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Signals – sensors 1.

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Purposes of sensors

- Any sophisticated equipment needs to be reactive.
- Reaction must depends on the state of the environment or other external parameters.
- The decision logic – which create the appropriate reaction – must be aware of these external parameters.
- The more sophisticated equipment need electronic controllers.
- We need devices which can convert many different types of parameters to information.
- These converters usually called „sensors”.

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What is a Sensor?

- A sensor detects some kind of input from the physical environment. The input could be any environmental phenomena (for example: light, heat, motion, moisture, pressure).
- Sensors convert these physical inputs into readable signals, which can then be measured, analyzed and used for controlling purposes.
- Most popular signal type: electric signal.
- Electric signals can easily and quickly be processed.

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Types of Sensors 1.

- Temperature Sensors: Detect heat energy to measure temperature. There are multiple types of temperature sensors: termistors, semiconductor-based sensors, infrared sensors.
- Pressure Sensors: Measure force applied by liquids or gases. This force usually converted to precession which change the electrical attributes (e.g., piezoelectric devices).
- Light Sensors: Detect light intensity (e.g., photodiodes).
- Proximity Sensors: Detect the distance of an object (e.g., capacitive or inductive sensors).

Types of Sensors 2.

- Motion Sensors: Detect movements. There are two main types: accelerometers and gyroscopes. Accelerometers can measure the acceleration on an axis – or multiple axis – but cannot detect the orientation of the sensor. Gyroscopes, however, hold the original position and measure the relative motion from this.
- Chemical Sensors: Detect chemical attributes in the environment (e.g., pH sensors, gas sensors).
- Radiation Sensors: Detect radioactivity (e.g., Geiger-Müller counters).

Information, signal

- In a mechatronic system, there are energy and information flows.
- Information: a complex term, it could be in different forms and types. Information is the meaningful content or message, usually data or knowledge.
- Signal: a physical or electronic transmission of data. Usually we consider electric signals as „signals”.
- Electric signals are variations in voltage or current. These variations carry the information.

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Taxonomy of signals 1.

- Based on determination:
  - Deterministic Signals: A deterministic signal is a signal that is precisely predictable or can be described by a mathematical function. It means, if no other signal is making distortion, the parameter of the signal can be predicted based on the initial state and the mathematical function.
  - Stochastic Signals: also known as random signals, are signals whose values cannot be precisely predicted. It means, the generation of these signals involve some randomness.

Taxonomy of signals 2.

- Based on periodicity:
  - Periodic signals: these are signals that repeat themselves at regular intervals over time.
    - Sine wave: it can be described mathematically by the function

      $x(t)=A*\sin(2\pi*f*t+\phi)$, where

      „A” is the amplitude

      „f” is the frequency, and

      „ϕ” is the phase.
    - Harmonic waveform: it is a composition of multiple sine waves. According to Fourier, any periodic signal can be composed as a summation of multiple sinusoidal waves with different frequencies and amplitudes.
  - Aperiodic Signals: these are signals that do not exhibit periodicity and cannot be represented by a single fundamental period.

Taxonomy of signals 3.

- Based on the physical attribute that carry information:
  - Electrical signals: changes in voltage or current (amplitude, frequency, phase).
  - Optical signals.
  - Radio waves.
  - Pressure.
  - Motion.

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Electric signals

- Electric signals change their attributes over the time.
- In the real life these changes are always continuous, however, we can make some distinctions:
  - Continuous signal: a signal with a continuous range of values, where its samples have an infinite number of different values.
  - Discrete signal: a signal with a finite number of values between maximum and minimum range.
- A signal can be discrete in terms of amplitude and time.
- Discrete signals:
  - By time: sampling.
  - By amplitude: quantization.

Processing of analog electric signals - amplification

- Purpose: To increase the amplitude of the signal. Amplitude: voltage or current.
- Amplification is used when the amplitude of the signal is too weak for processing.
- Operational amplifier devices includes active components (e.g. transistors or FETs) which are non-linear devices. It will cause some kind of distortion on the signal.

Processing of analog electric signals - attenuation

- Purpose: To decrease the amplitude of the signal. Amplitude: voltage or current.
- Attenuation is used when the amplitude of the signal is too strong for the processing circuits. Too strong signal level could prevent the correct measurements or even make damage to the circuits.
- Resistors could be used for attenuation but they can cause some unwanted effects (the resistance of subsequent circuits could change the attenuation in a non-linear way).

Processing of analog electric signals - filtering

- Purpose: To remove unwanted frequencies or noise from a signal or to extract a specific frequency range.
- Filter types:
  - Low-pass filters: Allow frequencies below a certain cutoff frequency to pass through.
  - High-pass filters: Allow frequencies above a certain cutoff frequency to pass through.
  - Band-pass filters: Allow a specific range of frequencies to pass through.
  - Band-stop (notch) filters: Block a specific range of frequencies.
- Devices: RC filters, LC filters or combinations.

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Processing of analog electric signals - modulation

- Purpose: To change the characteristics of a signal (such as amplitude, frequency, or phase) to encode information or to suit transmission requirements.
- Types:
  - Amplitude Modulation (AM): Change the amplitude of the carrier signal.
  - Frequency Modulation (FM): Change the frequency of the carrier signal.
  - Phase Modulation (PM): Varies the phase of the carrier signal.
  - Quadrature Amplitude Modulation: Change both the amplitude and the phase of the carrier signal.
- Modulation is widely used in many area (it enables to use the same media for multiple transmission in the same time).

Processing of analog electric signals - demodulation

- Purpose: To extract the original information from a modulated carrier signal.
- Demodulation is the reverse process of modulation.
- The operation is depending on the modulation process, different methods need to be used for different modulations.

Processing of analog electric signals - Integration

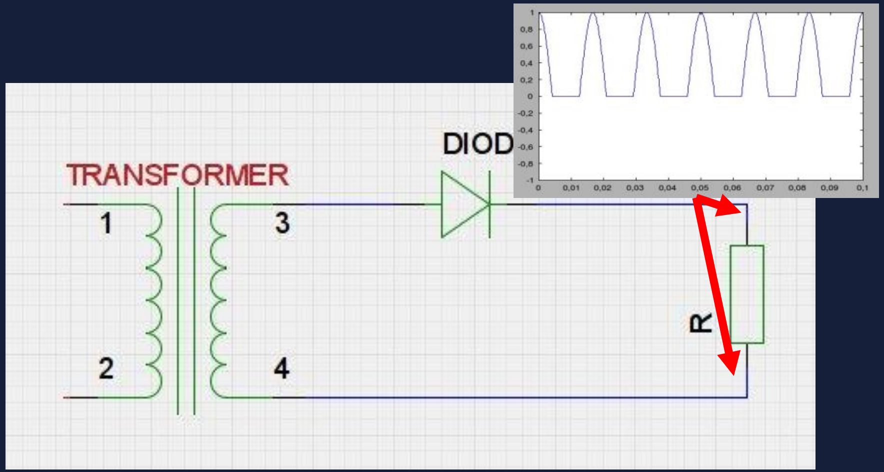
- Purpose: To compute the integral of a signal with respect to time, which can be used to find the effective value of a signal or to smooth a signal.
- Integration is used in analog computation, signal smoothing, and in creating signals that represent cumulative (effective) values. The most simple integration tag is a parallel capacitor and a serial resistor.

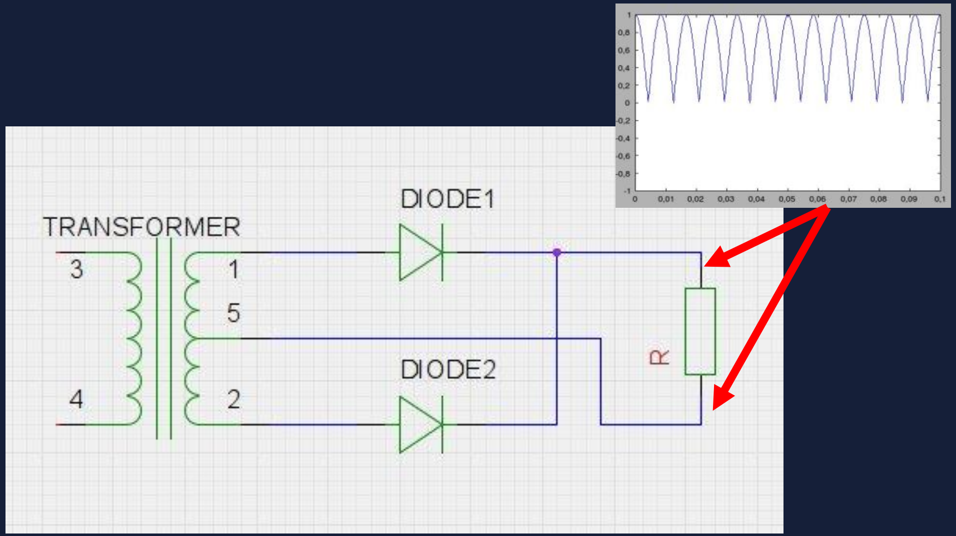
Processing of analog electric signals - differentiation

- Purpose: To compute the derivative of a signal with respect to time, detect changes in the signal.
- Differentiation is used in edge detection in signal processing. The most basic differentiation device is a serial capacitor and parallel resistor.

Processing of analog electric signals - rectifying

- Purpose: To convert an alternating current (AC) signal into a direct current (DC) signal.
- Types: half-wave rectifiers, full-wave rectifiers, Graetz bridge.





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Processing of analog electric signals - clipping

- Purpose: To limit the amplitude of a signal by "clipping" it when it exceeds a certain threshold.
- Used in signal processing to prevent overload in circuits. Limitation of amplitude will distort the signal.

Processing of analog electric signals - clamping

- Purpose: To shift the voltage level of a signal to a desired level without affecting its shape.
- Used in electronic circuits where change of signal value must be change without changing the relative amplitude or shape (e.g., transistor coupling in analog amplifiers).

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Sampling

- Sampling is a process where a continuous signal is converted into a discrete signal by taking measurements - called „samples” - of the signal at regular intervals.
- By using smaller intervals the discrete signal and the continuous signal will be more similar.
- Smaller intervals will increase the amount of information.
- The minimal frequency of sampling is depending on the maximal frequency of input signal.

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Quantization

- The process of mapping continuous (infinite number) of input values to output values with a finite number of elements.
- Larger finite number of elements will represent signal more accurately.
- All input values must be assigned to a nearest output value.
- These differencies will cause distortion on the signal representation.
- This distortion called: Quantization Noise.
- The main goal of quantization: to reduce the amount of information.

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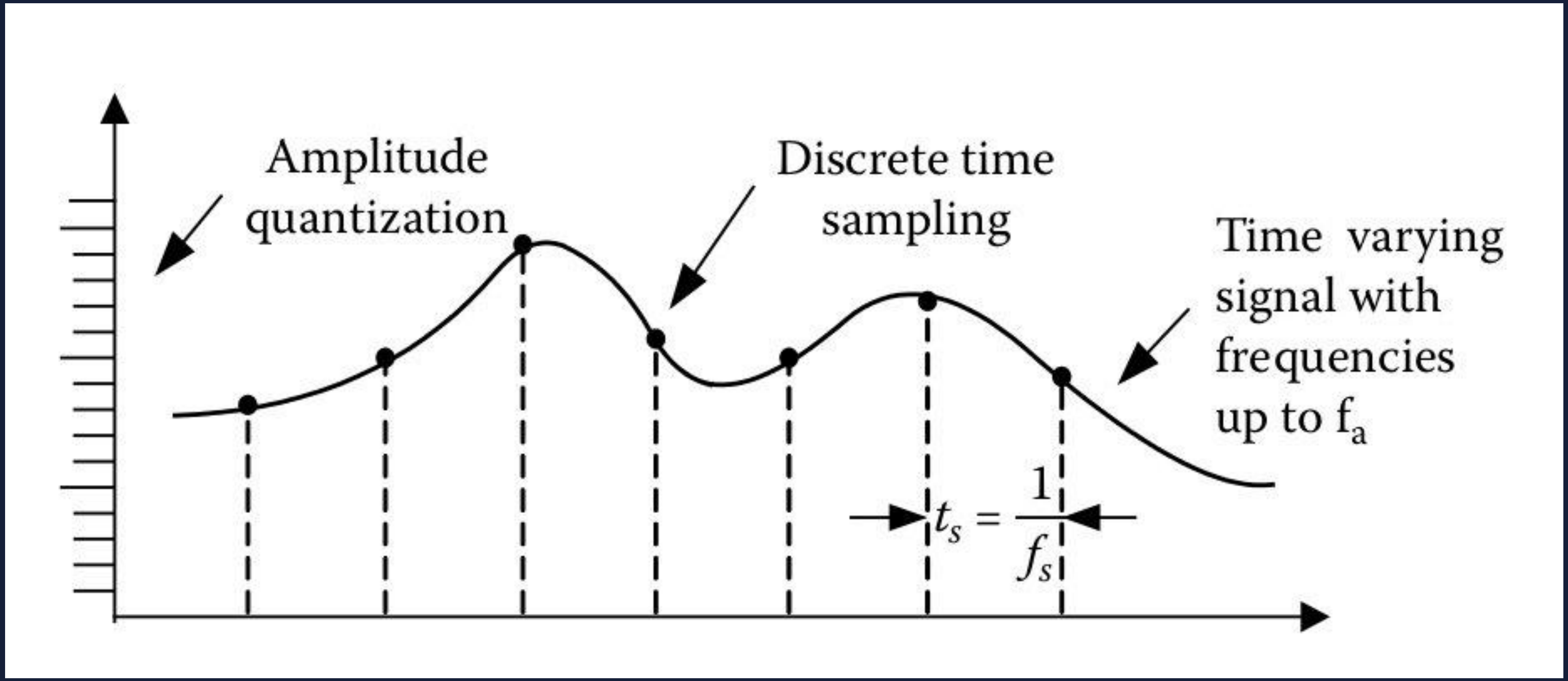
Noise

- In electronics, values must be processed.
- Every value must be represented by electrical attributes.
- An electric line (wire) could receive signals from external components or internally.
- These unwanted or random signals known as noise and could change attributes of signals (usually change the amplitude).
- There is a metric to quantify the relative level of the desired signal and the noise.
- Signal-toNoise Ratio (SNR).

Signal-to-Noise Ratio (SNR)

- SNR = Ps/Pn.
- Ps: power of the desired signal.
- Pn: power of the noise.
- Higher values mean less noise.
- More practical use: deciBell (dB). It is a logarithmic scale: SNR(dB) = 10 * log (Ps/pn)
- Ideally the noise is zero, therefore the SNR is infinite.
- In practice, the is always noise in the environment.

Analog-digital conversion



Shannon Sampling Theorem

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- Also known as the Nyquist-Shannon sampling theorem.
- Provides the criteria for sampling a continuous-time signal to convert it into a discrete-time signal without losing information.
- Shannon's Sampling theorem states that a digital waveform must be updated at least twice as fast as the bandwidth of the signal to be accurately generated.
- If a signal x(t) contains no frequencies higher than fmax, it can be fully reconstructed from its samples taken at intervals of 2*fmax.
- Nyquist Rate: $f_s \geq 2f_{max}$, where fs is the sampling frequency.

Aliasing effect

- When the sampling rate is lower than the Shannon-Nyquist frequency, information will be lost and false information will be created.
- Because of this effect, new – originally non-existent – frequency components appear.
- Stroboscopic effect is a known phenomenon of aliasing.