

Noise and Distortion

Noise

Noise is an electronic signal made up of many random frequencies at many amplitudes added to a radio or information signal when transmitted from one place to another or as it is processed. This shows up as a random AC voltage and can be seen on an oscilloscope regardless of the noise source.

It differs from **interference** from other information signals, which disrupts a signal when unwanted signals are added.

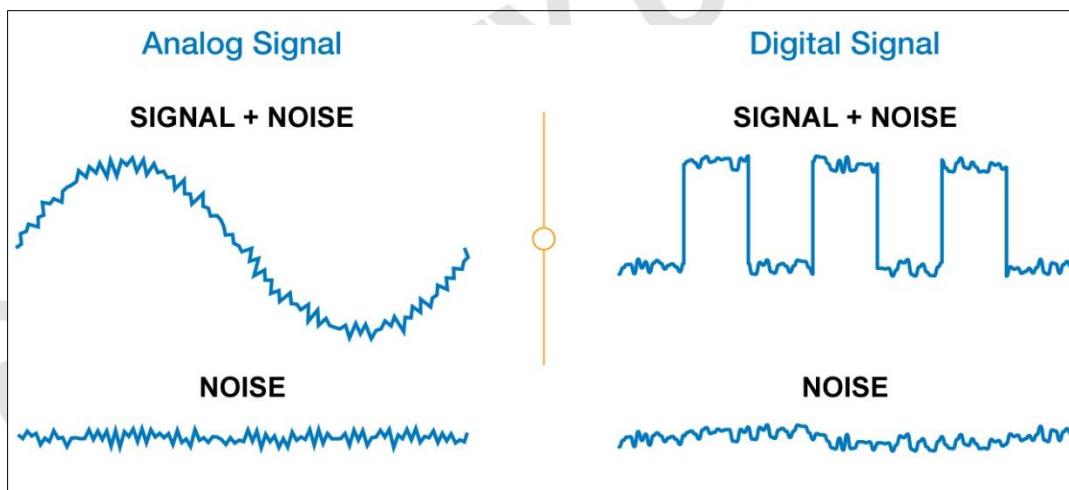


Figure 1. Noise signal. Retrieved from <https://www.predig.com/whitepaper/reducing-signal-noise-practice>

In general, **signal noise** is unwanted interference that degrades a communication signal and affects both analog and digital signals, as seen in *Figure 1*. However, a much higher amount of noise is needed to affect digital signals, as digital signals use binary pulses to convey digital bits. It requires a higher noise for both pulses to be confused with one another.

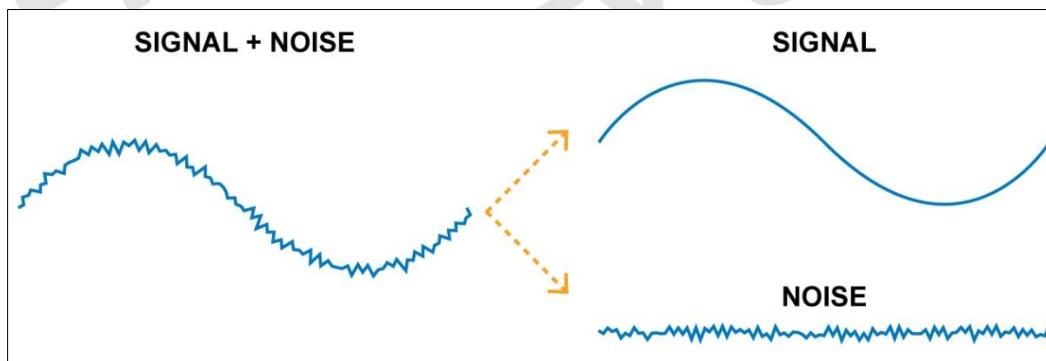


Figure 2. Noise signal. Retrieved from <https://www.predig.com/whitepaper/reducing-signal-noise-practice>

Figure 2 shows how noise affects a signal. A signal noise inserted into electrical communication will add or detract from the expected value, and any variation can lead to unpredictable and possibly damaging results.

Examples of Noise

Noise can be observed on simple devices at home. For example, when manually tuning into an AM or FM radio and going between stations, the hiss or the static that can be heard is considered noise. In television, noise can be observed as “**snow**” on a black-and-white TV screen and “**confetti**” on a colored screen.

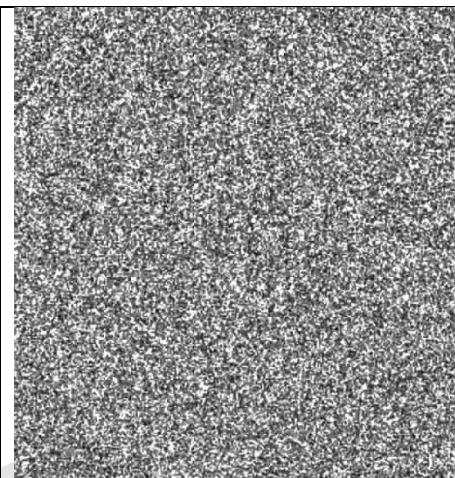


Figure 3. Snow. Retrieved from
<https://stackoverflow.com/>

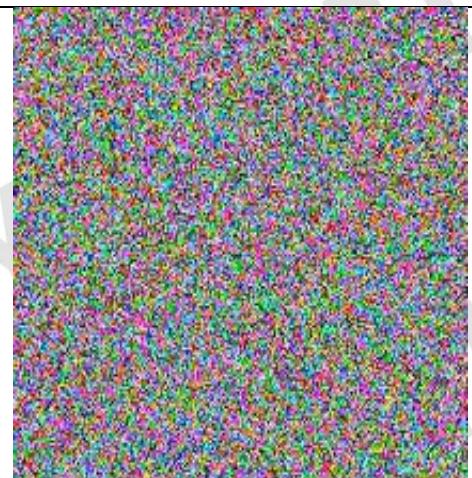


Figure 4. Confetti. Retrieved from
<https://www.vecteezy.com/>

As with these examples, if the noise level is high enough or the signal is weak enough, the noise can completely overshadow the original signal, may it be on the radio or television.

Types of Noise

There are two (2) classifications of noise, with each type of their own.

External Noise: This comes from sources that cannot be controlled by humans, such as in industrial, atmospheric, or space.

- **Industrial Noise** – produced by manufacturing equipment like automotive ignition systems, generators, and electric motors. Such electrical equipment that causes high voltages or currents to be switched creates transients, or momentary bursts of energy, that produce noise. Gas-filled lights, such as fluorescent lights, are also sources of industrial noise.
- **Atmospheric Noise** – electrical disturbances that happen naturally in the Earth’s atmosphere. This is also referred to as *static*, which usually comes from lightning. This type of noise also shows up as amplitude variations that add to a signal and interfere with it.

Atmospheric noise also has the greatest impact on signals with frequencies below 30 MHz.

- **Extraterrestrial Noise** – in solar or cosmic, comes from space. **Solar noise** comes from the sun, which radiates a wide range of signals in a broad noise spectrum. The sun has a repeatable 11-year noise cycle where, at its peak, the sun produces an intense amount of noise that produces immense radio signal interference and makes many frequencies unusable for communication.

Cosmic noise is generated by stars outside the solar system. Even though it does not produce impactful noise like the sun due to the stars' distance from each other, it still shows up in the 10 MHz to 1.5 GHz range and causes great disruptions in the $15 - 150\text{ MHz}$.

Internal Noise: This comes from electronic components in a receiver, such as resistors, diodes, and transistors. Internal noise is only low-level but often great enough to interfere with weak signals.

Common internal noise includes thermal noise, semiconductor noise, and intermodulation distortion.

- **Thermal Noise** – caused by *thermal agitation*, which is the random motion of free electrons in a conductor caused by heat. The movement of electrons starts a current flow that causes a small voltage to be produced across conductor components.

Electrons passing a conductor as current flows experience sudden obstacles in their path as they encounter thermally agitated atoms. The apparent resistance of the conductor thus changes, which creates thermal noise.

Thermal agitation is also referred to as **white noise** or **Johnson noise** after John Bertrand Johnson discovered it in 1928. White noise is believed to contain all frequencies randomly happening at random amplitudes based on the perception that white light has all other light frequencies. This will signify that a white noise signal occupies an infinite bandwidth. A filtered or band-limited noise, however, is called **pink noise**.

- **Semiconductor Noise** – comes from components such as diodes and transistors. Semiconductors produce three (3) types of noise, including shot noise, transit-time noise, and flicker noise.

The current flow in any device is not direct and linear, which sometimes makes the current carriers, such as electrons, take random paths from source to destination. It is this random movement that produces the **shot noise**.

Transit time measures the period for the current carrier, such as an electron, to move from the input to the output. When the transit time of the signal frequency is the same as the time a current carrier takes to traverse from sender to receiver, a **transit-time noise** is created.

Lastly, a **flicker noise** or excess noise comes from minute random variations of resistance in the semiconductor material. It is also referred to as $\frac{1}{f}$ noise as it is inversely proportional to frequency.

- **Intermodulation Distortion** – comes from generating new signals and harmonics caused by circuit nonlinearities since a circuit is never perfectly linear. This also occurs when two (2) or more signals are used in a non-linear circuit.

In communication systems, noise is an issue whenever the received signals are very low in amplitude. However, it is usually not a problem when the transmission is over short distances, or high-power transmitters are being used.

Signal-to-Noise Ratio (SNR)

This establishes the relative strengths of the signal and noise in communication systems. If the signal is strong and the noise is weaker, the S/N ratio is higher, while if the signal is weak and the noise is strong, the S/N ratio is low, and reception will be unreliable.

Signals can be expressed in voltage or power using the S/N ratio formula.

$$\frac{S}{N} = \frac{V_s}{V_n} \text{ or } \frac{S}{N} = \frac{P_s}{P_n}$$

Wherein:

V_s = signal voltage

P_s = signal power

V_n = noise voltage

P_n = noise power

For example, if the signal voltage is $4.2 \mu V$ and the noise voltage is $0.3 \mu V$. The S/N ratio is:

$$\begin{aligned}\frac{S}{N} &= \frac{V_s}{V_n} \\ \frac{S}{N} &= \frac{4.2 \mu V}{0.3 \mu V} \\ \frac{S}{N} &= 14\end{aligned}$$

Most S/N ratios are expressed in power than voltage. For example, if the signal power is $6 \mu W$ and the noise power is $120 nW$:

$$\begin{aligned}\frac{S}{N} &= \frac{P_s}{P_n} \\ \frac{S}{N} &= \frac{6 \mu W}{120 nW} \\ \frac{S}{N} &= \frac{6 \times 10^{-6}}{120 \times 10^{-9}} \\ \frac{S}{N} &= 50\end{aligned}$$

The S/N ratio uses decibels (dB) for its unit, so the results should be converted to decibel values first, such as:

For S/N voltage:

$$\begin{aligned}dB &= 20 \log \frac{S}{N} \\ dB &= 20 \log(14) \\ dB &= 20 (1.1461) \\ dB &= 22.92 \text{ dB}\end{aligned}$$

For S/N power:

$$\begin{aligned}dB &= 10 \log \frac{S}{N} \\ dB &= 10 \log(50) \\ dB &= 10(1.6990) \\ dB &= 16.99 \text{ dB}\end{aligned}$$

Noise Factor and Noise Figure

The quality of the noise of a receiver can be further expressed as noise figure and noise factor.

Noise factor or noise ratio (NR) is the ratio between S/N power at the input and S/N power at the output, such as:

$$NR = \frac{S/N_{input}}{S/N_{output}}$$

When the noise factor is expressed in decibels, it is referred to as **noise figure** (NF), such as:

$$NF = 10\log NR$$

Distortion (UIA, 2023)

Distortion is a condition that adds unwanted change in the signal. It is the alteration of the waveform of an information signal of an audio or video signal in an electronic device or communication channel.

Some factors that cause distortion are environmental factors, properties of the communication channel, and the distance between the transmission device and the receiving device.

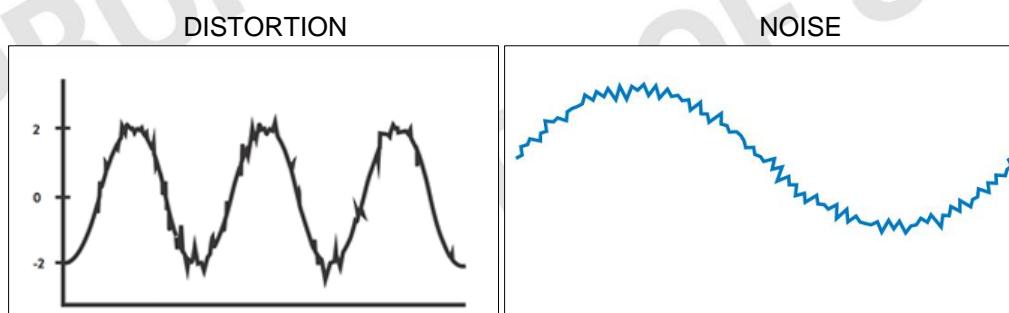


Figure 5. Distortion. Retrieved from <https://www.konftel.com/en/academy/dr-sound-explains-distortion>.

Figure 6 shows the difference between distortion and noise. Distortion differs from noise based on how it does not fully affect a signal; thus, it is harder to remove the effects of noise than to remove the effects of distortion in a signal.

Distortion is unwanted since if there is a distortion in voice transmission, it can result in garbled, harsh, and unnatural sounds in the speaker.

However, distortion can be desirable. In a Dolby system, which is a noise reduction system, an audio signal is purposely distorted to emphasize aspects of the signal subject to electrical noise. This process makes it symmetrically “undistorted” after passing a noisy communication channel, thus lessening the noise in the received signal. Distortion is also utilized as a musical effect for an instrument such as an electric guitar, as distortion can give an instrument a specific character.

References:

Frenzel, L. (2022). *Principles of electronic communication systems: 5th ed.* McGraw Hill.

The Encyclopedia of World Problems & Human Potential (2023). *Distortion*. [Web Article]. Retrieved on August 9, 2023, from <http://encyclopedia.uia.org/en/problem/distortion>