# CHAPTER - 3

# MULTIPLEXING AND SWITCHING

## MULTIPLEXING:

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. For example, one cable can carry a hundred channels of TV. For Multiplexing, the link can be shared whenever the bandwidth of a medium linking the two devices is greater than the bandwidth needs of the devices. Thus, in a multiplexed system, n lines share the bandwidth of the one link. That is, the MUX (Multiplexer) combines data from n input lines and transmit over a single high data capacity data link. The DEMUX (Demultiplexer) at the other side, accepts data string, separates the data according the channel and delivers them to the appropriate output lines as shown in the figure below:

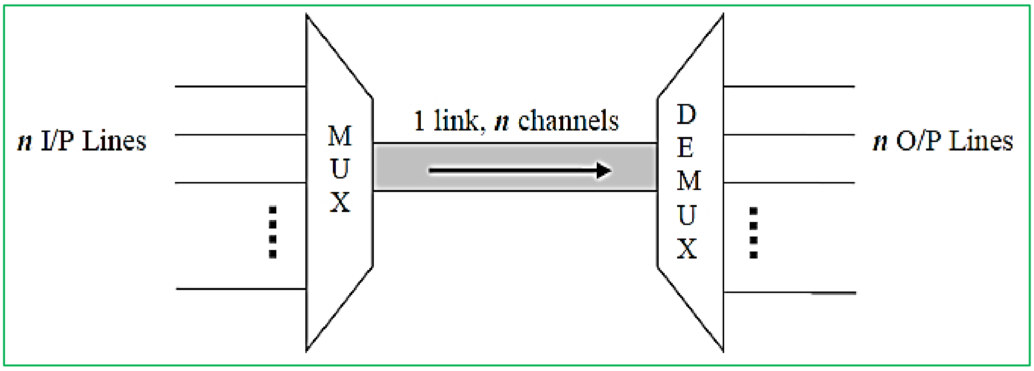



*Fig: Multiplexing*

In the figure above, the four lines on the left direct their transmission streams to a MUX, which combines them into a single stream and at the receiver end, that stream is fed into a DEMUX, which separates the stream back into its component transmissions and directs them to their corresponding lines.

Multiplexing can be done in one of the three basic techniques: FDM (Frequency Division Multiplexing), TDM (Time Division Multiplexing) & WDM (Wavelength Division Multiplexing).

### 1. FREQUENCY DIVISION MULTIPLEXING (FDM):

FDM is an analog technique (used for analog signals) in which the signals generated by different carrier frequencies are combined into a single composite signal that can be transported by the link. Here, the bandwidth of the link is greater than the combined bandwidths of the signals to be transmitted. In FDM, the frequency spectrum is divided into bands called sub-channels or logical channels. These sub-channels are separated by some unused channels called guard bands so as to prevent signals from overlapping and thus prevent interference.

In FDM, the total bandwidth required is equal to the sum of the individual bandwidth of the signals to be transmitted plus the guard bands that are required.

The most natural example of frequency-division multiplexing is radio and television broadcasting, in which multiple radio signals at different frequencies pass through the air at the same time. Another example is cable television, in which many television channels are carried simultaneously on a single cable. An analogous technique called wavelength division multiplexing is used in fiber optic communication, in which multiple channels of data are transmitted over a single optical fiber using different wavelengths (frequencies) of light.

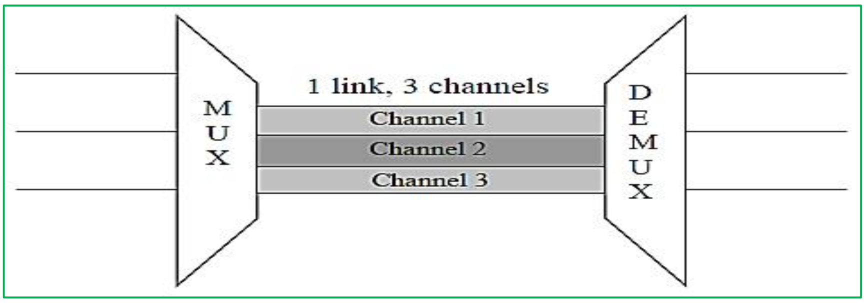



*Fig: Frequency Division Multiplexing*

### 2. Time Division Multiplexing (TDM):

TDM is the digital multiplexing technique. In TDM, the channel/link is not divided on the basis of frequency but on the basis of time. Total time available in the channel is divided between several users. Each user is allotted a particular time interval called time slot or time slice during which the data is transmitted by that user. Thus each sending device takes control of entire bandwidth of the channel for fixed amount of time.

In TDM the data rate capacity of the transmission medium should be greater than the data rate required by sending or receiving devices. In TDM all the signals are not transmitted simultaneously. Instead, they are transmitted one-by-one. Thus each signal will be transmitted for a very short time. One cycle or frame is said to be complete when all the signals are transmitted once on the transmission channel.

The TDM system can be used to multiplex analog or digital signals, however it is more suitable for the digital signal multiplexing. The TDM signal in the form of frames is transmitted on the common communication medium. Examples: Integrated Services Digital Network (ISDN), The GSM (Global System for Mobile Communications) telephone system

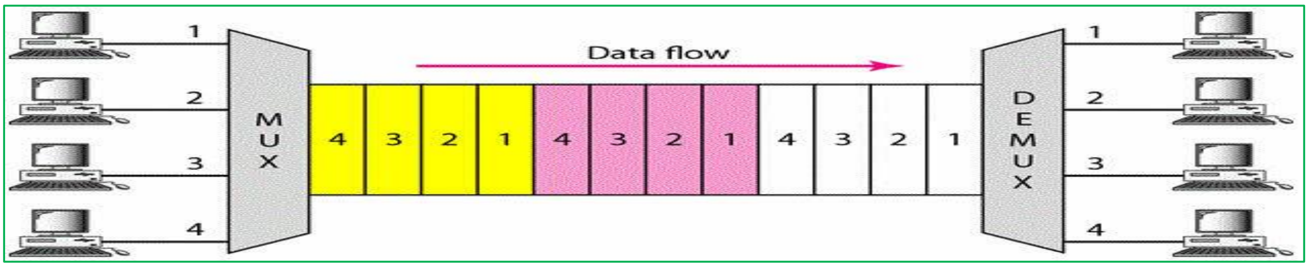



*Fig: Time Division Multiplexing*

### Types:

#### a. Synchronous Time Division Multiplexing:

In synchronous TDM, each device is given same time slot to transmit the data over the link, irrespective of the fact that the device has any data to transmit or not. Hence it is named as Synchronous TDM. Synchronous TDM requires that the total speed of various input lines should not exceed the capacity of path. Each device places its data onto the link when its time slot arrives i.e. each device is given the possession of line turn by turn. If any device does not have data to send then its time slot remains empty. The various time slots are organized into frames and each frame consists of one or more time slots dedicated to each sending device. If there are n sending devices, there will be n slots in frame i.e. one slot for each device.

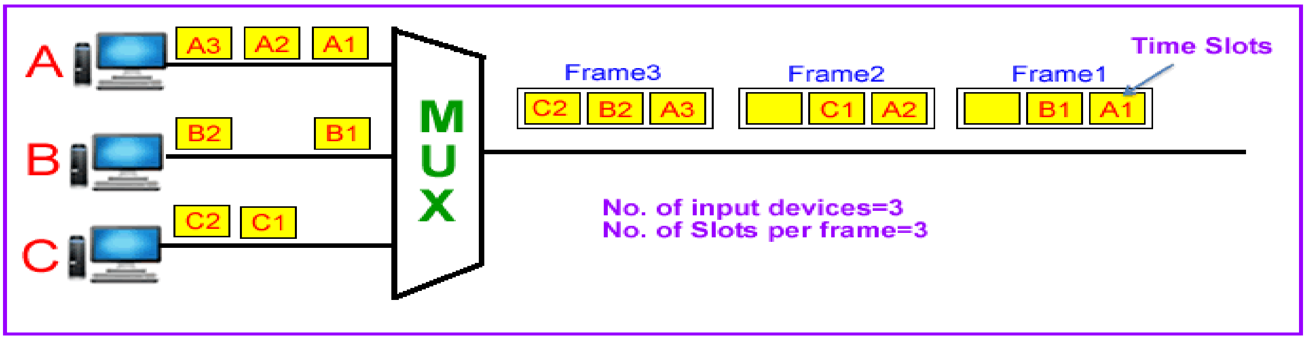



*Fig: Synchronous Time Division Multiplexing*

**Advantage:**

- This reduces overhead bits.
- It overcomes the two main deficiencies of the asynchronous method, that of inefficiency and lack of error detection.

**Disadvantage:**

- For correct operation the receiver must start to sample the line at the correct instant.
- The capacity of single communication line that is used to carry the various transmission should be greater than the total speed of input lines.

### b. Asynchronous Time Division Multiplexing:

Asynchronous TDM is also known as statistical time division multiplexing. Asynchronous TDM is called so because is this type of multiplexing, time slots are not fixed i.e. the slots are flexible. Here, the total speed of input lines can be greater than the capacity of the path. In synchronous TDM, if we have n input lines then there are n slots in one frame. But in asynchronous it is not so. In asynchronous TDM, if we have n input lines then the frame contains not more than m slots, with m less than n i.e. (m < n). In asynchronous TDM, the number of time slots in a frame is based on a statistical analysis of number of input lines.

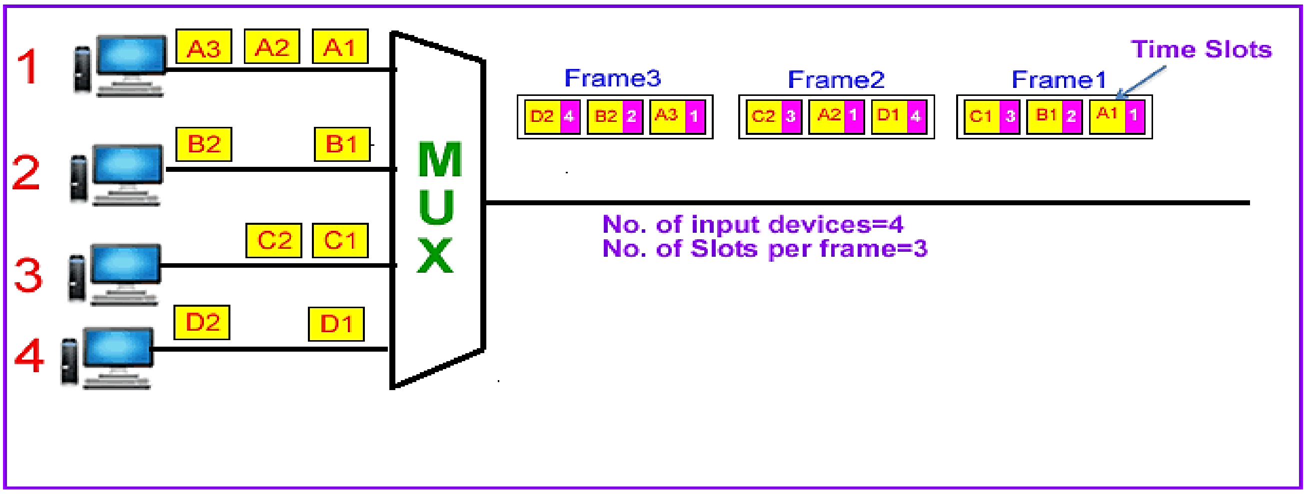



*Fig: Asynchronous Time Division Multiplexing*

**Advantages:**

- Full available channel bandwidth can be utilized for each channel.
- Intermodulation distortion is absent.
- TDM circuitry is not very complex.
- The problem of crosstalk is not severe.

**Disadvantages:**

- Synchronization is essential for proper operation.
- Due to slow narrowband fading, all the TDM channels may get wiped out.

## Modem, Modulation and its Types:

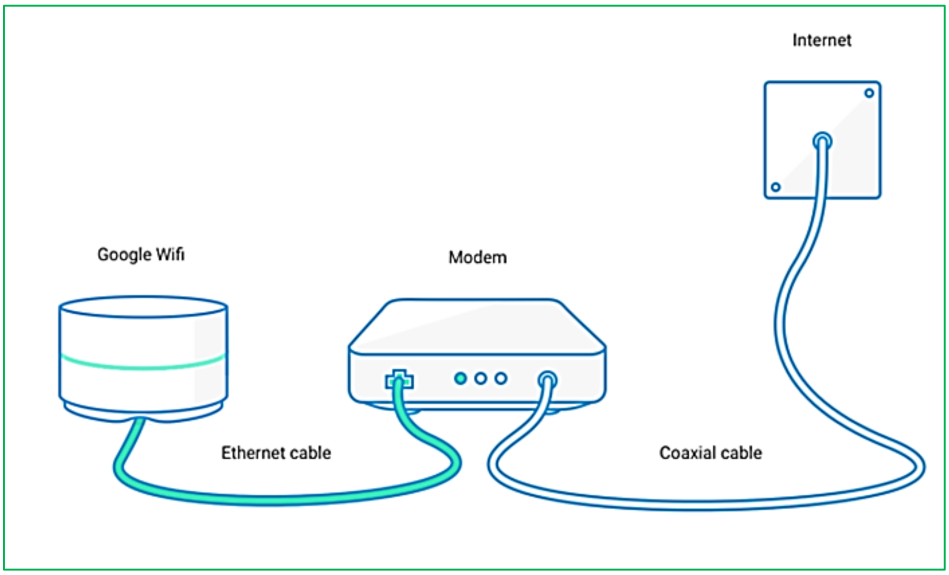
### Modem:

A **modem** (**mo**dulator-**dem**odulator) is a device that modulates an analog carrier signal to encode digital information and demodulates the signal to decode the transmitted information. The goal is to produce a signal that can be transmitted easily and decoded to reproduce the original digital data.

That is, a modem is a device or program that enables a computer to transmit data over, for example, telephone or cable lines. Computer information is stored digitally, whereas information transmitted over telephone lines is transmitted in the form of analog waves. A modem converts between these two forms.

The most familiar type is a voice band modem that turns the digital data of a computer into modulated electrical signals in the voice frequency range of a telephone channel. These signals can be transmitted over telephone lines and demodulated by another modem at the receiver side to recover the digital data.

Modems are generally classified by the amount of data they can send in a given unit of time, usually expressed in bits per second (bit/s or bps), or bytes per second (B/s). Modems can also be classified by their symbol rate, measured in baud. The baud unit denotes symbols per second, or the number of times per second the modem sends a new signal.



## MODULATION:

When audio signals are transmitted over thousands of kilometers through radio transmission, the audio frequencies that lie within the frequency range of 15 Hertz to 20 Kilohertz have very small signal power and thus cannot be transmitted via antenna for communication purposes. The radiation of electrical energy is only possible at frequencies above 20 Kilohertz. The main advantage of high frequency signals is that they can be transmitted over very long distances by dissipating very small power. Thus, the audio signals must be sent along with the high frequency signals for communication. This can be done by superimposing electrical audio signals on a high frequency wave called the carrier wave. Thus, when the audio-frequency signal is superimposed on a carrier wave, the resulting wave gets all the characteristics of the audio signal. The method of superimposing an audio signal over the carrier wave is called modulation.

After modulation is done, the resulting wave can be given to the antenna and the signal can be transmitted over a long distance. The process of impressing low-frequency information to be transmitted on to a high-frequency wave, called the carrier wave, by changing the characteristics of its amplitude, or frequency, or phase angle is called **modulation.** In other words, the process of altering the characteristics of the amplitude, frequency, or phase angle of the high-frequency signal in accordance with the instantaneous value of the modulating wave is called **modulation**.

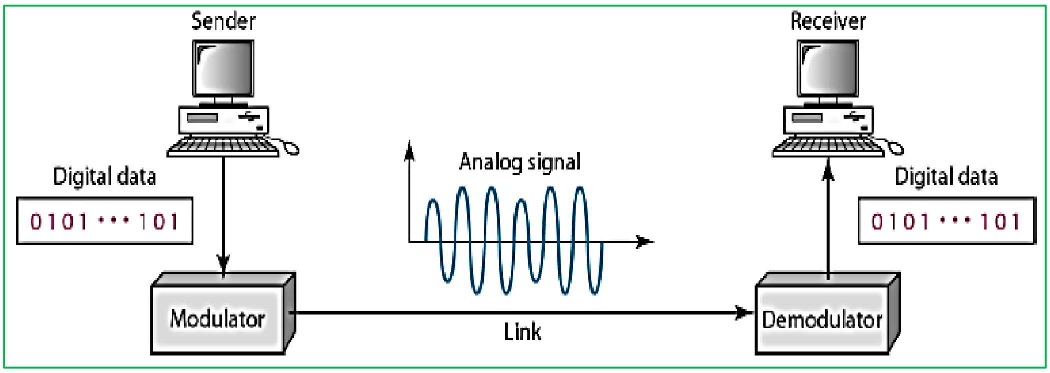



*Fig: Modulation*

## NEED FOR MODULATION:

The reason why low frequency signals cannot be transmitted over long distances through space is listed below:

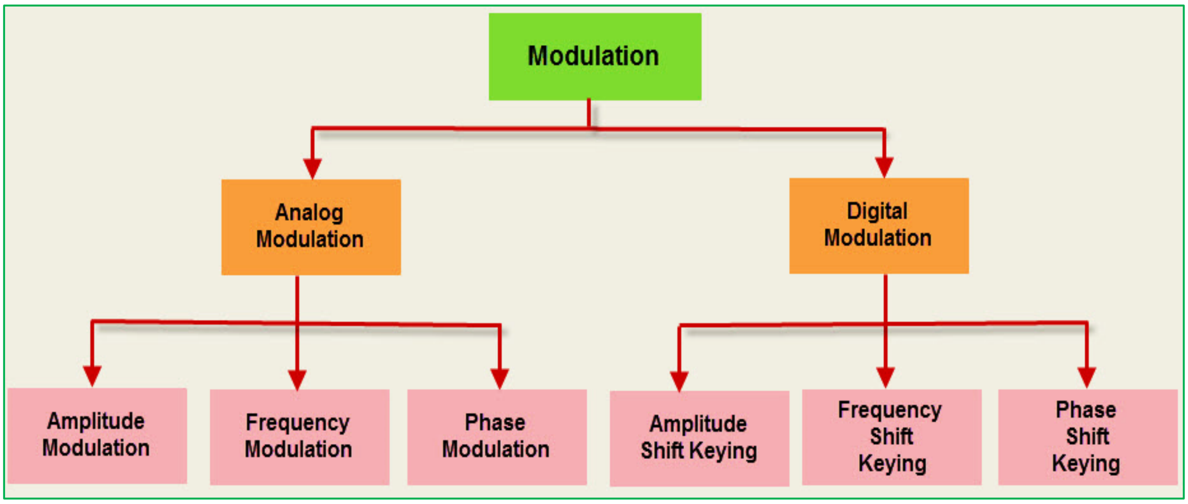
1. **Short Operating Range:** When a wave has a large frequency, the energy associated with it will also be large. Thus low frequency signals have less power that does not enable them to travel over long distances.
2. **Poor Radiation Efficiency:** The radiation efficiency becomes very poor for low frequency signals.
3. **Mutual Interference:** If all audio frequencies are send continuously from different sources, they would all get mixed up and cause erroneous interference air. If modulation is done, each signal will occupy different frequency levels and can be transmitted simultaneously without any error.

***Example:*** If two musical programs were played at the same time within distance, it would be difficult for anyone to listen to one source and not hear the second source. Since all musical sounds have approximately the same frequency range, from about 50 Hz to 10 KHz. If a desired program is shifted up to a band of frequencies between 100 KHz and 110 KHz, and the second program shifted up to the band between 120 KHz and 130 KHz, Then both programs gave still 10 KHz bandwidth and the listener can (by band selection) retrieve the program of his own choice. The receiver would down shift only the selected band of frequencies to a suitable range of 50 Hz to 10 KHz.

4. **Huge Antenna Requirement:** For an effective signal transmission, the sending and receiving antenna should be at least 1/4th of the wave length of the signal. Thus, for small frequencies, the antenna will have kilometers of length. But if the signal has the range of MegaHertz frequency, then the antenna size would be less. The carrier wave cannot be used alone for transmission purposes. Since its amplitude, frequency, and phase angle are constant with respect to some preference.

***Example:*** A second more technical reason to shift the message signal to a higher frequency is related to antenna size. It is to be noted that the antenna size is inversely proportional to the frequency to be radiated. This is 75 meters at 1 MHz but at 15 KHz it has increased to 5000 meters (or just over 16,000 feet) a vertical antenna of this size is impossible.

## TYPES OF MODULATION:

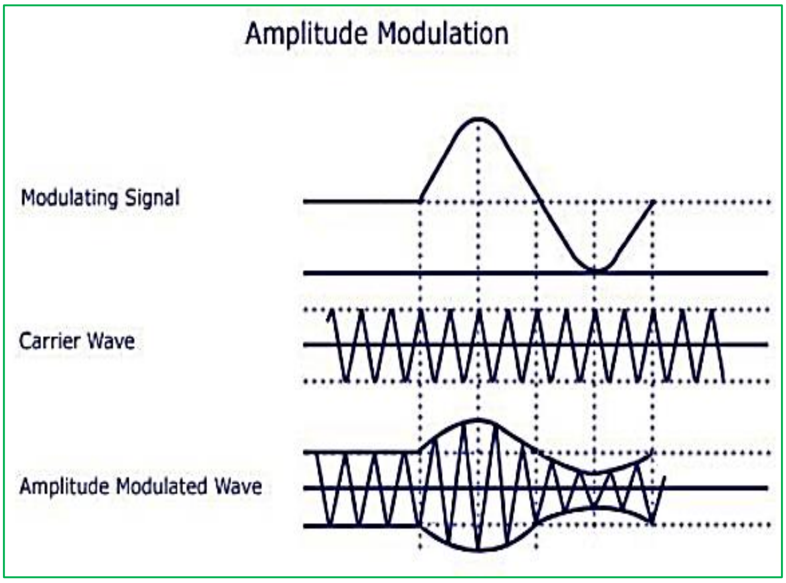



Since the three variables in the analog signal are the amplitude, frequency, and phase angle, the modulation can be done by varying any one of them. We can modulate the information bearing signal into two main types as:

### 1. ANALOG MODULATION:

The aim of analog modulation is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog bandpass channel at a different frequency, for example over a limited radio frequency band or a cable TV network channel. Analog modulation takes an analog signal while digital modulation takes a digital signal. The Analog modulation has a range of valid values while digital modulation only has two that is 0 & 1. Though the analog modulation is cheaper to implement, digital modulation produces more accurate output than analog modulation. The analog modulation is also divided into three different types as follows:

### a. Amplitude Modulation:

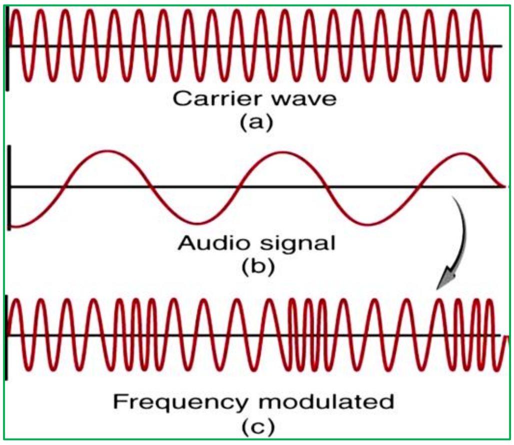



The method of varying amplitude of a high frequency carrier wave in accordance with the information to be transmitted, keeping the frequency and phase of the carrier wave unchanged is called Amplitude Modulation. The information is considered as the modulating signal and it is superimposed on the carrier wave by applying both of them to the modulator. The detailed diagram showing the amplitude modulation process is given at right.

As shown above, the carrier wave has positive and negative half cycles. Both these cycles are varied according to the information to be sent. The carrier then consists of sine waves whose amplitudes follow the amplitude variations of the modulating wave. The carrier is kept in an envelope formed by the modulating wave. From the figure, it can be seen that the amplitude variation of the high frequency carrier is at the signal frequency and the frequency of the carrier wave is the same as the frequency of the resulting wave.

Amplitude modulation (AM) is the modulation method used in the AM radio broadcast band. In this system the intensity, or amplitude, of the carrier wave varies in accordance with the modulating signal. When the carrier is thus modulated, a fraction of the power is converted to sidebands extending above and below the carrier frequency by an amount equal to the highest modulating frequency. If the modulated carrier is rectified (see rectifier) and the carrier frequency filtered out, the modulating signal can be recovered. This form of modulation is not a very efficient way to send information; the power required is relatively large because the carrier, which contains no information, is sent along with the information.

### b. Frequency Modulation:




In frequency modulation (FM), the frequency of the carrier wave is varied in such a way that the change in frequency at any instant is proportional to another signal that varies with time. Its principal application is also in radio, where it offers increased noise immunity and decreased distortion over the AM transmissions at the expense of greatly increased bandwidth. The FM band has become the choice of music listeners because of its low-noise, wide-bandwidth qualities; it is also used for the audio portion of a television broadcast.

### c. Phase modulation:

**Phase modulation**, like frequency modulation, is a form of angle modulation (so called because the angle of the sine wave carrier is changed by the modulating wave). In phase modulation, the carrier signal is systematically shifted to 0 or 180 degrees at uniformly spaced intervals. A better scheme is to use shifts of 45,135,225 or 315 degrees to transmit 2 bits of information per time interval. The phase modulation makes it easier for the receiver to recognize the boundaries of the time intervals.

Unlike its more popular counterpart, frequency modulation (FM), PM is not very widely used for radio transmissions. This is because it tends to require more complex receiving hardware and there can be ambiguity problems in determining whether, for example, the signal has changed phase by +180° or -180°. PM is used, however, in digital music synthesizers such as the Yamaha DX7, even though these instruments are usually referred to as "FM" synthesizers (both modulation types sound very similar, but PM is usually easier to implement in this area).

## 2. Digital Modulation:

For a better quality and efficient communication, digital modulation technique is employed. The main advantages of the digital modulation over analog modulation include available bandwidth, high noise immunity and permissible power. In digital modulation, a message signal is converted from analog to digital message, and then modulated by using a carrier wave.

The carrier wave is switched on and off to create pulses such that the signal is modulated. Similar to the analog, in this system, the type of the digital modulation is decided by the variation of the carrier wave parameters like amplitude, phase and frequency. The most important digital modulation techniques are based on keying such as Amplitude Shift Keying, Frequency Shift Keying, and Phase Shift Keying.

**In Amplitude shift keying**, the amplitude of the carrier wave changes based on the message signal or on the base-band signal, which is in digital format. It is sensitive to noise and used for low-band requirements.

**In frequency shift keying**, the frequency of the carrier wave is varied for each symbol in the digital data. It needs larger bandwidths. Similarly, the phase shift keying changes the phase of the carrier for each symbol and it is less sensitive to noise.

**In Phase Shift Keying (PSK)**, the phase of the carrier signal is changed by varying the sine and cosine inputs at a particular time. PSK technique is widely used for wireless LANs, bio-metric, contactless operations, along with RFID and Bluetooth communications.

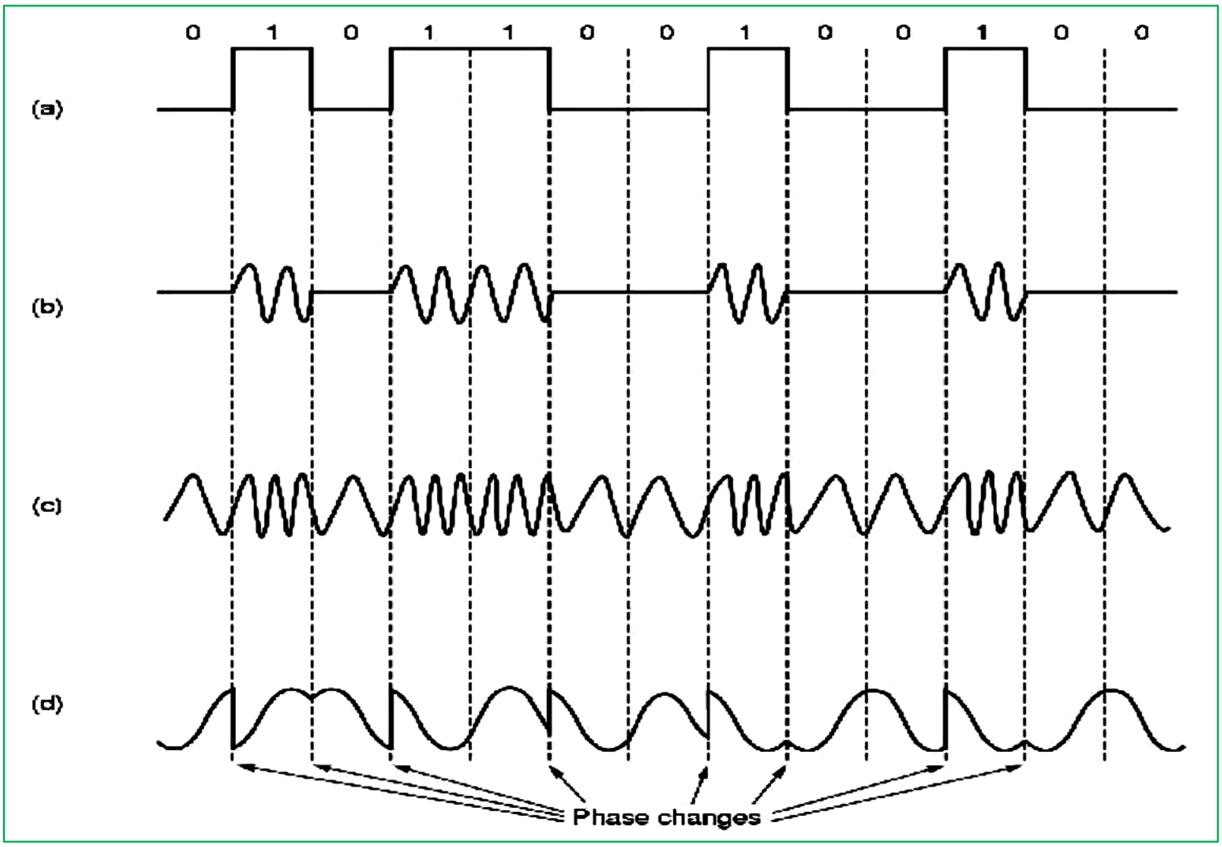
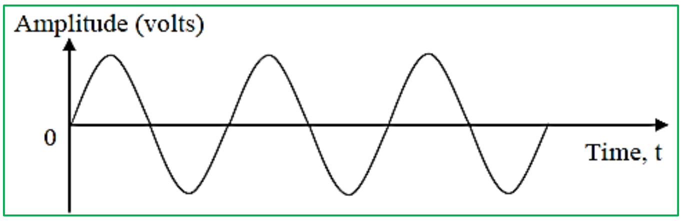


*Fig: (a) A binary signal. (b) Amplitude Shift Keying. (c) Frequency Shift Keying. (d) Phase Shift Keying.*

## Basic Terminologies:

### 1. Sine Wave:

The sine wave is the most fundamental form of a periodic analog signal which is visualized as a simple oscillating curve and its change over the course of cycle is smooth continuous and consistent. Mathematically, a sine wave can be expressed as: $x(t) = A \sin(2\pi f t + \Phi)$

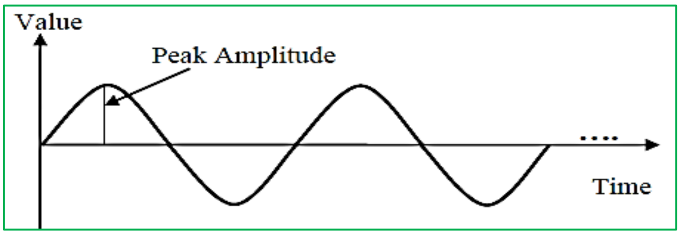



Where,

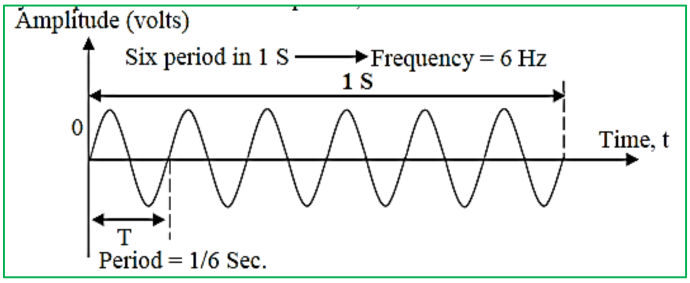
- $x(t)$ is the instantaneous amplitude
- A is the peak value of the amplitude
- f is the frequency and
- $\Phi$ is the phase

### 2. Amplitude:

The **amplitude** of a signal indicates the absolute value of the intensity. Then the maximum strength of a signal is called the **peak amplitude.** It is measured in volts.

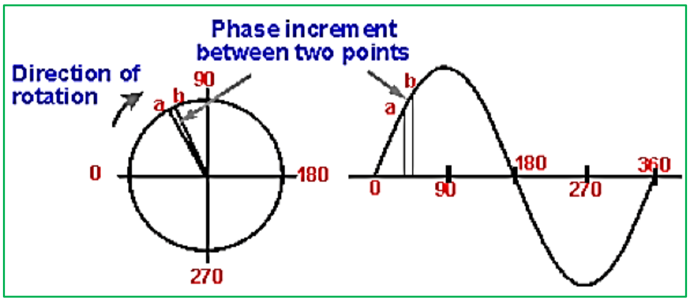


### 3. Frequency:




Period is the amount of time taken in seconds to complete one cycle and **frequency** is defined as the number of periods in one second. It is the rate of change of signal with respect to time. It is measured in Hertz (Hz) or cycles per second. If T is the period, then Frequency, f = 1/T. Thus the frequency in the above figure is 6 Hz. If the value of a signal changes over a very short period of time, then its frequency is high and if it changes over a long period of time, its frequency is low.

### 4. Phase:




**Phase** of a signal defines the position of the waveform relative to time zero. If the wave can be shifted backward or forward along the time axis, then phase describes the amount of that shift. It indicates the status of the first cycle.

Phase is measured in degrees or radians [360° is 2π rad; 1° is 2π/360 rad, and 1 rad is 360/(2π)]. Then a phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period.

## Switching and its Types:

Switching is a technique which is used in large network; it means those networks that contain large number of node, wire, device etc. In larger networks, it is difficult to connect nodes point to point. So in this situation we use Switching Technique. In simple words, Switching is a hardware or software device which creates a connection between one or more than one device/node/computer.

Network Switching can be of different types: Circuit Switching, Packet Switching & Message Switching.

### 1. Circuit Switching:

**Circuit switching** is a methodology of implementing a telecommunications network in which two network nodes establish a dedicated communications channel (circuit) through the network before the nodes may communicate. Dedicated channel (or *circuit*) is established for the duration of a transmission. The circuit guarantees the full bandwidth of the channel and remains connected for the duration of the communication session.

Circuit-switching systems are ideal for communications that require data to be transmitted in real-time. The defining example of a circuit-switched network is the analog telephone network. When a call is made from one telephone to another, switches within the telephone exchanges create a continuous wire circuit between the two telephones, for as long as the call lasts.

The channel remains open and in use throughout the whole call and cannot be used by any other data or phone calls. This is shown in figure below.

In circuit switching, it is required to set up an end-to-end path before any data can be sent. The elapsed time between the end of dialing and the start of ringing can easily be 10 sec, or more on long-distance or international calls. During this time interval, the telephone system is hunting for a path as shown in the figure (a).

It is quite notable that before the data transmission can even begin, the call request signal must propagate all the way to the destination and be acknowledged. However, the circuit switching is considered inefficient as the equipment may be unused for a lot of the call if no data is being sent.

### 2. Packet Switching:

**Packet switching** is a digital networking communications method that groups all transmitted data regardless of content, type, or structure – into suitably sized blocks, called *packets*.

Packet switching features delivery of variable bit-rate data streams (sequences of packets) over a shared network which allocates transmission resources as needed using statistical multiplexing or dynamic bandwidth allocation techniques. With this technology, packets are sent as soon as they are available, and there is no need to set up a dedicated path in advance, unlike with circuit switching. It is up to the routers to use **store-and-forward transmission** to send each packet on its way to the destination on its own, whereas in circuit switching, all data on the circuit follows the same path.

- In packet-based networks, the message gets broken into small data packets.
- These packets are sent out from the computer and they travel around the network seeking out the most efficient route to travel as circuits become available.
- This does not necessarily mean that they seek out the shortest route.
- Each packet may go a different route from the others.
- Each packet is sent with a 'header address' which tells it where its final destination is, so it knows where to go.
- The header address also describes the sequence for reassembly at the destination computer so that the packets are put back into the correct order.
- One packet also contains details of how many packets should be arriving so that the recipient computer knows if one packet has failed to turn up.
- If a packet fails to arrive, the recipient computer sends a message back to the computer which originally sent the data, asking for the missing packet to be resent.

**Advantages:**

- More Security options
- Bandwidth used to full potential
- Devices of different speeds can communicate
- Not affected by line failure (redirects signal), the packets may be transferred through alternate routes.
- Availability no waiting for a direct connection to become available
- During a crisis or disaster, when the public telephone network might stop working, e-mails and texts can still be sent via packet switching

**Disadvantages:**

- Since no bandwidth is reserved with the packet switching, packets may have to wait to be forwarded, which introduces queuing delay and congestion if many packets are sent at the same time. So, under heavy use, there can be a delay.
- Data packets can get lost or become corrupted
- Protocols are needed for a reliable transfer
- Not so good for some type's data streams (e.g. real-time video streams can lose frames due to the way packets arrive out of sequence)

### Two Major Packet Switching Modes Exist:

1. Connectionless packet switching, also known as datagram switching; in which the transmission occurs without any prior connection establishment between the communicating devices and no acknowledgement policy is facilitated.
2. Connection-oriented packet switching, also known as virtual circuit switching, in which each device in communication shares the handshaking signal for connection establishment prior to data transmission. Each packet sent and received is acknowledged by the receiver, so it is more reliable.

### Comparison between Packed Switching and Circuit Switching:

| Item | Circuit switched | Packet switched |
|---|---|---|
| Call setup | Required | Not needed |
| Dedicated physical path | Yes | No |
| Each packet follows the same route | Yes | No |
| Packets arrive in order | Yes | No |
| Is a switch crash fatal | Yes | No |
| Bandwidth available | Fixed | Dynamic |
| Time of possible congestion | At setup time | On every packet |
| Potentially wasted bandwidth | Yes | No |
| Store-and-forward transmission | No | Yes |
| Transparency | Yes | No |
| Charging | Per minute | Per packet |

## 3. Message Switching:

Message switching is a network switching technique in which data is routed in its entirety from the source node to the destination node, one hope at a time. During message routing, every intermediate switch in the network stores the whole message. If the entire network's resources are engaged or the network becomes blocked, the message-switched network stores and delays the message until ample resources become available for effective transmission of the message i.e. it also uses store-and-forward technique. In this technique a node receive a message and store the message until the free and appropriate route is found and if found then send it otherwise stored it.

The main difference between Message and Packet Switching is that - in Message Switching, the message is stored and related from Secondary memory while in Packet Switching, the message is stored and forwarded from primary storage.

Before the advancements in packet switching, message switching acted as an efficient substitute for circuit switching.

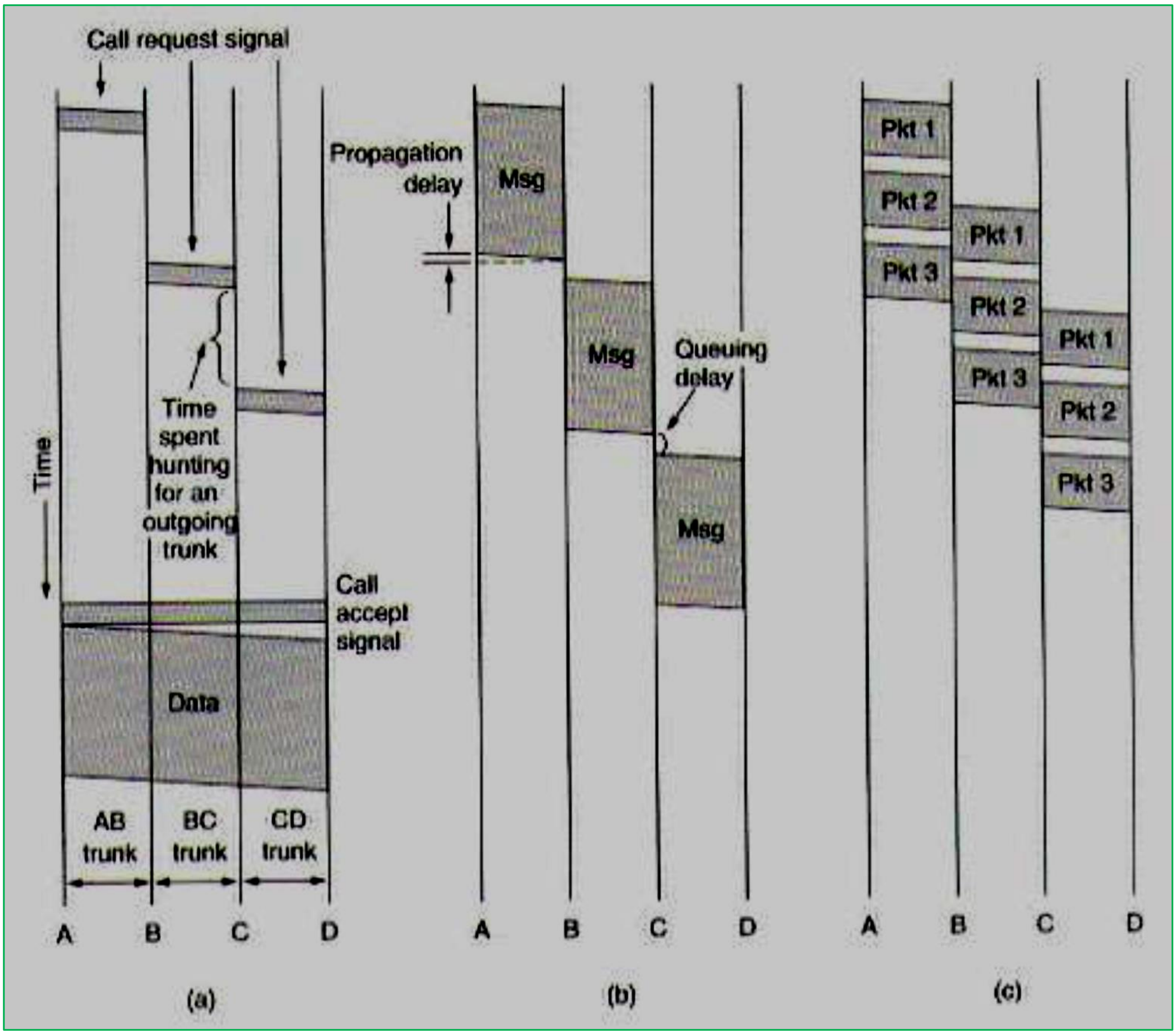



*Fig: (a) Circuit Switching Fig. (b) Message Switching Fig. (c) Packet Switching*