Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:14

# Lecture 14

# Noise in Analog and Digital Systems

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Noise can be defined as any undesired signal that interferes with the transmission, measurement, or processing of an information-carrying signal. It is an unavoidable phenomenon that exists in varying degrees across almost all environments. In communication systems, noise can degrade signal quality, cause errors, and even disrupt the communication process entirely.

For example, in a digital cellular mobile communication system, multiple sources of noise can negatively impact performance. These include:

- **Acoustic background noise:** Ambient sounds from the environment, such as traffic, conversations, or machinery, that can interfere with voice communication.
- **Thermal noise:** Random motion of electrons within electronic components, which generates a low-level but continuous noise.
- **Electromagnetic radio-frequency noise:** Interference caused by external electromagnetic sources, such as power lines, electronic devices, or other wireless signals.
- **Co-channel interference:** Disturbance caused by signals from nearby transmitters operating on the same frequency, leading to reduced signal clarity.
- **Radio-channel distortion:** Signal degradation due to multipath propagation, fading, and other environmental effects that alter the transmitted signal.
- **Echo:** Reflected signals that create delayed duplicates of the original signal, leading to distortion in communication.
- **Processing noise:** Noise introduced by digital signal processing operations, such as quantization noise or computational errors.

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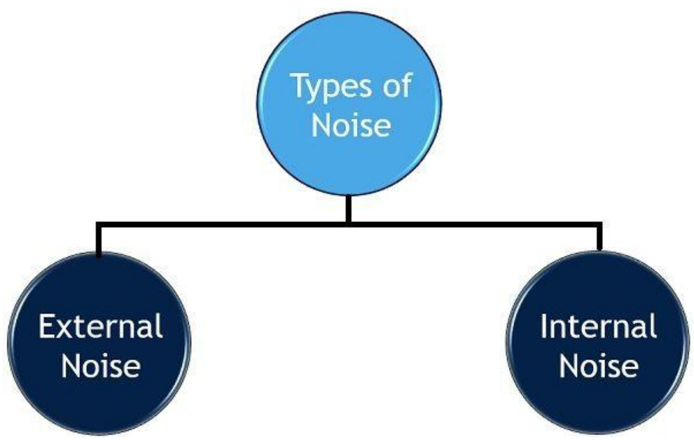
These various types of noise can introduce transmission errors, reduce communication quality, and, in severe cases, lead to communication failures. To mitigate these effects, communication systems employ noise reduction techniques such as error correction, filtering, and adaptive signal processing.

## Types of Noise in Communication Systems

Noise in a communication system can be categorized into two main types based on its source:




### 1. External Noise

External noise originates from sources outside the communication system and can significantly affect signal transmission. It includes the following types:

- **Atmospheric Noise:** Caused by natural atmospheric phenomena such as lightning, thunderstorms, and other weather-related disturbances that generate electromagnetic interference.

- **Man-Made Noise:** Also known as industrial noise, this type is produced by human activities, including electrical appliances, power lines, automotive ignitions, and other electronic devices.
- **Extraterrestrial Noise:** Originates from cosmic sources such as the sun, stars, and other celestial bodies, as well as galactic and solar noise that affects radio communication.
- **Fading:** A variation in signal strength caused by environmental factors such as obstacles, reflections, and multipath propagation, leading to signal attenuation or distortion.

**2. Internal Noise**

Internal noise is generated within the components of a communication system itself. It arises due to the inherent electrical properties of system elements, such as resistors, transistors, and amplifiers. The primary types of internal noise include:

- **Thermal Noise (Johnson Noise or Nyquist Noise):** Caused by the random motion of electrons in resistive components, generating continuous background noise that increases with temperature.
- **Shot Noise:** Occurs due to the random movement of charge carriers (electrons and holes) in semiconductor devices like diodes and transistors, leading to small fluctuations in current.
- **Flicker Noise (1/f Noise):** A low-frequency noise that appears in semiconductor devices and resistors, becoming more prominent at lower frequencies, particularly in transistors and operational amplifiers.

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## Thermal Noise

Thermal noise, also known as **Johnson-Nyquist noise**, is the electrical noise generated due to the random motion of charge carriers (electrons and holes) within a conductive or semiconductive medium. This random movement occurs as a result of thermal energy and is an inherent property of all matter at temperatures above absolute zero. Since this noise is caused by atomic-level agitation, it is unavoidable in electronic systems.

Thermal noise was first extensively studied by **Harry Nyquist**, who derived a mathematical expression to quantify its effect.

The power spectral density of thermal noise is proportional to the temperature and bandwidth:

$$P_n \propto TB$$

$$P_n = kTB$$

Where:

- $k$= Boltzmann's constant = $1.38 \times 10^{-23}$J/K
- $T$ = Absolute temperature in kelvin (K)
- $B$ = Noise bandwidth in hertz (Hz)

The **mean-square noise voltage** across a resistor R (in ohms) is given by:

$$V_n = \sqrt{kTBR}$$

**Key Characteristics of Thermal Noise**

1. **White Noise**: Thermal noise has a constant power spectral density over a wide range of frequencies.

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2. **Temperature Dependent**: As temperature increases, the intensity of thermal noise also increases.
3. **Resistor Dependent**: The noise voltage increases with the resistance value.
4. **Unavoidable**: Present in all passive and active electronic components.

**Example:**

An operational amplifier has a frequency range of **18 MHz to 20 MHz** and an input resistance of **10 kΩ**. If the amplifier operates at an ambient temperature of **27°C**, calculate the thermal noise voltage at the input.

**Solution:**

We use the thermal noise voltage formula:

$$V_n = \sqrt{kTBR}$$

- k= $1.38 \times 10^{-23}$ J/K
- T=27+273= 300 K (Temperature in Kelvin)
- B=20 MHz−18 MHz=$2\times10^6$ Hz (Noise Bandwidth)
- R=10 kΩ= $10^4$(Resistance)

$$V_n = \sqrt{1.38 \times 10^{-23} \times (300) \times 2 \times 10^6 \times 10^4}$$

$$V_n = 9.1\ \mu V$$

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## Determining Noise Levels in a Communication System

The impact of noise in a communication system can be evaluated using specific metrics that measure signal quality and transmission accuracy. The two primary methods for assessing noise effects are:

**1. Signal-to-Noise Ratio (SNR) – For Analog Systems**

The **Signal-to-Noise Ratio (SNR)** is a key metric used to measure the quality of a signal in analog communication systems. It represents the ratio of the signal power to the noise power affecting the signal. A **higher SNR** indicates a **better-quality** signal with less noise interference.

**SNR Formula:**

$$SNR = \frac{P_{signal}}{P_{noise}}$$

Where:

- $P_{signal}$ is the power of the desired signal.
- $P_{noise}$ is the power of the noise present in the system.

A high SNR ensures a clear and accurate transmission, while a low SNR indicates significant noise interference, leading to signal distortion and reduced clarity.

**2. Bit Error Rate (BER) – For Digital Systems**

For digital communication systems, the **Bit Error Rate (BER)** is used to evaluate the effect of noise. BER measures the **number of bit errors** that occur during transmission relative to the total number of transmitted bits. A **lower BER** signifies **better system performance** with fewer errors.

**BER Calculation:**

BER is determined by comparing the received bit stream with the original transmitted bit stream and counting the number of incorrect bits. It is typically expressed as a **ratio** or a **percentage**:

$$BER = \frac{Number\ of\ bit\ errors}{Total\ number\ of\ transmited\ bits}$$

A **high BER** suggests significant noise interference, which can lead to corrupted data, while a **low BER** indicates more reliable data transmission.

**Assessing Noise Impact on System Performance**

Both **SNR (for analog systems)** and **BER (for digital systems)** serve as crucial indicators of noise interference. Their values help in evaluating and optimizing communication system performance:

- A **low SNR** or **high BER** signifies increased noise levels, leading to degraded communication quality.
- A **high SNR** or **low BER** indicates effective signal transmission with minimal noise distortion.

**Example:**

An analog communication system transmits a signal with a power of 5mW, while the noise power affecting the system is 0.2mW**.** Calculate the **SNR** in decibels (dB).

**Solution:**

The SNR is given by the formula:

$$SNR = \frac{P_{signal}}{P_{noise}}$$

$$SNR = \frac{5}{0.2} = 25$$

To express SNR in decibels (dB), we use the logarithmic formula:

$$SNR_{dB} = 10log_{10}(SNR)$$

$$SNR_{dB} = 10log_{10}(25)$$

$$= 13.98\, dB$$

**Example:**

A digital communication system transmits 1000000 bits over a noisy channel. Upon reception, 250 bits are found to be in error. Calculate the **BER** of the system.

**Solution:**

The BER is given by:

$$BER = \frac{Number\ of\ bit\ errors}{Total\ number\ of\ transmited\ bits}$$

$$BER = \frac{250}{1000000} = 0.00025$$

To express BER as a percentage:

$$BER = 0.00025 \times 100 = 0.025\%$$

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