast transmissions which historically have been the central communications medium for operating naval units.

Common User Digital Information Exchange Subsystem (CUDIXS/Naval Modular Automated Communication System (NAVMACS)). These two installations (CUDIXS/NAVMACS) combine to form a communications network that is used for transmission of general service message traffic between designated ships and shore installations.

Submarine Satellite Information Exchange Subsystem (SSIXS). The SSIXS complements existing communications links between SSBN and SSN submarines and shore terminals.

Anti-submarine Warfare Information Exchange Subsystem (ASWIXS). This subsystem is designed as a communications link for ASW operations.

Tactical Data Information Exchange Subsystem (TADIXS). This is a direct communications network between command centers ashore and afloat.

Secure Voice Subsystem. This is a narrowband uhf link that enables voice communications between ships and connection with wide-area voice networks ashore.

Tactical Intelligence Subsystem (TACINTEL). This subsystem is specifically designed for special intelligence communications.

Control Subsystem. This subsystem is a communication network that facilitates status reporting and management of FLTSATCOM System assets.

The installation of subsystem baseband equipment and rf terminals aboard ships and aircraft is determined by communications traffic levels, types of communications, and operational missions. Fleet Satellite Broadcast message traffic, being a common denominator for naval communications, will be received by numerous types of ships. In some installations, such as large ships, the Fleet Broadcast receiver represents one part of the FLTSATCOM equipment suite. A typical suite on a large ship would include Fleet Broadcast, NAVMACS, Secure Voice, and TACINTEL equipment.

SHORE BASED TERMINALS

The installation of FLTSATCOM equipment at shore terminals has been structured by use of existing naval communications centers and the geographical locations of command and operations centers. Four Naval Communications Area Master Stations (NAVCAMS) bear prime responsibility, in selected geographical areas, for naval communications on FLTSATCOM satellites. These stations are:

- NAVCAMS LANT, Norfolk, Virginia
- NAVCAMS MED, Bagnoli, Italy
- NAVCAMS WESTPAC, Finegayan, Guam
- NAVCAMS EASTPAC, Wahiawa, Hawaii

Ten NAVCOMMSTAs are used to retransmit Fleet Satellite Broadcast message traffic via hf links. These COMMSTAs are located in:

Greece	Australia
Spain	Japan
United Kingdom	Philippines
Puerto Rico	Alaska
Diego Garcia	Iceland

The FLTSATCOM equipment installations address the unique requirements of the user. Each subsystem installation consists of two parts: the baseband equipment that is used for collecting and controlling the transmitted or received communications, and the rf terminal that is used by the subsystem.

The FLTSATCOM subsystems, with the exception of the Secure Voice and Control subsystems, apply some form of automated control to the communications being transmitted. This control includes message or data link processing, before and after transmittal, and control of the rf network (link control) in which they are being transmitted. The automation of these functions is handled by a processor. Much of the message processing prior to transmission and after receipt is fully automatic and does not require operator intervention. The actual message or data link transmissions are fully automated and under the control of a processor.

All subsystems have some form of backup mode, either from backup equipment/systems, facilities, or rf channels. Within the limitations of equipment capability, each subsystem has addressed the unique requirements of the user and the environment in which the user operates. The following information is intended to provide a basic understanding of the Fleet Satellite Broadcast Subsystem (FSB) and the CUDIXS/NAVMACS.

FLEET SATELLITE BROADCAST SUBSYSTEM

The Fleet Satellite Broadcast Subsystem (fig. 5-21) will provide the capability to transmit Fleet Broadcast message traffic in a high level jamming environment. The subsystem provides 15 subchannels of covered message traffic. These 15 subchannels are time division multiplexed and transmitted in a one-way shf transmission to the

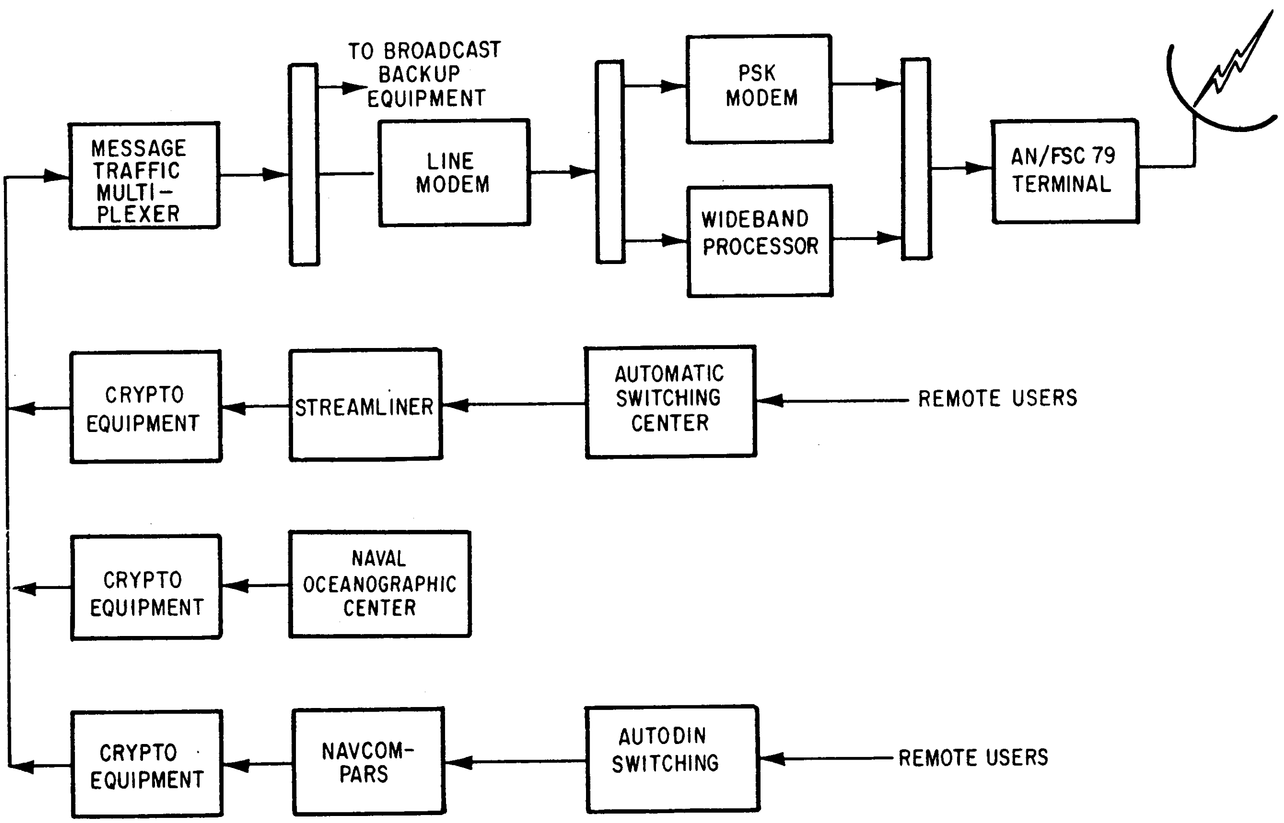

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Figure 5-21.—Fleet Satellite Broadcast Subsystem.

satellite. At the satellite, the transmission is translated from shf to uhf for transmission on the down link to the subscriber.

Message Traffic

The Fleet Broadcast message traffic is arranged and/or channelized prior to transmission by two processor-controlled message switching systems. These systems are the Naval Communication Processing and Routing System (NAVCOMPARS), for general service message traffic, and Streamliner, for special intelligence message traffic. Fleet weather data, which are also transmitted on Fleet Broadcast, are input to the transmission by teletype from Naval Oceanographic Center.

General Service Message Traffic

General service message traffic (fig. 5-22a) can be read into the NAVCOMPARS processor by over-the-counter facilities at the NAVCAMS/NAVCOMMSTA, or automatically input to the processor when the message traffic has been sent from an automatic digital information network (AUTODIN) switching center. The output of the NAVCOMPARS, which is general service message traffic, is fed to crypto equipment for encryption. The crypto equipment provides an output of 75 bps (bits per second), which is sent to a message traffic multiplexer for conversion to a 1200-bps signal.

Streamliner

The Streamliner (fig. 5-22b) uses basically the same format as the general service message traffic except it is designated for special intelligence messages. The output of this system is also 75 bps. It is fed to a message traffic multiplexer and converted to a 1200-bps rate.

Fleet Weather

The Naval Oceanographic Center (fig. 5-23) produces fleet weather data which is put on a teletypewriter or a punched-tape reader. This information is then passed on to crypto equipment where it is encrypted. The output of the crypto equipment, with a 75-bps rate, is passed on to the message traffic multiplexer.

RF Transmission

Two frequency bands, shf and uhf, are available for Fleet Broadcast transmission. The shf band uses the AN/FSC-79 Satellite Communications Terminal and the uhf band uses the AN/WSC-5(V) Transceiver for backup

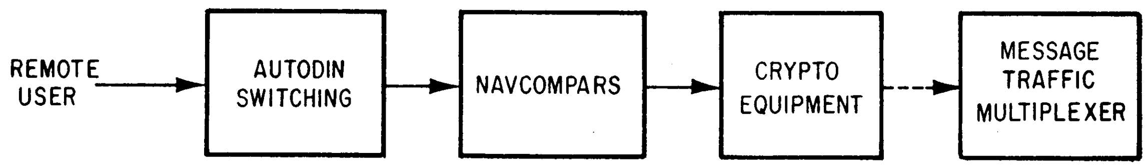

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Figure 5-22a.—General service message traffic.

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Figure 5-22b.—Special intelligence message traffic.

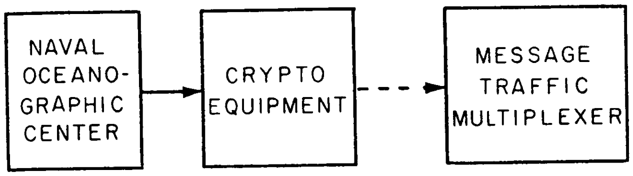

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Figure 5-23.—Fleet weather traffic.

operation. All other FLTSATCOM subsystems are transmitted only in the uhf band.

During normal operation, using the AN/FSC-79 Satellite Communications Terminal (fig. 5-24), the output of the message traffic multiplexer is fed to a patch panel where it can be routed to either the backup transceiver or to a line modem (modulator/demodulator). The output of the line modem is fed to another patch panel where selection can be made for the signal to go to either the PSK (phase-shift keying) modem or the wideband processor. Another patch panel selects the output of the PSK modem or the wideband processor for transmission by the AN/FSC-79. The output of the AN/FSC-79 is an shf signal, transmitted to the satellite. At the satellite, this shf signal is converted to a uhf signal for retransmission as the down-link signal.

CUDIXS/NAVMACS

This FLTSATCOM subsystem is divided into two major elements:

- Common User Digital Information Exchange Subsystem (CUDIXS)
- Naval Modular Automated Communications Subsystem (NAVMACS)

Collectively, these two subsystems will provide improved ship-to-shore and shore-to-ship operational communications over what was previously available with hf communications.

GENERAL INFORMATION ON NAVMACS

The NAVMACS (V) (fig. 5-25) is a shipboard message processing system that automatically guards as many as four broadcast channels, serves as an automated shipboard terminal for the CUDIXS, and provides accountability for all incoming and outgoing messages. It is intended to serve the message processing needs of small to medium size ships of the fleet.

The NAVMACS (V) consists of software, operator personnel, and the following equipment:

- NAVMACS (V) PROCESSOR.—This processor is a general purpose digital computer with 65,536 words of memory.
- 75-2400 BAUD PRINTERS (2).—These printers are used to print headings and the text of incoming messages and operator requested reports.
- CONTROL TELETYPE.—This teletype is used by the operator to control system operation.

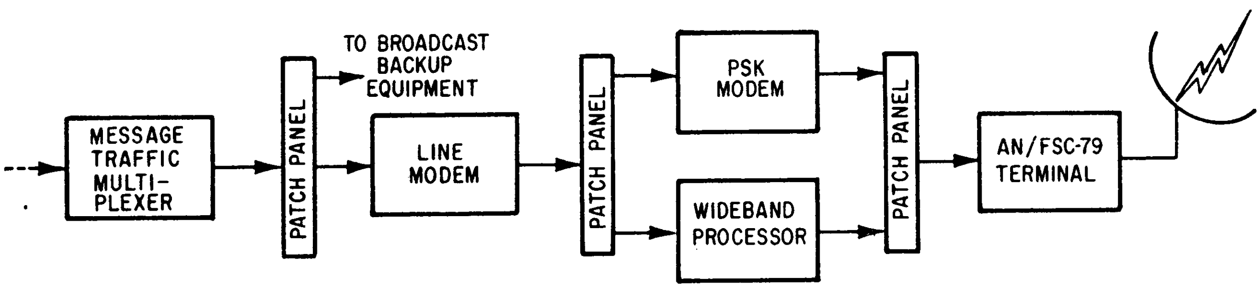

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Figure 5-24.—AN/FSC-79 Satellite Communications Terminal.

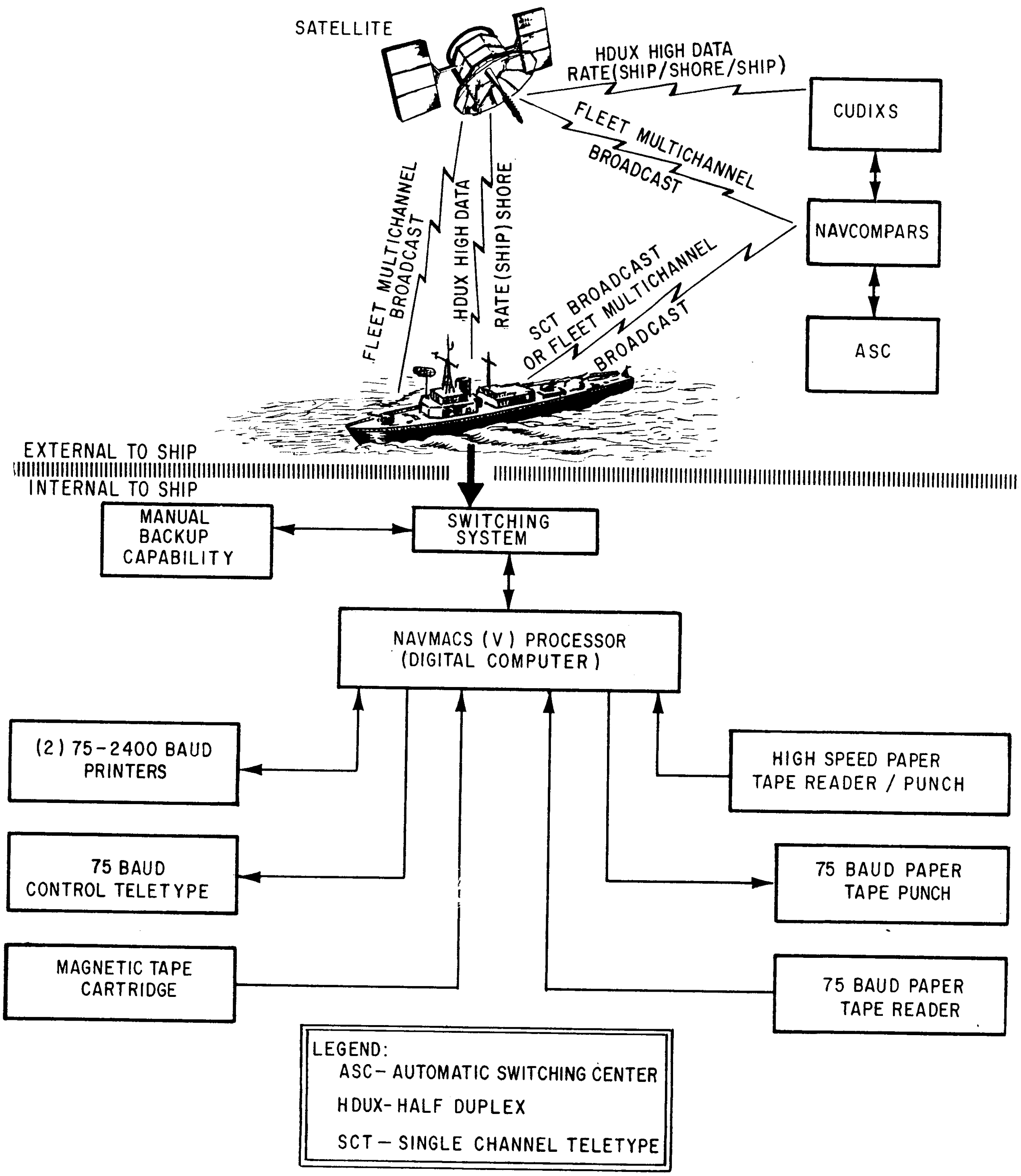

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Figure 5-25.—NAVMACS (V) communications interface.

MAGNETIC TAPE CARTRIDGES.—These cartridges are used for loading the computer program.

- HIGH SPEED PAPER TAPE READER/PUNCH.—The reader is used for inputting outgoing messages. The punch is used as an output device for operator requested retrievals of messages and off-line encrypted messages.

- 75 BAUD PAPER TAPE PUNCH.—This punch is used as a backup for the high-speed tape punch.

- 75 BAUD PAPER TAPE READER.—This reader is used as a backup for the high-speed tape reader.

The computer interfaces with the CUDIXS link through an interconnection group and with the broadcast channels through a converter or switchboard.

The operator communicates with the system via the control teletype. Using the control teletype, the operator instructs the system concerning major operational functions. These functions include identifying: wanted messages, broadcast channels to be guarded, the status of the CUDIXS link, and the status of the equipment.

Operation

The NAVMACS (V) reads the headings of incoming broadcast message traffic and separates those messages addressed to the ship or commands for which it is guarding. The system compares every addressee on each incoming first-run message against entries in its command guard list (CGL), which contains those addresses for which the ship is guarding. When the system finds one or more matches between addresses on the first-run message and the entries of the CGL, the message is printed (copied) completely on a line printer. If an Emergency or Flash procedence message (which could affect everyone in the system) on a first-run message is received, it is printed completely regardless of whether or not a match is found. When a match is not found with the CGL for a message having a precedence lower than Flash, only the heading of the message is printed.

CUDIXS LINK TRAFFIC

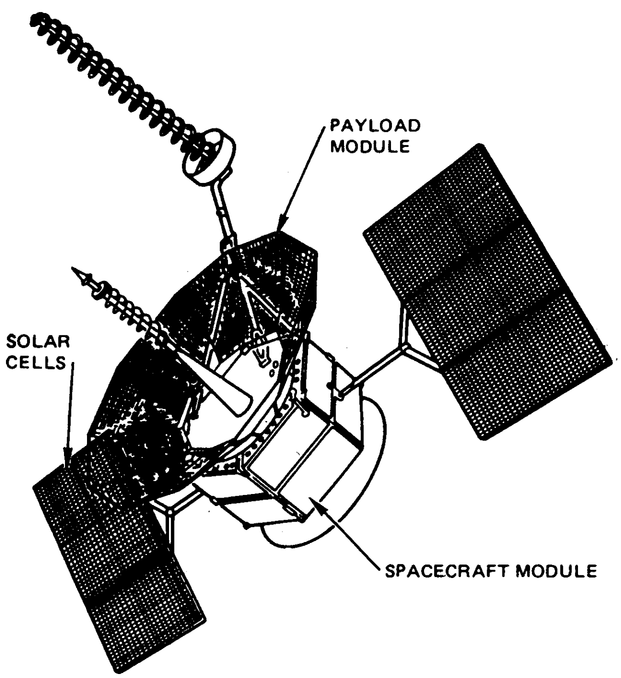
The CUDIXS is a high-speed, half-duplex, automated digital communications network using a satellite channel. Communication is between a shore-based network control station (NCS) and subscribers (ships). The NCS accepts and relays messages. There are two types of CUDIXS subscribers, a Primary Subscriber which can receive narrative message traffic from the NCS, and a Special Subscriber which can send or receive narrative message traffic to, or from, the NCS. Narrative message traffic refers to usual naval teletype messages as opposed to computer-to-computer control messages and operator-to-operator (order wire) messages. Information exchange is computer controlled at both the NCS and the shipboard subscriber terminals. NAVMACS (V) provides computer control for either type of shipboard subscriber.

SATELLITES

Satellites were leased for use during the early phase of operation, and this use of commercial satellites for Navy communications continues even though FLTSATCOM satellites have been launched. The FLTSATCOM satellites have both shf and uhf capabilities, while Navy communications used only the uhf section of leased satellites. For the purpose of management and control of communications on the uhf channels, the leased satellites were given the name Gapfiller by the Navy.

FLTSATCOM SATELLITE

The FLTSATCOM satellite (fig. 5-26) is considerably larger and heavier than the Gapfiller satellite. The estimated spacecraft weight at launch is 1859.73 kilograms. It consists of two major parts: a payload module that includes the antennas, and a spacecraft module with a solar array. The payload module consists of the uhf, shf, and S-band communications equipment, and antennas. Other subsystem equipment contained in the spacecraft includes the earth



162.391
Figure 5-26.—FLTSATCOM satellite.

sensors, attitude and velocity control, telemetry, tracking and command, and electrical power and distribution. The spacecraft is stabilized on three axes, with the body-fixed antennas kept pointed at the center of the earth. The solar array is kept pointed at the sun.

INTRODUCTION TO COMMUNICATION SYSTEM EQUIPMENT

Until recently, the term "radio communications" brought to mind telegraphy (cw), voice (AM), or possibly teletype communications. Today, radio communications has become a highly sophisticated field of electronics. Even small ships have the capabilities for "coming up" on the commonly used ship-to-ship, ship-to-air, and ship-to-shore communications circuits. These circuit operations are accomplished through the use of compatible and flexible communication systems.

A communication system consists of two or more sets, each having its own separate identity, arranged and interconnected to perform a circuit operation that cannot be performed by any one of the individual sets alone. Navy communication systems vary from simple to the very complex, depending upon the circuit operations involved. Each system requires the integrated use of various types of equipment. Thus, a large number of sets, groups, and units are involved when several systems must be operated separately and simultaneously. The concept of shipboard efficiency dictates not only where these sets, groups, and units will be located physically, but also that they be installed in a manner permitting operating flexibility for the various system applications. This flexibility is provided through a complex arrangement of interconnections which allows the physically separated sets, groups, and units to be selectively switched (patched) into the different circuit configurations.

Most shipboard communications equipment is, at one time or another, used in one or more different system operations. Therefore, it is important for the Electronics Technicians to know how to perform maintenance at a system level as well as on the individual equipment.

The following begins by defining a system and explaining how it is broken down into the various subdivisions, then continues by presenting a brief discussion of Navy communication systems.

> Equipment items covered in this and other chapters are meant to be merely representative of equipment which may be encountered aboard ship. No attempt will be made to include all of the possible equipment or equipment configurations.

INTRODUCTION TO EQUIPMENT SYSTEMS

As naval electronics has grown in capabilities, complexity, and extent, an orderly plan of designations has been adopted. The largest designator, SYSTEM, describes equipment which work together for a specific function. For example, a ship's radar system includes every item of electronics equipment used for, or with, a radar on board that ship. The smallest designator, PART, describes one single piece, such as a bolt or a resistor.

Most troubleshooting will be system oriented. A system is subdivided into sets, groups, units, assemblies, subassemblies, and parts. The definition of a system and how it is broken down into various subdivisions was explained in Chapter Four. A brief description of Navy communication systems follows.

COMMUNICATIONS EQUIPMENT SYSTEMS

A communication system is a collection of equipment used together to accomplish a specific requirement. This requirement could be to send voice communications, receive voice communications, or both, and to send, receive, or send and receive teletype information. Figure 5-27 is a pictorial view of a typical communication system containing the necessary components for transmission and reception of voice, cw, and teletype signals.

A basic block diagram (fig. 5-28) will be used to explain the equipment used and to show how they interconnect to form a basic communications system. The system used will be a nonsecure voice system.

HANDSET

The handset is a device used to convert acoustical energy to electrical energy for use in modulating the transmitter for the transmission of a signal, and to convert electrical energy to acoustical energy for the reproduction of the received signal. When the push-to-talk button is depressed on the handset, the d.c. keying circuit

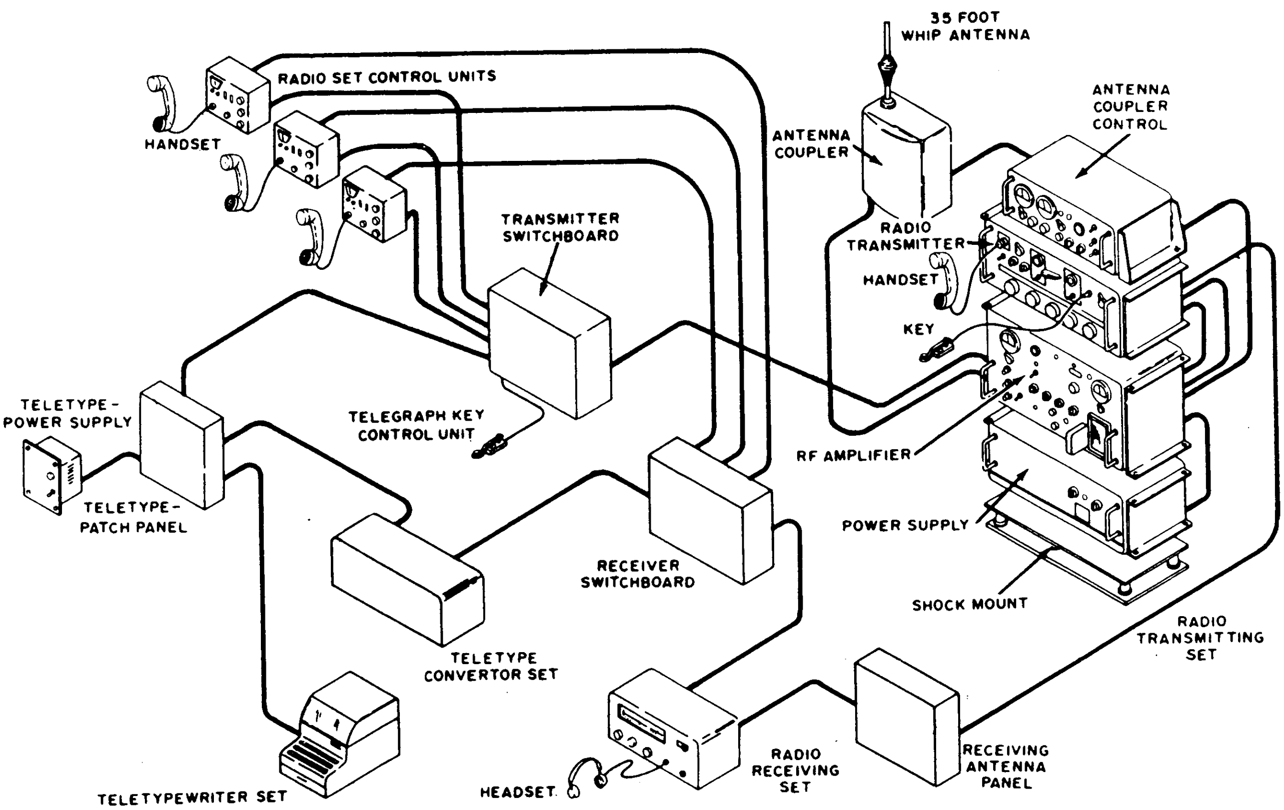
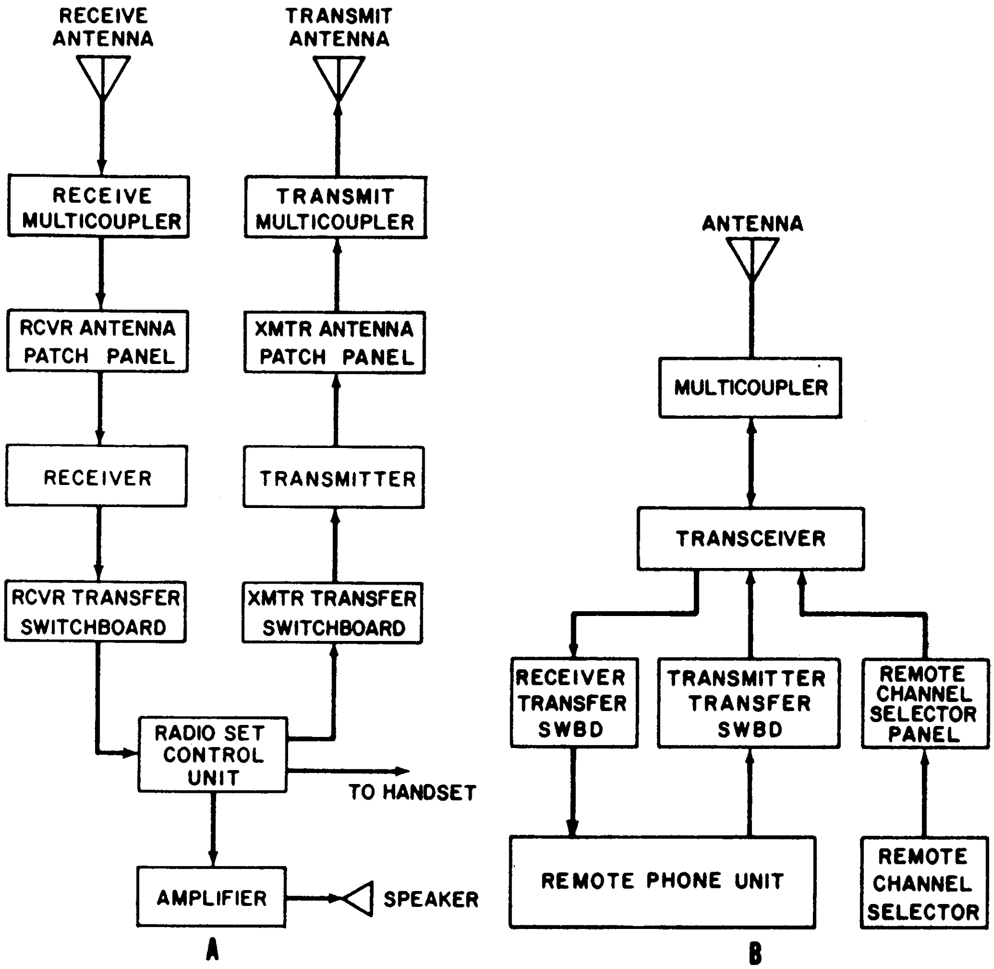


Figure 5-27.—Communication system pictorial view.



162.130

Figure 5-28.—Nonsecure voice systems.

to the transmitter is closed, placing the transmitter on the air.

The handset is normally connected to a radio set control.

RADIO SET CONTROL

The radio set control unit provides the capability to remotely control certain radiophone transmitter functions and the receiver output. Circuits are provided for turning the transmitter on and off, for voice modulating the transmission (or keying when cw operation is desired), for controlling the audio output level of the receiver, and for muting the receiver when transmitting.

A representative radio set control unit is shown in figure 5-29. Under standard operating conditions, as many as four of these, or similar units, may be paralled to a single transmitter/receiver group to provide additional operating positions.

TRANSFER SWITCHBOARDS

The transmitter transfer switchboard provides the capability for selectively transferring remote control station functions and signals to the transmitters. A representative transfer switchboard (fig. 5-30) provides the capability for selectively transferring any one, or all, of ten

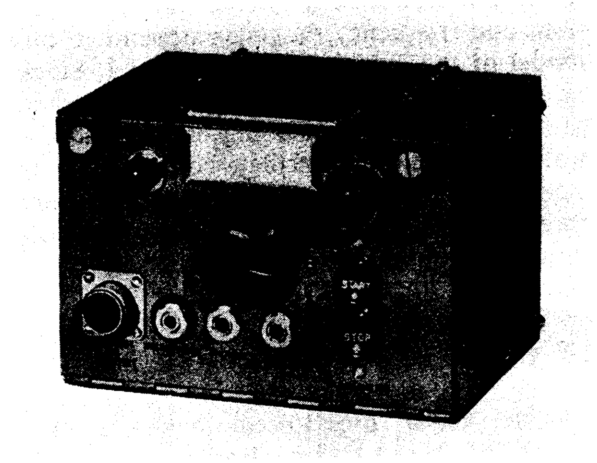


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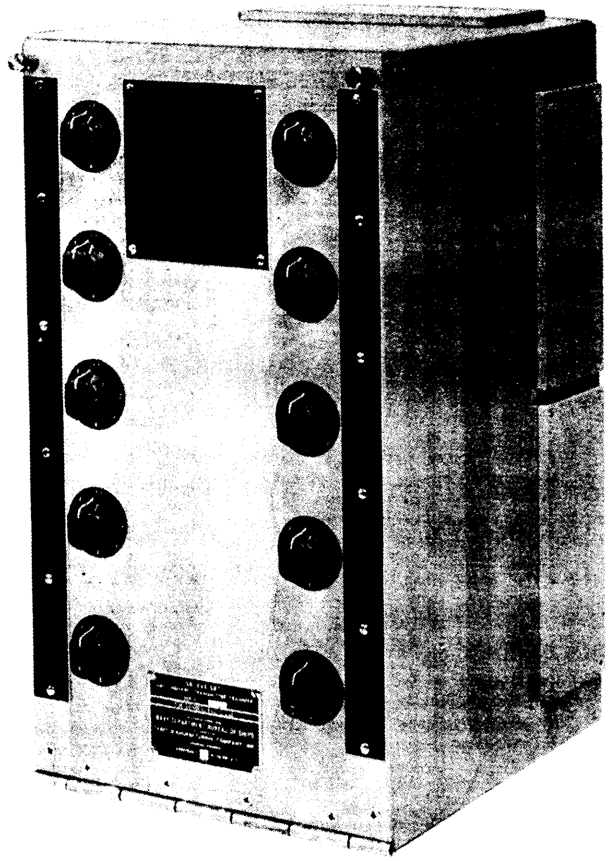
Figure 5-29.—Radio set control.

remote control station functions and signals to any one of six transmitters. The cabinet has ten rotary switches, arranged in two vertical rows of five switches each. Each switch has eight positions. Arrangement of the circuitry is such that it is impossible to parallel transmitter control circuits; that is, to connect more than one transmitter to any remote control station.

Each switch operating knob corresponds to a remote control station. Each rotary switch position (one through six) corresponds to a controlled transmitter. Rotary position X corresponds to an extension providing for the transfer of all circuits to additional Transmitter Transfer Switchboards when more than six transmitters are installed in the system. The rotary position OFF is used to remove the remote from the system.

When it is required, for example, that remote control station number two is to have control of transmitter number three, the switch knob designated number two is rotated until its pointer indicates position three on its respective dial plate. Any of the remote stations may thus be connected to control any of the transmitters installed in the system.

The receiver transfer switchboard provides for transferring the audio output from the receivers to remote control station audio circuits. A representative receiver transfer switchboard is shown in figure 5-31. This switchboard contains ten seven-position switches. Each switch relates to a remote control station, and each switch position (one through five) relates to a receiver.



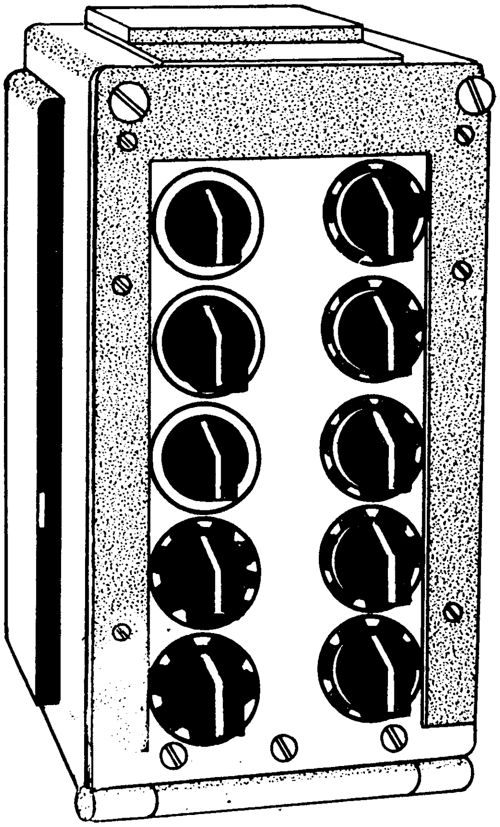
70.64

Figure 5-30.—Transmitter transfer switchboard (SB-988/SRT).

Position X on each switch serves to transfer the circuits to additional switchboards, as in the case of the transmitter transfer switchboard.

TRANSMITTERS

The transmitter may be a simple, low power (milliwatts) unit, for sending voice messages a short distance, or it may be a highly sophisticated unit, utilizing thousands of watts of power, for sending many channels of data (e.g., voice, teletype, t.v., telemetry, etc.) simultaneously over long distances.



120.16
Figure 5-31.—Receiver transfer switchboard (SB-973/SRT).

The transmitter that will be discussed is the AN/URT-23( ).

RADIO TRANSMITTING SET AN/URT-23(V)

Radio Transmitting Set AN/URT-23(V) (fig. 5-32) is a 1-kW , single-sideband radio transmitting set that can be supplied in any one of four possible configurations. The normal configuration includes Radio Transmitter T-827( )/URT, and is capable of general purpose voice, continuous wave, and radio teletypewriter transmissions in the frequency range of 2 to 30 MHz. The exact spacing and number of channels available, modes of operation, and frequency range are dependent on the model of the T-827( )/URT supplied. Stack or rack mounting may be used to install the units of the AN/URT-23(V) in a ship or shore fixed installation with other ancillary equipment to form a complete communications system. Any one of three 3-phase primary power sources can be used to provide operating power to the set: 115 volts 400 Hz; or 208 or 440 volts 60 Hz.

GENERAL DESCRIPTION

The major units used to make up the AN/URT-23(V) are: Radio Transmitter T-827( )/URT, Radio Frequency Amplifier AM-3924(P)/URT, Power Supply PP-3916/UR or (optionally) Power Supply PP-3917/UR, and Electrical Equipment Shock Mount Base MT-3399/U, as shown in figure 5-32. In both ship and shore installations, Antenna Coupler Group AN/URA-38( ) which consists of Antenna Coupler CU-938A/URA-38 and Antenna Coupler Control C-3698/URA-38( ), is normally used to automatically match the impėdance of the system to the 50-ohm transmission line. Provisions are included, however, which allow operation with any 50-ohm antenna coupling system.

The T-827( )/URT is a low level transmitter (exciter) which provides an Upper Sideband (usb), Lower Sideband (lsb), Independent Sideband (isb), cw, fsk, or compatible AM signal of sufficient power to drive the AM-3924(P)/URT. Digital tuning is used to cover the frequency range of 2 to 30 MHz. (Model T-827( )/URT tunes from 2.0 to 29.9995 MHz in 500-Hz increments; Model T-827A/URT and later models tune from 2.0 to 29.9999 MHz in 100-Hz increments.) A five-wire coded output from the T-827( )/URT is also applied to the AM-3924(P)/URT to automatically tune it to the correct frequency band.

Radio Frequency Amplifier AM-3924(P)/URT

The AM-3924(P)/URT (fig. 5-32) is a two-stage linear power amplifier, which produces an output of 1 kW with a nominal input of

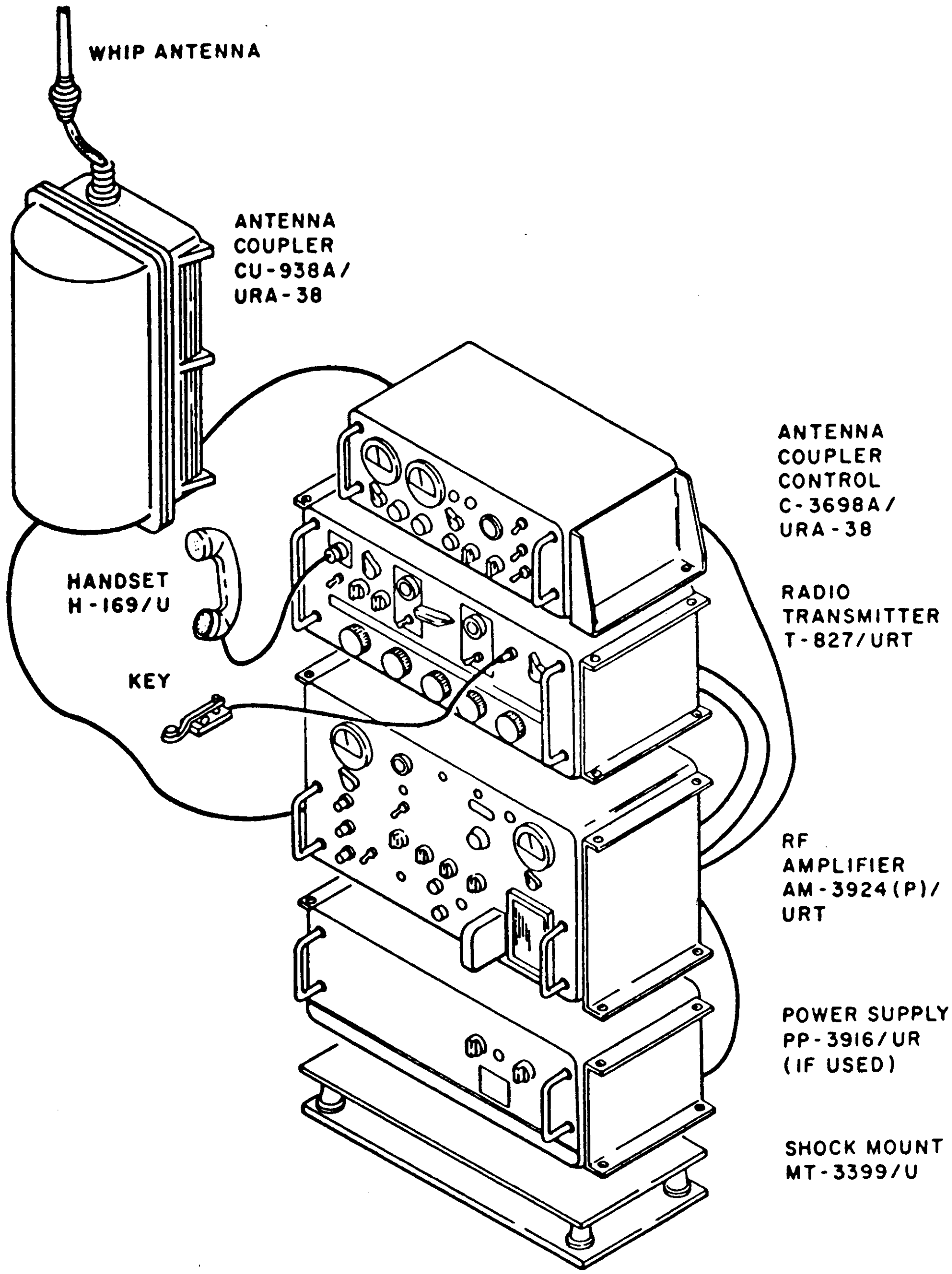


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Figure 5-32.—Radio Transmitting Set AN/URT-23(V).

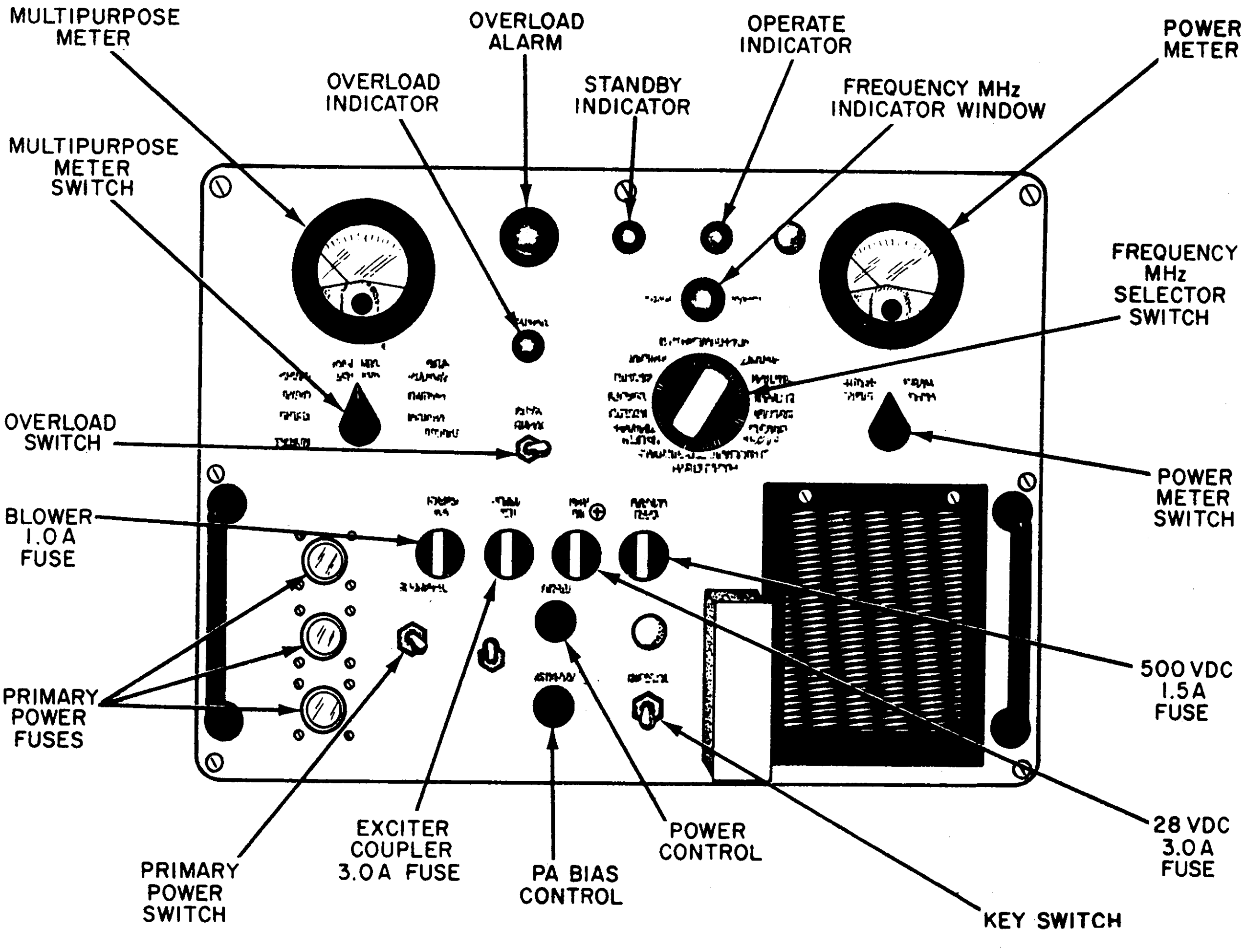
100 mW. Nineteen frequency bands are used to cover the operating frequency range of 2 to 30 MHz. The operating band is automatically selected by a five-wire code generated by the T-827( )/URT or internally generated if the T-827( )/URT is not used. The code controls two motor-driven bandswitch assemblies on which are mounted broadband transformers used as interstage and output-tuned circuits for the two amplifier stages. Automatic control

circuits compensate for variations in system gain, mode of operation, or loading to protect the unit against overload. The AM-3924(P)/URT can be modified to allow operation with an exciter other than the T-827( )/URT. Plugged mounting holes are provided in the front panel and rear of the case to allow the installation of the circuitry.

All operating controls and indicators are located on the front panel (fig. 5-33). Those controls used only for initial setup are protected by a hinged access cover. All connections are made at the rear of the case. The four electron tubes and the associated interstage broadband transformer assemblies are cooled by forced ventilation. Cooling air is drawn through a filter on the front panel and exhausted through a port on the rear of the case. Amplifiers AM-3924(P)/URT became designated AM-6909/URT after installation of field change 14.

Power Supplies

Power Supply PP-3916/UR (fig. 5-32) produces operating voltages for the AM-3924(P)/URT when operating from the 60-Hz power sources, as stated previously. All components of the PP-3916/UR, except the power transformers, are mounted on a chassis and panel assembly, which is hinge-mounted to a metal case. Loosening the front panel screws allows the chassis and panel assembly to be



162.175

Figure 5-33.—Radio Frequency Amplifier AM-3924(P)/URT.

dropped 90 degrees to a horizontal position for servicing and troubleshooting. The power transformers are constructed as an integral part of the case. Two self-indicating fuse holders and a POWER ON indicator are located on the front panel of the PP-3916/UR. There are no operating controls.

Antenna Coupler Group AN/URA-38( )

Antenna Coupler Group AN/URA-38( ) is an automatic antenna tuning system intended primarily for use with the AN/URT-23(V). However, the equipment design includes provisions for manual and semiautomatic tuning, thereby making the system readily adaptable for use with other radio transmitters. In addition, the manual tuning capability is useful when a failure occurs in the automatic tuning circuitry. Also, tuning can be accomplished without the use of rf power (silent tuning). This method is useful in installations where radio silence must be maintained except for brief transmission periods.

Antenna Coupler (CU-938A/URA-38( ) fig. 5-32) matches the impedance of a 15-, 25-, 28-, or 35-foot whip antenna to a 50-ohm transmission line, at any frequency in the 2- to 30-MHz range. When operating with the AN/URT-23(V), control signals from the associated antenna coupler control unit automatically tune the CU-938A/URA-38( ) Matching Network in less than five seconds. During manual and silent operation, tuning is accomplished by the operator with the controls mounted on the antenna coupler control unit. A low power (not to exceed 250 watts) cw signal is required for tuning. Once tuned, the CU-938A/URA-38( ) is capable of handling 1 kW of PEP and average power.

The CU-938A/URA-38( ) is enclosed in an aluminum, airtight, pressurized case. Access is gained to the chassis by removing the dome-shaped cover from the case. Fins on the bottom of the case carry heat from the unit. Six mounting feet enable the unit to be attached to the mast of a ship at the base of a whip antenna. The CU-938A/URA-38( ) is pressurized with dry nitrogen to aid internal heat transfer and prevent corona and arcing. All components of the CU-938A/URA-38( ) are secured to a chassis, which is mounted to the case so that an air duct exists between the chassis plate and the case. An internal fan circulates the nitrogen over and through the heat-producing elements and then through the air duct. While passing through the air duct, the nitrogen loses its heat to the bottom of the case. This heat is then transferred by convection through the fins on the case and by conduction through the mounting feet.

Antenna Coupler Control C-3698/URA-38( ) (fig. 5-34) provides power and control signals required to tune the CU-938A/URA-38( ). The control signals are either automatically produced by the C-3698/URA-38( ) when a tune cycle is initiated, or manually produced with the front panel controls.

RADIO TRANSMITTER T-827( )/URT

Radio Transmitter T-827( )/URT accepts audio or coded intelligence and converts it to one of 280,000 possible operating radio frequencies in the frequency range of 2.0 to 29.999 MHz. It is capable of operating in any of lsb, usb, isb, cw, fsk, and compatible AM (usb modulation plus carrier transmission) modes of operation. Tuning is accomplished digitally by means of five control knobs (MCS and KCS) and a switch (CPS) located on the front panel (fig. 5-35). The T-827( )/URT has a normal rf output level of at least 0.10 watt, and is designed to be used with an associated rf power amplifier such as the AM-3007/URT or the AM-3924(P)/URT.

In AM and ssb transmit modes of operation, the output from a handset is applied to the T-827( )/URT. The voice signals are amplified and used to modulate a 500-kHz local carrier, providing a 500-kHz IF. The resulting double sideband signal is filtered according to the mode of operation, amplified, and converted by a triple-conversion process to the desired rf operating frequency. The rf signal is power amplified to a nominal 0.1-watt level. In cw operation, the 500-kHz local carrier is inserted directly into the IF amplifiers at a coded rate. The signal is further processed in the same manner as the voice signals in the AM or ssb modes

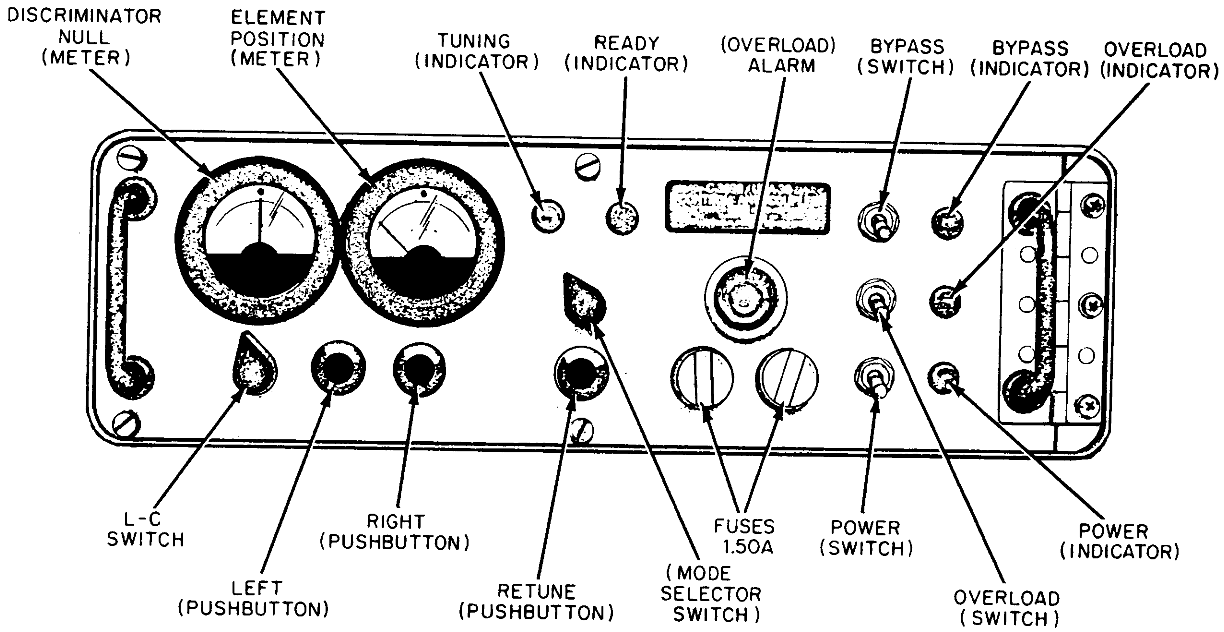


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Figure 5-34.—Antenna Coupler Control C-3698/URA-38.

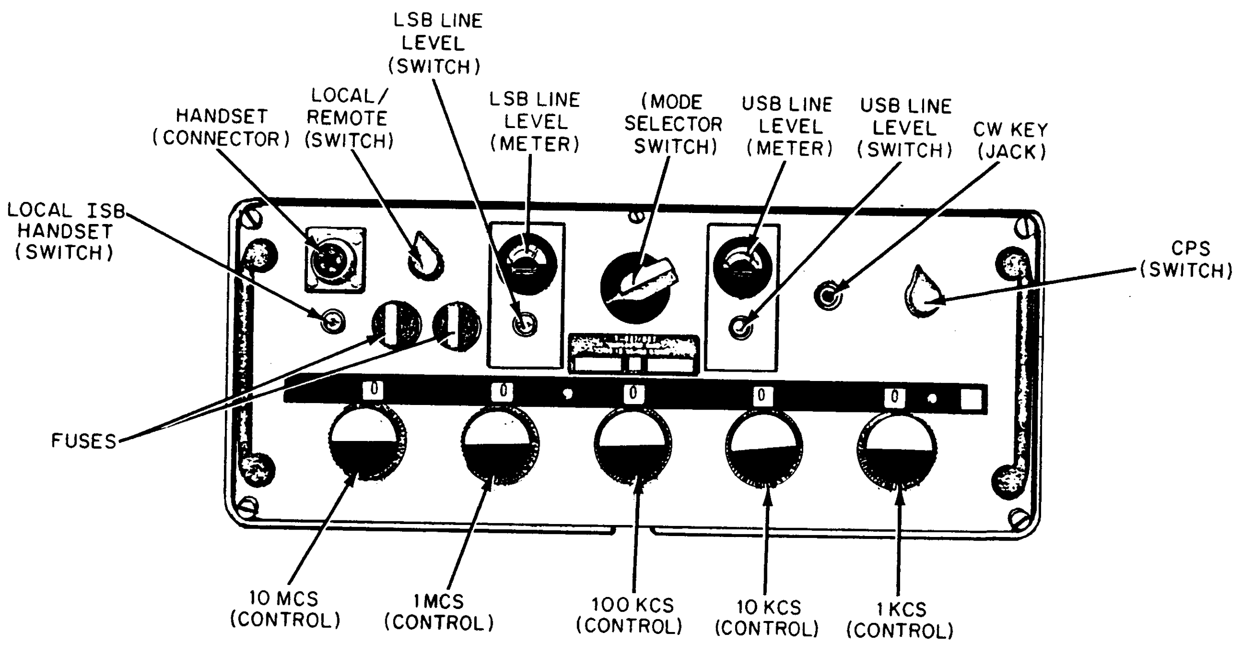

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Figure 5-35.—Radio Transmitting Set T-827( )/URT operating controls and indicators.

of operation. In fsk operation, the coded application of loop current is converted to audio frequencies representing marks and spaces. These audio signals are applied to the audio circuits of the T-827( )/URT. Thereafter, these signals are processed in the same manner as the voice signals in AM or ssb modes of operation.

RADIO RECEIVER R-1051/URR

Radio Receiver R-1051/URR is a triple-conversion superheterodyne receiver, tunable over the high frequency range from 2 to 30 MHz. Tuning of the R-1051/URR is accomplished digitally by five controls—MCS (MHz) and KCS (kHz)—and a switch, CPS (Hz), located on the front panel (fig. 5-36). A display window directly above each control provides a digital readout of the digits to which the controls are set. The displayed frequency can be changed in 1-kHz increments. The front panel switch allows the operating frequency to be changed in 500-Hz increments, or 100-Hz increments depending on the model. This tuning provides 280,000 discrete frequencies in which the receiver is locked to a very accurate frequency standard. Each 1-kHz increment can be continuously tuned through by selecting the VERNIER position of the CPS switch. When using the vernier, the full accuracy of the frequency standard is sacrificed. The R-1051/URR demodulates and provides audio outputs for the following types of received signals: lsb, usb, isb, AM, cw, and fsk.

ANTENNA DISTRIBUTION SYSTEMS

Receiving antenna distribution systems operate at low power levels and so are readily adaptable to a standard modular construction form. A basic patch panel is shown in figure 5-37. Even the most basic distribution system would have several antenna transmission lines and several receivers. The patch panel would consist of two of the basic patch panels shown in

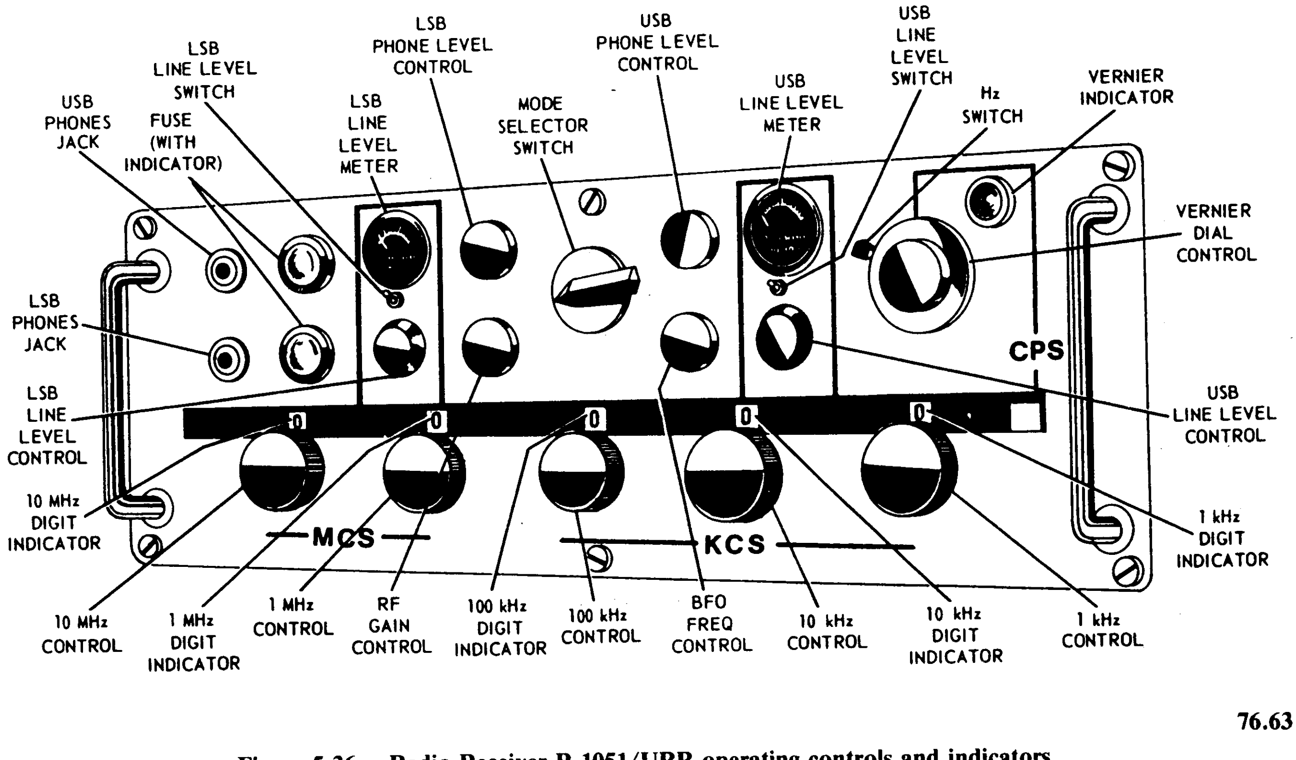


Figure 5-36.—Radio Receiver R-1051/URR operating controls and indicators.

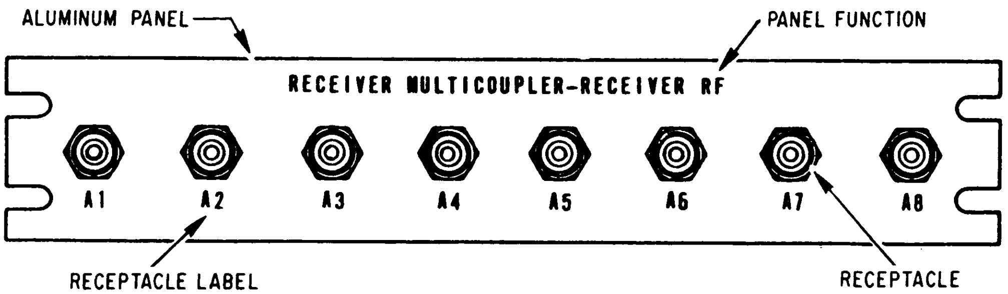


Figure 5-37.—Receiver patch panel. 67.226

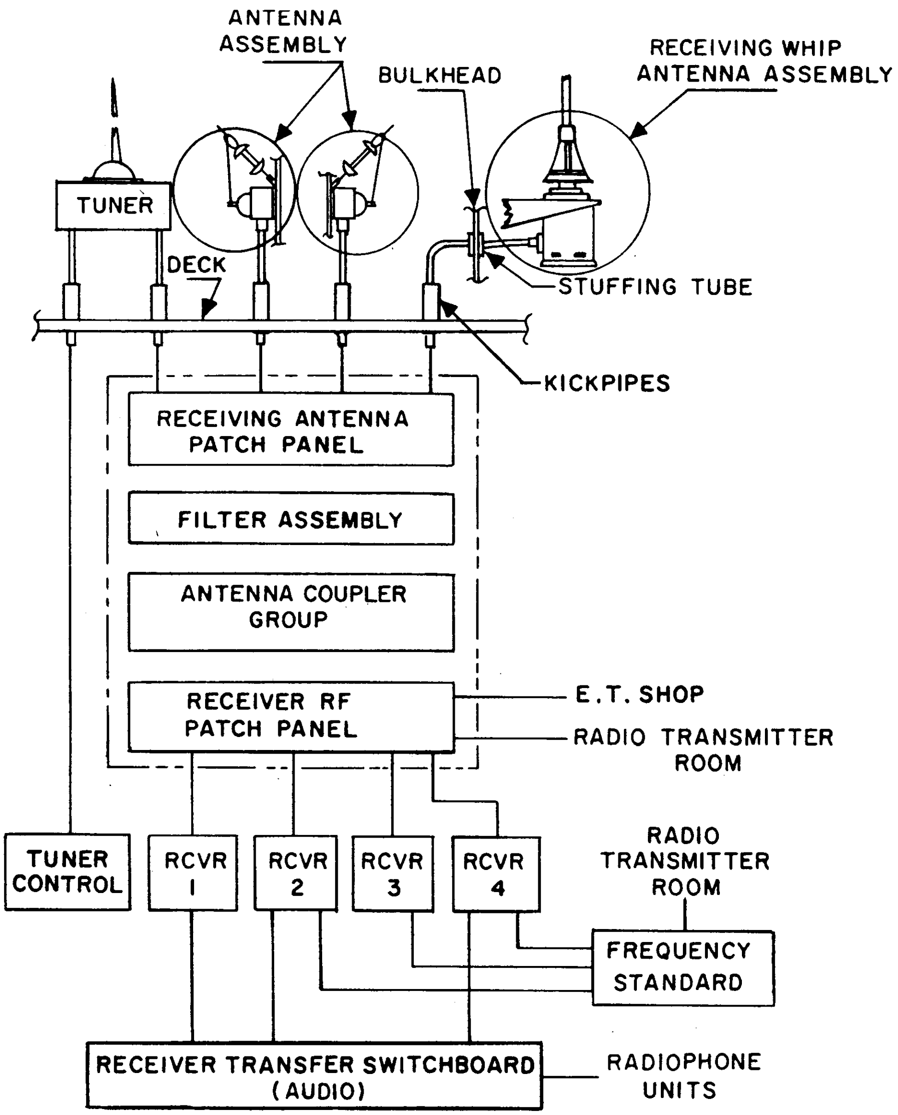


Figure 5-38.—Complex distribution system. 67.227

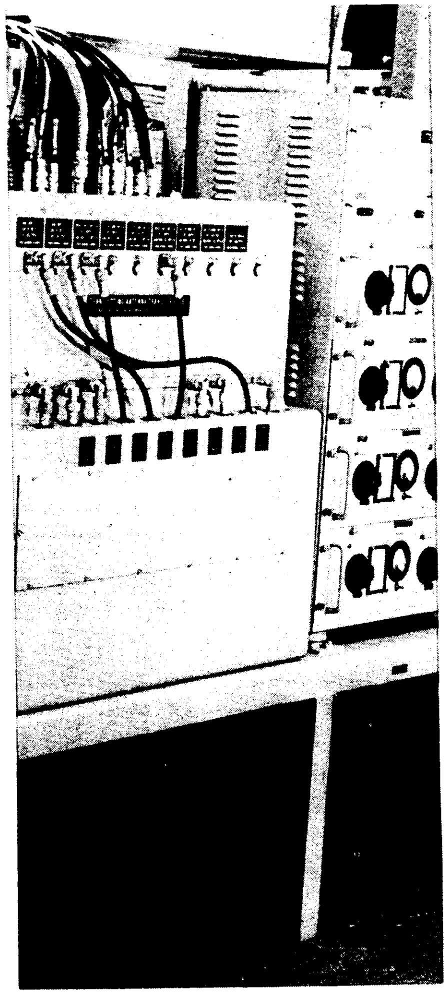
figure 5-37 mounted in a standard 19-inch rack. One panel would terminate the antenna transmission lines and the other the lines leading to the receivers. Thus any antenna could be patched to any receiver via patch cords.

Many distribution systems will be more complex. A complex distribution system to cover most situations is illustrated in figure 5-38. In this system, four antennas can be patched to four receivers, or one antenna can be patched to more than one receiver via the multicouplers. (Multicouplers are covered later in the chapter.) There are also provisions for patching rf and audio from one compartment to another. A frequency standard is connected (through a distribution amplifier not shown) to the receivers.

Transmitting antenna distribution systems perform the same functions as receiving systems. However, because of the range in power levels, design and fabrication problems are more difficult. The ideal design would be to have all the transmission lines designed for the highest power level. But, because of cost and the fact that high-power patch cords are large and difficult to handle, this approach is seldom followed.

In practice, a patch panel similar to the one shown for receiving systems (fig. 5-37) is practical for low power levels. Another type of transmitter patch panel is shown in figure 5-39.

These transmitting patch panels are interlocked with the transmitter so that no open jack connection can be energized and no energized patch cord can be removed. This provides safety for both personnel and equipment.



70.27

Figure 5-39.—Transmitting antenna patch panel.

RECEIVING MULTICOUPLER

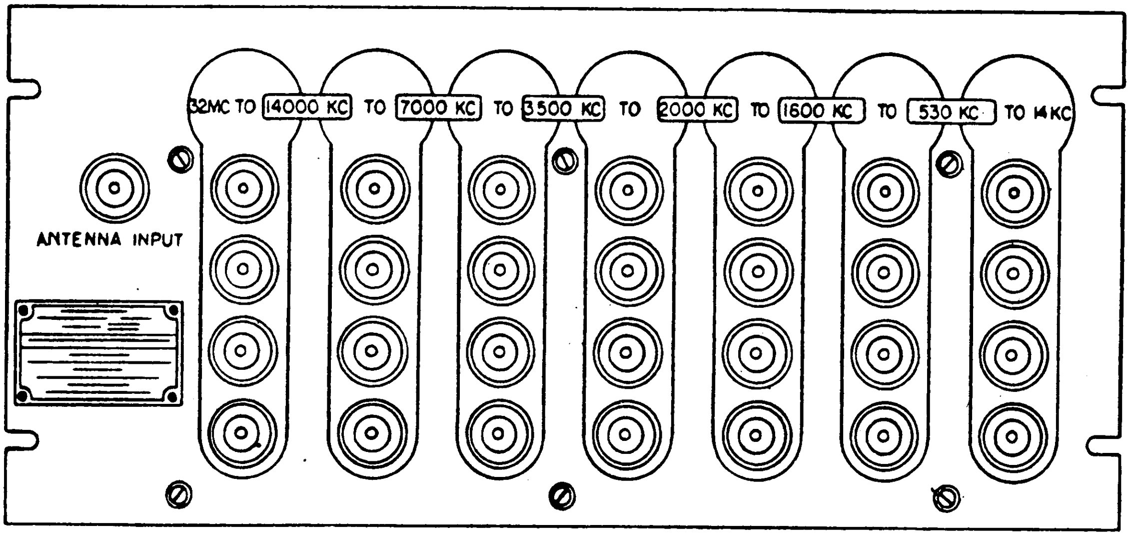
The AN/SRA-12 (fig. 5-40) filter assembly multicoupler provides seven radio frequency channels in the frequency range from 14 kHz to 32 MHz. Any or all of these channels may be used independently of any of the other channels, or they may operate simultaneously. Connections to the receiver are made by means of coaxial patch cords, which are short lengths of cable with plugs attached to each end.

A set of nine plug-in type filter assemblies is furnished with the equipment, but only seven of them may be installed at one time. The seven filters installed are selected to cover the most-used frequency bands.

Figure 5-38 illustrates how the AN/SRA-12 is used as a portion of the receiving multicoupler along with the receiving antenna patch panel (fig. 5-37) and the receiver rf patch panel. (The patch panels used for the receiver antenna and the receiver rf are normally the same panels.) The signal from the antenna can be passed to any number of receivers.

HF MULTICOUPLERS

Most of the multicouplers for the hf range are designed for use with either transmitters or



1.115

Figure 5-40.—Electrical Filter Assembly AN/SRA-12.

receivers, although there are some which are used with both. Because of the large size of antennas (particularly in the 2- to 12-MHz range), the number of channels in hf multicouplers is usually made as large as practical.

Antenna Coupler Groups AN/SRA-56,-57, and -58

Antenna Coupler Groups AN/SRA-56, -57, and -58 are designed primarily for shipboard use. Each coupler group permits several transmitters to operate simultaneously into a single, associated, broadband antenna, thus reducing the total number of antennas required in the limited space aboard ship.

These antenna coupler groups provide a coupling path of prescribed efficiency between each transmitter and the associated antenna. They also provide isolation between transmitters, tunable bandpass filters to suppress harmonic and spurious transmitter outputs, and matching networks to reduce antenna impedances.

GENERAL DESCRIPTION.—The three antenna coupler groups (AN/SRA-56, -57, -58, fig. 5-41) are similar in appearance and function. They differ in frequency ranges and the capability of providing four-channel or eight-channel configurations. Antenna Coupler Group AN/SRA-56 operates in the frequency range from 2 to 6 MHz. The AN/SRA-57, operates from 4 to 12 MHz, and the AN/SRA-58, operates in the 10- to 30-MHz range. Antenna Coupler Groups AN/SRA-56 or -57 can each be operated alone in a four-channel configuration, or two of the same antenna coupler groups can be combined by means of an impedance matching network to form an eight-channel configuration. Antenna Coupler Group AN/SRA-58 can be used in a four-channel configuration only.

A single antenna coupler group consists of four antenna couplers (channels), built as drawer assemblies and installed in an electrical equipment cabinet, and a power supply installed in the bottom position of the cabinet (fig. 5-41). The antenna coupler groups are modular in design. All antenna coupler drawers are interchangeable within the same antenna coupler group. The power supply assemblies and many of the subassemblies and components in the equipment cabinets and in the antenna coupler drawers are interchangeable within all three coupler groups. Each antenna coupler group is a self-contained unit having all required rf

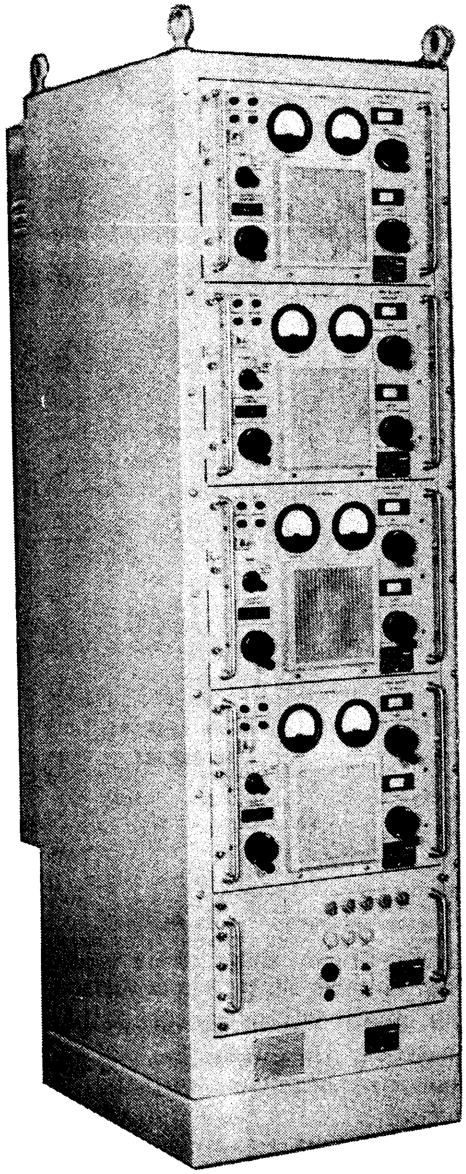


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Figure 5-41.—Antenna coupler group AN/SRA-56, AN/SRA-57, or AN/SRA-58.

circuits, operational controls, monitoring, control, and protective circuits, and power distribution and supply circuits housed within the electrical equipment cabinet.

Each antenna coupler group or eight-channel configuration operates with a separate broadband antenna having a maximum vswr of 3- to -1 over the nominal frequency range of the associated antenna coupler group. The antenna coupler groups can operate with transmitters having power outputs as high as 1 kilowatt average and 2 kilowatts peak envelope power for each channel, and as low as 50 watts average per channel. Any individual coupler within a coupler group may be operated at any frequency within its tuning range, provided that it does not operate within five percent of the frequency occupied by another coupler within the same group.

Each antenna coupler contains monitoring, control, and protective circuits that provide and enforce sequential tuning operation. The power supply panel in each coupler group contains a fused circuit that provides a.c. to operate the cooling air fans in each antenna coupler to remove the heat generated during tuning and operation. Also provided is a power supply that provides d.c. to operate the control and protective circuits, and a sonic generator that provides an audible alarm to warn the operator of a loss of air flow within an antenna coupler.

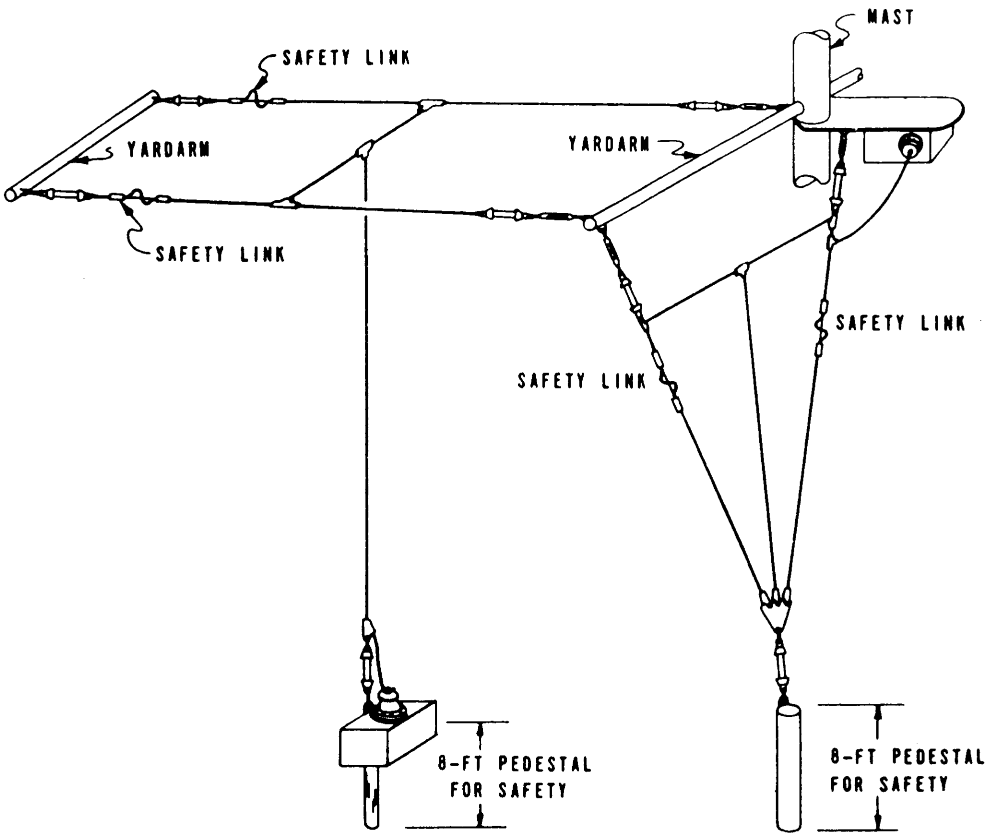
ANTENNAS

Antenna theory and basic antennas are discussed in *Basic Electronics, Volume 1,* NAVPERS 10087 (Series) and the Navy Electricity and Electronics Training Series (NEETS). This section describes some of the common types of antennas used with shipboard communication systems.

WIRE ANTENNAS

A wire antenna consists of a wire rope suspended either vertically or horizontally from a yardarm or the mast itself to outriggers, to another mast, or to the superstructure. A simplified diagram of a shipboard wire antenna is shown in figure 5-42.

Single wire antennas are not used aboard ship as extensively as they were used in the past. They have, to a large extent, been replaced by whip, dipole, and other antenna assemblies. In some installations, wire antennas are used only in emergencies.



1.46

Figure 5-42.—Wire rope antenna.

Because of the frequency range in which these antennas are used, the portion of the ship's structure used to support the wire and other nearby structures is an electrically integral part of the wire antenna. Therefore, wire antennas are usually designed for a particular ship or installation.

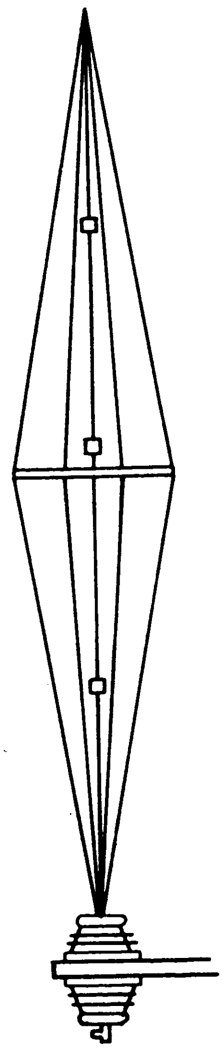
Transmitting and receiving antenna wire rope will have Vinylite insulating jacket (as will transceiving wire antennas) to reduce interference from precipitation static (static interference due to the discharge of large charges built up by rain, sleet, snow or electrically charged clouds).

WHIP ANTENNAS

Because whip antennas are essentially self-supporting, they may be installed in many locations aboard ship where space is at a premium, and locations are unsuitable for other antenna types. They may be deck mounted or mounted on brackets on the stacks or superstructure.

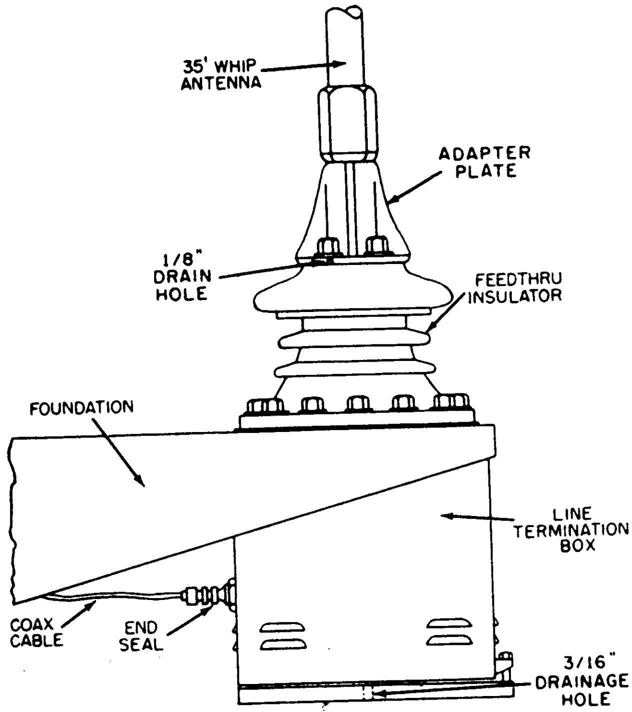
Whip antennas that are to be used for receiving only are mounted as far away from the transmitting antennas as possible so that a minimum of energy from the local transmitter will be picked up.

One type of whip antenna commonly used aboard ship is constructed with seven-foot sections of aluminum rod. The lower rod is three inches in diameter and the whip tapers to a diameter of one inch at the upper section. (Fiberglass whips are replacing the aluminum whips in some installations.) Some whips may be trussed with wire rope (which increases the



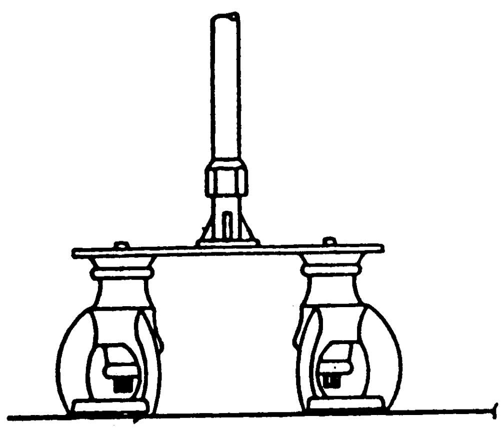
67.218

Figure 5-43.—Trussed whip antenna.



1.47

Figure 5-44.—Method of mounting whip antenna of 35 feet or less.

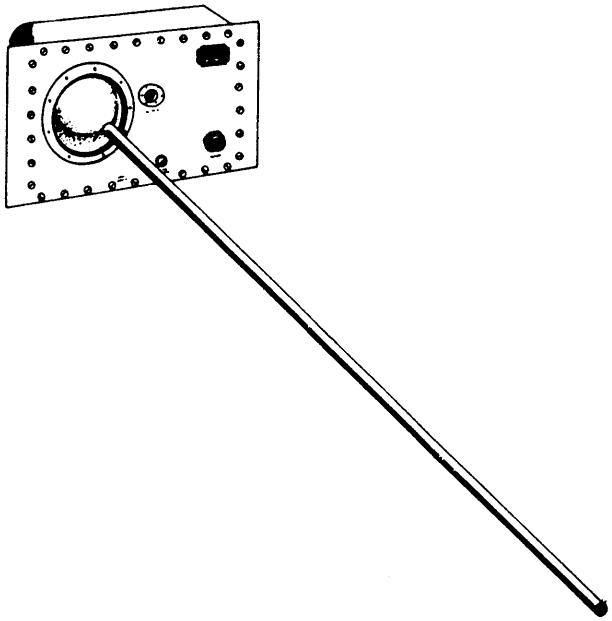


67.219

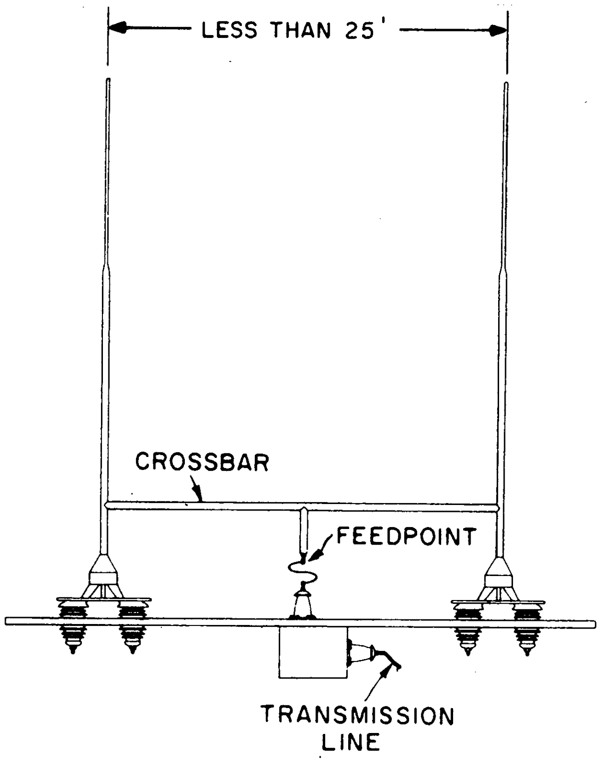
Figure 5-45.—Method of mounting whip antenna over 35 feet.

frequency bandwidth) resulting in better performance (fig. 5-43). The recommended method for mounting a receiving whip antenna up to 35 feet in length is shown in figure 5-44. Whip antennas over 35 feet are mounted on a plate supported by three or four insulators (fig. 5-45) for greater strength. Small whip antennas have been mounted horizontally on yardarms or masts in some installations for use as low-frequency probe antennas. Such antennas usually come supplied with a line termination box (fig. 5-46) which is normally mounted to the ship's structure. Some applications use two whips connected as a single antenna for better electrical performance.

If the antennas are less than 25 feet apart, they are usually connected with a crossbar (fig. 5-47) which is the feedpoint at its center. If the antennas are a considerable distance apart, or for some other reason a direct connection is not



67.220
Figure 5-46.—Small whip antenna with line termination box.



67.221
Figure 5-47.—Twin whip antennas with crossbar terminations.

practical, transmission line termination is used. In figure 5-48, the transmission lines (of equal length) are fed to a tee, which is the assembly feed point. Each whip is usually matched individually to the transmission line by antenna base matching networks. Wire rope is used in place of the whips in some installations.

On aircraft carriers and missile ships, a method of tilting the whip antenna (fig. 5-49) is employed for those installed along the edges of the flight deck or in the missile firing zone.

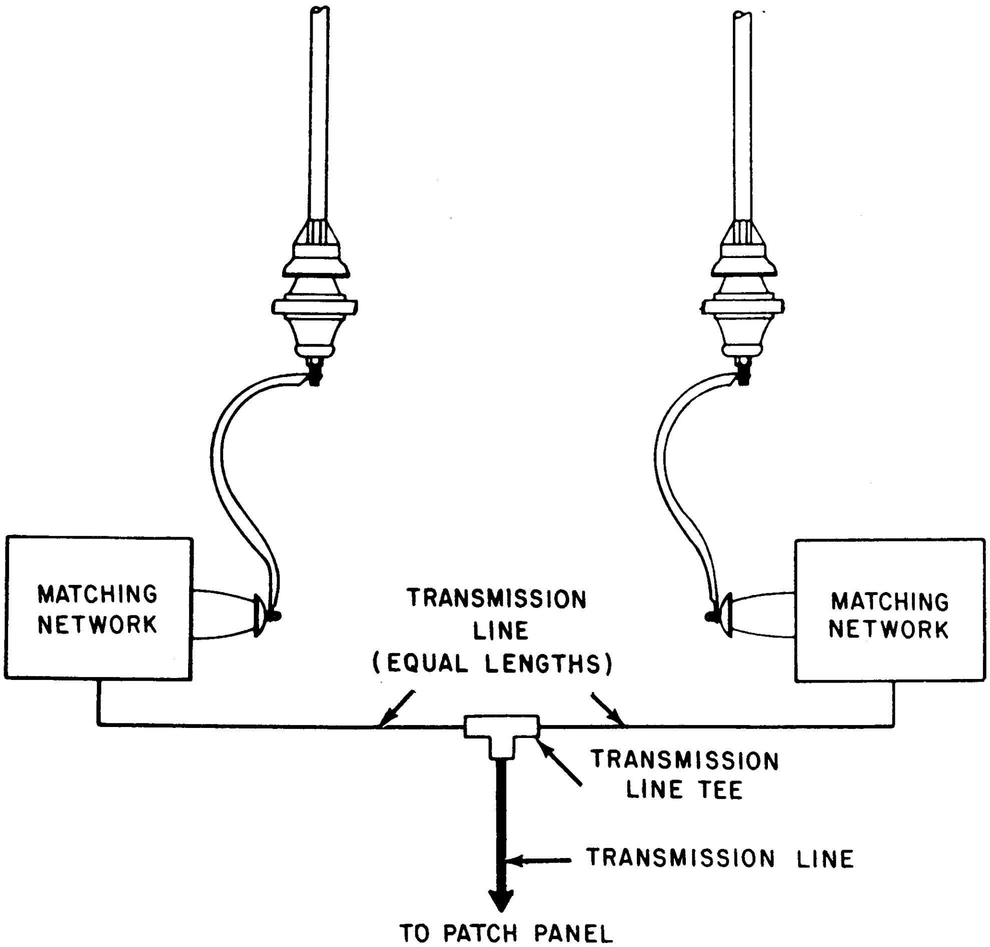
The tilting mounts may be mechanically or hydraulically operated. Mechanically operated mounts have a counterweight at the base of the antenna heavy enough to balance the antenna in almost any position. The antenna may be locked in either a vertical or horizontal position by positive locking devices in both the operating and stowed positions.

BROADBAND ANTENNAS

Broadband antennas for use in the hf and the uhf bands have been developed for use with antenna multicouplers. To be used with a multicoupler, the antenna must be capable of handling simultaneous transmissions from several transmitters without excessive loss of power in the multicoupler equipment. The antenna must, therefore, function satisfactorily over a relatively wide band of frequencies.

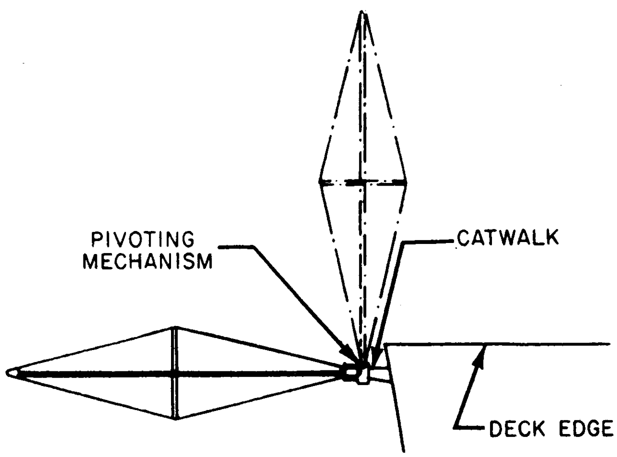
The effectiveness of a given antenna depends largely on impedance matching. If a good impedance match exists between the transmission line and the antenna throughout the operating band of frequencies, efficiency and power transfer are improved.

One type of broadband antenna, called a fan, is shown in figure 5-50. Effectively, this is a V-shaped plane radiator. Physically, it is composed of five wires cut for one-quarter wavelength at the lowest frequency to be used. The wires are fanned 30 degrees between



67.222

Figure 5-48.—Twin whip antennas with coaxial terminations.



67.223

Figure 5-49.—Tilting whip antenna.

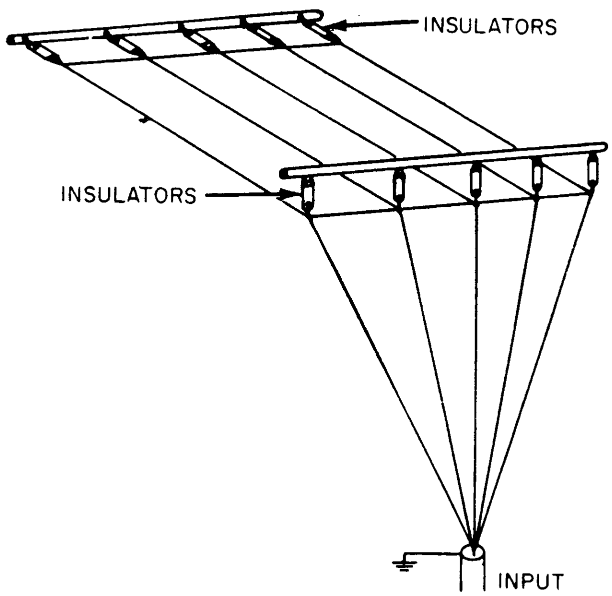
adjacent wires. On small ships, the fan antenna may consist of only three or four wires. Ships may have two fan antennas, one a vertical fan and the other a horizontal fan antenna.

UHF ANTENNAS

A large variety of uhf antennas have been developed for shipboard use. Two of these antennas (AT-150/SRC and AS-390/SRC) are shown in figures 5-51 and 5-52. They are used for transmitting or receiving vertically polarized waves in the 220- and 400-MHz range.

MATCHING NETWORKS

An antenna matching network consists of one or more parts such as coils, capacitors, and



67.134

Figure 5-50.—Five-wire vertical fan antenna.

lengths of transmission line connected in series or parallel with the transmission line to reduce the standing wave ratio on the line. Matching networks are usually adjusted upon installation and require no further adjustment for proper operation. Figure 5-53 shows a matching network outside of the antenna feedbox with a sample matching network schematic.

Matching networks can also be built with variable components so that they can be used for impedance matching over a band of frequencies. These networks are called antenna tuners.

Antenna tuners are usually adjusted automatically or manually each time the operating frequency is changed. Standard tuners are made with integral enclosures so that installation consists simply of mounting the tuner, assembling the connections with the antenna and transmission line, and pressurizing if required. Access must be provided to the pressure gauge and pressurizing and purging connections.

COMMUNICATIONS SYSTEMS EQUIPMENT CONFIGURATIONS

Shipboard communications are highly sophisticated and versatile. Through equipment design and installation, many equipments are compatible with each other and can be used to accomplish many functions. With this design concept, nearly all of the communications needs for a ship can be met with fewer pieces of communications equipment than were previously required.

An example of this is a radio operator operating a communications link with another ship. The radio operator is required to send and receive teletype information to the other ship. In order to do this, the operator must first establish voice communications with the ship that requires the service. From a position in Facilities Control, the operator can use switching arrangements to connect a uhf transceiver to a local position for voice communications, and can connect a teletypewriter to an hf transmitter and receiver for transmission and reception of the teletype information. This arrangement allows the operator to use the communications equipment for different functions, while remaining at the operating position. This is just one of the many combinations that are available and used in normal shipboard communications.

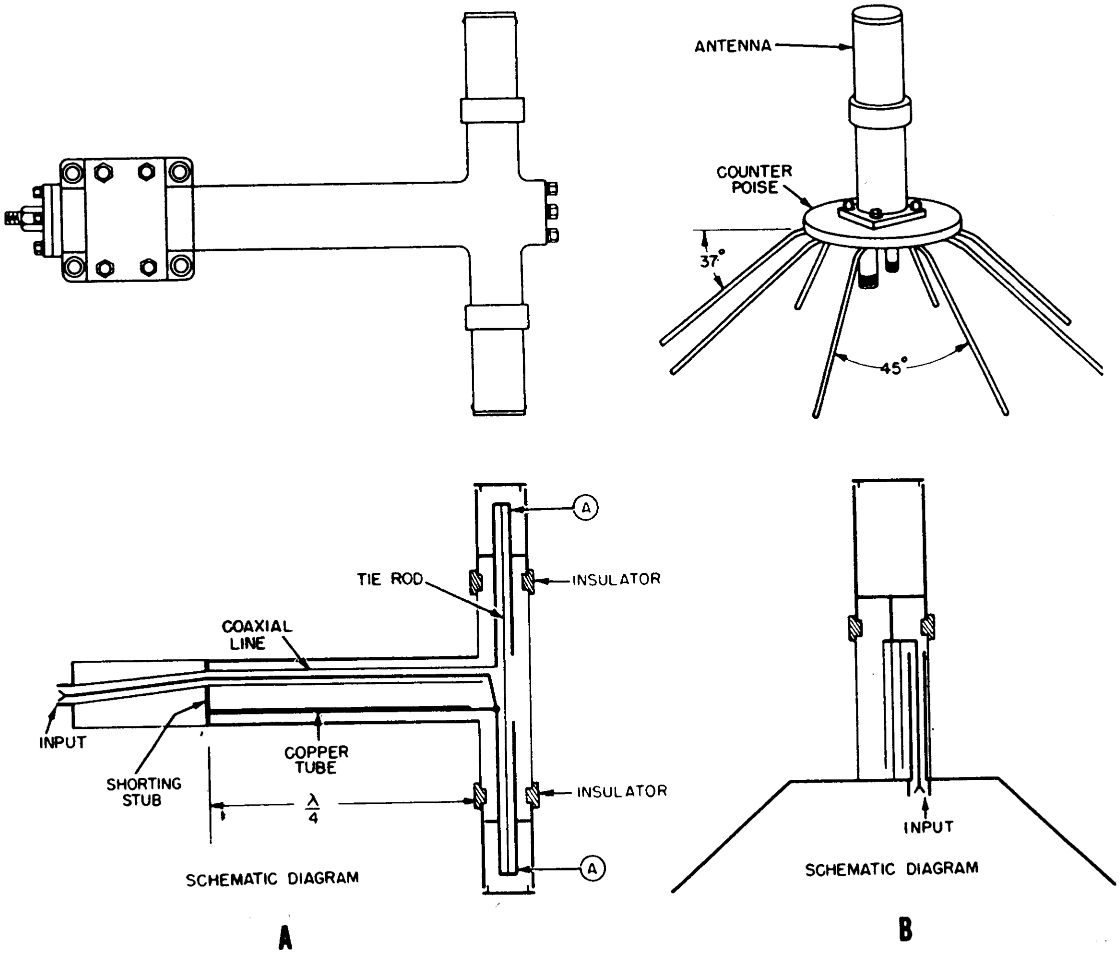
In this discussion, communication equipment configurations are explained individually. Then they are shown coupled with one another, forming a simple block diagram of the systems covered. Included are the low-frequency, high-frequency, very high frequency, and ultrahigh-frequency systems.

LOW FREQUENCY

The low-frequency band is used for long-range direction finding, medium- and long-range communications, and aeronautical radio navigation.

Low-frequency Transmit (Normally on shore stations or special applications only)

The low-frequency transmitter is used to transmit a high-powered signal over very long distances. The AN/FRT-72 transmitter (fig. 5-54) is designed for this purpose. The transmitter produces 50-kW peak-envelope power (25 kW average power) and covers a frequency range of 30 to 150 kHz.



67.80

Figure 5-51.—UHF antennas.

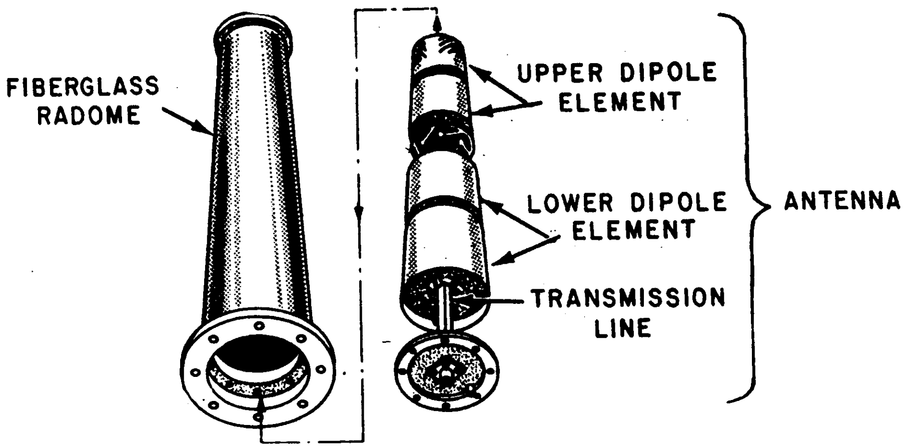


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Figure 5-52.—Mast covered UHF antenna.

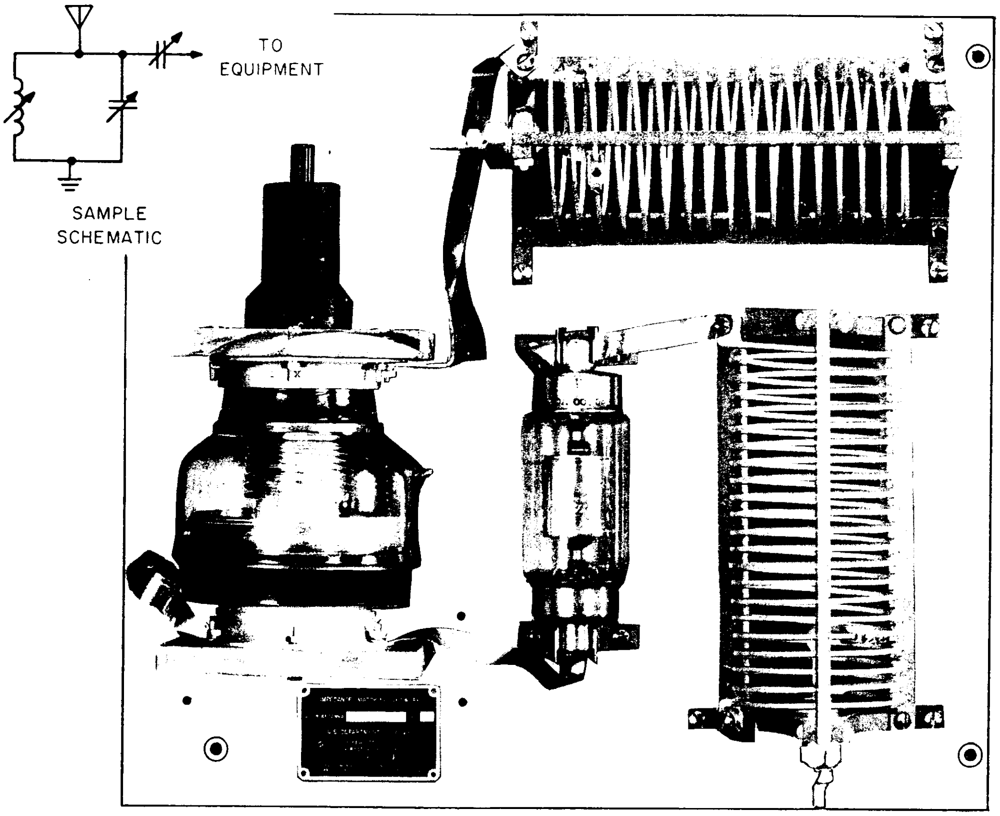
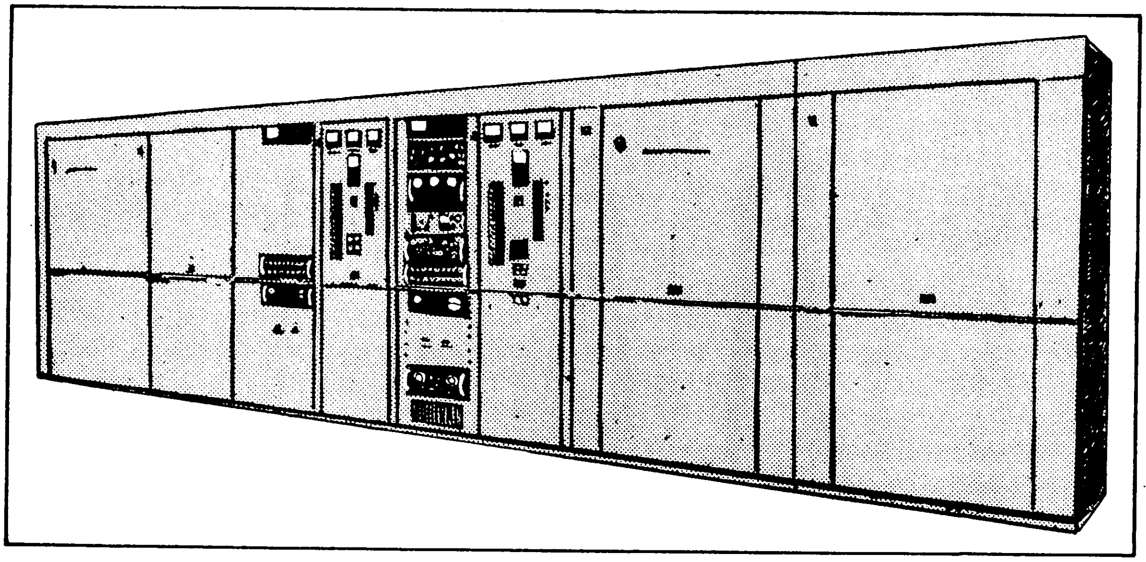


Figure 5-53.—Matching network. **67.225**



162.181

Figure 5-54.—Radio Transmitting Set AN/FRT-72.

Low-frequency Receive

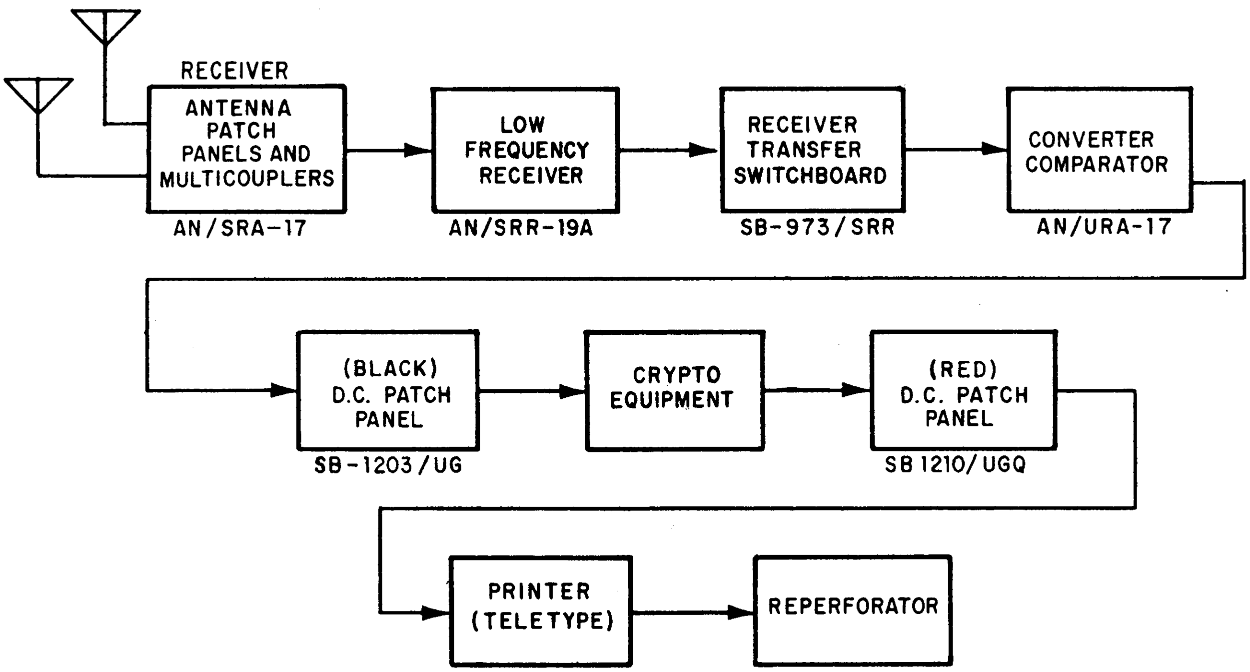
The low-frequency receive system is designed to receive low-frequency broadcast signals and reproduce the intelligence that is transmitted. A typical low-frequency receive system is shown in figure 5-55. The low-frequency signal is received by the antennas and connected to a receiver antenna multicoupler and patch panel. The multicoupler and patch panel AN/SRA-17, allow the operator to select different antennas and connect them to different receivers, thus selecting the correct combination suited for a particular job. In the low-frequency receive system in figure 5-55, the receiver used is the AN/SRR-19A. The AN/SRR-19A operates in the frequency range of 30 to 300 kHz. The output of the receiver (audio) is fed to Receiver Transfer Switchboard SB-973/SRR. The switchboard can connect the receiver output to numerous pieces of equipment. In figure 5-55, the receiver output is connected to Converter Comparator Set AN/URA-17. The converter comparator set converts the received signal to d.c. for use by the teletype equipment. The d.c. output of the AN/URA-17 is fed to D.C. Patch Panel SB-1203/UG. The d.c. patch panel permits the signal to be patched to any crypto equipment desired. The crypto equipment decrypts the signal and its output is connected to red D.C. Patch Panels SB-1210/UGQ. The SB-1210/UGQ can be patched to a selected teletype printer that prints the signal in plain text, or to a reperforator where a paper tape will be punched for storage to be printed at a later date.

HIGH FREQUENCY

The high-frequency band, 3 to 30 MHz, is used primarily by mobile and maritime units. The military uses this band for long-range voice and teletype communications. This band is also used as a backup system for the satellite communications system.

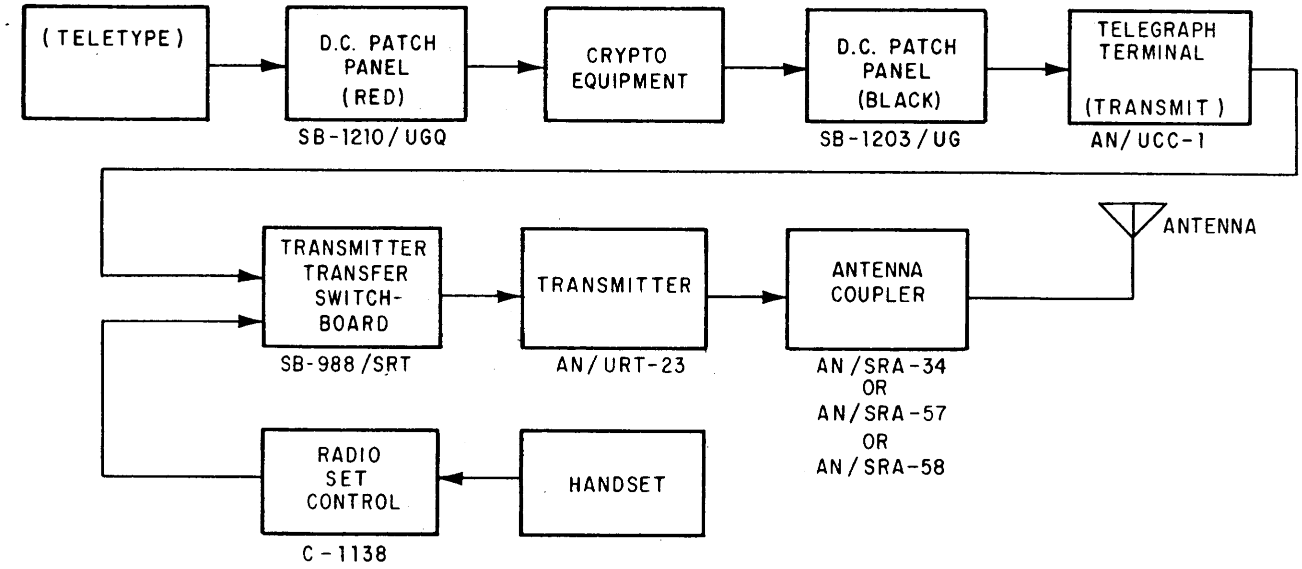
High-Frequency Transmit

The high-frequency transmit signal can be either voice or teletype information. Figure 5-56



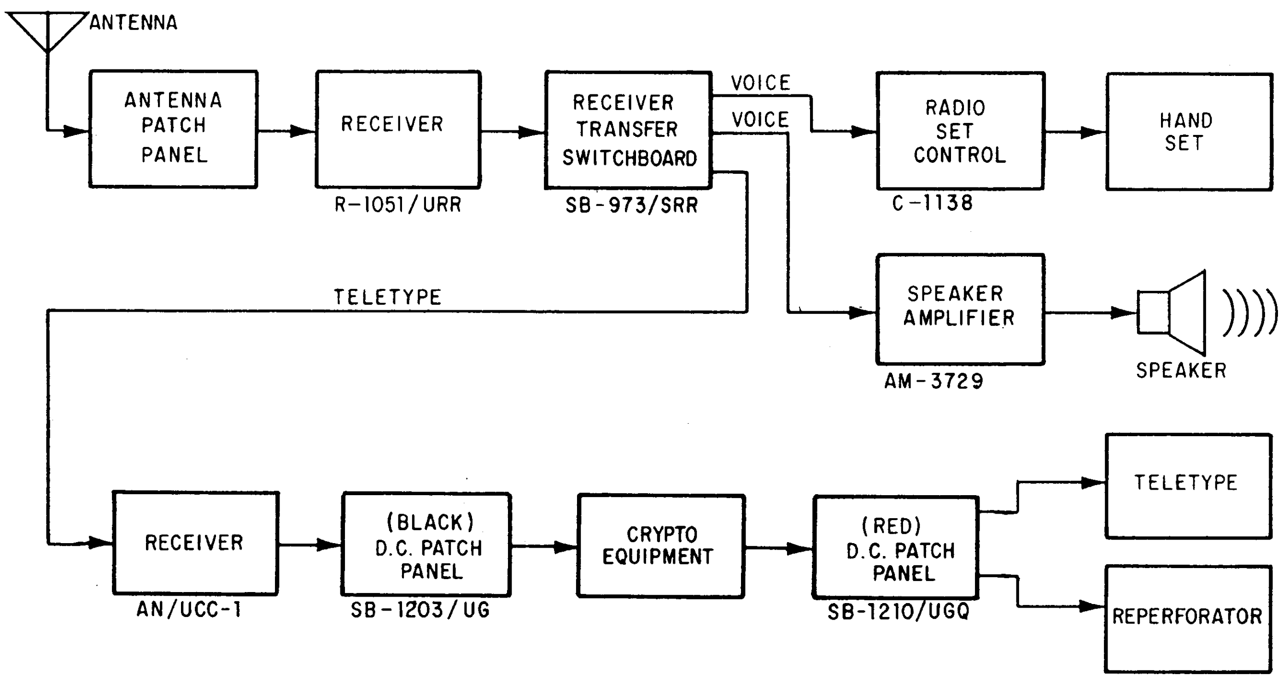
162.378

Figure 5-55.—Low-frequency receive system.



162.379

Figure 5-56.—High-frequency transmit system.



162.380

Figure 5-57.—High-frequency receive system.

shows a typical high-frequency transmit system employed aboard ship.

For the transmission of teletype information, the equipment used (the teletype, D.C. Patch Panel SB-1210/UGQ, the crypto equipment, and D.C. Patch Panel SB-1203/UG) are the same and perform the same functions as they did in the low-frequency receive system, except that they do it in reverse order.

Telegraph Terminal AN/UCC-1(V) (explained earlier in this text) converts d.c. signals into tone signals. The output of the AN/UCC-1(V) is connected to Transmitter Transfer Switchboard SB-988/SRT. Voice communications from some remote locations are also connected to this switchboard. The voice communications are developed at a handset (remote phone unit) and connected to Radio Set Control C-1138. The output of the radio set control is connected to Transmitter Transfer Switchboard SB-988/SRT. The transmitter transfer switchboard permits the operator to select the proper transmitter for the frequency to be transmitted. Transmitter AN/URT-23 receives the input signal from the switchboard and changes the signal to an rf signal that is connected to Antenna Coupler AN/SRA-34, -57, or -58. The antenna coupler is used to match the output impedance of the transmitter to the input impedance of the antenna. Antenna couplers also permit more than one transmitter to be connected to the same antenna as long as certain conditions are met. When the signal reaches the antenna it is radiated into the atmosphere.

High-Frequency Receive

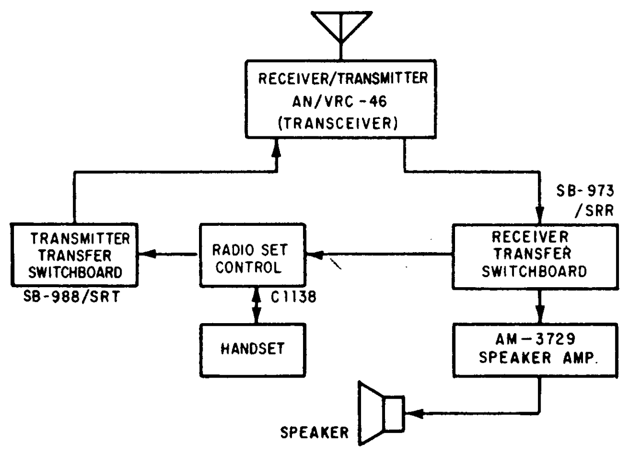
A typical high-frequency receive system is shown in figure 5-57. A transmitted signal, similar to the one just developed in the previous section, is received by the antenna, which converts electromagnetic energy to electrical energy. The signal is connected to an antenna patch panel where it can be distributed to any number of receivers. In figure 5-57, Receiver R-1051/URR converts the rf signal into a teletype signal (fsk) or a voice signal, depending upon which is desired. The output of the receiver is then connected to Receiver Transfer Switchboard SB-973/SRR. The teletype signal from the SB-973/SRR will follow the same path used by the low-frequency signal. Identical pieces of equipment are used and they perform the same functions. The voice signal from Receiver Transfer Switchboard SB-973/SRR is sent to Radio Set Control C-1138. The output is then connected to a handset. The voice signal can also be sent from the switchboard to remote Speaker Amplifier AM-3729. There, it can be placed on a speaker so that the user can listen to the received signal without holding onto the handset.

VERY HIGH FREQUENCY

The very high frequency band, 30 to 300 MHz, is used for aeronautical radio navigation and communications, radar, amateur radio, and mobile communications. The Navy uses this band for mobile communications, such as for boat crews and landing parties.

Very High Frequency Transmit

A basic block diagram of a vhf transmit and receive system is shown in figure 5-58. On the transmit side of the system, the operator, at a remote location, talks into the handset. The handset is connected to Radio Set Control C-1138. The output of the radio set control is connected to Transmitter Transfer Switchboard SB-988/SRT. The switchboard performs the



162.381

Figure 5-58.—Very high frequency transmit and receive.

same function as it did in the lf and hf systems. The output of the switchboard is connected to the transmit side of the Receiver/Transmitter AN/VRC-46 (transceiver). The transceiver converts the input signal to an rf signal for radiation by the antenna.

Very High Frequency Receive

The incoming signal (fig. 5-58) is received by the antenna. The signal is connected to the receive side of Transceiver AN/VRC-46. The output of the transceiver is connected to Receiver Transfer Switchboard SB-973/SRR. The output of the receiver transfer switchboard is connected to either Radio Set Control C-1138 or Speaker Amplifier AM-3729, or both, depending on the preference of the user. The output of the radio set control is connected to the handset. The output of the speaker amplifier is connected to the speaker.

ULTRAHIGH FREQUENCY

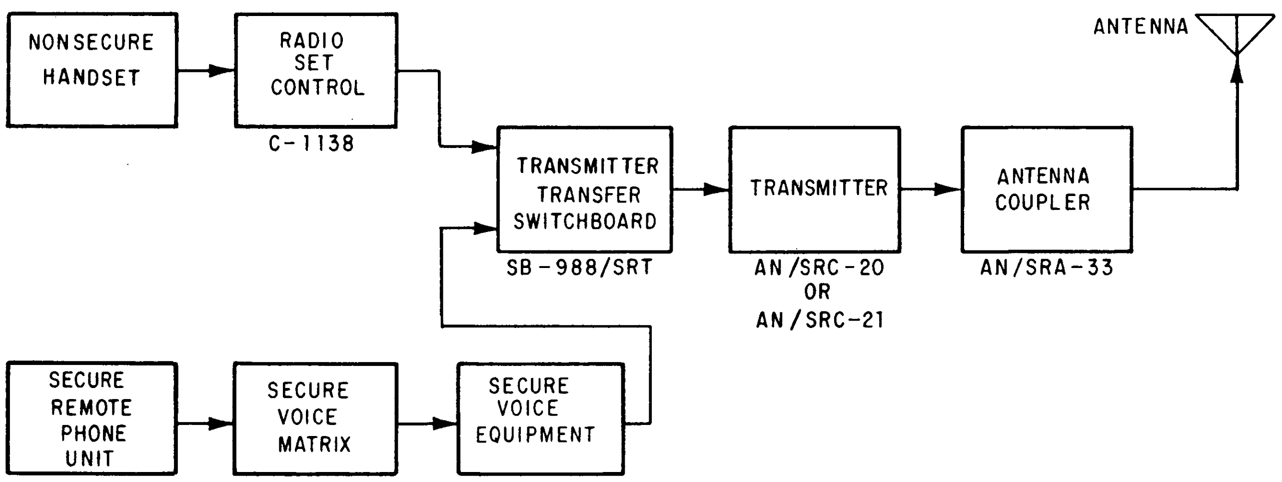
The ultrahigh-frequency band is used for line-of-sight (short-range) communications. Line-of-sight means that both antennas must be able to see each other for proper operation. This band is also used for satellite communications. Satellite communications are still line-of-sight (though the distance traveled by the signal is much greater than that of surface communications) because the antennas remain in sight of each other.

The transmitter and receiver used in the uhf system form one piece of equipment (a transceiver); however, the transmit and receive systems will be described separately. At the conclusion of this chapter, these two systems will be tied together and shown as a single complete system in the overall block diagram.

Ultrahigh-Frequency Transmit

A basic block diagram of a uhf transmit system is shown in figure 5-59. On the transmit side of the nonsecure voice system, the operator at a remote location talks into the handset. The handset is connected to Radio Set Control C-1138. The C-1138 is connected to Transmitter Transfer Switchboard SB-988/SRT, where it is patched to the transmitter.

On the transmit side of the secure voice system, the operator at a remote location talks into the secure voice remote phone unit (RPU). The RPU is connected to the secure voice matrix. The matrix is the tie point for the connection of more than one remote phone unit. The output of the matrix is connected to the secure voice equipment which encrypts the



162.382

Figure 5-59.—Ultrahigh frequency transmit.

information received. The output of the secure voice equipment is connected to Transmitter Transfer Switchboard SB-988/SRT.

The transmitter transfer switchboard is used to connect numerous remote phone units to any number of transmitters. The output of the patch panel is connected to the transmitter side of the AN/SRC-20/21, which in turn is connected to Antenna Coupler AN/SRA-33. The output of the AN/SRA-33 is connected to the antenna.

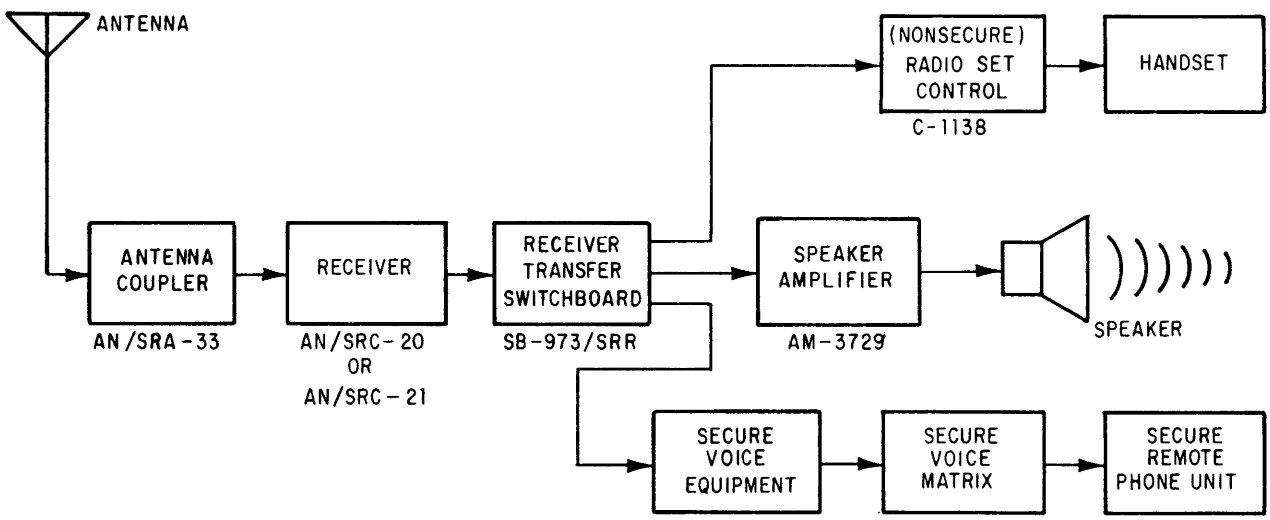
Ultrahigh-Frequency Receive

A basic block diagram of a uhf receive system is shown in figure 5-60. The received signal is picked up by the antenna and connected to the receiver side of the AN/SRC-20/21, through Antenna Coupler AN/SRA-33. The output of the receiver is connected to Receiver Transfer Switchboard SB-973/SRR, where it can be connected to either the nonsecure or the secure voice systems, depending upon the mode of transmission. When a nonsecure signal is received, the output of the receive transfer switchboard is connected to either Radio Set Control C-1138 or Speaker Amplifier AM-3729, or both, depending on the preference of the user. The output of the radio set control is connected to a handset. The output of the speaker amplifier is connected to a speaker.

If a secure voice transmission is received, the output of the receiver transfer switchboard is connected to the secure voice equipment, where it is decrypted. The output of the secure voice equipment is connected to the secure voice matrix which performs the same function as the matrix on the transmit system. The output of the secure voice matrix is connected to the secure remote phone unit, where the signal is converted back to its original form.

COMMUNICATIONS EQUIPMENT CONFIGURATION

All of the communications equipment described in this chapter are combined in figure 5-61 (a foldout at the end of this chapter) to show a representative shipboard communication system. Each system that has been described can be followed on figure 5-61. This figure illustrates that one piece of equipment can be used for more than one system. Examples of this are Transmitter Transfer Switchboard SB-988/SRT and the Receiver Transfer Switchboard SB-973/SRR. With the equipment connected as shown, it is readily apparent that one operator,



162.383

Figure 5-60.—Ultrahigh frequency receive.

at any given location, has access to any number of different pieces of equipment, using different patching arrangements. Such arrangements allow the operator to accomplish the mission assigned.

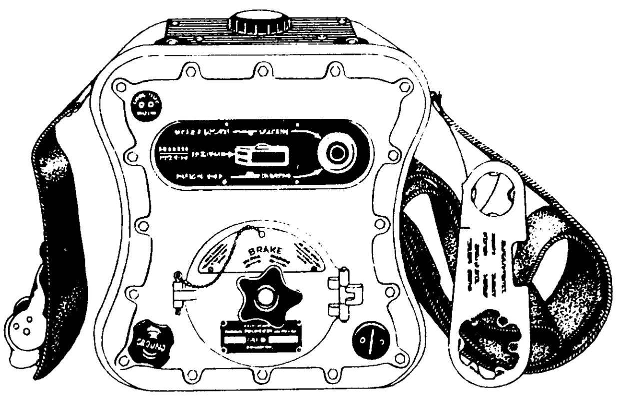
PORTABLE AND PACK RADIO EQUIPMENT

Because portable and pack radio sets must be lightweight, compact, and self-contained, they usually are powered by battery or hand generator, have low output power, and are either transceivers or transmitter-receivers. Navy ships carry a variety of these radio sets for emergency and amphibious communications. The numbers and types of this equipment vary according to the individual ship.

Transmitter AN/CRT-3A

Radio Transmitter AN/CRT-3A, popularly known as the "Gibson girl," is a rugged emergency transmitter carried aboard ships and aircraft for use in lifeboats and liferafts. It is shown in figure 5-62. No receiving equipment is included.

The transmitter operates on the international distress frequency (500 kHz) and the survival craft communication frequency (8364 kHz).



76.32

Figure 5-62.—Emergency lifeboat Radio Transmitter AN/CRT-3A.

The complete radio transmitter, including the power supply is contained in an aluminum cabinet that is airtight and waterproof. The cabinet is shaped to fit between the operator's legs, and has a strap for securing it in the operating position.

The only operating controls are a three-position selector switch and pushbutton telegraph key. A handcrank screws into a socket in the top of the cabinet. The generator, automatic keying, and automatic frequency changing are all operated by turning the handcrank. While the handcrank is being turned, the set automatically transmits the distress signal SOS in Morse code. The code consists of six groups of SOS followed by a 20-second dash, transmitted alternately on 500 kHz and 8364 kHz. The frequency automatically changes every 50 seconds. These signals are intended for reception by two groups of stations, each having distinct rescue functions. Direction-finding stations cooperating in long-range rescue operations normally make use of 8364 kHz, whereas aircraft or ships locally engaged in search and rescue missions make use of the 500-kHz signals.

Besides the automatic feature, the transmitter can be keyed manually, on 500 kHz only, by means of the pushbutton telegraph key.

Additional items (not shown) packaged with the transmitter include the antenna, a box kite, and balloons for supporting the antenna, hydrogen-generating chemicals for inflating the balloons, and a signal lamp that can be powered by the handcrank generator.

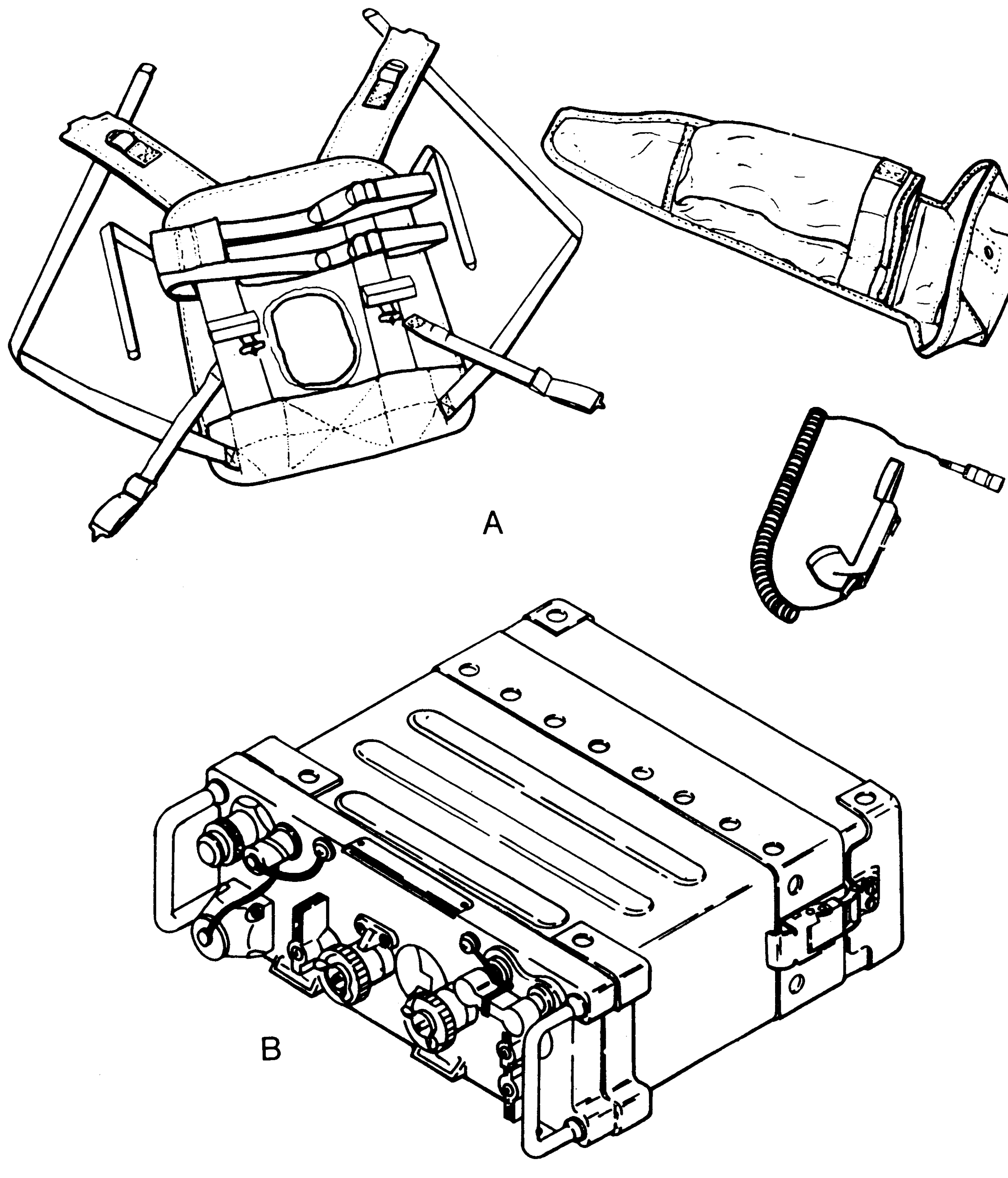
The equipment floats, and is painted brilliant orange-yellow to provide greatest visibility against dark backgrounds.

Receiver Transmitter AN/PRC-77

The AN/PRC-77 (fig. 5-63) is a vhf miniaturized manpack radio set that replaces the AN/PRC-25.

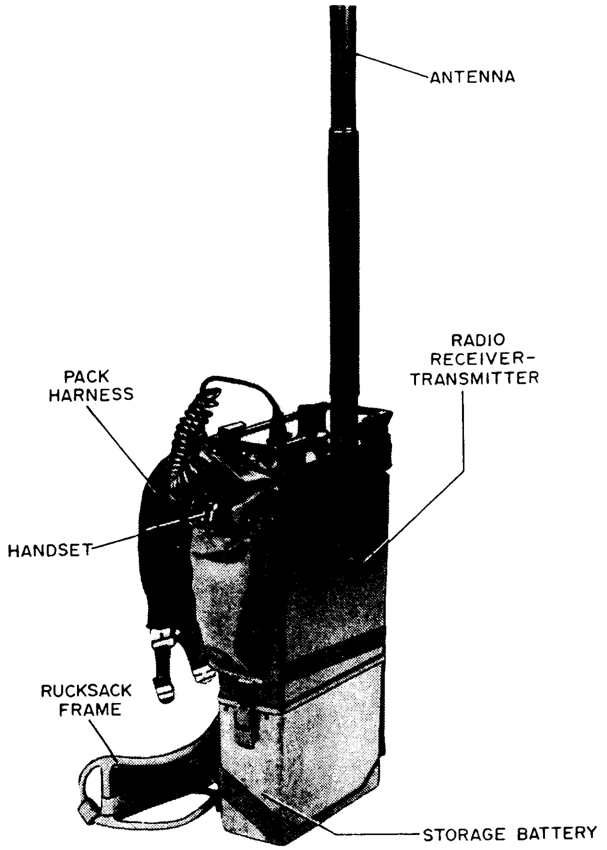
Transceiver AN/PRC-41

Radio Set AN/PRC-41 (fig. 5-64) is a watertight, lightweight, portable uhf equipment that may be operated on any of 1750 channels spaced 100 kHz apart in the 225- to 400-MHz range. Its only mode of operation is AM voice, which it



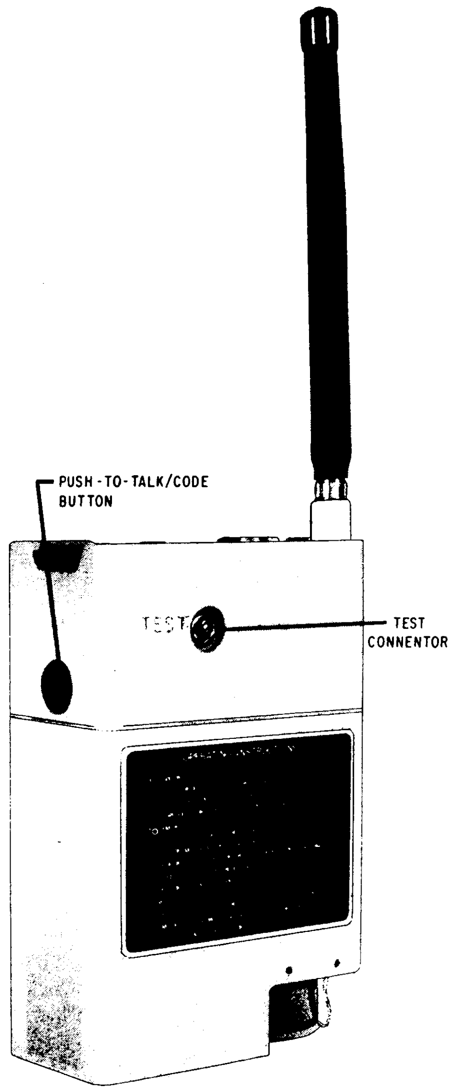
245.98

Figure 5-63.—Radio Set AN/PRC-77.



120.5
Figure 5-64.—Radio Transceiver AN/PRC-41.

supplies at an average output power of 3 watts. Although designed principally for manpack operation, the set may also be used for fixed station and vehicular operation when complemented by certain accessories. When not in use, the equipment is disassembled and stowed in a compartmentized aluminum transit case similar to an ordinary suitcase.



245.99
Figure 5-65.—Portable Transceiver AN/PRC-96.

Radio Set AN/PRC-96

The AN/PRC-96 Radio Set (fig. 5-65) is a dual-channel, battery powered, portable transceiver, which provides homing information and two-way voice communications between life rafts and searching ships and aircraft. A microminiature, solid state, hand-held radio, which operates on the 121.5-MHz and the 243-MHz guard channels, the transceiver has four operating controls which are the VOL control; the two-position FREQUENCY Selector; the PUSH-TO-TALK/CODE Button; and the three-position MODE Switch.

The antenna is a rubber covered, omnidirectional, flexible whip antenna which is 7.75 inches long. The batteries supplied with the radio set are lithium D cells. Each cell is fused to protect against damage from external short circuits. Two cells are installed in the transceiver and four are packaged as spare assemblies.

SHIPBOARD COMMUNICATION SYSTEMS QUALITY MONITORING (QMCS)

In recent years the volume of shipboard communications has increased dramatically. This rapid expansion has led to the shipboard installation of increasingly sophisticated equipment. Factors such as frequency accuracy, d.c. distortion, and distribution levels are critical to the operation of communication systems. Satisfactory operation of these systems demands precise initial line-up and subsequent monitoring to ensure certain standards are met and maintained. System degradation is often caused by many small contributing factors which, added together, render the system unusable. The traditional and widespread practice of confining monitor efforts to looking only at the page printer or listening to the signal is entirely inadequate.

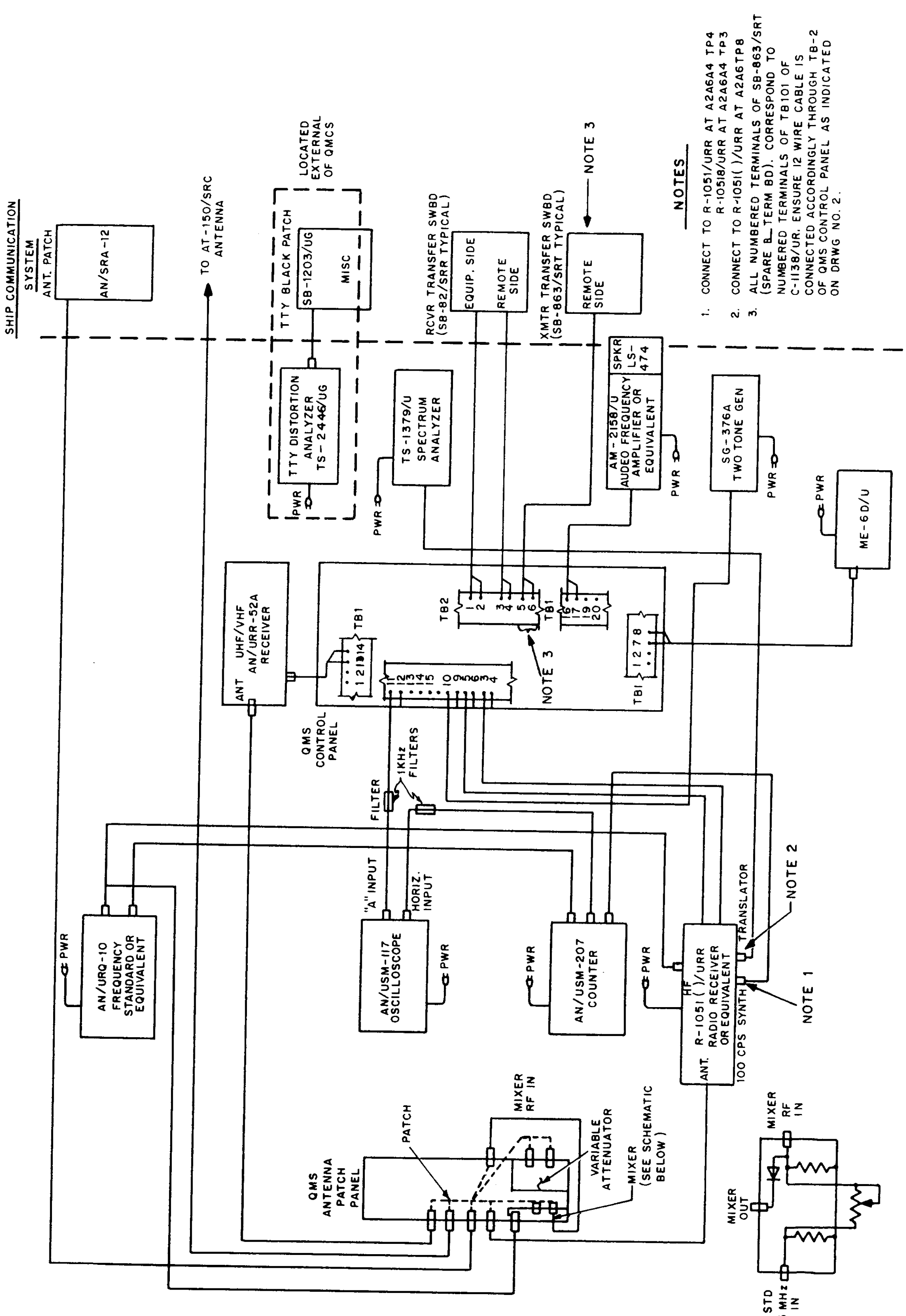
QUALITY MONITORING

Quality monitoring is the performance of scheduled, logical checks that will ensure continuous, optimum performance of shipboard communication systems and in many cases prevent outages before they occur. The importance of quality communications cannot be overemphasized. Unfortunately, quite often communications personnel fail to realize the benefits of quality monitoring. An attitude develops that questions the need for quality monitoring, since seemingly adequate communications are already being accomplished without it. The result of this incorrect attitude is that circuits are either IN or OUT. Communications personnel with this attitude perform no quality monitoring when the circuits are in and are therefore forced to treat each outage as if it were a unique occurrence. With no precise information concerning the trend of the systems' performance, personnel must jump from one assumed probable cause to another assumed probable cause while valuable circuit time is lost. Implementation of a monitoring program decreases communications personnel workload by allowing detection, isolation and correction of system degradation before outages occur. Additionally, a ship that has implemented an aggressive quality monitoring program will, as a result, produce personnel who are thoroughly familiar with all installed communication systems.

Shipboard Communication Systems Quality Monitoring (NAVTELCOMINST C2796.1) NAVTEL is a manual which provides the necessary information and instructions required to exercise effective quality monitoring of shipboard systems. Extensive instructional material has been included. The manual was developed by fleet communicators and is based on proven, successful quality monitoring techniques that have resulted in extraordinary improvement in quality and continuity of service. Chapters II and III contain the actual standards, schedules and test procedures. Chapter IV contains concise system descriptions as well as quality monitoring checks necessary upon activation and subsequent operation of the system. To provide the most thorough understanding of individual ship's systems, information on common shipboard equipments is contained in Chapter V. Insofar as possible Chapter VI contains detailed information on factors that affect the quality of shipboard communication systems. A thorough understanding of QMCS material is vital to maintaining effective communications. In this regard, the manual provides a primary reference for training. Performance of the initial line-up procedures and quality monitoring tests are required skills for shipboard communicators. Accordingly, an appropriate training program must be implemented to indoctrinate personnel on the contents of the manual.

Tests prescribed in the manual are based on the use of a Quality Monitoring System similar to the one depicted in figure 5-66. A list of test equipment including stock numbers and approximate price information to configure this system is contained in Appendix B of the manual.

With the advent of satellite communications transceivers, and communications automatic processing equipment at hand, the technical information related to the monitoring and control of such equipment is included.



NOTES

1. CONNECT TO R-1051/URR AT A2A6A4 TP4
R-1051B/URR AT A2A6A4 TP3
2. CONNECT TO R-1051( )/URR AT A2A6TP8
3. ALL NUMBERED TERMINALS OF SB-863/SRT (SPARE B TERM BD). CORRESPOND TO NUMBERED TERMINALS OF TB101 OF C-1138/UR. ENSURE 12 WIRE CABLE IS CONNECTED ACCORDINGLY THROUGH TB-2 OF QMS CONTROL PANEL AS INDICATED ON DRWG NO. 2.

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Figure 5-66.—Diagram/assembly of a typical shipboard quality monitoring system.

ELECTROMAGNETIC INTERFERENCE (EMI)

Many complex electronic systems are installed aboard today's modern ships. As more complicated systems, with higher power and greater receiver sensitivity, are crowded into a restricted and corrosive environment, the environment itself (fig. 5-67) becomes a major limitation to the effective employment of a Total Ship System. The problem is further aggravated by the requirement that all individual systems operate simultaneously, while still performing to specifications. Thus, the ship must be treated as a combination of systems whose overall performance is dependent upon system-to-system and platform-to-system compatibility.

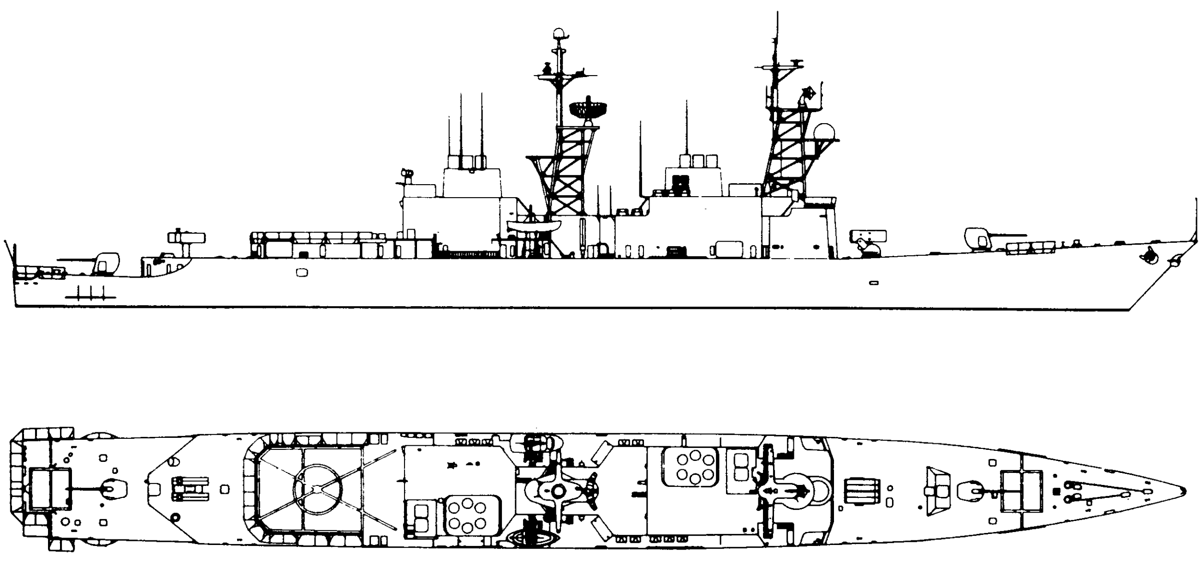
The decisions concerning design, installation, maintenance, and operation of a total ship system, capable of performing its mission in this unique shipboard environment, present a challenge to all concerned. Those tasked to meet this challenge must consider the limited space available and the complex technology and training needed to provide and operate a viable total ship system. They also must consider the effects that motion, temperature variations, and exposure to adverse elements will have on the performance of the total ship system, particularly on those system components which are mounted topside.

ELECTROMAGNETIC COMPATIBILITY

The Electromagnetic Compatibility (EMC) between a ship's structure and its electrical and electronic systems is tenuous, at best. If the ship is to perform its mission effectively by functioning at full operational capacity, EMC and the methods of achieving and maintaining it must be understood and applied.

A great deal of attention is given to keeping the topside shipshape, both cosmetically and mechanically. It is equally important to keep it electronically shipshape. What may appear to be a minor mechanical problem, such as a loose connection, a broken bond strap, or a rusty junction can have serious operational consequences in communications or radar acquisition and tracking systems.

Today's Navy relies heavily upon its superior electronics equipment to accomplish its mission in a combat or support role. Understanding EMI problems and managing an effective preventive and corrective maintenance program is essential to the successful execution of the mission.



SPRUANCE (DD 963)

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Figure 5-67.—Total ship.

The degrading effects of Electromagnetic Interference (EMI) are widespread and may develop slowly as the deterioration of system components spreads by corrosion and improper or inadequate maintenance or operation. Very often the operators are aware of interference encountered with a particular system and tolerate it in day-to-day operations. This may have a cumulative effect and adversely affect total ship system performance when several systems must be operated simultaneously. When there is loss or reduction of capability in communications, intelligence acquisition, or weapons control, the operational impact is obvious—the ship will not be able to perform effectively.

SOURCES OF ELECTROMAGNETIC INTERFERENCE

Sources of shipboard EMI can be divided into the following four broad categories:

1. Functional. EMI can originate from sources that are designed to generate electromagnetic energy and which may create interference as a normal consequence of their operation. This interference may be unintentional, caused by other on-board or adjacent platform systems, or it may be intentional, caused by electronic countermeasures (ECM).

2. Incidental. EMI can originate from manmade sources that are not designed specifically to generate electromagnetic energy, but which do, in fact, cause interference. Examples of incidental EMI sources include power lines, motors, and switches.

3. Natural. EMI is caused by natural phenomena, such as electrical storms, rain particles, and solar and interstellar radiation. It is recognized by the following audible noise:

Intermittent impulses of high intensity which are caused by nearby electrical storms

Steady rattling or cracking caused by distant electrical storms

Continuous noise of precipitation static caused by electrically charged rain drops

A steady hiss at high frequencies caused by interstellar noise

4. Hull-Generated. EMI can be caused by the interaction of functional signals with elements of the ship's hull and rigging. (The functional signals themselves would not cause interference.)

Little can be done to control natural interference, and operational work-arounds may need to be developed to minimize its impact upon ship operations. However, much interference which is assumed to be natural is, in fact, functional, incidental, or hull-generated. Therefore, it is a good engineering practice to investigate all interference to verify whether or not it is natural EMI, prior to selection of a corrective action or a decision to investigate further.

Incidental EMI usually can be eliminated, or effectively controlled, at its source by proper design and maintenance.

Functional EMI poses a more difficult problem, since the source of the interference generally is essential to the operation of the equipment. In complex systems, such as communications, radar, or Electronic Warfare (EW) transmitters, the generation of the functional signal often results in generation of undesired electromagnetic energy at frequencies other than the operating frequency. These spurious outputs, which impact adversely upon total ship system performance, should be eliminated, or be reduced to an acceptable level or amplitude, by the application of proven EMI-reduction techniques. Many of these techniques are available to, and can be applied successfully by, the ship's force in its efforts to improve total ship system performance.

Hull-generated EMI is of particular concern. The resulting intermodulation or broadband interference effects can easily mask a host of other EMI problems.

Transmission of Interference

Following are two general methods by which EMI is transmitted:

- Conduction. Undesired energy from one equipment is coupled to interconnecting cables or to components of another equipment and is conducted via the wiring into the shielded enclosure protecting sensitive circuits. Proper design, adequate isolation from power supplies, and shielding of cables and equipment can control most conducted interference.

- Radiation. Energy is beamed directly from the transmitting antenna, or source, to the victim receiving antenna. When the interference is picked up by a receiver, whose sole function is to intercept and to process radiated energy, the only solutions are to eliminate the interfering energy at the source, or to filter or blank it out at the victim equipment. Filtering and blanking are far less desirable, since the interference may be on the same frequency as the desired signal and, thus, it cannot be eliminated by filtering without affecting the signal strength of the desired signal. Similarly, the interference cannot be eliminated by blanking without affecting the reception of all desired signals during periods of blanker operation.

Radiated energy, in the form of spurious sidebands (splatter), occurs outside the necessary frequencies and distorts the transmission. This form of interference is so prevalent in naval communications that it almost is accepted as normal. It usually is caused by overmodulation, incorrect tuning and loading, or operating the transmitter at too high power.

A combination of radiated and conducted energy, in the form of cross modulation interference in communications, is introduced when transmitting antennas are spaced too closely and a high degree of coupling exists between them. Powerful off-frequency signals from one transmitter feed into the final stage of the other transmitter. The two transmitter frequencies combine and excite a nonlinear element within the victim transmitter, generating additional frequencies that interfere with the desired signal. This cross-modulation interference is best controlled by selecting transmitting antennas which are as widely separated as possible. In the limited space available, this is frequently impossible since other factors dictate which antenna will be used and where they can be placed. The problem usually is solved by installing tunable filters (multicouplers) between the transmitter and the antenna. The multicoupler has the additional advantage of allowing several transmitters to operate on one broadband antenna, permitting a reduction in the number of antennas required and, therefore, allowing greater antenna separation.

Military specifications for the control of interference usually are applied in the design of electronic systems and, in most cases, are effective. However, too often a good design is negated by improper operation, installation, or maintenance.

Susceptibility to EMI

Most unprotected shipboard receivers are susceptible to EMI over a frequency range which is much wider than that normally considered to be their passband. Off-frequency rejection rarely is sufficient to completely exclude strong, adjacent-channel signals which, having entered the receiver, degrade receiver performance by being processed along with the desired, tuned signal. Usually, the presence of EMI is apparent by its effect upon the desired signal quality (as in cross-modulation). Extremely strong, off-frequency signals may even burn out the sensitive front-end stages of a receiver. EMI also can degrade overall receiver performance in a less noticeable way by desensitizing the receiver front end, causing a decrease in desired signal amplification. For these reasons, shipboard receive systems are designed to include protective circuitry between the antenna and receiver to filter out off-frequency signals, thus preventing or limiting interference, desensitization, or burnout. Depending upon the system, these protective devices may include filters, multicouplers, pre-selectors, and the like. When properly used, these devices can minimize the interference caused by inadequate operating frequency separation or poor isolation between transmit and receive antennas.

ELECTRONICS MATERIAL OFFICER'S GUIDE TO SHIPBOARD ELECTROMAGNETIC INTERFERENCE (EMI) CONTROL

The guide was prepared in support of OPNAV ltr Ser 992F41/64299 dated 20 October 1976 which detailed the Shipboard

Electromagnetic Compatibility Improvement Program (SEMCIP). You will want to become thoroughly familiar with the guide, which is discussed here as a brief orientation.

The purposes of the *Electronics Material Officer's Guide to Shipboard Electromagnetic Interference* (EMI) *Control* are to:

Familiarize the EMO with the impact and cause of Electromagnetic Compatibility (EMC) degradation, including EMI and Radiation Hazards (RADHAZ), and with the need for a coordinated, all-hands effort to achieve EMC

Aid in the establishment of a management organization to achieve EMC for shipboard systems, under the Total Ship System concept

Provide guidance to the EMO concerning the managment and control of EMC degradation problems in the shipboard environment

Supplement and amplify the information in NAVEDTRA Manual 10478A, *The Shipboard Electronics Material Officer*; *The Electronics Installation and Maintenance Book* (EIMB) series; and other technical references

Explain the relationship of various existing Navy maintenance and management programs to the goal of achieving shipboard EMC

Provide guidance concerning the prevention and/or correction of common shipboard EMI problems, including those within the capabilities of the ship's force to correct, and those requiring outside assistance

Explain the Navy's Shipboard Electromagnetic Compatibility Improvement Program (SEMCIP) and how it may be used by the EMO in connection with the task of reducing EMC degradation problems aboard ship

The Guide is directed primarily to the EMO who has some operational and technical background, but limited experience in performing EMO duties, particularly as they pertain to EMI control. It is also designed for use in conjunction with other EMC materials for training prospective EMOs. The experienced EMO will benefit from the management concepts and aids provided, which can help increase effectiveness in dealing with individual cases of EMI degradation and in improving the ship's overall EMC readiness.

Because it is intended that the Guide be an "action" document, with "how to" procedures and management aids predominating, the technical content is limited to that necessary for a clear understanding of shipboard EMC. The philosophical discussions preceding the various procedures for implementing EMI control actions are included to help explain the "why" of the procedure and to show how it fits into the whole concept of managing EMI on a total ship system basis. Major emphasis is placed upon the most serious area of concern: the mutual interference of systems and structures affected by the topside environment.

Since the control of EMI will impact upon many other maintenance-related programs, such as the 3-M Program, reporting procedures, supply, and formal inspections, these programs are referred to throughout the Guide. In case of conflict, the formal guidance for each specific program will take precedence. The Guide will be periodically updated to reflect changes in formal guidance which impact upon the doctrine and concepts addressed.

Every effort is made to provide the EMO with assistance and guidance in establishing a management system aboard ship to achieve EMC. The material provided in the Guide is intended to minimize the need for burdensome paperwork and research in developing this system. To assist the EMO in this goal, various supplementary information is included in the appendixes to the Guide. Appendix A lists the current duties and tasks of the EMO. Appendix B provides a sample shipboard EMC instruction. Appendix C provides a list of EMC-related training and maintenance materials. Appendix D explains the SEMCIP and its eight subprograms. Appendix E provides guidance for establishing a library of reference materials.

Appendix F is a glossary of selected acronyms, abbreviations, and definitions.

The Guide is intended to serve as a reference tool, rather than as a textbook, so various parts of the Guide have each been designed to stand alone. In this way, pertinent portions of the Guide can be reproduced and distributed, or otherwise provided, to any member of the ship's company to assist in the achievement of Total Ship System EMC.