CH -1 INTRODUCTION

Electronic Communication System -

Any form of communication that's broadcast, transmitted, stored or viewed using electronic media, such as computers, phones, email and video. It is of two types:-

i. Analog Communication System

ii. Digital Communication System

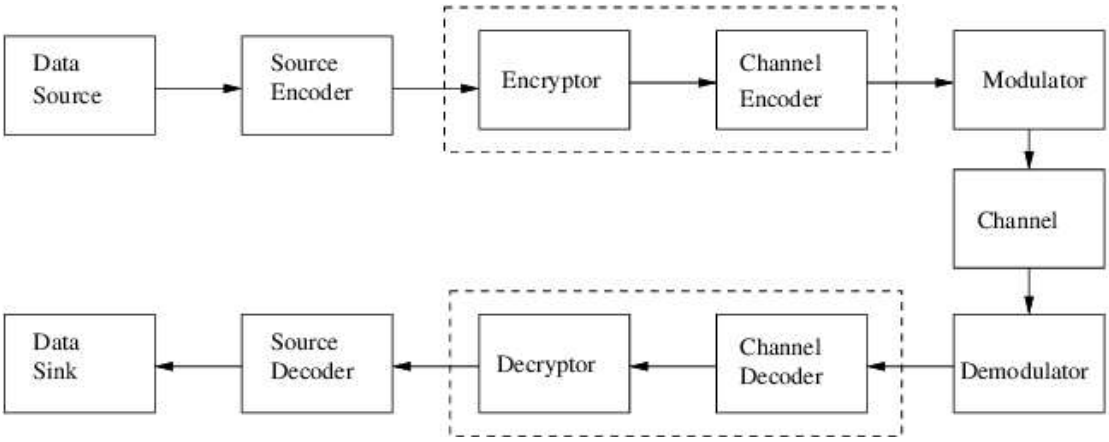
Analog communication system :-

- Analog communication is made from two words analog and communication. Analog refers to the continuous time-varying signal. Communication refers to exchanging information between two or more than two sources. Analog communication means communication with the help of analog signals.
- The analog communication is communication from the sender to the receiver in the form of an analog signal. The analog signal is a continuous time varying signal. The example of analog signal is sound waves. The signals that continuously vary with time are the examples of an analog signal, such as audio and video signals.

Digital communication system :-

- Digital communication is made from two words digital and communication. Digital refers to the discrete time-varying signal. Communication refers to the exchange of information between two or more sources. Digital refers to the discrete time-varying signal. Communication refers to the exchange of information between two or more sources. Digital communication refers to the exchange of digital information between the sender and receiver using different devices and methods.

- The data transmission using analog methods for long-distance communication suffers from distortion, delays, interferences, and other losses. To overcome these problems, the digitization and sampling of signals using different techniques help in making the transmission process more efficient, clear, and accurate.



BLOCK DIAGRAM OF DIGITAL COMM.

- Information Source:- is the actual source of a data from where the data is received to be communicated to other system. The dada can be anding at digital and it is handed that to the transmitter contains three Sub- blocks called Source encorider,channel encorder and modulator.
- Source encorder:- performs three basic. operations on the data to be transmitted and these operations are Data compression, Data Compaction and Data Encryption.
- Data compression:- means converting the analog signal to digital form. Such a mechanism is basically dependent on Sampling and introduces a minimum amount distortion.
- Data compaction:- is done to produce a data Stream or code that represents digital data more efficiantly as it uses number of bits per second.
- Data encryption:- by the encosider is done. So that only the required and key can only data only decode and reqired the data.
- Channel Encorder:- gets input from source encorder and it's output is coupled to the modulator. Channel encorder ensures that no case the transmitter's output exceeds the channel capacity of the transmission medium being used.
- Channel Modulator:- are type of channel in use for communication eg. telephone lines. Channel encoder gives a

of bite or a word. which is digital in nature. Now, to send such word on analog channel, modulator needed. It converts the digital data into signals analog that can be sent on the analog line easily.

- Transmission medium:- is basically the link between transmitter and the receiver. It can be the analog telephone line, a metallic cable, optical cable wherever it is just a transmite the data taken from the transmitter to the taken receiver. The transmision media is main source of noise that may cause distortion of data.
- Next block is receiver block that contains three sub- blocks called demodulator, Channel decoder, and source decorder.
- Demodulator:- performs the reverse function of modulator. It converts the received analog signals back into the digital data signal.
- Channel decorder:- performs reverse function of channel encoder and the data is handed over to a source decorder.

Advantages of Digital Communication System:-

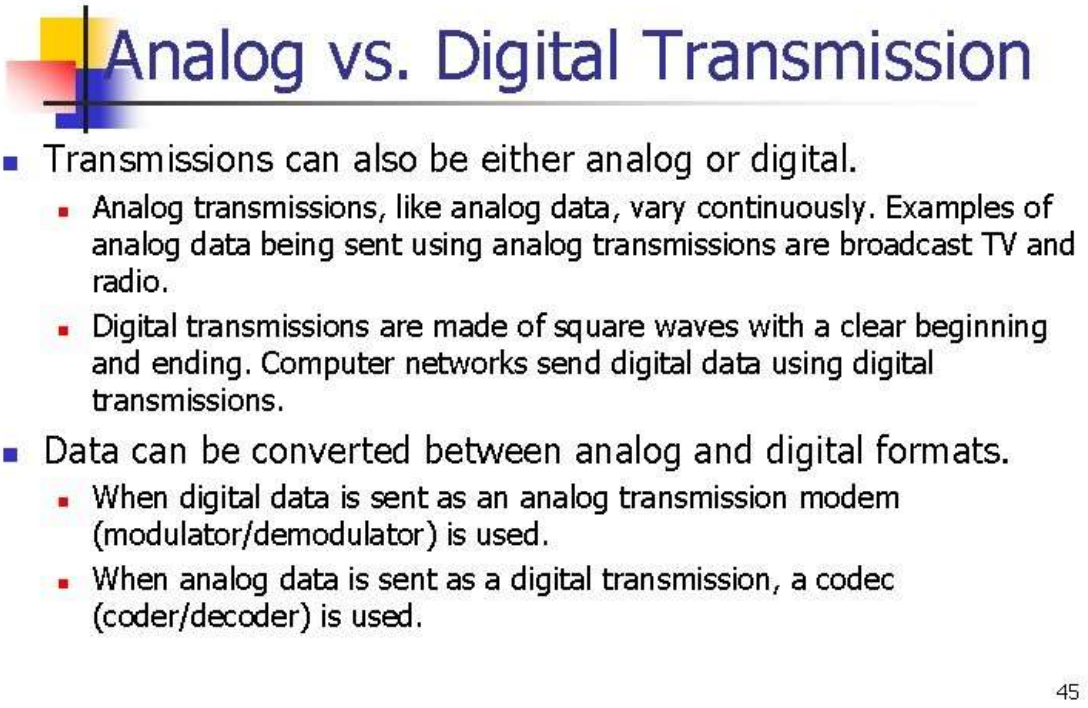
i. Easy to multiplexing and digital switching.
ii. High noise immunity.
iii. Low error rates.
iv. Cheaper and reliable components.

v. Ease of measurement.

Limitations of digital communication system :-

i. The bandwidth reqirement of digitally coded analog signal is very highest compared to the required in simple analog signal.

ii. Precise synchronization between transmitter and receiver is required in digital communication system.



Digital communication model:-

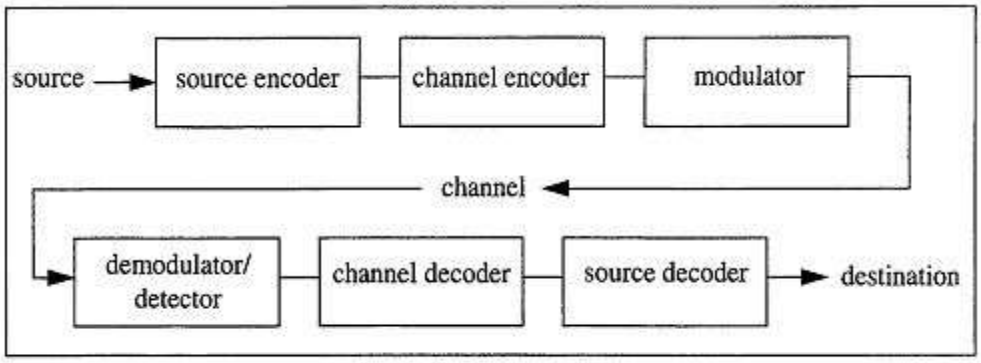


Figure 2.1: Digital Communication Model

Digital data transmission:-

It is of two types:

- Serial data transmission
- Parrallel data transmission

Serial data transmission sends data bits one after another over a single channel. Parallel data transmission sends multiple data bits at the same time over multiple channels.

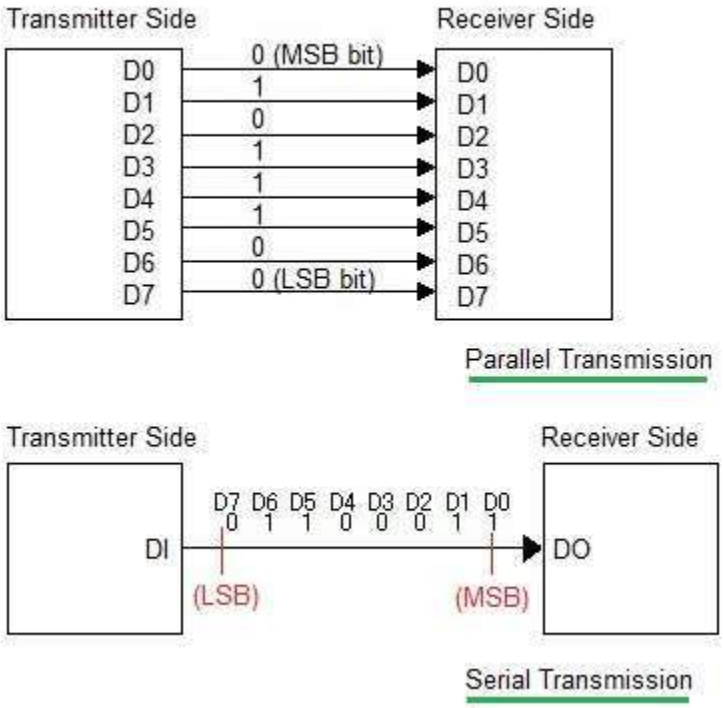
Asynchronous Serial Transmission:-

Data bits can be sent at any point in time. Stop bits and start bits are used between data bytes to synchronize the transmitter and receiver and to ensure that the data is transmitted correctly. The time between sending and receiving data bits is not constant, so gaps are used to provide time between transmissions.

Synchronous Serial Transmission:-

Data bits are transmitted as a continuous stream in time with a master clock. The data transmitter and receiver both operate using a synchronized clock frequency; therefore, start bits, stop bits, and gaps are not used. This means that data moves faster and timing errors are less frequent because

the transmitter and receiver time is synced.



CH-2 SAMPLING THEOREM AND ITS BASIC CONCEPTS

SAMPLING THEOREM:-

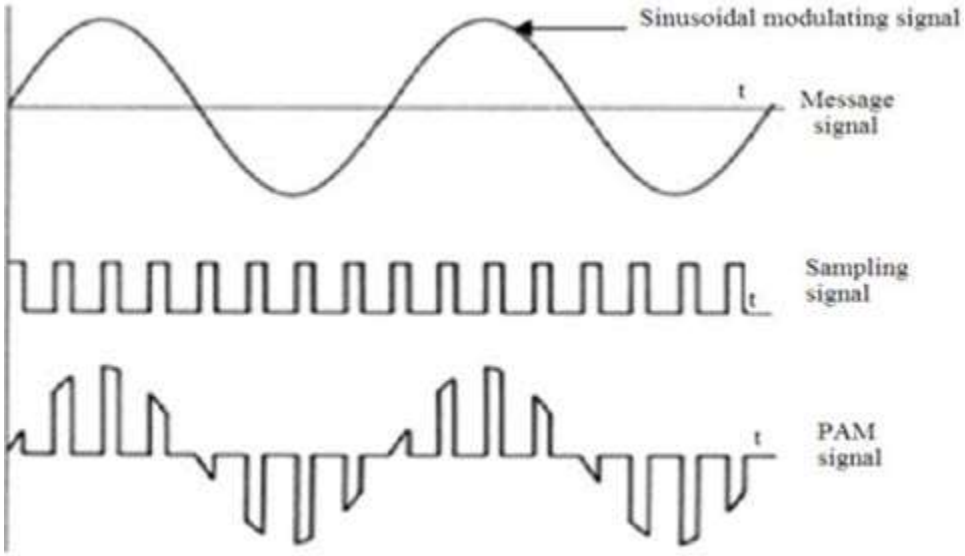
The sampling theorem states that in an analog signal a is periodically sampled every T second ,then these samples N (nTs) unequally determined the signal and the signal may be reconstructed from the samples with no distortion.

Types of sampling theorem:-

- PAM (pulse amplitude modulation)
- TDM(time division multiplexing)
- PPM (pulse position modulation)
- PWM (pulse width modulation)

PAM (pulse amplitude modulation)

Pulse amplitude modulation is the basic form of pulse modulation. In this modulation, the signal is sampled at regular intervals and each sample is made proportional to the amplitude of the modulating signal. Before we study in detail PAM lets us know the concepts of modulation.

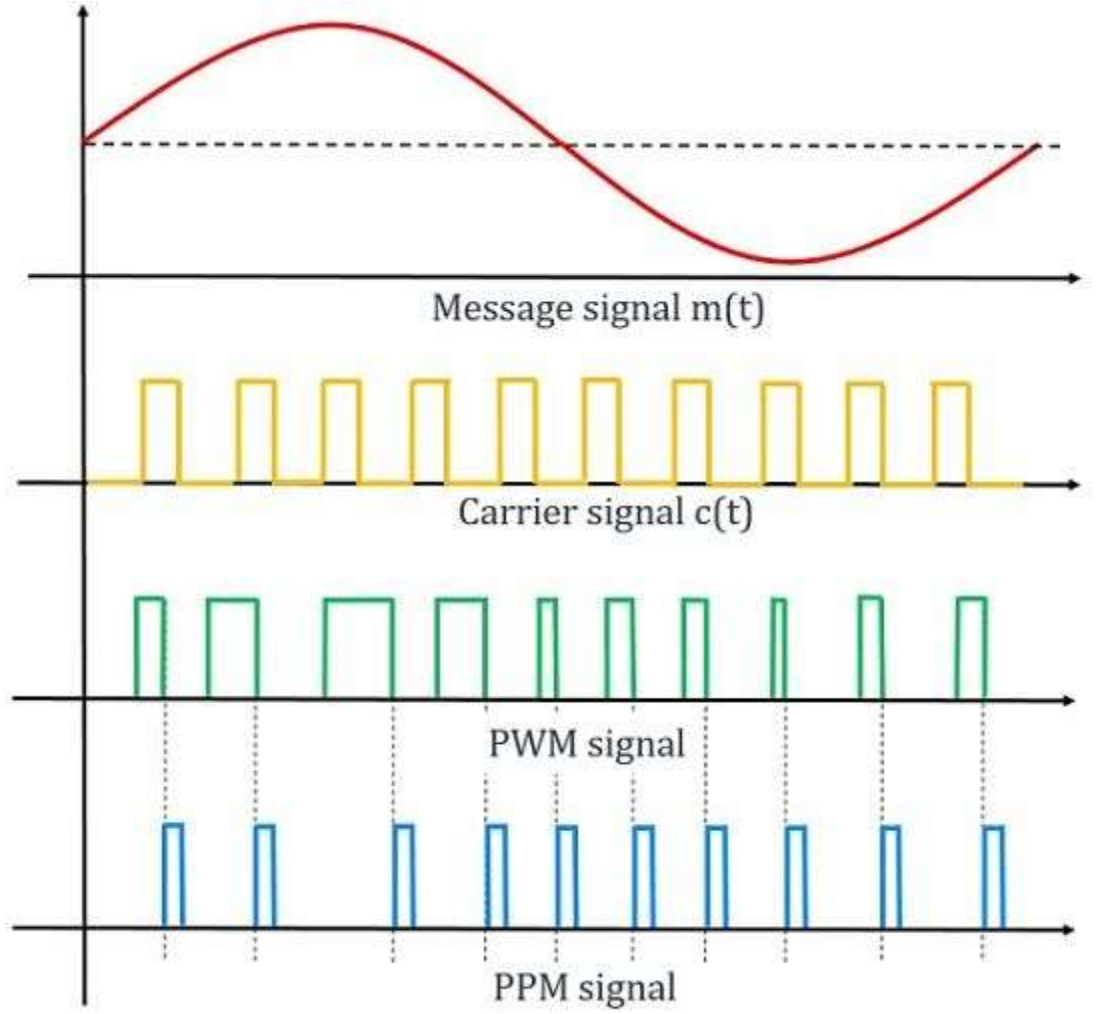


TDM(time division multiplexing)

Time-division multiplexing (TDM) is a method of transmitting and receiving independent signals over a common signal path by means of synchronized switches at each end of the transmission line so that each signal appears on the line only a fraction of time in an alternating pattern. It can be used when the bit rate of the transmission medium exceeds that of the signal to be transmitted. This form of signal multiplexing was developed in telecommunications for telegraphy systems in the late 19th century, but found its most common application in digital telephony in the second half of the 20th century.

PPM (pulse position modulation)

A modulation technique that allows variation in the position of the pulses according to the amplitude of the sampled modulating signal is known as Pulse Position Modulation (PPM). It is another type of PTM, where the amplitude and width of the pulses are kept constant and only the position of the pulses is varied. simply put the pulse displacement is directly proportional to the sampled value of the message signal.

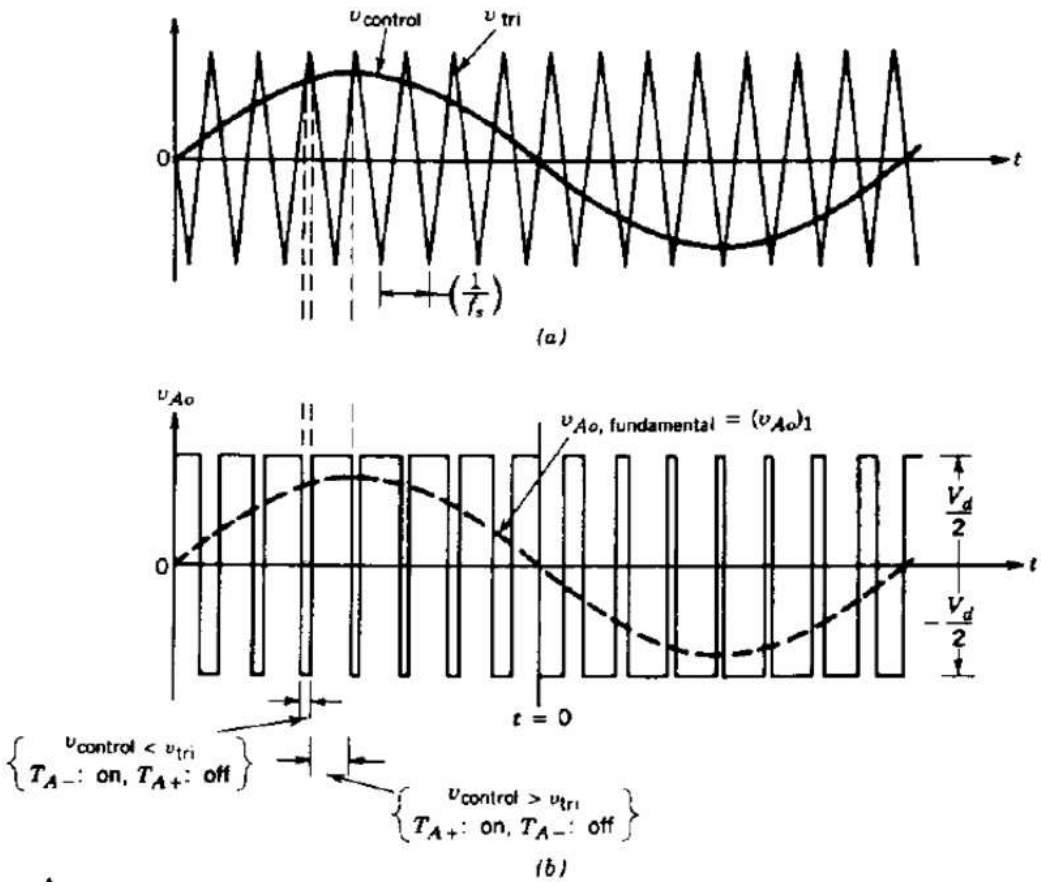


Waveform representation of PPM signal generation

Electronics Coach

PWM (pulse width modulation)

A modulation technique where the width of the pulses of the pulsed carrier wave is changed according to the modulating signal is known as Pulse Width Modulation (PWM). It is also known as Pulse duration modulation (PDM).Pulse Width Modulation (PWM)



QUANTIZATION PROCESS:- is a process to convert the continuous analog signal to the series of discrete values. A quantizer is a device known to perform the quantization process. The function of quantizer is to represent each level to the fixed discrete finite set of values.

The signals during transmission over long distances suffer from noise and interference. To overcome this, the quantization process creates a signal that is approximately equal to the message signal. It selects a quantized signal mq(t) with values nearest to the original analog signal m(t). The quantization process selects a value and rounds off these values to the nearest stabilized value. The quantized signal mq(t) can get easily separable from the additive noise.

PCM (pulse code modulation)

Modulation is a process where different parameter (amplitude, frequency, and phase) of a carrier signal varies with the instantaneous value of the message signal. A carrier signal is a high-frequency signal, and the message signal is the original signal transmitted from the transmitter to the receiver. The message signal carries the information from one place to the other. The carrier signal is used with the message signal to make it suitable for long-distance transmission.

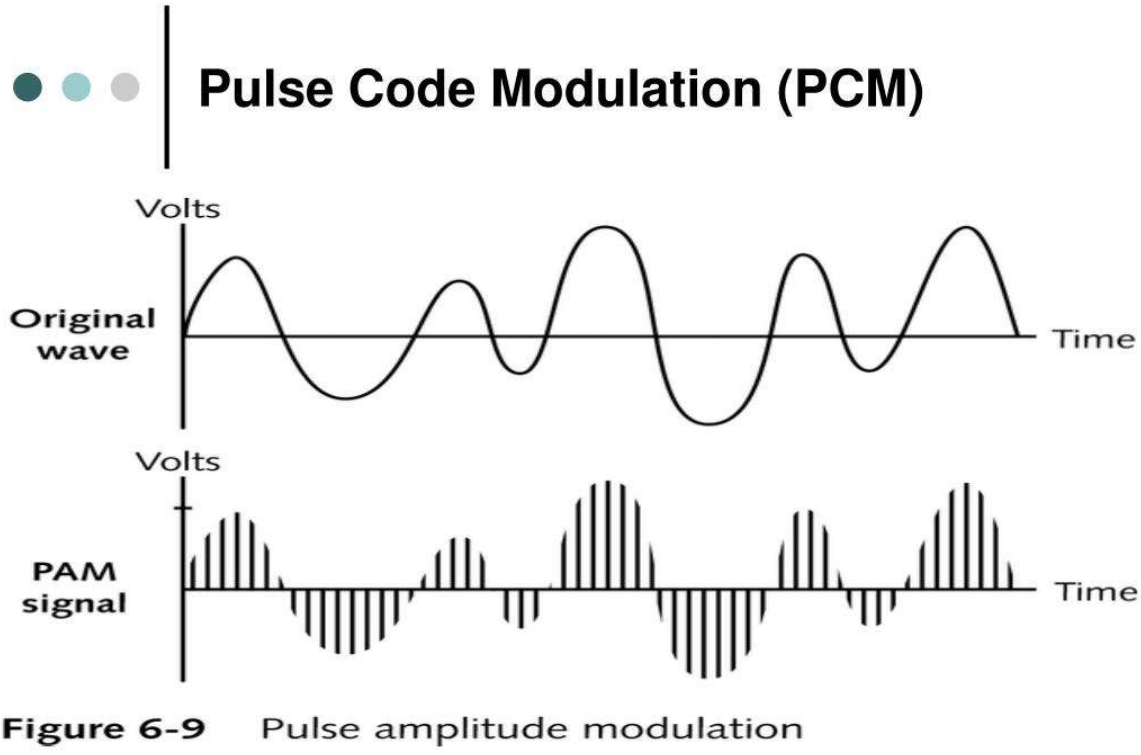


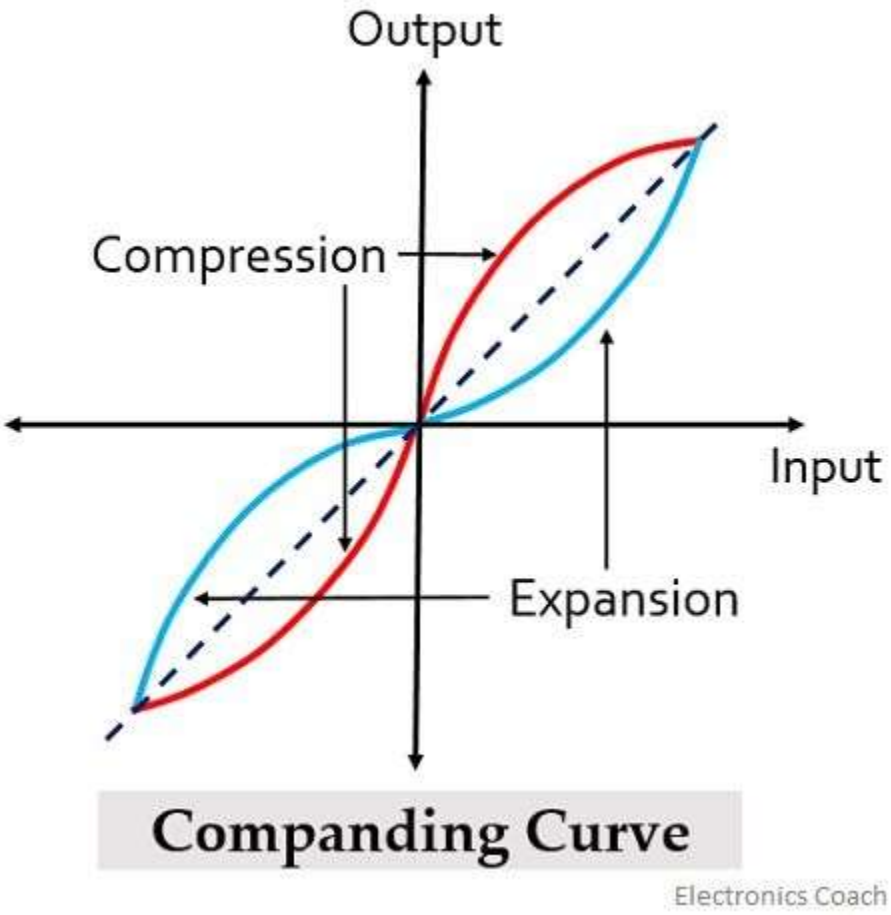
Figure 6-9 Pulse amplitude modulation

15 Tamra Dean -- Modified by: Brierley 8/9/2014

COMPANDING:-

In telecommunication and signal processing, companding (occasionally called compansion) is a method of mitigating the detrimental effects of a channel with limited dynamic range. The

name is a portmanteau of the words compressing and expanding, which are the functions of a compander at the transmitting and receiving ends, respectively. The use of companding allows signals with a large dynamic range to be transmitted over facilities that have a smaller dynamic range capability. Companding is employed in telephony and other audio applications such as professional wireless microphones and analog recording.



CHARACTERISTICS OF COMPRESSOR:-

- Operating pressure
- Throughput
- Compresses air/gases or vapours from low pressure to high

pressure.

- Can be classified as either kinetic machines or positive-displacement machines.
- Increases the pressure of a gas.
- Reduces the volume of fluid.
- Makes use of the compressibility of gases.
- There is a vast variety of compressor types available.

COMPANDER:-

The combination of a compression and an expander is called a compander. Naturally, in an actual PCM system, the combination of compressor and uniform quantizer is located in the transmitter whereas the expander is located in the receiver.

NOISE IN PCM SYSTEM :-

Noise in PCM system refers to the unwanted signals that affect the quality of the transmitted or received PCM signals. There are two major sources of noise in PCM system: transmission noise and quantization noise. Transmission noise is introduced by the channel and can be reduced by using regenerative repeaters. Quantization noise is introduced by the process of quantizing the analog signal and can be reduced by increasing the number of encoded bits.

DPCM (different pulse code modulation):-

There are two types of Pulse Code Modulation:-

- Differential pulse code modulation (DPCM):- In DPCM, the difference between the sample and the previous value of

the analog signal is encoded. The input signal is analog which is then sampled, and as a result, a discrete-time signal enters the DPCM encoder.

- Adaptive differential pulse code modulation (ADPCM):- In ADPCM, the quantizing levels are adapted to analog the signal characteristics.

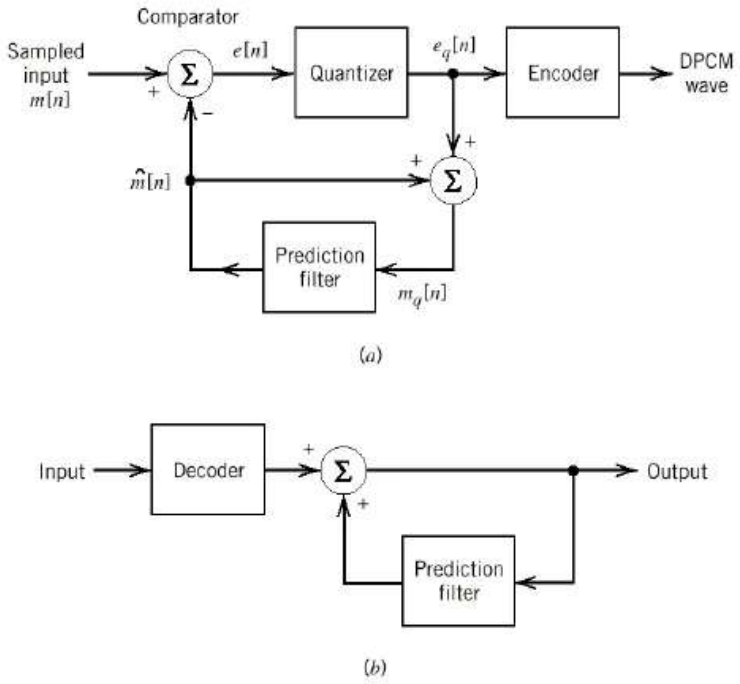


Figure 3.
DPCM syste
(*a*) Transmit
(*b*) Receive

Block diagram of DPCM

ADVANTAGES OF DPCM :-

- Improved Compression Efficiency – DPCM uses a clever trick to reduce the amount of data needed to represent audio signals. Instead of storing the exact signal value at each point in time, it only stores the difference between the

current value and the previous value. This reduces the amount of data needed to represent the signal, which makes it more efficient than traditional methods.Reduced Storage Space – Because DPCM is more efficient than traditional methods, it requires less storage space to store the same amount of audio data. This means that you can store more audio files on your computer or portable device without running out of space.

- Lower Transmission Bandwidth – When transmitting audio data over a network or the internet, bandwidth can be a limiting factor. DPCM reduces the amount of data that needs to be transmitted, which means that it requires less bandwidth to send the same amount of audio data as traditional methods.

- Better Audio Quality – DPCM can also improve the quality of audio recordings by reducing the amount of noise and distortion that can be introduced during the compression process. This means that DPCM can produce higher quality audio recordings than traditional methods, which can be especially important in professional audio applications.

- Increased Signal Fidelity – Lastly, DPCM can help to maintain the fidelity of the original audio signal. By only storing the difference between the current and previous values, it can preserve the shape and characteristics of the original signal more accurately. This means that the audio that is reconstructed from the compressed data is closer to the original than it would be with traditional methods.

DISADVANTAGES OF DPCM:-

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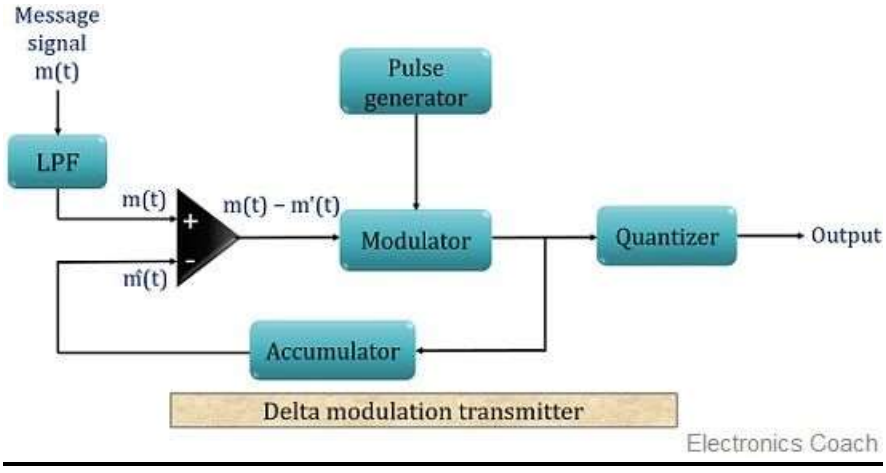
DELTA MODULATION (DM):-

A delta modulation (DM or Δ-modulation) is an analog-to-digital and digital-to-analog signal conversion technique used for transmission of voice information where quality is not of primary importance. DM is the simplest form of differential pulse-code modulation (DPCM) where the difference between successive samples is encoded into n-bit data streams. In delta modulation, the transmitted data are reduced to a 1-bit data stream representing either up (↗) or down (↘). Its main features are:

- The analog signal is approximated with a series of segments.
- Each segment of the approximated signal is compared to the preceding bits and the successive bits are determined by this comparison.
- Only the change of information is sent, that is, only an increase or decrease of the signal amplitude from the previous sample is sent whereas a no-change condition causes the modulated signal to remain at the same ↗ or ↘ state of the previous sample.



Advantages of digital modulation:-

- High capacity for data transmission - the amount of data transmitted through digital modulation is more than through analog communication.
- Incredible bandwidth efficiency - it can accommodate large amounts of data within a limited bandwidth.
- Flexible signals - there is an opportunity to multiplex various forms of data such as digital information, video, and voice.
- Less susceptibility to crosstalk, waveform distortion, non-linearities, and noise.
- Enhanced signal strength, which prevents unwanted signal intrusion and communication noises.
- By increasing the number of bits per sample, the signal-to-noise performance of digital modulation can be increased.
- It is the cheapest option while interfacing with digital switching systems.
- Enhanced data security - the easy encryption and decryption of digital signals with high security make it suitable for sensitive and reliable communication.

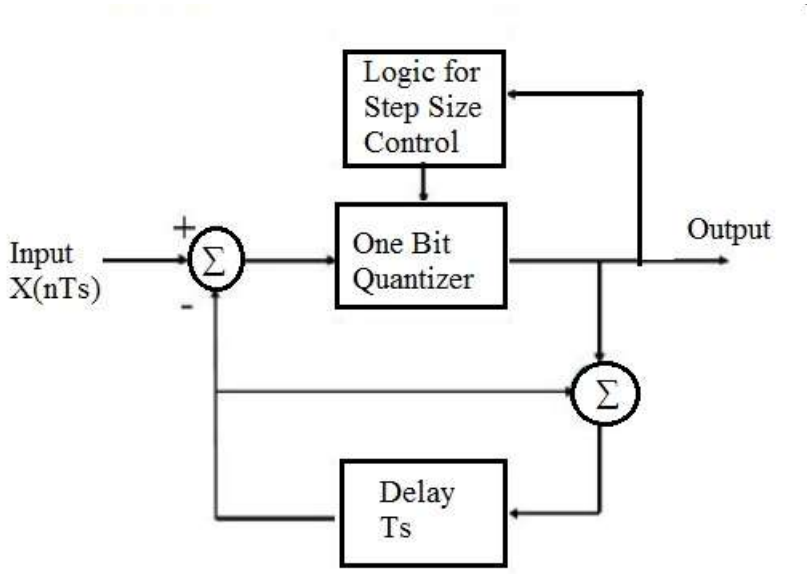
Disadvantages of data modulation:-

- Sampling may cause loss of information.
- A/D and D/A demands mixed-signal hardware.
- Processor speed is limited.

- Develop quantization and round-off errors.
- Systems and processing is more complex.
- A higher bandwidth is required for data communication in comparison to analog transmission of an equivalent information.
- The cost of the equipment is higher.

ADM(Adaptive delta modulation):-

This Modulation is the refined form of delta modulation. This method was introduced to solve the granular noise and slope overload error caused during Delta modulation.



BLOCK DIAGRAM OF ADM

FHSS(Frequencing hoping spread spectrum):-

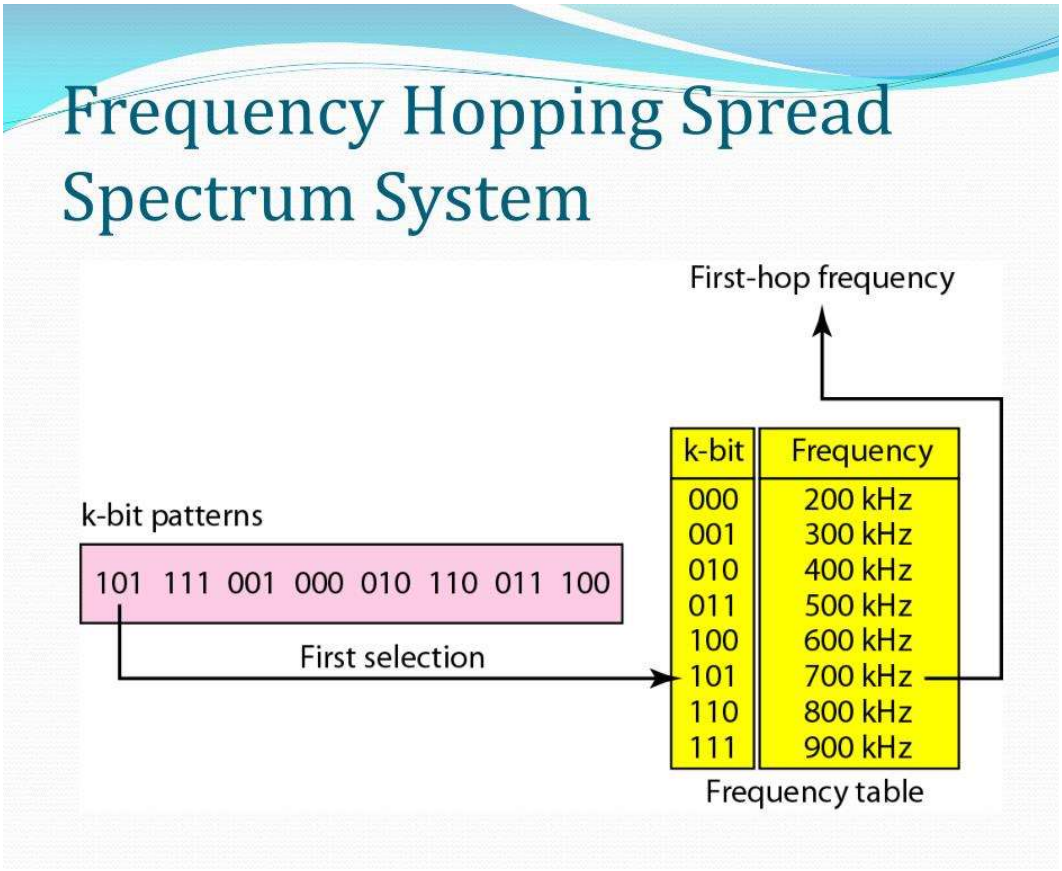
Frequency-hopping spread spectrum (FHSS) is a method of

transmitting radio signals by rapidly changing the carrier frequency among many frequencies occupying a large spectral band. The changes are controlled by a code known to both transmitter and receiver. FHSS is used to avoid interference, to prevent eavesdropping, and to enable code-division multiple access (CDMA) communications.

The frequency band is divided into smaller sub-bands. Signals rapidly change ("hop") their carrier frequencies among the center frequencies of these sub-bands in a determined order. Interference at a specific frequency will affect the signal only during a short interval.[1]

FHSS offers four main advantages over a fixed-frequency transmission:

- FHSS signals are highly resistant to narrowband interference because the signal hops to a different frequency band.
- Signals are difficult to intercept if the frequency-hopping pattern is not known.
- Jamming is also difficult if the pattern is unknown; the signal can be jammed only for a single hopping period if the spreading sequence is unknown.
- FHSS transmissions can share a frequency band with many types of conventional transmissions with minimal mutual interference. FHSS signals add minimal interference to narrowband communications, and vice versa.



CHAPTER - 3

DIGITAL MODULATION TECHNIQUES

Digital-to-Analog signals is the next conversion we will discuss in this chapter. These techniques are also called as Digital Modulation techniques.

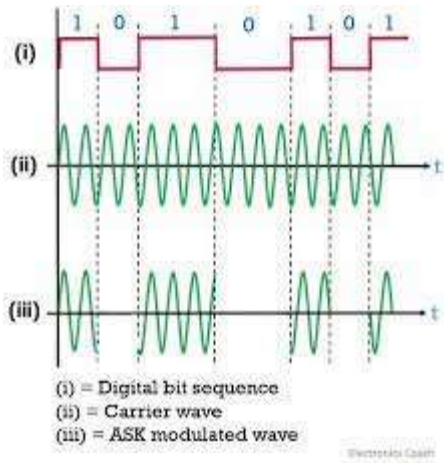
Digital Modulation provides more information capacity, high data security, quicker system availability with great quality communication. Hence, digital modulation techniques have a greater demand, for their capacity to convey larger amounts of data than analog modulation techniques.

There are many types of digital modulation techniques and also their combinations, depending upon the need. Of them all, we will discuss the prominent ones.

ASK – Amplitude Shift Keying

The amplitude of the resultant output depends upon the input data whether it should be a zero level or a variation of positive and negative, depending upon the carrier frequency.

Any modulated signal has a high frequency carrier. The binary signal when ASK modulated, gives a zero value for Low input while it gives the carrier output for High input.



Advantages of ASK modulation

Following are the benefits or advantages of ASK modulation.

➡It offers high bandwidth efficiency.

➡It has simple receiver design.

➡ASK modulation can be used to transmit digital data over optical fiber.

➡ASK modulation and ASK demodulation processes are comparatively inexpensive.

➡Its variant OOK is used at radio frequencies to transmit morse codes.

Disadvantages of ASK modulation

Following are the drawbacks or disadvantages of ASK modulation.

➡It offers lower power efficiency.

➡ASK modulation is very susceptible to noise interference. This is due to the fact that noise affects the amplitude. Hence another alternative modulation technique such as BPSK which is less susceptible to error than ASK is used.

APPLICATION

Low-frequency RF applications

Home automation devices

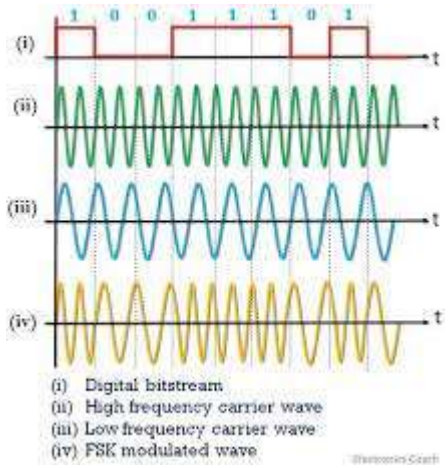
Industrial networks devices

Wireless base stations

Tire pressuring monitoring systems

Frequency Shift Keying FSK

is the digital modulation technique in which the frequency of the carrier signal varies according to the digital signal changes. FSK is a scheme of frequency modulation.



The output of a FSK modulated wave is high in frequency for a binary High input and is low in frequency for a binary Low input. The binary 1s and 0s are called Mark and Space frequencies.

Advantages of FSK :

1. It has a lower probability

2. Easy to implement

3. High data rate

4. It has better noise immunity than ASK method, so the probability of error-free reception of data is high

5. Easy to decode

6. Operate in virtually any wires available

7. FSK transmitter, as well as FSK receiver implementations, are

simple for low data rate application

8. It provides high SNR

9. Used in long-distance communication

10. Power requirement is constant

11. Good sensitivity

12. It has higher immunity to noise due to a constant envelope. Hence it is robust against variation in attenuation through a channel

13. Low noise

Disadvantages of FSK :

1. Extensively used in low-speed modems having bit rates below around 1200 bits/sec

2. This increases the channel bandwidth required to transmit the FSK signal type

3. It uses larger bandwidth compared to other modulation techniques like ASK and PSK. Hence it is not bandwidth efficient

4. FSK is not preferred for the high-speed modems because with increases in speed and also have the bit rate increases

5. When in the telecommunication media, the telephone lines have very low bandwidth, it is not possible to satisfy the bandwidth requirement of FSK at a too much higher speed. So in a

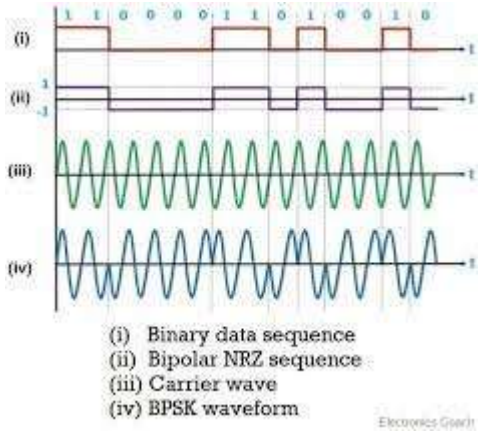
method of FSK is preferred only for the low-speed problem

APPLICATION

Frequency-shift keying (FSK) and phase-shift keying (PSK) modulation schemes are used in digital communications, radar, RFID, and numerous other applications.

Phase Shift Keying PSK

is the digital modulation technique in which 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.



(i) Binary data sequence
(ii) Bipolar NRZ sequence
(iii) Carrier wave
(iv) BPSK waveform

Advantages of PSK

Following are the benefits or advantages of PSK:

➡It carries data over RF signal more efficiently compare to other modulation types. Hence it is more power efficient modulation technique compare to ASK and FSK.

➡It is less susceptible to errors compare to ASK modulation and occupies same bandwidth as ASK.

➡Higher data rate of transmission can be achieved using high level of PSK modulations such as QPSK (represents 2 bits per constellation), 16-QAM (represents 4 bits per constellation) etc.

Disadvantages of PSK

Following are the disadvantages of PSK:

➡It has lower bandwidth efficiency.

➡The binary data is decoded by estimation of phase states of the signal. These detection and recovery algorithms are very complex.

➡Multi-level PSK modulation schemes (QPSK, 16QAM etc.) are more sensitive to phase variations.

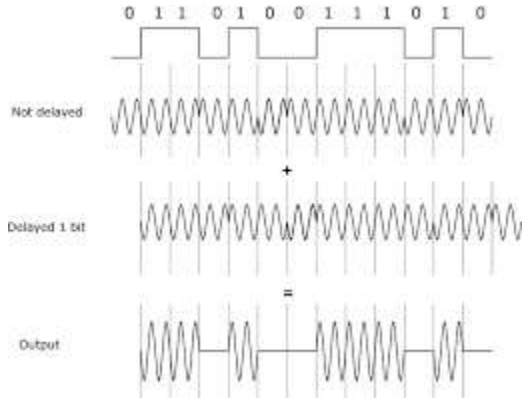
➡It is also one form of FSK and hence it also offers lower bandwidth efficiency compare to ASK modulation type.

APPLICATION

It is widely used for wireless LANs, RFID and Bluetooth communication. Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses a finite number of phases, each assigned a unique pattern of binary digits. Usually, each phase encodes an equal number of bits.

Differential Phase Shift Keying DPSK

the phase of the modulated signal is shifted relative to the previous signal element. No reference signal is considered here. The signal phase follows the high or low state of the previous element. This DPSK technique doesn't need a reference oscillator.



Advantages of DPSK modulation

Following are the benefits or advantages of DPSK modulation:

➡DPSK modulation does not require carrier at its receiver circuit. Hence complex circuits are not needed.

➡Bandwidth requirement of DPSK is less compared to BPSK modulation.

Disadvantages of DPSK modulation

Following are the drawbacks or disadvantages of DPSK modulation:

➡Probability of error or BER (Bit Error Rate) is higher in DPSK compare to BPSK.

➡Noise interference in DPSK is more.

➡DPSK modulation uses two successive bits for its reception. Hence error in first bit creates error in second bit and consecutively error propagates.

APPLICATION

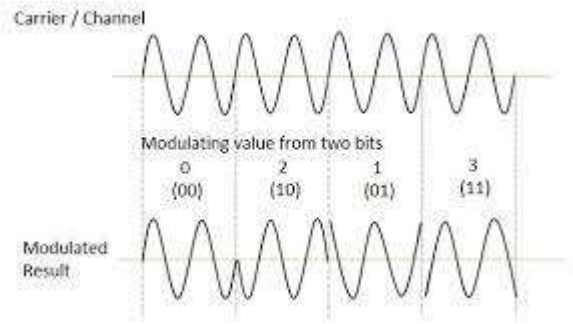
There are various applications of DPSK such as WLANs, Bluetooth and RFID communication. The most popular among them is its use of Bluetooth where π/4 - DQPSK and 8-DPSK modulation variants of DPSK has been employed. In DPSK demodulation, phase of the received bit is compared with phase of the previous bit..

Quadrature Phase Shift Keying QPSK

is a variation of BPSK, and it is also a Double Side Band Suppressed Carrier DSBSC

modulation scheme, which sends two bits of digital information at a time, called as bigits.

Instead of the conversion of digital bits into a series of digital stream, it converts them into bit pairs. This decreases the data bit rate to half, which allows space for the other users.



Advantages of QPSK

Following are the benefits or advantages of QPSK:

➡In QPSK modulation, two bit are carried by one single analog carrier. Hence bandwidth is twice efficient in comparison to BPSK modulation. Here symbol rate is half of the raw bit rate.

➡BPSK is bandwidth efficient modulation technique as two bits are carried by single carrier.

Disadvantages of QPSK

Following are the disadvantages of QPSK:

➡In QPSK modulation technique, one complex symbol represents two binary bits. Due to this, QPSK receiver is more complex compare to BPSK receiver due to four states needed to recover binary data information.

➡Due to above reason, QPSK is not power efficient modulation technique compare to other modulation types as more power is required to transmit two bits.

APPLICATION

QPSK allows the signal to carry twice as much information as ordinary PSK using the same bandwidth. QPSK is used for satellite transmission of MPEG2 video, cable modems, videoconferencing, cellular phone systems, and other forms of digital communication over an RF carrier.

CHAPTER - 4

DATA TRANSMISSION CIRCUITS TRANSMISSION MEDIA

Transmission media is a communication channel that carries the

information from the sender to the receiver. Data is transmitted through the electromagnetic signals.

The main functionality of the transmission media is to carry the information in the form of bits through LAN(Local Area Network).It is a physical path between transmitter and receiver in data communication.

In a copper-based network, the bits in the form of electrical In a fibre based network, the bits in the form of light pulses.
signals.

In OSI(Open System Interconnection) phase, transmission media supports the Layer 1. Therefore, it is considered to be as a Layer 1 component.
The electrical signals can be sent through the copper wire, fibre optics, atmosphere, water, and vacuum.
The characteristics and quality of data transmission are determined by the characteristics of medium and signal.

Transmission media is of two types are wired media and wireless media.
Different transmission media have different properties such as bandwidth, delay, cost and ease of installation and maintenance.
The transmission media is available in the lowest layer of the OSI reference model, i.e., Physical layer.

TRANSMISION MODE

Transmission mode refers to the mechanism of transferring of data between two. devices connected over a network. It is also called Communication Mode. These. modes direct the direction of flow of information.

Analog and digital transmissions

Analog and digital signals are the types of signals carrying information. The major difference between both signals is that the analog signals have continuous electrical signals, while digital signals have non-continuous electrical signals.

MULTIPLEXING

Multiplexing, or muxing, is a way of sending multiple signals or streams of information over a communications link at the same time in the form of a single, complex signal.

SIGNAL TYPES:-

1. Continuous-Time and Discrete-Time Signals.
2. Even and Odd signals.
3. Periodic and Aperiodic Signals.
4. Energy and Power signals.
5. Deterministic Signals and Random signals.
6. Causal and Non-causal Signals.
7. Analog and Digital Signals.

TYPES OF TRANSMISSION:-

In data communication terminology, a transmission medium is a physical path between the transmitter and the receiver i.e. it is the channel through which data is sent from one place to another. Transmission Media is broadly classified into the following types:

1. Guided Media: It is also referred to as Wired or Bounded transmission media. Signals being transmitted are directed and confined in a narrow pathway by using physical links.

Features:

1.High Speed
2.Secure
3.Used for comparatively shorter distances

2. Unguided Media:

It is also referred to as Wireless or Unbounded transmission media. No physical medium is required for the transmission of electromagnetic signals.

Features:

1.The signal is broadcasted through air

2.Less Secure

3.Used for larger distances

BANDWIDTH

The signal bandwidth is the distance between the crest and the trough of the signal wave in the transmission medium. If the signal bandwidth is high, the data transmission speed will be higher. So, the transmission medium used should be capable of transmitting the data without decreasing its quality.

The following techniques can be used for Digital to Analog Conversion:

- Amplitude Shift keying - Amplitude Shift Keying is a technique in which carrier signal is analog and data to be modulated is digital. The amplitude of analog carrier signal is modified to reflect binary data.
- Frequency Shift keying - In this modulation the frequency of analog carrier signal is modified to reflect binary data.
- Phase Shift keying - In this modulation the phase of the analog carrier signal is modified to reflect binary data.The amplitude and frequency of the carrier signal remains constant.

It is further categorized as follows:

Binary Phase Shift Keying (BPSK):

BPSK also known as phase reversal keying or 2PSK is the simplest form of phase shift keying. The Phase of the carrier wave is changed according to the two binary inputs. In Binary Phase shift keying, difference of 180 phase shift is used between binary 1 and binary 0.

This is regarded as the most robust digital modulation technique and is used for long distance wireless communication.
Quadrature phase shift keying:
This technique is used to increase the bit rate i.e we can code two bits onto one single element. It uses four phases to encode two bits per symbol. QPSK uses phase shifts of multiples of 90 degrees.
It has double data rate carrying capacity compare to BPSK as two bits are mapped on each constellation points.

MODULATION

Modulation is the process of converting data into electrical signals optimized for transmission.

DATA RATE

Data Rate is defined as the amount of data transmitted during a specified time period over a network. It is the speed at which data is transferred from one device to another or between a peripheral device and the computer.

DELAY IN DATA TRANSMISSION

In a network based on packet switching, transmission delay (or store-and-forward delay, also known as packetization delay or serialization delay) is the amount of time required to push all the packet's bits into the wire. In other words, this is the delay caused by the data-rate of the link.
Bit-Length

The number of bits in a bit string. A positive integer that expresses the number of bits in a bit string. The number of bits in a bit string (e.g., the bit length of the string 0110010101000011 is sixteen bits).

Asynchronous and Synchronous Transmision

Synchronous Transmission:-

Synchronous transmission is a method of sending large amounts of data. It is widely regarded as an effective and dependable method of data transfer. During synchronous transmission, the clocks of the sender and receiver are unified, and data transmission occurs between the two without an interval.

Asynchronous Transmission:-

Asynchronous transmission, sometimes referred to as start/stop transmission, involves sending data to the receiver using the flow control method. Data is synchronized between the sender and the receiver without the use of a clock.

COMMUNICATION PROTOCOLS

A communications protocol is a set of formal rules describing how to transmit or exchange data, especially across a network. A standardised communications protocol is one that has been codified as a standard. Examples of these include WiFi, the Internet Protocol, and the Hypertext Transfer Protocol (HTTP)

DATA TRANSMISSION CIRCUIT

Data transmission is the transfer of data from one digital device to another. This transfer occurs via point-to-point data streams or channels. These channels may previously have been in the form of copper wires but are now much more likely to be part of a wireless network.

Characteristics of Data Transmission Circuits:

Bandwidth Requirements - Characteristics of Data Transmission Circuits is the most instances consists of pulse-type energy. The data stream is similar to a square-wave signal with rapid transitions from one voltage level to another, with the repetition rate depending on the binary representation of the data word. For instance, if an 8-bit word has the value 01010101, the resulting voltage graph would appear as a series of four square waves with each negative half-cycle equal to each positive half-cycle. If, however, the data word has the form 00001111, the voltage graph would appear as a single square wave with negative and positive half-cycles equal but longer than the first example. Figure 14-16 shows the voltage graphs for these and other binary words. It can be seen that data circuits must provide a bandwidth for the data transmissions they carry. This will be governed by the pulse rate variations just explained, and by the fact, indicated in earlier, that even a single square wave occupies a frequency range because of the harmonics present.

DATA STORAGE TECHNOLOGY

There are two types of digital information: input and output data. Users provide the input data. Computers provide output data. But a computer's CPU can't compute anything or produce output data without the user's input.

Users can enter the input data directly into a computer. However, they have found early on in the computer-era that continually entering data manually is time- and energy-prohibitive. One short-term solution is computer memory, also known as random access memory (RAM). But its storage? capacity and memory retention are limited. Read-only memory

(ROM) is, as the name suggests, the data can only be read but not necessarily edited. They control a computer's basic functionality.
Although advances have been made in computer memory with dynamic RAM (DRAM) and synchronous DRAM (SDRAM), they are still limited by cost, space and memory retention. When a computer powers down, so does the RAM's ability to retain data. The solution? Data storage.

DATA TRANSFER IN DIGITAL CIRCUITS

Data transfer utilizes various communication medium formats to move data between one or more nodes. Transferred data may be of any type, size and nature. Analog data transfer typically sends data in the form of analog signals, while digital data transfer converts data into digital bit streams.
There are two methods used to transmit data between digital devices: serial transmission and parallel transmission. Serial data transmission sends data bits one after another over a single channel. Parallel data transmission sends multiple data bits at the same time over multiple channels.

TRANSMISSION OVER SHORT DISTANCES

Bluetooth is a short-range wireless technology standard that is used for exchanging data between fixed and mobile devices over short distances and building personal area networks (PANs).
In the most widely used mode, transmission power is limited to 2.5 milliwatts, giving it a very short range of up to 10 metres (33 ft). It employs UHF radio waves in the ISM bands, from 2.402 GHz to 2.48 GHz.[3] It is mainly used as an alternative to wire connections, to exchange files between nearby portable devices and connect cell phones and music players with wireless headphones.

NOISE AND ELECTRICAL DISTORTION

The concepts of distortion and noise in signal processing overlap to a limited extent, but they are distinct phenomena. Distortion in a signal is the alteration or change of the shape or some other characteristic of the waveform. In contrast, noise is an external random signal added to the original signal. It's harder to remove the effects of noise than to remove the effects of distortion. Noise also has a more stochastic nature compared to distortion.

Ordinary high-pass and low-pass filters can also cause distortion. A high-pass filter can distort the shape of a square wave by removing some or all of the low-frequency components. A low-pass filter can round the square-wave corners by removing the high-frequency components.

Characteristics of Data Transmission Circuits:

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harmonics present.

Data Transmission Speeds - The rate of data transfer depends on several aspects of the transmission channel, of which signaling speed is very important. Transmission engineers often refer to the transmission speed of a communications channel as the chan-nel's baud rate. The baud is an important unit of signaling speed. In a system in which all pulses have equal duration, the speed in bauds is equal to the maximum rate at which signal pulses are transmitted. This should be recognized as different from information bit rate. In a system which uses only one information bit per signaling pulse, i.e., a binary system, the baud rate and the bit rate happen to be the same. In systems which encode the data in such a way that more than one information bit can be placed on each signaling pulse, the information bit rate will exceed the baud rate.

Noise - The Shannon-Hartley law is related to random noise, but impulse noise can also be harmful to signals. The sampling theorem shows that all values of a signal can be determined by sampling the signal at a rate equal to at least twice the bandwidth. Noise affects this sampling process because the noise pulse will be interpreted as a data bit (see Figure 14-17), if the noise impulse occurs at the time a sample is taken, and has an amplitude equal to or exceeding the minimum level recognized by the system as a mark. The potential for impulse noise to become a source of errors increases with the number of levels of each code element. To achieve the 30,880-bps rate mentioned in the above example, it may be shown that five levels would be required for each code element. A noise-free channel would be necessary to preclude noise-induced data errors, but noise-free channels do not exist in practice. It is noise, among other impairments, which tends to limit the actual 4-kHz channel data speeds to 10,800 bps or less.

Crosstalk - Any transmission system which conveys more than one signal simultaneously can experience crosstalk, which is interference due to the reception of portions of a signal from one channel in another channel. This is common in multiplexed systems in which inadequate procedures are employed to ensure that over-modulation of the various carriers of the multiplexed groups is prevented. In modem transmission systems which convey many channels of voice and data simultaneously, the systems will become "loaded," or heavily utilized, so that the control of levels of the individual channels and the group levels becomes very important in order to preclude crosstalk. Data transmission engineers have developed specific level-setting parameters to ensure that as the circuit loading increases, crosstalk will not become a problem.

Echo suppressors - As discussed already, echo suppressors or echo can-cellers are used on long-distance circuits, in an effort to overcome echoes caused by circuit imbalances. This is of significance to Characteristics of Data Transmission Circuits because a lot of it occurs over the public switched telephone network, nationally and internationally.

Distortion - Communication channels tend to react to signals of different speeds within their bandpass in different ways. Specifically, signals of different frequencies can be passed by the channel with different values of amplitude attenuation and at different propagation speeds. The result is distortion.

Of great importance to systems using phase modulation is phase delay (or envelope delay) distortion. Phase delay distortion occurs in a channel when signals of one frequency are passed through the circuit at a different speed than other signals. The resulting distortion can take the form of

intersymbol interference. Since characters which have lower-frequency components pass at a different speed than data characters with high-frequency components, it is possible in higher-speed circuits for portions of one character to enter or remain in the time slot allocated to other characters.

Equalizers - Phase delay distortion can be reduced to acceptable levels by using equalization on the channel. As shown in Figure 14-19, it is possible to plot the delay characteristics of the channel and insert an equalizer which can be adjusted to compensate for the delay abnormalities. The result is a channel relatively free of phase delay.

CH-5 MODEM

What is MODEM?

A modulator-demodulator or modem is a computer hardware device that converts data from a digital format into a format suitable for an analog transmission medium such as telephone or radio. A modem transmits data by modulating one or more carrier wave signals to encode digital information, while the receiver demodulates the signal to recreate the original digital information. The goal is to produce a signal that can be transmitted easily and decoded reliably. Modems can be used with almost any means of transmitting analog signals, from light-emitting diodes to radio.

What is the need of MODEM ?

- It connects the internet from the Internet Service Provider to your device.
- It modulates and demodulates the electric signals from analog to digital and vice-versa.
- It basically provides a secure connection to your device.

Working Principle of MODEM:-

In a configuration like this, a dumb terminal at an off-site office or store could "dial in" to a large, central computer. The 1960s were the age of time-shared computers, so a business would often buy computer time from a time-share facility and connect to it via a 300-bit-per-second (bps) modem.

A dumb terminal is simply a keyboard and a screen. A very common dumb terminal at the time was called the DEC VT-100, and it became a standard of the day (now memorialized in terminal emulators worldwide). The VT-100 could display 25 lines of 80 characters each. When the user typed a character on the terminal, the modem sent the ASCII code for the character to the computer. The computer then sent the character back to the computer so it would appear on the screen.

FEATURES OF MODEM:

- Fewer Ethernet ports in comparison to a Router.
- A public IP Address.

- Use of Wide Area Network (WAN) for transmission.
- Auto-answer capability.
- Data/Voice capability.
- Fax capability.
- High uploading and communication rates.
- Upgradeable through a software patch to meet almost any universal standard.
- Enable high-speed downstream data transfers by digitally encoding all downstream data while upstream runs at conventional rates of 33.6 kbps.

MODULATION :

The process by which data/information is converted into electrical/digital signals for transferring that signal over a medium is called modulation. It increases strength for maximum reach of the signals.

FUNCTIONS OF A MODEM :

- Modulated Signals The primary function of a modem is to modulate digital signals into analog signals for transmission over traditional analog communication channels.
- Data Compression Data compression is another critical function of a modem.

- Error Correction
- Flow Control
- Modem Speed Classification
- Internal vs. External Modems
- Broadband: Cable and ADSL Modems

MODULATION METHOD :-

i. Analog to Analog Modulation - Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us. An example is radio. The government assigns a narrow bandwidth to each radio station. The analog signal produced by each station is a low-pass signal, all in the same range.

ii. Digital to analog modulation - Digital-to-Analog conversion or digital-to-analog modulation is the phase of converting one of the features of an analog signal depending on the data in a digital signal (0s and 1s) when we communicate information from one system to another across a public access phone line. For example, the initial data are digital, but mobile services use analog signals, the information should be transformed. The digital data should be inflected on an analog signal manipulated to a view like two definite

values equivalent to binary 1 and binary 0.

iii. DEMODULATION - Demodulation is defined as extracting the original information-carrying signal from a modulated carrier wave. A demodulator is an electronic circuit that is mainly used to recover the information content from the modulated carrier wave. There are different types of modulation, and so are demodulators. The output signal via a demodulator may describe the sound, images, or binary data.

Analog to digital conversion - In electronics, an analog-to-digital converter (ADC, A/D, or A-to-D) is a system that converts an analog signal, such as a sound picked up by a microphone or light entering a digital camera, into a digital signal. An ADC may also provide an isolated measurement such as an electronic device that converts an analog input voltage or current to a digital number representing the magnitude of the voltage or current. Typically the digital output is a two's complement binary number that is proportional to the input, but there are other possibilities.SPE[iv].

MODEM DATA TRANSMISSION - Transmission speed is the rate at which data packets cross a computer network from one server to another. Transmission speed is typically measured in megabits per second (Mbps), which equals one million bits per second, although gigabit and even terabit speeds are becoming common. The speed of light is considered the ideal rate of data

transmission; transmission speed across cables or wires is a fraction or percent of that.

MODEM INTERCONNECTION - The modem at the transmitting end converts the digital signal generated by DTE into an analog signal by modulating a carrier. This modem at the receiving end demodulates the carrier and hand over the ,demodulated digital signal to the DTE. The transmission medium between the two modems can be dedicated circuit or a switched telephone circuit.

CHAPTER- 06

SPACE AND TIME SWITCHING.

CIRCUIT SWITCHING

Circuit switching is a communication method where a dedicated communication path, or circuit, is established between two devices before data transmission begins. The circuit remains dedicated to the communication for the duration of the session, and no other devices can use it while the session is in progress. Circuit switching is commonly used in voice communication and some types of data communication.

Advantages of Circuit Switching:

- Guaranteed bandwidth: Circuit switching provides a dedicated path for communication, ensuring that bandwidth is guaranteed for the duration of the call.
- Low latency: Circuit switching provides low latency because the path is predetermined, and there is no need to establish a connection for each packet.
- Predictable performance: Circuit switching provides predictable performance because the bandwidth is reserved, and there is no

competition for resources.

- Suitable for real-time communication: Circuit switching is suitable for real-time communication, such as voice and video, because it provides low latency and predictable performance.

Disadvantages of Circuit Switching:

- Inefficient use of bandwidth: Circuit switching is inefficient because the bandwidth is reserved for the entire duration of the call, even when no data is being transmitted.
- Limited scalability: Circuit switching is limited in its scalability because the number of circuits that can be established is finite, which can limit the number of simultaneous calls that can be made.
- High cost: Circuit switching is expensive because it requires dedicated resources, such as hardware and bandwidth, for the duration of the call.

MESSAGE SWITCHING

Message Switching –

Message switching was a technique developed as an alternative to circuit switching before packet switching was introduced. In message switching, end-users communicate by sending and receiving *messages* that included the entire data to be shared. Messages are the smallest individual unit.

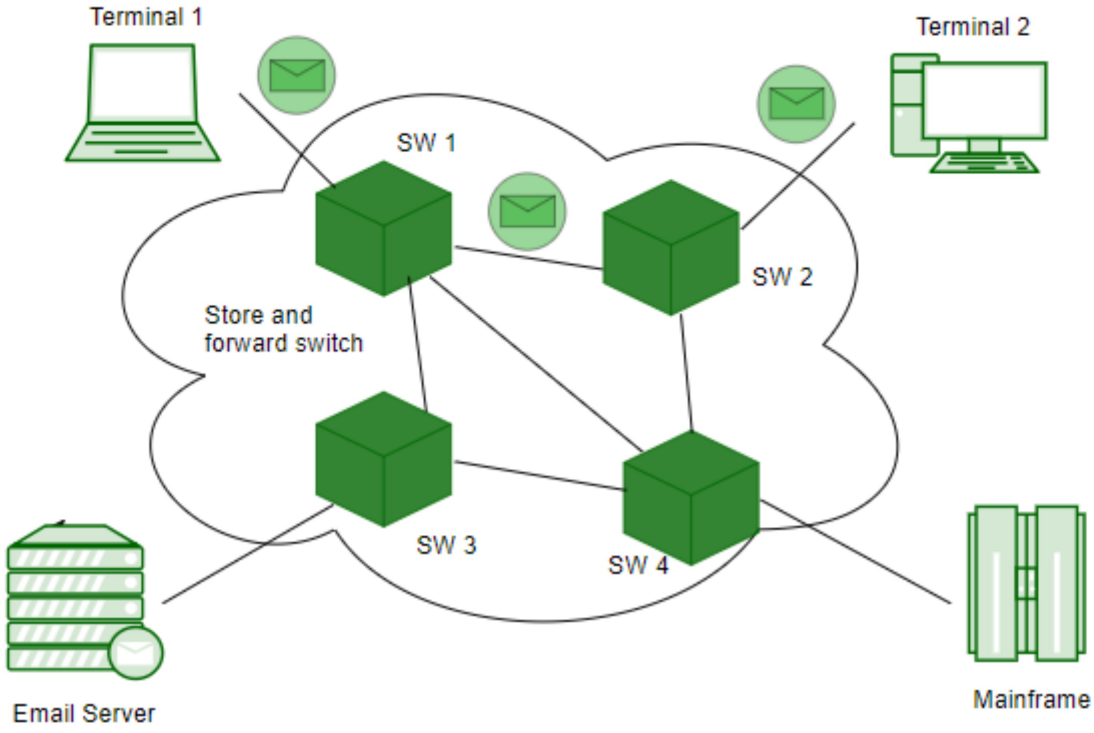
Also, the sender and receiver are not directly connected. There are a number of intermediate nodes that transfer data and ensure that the message reaches its destination. Message switched data networks are hence called hop-by-hop systems.

They provide 2 distinct and important characteristics:

1. **Store and forward –** The intermediate nodes have the responsibility of transferring the entire message to the next node. Hence, each node must have storage capacity. A message will only be delivered if the next hop and the link connecting it are both available, otherwise, it'll be stored indefinitely. A store-and-forward switch forwards a message only if sufficient resources are available and the next hop is accepting data. This is called the store-and-forward property.

2. **Message delivery –** This implies wrapping the entire information in a single message and transferring it from the source to the destination node. Each message must have a header that contains the message

routing information, including the source and destination.
Message switching network consists of transmission links (channels), store-and-forward switch nodes, and end stations as shown in the following picture:



Characteristics of message switching –
Message switching is advantageous as it enables efficient usage of network resources. Also, because of the store-and-forward capability of intermediary nodes, traffic can be efficiently regulated and controlled. Message delivery as one unit, rather than in pieces, is another benefit. However, message switching has certain disadvantages as well. Since messages are stored indefinitely at each intermediate node, switches require a large storage capacity. Also, these are pretty slow. This is because at each node, first there is a wait till the entire message is received, then it must be stored and transmitted after processing the next node and links to it depending on availability and channel traffic. Hence, message switching cannot be used for real-time or interactive applications like a video conference.

Advantages of Message Switching –
Message switching has the following advantages:
1. As message switching is able to store the message for which communication channel is not available, it helps in reducing the traffic

congestion in the network.
2. In message switching, the data channels are shared by the network devices.
3. It makes traffic management efficient by assigning priorities to the messages.
4. Because the messages are delivered via a store and forward method, it is possible to include priority in them.
5. It allows for infinite message lengths.
6. Unlike circuit switching, it does not necessitate the actual connection of source and destination devices.

Disadvantages of Message Switching –

Message switching has the following disadvantages:

1. Message switching cannot be used for real-time applications as storing messages causes delay.
2. In message switching, the message has to be stored for which every intermediate device in the network requires a large storing capacity.
3. Because the system is so intricate, people are frequently unaware of whether or not messages are correctly conveyed. This could cause problems in social relationships.
4. The type of message switching does not create a dedicated path between the devices. It is not dependable communication because there is no direct relationship between sender and receiver.

PACKET SWITCHING

Packet switching is a communication method where data is divided into smaller units called packets and transmitted over the network. Each packet contains the source and destination addresses, as well as other information needed for routing. The packets may take different paths to reach their destination, and they may be transmitted out of order or delayed due to network congestion.

Advantages of Packet Switching:

- Efficient use of bandwidth: Packet switching is efficient because bandwidth is shared among multiple users, and resources are allocated only when data needs to be transmitted.
- Flexible: Packet switching is flexible and can handle a wide range of data rates and packet sizes.
- Scalable: Packet switching is highly scalable and can handle large amounts of traffic on a network.

- Lower cost: Packet switching is less expensive than circuit switching because resources are shared among multiple users.

Disadvantages of Packet Switching:

- Higher latency: Packet switching has higher latency than circuit switching because packets must be routed through multiple nodes, which can cause delay.
- Limited QoS: Packet switching provides limited QoS guarantees, meaning that different types of traffic may be treated equally.
- Packet loss: Packet switching can result in packet loss due to congestion on the network or errors in transmission.
- Unsuitable for real-time communication: Packet switching is not suitable for real-time communication, such as voice and video, because of the potential for latency and packet loss.

DIGITAL SWITCHING

The term digital switching refers to a networked method of replacing conventional DC mechanical switches and circuit breakers. In comparison to mechanical circuit breakers, digital switching systems are programmable and can control electronic systems remotely. Digital switching incorporates a single power source with one connection to each load. This eliminates many of the parts and connections required by traditional mechanical systems, significantly reducing the likelihood of failure, corrosion, or other problems.

Digital switching modules are securely sealed to be completely protected from even the most challenging environments. Using a digital switching system that operates on an NMEA 2000 network allows users to control onboard electronic systems, such as lighting, bilge pumps, and security systems, from any area within the NMEA network using a connected device like a smartphone.

DIGITAL TELEPHONY

Digital telephony is used by any equipment with internet connection, and it **allows you to make and receive VoIP calls**. This technology enables a greater transmission capacity. So, both voice and data can travel at the same time. Digital telephony is not new, it has been on the market since the end of the 90s. But it has become widespread in recent years thanks to the improvement of voice quality and the expansion of the internet.
The “Voice over Internet Protocol”, known worldwide as VoIP, is responsible for the transmission of voice traffic over Internet networks. You can use this instead of the traditional telephone networks. It **allows you to**

have telephone conversations using the Internet network.
Digital telephony has become the most widely used form of communication by businesses. It has replaced traditional telephone systems and analogue telephone lines.

WORKING OF DIGITAL TELEPHONY

Since it is a cloud-based telephony, we can say that digital telephony works through the Internet. More specifically, it uses **"Internet protocols"** to communicate by digital means, so the user communicates thanks to the Internet connection. This facilitates the convergence of multiple systems into one. That is, employees can enjoy a digital telephony tool that **unifies the company's communications.**

Advantages of digital telephony

Digital telephony has many advantages. It becomes noticeable especially when compared to analogue lines.
What are analogue lines? These lines belong to the Switched Telephone Network. They are part of the **traditional** telephony. This telephony works with copper cables that transmit electrical signals. These signals are converted into sound waves, and then they transfer the voice into the call. Analogical lines allow **only one communication per contracted line.** Besides, each line goes under a geographic number. Therefore, in order to receive several simultaneous calls, it is necessary to contract as many lines as channels are desired.

SPACE SWITCHING

When we consider Space switching there is a dedicated path (two parallel wires) established between the caller and called subscribers for the entire duration of call in the exchange by the switch. It was originally designed for analog networks, but is used currently in both digital and analog switching. This means then the conversation is going on the switch create the link between two sides. At that time only that call is going in the path.

TIME SWITCHING

Time division switching involves the sharing of cross points for shorter periods of time. This paves way for the reassign of cross points and its associated circuits for other needed connections. Therefore, in time division switching, greater savings in cross points can be achieved. Hence, by using dynamic control mechanisms, a switching element can be assigned to many inlet-outlet pairs for few microseconds. This is the principle of time division switching. Time division switching uses time division multiplexing to achieve switching. Two popular methods that are used in time division multiplexing are (a) the time slot interchange (TSI) and (b) the TDM bus. In ordinary time division multiplexing, the data reaches the output in the same order as they sent. But TSI changes the ordering of slots based on the desired connections. The de-multiplexer separates the slots and passes them to the proper outputs. The TDM uses a control unit. The control unit opens and closes the gates according to the switching need. The principle of time division switching can be equally applied to analog and digital signals.

SPACE TIME SPACE SWITCHING(STS)

One objective in the design of a modern digital switching system is to reduce costs and improve the switching efficiency of the fabric. Obviously there is a practical limit to the size of a single switching stage that can be effectively utilized. At present, various combinations of S switches and T switches are used to accomplish the above objective. One combination uses an S switch followed by a T switch and a final S switch. This arrangement, referred to as STS fabric, is shown in Fig. 2.6. This particular arrangement depicts N x M (meaning N inputs and M outputs) size, with NS switches separated by MT switches. In an STS switching fabric, a path through the network is established via smart network controllers that link an incoming time slot with an outgoing time slot. This type of time slot

linkage is then dynamically updated throughout the duration of a call. F

TIME SPACE TIME SWITCHING(TST)

One of the most popular switching fabric arrangements currently deployed by digital switching systems is based on time-space-time (TST) architecture, as shown in Fig. 2.7 An incoming time slot enters a T switch; a path is hunted through the S switch for an appropriate outgoing time slot; and once identified, the path through the switching fabric is established and dynamically updated throughout the duration of the call. One of the basic advantages of the TST architecture over the STS architecture is that it can be implemented at a lower cost, since T switches are less expensive than S switches and under heavy traffic offer more efficient utilization of time slots with lower blocking probabilities.

TIME AND SPACE SWITCHES

Time Switch

The figure-1 depicts concept of time switch. As shown it is basically a time slot interchanger (ISI). A time slot in PCM consists of 8 bits and represents 1 voice channel. The time slot is repeated 8000 times in a second. DS1 has 24 time slots in a frame and E1 has 32 time slots in a frame. Refer T1 Frame Vs E1 Frame for more information.

As shown in the figure, connectivity is established between user-C on slot-C to user-G on Slot-G. In order to perform time switch operation following steps are needed:

• Memory to store time slot speech data to write and to read at the output for changing the position.

• Memory to store control action to be performed on the stored data.
• Time slot counter or processor.

Space Switch

Figure-2 depicts time division space switch. It consists of cross point matrix made up of logic gates which allow switching of time slots in spatial domain. There will be input horizontals and output verticals with logic gate at each of the crosspoints of the space switch.

A tandem switching centre, or the route switch of a local exchange must be able to connect any channel on one of its incoming PCM highways to any channel of an outgoing PCM highway. The incoming and outgoing highways are spatially separate. Hence connection here need space switch.

In general, a connection will occupy different time slots on the incoming and outgoing highways. Hence switching network must be able to receive PCM samples from one time slot and re-transmit them in a different time slot. This is referred as time slot interchange or simple time switching.

Figure mentions the data transmitted on time slot no. 1 and 2 are later transmitted on time slot no. 24 of stream A and stream B at the output. Consequently, switching network of a tandem exchange or route switch of a local exchange must perform both time switching as well as space switching.

Space switch is like matrix of N x M physical lines. Time switch is like

memory having data at its different consecutive address locations.

TWO STAGE COMBINATION SWITCHES

Time multiplexed time division space switches do not provide full availability as they are not capable of performing time slot interchange. Time slot interchange switches are not capable of switching sample values across the trunks without the help of some space switching matrices. Therefore, a combination of the time and space switches leads to configurations that achieve both time slot interchange and sample switching across trunks. simultaneous connections to be supported for a given technology. A combination switch can be built by using a number of stages of time and space switches. A two-stage combination switch may be organized with time switch as the first stage and the space switch as the second stage or vice versa. Accordingly, the two switch configurations are known by the nomenclature time-space (TS) or space-time (ST) switches respectively. Each time multiplexed inlet/outlet stream carries M channels. A subscriber on the input side is assigned to one of the inlets and a time slot in that inlet. An input subscriber assigned to line i at time slot j is identified by the label Iij. Similarly, a subscriber connected to the outlet m and time slot n is identified by 0mn.The corresponding time slots are identified as lSij and OSmn. Theoretically, the TS switch can be made nonblocking by using an expanding time switch and a concentrating space switch. In the worst case, all the subscribers in one line may want to establish connection to the same output time slot. In order that they can be accommodated without blocking, we need (M - 1) additional slots for each time slot. The space switch must be able to establish M connections for each input time slot. This implies M2 time slots on the output side of TSI. A time switch providing expansion from M inlet time slots to M2 outlet time slots is very expensive. Moreover, the space switch at the second stage has

to concentrate the time slots on the output side. Design of such a space switch is complex. Instead, the space switch may be symmetric with regard to time slots and a concentrating TSI switch may be added as another stage in the network. Similar to a TS switch, the Space-Time switch is also blocking. This happens when the input samples originate from two different inlets during the same time slot and are destined to the same outlet though to different time slots.

3 STAGE COMBINATION SWITCHES

Three-stage time and space combination switches are more flexible than their two-stage counterparts. The most common three-stage configurations are: Those which place time stages on either side of a space stage giving rise to TST configuration Those which place space stages on either side of a time stage giving rise to STS configuration. A TST network is shown in the figure below. The two time stage exchange information between external channels and the internal space array Version .The first flexibility that becomes obvious in this arrangement is that there is no need to have a fixed space stage time slot for a given input or output time slot. There are many alternative paths between a prescribed input and output unlike a two stage network which has only one fixed path. This factor reduces the value of the blocking probability of a three-stage Three-stage combina combination switch. tion switches are still blocking. Consider a situation when (M -1) slots in an inlet Ij are all busy. Let traffic arrive in the Mth slot destined to a time slot outlet Ok. It is possible that during the time slot M, the outlet Ok is busy receiving some other output. As a result, blocking occurs. The worst case happens when (M -1) slots of Ok are busy and the outlet is occupied for this purpose during (M - 1) slots when the inlet Ij is free. If this happens, we would need one more additional time slot to establish a connection between the free time slots of Ij and Ok. This means that we need a total of (M-1) + (M-1) + 1 time slots, i.e. 2M- 1 time slots in

the intermediate space stage.