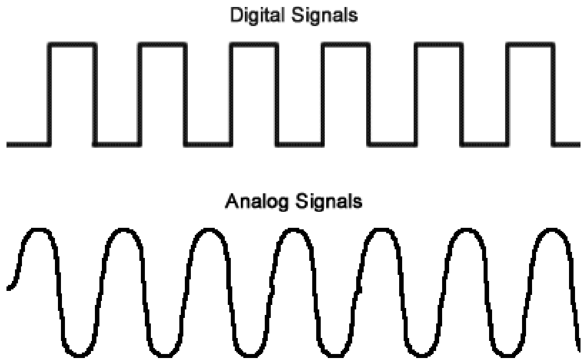
Computer Interfacing

Chapter-4: Signals & Sensors

Analog Signal

A signal that is continuous in time and can assume an infinite number of values in a given range (continuous in time and value).

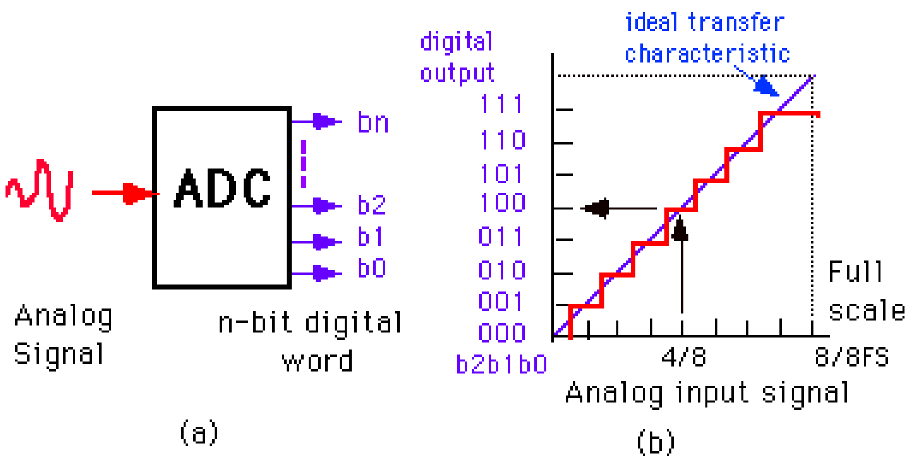


Digital Signal

A signal that is continuous in time and assumes only a limited number of values (maintains a constant level and then changes to another constant level).

Analog to Digital Converter (ADC)

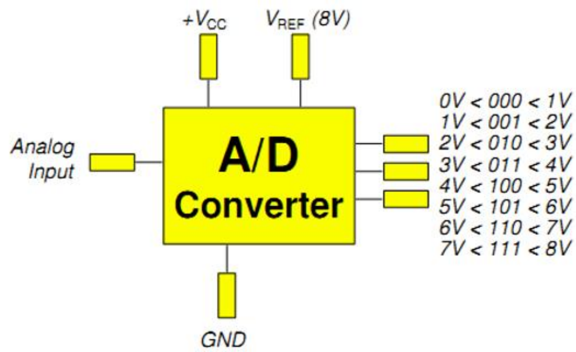
An ADC inputs an analog electrical signal such as voltage or current and outputs a binary number as digital output.



Resolution of ADC

The resolution of the converter indicates the number of discrete values it can produce over the range of analog values.

- A 3-bit ADC gives 8 possible output codes.
- More bits give better resolution and smaller steps.
- A lower reference voltage gives smaller steps but can be at the expense of noise.
- In the left, we can see an example. If input voltage is 5.5V and reference voltage is 8V then, output will be 101.



Least Significant Bit (LSB)

Resolution can also be defined electrically, and expressed in volts. The minimum change in voltage required to guarantee a change in the output code level is called the least significant bit (LSB) voltage.

Calculating LSB

For calculating LSB of an ADC, we need to know the Full Scale (FS) range and the resolution of the ADC.

Let,
Resolution = 8
FS Range = 10 (-5V to +5V)

So,
LSB = $10/2^8$ V = 0.03906 V = 39.06 mV

The Full Scale (FS) Range can also be given in the form of Reference Voltage (V_{ref}).

ADC Reading

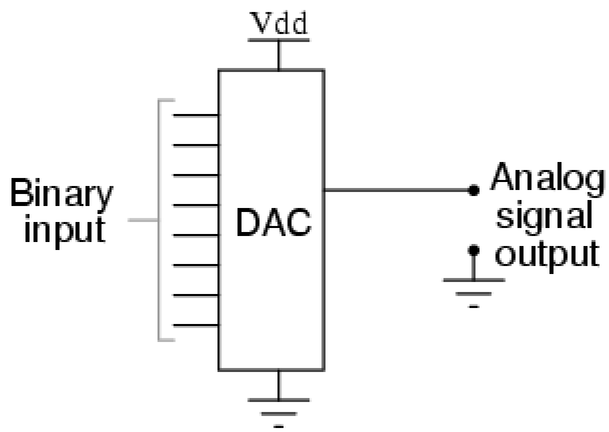
$$\frac{Resolution\ of\ ADC}{System\ Voltage} = \frac{ADC\ Reading}{Analog\ Voltage\ Measured}$$

$$\frac{1024}{5V} = \frac{x}{2.12V}$$

$$x = 434$$

Digital to Analog Converter (DAC)

A Digital to Analog Converter (DAC) is a device that converts a digital signal into an analog signal. A DAC is a type of integrated circuit that is used to convert a parallel binary input from the processor to an analog output current or voltage in proportion to the binary input value.



DAC Calculation

Formula:

$$V_{out} = V_{ref} \times \sum_{i=1}^{n} \frac{b_{n-i}}{2^i}$$

Example:

Given the binary input 1101 0000 and V_{ref} = 5V

$$V_{out} = 5V \times \left(\frac{1}{2} + \frac{1}{4} + \frac{1}{16}\right) = 4.0625\ V$$

Resolution of DAC

The smallest analog output change that can occur as a result of changing the LSB of the digital input. This is also equal to the step size.

Settling time

Amount of time required for a new DAC output to settle to 99.95% of its expected new value after receiving a new digital input, typically 50ns~20µs.

Accuracy / Linearity

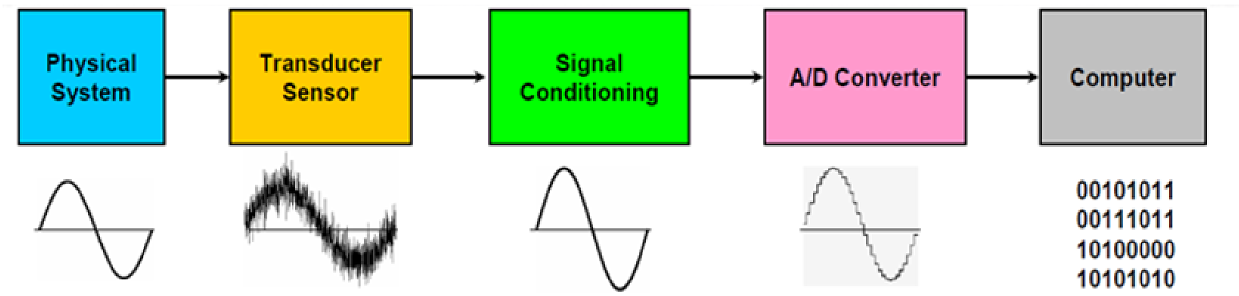
The actual DAC output compared to the expected output expressed as a percentage of maximum rated output.

Data Acquisition System (DAQ/DAS)

Data Acquisition is the sampling of the real world to generate data that can be manipulated be a computer.

Data acquisition systems, abbreviated by the acronyms DAS or DAQ, typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

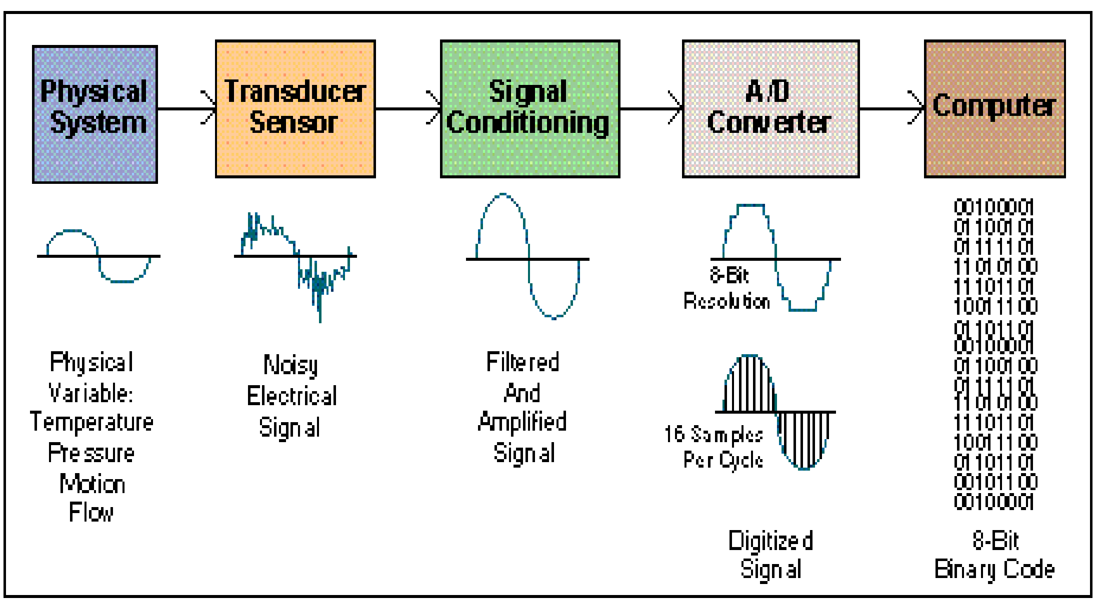
- Sensors, to convert physical parameters to electrical signals.
- Signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, to convert conditioned sensor signals to digital values.



Components of DAS

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog to digital converters, which convert conditioned sensor to digital values.

DAS Block Diagram



Physical System

Physical condition that can be used as input of DAS or which can be represented in digital form are:

- Temperature
- Pressure
- Light
- Force
- Displacement
- Level
- Electric Signals
- On/OFF switch

Objective

- DAS must acquire the necessary data, at correct speed and at correct time.
- It must monitor the complete plant operation to maintain on line and safe operations.
- It must be able to collect, summarize and store data for diagnosis of operation and record purpose.
- It must be flexible and capable of being expanded for future requirements.
- It must be able to compute unit performance indices using on-line, real time data.
- It must be reliable, easy to operate and must be user friendly.

Transducers

A transducer converts the physical conditions in electrical waveform for easy signal processing. It converts temperature, pressure level, length, position etc. into voltage, current, frequency, pulses or other signals.

Signal Conditioning

Signal conditioning circuits improve the quality of signals generated by transducers before they are converted into digital signals by the PC’s data acquisition hardware.

Most common signal conditioning functions are amplification, linearization, cold-junction compensation, filtering, attenuation, excitation, common-mode rejection and so on.

Methodology/Process of Data Acquisition System

- DAS begins with the physical property to be measured. Examples of this include temperature, light intensity, gas pressure, fluid flow, force etc.
- A sensor, which is a type of transducer converts a physical property into a corresponding electrical signal
- Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used.
- After signal conditioning the analog wave output is converted into digital form using A/D converter.
- Once digitized, the signal can be encoded to reduce and correct transmission errors.

Sensor and Transducer

A sensor is a device which detects one form of energy and converts the data to electrical energy. For example, microphone.

A transducer is a device which converts one form of energy into another. So sensors are, in fact, a type of transducer. However, transducers also consist of devices that convert energy into other forms, such as actuators. An actuator is something that can convert a different form of energy into motion.

Examples of Sensors and Transducers

Medium	**Input Device (Sensor)**	**Output Device (Actuator)**
Light Device	Light Dependent Resistor (LDR), Photodiode, Photo-Transistor, Solar Cell	Lights & Lamps, LED, Displays, Fiber Optics
Temperature	Thermocouple, Thermistor, Thermostat, Resistive Temperature Detectors	Heater, Fan
Force/Pressure	Strain Gauge, Pressure Switch, Load Cells	Lifts, Vibrators
Position	Potentiometer, Encoders, Reflective/ Slotted Opto-Switch (LVDT)	Motor, Solenoid, Panel Meters
Speed	Techo-generator, Reflective/ Slotted Opto-coupler, Doppler Effect Sensors	AC and DC motors, Stepper Motor Brake
Sound	Carbon Microphone, Piezo-electric Crystal	Bell, Buzzer, Loudspeaker

Types of Transducer

- Active Transducer

  Active transducers are those which do not require any power source for their operation. They work on the energy conversion principle. They produce an electrical signal proportional to the input (physical quantity). For example, a thermocouple is an active transducer.

- Passive Transducers

  Transducers which require an external power source for their operation is called as a passive transducer. They produce an output signal in the form of some variation in resistance, capacitance or any other electrical parameter, which then has to be converted to an equivalent current or voltage signal. For example, a photo-cell (LDR) is a passive transducer which will vary the resistance of the cell when light falls on it.

Characteristics of Transducers

1. Range

   Minimum and maximum values of input or output variables. For example, input range 100-250^{o}C or output range 0.5A to 2A

2. Span

   Maximum variation of input or output. For example, 200-220V input.
3. Linearity-Nonlinearity

   Input values or output values lie on a straight line or not.
4. Accuracy

   The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measured.
5. Response Time

   Time to be taken by a sensor to approach its true output.
6. Stability

   Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time. The term “drift” is used to indicate the change in output that occurs over a period of time.
7. Dead band/time

   The dead band or dead space of a transducer is the range of input values for which there is no output.
8. Repeatability

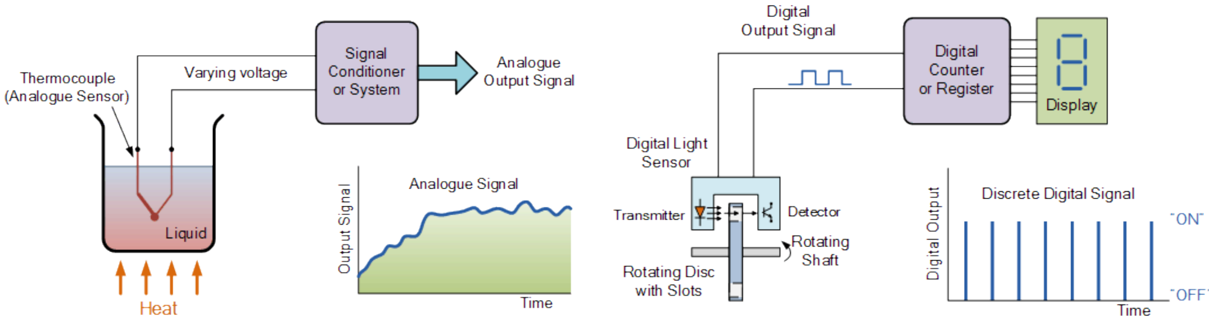
   It specifies the ability of a sensor to give same output for repeated applications of same input value.

   Repeatability = (maximum – minimum values given) X 100 / full range.
9. Sensitivity

   Sensitivity implies change in electrical quantity per unit change in physical quantity. For example, a general purpose thermocouple may have a sensitivity of 41 µV/^{o}C.

Analogue Sensors

Analogue Sensors produce a continuous output signal or voltage which is generally proportional to the quantity being measured. For example, the temperature of a liquid can be measured using a thermometer or thermocouple which continuously responds to temperature changes as the liquid is heated up or cooled down.

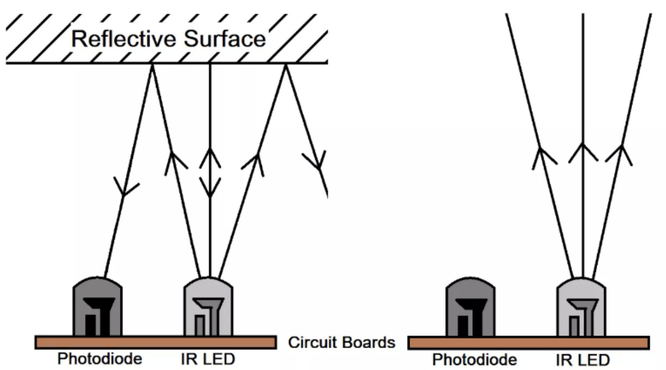


Digital Sensors

Digital Sensors produce a discrete digital output signals or voltages that are a digital representation of the quantity being measured. Digital sensors produce a Binary output signal in the form of a logic "1" or a logic "0", ("ON" or "OFF").

IR Sensor

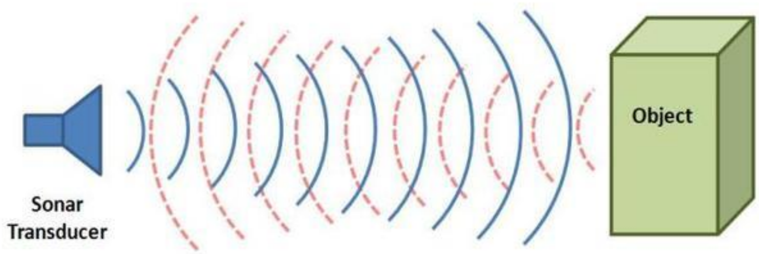
- An Infrared (IR) sensor is used to detect obstacles in front or to differentiate between colors depending on the configuration of the sensor.
- The sensor emits IR light and gives a signal when it detects the reflected light.
- The circuit required to make an IR sensor consists of two parts; the emitter circuit and the receiver circuit.



- The emitter is simply an IR LED (Light Emitting Diode) and the detector is simply an IR photodiode which is sensitive to IR light of the same wavelength as that emitted by the IR LED.
- When IR light falls on the photodiode, its resistance and correspondingly, its output voltage, change in proportion to the magnitude of the IR light received. This is the working principle of an IR sensor.

Sonar Sensor

- An Ultrasonic sensor is a device that can measure the distance to an object by using sound waves. It measures distance by sending out a sound wave at a specific frequency and listening for that sound wave to bounce back. By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object.



Basic sonar illustration – a transducer generates a sound pulse and then listens for the echo.

- Since it is known that sound travels through air at about 344 m/s (1129 ft/s), you can take the time for the sound wave to return and multiply it by 344 meters (or 1129 feet) to find the total round-trip distance of the sound wave.
- Round-trip means that the sound wave traveled 2 times the distance to the object before it was detected by the sensor; it includes the 'trip' from the sonar sensor to the object AND the 'trip' from the object to the Ultrasonic sensor (after the sound wave bounced off the object).

$$distance = \frac{speed\ of\ sound\ \times time\ taken}{2}$$

- To find the distance to the object, simply divide the round-trip distance in half.

Resistance Temperature Detector (RTD)

- A Resistance Thermometer or Resistance Temperature Detector is a device which used to determine the temperature by measuring the resistance of pure electrical wire. This wire is referred to as a temperature sensor.
- The variation of resistance of a wire with temperature can be represented by following equation:

$$R_t = R_0[1 + \alpha(T_t - T_0)]$$

Where,
R_0 = Resistance at temperature T_0
R_t = Resistance at temperature T_t
α = Temperature coefficient of the material

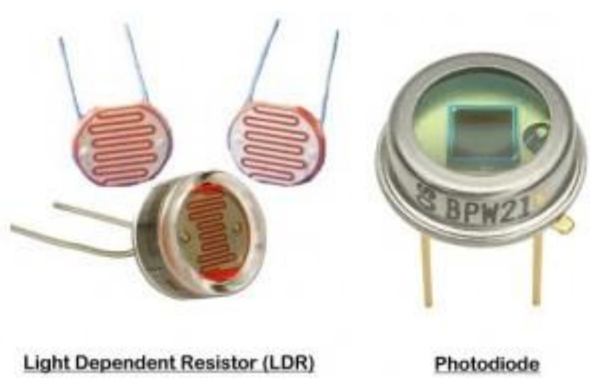
Temperature Sensor (LM-35)

- The LM35 is an integrated sensor circuit that can be used to measure temperature with an electrical output proportional to the temperature (in ^{o}C)
- **Usage of ML-35:**
  - Measures temperature more accurately than a using a thermistor.
  - The sensor circuitry is sealed and not subject to oxidation.
  - The LM35 generates a higher output voltage than thermocouples and may not require that the output voltage be amplified.

- **LM-35 Features**
  - It has an output voltage that is proportional to the Celsius temperature.
  - The scale factor is .01V/^{o}C
  - The LM-35 does not require any external calibration or trimming and maintains an accuracy of ±0.4^{o}C at room temperature and ±0.8^{o}C over a range of 0^{o}C to 100^{o}C.
  - Another important characteristic of the LM-35 is that it draws only 60 micro amps from its supply and possesses a low self-heating capability. The sensor self-heating causes less than 0.1^{o}C temperature rise in still air.

Light Sensor

The light sensor measures how much light is shining on it. It has two modes: “light” and “dark.”



In “light” mode, the more light shines on the sensor, the higher the signal it sends out. In “dark” mode, it's just the opposite, that is, the signal increases the darker it gets.