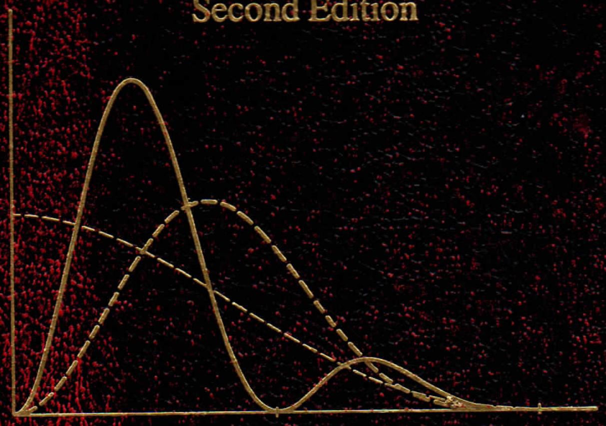
MODERN DIGITAL AND ANALOG COMMUNICATION SYSTEMS

Second Edition



B.P. Lathi

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level to every possible message. For example, the contents of this book will be assigned one level; if it is desired to transmit this book, all that is needed is to transmit one pulse of that level. Because an infinite number of levels are available, it is possible to assign one level to any conceivable message. Cataloging of such a code may not be practical, but that is beside the point. The point is that if the noise is zero, communication ceases to be a problem, at least theoretically. Implementation of such a scheme would be difficult because of the requirement of generation and detection of pulses of precise amplitudes. Such practical difficulties would then set a limit on the rate of communication.

In conclusion, we have demonstrated qualitatively the basic role played by B and SNR in limiting the performance of a communication system. These two parameters then represent the ultimate limitation on a rate of communication. We have also demonstrated the possibility of trade or exchange between these two basic parameters.

Equation (1.1) can be derived from Eq. (1.2). It should be remembered that Shannon's result represents the upper limit on the rate of communication over a channel and can be achieved only with a system of monstrous and impracticable complexity and a time delay in reception approaching infinity. Practical systems operate at rates below the Shannon rate. In Chapter 8, we shall derive Shannon's result and compare the efficiencies of various communication systems.

1.4 MODULATION

Baseband signals produced by various information sources are not always suitable for direct transmission over a given channel. These signals are usually further modified to facilitate transmission. This conversion process is known as **modulation.** In this process, the baseband signal is used to modify some parameter of a high-frequency carrier signal.

A **carrier** is a sinusoid of high frequency, and one of its parameters—such as amplitude, frequency, or phase—is varied in proportion to the baseband signal $m(t)$. Accordingly, we have amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM). Figure 1.7 shows a baseband signal $m(t)$ and the corresponding AM and FM waveforms. In AM, the carrier amplitude varies in proportion to $m(t)$, and in FM, the carrier frequency varies in proportion to $m(t)$.

At the receiver, the modulated signal must pass through a reverse process called **demodulation** in order to retrieve the baseband signal.

As mentioned earlier, modulation is used to facilitate transmission. Some of the important reasons for modulation are given below.

Ease of Radiation

For efficient radiation of electromagnetic energy, the radiating antenna should be of the order of one-tenth or more of the wavelength of the signal radiated. For many baseband signals, the wavelengths are too large for reasonable antenna dimensions. For example, the power in a speech signal is concentrated at frequencies in the range of 100 Hz to 3000 Hz. The corresponding wavelength is 100 km to 3000 km. This long wavelength would necessitate an impracticably large antenna. Instead, we modulate a high-frequency carrier, thus translating the signal spectrum to the region of

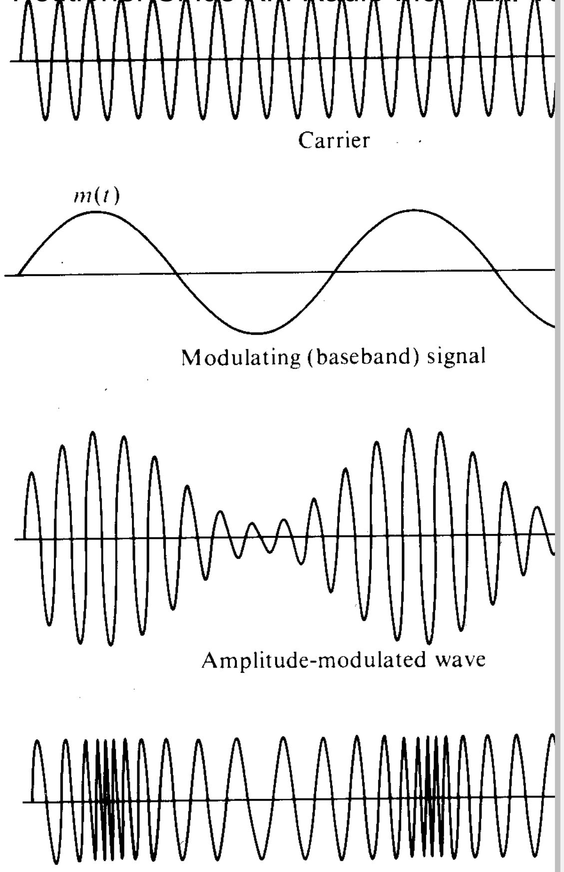

Figure 1.7 Modulation.

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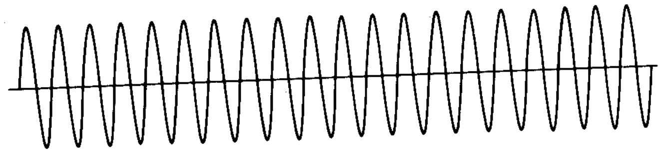
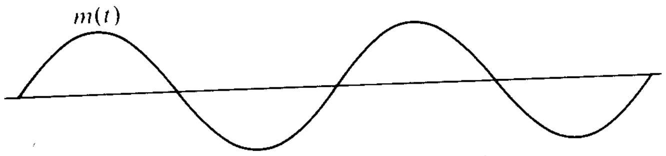
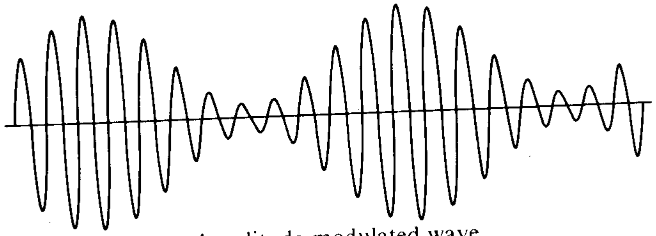


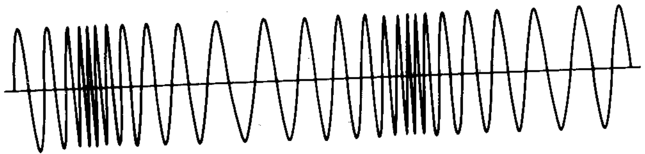
Carrier



Modulating (baseband) signal



Amplitude-modulated wave



Frequency-modulated wave

Figure 1.7 Modulation.

carrier frequencies that corresponds to a much smaller wavelength. For example, a 1 MHz carrier has a wavelength of only 300 meters and requires an antenna whose size is of the order of 30 meters. In this aspect, modulation is like letting the baseband signal hitchhike on a high-frequency sinusoid (carrier). The carrier and the baseband signal may be compared to a stone and a piece of paper. If we wish to throw a piece of paper, it cannot go too far by itself. But by wrapping it around a stone (a carrier), it can be thrown over a longer distance.

Simultaneous Transmission of Several Signals

Consider the case of several radio stations broadcasting audio baseband signals directly, without any modification. They would interfere with each other because the spectra of all the signals occupy more or less the same bandwidth. Thus, it would be possible to broadcast from only one radio or TV station at a time. This is wasteful because the channel bandwidth may be much larger than that of the signal. One way

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MMUNICATION

e the band of frequencies of the signal delivered
see Fig. 1.2). In telephony, the baseband is the
0 to 3.5 kHz. In television, the baseband is the
For digital data or PCM using bipolar signaling
band is 0 to f_o Hz.

In baseband communication, baseband signals are transmitted without modulation, that is, without any shift in the range of frequencies of the signal. Because the baseband signals have sizable power at low frequencies, they cannot be transmitted over a radio link but are suitable for transmission over a pair of wires or coaxial cables. Local telephone communication and short-haul PCM (between two exchanges) use baseband communication. Because baseband communication uses only baseband frequencies, its uses are rather restricted. Also, because the transmission of signals at lower frequencies is in general more difficult, it is desirable to shift the signal spectrum to a higher-frequency range by modulation. Moreover, the vast spectrum of frequencies available because of technological advances cannot be utilized by a baseband scheme. By modulating several baseband signals and shifting their spectra to non-overlapping bands, one can use all the available bandwidth more efficiently. Long-haul communication over a radio link also requires modulation to shift the signal spectrum to higher frequencies to enable efficient power radiation using antennas of reasonable dimensions. Yet another use of modulation is to exchange transmission bandwidth for the SNR.

Communication that uses modulation to shift the frequency spectrum of a signal is known as *carrier communication*. In this mode, one of the basic parameters (amplitude, frequency, or phase) of a *sinusoidal carrier* of high frequency ω_c is varied in proportion to the baseband signal $m(t)$. This results in amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), respectively. The latter two types of modulation are similar, in essence, and are grouped under the name *angle modulation*. Modulation is used to transmit analog as well as digital baseband signals.

A comment about pulse-modulated signals (PAM, PWM, PPM, PCM, and DM) is in order here. Despite the term modulation, these signals are baseband signals. The term modulation is used here in another sense. Pulse-modulation schemes are really baseband coding schemes, and they yield baseband signals. These signals must still modulate a carrier in order to shift their spectra.

4.2 AMPLITUDE MODULATION: DOUBLE SIDEBAND (DSB)

In amplitude modulation, the amplitude A_c of the unmodulated carrier $A_c \cos(\omega_c t + \theta_c)$ is varied in proportion to the baseband signal (known as the *modulating signal*). The frequency ω_c and the phase θ_c are constant. We can assume $\theta_c = 0$ without a loss of generality. If the carrier amplitude A_c is made directly proportional to the modulating signal $m(t)$, the modulated carrier is $m(t) \cos \omega_c t$ (Fig. 4.1*c*). As seen earlier [Eq. (2.63a)], this type of modulation simply shifts the spectrum of $m(t)$ to the carrier frequency (Fig. 4.1*c*); that is, if

$$m(t) \leftrightarrow M(\omega)$$

$$m(t) \cos \omega_c t \leftrightarrow \tfrac{1}{2}[M(\omega + \omega_c) + M(\omega - \omega_c)] \tag{4.1}$$

The bandwidth of the modulated signal is $2B$ Hz, which is twice the bandwidth of the modulating signal $m(t)$. From Fig. 4.1*c*, we observe that the modulated carrier spectrum centered at ω_c is composed of two parts: a portion that lies above ω_c, known as the *upper sideband (USB)*, and a portion that lies below ω_c, known as the *lower sideband (LSB)*. Similarly, the spectrum centered at $-\omega_c$ has upper and lower side-

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