With gratitude to Hal Herrick for his dedication and fortitude in writing this handbook .

RADIO COMMUNICATIONS IN THE DIGITAL AGE

VOLUME TWO: VHF/UHF TECHNOLOGY

HARRIS

TABLE OF CONTENTS

Note: *Throughout this handbook, technical terms and acronyms*
            shown in italics are defined in the Glossary.

INTRODUCTION

This is Volume 2 of an introductory series on radio communications Technology. This volume covers very high frequency (VHF), ultra high frequency (UHF), and Satellite Communications (SATCOM) technologies, as well as the modern digital coding and modulation capabilities that optimize information output and security.

The Communicator's Tool Kit

A carpenter relies upon an assortment of chisels, drills, and hammers to do the job. Each type of tool is suited for a particular task. Likewise, the modern communications system designer makes use of HF, VHF, UHF, and SATCOM tools, and capitalizes on the unique capabilities that each brings to meet the requirements. Summaries of the most prominent capabilities of each radio frequency band are given below. Subsequent chapters will describe them in more detail.

HF: Around the Corner to Around the World

Before SATCOM technology existed, HF radios were the only means of communicating to ships at sea. The fact that HF can communicate beyond the horizon makes it an indispensable tool for long distance ship-to-ship and ship-to-shore messages. Likewise, before the days of the transatlantic cables, HF (or short wave) radios were the only way to talk between continents. Today they are still used to share the overall burdens of long distance communications.

But the unique virtue of HF radio has also created some challenges. Worldwide radio transmissions are easy to intercept and the HF spectrum is complicated by signals emanating from the many individual transmitters located around the world. Special techniques must be implemented in the radios to take advantage of the radio's long range, while still preserving the clarity of the channel and reduce interception.

Encryption reduces unfriendly utilization of intercepted signals and sophisticated coding schemes helps fight through clutter, but these techniques can reduce throughput (compared to that of a clear channel). Nevertheless, HF radios still play an indispensable role in the communicator's tool kit. HF manpack radios with various antenna options can cover a practical range of from "around the corner" to "around the world."

Although some long range communications are now transmitted via satellite, HF still has the advantage of not requiring (or relying on) any infrastructure.

VHF: Man to Man

The VHF band was an early choice for manpack radios used by ground troops to communicate within a local (five-mile or so) area. Antennas and selective-tuning components of VHF radios are very much smaller than their HF counterparts.

Advances in the semiconductor industry have also increased the efficiency of VHF radios because batteries are smaller, lighter, and longer-lived than those required in the past.

Unlike HF, VHF transmissions lack the ability for ionospheric bounce and are limited to line-of-sight (LOS) communication. This reduces radio emission clutter throughout an extended battlefield and limits the vulnerability to unfriendly interception.

The wider channel bandwidth capabilities of VHF radios increase the efficiency of coding and encryption schemes and allow greater data throughput than that of HF radios. Wider bandwidth and limited range make these radios ideal for squad-to-squad communications.

UHF: Ground to Air for Close Support

UHF tuning elements and antennas are even smaller than those of VHF and are much easier to mount on supersonic fighter aircraft, making UHF an ideal choice for ground-to-air communications. Like VHF radios, UHF radios share the advantages of being line of sight and having wide bandwidth. Modern military forces now prefer the UHF spectrum for ground-to-air communications.

SATCOM: Hails to (and from) the Chief

It is essential for front line units to communicate with the command centers that are sometimes hundreds, if not thousands, of miles away. With the advent of military satellites, SATCOM technology can complement HF equipment.

Although LOS is typically five miles or less along the ground between manpack radios, the vertical LOS range of a UHF signal is tens of thousands of miles. This enables UHF radios to reach orbiting military satellites that are designed to retransmit the signal back to earth. The retransmitted signal covers a huge footprint and is ideal for long range communications.

The highly directional antennas pointed up at the sky that are used with Tactical Satellite (TACSAT) radios, reduce ground radiation of front line TACSAT traffic. This makes SATCOM traffic much more difficult to intercept than that from HF radios.

Although it is true that the enemy can receive a downlink from a satellite, encryption denies access to the data and the source of the emanations gives no clue as to the location of either the source or the destination of the data path.

The Multiband Radio

In this age of specialization a large, conventional military force has the ability to carry an assortment of radios, each carefully designed for a specific purpose. But the situation of a small Special Forces combat team is very different. Although they need to have access to all of the available military communication channels, they can't afford the luxury (or the weight) of carrying the required multitude of radios. Hence, the multiband radio.

Similarly, installation space constraints in vehicles, shelters, small boats, etc., are being addressed with multiband radios.

Just as the small multipurpose pocket tool that folds open to display a knife, screw driver, pliers, and can opener can serve as an emergency tool box, the multiband manpack radio is designed for the multipurpose needs of Special Forces. Some multiband radios also provide a satellite link allowing them to extend their range further.

Putting it all together

Subsequent chapters in this handbook develop the basic principles and operating modes of the radios mentioned in this introduction. Operating characteristics of each radio frequency band will be described and compared with respect to performance and application.

But there is a lot more than frequency band that defines the performance of a radio. The following pages also touch upon the world of exotic waveforms that punch through noise, defy attempts at interception, and provide data high data rates that previously were considered impossible.

Stay tuned!

PRINCIPLES OF RADIO COMMUNICATIONS

Developing an understanding of radio communications begins with the comprehension of basic electromagnetic radiation.
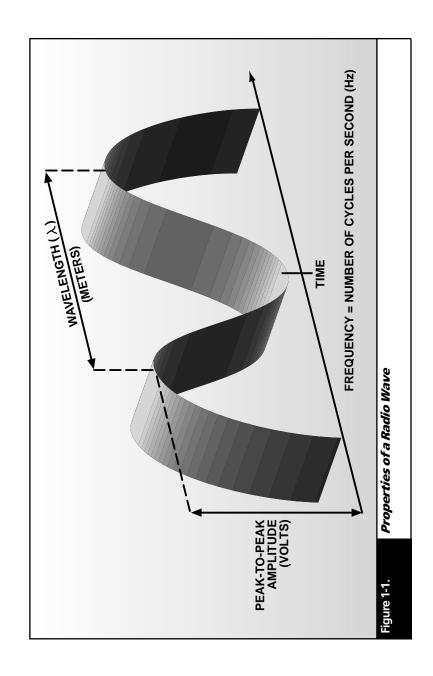
Radio waves belong to the electromagnetic radiation family, which includes x-ray, ultraviolet, and visible light — forms of energy we use every day. Much like the gentle waves that form when a stone is tossed into a still lake, radio signals radiate outward, or propagate, from a transmitting antenna. However, unlike water waves, radio waves propagate at the speed of light.

We characterize a radio wave in terms of its *amplitude*, *frequency*, and *wavelength* (Figure 1-1).

Radio wave amplitude, or strength, can be visualized as its height — the distance between its peak and its lowest point. Amplitude, which is measured in volts, is usually expressed in terms of an average value called root-mean-square, or *RMS*.

The frequency of a radio wave is the number of repetitions or cycles it completes in a given period of time. Frequency is measured in hertz (*Hz*); one hertz equals one cycle per second. Thousands of hertz are expressed as kilohertz (*kHz*), and millions of hertz as megahertz (*MHz*). You would typically see a frequency of 2,182,000 hertz, for example, written as 2,182 kHz or 2.182 MHz.

Radio wavelength is the distance between crests of a wave. The product of wavelength and frequency is a constant that is equal to the speed of propagation. Thus, as the frequency increases, wavelength decreases, and vice versa.

WAVELENGTH (λ) (METERS)

FREQUENCY = NUMBER OF CYCLES PER SECOND (Hz)

TIME

PEAK-TO-PEAK AMPLITUDE (VOLTS)

Properties of a Radio Wave

Figure 1-1.

Since radio waves propagate at the speed of light (300 million meters per second), you can easily determine the wavelength in meters for any frequency by dividing 300 by the frequency in megahertz. So, the wavelength of a 10-MHz wave is 30 meters, determined by dividing 300 by 10.

The Radio Frequency Spectrum

In the radio frequency spectrum (Figure 1-2), the usable frequency range for radio waves extends from about 20 kHz (just above sound waves) to above 30,000 MHz. A wavelength at 20 kHz is 15 kilometers long. At 30,000 MHz, the wavelength is only 1 centimeter.

The High Frequency (HF) Band

The *HF* band is defined as the frequency range of 3 to 30 MHz. In practice, most HF radios use the spectrum from 1.6 to 30 MHz. Most long-haul communications in this band take place between 4 and 18 MHz. Higher frequencies (18 to 30 MHz) may also be available from time to time, depending on ionospheric conditions and the time of day (see Volume One, HF Technology).
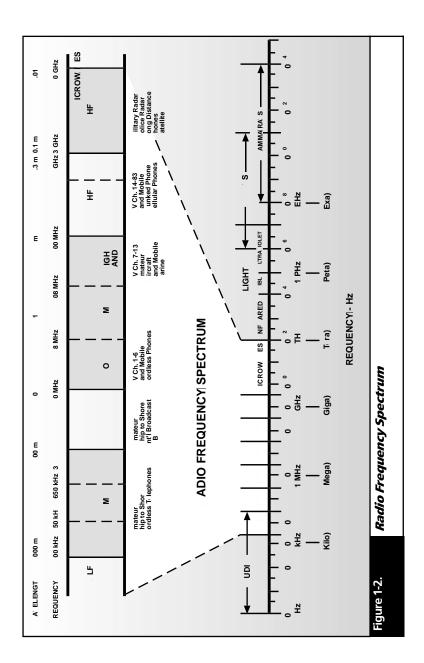
Very High Frequency (VHF) Band

The *VHF* frequency band is defined as the frequency range from 30 to 300 MHz. From the previous discussion about the relationship between frequency and wavelength, it should be noted that VHF wavelengths vary from 10-meters at the low end to one meter at the high end. This means that the size of antennas and tuning components used in VHF radio are much smaller and lighter than those of HF radios. This is a big advantage for manpack radios. We will also see in later chapters that the higher frequency and shorter wavelengths of VHF radios have a profound effect on radio range.

Ultra High Frequency (UHF) Band

The *UHF* band goes from 300 MHz to 2450 MHz, although TACSAT manpack UHF radios do not utilize frequencies above 512 MHz. The wavelengths associated with 300 to 512 MHz range from one meter to 0.58 meters (58 centimeters). The very small antennas required for these wavelengths make them ideal for use on high-speed aircraft.

Frequency Allocations

Within the HF spectrum, groups of frequencies are allocated to specific radio services — aviation, maritime, military, government, broadcast, or amateur

Figure 1-2. *Radio Frequency Spectrum*

(Figure 1-3). Frequencies are further regulated according to transmission type: emergency, broadcast, voice, Morse code, facsimile, and data. International treaty and national licensing authorities govern frequency allocations.

Frequencies within the VHF/UHF bands are similarly allocated (Figure 1-4).

Modulation

The allocation of a frequency is just the beginning of radio communications. By itself, a radio wave conveys no information. It's simply a rhythmic stream of continuous waves (*CW*).
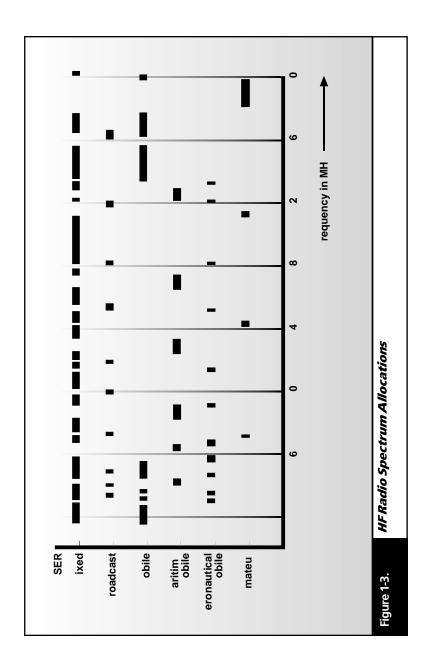
When we modulate radio waves to carry information, we refer to them as *carriers*. To convey information, a carrier must be varied so that its properties — its *amplitude*, *frequency,* or *phase* (the measurement of a complete wave cycle) — are changed, or *modulated*, by the information signal.
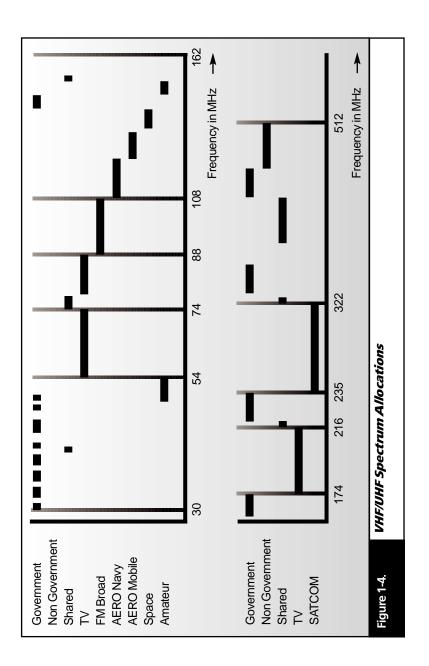
The simplest method of modulating a carrier is by turning it on and off by means of a telegraph key. In the early days of radio, *On-Off keying*, using Morse code, was the only method of conveying wireless messages.

Today's common methods for radio communications include amplitude modulation (*AM*), which varies the strength of the carrier in direct proportion to changes in the intensity of a source such as the human voice (Figure 1-5a). In other words, information is contained in amplitude variations.

The AM process creates a carrier and a pair of duplicate *sidebands* — nearby frequencies above and below the carrier (Figure 1-5b). AM is a relatively inefficient form of modulation, since the carrier must be continually generated. The majority of the power in an AM signal is consumed by the carrier that carries no information, with the rest going to the information-carrying sidebands.

In a more efficient technique, single sideband (*SSB*), the carrier and one of the sidebands are suppressed (Figure 1-5c). Only the remaining sideband, upper (*USB*) or lower (*LSB*), is transmitted. An SSB signal needs only half the bandwidth of an AM signal and is produced only when a modulating signal is present. Thus, SSB systems are more efficient both in the use of the spectrum, which must accommodate many users, and of transmitter power. All the transmitted power goes into the information-carrying sideband.

Figure 1-3. *HF Radio Spectrum Allocations*

VHF/UHF Spectrum Allocations

Government
Non Government
Shared
TV
FM Broad
AERO Navy
AERO Mobile
Space
Amateur

Frequency in MHz
30   54   74   88   108   162

Government
Non Government
Shared
TV
SATCOM

Frequency in MHz
174   216   235   322   512

Figure 1-4.

One variation on this scheme, often used by military and commercial communicators, is amplitude modulation equivalent (*AME*), in which a carrier at a reduced level is transmitted with the sideband. AME lets one use a relatively simple receiver to detect the signal. Another important variation is independent sideband (*ISB*), in which both an upper and lower sideband, each carrying different information, is transmitted. This way one sideband can carry a data signal and the other can carry a voice signal.

Frequency modulation (*FM*) is a technique in which the carrier's frequency varies in response to changes in the modulating signal (Figure 1-5d). For a variety of technical reasons, conventional FM generally produces a cleaner signal than AM, but uses much more bandwidth. Narrowband FM, which is sometimes used in HF radio, provides an improvement in bandwidth utilization, but only at the cost of signal quality.
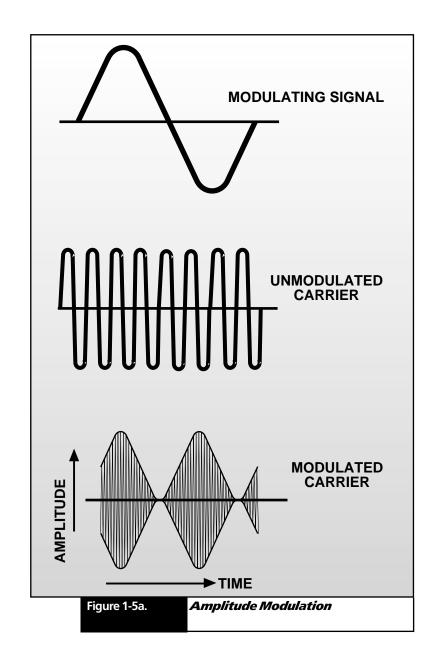
It is in the UHF and VHF bands that FM comes into its own. Remember that the HF band is generally defined as occupying the spectrum from 1.6 MHz to 30 MHz. This is a span of only 28.4 MHz. The VHF band covers the span of from 30 MHz to 300 MHz, which is a span of 270 MHz; nearly 10 times the span of HF. This extra room means that a channel bandwidth of 25 kHz is used to achieve high signal quality.

Other schemes support the transmission of data over radio channels, including shifting the frequency or phase of the signal. We will cover these techniques in Chapter 5.

Radio Wave Propagation

Propagation describes how radio signals radiate outward from a transmitting source. The action is simple to imagine for radio waves that travel in a straight line (picture that stone tossed into the still lake). The true path radio waves take, however, is often more complex.

There are two basic modes of propagation: *ground waves* and *sky waves*. As their names imply, ground waves travel along the surface of the earth, while sky waves "bounce" back to earth. Figure 1-6 shows the different propagation paths for radio waves.

MODULATING SIGNAL

UNMODULATED
CARRIER

AMPLITUDE

MODULATED
CARRIER

TIME

Figure 1-5a. *Amplitude Modulation*

PPER
IDEBAND

ARRIER

OWER
IDEBAND

REQUENCY

MPLITUDE

Amplitude Modulation

Figure 1-5b.

13

14

AMPLITUDE

FREQUENCY

UPPER
SIDEBAND

SUPPRESSED
CARRIER AND
LOWER
SIDEBAND

Figure 1-5c. *SSB in the Frequency Domain*

15

(A)

WAVESHAPE OF MODULATING SIGNAL

(B)

(C)

Figure 1-5d. *FM Modulation*

16

IONOSPHERE

SKY WAVE

REFRACTED WAVE

TRANSMITTING ANTENNA

DIRECT WAVE

SURFACE WAVE

GROUND REFLECTED WAVE

RECEIVING ANTENNA

Figure 1-6. *Propagation Paths*

Ground waves consist of three components: *surface waves*, *direct waves*, and *ground-reflected waves*. Surface waves travel along the surface of the earth, reaching beyond the horizon. Eventually, the earth absorbs surface wave energy. The frequency and conductivity of the surface over which the waves travel largely determine the effective range of surface waves. Absorption increases with frequency.

Transmitted radio signals, which use a carrier traveling as a surface wave, are dependent on transmitter power, receiver sensitivity, antenna characteristics, and the type of path traveled. For a given complement of equipment, the range may extend from 200 to 250 miles over a conductive, all-sea-water path. Over arid, rocky, non-conductive terrain, however, the range may drop to less than 20 miles, even with the same equipment.

Direct waves travel in a straight line, becoming weaker as distance increases. They may be bent, or *refracted*, by the atmosphere, which extends their useful range slightly beyond the horizon. Transmitting and receiving antennas must be able to "see" each other for communications to take place, so antenna height is critical in determining range. Because of this, direct waves are sometimes known as line-of-sight (*LOS*) waves. This is the primary mode of propagation for VHF and UHF radio waves.

Ground-reflected waves are the portion of the propagated wave that is re-flected from the surface of the earth between the transmitter and receiver.

Sky waves make beyond line-of-sight (*BLOS*) communications possible. At frequencies below 30 MHz, radio waves are refracted (or bent), returning to earth hundreds or thousands of miles away. Depending on frequency, time of day, and atmospheric conditions, a signal can bounce several times before reaching a receiver.

SUMMARY

■ Radio signals radiate outward, or propagate, from a transmitting antenna at the speed of light.

■ Radio frequency is expressed in terms of hertz (cycles per second), kilohertz (thousands of hertz), or megahertz (millions of hertz).

■ Frequency determines the length of a radio wave; lower frequencies have longer wavelengths and higher frequencies have shorter wavelengths.

■ Long-range radio communications beyond line of sight (BLOS) take place in the high-frequency (HF) range of 1.6 to 30 MHz. Different portions of this band are allocated to specific radio services under international agreement.

■ Short-range radio communications (LOS) communications can take place at all radio frequencies, but that task is most often given to the VHF and UHF radio bands.

■ Using sky waves can be tricky, since the ionosphere is constantly changing. Sky wave propagation is generally not available in the VHF and UHF frequency bands.

■ Modulation is the process whereby the phase, amplitude, or frequency of a carrier signal is modified to convey information.

CHAPTER
2

VHF/UHF RADIO PROPAGATION

Chapter 1 explains that HF, VHF, and UHF radio waves have different propagation characteristics. VHF and UHF radio frequencies propagate principally along LOS paths. On the other hand, HF waves, those below 30 MHz, can also reflect off the ionosphere and then travel back to earth. These sky waves, as they are called, give rise to one of the most important attributes of HF radio and that is beyond the line of sight (BLOS) communication. Volume One, "HF Technology", of this series "Radio Communications in the Digital Age" provides a detailed description of HF propagation. This chapter deals primarily with LOS propagation characteristics of the VHF and UHF frequency bands.

While many HF propagation characteristics are associated with the ionosphere and wave reflections from it, the effects of local area topography and conditions in the lower atmosphere mostly govern VHF and UHF propagation. Similarly, ground wave propagation is a very important mode of HF wave propagation, but at frequencies above 30 MHz, ground waves are absorbed almost immediately and have a negligible beneficial impact.

Frequencies in the VHF and UHF bands usually penetrate the ionosphere and speed out into space. That means that reflection off the ionosphere can not be used to reliably extend communications range of these frequencies. For the most part, the transmitting and receiving antennas must have a fairly unobstructed path between them for communication to take place, hence the term line-of-sight (LOS).

Height Matters for LOS Range

The visible horizon observed at approximately five feet above a flat surface of earth is less than 2.7 miles away (Figure 2-1a). This is approximately the maximum LOS radio range from a manpack radio on the back of a standing man to another manpack radio that is lying on the ground (Figure 2-1b).

Figure 2-1b shows that if the receiving radio were elevated to the back of a standing man, this maximum distance would be doubled. In this case the LOS distance would be 5.4 miles. But, if the second man was standing beyond this distance, say at 7 miles from the transmitting radio, the shadowing effects of the earth's curvature would prevent the second man from receiving the radio wave. In this case, 7 miles is BLOS and is not within reach of VHF or UHF radios in these positions.

It is clear that the elevation of both the transmitting and receiving antennas is crucially important. For example if the receiving antenna were mounted on a 26-foot tower, the total LOS distance would be increased to 9 miles. Of course if the radiomen were both located on the tops of mountains, the LOS range might be as much as from 50 to hundred miles.
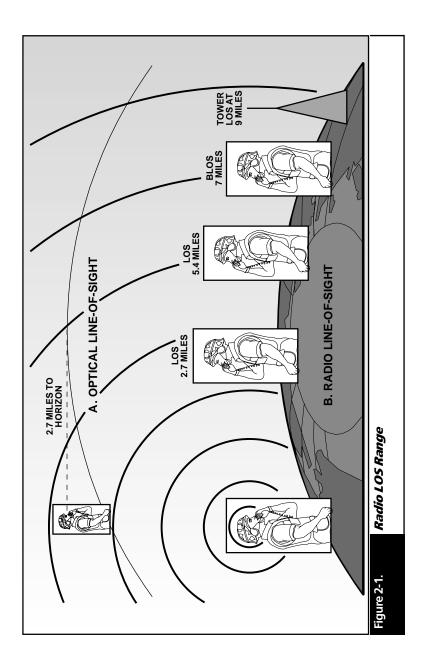
For ground-to-air UHF communications, the aircraft can be 100 miles away or more and still maintain contact.

Transmit Power and Radio Range

For HF radio communications, transmit power is an important item. For very long distances, particularly for both skywave and ground wave propagation, every mile of distance *attenuates* (decreases) the signal. For most systems, when doubling the distance, the radiated signal is divided by four! Therefore, transmit power is often the limiting range factor. It is common to see 500-watt and 1-kW HF transmitters in vehicular or shipboard HF applications, and 10-kW or greater for HF fixed station broadcast sites.

VHF and UHF waves are also attenuated with every mile of distance. However, for tactical manpack applications, it is most often the shadowing effects of irregular terrain, buildings, and other objects that limit the effective range and not transmit power.

Many manpack radios have two power settings: 2 Watts and 5 to 10-Watts. The 2-Watt setting is often adequate and extends battery life when this power level is selected. On the other hand, there are situations where increased power is beneficial. In urban areas where high radio frequency noise is prevalent, higher power increases the signal-to-noise (*SNR*) ratio and improves reception. Also, modern high data rate modulation wave-forms require a high SNR to be effective.

A. OPTICAL LINE-OF-SIGHT

B. RADIO LINE-OF-SIGHT

2.7 MILES TO HORIZON

LOS 2.7 MILES

LOS 5.4 MILES

BLOS 7 MILES

TOWER LOS AT 9 MILES

Figure 2-1. *Radio LOS Range*

UHF ground-to-air communications benefit from higher power because the typical range is 100-miles or more.

Lastly, although tactical manpack UHF SATCOM radios with only 18-Watts located in Europe can contact a satellite in an orbit 22,000 miles above the earth's equator, communication is more reliable when higher power is used.

These higher power VHF and UHF radio sets are typically mounted in vehicles or fixed stations with 50-watt power amplifiers to boost the power of the manpack transceiver.
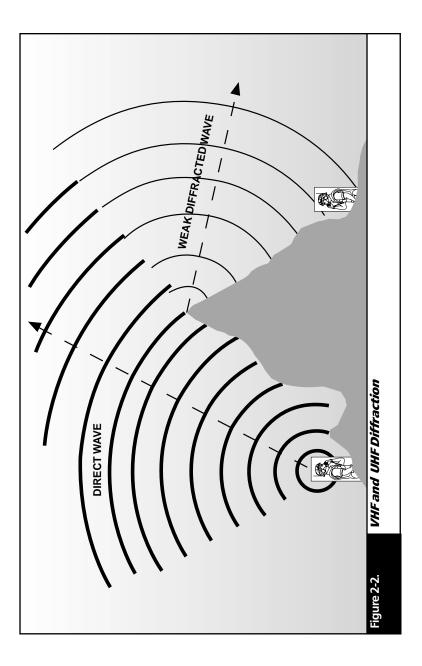
VHF and UHF Radio Reception Behind Ridges

For the most part, ridges and hills form shadows of VHF and UHF radio waves. However, there is an important exception when it comes to very sharp ridges or other kinds of abrupt barriers. This is caused by a phenomenon known as *Diffraction* (Figure 2-2). When a VHF or UHF wave comes to a sharp edge, a portion of the wave bends around the edge and continues propagation as if a very low power radio was placed at the top of the ridge. It is important that the ridge be relatively sharp. A well-rounded hill or the curvature of the earth is not sufficient to cause this effect. This effect is important in a battle field situation where a soldier must seek shelter behind a ridge.
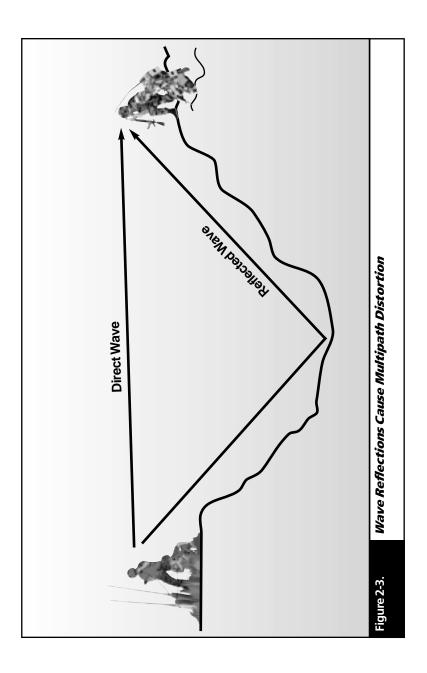
Reflections and Multipath Distortion

VHF and UHF waves can be reflected off of dense surfaces like rocks or conductive earth, just like a beam of light can be reflected off a wall or a ceiling. Sometimes several paths exist between a transmitting and receiving antenna (Figure 2-3). In this figure there is a direct LOS path between two radios, but there is also a reflected path from the bottom of a valley between them.

It is clear that these two paths are of different length, and that the direct path is the shorter of the two. Since radio waves travel at a constant velocity, the direct path wave arrives at the receiver before the reflected path. This means that the same broadcast information reaches the receiver at two different times.

The effect of this is much like echoes that one hears in an acoustically poor room. If the echoes are close enough to each other, it is hard to understand what is being said. In radio terminology, this is called *multipath distortion*. Although it is annoying with voice communications, it is devastating to high

WEAK DIFFRACTED WAVE

DIRECT WAVE

Figure 2-2.

VHF and UHF Diffraction

Direct Wave

Reflected Wave

Wave Reflections Cause Multipath Distortion

Figure 2-3.

data rate digital communication. A subsequent chapter will discuss some of the ingenious ways that have been devised to minimize the effects of this type of distortion.

"*Picket fencing*" is a form of multipathing common to vehicular mounted radios. It is prevalent with VHF and UHF. The higher the frequency, the more pronounced the effect is. It is usually caused by interference or reflections of signals from man-made objects such as buildings, houses, and other structures.

These objects cause constructive and destructive fields (or strengthened and weakened signals) so that when a vehicle travels through these fields, it receives alternately stronger and weaker signals. There is usually a "swishing" sound in the receiver, as the signals rapidly grow weaker, then stronger, then weaker again.

The signal peaks and *nulls* are a function of *wavelength*. A 450-MHz signal being received on board a vehicle travelling at 60 mph can "flutter" very rapidly as the vehicle travels through the downtown area of a city. You can experience the same phenomenon on the lower VHF bands, but the flutters are not quite as rapid.
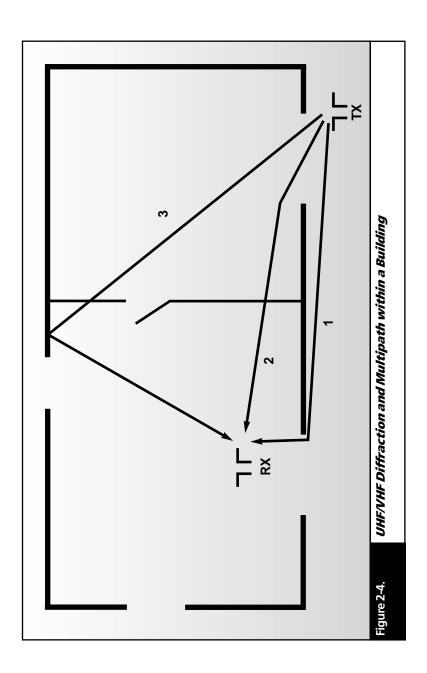
Sometimes this same effect is caused by signals of two stationary radios reflecting off a moving aircraft above them.

Multipath within a Building

In tactical situations, manpack radios are frequently operated under cover in buildings. VHF and UHF waves have trouble penetrating reinforced concrete exterior walls, but they pass through windows and light interior wall partitions with comparative ease.

Figure 2-4 shows a receiver in a room of a building with a transmitter located outside. In this case, there are three paths from the transmitter to the receiver, and none of them are direct.

Path 1 passes through the window nearest the receiver location, and is diffracted around the sharp edge of the window frame to the receiver. Likewise, path 2 just misses having a direct path to the receiver. It is diffracted slightly by the window frame nearest the transmitter and then passes through an interior wall on the way to the receiver. Path 3 goes through a window and an interior wall before striking an outside wall of the building and then reflecting back to the receiver.

Figure 2-4. *UHF/VHF Diffraction and Multipath within a Building*

Each of these paths has a different distance and, therefore, can cause multipath distortion. Frequently just moving the receiver a few feet in some direction will avoid one or more of the available paths and the reception of the signal may be greatly improved.

VHF and UHF Wave Ducting

The suggested limits on LOS range are sometimes exceeded in practice. One of the principal reasons for this is an effect called "*ducting*." VHF and UHF waves traveling through the atmosphere travel slightly slower than they do in free space, and that is because the density of air slows them down. The denser the air, the slower the wave speed through it.

Under normal conditions, the density of air is the greatest at the surface of the earth and gradually reduces in density with altitude. Under fair, dry, and moderate weather conditions; the slight variations in air density have negligible effects on the path of radio waves passing through it.

Frequently there are abrupt changes in air density due to weather fronts passing over an area or the heavy moisture burden of rain clouds. In such cases VHF and UHF can bend or duct between air layers of different densities. Sometimes this ducting bends the radio waves downward so that the radio waves tend to follow the curvature of the earth. In such cases the LOS range is considerably greater than the optical LOS range.

This type of wave propagation is impossible to predict; it is not practical to plan on it for range improvement. However, when ducting conditions exit, they generally do so for hours at a time.

SUMMARY

■ HF propagation can be LOS through ground waves or direct waves and BLOS though the use of sky waves.

■ VHF and UHF frequencies cannot make use of skywave or ground wave propagation and depend almost exclusively on the direct wave. This restricts their use to LOS communications.

■ Radio wave propagation at VHF and UHF frequencies are primarily affected by local area topography (hills and valleys) and atmospheric conditions.

■ VHF and UHF range is usually limited by physical wave shadowing of obstructions such as buildings and mountains.

■ Diffraction of VHF and UHF waves can bend them around sharp edges such as window frames or sharp ridges.

■ Multipath distortion is caused by waves arriving at a receiver from more than one path.

■ LOS range is greatly improved with increased height of either (or both) transmit or receive antennas.

■ Ducting caused by certain weather conditions can sometimes increase the range of VHF and UHF waves.

CHAPTER

3

ELEMENTS IN A VHF/UHF RADIO SYSTEM

Now that you have an overview of how radio waves propagate, let's take a look at how they are generated. The primary components in a VHF or UHF radio system fall into three groups: transmitters, receivers, and antennas. In most modern radio tactical sets, the transmitter and receiver are contained in a single unit called a *transceiver*. This chapter presents an overview of these radio system elements.
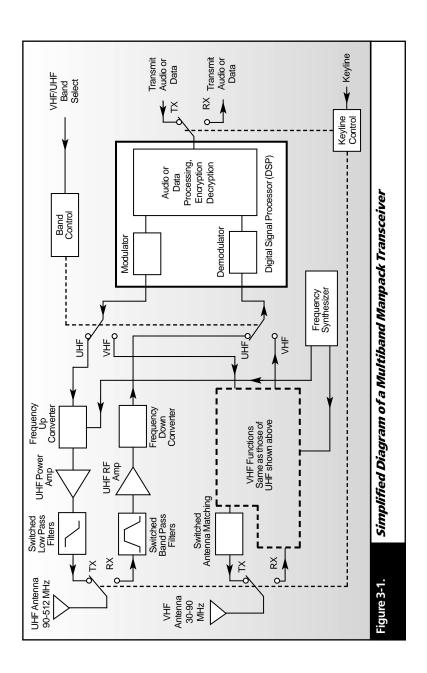
The Anatomy of a Multiband VHF/UHF Transceiver

In times past, a tactical transceiver was restricted to a single band. That is to say that a separate radio was required for HF, VHF, and UHF service. With the increased requirement for greater troop mobility there is enormous pressure to compress all of these separate radios into a single *multiband* radio. Thanks to electronics miniaturization; multiband, multimode radio systems are a reality.

Currently, transceivers capable of VHF, UHF, and Tactical Satellite (*TACSAT*) service are common. A combined HF/VHF/UHF and TACSAT transceiver is the latest innovation in this area.

The simplest transceiver must generate a modulated signal to the antenna and to receive a signal from an antenna, demodulate it, and feed the information to a headset, computer, or some other human or machine interface. A multiband transceiver must perform these functions for each of its frequency bands (Figure 3-1).

Most functions of the multiband transceiver are common to all frequency bands; however, the electronic means to accomplish these functions

Figure 3-1. *Simplified Diagram of a Multiband Manpack Transceiver*

differ depending upon the operating frequency band. Thus those functions that are associated with VHF transmit and receive frequencies must be grouped separately from those that perform that function for the UHF band. That is why most of the RF portions of the transceiver must be duplicated for each band, as shown in Figure 3-1.

Transmit Path Begins with the Digital Signal Processor

The transmitted voice or data information is applied to a common block in a multiband transceiver called the Digital Signal Processor (*DSP*). The DSP is actually a powerful but miniature computer that turns the input information into a digital form that is manipulated within the computer.

The functions performed by the DSP include audio *bandwidth* filtering, voice digitization, encryption, and modulation. The output of the DSP is actually a Low Frequency (*LF*) modulated carrier that is an exact replica of what is to be transmitted, except for its frequency. This signal is referred to as being at an Intermediate Frequency (*IF*).

UHF Frequency Up-Conversion, and Frequency Synthesizer

If a UHF frequency is selected, the IF signal at the output of the DSP is applied to the UHF up-converter circuits. Another block of circuits, called a frequency synthesizer creates the various signals that are required by the up-converter to create the desired UHF output frequency.

Power Amplifier and Transmit Filters

The up-converted signal is then applied to a wideband power amplifier which covers the entire transmit band selected. In this case it is the UHF band and the amplifier that handles signals from 90 to 512 MHz. The signal power output of this amplifier is typically operator selected from 1 to 10 watts.

Following the power amplifier is a group of switched low pass filters that "clean up" its output. These remove noise, spurious signals, and harmonics generated by other transmitter circuits including frequency harmonics generated by the power amplifier. This process reduces interference with adjacent communications channels.

UHF Antenna Port

The output of the UHF low pass filters is applied through a Transmit/Receive (TX/RX) switch (shown in Figure 3-1 in the TX position) to the UHF antenna port of the transceiver. UHF antennas have a 50-ohm input impedance.

Receive Path Begins with Switched Bandpass Filters

A receive UHF signal is applied by the antenna to the antenna port, and then through the TX/RX switch to a group of switched *bandpass filters*. The purpose of these filters is to remove signals above and below the desired signal.

RF Amplifiers and Down-Converter

The filtered input signals are applied to several radio frequency amplifier stages (shown as one block in Figure 3-1). The typical input signal has a signal strength in the micro-watt range (one millionth of a watt). The RF amplifiers boost this signal to the milli-watt range for further processing.

The next step in this process is to down-convert the signal to the LF IF frequency used by the DSP block. Again, this is accomplished by the down-converter in conjunction with signals from the synthesizer. In modern radios, this process is performed in several separate amplification and down conversion steps. It is shown in Figure 3-1 as occurring in just one step for simplicity.

DSP Demodulation and Decryption

The final steps in the receive process are performed by the DSP. Here the IF signals from the down-converter is demodulated and decrypted to form the base band signals (audio or data) that are used by the operator.

VHF Band Portion of the Transceiver

The VHF transmit and receive functions are similar to those of the UHF band except that they are performed by the VHF portions of the radio. However there is one additional function required in the VHF band and that is antenna matching.

VHF Whip Antenna Matching

The whip antenna frequently used with a VHF manpack radio does not present a 50-ohm impedance to the radio over the 30 to 90 MHz band. In order to maximize the power radiated from this type of antenna, a series of switched matching circuits are used in the transmit path following the switched low pass filters. The correct matching network is selected automatically by the frequency selector switch on the transceiver front panel.

50-Watt Multiband Transceiver Group

It is common for radios used in vehicles and in fixed stations to require higher power than the tactical manpack transceiver can deliver on its own. In these applications, the manpack transceiver is attached to a mounting base that includes power amplifiers and some additional antenna ports (Figure 3-2).
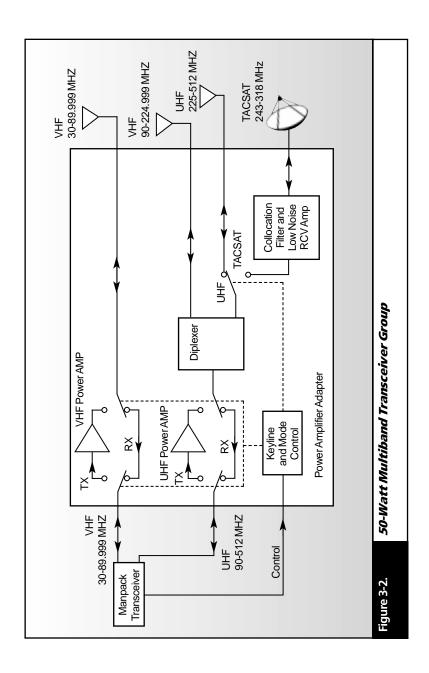
Power Amplifiers

A multiband vehicular adapter is likely to have two or more power amplifiers that are tailored to the frequency ports of the manpack transceiver. Figure 3-2 shows a vehicular adapter with both VHF and UHF transceiver ports. Each of these ports is associated with a power amplifier that is capable of producing 50 watts of output power.

Each of these amplifiers has a receive bypass path which is selected by the transceiver keyline. In the key-down transmit condition, the bypass is open and the signal is applied to the power amplifiers. However, in the receive condition, the amplifiers are bypassed so that the signal from the antenna ports can pass back to the receiver circuits in the manpack transceiver.

VHF Low, VHF High, UHF, and TACSAT Antenna Ports

Most multiband transceivers have two antenna ports, one for VHF and the other for UHF. In vehicular and fixed station installations it is common to have antennas that are larger and more efficient than those used with a manpack alone. It is therefore, convenient to have four antenna ports. The first port is used for low band VHF over the 30 to 89.999 MHz range. But the UHF path is spread between three separate antenna ports, as shown in Figure 3-2.

VHF 30-89.999 MHZ

VHF 90-224.999 MHZ

UHF 225-512 MHZ

TACSAT 243-318 MHz

Collocation Filter and Low Noise RCV Amp

TACSAT

UHF

Diplexer

VHF Power AMP

UHF Power AMP

TX

RX

TX

RX

Keyline and Mode Control

Power Amplifier Adapter

VHF 30-89.999 MHZ

UHF 90-512 MHZ

Control

Manpack Transceiver

Figure 3-2. **50-Watt Multiband Transceiver Group**

The output of the UHF amplifier is applied to a diplexer, which splits the UHF port into two frequency ranges, 90 to 224.999 MHz and 225 to 512 MHz. Each of these frequency outputs is applied to a corresponding antenna port.

The 225 to 512 MHz path is further divided by a relay switch into a UHF path and a TACSAT path. This is because the TACSAT path requires a collocation filter, a Low Noise Receive Amplifier (*LNA*), and a separate antenna port. This additional filtering and amplification on the TACSAT path is useful because of the typically low level of received signal from the tactical satellite in orbit 22,300 miles above the equator. The collocation filter is there to remove radio noise generated by vehicle ignition, motors, and other transmitters that would otherwise obscure the faint signals from the satellite.

The Antenna Group

The antenna is one of the most critical elements in a radio circuit. Here, we will look at typical antenna types and their applications.

Antenna Characteristics and Parameters

Some of the most commonly used terms to describe antennas are *impedance*, *gain*, *radiation pattern*, *take-off angle*, and *polarization.*

Every antenna has an input impedance that represents the load to be applied to the transmitter. This impedance depends upon many factors such as antenna design, frequency of operation, and location of the antenna with respect to surrounding objects.

The basic challenge in radio communications is finding ways to get the most power possible, where and when you need it, to generate and transmit signals. Most transmitters are designed to provide maximum output power and efficiency into a 50-ohm load. (*Ohm* is a unit of measurement of resistance.) Some antennas, such as log periodic antennas, can provide a 50-ohm load to the transmitter over a wide range of frequencies. These antennas can generally be connected directly to the transmitter. Other antennas, such as dipoles, whips, and long-wire antennas, have impedances that vary widely with frequency and the surrounding environment.

HF applications use an *antenna tuner* or *coupler*. This device is inserted between the transmitter and antenna to modify the characteristics of the load presented to the transmitter so that maximum power may be transferred from the transmitter to the antenna.
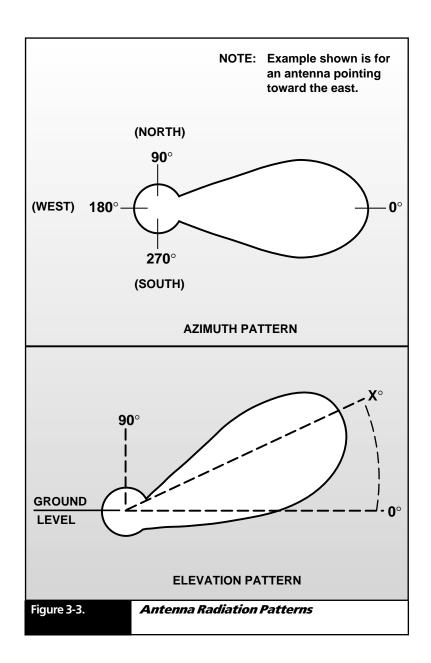
For most VHF and UHF applications, the antennas have built-in broadband-matching units so separate antenna coupler units are generally not required.

Antenna Gain and Radiation Pattern

The *gain* of an antenna is a measure of its directivity — its ability to focus the energy it radiates in a particular direction. The gain may be determined by comparing the level of signal received from it against the level that would be received from an isotropic antenna, which radiates equally in all directions. Gain can be expressed in dBi; the higher this number, the greater the directivity of the antenna. Transmitting antenna gain directly affects transmitter power requirements. If, for example, an *omnidirectional antenna* were replaced by a *directional antenna* with a gain of 10 dBi, a 100-watt transmitter would produce the same effective radiated power as a 1-kW transmitter and omnidirectional antenna.

In addition to gain, radio users must understand the radiation pattern of an antenna for optimal signal transmission. Radiation pattern is determined by an antenna's design and is strongly influenced by its location with respect to the ground. It may also be affected by its proximity to nearby objects such as buildings and trees. In most antennas, the pattern is not uniform, but is characterized by *lobes* (areas of strong radiation) and *nulls* (areas of weak radiation). These patterns are generally represented graphically in terms of plots in the vertical and horizontal planes (Figure 3-3), which show antenna gain as a function of elevation angle (vertical pattern) and azimuth angle (horizontal plot). The radiation patterns are frequency dependent, so plots at different frequencies are required to fully characterize the radiation pattern of an antenna.

In determining communications range, it is important to factor in the take-off angle, which is the angle between the *main lobe* of an antenna pattern and the horizontal plane of the transmitting antenna. For VHF and UHF applications, low take-off angles are generally used for LOS communications; high take-off angles are used for ground-to-air, close air support.

Figure 3-3. *Antenna Radiation Patterns*

The orientation of an antenna with respect to the ground determines its polarization. Most VHF and UHF whips and center fed monopole antennas are vertically polarized.

A vertically polarized antenna produces low take-off angles. The main drawback of vertical whip antennas is their sensitivity to ground conductivity and locally generated noise. Center fed monopoles avoid the sensitivity to ground conductivity and are preferred for vehicular mounts.

Horizontally polarized antennas, such as a 1/2-wave *dipole*, have high elevation angles. This type of antenna is particularly useful when the transmitter is near a forest or jungle. This allows the radiation to get above the trees rather than having them absorbed. Diffraction at the treetops tends to bend the radiation down so that it follows the treetops. For best results, the transmitting and receiving antennas should have the same polarization.
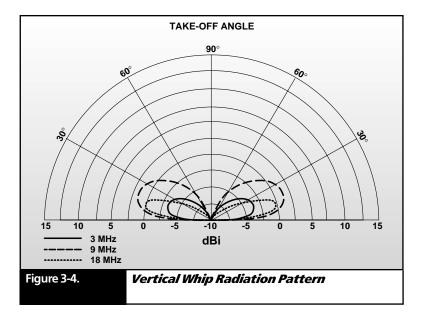
VHF Antennas

There are a countless variety of antennas used in VHF communication. We'll focus here on some of the more common types.
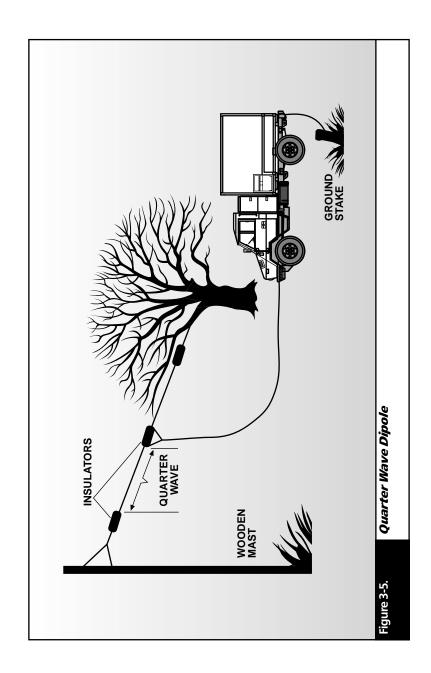
The *vertical whip antenna* is frequently used since it is omnidirectional and has low take-off angles. It is vertically polarized. A typical vertical whip radiation pattern is shown in Figure 3-4. A reflector, consisting of a second vertical whip, can add directivity to the radiation pattern of a whip.

Another useful type of antenna is the center fed 1/4 wave dipole, which is basically two lengths of wire fed at the center (Figure 3-5). This is a horizontally polarized antenna and is frequently used for vehicular and fixed station applications.

The radiation pattern can change dramatically as a function of its distance above the ground. Figure 3-6 shows the vertical radiation pattern of a horizontal dipole for several values of its height (in terms of transmitting wavelength) above the ground.

An inverted vee (sometimes called a "drooping dipole") produces a combination of horizontal and vertical radiation with omnidirectional coverage. See Figure 3-7.

Figure 3-4. *Vertical Whip Radiation Pattern*

INSULATORS

QUARTER WAVE

WOODEN MAST

GROUND STAKE

Figure 3-5.

Quarter Wave Dipole

DIPOLE .25λ ABOVE GROUND

DIPOLE .5λ ABOVE GROUND

DIPOLE .75λ ABOVE GROUND

DIPOLE 1.25λ ABOVE GROUND

λ Symbol for wavelength.

Figure 3-6.

Horizontal Dipole Antenna,
Vertical Radiation Patterns

90°
TO
120°

λ/4

HEIGHT = 50 FT

NON-METALLIC
SUPPORT

TO TRANSMITTER

INVERTED VEE ANTENNA

TAKE-OFF ANGLE

90°

60°   60°

30°   30°

15 10 5 0 -5 -10 -5 0 5 10 15

dBi

——————— 3 MHz
— · — · — · 9 MHz
·············· 18 MHz

λ **Symbol for wavelength.**

Figure 3-7.   *Inverted Vee Antenna*

TAKE-OFF ANGLE

90°

60°   60°

30°   30°

15 10 5 0 -5 -10 -5 0 5 10 15

dBi

——————— 4MHz
— · — · — · 12 MHz
·············· 30 MHz

Figure 3-8.   *Horizontal Log Periodic Antenna*

43   44

For fixed station use on high elevations (high hills or mountain tops) a log periodic directional antenna can be used for very long LOS communications of 100 miles or more. See Figure 3.8

UHF and SATCOM Antennas

For most UHF manpack applications, the transceiver is mounted with a short, stubby antenna that resembles a hot dog in shape. This antenna is used for relatively short LOS distances and its virtue is its small size.
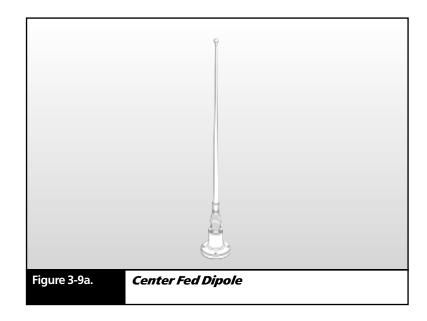
For vehicular or shelter mounted applications, an effective general-purpose UHF antenna is a center-fed dipole (Figure 3-9a). This antenna looks like a thick whip antenna. It is constructed within a fiberglass tube and consists of a dipole mounted vertically within the tube along with its feed point. Its significant virtue is that it is relatively independent of the ground quality. It has a low take off angle, and it is vertically polarized. The center-fed *dipole antenna* has a pattern similar to the whip pattern shown in Figure 3-4. There are center-fed dipoles designed for VHF frequencies as well.
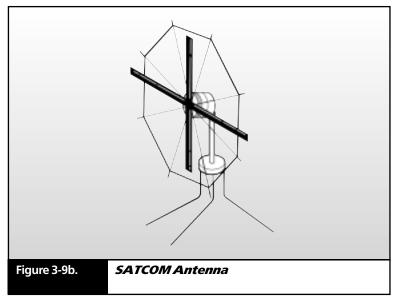
The UHF Tactical Satellite (TACSAT) antenna has a unique inverted umbrella shape (Figure 3-9b). It produces a directed beam that must be pointed directly at the satellite in order to be effective.
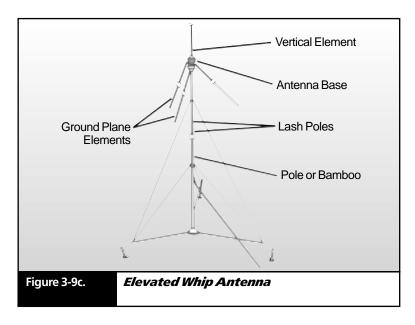
For fixed station use, an elevated whip or center-fed dipole greatly increases the LOS range (Figure 3-9c). This antenna assembly consists of a mast and a vertical whip or dipole mounted above ground plane rods. Again, this antenna structure can be used for both VHF and UHF applications with the proper selection of antenna and ground plane rod lengths.

Another popular UHF antenna used for fixed station use is the *Biconical Antenna* shown in Figure 3-9d. An antenna of this type has been designed to cover the 100 to 400 MHz range. Its broadband capability makes it an excellent choice for wide band Transmission Security (*TRANSEC*) modes such as frequency hopping. Refer to Chapter 7 for a discussion of TRANSEC.

The Biconical Antenna is usually mounted on a mast similar to the one shown in Figure 3-9c.

Figure 3-9a.   *Center Fed Dipole*

Figure 3-9b.   *SATCOM Antenna*

Figure 3-9c. *Elevated Whip Antenna*

Labels: Vertical Element, Antenna Base, Ground Plane Elements, Lash Poles, Pole or Bamboo

Figure 3-9d. *VHF/UHF Biconical Antenna 100 to 400 MHZ*

SUMMARY

- A radio system consists of a transceiver and an antenna group.

- The transceiver provides both transmitting and receiving functions.

- The transmit function consists of modulation, carrier generation frequency translation, and power amplification.

- The receive function consists of RF signal filtering, amplification, frequency down conversion, and demodulation.

- Antenna selection is critical to successful VHF, UHF, and TACSAT communications. Antenna types include vertical whips, center-fed dipoles, biconical antennas, directional log periodic arrays, and umbrella TACSAT antennas.

- An antenna coupler matches the impedance of the antenna to that of the transmitter, transferring maximum power to the antenna.

- The gain of an antenna is a measure of its directivity — its ability to focus the energy it radiates in a particular direction.

- Antenna radiation patterns are characterized by nulls (areas of weak radiation) and lobes (areas of strong radiation).

4

NOISE AND INTERFERENCE

While listening to the radio during a thunderstorm, you're sure to have noticed interruptions or static at one time or another. Perhaps you heard the voice of a pilot communicating to a control tower when you were listening to your favorite FM station. These are examples of interference that affect a receiver's performance. Annoying as this may be while you're trying to listen to music, noise and interference can be hazardous in the world of communications, where a mission's success or failure depends on receiving and understanding the transmitted message.

Sources of Noise

Receiver noise and interference come from both external and internal sources. Internal noise is created within the circuits of the receiver itself. Power supplies and frequency synthesizers are prominent sources of noise within the radio. But some noise comes from thermal agitation of the molecules that comprise electronic components in the amplifier stage closest to the receiver antenna.

External noise comes to the receiver by way of the antenna from sources outside the radio and frequently exceed internal receiver noise.

Natural Sources of Noise

In the HF frequency band, lightning is the main atmospheric (natural) source of noise. *Atmospheric noise* is highest during the summer and greatest at night, especially in the l- to 5-MHz range. One of the advantages of the VHF and UHF bands is that they are above this large source of noise.

Another natural noise source is galactic or *cosmic noise*, generated in space. At 20 MHz (just below the VHF band), space noise is generally larger than that of internally generated noise. This noise tapers off so that at around 200 MHz, it is about equal to internal noise. At higher frequencies it is insignificant.

Man-Made Noise

Power lines, computer equipment, and industrial and office machinery produce man-made noise, which can reach a receiver through radiation or by conduction through power cables. This type of man-made noise is called electromagnetic interference (*EMI*) and it is highest in urban areas. Grounding and shielding of the radio equipment and filtering of AC power input lines are techniques used by engineers to suppress EMI.

Unintentional Radio Interference

At any given time, thousands of radio transmitters compete for space on the radio spectrum above and below the VHF/UHF range of frequencies. Harmonics of HF transmitters fall within the VHF band, and commercial FM stations and other wireless radio emissions fall directly within the VHF and UHF bands. The radio spectrum is especially congested in Europe due to population density.

A major source of unintentional interference is the *collocation* of transmitters, receivers, and antennas. It's a problem on ships where space limitations dictate that several radio systems are located together.

Ways to reduce collocation interference include locating and carefully orienting antennas; using receivers that won't overload on strong, undesired signals; and using transmitters designed to minimize harmonics and other spurious emissions.

Intentional Interference

Deliberate interference, or *jamming*, results from transmitting on operating frequencies with the intent to disrupt communications. Jamming can be directed at a single channel or be wideband. It can be continuous (constant transmitting) or look-through (transmitting only when the signal to be jammed is present).

Modern military radio systems use spread-spectrum or frequency-hopping techniques to overcome jamming and reduce the probability of detection or interception. Spread-spectrum techniques are techniques in which the modulated information is transmitted in a bandwidth considerably greater than the frequency content of the original information.

Multipath Distortion

Signals from a transmitter reach the receiver via multiple paths and arrive at slightly different times (see Chapter 2). These multiple signals are as disruptive to communication as signal interference from other transmitters.

Signal Quality Measurement

Signal quality is indicated by signal-to-noise ratio (SNR), measured in decibels (dB). The higher the SNR, the better the signal quality. Every 3 *dB* of SNR corresponds to a ratio of two-to-one. Thus a 9 dB SNR means that the signal is eight times greater than the noise. A commonly considered SNR lower limit for adequate reception is 10 dB. This means that the signal has ten times as much power as the noise.

Reducing the Effect of Noise and Interference

Engineers use various techniques to combat noise and interference, including: (1) boosting the effective radiated power, (2) providing a means for optimizing operating frequency, (3) choosing a suitable modulation scheme, (4) selecting the appropriate antenna system, and (5) designing receivers that reject interfering signals.

SUMMARY

■ Natural (atmospheric) and man-made sources cause noise and interference. Power lines, computer terminals, and industrial machinery are prominent causes of man-made noise.

■ Congestion of radio transmitters competing for limited radio spectrum causes interference.

■ Collocated transmitters interfere with nearby receivers.

■ Jamming, or deliberate interference, results from transmitting on operating frequencies with the intent to disrupt communications.

■ Multipath interference can be considered another form of noise.

■ Proper antenna selection and advanced modulation techniques can reduce the effects of noise and interference.

DATA COMMUNICATION VIA VHF/UHF RADIO

From the very beginning, radio communications used Morse code for data communications. Over time, improved techniques were developed for data transmission that take into account the variability of the radio medium and greatly increase the speed at which data transmission occurs over a radio link. In addition, the application of error-correcting codes and automatic repeat request (ARQ) techniques offering error-free data transfer permits the use of radio transmissions for computer-to-computer communications systems.

To understand the principles of radio data communication, we'll define some common data terminology and explain the significance of the modem. We will also outline some of the problems and solutions associated with radio data communication.

Binary Data

Communication as an activity involves the transfer of information from a transmitter to a receiver over a suitable channel. Consider this book, for instance. It uses symbols (the alphabet) to encode information into a set of code groups (words) for transmission over a channel (the printed page) to a receiver (the reader). Applying this principle to data (information), we begin by using a kind of shorthand to transform the data into code words (*binary digits* or *bits*) for transmission over a channel (HF radio) to a receiver (the reader).

Bits are part of a number system having a base of two that uses only the symbols 0 and 1. Thus, a bit is any variable that assumes two distinct

states. For example, a switch is open or closed; a voltage is positive or negative, and so on.

A simple way to communicate binary data is to switch a circuit off and on in patterns that are interpreted at the other end of a link. This is essentially what was done in the early days of telegraphy. Later schemes used a bit to select one of two possible states of the properties that characterize a carrier (modulated radio wave) — either frequency or amplitude. More sophisticated approaches allow the carrier to assume more than two states and hence to represent multiple bits.

Baud Rate

Data transmission speed is commonly measured in bits per second (*bps*). Sometimes the word *baud* is used synonymously with bps, although the two terms actually have different meanings. Baud is a unit of signaling speed and is a measure of symbols per second that are being sent. A symbol may represent more than one bit.

The maximum baud rate supported by a radio channel depends on its bandwidth — the greater the bandwidth, the greater the baud rate. The rate at which information is transmitted, the bit rate, depends on how many bits there are per symbol.
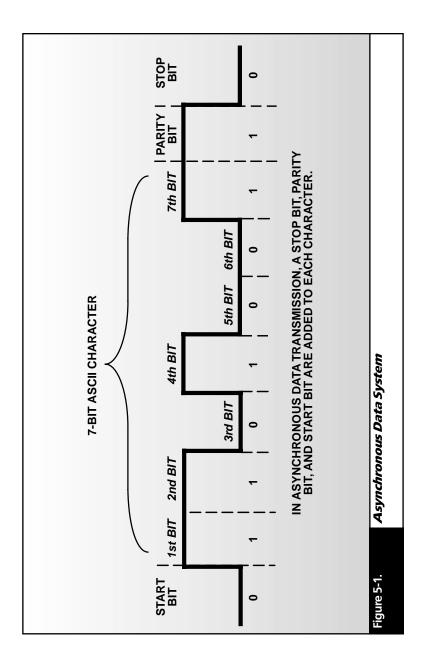
Asynchronous and Synchronous Data

The transmission of data occurs in either an *asynchronous* or *synchronous* mode.

In asynchronous data transmission, each character has a start and stop bit (Figure 5-1). The start bit prepares the data receiver to accept the character. The stop bit brings the data receiver back to an idle state.

Synchronous data transmission eliminates the start and stop bits. This type of system uses a *preamble* (a known sequence of bits, sent at the start of a message, that the receiver uses to synchronize to its internal clock) to alert the data receiver that a message is coming.

Asynchronous systems eliminate the need for complex synchronization circuits, but at the cost of higher overhead than synchronous systems. The stop and start bits increase the length of a character by 25 percent, from 8 to 10 bits.

7-BIT ASCII CHARACTER

START BIT | 1st BIT | 2nd BIT | 3rd BIT | 4th BIT | 5th BIT | 6th BIT | 7th BIT | PARITY BIT | STOP BIT

0 1 1 0 1 0 0 1 1 1 0

IN ASYNCHRONOUS DATA TRANSMISSION, A STOP BIT, PARITY BIT, AND START BIT ARE ADDED TO EACH CHARACTER.

Figure 5-1. *Asynchronous Data System*

Radio Modems

Radios cannot transmit data directly. Data digital voltage levels must be converted to radio signals, using a device called a *modulator*, which applies the audio to the transmitter. Conversely, at the receiver, a *demodulator* converts audio back to digital voltage levels. The Harris radios are equipped with built-in high-speed *modems* (the MOdulator and the DEModulator packaged together), which permit the radios to operate with either voice or data inputs.

Radio modems fall into three basic categories: (1) modems with slow-speed frequency shift keying (FSK); (2) high-speed parallel tone modems; and (3) high-speed serial (single) tone modems.

The simplest modems employ FSK to encode binary data (0s and 1s) (see Figure 5-2). The input to the modulator is a digital signal that takes one of two possible voltage levels. The output of the modulator is an RF signal that is one of two possible tones. FSK systems are limited to data rates less than 75 bps due to the effects of multipath propagation.

Amplitude Shift Keying (A*SK*) is similar to FSK except that it is the amplitude of the carrier that is modulated rather than the frequency.
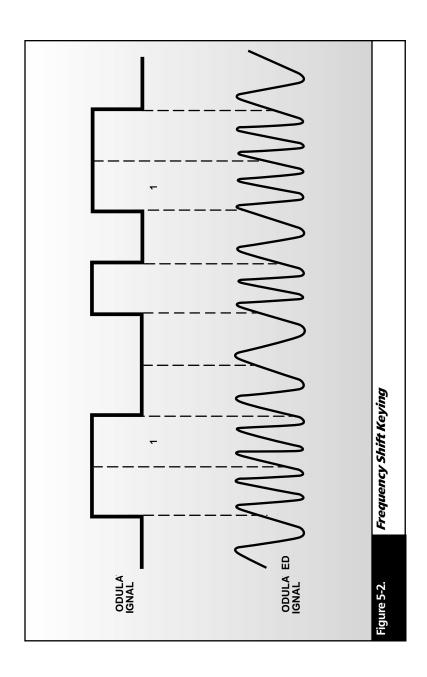
Higher rates are possible with more modern Phase Shift Keying (*PSK*) modulation methods and advanced coding schemes. PSK is described later in this chapter.

Error Control

There are several different approaches to avoid data transmission problems.

Forward Error Correction (*FEC*) adds redundant data to the data stream to allow the data receiver to detect and correct errors. An important aspect of this concept is that it does not require a return channel for the acknowledgment. If a data receiver detects an error, it simply corrects it and accurately reproduces the original data without notifying the data sender that there was a problem. Downsides of FEC: Unlike ARQ, FEC does not ensure error-free data transmission; FEC decreases the effective data throughput.

The FEC coding technique is most effective if errors occur randomly in a data stream. The radio medium, however, typically introduces errors that

ODULAT
IGNAL

1

1

ODULA ED
IGNAL

Figure 5-2. *Frequency Shift Keying*

occur in bursts — that is, intervals with a high bit error ratio (*BER*) in the channel are interspersed with intervals of a low BER. To take full advantage of the FEC coding technique, it's best to randomize the errors that occur in the channel by a process called *interleaving* (Figure 5-3).

For example, at the modulator, the data stream enters a 9-row by 10-column matrix. The blocks are entered by rows and unloaded by columns. When the data stream leaves the matrix for transmission, the sequence of output bits will be 1, 11, 21, and so on.

At the demodulator, de-interleaving reverses the process. Data is entered by columns in a matrix identical to that at the transmitter. It is read out in rows, restoring the sequence of data to its original state. Thus, if a burst were to cause 9 consecutive bits to be in error, no more than 3 of them will fall in any 30-bit sequence of bits after de-interleaving. Then, if an FEC coding technique were used, the errors would be corrected.
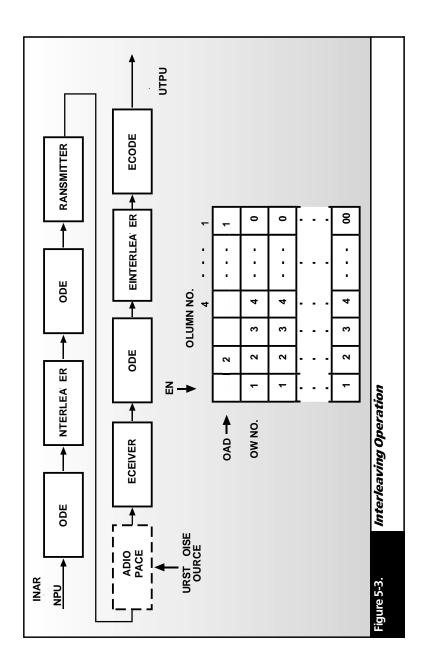
Soft-decision decoding further enhances the power of the error-correction coding. In this process, a group of detected symbols that retain their analog character are compared against the set of possible transmitted code words. The system "remembers" the voltage from the detector and applies a weighing factor to each symbol in the code word before making a decision about which code word was transmitted.

Vocoder

Data communications techniques are also used for encrypting voice calls by a device called a *vocoder* (short for voice coder- decoder). The vocoder converts sound into a data stream for transmission over an HF radio channel. A vocoder at the receiving end reconstructs the data into telephone-quality sound.

Channel Equalization and Excision Filtering

In addition to error correction techniques, high-speed serial modems may include two signal-processing schemes that improve data transmissions. An automatic channel equalizer compensates for variations in the channel characteristics as data is being received. An *adaptive excision filter* seeks out and suppresses narrowband interference in the demodulator input, reducing the effects of co-channel interference, that is, interference on the same channel that is being used. Harris has patented several techniques to perform these functions.

Figure 5-3. *Interleaving Operation*

Modern High Data Rate Modem Waveforms

High-speed modem technology, permits data rates as high as 64 kbps. Radio transmission paths have varying characteristics depending upon the frequency band (HF, VHF, and UHF) and the bandwidth of the channel. Although most HF channels are bandwidth limited to 3 kHz; VHF, UHF, and SATCOM channels have both 5 kHz and 25 kHz bandwidths. To accommodate and maximize the data throughput rate for these radio transmission types, a number of robust data waveforms have been created. Table 6-1 lists these different waveform types and their applications.

TABLE 6-1

Waveform Application	Channel Bandwidth	Data Rate in kbps
ASK UHF HAVEQUICK	25 kHz	16 kbps
FSK VHF SINCGARS	25 kHz	16 kbps
PSK SATCOM DAMA	5 and 25 kHz	2.4 kbps
4-ary CPFSK SATCOM DAMA	5 kHz	4.8 k to 9.6 kbps
SATCOM DAMA	25 kHz	9.6 k to 56 kbps
16-ary TCM VHF/UHF	25 kHz	64 kbps
M-ary CPM VHF/UHF	5 kHz	4.3 k to 8.5 kbps
VHF/UH	25 kHz	21 k to 64 kbps

Phase Shift Keying (PSK)

PSK is similar to FSK, shown in Figure 5-2, except that it is the phase of the carrier rather than the frequency that is modulated.

Binary Phase Shift Keying (BPSK)

The simplest form of PSK is called Binary Phase Shift Keying (BPSK) shown in Figure 5-4. Figure 5-4a shows a reference wave covering two bit periods. Figure 5-4b shows the wave after modulation with a (0) bit and a (1) bit. Notice that the signal corresponding to the second bit (1) is an upside-down version of the reference waveform. This portion of the signal is 180˚ with respect to the reference waveform.

Notice also that the transition from the first bit to the second is abrupt. This sudden phase discontinuity creates a burst of noise sidebands referred to as "splatter." This noise causes inter-symbol interference which severely limits the data rate that this simple form of PSK can deliver.
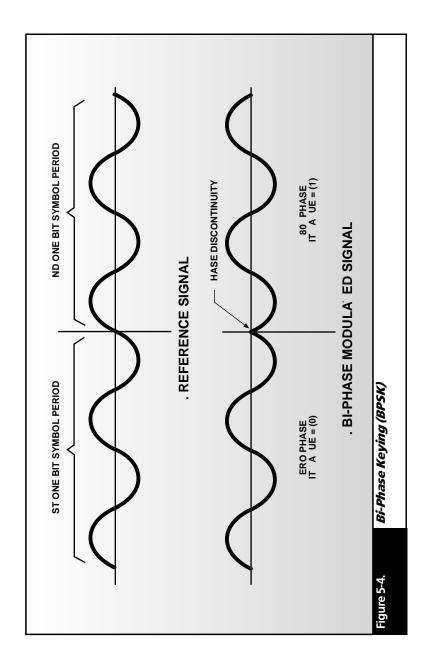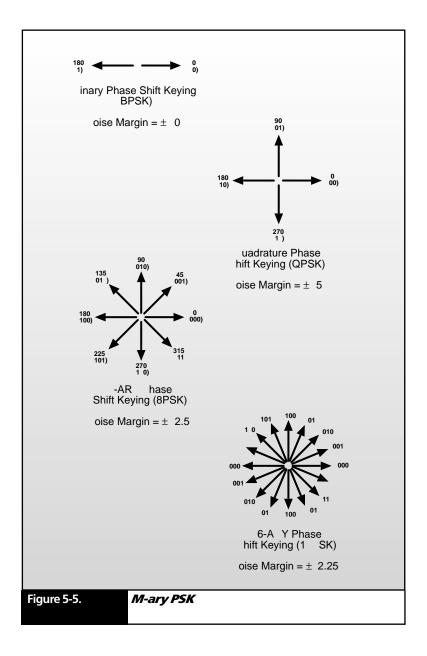
M-ary PSK

There are many forms of PSK. BPSK is modulated with just two phases of the carrier. Another term for BPSK is 2-ary PSK. In this case M=2. Figure 5-5 shows a diagram that represents M-ary PSK by showing vectors that represent the phase angles associated with the most common types of M-ary PSK modulation.

BPSK is represented by two arrows facing away from each other at a 180˚ angle. Each of the two phases of BPSK can represent only one bit of information, either a (0) or a (1).

Quadrature Phase Shift Keying (QPSK), or 4-ary PSK, is shown with four arrows arranged around a circle so that each is 45˚ apart. Since there are four phase states used in this modulation, each of these phases can represent two bits of information. Going clockwise around the circle, these bits are (00), (01), (10), and (11). This multi-bit representation per phase is the key to faster data rates, because each phase represents two bits rather than just one.

The figure also shows 8-ary PSK modulation, in which each phase represents three bits. Finally, 16-ary PSK is shown. Each phase represents four bits of information. On a non-noisy radio channel, 16-ary PSK has a data rate that is four times faster than BPSK because each modulation phase state represents four times as many bits.

Bi-Phase Keying (BPSK)

Figure 5-4.

61

62

180
1) ⟷ 0
0)

inary Phase Shift Keying
BPSK)

oise Margin = ± 0

90
01)

180
10) ⟷ 0
00)

270
1)

uadrature Phase
hift Keying (QPSK)

oise Margin = ± 5

90
010)

135
01)   45
001)

180
100) ⟷ 0
000)

225
101)   315
11

270
1 0)

-AR   hase
Shift Keying (8PSK)

oise Margin = ± 2.5

101 100 01

1 0   010

001

000 ⟷ 000

001

010   11

01 100 01

6-A Y Phase
hift Keying (1   SK)

oise Margin = ± 2.25

Figure 5-5.   *M-ary PSK*

63

Continuous Phase QPSK

Figure 5-6a shows what the waveforms of QPSK look like for each of the four possible modulation states of (00), (10), (10), and (11). Each of these bit pairs represents a code symbol.

Figure 5-6b shows a QPSK waveform covering two symbol periods in which the symbols change from (00) to (10). Notice that although this requires an 180° shift, there is no sudden discontinuity in the waveform. This is because a transition period equal to half of the symbol period has been taken to gradually change the phase. Although this slows down the data rate, the extra time is made up by the decrease in discontinuity noise (splatter) and attendant inter symbol interference.

Noise Margin

The problem with PSK waveforms with M = to 8 or 16 is that the difference in phase between each modulation state is very small. For example, in 8-ary and 16-ary PSK, the phase difference between the (0000) and (0001) symbols is only 45° and 22.5°, respectively. The noise margin is only half of those values because any noise that would make the signal appear to be half way between the true values would yield a doubtful decision. Thus the noise margin for 8-ary and 16-ary PSK is only 22.5° and 12.5°, respectively.
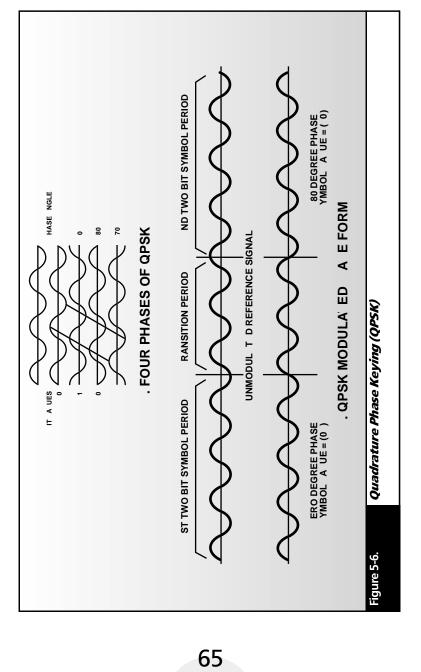
In a noisy radio channel, such a narrow phase difference is much harder to detect than the 90° noise margin of the two possible phase states in BPSK for the symbols (0) and (1). So, although 16-ary PSK can be four times as fast as BPSK in a perfect channel, it may be totally unreadable in a noisy channel.
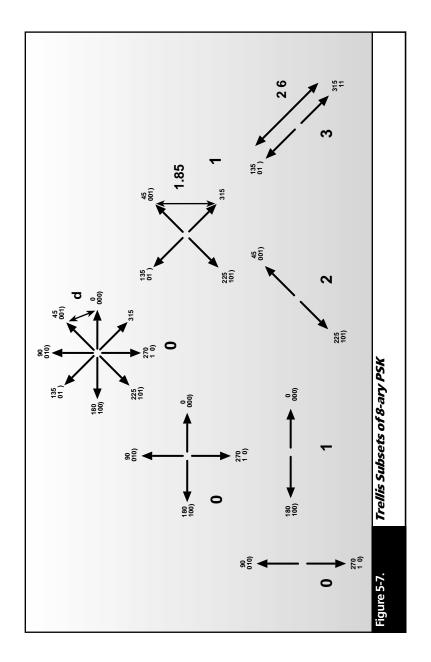
The phase difference between adjacent phase states in a PSK scheme is called its "noise margin". The greater this noise margin, the more immune to noise this symbol transition is.

BPSK may be slow, but it is very robust in a noisy channel.

Trellis Coded Modulation (TCM)

Figure 5-7 (A0) is a representation of an 8-ary PSK phase diagram where the linear distance between the arrows of adjacent phase points is labeled (d). As mentioned above, the noise margin corresponding to this distance is 22.5°. The term "distance" is another way of referring to noise margin.

Quadrature Phase Keying (QPSK)

Figure 5-6.

Trellis Subsets of 8-ary PSK

Figure 5-7.

65

66

The distance between successive symbols in a data stream can be maximized by partitioning into code subsets having increasing distance between their elements. Starting from 8-PSK constellation (in Figure 5-7 A0), we can create two 4-PSK subsets by taking every other signal point on the circle and putting them in one set and the rest of the signal points into another set (sets B0 and B1). The distance between adjacent phases on each of these sets is 1.85 times (d).

Each of the resulting 4-PSK sets can be further partitioned into two BPSK subsets (C0, C1, and C2, C3). The distance between the two signal points in each BPSK subset is 2.6 times (d). Considering all combinations of phases for each constellation, there are a total of six subsets of the basic 8-PSK signal set.

Each choice of subset, including the choice of one of the BPSK symbols in the last set, is assigned a bit value for a total of three bits. Because each bit has a different signal distance associated with it, each bit has a different likelihood of error.

The bits with the highest likelihood of error are coded into subsets with a greater distance between bits. The effect of coding is to make the signal different over multiple symbols due to the bit input at the present symbol. Distance is now measured over the several symbol intervals allowing the signal to "build up" more distance for any bit decision.

This process of subset partitioning and coding is called Trellis Coded Modulation. This basic concept can be extended to a 16-ary PSK signal with a bit rate of up to 64 kbps in a 25 kHz bandwidth radio channel.

SUMMARY

■ The transmission of data requires the use of modems to convert digital data RF signal form when transmitting, and convert the RF signal back to digital form when receiving.

■ Radio modems are classified as slow-speed FSK, high-speed parallel tone, or high-speed serial tone.

■ Serial tone modems provide vastly improved data communications, including a higher data rate with powerful forward error correction (FEC), greater robustness, and reduced sensitivity to interference.

■ FEC systems provide error correction without the need for a return link.

■ Interleaving is a technique; mostly used for HF channels that randomizes error bursts, allowing FEC systems to work more effectively.

■ Soft-decision decoding further reduces bit error rates by comparing a group of symbols that retain their analog character against the set of possible transmitted code words.

■ A vocoder converts voice signals into digital data for coded transmission over HF channels.

■ Automatic channel equalization and adaptive excision filtering are signal processing techniques that improve data communications performance.

■ M-ary Phase Shift Keying is a method of increasing the data rate of radio transmissions. "M" refers to the number of phases used in the modulation scheme.

■ Trellis Coded Modulation (TCM) is a coding technique that provides maximum data rate capability to PSK data streams by improving the noise margin.

UHF SATCOM

The increased requirement for greater troop mobility has been accommodated by the trend toward multiband, multimode radio systems. While technology permits the production of smaller, lighter-weight radio equipment, overall communications capability has not kept up with the demand. The need for flexibility, security, and reliability of terrestrial radio communications remains a critical problem.
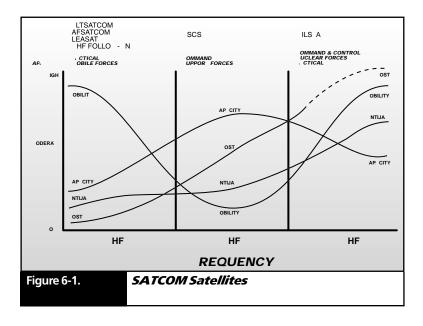
The two most significant radio limitations are the congested frequency spectrum and the physical limits on radio wave propagation. The development and use of communications satellites are an attempt to overcome these limitations.

Even as there is a need for HF, VHF, and UHF radio in the tactical environment, there is also a need for different types of satellite systems. These can also be grouped by frequency bands as follows: Ultra High Frequency (*UHF*), Super High Frequency (*SHF*), and Extra High Frequency (*EHF*). Figure 6-1 summarizes the chief characteristics of these three groups.

Figure 6-1 shows that the outstanding characteristics of the UHF group are the mobility of the ground terminals and its overall lower cost. It is this group that is used by our tactical mobile forces. The SATCOM discussions in this volume will be limited to this UHF Satellite system.

A Communications Satellite is a Radio Repeater

Just as cell phones use radio repeaters placed on towers and tall buildings to increase area coverage, SATCOM transceivers achieve coverage by using radio repeaters placed in satellites.

Figure 6-1. *SATCOM Satellites*

Technically, any ground radio with no obstructions above it is within the LOS of any satellite that is above the horizon. Chapter 2 stressed the advantage that antenna height makes in extending LOS distance. A satellite is the ultimate high antenna tower.

UHF is an excellent candidate frequency to contact a satellite because it can penetrate the atmosphere and ionosphere with little attenuation.

Uplink and Downlink Frequencies

The function of a repeater is to receive a radio signal at a particular frequency, amplify it, and then convert it to another frequency for rebroadcast. The radio paths up and back from a satellite are called *uplinks* and *downlinks*.

Different uplink and downlink frequencies are required to avoid feedback between the satellite transmitter and receiver. UHF uplink frequencies range from 292.95 MHz to 310.95 MHz, while downlink frequency range from 250.45 MHz to 269.95 MHz.

Uplink and downlink frequencies are paired within specific channel groups and frequency plans within that group. For example, Channel 2, Plan A, specifies an uplink frequency of 251.95 MHz and a downlink frequency of 292.95.

SATCOM transceivers can be programmed so that when in the SATCOM mode, a transceiver adjusted for a given channel will automatically choose the correct uplink and downlink frequencies for transmitting and receiving.
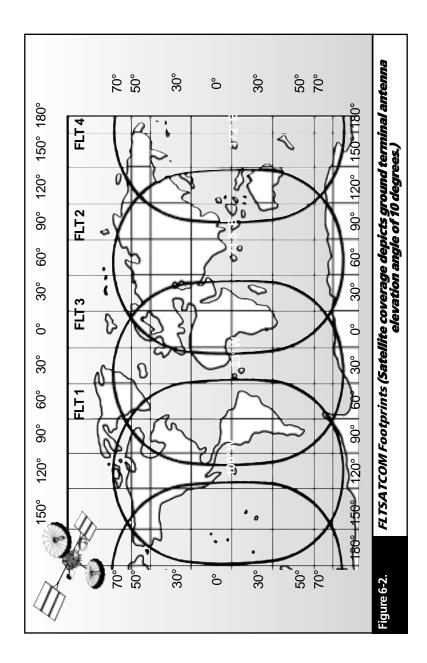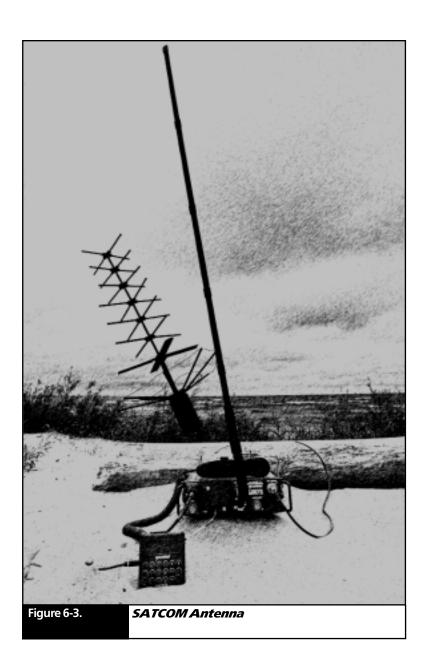
The Geostationary Orbit, and Coverage Footprint

The laws of physics are such that the speed of a stable satellite orbit depends upon its distance above the earth. If a satellite is placed in a stable orbit 22,300 miles above the equator, it must travel just fast enough to make a rotation around the earth in 24 hours. Since that is exactly the same speed that the earth rotates, a satellite placed in that orbit will hover over the same spot on earth as they both rotate together. This is called a *geostationary orbit*. Satellites closer to the earth must travel faster to remain in orbit and their positions would drift around the earth to the east.

A great advantage of having a communications satellite in a geostationary orbit is that it has a fixed, huge LOS coverage area. Figure 6-2 represents overlapping LOS areas created by having four such satellites evenly distributed around the earth above the equator. These LOS areas are called *footprints* of the satellite. Just four of these satellites provide foot-prints that cover the earth from the latitudes of 70° north to 70° south.

A ground transceiver located anywhere within a footprint can link with the associated satellite, and then back down to any other transceiver located within the footprint. For example, Figure 6-2 shows that a transceiver located anywhere in North America can link with a transceiver located anywhere in South America.

Many locations are under two adjacent footprints. This gives two possible satellite path choices. For example, a transceiver located near the East Coast of the US is within the footprints of both satellites FLT1 and FLT3. The footprint of FLT3 includes all of Europe and Africa. Being able to use both of these footprints provides a range that includes most the US, South America, Europe, and Africa.

71

Figure 6-2. *FLTSATCOM Footprints (Satellite coverage depicts ground terminal antenna elevation angle of 10 degrees.)*

72

Figure 6-3. *SATCOM Antenna*

With the use of ground repeating relay stations, the communication range of a SATCOM transceiver can have worldwide coverage.

SATCOM Antennas

The bad news about geostationary satellites is that they must be 23,300 miles above the earth's equator. That is a very long LOS distance for a relatively low power UHF transceiver. (Manpack SATCOM transceivers are generally limited to 20 watts or less of transmit signal power.)

The good news about geostationary satellites is that their exact location is known, so the LOS direction to it from any place within its footprint can be calculated.

To make the most of both the good and bad news, the antennas used for SATCOM work are directional (Figure 6-3). That is, they are constructed with a reflector similar to those used in a flashlight to focus the beam. By focusing the beam of a directional antenna, you can boost the effective radiated power by four times or more. Ground troops in a given theater of operation are told the precise compass bearing and elevation to aim the antenna so that it points directly toward the desired satellite.

To achieve a greater margin of link closure, vehicular and fixed station applications usually include adapters that provide amplification of the manpack transmit signal to 50 watts.

UHF SATCOM Channel Characteristics

As an example of UHF SATCOM channel characteristics, the U.S. Navy has a group of satellites called Fleet SATCOM (*FLTSATCOM*) frequency channels. The channel capabilities of a FLTSATCOM satellite are as follows:

- One 25-kHz channel downlink with a special 15 kHz SHF uplink dedicated to Navy fleet broadcast use.
- Nine 25-kHz relay channels for general use.
- Twelve Air Force narrowband, 5-kHz channels.
- One DOD wideband, 500-kHz channel for special use.

The fleet broadcast channel mentioned above is a one-way, shore-to-ship channel of 25-kHz bandwidth, which supports 15 time-division multiplexed, 100 wpm Teletype circuits. Its uplink is transmitted as an

anti-jam protected SFH signal, which is then processed, and frequency translated to a UHF downlink by circuits within the satellite.

The nine 25-kHz channels for general use are dedicated to FM modulated signals. Any data waveform that results in an FM, 25-kHz bandwidth can take advantage of these channels.

Demand Assigned Multiple Access (DAMA)

The few channels available from each satellite require that strict controls must be enforced about sharing. Each theater of operation has a Satellite Management Center (SMC) that is located away from the immediate battle zone, but is within communication distance of those within the battle zone. An operation that requires the use of SATCOM must get a plan approved from the SMC. This plan includes specific designated channels and channel access protocols.

One of the widely used protocols is Demand Assigned Multiple Access (*DAMA*). This is a technique that matches user demands to available satellite time.

Satellite channels are grouped together as a bulk asset, and DAMA assigns users variable time slots that match the user's information transmission requirements. The user notices no difference — it seems he has exclusive use of the channel. The increase in nets or users available by using DAMA depends on the type of users. DAMA is most effective where there are many users operating at low to moderate duty cycles. This describes many tactical nets; therefore, DAMA is particularly effective with TACSAT systems.

DAMA efficiency also depends on how the system is formatted. Formatting a DAMA system is how the access is controlled. The greatest user increase is obtained through unlimited access. This format sets up channel use on a "first-come-first-serve" basis. Other types of formats are prioritized cuing access and minimum percentage access.

The prioritization technique is suitable for command type nets, while the minimum percentage is suitable for support/logistic nets. Regardless of format, DAMA generally increases satellite capability by 4 times over normal dedicated channel operation.

SUMMARY

■ There are UHF, SHF, and EHF military satellites.

■ UHF satellites are used for tactical military use, which includes ground forces as well as those of the Navy and Air Force.

■ A footprint of a satellite is the total ground area for which a LOS path exists.

■ A UHF SATCOM transceiver can link with any satellite that includes the transceiver in its footprint.

■ The use of multiple footprints and ground relay stations can extend the SATCOM range to nearly the entire world.

■ The Satellite Management Center (SMC) regulates and assigns the satellite resources to users.

■ Directional antennas must be used with UHF SATCOM transceivers.

■ Demand Assigned Multiple Access (DAMA) is a way to timeshare available satellite resources in an efficient way.

7

SECURING COMMUNICATIONS

Information security is becoming a high priority for businesses around the world. With the dramatic increase in electronic communications and electronic commerce, there has been a corresponding increase in the malicious compromise of that information. In this chapter, we'll discuss communications security (*COMSEC*), that is; methods that keep important communications secure. We'll also talk about transmission security (*TRANSEC*) — schemes that make it difficult for someone to intercept or interfere with your communications.

COMSEC

COMSEC uses scrambling or cryptographic techniques to make information unintelligible to people who do not have a need to know or who should not know. We'll differentiate here between cryptographic or ciphering techniques applied to digital signals and scrambling techniques applied to analog signals.

Cryptography is the process of *encrypting* (translating) information into an apparently random message at the transmitter and then deciphering the random message by decryption at the receiver.

Historically, sensitive information has been protected through the use of codes. The sender would manually encode the messages before transmission and the recipient would manually decode the messages upon receipt. Today's electronic technologies allow the coding/decoding process to occur automatically.

The process involves using a mathematical algorithm, coupled with a key, to translate information from the clear to the encrypted state. If sensitive information is transmitted without the protection of cryptography and the information is intercepted, it would require little effort or resources

to understand the transmittal. The US Government has established standards for the degree of protection required for different levels of classified and sensitive information.

In voice communications systems that do not require extremely high security, you can protect against casual eavesdropping by *scrambling*. Scrambling, as an analog COMSEC technique, involves separating the voice signal into a number of audio sub-bands, shifting each sub-band to a different audio frequency range, and combining the resulting sub-bands into a composite audio output that modulates the transmitter. A random pattern controls the frequency shifting. The technique of scrambling the pattern is similar to sending a message with a decoder ring, like the ones sometimes found in children's cereal boxes. You can, for example, designate that the letter c be ciphered as g, a as n, and t as w, so that when you receive the message *gnw*, you decode it as cat. Descrambling occurs at the receiver by reversing the process. In today's digital age, analog scrambling has given way to digital encryption.

Digital Encryption

To digitally encrypt a transmission, analog voice information must be first digitized by a VOCODER (as mentioned in Chapter 5), which converts the signal into a binary data stream.

The binary data stream is then applied to what is called a "cryptographic engine." This is a processor which creates an extremely long, non-repeating binary number stream based on a complex mathematical algorithm and a traffic encryption key (*TEK*). The TEK is a binary number that is used to control the algorithm.

Binary addition is then used on a bit by bit basis to merge the cryptographic stream with the data stream. A binary stream created in this fashion is inherently unpredictable, and bears little resemblance to the original data stream. It is now called encrypted data or *cipher text*. Decryption can only be accomplished by knowing the algorithm and the TEK, and then by reversing the encryption process.

The data encryption strength is a function of the complexity of the mathematical algorithm coupled with the TEK (sometimes just called the key). Protection of the key is vital.

Even if an unwanted organization gains access to the encrypted information and has the algorithm, it is still impossible to decrypt the information without the key. The US Government has developed rigorous key management procedures to protect, distribute, store, and dispose of keys.

In the past, keys were manually loaded into a cryptographic device by using a paper tape, magnetic medium, or plug-in transfer device. Creation and secure delivery of keys to each user were significant problems in both logistics and record keeping.

One type of key management system also used in the commercial sector is *public key cryptography*. Under this standard, each user generates two keys. One is the public key, "Y," and the other is the *private key*, "X." The Y value derives from the X value. The strength of such a system lies in the difficulty of deriving X from Y; what is encrypted with the Y key can only be decrypted with the X key. By openly disseminating the user's public Y key, and retaining sole access to the private X key, anyone can send a secure message to you by encrypting it with your public Y key. You are the only one, though, who can decrypt the message, since only you have the private X key.

In a network using this public key system, two-way secure communications are possible among all network users. This is called an *asymmetrical key system*. The alternative is a *symmetric key system*, in which the same key encrypts and decrypts data. Because both the originator and all recipients must have the same keys, this system offers the highest levels of security. Harris has led the way in developing state-of-the-art electronic means to secure and distribute key material for these symmetric key-based communications systems.

A recent development applicable to radio networks employs Over-The-Air-Rekeying (*OTAR*). This technique nearly eliminates the need for manual loading of keys and provides a secure key management.

OTAR is based upon a benign key distribution system. It includes a key encryption key (*KEK*) used to encrypt the TEK and any other operational COMSEC or TRANSEC keys. This process is referred to as "wrapping" to differentiate it from traffic encryption. The KEK is the only key that must be initially loaded into both the sending and receiving units. Usually, an initial set of operational keys is loaded at the same time.

After wrapping, subsequent distribution can use any physical or electronic means. In an OTAR system, the wrapped keys are inserted into a message and sent over a radio link to the intended station using error-free transmission protocols (an error would render the keys useless). The link used for transmission is usually secured by the TEK currently in use. Thus, the key material is doubly protected when sent over the air, practically eliminating any possibility of compromise.

TRANSEC

TRANSEC employs a number of techniques to prevent signal detection or jamming of the transmission path. These techniques include hiding the radio transmission or making it a moving target.

Low Probability of Detection (*LPD*) systems hide the radio transmission by transmitting it using very low power, or by spreading the signal over a broad bandwidth so that the natural noise in the environment masks the signal.

The most commonly used TRANSEC technique is frequency hopping. In this system, the transmitter frequency changes in accordance with a complex algorithm so rapidly that it is difficult for an unauthorized person to listen in or to jam the signal. The receiver is synchronized so that it hops from frequency to frequency in unison with the transmitter. A TRANSEC key system modifies the hopping algorithm so that only transmitters and receivers that use the same key can communicate.

Frequency hopping scatters the intelligence over several hundred discrete frequencies. A radio operator listening to one of these frequencies may hear a short "pop" of static. A broadband receiver could perhaps capture all of these little bursts; however, the task of picking these bursts out of the other natural and man-made bits of noise would be daunting, requiring a team of experts several hours just to reassemble a short conversation.

Jamming one channel would have minimal impact on the hopping communicator. To effectively jam a frequency-hopping radio, most or all of the frequencies that the hopping communicator uses would have to be jammed, thus preventing the use of those frequencies as well. Harris Corporation's AN/PRC-117, AN/PRC-138, FALCON and FALCON II transceivers are highly rated for their frequency-hopping capabilities.

National Security Agency (NSA) Certification

The inclusion of COMSEC and TRANSEC capabilities into radio equipment requires stringent design practices to ensure that not even a trace amount of the unencrypted signal gets inadvertently transmitted along with the encrypted signal.

For example, an analog voice signal applied to the input of a radio has a tendency to cause slight fluctuations in the radio power supply that can actually amplitude modulate the output power amplifier of the radio. If this happens, a sensitive receiver can detect the unencrypted audio signal.

Having a copy of both an original and encrypted message not only gives the enemy the specific unencrypted message, but places in jeopardy any signals transmitted with that same TEK and algorithm.

Similarly, the cryptographic stream created by the COMSEC engine can "leak" to the output through the power supply or because of inadequate internal shielding. If the enemy has a copy of the cryptographic stream, it can be used to decode the encrypted data.

To avoid these and other similar problems, an impenetrable interface must be designed into the radio and the COMSEC and TRANSEC modules that keep the unencrypted signals totally separated from the circuits that create the radio frequency signal. Those circuits that are associated with unen-crypted input signal are called "Red." Those associated with the encrypted signal are called "Black." Red/Black interface is the barrier between them.

In order for a manufacturer to furnish COMSEC and TRANSEC modules and radios for high-grade US Government use, a thorough testing program must be designed and then approved by the National Security Agency. The radios are then meticulously tested by NSA experts to ensure that not a trace of unencrypted signals escape into the radio frequency signal stream. Only after passing many such tests can a company be certified to produce this high-grade type of cryptographic equipment.

Harris Corporation, RF Communications Division, is a supplier of NSA-certified products and is a preferred supplier of information security for the US Government and the US Department of Defense. It is a leader in the development and production of US Government and exportable security products. The company also provides a comprehensive line of secure products for the non-US Government market.

Harris radios have a wide variety of modern COMSEC and TRANSEC engine options. These engines are also available as modules for incorporation in OEM hardware.

Presidio

Presidio is a high-speed full or half-duplex embeddable US government COMSEC module, used to secure digital voice or data traffic over radio, wireline or other telecommunications media. Presidio is capable of data encryption/decryption at speeds up to E1 (2.048 Mbps) data rate. Presidio offers COMSEC equipment manufacturers a wide range of interoperability and key management features as well as reduced size, weight and number of devices required, making Type 1 certification an easier process.

CITADEL™

The CITADEL cryptographic engine provides high-grade protection for US domestic and international customers over all modern communications media. It is available with configurable key lengths and multiple algorithm options, making CITADEL an ideal export encryption solution for a broad range of communication products. The CITADEL supports both COMSEC and TRANSEC functions allowing the device to be adapted to virtually any communication environment.

Sierra™

The Sierra module addresses the need for an encryption technology that combines the advantages of the government's high-grade security with the cost efficiency of a reprogrammable, commercially produced encryption module. It provides a common security solution to users that can take on multiple encryption personalities depending on the mission that has been programmed.

SUMMARY

■ COMSEC uses cryptography or scrambling to make information unintelligible to people who do not have a need to know or who should not know.

■ The security level of a COMSEC system depends on the mathematical complexity of the algorithms and the number of variables in the key.

■ Protection of the key is vital to securing the transmitted information.

■ Public key cryptography is widely used in the commercial sector.

■ Over-The-Air-Rekeying (OTAR) eliminates the need for manual loading of keys and provides a more secure method of key management.

■ TRANSEC protects the transmitted signal itself, to prevent signal detection or jamming of the transmission path.

■ Low Probability of Detection (LPD) systems use spread-spectrum and other techniques to "hide" the signal beneath the natural noise level.

■ Frequency-hopping radio systems jump rapidly in unison, from one frequency to another in apparently random patterns, using a common timing reference.

■ Presidio, CITADEL, and Sierra are modern COMSEC and TRANSEC engines.

CHAPTER
8

SYSTEMS AND APPLICATIONS

Today's communications system designer makes use of HF, UHF, VHF, and SATCOM tools and capitalizes on the unique capabilities that each brings to the job. HF radio offers a unique combination of cost effectiveness and versatility for long-haul communications, while VHF/UHF radio products bring solutions to classical line-of-sight communications requirements.

Recent developments in digital signal processing and manufacturing miniaturization have pushed the technology to smaller, lighter, and less expensive equipment. Software-based radio platforms are now able to solve complex system requirements. This chapter can only touch on a few of the many modern radio system possibilities available today.
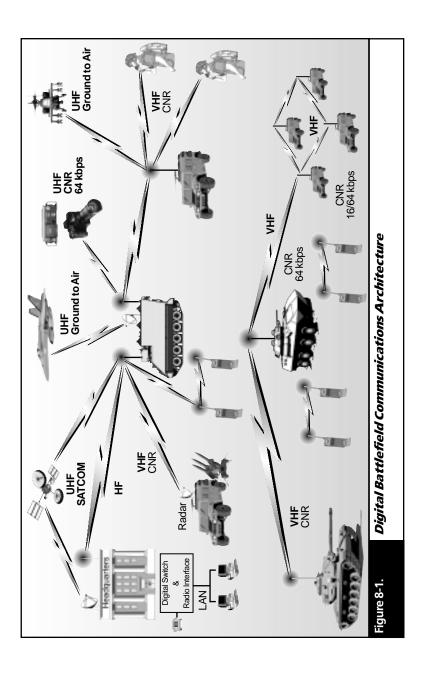
The Digital Battlefield
Figure 8-1 illustrates a modern battlefield communications network architecture that uses SATCOM, UHF, VHF, and HF technologies.

Mobile communications vehicles provide hubs that receive and retransmit radio signals that cover the entire available spectrum. VHF Combat Net Radios (CNR) provide ground LOS communications between squads, while UHF radios provide the same for ground-to-air (G/A) close support.

Harris VHF/UHF radios are interoperable with all common waveforms used in aircraft. The operator can easily program channels on frequencies for a G/A net, in plain text AM or FM, as well as cipher text AM or FM.

HF and SATCOM radios provide long haul communications from the front line back to theater headquarters. Such a tactical communications network provides coverage over distances ranging from less than 50 miles to more than 1,500 miles.

Figure 8-1. *Digital Battlefield Communications Architecture*

Individual elements of this network include frequency hopping, encryption, and HF Automatic Link Establishment (ALE) capabilities.

Network requirements dictate that links are provided between the fixed headquarters site and fixed installations for quasi-permanent military regions and zones. Provisions are then made for communications between headquarters and task forces at fixed, non-permanent, installations.

Lower echelon communications have a combination of fixed, mobile, and man-portable equipment. Frequency management of the network is a headquarters responsibility.

Video Imaging

VHF/UHF bandwidth considerations support 16 kbps to 64 kbps within a typical 25 kHz channel, improving the speed in which a text string, file, or document can be sent.

Figure 8-2 shows a scenario in which an unattended still-video camera sends images to an imaging terminal via a fiber-optic link. The terminal captures and digitizes the image and sends the data to a modem in the transceiver, which relays the data to the base. Communications may be via a two-way link that uses an ARQ protocol to obtain error-free transmission of the image, or a one-way link in which FEC coding reduces the probability of error in the received message.
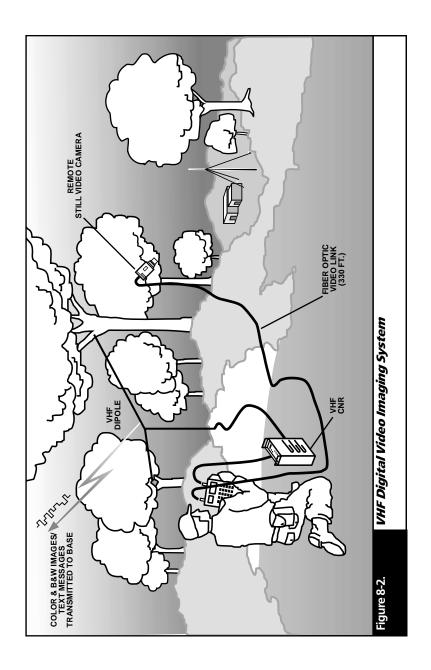
High data rates for detailed images or maps shorten the on-air time required to pass the image files.
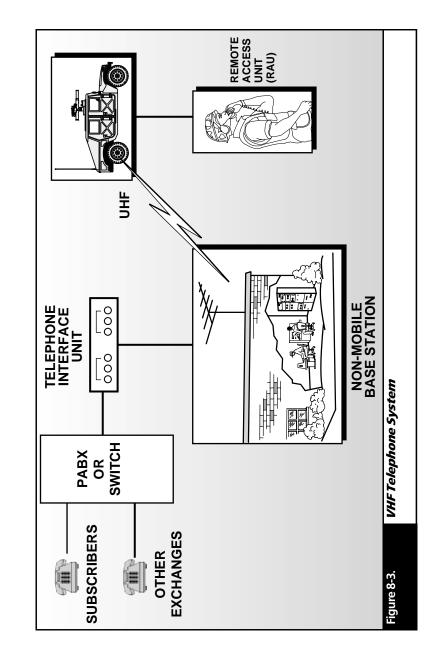
The Harris Universal Image Transmission System (HUITS) digital imaging product optimizes the compression of digital images and uses an ARQ protocol specifically designed for transmission over tactical radio channels.

VHF/UHF Telephone System

A VHF or UHF radio link extends the reach of a telephone network to the battlefield as shown in Figure 8-3. The telephone system enables users to place calls to and from mobile radio transceivers in the field to commercial switched telephone networks or private subscriber telephone lines.

Calls from the field are placed over HF, VHF, or UHF to anywhere in the world through the base station telephone switch or exchange. To initiate

REMOTE
STILL VIDEO CAMERA

VHF
DIPOLE

FIBER OPTIC
VIDEO LINK
(330 FT.)

VHF
CNR

COLOR & B&W IMAGES/
TEXT MESSAGES
TRANSMITTED TO BASE

Figure 8-2. *VHF Digital Video Imaging System*

87

REMOTE
ACCESS
UNIT
(RAU)

UHF

TELEPHONE
INTERFACE
UNIT

PABX
OR
SWITCH

NON-MOBILE
BASE STATION

SUBSCRIBERS

OTHER
EXCHANGES

Figure 8-3. *VHF Telephone System*

88

a call, the user enters a telephone number just as if the Remote Access Unit (RAU) was a telephone set connected directly to the base station telephone exchange.

At this point, the number dialed is transmitted through the RAU to the Telephone Interface Unit (TIU). As the TIU dials the digits and the target telephone rings, the mobile operator hears call progress tones, just as if a regular telephone was used.

In order to contact anyone in the field, a telephone user dials a telephone number (or the extension) to which the TIU is connected — from anywhere in the world. The TIU automatically answers the call and the user is connected directly with the field radio.

Secure communications can be achieved through interfaces to the common inventory of encryption devices. The high data rates available over a 25 kHz VHF channel improve the intelligibility of wide-band secure voice.
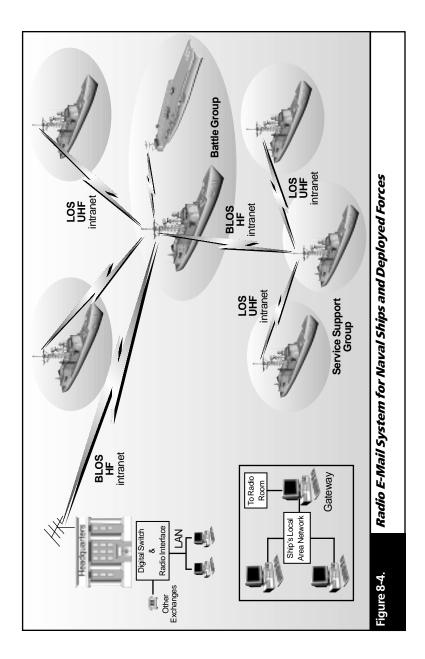
Radio E-mail

Electronic mail and other inter-networking technologies are becoming increasingly important for interoffice communications. However, many users find that communications between remote stations are difficult and/or expensive, due to costly telephone or satellite charges. Harris has developed radios and systems that are an excellent alternative for providing these services to distant users or stations. Typical applications include:

- Naval ship-to-shore and ship-to-ship communications
- Embassy Ministry of Foreign Affairs communications
- Oil/Gas/Mining operations

In the following discussion, we will focus on naval applications; similar configurations support other radio e-mail and inter-networking communications system requirements.

A radio e-mail system for naval ships and deployed forces that supports naval communications, including administrative, logistic, and engineering order-wire traffic, is shown in Figure 8-4.

Local Area Networks (LANs) within a ship provide an intranet with e-mail capability between various on-board duty stations. This LAN can also

Figure 8-4. *Radio E-Mail System for Naval Ships and Deployed Forces*

connect to a Harris Wireless Gateway, which extends the intranet using UHF LOS radio links to the various ships of the group. The Gateway provides seamless data transfers between common networked applications, such as E-mail and FTP file transfer, running on geographically separated LANs. HF long haul BLOS radio links, can extend the group intranet to distant support groups or to headquarters on shore.

Applications such as the Harris Wireless Messaging Terminal make the operator interface nearly identical to the office environment e-mail handling applications. This makes training of personnel easier and message handling simpler.

System Design Considerations

Harris RF Communications Division has a communications systems engineering department staffed by specialists in the design of custom equipment for the "one-of-a-kind" type of application. The following are some of the factors that systems engineers consider when designing a modern radio system.

System definition

- Who are the users?
- What is their location?
- Are communications one-way or two-way?
- What are the interfaces with other communications media?
- What is the operating environment (hostile or friendly, rural or urban)?

Transfer of information

- What type of traffic is there (voice, data, images)?
- Do the priority levels differ, depending on the message source and/or content?
- What are the security levels for safeguarding the information?

Message protection and security

- What is the correct type of error detection and correction for data?
- What type of COMSEC is needed?
- Will spread-spectrum or frequency-hopping techniques be used to avoid interception or jamming?
- Is excision filtering needed to remove interfering signals?

System availability

- What is the probability of transferring messages in real time?
- Can alternate routing be used to enhance message availability?
- Can lower priority traffic use store-and-forward techniques?
- Are there any operational restrictions due to propagation, transmitter power, or other constraints?

Traffic analysis

- What are the typical message lengths?
- What is the average number of messages per unit of time?
- What are the message priorities?
- When is the peak traffic?
- What are the types of traffic?

Projected growth for each category of traffic

- What impact does higher traffic levels have on system implementation?
- Are additional nodes and/or relays necessary?

Impact on message structure

- Is the format for data message compatible with traffic requirements?
- Include security classification, priority, source, and destination address.

Fixed site

- Are the receiving, transmitting, and control functions collocated or separate?
- Is this a permanent or temporary installation?
- Are there any frequency restraints for collocated receivers and transmitters?
- What are the staffing requirements?
- What are the environmental considerations?
- What type of power is available?
- Is uninterrupted power a requirement?

Mobile site

- Is the equipment designed for a vehicle, ship, shelter, or aircraft?
- Are manpacks required?
- What are the antenna limitations and constraints?
- What are the physical size constraints?

- What are the bandwidth and primary power requirements?
- What are the environmental considerations?

Communications protocol

- Is there a return channel for ARQ?
- Is ALE being used?
- What are the data protocols?

Equipment selection

- Transmitter requirements: Power output, solid state versus tube, broadband or narrowband, allowable distortion, frequency range, tuning speed, remote control?
- Receiver requirements: Selectivity, dynamic range, distortion, remote control?
- Antenna requirements: Gain, bandwidth, polarization, radiation pattern, available terrain, remote control?

Data communications systems

- What is the data rate?
- How is data being protected (type of encryption)?
- What is the modulation scheme?

Interface to other equipment and systems

- What other equipment is required (fax, data terminal, imaging systems)?
- What other types of systems are involved?
- What interfaces are required between HF/ VHF/UHF radio systems, satellite, or switched telephone networks?

Command and control

- Will operation be attended or unattended?
- Is self-test required?
- Are the transmitter, receiver, and control sites at different places (split site)?

93

SUMMARY

- Modern radios are small and lightweight. Features and capabilities, which formerly required additional equipment, are now fully embedded into the radio transceiver.

- HF, VHF/UHF and SATCOM radios play key roles in modern worldwide telecommunications systems, often working in conjunction with other media, such as cellular networks, and telephone landlines.

- Radio e-mail is becoming a very important part of military communications systems.

- A systems approach is needed to obtain the best results in designing a modern radio communications network.

94

FUTURE DIRECTIONS
by George Helm
Product Director, Tactical Business Unit

The first radios were substitutes for a pair of copper wires and were commonly referred to as wireless communications. These radios were used to bridge gaps that couldn't be managed with wire lines, such as between ships at sea and the shore. Later, as FSK, facsimile, video, and encryption became popular, special purpose boxes were invented to encode and decode base band signals that were transmitted over these simple radio channels.

As the mobility of communications equipment became more and more important, the hardware in these external boxes were miniaturized and incorporated into the radios. The advent of powerful Digital Signal Processing (DSP) chips and controlling microprocessors enabled the very complex coding and modulation schemes described earlier in this handbook. These schemes have been used to increase the efficient use of bandwidth up to the point that is now approaching theoretical limits.

What challenges await military tactical radio communications equipment in the 21st Century? The answer to this can be found by looking at the changes that have emerged on the modern battlefield. During the Gulf War, we witnessed a dramatic increase in the operational tempo of the battlefield. Command and control communications were lost as the military forces moved rapidly across the flat desert terrain, outpacing the conventional military communication systems. Increased information flow demands the use of data communications in place of voice communications, with an ever-increasing thirst for bandwidth. Critical battlefield information must flow both horizontally and vertically, driving the need for tactical networking.

There also emerges an increased need for situational awareness (SA) – knowing the precise location of military assets and personnel. As force

sizes are reduced through cuts in military spending, accurate situational awareness is a key to maintaining the dominant level of force lethality. In the future, SA will become a background task of the command and control communications structure. Position information will be securely appended to all voice and data traffic, and routed to a SA collection point so that military commanders can plan and execute a successful military campaign.

Finally, increased sophistication of enemy forces will demand the use of improved information security (INFOSEC) techniques. This includes stronger, embedded encryption/decryption devices used for all voice and data traffic, advanced electronic counter-counter measures (ECCM) methods to sustain communications in the presence of intentional jamming, and the use of Low-Probability of Intercept (LPI) and Low Probability of Detection (LPD) methods to protect forward-deployed troops operating in hostile areas.

Tactical Networking – Simple, Seamless and Secure Communications

During this past decade, we have all witnessed the impact the growth of the commercial Internet has had on countries around the globe. It demonstrates the power of seamless connectivity and the benefits gained from establishing common interfaces and protocols. Today the commercial Internet is starting to embrace the challenges presented by a wireless world. Many of these challenges are the same as those encountered in a modern military communications system – the demand for seamless connectivity, self-forming and healing networks, and secure communication links – to name but a few. Successful military communications equipment of the future will embrace this technology, building on the technological base established from enormous investments in the commercial sector.

Tactical networking will become an enabler for many military applications in the 21st Century. Example applications include: command/control systems; situational awareness systems; automatic range extension; tactical messaging systems; fire-control systems; full duplex and simultaneous voice/data systems; common database access; even combat net radio interface (CNRI) systems which link tactical and land-based infrastructures.

Radios, such as the Harris Falcon™ II Tactical Radio Family, will provide a seamless IP networking interface to other systems and application programs. New systems will be quickly and cost-effectively developed using commercial-off-the-shelf (COTS) tools and applications. Advanced channel

access protocols are under development to ensure the maximum effective use of the available frequency spectrum. Packet data transmissions will enable multiple applications to be simultaneously supported on a priority-driven basis and will allow voice and data traffic to coexist, even on a single, narrowband radio channel.

Packet data transmission, combined with very fast receive-to-transmit switching techniques, allow a simplex channel (one that alternately transmits and receives on the same frequency) to emulate the performance of full-duplex channels (one that receives and transmits on different frequencies simultaneously). It used to take two radios for retransmission, one to receive and the other to transmit simultaneously on another frequency. Cutting edge radios of today can accomplish this with only one radio.

The trend in this area is to build a seamless network supporting any combination of point-to-point and point-to-multipoint voice and/or data connections. Information will be encrypted and decrypted only at the origination and destination stations, ensuring information securing from end-to-end.

Higher Speed Data

During conflict, timely information collection and dissemination is critical to operating within the enemy's decision cycle. This need for increased information flow is driving the desire for ever-increasing data transmission rates. The latest generation of tactical radios offers a 4x increase over those currently fielded. This increase in data rate significantly increases message throughput and reduces the message latency.

According to Chester Massari, Harris RF Communications division president, "Data transmission is the future of military communications. As one of the pioneers in this area, we can send high-speed imagery and data across the radio spectrum better than anyone in the industry – plus, we offer this capability for land, sea, and air missions."

Where Do We Go From Here?

It is natural to ask the question, where do we go from here? Of course, with technology expanding at an ever-increasing rate, it is difficult to predict specifics more than a year or so in the future, but these are some of the important trends that are likely to influence radio technology for many years to come.

As we said in the introduction to this handbook, "Stay tuned!"

GLOSSARY

ADAPTIVE EXCISION FILTER — A signal-processing technique that improves data transmissions. It seeks and suppresses narrowband interference in the demodulator input and reduces the effects of co-channel interference (interference on the same channel that is being used).

ALE (Automatic Link Establishment) — A technique that permits radio stations to make contact with one another automatically.

AM (Amplitude Modulation) — A technique used to transmit information in which the amplitude of the radio frequency carrier is modulated by the audio input and the full carrier and both sidebands are transmitted.

AME (Amplitude Modulation Equivalent) — A method of single sideband transmission where the carrier is reinserted to permit reception by conventional AM receivers.

AMPLITUDE — The peak-to-peak magnitude of a radio wave.

ANTENNA COUPLER/TUNER — A device between the transmitter and antenna that modifies the characteristics of the load presented to the transmitter so that it transfers maximum power to the antenna.

ARQ (Automatic Repeat Request) — Data transmission technique for error-free data transfer.

ASK (Amplitude Shift Keying) — A form of modulation in which a digital signal shifts the amplitude of the carrier.

ASYMMETRICAL KEY SYSTEM — A key management system that allows two-way secure communications among all users that have a public key and a private key.

ASYNCHRONOUS — A data communication system that adds start-and-stop signal elements to the data for the purpose of synchronizing individual data characters or blocks.

ATMOSPHERIC NOISE — Radio noise caused by natural atmospheric processes (primarily by lightning discharges in thunderstorms).

ATTENUATES — Decreases.

AUTOMATIC CHANNEL EQUALIZER — A signal processing technique that improves data transmissions by compensating for variations in the channel characteristics as data is received.

BANDPASS FILTER — A filter that passes a limited band of frequencies. It removes noise and spurious signals generated in the exciter or output frequency harmonics from the power amplifier.

BANDWIDTH — The range of frequencies occupied by a given signal.

BAUD — A unit of signaling speed equal to the number of symbols, i.e., discrete signal conditions per second.

BER (Bit Error Ratio) — The number of erroneous bits divided by the total number of bits communicated.

BICONICAL ANTENNA — An antenna used for fixed station use; designed to cover the 100 to 400 MHz range.

BINARY — Number system having base of 2, using only the symbols 0 and 1.

BIT — One binary digit (0 or 1).

BLOS (Beyond Line-of-Sight) — Communications that occur over a great distance.

BROADBAND — A term indicating the relative spectrum occupancy of a signal as distinguished from a narrowband signal. A broadband signal typically has a bandwidth in excess of twice the highest modulating frequency. Synonym: Wideband.

CARRIER — A radio frequency signal that may be modulated with information signals.

CHANNEL — A unidirectional or bi-directional path for transmitting and/or receiving radio signals.

CIPHER TEXT — Encrypted data.

CNR — Combat Net Radios.

COLLOCATION — The act or result of placing or arranging side by side.

COMSEC (Communications Security) — Scrambling or cryptographic techniques that make information unintelligible to unauthorized persons.

COSMIC NOISE — Random noise originating outside the earth's atmosphere.

CRYPTOGRAPHY — A COMSEC technique that translates (encrypts) information into an apparently random message and then interprets (deciphers) the random message by decryption.

CW (Continuous Wave) — A radio wave of constant amplitude and constant frequency. Also, Morse code.

DAMA (Demand Assigned Multiple Access) – A technique that matches user demands to available satellite time.

dB (Decibel) — The standard unit for expressing transmission gain or loss and relative power ratios.

DE-INTERLEAVING — Process used by a demodulator to reverse interleaving and thus correct data transmission errors used in FEC coding.

DEMODULATION — The process in which the original modulating signal is recovered from a modulated carrier.

DIFFRACTION — When a VHF or UHF wave comes to a sharp edge, a portion of the wave bends around the edge and continues propagation as if a very low power radio was placed at the top of the ridge.

DIPOLE ANTENNA — A versatile antenna that is usually a wire fed at the center of its length. Its orientation provides either horizontal or vertical polarization.

DIRECT WAVES — Travel in straight line, becoming weaker as distance increases.

DIRECTIONAL ANTENNA — An antenna that has greater gain in one or more directions.

DOWNLINK — Radio paths back from a satellite.

DSP (Digital Signal Processing) — A recently developed technology that allows software to control digital electronic circuitry.

DUCTING — An effect where radio waves can bend between air layers of different densities

EMI (Electromagnetic Interference) — An electromagnetic disturbance that degrades communications performance. Synonym: Radio Frequency Interference (RFI).

ENCRYPTION — Process of translating information into an apparently random message.

ERP (Effective Radiated Power) — Equivalent power transmitted to the atmosphere, which is the product of the transmitter power output multiplied by the gain of the antenna.

EXCITER — The part of the transmitter that generates the modulated signal for a radio transmitter.

FADING — The variation of the amplitude and/or phase of a received signal due to changes in the propagation path with time.

FEC (Forward Error Correction) — A system of error control for data transmission whereby the receiver can correct any code block that contains fewer than a fixed number of bits in error.

FLTSATCOM (Fleet SATCOM) — A group of Navy satellites.

FM (Frequency Modulation) — A form of modulation where the frequency of a carrier varies in proportion to an audio modulating signal.

FOOTPRINT — The line of sight (LOS) areas covered by a satellite.

FREQUENCY — The number of completed cycles per second of a signal, measured in hertz (Hz).

FREQUENCY HOPPING — The rapid switching (hopping) of radio system frequency for both the receiver and transceiver from frequency to frequency in apparently random patterns, using a common timing reference.

FSK (Frequency Shift Keying) — A form of modulation in which a digital signal shifts the output frequency between discrete values.

GAIN — The ratio of the value of an output parameter, such as power, to its input level. Usually expressed in decibels.

GEOSTATIONARY ORBIT — The speed of a stable satellite orbit depends upon its distance above the earth. If a satellite is placed in a stable orbit 22,300 miles above the equator, it must travel just fast enough to make a rotation around the earth in 24 hours. Since that is exactly the same speed that the earth rotates, a satellite placed in that orbit will hover over the same spot on earth as they both rotate around together. This is called a geostationary orbit.

GROUND REFLECTED WAVE — The portion of the propagated wave that is reflected from the surface of the earth between the transmitter and receiver.

GROUND WAVE — A radio wave that is propagated over the earth and ordinarily is affected by the presence of the ground.

HF (High Frequency) — Normally, the band from 3 to 30 MHz. In practice, the lower end of the HF band extends to 1.6 MHz.

Hz (Hertz) — Basic unit for frequency.

IF (Intermediate Frequency) — A frequency used within equipment as an intermediate step in transmitting or receiving.

IMPEDANCE — Opposition to current flow of a complex combination of resistance and reactance. Reactance is the opposition to AC current flow by a capacitor or an inductor. An ideal antenna coupler will act so as to cancel the reactive component of antenna impedance, i.e., by providing an equal inductive reactance if the antenna has a capacitive reactance or an equal capacitive reactance if the antenna presents an inductive reactance.

INTERLEAVING — A technique that increases the effectiveness of FEC codes by randomizing the distribution of errors in communication channels characterized by error bursts.

IONOSPHERE — A region of electrically charged particles or gases in the earth's atmosphere extending from 50 to 600 kilometers (approximately 30 to 375 miles) above the earth's surface.

ISB (Independent Sideband) — Double sideband transmission in which the information carried by each sideband is different.

JAMMING — Deliberate interference that results from transmission on operating frequencies with the intent to disrupt communications.

KEK (Key Encryption Key) — Used in digital encryption.

KEY — A variable that changes the mathematical algorithm in cryptography.

KEY GENERATOR — A device or process that generates the variable for a cryptographic encoding system.

LF (Low Frequency) — The frequency range from 30 to 300 kHz.

LNA — Low noise receive amplifier.

LOBE — Area of strong radiation

LOS (Line of Sight) — A term that refers to radio signal propagation in a straight line from the transmitter to a receiver without refraction; generally extends to the visible horizon.

LPD (Low Probability of Detection) — Techniques for minimizing the probability that the transmitted signal is detected by an unauthorized party.

LSB (Lower Sideband) — The difference in frequency between the AM carrier signal and the modulation signal.

LUF (Lowest Usable Frequency) — The lowest frequency in the HF band at which the received field intensity is sufficient to provide the required signal-to-noise ratio.

MAIN LOBE — In an antenna radiation pattern, the lobe containing the direction of maximum radiation intensity.

M-ARY PSK (M-ary Phase Shift Keying) — A method of increasing the data rate of radio transmissions. "M" refers to the number of phases used in the modulation scheme.

MODEM (MOdulator-DEModulator) — A device that modulates and demodulates signals. The modem converts digital signals into analog form for transmitting and converts the received analog signals into digital form.

MODULATION — The process, or result of the process, of varying a characteristic of a carrier in accordance with a signal from an information source.

MUF (Maximum Usable Frequency) — The upper limit for the frequencies used at a specified time for radio transmission between two points via ionospheric propagation.

MULTIBAND — Military radios that combine VHF and UHF, HF and VHF, or HF-VHF-UHF capabilities.

MULTIPATH — The propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths.

MULTIPATH SPREAD — The range of timed differences that it takes for radio signals to reach the receiving antenna when they arrive from several routes, which may include one or more sky wave paths and/or a ground-wave path. The effect of multipath spread is minimized by selecting a frequency as close as possible to the MUF.

NULL — Area of weak radiation

OHM — Unit of measurement of resistance.

OMNIDIRECTIONAL ANTENNA — An antenna whose pattern is non-directional in azimuth.

ON-OFF KEYING — Turning the carrier on or off with telegraph key (Morse code). Same as CW.

OTAR (Over-The-Air-Rekeying) — This technique developed by Harris eliminates the need for manual loading of encryption keys and provides a more secure method of key management.

PARALLEL TONE MODEM — Carries information on simultaneous audio tones, where each tone is modulated at a low-keying rate.

PHASE — In a periodic process such as a radio wave, any possible distinguishable state of the wave.

PICKET FENCING — Form of multipathing common to vehicular mounted radios

POLARIZATION — The orientation of a wave relative to a reference plane. Usually expressed as horizontal or vertical in radio wave terminology.

PREAMBLE — A known sequence of bits sent at the start of a message, which the receiver uses to synchronize to its internal clock.

PROPAGATION — The movement of radio frequency energy through the atmosphere.

PSK (Phase Shift Keying) — PSK is similar to FSK except that it is the phase of the carrier rather than the frequency that is modulated.

PUBLIC KEY CRYPTOGRAPHY — A type of key management system used in the commercial sector. Under this standard, each user generates two keys, a public key and a private key. The strength of such a system lies in the difficulty of deriving the private key from the public key.

RADIATION PATTERN — Pattern determined by an antenna's design and strongly influenced by its location with respect to the ground. Radiation patterns are frequency dependent.

RAU — Remote Access Unit.

REFRACTION — The bending of a radio wave as it passes obliquely from one medium to another with different indices of refraction.

SATCOM — Satellite Communications.

SCRAMBLING — A COMSEC technique that involves separating the voice signal into a number of bands, shifting each band to a different audio frequency range, and combining the resulting bands into a composite audio output that modulates the transmitter.

SERIAL TONE MODEM — Carries digital information on a single audio tone.

SHORT WAVE — Radio frequencies above 3 MHz.

SIDEBAND — The spectral energy, distributed above or below a carrier, resulting from a modulation process.

SKY WAVE — A radio wave that is reflected by the ionosphere.

SMC (Satellite Management Center) — Regulates and assigns the satellite resources to users.

SNR (Signal-to-Noise Ratio) — The ratio of the power in the desired signal to that of noise in a specified bandwidth.

SOFT-DECISION DECODING — An error-correction technique where a group of detected symbols that retain their analog character are compared against the set of possible transmitted code words. A weighing factor is applied to each symbol in the code word before a decision is made about which code word was transmitted.

SSB (Single Sideband) — A modulation technique in which the carrier and one sideband (upper or lower) are suppressed so that all power is concentrated in the other sideband.

SURFACE WAVES — Travel along the surface of the earth and may reach beyond the horizon.

SYMMETRIC KEY SYSTEM — A key management system in which the same key encrypts and decrypts data.

SYNCHRONOUS — A form of data communications that uses a preamble to alert the data receiver that a message is coming and to allow it to synchronize to an internal bit clock.

TACSAT — Tactical Satellite.

TAKE-OFF ANGLE — The angle between the axis of the main lobe of an antenna pattern and the horizontal plane at the transmitting antenna.

TCM (Trellis Coded Modulation) — A coding technique that provides maximum data rate capability to PSK data streams by improving the noise margin.

TEK (Traffic Encryption Key) — Used in digital encryption.

TIU — Telephone Interface Unit.

TRAFFIC — The information moved over a communications channel.

TRANSCEIVER — Equipment using common circuits in order to provide transmitting and receiving capability.

TRANSEC (Transmission Security) — Techniques that prevent signal detection or jamming of the transmission path.

UHF (Ultra High Frequency) — The portion of the radio spectrum from 300 MHz to 3 GHz.

UPLINK — Radio paths up to a satellite.

USB (Upper Sideband) — The information-carrying band and is the frequency produced by adding the carrier frequency and the modulating frequency.

VERTICAL WHIP ANTENNA — An omnidirectional antenna that has low take-off angles and vertical polarity.

VHF (Very High Frequency) — The portion of the radio spectrum from approximately 30 MHz to 300 MHz.

VOCODER — A device that converts sounds into a data stream that can be sent over a radio channel. Short for voice coder-decoder.

WAVELENGTH — Distance between point on wave to corresponding point on adjacent wave.