Module 4

Analog and Digital Communication: Modern communication system scheme, Information source and input transducer, Transmitter, Channel – Hardwire and Softwired, Noise, Receiver, Multiplexing, Types of communication systems.

Types of modulation (only concepts): AM, FM, Phase Modulation, Pulse Modulation, PAM, PWM, PPM, PCM, and Concept of Radio wave propagation.

Digital Communication: Concepts of Sampling theorem, Nyquist rate, Digital Modulation Schemes: ASK, FSK, PSK, Radio signal transmission,

Multiple access techniques: Multipaths and fading, Error Management.

Antenna: Types of antennas.

4.1 MODERN COMMUNICATION SYSTEM

4.1.1 Introduction

- Communication engineering means electrical communication, in which information is transmitted through electrical signals.
- In this process, the information or message, e.g. spoken words, photographs, & 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.

4.1.2 Basic Communication System

- There are many types of communication systems, e.g. analog, digital, radio, and line communication systems.
- Figure 1.1 shows a block schematic diagram of a basic communication system.

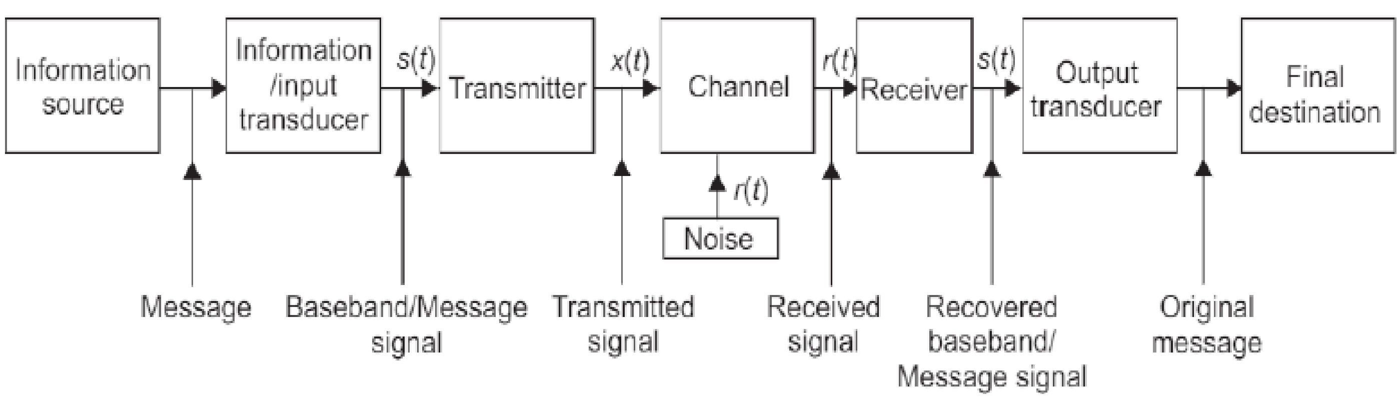


Fig. 4.1: Schematic block diagram of a basic communication system in most general form

- The main constituents of basic communication system are:
  - Information source and input transducer
  - Transmitter
  - Channel or medium
  - Noise
  - Receiver
  - Output transducer and final destination.

Information Source and Input Transducer

- The physical form of information is represented by a message that is originated by an information source.
- For example, a sentence or paragraph spoken by a person is a message that contains some information. The person, in this case, acts as information source.
- If the information produced by the source is not in an electrical form, it has to be converted into an electrical form using a transducer. Eg. Microphone.
- The electrical signal produced by transducer is called the baseband signal. It is also called a message signal, an information signal and is usually designated by s(t).
- There are two types of signals: Analog signal and Digital signal.

Transmitter

- Transmitter processes the base band signal received from transducer prior transmission
- There are two following options for processing signals prior transmission:
  - The baseband signal, which lies in the low frequency spectrum, is translated to a higher frequency spectrum (Carrier communication system).
  - The baseband signal is transmitted without translating it to a higher frequency spectrum (Baseband communication system).
- The carrier communication system is based on the principle of translating a low frequency baseband signal to high frequency spectrum. This process is **modulation**.

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.
- Most of the noise is added to the signal during its transmission through the channel.

- Depending on physical implementations, channels can be classified into two groups:
  - **Hardware Channels:** These channels are manmade structure. The three possible implementations of the hardware channels are: Transmission lines, Waveguides, and Optical Fiber Cables (OFC)
  - **Software Channels:** These are certain natural resources. The natural resources that can be used as software channels are: air or open space and sea water.

Noise

- Noise is defined as unwanted electrical energy of random and unpredictable nature.
- Noise is an electrical disturbance, which does not contain any useful information.
- Noise is a highly undesirable part of a communication system, and has to be minimized.
- When noise is mixed with transmitted signal, it rides over it & deteriorates it waveform.
- This results in alteration of original information so that wrong information is received.
- The designer provides adequate signal strength at the time of transmission so that a high SNR (Signal to Noise Ratio) is available at the receiver.

Receiver

- The function of the receiver section is to separate the noise from the received signal, and then recover the original baseband signal by performing demodulation process.
- A voltage amplifier first amplifies the received signal so that it becomes strong enough for further processing, and then recovers the original information.
- The demodulation process removes the high frequency carrier from the received signal and retrieves the original baseband.

Output Transducer & Final Destination

- The recovered baseband signal is handed over to the final destination, which uses a transducer to convert this electrical signal to its original form.
- Prior to handing over the recovered baseband signal to its final destination, the voltage and power are amplified by the amplifier stages.

4.1.3 Basic Communication System in detail

- **Analog Signal & Digital Signal**
- An analog signal is a function of time, and has a continuous range of values. A familiar example of analog signal is a pure sine wave form. A practical example of an analog signal is a voice signal. Analog signals are shown in Fig. 4.2.
- A digital signal does not have continuous function values on a time scale. It is discrete

in nature. In between two consecutive values, the signal values are either zero, or different value. A familiar example of a digital signal is the sound signal produced by drumbeats. Figure 4.3 shows a graphical representational of a digital signal.

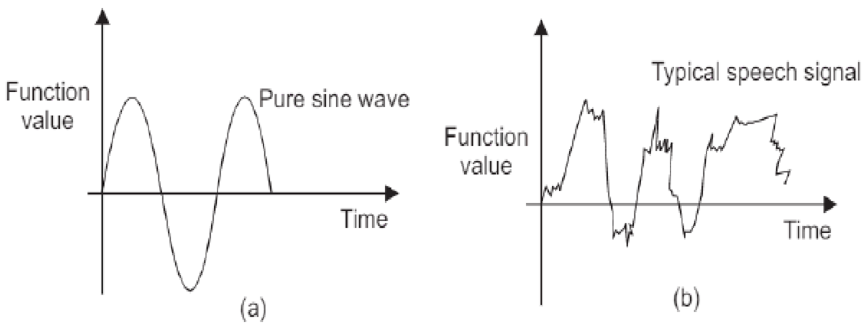


Fig. 4.2: Analog signals: (a) Pure sine wave, (b) Typical speech signal

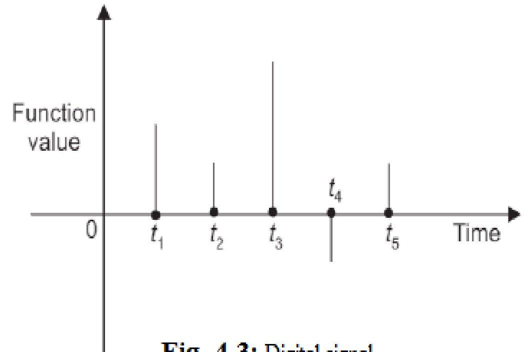


Fig. 4.3: Digital signal

- Analog signal, which is continuous in time, is converted to discrete time, using a procedure calling sampling and quantization. Sampling and quantization are together termed as analog-to-digital conversion (ADC) and the circuitry that performs this operation is called an analog to-digital Converter.

Transmitter Block

- Figure 4.4 shows the block diagram of a typical transmitter.
- The baseband signal s(t) is applied to the modulated stage, which translates the low frequency spectrum baseband signal 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 & the output of the modulated stage is called the modulated signal, x(t).
- The voltage of the modulated signal is then amplified to the power amplifier stages.
- Finally, the signal is passed to the transmission medium or channel.

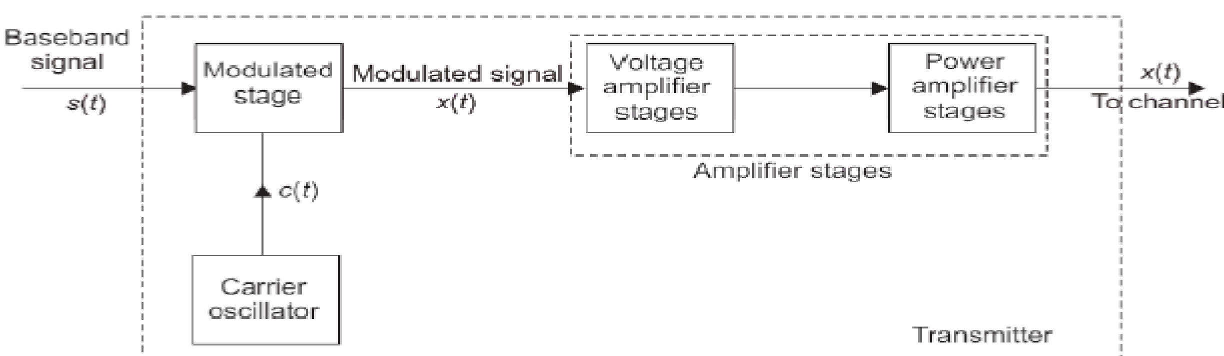


Fig. 4.4: Block diagram representing schematic of an analog transmitter section

Hardware and Software channels

- The three possible implementations of the hardware channels are: Transmission lines, Waveguides, and 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.
- Waveguides are employed as medium to transmit signals at UHF range. Waveguides are hollow, circular, or rectangular metallic structures.
- Optical fiber cables are in the form of thin circular pipes. Signals are transmitted in the form of light energy in OFCs. E.g. landline telephony and cable TV network.
- In communication systems that use software channels, the signals propagate through the natural resource and reach the receiver and there is no physical link between the transmitter and the receiver.
- The most widely used software channel is air or open space.
- Signals are transmitted in the form of electromagnetic (em) waves, called radio waves. Radio waves travel through open space at a speed equal to that of light (**$c = 3\times10^8$ m/s**).
- The transmitter section converts the electrical signal into em waves by using a transmitting antenna and is radiated into the open space.
- At the receiver side, receiving antenna, picks 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.

SNR and Noise Figure

- SNR is defined as the ratio of signal power to the noise power at a point in the circuit.
- It is the measure of the signal power relative to the noise power.
- If P_s, is signal power and P_n, is noise power, then SNR expressed as S/N, is given as

$$S/N = P_s / P_n$$

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

$$\frac{S}{N} = \frac{P_s}{P_n} = \frac{V_s^2R}{V_n^2R}$$

where V_s is the signal voltage and V_n is the noise voltage.

- The SNR can be expressed in terms of decibel (dB) as

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

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

- 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

$$F = \frac{\frac{S}{N}\text{ Power at the input terminals of the circuit}}{\frac{S}{N}\text{ Power at the output terminals of the circuit}}$$

Receiver Block

- The detailed block diagram of a typical receiver section is shown in Fig. 4.5
- The received signal r(t) is first amplified at voltage amplifier stage so that it becomes strong enough for further processing.
- The demodulator stage performs demodulation operation i.e. converts 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.
- The voltage and power of the recovered baseband signal s'(t) is amplified by the amplifier stages and then handed over to the final destination.

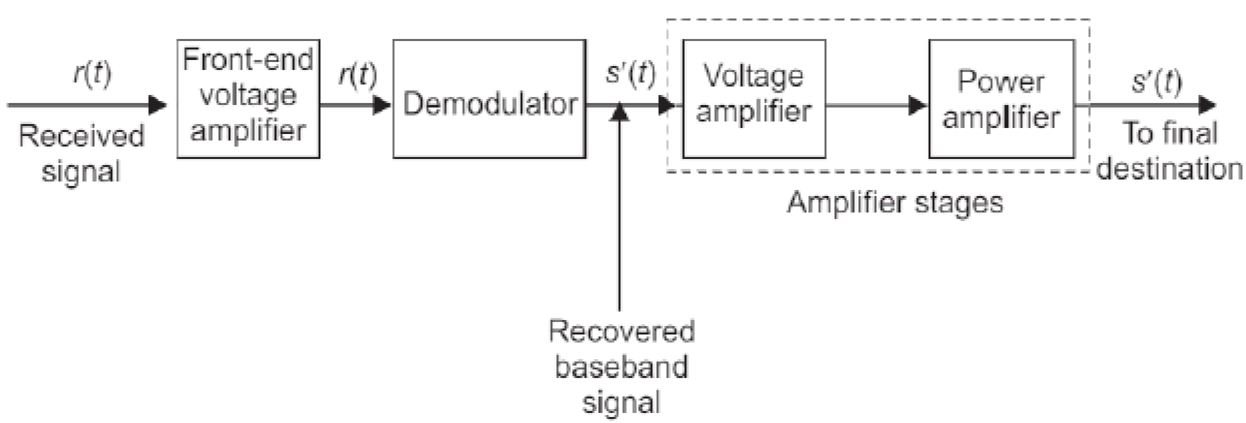


Fig. 4.5: Detailed block diagram of a typical receive section

- Radio signals are transmitted through electromagnetic (em) waves are referred as radio waves in a radio communication system.
- Radio Frequency (RF) bands spread in the range between 30 kHz and 300 GHz.
- Transmission systems are operated in the RF spectrum range and its application in communication systems is listed in table - 4.1.

Table 4.1: Classification of Radio Frequency (RF) spectrum & their applications

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

4.1.4 MULTIPLEXING

- It is a process which allows more than one signal to transmit through a single channel.
- Multiplexing facilitates the simultaneous transmission of multiple messages over a single transmission channel.
- Multiplexing allows maximum possible utilization of available bandwidth of the 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.
- The multiple signals are translated to higher frequencies by using different carrier frequencies, mixed at the transmitter and transmitted.
- At the receiver, the different signals can be easily separated because they are at different frequencies, and are delivered to the next stages of the receiver for further processing.

4.1.5 Types of Communication Systems

- Communication systems can be categorized based on their physical infrastructure and the specifications of the signals they transmit.

4.1.5.1 Communication Systems based on Physical Infrastructure

- Two types of communication systems based on the physical infrastructure are:

Line Communication System

- There is a physical link, called the hardware channel, between the transmitter and the receiver in the line communication systems. E.g.: Landline telephony.
- In a radio communication system, there is no such link and natural resources, such as space and water are used as softwire channels. E.g.: Radio broad cast
- A communication system can be simplex (one way transmission) or a duplex (two way transmission. Some communication system can be half duplex (two-way transmission is carried out, but not simultaneously) as well.
- Thus communication system can be grouped as:
    - Line/radio communication
    - Simplex/duplex communication
- TV communication system is a combination of the radio and simplex communication system & landline telephony is a combination of line & duplex communication systems.

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 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, four types of communication system categories based on signal specification are:
    - Analog communication system
    - Digital communication system
    - Baseband communication system
    - Carrier communication system

- Of the four, two groups consisting each of two types can be formed as:
  - Analog/digital communication system
  - Baseband/carrier communication system
- A particular communication system can be either an analog communication system or a digital communication system at a time. E.g.: TV transmission is an analog communication system while high definition television (HDTV) is a digital communication system.
- Similarly, a particular communication system can be either a baseband communication system or a carrier communication system.
- E.g. for baseband communication system: Landline telephony and fax.
- E.g. for carrier communication system: TV transmission, Radio broadcast & Cable TV.

4.2 Types of Modulation

- Modulation is the process in which any one of the parameters (amplitude, frequency or phase) of the high frequency carrier signal is varied according to the instantaneous values of the low frequency message signal, keeping other parameters constant.

4.2.1 Amplitude Modulation (AM)

- AM is defined as the modulation technique in which the amplitude of carrier signal is varied in accordance with the amplitude of 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.

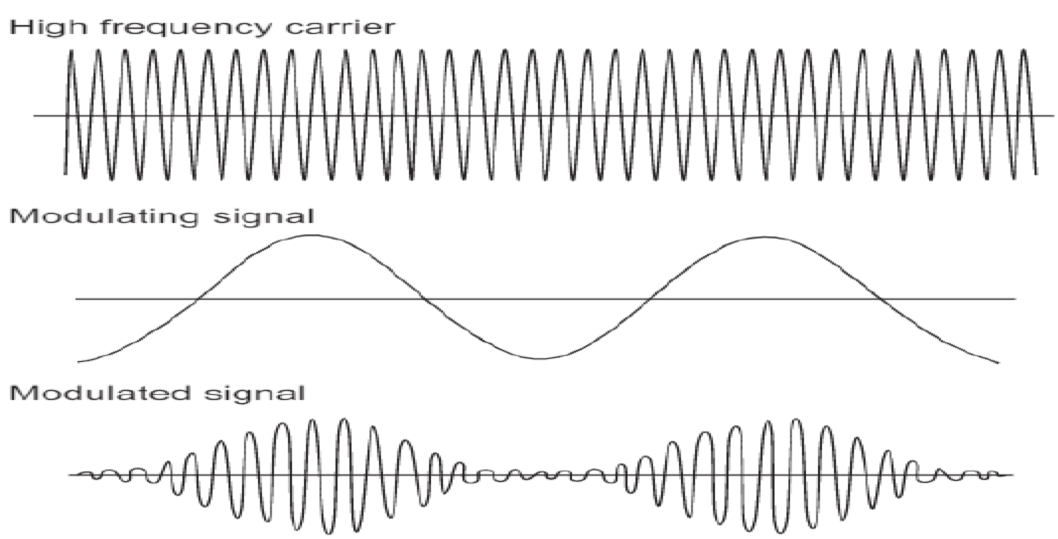


Fig. 4.6: Waveforms related to amplitude modulation

- Figure 4.6 shows the high frequency carrier, modulating and the modulated signal.
- As shown, the amplitude of the carrier signal is varies in accordance with the modulating signal while the frequency & phase of the carrier signal remain unchanged.
- It can be observed that the modulating signal is 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.**

4.2.2 Frequency Modulation (FM)

- The frequency modulation is the process of changing the frequency of the carrier voltage in accordance with the instantaneous value of the modulating voltage.
- Original frequency of carrier signal is called centre or resting frequency, denoted as 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).
- The total variation is frequency of FM wave from the lowest to the highest is termed as carrier saving (CS), i.e.

  CS= 2 x 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,

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

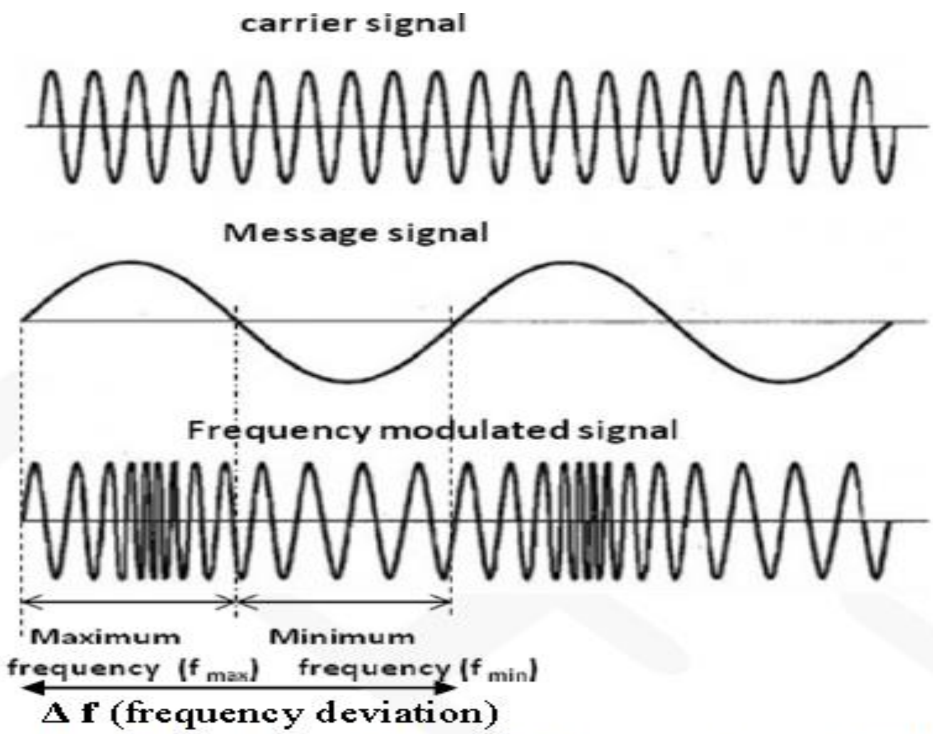


Fig. : Waveforms related to frequency modulation

4.2.3 Phase modulation (PM)

- Phase modulation is another form of angle modulation.
- 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.
- Pulse modulation may be used to transmit analog information, such as continuous speech or data.
- It is system in which continuous waveforms are sampled at regular intervals.
- Pulse modulation may be subdivided into two categories, analog and digital.
- Pulse-amplitude and pulse-time modulation are both analog, while the pulse code and delta modulation systems are both digital.

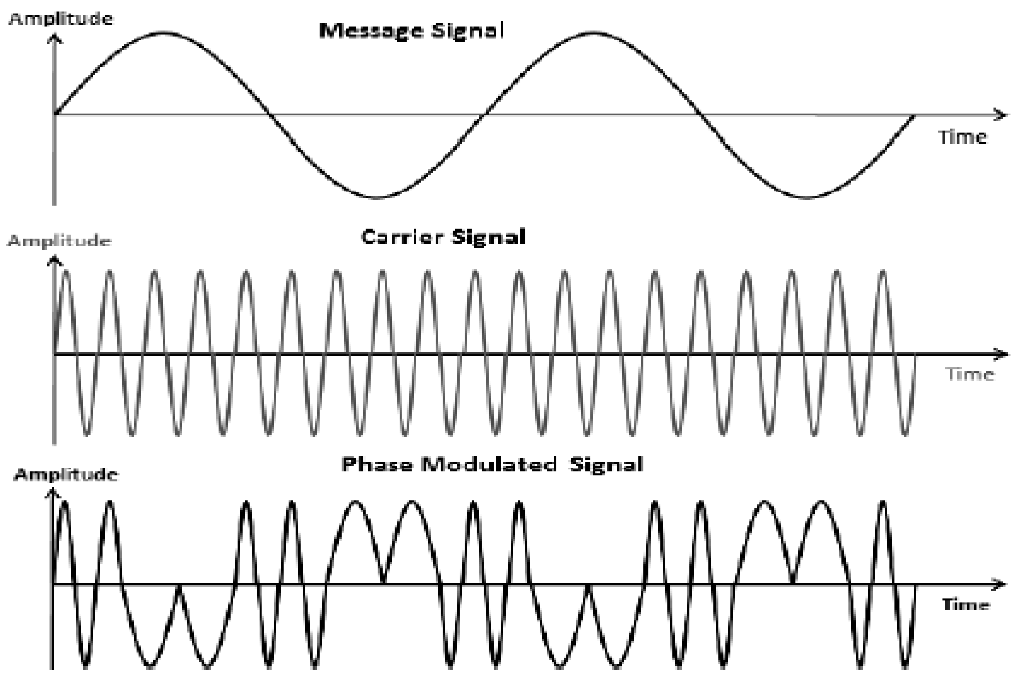


Fig. : Waveforms related to phase modulation

Phase-amplitude modulation (PAM)

- PAM is a pulse modulation system in which the signal is sampled at regular intervals, & each sample is made proportional to amplitude of the signal at the instant of sampling.
- In PAM, the amplitudes of regularly spaced rectangular pulses vary according to the instantaneous value of the modulating signal.

- Any three types of sampling: flat top, natural and ideal type can be applied in PAM.
- A sample and hold circuit is used to produce flat top sampled PAM.

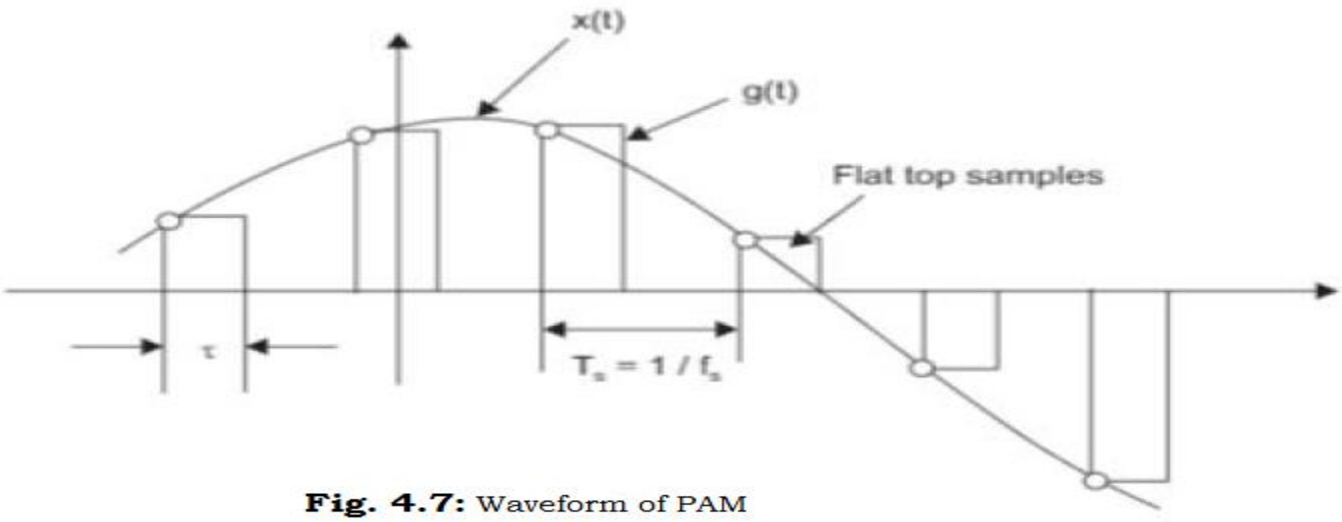


Fig. 4.7: Waveform of PAM

Pulse width or pulse-duration modulation (PWM or PDM)

- In this system, the starting time and amplitude of each pulse are constant but width or duration of each pulse is made proportional to the instantaneous value of analog signal.
- Three formats of PWM are possible which are states as follows:
  - In one variation, the leading edge of the pulse is held constant and change in pulse width with signal is measured with respect to the leading edge (fig. 4.8 (a)).
  - In second type of format, the tail edge is held constant and with respect to it, pulse width is measured(fig. 4.8 (b)).
  - In third type of variation, the centre of the pulse is held constant and pulse width changes on either side of the centre of the pulse(fig. 4.8 (c)).

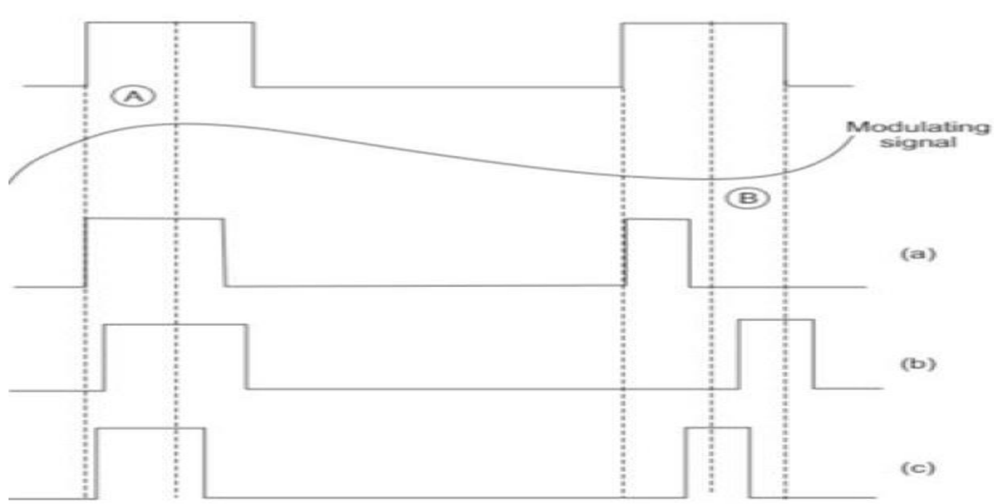


Fig. 4.8: PWM waveforms

Pulse position-modulation (PPM)

- In this system, the amplitude and width of the pulses is kept constant, while the position of each pulse, in relation to the position of a recurrent reference pulse is varied by instantaneous sampled value of the modulating wave.
- As compared to PWM, PPM has the advantage of requiring constant transmitter power output, but the disadvantage of depending on transmitter receiver synchronization.
- In this system, the position of pulse relative to its unmodulated time of occurrence is varied in accordance with the instantaneous value of the message signal.

Pulse-code modulation (PCM)

- PCM is a digital process in which the message signal is sampled is rounded off to the nearest value of a finite set of allowable values and rounded values are coded.
- PCM generator produces a series of numbers or digits. Each one of these digits, represents the approximate amplitude of the signal sample at that instant.
- Obviously, signals are transmitted as binary code.

4.3 Concept of Radio Wave Propagation

- In space communication electromagnetic waves of different frequencies are used to carry information through the physical space acting as the transmission medium.
- EM waves with frequencies from about 10 kHz to 300 GHz are classed as **radio waves**.
- 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
  - (iii) Sky wave.
- Accordingly, we have three types of propagation:

i) Ground wave propagation:

- In ground wave propagation, radio waves are guided by the earth and move along its curved surface from the transmitter to the receiver.
- 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 kilometres from the transmitter.
- Ground wave transmission is very reliable whatever the atmospheric conditions be.

ii) Space or Tropospheric wave propagation

- When a radio wave 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 direct or line-of sight wave form the transmitting to the receiving antenna
  - 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, radio waves transmitted from the transmitting antenna reach the receiving antenna after reflection form the ionosphere.
- 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 earth, is referred to as 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.

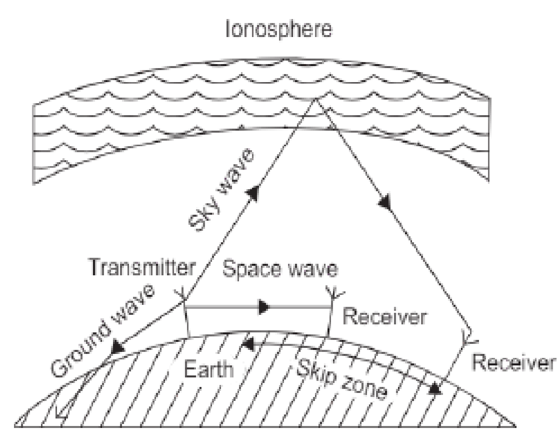


Fig. 4.9: Modes of propagation of e.m. waves

- Figure 4.9 shows three different modes of propagation of electromagnetic waves.

4.4 Digital Communication

4.4.1 Concepts of sampling theorem

- There are two types of signals: continuous-time and discrete-time signals. A continuous-time signal can be converted into a discrete-time signal by sampling process.

- Sampling theorem basically consists of two parts: First part represents the signal in its samples and minimum sampling rate required to represent a continuous-time signal into its samples. Second part represents the reconstruction of the original signal from its samples by giving the required sampling rate for satisfactory reconstruction.
- Sampling theorem is stated as: "A continuous-time signal may be completely represented in its samples and recovered back if the sampling frequency is $f_s \geq 2f_m$, where f_s is the sampling frequency & f_m the maximum frequency present in the signal."
- The process of reconstructing the continuous-time signal from its samples is known as interpolation.

4.4.2 Nyquist Rate, Nyquist Interval & Aliasing

- When the sampling rate becomes exactly equal to twice the maximum signal frequency, i.e. $2f_m$ samples per second, then it is called Nyquist rate.
- Nyquist rate is the minimum sampling rate required to represent any continuous-time signal into its samples. It is given as: $f_s \geq 2f_m$
- Similarly, maximum sampling interval is known as Nyquist interval which is given as $T_s = 1 / 2f_m$ second.
- When a continuous-time signal is sampled at a rate lower than Nyquist rate i.e. when the sampling frequency is less than the Nyquist rate, aliasing problem occurs.
- Aliasing is the phenomenon in which a high frequency component in the frequency spectrum of signal takes the identity of a lower frequency component in the spectrum of the sampled signal.
- Aliasing makes it difficult to recover the original signal from the sampled signal.
- To avoid aliasing, two steps must be followed, as follows:
  - 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 $f_s \geq 2f_m$.

4.4.2 Digital Modulation Techniques

- 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. For this purpose, digital modulation techniques are used.
- Digital modulation techniques may be classified into coherent and non-coherent techniques, depending upon whether receiver consists of a phase-recovery circuit or not.

Coherent Digital Modulation Technique

- These techniques employ coherent detection in which the local carrier generated at the receiver is phase locked with the carrier at the transmitter.
- Detection is done by correlating the received noisy signal and locally generated carrier.
- It is also known as synchronous detection.

Non-Coherent Digital Modulation Techniques

- In these techniques, the detection process does not require receiver carrier to be phase locked with the transmitter carrier. So, the system becomes simple in design.
- In such systems, the probability of error increases.

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.
- ASK signal may be generated by simply applying the incoming binary data and the sinusoidal carrier to the two inputs of a product modulator.
- Demodulation of binary ASK waveform can be achieved with help of coherent detector.

4.5 RADIO TRANSMISSION AND RECEPTION

4.5.1 Signal Transmission

- Figure 4.10 shows the most important components of a wireless transmission system.
- 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 its amplitude or phase.
- The transmitter 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 analog transmitter, which generates the radio wave itself.

- Modulation scheme used in Fig. 4.10 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. 4.11(a)) which corresponds to bit combination of 00, 10, 11 and 01 respectively.

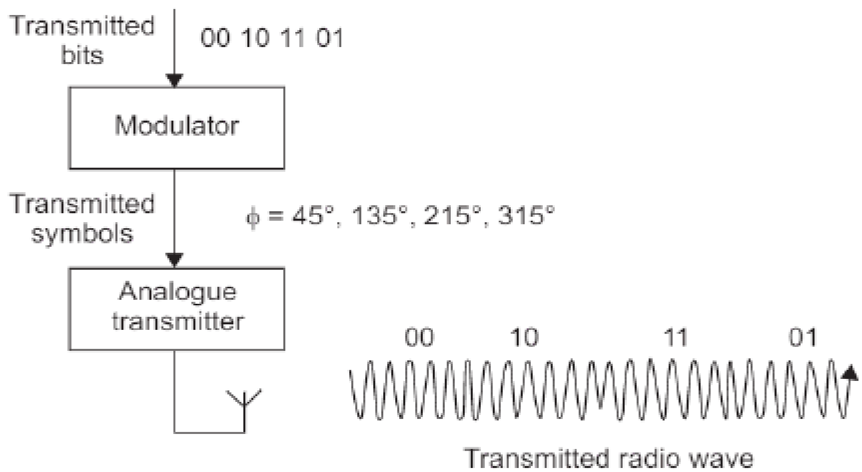


Fig. 4.10: Architecture of a wireless communication transmitter

- The 4 states of QPSK can be represented using constellation diagram using fig 4.11(b).

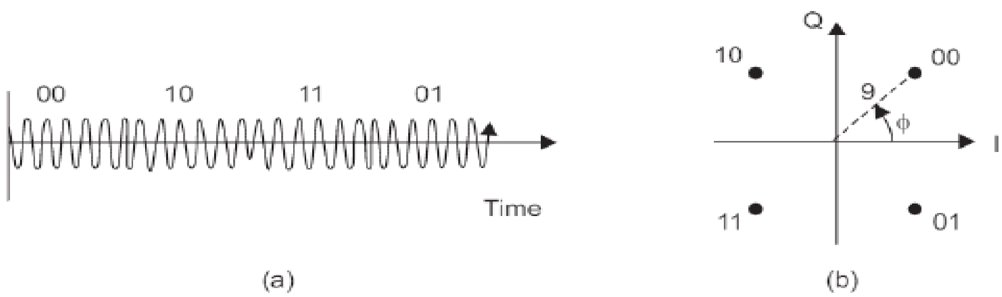


Fig. 4.11: Quadrature phase shift keying. (*a*) Example QPSK waveform. (*b*) QPSK constellation diagram

- 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.
- Each symbol is represented as the in-phase (I) and quadrature (Q) components and these are computed as: $I = a \cos\Phi$ and $Q = a \sin\Phi$, where a is the amplitude of the transmitted wave and Φ is its phase.
- Fig. 4.12 shows a LTE system that 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.

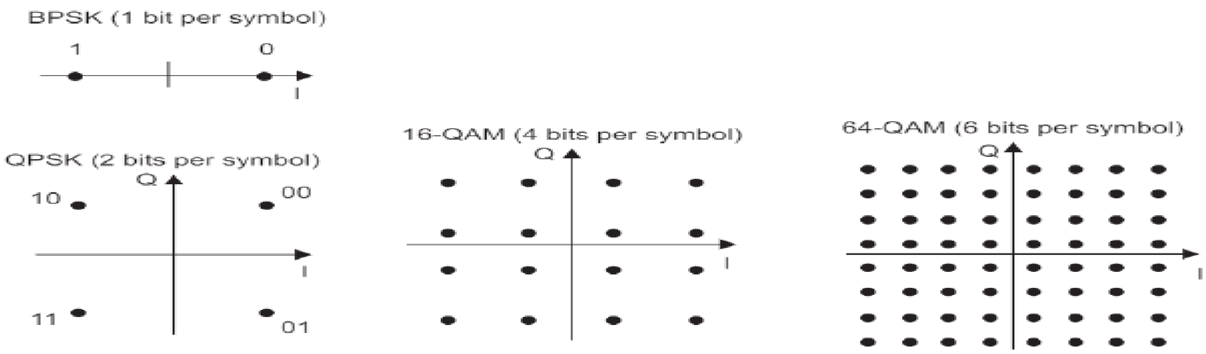


Fig. 4.12: Modulation schemes used by LTE

4.6 MULTIPLE ACCESS TECHNIQUES

- In cellular network, the base station has to transmit to many different mobiles at once by sharing the resources of air interface using a technique known as multiple access.
- Different multiple access techniques used are:
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)

Frequency Division Multiple Access (FDMA)

- FDMA was used by first generation (1G) analog systems.
- Each mobile receives signal on its own carrier frequency, which it distinguishes from the others using analogue filter.
- Carriers are separated by unused guard bands to minimize interference between them.

Time Division Multiple Access (TDMA)

- Mobiles receive signals on the same carrier but at different times.
- GSM uses the TDMA technique.
- TDMA requires time synchronization.

Code Division Multiple Access (CDMA)

- CDMA technique was used by third generation (3G) communication systems.
- Mobiles receive signals on the same carrier frequency and at the same time but the signals are labeled by the use of codes, which allows a mobile to separate its own signal from the others.

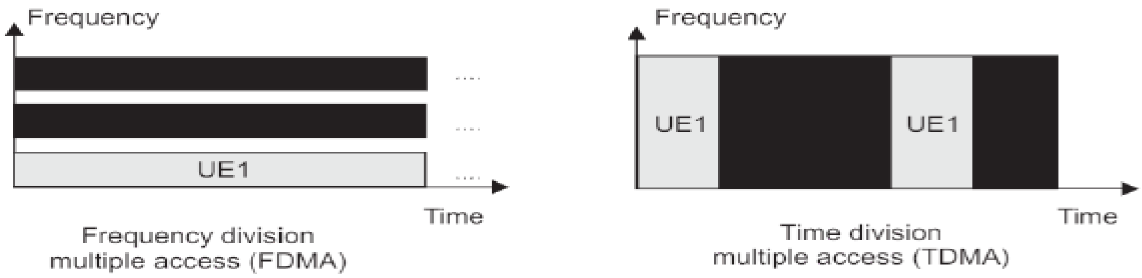


Fig. 4.13: Example multiple access techniques

4.6.1 FDD and TDD Modes

- By using the multiple access techniques, a base station can distinguish the transmissions to and from the individual mobiles in the cell.
- To distinguish the mobiles transmissions from those of the base stations, a mobile communication system can operate in different transmission modes.
- **Frequency division duplex (FDD):**
  - In FDD, the base station and mobile transmit and receive at the same time, but using different carrier frequencies.
  - The bandwidths of the uplink and downlink are fixed and are usually the same.
  - Suitable for voice communications, in which the uplink and downlink data rates are very similar.
  - FDD is often preferred for wide-area networks that have no isolated regions.

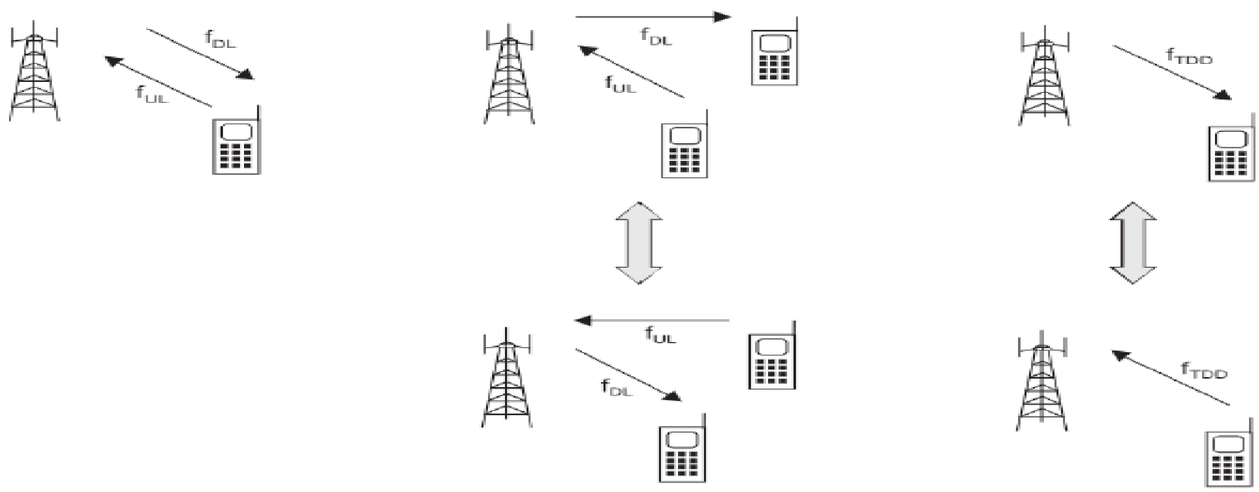


Fig. 4.14: Operation of FDD and TDD modes

- **Time division duplex (TDD):**
  - In TDD, the base station and mobile transmit and receive on the same carrier frequency but at different times.
  - The system can adjust how much time is allocated to the uplink and downlink.

- 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, 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.

➢ Figure 4.14 shows the operation of FDD and TDD modes.
- LTE supports each of the modes described above.
- A cell can use either FDD or TDD mode.
- Mobile can support any combination of full duplex FDD, half duplex FDD & TDD.

4.6.2 MULTIPATH and FADING

➢ 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, incoming rays can add together in different ways, as shown in Fig. 4.15.

➢ If the peaks of the incoming rays coincide then they reinforce each other, a situation known as **constructive interference**.

➢ If, the peaks of one ray coincide with the troughs of another, then the result is **destructive interference**, in which the rays cancel.

➢ Destructive interference makes the received signal power drop to a very low level, leading to the situation known as **fading**.

➢ If the mobile moves from one place to another, then the ray geometry changes, so the interference pattern changes between constructive and destructive. Fading is therefore a function of time.

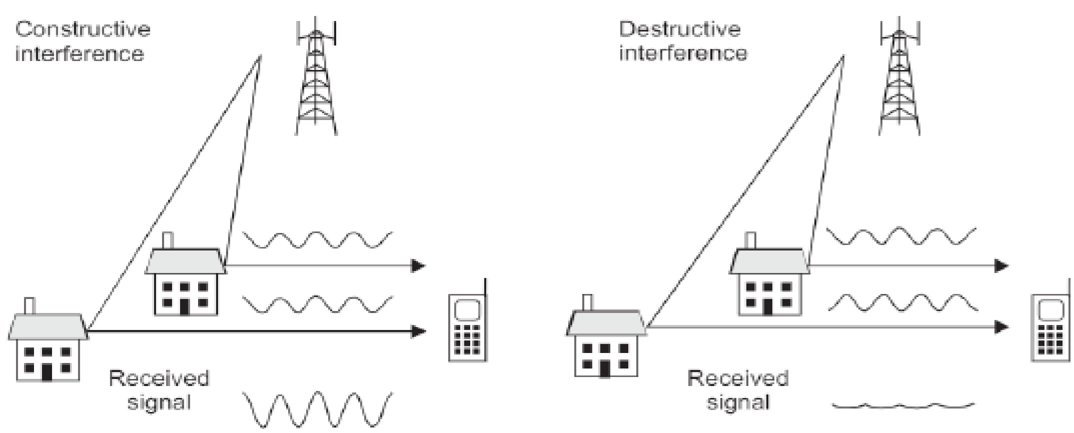


Fig. 4.15: Generation of constructive interference, destructive interference and fading in a multipath environment

- The amplitude and phase of the received signal may vary over a timescale called the **coherent time** T_C, which can be estimated as: $T_C \approx 1 / f_D$
- Here f_D is the Doppler frequency given by $f_D = (v / c) f_C$, where f_C is the carrier frequency, v is the speed of mobile and c is the speed of light.
- If the carrier frequency changes, then the wavelength of the radio signal changes. This also makes the interference pattern change between constructive and destructive, so fading is a function of frequency as well.
- The amplitude and phase of the received signal vary over a frequency scale called the **coherence bandwidth**, B_C, which can be estimated as follows: $B_C \approx 1 / \tau$
- Here, τ is the delay spread of the radio channel, which is the difference between the arrival times of the earliest and latest rays, calculated as: $\tau = \Delta L / c$, where ΔL is the difference between the path lengths of the longest and shortest rays.

4.6.3 Error Management

Forward Error Correction

- Noise and interference lead to errors in a wireless communication receiver.
- To solve this problem, the most important technique is **forward error correction**.
- In this technique, the transmitted information is represented using a **codeword** that is typically two or three times as long.
- For example, a transmitter might represent the information sequence 10 using the codeword 110010111. After an error in the second bit, the receiver might recover the codeword 100010111. If the coding scheme has been well designed, then the receiver can conclude that this is not a valid codeword, and that the most likely transmitted codeword was 110010111. The receiver has therefore corrected the bit error and can recover the original information.
- As shown in block diagram below, in the first stage, the information bits are passed through a fixed-rate coder. The algorithm used is known as **turbo coding** and has a fixed coding rate of 1/3.
- In the second stage, called **rate matching**, some of the coded bits are selected for transmission, while the others are discarded in a process known as **puncturing**.
- The receiver has a copy of the puncturing algorithm, so it can insert dummy bits at the points where information was discarded.
- It can then pass the result through a turbo decoder for error correction.

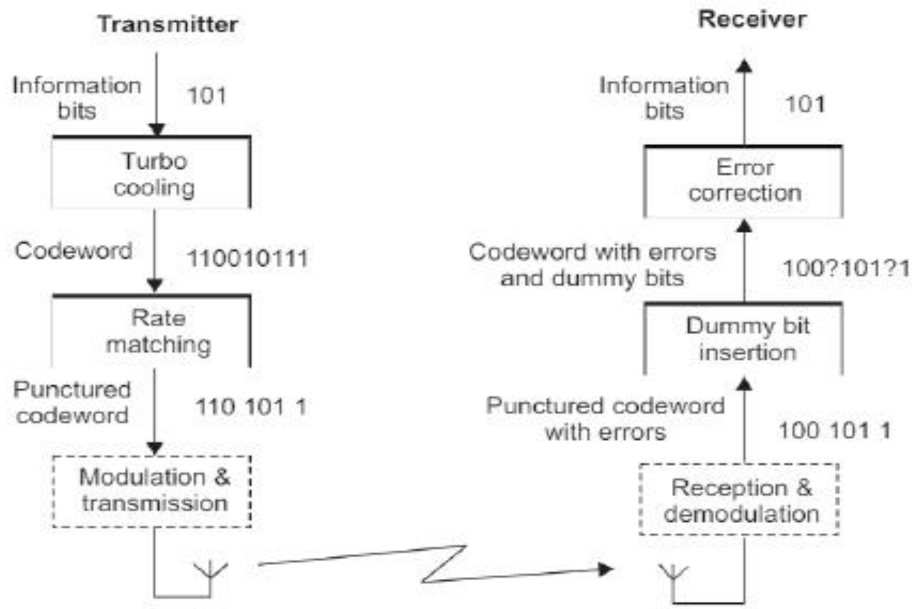


Fig. 4.16: Block diagram of a transmitter and receiver using forward error correction and rate matching

Automatic Repeat Request

- It is another error management technique, which is illustrated in Fig. 4.17.
- The transmitter takes a block of information bits and uses them to compute some extra bits known as a **cyclic redundancy check** (CRC).
- It appends these to the information block and then transmits the data in the usual way.
- The receiver separates the two fields and uses the information bits to compute the expected CRC bits.
- If the observed & expected CRC bits are the same, then it concludes that the information is received correctly & sends a positive acknowledgement (ACK) back to the transmitter.
- If the CRC bits are different, it concludes that an error has occurred sends a negative acknowledgement (NACK) to request a re-transmission.

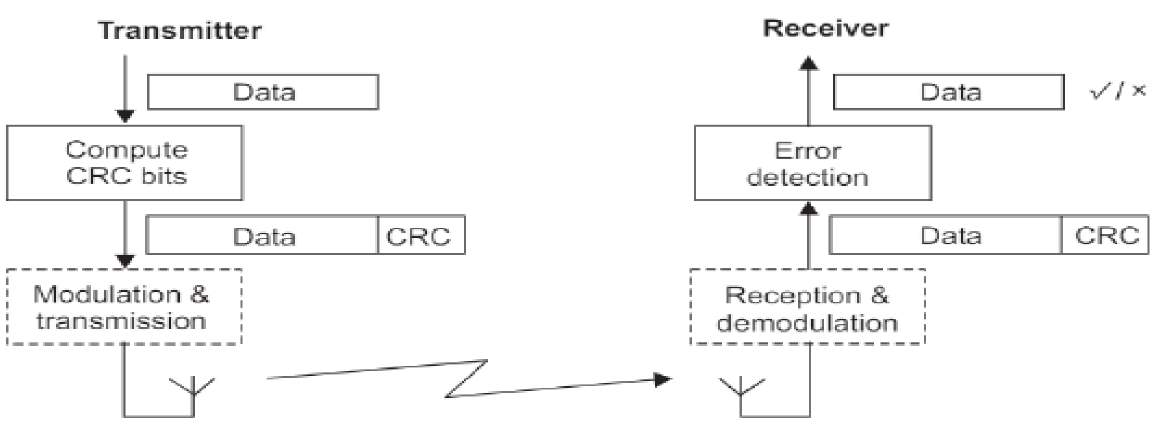


Fig. 4.17: Block diagram of a transmitter and receiver using automatic repeat request

4.7 ANTENNAS

- An antenna is a device for converting electromagnetic radiation in space into electrical currents in conductors or vice-versa, depending on whether it is being used for receiving or for transmitting, respectively.
- Antennas transform wire propagated waves into space propagated waves.
- An antenna must have the following features:
  - Strictly defined radiation patterns for a most accurate network planning.
  - Growing concern for the level of inter modulation due to the radiation of many HF carriers via one antenna.
  - Dual polarization.
  - Electrical down-tilting of the vertical diagram.
  - Unobtrusive design.

4.7.1 Types of antenna

Omnidirectional Antenna

- An Omnidirectional antenna is an antenna that has a circular pattern in a given plane.
- It radiates equal power in all directions perpendicular to the axis.
- Examples: Dipole antennas and collinear antennas.

Dipole Antennas

- The dipole antenna consists of two identical conductive elements such as rods or metal wires. The length of the metal wires is approximately half of the maximum wavelength (i.e., $\lambda/2$) in free space at the frequency of operation.
- Hence, dipole antennas are commonly referred to as half-wavelength ($\lambda/2$) dipole.
- Applications: Radio, TV receivers.

Collinear Omni Antennas

- A collinear antenna consists of an array of dipole antennas mounted in such a manner that the corresponding elements of each antenna are parallel and collinear.
- Collinear arrays are high gain omnidirectional antennas.
- Higher gain implies same power radiated in a more focused way.
- Applications: Base station antenna for dispatcher for police, fire, ambulance etc.

Directional Antennas

- Radiates its energy more effectively in one direction than the others.
- They have one main lobe and several minor lobes.

- Used for coverage as well as point to point links.
- Examples: Patch antennas, dish antenna, horns etc.

Patch Antennas

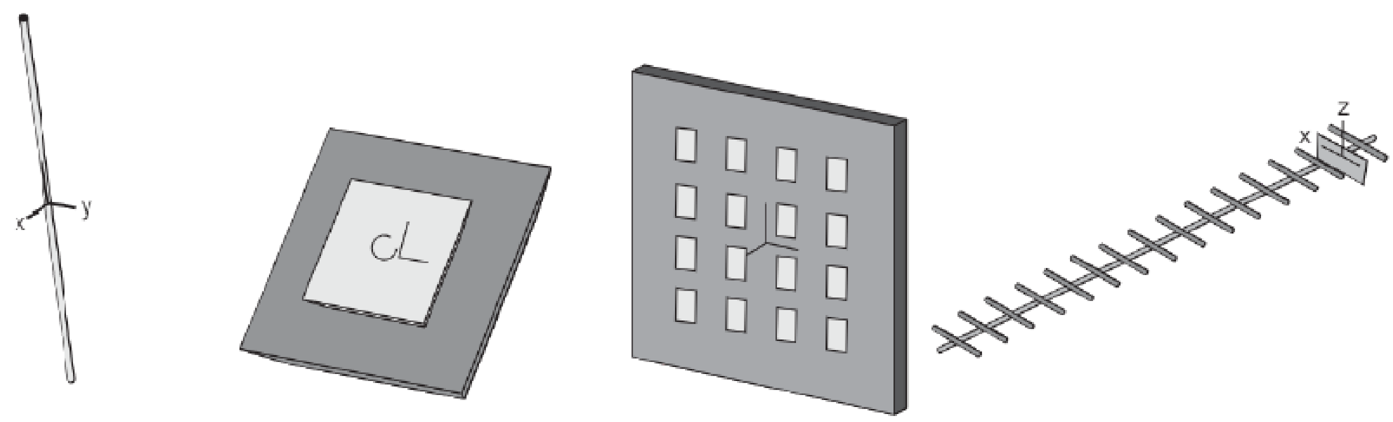
- In its simplest form, a patch antenna is a single rectangular conductive plate that is spaced above a ground plane.
- Attractive due to their low profile and ease of fabrication.
- It is widely used in portable wireless devices.

Patch Array Antennas

- It is an arrangement of multiple patch antennas that are all driven by the same source.
- Frequently this arrangement consists of patches arranged in orderly rows and columns.
- Reason for this arrangement is higher gain.

Yagi Antenna

- Yagi antenna is a directional antenna that radiates its energy out in one main direction.
- It consists of a long transmission line with a single driven element consisting of two rods connected on either side of the transmission line.
- A typical Yagi antenna has one reflector and one or more directors.
- Reflector reflects all the energy towards the direction of the radiation pattern and the director directs the beam towards the desired angle.
- Applications: Used for TV reception



(a) Dipole antenna model (b) Patch antenna model (c) 4 × 4 Patch array antenna (d) Yagi antenna model

Fig. 4.18: Types of antenna