# CSC 216

# Analogue and Digital Communication Systems

Expected Learning Outcomes

- Identify modern communications systems.
- Describe analog modulation techniques; amplitude modulation (AM) and “angle” modulation (FM and PM).
- Discuss digital communications; sampling, quantization, coding.

## Course Content

- Fundamental concepts: Signals, waveforms and noise. Parameters of periodic waveforms. Composite waveforms. Signal sources.
- Concept of systems. Baseband signals. Modulated signals. The need for signal modulation. Generic structure of a communication system.
- Analog signals and systems: Representation of analog signals in the time and frequency domains. Analog systems: characterization of features in the time domain and frequency domains. Analog signal filtering. Analog modulation techniques. Analog demodulation techniques. Basic structures of analog communication systems.

## Course Content continued

- Digital signals and systems: Representation of digital signals in the time and frequency domains. Digital signal modulation techniques. Digital signal demodulation techniques. Basic structures of digital communication systems.
- Relating analog and digital regimes: Relative merits of each regime. Analog-to-digital (A/D) signal processing: signal sampling, quantization and A/D conversion. Digital-to-analog (D/A) signal conversion. Architectures of A/D and D/A converters.
- Transmission media: Guided media: twisted-pair, coaxial and fiber-optic cables. Unguided media: radio wave, microwave and infrared media.

# Core Reading Material

- Haykin S., & Moher M., Introduction to Analogue and Digital Communication 2nd Edition (2007) John Wiley & Sons 2007
- Martin & Roden (2003). Analogue and Digital Communications. Discovery Press

## Reference material

- Principle of communication: Tutorialspoint www.tutorialspoint.com

## Introduction to communications

- Before modern times, messages were carried by runners, carrier pigeons, lights, fires, rivers etc.
- These were adequate for the instances and data rates of the age.
- In most part, these modes of communication have been superseded by electrical communication systems which can transmit signals over such longer distances (even to distant planets and galaxies) and at the speed of light.
- Eg email, radio, internet, satellite communication etc

## History of communication

- **Telegraph** (1844): development of Morse code
- **Radio** (1864-1987): formulation of Electromagnetic theory of light and demonstration of radio waves.
- **Telephone** (1875): real-time transmission of speech by electrical enconding and application of sound a practical reality.
- **Electronics** (1904): Invention of the vacuum tube diode. Invention of triode leading to transcontinental telephony.
- Television (1928): the first all electronic television

## History of communication

- **Digital communications (1928-1958):** nyquist theory. Invention of Pulse-code modulation of digital encoding of speech signals. Invention of transistors leading to digital switching. The first T1 carrier system. Development of Shannons theory; the mathematics of communication.
- **Computer networks (1943-1946):** the first electronic digital communication (ENIAC). Advanced Research Projects Agency Network (ARPANET)
- **Satellite communications (1955-1962):** use of earth-orbiting satellites to relay telemetric signals and TV programs across the Atlantic
- **Optical communications (1966-):** proposal to use clad glass fiver as a dielectric waveguide. LASER and fiber transmission demonstrated.

## Communication

- Can be defined as the process of exchange of information through means such as words, actions, signs, etc., between two or more individuals.
- Electrical communication is:
    - Dependable
    - Economical
    - Energy efficient
    - Scalable
    - Time saving
    - Is real time

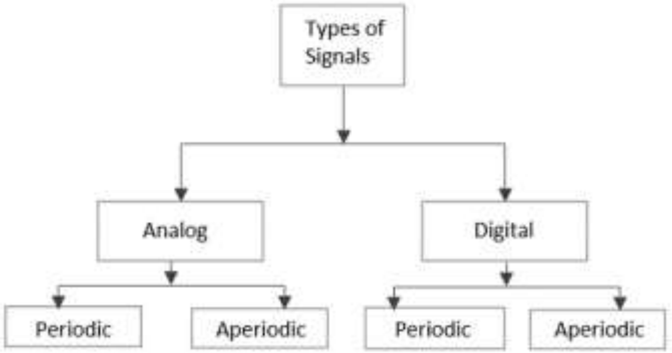
## three important and basic parts of a communication system

- The **Sender** is the person who sends a message. It could be a transmitting station from where the signal is transmitted.
- The **Channel** is the medium through which the message signals travel to reach the destination.
- The **Receiver** is the person who receives the message. It could be a receiving station where the signal transmitted is received.

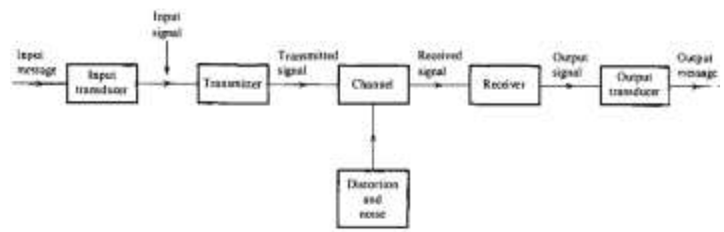
## What is a Signal?

- Conveying an information by some means such as gestures, sounds, actions, etc., can be termed as **signaling**.
- a signal can be a **source of energy which transmits some information**. This signal helps to establish communication between a sender and a receiver.
- An electrical impulse or an electromagnetic wave which travels a distance to convey a message, can be termed as a **signal** in communication systems.

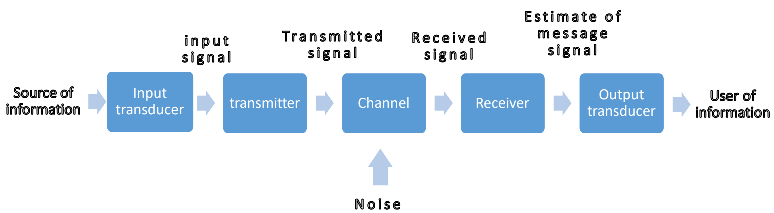
## Types of signals: based on their characteristics



# A communication system

## Key components of a typical communication system




## Basic components of a communication system

- Transmitter
- Medium or communication channel
- Receiver

The elements of communication system may be listed as under:

i. Information or source
ii. Transmitter
iii. Communication channel or medium
iv. Noise
v. receiver

# Components of a communication systems

- **The source:** originates a message, such as a human voice, physical environment, a television picture, an e-mail message, code, data. The message is in its raw form and unsuitable for transmission.
- **Input transducer:** it converts nonelectric data (e.g. human voice, e-mail text, television video) into an electric waveform referred to as the baseband signal or message signal. Examples of input transducers are microphones, CCD cameras, keyboards e.t.c.
- **The transmitter:** a collection of electronic circuits which modifies the baseband signal for efficient transmission. It converts the message signal produced by a source of information into a form suitable for transmission over the channel. Transmitter may consist one or more subsystems: an A/D converter, an encoder, a modulator.

- **The channel:** is a physical media of transporting the message signal and delivers it to the receiver at some other location in space.
  - However, in the course of transmission over the channel, the signal is distorted due to channel imperfections.
  - Moreover, noise and interfering signals (originating from other sources) are added to the channel output, with the result that the received signal is a corrupted version of the transmitted signal.
  - Channel may be
    - Wire (line) communication or Wireless (radio) communication
    - Power limited or bandlimited

- **The receiver:** processes the received signal from the channel to extract an estimate of the original message signal for the user of information. The receiver attempts to reconstruct the message by removing distortion introduced by the channel noise.
  - The receiver consist: amplifier, a demodulator, a decoder, and a D/A converter.
  - Its output is fed to the output transducer.
- **The output transducer:** converts the electrical signals back to the message suitable for the user to interpret and use.
- **The user:** is the unit of destination which the information is communicated to.

# Key resources in communication systems

Communication systems are designed to make efficient utilization to the following key resources:

- **Transmitted power**, which is defined as the average power of the transmitted signal.
- **Channel bandwidth**, which is defined by the width of the passband of the channel.

# Classification of communication channels

i. Line communication: channel is a physical media connecting transmitter to receiver.
   - Example: twisted copper wires, telegraphy, telephone cables, fibre optic cable, coaxial cable

ii. Radio communication: provides wireless (no physical wires) link between transmitter and receiver.
   - Signals are sent through free space or air
   - The transmitter through its antenna, sends signals over a carrier wave into free space.
   - The receives antenna picks the signal and separates the carrier from the message.

# Classification of communication channels:

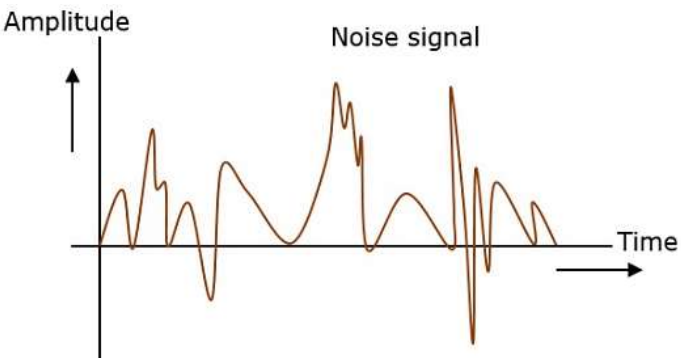
Depending on these two resources:

a. Power-limited channels. Examples include:
   i. Wireless channels, where it is desirable to keep transmitted power low so as to prolong battery life.
   ii. Satellite channels, where the available power on board the satellite transponder is limited, which, in turn, necessitates keeping the transmitted power on the downlink at a low level.
   iii. Deep-space links, where the available power on board a probe exploring outer space is extremely limited, which again requires that the average power of information-bearing signals sent by the probe to an Earth station be maintained as low as possible.

b. Band-limited channels, where channel bandwidth is at a premium. Examples include:
   i. Telephone channels, where, in a multi-user environment, the requirement is to minimize the frequency band allocated to the transmission of each voice signal while making sure that the quality of service for each user is maintained.
   ii. Television channels, where the available channel bandwidth is limited by regulatory agencies and the quality of reception is assured by using a high enough transmitted power.

# Noise in communication systems

- Refers to unwanted signals that tend to disturb the quality of the received signal in a communication system.
- In a practical environment, signals passing through communication channels experience noise (thus channel distortion, undesirable interferences and disturbances)
- Sources of noise may be internal or external to the system.
- Interferences are random and unpredictable.
- Hence, noise is some random and unpredictable signal which has no pattern and no constant frequency or amplitude.
- Measures are usually taken to reduce noise, though it can’t be completely eliminated



## Most common examples of noise are:

- **Hiss** sound in radio receivers
- **Buzz** sound amidst of telephone conversations
- **Flicker** in television receivers, etc.

## Effects of Noise:

Noise affects the system performance in the following ways:

i. It limits the operating range of the systems
ii. It indirectly places a limit on the weakest signal that can be amplified by an amplifier. Hence, smallest signal that a receiver is capable of processing.
iii. It affects the sensitivity of receivers
iv. Sensitivity is the minimum amount of input signal necessary to obtain the specified quality output.

## Types of Noise

- Noise is classified depending on:
  - the type of the source,
  - the effect it shows or the relation it has with the receiver, etc.
- There are two main sources of noise:
  i. external source
  ii. internal source, within the receiver section.

## Types of Noise: **External Source**

- Due to external sources that are not within the medium or channel of communication.

Examples

- Atmospheric noise (due to irregularities in the atmosphere).
- Extra-terrestrial noise, such as solar noise and cosmic noise (intergalactic radiation).
- Industrial noise e.g. faulty contact switches in electrical equipment, automobile ignition radiation, fluorescent lights and microwave ovens
- radiation from nearby transmitting channels and cellphone emissions, electric storms.

## Types of Noise: **Internal Source**

- Is produced by the receiver components while functioning.
- A proper receiver design may lower the effect of this internal noise.

Examples

- Thermal agitation noise of electrons in the front-end amplifier of the receiver
- Shot noise (due to diffusion or recombination of electrons & holes).
- Transit-time noise (during transition) of thermal motion of charged particles in conductors,
- Miscellaneous noise includes flicker, resistance effect and mixer generated noise, etc

## Types of noise

- External noise can be minimized or may even be eliminated in some cases. The best way is to avoid the noise from affecting the signal.
- Internal noise can be minimized but no eliminated. This noise is quantifiable.

NB: As channel length increases, signal strength decreases and noise cumulatively increases.

## Signal to Noise Ratio (SNR)

- The SNR at the receiver input is defined as the ratio of the average power of the received signal (i.e., channel output) to the average power of noise measured at the receiver input.
- SNR is expressed in decibels (dBs), which is defined as 10 times the logarithm (to base 10) of the power ratio.
- For example, signal-to noise ratios of 10, 100, and 1000 are 10, 20, and 30 dBs, respectively.
- SNR offers a quantitative way to account for the beneficial effect of the transmitted power in relation to the degrading effect of noise (i.e., assess the quality of the received signal)
- SNR is a dimensionless parameter.

## Design of a communication system

- It boils down to a tradeoff between signal-to-noise ratio and channel bandwidth.
- Thus, we may improve system performance by following one of two alternative design strategies, depending on system constraints:
  - Signal-to-noise ratio is increased to accommodate a limitation imposed on channel bandwidth.
  - Channel bandwidth is increased to accommodate a limitation imposed on signal-to-noise ratio.
- Strategy 1 is simpler to implement than strategy 2, because increasing signal-to-noise ratio can be accomplished simply by raising the transmitted power.
- On the other hand, increased channel bandwidth needs increased bandwidth of the transmitted signal, which, in turn, requires increasing the complexity of both the transmitter and receiver.

## Types of electronic communication systems

i. Analogue:
   i. An analogue signal is a continuously varying signal
ii. Digital:
   i. A digital signal has two distinct levels, HIGH and LOW.

## Baseband signals and baseband transmission

- Baseband signals: are the original information (message) signals. Thus the raw source message that has been converted into electrical signals or code. Whether analogue or digital.
  - May be transmitted over the medium
- Putting this baseband signal directly into the medium and transmitting is referred to Baseband transmission.
  - Example: local call telephony: where voice signal is converted into electrical form, and placed into wires and transmitted over some distance.
  - In some computer networks: digital signals are applied directly to co-axial cable for transmission to another computer

## Limitations of baseband transmission

- Are incompatible for direct transmission over the medium.
  - For example: voice signals cannot travel longer distances in air, the signal gets attenuated rapidly.
- Hence radio and modulation techniques have to be used for longer transmission.

## BASICS OF MODULATIONS

- Modulation is the process where the base band signal (such as voice, video etc) modifies another higher-frequency signal called carrier.
- A carrier is usually of very high frequency compared to the highest baseband signal frequency.
- The baseband signal modifies the amplitude or frequency or phase of the carrier in the modulation process.

# Modulation techniques:

- Amplitude modulation: the amplitude of the carrier is varied according to the baseband signal keeping its frequency and phase constant.
- Frequency modulation: the frequency of the carrier is varied according to the baseband signal
- Phase modulation: the phase (shift) of the carrier is varied according to the baseband signal.
- Pulse Amplitude Modulation: the amplitude of periodic sequential pulses are varied according with sample values of the baseband signal.
- Pulse Duration Modulation: The duration of periodic sequential pulses are varied according with sample values of the baseband signal.
- Pulse Position Modulation: The position of periodic sequential pulses are varied according with sample values of the baseband signal.

# Demodulation

- Is the process of converting the modulated carrier signal back to original information.
- It is the reverse of modulation.

## Need for modulation

i. Reduce the height of antenna
ii. Avoids mixing of signals
iii. Increases the range of communication
iv. Allows multiplexing of signals
v. Allows adjustments in the bandwidth
vi. Improves quality of reception

## i) Reduces the height of the antenna

- The height of the antenna is a function of wavelength of the frequency of transmission used.
- The minimum height of an antenna is given by:

  $$Height_{min} = \frac{\lambda}{4}$$

  The wavelength, $\lambda$ is given by:

  $\lambda = \frac{c}{f}$ where c is the velocity of light and

  f is frequency of transmission

  Hence minimum height is given by:

  $$Height_{min} = \frac{c}{4f}$$

- Therefore at low frequencies, wavelength is very high and hence antenna height.

- Example 1: determine the minimum height of the antenna for baseband transmission given the baseband signal is 15kHz.
- Solution:

  $Height_{min} = \frac{3x108}{4(15x103)}$ = 5000 metres

  An antenna 5000m is unthinkable and impractical
- Example 2: Determine the minimum height of the antenna required to transmit a 1MHz modulated signal.
- Solution:

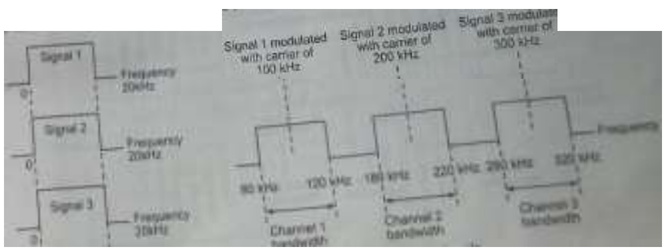
  $Height_{min} = \frac{3x108}{4(1x106)}$ = 75 metres

  An antenna 75000m is reasonable and practical.

## ii) Avoids mixing of signals

- Sound signals are concentrated within the range of 20Hz to 20kHz.
- When sound signals from different sources are mixed, it becomes difficult to separate them because all are in within the same range.
- Modulated signals will be translated to differented portions of the EM spectrum (channel) and separate channel bandwidth using carrier frequency.
- Separation can then be done by tuning circuits to the desired frequency.

- Baseband will share same frequency hence not separable.
- Modulated will be allocated different frequencies hence easily separable




## iii) Increase the range of communication

- Baseband signals have low frequencies, and at low frequencies, radiation is poor and signal gets highly attenuated this is due to low power in the signal.
- Therefore cannot be transmitted over long distances.
- Modulation increases the frequency of a signal thus increases distance of faithful transmitted.

## iv) Allows multiplexing of signals

- Multiplexing is the transmission of two or more signals simultaneous over the same channel.
- Modulated signal from different sources (eg. TV and radio stations) can be multiplexed and transmitted simultaneously.
- Separation can then be done by tuning circuits to the desired frequency

## v) Allows adjustments in the bandwidth

- The bandwidth of a modulated signal may be made larger or smaller than the original signal.
- The signal-to-noise ratio in the receiver which is a function of the signal bandwidth can thus be improved by proper control of the bandwidth at the modulating stage.

# vi) Improves quality of receiption

- Modulation techniques such as FM, PCM reduce the effect of noise to great extent hence improve quality.