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Basics of Electronics and Communication Engineering (21ELN14/24)

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MODULE 4

Module-4	RBT Level
Analog and Digital Communication – Modern communication system scheme,Information source, and input transducer, Transmitter, Channel or Medium – Hardwired and Softwired, Noise, Receiver, Multiplexing, Types of communication systems. Types of modulation (only concepts) – AM, FM, Phase Modulation, Pulse Modulation-PAM , PWM , PPM, PCM. Concept of Radio wave propagation (Ground, space, sky **),**Concepts of Sampling theorem, Nyquist rate. Digital Modulation Schemes – ASK, FSK, PSK Radio signal transmission Multiple access techniques Multipath and fading Error Management Antenna, Types of antennas – (only definition and antenna model, **exclude radiation patterns).** Textbook:S L Kakani and Priyanka Punglia, 'Communication Systems', New Age International Publisher, 2017. https://elib4u.ipublishcentral.com/pdfreader/communication-systems	**L1, L2**

Analog and Digital Communication

MODERN COMMUNICATION SYSTEM SCHEME

- 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.
- 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.

- The block schematic diagram of the most general form of basic communication system is as shown in the fig .

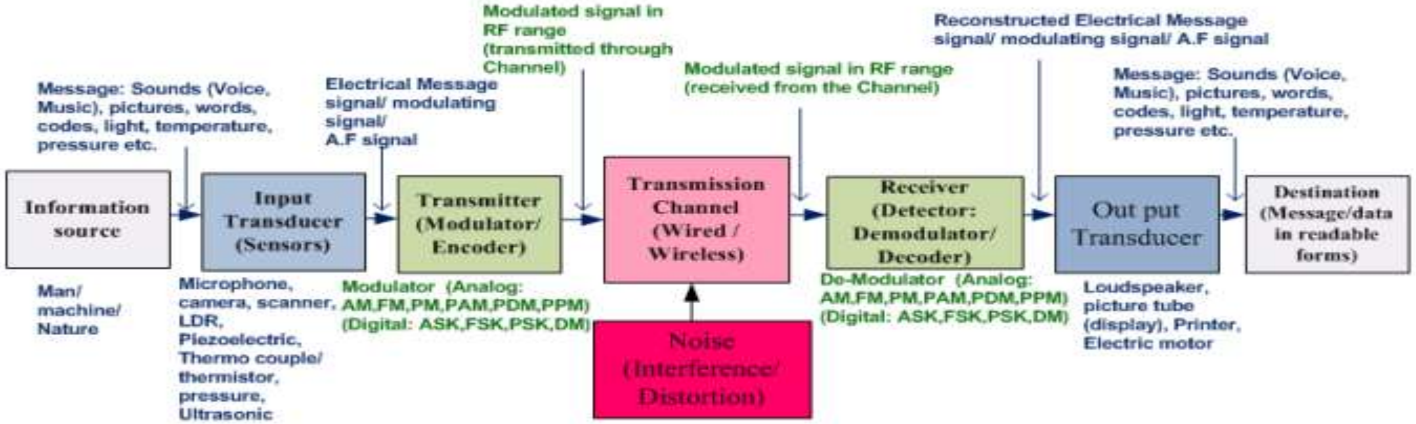


Figure: Basic Model of a Communication System

- Information Source: The information is represented by a message that is originated by an information source, e.g. a sentence or paragraph spoken by a person , voice, live scenes, music, written text, and e-mail is a message that contains some information.
- Input transducer is a device that converts a non-electrical energy into its corresponding electrical energy signal prior it is transmitted. An example of a transducer is a microphone.

•The information produced by the information source is applied to the next stage, termed the information or Function input transducer. This in turn, produces an electrical signal value corresponding to the information as output. This electrical signal is called the base band signal s(t) message/information.

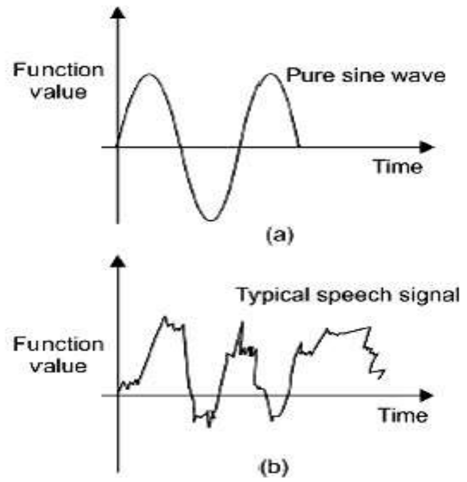
There are two types of signals. (a) analog signal, and (b) digital signal.

- 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. example :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.

- 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.

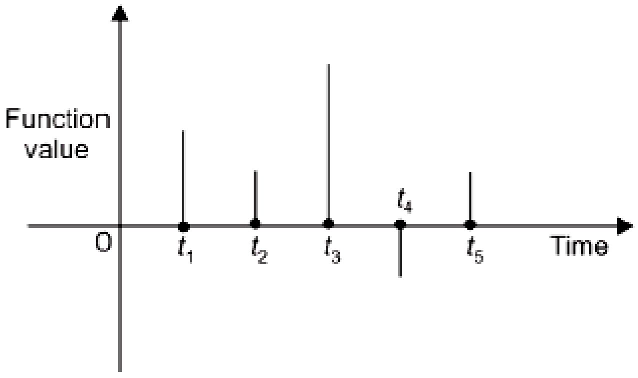
Analog Signal

(continuous in time)



Digital Signal

(The discrete amplitude of the signal is coded into binary digits represented by '0' and '1 ‘)



- The analog 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 circuitry that performs this operation is called an analog-to-digital converter.

Transmitter: The base band signal, which is the output of an input transducer, is input to the transmitter. This baseband 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.

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:
- The baseband signal, which lies in the low frequency spectrum, is translated to a higher frequency spectrum.we call the communication system as a carrier communication system.
- The baseband signal is transmitted without translating it to a higher frequency spectrum.

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.

- Eg. 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.
- 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.
- There are two options for processing signals prior transmission

(i)The baseband signal, which lies in the low frequency spectrum, is translated to a higher frequency spectrum---carrier communication system

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

Figure below illustrates baseband signal processing.

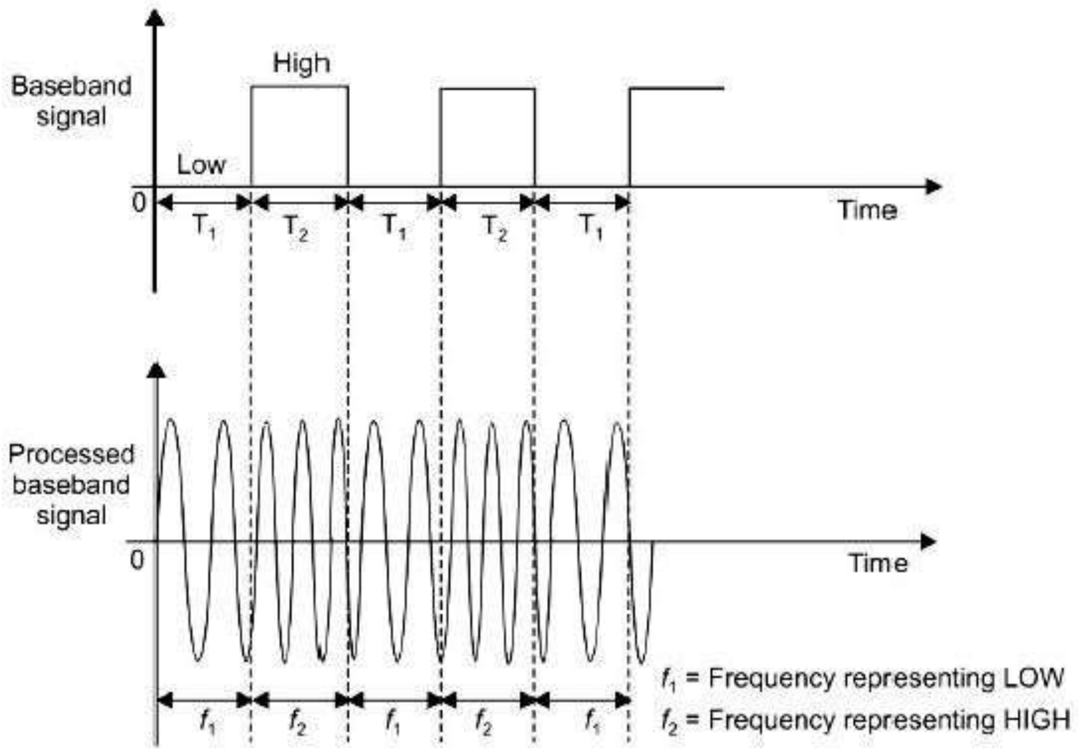


Fig. The processing of a baseband signal

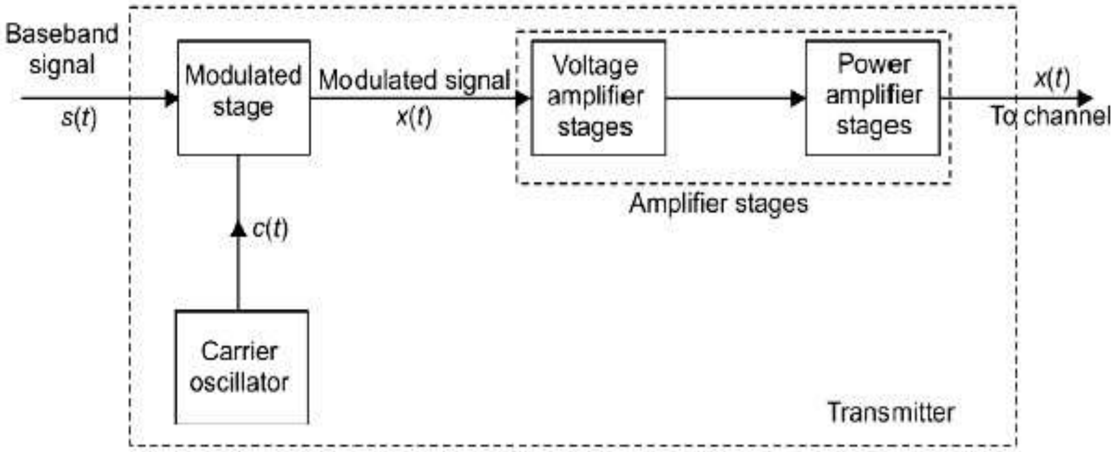


Fig block diagram of a typical analog transmitter section.

- 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 . 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.

Radio frequency range	Wavelength (meters)	Class	Applications
10-30 kHz	3×10^4 - 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

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.

- 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.

- 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:

- Hardwired 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.
- 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.
- 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.

Softwired 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.

- 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.

Noise:

- 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.
- 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.
- In order to avoid this 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. SNR (signal to noise ratio).
- 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

- 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

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

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

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

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

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.
- 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.

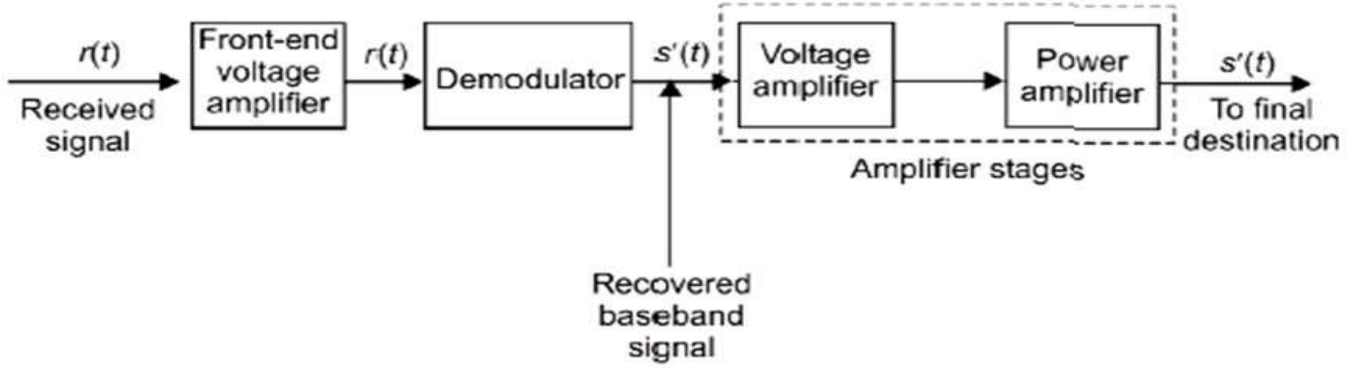


Fig:Block diagram of a typical receiver section

- 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 communication system.

- 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.

- Hence, 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.

Multiplexing

Multiplexing is the technology that is able to combine multiple communication signals together in order for them to traverse an otherwise single signal communication medium simultaneously. Multiplexing can be applied to both analog and digital signals.

- Multiplexing allows the maximum possible utilization of the available bandwidth of the system.
- The purpose of multiplexing is to enable signals to be transmitted more efficiently over a given communication channel, thereby decreasing transmission costs.

TYPES OF COMMUNICATION SYSTEMS

One may categorize communication systems based on their physical infrastructure and the specifications of the signals they transmit.

•Communication Systems based on Physical Infrastructure

- **Line Communication Systems**

•Communication systems based on Signal specifications

- **Analog/ Digital Communication systems**
- **Baseband/ Carrier Communication systems**

Communication Systems based on Physical Infrastructure

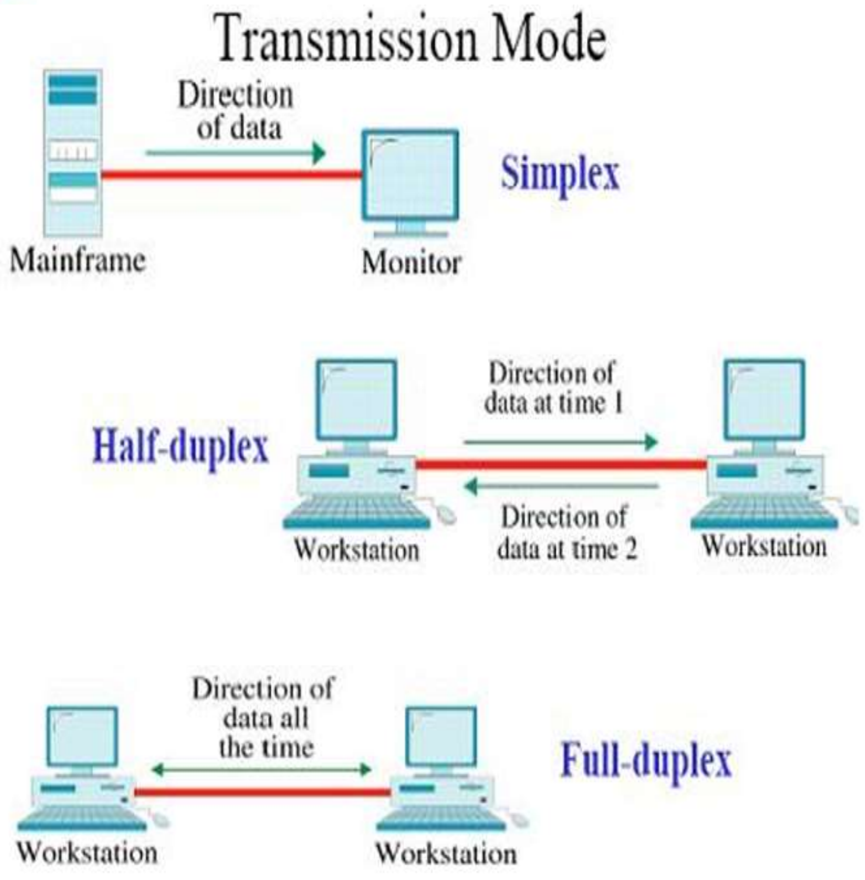


Fig: Simplex, half-duplex,full-duplex transmission mode

Simplex: The information is communicated in only one direction. For example, the radio or TV broadcasting system can only transmit, they cannot receive

Half –Duplex: These systems are bidirectional, i.e. they can transmit as well as receive but not simultaneously. At a time, these systems can either transmit or receive, for example, a transceiver or walky talky set.

Full-Duplex: These are truly bidirectional systems as they allow the communication to take place in both the directions simultaneously. These systems can transmit as well as receive simultaneously. For example: the telephone systems.

Communication systems based on Signal specifications

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

•Nature of baseband or information signal

•Nature of the transmitted signal.

A. Based on the **nature of the baseband signal**

- Analog communication systems
- Digital communication systems.

B. Based on the Nature of the transmitted signal.

The two systems can then be put under following categories:

(i)The baseband signal, which lies in the low frequency spectrum, is translated to a higher frequency spectrum---carrier communication system

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

Types of Modulation and Digital Modulation Schemes

Modulation:

- Modulation – process of translating the low frequency baseband signal to higher frequency spectrum
- Process of changing the parameters of the carrier signal, in accordance with the instantaneous values of the modulating signal.

Need for Modulation:

- Improves Quality of reception
- Reduces Height of antenna
- Options for Multiplexing
- Bandwidth Extension
- Increased Range of Communication
- Reduced noise and interference

Types of Modulation

1.Analog modulation

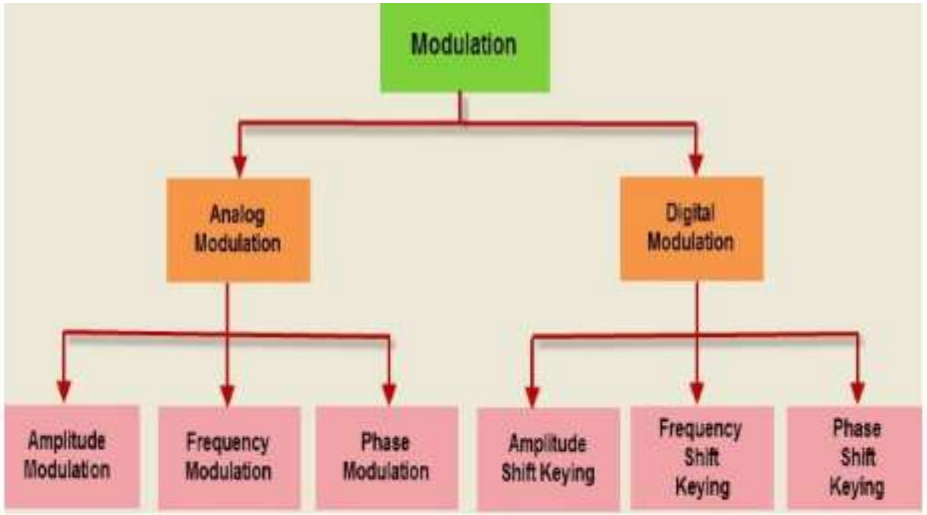
In analog modulation, a continuously varying sine wave is used as a carrier wave that modulates the message signal or data signal.

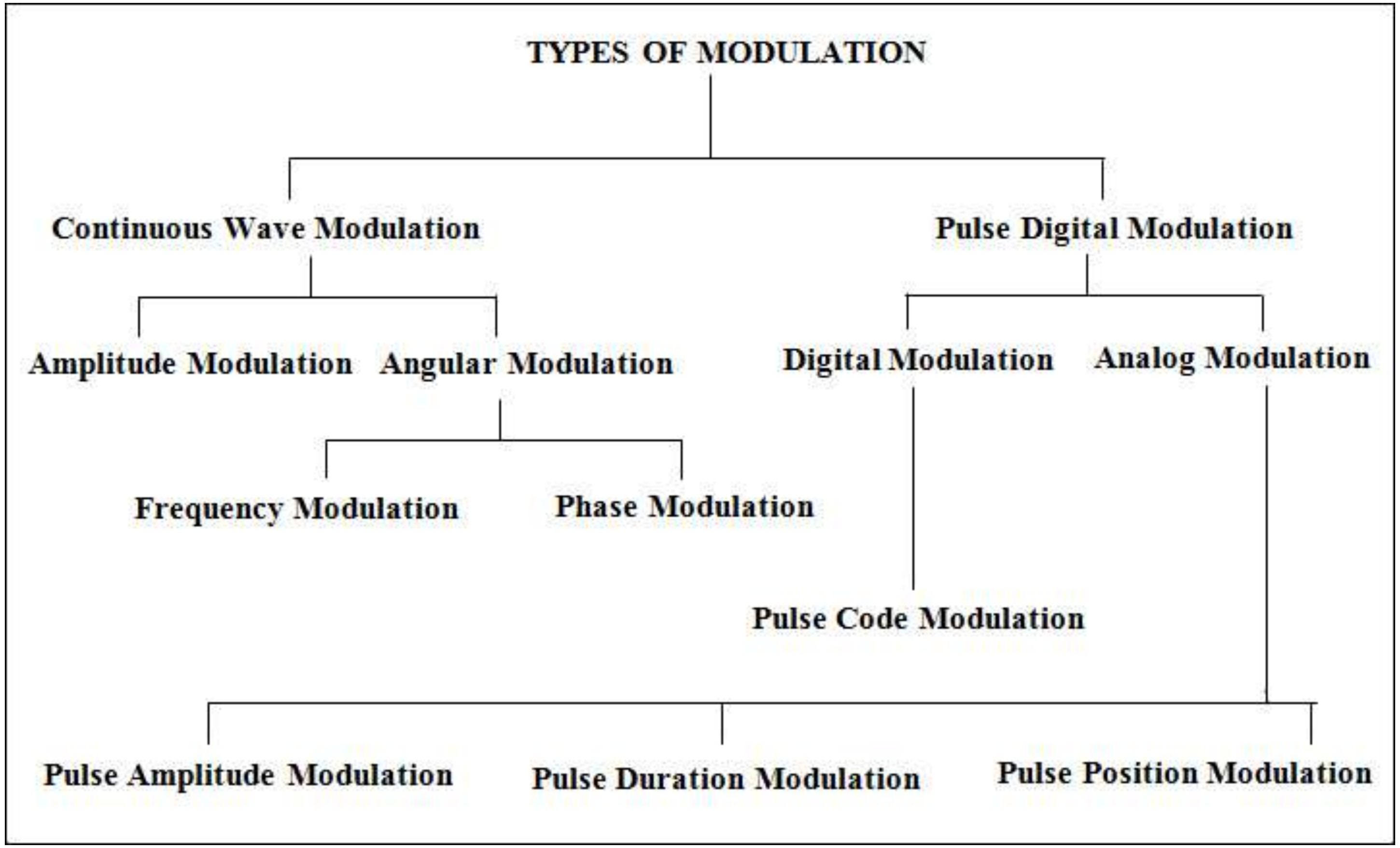
Types: AM,FM,PM

2.Digital modulation is similar analog except base band signal is of discrete amplitude level. For binary signal it has only two levels, either high or logic 1 or low or logic 0.

The modulation scheme are of three main types.

- ASK or Amplitude Shift Key
- FSK or Frequency Shift Key
- PSK or Phase Shift Key

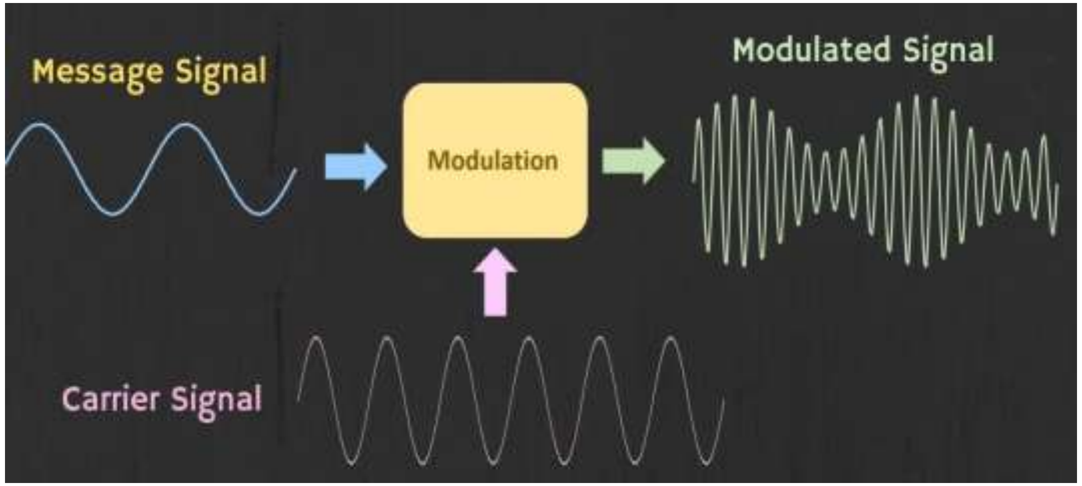



TYPES OF MODULATION
Continuous Wave Modulation
Pulse Digital Modulation
Amplitude Modulation
Angular Modulation
Digital Modulation
Analog Modulation
Frequency Modulation
Phase Modulation
Pulse Code Modulation
Pulse Amplitude Modulation
Pulse Duration Modulation
Pulse Position Modulation

Continuous wave modulation

Amplitude Modulation

- **Amplitude modulation (AM)** -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
- Modulating signal - an analog baseband signal which is random and has a low frequency
- Carrier signal- a sinusoidal wave with high frequency
- Variations in amplitude of carrier signal represent the information



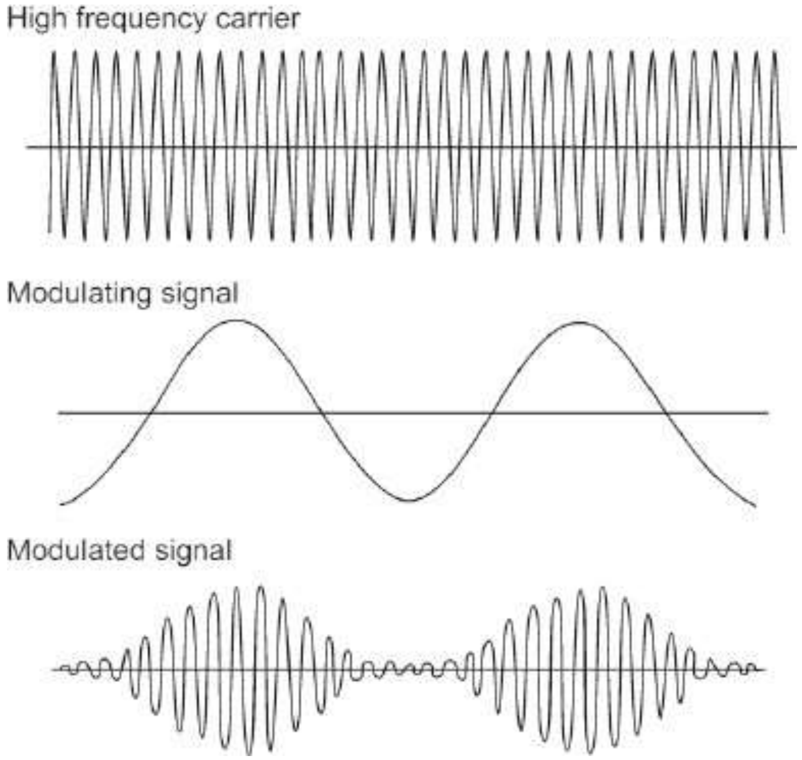


Fig: Waveform representation of AM

- Note : It can be observed from the figure that the amplitude of the carrier wave is varied in accordance with the modulating signal while the frequency and phase of the carrier signal remains unchanged
- Modulating signal seems to be superimposed on the carrier signal
- Amplitude variations in the peak values of the carrier signal exactly replicates the modulating signal at different points of time which is known as an envelope.
- The AM frequency ranges from 535 kHz – 1705 kHz.
- The modulation index of AM ranges from 0 to 1

Modulation index describes the extent to which modulation is done on a carrier signal. In an amplitude modulation, it is defined as the ratio of the amplitude of modulating signal to that of the carrier signal.

Mathematically, this is represented as: $m = \frac{A_m}{A_c}$

Frequency Modulation

- Process of changing the frequency of the carrier signal in accordance with the instantaneous value of the modulating voltage while keeping the amplitude and phase of the carrier constant.
- The original frequency of the carrier signal is called the centre or resting frequency denoted as f_c.
- Frequency deviation (Δf) -The amount by which the frequency of the carrier wave changes or shifts above or below the resting frequency. $\Delta f \propto m(t)$
- The total variation of frequency of FM wave from the lowest to highest is termed as carrier saving $CS = 2 \times \Delta f$.
- The FM frequency ranges from 88 MHz – 108 MHz in the higher spectrum.

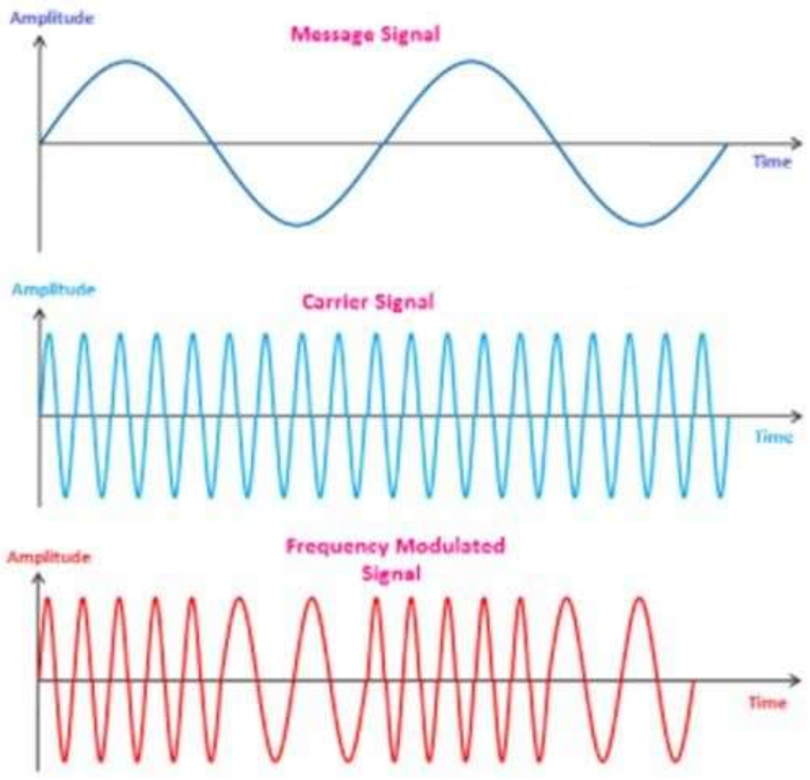


Fig: Waveform representation of FM

For a sine wave modulation, the modulation index is seen to be the **ratio of the peak frequency deviation of the carrier wave to the frequency of the modulating sine wave**. The modulation index of FM is higher than 1

$$\text{Modulation Index} = \frac{Frequency\ deviation}{Modulating\ frequency} = \frac{\Delta f}{f\text{m}}$$

Phase Modulation

- Process in which the instantaneous phase of the carrier signal is varied in accordance with the instantaneous amplitude of the modulating signal
- After phase modulation, amplitude and frequency of the carrier signal remains Unaltered. The modulating signal is mapped to the carrier signal in the form of variations in the instantaneous phase of the carrier

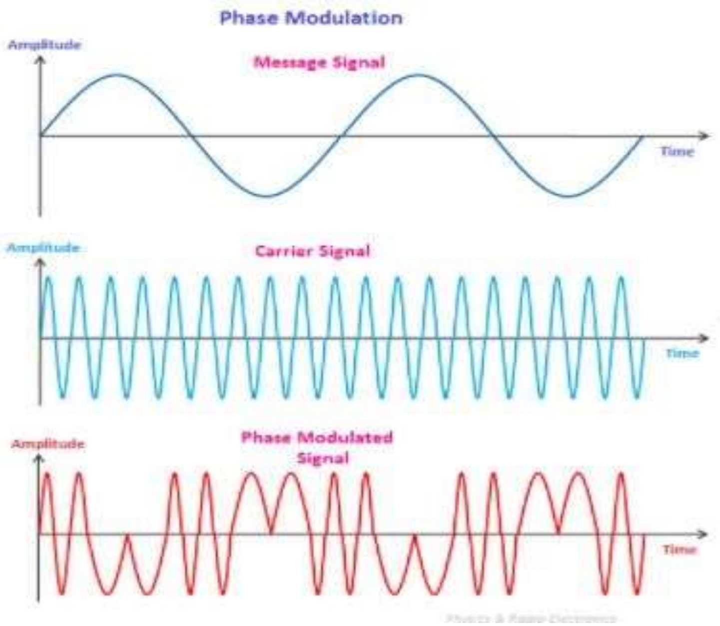


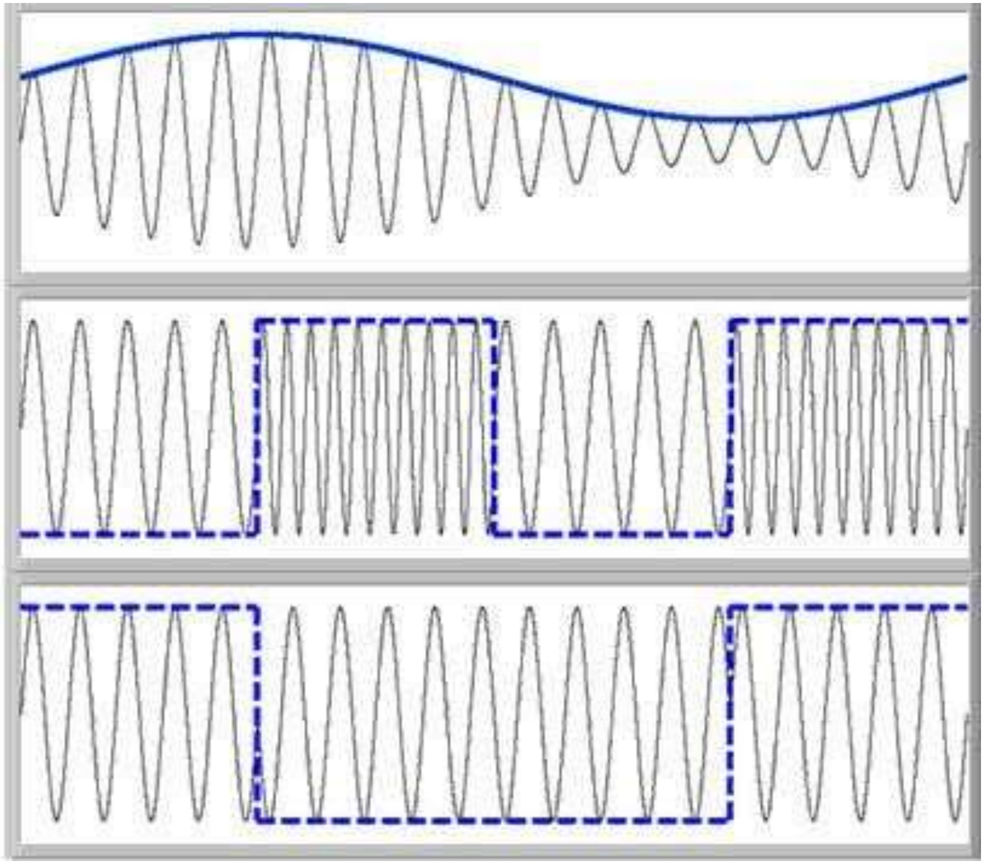
Fig: Waveform representation of PM

Summary of Waveforms

Amplitude Modulation

Frequency Modulation

Phase Modulation



Pulse Modulation

Pulse Modulation

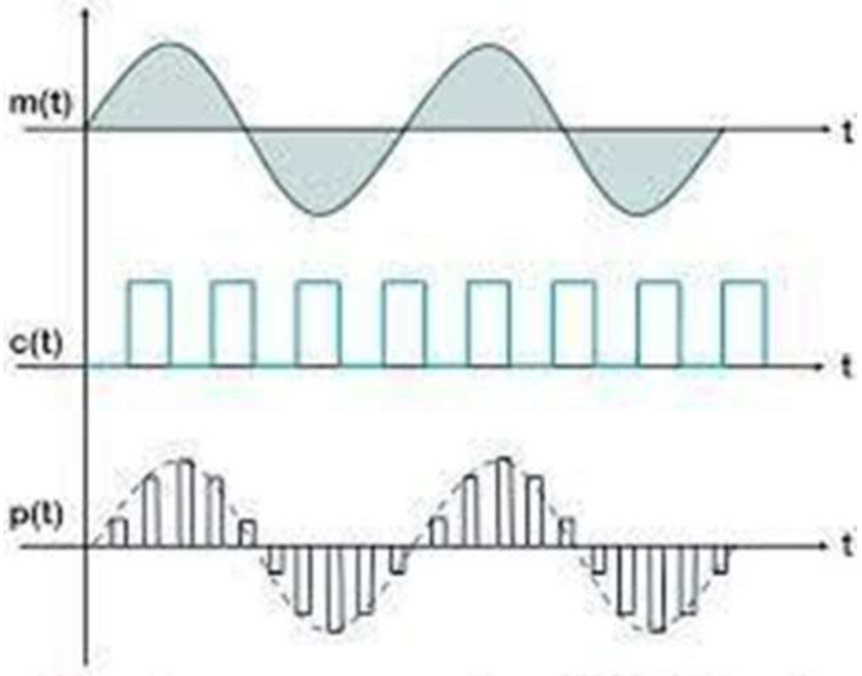
- Pulse modulation maybe used to transmit analog information, such as continuous speech or data. It is system in which continuous wave Pulse modulation may be subdivided into two categories, analog and digital.
- Pulse amplitude and pulse-time modulation are both analog, while the pulse code and delta modulation systems are both digital.
- Has the advantage of ability to use constant amplitude pulses.
- Types of Analog pulse modulation schemes

1. Pulse Amplitude Modulation(PAM)
2. Pulse Width Modulation (PWM)
3. Pulse Position Modulation (PPM)

Pulse Amplitude Modulation(PAM)

- Simplest form of pulse modulation
- Signal is sampled at regular intervals and each sample is made proportional to the amplitude of the signal at the instant of sampling
- PAM acts as a signal converter that helps in encoding the amplitude of the pulse and converts analog signal transmission into a digital version.

- In PAM , the amplitude of the pulses of the carrier pulse train is varied in accordance with the modulating signal.



Waveform representation of PAM signal

Pulse width or Pulse duration modulation(PWM or PDM)

- Starting time and amplitude of the pulse are constant but the width or duration of each pulse is made proportional to the instantaneous value of analog signal
- <u>Disadvantage</u>
- PDM Pulses are of varying width and hence of varying power content.
- The transmitter must be powerful to handle the maximum width pulses.

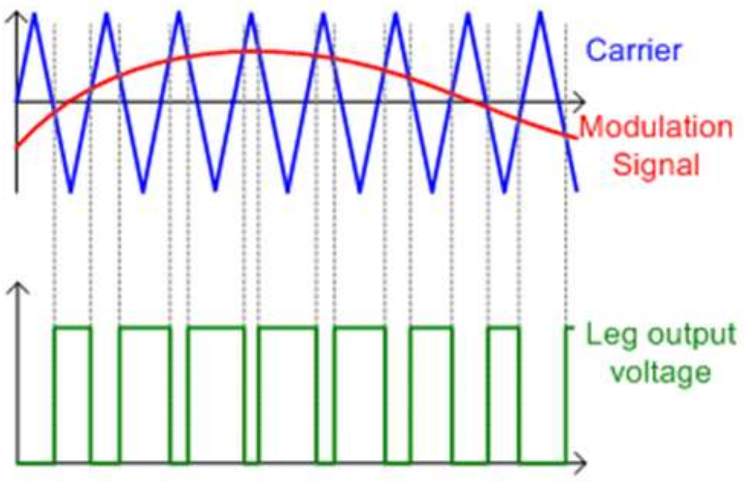


Fig: Waveform representation of PWM

Pulse Position Modulation (PPM)

- Amplitude and width of the pulses are constant but the position of each pulse in relation to the position of the reference pulse is varied according to the instantaneous sampled value of the modulating signal.
- PPM has the advantage of requiring constant transmitter power output.

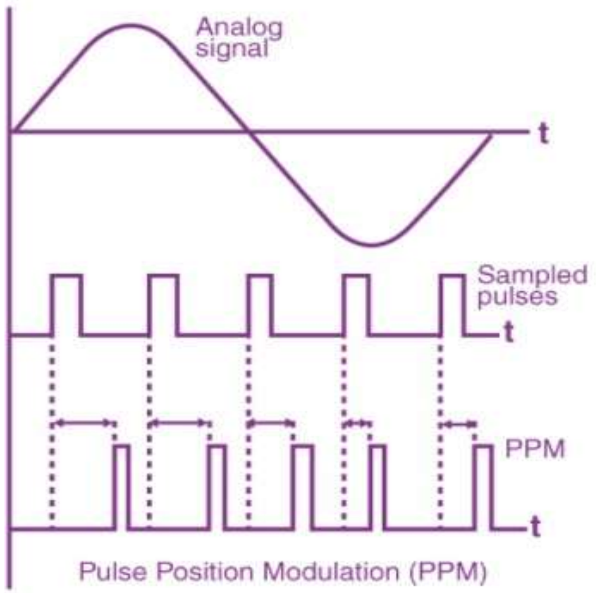
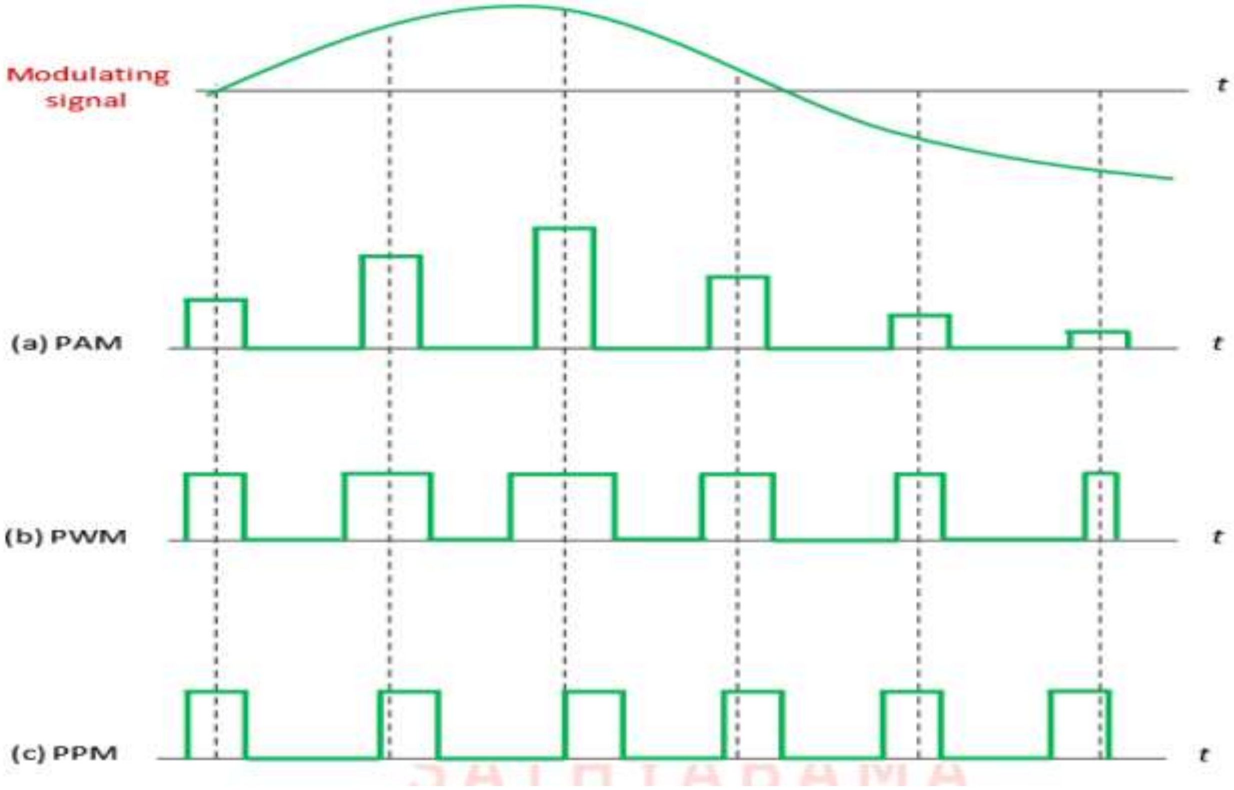


Fig: Waveform representation of PPM

Summary of Waveforms



Pulse digital modulation Technique -Pulse Code Modulation(PCM)

- A standard technique in telecommunications transmission.
- A digital process in which the message is sampled and rounded off to the nearest value of a finite set of allowable values
- The rounded off values are coded
- PCM generator produces a series of numbers or digits
- Each of these digits in binary code represents the amplitude of the signal sample at that instant.
- Pulse code modulation is a digital scheme for transmitting analog data. It converts an analog signal into digital form.
- Why PCM?

It is a technique mainly used to change the signal from analog to digital signal so that an analog signal which is changed can be broadcasted throughout the digital communication network.

Drawback -large bandwidth is required for transmission. Noise and crosstalk leaves low but rises attenuation.

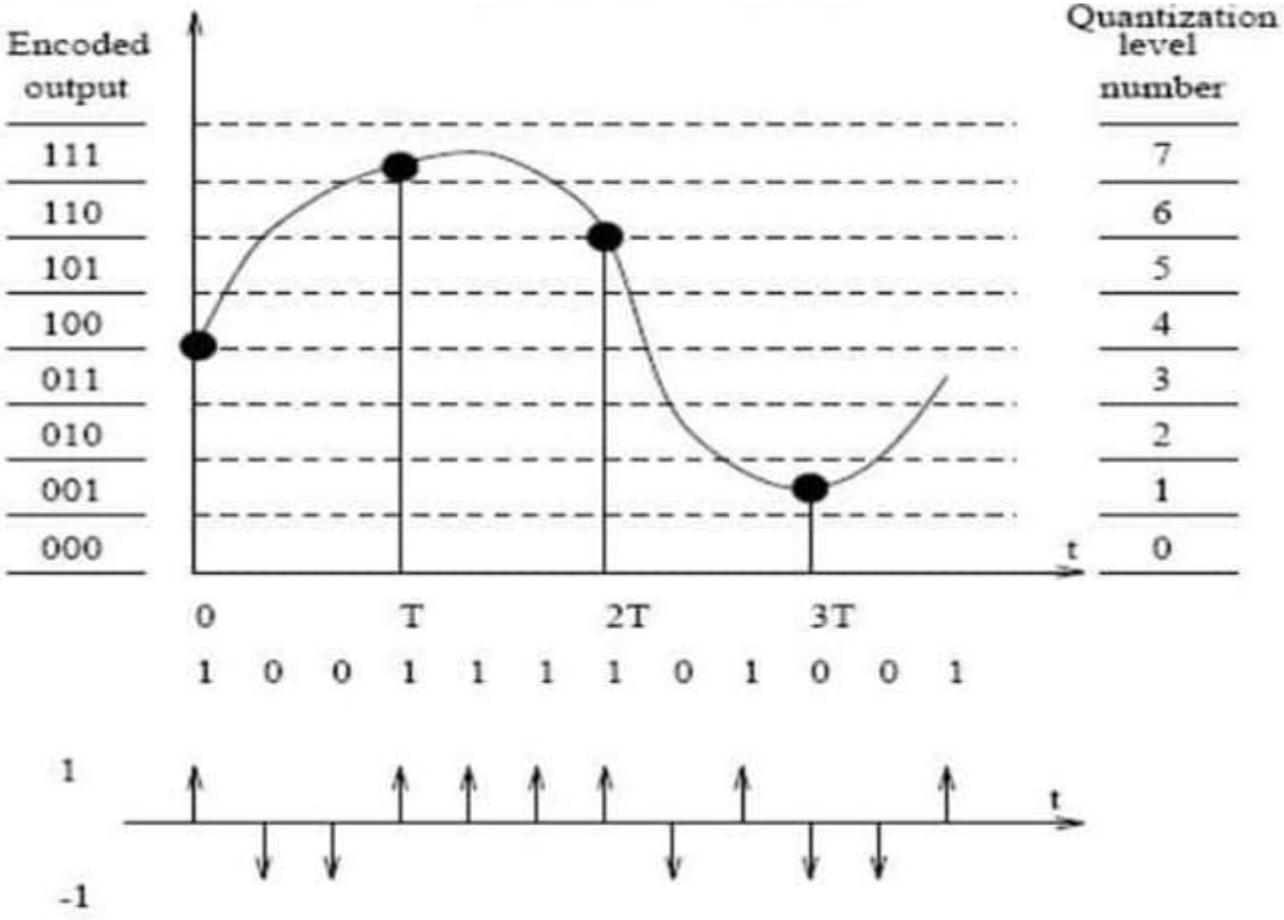


Fig :Pulse Code Modulation(PCM)waveforms

Radio wave propagation

Radio wave propagation

- Depending 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 waves

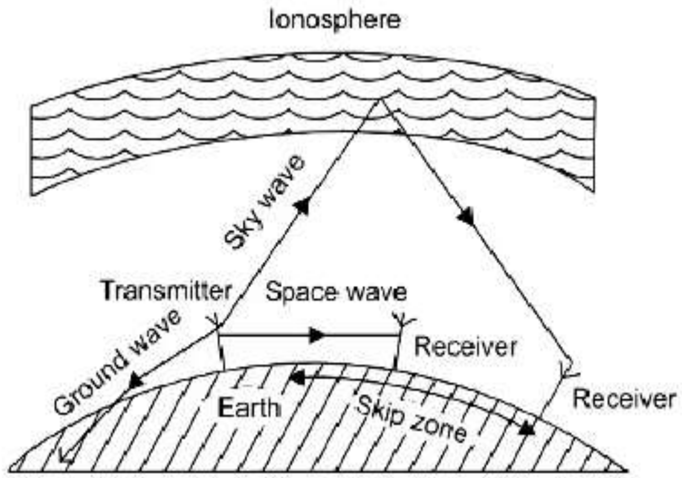


Fig: Radio Waves

Ground wave propagation

- Ground waves are electromagnetic waves refer to propagation of radio waves parallel to and adjacent to the surface of the Earth, following the curvature of the Earth.
- They are strongly influenced by the electrical properties of the ground.
- They are useful only at low frequencies as high frequency waves are strongly absorbed by ground.
- 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 Earth has one refractive index and the atmosphere has another, thus constituting an interface that supports the surface wave transmission.
- Ground waves propagate in vertical, with their magnetic field horizontal and electric field (close to) vertical. Any horizontal component of electric field would be shorted out by the ground.
- For this reason vertical antenna must be used for ground wave transmission
- Ground wave transmission is very reliable whatever the atmospheric conditions be.

Space or tropospheric wave propagation

- Radio wave transmitted from an antenna, travels in a straight line directly reaches the receiving antenna
- 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* from the transmitting *to* the receiving antenna
- *(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.
- A transmitter launches a high power signal, most of which passes through the atmosphere into outer space. However a small amount is scattered when is passes through this area of the troposphere, and passes back to earth at a distant point.

Sky wave propagation

- The energy radiated by an antenna, that is sky wave, would be wasted energy as far as radio communication is concerned if it is continued on its path and did not return to earth but under certain conditions it is reflected from the ionosphere.
- Sky waves may undergo reflection and refraction or both.
- The ionized layer made possible long-distance radio communication by sky waves because of reflection and refraction.
- Ionosphere - 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.
- 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.

Sampling theorem

- The processing of discrete-time signals is more flexible and is also preferable than the continuous-time signals.
- The sampling theorem governs the conversion of continuous-time signal into discrete- time signal.
- The concept of sampling provides a widely used method for using discrete-time system technology to implement continuous-time systems and process the continuous-time signals. A continuous-time signal may be completely represented in its samples and recovered back if the sampling frequency is fs $\geq$ 2fm. Here, fs is the sampling frequency and fm is the maximum frequency present in the signal.
- When the sampling rate becomes exactly equal to 2fm samples per second, then it is called Nyquist rate.
- Nyquist rate is the minimum sampling rate.

- A low pass filter is used to recover the original signal from its samples.
- The process of reconstructing the continuous-time signal from its samples is known as interpolation.

•When the sampling frequency is less than the Nyquist rate, aliasing problem is said to occur.

•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 fm Hz.

✓ Sampling frequency must be selected such that $f_s \geq 2f_m$.

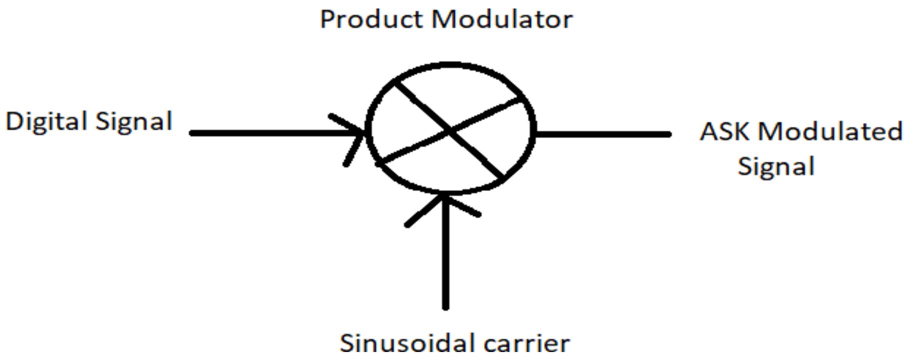
Digital modulation

- 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:

1. Amplitude Shift Keying (ASK)
2. Frequency Shift Keying (FSK)
3. Phase Shift Keying (PSK)

Amplitude Shift Keying(ASK)

- Represents digital data as variations in the amplitude of a carrier wave
- ASK signal may be generated by simply applying the incoming binary data and the sinusoidal carrier to the inputs of a product modulator.



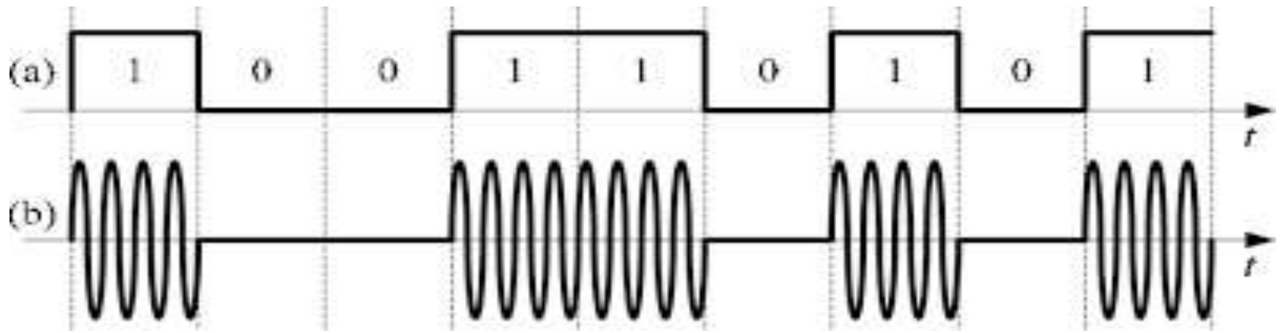


Fig: ASK Modulation and its waveforms

Frequency Shift Keying(FSK)

- Digital information is transmitted through discrete frequency changes of a carrier signal
- The simplest FSK is **binary FSK** (**BFSK**).
- BFSK uses a pair of discrete frequencies to transmit binary (0s and 1s) information

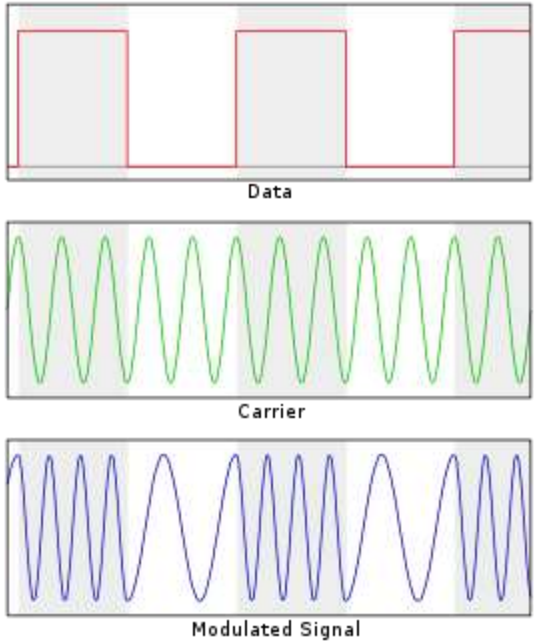


Fig: FSK Modulation and its waveforms

Phase Shift Keying(PSK)

- Conveys data by changing (modulating) the phase of constant frequency carrier
- Each symbol(pattern of bits) is represented by a particular phase.
- BPSK (Binary PSK), the simplest form of PSK, uses phases 0^0 and 180^0
- It is widely used for wireless LANs, RFID and Bluetooth communication

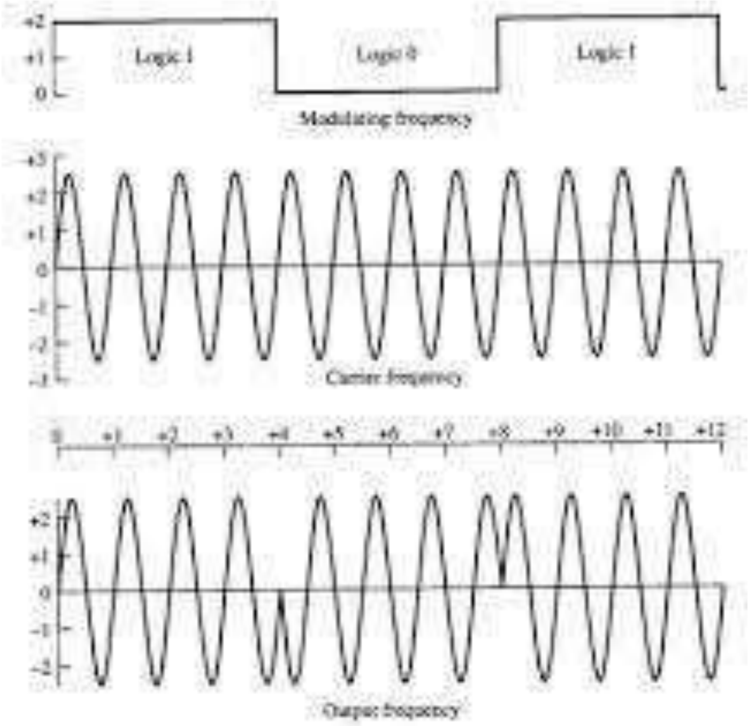


Fig: PSK Modulation and its waveforms

PSK and FSK more preferred over ASK?

- Because of the constant amplitude of FSK or PSK, the effect of noise and interference is minimum whereas it is more pronounced in ASK

Link for ASK, PSK and FSK video

- https://www.youtube.com/watch?v=C8eebS5MhuU

Radio signal transmission

- Important components of wireless transmission system

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.

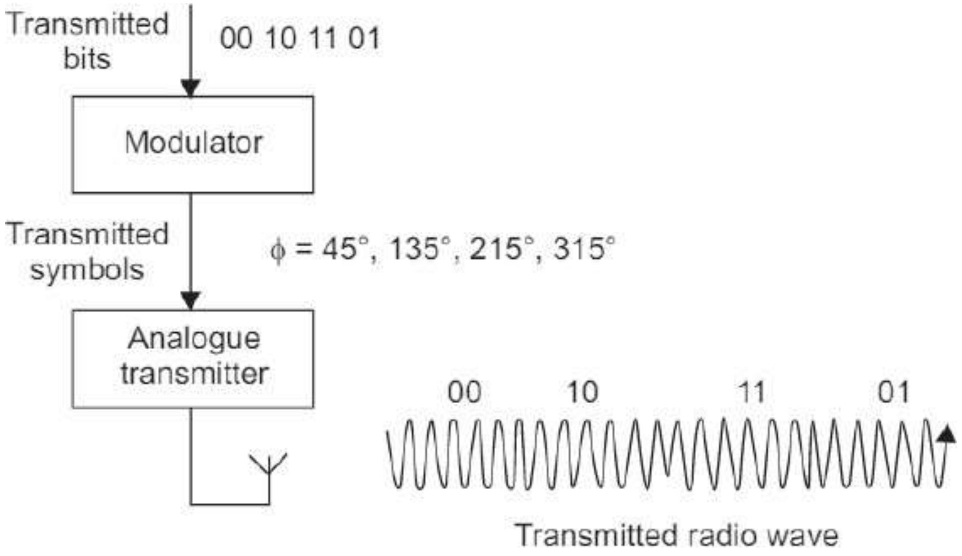
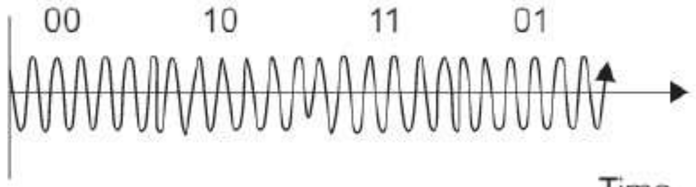


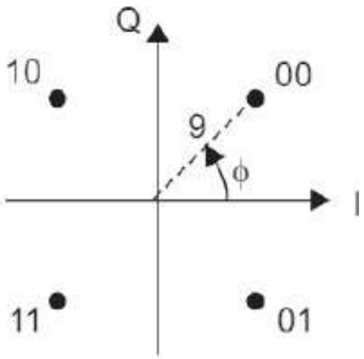
Fig :Architecture of wireless communication transmitter

Note : The modulation scheme used here is QPSK. The modulator takes 2 bits at a time and transmits them using radio waves having 4 different states with phases 45^0, 135^0, 225^0 and 315^0

Modulation scheme used - QPSK



(a)



(b)

Fig (a) QPSK Waveform (b) QPSK Constellation Diagram

- The distance of each state from the origin represents the amplitude of the transmitted wave while angle measured anti-clockwise from x-axis represents the phase

Modulation schemes used in LTE

LTE ((Long Term Evolution(LTE) - standard for wireless broadband communication for mobile devices marketed as 4G)

- Binary Phase Shift Keying - BPSK
- Quadrature Phase Shift Keying- QPSK
- 16 Quadrature Amplitude Modulation -16 QAM
- 64 Quadrature Amplitude Modulation - 64 QAM

Binary Phase Shift Keying (BPSK)

- **Binary Phase Shift Keying (BPSK) -** sends bits one at a time, using 2 states that can be interpreted as phases 0 and 180 or as amplitudes +1 and -1.
- One bit per symbol

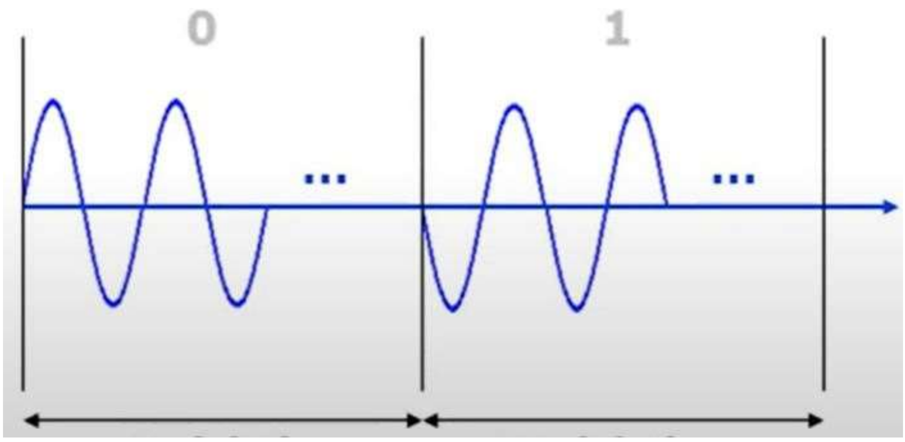


Fig :Constellation diagram of BPSK

- Note : LTE uses this scheme for 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.

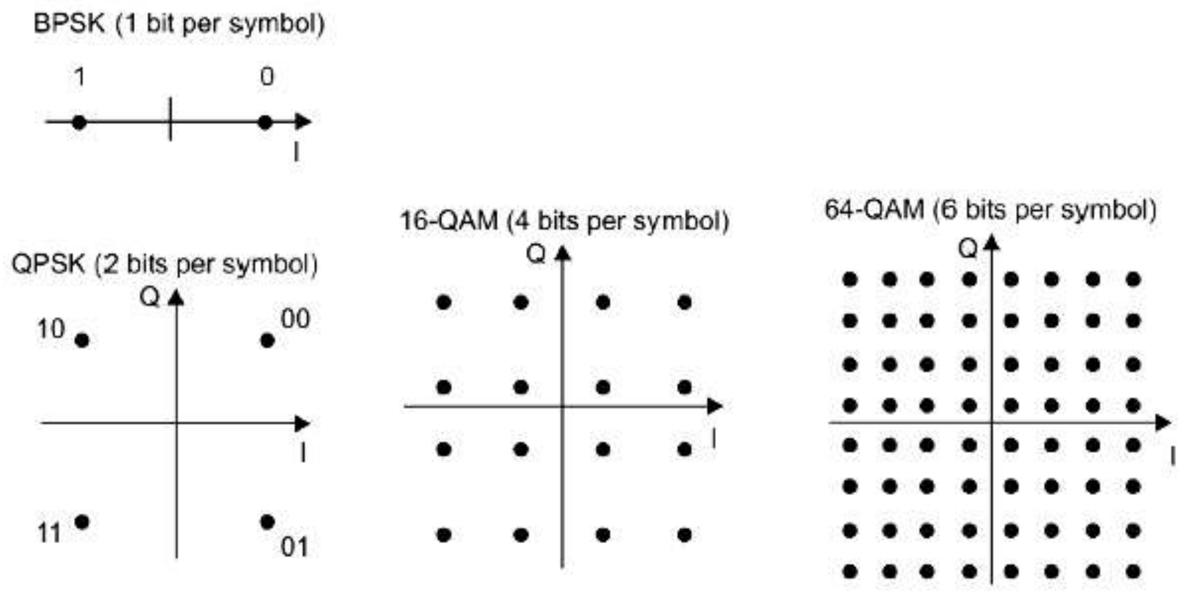


Fig. Modulation schemes used by LTE

Multiple Access Techniques

- The techniques described so far work well for one-to-one communications.
- 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.
- 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.
- Few types of Multiple access techniques:
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)

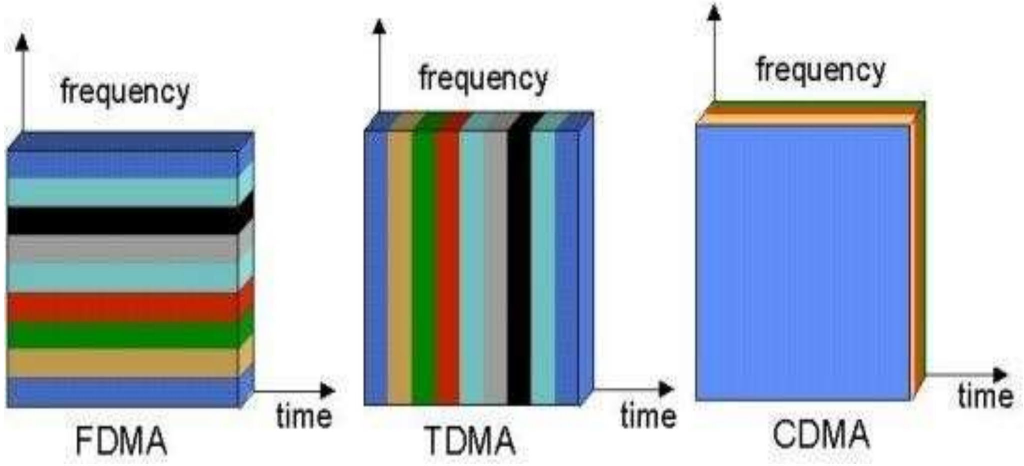
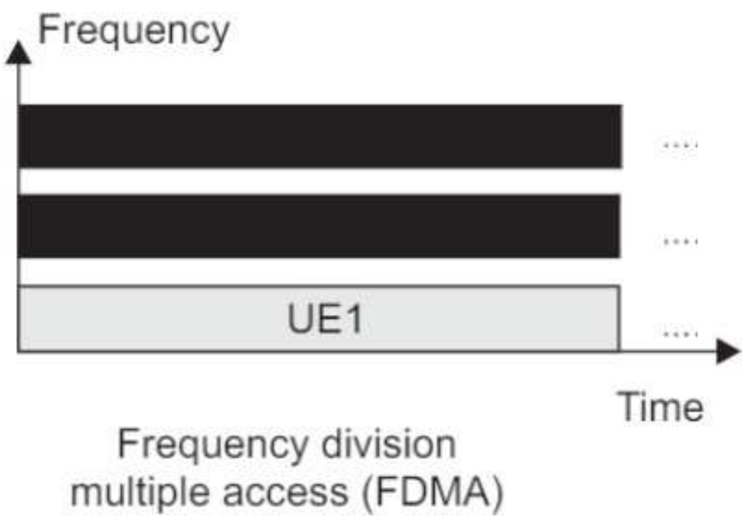


Fig: Multiple access techniques

Frequency Division Multiple Access (FDMA)

Each mobile receives signal on its own carrier frequency, which it distinguishes using analogue filter. The carriers are separated by unused guard rings to minimize the interference between the carriers.



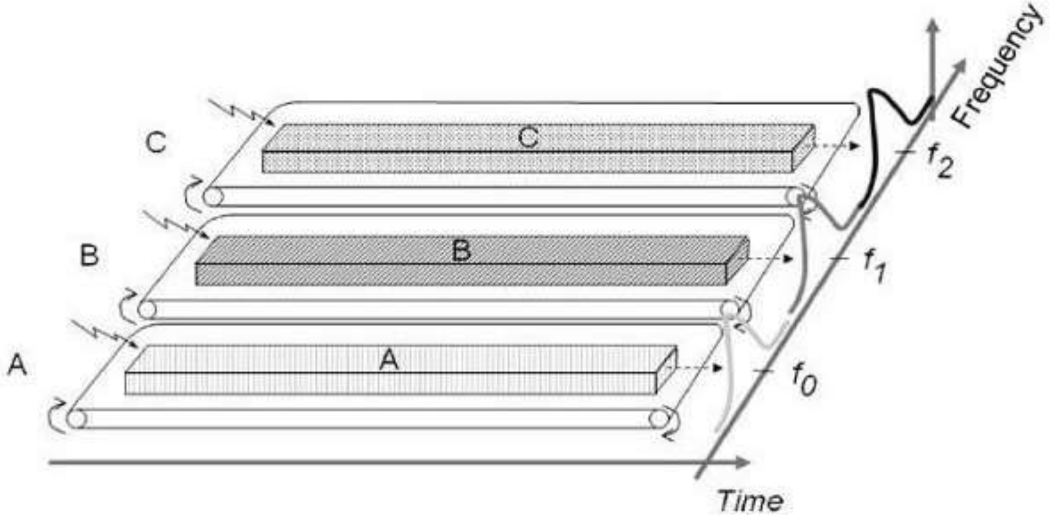
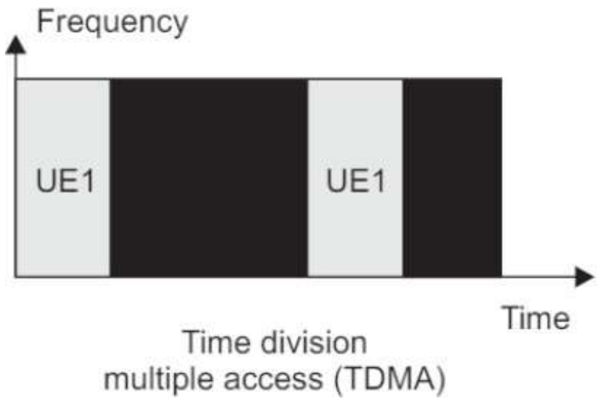


Fig:FDMA

TIME Division Multiple Access (TDMA)

Mobiles receive signals on the same carrier but at different times



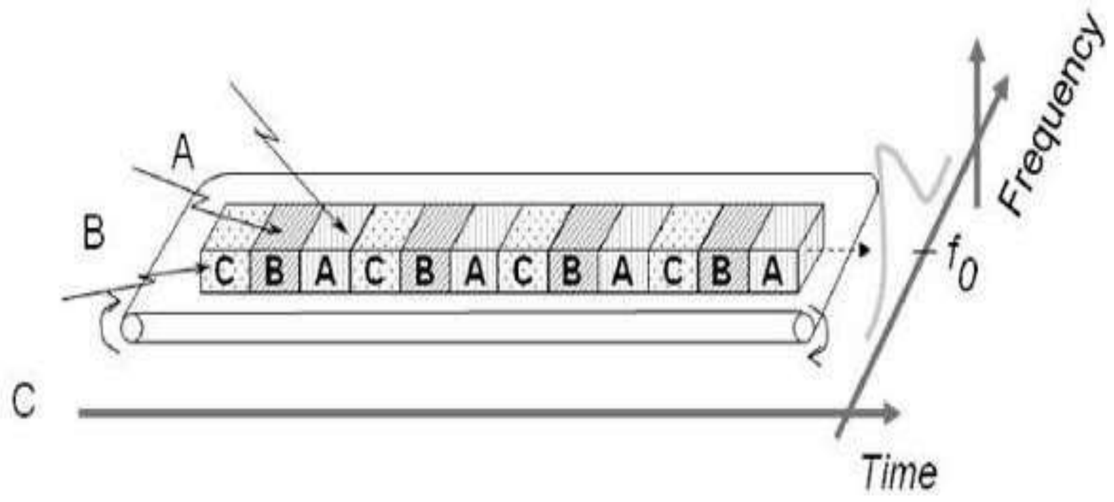


Fig:TDMA

- GSM(2G) 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).

- 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.

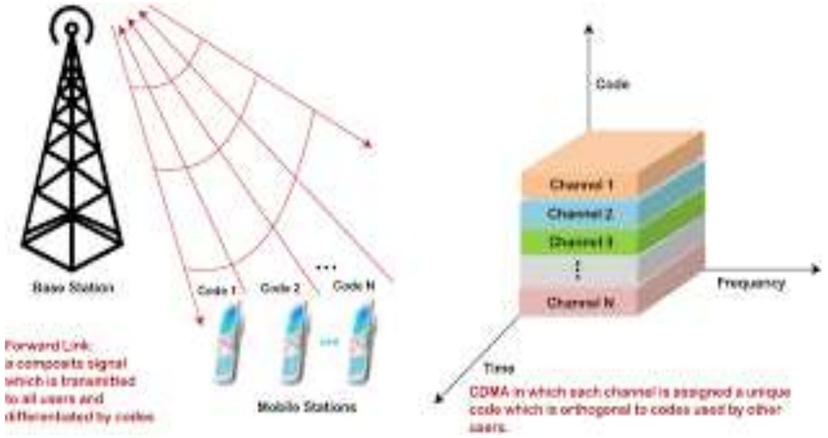


Fig: CDMA

FDD and TDD Modes

- By using the various 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)** -the base station and mobile transmit and receive at the same time, but using different carrier frequencies.
- **Time Division Duplex (TDD)** - the base station and mobile transmit and receive on the same carrier frequency but at different times. 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.

Operation of FDD and TDD modes

uplink and downlink frequency

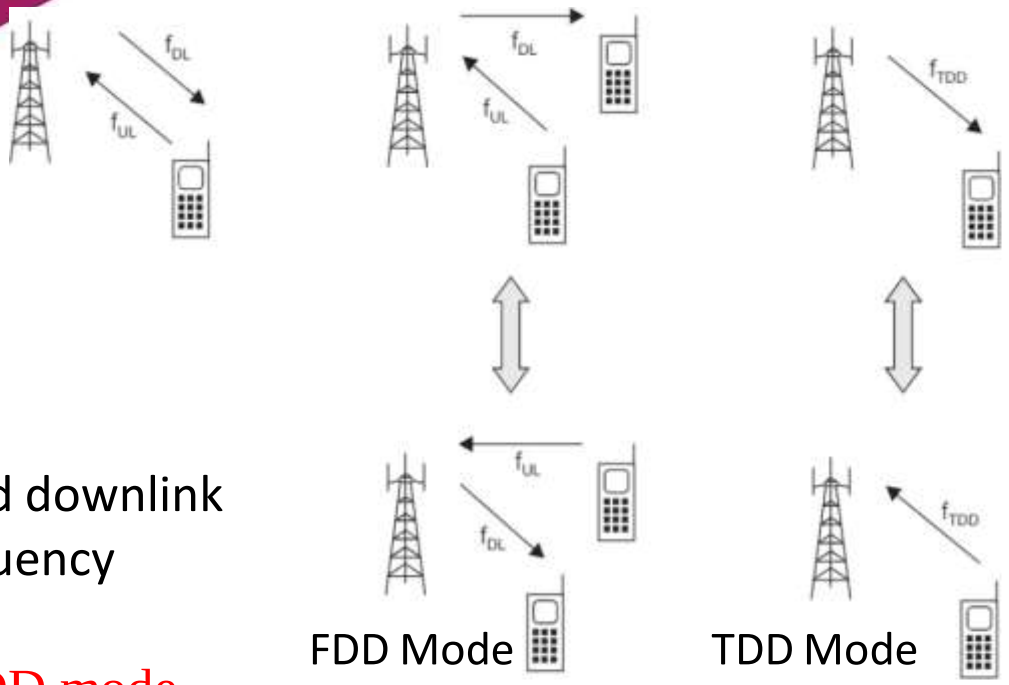


Fig: Operation of FDD and TDD modes

- In FDD mode,

  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.

- In TDD mode,

  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.

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.

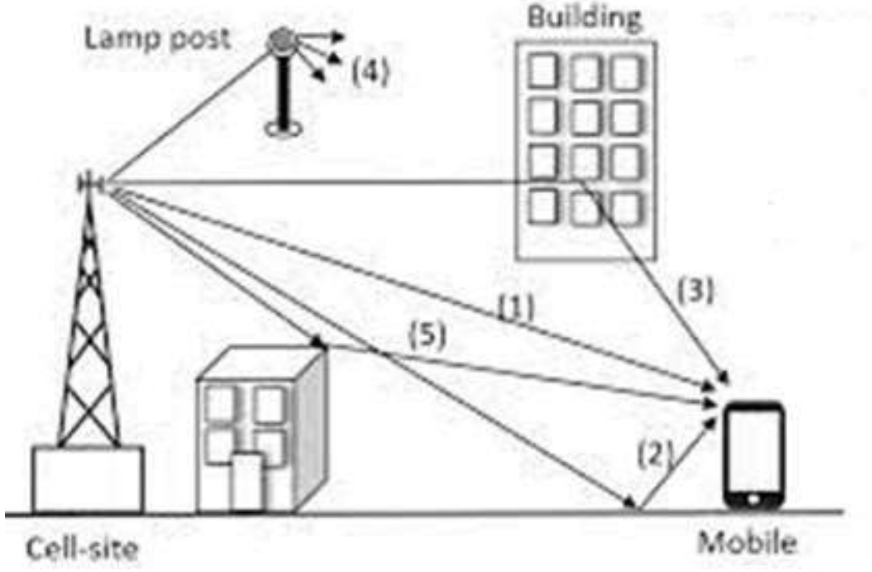
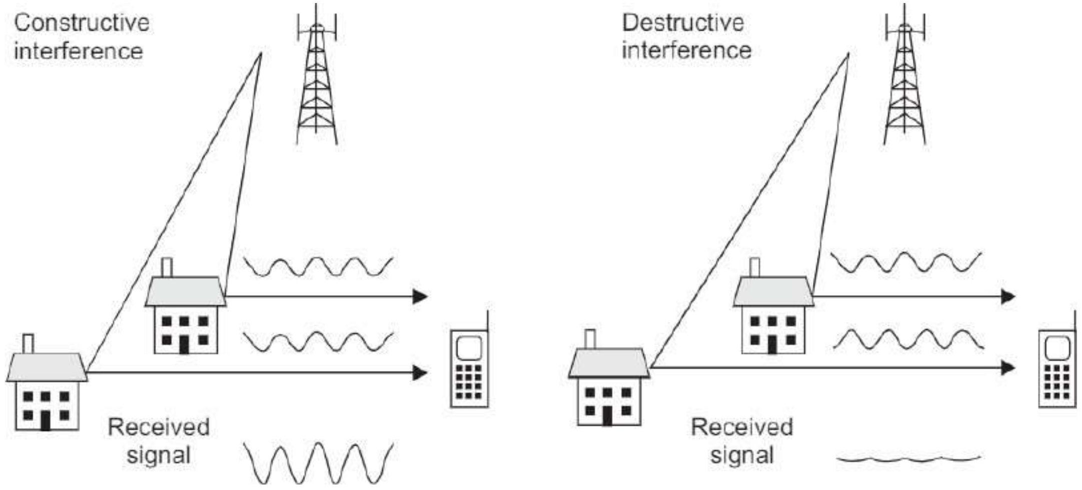


Fig: Multipath propogation

Interference

- At the receiver, the incoming rays can add together in different ways, which are shown in Fig.
- 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 interference can make the received signal power drop to a very low level, a situation known as fading. The resulting increase in the error rate makes fading a serious problem for any mobile communication system.



- Fig: Constructive interference and Destructive interference

Fading as a function of time and frequency

•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, as shown in Fig.

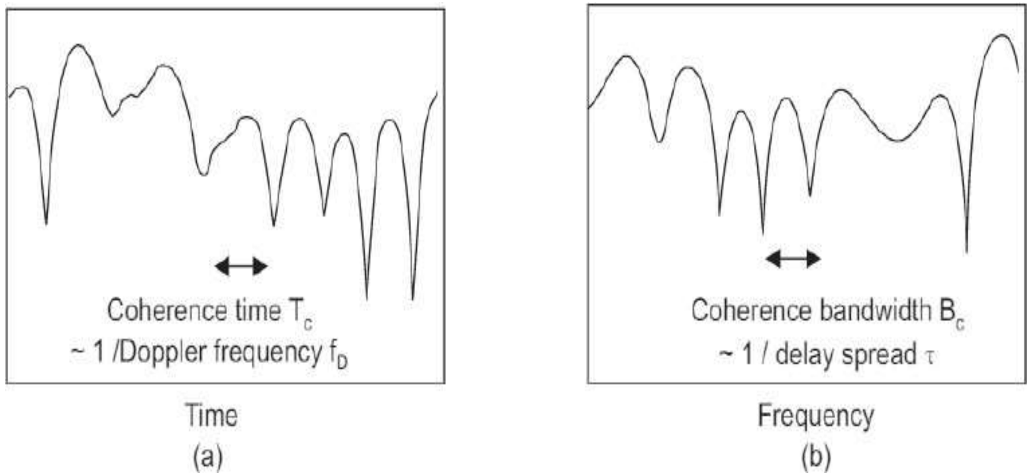


Fig :Fading as a function of (a) time and (b) frequency

- The amplitude and phase of the received signal vary over a timescale called the *coherence time* Tc which can be estimated as follows: $T_c \approx 1 / f_D$
- Here f_c is the carrier frequency, υ is the speed of the mobile and c *is* the speed of light (3×10^8 ms^{-1})
  f_D is the mobile's Doppler frequency: $f_D = v f_C / c$

Coherence Bandwidth

- 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.

Delay Spread is the difference between the arrival times of the earliest and latest rays. It can be calculated as follows: $\tau = \Delta L/c$

where ∆L is the difference between the path lengths of the longest and shortest rays.

Error Management

- Noise and interference lead to errors in a wireless communication
- **Forward error correction** - technique used for controlling errors in data transmission over unreliable or noisy communication channels.
- the transmitted information is represented using a codeword that is typically two or three times as long.
- The extra bits supply additional, redundant data that allow the receiver to recover the original information sequence.
- For example, a transmitter might represent the information sequence 101 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 coding rate - number of information bits divided by the number of transmitted bits (1/3 in the example above).

- Forward error correction algorithms operate with a fixed coding rate. Despite this, a wireless transmitter can still adjust the coding rate using the two- stage process shown in the fig

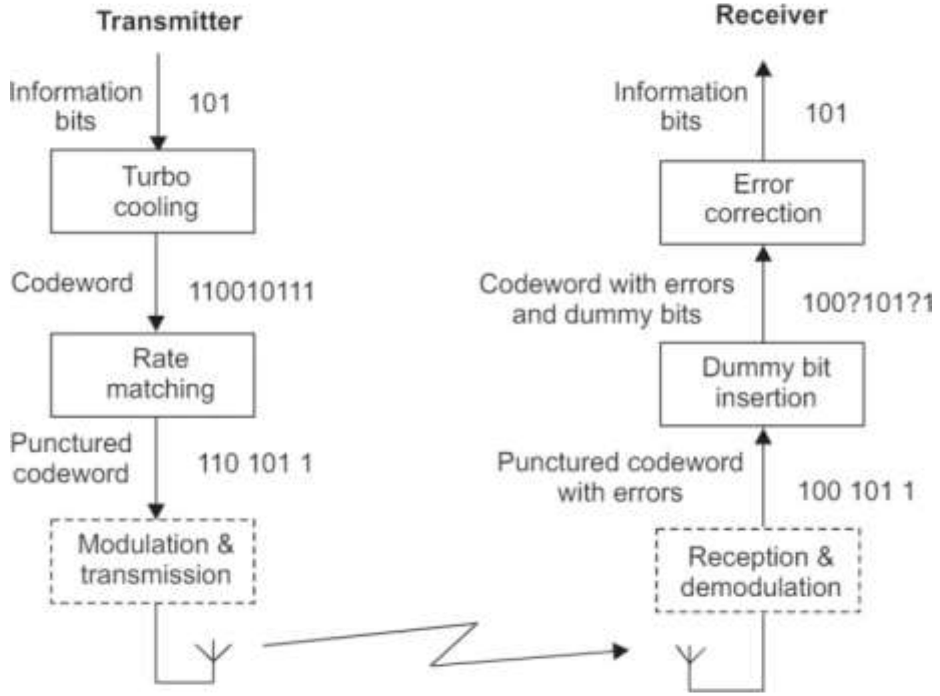


Fig:Block diagram of a transmitter and receiver using forward error correction and rate matching

- The main algorithm used by LTE 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.
- If the coding rate is low, the transmitted data contain many redundant bits which allows the receiver to correct a large number of errors and to operate successfully at a low SINR(Signal to Interference & Noise ratio), but at the expense of a low information rate.
- If the coding rate is close to 1, then the information rate is higher but the system is more vulnerable to errors.
- A trade-off between information rate and SINR has to be achieved.
- **Note : SINR(Signal to Interference & Noise ratio) -** the power of a certain signal of interest divided by the sum of the interference power (from all the other interfering signals) and the power of some background noise.

Automatic Repeat Request

- Automatic repeat request (ARQ) is another error management technique, which is illustrated in Fig.
- Here, the transmitter takes a block of information bits and uses them to compute some extra bits that are known as a cyclic redundancy check (CRC). It appends these to the information block and then transmits the two sets of data in the usual way.

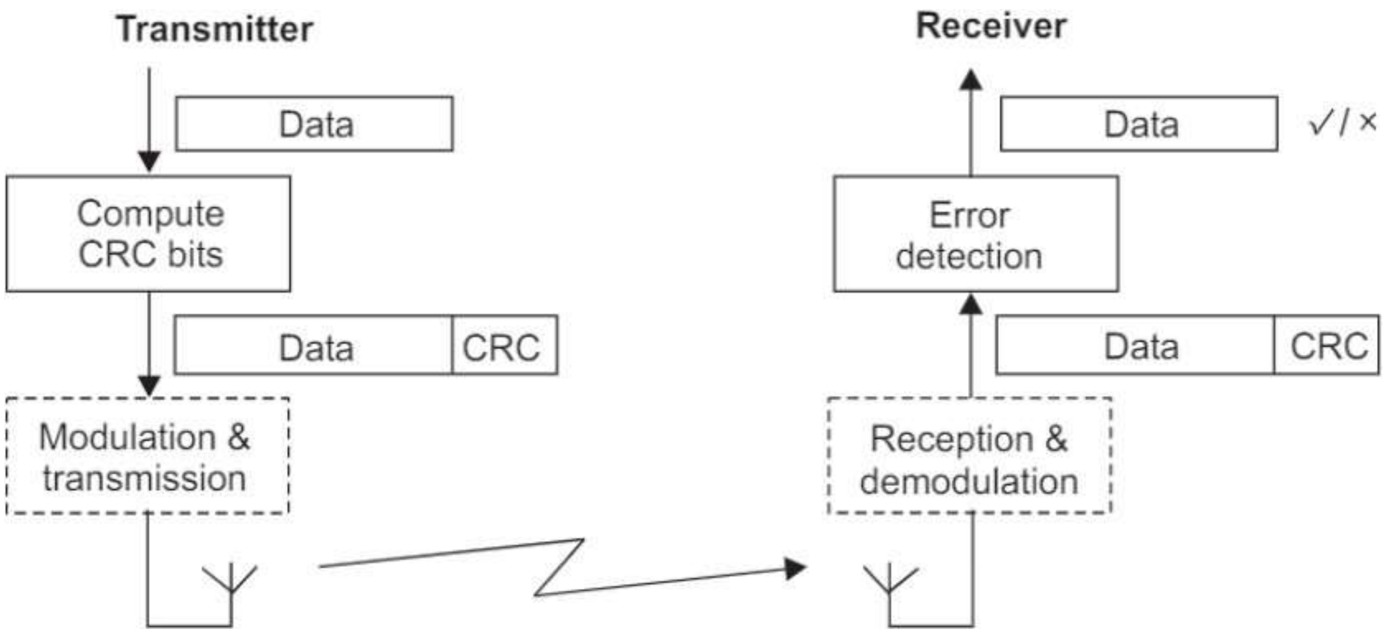


Fig :Block diagram of a transmitter and receiver using automatic repeat request

- Transmitter takes a block of information bits and uses them to compute some extra bits that are known as a cyclic redundancy check (CRC).
- It appends these to the information block and then transmits the two sets of data in the usual way.
- Receiver separates the two fields and uses the information bits to compute the expected CRC bits.
- If the observed and the expected CRC bits are the same, then it concludes that the information has been received correctly and sends positive acknowledge back to the transmitter.
- If CRC bits are the different, then it concludes that the error has occurred and sends negative acknowledge back to the transmitter to request retransmission
- Positive and negative acknowledgements are often abbreviated to ACK and NACK respectively.
- A wireless communication system often combines these two error management techniques. Such a system corrects most of the bit errors by the use of forward error correction and then uses automatic repeat requests to handle the remaining errors that leak through.

Antennas

- 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.
- Antennas receive electromagnetic waves and pass them onto a receiver or they transmit electromagnetic waves which have been produced by a transmitter.
- Following are the required features of an antenna:
- Strictly defined radiation pattern for most accurate network planning
- Dual polarization
- Electrical down tilting of vertical diagram
- Unobstructive design

Some Common Antennas are

- Omnidirectional Antennas
- Dipole Antennas
- Collinear omni Antennas
- Directional Antennas
- Patch Antennas
- Patch Array Antennas
- Yagi Antennas

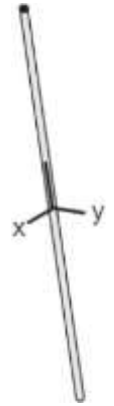
Omnidirectional Antennas

- Non directional pattern (circular pattern) in a given plane
- Radiates equal power in all directions perpendicular to the axis
- Examples of omnidirectional Antennas – Dipole Antennas and Collinear antennas.

Dipole Antennas

- Most commonly referred as half-wavelength ($\lambda/2$) dipole
- The physical antenna is constructed of conductive elements whose combined length is half of the wavelength at its intended frequency of operation.
- This is a simple antenna that radiates its energy out toward the horizon.

Fig: Dipole Antenna model



Collinear Omni Antennas

- To create an omnidirectional antenna with higher gain, multiple omnidirectional structures are arranged in linear or vertical fashion to retain the same omnidirectional pattern in the azimuth plane but a more focused elevation beam which leads to higher gain.
- Also frequently referred as collinear array.
- Higher gain implies same power radiated in a more focused way.

Fig: omni Antenna model

Directional Antennas

- Radiates energy most 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
- They can be patch, dish or horn antennas
- They accomplish the main goal- radiating their energy in a particular direction

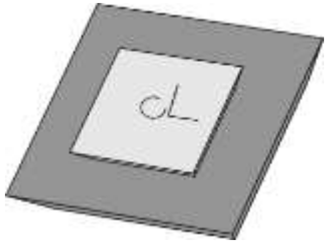
horn

dish

Fig: Directional Antenna model

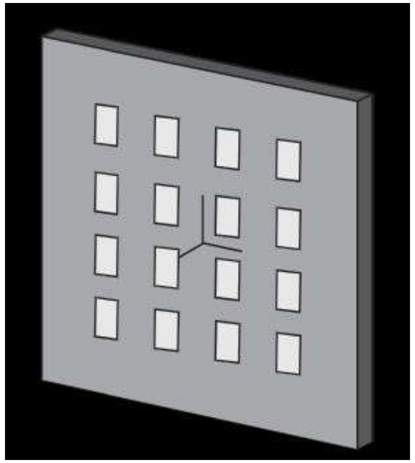
Patch Antennas

- In its simplest form is a single rectangular conductive plate that is spaced above a ground place.
- Attractive due to their ease of fabrication.



Patch Array Antennas

- 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.
- Very often, these antennas are enclosed in a tube, with the result that the user may not see all the antenna elements.

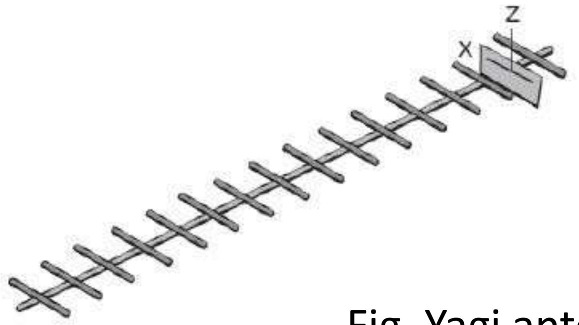


Fig. Yagi antenna model

- A Yagi antenna is formed by driving a simple antenna, typically a dipole or dipole-like antenna, and shaping the beam using a well-chosen series of elements whose length and spacing are tightly controlled.
- The Yagi shown in the figure is built with one reflector (the bar behind the driven antenna) and 14 directors (the bars in front of the driven antenna).

THANK YOU