1 Radio Communication Systems

1-1 Introduction

This book is devoted to the analysis and design of the electronic circuitry used in radio communication systems. It presumes that the reader is familiar with audio-frequency amplifiers; hence the primary emphasis will be on radio transmitter and receiver circuits. The transmitting and receiving antennas and the propagation path between them are important parts of an overall system, but a discussion of these elements is left to other texts.

Communication systems transmit information in the form of electrical signals that represent speech, music, television pictures, scientific and business data, and so forth. The waveforms of these signals are complex and continually changing, but the frequency spectrum of the signals is usually limited to a specified bandwidth either by the nature of the signal source or by filters in the transmitting equipment. Since many of these signals occupy a frequency band that extends downward to a few hertz, they cannot be transmitted in their original form over a common transmission path because it would not be possible to separate them at the receiving end. A separate transmission line or separate radio path for each signal would not be feasible from either an economic or a practical standpoint. Hence the overall communication system must provide a means for simultaneous transmission of a number of signals either by shifting them into different parts of the frequency spectrum or by sending samples of the signals on a time-shared basis.

The wavelength (λ) in meters of a radio wave is given by c/f, in which c is the velocity of light (3×10^8 meters per second), and f is in hertz. (For RF calculations it is convenient to remember that f in megahertz $\times$ λ in meters = 300.) A radio antenna should have a physical size of one-half wavelength or more for reasonable efficiency. Hence, as the transmission frequency is increased, the physical size and cost of the antenna are reduced and its efficiency increases.

1-2 Elements of a radio system

The process whereby the original message is converted into a new form suitable for radio transmission is called modulation. The modulation process causes some property—such as the amplitude, frequency, or phase—of a high-frequency carrier[1] wave to be deviated from its unmodulated value by an amount proportional to the instantaneous value of the modulating (message) signal. Thus the content of the original message is shifted to a portion of the frequency spectrum in the vicinity of the carrier frequency. In the receiver this process is reversed in a detector that recovers the original signal.

Figure 1-1 shows a simplified block diagram of a radio transmitter and receiver in order to illustrate the signal processing that takes place. The function of each block is explained below.

1. The source of the message signal may be a microphone, phono pickup, television camera, or other device that transforms the desired information into an electrical signal.

2. The signal is amplified and often passed through a low-pass filter to limit the bandwidth.

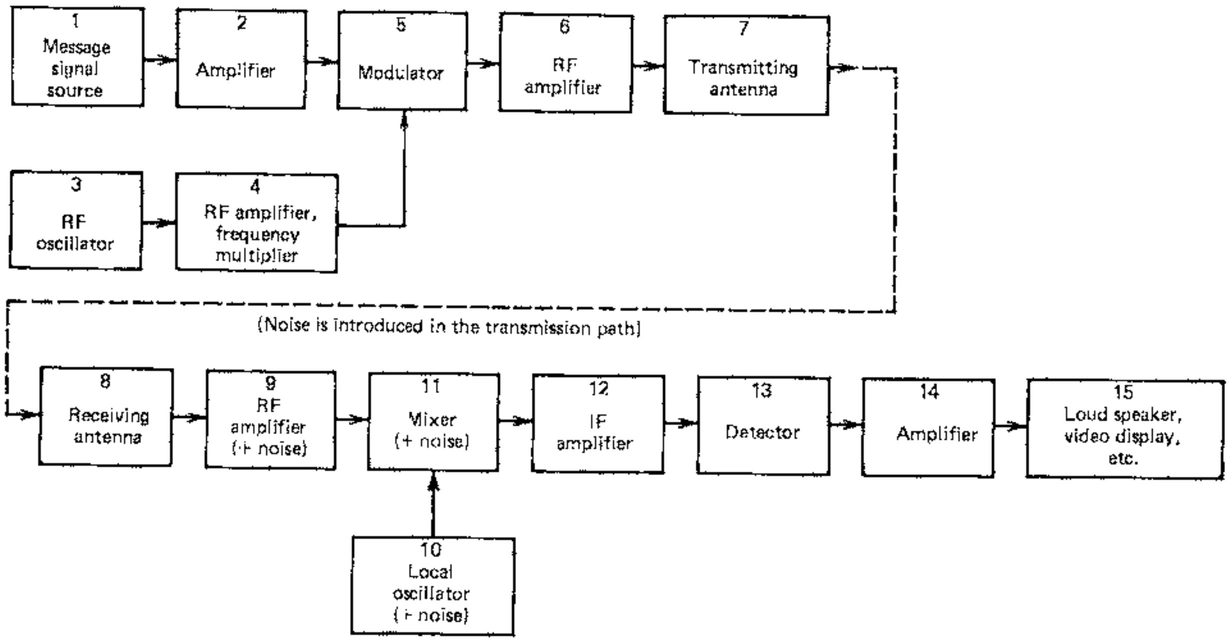
3. The RF oscillator establishes the carrier frequency or some submultiple of it. Since good frequency stability is required to keep the transmitter on its assigned frequency, the oscillator is often controlled by a quartz crystal.

4. One or more amplifier stages increase the power level of the signal from the oscillator to that needed for input to the modulator. Class C operation is used wherever possible to obtain high efficiency. Tuning of the output circuits to a harmonic of the input frequency results in "frequency multiplication" so that the final carrier frequency can be a multiple of the oscillator frequency.

5. The modulator combines the signal and carrier frequency components to produce one of the varieties of modulated waves discussed in Section 1-3. In the simplified system shown in Fig. 1-1 the output signal spectrum lies in the vicinity of the desired RF carrier frequency. In many transmitters a second oscillator and mixer (similar to blocks 10 and 11) are inserted between

[1]The "carrier" may be a sinusoidal wave or a train of pulses.

Fig. 1-1 **Radio transmitter and receiver block diagram.**



blocks 5 and 6 in order to shift the modulated wave to a higher-frequency range.

6. Additional amplification may be required after modulation to bring the power level of the signal to the desired value for input to the antenna.

7. The transmitting antenna converts the RF energy into an electromagnetic wave of the desired polarization. If a single (fixed) receiver is to be reached, the antenna is designed to direct as much of the radiated energy as possible toward the receiving antenna.

8. The receiving antenna may be omnidirectional for general service or highly directional for point-to point communication. The wave propagated from the transmitter induces a small voltage in the receiving antenna. The range of amplitudes of the induced antenna voltage may be from tens of millivolts to less than 1 microvolt, depending upon a wide variety of conditions.

9. The RF amplifier stage increases the signal power to a level suitable for input to the mixer and it helps to isolate the local oscillator from the antenna. This stage does not have a high degree of frequency selectivity but does serve to reject signals at frequencies far removed from the desired channel. The increase in signal power level prior to mixing is desirable because of the noise that is inevitably introduced in the mixer stage.

10. The local oscillator in the receiver is tuned to produce a frequency f_{LO} that differs from the incoming signal frequency f_{RF} by the intermediate frequency f_{IF}; that is, f_{LO} can be equal to $f_{RF}+f_{IF}$ or $f_{RF}-f_{IF}$.

11. The mixer is a nonlinear device that shifts the received signal at f_{RF} to the intermediate frequency f_{IF}. Modulation on the received carrier is also transformed to the intermediate frequency.

12. The IF amplifier increases the signal to a level suitable for detection and provides most of the frequency selectivity necessary to "pass" the desired signal and filter out the undesired signals that are found in the mixer output. Because the tuned circuits in blocks 11 and 12 always operate at a fixed frequency (f_{IF}), they can be designed to provide good selectivity. Ceramic or crystal filters are often used.

13. The detector recovers the original message signal from the modulated IF input.

14. The audio or video amplifier increases the power level of the detector output to a value suitable for driving a loudspeaker, a television tube, or other output device.

15. The output device converts the signal information back to its original form (sound waves, picture, etc.).

In addition to the desired signal that is processed by the receiver, electrical noise is added in the transmission path, and is generated within the RF amplifier, local oscillator, mixer, and so forth. The block diagrams shown in Fig. 1-1 are for illustrative purposes only. In practice, so many variations in transmitter and receiver systems are encountered that no single block diagram could even be considered typical. The general layout of receivers or transmitters for particular applications will be discussed in detail in later chapters.

1-3 Modulation

To extend the concept of modulation introduced in the previous section, the basic definitions of commonly used types of modulation will be given here. Let the voltage of an unmodulated carrier wave be given by

$$v(t) = V_c \sin(\omega_c t + \phi) = V_c \sin \theta(t) \tag{1-1}$$

in which ω_c is the carrier (radian) frequency, V_c the amplitude, and ϕ an arbitrary phase angle.

Amplitude Modulation

In an amplitude-modulated (AM) wave, the deviation of the amplitude V_c from its unmodulated value is proportional to the instantaneous value of the modulating wave. In other words, if the modulating signal is $F(t)$, the carrier amplitude must vary in time according to the expression

$$V_c(t) = V_c[1 + m_a F(t)] \tag{1-2}$$

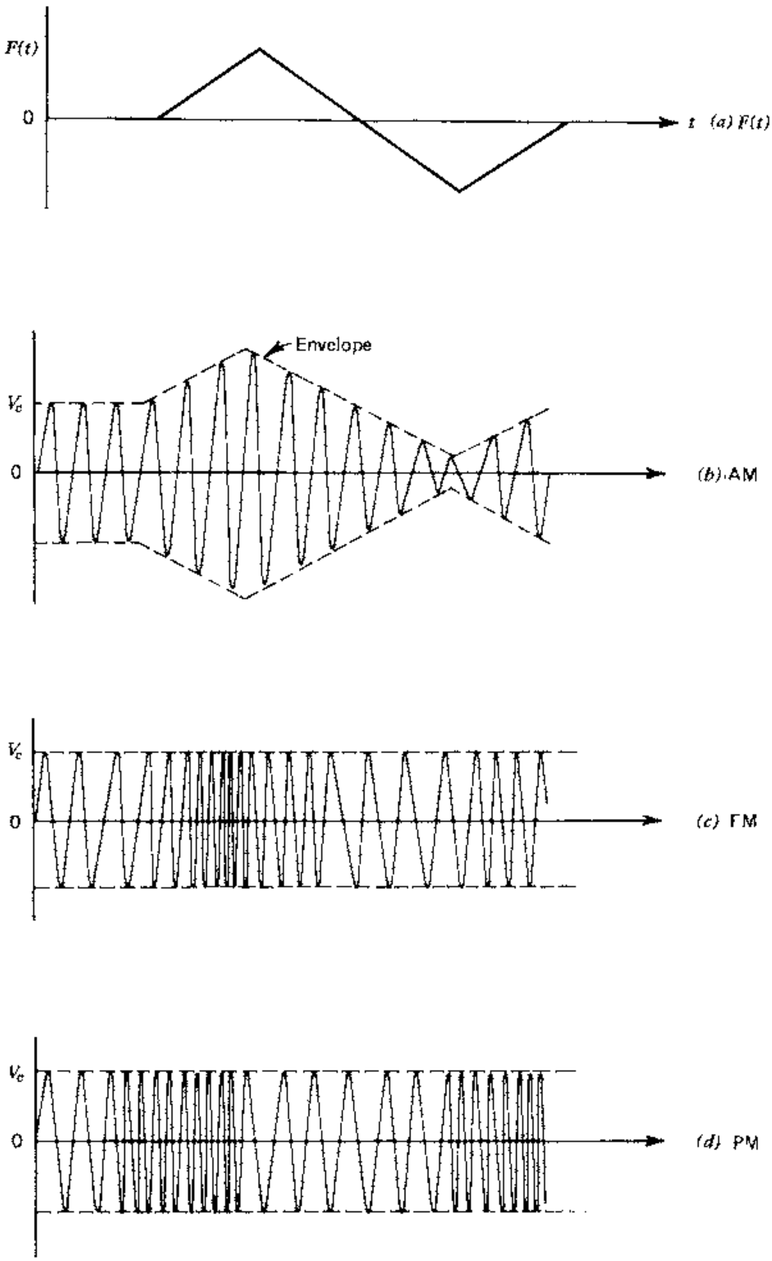
in which m_a is the ***modulation factor***. The value of $m_a F(t)$ cannot exceed unity without introducing distortion. Figure 1-2*a* illustrates a modulating signal $F(t)$, and the corresponding amplitude-modulated wave is shown in Fig. 1-2*b*. Note that the ***envelope*** of the AM wave [given by (1-2)] has the same shape as the modulating signal.

Angle Modulation

In angle modulation, the angle $\theta(t)$ in (1-1), rather than the amplitude, is varied from its unmodulated value by the modulating signal. Phase and frequency modulation are particular forms of angle modulation. In ***phase modulation*** (PM), the angle $\theta(t)$ in (1-1) is made to vary proportionately to the modulating signal $F(t)$. In ***frequency modulation*** (FM) the instantaneous frequency,

$$\omega(t) = \frac{d\theta(t)}{dt}$$

Fig. 1-2 (*a*) A triangular modulating signal; and the resulting (*b*) AM, (*c*), FM, and (*d*) PM waves.



is caused to vary from its unmodulated value in a manner proportional to $F(t)$. In both cases the amplitude of the wave remains constant. Figure 1-2 illustrates AM, FM, and PM waves resulting from a triangular modulating signal.

Pulse Modulation

In pulse modulation systems, the "carrier" consists of a train of pulses that can be modulated in amplitude, repetition frequency, or spacing in a manner completely analagous to the AM, FM, and PM waves previously discussed. The sampling theorem shows that the continuous transmission of a message signal is unnecessary—it can be reconstructed completely from samples taken at a rate at least twice the highest frequency present in the signal. Thus, for a signal that is bandlimited to 4 kHz, a modulated pulse train with a mean repetition frequency of 8 kHz is sufficient and the pulses can be of arbitrarily short duration.

In pulse code modulation, each sample is represented by a set of seven or more pulses (or spaces) that represent a binary code for the sample amplitude. This system has greater immunity to noise at the expense of higher pulse repetition rates and greater bandwidth.

1-4 Frequency and Time Multiplexing

The modulated pulse train produced by any of the foregoing methods is still of relatively low frequency. For radio transmission, this pulse train forms the modulating signal that in turn modulates (by AM, FM, etc.) a high-frequency carrier.

In *frequency-division multiplexing* (FDM) the modulating process shifts the signal to a portion of the frequency spectrum in the vicinity of the carrier frequency. Since the portion of the spectrum to be utilized is determined by the carrier frequency, different signals can modulate carriers of different frequencies and all of them can be transmitted simultaneously. The receiver can choose the desired signal band by means of selective filters. This is done, for example, in AM, FM, and TV broadcasting, and in long-distance carrier-telephone systems.

Time-division multiplexing (TDM) is an alternate process in which a number of signals are transmitted over a common facility by letting the signals occupy the same frequency band on a time-sharing basis. This method is used with pulse modulation systems. The individual "samples" of a given signal are of sufficiently short duration that the time between samples can be used to transmit other signals. In such systems the transmitter is switched or commutated to each signal channel sequentially. The receiving system must then be switched in synchronism with the transmitter to separate the various signals prior to final demodulation.

1-5 Comparison of Modulation Systems

Each of these modulation systems has its good and bad features. Amplitude modulation utilizes the simplest detectors and requires the least bandwidth (particularly if only one sideband is transmitted). However, it has the lowest immunity to noise and both transmitter and receiver circuitry becomes more complicated if single-sideband transmission is used.

Wideband frequency modulation employs simpler transmitter circuitry and provides much better rejection of noise and interfering signals than AM. It requires a bandwidth approximately five times that of a comparable AM signal, however. Pulse code modulation (PCM) provides even better transmission in the presence of noise but requires a further increase in circuit complexity and bandwidth. The choice of a particular technique depends upon the communication system requirements.