Course Code: CSE 3107
Course Title: Communication Engineering

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Lecture-02
Communication Engineering Fundamentals
Noise

Outline

- Communication Engineering Fundamentals,
- Waveforms Spectra,
- Elements of basic communication systems,
- Periodic and nonperiodic waveforms and their properties.
- Noise and its different types

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Communication Engineering

- **Communication Engineering?**
  - ✓ It is a specialized branch of **electrical and computer engineering** that focuses on the
    - **research,**
    - **design,**
    - **development,**
    - **analysis, and**
    - **maintenance** of **communication systems**.
  - ✓ It involves applying scientific and mathematical principles to ensure information is transmitted **efficiently, reliably, and securely**.
  - ✓ In simpler terms, **it is the technical discipline behind building and optimizing the technologies that connect the world**.

Communication Engineering

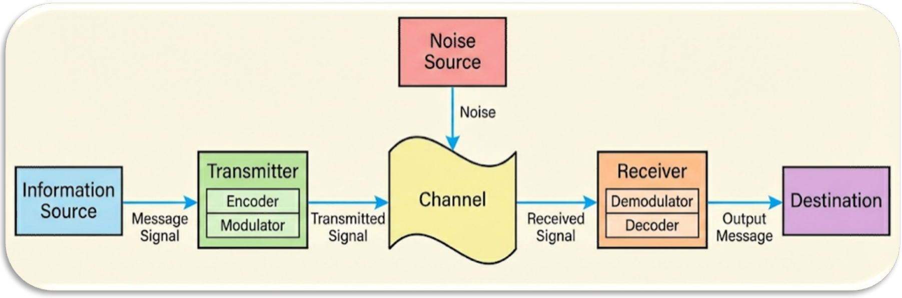
- **Focus Areas of CE?**
  - ✓ It deals with challenges such as **signal processing**, **modulation techniques** (embedding information onto waves), **managing bandwidth, reducing noise and interference**, and **error detection and correction**.
- **Scope?**
  - ✓ It covers a vast range of technologies, including **wireless communications** (5G, 6G, Wi-Fi), **optical fiber networks, satellite communications, radar systems**, and **data networking**.
- **The Engineer's Role?**
  - ✓ A communication engineer determines **the best way to format signals and choose the right hardware** so that the "**Communication System**" functions correctly in the real world.

Communication System

- **Communication System:**
  - ✓ A communication system is an **integrated collection** of **hardware components, software,** and **transmission media** designed to facilitate the transfer of information (data, voice, video) from a **source** to a **destination** over a geographical distance.
  - ✓ In simpler terms, it is the complete infrastructure required to move a message from point A to point B **reliably**.
- **Key Aspects:**
  - ✓ **Goal**: To overcome physical separation between the **sender** and the **receiver**.
  - ✓ **Core Components**: Every communication system must contain at least **three elements**:
    - **Transmitter** (to send the signal),
    - **Channel** (the medium the signal travels through), and
    - **Receiver** (to recover the signal).

Communication System

- **Basic block diagram of communication system?**



- **Examples:**
  - ✓ A mobile phone network, the internet, satellite television, a pair of walkie-talkies, or even two tin cans connected by a string.

Communication System

1. Information Source:

- ✓ This is the origin of the message. It produces the raw data or "information" to be communicated, e.g., human voice, a text document, an image, or a video file.
- ✓ This information is usually converted into an **Electrical Message Signal** (**baseband signal**) before being passed to the transmitter.

2. Transmitter:

- ✓ The transmitter processes the message signal to make it suitable for transmission over the chosen channel. It contains **two key sub-components**:
- ✓ **Encoder:** Converts the information into a specific format or code for **efficiency, error detection and/or security**.
- ✓ **Modulator:** Mounts the message signal onto a **high-frequency carrier wave**. This allows the signal **to travel long distances** through the physical medium.

Communication System

3. Channel:

- ✓ The channel is the **physical medium** that carries the **Transmitted Signal** from the transmitter to the receiver.
- ✓ **Guided Media:** Wires, coaxial cables, or fiber optics.
- ✓ **Unguided Media:** Wireless space (air or vacuum) used for radio, microwave, or satellite communication.

4. Noise Source:

- ✓ Noise refers to unwanted, random electrical signals that get added to the message during transmission through the channel.
- ✓ This can come from natural sources (lightning, thermal agitation) or man-made sources (other electronic devices).
- ✓ Noise can distort the signal and make it difficult for the receiver to recover the original message.

Communication System

5. Receiver:

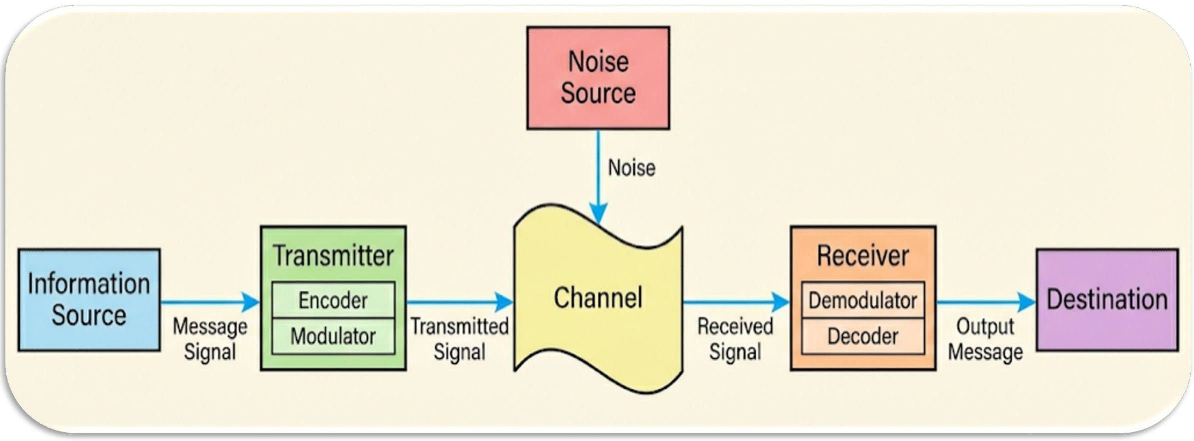
- ✓ The receiver's job is to extract the original message from the **Received Signal**, which may now be weak and distorted by noise.
- ✓ **Demodulator:** Separates the message signal from the high-frequency carrier wave.
- ✓ **Decoder:** Reverses the encoding process to reconstruct the original data format.

6. Destination:

- ✓ The final stage of the system.
- ✓ This is the person or machine (such as a computer, phone speaker, or television screen) intended to receive the **Output Message**.

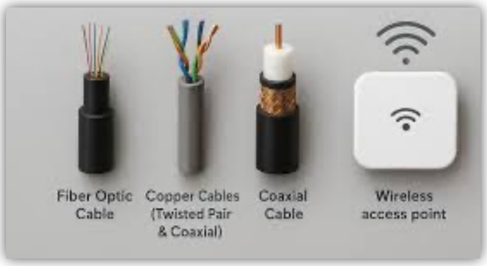
Communication System

❑ **Basic block diagram of communication system?**



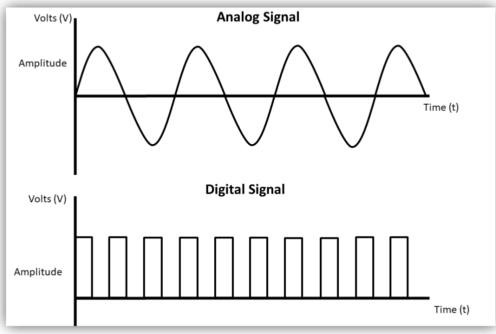
Type of Communication

❑ **Type of Communication?**



1. Depending on the **medium -**
   - ✓ **Wired Communication** (Using Cables/Wires)
   - ✓ **Wireless Communication** (Radio / Optical / Satellite / μWave Communication)

2. Depending on the **type of signal -**
   - ✓ **Analog Communication**
   - ✓ **Digital Communication**



Effectiveness of Communication System

❑ The **effectiveness** of a data communications system depends on **four fundamental characteristics**:

1. **Delivery**: The system must deliver data to the correct destination.
2. **Accuracy**: The system must deliver the data accurately.
3. **Timeliness**: The system must deliver data in a timely manner.
4. **Jitter**: Jitter in communication refers to the **variation in packet delay** (latency) over time when data is transmitted across a network.
   - ✓**Latency ->** how long data takes to arrive & **Jitter** -> how much that latency changes from packet to packet
   - ✓For example, let us assume that video packets are sent every 3 ms. If some of the packets arrive with 3-ms delay and others with 4-ms delay, an uneven quality in the video is the result.

Signals and Properties

❑Signal?

- ✓In signals and systems, a **signal** is a function of one or more variables (usually <u>time</u> or <u>space</u>) that carries information about a physical phenomenon, like **sound**, **light**, or **temperature**, often represented as a varying physical quantity such as **voltage, current**, or **wave**.

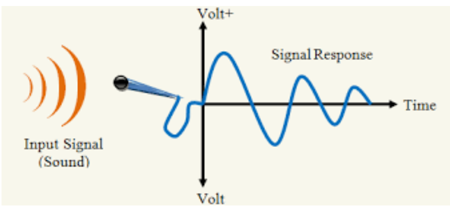
- ✓Mathematically, a signal is often written as:

$$x(t) \text{ or } x[n]$$

Signals and Properties

- ❑ **Example**: When we speak (**Sound Signal**), **air pressure changes with time** and **these changes carry our message**, which is Represented as:

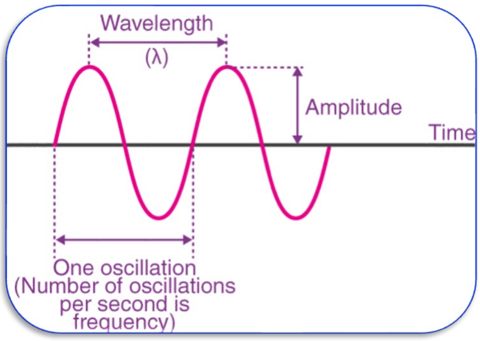
x(t)=sound amplitude vs time



Signals and Properties

❑Wave Signals:

- ✓ **Amplitude**: The maximum displacement of the wave from the mean position is called the amplitude of the wave.
- ✓ **Frequency**: The number of vibrations passing a fixed point in a given amount of time is called frequency. The unit of frequency is Hertz (Hz).
- ✓ **Wavelength**: Wavelength is the distance between two identical points (adjacent crests or troughs).
- ✓ **Time Period:** The time taken by a complete wave to pass through a particular point is called the time period.



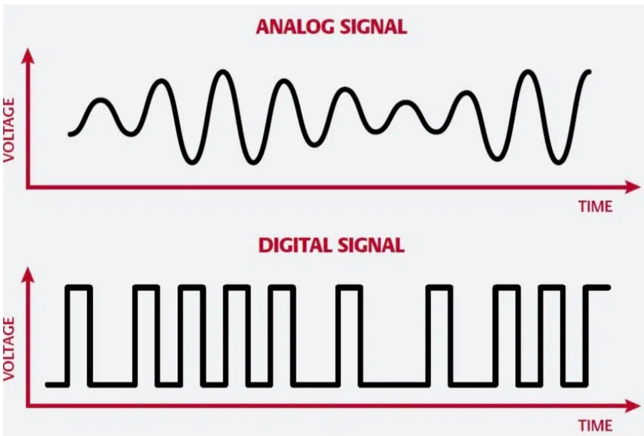
- ✓ **Speed**: For a wave, speed is the distance travelled by a particular point on the wave in the given interval of time.
- ✓ **Phase**: Phase describes the position of the waveform relative to time.

Signals and Properties

❑Analog and Digital signals:

- ✓ **Analog Signal:** It is a **continuous signal** that varies smoothly with time and can take **any value within a given range**.
- ▪ Examples: Human voice, sound

- ✓ Digital Signal: It is a **discrete signal** that represents information using **fixed values**, usually in the form of **binary digits (0 and 1)**.
- ✓ Examples: Computer data, Digital clock

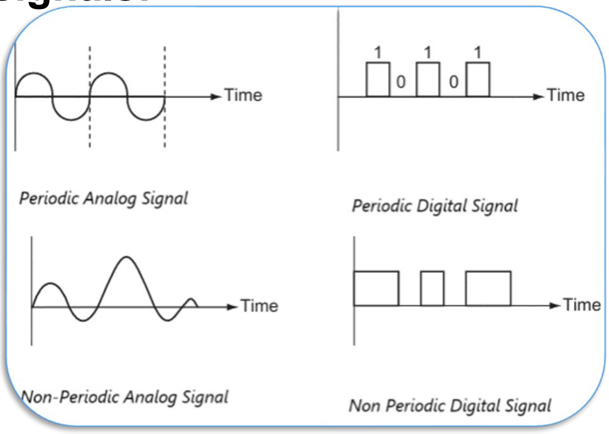


Signals and Properties

❑Periodic and Non-periodic signals:

- ✓ Both analog and digital signals can take one of two forms: ***periodic*** or ***nonperiodic.***

- **Periodic Signal*:***
  - Completes a pattern within a measurable time frame, called a **period**, and repeats that pattern over subsequent identical periods.
  - One full pattern is called a **cycle**.



- **Non-periodic Signal:**
  - Changes without exhibiting a pattern or cycle that repeats over time.

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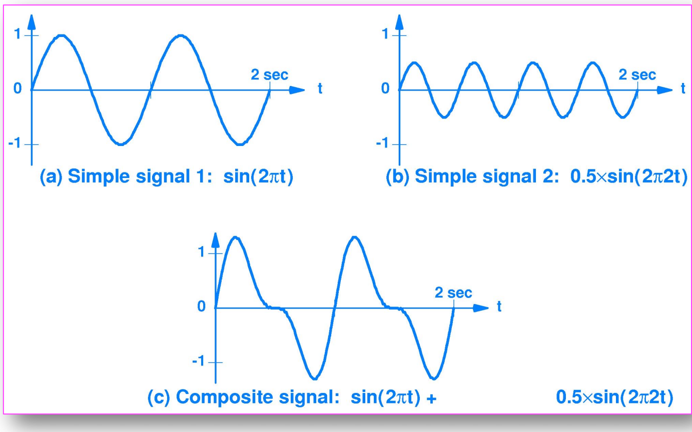
Signals and Properties

❑Composite signal:

- ✓ In communication engineering, a **composite signal** is a signal that is made up of two or more simple sine waves.

- ✓ According to **Fourier Analysis**, any complex waveform—no matter how messy it looks in the time domain—is actually just a sum of simple sine waves, each with its own **Amplitude, Frequency, and Phase**



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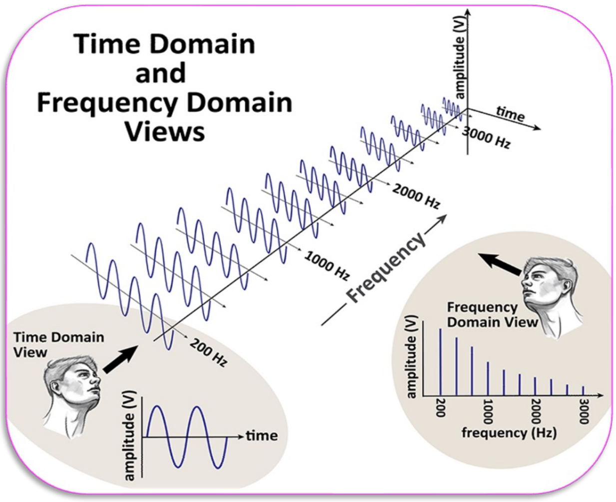
Signals and Properties

❑Time Domain vs Frequency Domain signal:

- ✓ A **time domain signal** represents how a signal's **amplitude changes with time.** It shows the signal's behavior at each moment
- ✓ A **frequency domain signal** represents how a signal's **energy or amplitude is distributed over different frequencies**.



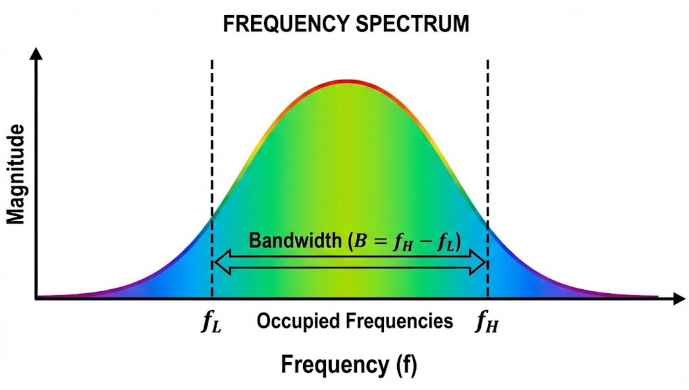
Signals and Properties

❑Bandwidth:

- ✓ The most important characteristic of a composite signal is its **Bandwidth**. This is the range of frequencies it occupies.

$$B = f_{High} - f_{Low}$$

Example: If a composite signal contains frequencies ranging from 1000 Hz to 5000Hz, its bandwidth is 4000Hz



Mathematical Examples

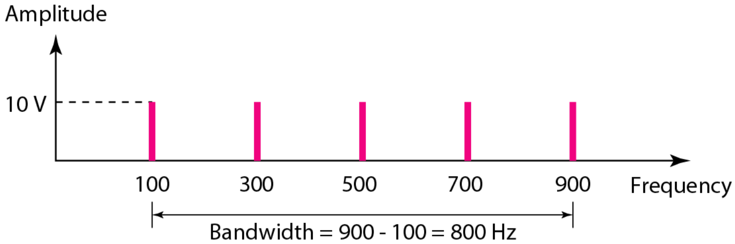
Example 1: If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure).



Mathematical Examples

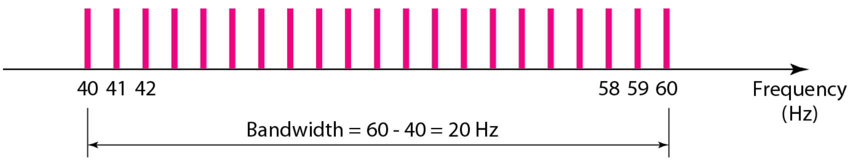
Example 2: A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$\boxed{B = f_h - f_l \quad \Rightarrow \quad 20 = 60 - f_l \quad \Rightarrow \quad f_l = 60 - 20 = 40 \text{ Hz}}$$

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure).

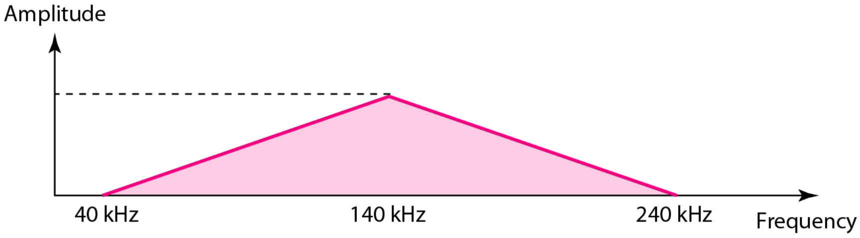


Mathematical example

Example 3: A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.



TRANSMISSION IMPAIRMENTs

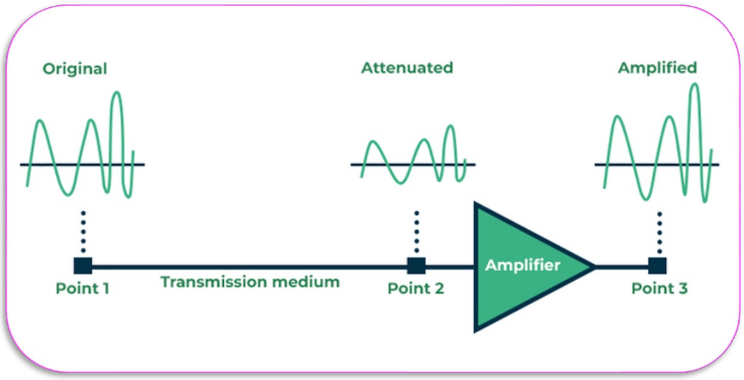
❑Cause of Signal Impairments:

- ✓ Signals travel through transmission media, which are not perfect. Such imperfection causes signal impairment.
- ✓ This means that the signal at the beginning of the medium differs from the signal at the end of the medium.
- ✓ What is sent is not what is received.
- ✓ Three causes of impairment are **attenuation**, **distortion**, and **noise**.

TRANSMISSION IMPAIRMENTs

❑Attenuation:

- ✓ It means loss of energy (weaker signal).
- ✓ When a signal travels through a medium, it loses energy overcoming the resistance of the medium.



- ✓ **Amplifiers** are used to compensate for this loss of energy by amplifying the signal.

TRANSMISSION IMPAIRMENTs

❑Measurement of Attenuation:

- ✓ To show the loss or gain of energy the unit "decibel" is used.

dB = 10log10(P2/P1)

P1 - input signal power and P2 - output signal Power

Example 1: Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

- ✓ A loss of 3 dB (–3 dB) is equivalent to losing **one-half the power**.

TRANSMISSION IMPAIRMENTs

❑Measurement of Attenuation:

✓ To show the loss or gain of energy the unit “decibel” is used.

dB = 10log10(P2/P1)

P1 - input signal power and P2 - output signal Power

Example 2: A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1 . In this case, the amplification (gain of power) can be calculated as

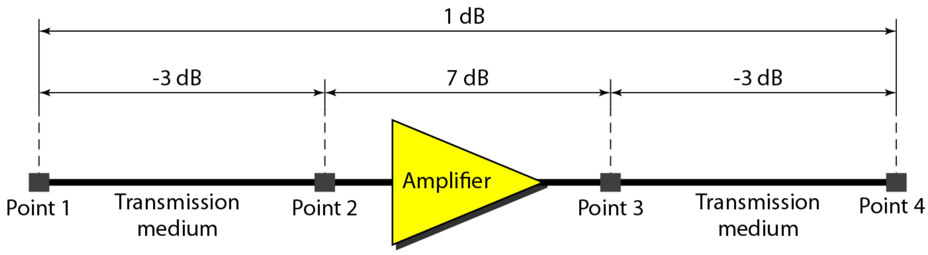
$$\boxed{10\log_{10}\frac{P_2}{P_1} = 10\log_{10}\frac{10P_1}{P_1}}$$

$$\boxed{= 10\log_{10}10 = 10(1) = 10\ \text{dB}}$$

TRANSMISSION IMPAIRMENTs

❑Measurement of Attenuation:

✓ One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure below, a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as



$$\boxed{\text{dB} = -3 + 7 - 3 = +1}$$

TRANSMISSION IMPAIRMENTs

❑Measurement of Attenuation:

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal with $dB_m = -30$.

Solution:

We can calculate the power in the signal as

$$dB_m = 10 \log_{10} P_m = -30$$
$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \text{mW}$$

TRANSMISSION IMPAIRMENTs

❑Measurement of Attenuation:

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution:

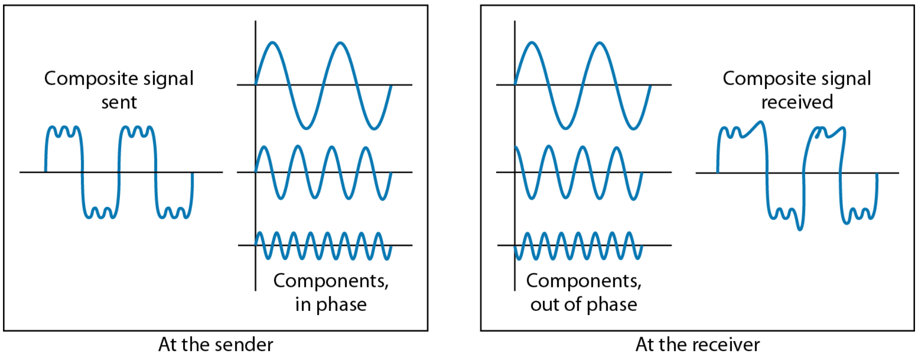
The loss in the cable in decibels is $5 \times (-0.3) = -1.5$ dB. We can calculate the power as

$$dB = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$
$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$
$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4\ \text{mW}$$

TRANSMISSION IMPAIRMENTs

❑Distortion:

- ✓ It means that the signal changes its form or shape. The signals have different phases at the receiver than they did at the source. Distortion occurs in composite signals.



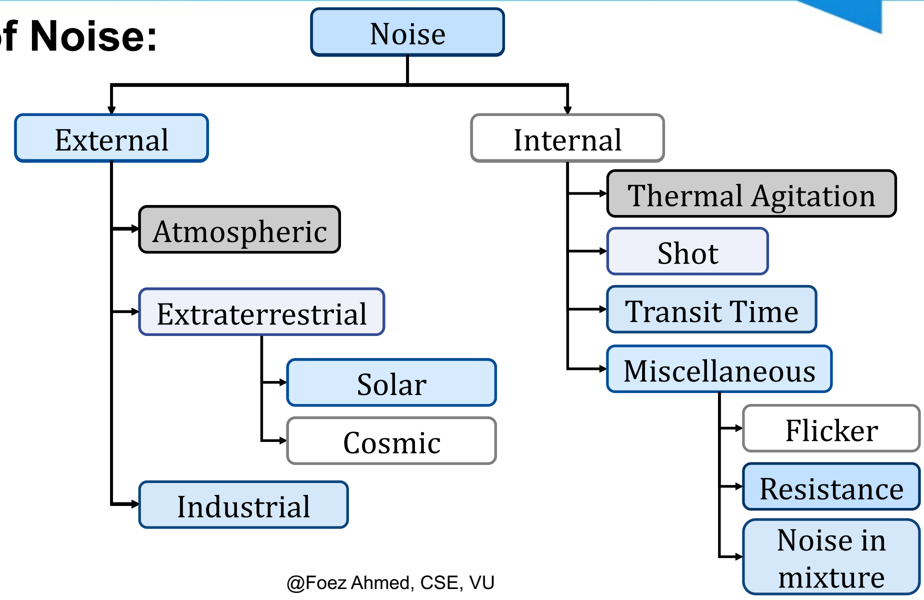
TRANSMISSION IMPAIRMENTs

❑Noise:

- ✓ Noise can be defined as an unwanted introduction of energy tending to interfere with the proper reception and reproduction of the transmitted signal.
- ✓ Noise can be added with the signal in the medium or at the receiver.
- ✓ Noise can limit the range of systems, for a given transmitted power.
- ✓ It may sometimes even force a reduction in the bandwidth of a system.

TRANSMISSION IMPAIRMENTs

❑Types of Noise:



TRANSMISSION IMPAIRMENTs

❑Thermal Agitation Noise:

✓ The noise which is generally produced in the resistances or resistive elements is called ***Thermal agitation noise/White noise/Jhonson noise.***

Here, this noise power can be represented by

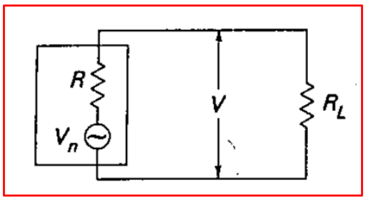
$$P_n \propto T\,\delta f = kT\,\delta f$$

Where

k= Boltzmann Constant= 1.38×10^{-23} J/K
T= Absolute temperature
δf= Signal bandwidth

TRANSMISSION IMPAIRMENTs

❑Thermal Agitation Noise: Thevenin noise model



$$P_n = \frac{V^2}{R_L} = \frac{\left(\frac{V_n}{2}\right)^2}{R} = \frac{V_n{}^2}{4R} = kT\,\delta f$$

So,

$$V_n = \sqrt{4RkT\,\delta f}$$

Where

V_n= Noise Voltage

TRANSMISSION IMPAIRMENTs

❑Thermal Agitation Noise: Thevenin noise model

Example 2.1

If the resistor is operating at 27°C and the bandwidth of interest is 2 MHz, then what is the maximum noise power output of a resistor?

Solution

$$P_n = k.T.\Delta f = 1.38 \times 10^{-23} \times 300 \times 2 \times 10^{6}$$

$$P_n = 1.38 \times 10^{-17} \times 600 = 0.138 \times 0.6 \times 10^{-12}$$

$$P_n = 0.0828 \times 10^{-12} \text{ Watts}$$

TRANSMISSION IMPAIRMENTs

❑Thermal Agitation Noise: Thevenin noise model

Example 2.2

An amplifier operating over the frequency range from 18 to 20 MHz has a 10-kilohm (10-kΩ) input resistor. What is the rms noise voltage at the input to this amplifier if the ambient temperature is 27°C?

Solution

$$V_n = \sqrt{4kT\Delta f R}$$
$$= \sqrt{4 \times 1.38 \times 10^{-23} \times (27 + 273) \times (20 - 18) \times 10^6 \times 10^4}$$
$$= \sqrt{4 \times 1.38 \times 3 \times 2 \times 10^{-11}} = 1.82 \times 10^{-5}$$
$$= 18.2 \text{ microvolts } (18.2\mu V)$$

TRANSMISSION IMPAIRMENTs

❑Shot Noise:

- ✓ It is caused by random variations in the arrival of electrons (or holes) at the output electrode of an amplifying device and appears as a randomly varying noise current superimposed on the output.
- ✓ When amplified, it is supposed to sound as though a shower of lead shot were falling on a metal sheet. Hence the name shot noise.
- ✓ Here, the shot noise current can be represented by

$$i_n = \sqrt{2ei_p\delta f}$$

Where

e= charge of electron

i_p= Direct diode current

δf= Signal bandwidth

TRANSMISSION IMPAIRMENTs

❑Transit Time Noise:

- ✓ If the time taken by an electron to travel from the emitter to the collector of a transistor becomes significant to the period of the signal being amplified, then it is said that the transit-time effect has taken place.
- ✓ This noise is caused due to increase in conductance with increase in frequency.

TRANSMISSION IMPAIRMENTs

❑ Noise Due to Several Sources:

- ✓ If there are two noise sources namely V_{n1} and V_{n2} (produced due to R_1 and R_2 respectively), then total noise voltage will be,

$$V_{n,tot} = \sqrt{{V_{n1}}^2 + {V_{n2}}^2} = \sqrt{4R_1kT\ \delta f + 4R_2kT\ \delta f}$$

$$\therefore V_{n,tot} = \sqrt{4kT\ \delta f\ (R_1 + R_2)} = \sqrt{4R_{tot}kT\ \delta f}$$

So, for "n" sources, the total resistance will be,

$$R_{tot} = R_1 + R_2 + \cdots + R_n$$

And the total noise voltage will be,

$$V_{n,tot} = \sqrt{4R_{tot}kT\ \delta f}$$

TRANSMISSION IMPAIRMENTs

❑ Noise Due to Several Sources:

Example 2.3

Calculate the noise voltage at the input of a television RF amplifier, using a device that has a 200-ohm (200-Ω) equivalent noise resistance and a 300-Ω input resistor. The bandwidth of the amplifier is 6 MHz, and the temperature is 17°C.

Solution

$$V_{n,\text{tot}} = \sqrt{4kT\,\Delta f\,R_{\text{tot}}}$$
$$= \sqrt{4\times 1.38\times 10^{-23}\times(17+273)\times 6\times 10^{6}\times(300+200)}$$
$$= \sqrt{4\times 1.38\times 2.9\times 6\times 5\times 10^{-13}} = \sqrt{48\times 10^{-12}}$$
$$= 6.93\times 10^{-6} = 6.93\,\mu\text{V}$$

TRANSMISSION IMPAIRMENTs

❑ Signal to Noise Ratio and Noise Figure:

- ✓ **Signal to Noise Ratio (SNR):** SNR is defined as the ratio of signal power to noise power.

$$SNR = \frac{P_s}{P_n}$$

- ✓ **Noise Figure:** Noise figure is defined as the ratio of input SNR to output SNR.

$$F = \frac{Input\ SNR}{output\ SNR}$$

TRANSMISSION IMPAIRMENTs

❑ Signal to Noise Ratio and Noise Figure:

Problem: The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

Solution: The values of SNR and SNR_{dB} can be calculated as follows:

$$\boxed{\mathrm{SNR} = 10{,}000} \quad \boxed{\mathrm{SNR_{dB}} = 40\ \mathrm{dB}}$$

TRANSMISSION IMPAIRMENTs

Mathematical Problems:

Review Problems

from

Electronic Communication Systems by George Kennedy & Bernard Davis

Communication Engineering

Thank You All