ENJOY YOUR Communication System

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PREFACE

ENJOY YOR COMMUNICATION SYSTEM introduces the readers to the concepts of communication system. This book covers the principles of communications, analog and digital modulation techniques, multiplexing and transmission medium. It also exposes the readers to the basic of data communication system.

In advance, the readers will be able to apply the concept of electronic communication system by using appropriate diagram and standard formula and can participate in assembling the related communication equipment systematically to perform the measurement of appropriate signals parameter.

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3.0 MULTIPLEXING & TRANSMISSION MEDIUM

4.0 DATA COMMUNICATION

CHAPTER 1

INTRODUCTION TO COMMUNICATION SYSTEM

1.1 What would you get?

- Know the element in basic communication system.
- Know noise, interference, and distortion.
- Know Signal-to-Noise Power Ratio, Noise Factor and Noise Figure.
- Apply SNR, Noise Factor, and Noise Figure formula.
- Know the frequency spectrum, bandwidth, and wavelength.
- Apply bandwidth and wavelength formula.
- Understand Transmission Modes.
- Understand various types of communication system.

1.2 Communication

DEFINITION: Communication system is a process of transmission, reception and processing the information ***between two or more*** locations through transmission medium.

Examples:

- People–people, people–peoples,
- Computer–computer, computer–computers
- People–computer

1.3 Telecommunication

HISTORY:

- **TELE** (in Latin) = Far
- **COMMUNICATION** = Process of sending the information between two or more locations through transmission medium.
- **TELECOMMUNICATION** = Process of sending the information between two or more locations through transmission medium at **far** distance.
- **Early Telecommunication:**

  1. In earlier times, telecommunications involved the use of visual signals or audio signals such as;

     i. Smoke signals, Flag signals

     ii. Coded drumbeats, Lung-blown horns

     iii. Visual telegraphy (or Semaphore in 1792)

- **Modern Telecommunication:**

  1. In the modern age of electricity and electronics, telecommunication has typically involved;

     i. Telegraph (1839), Telephone (1876), Teletype, Radio, TV

     ii. Microwave Communication – Satellite, Radar, Cellular

     iii. Data Communication – Internet, Computer communication

     iv. Fiber Optic Communication.

Claude Shannon's General Communication Model

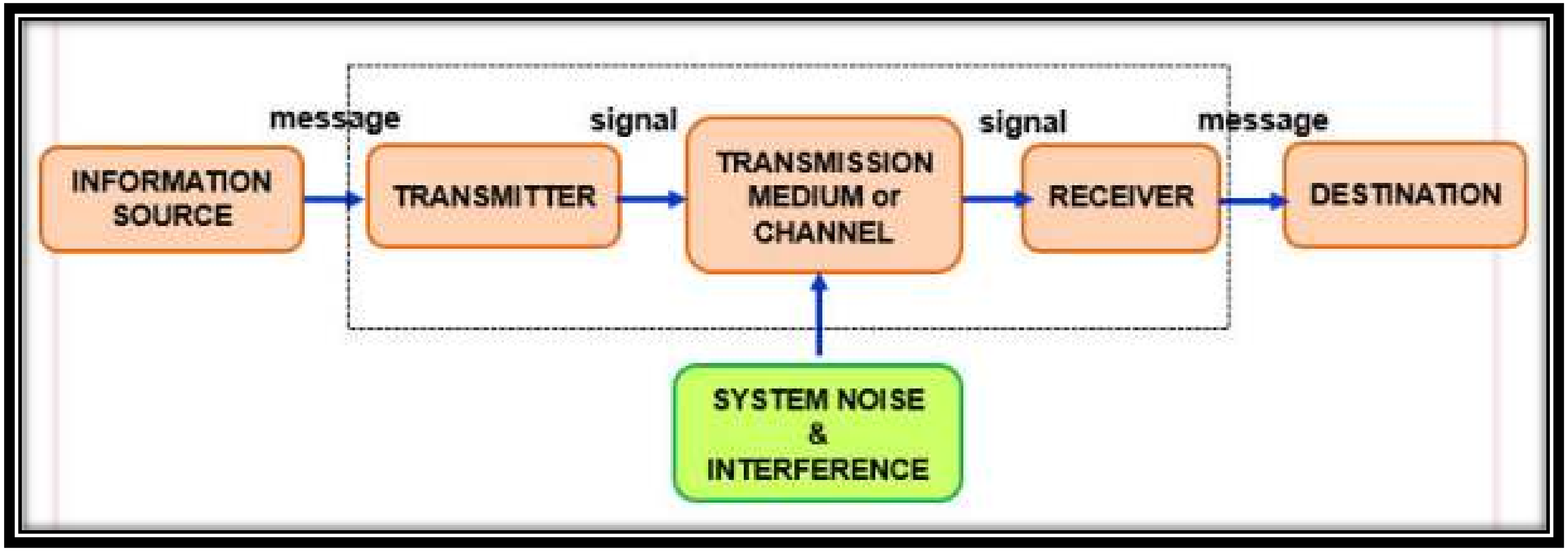


Figure 1.1: Shannon's Basic Block Diagram of an Electronic Communication System

1.4 Elements of Communication System

- From Figure 1.1: **Shannon's basic communication block diagram**, there are **FIVE (5) + ONE (1)** elements that must have in basic communication system which are:
  1) Information Source
  2) Transmitter (Tx)
  3) Transmission Medium or Communication Channel
  4) Receiver (Rx)
  5) Destination
  6) System Noise

1. Information Source

2. The original source that generate the information (audio, text, image or video) that need to be transferred to Receiver.
3. The information that have been generated by source could be an analog form (human voice, audio) or digital form (binary coded numbers, alphanumeric codes).
4. Examples: ***people***, ***computer***, ***hand phone***, ***electronic devices***

2. Transmitter

- ✓ A collection of one or more electronic devices or circuits that converts the original source information to a form more suitable for transmission over a particular transmission medium.
- ✓ Includes the modulation, multiplexing and encoding process.
- ✓ Examples: ***Modulator***, ***Multiplexer***, ***Transducer***, ***Encoder***, ***Light Source*** etc.

3. Transmission Medium / Channel

- ✓ Transmission Medium or Communication Channel is a **media/link/path** that capable to transfer the electronic signal from Transmitter to receiver.
- ✓ Examples: ***Twisted Pair Cable***, ***Coaxial Cable, Fiber Optic Cable, Waveguide, Microstrip, Free Space***, etc.

4. Receiver

- ✓ A collection of **one or more** electronic **devices** or **circuits** that **accept** the transmitted signals from the transmission medium and then **convert back** to their original information form.
- ✓ Includes the **demodulation, demultiplexing** and **decoding** process.
- ✓ Examples: ***Demodulator, Demultiplexer, Transducer, Decoder, Photo Detector,*** etc.

5. Destination

- ✓ Anything that **receive** the transmitted **information** and capable to ***store*** them.
- ✓ Examples: ***people, computer, hand phone, electronic devices.***

6. System Noise

- ✓ Noise is any **unwanted** electrical signals that **interfere** with the information signal.
- ✓ Examples: ***Atmospheric noise, Thermal Noise, Man-made Noise, Cosmic Noise, Internal Noise*** etc.

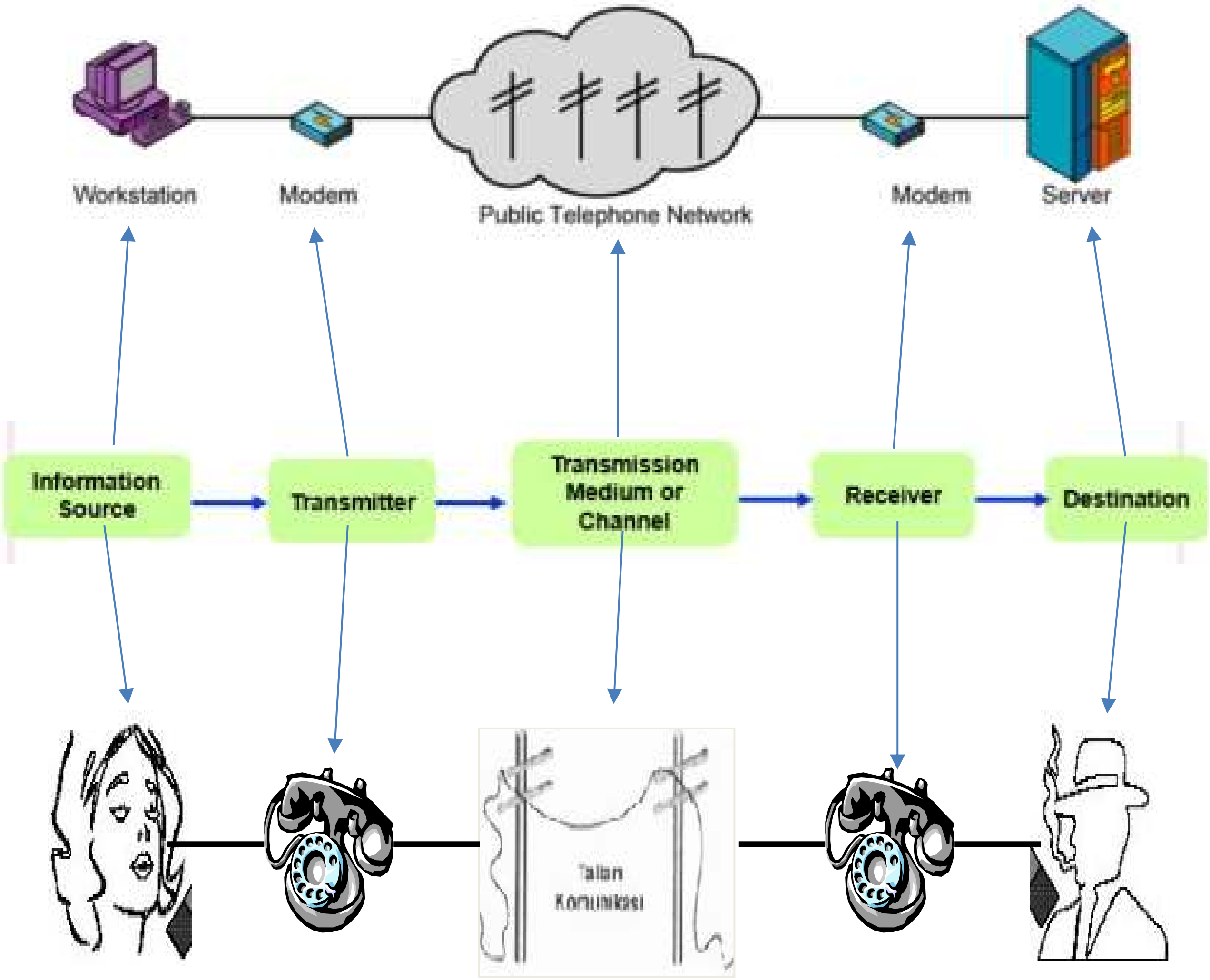


Figure 1.2: Telephony Communication System Block Diagram

1.5 Information, Message & Signal

- Information

  1. Information = ***knowledge*** = ***intelligence***.
  2. Information is an ***original source information*** which do NOT processed yet by transmitter or do NOT converted ***into signal***.
  3. It can be stored in ***people*** or ***any devices*** like computer, digital camera, video camera, recorder etc.
  4. Examples: audio, alphanumeric, text, image, video

- Message

  1. Message represents ***the content*** of Information.

- Signal

  1. Signal is a ***converted*** **information** into **time-varying** or **spatial-varying** quantity that ***could be measured.***
  2. Signal can be an **electric current, light** or **electromagnetic wave** which is used to convey data from one place to another.
  3. A signal may be expressed as a function of **time** or **frequency**.
  4. When a signal is expressed as a function of time, there are **two basic types** of signals.
     i. **Digital Signal** (Discrete-time signal)
     ii. **Analog Signal** (Continuous-time signal)

ANALOG SIGNAL

A **continuous** or infinite signal that generates **continuous values,** leading to continuous wave pattern. It has **infinite (uncountable)** of **amplitudes**.

For example; human voice, audio etc.

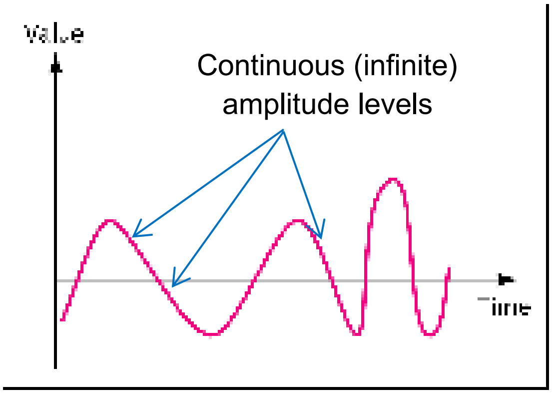


Figure 1.3: Analog Signal

DIGITAL SIGNAL

A **discrete** or finite signal that generates and process data in form of zeroes and ones (**0**s and **1**s). It has **finite (countable)** set of **amplitudes**.

For example; binary-encoded digit, alphanumeric codes, computer-generated data, digitally encoded analog signals etc.

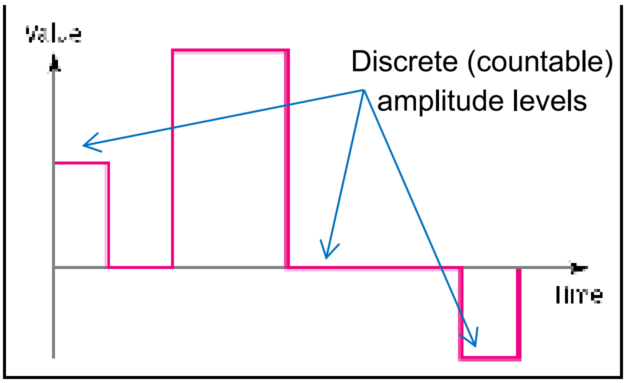


Figure 1.4: Digital Signal

1.6 Noise, Distortion & Interference

- **Noise**

  1. Definition: ***Noise*** is **unwanted signal** from sources other than the transmitted signal source.

  2. It is a signal that does not convey any information.

  3. ***Electrical noise*** is defined as any **unwanted electrical signal** that falls within the **passband** of the signal.

  4. For example, in audio recording, any **unwanted electrical signals** that fall within the audio frequency band of 0 Hz to 15kHz will interfere the music will be considered as **NOISE**.

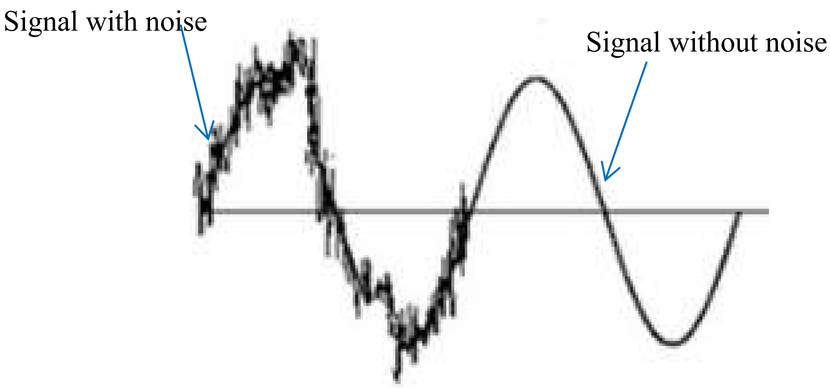


Figure 1.5: Signal with and without noise

- Particularly noise can be divided into two general categories:

  1. Correlated Noise (No Signal, No noise)
  2. Uncorrelated Noise (Always has noise in the system)

- Uncorrelated Noise is divided into 2 groups:

  1. External Noise
  2. Internal Noise

- **External Noise**

    1. Definition: External Noise is the noise which is generated **outside** the device or circuit system.

    2. External noises are somewhat **uncontrollable** and these are:
        1. Atmospheric Noise
        2. Extra-Terrestrial/ Space Noise
        3. Man-made or Industrial Noise

1. Atmospheric Noise

- ✓ It is caused by **lighting discharge** in **thunderstorm** and other **natural disturbance** in atmosphere.
- ✓ It spreads over the complete frequency spectrum which is used for radio communication.
- ✓ The **receiving antenna** not only picks up the desired signal but also the noise from thunderstorm and various disturbance causes at the output.
- ✓ Thus, large atmospheric noise is generated in **low or medium frequency band (LF @ MF)** while very little noise is generated in very high frequency (VHF) band.

2. Extra-Terrestrial/ Space Noise

- ✓ Space noise is divided into two categories:
    1. Solar noise
    2. Cosmic noise
- ✓ Solar noise
    - Solar noise is an **electrical noise** generated from the **sun** heat
    - This is continuous radiation from sun.
    - For example, result from large body of **very high temperatur**e (60000°C) will radiate **electrical energy spectrum** which is in the

form of noise which spread over all the spectrum used for radio communication.

- ✓ Cosmic noise
    - Cosmic noise is an **electrical noise** generated from the **galaxies** such as star.
    - The star and distant also like a sun which have high temperature.
    - Therefore, these stars radiate the noise in the same way as sun.
    - The noise receives from the distant, star is known as **thermal noise** and distributed almost uniformly over the entire and almost effects on communication of radio waves.

3. Man-made or Industrial Noise
    - ✓ It is an **electrical noise** which produced by a source like **automobiles** such as an aircraft ignition, electric motors, switch gear leakage from higher voltage light, etc.
    - ✓ Fluorescent light and many of man-made noise like electrical machine are intensive in industrial area and populated urban area.

- **Internal Noise**
    - ✓ Definition: Internal Noise is the noise which is generated inside the communication system, within a device or circuit.
    - ✓ It is produced by properly design of receiver circuitry and these are:
        1. Thermal Noise
        2. Shot Noise
        3. Transit-time Noise

1. Thermal Noise
    - ✓ Thermal noise is produced by the **random motion of electrons** in a conductor due to **heat (thermal agitation)**.
    - ✓ Each electron in a conductor carry a unit negative charge and its velocity is proportional to the absolute temperature.
    - ✓ Because this type of electron movement is totally random and in all directions, it is sometimes called **random noise**.
    - ✓ Thermal noise is present in all electronic communications system.
    - ✓ It is a form of **additive noise** which meaning that it **cannot be eliminated** and it increases in intensity with the number of devices and circuit length.
    - ✓ Also known as **Brownian Noise**, **Johnson Noise**, and **White Noise** (because the random movement of electrons is at all frequencies).

2. Shot Noise
    - ✓ Shot noise is caused by the **random arrival** of current carriers (**holes and electrons**) at the **output** element of an electronic device, such as a **diode**, **field-effect transistor (FET)** or **bipolar transistor (BJT)**.
    - ✓ These **random arrival** of the carriers because of the **random paths** and difference distance of travels.
    - ✓ Shot noise is sometimes called **transistor noise** and is **additive** with **thermal noise**.

3. Transit-time Noise
    - ✓ Transit-time noise is any **modification** to a **stream of carrier signals** as they pass from the input to the output of a device (such as from the emitter to the collector of a **transistor**) produces an **irregular, random variation**.
    - ✓ Transit-time noise in **transistors** is determined by carrier mobility, bias voltage, and transistor construction.

- **Distortion**
  - Definition**: Distortion** is any **changes** in the original signal which has a **corrupting effect** on its form or shape.
  - It is the **modification** of the original **shape** (or **other characteristics**) of original information signal.
  - It creates **unwanted frequencies (Harmonics)** that **interfere** with the original signal and **degrade** the performance.
  - It is a kind of **Correlated noise** which the noise (distortion) is exist when the signal is exist.
  - Below diagram shows various types of distortion of original signal after passed through **various distorting functions.**

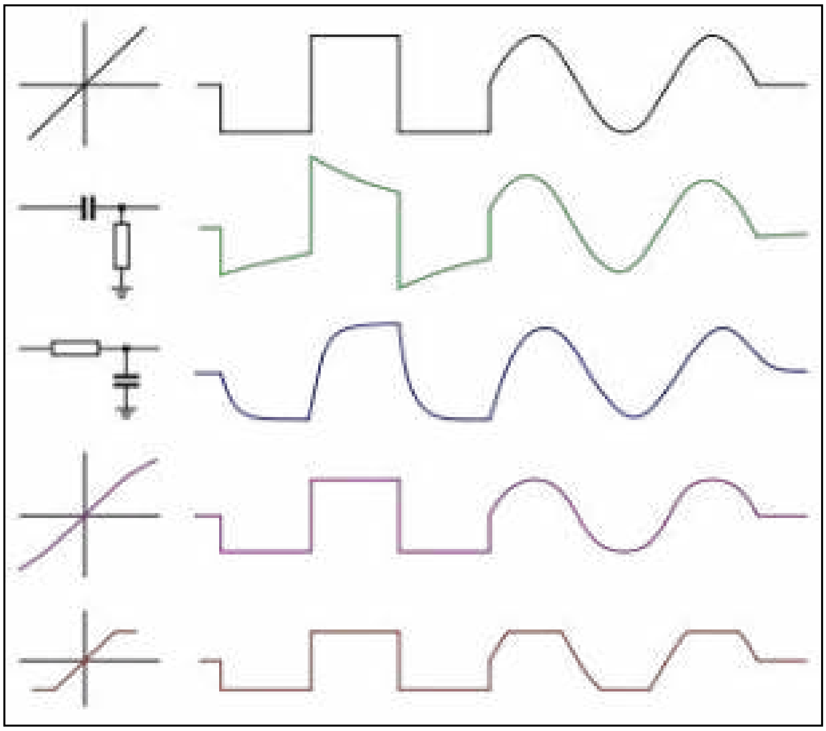


Figure 1.6: Distortion

  - The original signal is ***square wave*** shape but have been distorted, become a ***sine wave*** shape.

- Some possible types of ***nonlinear*** **distortion** are:
  - ✓ **Harmonic Distortion/ Amplitude Distortion:** Occurs when **unwanted harmonics** of a signal are produced through **non-linear amplification**. (*Noted: Harmonics are **integer multiples** of the original signal's frequency, e.g: **2**f_1**, 3**f_1**, etc..***)

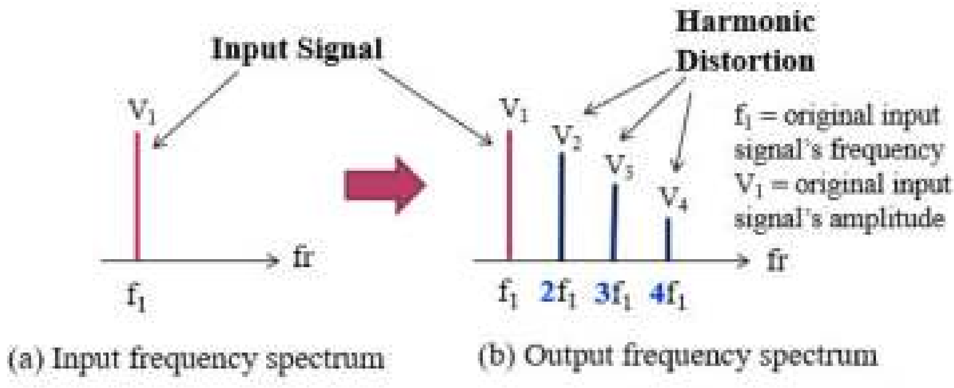


Figure 1.7: Harmonic Distortion

  - ✓ **Intermodulation Distortion:** The generation of **unwanted *sum (***f_1+f_2***)*** **and *difference (***f_1-f_2***)*** **frequencies** (or **cross-product frequencies**) produced when **2 or more signals** mix in a **nonlinear device**.

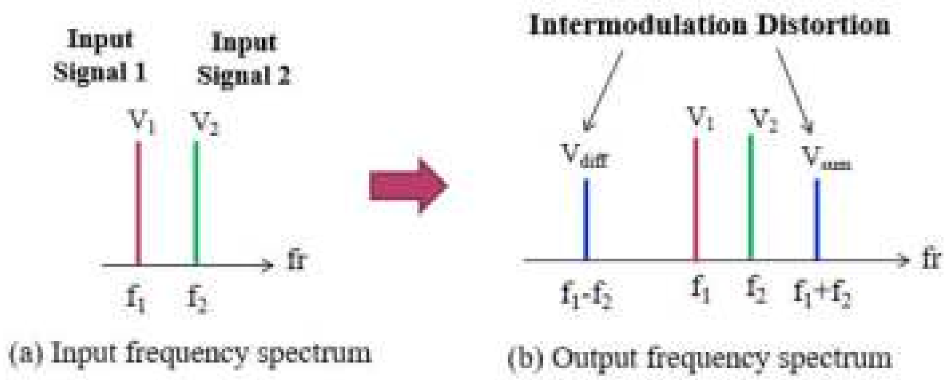


Figure 1.8: Intermodulation Distortion

- ✓ **Frequency Response Distortion:** A distortion that occurs when **different frequencies** are **amplified** by different amounts, caused by filters.
    - For example, the non-uniform frequency response curve of AC-coupled cascade amplifier. In the audio case, this is mainly caused by room acoustics, poor loudspeakers etc.

- ✓ **Phase Distortion:** A distortion that occurs due to the **reactive component,** such as **capacitive** reactance or **inductive** reactance. As the results, a **phase shift** occurs between components of the original signal.

- **Interference**
    - Definition**:** ***Interference*** is a form of **external noise_**which means **"to disturb or detract from"**
    - Interference is when **information signals** from **one source** produce **frequencies** that **fall outside** their **allocated bandwidth (Harmonics)** and **interfere** with information signals from **another source**.
    - Most of interference occurs when **harmonics** or **cross-product frequencies** from one source fall into the ***passband*** of a **neighbouring channel**.
    - For example, radio channels Interference where a channel is interfered by **adjacent radio channel's** frequencies.
    - Some possible types of interference are:
        - ✓ Adjacent-Channel Interference (ACI) - caused by extraneous power from a signal in an adjacent channel.
        - ✓ Co-Channel Interference (CCI) or **Crosstalk** - is crosstalk from two different radio transmitters using the same frequency.
        - ✓ Electromagnetic Interference (EMI) - is disturbance that affects an electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source.

✓ Inter-carrier interference (ICI) - caused by doppler shift in OFDM modulation

- **Signal to Noise Power Ratio (SNR)**
  - Definition**:** the **ratio** of **Signal Power(S)** to the **Noise Power(N)** which corrupting the signal.
  - Signal-to-Noise Power Ratio is also called as **SNR** or **S/N**.
  - SNR is a defining factor when it comes to **quality** of **measurement** where a **high SNR** guarantees clear acquisitions with **low distortions** caused by noise.
  - The better your SNR, the better the signal stands out, the better the quality of your signals, and the better you ability to get the results you desire.
  - How to calculate SNR?

- **SNR (unit less):**

$$SNR = \frac{S}{N} = \frac{P_S}{P_N}$$

$$SNR = \frac{V_S^2/R_{in}}{V_N^2/R_{out}}$$

where;
- S = signal power (watts)
- N = noise power (watts)
- V_S = signal voltage (volts)
- V_N = noise voltage (volts)
- R_{in} = input resistance (ohms)
- R_{out} = output resistance (ohms)

- **SNR (dB):**

$$SNR(dB) = 10\log\left(\frac{S}{N}\right) \qquad SNR(dB) = 10\log\left(\frac{V_S^2/R_{in}}{V_N^2/R_{out}}\right)$$

- **Noise Factor & Noise Figure**
  - Noise Factor (F) and Noise Figure (NF) are **figures of merit** used to indicate how much the signal to noise ratio **deteriorates** as a signal passes through a circuit or series of circuits.
  - Noise Factor (F):

$$F = \frac{Input\ signal - to - noise\ power\ ratio}{Output\ signal - to - noise\ power\ ratio}$$

$$F = \frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} (unitless)$$

  - Noise Figure (NF) is simply the noise factor stated in **dB** and is a parameter commonly used to indicate **the quality of a receiver**.

$$NF(dB) = 10logF$$

$$NF(dB) = 10log\left(\frac{SNR_{in}}{SNR_{out}}\right)$$

$$NF(dB) = 10log\left(\frac{S_{in}/N_{in}}{S_{out}/N_{out}}\right)$$

1.7 Frequency Spectrum

- The **electromagnetic frequency spectrum** is divided into **subsections**, or **bands** or **range** with each band having a different name and boundary.

- The International Telecommunications Union (ITU) is an international agency in control of allocation frequencies and services within the overall frequency spectrum.

- The ITU band designations are summarized as follows:

    1. **Extremely Low Frequencies (ELF)** - are signals in the **30 Hz to 300 Hz** range and include **AC power distribution** signals (60Hz) and low frequency **telemetry** signals.

    2. **Voice Frequencies (VF)** - are signals in the **300 Hz to 3000 Hz** range and include frequencies generally associated with **human speech**.

    3. **Very Low Frequencies (VLF)** - are signals in the **3 kHz to 30 kHz** range, which include the upper end of the **human hearing** range. VLFs are used for some specialized government and **military systems**, such as **submarine** communications.

    4. **Low Frequencies (LF)** - are signals in the **30 kHz to 300 kHz** range and are used primarily for **marine** and **aeronautical navigation**.

    5. **Medium Frequencies (MF)** - are signals in the **300kHz to 3 MHz** range and are used primarily for commercial **AM radio broadcasting** (535kHz – 1605kHz).

    6. **High Frequencies (HF)** - are signals in the **3MHz to 30 MHz** range and are often referred as ***short waves***. Most **two-way radio** communications use this range. Amateur radio and Citizens band (CB) radio also use signals in this range.

7. **Very High Frequencies (VHF)** - are signals in the **30 MHz to 300 MHz** range and are used for mobile radio, marine and **aeronautical** communications, commercial **FM broadcasting**, and commercial **television broadcasting** of TV1 and TV2.

8. **Ultra-High Frequencies (UHFs)** - are signals in the **300 MHz to 3 GHz** range and are used by commercial television broadcasting, land mobile communication services, **cellular telephones**, certain **radar,** navigation systems, **microwave** and **satellite** radio systems.

9. **Super High frequencies (SHF)** - are signals in the **3GHz to 30 GHz** range and include the majority of the frequencies used for **microwave** and **satellite** radio communications systems.

10. **Extremely High Frequencies (EHF)** - are signals in the **30 GHz to 300 GHz** range and are **seldom** used for radio communications except in very sophisticated, expensive, and specialized applications.

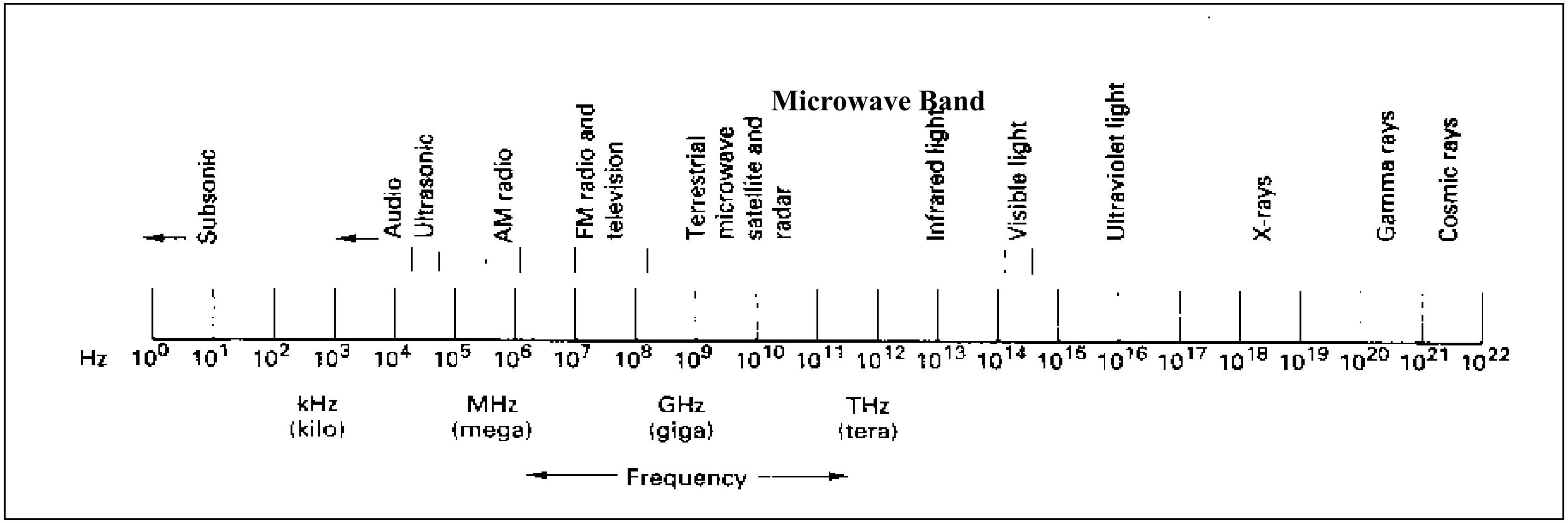
11. **Infrared -** Infrared frequencies are signals in the **0.3THz to 300 THz** range and are not generally referred to as radio waves. Infrared refers to **electromagnetic radiation** generally associated with **heat**. Infrared signals are used in the **heat-seeking guidance systems**, electronic photography, and **astronomy**.

12. **Visible Light** - Visible light includes electromagnetic frequencies that fall within the **visible range** of humans (**0.3 PHz to 3 PHz**). Light wave communications is used with **optical fiber systems**, which in recent years have become a primary transmission medium for electronic communications systems.

13. **Ultraviolet rays, X rays, Gamma rays, and Cosmic rays -** Ultraviolet rays, X rays, gamma rays, and cosmic rays have little application to electronic communications.

Frequency Band	Frequency	λ	Application
Very Low Frequency (VLF)	3 - 30 kHz	> 10000m	Telegraphy, human range frequency
Low Frequency (LF)	30-300 kHz	10000-1000m	Point to point, navigation
Medium Frequency (MF)	300K-3 MHz	1000-100m	AM radio broadcast, maritime/aeronautical mobile
High Frequency(HF)	3 - 30 MHz	100 - 10 m	Shortwave Broadcast Radio
Very high Frequency(VHF)	30 - 300 MHz	10 - 1 m	Low band: TV Band1- Channel 2-6, Mid band: FM radio, High Band: TV Band 2- Channel 7-13
Ultra High frequency (UHF)	300M - 1GHz	1 m - 10 cm	Mobile phone, Channel 14 - 70
Super high frequency (SHF)	3-30 GHz	0.01-0.001 m	Satellite communication, C-band, x- band, Ku-band, Ka-band.
Extremely High Frekuensi (EHF)	30 - 300 GHz	< 0.01m	Satellite, radar system, IR, UV, X-rays, Gamma Rays.

Table 1.1: Frequency Band



- Radio wave band:**1MHz - 1THz**
- Microwave band**: 0.3GHz - 300GHz (0.3THz)**
- Fiber optic band: **0.3THz – 300THz**

Figure 1.9: Electromagnetic Frequency Spectrum

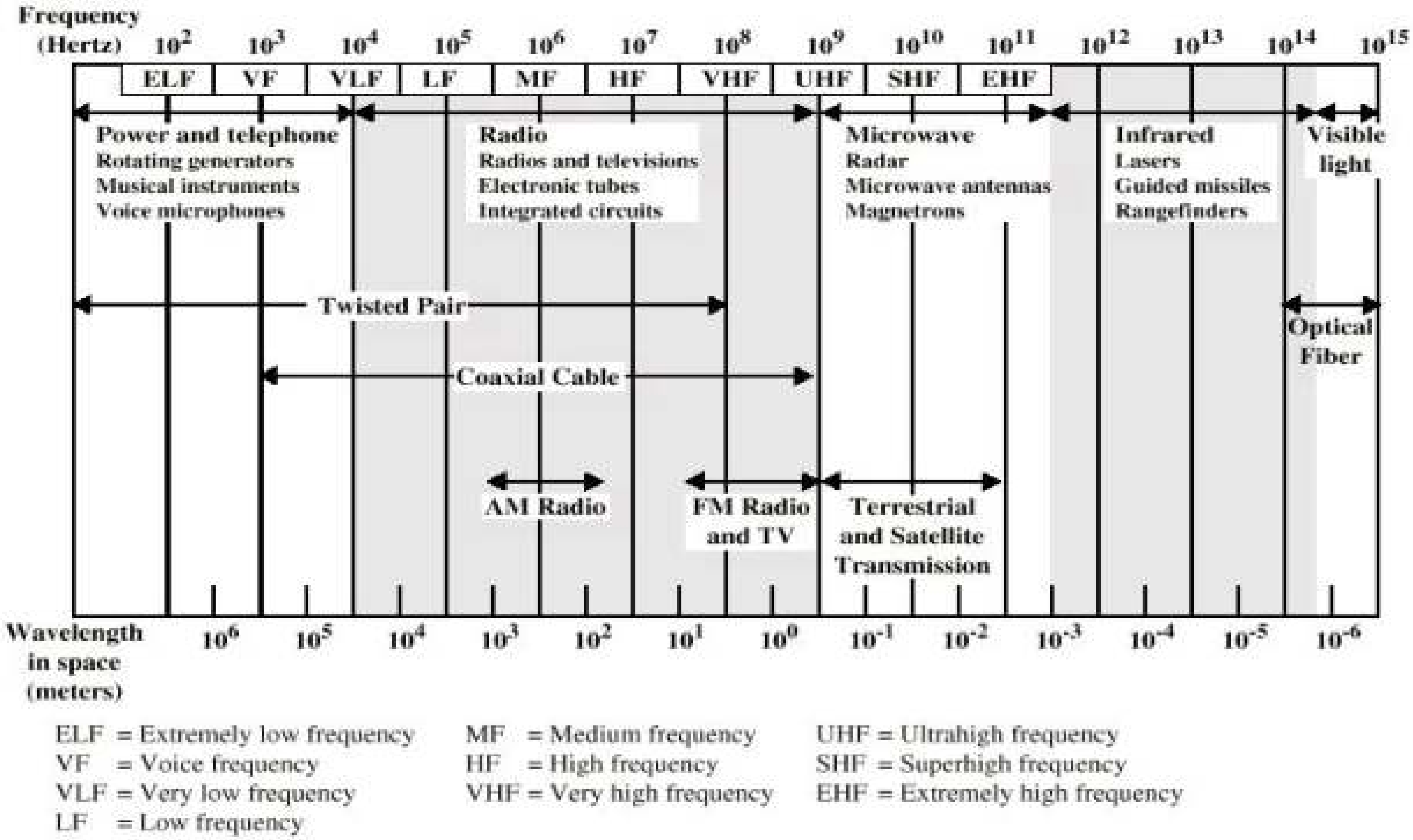


Figure 1.10: Frequency Spectrum

- **Bandwidth (BW)**
  - ✓ Definition: The range of frequencies = the difference between the highest and the lowest frequencies.
  - ✓ The bandwidth of a ***frequency spectrum*** is **the range of frequencies** contained in the **spectrum.**
  - ✓ The bandwidth of an ***information signal*** is simply **the difference between the highest and lowest frequencies** contained in the **information.**

BW (Hz) = frequency range = $f_{max} - f_{min}$

  - ✓ BW indicates the **capacity of data.** The larger size of BW means the bigger capacity of data and more data could be transfer at one time.

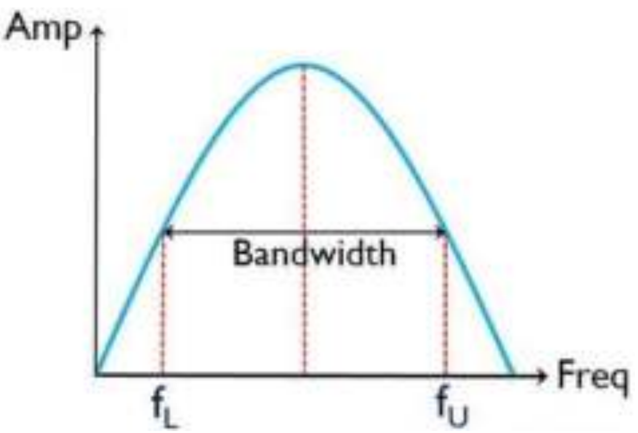


Figure 1.11: Bandwidth

- **Wavelength (λ)**
  - ✓ Definition: Wavelength is the **length** of one cycle (or **one oscillation**) of a waveform.

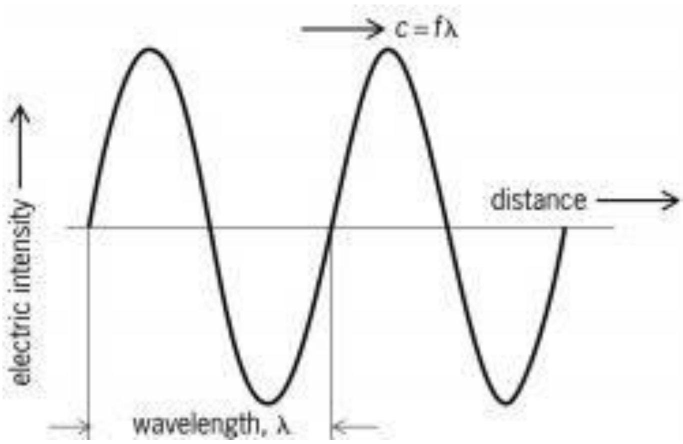


Figure 1.12: Wavelength

  - ✓ The relationship among frequency f, light velocity c, and wavelength λ is expressed mathematically as:

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

where;
λ = wavelength (meter)
c = velocity of light (3 x 10^8 m/s)
f = frequency (Hz)

  - ✓ From above equation, wavelength is **inversely proportional to the frequency** of the wave and **directly proportional to the velocity** of propagation

1.8 Transmission mode

- Transmission mode is the flow of information signal between two points.
- These modes direct the direction of flow of information signal.
- There are three modes of transmission for communications circuit:
    1. Simplex
    2. Half duplex
    3. Full duplex

1. Simplex
    - ✓ Information signal flows only in **one direction** on the transmission medium.
    - ✓ Simplex lines are also called **receive- only**, **transmit- only**, or **one- way- only** lines.
    - ✓ Examples: radio broadcast, television broadcast, workstation-monitor.

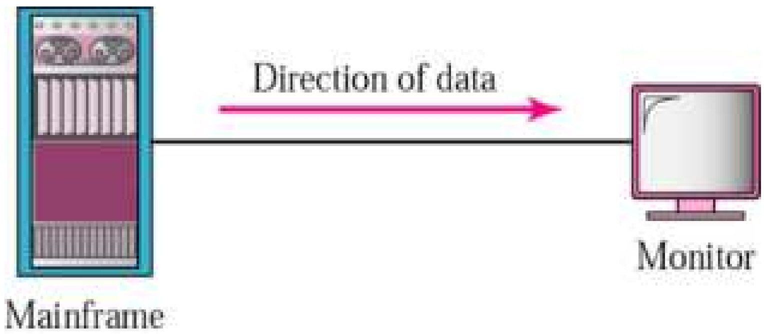


Figure 1.13: Simplex

2. Half duplex
   - ✓ Information signal flows in **both directions** but **only one direction at a time** on the transmission medium.
   - ✓ Half duplex communications lines are also called **two way alternate** or **either way lines**.
   - ✓ For example, a conversation on walkie-talkies is a half-duplex data flow. Each person takes turns talking. If both talk at once - nothing occurs.

Figure 1.14: Half Duplex

3. Full duplex
   - ✓ Information signal flows in **both directions simultaneously.**
   - ✓ They must be between the **same** two stations.
   - ✓ Full duplex lines are also called **two- way simultaneous**, **duplex**, or **both-way lines.**
   - ✓ Example: local telephone call, website chat.

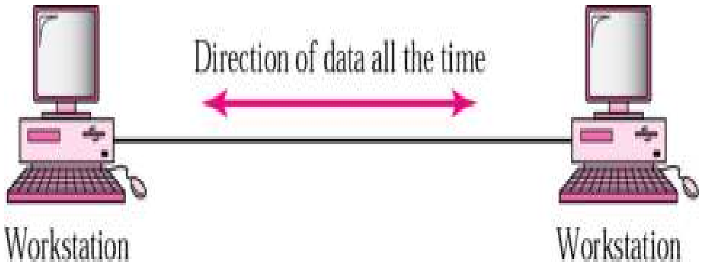


Figure 1.15: Full Duplex

1.9 Types of Communication System

- There are 4 types of Communication System:
    1. Broadcast Communication System
    2. Mobile Communication System
    3. Fixed Communication System
    4. Data Communication System

1. Broadcast Communication System
    - ✓ Definition: Broadcast is the **wireless** transmission of **audio** and **video** signal to a receiver via radio, television, or others.
    - ✓ It is a method of sending a signal where **multiple receivers** may receive from a **single sender.**
    - ✓ Broadcast is a type of communications called ***Simplex*** (data flow in one direction).
    - ✓ There is no interaction between the **originator** of the content and the **user** of the content, so if the content delivery is **delayed** by even a second or so, there will be little effect on the value of the communications.
    - ✓ Historically, there have been several different types of electronic broadcasting media:
        - i. ***Telephone broadcasting*** (1881)
        - ii. ***Radio broadcasting*** (1906)
        - iii. ***Television broadcasting*** (telecast) (1925)
        - iv. ***Cable radio*** (1928)
        - v. ***Satellite television*** (1974) and ***Satellite radio*** (1990)
        - vi. ***Webcasting*** of video/television (1993) and audio/radio (1994) streams.

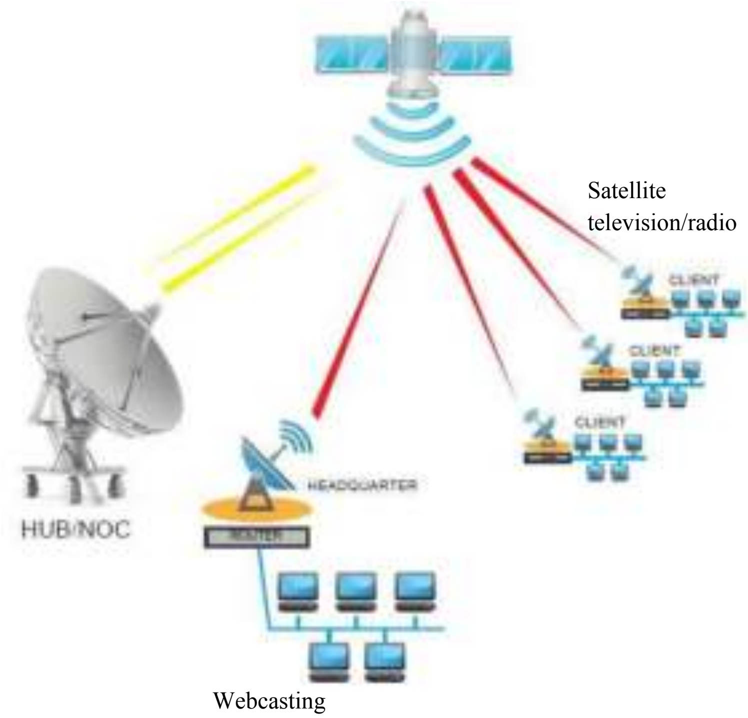
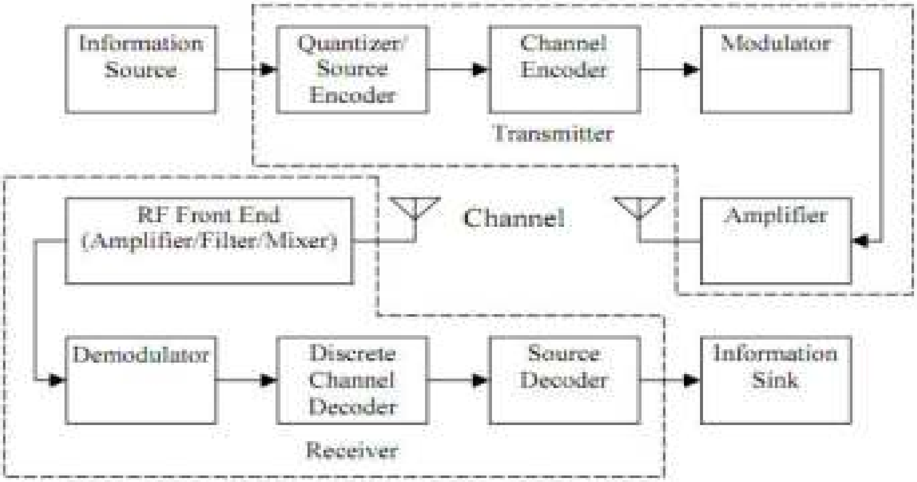


Figure 1.16: Broadcast Communication System

2. Mobile Communication System
   - ✓ Definition**:** **Mobile** communication system is a **wireless** communication in which voice and data information is emitted, transmitted and received via **microwave signals.**
   - ✓ Example: talking on the hand phone, SMS via hand phone and so on
   - ✓ It is a ***Full Duplex*** communication (data flow in 2 directions simultaneously).
   - ✓ Using **GSM (Global System for Mobile)** which is a standard set developed by the European Telecommunications Standards Institute (ETSI)



1.17: Block Diagram of Mobile Communication

- ✓ A wireless communication link includes a **transmitter,** a **receiver,** and a **channel** as shown in figure Block Diagram of Mobile Communication System. Most links **are full duplex** and include a transmitter and a receiver or a transceiver at each end of the link.
- ✓ Figures below show the wireless mobile communication system with different system
  - a) Mobile - base station
  - b) Peer-to-peer
  - c) Mobile-repeater-mobile
  - d) Mobile-satellite

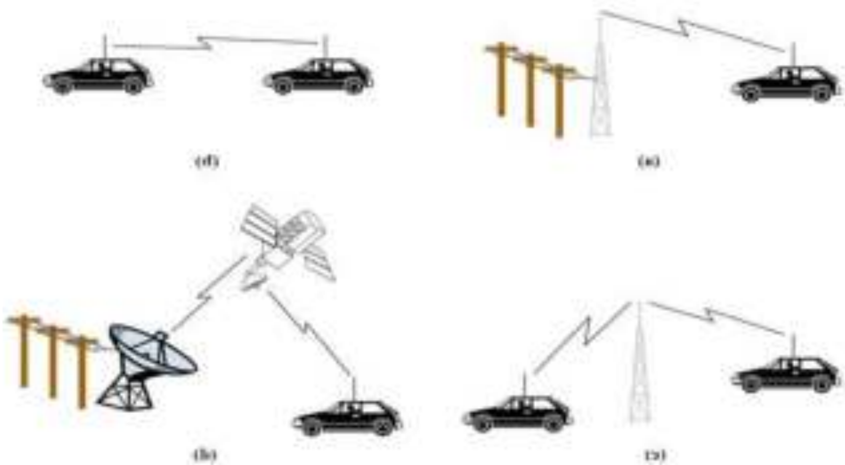


Figure 1.18: Wireless Mobile Communication System

3. Fixed Communication System
   - ✓ Definition: Fixed Communication is a **full-duplex** (FDX) or sometimes **double-duplex** system, allows communication in both directions using **fixed line**.
   - ✓ Example: Land-line telephone networks
   - ✓ Using **Public Switching Telephone Network (PSTN)** which is a standard set developed by ITU-T. Now, Malaysia is moving towards NGN **(Next Generation Network).**

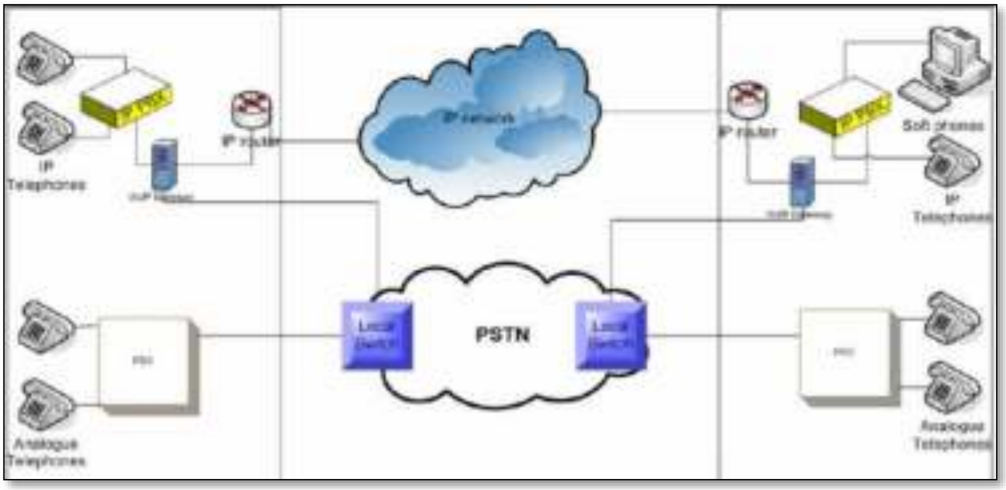


Figure 1.19: Fixed Communication

4. Data Communication System
   - ✓ Definition**:** Data communication is the **process** of transferring **digital information** (usually in binary form) between two or more points.
   - ✓ Example: computer communications (because much of the information is exchanged between computers and peripheral devices).
   - ✓ Data may be as simple as binary ones and zeros, or it may include complex information, such as digital audio or video.

✓ Data Communication Components:

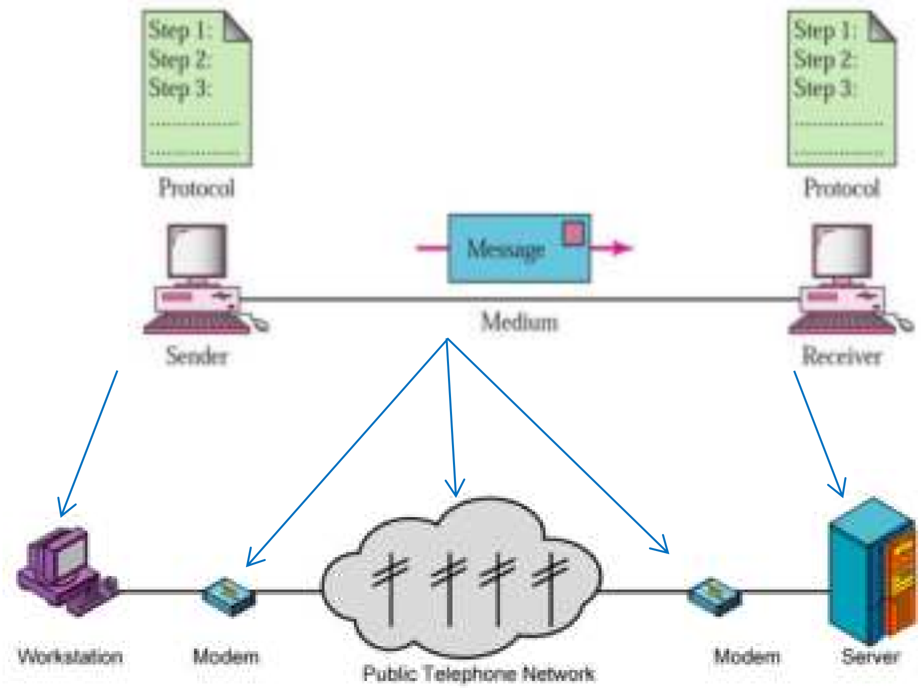


Figure 1.20: Block Diagram of Data Communication

CHAPTER 2

MODULATION TECHNIQUES

2.1 What would you get?

- Know, understand modulation and demodulation.
- Know and understand Analog Modulation
- Understand digital information in communication system
- Understand and apply M-ary encoding
- Know Pulse Modulation
- Know and understand Pulse Code Modulation (PCM)
- Understand and solve the problems related on Sampling, Quantization, and Encoding process in PCM.
- Know and understand digital modulation techniques

2.2 Modulation & Demodulation

DEFINITION: Modulation is a ***process of changing*** one or more properties of the **high frequency analog carrier signa**l in proportion with the values of **information signal**.

- Modulation being utilized because it's often **impractical** to propagate **low frequency information signals** over standard transmission media and it's often necessary to **modulate** the information signal onto a **higher-frequency analog** signal called a **carrier signal**.

- This is because the modulation will transform the **low frequency baseband information signal** into a **higher frequency passband** signal. For example: low-frequency audio signal into a high radio-frequency (RF) signal.
- In essence, the **high frequency carrier signal** is used to **carry** the **low frequency information signal** through the system.
- The **information (modulating) signal *modulates*** the **carrier signal** by ***changing*** either its **amplitude**, **frequency**, or **phase** to produce **modulated signal**.
- **Modulated signal** is the **carrier signal** that have been **modified** by information signal.

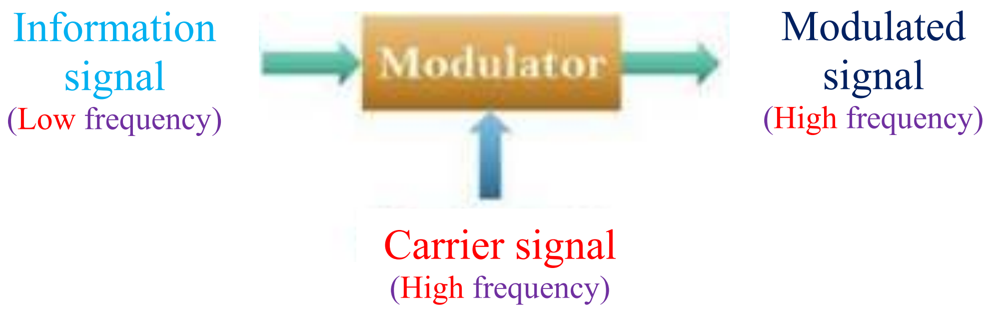


Figure 2.1: Modulation Process

- **MODULATION** is performed in a **transmitter** by a circuit called a **Modulator.**
- The **information** can be in **analog** or **digital** form, and the **modulator** can perform either **analog** or **digital modulator.**
- The **information** signal **combines** with the **carrier** in the **modulator** to produce a high frequency **modulated signal**.

Figure 2.2: Demodulation Process

- **DEMODULATION** - the **reverse process** of modulation. It is a process extracting the information signal from the modulated-carrier signal.
- Demodulation is performed in a receiver by a circuit called **Demodulator**.
- Demodulated signal = Original Information Signal

- Types of modulation:
  - ✓ Analog Modulation
    1. Amplitude Modulation (AM)
    2. Frequency Modulation (FM)
    3. Phase Modulation (PM)
  - ✓ Digital Communication
    1. Pulse Modulation
       a. Pulse Width Modulation (PWM)
       b. Pulse Position Modulation (PPM)
       c. Pulse Amplitude Modulation (PAM)
       d. Pulse Code Modulation (PCM)
    2. Digital Modulation

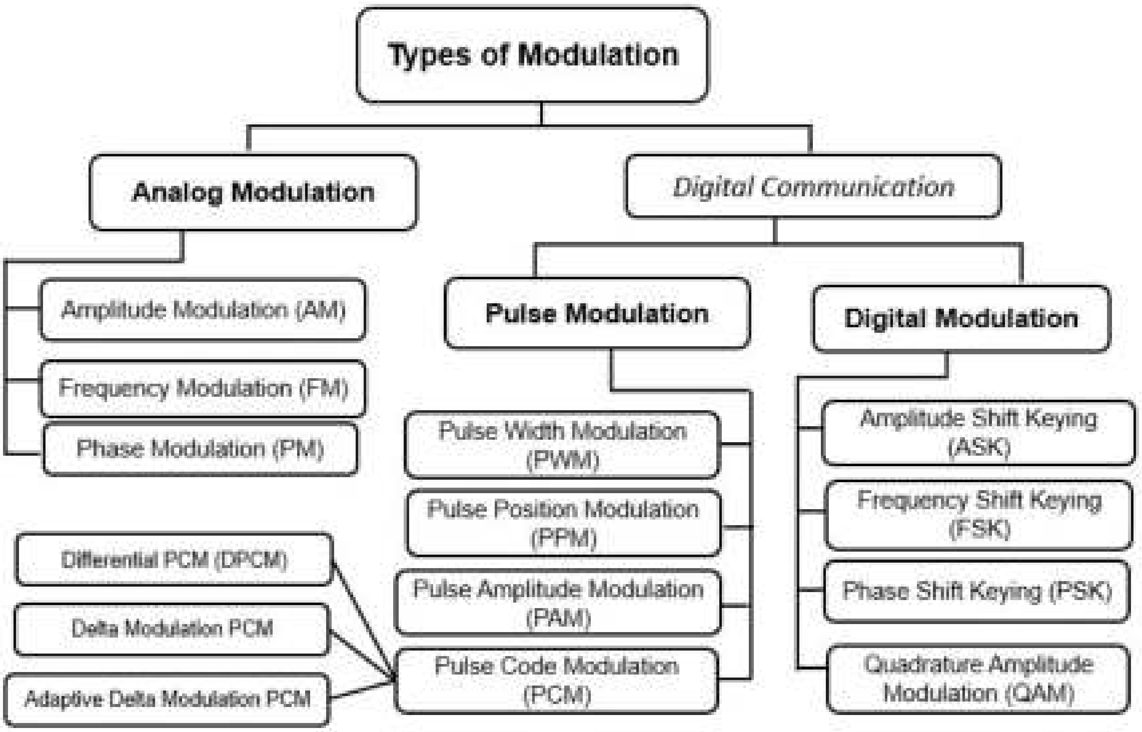
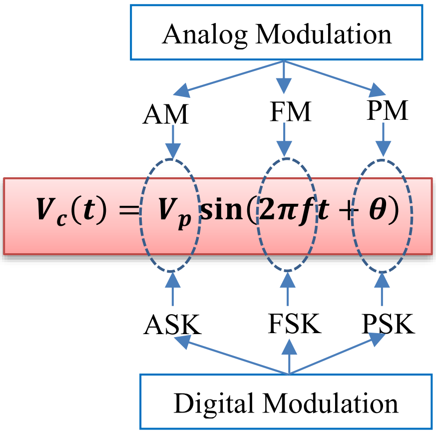


Figure 2.3: Types of Modulation

- In **Analog Modulation**, both Information Signal and Carrier signal are in analog waveform.
- In **Digital Modulation**, **Information** Signal is in **digital** waveform, while **Carrier** Signal is in **analog** waveform.
- In **Pulse Modulation**, **Information** Signal is in **analog** waveform, while Sampling Signal is in **digital** waveform.
- Pulse modulation is necessary to convert the analog signal to digital signal and vice versa for ***digital transmission.***
- Digital Modulation is necessary to convert the digital signal to analog signal and vice versa for ***digital radio.***

- Equation below is the summary of the various modulation technique:



where:

$V_c(t)$ = time-varying signal wave
A = peak amplitude (volts)
f = frequency (hertz)
θ = phase shift (radian)

Figure 2.4: General Equation for Modulation Technique

- Modulation is necessary due:
  - ✓ It is extremely difficult to radiate **low-frequency signals** from an **antenna** in the form of **electromagnetic energy**. So we need to **increase** the **frequency** of information signal by doing the modulation process.
  - ✓ To convert the **analog signal** to **digital signal** and **vice versa** for matching with communication medium and communication needs.
  - ✓ Information signals often occupy the same **frequency band**. If signals from **two or more** sources are transmitted at the **same time**, they would **interfere** with each other. To avoid interfering with each other, each station(source) converts its information to a **different frequency band** or **channel** by modulation process.
  - ✓ To increase the bandwidth of the signal.
    To multiplex more numbers of signal.
  - ✓ To reduce the antenna height and size.
  - ✓ To reduce equipment complexity.

2.3 Analog Modulation

In ***Analog Modulation***, **both** Information Signal and Carrier signal are in **analog** waveform. There are THREE (3) types of Analog Modulation which are:

1. **Amplitude Modulation (AM)** - the **amplitude (Vp)** of the ***analog carrier signal*** is varied proportional to the ***analog information signal***.

2. **Frequency Modulation (FM)** - the **frequency (f)** of the ***analog carrier signal*** is varied proportional to the ***analog information signal***.

3. **Phase Modulation (PM)** - the **phase (Θ)** of the ***analog carrier signal*** is varied proportional to the ***analog information signal***.

- Amplitude Modulation (AM)
  - ✓ **DEFINITION:** Amplitude Modulation (AM) is the process of changing the **amplitude** of **analog carrier signal** in proportion with the **amplitude** of the **analog information signal**.
  - ✓ In AM, the **amplitude (V)** of the ***carrier signal*** <u>is varied</u> proportional to the ***information signal***. While the **frequency (f)** and **phase (Θ)** of carrier signal are remains <u>unchanged</u>.
  - ✓ The **carrier amplitude** is simply changed according to the **amplitude** of the **information** signal. When the information signals amplitude is increased, the carrier signal amplitude also increased and vice versa.

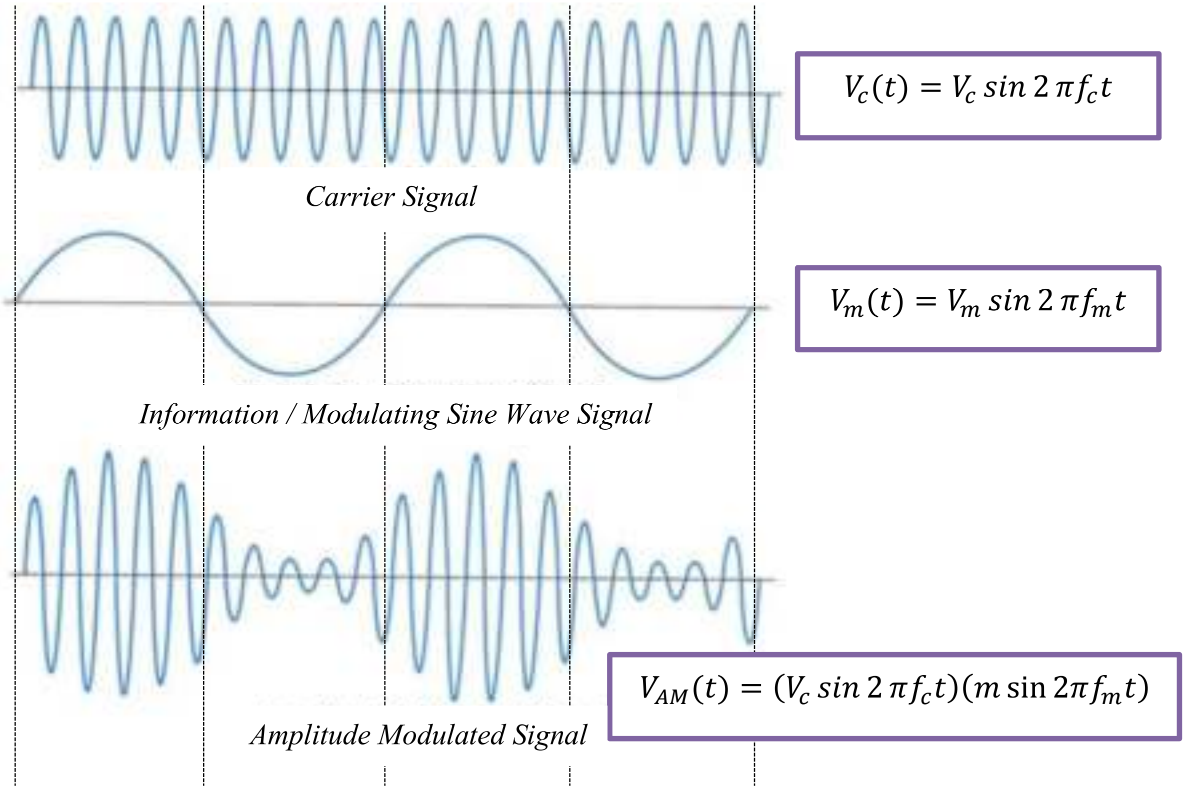


Figure 2.5: AM Generation Using non-liner AM Modulator

- ✓ The **information/modulating** signal will modulate the **amplitude** of **carrier** signal to produce high frequency **AM modulated signal** by using **AM Modulator** circuit.

- ✓ The **shape** of AM modulated signal is called **AM envelope**. This "envelope" contains the information signal.

- ✓ Information Signal, **(V_m)**:
  - o <u>**Characteristics:**</u>
    - ▪ Low frequency
    - ▪ eg: audio signal, voice
    - ▪ May contains single frequency or multiple frequency such as human voice.

✓ Carrier Signal, **(V_C)**:

- **Characteristics:**
  - High frequency
  - example: microwave frequency
  - frequency and amplitude fixed

✓ Modulated Signal, **(V_{AM})**:

- **Characteristics:**
  - The amplitude of carrier signal is varied by the modulating signal.
  - Frequency and phase remain constant
  - High frequency

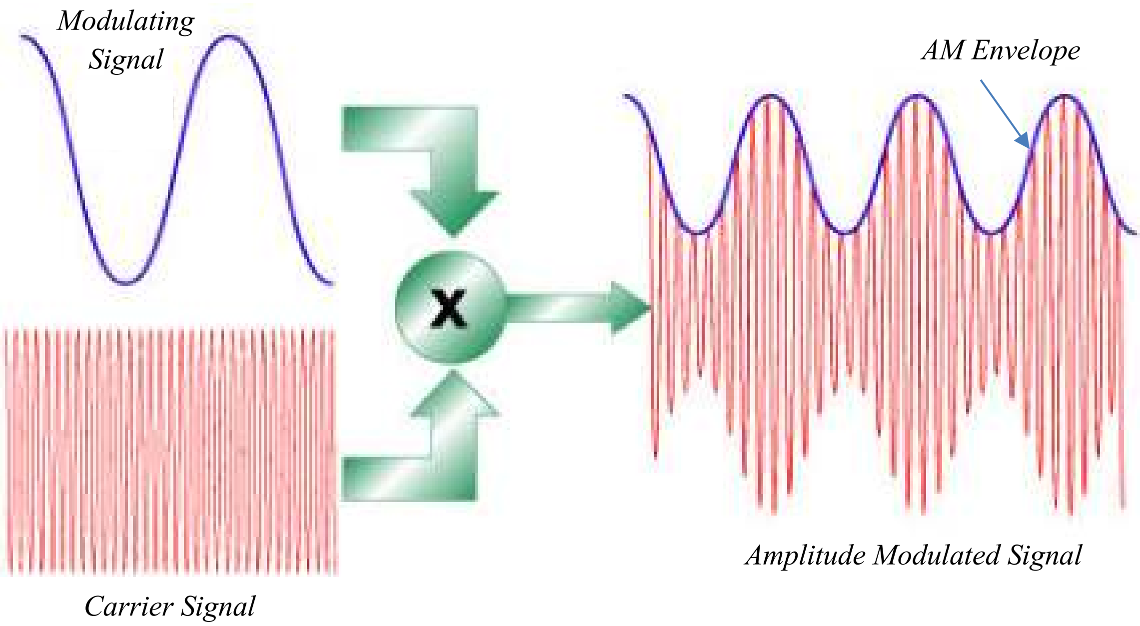


Figure 2.6: Single-Frequency Amplitude Modulation

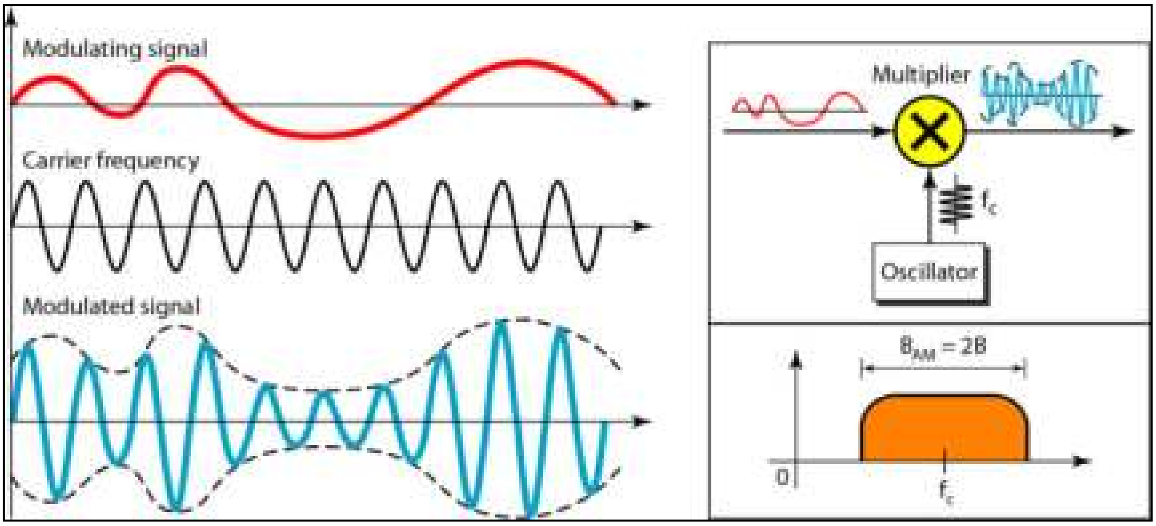


Figure 2.7: Multi-Frequency Amplitude Modulation

- Angle Modulation
  - ✓ Angle Modulation can be classified into TWO (2) categories:
    1. Frequency Modulation
    2. Phase Modulation
  - ✓ Whenever the frequency of a carrier is varied, the phase is also varied and vice versa.
  - ✓ Therefore, **FM** and **PM must both occur** whenever either form of **angle modulation** is performed.
  - ✓ The difference between FM and PM lies in which property of the carrier (the **frequency** or **phase**) is **directly varied** by modulating signal and which property is **indirectly varied**.
  - ✓ If **frequency** is varied **directly** in accordance with modulating signal – FM.
  - ✓ If **phase** is varied **directly** in accordance with modulating signal – PM.

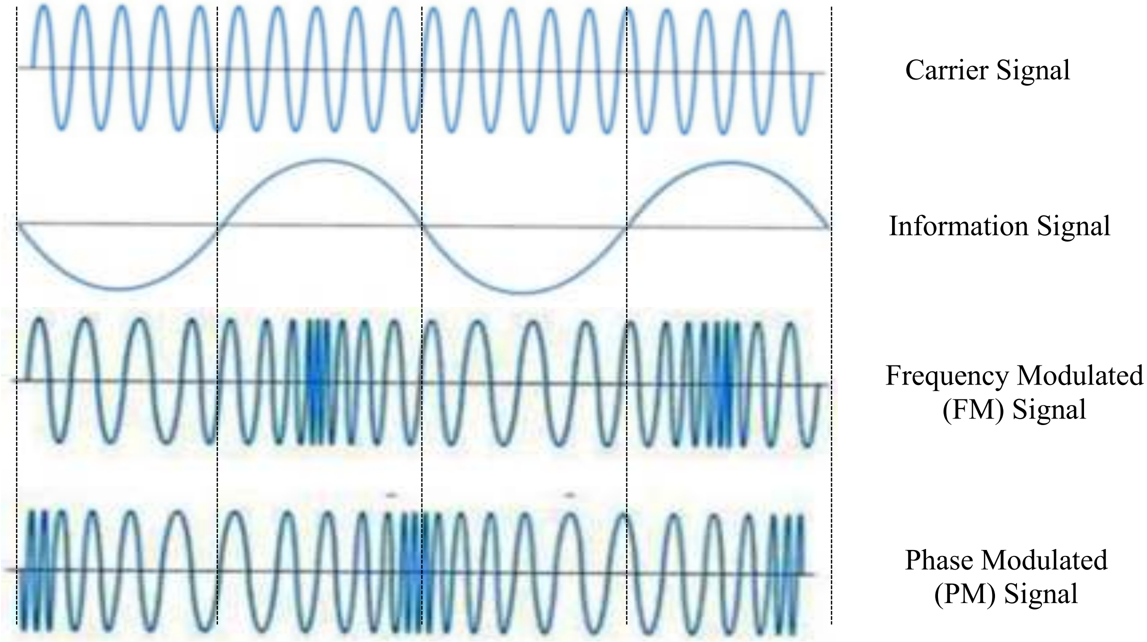


Figure 2.8: Angle Modulation

1. Frequency Modulation

   ✓ **DEFINITION**: FM is the process of changing the **frequency** of **analog carrier signal** in proportion with the **amplitude** of the **analog information signal**.

   ✓ In FM, the carrier **amplitude** and **phase** remain **constant** while the carrier **frequency** is **varied** by the modulating signal.

   ✓ The amount of carrier frequency changes is **proportional** to the amplitude of the information signal. As the modulating signal **amplitude** increases, the carrier **frequency** increases and **vice versa**.

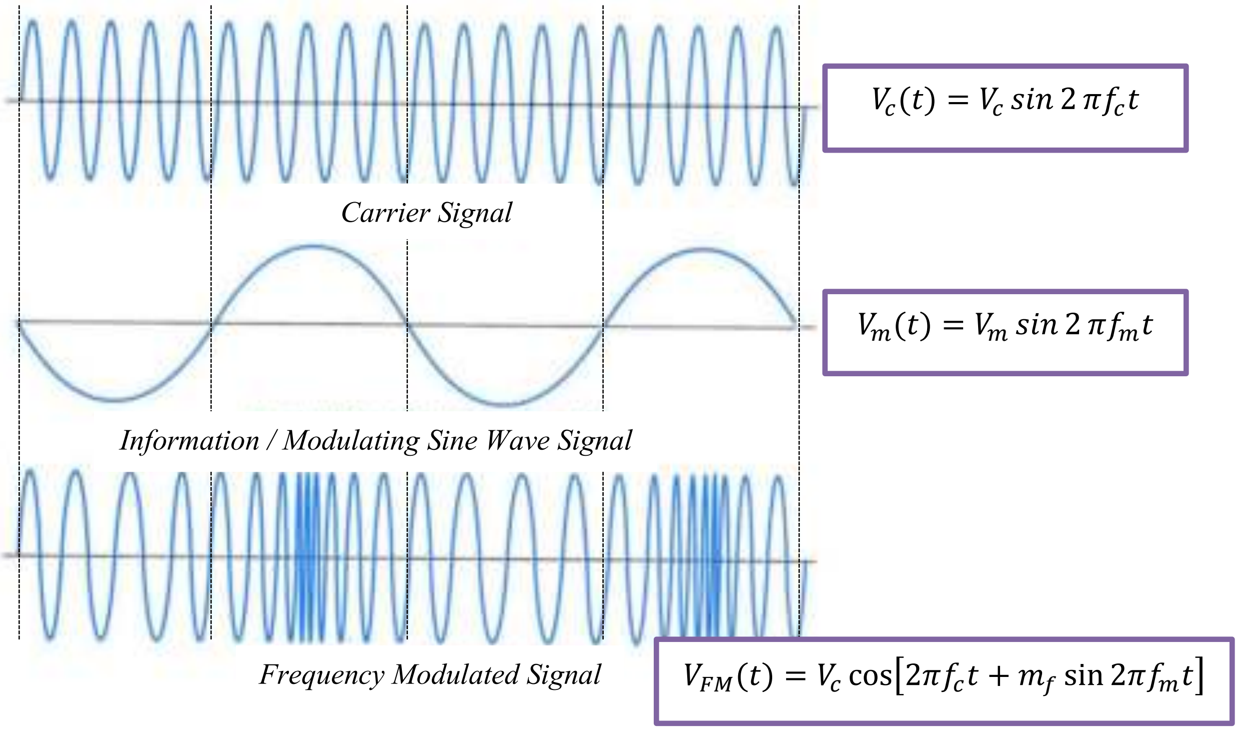


Figure 2.9: FM Generation Using FM Modulator

2. Phase Modulation

✓ **DEFINITION:** PM is the process of changing the **phase** of **analog carrier signal** in proportion with the **amplitude** of the **information signal**

✓ In PM, the **carrier amplitude** and **frequency** remain **constant** while the **carrier phase** is varied by the modulating signal.

✓ As the modulating signal **amplitude** increases, the carrier **phase** increases and vice versa.

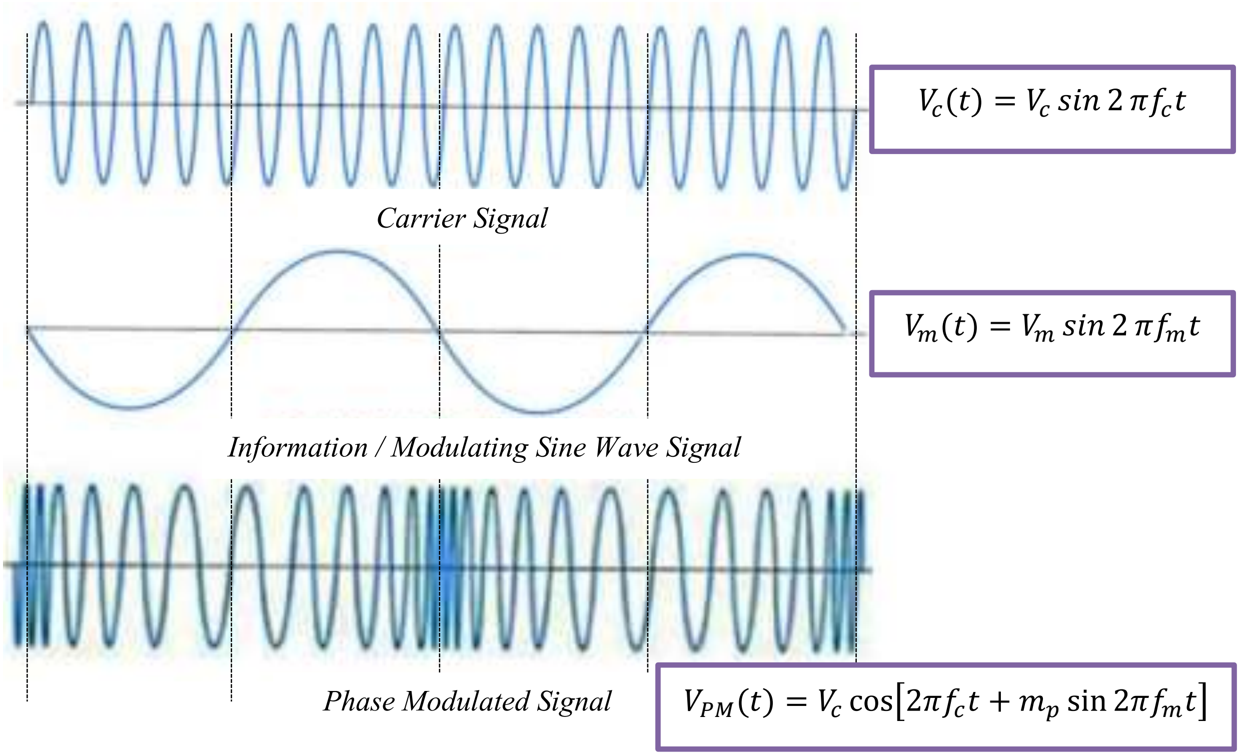


Figure 2.10: PM Generation Using PM Modulator

- Comparison of Frequency Modulation and Phase Modulation

	Frequency Modulation	**Phase Modulation**
1	the frequency of the carrier waveform varies with the information signal.	the phase of the carrier waveform varies with the information signal.
2	By varying the frequency, f_c	By varying the phase, θ
3	$V_{FM}(t) = V_c \cos[2\pi f_c t + m_f \sin 2\pi f_m t]$	$V_{PM}(t) = V_c \cos[2\pi f_c t + m_p \sin 2\pi f_m t]$

Table 2.1: Comparison of Frequency Modulation and Phase Modulation

2.4 Digital Communication

Digital Communication covers a broad range of communication techniques including:

- ***Digital transmission*** and
- ***Digital radio*.**

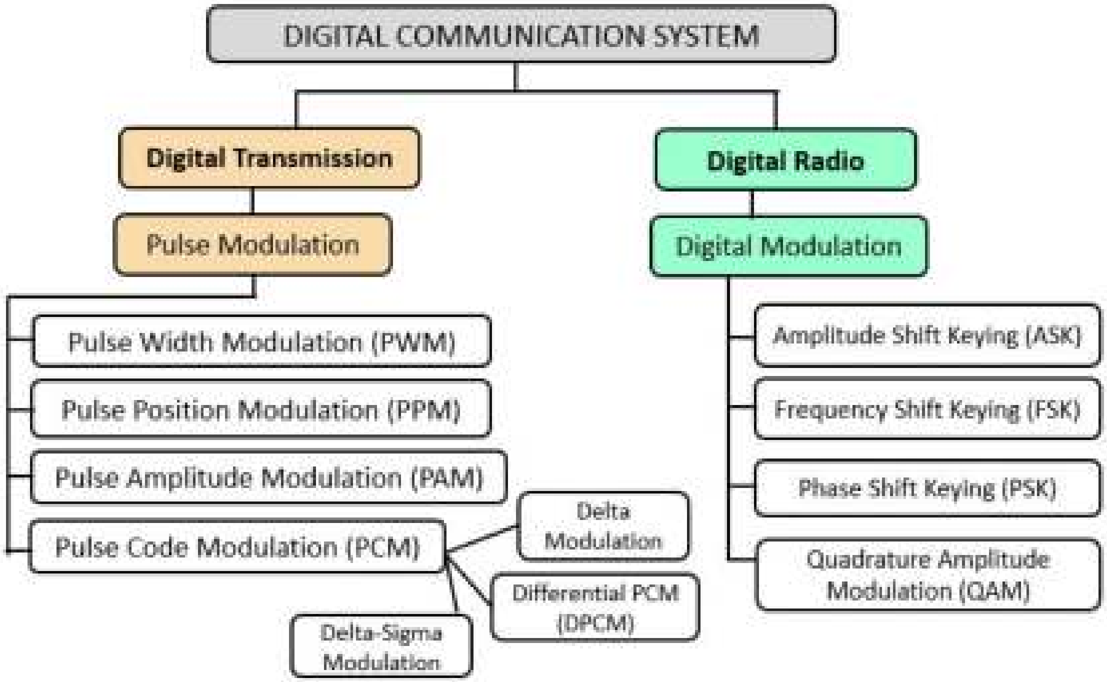


Figure 2.11: Types of Digital Communication

1. **Digital transmission** is a true digital system where **digital signals** are transferred between two or more points in a communication system.

   ✓ **Digital signals** could be a *binary digit* (bit 0 and bit 1) or other form of *discrete-level* digital pulses.

   ✓ With digital transmission, there is **NO analog carrier** and the original source information may be in **digital** or **analog** form.

- ✓ If the information signal is in **analog** forms, it must be converted to **digital pulses** prior to **digital transmission** and converted back to **analog** form at the **receive end.**

- ✓ The analog signal is converted into digital signal by using Pulse Code Modulation (PCM) technique.

- ✓ Since **digital pulses CANNOT** be propagated through a wireless transmission medium (**free space**); therefore, the digital transmission required physically medium such as a **metallic cable** (twisted, coaxial cable) or a fibre optic cable.

2. **Digital Radio** is a transmittal of ***digitally-modulated*** *analog carrier signals* between two or more points in a communication system.

   - ✓ With digital radio, the **information signal** and **demodulated signal** are in **digital form**. While the **carrier signal** and **modulated signal are** in **analog form**.
   - ✓ The **digital pulses** could be originated from computer-generated data or ***digital transmission*** system or ***digitally-encoded analog*** *information signal*.

   - ✓ In digital radio system, **digital pulses** modulate the **analog carrier signal** to produce *digitally-modulated carrier signal* in **analog form**.

   - ✓ Since the modulated signal is in analog form, therefore the transmission medium could be a wireless transmission medium (free space) or physically facility (metallic or fiber optic cable).

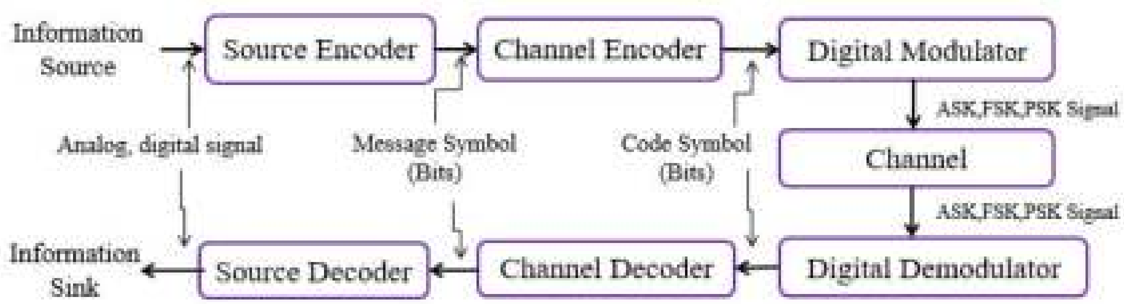


Figure 2.12: Basic Elements of Digital Communication System

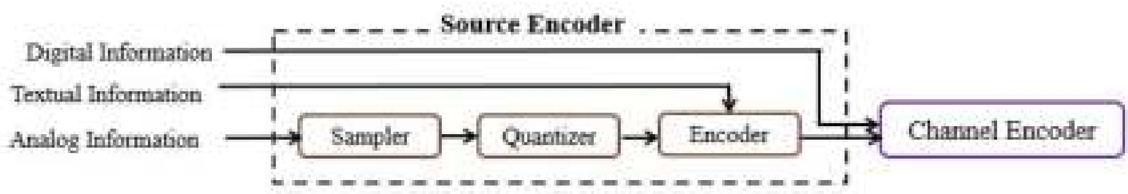


Figure 2.13: Digital Formatting Process

✓ Basic Elements of Digital Communication System:

1. **Information Source** - The source of information can be analog or digital, example Analog- audio, voice; Digital- teletype signal.

2. **Source Encoder – to *convert* the information signal from source into digital signals (serial bits)** by *formatting the signals* (refer Figure 2.5) and ***compressed* that signal.** Then, these bits are grouped to form *message symbols*. For example: PCM process, Character Encoding (ASCII code) process.

3. **Channel Encoder** – is used **for error correction coding**. It can reduces the probability of error by introduces some redundancy in the *message symbols* and transform it into *code symbols (code words)*.

4. **Digital Modulator - to convert the serial bits (digital waveform) into electric signals (analog waveform)** so that we can transmit them on channel. For example; ASK, FSK & PSK Modulation process.

5. **Channel** - The communication channel is the physical medium that is used for transmitting signals from transmitter to receiver. In wireless system, this channel consists of atmosphere. For telephony, this channel is wired like twisted pair cable & optical fiber.

6. **Digital Demodulator** – the reverse process of modulation and converts the electric signals back to the serial bits (*code symbols*).

7. **Channel Decoder** - to reconstruct the original serial bits (*message symbols*) from the *code symbols* used by the channel encoder and the redundancy contained in the received data. Example: Bit Error Rate (BER) process**.**

8. **Signal Decoder** - to *convert back* the serial bits (message symbols) into original source information signal.

✓ The advantages of digital transmission compared to analog transmission are:

1. **Noise Immunity** - Digital signals are less susceptible than analog signals to interference caused by noise.

2. **Reduction of errors** - Errors caused by noise and interference can be detected and corrected systematically.

3. **High security** - Digital system more secure than analog system because the system can be encoded digital data to a unique code (data encryption) and data can only be understood by the sender and receiver only.

4. Digital circuit easier to be interfaced compare to analog circuits (because there are two levels of digital signals only '1 'and '0').

5. Ease of processing and multiplexing.

6. Inexpensive digital circuitry may be used extensively.

✓ Application of Digital Communication:

1. ADC – Analog to Digital Converter

2. DAC – Digital to Analog Converter

3. MODEM – Modulator-Demodulator

4. Digital Camera

5. Digital Video

6. Broadband digital subscriber lines (DSL)

7. Telemetry

8. Teleconferencing

9. Compact Disk (CD)

10. Hard Disk Drive

11. Personal Communication System (PCS)

12. Satellite Communication System

2.5 M-ary Encoding

M-*ary* is a term derived from the word *binary*. M = represents a **digit** that corresponds to the number of **conditions** or **levels** or **combinations** possible for a given number of **binary** variables (n).

- ✓ For example, a digital signal with **4 possible conditions** (either voltages, levels, frequencies, phases and so on) is an M-*ary* system where **M = 4**.
- ✓ The **number of conditions, M** possible with **n bits** is expressed mathematically as;

$$M = 2^n$$

Where,

n = number of bits

M = number of conditions, or levels, or combinations possible with n bits

- ✓ The **number of bits,n** that necessary to produce a given **number of cxonditions, M** is expressed mathematically as:

$$n = \log_2 M$$

or easily *(in log_{10})* as:

$$n = \frac{\log_{10} M}{\log_{10} 2}$$

2.6 Pulse Modulation

In *Pulse Modulation*, **Information Signal** is in **analog** waveform. While **Sampling signal** is in **digital** waveform. (*there is **NO** carrier signal in pulse modulation*). This modulation is necessary to convert the **analog signal to digital signal** for **digital transmission.** Usually used metallic cable & fiber optic cable. Cannot use **free space** as channel.

- **DEFINITION:** Pulse Modulation (PM) is a process of **sampling** the **analog** information signals into **sampled signal** before converting those into digital signals.
- In Pulse Modulation the **Information Signal** is in **analog** waveform. While **Sampling signal** is in **digital pulses** waveform.
- The **properties** of sampling pulses signal such as **width**, **position** and **amplitude** will be varied in proportion with **amplitude** of information signal.
- There are FOUR (4) predominant techniques for Pulse Modulation:
    1. Pulse Width/Duration Modulation (PWM @ PDM)
    2. Pulse Position Modulation (PPM)
    3. Pulse Amplitude Modulation (PAM)
    4. Pulse Code Modulation (PCM)

1. **PWM -** the **width** of the **pulses** is varied proportional to the analog **amplitude** information signal. **Amplitude (A)** and **Position (P)** of **pulses** are **constant.** *(The higher **amplitude** of Information signal, the **wider** of pulse.)*

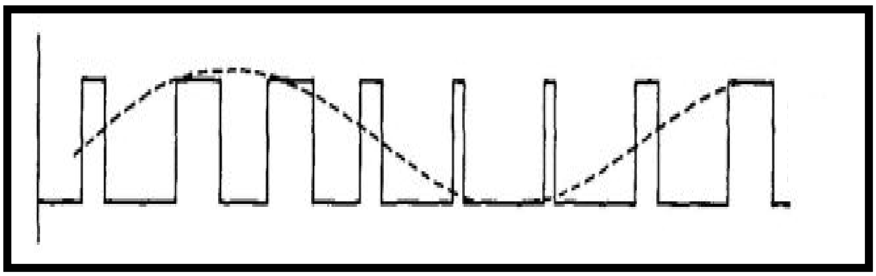


Figure 2.14: Pulse Width Modulation (PWM)

2. **PPM** – the **position** of the **pulses** is varied proportional to the analog **amplitude** information signal. **Amplitude (A)** and **Width (W)** of **pulses** are **constant.** *(The higher **amplitude** of Information signal, the **farther** to the **right** the pulse is positioned).*

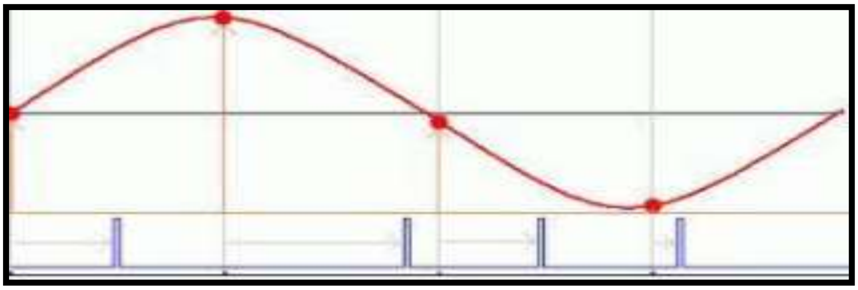


Figure 2.15: Pulse Position Modulation (PPM)

3. **PAM -** the **amplitude** of the **pulses** is varied proportional to the analog **amplitude** information signal. **Width (W)** and **Position (P)** of **pulses** are **constant.** *(The higher **amplitude** of Information signal, the higher **amplitude** of pulse).*

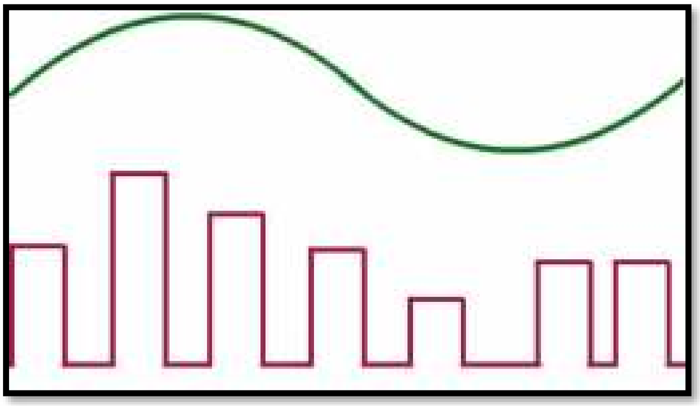


Figure 2.16: Pulse Amplitude Modulation (PAM)

4. **PCM** – With PCM, the **analog** information signal is **sampled** into **PAM signal** and then converted to a **serial n-bit binary code** for transmission.

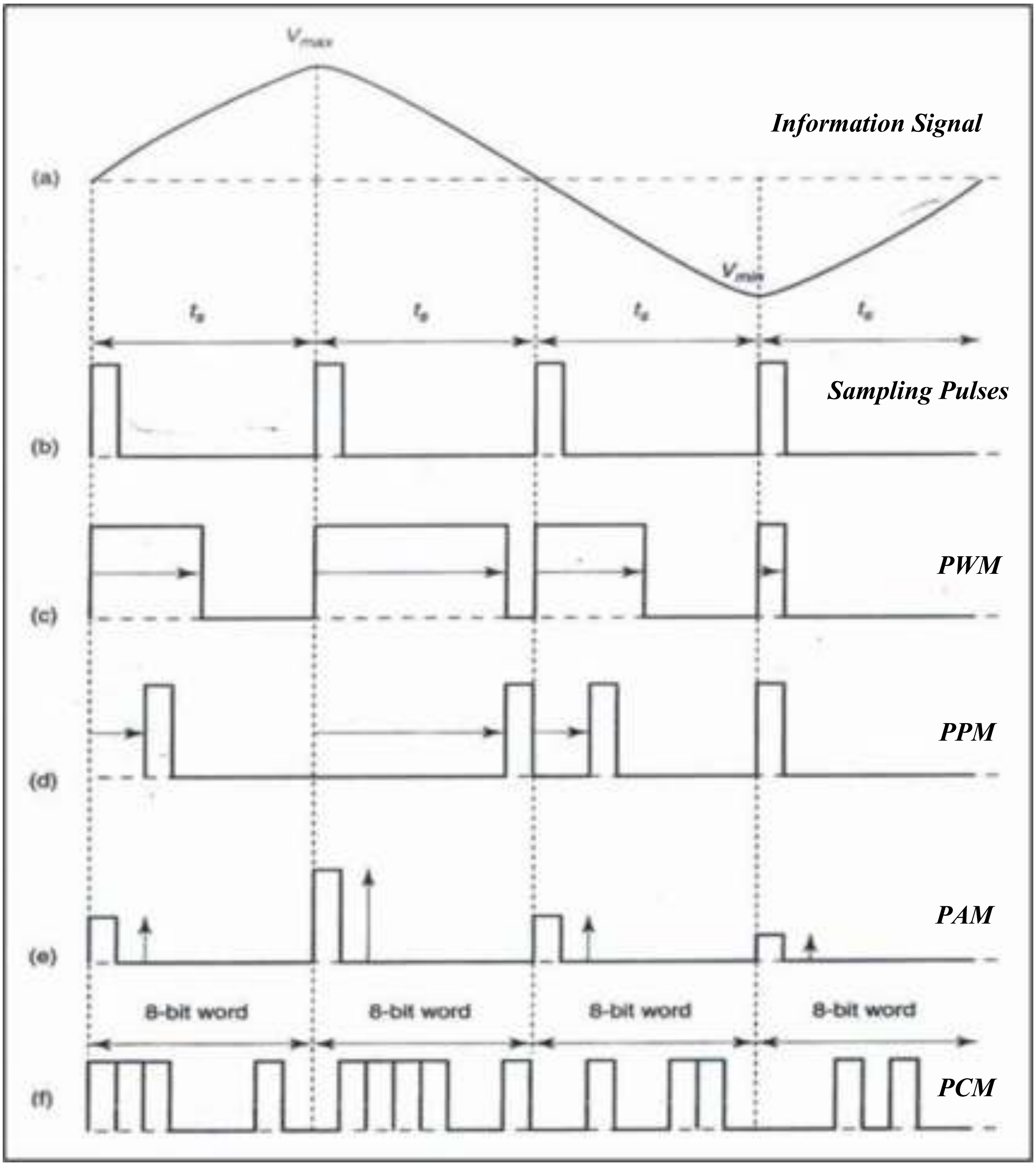


Figure 2.17: Pulse Modulation Technique

- **PWM** and **PPM** are used in special-purpose communication systems, seldom used for commercial digital transmission.
- **PAM** is used as an **intermediate** form of modulation with **PCM**, PSK and QAM; seldom it is used by itself.

- Among all pulse modulation techniques, there are two important digital pulse modulation techniques which are Pulse Code Modulation (PCM) and Delta Modulation (DM).
- In DPM, a **code** is used to represent the amplitude of the **samples** that has been divided into various levels.
- The types of DPM:
    1. Pulse Code Modulation (PCM)
    2. Delta Modulation (DM)
    3. Delta-Sigma Modulation

2.7 Pulse Code Modulation

In digital transmission, any analog information data should be changed into digital signal for the digital transmission. PCM is the only **digitally encoded** modulation technique that is commonly used for digital transmission.

Pulse Code Modulation **is not real a type of modulation but rather a form of digitally coding** analog signals. PWM, PPM, and PAM signals are digital signal (discrete-time signal), but those signals **do not** represent in a single binary digit (bits). Therefore, PCM technique is needed to convert the **discrete sampled signal** (usually PAM) to **serial bits**.

- **DEFINITION:** PCM is a **digital pulse modulation** technique to convert the analog signal to digital signal.

- The PCM technique is the conventional/basic digital pulse modulation technique. However, there are few others type of PCM technique such as:

    1. Delta Modulation PCM
    2. Adaptive Delta Modulation PCM
    3. Differential PCM (DPCM)
    4. Adaptive Differential (ADPCM)

- **APPLICATION:** In electronic communication circuit, the PCM technique is applied at:
    1. Analog to Digital Converter (ADC) device - in **Co**der
    2. Digital to Analog Converter (DAC) device - in **Dec**oder
    3. Digital telephony Multiplexing (TDM-PCM)
    4. Digital PABX
    5. Digital Audio recording
    6. CD laser disks, etc.

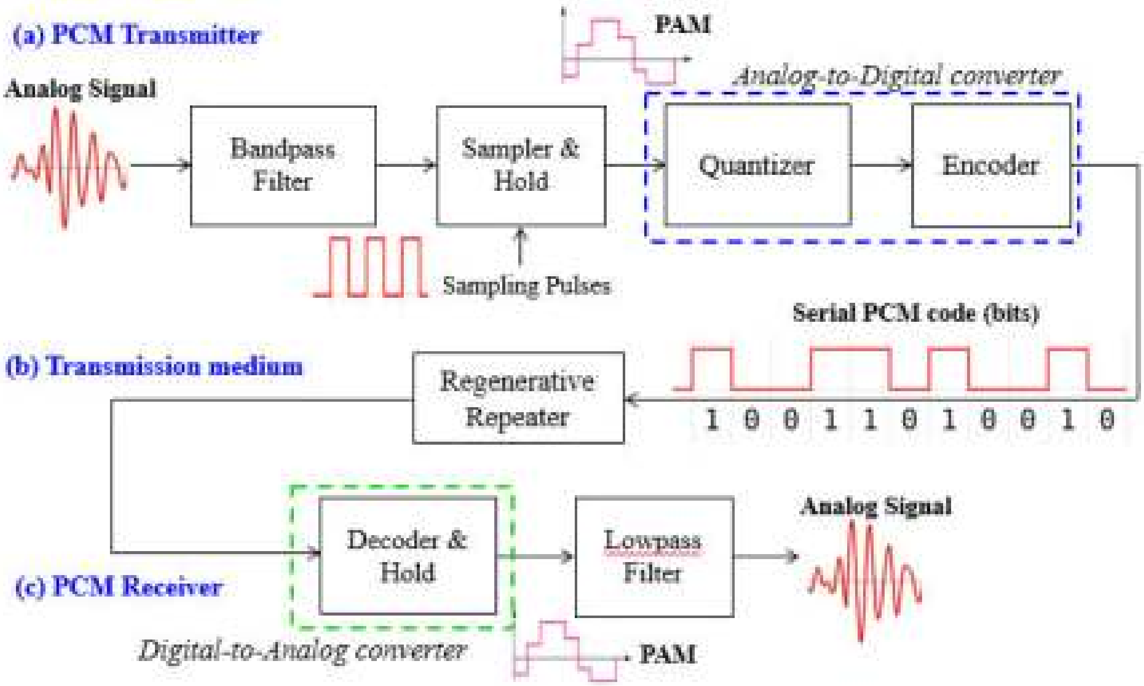


Figure 2.18: Block Diagram of PCM

- Figure above shows a simplified block diagram of a simplex PCM system:

1. **Bandpass Filter** – the bandpass filter limits the analog input signal to a certain **bandwidth** (f_{min} to f_{max}) to enter the Sampler. For example: the filter allows only human voice bandwidth, 300Hz - 3.4kHz to enter the Sampler circuit.

2. **Sampler & Hold** – Periodically samples the **analog input signal** and convert the **Sampling Pulses signal** to a multilevel **sampled PAM signal.**

3. **Quantizer** - Convert the **sampled PAM signal** to **quantized PAM signal** by rounding off the amplitude of sampled signal to quantization levels, L.

4. **Encoder** – convert the quantized PAM signal to a **parallel** code number. Then, convert the code numbers to a **serial** binary pulse (encoded words).

5. **Repeater** – Amplify and regenerate the weaken digital pulses during transmission on transmission line.

6. **Decoder & Hold** – Convert back he digital pulses signal to multilevel PAM signals.

7. **Low pass Filter** - to smooth the staircase amplitude of PAM signals into an **analog signal**.

- PCM consists of three steps to digitize an analog signal:
  1. Sampling
  2. Quantizing
  3. Encoding

- Before sampling process, the information signal should be filtered to limit the **maximum information frequency** ($f_{m(max)}$) that can enter into the sampler as it affects the **sampling rate (f_s).**

- Filtering should ensure that we do not distort the signal, such as remove high frequency components that affect the signal shape.

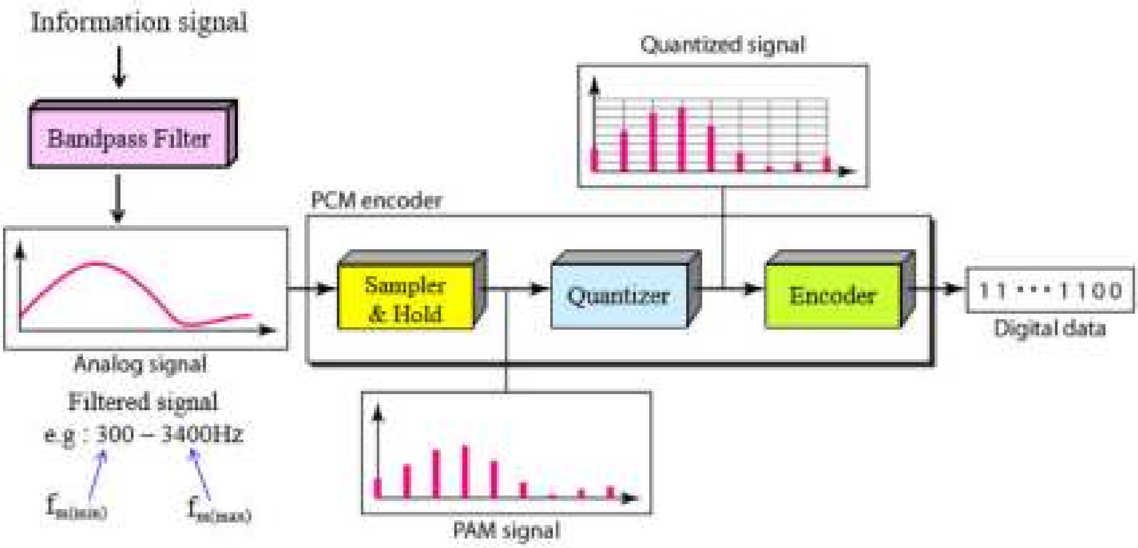


Figure 2.19: Block Diagram of PCM Encoder (Transmitter)

- Sampling
  - ✓ **DEFINITION:** Sampling is a process where the information signal (in analog signal) is sampled by **sampling pulse signal** which is generated at certain sampling rate, fs.
  - ✓ Sampling process will converts an **analog signal** (*in **continuous-time** signal*) to a **sampled signal** (*in **discrete-time** signal*) either in PAM, PWM or PPM.
  - ✓ For **PCM**, the sampled signal is **PAM signal**.
  - ✓ By this process, the **amplitude** of pulses signal is varied **proportional** to the **analog amplitude** of information signal.

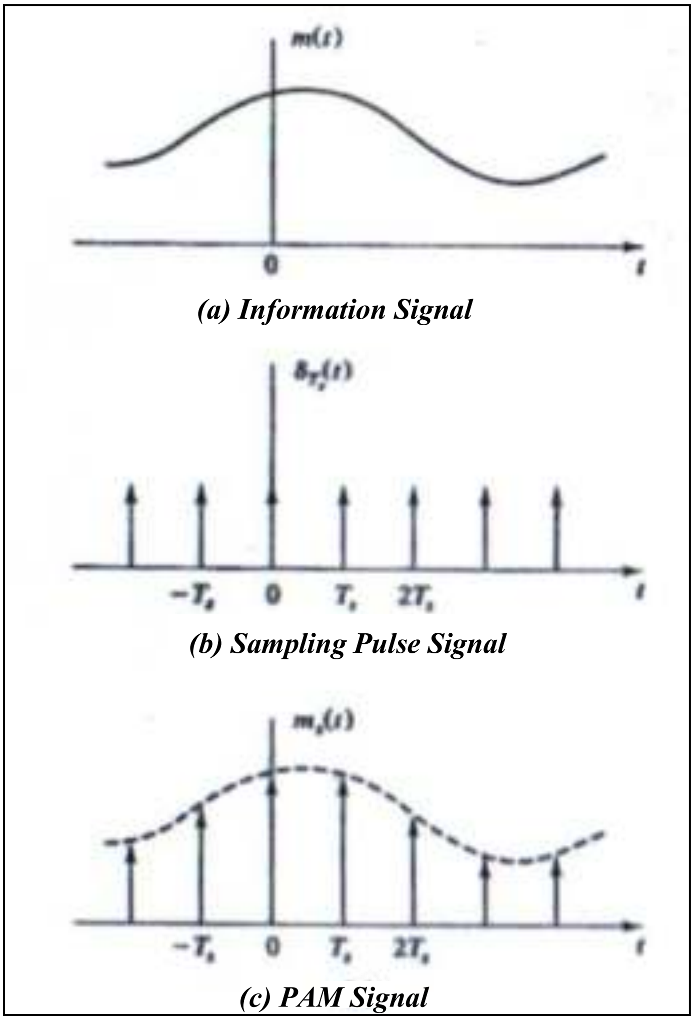


Figure 2.20: Sampling

- ✓ The **amplitude** of sampling pulse signal **is varied** according to **amplitude** of information signal which produce a **PAM signal.**
- ✓ Analog information signal is sampled every **Ts** seconds.
- ✓ **T_s** is referred to as the **Sampling Interval** or **Sampling Period.**
- ✓ $f_s = \frac{1}{T_s}$ is called the **Sampling Rate** or **Sampling Frequency**.
- ✓ The **higher** the sampling rate, f_s the **smaller** sampling interval, T_s, the **closer** the **recovered signal** approaches the original signal.

✓ Ideally, an **infinite sampling rate** would be desirable in terms of reproducing the original signal, but it is not practical due to the bandwidth limitation.

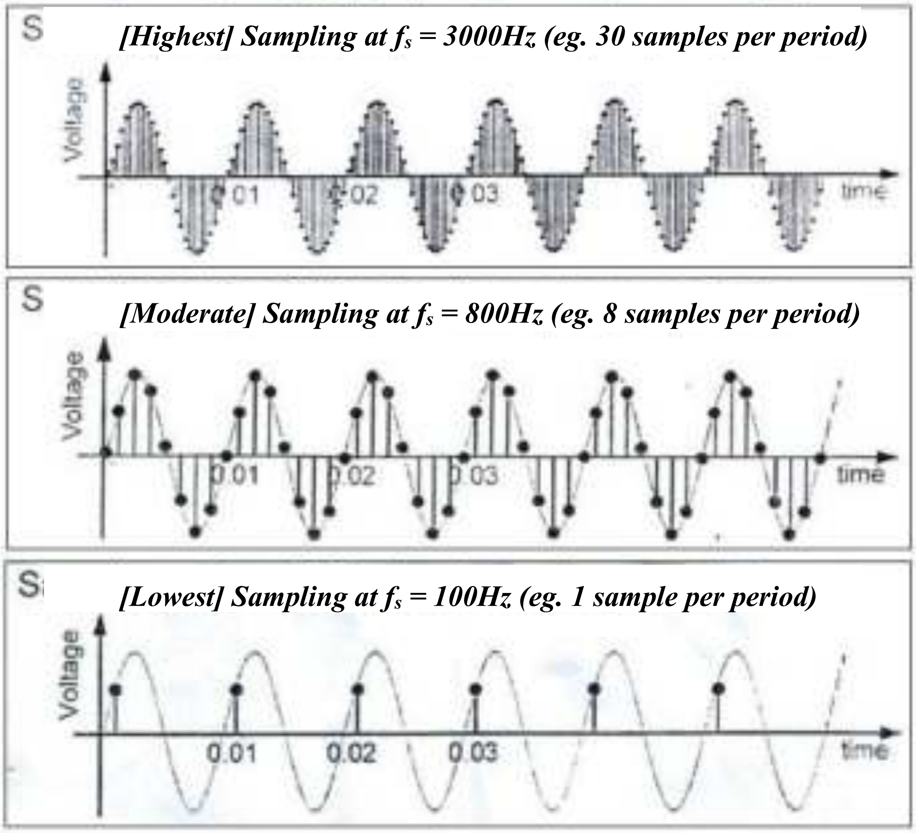


Figure 2.21: Example of Highest, Moderate and Lowest Sampling Rate for PCM

✓ There are THREE (3) methods of sampling which are:

1. Ideal Sampling
2. Natural Sampling
3. Flat-Top Sampling

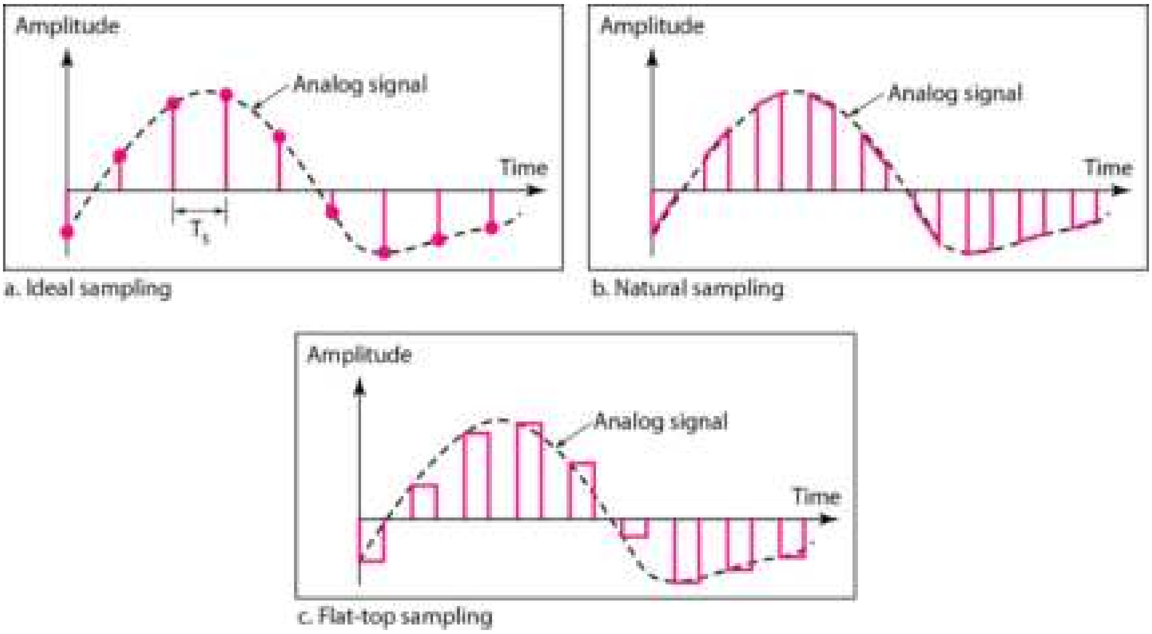


Figure 2.22: Three different sampling methods for PCM

1. **Ideal Sampling** – the analog information signal is sampled instantaneously by pulses. This sampling is not practical and cannot be easily implemented.

2. **Natural Sampling** – The more practical sampling which is performed by **high-speed switching circuits** as shown in figure below.

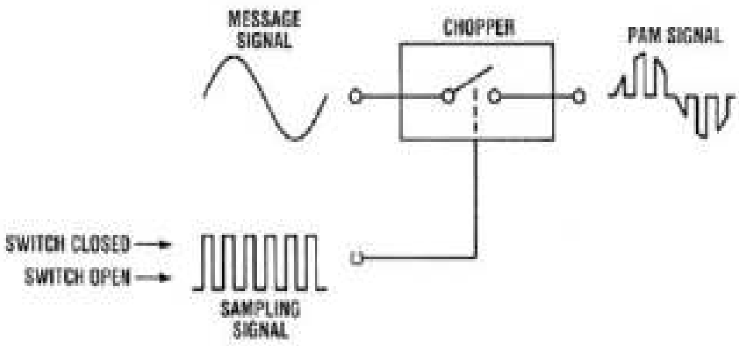


Figure 2.23: Natural Sampling

3. **Flat-Top Sampling** – The simplest and the most popular sampling method which is performed by **Sample-and-Hold circuit** as shown in figure below. However, this circuit creates a flat-top (staircase) sampled signal. When the pulse is generated, the switch will CLOSED and the amplitude of information signal will be produced. When there is no pulse, the switch will OPEN and there is no output will produce.

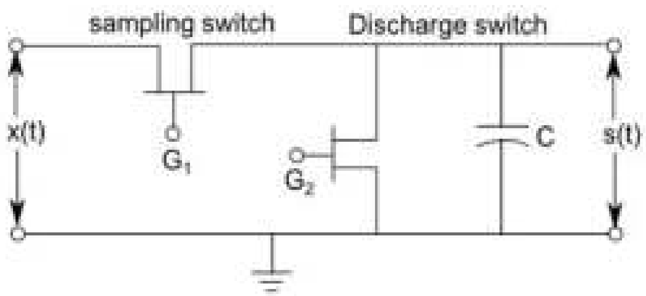


Figure 2.24: Flat-Top Sampling

- Sampling Theorem

  ✓ According to the **Nyquist Sampling theory;** to reconstruct the original signal, the sampling rate must be **at least (minimum) two times** the **highest frequency** contained in the info signal.

$$f_s \geq 2f_{m(max)}$$

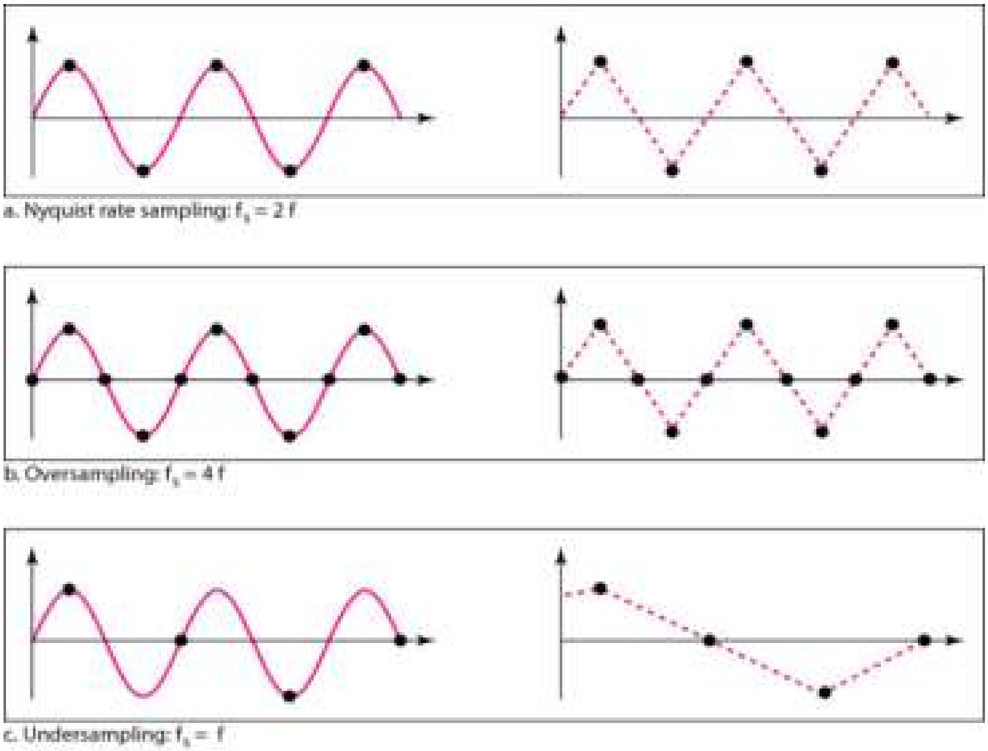


Figure 2.25: Recovery of A Sampled Sine Wave for Different Sampling Rates

- Quantization

DEFINITION: Quantization is a process **rounding off** the **amplitudes** of **sampled (PAM) signal** to a **countable** number of **quantization levels**. **Analog signal** has an **infinite (uncountable)** number of **amplitude possibilities**. By using the quantization process, the **amplitudes** of **sampled PAM signal** is rounding off to a **finite(countable)** set of **quantization levels, L.**

The **number of amplitude levels, L** for the **quantization** depend on the **number of bits, n** used to code the signal. It uses M-ary formula to determine the **number of quantization levels, L**.

$$L = 2^n$$

Where,

n = number of bits per level
L = number of finite quantization level

- ✓ For example, if 3 bits is used to code the signal, therefore the number of quantization levels, L are:

$$\boldsymbol{L = 2^n} = 2^3$$
$$L = 8\ levels$$

- ✓ The **more levels, L** used means that an analog signal can be described **more accurate** during signal recovery at receiver.
- ✓ This is because the greater number of bits (n) and quantization level (L) are used, the more quantization error (Qe) could be reduced and the more accurate the recovery original signal.
- ✓ However, a PCM code could have only **8 bits maximum** which equates to only **L= 2^8** or **256 levels**.

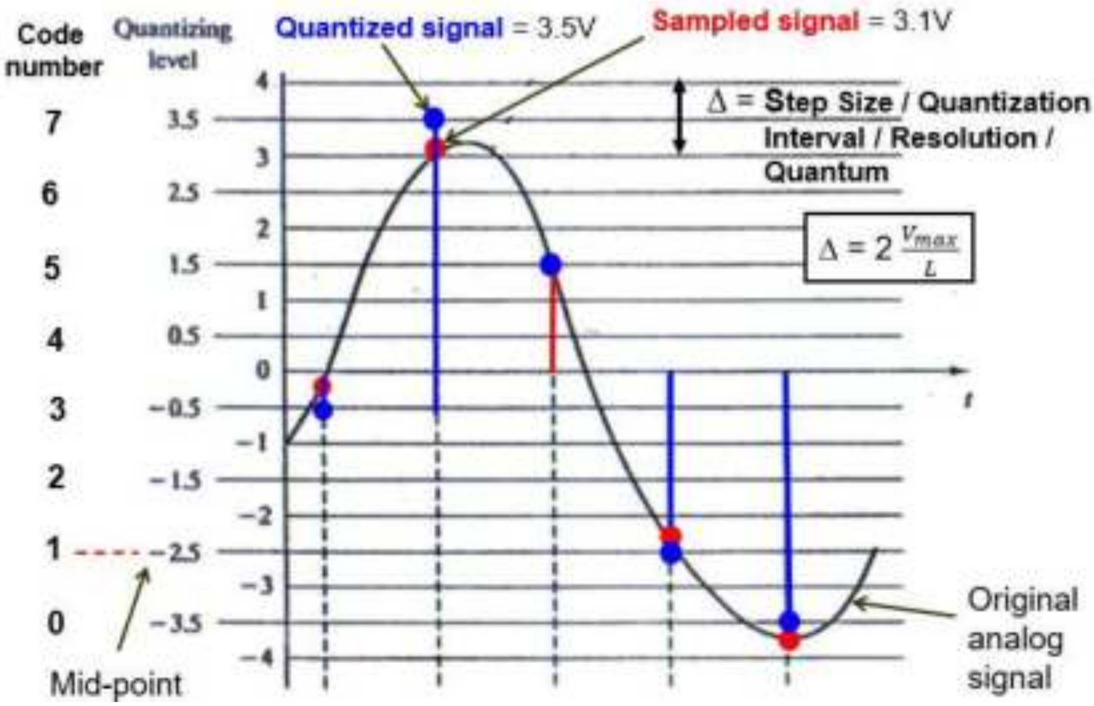


Figure 2.26: Quantization

- ✓ According to figure above, we assumed that the amplitude of sampled PAM signal is confined between **two limits**: **V_{max} = 4V** and **V_{min} = -4V.**

- ✓ The amplitude values of sampled PAM signal are ***infinite*** between these two limits. So, we need to map the ***infinite*** amplitude values onto a ***finite*** set of known values (L zone).
- ✓ This is achieved by dividing the distance between V_{max} and V_{min} into **L zones**, each of **height** of step size, Δ.
- ✓ Since we want to **use 3 bits** PCM code **(n=3),** so the **Quantization Level** is:

$$\boldsymbol{L} = \boldsymbol{2^n} = 2^3$$

$$L = 8\ levels$$

- ✓ Step size, $\Delta = \frac{\boldsymbol{2V_{max}}}{\boldsymbol{L}} = \frac{\boldsymbol{2(4)}}{\boldsymbol{8}} = \boldsymbol{1V}$

✓ The 8 zones are:	✓ The midpoints are:
1. -4V to -3V	1. -3.5V
2. -3V to -2V	2. -2.5V
3. -2V to -1V	3. -1.5V
4. -1V to 0V	4. -0.5V
5. 0V to 1V	5. 0.5V
6. 1V to 2V	6. 1.5V
7. 2V to 3V	7. 2.5V
8. 3V to 4V	8. 3.5V

- ✓ This **midpoint** is called **quantization level, L**. The midpoint of each zone is assigned a value from 0 to L-1 quantization levels.

- ✓ Each sampled signal's **amplitude** is **quantized** (rounding-off) to the **midpoint** of the interval (quantization level) in which it lies.
- ✓ For example, in last page figure, the **second sample** has sampled amplitude value of **3.1V.** After quantization, the sampled amplitude value is **quantized** to **3.5V** level.
- ✓ There are two types of Quantizing method which are:
  1. Uniform Quantization – uniform step size, Δ
  2. Non-uniform Quantization – non-uniform step size, Δ

- ✓ The previous example is Uniform quantization where the step size is uniform for each zone.
- ✓ However, a non-uniform quantization is commonly used because the **uniform quantization is not efficient for a signal that has smaller amplitude.**
- ✓ For example, in speech communication (voice signal), the signal is found have more smaller amplitudes rather than larger amplitudes
- ✓ Thus, uniform quantization scheme is **wasteful** for speech signals because many of quantization levels, L are **rarely used**. The non-uniform quantizing method is more suitable because the step size could be adjusted depends on the amplitude of signal (smaller step size for lower amplitude and larger for higher amplitude).

- ✓ Quantization Error (Q_e)
  1. When a signal is quantized, we introduce **an error** because Quantization is an **approximation** process.
  2. The difference between sampled and quantized value is referred as the quantization error (Q_e).

$$\boldsymbol{Q_e = Quantized\ value - Sampled\ value\ (V)}$$

  3. For example, for **second sample** in Figure 2.26 *(page 62)*, the sampled value is 3.1V, while the quantize value is 3.5V. So:

$$\boldsymbol{Q_e = Quantized\ value - Sampled\ value\ (V)}$$

$$Q_e = 3.5V - 3.1V = \mathbf{0.4V}$$

  4. Quantization error (Q_e) is also called Quantization noise (Q_n) where the **maximum** error is $\mathbf{Q_e} = \pm\frac{\Delta}{2}$ for Uniform Quantization.

✓ Signal to Quantization Noise Power Ratio (SQR)

1. The ***Signal-to-Quantization Noise Power Ratio*** (**SQR**) is defined by the equation:

$$\boldsymbol{SQR\ (dB) = 6.20n + 1.76\ dB}$$

Where,
n = number of bits

2. From the SQR equation, it could be seen that the values of **SQR** is depends on the **number of bits, n.**
3. The higher number of bits, the higher value of SQR could be achieved, the more quantization error could be reduces, and the more accurate recovery signal could be achieved.
4. This is because when the number of bits, n is increased, the number of quantization level, L also increase and the step size, Δ will become smaller.
5. When the step size become smaller, the **amplitude difference (gap)** between **sampled signal** and **quantized signal** could be **minimized** (or maybe no gap) which results in **smaller errors.**
6. Thus, the recovery original signal is more accurate when the quantization errors are reduced.
7. In conclusion, the quality of sampled PAM signal can be improved by using a PCM code with **more bits, n**. BUT, the more bits will introduce **higher bit rate**.
8. **Bit Rate** is the number of bits transmitted during one second and is expressed in **bits per second (bps).**
9. The Bit Rate for PCM could be found from the formula:

$$\boldsymbol{Bit\ Rate = f_s \times n}$$

Where,
f_s = sampling rate
n = number of bits per sample

- Encoding

  ✓ **DEFINITION**: Encoding is a process of translating the **quantized signal** into a **decimal code number**. Then this decimal code number is converted to its representative **binary sequence**.

  ✓ The **number of bits, n** for each **level** of **code number** depends on the **number of quantization level, L** used to quantize the samples which can be determined using M-ary formula:

$$n = \log_2 L \quad \text{or (in } \log_{10}\text{)} \quad n = \frac{\log_{10} L}{\log_{10} 2}$$

  ✓ The quantizing and encoding operations are usually performed in the same circuit which is called analog-to-digital converter (ADC).

  ✓ The **Decimal Code Number** for each quantization level is converted to its representative **binary sequence** by using **Binary Code** or **Grey Code** or **Folded Binary Code.**

Code Number	Binary Code	Gray Code
7	111	110
6	110	111
5	101	101
4	100	100
3	011	000
2	010	001
1	001	011
0	000	010

Figure 2.27: Binary and Grey Code

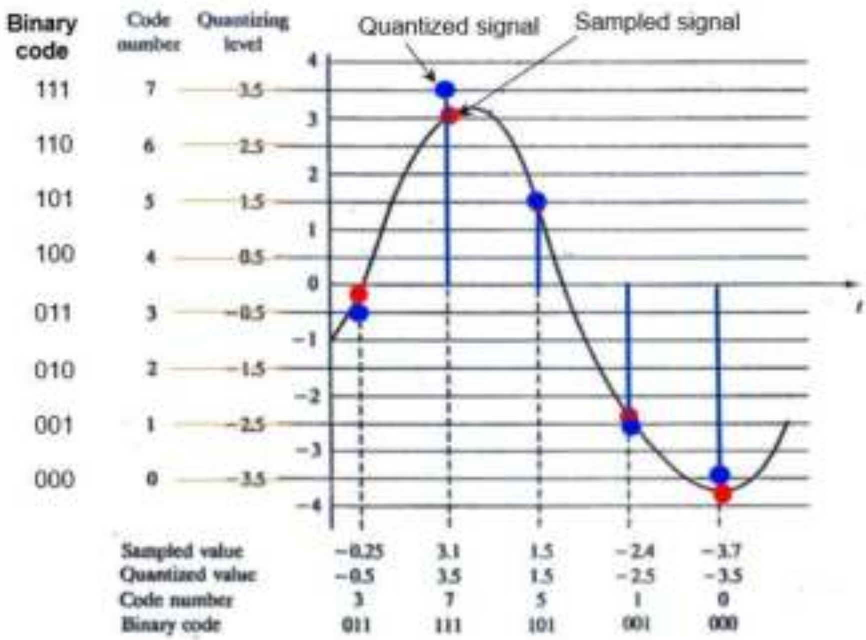


Figure 2.28: The essential features of binary PCM

- ✓ From Figure 2.28, we assign the **decimal** code number **0** to the level **-3.5V**, the code number 1 to level -2.5V, and so on until level +3.5V.
- ✓ Each **decimal code number (0 - 7)** has its own **3 bits binary code** representation, ranging from **000** for code number **0** to **111** for code number **7**.
- ✓ Therefore, the binary sequences (digital signal) that produce from PCM are:

011 111 101 001 000

- PCM Decoder

  ✓ In order to recover an analog signal from a digitized signal we follow the following steps:

  1. Use a **decoder and hold** circuit that holds the amplitude value of a pulse till the next pulse arrives. This will produce **a staircase PAM signal.**

  2. Pass this PAM signal through a **low pass filter** which has the same cutoff frequency as the original information signal at sender. The filter will **smooth** the staircase amplitude of PAM signals into an analog signal.

  ✓ If the original info signal is **sampled at** (or **greater than**) Nyquist Sampling Rate AND if there are **enough Quantization levels,** the original signal would be recovered back with less distortion.

  ✓ The higher the value of quantization level L, the less distorted a signal is recovered.

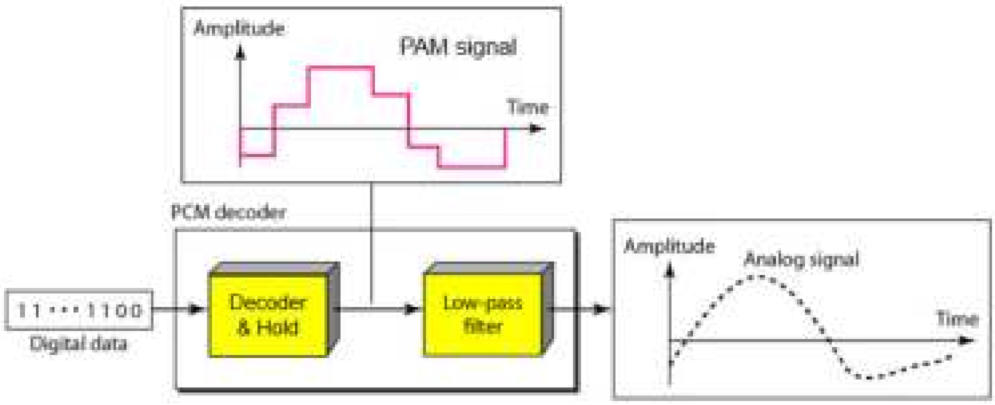


Figure 2.29: Block Diagram of PCM Decoder (Receiver)

- Differential PCM (DPCM) & Adaptive Differential PCM (ADPCM)

  - ✓ In a typical PCM-encoded **speech (human voice) waveform**, the successive samples signal has a **little difference** of **amplitude** between **two sampled signals**.
  - ✓ This necessitates transmitting several **identical(same) PCM codes**, which is **redundant.**
  - ✓ Therefore, Differential Pulse Code Modulation (DPCM) is designed specifically to **remove this redundancy** in PCM technique.
  - ✓ With DPCM, the **Prediction Error** is quantized, encoded and transmitted rather than **actual samples** themselves.
  - ✓ ***Differential PCM (DPCM)***

    1. **DEFINITION**: Differential Pulse Code Modulation (DPCM) is a technique of converting an analog into a digital signal in which an analog signal is sampled and then **the difference between the actual sample value and its predicted sample value** is quantized and then encoded forming a digital value.
    2. **Predicted Sample** = is a value where the **current sample** is predicted based on **previous sample**.
    3. The **difference** between the **actual** sample value and its **predicted** sample value = **Prediction Error**
    4. In DPCM, the **prediction error (or difference)** at the output of a **prediction filter** is quantized, rather than the voice signal itself.
    5. The **prediction error** of the prediction filter is generally **much smaller** than the **actual sample** values.

6. Since the **difference between samples (or prediction error)** are expected to be smaller than the samples themselves, **fewer bits** are required to represent the difference.

7. For example;

    - PCM codes : 220, 218, 221, 219, 220, 221, 222, 218,.. (all values between 218 and 222 and **redundant**) → need 8 bits
    - DPCM codes: 220, +2, -3, 2, -1, -1, -1, +4...→ need 3 bits only

✓ ***Adaptive Differential PCM (ADPCM)***

1. Adaptive similar to DPCM, but adjusts the width of the quantization steps, Δ
2. Encode **difference** in **4 bits**, but **vary** the mapping of bits to difference **dynamically**.
    - If rapid change, use large differences
    - If slow change, use small differences
3. Main application is Telecommunications
    - Speech compression for transmission, storage and reconstruction (Audio Compression: WAV)
    - Image compression (JPEG, MPEG)
    - Reduce the bit data rate while maintaining good voice quality
    - Technique can apply to all waveforms which need high-quality audio, image and modem data.

2.8 Digital Modulation

Digital Signal cannot be transmitted through free space (wireless) medium but Analog signal does. Therefore, digital data needs to be converted into analog signal by doing the Digital Modulation techniques.

Digital Modulation is the process of changing **one** of the **characteristics** of an **analog carrier signal** based on the **information in digital data.** A carrier signal (fc) performs the function of transporting the digital data in an analog waveform.

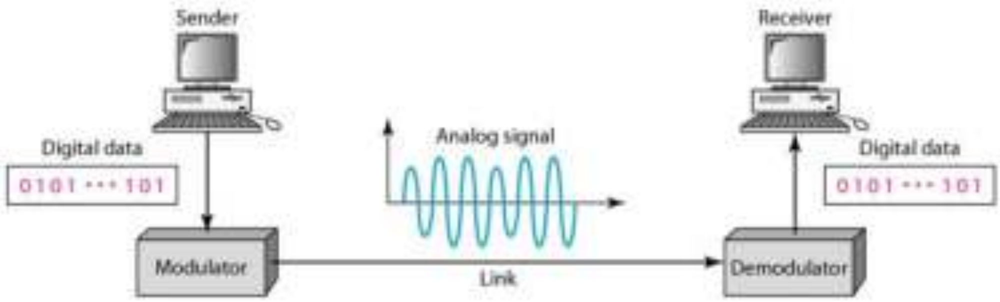


Figure 2.30: Digital-to-analog conversion

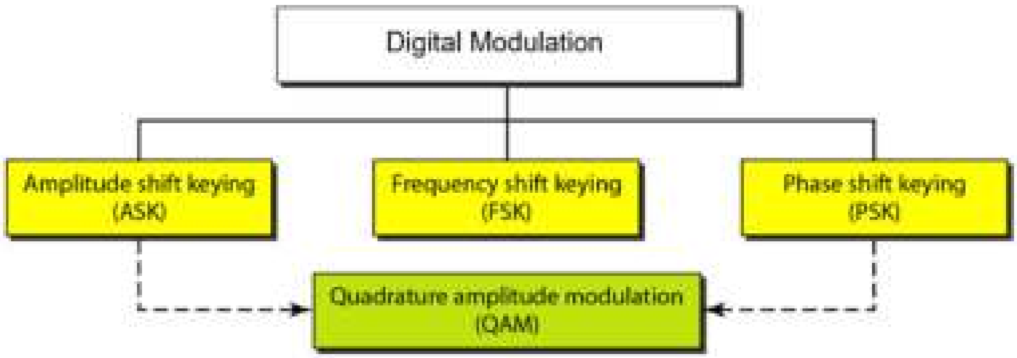


Figure 2.31: Types of Digital Modulation

In ***Digital Modulation*****, Information Signal** is in **digital** waveform; while **Carrier signal** is in **analog** waveform.

- **Amplitude Shift Keying (ASK)** - the **amplitude (Vp)** of the ***analog carrier signal*** is varied proportional to the ***digital information signal.***

- **Frequency Shift Keying (FSK)** - the **frequency (f)** of the ***analog carrier signal*** is varied proportional to the ***digital information signal.***
- **Phase Shift Keying (PSK)** - the **phase (Θ)** of the ***analog carrier*** is varied proportional to the ***digital information signal.***

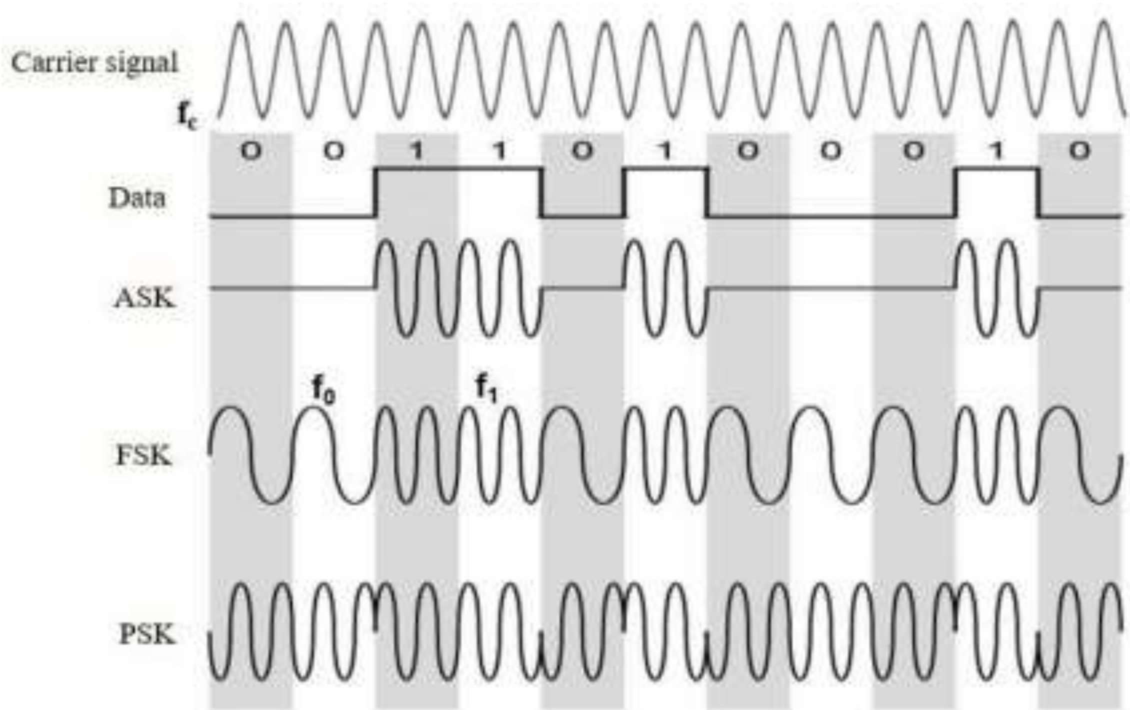


Figure 2.32: Digital Modulation Techniques

- **Amplitude Shift Keying (ASK)**
  - ✓ ASK is the simplest digital modulation techniques.
  - ✓ Also called Digital Amplitude Modulation (DAM) or On-Off Keying (OOK).
  - ✓ ASK is a process where the **binary information signal** directly modulates the **amplitude** of an analog carrier.

- ✓ ASK is similar to standard amplitude modulation except there are only **two** output **amplitudes** possible. Both **frequency** and **phase** remain **constant**.

- ✓ When the binary data is **logic '1'**, the carrier signal has the **constant amplitude** (Vp = A cosω_ct). When the data is **logic '0'**, the carrier signal has **no amplitude** (Vp=0V).

- ✓ Whenever the binary input is 'high' (logic 1), the output of carrier is a **constant-amplitude, constant-frequency** signal. While, when the binary input is 'low' (logic 0), the carrier **is off**.

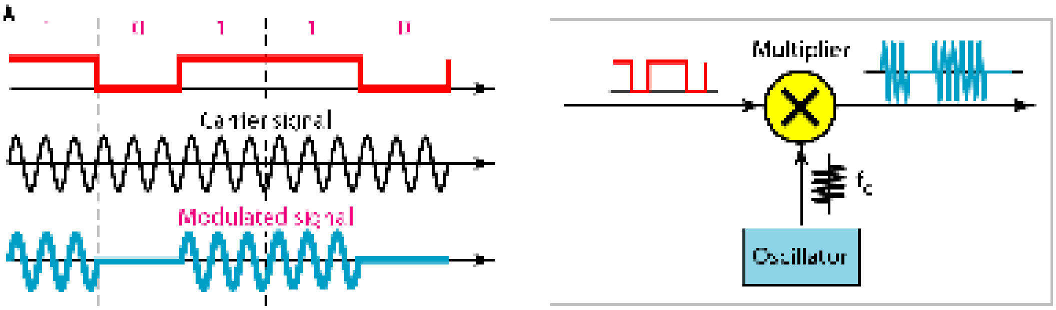


Figure 2.33: Binary Amplitude Shift Keying (ASK)

- **Frequency Shift Keying (FSK)**

  - ✓ FSK is another relatively simple, low-performance type of digital modulation.

  - ✓ FSK is a form of **angle modulated, constant-amplitude** similar to standard FM except the information signal is a **binary** signal that varies between **two discrete voltage levels**.

  - ✓ Sometimes called *binary* FSK (BFSK).

  - ✓ With FSK, the carrier centre frequency (fc) is **shifted (deviated)** up and down in the frequency domain by the binary input as shown in Figure 2.33.

- ✓ As the binary input signal changes from a logic 0 to a logic 1 and vice versa, the output frequency shifts between **two** frequencies: **logic 1 - frequency** (f_1) and **logic 0 - frequency** (f_0).

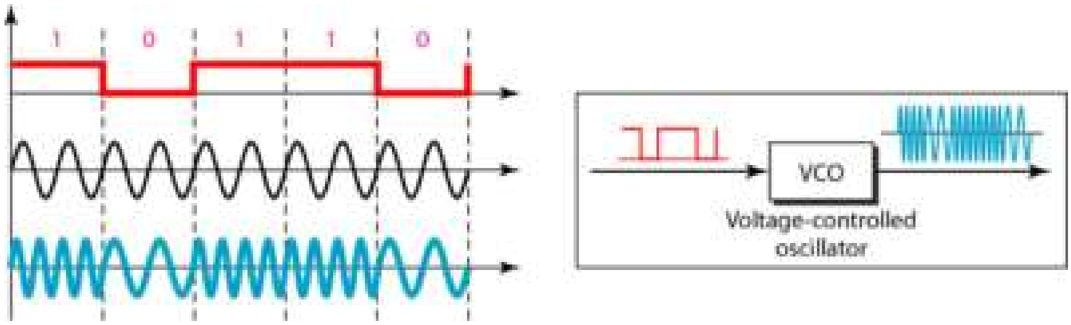


Figure 2.34: Binary Frequency Shift Keying (FSK)

- **Phase Shift Keying (PSK)**

  - ✓ PSK is another form of **angle-modulated, constant-amplitude** digital modulation.

  - ✓ PSK is an ***M-ary*** digital modulation scheme

  - ✓ Similar to conventional PM except with PSK the input is **a *binary* digital signal** and there are a limited number of output **phase** possible.

  - ✓ The input binary information is encoded into **groups of bits** before **modulates** the **carrier**.

  - ✓ A group has **n** bits (n = 1….12).

  - ✓ The **number of output phases** is defined by $M = 2^n$.

  - ✓ The simplest form of PSK is *binary* phase shift keying (BPSK) where n=1 and M=2.

  - ✓ Therefore **two phases** are possible ($2^1 = 2$) for the carrier which are logic '1' and logic '0'.

- ✓ One phase represents a logic ‘1’ and other phase represents logic ‘0’.
- ✓ As the input digital signal changes (i.e. from a 1 to a 0 or from a 0 to a 1), the phase of the output carrier shifts between two angles that are separated by 180º as shown in Figure 2.34.

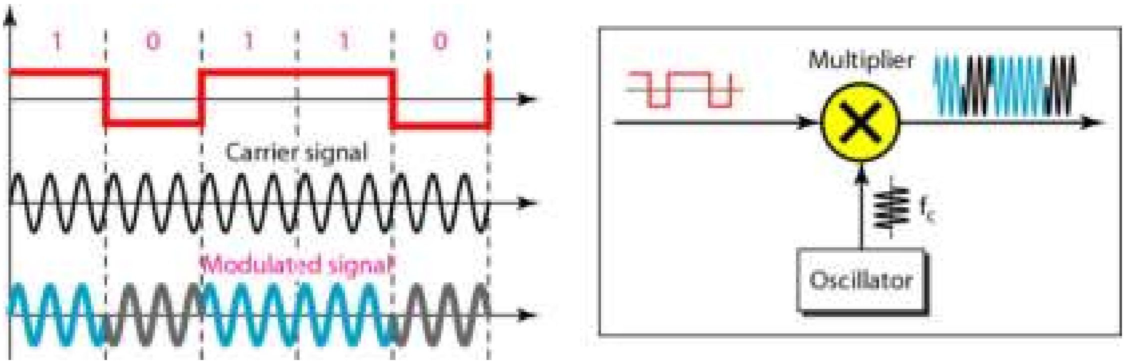


Figure 2.35: Binary Phase Shift Keying (PSK)

CHAPTER 3

MULTIPLEXING & TRANSMISSION MEDIUM

3.1 What would you get?

- Know and understand Multiplexing and Demultiplexing
- Know and understand Guided Medium
- Know and understand Unguided Medium
- Know and understand Antenna

3.2 Multiplexing & Demultiplexing

NOTE: Bandwidth utilization is the wise use of available bandwidth to achieve specific goals. Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, **the link can be shared**. Efficiency of bandwidth utilization can be achieved by **multiplexing,** which is **sharing** of the **bandwidth** of **one link** between **multiple** users/sources.

DEFINITION: **Multiplexing** is a technique that **combine** the information signals (in any form) from **more than one information sources** over the **same transmission medium.**

DEFINITION: **Demultiplexing** is a technique to **separate** the multiplexed (merged) signal from **one link** back to its component transmissions.

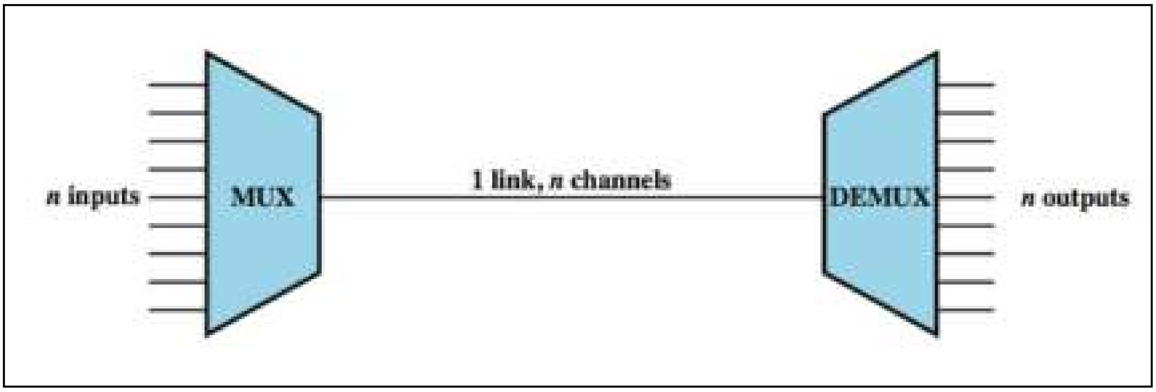


Figure 3.1: Multiplexing & Demultiplexing

- In a multiplexed system, **n-input lines-sources share** the **bandwidth** of **one link**.
- **Multiplexer:** the **n-input** lines-sources are multiplexed (merged) into a **single link** and then **dividing** a link into many **n-channels.**
- **Demultiplexer** receives the multiplexed data stream and **extracts** them back into their original n-input channels and directs them to their corresponding lines.
- The word **link** refers to the **transmission medium**. While, the word **channel** refers to the **portion of a link** that carries a transmission between a given pair of lines.
- **One link** can have **many (n) channels**.
- The **transmission medium** may be a metallic wire pair, a coaxial cable, a PCS mobile telephone, a terrestrial microwave radio system, a satellite microwave system or an optical fiber.
- The terms “multiplexing” also refers to the **Communication Resources (CR) allocation.**
- **Function:**
  - ✓ Combine the information signals that might have **difference characteristics @ forms** (analog, digital) or might originate from **difference sources** over the **same transmission medium**. (*the combining signals is called Communication Resources*)
  - ✓ Distribute/allocate/divide the combining signals (CR) into **difference channels** over the **same transmission medium.**

- Although the transmissions occur on the same transmission medium, they do not necessarily occur at the same time (t) or occupy the same bandwidth (BW).
- **Multiplexing (MUX)** is an efficient approach of **CR allocation** into difference **channels** over the **same transmission medium**.
- For the **efficient** use of high-speed telecommunications line, it is important to plan out the **communication resource allocation** among users system, so that no block of **time or frequency** is wasted, so that the users can **share** the CR in an equitable manner.
- **Advantages:**
  - ✓ Could increase the number of channels in a single transmission line. Therefore, more information can be transmitted.
  - ✓ Reduce cost of transmission because higher utilization of transmission medium.
  - ✓ Efficiency of bandwidth utilization
- **Types** - There are several techniques for multiplexing/multiple access but the basic ways of CR allocation are:
  1. Time Division: **TDM**, TDMA
  2. Frequency Division: **FDM**, FDMA
  3. Wavelength Division: **WDM**, WDMA
  4. Code Division: CDMA (TDMA + FDMA)

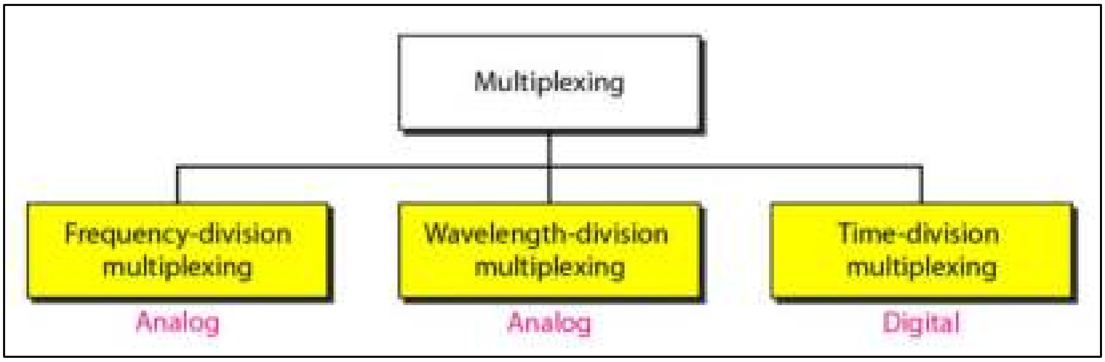


Figure 3.2: Categories of Multiplexing

3.3 Time Division Multiplexing (TDM)

- TDM is a digital multiplexing technique for combining several low-rate digital channels/sources into one high-rate one.

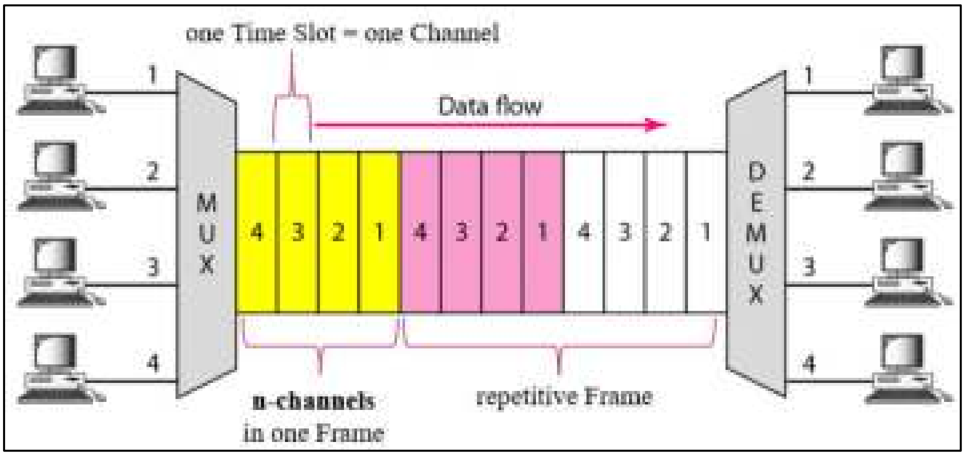


Figure 3.3: Time Division Multiplexing (TDM)

- With TDM, the transmission of info signals from various sources occur on the **same transmission medium** but **NOT** at the same **time**.
- The **CR** is shared by assigning each of signals for a **short duration** of time called a **time slot.**
- Each **time slot** is assigned as a **channel.**

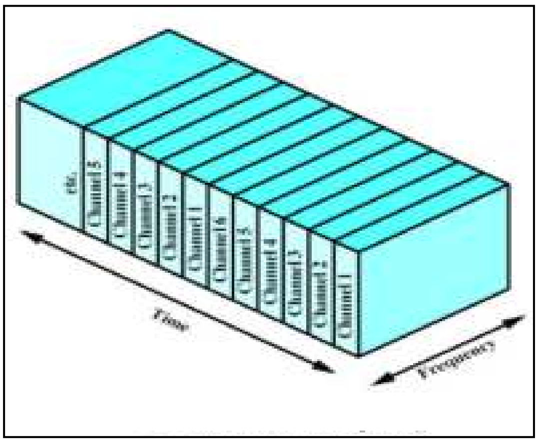


Figure 3.4: TDM Communication Resources (CR) Allocation

- From Figure 3.3, it could be seen that the information signals from various sources are carried in **repetitive Time Frames**.
- In synchronous TDM, **each Input information source** is divided into **n -input units/time slots.** (*n = number of input information sources*).
- For example, in Figure 3.5 **information source A** is divided to 3 units or time slots which are A1, A2, A3.
- Then, **each input unit** becomes **one output unit** and occupies **one output time slot per frame.**
- **A unit** can be one bit, one character or one block of data.

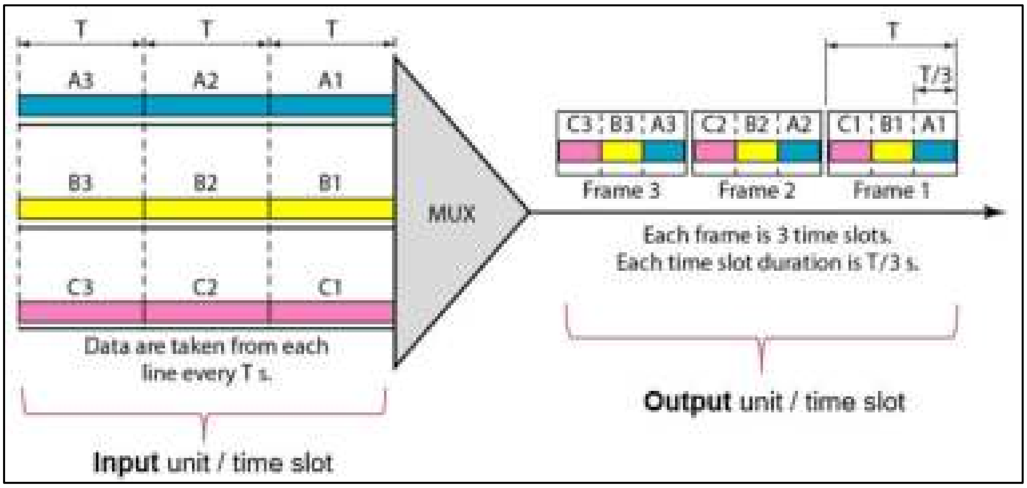


Figure 3.5: Synchronous time-division multiplexing

- Each Time Frame consists of **a set** of **n-output time slots**. (*n = number of input information sources*). If there are 10 input signals, then there are **10 output time slots per frame**.
- However, the **duration** of **an output time slot** is **n shorter** than the duration of **an input time slot**.
- If an **input** time slot is **T second,** then **the output** time slot is **T/n second**.

- In other words, a unit of output time slot has a shorter duration: but faster transmission.
- TDM usually used with digital signals or analogue signals.
- An analog signal must be converted into digital signal using PCM technique before multiplexed by TDM.
- **Application**: in Telephony PCM-TDM.
- For TDM the modulation process is done after multiplexing.
- **Disadvantage**: The signal sources take times to transmit.

3.4 Frequency Division Multiplexing

- FDM is an analog multiplexing technique that combines analog signals. It uses the concept of analog modulation discussed in Chapter 2.

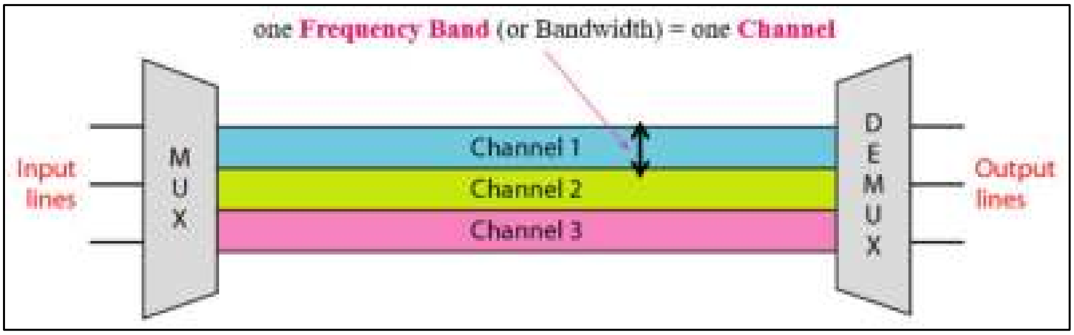


Figure 3.6: Frequency Division Multiplexing (FDM)

- With FDM, the info signals from multiple sources that originally occupied the **same frequency spectrum (BW)** are each **converted** to a **different frequency bands**.
- The **CR** is shared by allocate each of signals to a different **frequency band**.
- Each **frequency band** is assigned as a **channel.**

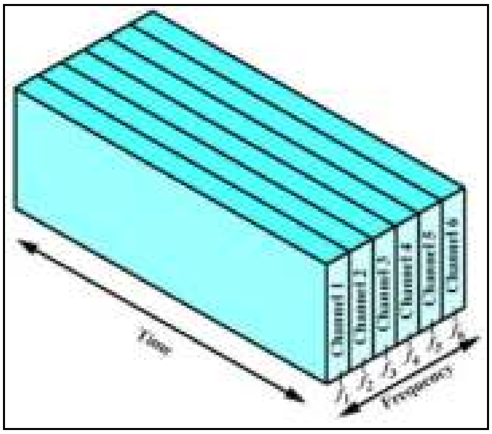


Figure 3.7: FDM Communication Resources (CR) Allocation

- FDM is an analog technique that can be applied when the bandwidth of a link is greater than the combined bandwidths of the information signals to be transmitted.

- FDM is used to combine **many relatively narrowband sources** into a **single wideband** before allocated to **different frequency bands (or bandwidth)** such as in Public Telephone Systems.

- FDM is an analog multiplexing scheme. So, the information signal must be analog.

- For FDM, the modulation process is done **before** multiplexing.

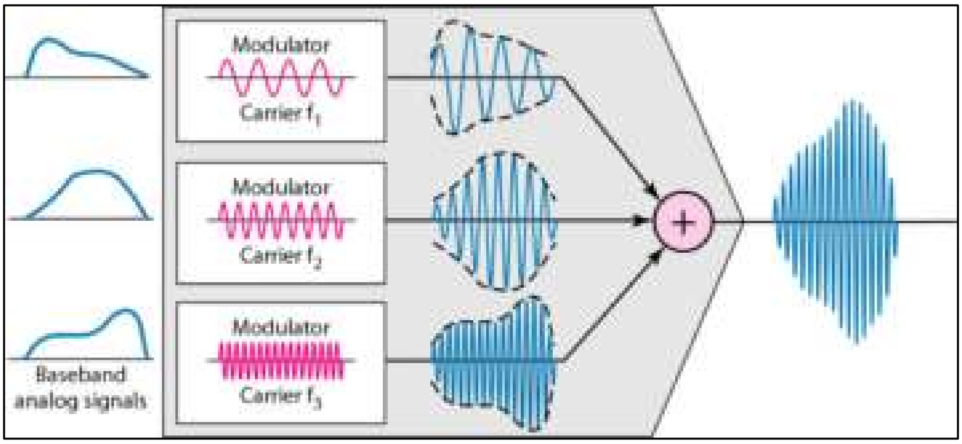


Figure 3.8: FDM Process

✓ Modulation is needed to move each info signal source to the required **frequency band (bandwidth).**

✓ Therefore, multiple carriers are used where each is called subcarrier.

✓ **Each** information signal source modulates at **different subcarrier frequency** to form a **modulated signa**l at **its own frequency band** as shown in Figure 3.8.

✓ Multiplexing process is needed to **combine** the **modulated signals** on a single transmission line.

✓ Example: Commercial AM or FM Radio Broadcasting.

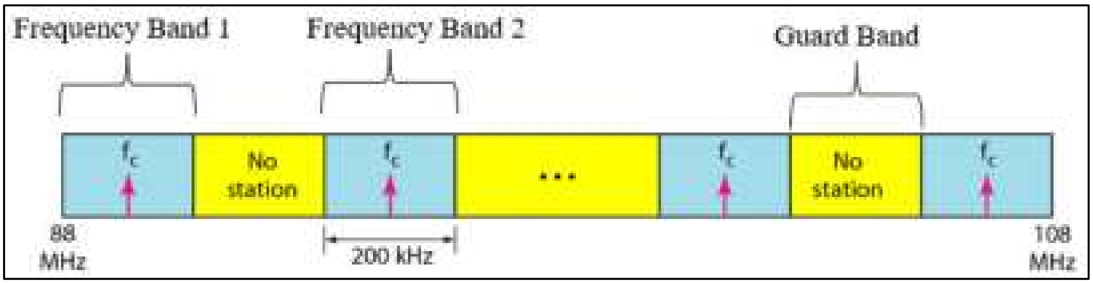


Figure 3.9: FM Radio Broadcasting

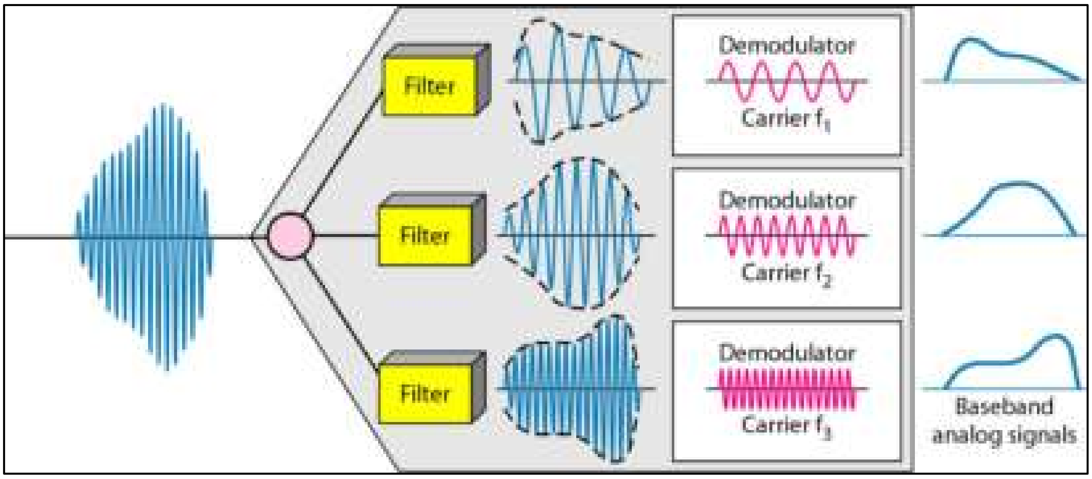
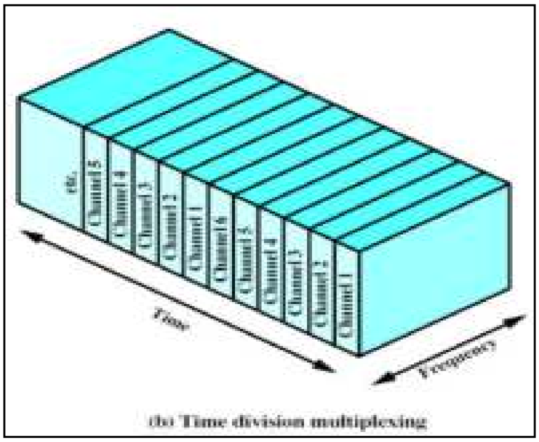
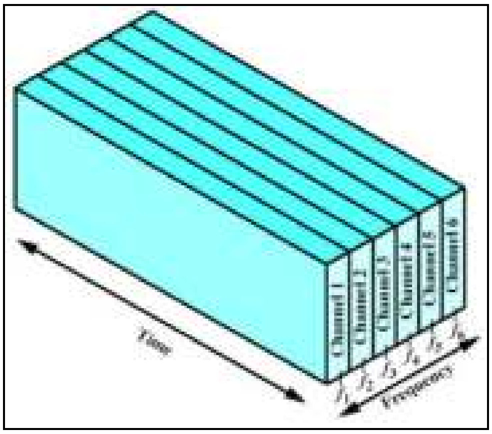


Figure 3.10: FDM Demultiplexing Process

✓ **Comparison of TDM & FDM**

	TDM	FDM
1	 (b) Time division multiplexing	
2	The Communication resources are allocated into many time slots	The Communication resources are allocated into many frequency bands
3	Used for Digital signal	Used for Analog signal
4	Only one carrier signal (only one modulator)	Multiple carriers are used, each is called sub-carrier (has many modulator→ 1 info source, 1 modulator)
5	Modulation after multiplexing process	Modulation before multiplexing process

3.5 Wavelength Division Multiplexing

WDM is an analog multiplexing technique to combine optical signals. WDM is a method of combining multiple information signals of **light beams** at various **infrared frequencies** for transmission along **fiber optic** media. Since wavelength (λ) and frequency (f) are closely related, WDM is similar to FDM.

WDM is conceptually the same as FDM, except that the multiplexing and demultiplexing involve **optical signals** transmitted through **fiber-optic** transmission mediums. The idea is the same: combine different signals of different frequencies; but the difference is that the frequencies are very high (infrared light).

Usually **WDM** is used for **analog** signal. It is used to overcome **the growth in data traffic** because WDM capable to **increase the bandwidth capacity** (because use fiber optic cable). The **optical fiber** data rate is higher than the data rate of **metallic cable** because of utilization of **light signal** which has **very high frequency**. In WDM, the CR is shared by allocate each of signals to a **different wavelength**.

- ✓ One wavelength = one channel.
- ✓ Different wavelength of light gives a different color of light.

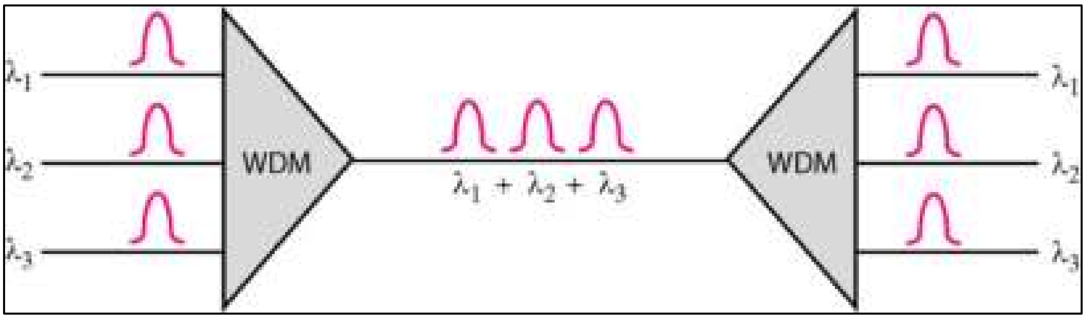


Figure 3.11: Wavelength-division multiplexing (WDM)

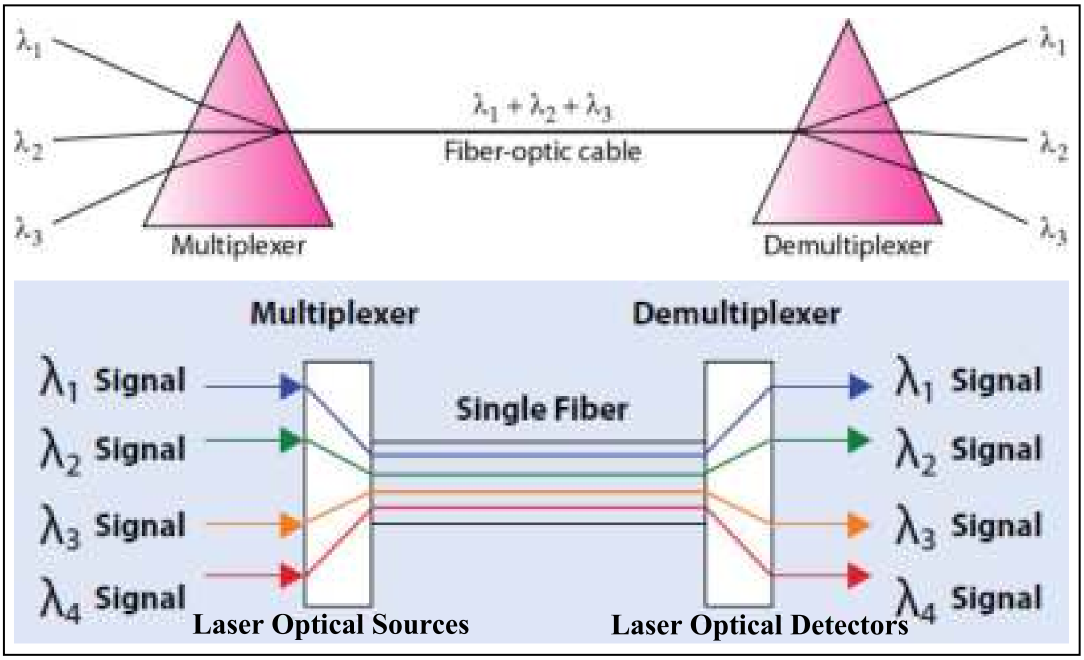


Figure 3.12: Prisms in WDM

- According to Figure 3.12, multiple **beams of light** at different **frequencies** or **wavelengths** (different **colors** of light) are transmitted on the **same** fiber optic cable.
- Each **light beam** carries separate data channel.
- WDM combines multiple light sources that have different wavelength into one single light at multiplexer and do the reverse at the demultiplexer.
- The combining and splitting of light sources are easily handled by a **prism** as shown in Figure 3.13.

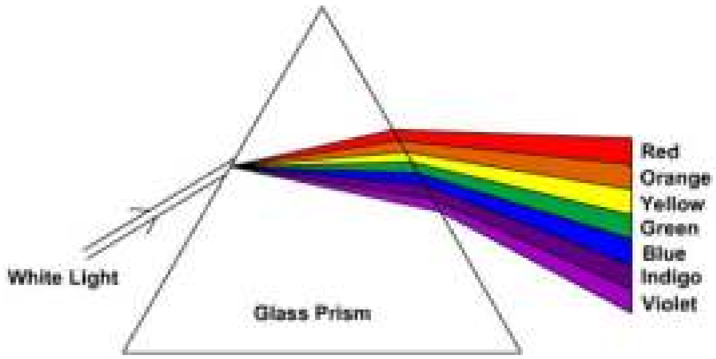


Figure 3.13: Dispersion of light by Glass Prism

- Unlike FDM (has same time, same transmission path); the different light beam, λ travels at **different speed** and did not take the same path but enter the fiber at the same time and the same transmission medium.
- Each beam arrives at receiver at a slightly different time.

3.6 Guided Medium

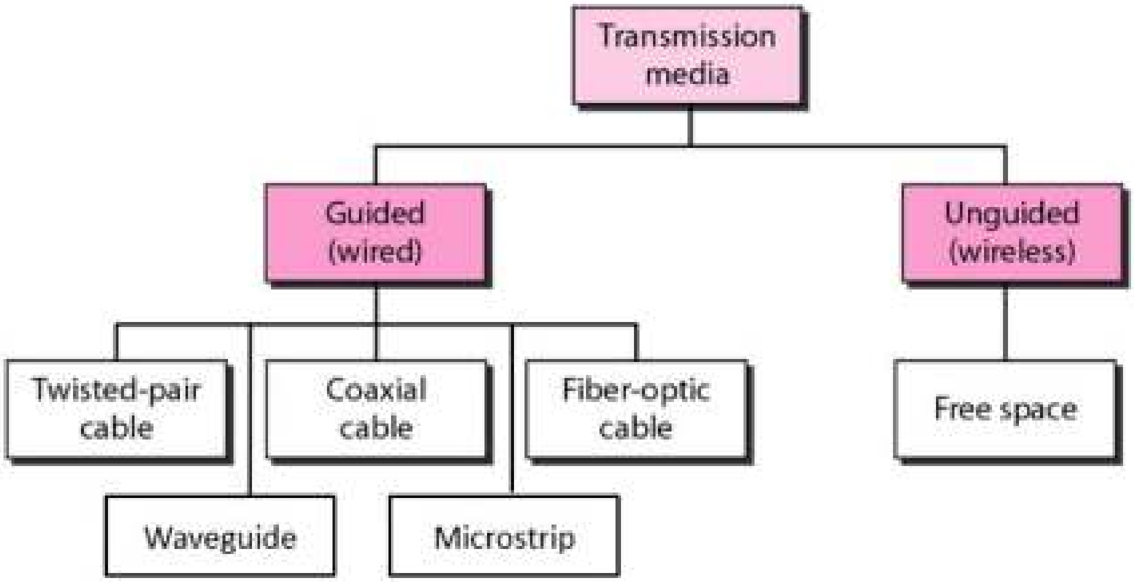


Figure 3.14: Transmission Medium

Guided media, is a media that provide a **conduit** from one device to another device such as:

1. Twisted-Pair Cable
2. Coaxial Cable
3. Fiber-optic Cable
4. Microwave transmission medium (waveguide and microstrip)

Twisted pair and coaxial cable use **metallic(copper) conductor** that accept and transport signals in form of **electrical current**. Fiber optic cable use **transparent material** that accepts and transports signals in the form of **light.**

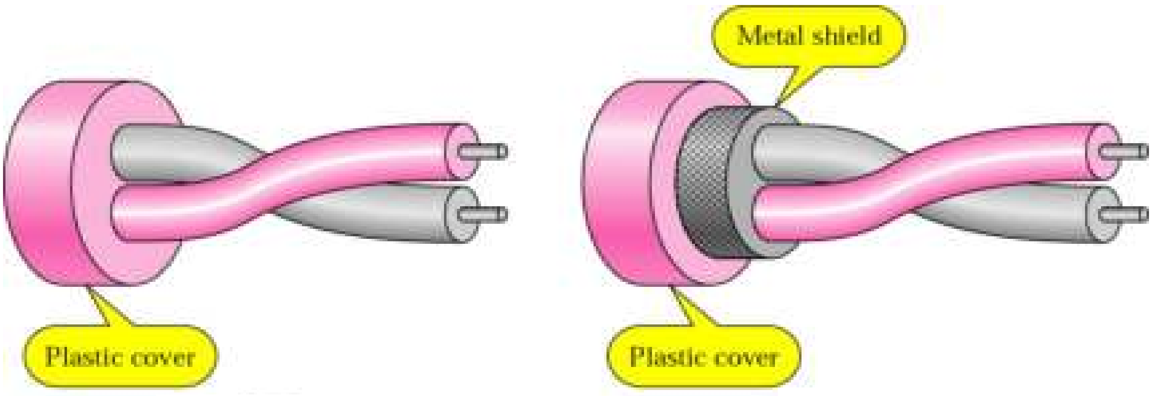
- **Twisted pair cable**
  - ✓ A twisted pair cable consists of **two** insulated **copper** wires in a regular **spira**l pattern as shown in below figure.
  - ✓ A **pair of wire** acts as a **single communication link**.
  - ✓ One of the wires is used to carry signals to the receiver, while the other one is used only as a ground reference.
  - ✓ Twisted is used to **reduce electrical interference** from similar pairs close by (more twists mean better quality).

Figure 3.15: Twisted Pair Cable

✓ There are TWO (2) types of twisted pair cable:

i. Unshielded Twisted Pair (UTP)

ii. Shielded Twisted Pair (STP)



ii. UTP i. STP

Figure 3.16: Types of Twisted Pair Cable

✓ **Comparison** of UTP and STP

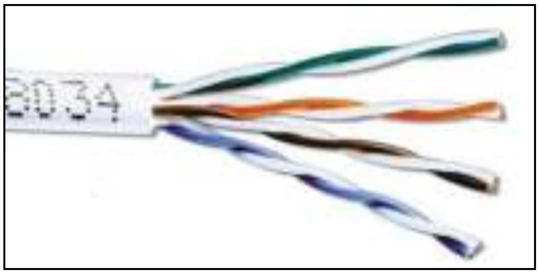
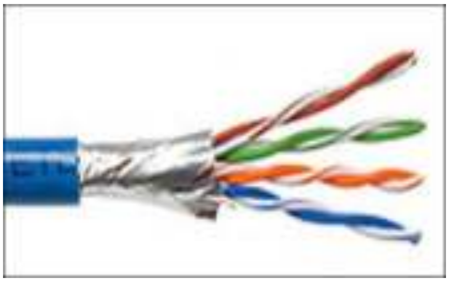
	Unshielded Twisted Pair (UTP)	Shielded Twisted Pair (STP)
1		
2	**Cheapest** type of cable	More **expensive**
3	**Easiest** type **to be installed**	**Harder** to be installed (thick, heavy)
4	Suffers from external Electromagnetic Interference (EMI)	Has a metal braid for covering that can reduces EMI

Table 3.1 Comparison of UTP and STP

✓ **Categories** of twisted pair cables

- The Electronic Industries Association (EIA) has developed standards to classify UTP cable into seven categories.
- Categories are determined by cable quality, with 1 as the lowest and 7 as the highest.
- Each EIA category is suitable for specific uses.

✓ Twisted pair cable **connector**

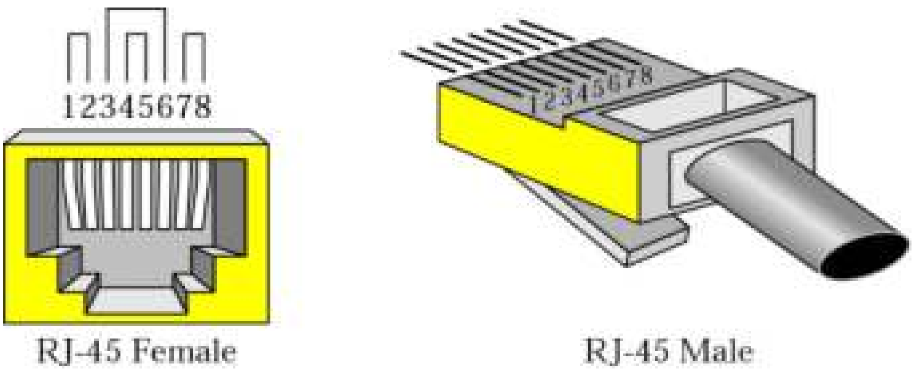


Figure 3.17: Registered Jack (RJ)

✓ **Advantages & disadvantages** of twisted pair

	Advantages	Disadvantages
1.	A high installed base	Very noisy
2.	Cheap to install	Limited in distance • Analog Transmission ✓ Need amplifiers every 5km to 6km • Digital Transmission ✓ Need repeater every 2km or 3km
3.	Easy to terminate	Suffers from interference
4.	Easy to work with	Limited of data rate
5.		Easily affected by **outer interference** and noise

Table 3.2: Advantages and Disadvantages of Twisted Pair

✓ **Applications** of twisted pair

- Most common medium
- Telephone network
  - Between house and local exchange (subscriber loop)
- Within buildings
- For Local Area Networks (LAN)
  - 10Mbps or 100Mbps

- **Coaxial Cable**
  - ✓ At higher frequency (above 1MHz), the twisted pair cable is not any more efficient to be used because of the radiation loss in heat form.
  - ✓ This is because the twisted pair cable has no sufficient insulator to protect the signal from radiated.
  - ✓ Therefore, coaxial cable is designed to overcome this radiation loss problem by **insulated the copper twice.**
  - ✓ Coaxial cable carries signals of higher frequency ranges than those in twisted-pair cable, in part because the two media are constructed quite differently.
  - ✓ Instead of having two wires, coaxial cable has a central core conductor of **solid** and stranded/braided wire (usually copper) enclosed in an insulating sheath.
  - ✓ The **outer metallic conductor** wrapping serves two function:
    1. As a shield against noise,
    2. As the second conductor which completes the circuit.

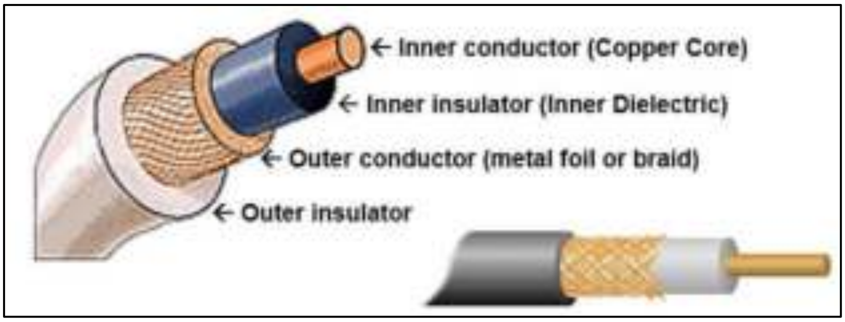


Figure 3.18: Structure of Coaxial Cable

Figure 3.19: Coaxial Cable Connector

✓ **Application** of coaxial cable

1. Widely used in **analog telephone** network (single coaxial cable could carry 10,000 voice signals).
2. **Digital telephone** network (single coaxial cable could carry digital data up to 600Mbps).
3. Satellite TV cable (ASTRO)
4. Oscilloscope probes
5. LAN cable

✓ **Advantages & disadvantages** of coaxial cable

	ADVANTAGES	DISADVANTAGES
1	cheap to install	limited in distance
2	conforms to standards	limited in number of connections
3	widely used	terminations and connectors must be done properly
4	Because of the shield or jacket that covers the outer and inner conductors, it has better protection from EM Interference and crosstalk noise than twisted pair.	High attenuation rate makes it expensive over long distance (needs more repeaters)
5		Fragile - transmission can be easily stopped.
6		Size - thicker than twisted

Table 3.3: Advantages and Disadvantages of Coaxial Cable

- **Fiber Optic Cable**
  ✓ Fiber optic consists of THREE (3) concentric sections
    1. **Core** - consists a **fiber** made of **glass** or **plastic** or any **transparent** material. The core is a path for light propagation.
    2. **Cladding** – an **insulator** made of a **glass** or **plastic** or any **transparent** material that has optical properties different from the core.
    3. **Coating/Jacket** - a **non-transparent** material which acts as a layer to protect the fiber against moisture, crushing, and other environmental dangers

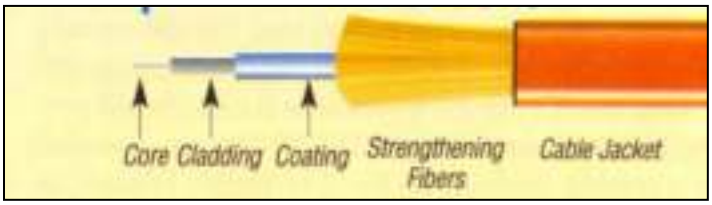


Figure 3.20: Fiber Optic Concentric Sections

- ✓ There are THREE (3) elements in Optical Fiber Communication:
  1. Light Source (Transmitter)
     - converts the pulses of **electrical current** to **light pulses**. eg: **LED** (light emitting diode) and **ILD** (Injection laser diode).
  2. Fiber Optic Cable (Transmission Medium)
     - transmit the light-beam pulses
  3. Photo Detector (Receiver)
     - converts the received **light pulses** back to pulses of **electrical current**. Eg: **APD** (Avalanche Photodiode) and **PIN** (Positive Intrinsic Negative) photodiode.

- ✓ Light propagation: Bending of light ray

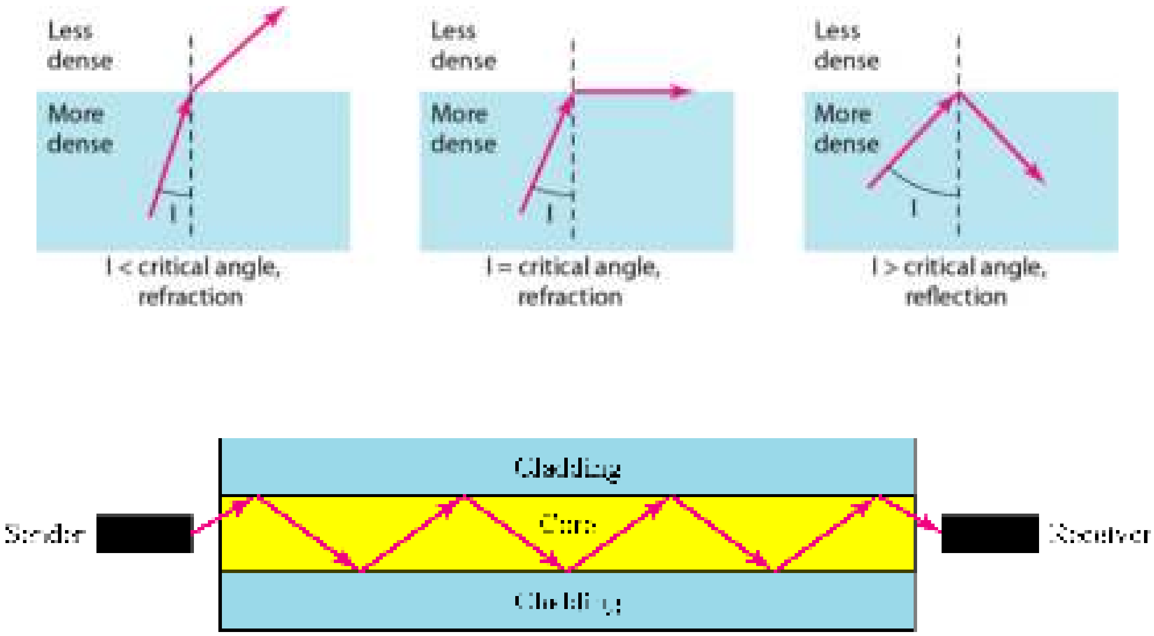
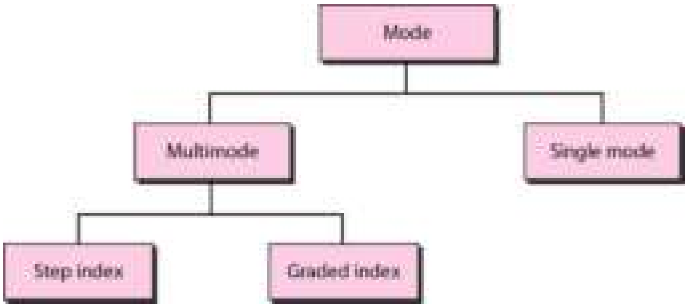


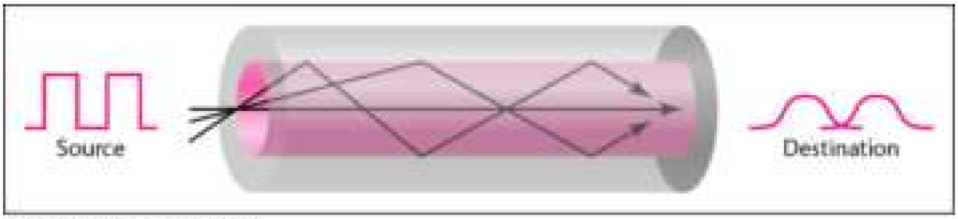
Figure 3.21: Light Propagation

✓ Propagation Modes

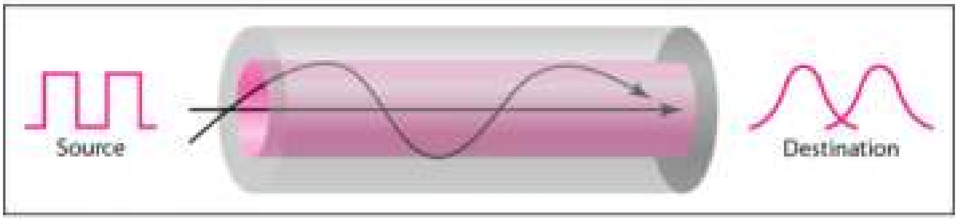
1. **Mode** = path
2. **Index** = refractive index, n



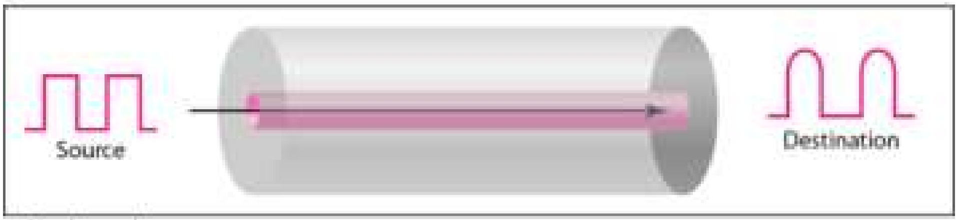
Type	*Core (µm)*	*Cladding (µm)*	*Mode*
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode



a. Multimode, step index



b. Multimode, graded index



c. Single mode

Figure 3.22: Propagation Modes

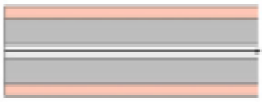
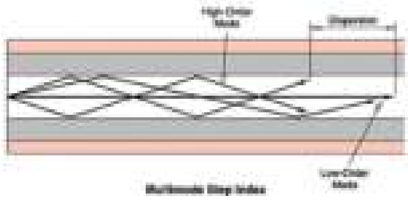
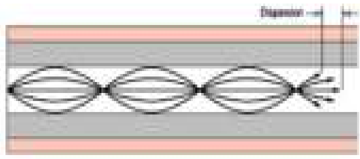
	SINGLE MODE	MULTIMODE STEP INDEX	MULTIMODE GRADED INDEX
1			
2	Small diameter of core (7 - 10µm)	50µm - 100µm).	50µm - 85µm).
3	The fastest transfer rate	Slower transfer rate	Modest transfer rate
4	Low attenuation	High attenuation	Modest attenuation
5	No modal dispersion	High modal dispersion	Low modal dispersion
6	Suitable for long distance transmission	For short distance (high attenuation)	For modest distance
7	Expensive because hard to build	Cheapest because easy to build	Cheaper

Table 3.4: Differences for Each Propagation Modes

✓ Fiber optic cable connectors

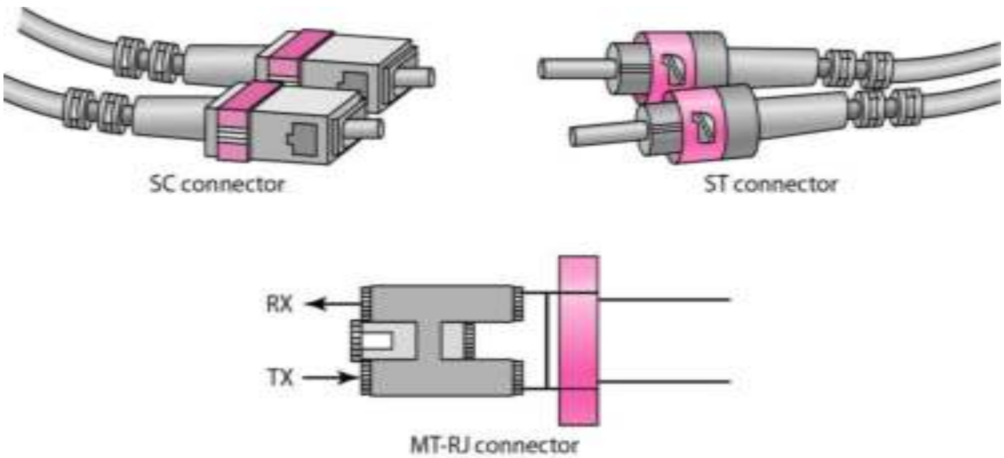


Figure 3.23: Fiber Optic Cable Connectors

- ✓ **Advantages** of fiber optic cable:
  1. **Greater capacity and higher bandwidth**
     - Data rates of hundreds of Gbps.
  2. **Smaller size & light weight**
  3. **Lower signal attenuation** (signal loss)
     - A signal can run for 50km without requiring regeneration (repeater).
  4. **No crosstalk** (no light leaking)
  5. **Immunity to Electromagnetic Interference (EMI)**
  6. **Highly secure** (no light leaking)
  7. **Resistance to corrosive materials.**
     - Glass is more resistant to corrosive materials than copper.
- ✓ **Disadvantages** of fiber optic cable:
  1. **Not easy to install and maintain** - Require expertise to do maintenance and installation of cable.
  2. **Unidirectional light propagation** – Propagation of light is unidirectional. Two fibers are needed for bidirectional.
  3. **Expensive cost - more expensive interfaces** than electrical interfaces used with other types (twisted, coaxial).
- ✓ **Application** of fiber optic cable:
  1. Long-distance trunks (1500 km)
  2. Subscriber loops (to replace twisted pair)
  3. LANs (100 Mbps – 10 Gbps)
  4. CCTV for TV studio
  5. Communication system in military
  6. Communication system in air force
  7. Control system at nuclear plant
  8. Communication and control system in marine
  9. Connection between monitor and measurement equipment at laboratory and factory.

- **Comparison of guided medias**

	Twisted Pair Cable	Coaxial Cable	Fiber Optic cable (FOC)
1	It uses electrical signals for transmission	It uses electrical signals for transmission	It uses optical form of signal for transmission
2	It uses metallic conductor to carry the signal	It uses metallic conductor to carry the signal	It uses glass or plastic to carry the signal
3	Noise immunity is low. Therefore, more distortion	Higher noise immunity than twisted pair cable due to the presence of shielding conductor	Highest noise immunity as the light rays are unaffected by the electrical noise
4	Affected due to external magnetic field	Less affected due to external magnetic field	Not affected by the external magnetic field
5	Cheapest	Moderately costly	Costly
6	Can support low data rates	Moderately high data rates	Very high data rates
7	Power loss due to conduction and radiation	Power loss due to conduction	Power loss due to absorption, scattering, dispersion
8	Short circuit between two conductors is possible	Short circuit between two conductors is possible	Short circuit is not possible
9	Low bandwidth	Moderately high bandwidth	Very high bandwidth

- **Waveguide**
  - ✓ Waveguide is a **hollow metal tube** designed to carry **microwave energy** from one place to another **without losses.**
  - ✓ Constructed from **highly conductivity material** or **non-transparent dielectric** material such as **copper**, **aluminum,** or **brass.**
  - ✓ Aluminium is highly conductive and **ligh**t but difficult to weld and solder.
  - ✓ Brass has the lowest conductivity but easy to manufacture.

- ✓ **Internally plated** with gold or silver to reduce radiation loss and low electrical resistance.
- ✓ Has TWO (2) **propagation mode** of electromagnetic waves moves inside the waveguide which are:
  1. TE (Transverse Electric) mode
  2. TM (Transverse Magnetic) mode
- ✓ Has THREE (3) basic **types** of waveguide:
  1. Rectangular
  2. Circular
  3. Rigged

1. Rectangular Waveguide
   a. Widely used as connector between antenna and electronic equipment.
   b. Used in laboratory due to its light structure.

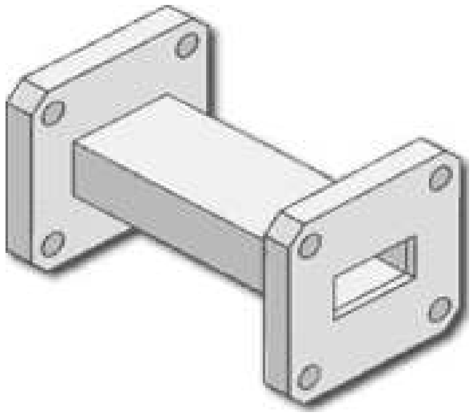



Figure 3.24: Rectangular Waveguide

2. Circular Waveguide
    a. Bigger cross section than rectangular.
    b. Possibility of plane of polarization to rotate due to discontinuities or roughness.
    c. Easier to manufacture than rectangular.
    d. Easier to join together.

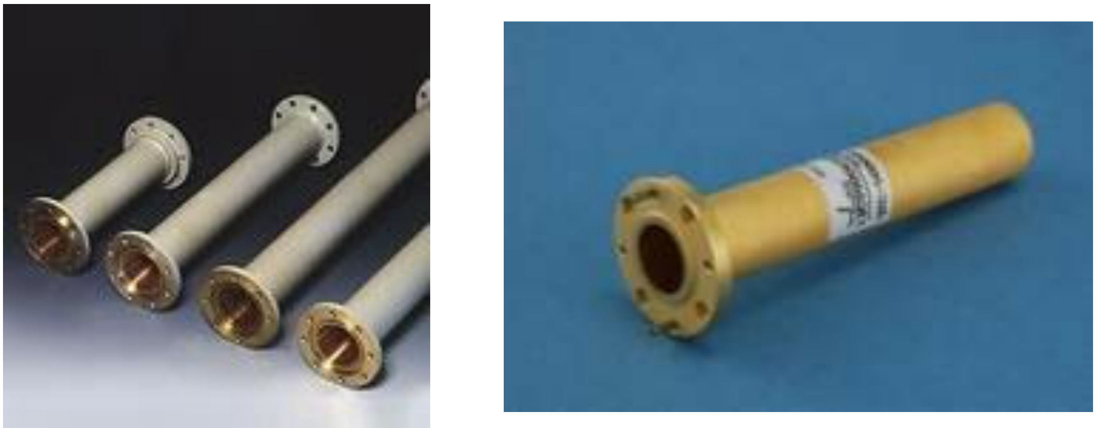


Figure 3.25: Circular Waveguide

3. Ridged Waveguide
    a. Single or double ridge type lowers the value of the cut-off wavelength, hence decreases the guide's size.
    b. Increases the useful frequency range.
    c. Reduce the phase velocity.
    d. Higher loss than ordinary rectangular waveguide.

Figure 3.26: Ridged Waveguide

✓ **Advantages** of waveguide

1. Easier to fabricate than coaxial cable
2. No flashover
3. Better power handling capability (10x as much as coaxial cable)
4. **Lower power loss** - wave travels along the guide **without** greatly attenuating as it goes.
5. Higher operating frequency.
6. **Routable** - can easily bend the guiding structure without generating reflection and without incurring additional losses.

- Microstrip
  - ✓ Microstrip is a type of electrical transmission line whi**ch can be fabricated** using printed circuit board (PCB) technology and is used **to convey microwave** frequency signals.
  - ✓ It consists of a **conducting strip** separated from a **conductor ground plane** by a dielectric layer known as the substrate.
  - ✓ Microwave components such as antennas, couplers, filters, power dividers etc. can be formed from microstrip. The entire device existing as the pattern of metallization on the substrate.

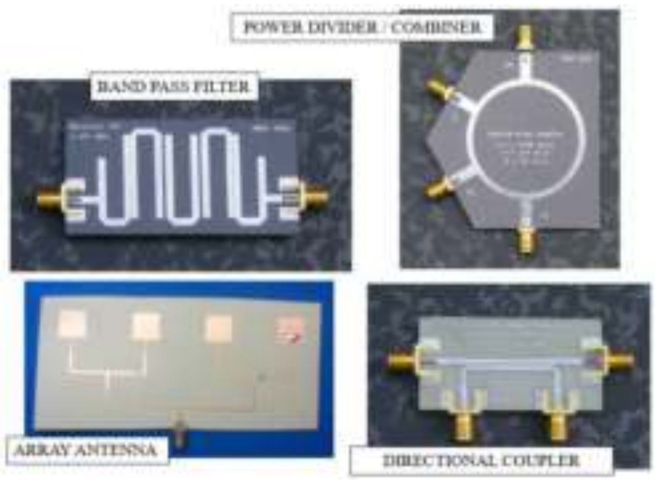


Figure 3.27: Microstrip

✓ Microstrip **connector**:

Figure 3.28: Microstrip Connector

✓ **Advantages** of microstrip:

1. Much **less expensive** than traditional waveguide technology,
2. Well as being far **lighter** and **more compact** than waveguide.

✓ Compare to waveguide, **disadvantages** of microstrip:

1. **lower power handling capacity**.
2. **higher losses.**
3. microstrip is not enclosed and is therefore susceptible to **crosstalk** and **unintentional radiation**.

3.7 Unguided Medium

Unguided medium transport the electromagnetic waves through the air/free space without guidance from a physical conductor. This type of communication is often referred as ***wireless communication.*** Signals are normally broadcast **through free space** by using **antenna** and thus are available to anyone who has a device to capture the signals.

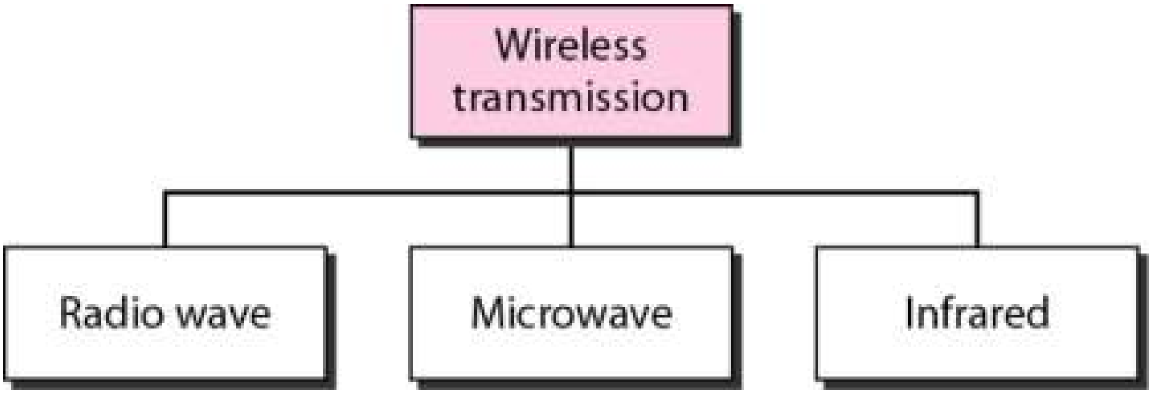


Figure 3.29: Wireless Transmission

Figure 3.30: Electromagnetic Spectrum for Wireless Communication

- Radio Waves
  - ✓ Frequency below **1GHz**
  - ✓ Frequency range: **1MHz – 1THz.**
  - ✓ Radio wave is an **electromagnetic wave.**
  - ✓ Easily interfere with other signals sent at the same frequency range.
  - ✓ Can penetrate walls and can be received in the building.

- ✓ Can travel long distance – suitable for long distance broadcasting such as AM radio.
- ✓ Highly regulated. Use Omni-directional antennas
- ✓ **Radio waves are used for multicast communications, such as radio and television, paging systems & cellular phones.**

- Microwaves
  - ✓ Frequency: **1GHz to 300GHz**
  - ✓ Frequency Range: **0.3GHz – 300GHz (0.3THz)**
  - ✓ The microwaves also a radio wave because its frequency range (0.3GHz – 0.3THz) is lied in radio wave frequency range (1MHz – 1THz).
  - ✓ However, for not confusing, frequency above 1GHz is refer as microwave, while below 1GHz is radio wave.
  - ✓ Microwave propagation is highly **directional (line-of-sight propagation)** – used Directional Antenna.
  - ✓ Very high frequency microwaves, usually, cannot penetrate walls (disadvantage if receivers are inside buildings).
  - ✓ **Microwaves are used for long distance telephone communications using repeaters, short point-to-point transmission between buildings to connect their LANs, and satellite communication.**

- Waves Propagation
  - ✓ There are 4 types of **radio wave propagation** which are:
    1. Ground wave
    2. Sky wave
    3. Space wave
    4. Satellite link

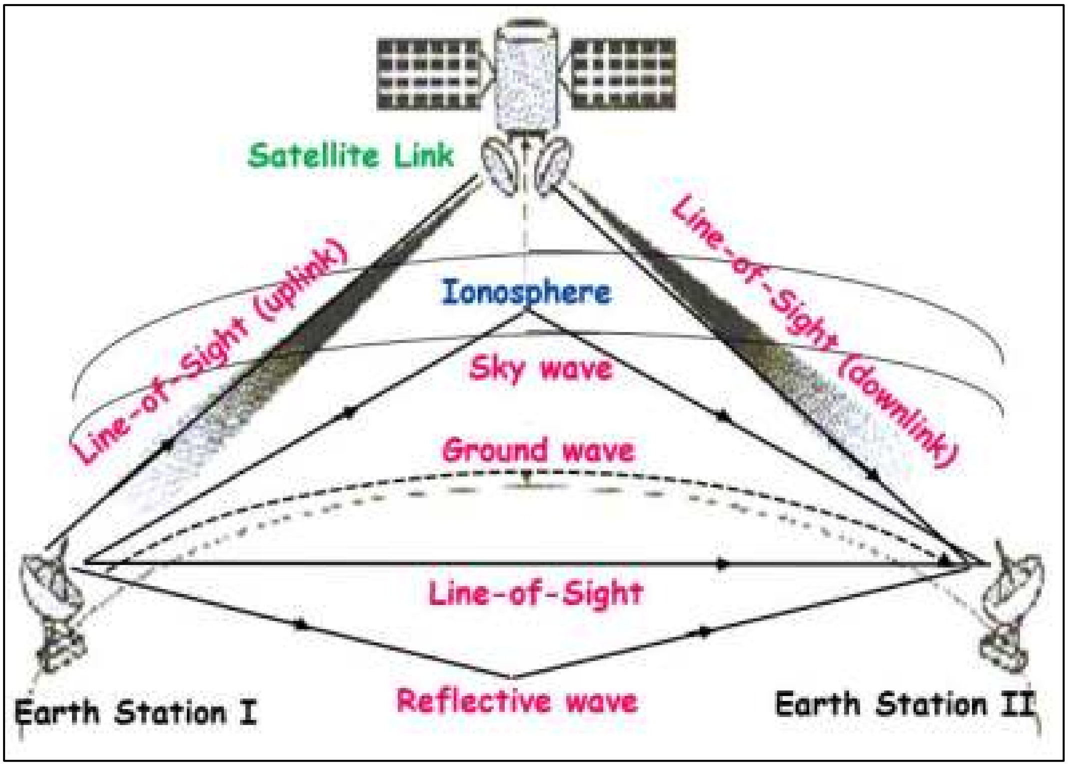


Figure 3.31: Radio Waves Propagation

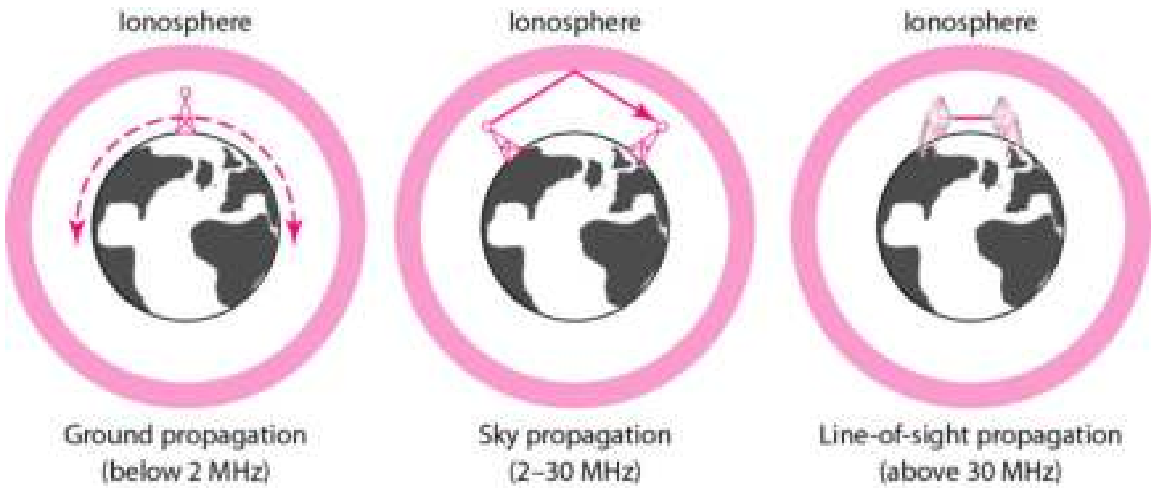


Figure 3.32: Propagation Methods

- ✓ Ground Propagation *(Ground Waves)*
  - Radio wave that propagates **close to the surface of earth.**
  - The waves are diffracted by the figure of the earth due to their **low frequencies.**
  - **Conductivity** of the surface affects the propagation of ground waves, with more **conductive surfaces** such as water providing better propagation.
  - Since the ground is not a perfect electrical conductor, ground waves are attenuated as they follow the earth's surface.
  - **Application:**
    1. Over-the-horizon radar
    2. AM long wave broadcasting
    3. Amateur radio
- ✓ Sky Propagation *(Sky Waves)*
  - Sky wave is the propagation of electromagnetic waves **bent** (refracted) back to the Earth's surface by the **ionosphere**.
  - The ionosphere is **a region** of the **upper atmosphere**, where neutral air is ionized by solar photons and cosmic rays.
  - When radio waves reach the ionosphere at oblique incidence they are bent downwards (refracted) in the ionized layer.
  - Waves **above 30 MHz** usually penetrate the ionosphere and are not returned to the Earth's surface.
  - **Application:**
    1. Long distance (high frequency) radio communication.
    2. Amateur radio
- ✓ Line-of-sight Propagation *(Space Waves)*
  - Radio wave that propagates **a few meters** from the earth surface (troposphere)
  - Has two components:
    1. **Line-of-sight** (wave propagates straight from Transmitter antenna to Receiver antenna)
    2. **Reflective wave**

- Used in VHF band with frequency over 30MHz.
- The maximum distance between earth base stations is determined by antenna height and the curvature of earth surface because the high frequency wave propagates at line-of-sight.
- Application:
    1. Long distance (high frequency) radio communication.

- **Radio Frequency Bands**

	Band	Range	Propagation	Application
1	VLF (Very Low Frequency)	3-30 kHz	Ground	Long-range radio navigation
2	LF (Low Frequency)	30-300 kHz	Ground	Radio beacons and navigational locators
3	MF (Middle Frequency)	300 kHz-3 MHz	Sky	AM radio
4	HF (High Frequency)	3-30 MHz	Sky	Citizen band (CB), ship/aircraft communication
5	VHF (Very High Frequency)	30-300 MHz	Sky and line-of-sight	VHF TV, FM radio
6	UHF (Ultra High Frequency)	300 MHz-3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
7	SHF (Superhigh Frequency)	3-30 GHz	Line-of-sight	Satellite communication
8	EHF (Extremely High Frequency)	30-300 GHz	Line-of-sight	Radar, satellite

Table 3.5: Radio Frequency Bands

3.8 Antenna

DEFINITION: an **antenna** (or **aerial**) is an **electrical device** which converts **electric currents** into **electromagnetic waves** and vice versa. Any **conducting material** can become an antenna.

However, an antenna is design to **radiate or receive electromagnetic wave** with **directional** and **polarization** suitable for **intend application**. Antennas are made in various shape & size and usually used with a radio transmitter or radio receiver. An antenna can be used for both **transmitting** and **receiving radio waves**.

Figure 3.33: Various Types of Antenna

- **Function** of antenna:
  - ✓ **In transmission**, a radio transmitter applies an oscillating radio frequency electric current to the antenna's terminals, and the antenna **radiates the energy from the current as electromagnetic waves.**
  - ✓ **In reception**, an antenna **intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage** at its terminals, that is applied to a receiver to be amplified.

- **Radiation Pattern** of antenna:
  - ✓ Antenna Radiation Pattern is a **graphical depiction** of the relative **electromagnetic field strength** transmitted from **or** received by the antenna.
  - ✓ Is measured in **power(dB)**.

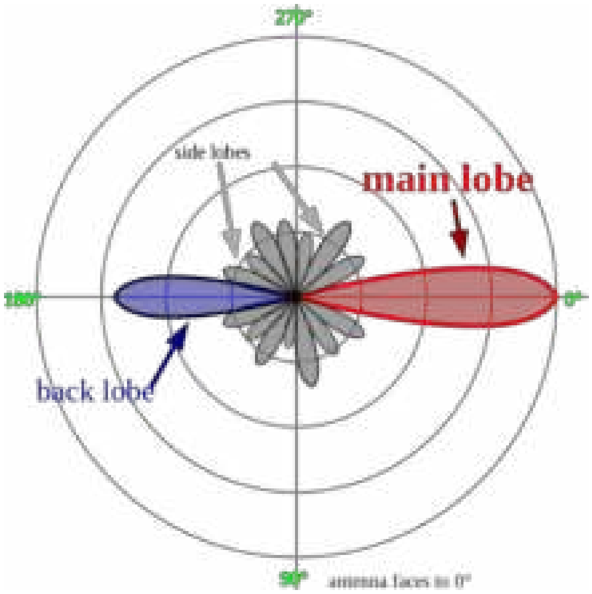


Figure 3.34: Radiation Pattern of Antenna

- **Types** of antenna:
    - ✓ **Omni-directional Antenna**
        - receive or radiate radio waves in all directions (360º)
        - In cellular system, only **one** Omni-directional antenna is used to cover 360º coverage.
        - Usually used in **macro-cell** which has less subscriber.

Figure 3.35: Omnidirectional Antenna

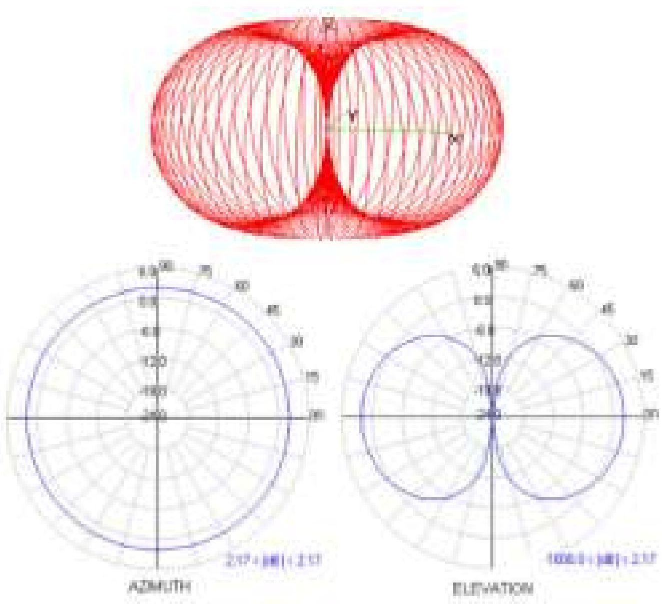


Figure 3.36: Omnidirectional Radiation Pattern

✓ **Directional Antenna**

- receive or radiate radio waves in one particular direction
- In cellular system, needs **3** directional (120º) antenna or **6** directional (60º) antenna to cover 360º coverage.
- Usually used in **micro-cell** which has **more** subscriber.

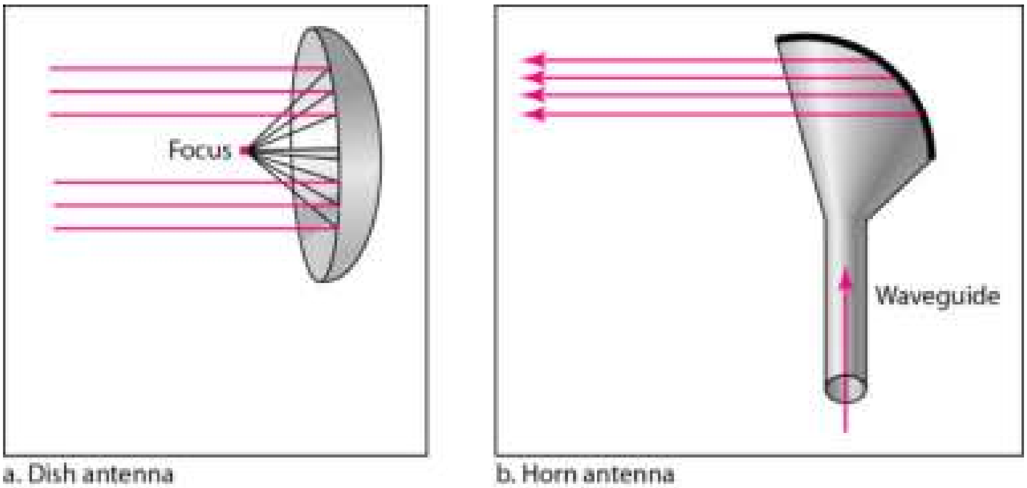


Figure 3.37: Directional Antenna

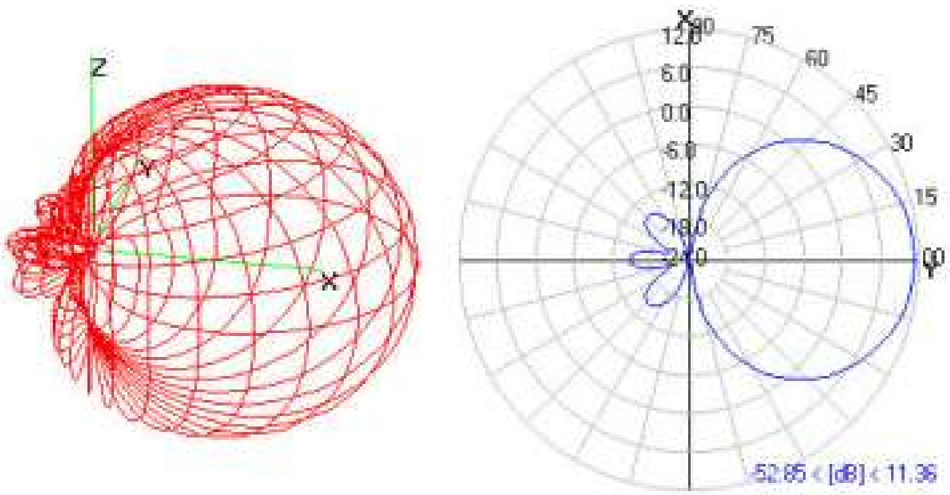


Figure 3.38: Directional Radiation Pattern

CHAPTER 4

DATA COMMUNICATION

4.1 What would you get?

- Know the principle of data communication
- Know and apply the communication codes
- Understand and apply bit, bit rate, baud rate and information capacity
- Understand the elements of Data Communication
- Understand Data Transmission

4.2 Introduction to Data Communication

DEFINITION: **Data communication** can be summarized as the transmission, reception, and processing of digital information. The fundamental **purpose** of data communication circuit is to transfer **digital information** from one place to another.

The **original source information** can be analog form (human voice or music), or in digital form (binary-coded numbers or alphanumeric codes). If the source information is in **analog** form, it must be **converted to digital** form (using PCM technique) at the transmitter and then converted back to analog form at the receiver.

Generally:

- ✓ **Data** are defined as **information** that is **stored** in **digital form**.
- ✓ **Information** is defined as **knowledge** or **intelligence** or **original source information.**

- ✓ Information that has been processed, organized, and stored by computer (or any digital system) is called **data**.
- ✓ **Data communication** is the **process** of transferring **digital information signal** between two or more points.
- ✓ **Character** is a kind of information that consist **alphabet**, **numeric** and **symbol**. **(eg: 0, 1, 8, a, A, *,&, ")**

- **Principle** of data communication

  - ✓ For data communications to occur, the communicating devices must be part of a communication system made up of a combination of **hardware** (physical equipment) and **software** (programs).

  - ✓ The effectiveness of a data communications system depends on four fundamental characteristics:

    1. **Delivery**: The system must deliver data to the correct destination. Data must be received by the intended device or user and only by the device or user.

    2. **Accuracy**: The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.

    3. **Timeliness**: The system must deliver data in timely manner. Data delivered late are useless

    4. **Jitter**: Jitter refers to the variation in the packet arrival time. It is ***uneven delay*** in the delivery of audio **or** video packets. For example, let us assume that video packets are sent every 30ms. If some of the packets arrive with 30ms delay and others with 40ms delay, uneven quality in the video is the result.

- Data communications system has FIVE (5) components:
    1. **Message**: is the information (data) to be transmitted. The information may includes **characters**, **text** (combination of characters), **images**, **audio**, or **video** (combination of text, image and audio).
    2. **Transmitter/Sender**: is an equipment that sends the data message. It can be a host computer, terminals, mainframe, workstation, telephone handset, video camera, and so on.
    3. **Receiver**: is an equipment that receives the message. It can be a computer, workstation, telephone handset, television, and so on.
    4. **Transmission medium**: is the ***physical*** path by which a message travels from sender to receiver. For example, twisted-pair cable, coaxial cable, and fibre optic cable.
    5. **Protocol**: is a set of **rules** that govern the data communication. It represents **an agreement** between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.

- **Application** of data communication
    - ✓ **Electronic Mail (e-mail)** - replaces snail mail. E-mail is the forwarding of electronic files to an electronic post office for the recipient to pick up.
    - ✓ **Scheduling Programs** - allow people across the network to schedule appointments directly by calling up their fellow worker's schedule and selecting a time.
    - ✓ **Videotext -** is the capability of having a two-way transmission of picture and sound. For example, games like Red Alert, distance education lectures, etc.
    - ✓ **Groupware** - is the latest network application. It allows user groups to share documents, schedules, data bases, etc. (ex. Lotus Notes)

- ✓ **Teleconferencing** - allows people in different regions to "attend" meetings using telephone lines.
- ✓ **Telecommuting** - allows employees to perform office work at home by "Remote Access" to the network.
- ✓ **Automated Banking Machines** - allow banking transactions to be performed everywhere: at grocery stores, drive-in machines etc.

4.3 Communication Codes

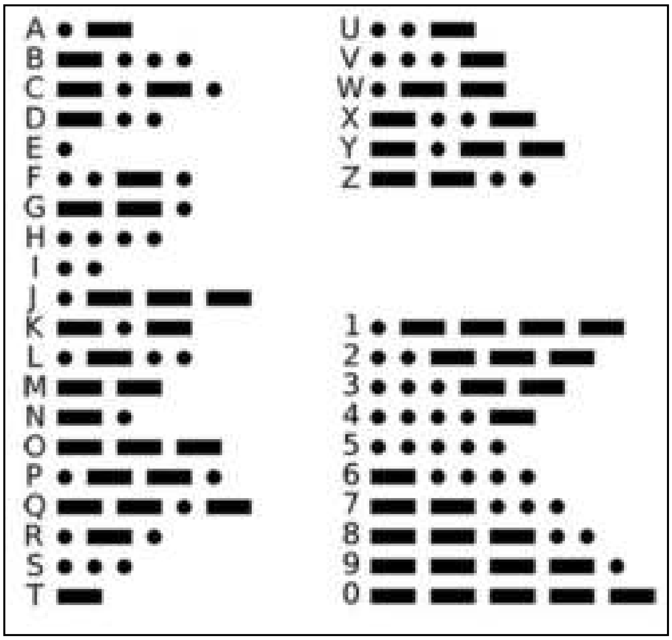
In Data Communication, the communication occurs in digital form which is in binary number (0 and 1). Therefore, any information such as **character**, **text**, **image**, **audio** and **video** must be converted into digital signal.

Communication Code is a combination of bit 0 and bit 1 to represent a **character.** A character can be represented in 8 bits, or 16 bits or maybe 32bits. We need the communication codes **to encode the characters into digital signal.**

There are a few standard codes that have been designed for **character encoding** which are:

1. Morse Code
2. Baudot Code
3. ASCII Code
4. EBCDIC Code
5. Unicode

- Morse Code
  - ✓ Morse Code is the first communication code which have been invented by Samuel Morse (1791-1872) in the 1830s and 1840s for Telegraph technology.
  - ✓ This code contains the combination of dot and dash (• and -)
  - ✓ A dot represents a unit of time. While one single dash represents three units of time.
  - ✓ Samuel Morse developed a code that assigned a set of dots and dashes to each letter of the English alphabet and allowed for the simple transmission of complex messages across telegraph lines.
  - ✓ Below Table 4.1 shows the International Morse Code.



1. A dash is equal to 3 dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to 3 dots.
4. The space between two words is equal to 7 dots.

Figure 4.1: International Morse Code

- Baudot Code
  - ✓ First code was invented for Computer technology.
  - ✓ It uses binary number, bit 0 and bit 1 to represent the character where each character represents in 5 bits.
  - ✓ Also known as Murray, CCITT Alphabet No 2, International Alphabet No 2 or Telex Code.
  - ✓ Table 4.1 shows the Baudot Code.

CHARACTER		BINARY				
LOWER CASE	UPPER CASE	5	4	3	2	1
A	-	0	0	0	1	1
B	?	1	1	0	0	1
C	:	0	1	1	1	0
D	$	0	1	0	0	1
E	3	0	0	0	0	1
F	!	0	1	1	0	1
G	&	1	1	0	1	0
H	#	1	0	1	0	0
I	8	0	0	1	1	0
J	'	0	1	0	1	1
K	(	0	1	1	1	1
L	)	1	0	0	1	0
M	.	1	1	1	0	0
N	,	0	1	1	0	0
O	9	1	1	0	0	0
P	0	1	0	1	1	0
Q	1	1	0	1	1	1
R	4	0	1	0	1	0
S	BELL	0	0	1	0	1
T	5	1	0	0	0	0
U	7	0	0	1	1	1
V	;	1	1	1	1	0
W	2	1	0	0	1	1
X	/	1	1	1	0	1
Y	6	1	0	1	0	1
Z	"	1	0	0	0	1
Shift to lowercase		1	1	1	1	1
Shift to Uppercase		1	1	0	1	1
Space		0	0	1	0	0
Carrige Return		0	1	0	0	0
Line Feed		0	0	0	1	0
Blank		0	0	0	0	0

Table 4.1: Baudot Code

- ASCII Code
  - ✓ ASCII is stand for *American Standard Code for Information Interchange.*
  - ✓ This code was developed by *American National Standard Institution* (ANSI) and had become an international standard for character encoding.
  - ✓ This code has 7 bits data and 1 parity bit of **binary code** (bit 0 and 1) to represents a character. A parity bit is used for error checking.
  - ✓ That means ASCII code has 2^7= 128 characters to be encoded. Extended ASCII code use 8 bits to represent a character, where parity bit is turned to data bit.
  - ✓ Besides Binary code, ASCII code also has Decimal, Octal and Hexa-decimal code.
  - ✓ Below Table 4.2 shows the Binary ASCII Code.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1								
→							**0**	**0**	**0**	**0**	**1**	**1**	**1**	**1**
	→						**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**
		→					**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
			0	**0**	**0**	**0**	**NUL**	**DLE**	**SP**	**0**	**@**	**P**	****	**p**
			0	**0**	**0**	**1**	**SOH**	**DC1**	**!**	**1**	**A**	**Q**	**a**	**q**
			0	**0**	**1**	**0**	**STX**	**DC2**	**“**	**2**	**B**	**R**	**b**	**r**
			0	**0**	**1**	**1**	**ETX**	**DC3**	**#**	**3**	**C**	**S**	**c**	**s**
			0	**1**	**0**	**0**	**EOT**	**DC4**	**$**	**4**	**D**	**T**	**d**	**t**
			0	**1**	**0**	**1**	**ENQ**	**NAK**	**%**	**5**	**E**	**U**	**e**	**u**
			0	**1**	**1**	**0**	**ACK**	**SYN**	**&**	**6**	**F**	**V**	**f**	**v**
			0	**1**	**1**	**1**	**BEL**	**ETB**	**‘**	**7**	**G**	**W**	**g**	**w**
			1	**0**	**0**	**0**	**BS**	**CAN**	**(**	**8**	**H**	**X**	**h**	**x**
			1	**0**	**0**	**1**	**HT**	**EM**	**)**	**9**	**I**	**Y**	**i**	**y**
			1	**0**	**1**	**0**	**LF**	**SUB**	*****	**:**	**J**	**Z**	**j**	**z**
			1	**0**	**1**	**1**	**VT**	**ESC**	**+**	**;**	**K**	**[**	**k**	**l**
			1	**1**	**0**	**0**	**FF**	**FS**	**,**	**<**	**L**	****	**l**	**:**
			1	**1**	**0**	**1**	**CR**	**GS**	**-**	**=**	**M**	**]**	**m**	**;**
			1	**1**	**1**	**0**	**SO**	**RS**	**.**	**>**	**N**	**^**	**n**	**~**
			1	**1**	**1**	**1**	**SI**	**US**	**/**	**?**	**O**	**-**	**o**	**DEL**

Table 4.2: Binary ASCII Code

- ✓ From Table 4.2, there are 7 data bits start from bit 1 until bit 7 for each character.
- ✓ Bit 1 is **LSB (**less significant bit), while Bit 7 is **MSB** (most significant bit).
- ✓ How to encode the character using this ASCII code is by reading the code from bit 1 until bit 7 and then Bit 8 which is parity bit. Parity bit is either bit 0 or 1.
- ✓ For example, letter Z is encoded as 0101 1010. Assume parity bit is 0, then:

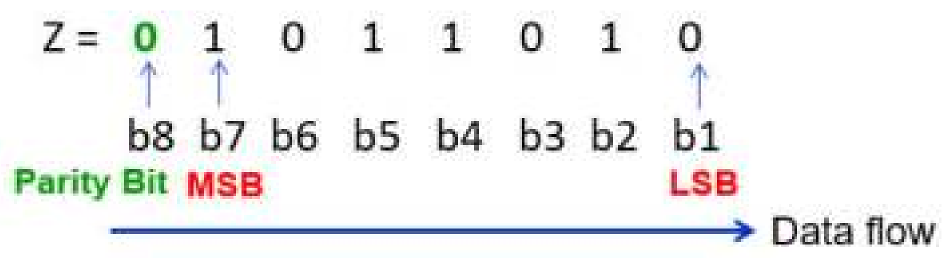


Figure 4.2: ASCII Code

- EBCDIC Code
  - ✓ EBCDIC is stand for *Extended Binary Coded Decimal Interchanged Code.*
  - ✓ This code was developed by *International Business Machines Corporation* (IBM).
  - ✓ Another famous code besides ASCII code. Most of the IBM computers and devices use this code.
  - ✓ This code uses 8 data bits. Therefore, there are $2^8 = 256$ characters can be encoded using EBCDIC code.
  - ✓ This code is extended from BCD code (*Binary Coded Decimal*).
  - ✓ Table 4.3 shows the EBCDIC Code.

2nd hex digit ↓ / 1st hex digit →

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	NUL	DLE	DS		SP	&	-									0
1	SOH	DC1	SOS				/		a	j			A	J		1
2	STX	DC2	FS	SYN					b	k	s		B	K	S	2
3	ETX	TM							c	l	t		C	L	T	3
4	PF	RES	BYP	PN					d	m	u		D	M	U	4
5	HT	NL	LF	RS					e	n	v		E	N	V	5
6	LC	BS	ETB	UC					f	o	w		F	O	W	6
7	DEL	IL	ESC	EOT					g	p	x		G	P	X	7
8		CAN							h	q	y		H	Q	Y	8
9		EM							i	r	z	`	I	R	Z	9
A	SMM	CC	SM		¢ CENT	!		:								
B	VT	CU1	CU2	CU3		$	,	#								
C	FF	IFS		DC4	<	*	%	@								
D	CR	IGS	ENQ	NAK	(	)	_	'								
E	SO	IRS	ACK		+	;	>	=								
F	SI	IUS	BEL	SUB	|	¬	?	"								

Table 4.3: EBCDIC Character Codes

Hex	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111

Hex	Binary
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

Table 4.4: Hex to Binary

- ✓ The space in the EBCDIC table can be used for others character such as graphic and so on.
- ✓ From above table, there are 8 data bits start from bit 1 until bit 8 for each character.
- ✓ How to encode the character using this code is by reading the code from bit 1 until bit 8.
- ✓ For example, letter Z is encoded as 1110 1001.

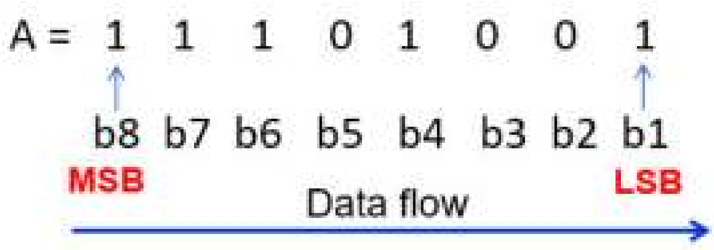


Figure 4.3: EBCDIC Code

4.4 Bit, Bit Rate, Baud Rate & Information Capacity

- DEFINITION:
  - ✓ **Bit:**
    - Bit is a digit in the **binary** number system. It can have two values, 0 or 1. (basic **digital symbol**)
  - ✓ **Bit Rate:**
    - Bit Rate is the number of **bits** transmitted during one second and is expressed in ***bits per second*** **(*bps*)**.
    - The **rate of change** of a digital signal which usually **binary**.
    - Sometimes is written as **bitrate** or **data rate**.
  - ✓ **Baud Rate**:
    - Baud Rate is the number of **symbols** transmitted during one second and is expressed in ***symbols per second***.
    - The **rate of change** of a digital signal on the transmission medium after encoding and modulation have occurred.
    - Sometimes is written as **transmission rate, modulation rate** or **symbol rate**.
  - ✓ **Information Capacity (I), unit: bps**
    - Information capacity is a measure of how much information can be propagated through a communications system. It is a function of **bandwidth** and transmission time.
    - Information capacity represents the number of independent symbol that can be carried through a system in a given unit of time.
    - Usually expressed as a **bit rate**

- ✓ **Bandwidth (BW), unit: Hz**
  - Bandwidth **is the range of frequencies** contained in the frequency spectrum.
  - The difference between the highest and lowest frequencies contained in the information.
  - Indicates the **capacity of data**.

- Shannon's Limit
  - ✓ In 1948, a mathematician **Claude E. Shannon** from Bell Telephone Laboratories developed a useful relationship among Information Capacity (I) of a communication channel, Bandwidth (BW), and signal to noise ratio (S/N).
  - ✓ The higher the signal-to-noise ratio, the better the performance and the higher the information capacity.
  - ✓ Mathematically stated, the *Shannon Limit for information capacity* is:

$$I = B\ \log_2\left(1 + \frac{S}{N}\right)$$

or

$$I = 3.32\,B\ \log_{10}\left(1 + \frac{S}{N}\right)$$

4.5 Data Communication Elements & Block Diagram

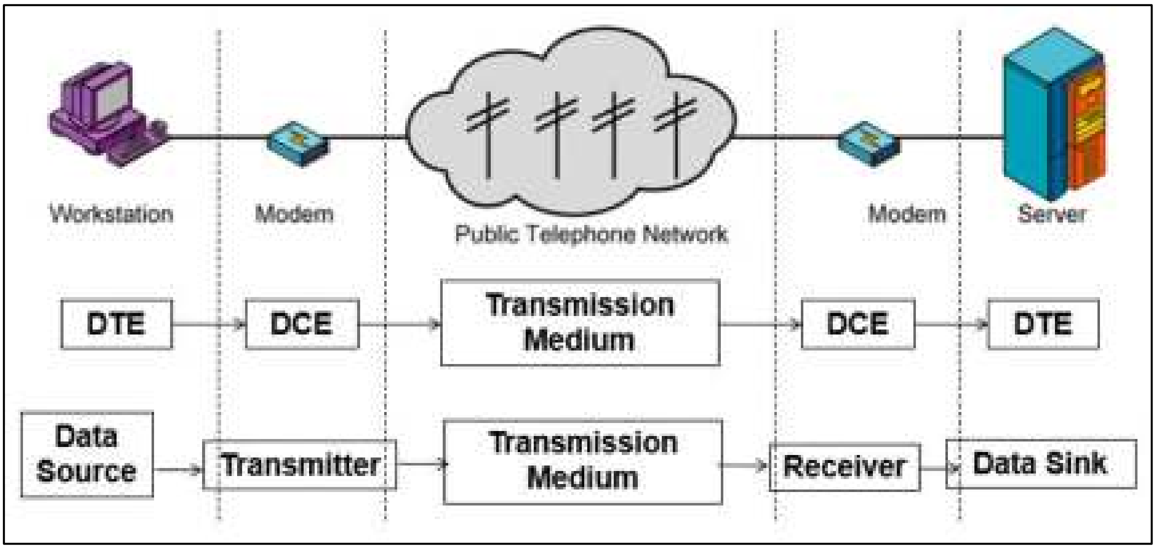


Figure 4.4: Data Communication Block Diagram

- **Data Terminal Equipment (DTE)**
  - ✓ is ***an interface equipment*** between the **host computer** and **DCE** to adapt the digital signals from the computer to a suitable form for transmission.
  - ✓ is an **end instrument** that converts user information into **signals** or **reconverts** received signals.
  - ✓ is a **data source** or a **data sink** and provides the data communication **control function** to be performed in accordance with the **link protocol**.
  - ✓ is a **data source** equipment that **generate** and transmit the data. *(Sender)*
  - ✓ is a **data sink** equipment that received and **stored** the data.*(Receiver)*
  - ✓ Example: workstation, host computer, server, terminals

- **Data Communication Equipment (DCE)**

  - ✓ is ***an equipment that*** interfaces the **DTE** to the **analogue transmission medium**.
  - ✓ is a **transmitter** equipment that converts digital signals to analogue signals such as ASK, FSK, PSK etc.
  - ✓ is a **receiver** equipment that that converts back analogue signals to digital signals.
  - ✓ Example: MODEM, bridge, router, hub, network interface card (NIC), repeater etc.

- **Transmission Medium**

  - ✓ an **analogue** medium for data transmitted. For example, twisted-pair cable, coaxial cable, and radio frequency waves.

4.6 Data Transmission

- Data transmission method
  - ✓ There are two basic ways to transfer binary information from one place to another**:**
    1. Parallel data transmission
    2. Serial data transmission
       - 2.1 Asynchronous serial data transmission
       - 2.2 Synchronous serial data transmission

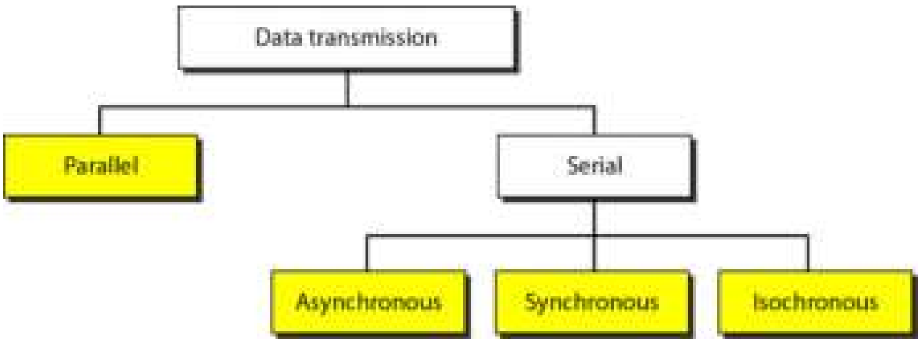


Figure 4.5: Data Transmission and Modes

- Parallel data transmission
  - ✓ In parallel data transfer, ***all the bits of a code word are*** transmitted **simultaneously.**
  - ✓ there is **one wire for each bit** of information to be transmitted.
  - ✓ That means **multi wire** are used. If 8 bits of data are transmitted, so, there are 8 wires are needed.
  - ✓ As a result, the transmission of data is **extremely fast** compare to serial data transmission.
  - ✓ However, since there are many wires are used, so it will **increase the cost**.
  - ✓ That why this transmission is **suitable for short-distance** communications such as transmission within in a computer devices, transmission between computer and printer.
  - ✓ **Difficult to detect the fault** because there are many wires are used.

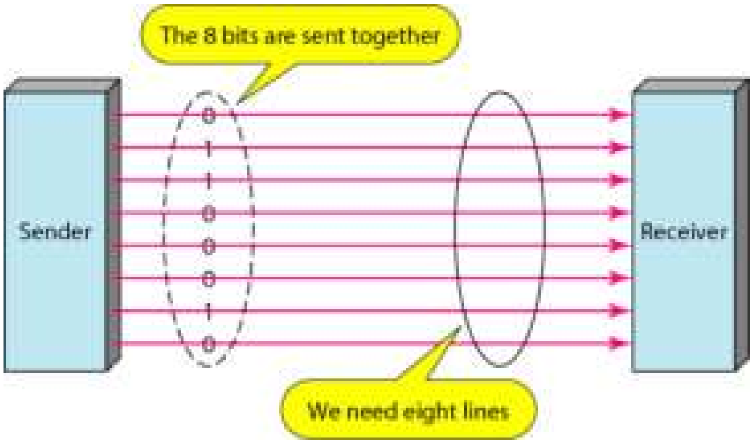


Figure 4.6: Parallel Data Transmission

- Serial Data Transmission
  - ✓ In serial data transfer, ***each bit of a code word*** is transmitted **one by one**.
  - ✓ **Only one wire** is needed to transmit all bits.
  - ✓ As a result, the transmission of data is **slower** than parallel data transmission. It takes longer time to send the data.
  - ✓ However, since there is only one wire is used for transmission, so it will **reduce the cost**.
  - ✓ That why this transmission is **suitable for long-distance** communications such as transmission between computer and computer.
  - ✓ **Easy to detect the fault** because there is only a wire is used.

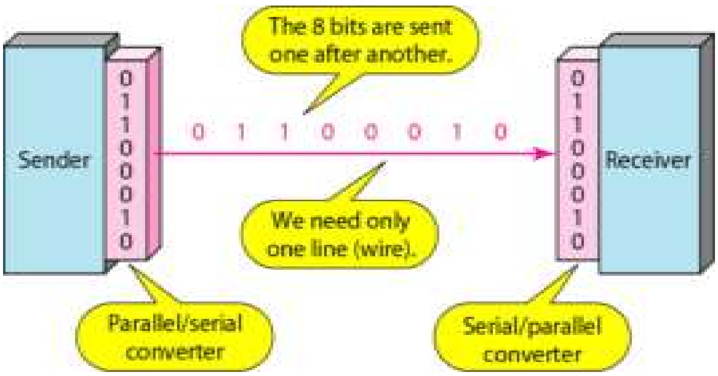


Figure 4.7: Serial Data Transmission

✓ There are TWO (2) types of serial data transmission

1. Asynchronous (*timing clock is asynchronous*)
2. Synchronous (*timing clock is synchronous*)

✓ Differences between serial and parallel data transmission

	Aspect	Parallel	Serial
1.	Bits transmission	All bits are transmitted simultaneously	Bits are transmitted one by one
2.	Number of wire	Multi-wires are used	Only one wire is needed
3.	Data transfer rate	Faster than serial because all bits are transmitted simultaneously	Slower than parallel because the bits are transmitted one by one
4.	Utilizing cost	Expensive because used many wires	Less expensive because only use one wire
5.	The distance of data transfer	Short distance transmission because of high utilizing cost	Long distance transmission because the utilization cost is low
6.	Fault detection	Difficult to trace the wire fault because there are many wires are used	Easy to trace the fault since only one wire is used

Table 4.5: Differences Between Serial and Parallel Data Transmission

✓ **ASYNCHRONOUS SERIAL DATA TRANSMISSION**

- DEFINITION: Asynchronous Serial data transmissions is a transmission of a **character** one by one.
- Also known as Start-Stop Transmission.
- Asynchronous transmission is so named because the timing of a signal is unimportant. Instead, information is received and translated by agree upon patterns.

- As long as those patterns are followed, the receiving device can retrieve the information without regard to the rhythm in which it is sent.
- In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between each byte.
- Asynchronous here means "asynchronous at the byte level" but the bits are still synchronized; their durations are the same.
- Patterns are based on **grouping** the **bit stream** into **bytes** *(8 bits = 1 byte)*
- Each **group**, usually **8 bits** is sent along the transmission link as **a unit**.
- The sending system handles each group **independently**, relaying it to the link whenever ready, without regard to a timer.
- Without synchronization, the receiver **cannot** use timing to predict when the **next group** will arrive.

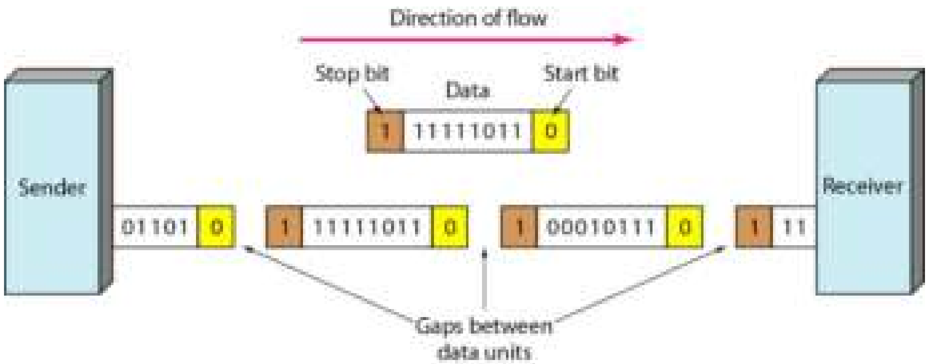


Figure 4.8: Asynchronous Transmission

- **To alert** the Receiver to the arrival of a new group, therefore, an **extra bit** is added to the **beginning** of each byte of group.
- This bit is usually a **bit 0** which is called **Start Bit**.
- To let the receiver know that the byte is **finished**, one or more additional bits are appended to the end of byte.

- These bits are usually a **bit 1** which is called **Stop Bits**.
- By this method, each byte is increased in size to **at least** 10 bits, of which 8 bits of data and **2 or more** bits of synchronization control to the receiver.
- The **gap** between **each group of character** can be represented either by an **idle channel or by a stream of additional stop bit (eg. 111111111).**
- For **Figure 4.8**, the **GAP** is represented by **an idle line** rather than by additional stop bits.
- The **Start Bit**, **Stop Bits** and **Gap** alert the receiver to the beginning and end of each **byte group of character** and allow it to synchronize with the data stream.
- This mechanism is called **ASYNCHRONOUS** because, at the byte level, the **sender** and **receiver do not** have to be synchronized. But within each byte, the **receiver** must still be synchronized with the incoming bit stream.
- Advantages and disadvantages:

<table>
<tr><th></th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>1.</td><td>Cheap and effective</td><td rowspan="3">The addition of Start bit, Stop bits and Gaps into the bit stream make asynchronous transmission slower than forms of transmission that can operate without the addition those control bits.</td></tr>
<tr><td>2.</td><td>If there is an error in transmission, only one byte of character will be sent.</td></tr>
<tr><td>3.</td><td>These 2 advantages make this transmission is an attractive choice for situations such as low-speed communication. For example, the communication between keyboard and computer</td></tr>
</table>

Table 4.6 Advantages and Disadvantages of Asynchronous

✓ SYNCHRONOUS SERIAL DATA TRANSMISSION

- DEFINITION: Synchronous Serial data transmissions is a transmission of **one block (or frame) of character** one by one.
- In Synchronous transmission, the bit stream is combined into **longer frames**, which may contain **multiple bytes.**
- Each byte, however is introduced onto the transmission link **without a gap** between it and the next one.
- It is left to the receiver to separate the bit stream into bytes for decoding purposes.
- In synchronous transmission, we send bits one after another **without start or stop bits or gaps**. It is the responsibility of the receiver to group the bits. The bits are usually sent as bytes and many bytes are grouped in a **frame**. A frame is identified with a **start and an end byte**.

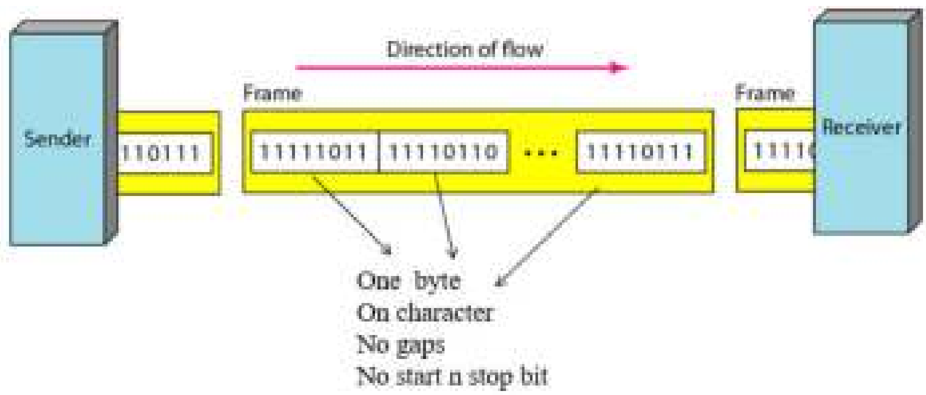


Figure 4.9: Synchronous Transmission

- In other word, data are transmitted as an unbroken string of bit 1s and 0s, and the receiver separates that string into the bytes (or characters).
- Above Figure 4.7 shows the illustration of Synchronous transmission. We have drawn in the division between bytes.
- In realty, those divisions do not exist; the sender puts its data onto the transmission line as **one long string.**

- If the sender wishes to send data in separate bursts, the gaps between frame/burst must be filled with a special sequence of bit 0s or 1s, which means *idle*.
- Without start bit, stop bits and gaps, there is no built-in mechanism to help the receiving device adjust its bit synchronization midstream.
- **Timing** becomes very important, therefore, because the accuracy of the received information is completely dependent on **the ability of the receiving devic**e to keep an **accurate count** of the bits as they come in.
- It's need to be emphasized here; ***although there is no gap between characters in synchronous serial transmission, there may be uneven gaps between frames***.
- Advantages and disadvantages:

<table>
<tr><th></th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>1.</td><td>With no extra bits or gaps, synchronous transmission is faster than asynchronous transmission</td><td rowspan="2">If there is an error in transmission, one block of characters or frame will be sent.</td></tr>
<tr><td>2.</td><td>For this reason, it is more useful for high speed applications such as the transmission of data from one computer to another.</td></tr>
</table>

Table 4.7 Advantages and Disadvantages of Synchronous

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