Al-Mustaqbal University
Department (Medical Instrumentation Techniques Engineering)
Class (3rd)
Subject (Medical Communication systems)
Lecturer (Dr. Osamah Jaber Ghayyib)
6th Semester – Lect. (Noise In Communication System)

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CONTENTS

LEARNING OBJECTIVES

By the end of this lecture, students will be able to:

1- Define transmission impairments in communication systems.

2- Explain the three main types of signal impairments: attenuation, distortion, and noise.

3- Differentiate between internal and external noise sources.

4- Classify external noise into atmospheric, extraterrestrial, and industrial noise.

5- Describe internal noise types such as thermal noise and shot noise.

6- Apply mathematical expressions related to thermal noise and shot noise.

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7- Define Noise Figure (NF) and calculate it for communication systems.

8- Explain Equivalent Noise Temperature and its significance in system performance.

9- Analyze the impact of noise on signal-to-noise ratio (SNR).

10- Evaluate practical methods for reducing noise in communication systems, especially in medical communication applications

1 INTRODUCTION

In communication systems, particularly in **medical communication systems**, accurate and reliable signal transmission is essential. Biomedical signals such as ECG, EEG, EMG, and other physiological measurements are typically very weak and highly sensitive to interference. Therefore, understanding signal impairments is critical for designing efficient and reliable medical communication equipment.

When a signal travels through a transmission medium, it does not remain unchanged. Due to imperfections in the medium and electronic components, the received signal differs from the transmitted signal. These degradations are known as **transmission impairments**.

There are three primary types of transmission impairments:

Attenuation

Attenuation is the loss of signal strength as it propagates through a medium. Energy is dissipated in the form of heat due to resistance. Amplifiers are used to compensate for this loss.

Distortion

Distortion occurs when different frequency components of a composite signal experience different delays. This causes changes in the shape of the signal waveform, which may lead to incorrect interpretation at the receiver.

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Noise

Noise is any unwanted electrical signal that interferes with the desired message signal. It is unavoidable in communication systems and can originate from internal electronic components or from external environmental sources.

Noise plays a particularly critical role in medical communication systems because biomedical signals often have low amplitudes. Even small noise levels can significantly degrade signal quality and diagnostic accuracy.

Understanding noise sources, noise modeling, noise figure, and equivalent noise temperature enables engineers to design low-noise amplifiers and high-performance medical communication systems.

2 TRANSMISSION IMPAIRMENT

Signal travel through transmission medium, which are not perfect. the imperfection cause impairment in the signal. This means that the signal at the beginning and end of the medium are not the same. what is sent is not what received. Three types of impairment usually occur is:

1-ATTENUATION

2- DISTORTION

3- NOISE.

2.1 ATTENUATION

Attenuation means loss of energy. When a signal, simple or composite, travel through a medium, it loses some of its energy so that it can overcome the resistance of the medium that is why a wire carrying electrical signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifier

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is used to amplify the signal. Figure 1 shows the effect of attenuation and amplification on a signal.
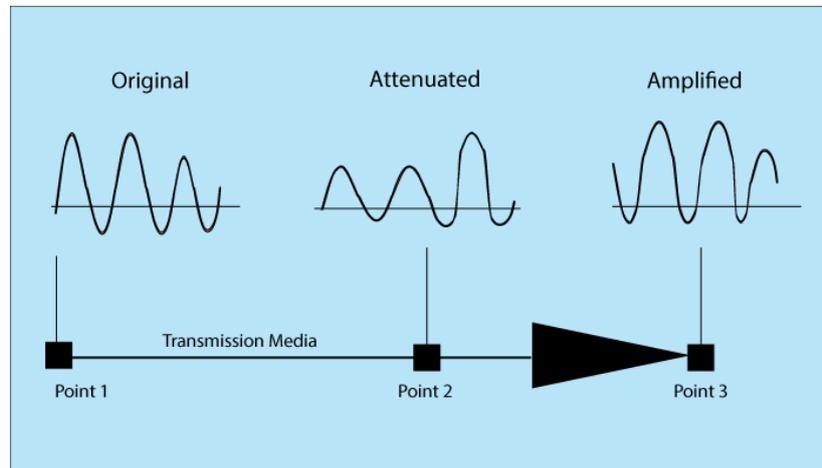

Figure 1: The effect of attenuation.

2.2 DISTORTION

This kind of distortion is mainly appearing in case of composite signals in which a composite signal has various frequency components in it and each frequency component has some time constraint which makes a complete signal.

But while transmitting this composite signal, if a certain delay happens between the frequency's components, then there may be the chance that the frequency component will reach the receiver end with a different delay constraint from its original which leads to the change in shape of the signal. The delay happens due to environmental parameters or from the distance between transmitter and receiver etc. Distortion is diagrammatically represented as follows:
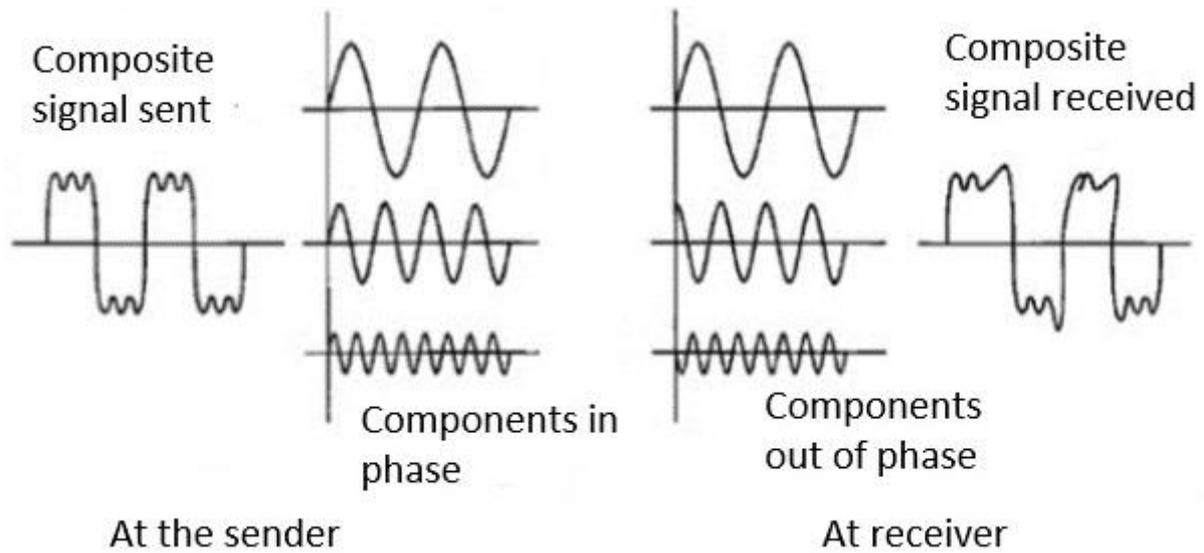
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Figure 2: Distortion effect.

2.3 NOISE

It is another problem; noise signals are any electrical signal (voltages or currents) that interfere with the error-free reception of the message bearing signal.

Noise in communication systems originates both in the **channel** and in the communication **equipment**. Noise consists of undesired, usually random, variations that interfere with the desired signals and inhibit communication. It cannot be avoided completely, but its effects can be reduced by various means, such as: **reducing the signal bandwidth**, **increasing the transmitter power**, and using **low noise amplifiers for weak signals**. It is helpful to divide noise into two types: **internal noise**, which originates within the communication equipment, and **external noise**, which is a property of the channel.
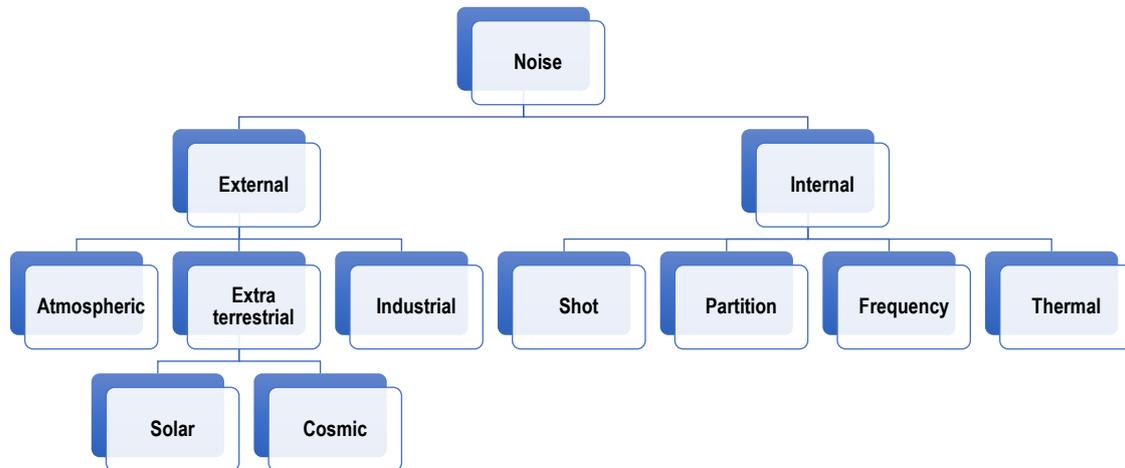
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Figure 3: Distortion effect.

2.3.1 EXTERNAL NOISE

External noise refers to unwanted disturbances that originate outside the communication system.
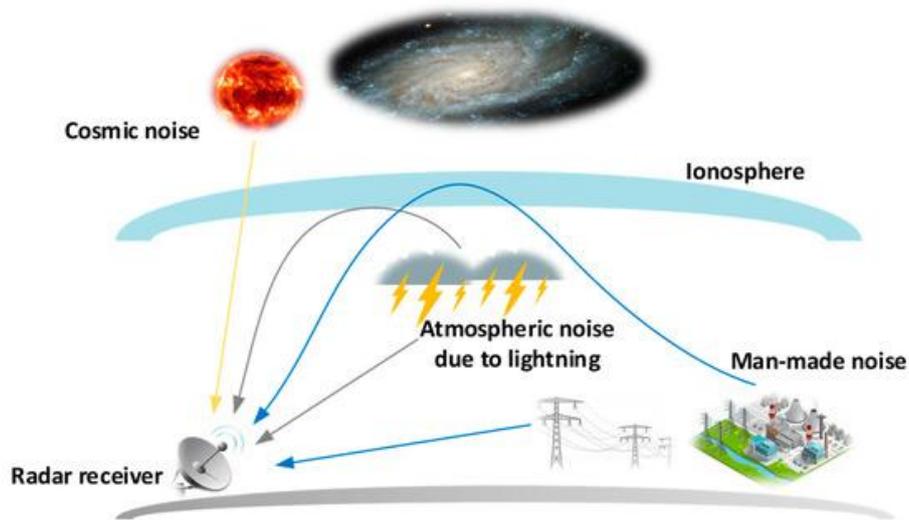
Figure 4:External Noise.

2.3.1.1 Atmospheric

Atmospheric noise is often called static because **lightning**, which is a static electricity discharge, is a principal source of atmospheric noise. This type of disturbance can propagate for **long distances** through space. Most of the energy of lightning is found at relatively low frequencies, up to **several megahertz**. Obviously, nothing can be done to reduce

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atmospheric noise at the source. However, circuits are available to reduce its effect by taking advantage of the fact that this noise has a very high peak-to- average power ratio; that is, the noise occurs in short intense bursts with relatively long periods of time between bursts. It is often possible to improve communication by simply disabling the receiver for the duration of the burst. This technique is called noise blanking.

2.3.1.2   Extra terrestrial

It refers to electromagnetic radiation originating from space sources like the Sun, stars, and galaxies that interfere with radio communications. Primarily consisting of solar and cosmic noise.

The sun is a powerful source of radiation over a wide range of frequencies, including the radio-frequency spectrum. Other stars also radiate noise called cosmic, stellar, or sky noise. Its intensity when received on the earth is naturally much less than for solar noise because of the greater distance. Solar noise can be a serious problem for satellite reception, which becomes impossible when the satellite is in a line between the antenna and the sun. Space noise is more important at higher frequencies (VHF and above) because atmospheric noise dominates at lower frequencies and because most of the space noise at lower frequencies is absorbed by the upper atmosphere.

2.3.1.3   Industrial

Noise is generated by equipment that produces sparks. Examples include automobile engines and electric motors with brushes. Any fast rise time voltage or current can also generate interference, even without arcing. Light dimmers and computers fall into this category. Noise of this type has a broad frequency spectrum, but its energy is not equally distributed over the frequency range. This type of interference is generally more severe at lower frequencies, but the exact frequency distribution depends upon the source itself and any conductors to which it is connected. Computers, for instance, may produce strong signals at multiples and submultiples of their clock frequency and little energy elsewhere.

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Man-made noise can propagate through space or along power lines. It is usually easier to control it at the source than at the receiver. A typical solution for a computer, for instance, involves shielding and grounding the case and all connecting cables and installing a low-pass filter on the power line where it enters the enclosure.

2.3.2   INTERNAL

Internal noise can be a major barrier to effective communication. It can make it difficult to pay attention to the message being communicated. It can also make it difficult to understand and remember the message. Internal noise is *any interference that comes from within the communicator or the receiver.*

2.3.2.1   Shot

This type of noise has a power spectrum that resembles that of thermal noise, having equal energy in every hertz of bandwidth, at frequencies from dc into the gigahertz region. However, the mechanism that creates shot noise is different. Shot noise is due to random variations in current flow in active devices such as tubes, transistors, and semiconductor diodes. These variations are caused by the fact that current is a flow of carriers (electrons or holes), each of which carries a finite amount of charge. Current can thus be considered as a series of pulses, each consisting of the charge carried by one electron. The name shot noise describes the random arrival of electrons arriving at the anode of a vacuum tube, like individual pellets of shot from a shotgun. One would expect that the resulting noise power would be proportional to the device current, and this is true both for vacuum tubes and for semiconductor junction devices. Shot noise is usually represented by a current source. The noise current for either a vacuum or a junction diode is given by the equation:

$$I_N = \sqrt{2qI_0B} \tag{1}$$

Where,

$I_N = RMS$ noise current, in amperes.

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q = magnitude of the charge on an electron, equal to 1.6×10^{-19} coulomb.

I_0 = dc bias current in the device, in amperes.

B = bandwidth over which the noise is observed, in hertz.

EXAMPLE 1 :   A diode noise generator is required to produce 10μ V of noise in a receiver with an input impedance of 75Ω, resistive, and a noise power bandwidth of 200 kHz. (These values are typical of FM broadcast receivers.) What must the current through the diode be?

Solution

First, convert the noise voltage to current, using Ohm s Law:

$$I_N = \frac{V_N}{R}$$
$$= \frac{10\mu \text{ V}}{75\Omega}$$
$$= 0.133\mu \text{ A}$$
$$I_N = \sqrt{2qI_0B}$$
$$I_N^2 = 2qI_0B$$
$$I_0 = \frac{I_N^2}{2qB}$$
$$= \frac{(0.133 \times 10^{-6} \text{ A})^2}{2(1.6 \times 10^{-19}\text{C})(200 \times 10^3 \text{ Hz})}$$
$$= 0.276 \text{ A or 276 mA}$$

2.3.2.2   Thermal

Thermal noise is produced by the random motion of electrons in a conductor due to heat. The term noise is often used alone to refer to this type of noise, which is found everywhere in electronic circuitry. The power density of thermal noise is constant with frequency, from zero to frequencies well above those used in electronic circuits. That is, there is equal power in every hertz of bandwidth. Thermal noise is thus an equal mixture of noise of all frequencies. It is sometimes called white noise, in analogy with white light,

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which is an equal mixture of all colors. The noise power available from a conductor is a function of its temperature, as shown by the equation:

$$P_N = kTB \tag{2}$$

Where,

P_N = noise power in watts
k = Boltzmann's constant, 1.38×10^{-23} joules/kelvin (J/K)
T = absolute temperature in kelvins (K); this can be found by adding 273 to the celcius temperature
B = noise bandwidth in hertz

EXAMPLE 2 : A receiver has a noise power bandwidth of 10 kHz. A resistor that matches the receiver input impedance is connected across its antenna terminals. What is the noise power contributed by that resistor in the receiver bandwidth, if the resistor has a temperature of 27°C ?

Solution

First, convert the temperature to Kelvin's:
$$T(\text{K}) = T(°\text{C}) + 273$$
$$= 27 + 273$$
$$= 300 \text{ K}$$

$$P_N = kTB$$
$$= (1.38 \times 10^{-23} \text{ J/K})(300 \text{ K})(10 \times 10^3 \text{ Hz})$$
$$= 4.14 \times 10^{-17} \text{ W}$$

Often, we are more interested in the noise voltage than in the power involved. The noise power depends only on bandwidth and temperature, as stated above. Power in a resistive circuit is given by the equation:

$$P = \frac{V^2}{R}, \qquad V^2 = PR, \qquad V = \sqrt{PR}, \qquad P_N = kTB \tag{3}$$

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In this situation, one-half the noise voltage appears across the load, and the rest is across the resistor that generates the noise The root-mean-square (RMS) noise voltage across the load is given by:

$$V_L = \sqrt{PR}$$
$$= \sqrt{kTBR} \tag{4}$$

An equal noise voltage will appear across the source resistance, so the noise source must have double this voltage or

$$V_N = 2\sqrt{kTBR}$$
$$= \sqrt{4kTBR} \tag{5}$$

EXAMPLE 3 :   A 300Ω resistor is connected across the 300Ω antenna input of a television receiver. The bandwidth of the receiver is 6 MHz , and the resistor is at room temperature (293 K or 20°C or 68°F). Find the noise power and noise voltage applied to the receiver input?

Solution

The noise power is given by
$$P_N = kTB$$
$$= (1.38 \times 10^{-23} \text{ J/K})(293 \text{ K})(6 \times 10^6 \text{ Hz})$$
$$= 24.2 \times 10^{-15} \text{ W}$$
$$= 24.2 \text{fW}$$
$$V_N = \sqrt{4kTBR}$$
$$= \sqrt{4(1.38 \times 10^{-23} \text{ J/K})(293 \text{ K})(6 \times 10^6 \text{ Hz})(300\Omega)}$$
$$= 5.4 \times 10^{-6} \text{ V}$$
$$= 5.4\mu \text{ V}$$

Of course, only one-half this voltage appears across the antenna terminals; the other half appears across the source resistance. Therefore, the actual noise voltage at the input is 2.7μ V.

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2.3.2.3   Noise Figure

Since thermal noise is produced by all conductors and since active devices add their own noise as described previously, it follows that any stage in a communication system will add noise. An amplifier, for instance, will amplify equally both the signal and the noise at its input, but it will also add some noise. The signal-to noise ratio at the output will therefore be lower than at the input.

Noise figure (abbreviated NF or just F) is a figure of merit, indicating how much a component, stage, or series of stages degrades the signal-to-noise ratio of a system. The noise figure is, by definition

$$NF = \frac{(S/N)_i}{(S/N)_o} \tag{6}$$

Where

$(S/N)_i$ = input signal-to-noise power ratio (not in dB).

$(S/N)_o$ = output signal-to-noise power ratio (not in dB).

Very often both S/N and NF are expressed in decibels, in which case we have:

$$NF(\text{ dB}) = (S/N)_i(\text{ dB}) - (S/N)_o(\text{ dB}) \tag{7}$$

Since we are dealing with power ratios, it should be obvious that:

$$NF(\text{ dB}) = 10\log NF \text{ (ratio)} \tag{8}$$

EXAMPLE 4 :   The signal power at the input to an amplifier is 100μ W and the noise power is 1μ W. At the output, the signal power is 1 W and the noise power is 30 mW . What is the amplifier noise figure, as a ratio?

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Solution

$$(S/N)_i = \frac{100\mu \text{ W}}{1\mu \text{ W}} = 100$$

$$(S/N)_o = \frac{1 \text{ W}}{0.03 \text{ W}} = 33.3$$

$$NF(\text{ ratio }) = \frac{100}{33.5} = 3$$

EXAMPLE 5 :   The signal at the input of an amplifier has an S/N of 42 dB . If the amplifier has a noise figure of 6 dB , what is the S/N at the output (in decibels)?
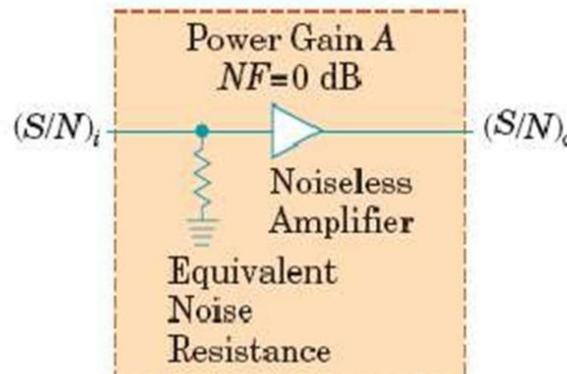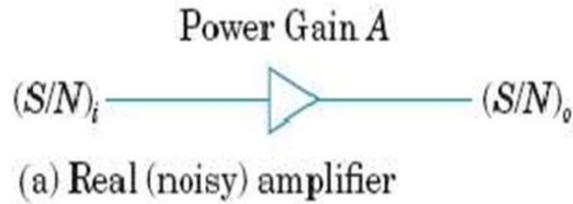
Solution

The S/N at the output can be found by rearranging Equation

$$NF(\text{ dB}) = (S/N)_i(\text{ dB}) - (S/N)_o(\text{ dB})$$
$$(S/N)_o(\text{ dB}) = (S/N)_i(\text{ dB}) - NF(\text{ dB})$$
$$= 42 \text{ dB} - 6 \text{ dB}$$
$$= 36 \text{ dB}$$

2.3.2.4   Equivalent Noise Temperature

Equivalent noise temperature is another way of specifying the noise performance of a device. Noise temperature has nothing to do with the actual operating temperature of the circuit. Rather, as shown in Figure below, it is the absolute temperature of a resistor that, connected to the input of a noiseless amplifier of the same gain, would produce the same noise at the output as the device under discussion.

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Power Gain A

$(S/N)_i$ ⟶ ▷ ⟶ $(S/N)_o$

(a) Real (noisy) amplifier

Power Gain A
$NF = 0$ dB

$(S/N)_i$ ————▷———— $(S/N)_o$

Noiseless Amplifier

Equivalent Noise Resistance

We can evaluate the Equivalent noise temperature by:

$$T_{eq} = 290(NF - 1) \qquad (9)$$

EXAMPLE 6 : An amplifier has a noise figure of 2 dB . What is its equivalent noise temperature?

Solution

$$NF(\text{dB}) = 10\log NF (\text{ratio})$$

From which we get:

$$NF(\text{ratio}) = \text{antilog}\frac{NF(\text{dB})}{10}$$
$$= \text{antilog}0.2$$
$$= 1.585$$
$$T_{eq} = 290(NF - 1)$$
$$= 290(1.585 - 1)$$
$$= 169.6 \text{ K}$$

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