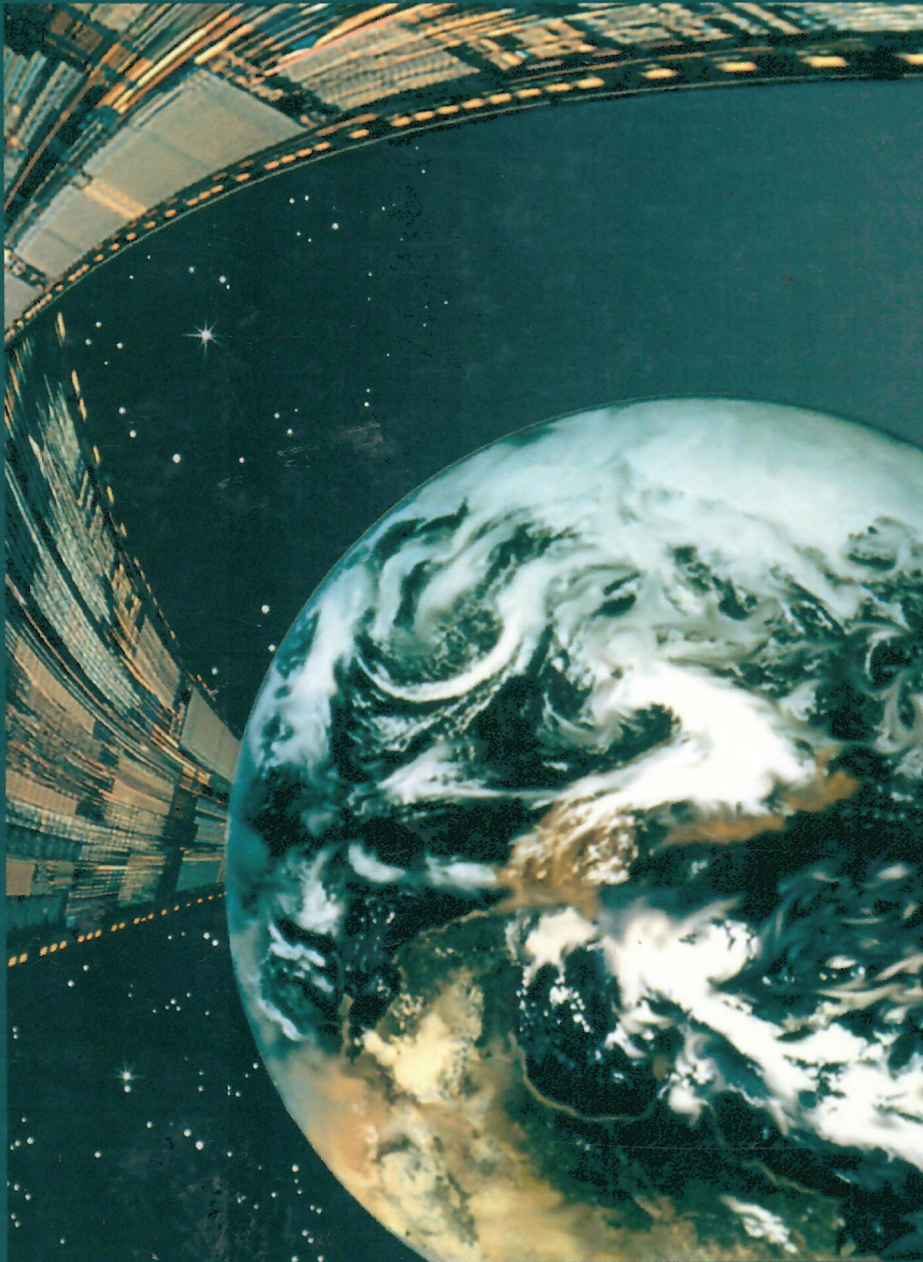


ELECTRONIC COMMUNICATIONS SYSTEMS FUNDAMENTALS THROUGH ADVANCED

FOURTH EDITION



WAYNE TOMASI

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Electronic Communications Systems

Fundamentals Through Advanced

Fourth Edition

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Introduction to Electronic Communications

INTRODUCTION

The fundamental purpose of an *electronic communications system* is to transfer *information* from one place to another. Thus, electronic communications can be summarized as the *transmission, reception, and processing* of information between two or more locations using electronic circuits. The original source information can be in *analog* (continuous) form, such as the human voice or music, or in *digital* (discrete) form, such as *binary-coded numbers* or *alphanumeric codes*. All forms of information, however, must be converted to *electromagnetic energy* before being propagated through an electronic communications system.

Samuel Morse developed the first electronic communications system in 1837. Morse used *electromagnetic induction* to transfer information in the form of dots, dashes, and spaces between a simple transmitter and receiver using a transmission line consisting of a length of metallic wire. He called his invention the *telegraph*. In 1876 Alexander Graham Bell and Thomas A. Watson were the first to successfully transfer human conversation over a crude metallic-wire communications system they called the *telephone*.

Guglielmo Marconi successfully transmitted the first *wireless* radio signals through Earth's atmosphere in 1894, and in 1908 Lee DeForest invented the triode vacuum tube which provided the first practical means of amplifying electrical signals. Commercial radio began in 1920 when radio stations began broadcasting *amplitude-modulated* (AM) signals, and in 1933, Major Edwin Howard Armstrong invented *frequency modulation* (FM). Commercial broadcasting of FM began in 1936.

Although the fundamental concepts and principles of electronic communications have changed little since their inception, the methods and circuits used to implement them have undergone considerable change. In recent years, *transistors* and *linear integrated circuits* have simplified the design of electronic communications circuits, thus allowing for miniaturization, improved performance and reliability, and reduced overall costs. In recent years, there has been an overwhelming need for more and more people to communicate

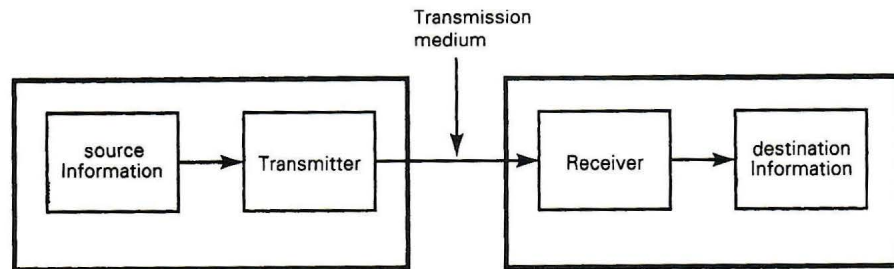


FIGURE 1-1 Simplified block diagram of an electronic communications system

with each other. This tremendous need has stimulated a monumental growth in the electronic communications industry. Modern electronic communications systems include *metallic cable* systems, *microwave* and *satellite radio* systems, and *optical fiber* systems.

ELECTRONIC COMMUNICATIONS SYSTEMS

Figure 1-1 shows a simplified block diagram for an electronic communications system, which includes a *transmitter*, a *transmission medium*, and a *receiver*. A transmitter is a collection of one or more electronic devices or circuits that converts the original source information to a signal that is more suitable for transmission over a given transmission medium. The transmission medium provides a means of transporting signals from a transmitter to a receiver and can be as simple as a pair of copper wires that propagate signals in the form of electric current flow. Information can also be converted to electromagnetic light waves and propagated over optical fiber cables constructed from glass or plastic, and free space can be used for transmission of electromagnetic radio waves over great distances or over terrain where it is difficult or expensive to install a physical cable. A receiver is a collection of electronic devices and circuits that accepts the transmitted signals from the transmission medium and converts them back to their original form.

MODULATION AND DEMODULATION

Because it is often impractical to propagate information signals over metallic or optical fiber cables or through Earth's atmosphere, it is often necessary to modulate the source information onto a higher-frequency analog signal called a *carrier*. In essence, the carrier signal carries the information through the system. The information signal *modulates* the carrier by changing either its amplitude, frequency, or phase. *Modulation* is simply the process of changing one or more properties of the carrier in proportion with the information signal.

The two basic types of electronic communications systems are *analog* and *digital*. An *analog communications system* is a system in which energy is transmitted and received in analog form (a continuously varying signal such as a sine wave). With analog communications systems, both the information and the carrier are analog signals.

The term *digital communications*, however, covers a broad range of communications techniques including *digital transmission* and *digital radio*. Digital transmission is a true digital system where digital pulses (discrete levels such as +5 V and ground) are transferred between two or more points in a communications system. With digital transmission there is no analog carrier and the original source information may be in digital or analog form. If it is in analog form, it must be converted to digital pulses prior to transmission and converted back to analog form at the receive end. Digital transmission systems require a physical facility between the transmitter and receiver such as a metallic wire or an optical fiber cable.

Digital radio is the transmittal of digitally modulated analog carriers between two or more points in a communications system. With digital radio, the modulating signal and the demodulated signal are digital pulses. The digital pulses could originate from a digital transmission system, from a digital source such as a computer, or be a binary encoded analog signal. In digital radio systems, the transmission medium may be a physical facility or free space (i.e., the Earth's atmosphere). Analog communications systems were the first to be developed; however, in recent years digital communications systems have become more popular.

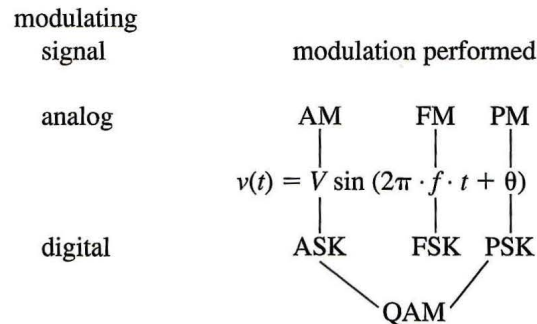
Equation 1-1 is the general expression for a time-varying sine wave of voltage such as a high-frequency carrier signal. If the information signal is analog and the amplitude (V) of the carrier is varied proportional to the information signal, *amplitude modulation* (AM) is produced. If the frequency (f) is varied proportional to the information signal, *frequency modulation* (FM) is produced, and, if the phase (θ) is varied proportional to the information signal, *phase modulation* (PM) is produced.

If the information signal is digital and the amplitude (V) of the carrier is varied proportional to the information signal, a digitally modulated signal known as *amplitude shift keying* (ASK) is produced. If the frequency (f) is varied proportional to the information signal, *frequency shift keying* (FSK) is produced, and, if the phase (θ) is varied proportional to the information signal, *phase shift keying* (PSK) is produced. If both the amplitude and phase are varied proportional to the information signal, *quadrature amplitude modulation* (QAM) results. ASK, FSK, PSK, and QAM are forms of digital modulation and are described in detail in Chapter 12.

$$v(t) = V \sin(2\pi ft + \theta) \quad (1-1)$$

where $v(t)$ = time-varying sine wave of voltage
 V = peak amplitude (volts)
 f = frequency (hertz)
 θ = phase shift (radians)

A summary of the various modulation techniques is shown below:



Modulation is performed in a transmitter by a circuit called a *modulator*. A carrier that has been acted upon by an information signal is called a *modulated wave* or *modulated signal*. *Demodulation* is the reverse process of modulation and converts the modulated carrier back to the original information (i.e., removes the information from the carrier). Demodulation is performed in a receiver by a circuit called a *demodulator*.

There are two reasons why modulation is necessary in electronic communications: (1) It is extremely difficult to radiate low-frequency signals from an antenna in the form of electromagnetic energy, and (2) information signals often occupy the same frequency band and, if signals from two or more sources are transmitted at the same time, they would

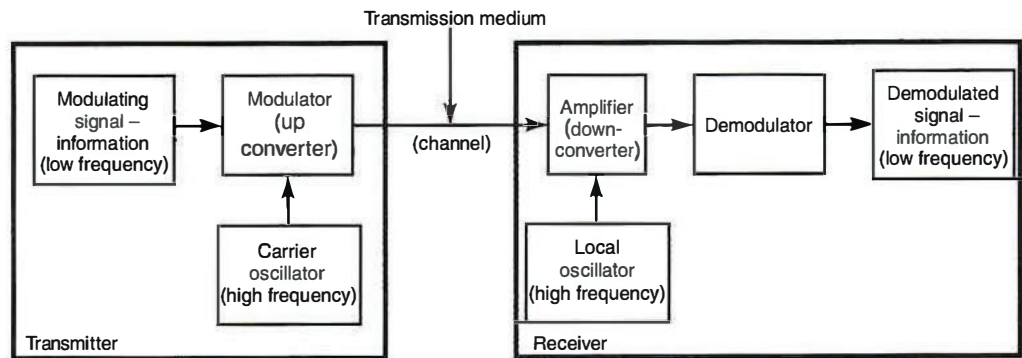


FIGURE 1-2 Communications system block diagram

interfere with each other. For example, all commercial FM stations broadcast voice and music signals that occupy the audio-frequency band from approximately 300 Hz to 15 kHz. To avoid interfering with each other, each station converts its information to a different frequency band or channel. The term *channel* is often used to refer to a specific band of frequencies allocated a particular service. A standard voice-band channel occupies approximately a 3-kHz bandwidth and is used for transmission of voice-quality signals; commercial AM broadcast channels occupy approximately a 10-kHz frequency band, and 30 MHz or more of bandwidth is required for microwave and satellite radio channels.

Figure 1-2 is the simplified block diagram for an electronic communications system showing the relationship among the modulating signal, the high-frequency carrier, and the modulated wave. The information signal (sometimes called the intelligence signal) combines with the carrier in the modulator to produce the modulated wave. The information can be in analog or digital form and the modulator can perform either analog or digital modulation. Information signals are *up-converted* from low frequencies to high frequencies in the transmitter and *down-converted* from high frequencies to low frequencies in the receiver. The process of converting a frequency or band of frequencies to another location in the total frequency spectrum is called *frequency translation*. Frequency translation is an intricate part of electronic communications because information signals may be up- and down-converted many times as they are transported through the system called a channel. The modulated signal is transported to the receiver over a transmission system. In the receiver the modulated signal is amplified, down-converted in frequency, then demodulated to reproduce the original source information.

THE ELECTROMAGNETIC SPECTRUM

The purpose of an electronic communications system is to communicate information between two or more locations commonly called *stations*. This is accomplished by converting the original information into electromagnetic energy and then transmitting it to one or more receive stations where it is converted back to its original form. Electromagnetic energy can propagate as a voltage or current along a metallic wire, as emitted radio waves through free space, or as light waves down an optical fiber. Electromagnetic energy is distributed throughout an almost infinite range of frequencies.

Frequency is simply the number of times a periodic motion, such as a sine wave of voltage or current, occurs in a given period of time. Each complete alternation of the waveform is called a *cycle*. The basic unit of frequency is hertz (Hz) and one hertz equals one cycle-per-second (1 Hz = 1 cps). In electronics it is common to use metric prefixes to represent higher frequencies. For example, kHz (kilohertz) is used for thousands of hertz and MHz (megahertz) is used for millions of hertz.

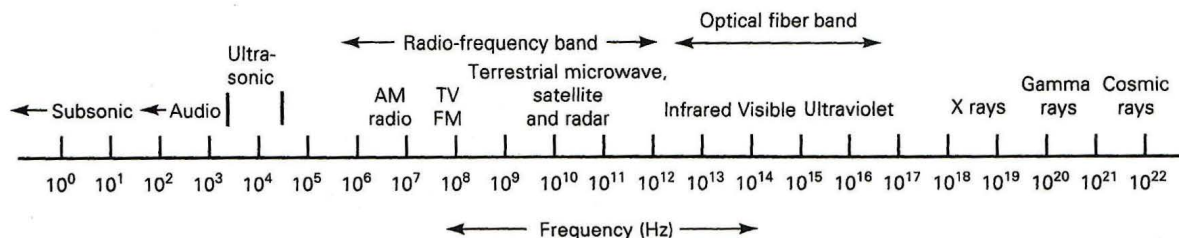


FIGURE 1-3 Electromagnetic frequency spectrum

Transmission Frequencies

The total *electromagnetic frequency spectrum* showing the approximate locations of various services is shown in Figure 1-3. The frequency spectrum extends from *subsonic* frequencies (a few hertz) to *cosmic rays* (10^{22} Hz).

The frequency spectrum is further divided into *subsections* or *bands*. Each band has a name and boundaries. In the United States, frequency assignments for *free-space radio propagation* are assigned by the *Federal Communications Commission* (FCC). For example, the commercial FM broadcast band has been assigned the 88-MHz to 108-MHz band. The exact frequencies assigned specific transmitters operating in the various classes of services are constantly being updated and altered to meet the nation's communications needs.

The total usable *radio-frequency* (RF) spectrum is divided into narrower frequency bands, which are given descriptive names and band numbers, and several of these bands are further broken down into various types of services. The *International Radio Consultative Committee's* (CCIR's) band designations are listed in Table 1-1. The CCIR band designations are summarized as follows:

Extremely low frequencies. Extremely low frequencies (ELFs) are signals in the 30-Hz to 300-Hz range and include ac power distribution signals (60 Hz) and low-frequency telemetry signals.

Voice frequencies. Voice frequencies (VFs) are signals in the 300-Hz to 3000-Hz range and include frequencies generally associated with human speech. Standard telephone channels have a 300-Hz to 3000-Hz bandwidth and are often called *voice-frequency* or *voice-band channels*.

Very low frequencies. Very low frequencies (VLFs) are signals in the 3-kHz to 30-kHz range, which include the upper end of the human hearing range. VLFs are used for some specialized government and military systems such as submarine communications.

Low frequencies. Low frequencies (LFs) are signals in the 30-kHz to 300-kHz range and are used primarily for marine and aeronautical navigation.

Medium frequencies. Medium frequencies (MFs) are signals in the 300-kHz to 3-MHz range and are used primarily for commercial AM radio broadcasting (535 kHz to 1605 kHz).

High frequencies. High frequencies (HF) are signals in the 3-MHz to 30-MHz range and are often referred to as *short waves*. Most two-way radio communications use this range, and Voice of America and Radio Free Europe broadcast within the HF band. Amateur radio and citizens band (CB) radio also use signals in the HF range.

Very high frequencies. Very high frequencies (VHF) are signals in the 30-MHz to 300-MHz range and are used for mobile radio, marine and aeronautical communications, commercial FM broadcasting (88 MHz to 108 MHz), and commercial television broadcasting of channels 2–13 (54 MHz to 216 MHz).

TABLE 1-1 CCIR Band Designations

Band Number	Frequency Range*	Designations
2	30 Hz–300 Hz	ELF (extremely low frequencies)
3	0.3 kHz–3 kHz	VF (voice frequencies)
4	3 kHz–30 kHz	VLF (very low frequencies)
5	30 kHz–300 kHz	LF (low frequencies)
6	0.3 MHz–3 MHz	MF (medium frequencies)
7	3 MHz–30 MHz	HF (high frequencies)
8	30 MHz–300 MHz	VHF (very high frequencies)
9	300 MHz–3 GHz	UHF (ultrahigh frequencies)
10	3 GHz–30 GHz	SHF (superhigh frequencies)
11	30 GHz–300 GHz	EHF (extremely high frequencies)
12	0.3 THz–3 THz	Infrared light
13	3 THz–30 THz	Infrared light
14	30 THz–300 THz	Infrared light
15	0.3 PHz–3 PHz	Visible light
16	3 PHz–30 PHz	Ultraviolet light
17	30 PHz–300 PHz	X rays
18	0.3 EHz–3 EHz	Gamma rays
19	3 EHz–30 EHz	Cosmic rays

* 10^0 , hertz (Hz); 10^3 , kilohertz (kHz); 10^6 , megahertz (MHz); 10^9 gigahertz (GHz); 10^{12} , terahertz (THz); 10^{15} , petahertz (PHz); 10^{18} exahertz (EHz)

Ultrahigh frequencies. Ultrahigh frequencies (UHF) are signals in the 300-MHz to 3-GHz range and are used by commercial television broadcasting of channels 14–83, land mobile communications services, cellular telephones, certain radar and navigation systems, and microwave and satellite radio systems. Generally speaking, frequencies above 1 GHz are considered microwave frequencies, which includes the upper end of the UHF range.

Superhigh frequencies. Superhigh frequencies (SHFs) are signals in the 3-GHz to 30-GHz range and include the majority of the frequencies used for microwave and satellite radio communications systems.

Extremely high frequencies. Extremely high frequencies (EHFs) are signals in the 30-GHz to 300-GHz range and are seldom used for radio communications except in very sophisticated, expensive, and specialized applications.

Infrared. Infrared frequencies are signals in the 0.3-THz to 300-THz range and are not generally referred to as radio waves. Infrared refers to electromagnetic radiation generally associated with heat. Infrared signals are used in heat-seeking guidance systems, electronic photography, and astronomy.

Visible light. Visible light includes electromagnetic frequencies that fall within the visible range of humans (0.3 PHz to 3 PHz). Light wave communications is used with optical fiber systems, which in recent years have become a primary transmission medium for electronic communications systems.

Ultraviolet rays, X rays, gamma rays, and cosmic rays have little application to electronic communications and, therefore, will not be described.

When dealing with radio waves, it is common to use the units of wavelength rather than frequency. Wavelength is the length that one cycle of an electromagnetic wave occupies in space (i.e., the distance between similar points in a repetitive wave). Wavelength is inversely proportional to the frequency of the wave and directly proportional to the veloc-