1.2 MODERN COMMUNICATION SYSTEM SCHEME

We know that communication is the science and practice of transmitting information. Further, communication engineering also deals with the techniques of transmitting information. In brief, communication engineering means *electrical communication,* in which information is transmitted through electrical signals. In this process, the information or message, *e.g.* spoken words, live scenes, photographs, and sounds is first converted into electrical signals and then transmitted through electrical links. Thus, *electrical communication is a process by which the information/message is transmitted from one point to another, from one person to another, or from place to another in the form of electrical signals, through some communication link.*

We may note that a basic communication system provides a link between the information source and its destination. The process of electrical communication involves sending, receiving, and processing information in electrical form. A basic communication system consists of certain units, called *constituents, subsystems,* or *stages.* We may also note that the information to be transmitted passes through a number of stages of the communication system prior it reaches its destination. Figure 1.1 shows a block schematic diagram of the most general form of basic communication system.

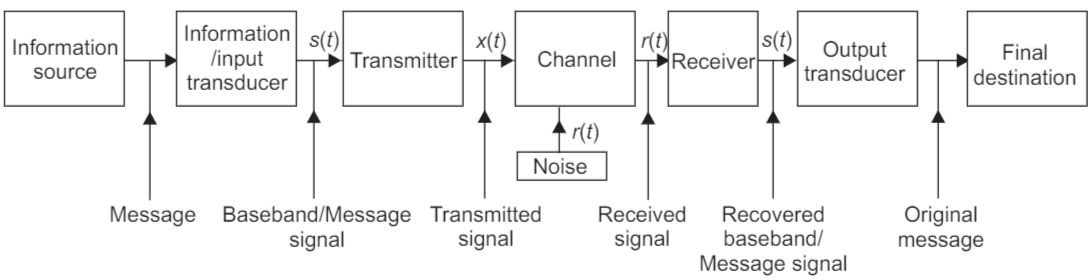

Fig. 1.1 Schematic block diagram of a basic communication system in most general form

We see from Fig. 1.1, the main constituents of basic communication system are:

(*i*) Information source and input transducer
(*ii*) Transmitter
(*iii*) Channel or medium
(*iv*) Noise
(*v*) Receiver
(*vi*) Output transducer and final destination.

We may note that there are many types of communication systems, *e.g.* analog, digital, radio, and line communication systems. Figure 1.1 shows each type of communication system comprises the constituents. However, different communication systems apply different principles of operation and physical appearance to each constituents, in accordance with its type.

Now, we briefly describe each of the constituents or subsystems, explain the correlation between the subsystems, and provide a brief description of the working of a basic communication system.

1.2.1 Information Source and Input Transducer

A communication system transmits information from an information source to a destination and hence the first stage of a communication system is the *information source.* The physical form of information is represented by a message that is originated by an information source, *e.g.* a sentence or paragraph spoken by a person is a *message* that contains some *information.* The person, in this case, acts as *information source.* Few other familiar examples of messages are voice, live scenes, music, written text, and e-mail.

A communication system transmits information in the form of electrical signal or signals. If the information produced by the source is not in an electrical form, one will have to use a device, known as *transducer,* to convert the information into electrical form.

A *transducer is a device that converts a non-electrical energy into its corresponding electrical energy* called *signal and vice versa, e.g.* during a telephone conversation, the words spoken by a person are in the form of sound energy. This has to be converted to its equivalent electrical form prior it is transmitted.

An example of a transducer is a *microphone.* Microphone converts sound signals into the corresponding electrical signals. Similarly, a television (TV) picture tube converts electrical signals into its corresponding pictures. Some other examples of transducers are movie cameras, Video Cassette, Recorder (VCR) heads, tape recorder heads, and loudspeakers.

The information produced by the information source is applied to the next stage, termed the *information* or *input transducer.* This in turn, produces an electrical signal corresponding to the information as output. This electrical signal is called the *baseband signal.* It is also called a *message signal,* an *information signal,* an *intelligent signal,* or an *envelope.* In the communication theory, the baseband signal is usually designated by $s(t)$.

There are *two types of signals.* (*a*) *analog signal,* and (*b*) *digital signal.*

(a) Analog Signal

An analog signal is a function of time, and has a continuous range of values. However, there is a definite function value of the analog signal at each point of time.

An familiar example of analog signal or analog wave form is a *pure sine wave form.* A practical example of an analog signal is a *voice signal.* When a voice signal is converted to electrical form by a microphone, one get a corresponding electrical analog signal. One can see this electrical signal on an oscilloscope. Obviously, being an analog signal, this wave form has definite values at all points of time. Analog signals are shown in Fig. 1.2.

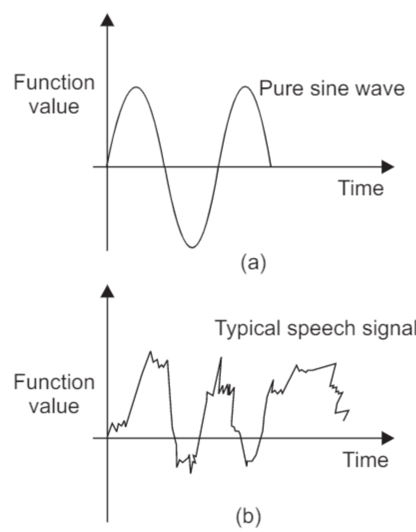

Fig. 1.2 Analog signals: (*a*) Pure sine wave, (*b*) Typical speech signal

(b) Digital Signal

A digital signal does not have continuous function values on a time scale. It is discrete in nature, *i.e.,* it has some values at discrete timings. In between two consecutive values, the signal values is either zero, or different value. A familiar example of a digital signal is the *sound signal* produced by *drumbeats.*

Figure 1.3 shows a graphical representational of a digital signal.

Digital signals in their true sense correspond to a binary digital signal, where the discrete amplitude of the signal is coded into binary digits represented by '0' and '1'. The analog signal,

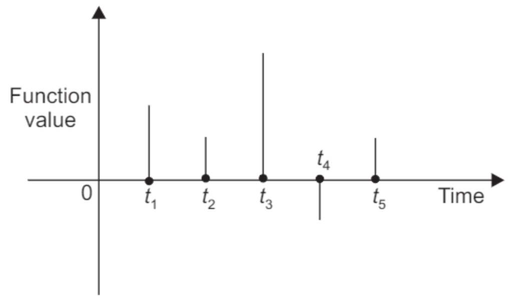

Fig. 1.3 Digital signal

which is continuous in time, is converted to discrete time, using a procedure calling *sampling*. The continuous amplitude of the analog signal is converted to discrete amplitude using a process called *quantization*. Sampling and quantization are together termed as *analog-to-digital* conversion (ADC) and the circuitary that performs this operation is called an *analog to-digital converter*.

1.3 TRANSMITTER

We can see that the next block in the communication system of Fig. 1.1 is the *transmitter*. The base band signal, which is the output of an input transducer, is input to the transmitter. This base band signal, $s(t)$, is suitable for transmission in the form in which it is generated by the *transducer*. The transmitter section processes the signal prior transmission. We may note that the nature of processing depends on the type of communication system. However, the processing carried out for signal transmission in the analog form is different from signal transmission in the digital form.

There are two following options for processing signals prior transmission:

(*i*) The baseband signal, which lies in the low frequency spectrum, is translated to a higher frequency spectrum.

(*ii*) The baseband signal is transmitted without translating it to a higher frequency spectrum.

In the former case, we call the communication system as a *carrier communication system*. In this system, the baseband signal is carried by a higher frequency signal, called the *carrier signal*. In the latter case, we call the system as a *baseband communication system*, because the baseband signal is transmitted without translating it to a higher frequency spectrum. However, some processing of the signal is required prior its transmission, *e.g.* a train of pulses that are to be transmitted can be replaced by a series of two sine waves of different frequencies prior to transmission. One of these two frequencies represent a low and the other represents a high value of the digital pulse.

Therefore, the baseband signal is converted into a corresponding series of sine waves of two different frequencies prior to transmission. Figure 1.4 illustrates this processing.

The carrier communication system is based on the principle of translating a low frequency baseband signal to higher frequency spectrum. This process is termed as *modulation*.

Now, if the baseband signal is a digital signal, the carrier communication system is called a *digital communication* system. The digital modulation methods are employed for this. If the baseband signal is an analog signal, the carrier communication system is called as an *analog communication system* and for processing the analog modulation techniques are used.

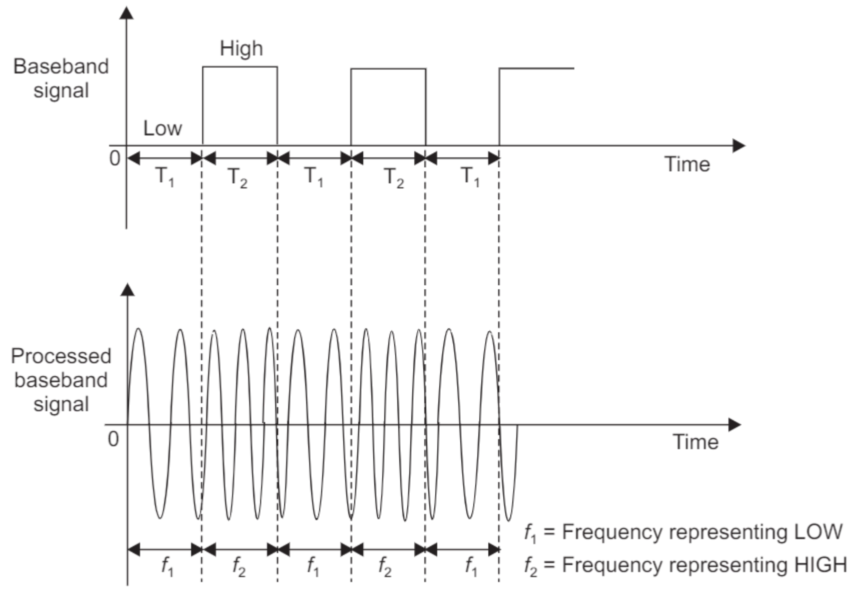

Fig. 1.4 The processing of a baseband signal

Figure 1.5 shows the block diagram of a typical transmitter.

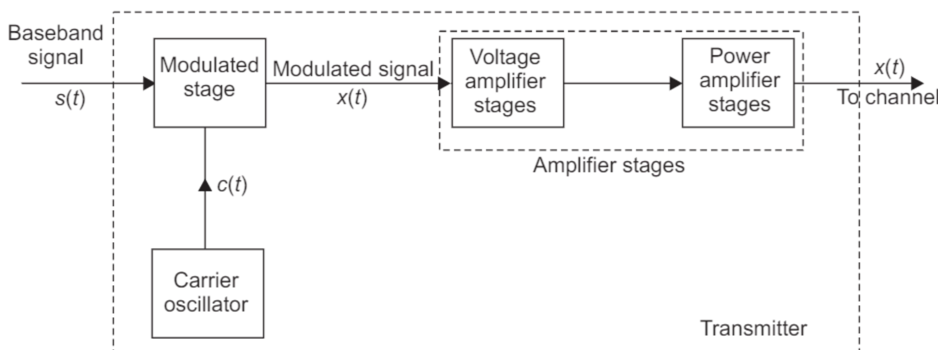

Fig. 1.5 Block diagram representing schematic of an analog transmitter section

Figure 1.5 shows the baseband signal, $s(t)$ applied to the modulated stage. This stage translates the baseband signal from its low frequency spectrum to high frequency spectrum. This stage also receives another input called the *carrier signal*, $c(t)$, which is generated by a high frequency carrier oscillator. Modulation takes place at this stage with the baseband and the carrier signals as two inputs after modulation, the baseband signal is translated to a high frequency spectrum and the carrier signal is said to be modulated by the baseband signal. The output of the modulated stage is called the *modulated signal,* and is designated as $x(t)$.

The voltage of the modulated signal is then amplified to drive the last stage of the transmitter, called the *power amplifier stage* (Fig. 1.5). This stage amplifies the power of the modulated signal and thus it carries enough power to reach the receiver stage of the communication system. Finally, the signal is passed to the transmission medium or channel.

Radio signals are transmitted through *electromagnetic* (*em*) *waves*, also referred as *radio waves,* in a radio communication system. The radio waves have a wide frequency range starting from a few ten kilo Hertz (Hz) to several thousand Mega Hertz (MHz). This wide range of frequencies is referred as the *radio frequency* (*RF*) *spectrum*.

The RF spectrum is classified according to the applications of the spectrum in different service areas .

Table 1.1 shows the classification of the RF spectrum along with the associated applications in communication systems.

Table 1.1: Classification of radio frequency (RF) spectrum alongwith the associated applications in communication systems.

Radio frequency range	Wavelength (meters)	Class	Applications
10–30 kHz	$3 \times 10^4 - 10^4$	Very Low Frequency (VLF)	Point-to-point communication (long distance)
30–300 kHz	$10^4 - 10^3$	Low Frequency (LF)	Point-to-point communication (long distance) and navigation
300–3000 kHz	$10^3 - 10^2$	Medium Frequency (MF)	Radio broadcasting
3–30 MHz	$10^2 - 10$	High Frequency (HF)	Overseas radio broadcasting, Point-to-point radio telegraphy, and telephony
30–300 MHz	10 – 1.0	Very High Frequency (VHF)	FM broadcast, television, and radar
300–3000 MHz	1.0 – 0.1	Ultra High Frequency (UHF)	Television and navigation
3000–30,000 MHz	0.1 – 0.01	Super High Frequency (SHF)	Radar navigation and radio relays

1.4 CHANNEL OR MEDIUM

After the required processing, the transmitter section passes the signal to the transmission medium. The signal propagates through the transmission medium and is received at the other side by the receiver section. The transmission medium between the transmitter and the receiver is called a *channel*.

We may note that the *channel* is a very important part of a communication system as its characteristics add many constraints to the design of the communication system, e.g. most of the *noise* is added to the signal during its transmission through the channel. The transmitted signal should have adequate power to withstand the channel noise. Further, the channel characteristics also impose constraints on the *bandwidth.* The bandwidth is the frequency range that can be transmitted by a communication system. Moreover, the channel characteristics are also taken into consideration as a *design parameter* while designing the transmitting and receiving equipment.

In general, we can say that the transmitting power, signal bandwidth, and cost of the communication system are affected by channel characteristics.

Depending on the physical implementations, one can classify the channels in the following two groups:

1.4.1 Hardware Channels

These channels are manmade structure which can be used as transmission medium. There are following three possible implementations of the hardware channels.

- Transmission lines
- Waveguides
- Optical Fiber Cables (OFC)

The examples of transmission lines are *twisted-pair cables* used in landline telephony and *coaxial cables* used for cable TV transmission.

However, transmission lines are not suitable for ultra high frequency (UHF) transmission. To transmit signals at UHF range, *waveguides* are employed as medium. Waveguides are hollow, circular, or rectangular metallic structures. The signals enter the waveguide, are reflected at the metallic walls, and propagate towards the other end of the waveguide.

Optical fiber cables are highly sophisticated transmission media, in the form of extremely thin circular pipes. Signals are transmitted in the form of light energy in optical fiber cables.

In general, there is always a physical link between the transmitter and receiver in hardware channels. A communication system that makes use of a hardware channel is called as a *line communication* system, *e.g.* landline telephony and cable TV network.

1.4.2 Software Channels

There are certain natural resources which can be used as the transmission medium for signals. Such transmission media are called *software channels.* The possible natural resources that can be used as software channels are: *air or open space* and *sea water.*

We may note that in communication systems that use software channels there is no physical link between the transmitter and the receiver. The transmitter passes the signals in the required form to the software channel. The signals propage through the natural resource and reach the receiver.

The most widely used software channel is *air* or *open space.* The signals are transmitted in the form of *electromagnetic* (em) *waves'*, also called *radio waves.* Radio waves travel through open space at a speed equal to that of light ($c = 3 \times 10^8$ ms^{-1}).

The transmitter section converts the electrical signal into em waves or radiation by using a *transmitting antenna.* These waves are radiated into the open space by the transmitting antenna.

At the receiver side, another antenna, called the receiving antenna, is used to pick up these radio waves and convert them into corresponding electrical signals. Systems that use radio waves to transmit signals through open space are called *radio communication systems, e.g.* radio broad cast, television transmission, satellite communication, and cellular mobile communication.

1.5 NOISE

In electronics and communication engineering, noise is defined as *unwanted electrical energy of random and unpredictable nature present in the system due to any cause.* Obviously, *noise is an electrical disturbance, which does not contain any useful information.* Thus, noise is a highly undesirable part of a communication system, and have to be minimized. We may note that noise cannot be eliminated once it is mixed with the signal. When noise is mixed with the transmitted signal, it rides over it and deteriorates it waveform. This results in the alteration of the original information so that wrong information is received.

The receiver processes the signal to cover the original information produced by the information source at the transmitter end. If the amplitude of the noise is comparable with that of the signal, then the noise may render the transmitted signal unintelligible, and the receiver recovers nothing but the noise. In order to avoid this underiable situation, the system designer can make the signal adequately powerful prior to transmitting it. This enables the signal to withstand the noise. In fact, the system designer increases the power of the signal in comparison with that of the noise. This increases the ratio of the signal power to the noise power, *i.e.* SWR (*signal to noise ratio*).

The designer provides adequate signal strength at the time of transmission so that a high SNR is available at the receiver.

The noise block in Fig. 1.1 represents the total noise present in the system, contributed by all the sources. The noise signal $n(t)$, is applied to the channel block. However, this does not mean that the noise is intermingled with the signal only during its propagation through the channel. In fact, the channel contributes the major part of the noise. However, other noise sources along the communication chain can also add noise to the signal. We may note that the noise may also be mixed with the signal from within the transmitting and receiving equipments. Since it is not possible to show all the individual sources of noise along the communication chain, we have shown only one noise block in Fig. 1.1, beneath the channel block, as the channel in the main source of noise.

The noise introduced by the transmission medium is called *extraneous or external noise.* The main cause of the *internal noise* is the thermal agitation of atoms and electrons of electronic components used in the equipment.

1.5.1 External Noise

We have read that external noise is introduced by the transmission medium. External noise is so called because the transmission medium is external to the receiver. One can divide the external noise into the following three groups:

(i) Atmospheric or static noise

The main sources of this noise are lightning discharges and natural electrical disturbances in the atmosphere. These electrical disturbances are received by the receiving antenna and are mixed with the signal as noise. Atmospheric noise is in the form of impulses that are random in nature. Atmospheric noise has a wide range of frequency components and is practically spread over the entire ratio frequency spectrum. As atmospheric noise is caused by nature and hence there is no way to eradicate it. The only remedy is that the receiver is provided with *ample gain* so that atmospheric noise is countered.

(ii) Man-made or Industrial noise

The main sources of this noise are automobile and aircraft ignition, electric motors, heavy electrical machines, switching gears, leakage from high-voltage electrical supply lines, and fluorescent lights. This noise is heavier in industrial areas than in non-industrial areas, and this is why it is called as industrial noise. This type of noise spans a frequency of several hundred MHz. The amount of noise received increases with the increase in the bandwidths of the receiver. This is why the transmitting equipment be installed away from the industrial areas.

(iii) Extraterrestrial or Space noise

Outer space is also a source of external noise that comes from sun and stars. This noise is of two types: (*a*) *solar noise,* and (*b*) *cosmic noise.*

The *source of solar noise* is the sun, which continuously emits electrical energy consisting of frequencies that lie within a very large frequency spectrum. These frequencies also cover the radio frequency that is used for communication system. Therefore, the electrical energy from the sun is mixed with the transmitting radio signal and appears as noise.

The source of cosmic noise is also stars, which also radiate electrical energy over a wide frequency range covering the radio frequency spectrum.

Galaxies are also the source of space noise. The noise from galaxies is very strong but weakens as it reaches the earth due to the distance. This is why solar noise dominates the cosmic noise in a communication system.

(iv) Internal noise

The noise introduced within the receiver is known as internal noise. This noise can be grouped into: (*a*) *Thermal or Johnson's noise* or *white noise,* and (*b*) *Shot* or *transistor noise*.

Thermal or Johnson's noise or white noise

This noise is generated with resistors used in the circuit. This noise appears due to the random motion of electrons and molecules inside the resistor. The resistive part of the complex impedance in a circuit is also a source of thermal noise. Due to thermal energy, the electrons and atoms or molecules within a resistor agitate and generate random electrical signals, which is noise. The maximum output noise power, P_n, of a resistor is given as:

$$P_n = kTB \qquad ...(1)$$

where k (= 1.38×10^{-23} JK^{-1}) is Boltzmann constant, T is absolute temperature and B is bandwidth in Hertz.

One can measure thermal noise by connecting a high sensitivity *ac* voltmeter across the resistor. The random movement of electrons constitutes a current and develops a voltage across the resistor. This voltage is called the *noise voltage,* and is measured by an *ac* voltmeter.

Shot or Transistor noise

This noise is generated inside a transistor used in an amplifier. Shot noise is not only generated in an amplifier, it is also present in active devices *e.g.* bipolar junction transistor (BJT). Shot noise appears because of the random movement of *electrons* and *holes* inside the transistor and the presence of random electrons at the output terminal of the transistor in an amplifier. However, if there is an amplifier in the next stage, this noise is amplified. If the amplified noise is fed to a speaker, it produces an effect similar to lead shots falling on a metallic sheet, and hence the name shot noise.

Shot noise is similar to thermal noise in that its spectrum is flat (except in the high microwave frequency range).

The expression for shot noise shows that it is directly proportional to the output current, and inversely proportional to the transconductance of the transistor.

1.5.2 SNR and Noise Figure (F)

One can define the SNR as the ratio of the signal power to the noise power at a point in the circuit. We may note that SNR is the measure of the signal power relative to the noise power at a particular point in a circuit.

Now, if P_s is signal power and P_n is noise power, then SNR expressed as S/N, is given as

$$\frac{S}{N} = \frac{P_s}{P_n}$$

If $P_s = V_s^2 R$ and $P_n = V_n^2 R$, then

$$\frac{S}{R} = \frac{P_s}{P_n} = \frac{V_s^2 R}{V_n^2 R} \qquad \text{...(2)}$$

where V_s is signal voltage and V_n is noise voltage.

In addition, it is assumed that both the signal and noise powers are dissipated in the same resistor R. Therefore, SNR can be expressed in terms of decibels (dB) as

$$\left(\frac{S}{N}\right)_{dB} = 10 \log_{10}\left(\frac{V_s^2}{V_n^2}\right)$$

$$\left(\frac{S}{N}\right)_{dB} = 20 \log_{10}\left(\frac{V_s}{V_n}\right) \qquad \text{...(3)}$$

For example, if, at a particular point in a circuit, the signal and noise voltages are given as 3.5 mV and 0.75 mV, respectively, SNR in dB is calculated as:

$$\left(\frac{S}{N}\right)_{dB} = 20 \log_{10}\left(\frac{3.5}{0.75}\right)$$

or

$$\text{SNR} = 20 \log_{10}(4.66)$$

$$= 13.38\ dB$$

Clearly, the SNR of the circuit at the point is 13.38 dB.

The *noise figure* (F) is the measure of the noise introduced by the circuit. It is defined as the ratio of the signal-to-noise power at the input of the circuit and the signal-to-noise power at the output of the circuit. Noise figure (F) can be expressed as

$$F = \frac{\frac{S}{N}\ \text{Power at the input terminals of the circuit}}{\frac{S}{N}\ \text{Power at the output terminals of the circuit}} \qquad \text{...(4)}$$

We can see that if F is unity, the noise power introduced by the circuit is zero, as both the input and output S/N powers are the same.

1.5.3 Noise Measurement Technique

The noise figure (F) is the measure of the noise performance of a device, such as an amplifier or a receiver. The device whose noise figure is measured is known as the *device under test* (DUT). The noise figure of a DUT is measured using a *diode noise generator.* When a *dc* voltage is applied across the diode, this generator produces shot noise. The DUT is connected at the output. The DUT is connected at the output terminals of the diode noise generator. Figure 1.6 shows the circuit arrangement for the measurement of noise figure of a DUT using a diode noise generator.

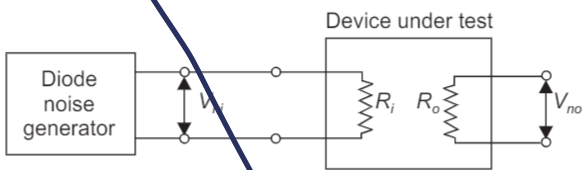

Fig. 1.6 Circuit for the measurement of noise figure (F) of a DUT

In Fig. 1.6, V_{ni} denotes the output noise voltage of the diode noise generator, which is the input noise voltage for the DUT. R_i and R_o are respectively the input impedance and output impedance of the DUT. The voltage developed across R_o, marked as V_{no} (Fig. 1.6) is the output voltage of the DUT. For measuring the noise figure (F) of the DUT using the circuit shown in Fig. 1.6, one will have to perform the following steps:

(*i*) The input *dc* voltage of the diode generator is switched off. The diode current is zero under this condition.

(*ii*) The output power of the DUT is measured with zero diode current conditions.

(*iii*) The input *dc* supply of the diode noise generator is switched on. This supply is variable and can be adjusted to any value.

(*iv*) The input *dc* supply of the diode noise generator is increased until the output power of the DUT becomes double the output power under zero diode current conditions, obtained in step (*ii*).

(*v*) The diode noise generator current under the condition stated in step (*iv*) is measured and designated as I_D.

(*vi*) The noise figure can be estimated using the following relation:

$$F = 19.3\, R_i\, I_D \qquad \text{...(5)}$$

where R_i is in Ohms and I_D is in amperes.

1.6 RECEIVER

The task of the receiver is to provide the original information to the user. This information is altered due to the processing at the transmitter side. The signal received by the receiver, thus, does not contain information in its original form. The receiver system receives the transmitted signal and performs some processing on it to recover the original baseband signal.

We have marked the signal received by the receiver by $r(t)$ in Fig. 1.1. This signal contains both the transmitted signal, $x(t)$, and the noise, $n(t)$, added to it during transmission. The function of the receiver section is to separate the noise from the received signal, and then recover the original baseband signal by performing some processing on it. The receiver receives a weak signal because the transmitted signal losses its strength during its propagation through the channel. This occurs due to the attenuation of the signal.

A voltage amplifier first amplifies the received signal so that it becomes strong enough for further processing, and then recovers the original information. The original baseband signal is recovered by performing an operation opposite to the one performed by the transmitter section. The transmitter performs *modulation* on the baseband signal to translate it to a higher spectrum from its low frequency spectrum. The receiver, in turn, performs an operation known as *demodulation,* which brings the baseband signal from the higher frequency spectrum to its original low-frequency spectrum. The demodulation process removes the high frequency carrier from the received signal and retrieves the original baseband. This occurs in a carrier communication system. The baseband communication systems, assume that the transmitter replaces the digital baseband signal with a series of two sinusoidal wave forms of different frequencies as shown in Fig. 1.4. When the receiver receives this signal, it recovers the original baseband pulse by replacing the two sinusoidal waveforms with the corresponding original levels.

The recovered baseband signal is then handed over to the final destination, which uses a transducer to convert this electrical signal to its original form. It is essential that enough signal power is given to the transducer so that it satisfactorily reproduces the message. Therefore, prior to handing over the recovered baseband signal to its final destination, the voltage and power are amplified by the amplifier stages.

The detailed block diagram of a typical receiver section is shown in Fig. 1.7.

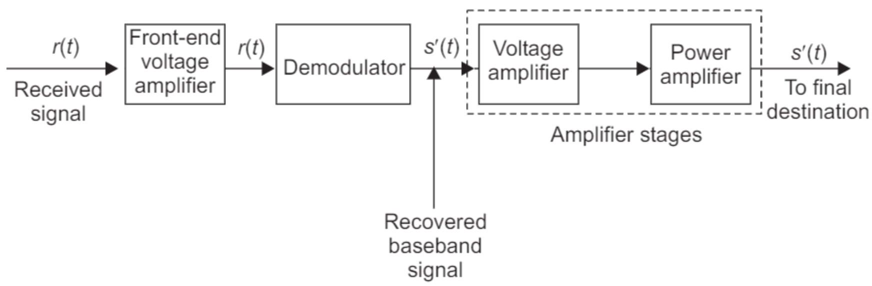

Fig. 1.7 Detailed block diagram of a typical receive section

From Fig. 1.7 it is evident that the received signal, $r(t)$, is first amplified by the front-end voltage amplifier. This is done to strengthen the received signal, which is weak and to facilitate easy processing. Next, this signal is given to the demodulator, which in turn, demodulates the received signal to recover the original baseband signal. Interestingly, the type of demodulation is based on the type of modulation employed at the transmitter. After recovering the original baseband signal, its voltage and power is amplified prior it to final destination block.

1.6.1 Final Destination

The final destination is the last block of the communication chain. The destination is the user that receives the information and interprets it for useful purposes.

The user can either be a human being or a machine that can make certain decisions based on the information received, *e.g.* if a message is transmitted in the form of spoken words, then the user can be a human being who makes certain decisions on its reception. A live telecast of a football match is meant for a human being as a user. In meant for a human being as a user. In some cases, one can use a computer for the interpretation of the received information and takes appropriate action based on the information.

The destination block converts the baseband signal, which contains information in electrical form back into its original non-electrical form back into its original non-electrical form, to be delivered to the user. The constituents of the destination block are an output transducer, which converts the baseband signals from its electrical form to its original non-electrical form and the user. However, the output transducer works opposite to the input transducer.

high power intensity is required so that the signal can cope with the noise and disturbances present in free space. Further, the concentration of the radiated energy is more at the specific target, *i.e.,* the receiver, if the beam is narrow.

When the narrow beam travels through the channel, it may strike some obstacles, resulting in diffraction. After diffraction, the beam spreads and its narrowness reduces. This results in reduced power intensity at the receiver, which is undesirable. It is established that the spreading of a beam is proportional to the diffraction angle.

In other words, the *spreading of a beam is more if the diffraction angle is large.* Therefore, to avoid spreading the beam, the diffraction angle should be as small as possible.

The diffraction angle (α) is proportional to the ratio of the wavelength (λ) of the signal to the diameter (D) of the antenna, *i.e.*

$$\alpha = \frac{\lambda}{D} \qquad ...(17)$$

In addition, the wavelength (λ) of the signal is given by Eq. (10)

$$\lambda = \frac{c}{f}$$

Substituting this in Eq. (17), one obtains

$$\alpha \propto \frac{c}{fD} \qquad ...(18)$$

Eq. (18) clearly indicates that the diffraction angle is inversely proportional to the frequency, f, of the signal. Thus, to reduce the diffraction angle, the frequency of the signal should be increased. Based on this fact, the baseband signal is not transmitted at its own frequency. The modulation process increases the frequency of the transmitted signal. As a result, the diffraction angle reduces, which in turn helps to avoid severe spreading the beam.

1.14 MULTIPLEXING

This is a technique that is most widely used in nearly all types of communication systems, radio and line communication systems. Basically, multiplexing is a process which allows more than one signal to transmit through a single channel. Clearly, multiplexing facilitates the simultaneous transmission of multiple messages over a single transmission channel.

Multiplexing allows the maximum possible utilization of the available bandwidth of the system. Bandwidth is an important entity in any communication system. The use of multiplexing also makes the communication system economical because more than one signal can be transmitted through a single channel. Multiplexing is possible in communication system only through modulation.

To consider multiplexing, let us consider the following example. If many people speak loudly and simultaneously, then it becomes nearly impossible to understand their conversion because the overall result is noise. This noise is the result of mixing of all the speeches. The human ear is not capable of separating these intermingled speeches and therefore no intelligent words are communicated to brain.

The same situation is now applied to the transmission of audio signals. These audio signals may come from, say ten different persons. While the speech frequency of different persons will be different, all the ten signals will lie in the same audio range of 20 Hz to 20 kHz. If all these baseband audio signals are simultaneously transmitted through a single channel, then they will be mixed together. The transmitter will transmit these mixed signals, and the receiver will receive them. The purpose of the receiver is to deliver the audio signals in their original form. However, all the received signals lie within he same audio range, and the receiver is not capable of separating them into individual signals, similar to the case with human ears.

In order to avoid this difficulty, each signal can be translated to a different frequency spectrum, such that every signal differs in its transmitted frequency. This is done through modulation. Therefore, if all the baseband signals are modulated, *i.e.,* translated to higher frequencies by using different carrier frequencies, then each signal is easily distinguishable from the other although they all lie within the same audio band. At the transmitter they can be mixed and transmitted.

At the receiver, the different signals can be easily separated because they are at different frequencies, and these can be delivered to the next stages of the receiver for further processing. Obviously, multiplexing becomes possible only because of modulation.

1.15 TYPES OF COMMUNICATION SYSTEMS

One may categorize communication systems based on their *physical infrastructure* and the *specifications of the signals they transmit.* The physical infrastructure pertains to the type of the channel used and the hardware design of the transmitting and receiving equipment. The signal specifications signify the nature and type of the transmitted signal.

1.15.1 Communication Systems based on Physical Infrastructure

There are two types of communication systems based on the physical infrastructure:

(i) Line Communication Systems

There is a physical link, called the hardware channel, between the transmitter and the receiver in the line communication systems. In a radio communication system, there is no such link and natural resources, such as space and water are used as *softwire channels.* A particular communication system can be one of these two types, *e.g. radio broad cast* is a purely radio communication system and cannot be categorized as a line communication system. on the other hand, *landline telephony* is purely a line communication system and cannot be typed as a radio communication system.

Let us consider a TV system in which a user can only receive the signals and view available channels. A television receiver cannot transmit the signals. In an another example, we consider telephony. In this case, one can simultaneously send and receive signals. *TV transmission* is a *one-way transmission.* This is called as *simplex,* while a two way transmission is called *duplex.* A derivative of duplex is *half duplex,* in which two-way transmission is carried out, but not simultaneously. In this system, the signal can either be sent or received at a time.

The one-way or two-way transmission feature of a communication system depends on the design of the equipment used on the two sides of the communication system, and is therefore included in the physical structure specifications of the system. As a rule, a communication system can be *simplex* or a *duplex,* but not both.

Obviously, based on the physical structure of a communication system, one can define two groups, and only one specification from each group is required to decide the type of communication system. These groups are:

- Line/radio communication
- Simplex/duplex communication

For example, a TV communication system is a combination of the radio and simplex communication system and landline telephony is a combination of the line and duplex communication systems. A particular communication system can be implemented as both line and radio communication system, *e.g.* landline telephony is a line communication system. However, overseas or long-distance telephony is carried out through satellites and the system is called radio telephony as it makes use of radio waves for transmission and reception. This system is then categorised as radio communication system.

(ii) Communication Systems Based on Signal Specifications

The signal specifications used to decide the type of communication include:

- Nature of *baseband* or informal signal
- Nature of the *transmitted* signal.

Based on the nature of the baseband signal, there are two types of communication systems:

- Analog communication systems
- Digital communication systems.

Based on the nature of the transmitted signal, the baseband signal can either be transmitted as it is, without modulation, or through a carrier signal with modulation. The two systems can then be put under following categories:

- Baseband communication system
- Carrier communication system

Thus, there are four types of communication system categories based on *signal* specification. These are:

- Analog communication system
- Digital communication system
- Baseband communication system
- Carrier communication system

Of the four, at least two types are required to specify a particular communication system. Thus, one can form two groups consisting each of two types such that at least one of the types from each group is necessarily required to specify a communication system. These groups can be put as:

- Analog/digital communication system
- Baseband/carrier communication system

We may note that a particular communication system is either an *analog communication* system or a *digital* communication system at a time. For example, TV transmission is an analog communication system while *high definition television* (HDTV) is a digital communication system. Another example of a digital communication system is *Internet.*

Similarly, a particular communication system is either a *baseband* communication system or a carrier communication system. Examples of *baseband* communication systems are *landline telephony* and *Fax.* Examples of carrier communication systems are TV transmission, radio broadcast, and cable TV.

CHAPTER 2

Amplitude Modulation

2.1 INTRODUCTION

Amplitude modulation is the oldest analog modulation technique, in which the instantaneous amplitude of the carrier signal is varied in proportion to the instantaneous amplitude of the modulating signal and the baseband signal is translated to a higher frequency spectrum. Amplitude modulation has various applications which include radio broadcasting, television broadcasting, satellite communication, etc.

In this chapter, the following points are covered so that one can easily learn about amplitude modulation (AM):

- Definition of amplitude modulation
- Equation of AM wave
- Modulation index in AM wave
- Frequency spectrum and bandwidth of AM wave
- Types of amplitude modulation:
  - Double Sideband-Suppressed Carrier (DSB-SC) modulation
  - Single Sideband-Suppressed Carrier (SSB-SC) modulation
  - Vestigial Sideband (VSB) modulation
- Generation of AM signals
- Demodulation of AM signals

2.2 AMPLITUDE MODULATION

Amplitude modulation is defined as the modulation technique in which the instantaneous amplitude of the carrier signal is varied in accordance with the instantaneous amplitude of the analog modulating signal to be transmitted.

The modulating signal is the analog baseband signal which is random and has low frequency while the carrier signal is always a sinusoidal wave with high frequency. The variations in the amplitude of carrier signal represent the information carried.

Figure 2.1 shows the high frequency carrier signal, modulating signal and the modulated signal. It can be seen from the figure that the amplitude of the carrier signal is varies in accordance with the modulating signal while the frequency and the phase of the carrier signal remain unchanged.

It can be clearly seen from the figure 2.1 that the modulating signal seems to be superimposed on the carrier signal. The amplitude variations in the peak values of the carrier signal exactly replicate the modulating signal at different points in time which is known as an *envelope.*

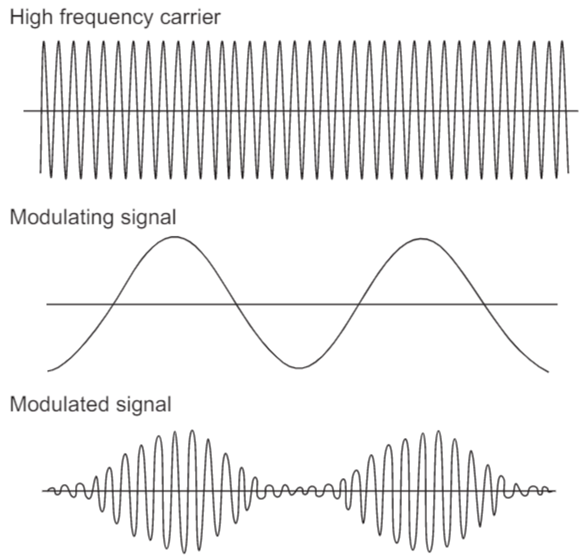

Fig. 2.1 Waveforms related to amplitude modulation

2.2.1 Equation of AM Wave

To design a communication system, mathematical modeling is the very first step to be carried out. For this, mathematical representation of the AM wave is required. This section will give the equation which represents the AM wave.

First of all, the basic waveforms namely, the modulating signal and the carrier signal are mathematically represented. Modulating signal is taken as a pure sinusoidal wave as given by the equation:

$$x(t) = Am\cos(\omega_m t + \theta_m) \qquad \text{...(1)}$$

Now, consider the carrier signal, which is always a high frequency wave given as:

$$c(t) = Ac\cos(\omega_c t + \theta_c) \qquad \text{...(2)}$$

The parameters used in the equations 1 and 2 represent:

- $x(t)$: Instantaneous amplitude of the modulating signal
- $c(t)$: Instantaneous amplitude of the carrier signal
- A_m : Peak value of the amplitude of the modulating signal
- A_c : Peak value of the amplitude of the carrier signal
- : Initial phase of the modulating signal
- : Initial phase of the carrier signal
- ω_m : Angular frequency of the modulating signal
- ω_c : Angular frequency of the carrier signal $(\omega = 2\pi f)$

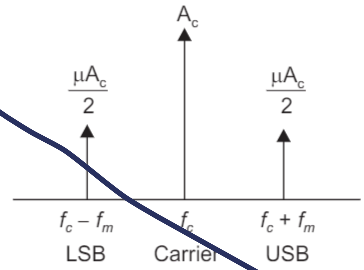

Fig. 1.19 Frequency spectrum of A.M. wave

- One can represent the frequency spectrum of A.M. wave is as shown in Fig. 1.19 below.

$$\text{Bandwidth} = (f_c + f_m) - (f_c - f_m) = 2f_m$$

- Obviously *bandwidth* of A.M. wave is the difference between the highest and lowest frequencies present in the A.M. wave and is twice the frequency of the modulated signal.
- A modulating signal may vary the frequency of the carrier keeping the amplitude and phase constant. This type of modulation is called *frequency modulation.* Broadly speaking, the frequency modulation is the process of changing the frequency of the carrier voltage in accordance with the instantaneous value of the modulating voltage. The original frequency of the carrier signal is called centre or resting frequency and denoted by f_c. The amount by which the frequency of the carrier wave changes or shifts above or below the resting frequency is termed as frequency deviation (Δf). This means $\Delta f \propto m(t)$.
- The total variation is frequency of F.M. wave from the lowest to the highest is termed as carrier saving (CS), *i.e.* $CS = 2 \times$ frequency deviation in centre frequency or $CS = 2\ \Delta f$.
- Modulation index in F.M. is the ratio of frequency deviation to the modulating frequency, *i.e.*

$$\mu_f = \frac{\text{Frequency deviation}}{\text{Modulating frequency}} = \frac{\Delta f}{f_m}$$

- When the various sidebands are separated by the modulating frequency f_m, then bandwidth = $2\ n \times f_m$, where n is the number of significant bands present in the F.M. wave and f_m is the modulating frequency.
- *Phase modulation* is another form of angle modulation. Phase modulation (PM) is the process in which amplitudes of the regularly spaced rectangular rules vary in direct proportion to the instantaneous values of continuous message signal. Phase modulation and frequency modulation are closely related to each other. In both the cases, the total phase angle ϕ of the modulated signal varies.
- *Phase modulation* is the process in which the instantaneous phase of the carrier signal is varied in accordance with the instantaneous amplitude of the modulating signal. In this type of modulation, the amplitude and frequency of the carrier signal remains unaltered after pulse modulation. The modulating signal is mapped to the carrier signal in the form of variations in the instantaneous phase of the carrier signal.

- *Free space* is a medium that is free of gravitational or magnetic fields and has no ionized particles that are comparable in size to the wavelengths used for transmission. The free space propagation model is used to determine the free space path loss between the transmitter and receiver in line-of-sight communication.
- *In space communication* electromagnetic waves of different frequencies are used to carry information through the physical space acting as the transmission medium. Electromagnetic waves with frequencies extending from about 10 kHz to 300 GHz are classed as *radio waves.*
- Depending primarily on the frequency a radio wave travels from the transmitting to the receiving antenna in several ways. On the basis of the mode of propagation, radio waves can be broadly classified as:
  (*i*) ground or surface wave (*ii*) space or tropospheric wave, and (*iii*) sky way. Accordingly, we have three types of propagation:
  (*i*) **Ground wave propagation:** In ground wave propagation, radiowaves are guided by the earth and move along its curved surface from the transmitter to the receiver. As the waves moves over the ground, they are strongly influenced by the electrical properties of the ground. As high frequency waves are strongly absorbed by ground, ground wave propagation is useful only at low frequencies. Below 500 kHz, ground waves can be used for communication within distances of about 1500 km from the transmitter. AM radio broadcast in the medium frequency band cover local areas and take place primarily by the ground wave. The ground waves at higher frequencies employed by frequency modulation (FM) and television (TV) are increasing absorbed and therefore become very weak beyond a distance of several kilometers from the transmitter. Ground wave transmission is very reliable whatever the atomospheric conditions be.
  (*ii*) **Space or tropospheric wave propagation:** When a radiowave transmitted from an antenna, travelling in a straight line directly reaches the receiving antenna, it is termed as space or tropospheric wave. In space wave or line of sight propagation, radio waves move in the earth's troposphere within about 15 km over the surface of the earth. The space wave is made up of two components: (*a*) *a direct or line-of-sight wave* form the transmitting to the receiving antenna and (*b*) the *ground-reflected wave* traversing form the transmitting antenna to ground and reflected to the receiving antenna. Television frequencies in the range 100-220 MHz are transmitted through this mode.
  (*iii*) **Sky wave propagation:** In this mode of propagation, radiowaves transmitted from the transmitting antenna reach the receiving antenna after reflection form the ionosphere, *i.e.* the ionized layers lying in the earth's upper atmosphere. Short wave transmission around the globe is possible through sky wave via successive reflections at the ionosphere and the earth's surface.
- The *ionized region* of the earth's upper atmosphere extending from about 40 km to the height of a few earth radii above the earth, is referred to as the *ionosphere.* The ionosphere is made up of electrons, and positive and negative ions in the background of neutral particles of the atmosphere.
- *The propagation of radio wave through the ionosphere* is affected by the electrons and ions in the ionosphere. The effect of the electrons on the propagation is much greater than that of the ions since the electronic mass is much less than the ionic mass.

Amplifier. This strengthens the detected signal which is not strong enough to be made use of directly.

46. Name the three different modes of propagation used in communication system. Explain with the help of a diagram how long distance communication can be achieved by ionospheric reflection of radio waves.

OR

Name the three different modes of propagation of electromagnetic waves. Explain, using a proper diagram the mode of propagation used in the frequency range from a few MHz to 40 MHz.

Ans. There are three different modes of propagation of e.m. waves: (*i*) Ground wave propagation (*ii*) Space wave propagation, and (*iii*) Sky wave propagation.

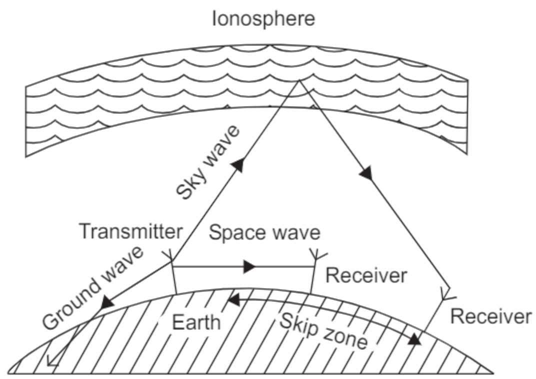

Fig. 1.28

Sky wave propagation is used for the transmission of e.m. waves having frequency range lying from a few MHz to 40 MHz. Fig. 1.28 depicts how a radio wave is directed towards the sky and reflected by the ionosphere toward the desired destination of the earth.

47. How do we make the choice of a communication channel? A message signal has a bandwidth of 5 MHz. Suggest a possible communication channel for its transmission.

Ans. We know that the choice of communication channel depends on (*i*) nature of the signal and (*ii*) the nature of the communication of the medium.

(*a*) For guided media, the medium itself is important, and

(*b*) For unguided media, the frequency band of the signal is important.

The suitable communication channels for the transmission of a message signal of bandwidth 5 MHz are: (*i*) Coaxial Cable, and (*ii*) AM radio

48. What is a ground wave? Why short wave communication over long distance is not possible via ground waves?

Ans. Ground waves progress along the surface of the earth from one point to another. A ground wave must be vertically polarized to prevent short circuiting the electric component. A wave induces current in the ground over which it passes and thus loses some energy absorption. In ground wave propagation, loss of energy due to interaction with matter increases with the increase in frequency (or decrease in wavelength). However, wavelengths less than 200 m (or frequencies > 1500 kHz) get heavily damped and hence short wave communication via ground wave is not possible.

- Aliasing is the phenomenon in which a high frequency component in the frequency spectrum of the signal takes the identity of a lower frequency component in the spectrum of the sampled signal.
- To avoid aliasing:
  - Prealias filter must be used to limit the band of frequencies of the signal to f_m Hz.
  - Sampling frequency must be selected such that $f_s \geq 2f_m$.
- There are two types of pulse modulation schemes as follows:
  - Pulse Amplitude Modulation (PAM)
  - Pulse Time Modulation (PTM)
- In PAM, the amplitude of the pulses of the carrier pulse train is varied in accordance with the modulating signal whereas, in PTM, the timing of the pulses of the carrier pulse train is varied.
- There are two types of PTM:
  - Pulse Width Modulation (PWM)
  - Pulse Position Modulation (PPM)
- In PWM, the width of the pulses of the carrier pulse train is varied in accordance with the modulating signal whereas, in PPM, the position of the pulses of the carrier pulse train is varied.
- All of the above pulse modulation methods (*i.e.*, PAM, PWM and PPM) are called analog pulse modulation methods because the modulating signal is analog in nature.
- In digital communications, the modulating signal consists of binary data or an M-ary version of it.
- When it is required to transmit digital signals on a bandpass channel, the amplitude, frequency or phase of the sinusoidal carrier is varied in accordance with the incoming digital data.
- Since, the digital data is in discrete steps, the modulation of the bandpass sinusoidal carrier is also done in discrete steps. Due to this reason, this type of modulation is known as digital modulation.
- Digital modulation schemes as classified as under:
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
- Because of constant amplitude of FSK or PSK, the effect of non-linearities, noise interference is minimum on signal detection. However, these effects are more pronounced on ASK. Therefore, FSK and PSK are preferred over ASK.
- Coherent digital modulation techniques are those techniques which employ coherent detection. In coherent detection, the local carrier generated at the receiver is phase locked with the carrier at the transmitter. Thus, the detection is done by correlating the received noisy signal and locally generated carrier. The coherent detection is also called synchronous detection.
- ASK signal may be generated by simply applying the incoming binary data and the sinusoidal carrier to the two inputs of a product modulator.
- The demodulation of binary ASK waveform can be achieved with the help of coherent detector.

APPENDIX 6A

DIGITAL WIRELESS COMMUNICATION

6A.1 RADIO TRANSMISSION AND RECEPTION

6A.1.1 Signal Transmission

Figure 6A.1 shows the most important components of a wireless transmission system. In the figure, the transmitter accepts a stream of bits from the application software. It then encodes these bits onto a radio wave, known as a *carrier,* by adjusting parameters of the wave such as its amplitude or phase.

As shown in the figure, the transmitter usually processes the information in two stages. In the first stage, a *modulator* accepts the incoming bits, and computes *symbols* that represent the amplitude and phase of the outgoing wave. It then passes these to the analogue transmitter, which generates the radio wave itself.

The modulation scheme used in Fig. 6A.1 is known as *quadrature phase shift keying* (QPSK). A QPSK modulator takes the incoming bits two at a time and transmits them using a radio wave that can have four different states. These have phases of 45°, 135°, 225° and 315°

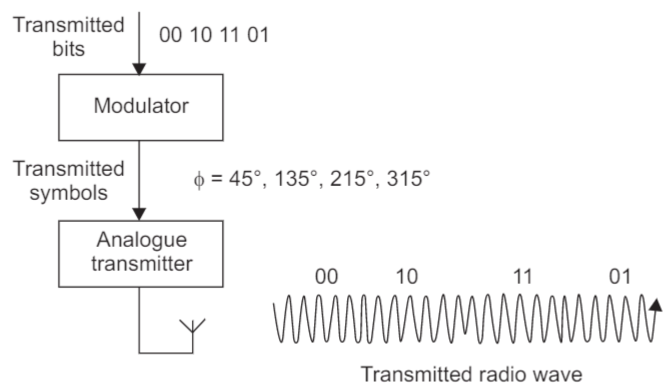

Fig. 6A.1 Architecture of a wireless communication transmitter

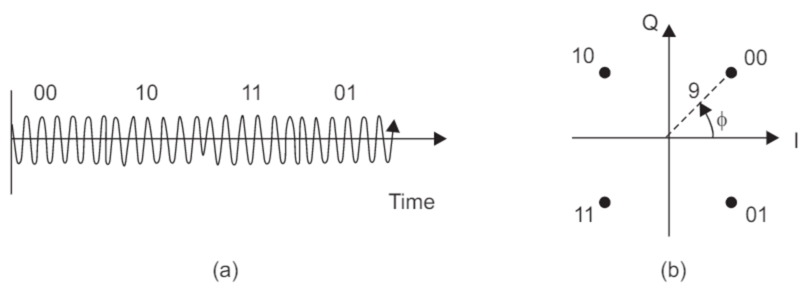

Fig. 6A.2 Quadrature phase shift keying. (*a*) Example QPSK waveform. (*b*) QPSK constellation diagram

(Fig. 6A.2*a*), which correspond to bit combinations of 00, 10, 11 and 01 respectively. We can represent the four states of QPSK using the *constellation diagram* shown in Fig. 6A.2*b*. In this diagram, the distance of each state from the origin represents the amplitude of the transmitted wave, while the angle (measured anti-clockwise from the x-axis) represents its phase.

Usually, it is more convenient to represent each symbol using two other numbers, which are known as the *in-phase* (I) and *quadrature* (Q) components. These are computed as follows:

$$I = a \cos \phi$$
$$Q = a \sin \phi, \quad \text{...(1)}$$

where a is the amplitude of the transmitted wave and ϕ is its phase. Mathematicians will recognize the in-phase and quadrature components as the real and imaginary parts of a complex number.

As shown in Fig. 6A.3, **LTE** uses four modulation schemes altogether. *Binary phase shift keying* (BPSK) sends bits one at a time, using two states that can be interpreted as starting phases of 0° and 180°, or as signal amplitudes of +1 and –1. LTE uses this scheme for a limited number of control streams, but does not use it for normal data transmissions. *16 quadrature amplitude modulation* (16-QAM) sends bits four at a time, using 16 states that have different amplitudes and phases. Similarly, 64-QAM sends bits six at a time using 64 different states, so it has a data rate six times greater than that of BPSK.

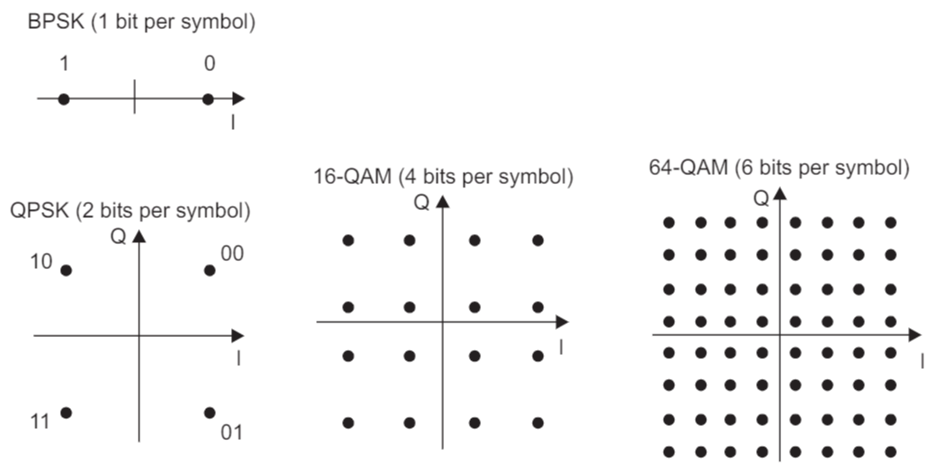

Fig. 6A.3 Modulation schemes used by LTE

6A.1.2 Signal Reception

In a wireless communication system, the signal spreads out as it travels from the transmitter to the receiver, so the received power P_R is less than the transmitted power P_T. The *propagation loss* or *path loss*, PL, is the ratio of the two:

$$PL = \frac{P_T}{P_R} \quad \text{...(2)}$$

If the signal is travelling through empty space, then at a distance r from the transmitter, it occupies a spherical surface with an area of $4\pi r^2$. The propagation loss is therefore proportional to r^2. In a cellular network, the signal can also be absorbed and reflected by obstacles such as

6A.1.3 Channel Estimation

There is one remaining problem with the receiver from Fig. 6A.4. The phase of the received signal depends not only on the phase of the transmitted signal, but also on the receiver's exact position. If the receiver moves through a half a wavelength of the carrier signal (a distance of 10 cm at a carrier frequency of 1500 MHz, for example), then the phase of the received signal changes by 180°. When using QPSK, this phase change turns bit pairs of 00 into 11 and vice versa, and completely destroys the received information.

To deal with this problem, the transmitter inserts occasional *reference symbols into the* data stream, which have a pre-defined amplitude and phase. In the receiver, a *channel estimation* function measures the reference symbols, compares them with the ones transmitted and estimates the phase shift that the air interface introduced. It can then remove this phase shift from the information symbols, and can recover the information bits.

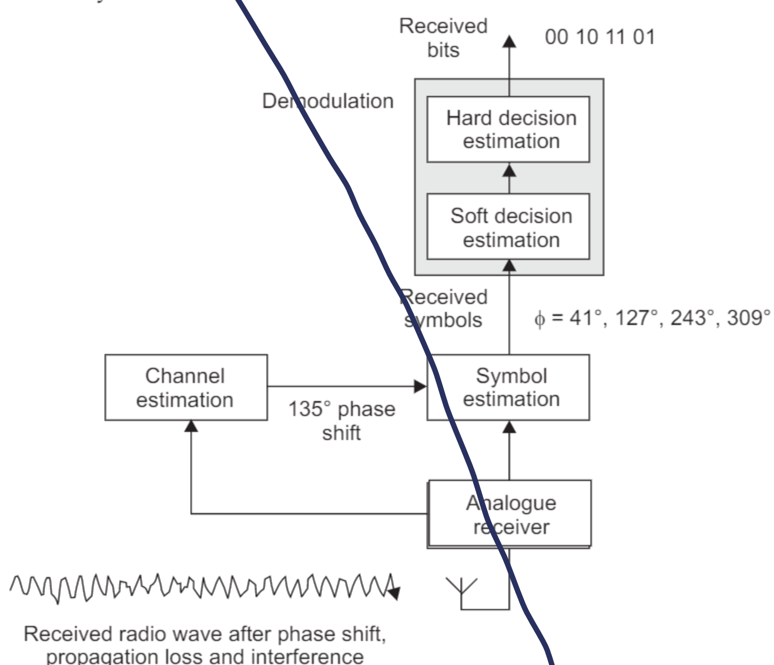

Fig. 6A.5 Architecture of a wireless communication receiver, including the use of channel estimation

The resulting receiver architecture is shown in Fig. 6A.5. The incoming signal arrives with a different phase angle from the one shown earlier. However, the channel estimator detects this phase shift, which allows the receiver to reconstruct the transmitted bits in the same way as before. The phase shift does not change much from one symbol to the next, so the reference symbols only need to take up a small part of the transmitted data stream. The resulting overhead in LTE is about 10%.

6A.1.4 Multiple Access Techniques

The techniques described so far work well for one-to-one communications. In a cellular network, however, a base station has to transmit to many different mobiles at once. It does this by sharing the resources of the air interface, in a technique known as *multiple access.*

Mobile communication systems use a few different multiple access techniques, two of which are shown in Fig. 6A.6. *Frequency division multiple access* (FDMA) was used by the first generation analogue systems. In this technique, each mobile receives on its own carrier frequency, which it distinguishes from the others by the use of analogue filters. The carriers are separated by unused *guard bands,* which minimizes the interference between them. In *time division multiple access* (TDMA), mobiles receive information on the same carrier frequency but at different times.

GSM uses a mix of frequency and time division multiple access, in which every cell has several carrier frequencies that are each shared amongst eight different mobiles. LTE uses another mixed technique known as *orthogonal frequency division multiple access* (OFDMA).

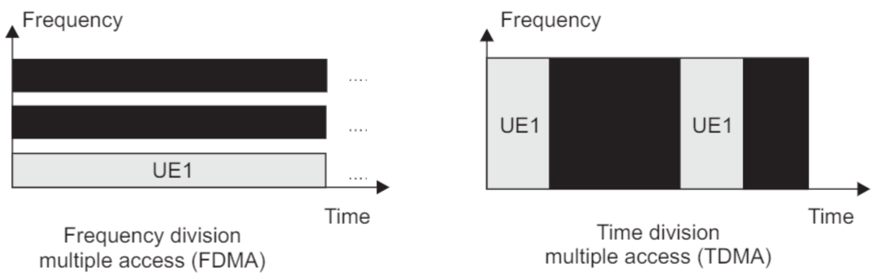

Fig. 6A.6 Example multiple access techniques

Third generation communication systems used a different technique altogether, known as *code division multiple access* (CDMA). In this technique, mobiles receive on the same carrier frequency and at the same time, but the signals are labelled by the use of codes, which allow a mobile to separate its own signal from those of the others. LTE uses a few of the concepts from CDMA for some of its control signals, but does not implement the technique otherwise.

Multiple access is actually a generalization of a simpler technique known as *multiplexing.* The difference between the two is that a multiple access system can dynamically change the allocation of resources to different mobiles, while in a multiplexing system the resource allocation is fixed.

6A.1.5 FDD and TDD Modes

By using the multiple access techniques described above, a base station can distinguish the transmissions to and from the individual mobiles in the cell. However, we still need a way to distinguish the mobiles' transmissions from those of the base stations themselves.

To do this, a mobile communication system can operate in the transmission modes that we introduced in Fig. 6A.7. When using frequency division duplex (FDD), the base station and mobile transmit and receive at the same time, but using different carrier frequencies. Using time division duplex (TDD), they transmit and receive on the same carrier frequency but at different times.

FDD and TDD modes have different advantages and disadvantages. In FDD mode, the bandwidths of the uplink and downlink are fixed and are usually the same. This makes it suitable for voice communications, in which the uplink and downlink data rates are very similar. In TDD mode, the system can adjust how much time is allocated to the uplink and downlink. This makes it suitable for applications such as web browsing, in which the downlink data rate can be much greater than the rate on the uplink.

TDD mode can be badly affected by interference if, for example, one base station is transmitting while a nearby base station is receiving. To avoid this, nearby base stations must be carefully time synchronized and must use the same allocations for the uplink and downlink, so that they all transmit and receive at the same time. This makes TDD suitable for networks that are made from isolated hotspots, because each hotspot can have a different timing and resource allocation. In contrast, FDD is often preferred for wide-area networks that have no isolated regions.

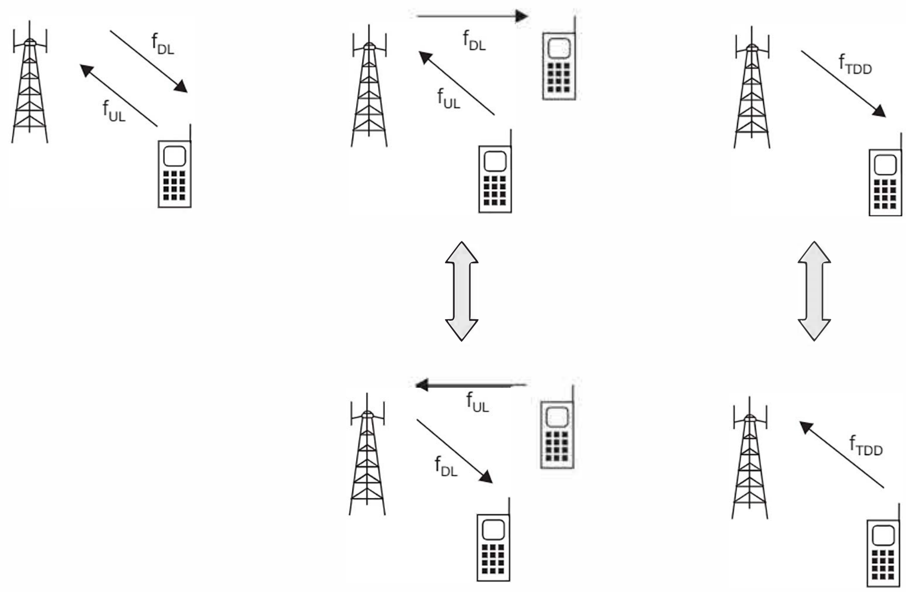

Fig. 6A.7 Operation of FDD and TDD modes

When operating in FDD mode, the mobile usually has to contain a high attenuation duplex filter that isolates the uplink transmitter from the downlink receiver. In a variation known as *half duplex FDD mode,* a base station can still transmit and receive at the same time, but a mobile can only do one or the other. This means that the mobile does not have to isolate the transmitter and receiver to the same extent, which eases the design of its radio hardware.

LTE supports each of the modes described above. A cell can use either FDD or TDD mode. A mobile can support any combination of full duplex FDD, half duplex FDD and TDD, although it will only use one of these at a time.

6A.2 MULTIPATH, FADING AND INTER-SYMBOL INTERFERENCE

6A.2.1 Multipath and Fading

Propagation loss and noise are not the only problem. As a result of reflections, rays can take several different paths from the transmitter to the receiver. This phenomenon is known as *multipath.*

At the receiver, the incoming rays can add together in different ways, which are shown in Fig. 6A.8. If the peaks of the incoming rays coincide then they reinforce each other, a situation known as *constructive interference.* If, however, the peaks of one ray coincide with the troughs of another, then the result is *destructive interference,* in which the rays cancel. Destructive