MEE303 Sensor Systems

W01
Sensor system componets

Sensor Systems

System Components

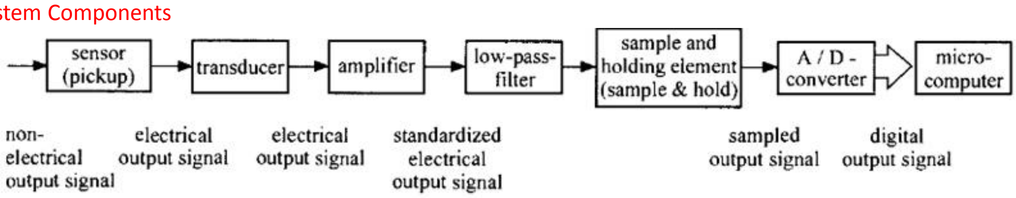


Figure 2. Measuring system components

Transducers and amplifiers transform the electric sensor output signal into a standardized electrical signal, e.g., 0...20 mA or 4...20 mA or 0...10 V, which is more suitable for further processing. **The type of signal** supplied by the sensor depends on both the measuring principle and on the associated signal transmission and signal processing devices. Signal types may be subdivided into the following categories:

- amplitude-modulated signals;
- frequency-modulated signals;
- digital signals.

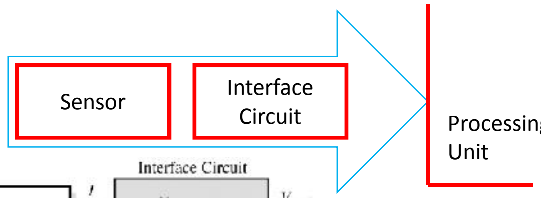
If high-frequency disturbances contaminate the usable signal**, a low-pass filter** is applied in order to decrease the influence.
A **sample and hold device and an analog-to-digital converter** are necessary if the sensor signal is to be processed by a microcomputer.

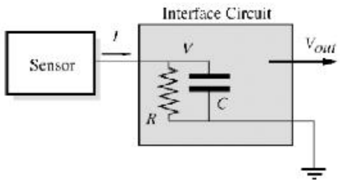
Sensor Systems

Sensor Output Characteristics

signal type / properties	amplitude-modulated	frequency-modulated	digital
static accuracy	large	large	limited by word length
dynamic behavior	very fast	limited through transducer	limited through sampling
noise sensitivity	medium/large	small	small
galvanic separation	costly	simple (transducer)	simple (optical coupling)
interfacing to a digital computer	analog-digital converter	simple (frequency counter)	simple
computational operation	very limited	limited	simple, if microcomputer

It is rarely possible to connect a sensor directly to processing, monitoring ,or recording instruments, unless a sensor has a built-in electronic circuit with an appropriate output format.





a sensor usually has to be conditioned before it is fed into a processing device

An interface or a signal conditioning circuit has a specific purpose: to bring the signal from the sensor up to the format which is compatible with the processing device

The input impedance shows by how much the circuit loads the sensor.

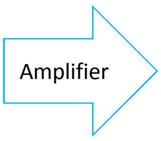
The voltage e_0 is called the input offset voltage

The *input bias current i_0* is also internally generated by the circuit

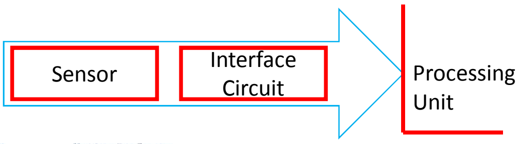
Interface Circuits

Amplifiers

Passive sensors output signals. microvolts (µV) or picoamperes (pA)



data processor inputs accepts volts (V) and milliamperes (mA).



Amplification: voltage gain up to 10,000 and a current gain up to 1,000,000. Amplification is part of signal conditioning with additional capabiliites:

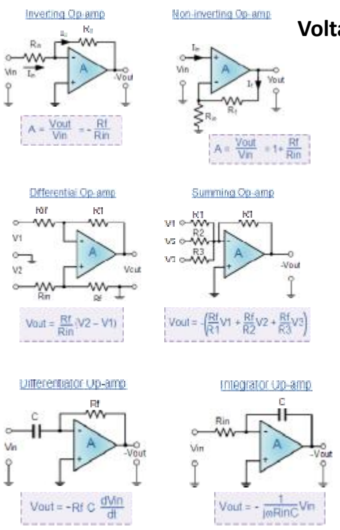
- an impedance matching device
- an enhancer of a signal-to-noise ratio,
- a filter,
- an isolator

Structure

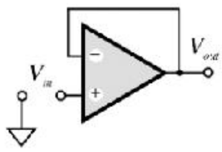
Principal building blocks OPAMP IC

Passive Components

ASICs: application-specific integrated circuits



Voltage Follower



A follower, when connected to a sensor, has very little effect on the latter's performance, thus providing a buffering function between the sensor and the load.

IKCU\Mechatronics Engineering\MEE303 Sensor Systems Dr.Levent ÇETİN

Interface Circuits

Instrumentation Amplifiers

The main function of the IA is to produce an output signal which is proportional to the difference in voltages between its two inputs It is distinguished from an operational amplifier

- by its finite gain (which is usually no more than 100) and
- the availability of both inputs for connecting to the signal sources.

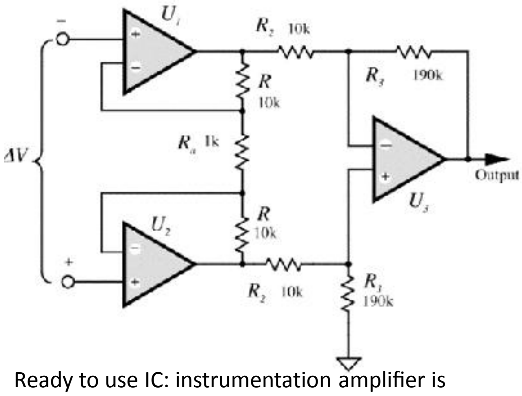
The gain is programmed by a set of resistor.

$$A = \left(1 + \frac{2R}{R_a}\right)\frac{R_3}{R_2}$$

It is important to assure high input resistances for both inputs, so that the amplifier can be used in a true differential form

A differential input of the amplifier is very important for rejection of common-mode interferences having an additive nature.

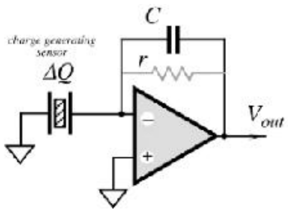
A good and cost-effective instrumentation amplifier can be built of two identical operational amplifiers and several precision resistors



Ready to use IC: instrumentation amplifier is INA118 from Burr-Brown/Texas Instruments

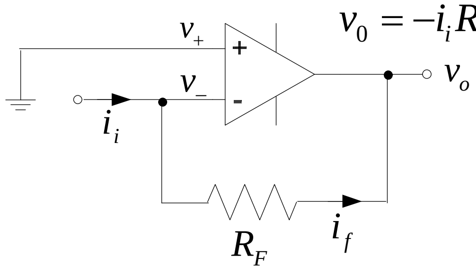
Interface Circuits

Charge to Voltage Amplifiers



Current to Voltage Amplifiers

$$v_0 = -i_i R_F$$



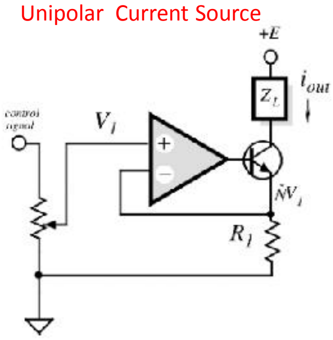
voltage signals from the capacitive sensors, quantum detectors, pyroelectric sensors, and other devices which generate very small charges (on the order of picocoulombs, pC) or currents (on the order of picoamperes)

Interface Circuits

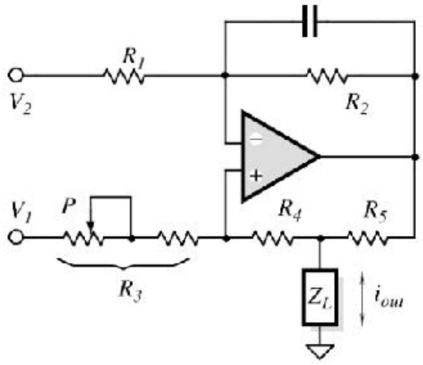
Excitation Circuits

External power is required for the operation of active sensors

Unipolar Current Source



Bipolar Current Source



The pump operation is based on utilizing both negative and positive feedbacks around the operational amplifier. The load is connected to the positive loop. Current through the load is defined by

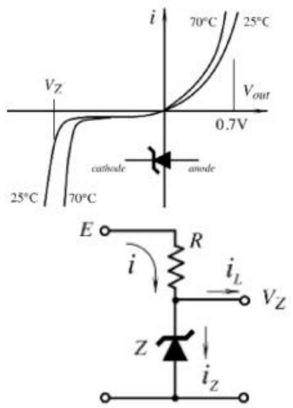
$$i_{out} = \frac{R_2}{R_1}\frac{(V_1 - V_2)}{R_5} \qquad R_3 = R_1\frac{R_4 + R_5}{R_2}$$

Interface Circuits

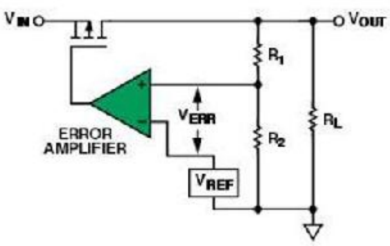
Excitation Circuits

A voltage reference is an electronic device which generates constant voltage that is little affected by variations in power supply, temperature, load, aging, and otherfactors.

Shunting Reference (Zener Diode)



Opamp based voltage source



In the linear regulator design, an error amplifier (op amp) compares its output voltage to a fixed voltage, usually provided by a specialized reference diode, shown on the left. The closed-loop nature of the design forces the amplifier to maintain the output at the reference voltage, regardless of load

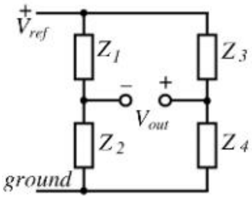
Interface Circuits

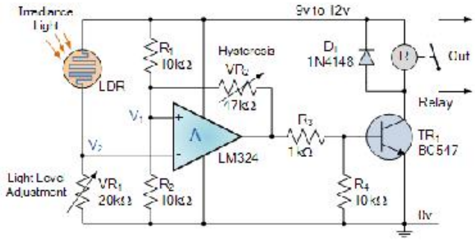
Ratiometric Circuits

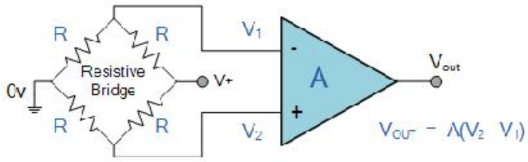
The Wheatstone bridge consists of two parallel impedance branches with each branch containing two series impedance elements

The bridge output voltage is represented by

$$V_{out} = V_{ref}\left(\frac{Z_2}{Z_1+Z_2}-\frac{Z_4}{Z_3+Z_4}\right)$$





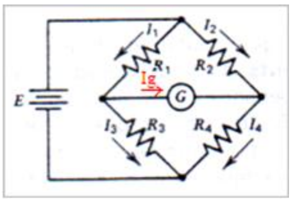


The standard Differential Amplifier circuit now becomes a differential voltage comparator by "Comparing" one input voltage to the other.
For example, by connecting one input to a fixed voltage reference set up on one leg of the resistive bridge network and the other to either a "Thermistor" or a "Light Dependant Resistor" the amplifier circuit can be used to detect either low or high levels of temperature or light

Interface Circuits

Ratiometric Circuits

Calculate the current through the galvanometer in the circuit. Given that Vref=6V, R1= 1kΩ, R2= 1.6kΩ, R3 = 3.5kΩ, R4= 7.5kΩ and Rg=200Ω



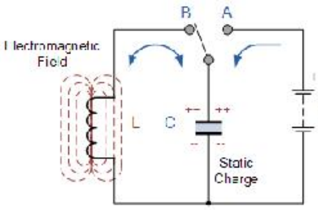
$$V_g = V_{ref}\left(\frac{R_3}{R_3+R_1}-\frac{R_4}{R_4+R_2}\right)$$
$$=6V\left(\frac{3.5K\Omega}{3.5K\Omega+1K\Omega}-\frac{7.5K\Omega}{7.5K\Omega+1.6K\Omega}\right)$$
$$=6V(0.778-0.824)=0.276V$$

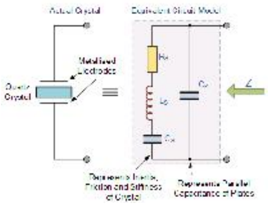
Interface Circuits

Freuency Based Circuits

Oscilators (for frequency modulation)

The term oscillator is used to describe a circuit which will produce a continuing, repeated waveform without input other than perhaps a trigger.





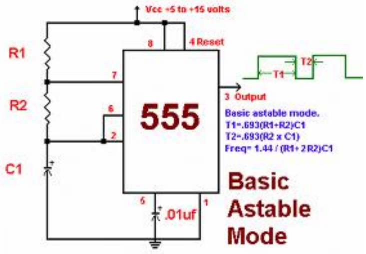
An Oscillator is basically an Amplifier with “Positive Feedback”, or regenerative feedback (in-phase) and one of the many problems in electronic circuit design is stopping amplifiers from oscillating while trying to get oscillators to oscillate

555-Timers, like op-amps can be configured in different ways to create different circuits.

The capacitor voltage cycles back and forth between (2/3)Vcc and (1/3)Vcc at times:

$$^{2}{}_{1} = 0.693(R1 + R2)C1$$

$$^{2}{}_{2} = 0.693(R2)C1$$

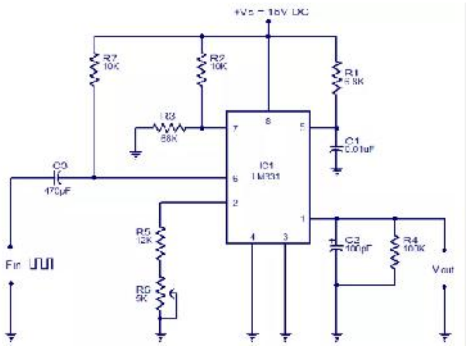


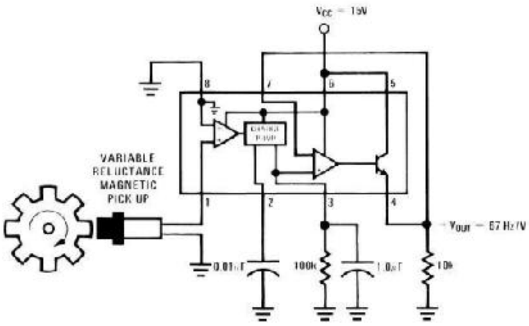
Interface Circuits

Freuency Based Circuits

Frequency to voltage converters

Frequency to voltage converter is an electronic device which converts the input frequency into a proportional current or output voltage.
The basic circuit includes operational amplifiers and RC circuits (Resistor Capacitor networks).
The circuits are mostly in the form of ICs

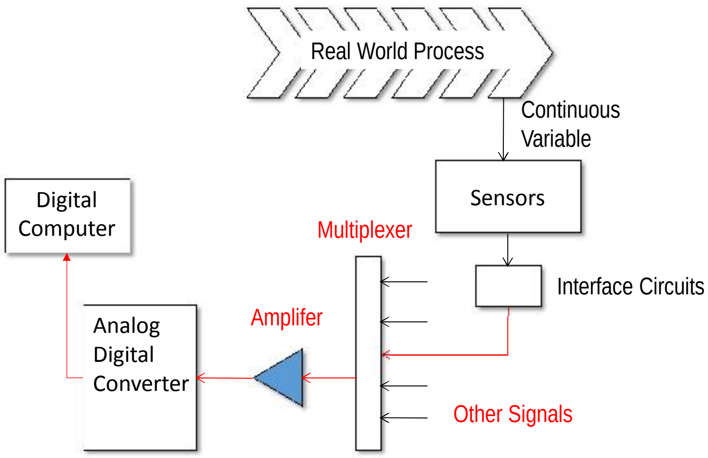


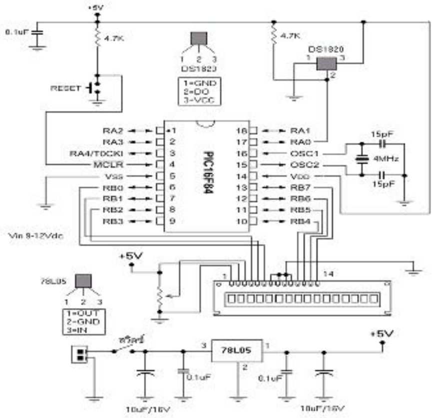


Interface Circuits

Data Aqcuisition

Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software.



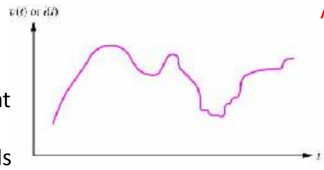


Interface Circuits

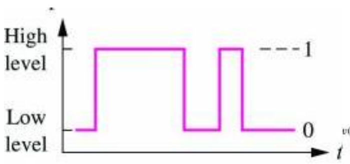
Analog to Digital Conversion

Analog vs. Digital Signals

Analog signals take on continuous amplitude values.Analog Signals represent the physical world. e.g. Electrocardiogram (ECG) signals are analog signals



Digital signals take on discrete amplitude levels. Typically, we use binary signals which utilize only two levels. One level is referred to as logical 1, the other level is referred to as logical 0.



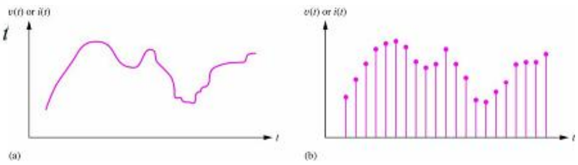
Modern computers and data communications systems process digital signals

Analog-to-Digital Conversion

ADC (Analog to Digital Converter) is an electronic device that converts a continuous analog input signal to discrete digital numbers (binary)

Analog signals are converted to digital signals through a process we call sampling – the amplitude of the analog signal is measured at specific instants in time (i.e. at a particular sampling rate) and stored.

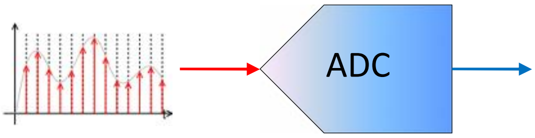
After digitization, the continuous analog signal becomes a set of amplitude values separated by fixed time intervals (we call this a discrete time analog signal).



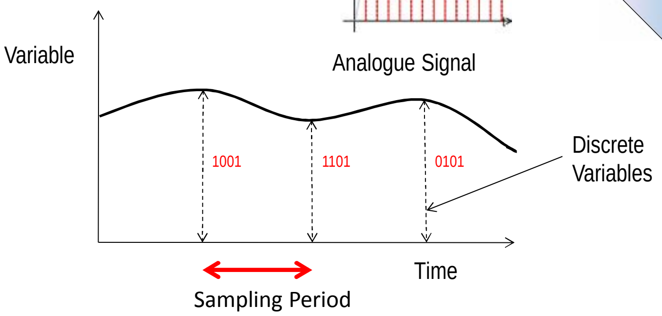
These discrete amplitude values are then converted to the closest digital (binary) representation

Interface Circuits

Analog to Digital Conversion

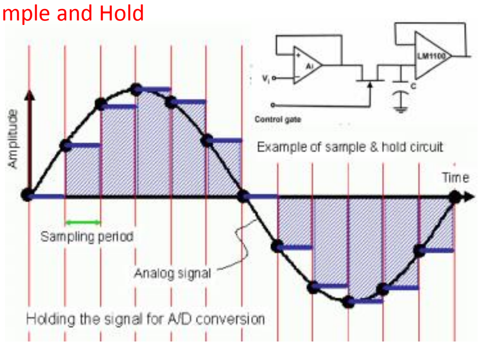


101 110 100 011 100 110 111…



Sampling converts the continuous signal into a series of discrete analog signals
at periodic intervals
Quantization – each discrete analog is converted into one of a finite number of (previously defined) discrete amplitude levels
Encoding – discrete amplitude levels are converted into digital code

Sample and Hold



Sampling rate – rate at which continuous analog signal is polled e.g. 1000 samples/sec

Sampled Signal T_w

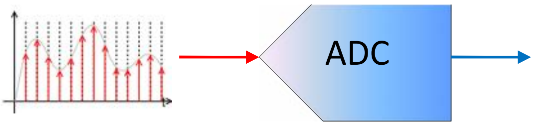
Sampling Period $T_s = \frac{1}{f_s}$

Nyquist Criterion

$$f_s > 2 * f_w$$

Interface Circuits

Analog to Digital Conversion

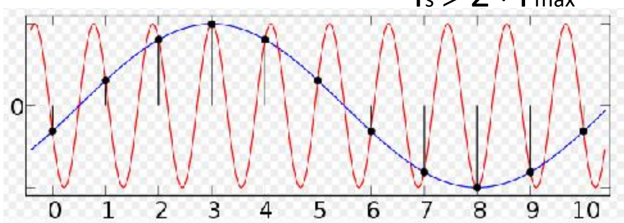


101 110 100 011 100 110 111…

Sample and Hold

Aliasing

Usually exists when Nyquist Criterion is violated, Results in improper conversion of the input signal $f_s > 2 * f_{max}$



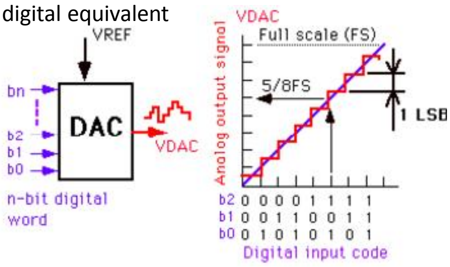
High and low frequency samples are indistinguishable
Prevented through the use of Low-Pass (Anti-aliasing) Filters

Conversion time – how long it takes to convert the sampled signal to digital code

Quantizing and Encoding

<u>Quantization – divide analog signal into discrete levels</u>
Approximates a continuous range of values and replaces it with a binary number.
Error is introduced between input voltage and output binary representation
Error depends on the resolution of the ADC
<u>Resolution – depends on number of quantization levels</u>

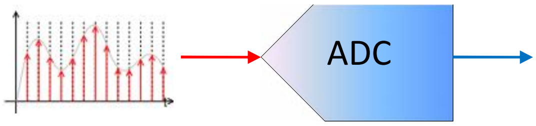
Conversion method – means by which analog signal is encoded into digital equivalent



Interface Circuits

Analog to Digital Conversion

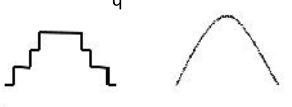
Quantizing and Encoding



101 110 100 011 100 110 111…

Quantisation levels is defined as follows, where Nq =quantisation levels; and n is the number of bits.

$$N_q = 2^n$$



3 Bit Representation of Waveform   16 Bit representation of Waveform

Resolution is defined as, where R_{ADC} is the resolution of the ADC; L is the full-scale range of the ADC

$$R_{ADC} = \frac{L}{N_q - 1} = \frac{L}{2^n - 1}$$

Devices with higher resolution (14-bit, 16-bit, etc) give us data that better approximates the original signal

Quantisation generates an error, because the digitised signal is only sampled from the original analogue signal. The maximum possible error occurs when the true value of the analogue signal is on the borderline between two adjacent quantisation levels

$$\text{Quanerr} = \pm\frac{1}{2}R_{ADC}$$

Using an analogue-to-digital converter, a continuous voltage signal is to be converted into its digital counterpart. The maximum voltage range is ±25 V. The ADC has a 16-bit capacity, and full scale range of 60 V. Determine (1) number of quantization levels, (2) resolution, (3) the spacing of each quantisation level, and the quantisation error for this ADC.

$$N_q = 2^n$$ (1) Number of quantization levels= 2^{16} = 65536

$$R_{ADC} = \frac{L}{N_q - 1} = \frac{L}{2^n - 1}$$

2) Resolution:

R_{ADC} = 60 / (65,536 -1)= 0.0009155 volts

$$\text{Quanerr} = \pm\frac{1}{2}R_{ADC}$$

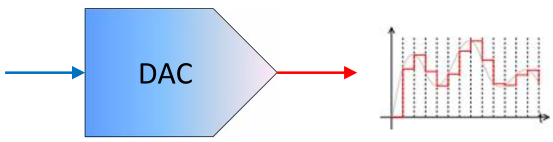
(3) Quantisation error:

= +/- (0.0009155)/2 = +/-0.00045778 volts

Interface Circuits

Digital to Analog Conversion

101 110 100 011 100 110 111…



Convert digital values into continuous analogue signal

- Decoding digital value to an analogue value at discrete moments in time based on value within register

$$V_0 = V_{ref}\left\{0.5B_1 + 0.25B_2 + \cdots + \left(2^n\right)^{-1}B_n\right\}$$

Where V_0 is output voltage; V_{ref} is reference voltage; B_n is status of successive bits in the binary register

Data Holding that changes series of discrete analogue signals into one continuous signal

A DAC has a reference voltage of 100 V and has 6-bit precision. Three successive sampling instances 0.5 sec apart have the following data in the data register:

Output Values:	Instant	Binary Data
	1	101000
	2	101010
	3	101101

E_{01} = 100{0.5(1)+0.25(0)+0.125(1)+0.0625(0)+0.03125(0)+0.015625(0)}
E_{01} = 62.50V
E_{02} = 100{0.5(1)+0.25(0)+0.125(1)+0.0625(0)+0.03125(0)+0.015625(0)}
E_{02} = 65.63V
E_{03} = 100{0.5(1)+0.25(0)+0.125(1)+0.0625(0)+0.03125(0)+0.015625(0)}
E_{03} = 70.31V