Interfacing instruments and computers:-

→ In order to control the machines in our electronic industries, medical instruments or automobiles with microprocessor, we have to determine the values of variables such as pressure, temperature and flow.

- There are many ways to get electrical signals to digital forms the microcomputer can work with.

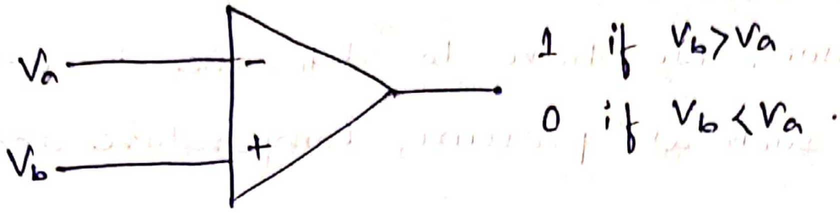
→ Talking about analog device, the first step of design involves sensor, which converts physical variables like pressure, temperature, humidity etc. to a proportional voltage or current.

→ The electrical signals from the sensors are quite small, so they must next be amplified and filtered. This is generally done with the help of op-amp circuit.

→ The final step that we can use it to convert to the digital form which can be done by an analog to digital (A/D) converter.

So, we will discuss the basic operations, interfacing with the microprocessor of both A/D converters and D/A converters.

→ The most elementary form of communication b/w analog and digital device is <u>comparator</u>.



One of the voltages on the comparator i/ps, V_a or V_b will be the variable i/p, and the other a fixed value called a trip, trigger or ~~volt~~ reference voltage.

And, one another comparator is hysteresis comparator using OPAMP (~~discuss~~ already discussed in classes before lockdown).

<u>Digital to Analog Converter (DAC)</u>

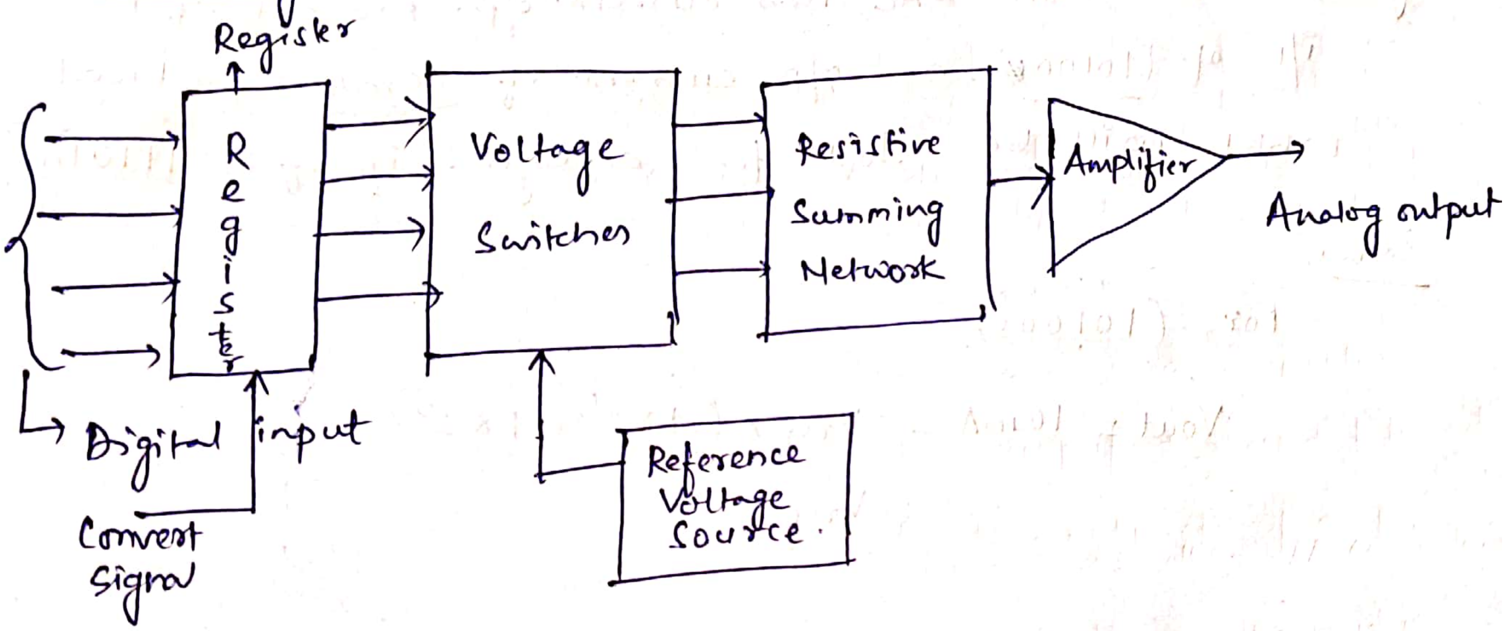
<u>Objective</u>:-

→ The digital-to-analog converter known as the D/A converter is a major interface circuit ~~the~~ that forms the bridge between the analog and digital worlds. DACs are the core of many circuits and instruments including digital voltmeters, plotters, oscilloscope displays, and many computer-controlled devices.

What is a DAC?

- A DAC is an electronic component that converts digital logic levels into an analog voltage.
- When DAC is used in connection with a computer, this binary no. or digital i/p is called a binary word or computer word. The digits are called bits of the word.

Block diagram:-



→ In general,

$$V_{out} = V_{ref} \times \text{decimal equivalent of digital i/p.}$$

$$= V_{ref} \times [\, b_1 2^{-1} + b_2 2^{-2} + \dots + b_n 2^{-n} \,]$$

V_{ref} = reference voltage.

$b_1, b_2, \dots b_n$ = n-bit binary word.

* V_{ref} is a constant value for a given DAC.

Eg:- (1) $V_{ref} = 1V$, compute V_{out} for digital i/p = $(1100)_2$

$$1100 = 1\times 2^3 + 1\times 2^2 + 0\times 2^1 + 0\times 2^0$$
$$= 8 + 4 + 0 + 0$$
$$= (12)_{10}$$

$\therefore$ $V_{out} = 1 \times 12$
$= 12V$

eg: (2) A 5-bit DAC has a current o/p. For a digital i/p of $(10100)_2$, an o/p current of 10mA is produced. What will be I_{out} for a digital i/p of $(11101)_2$?

Soln:- For $(10100)_2$

$$I_{out_1} = I_{ref} \times (1 \times 2^4 + 1 \times 2^2) = 10\,mA \text{ (given)}$$

$$= I_{ref} \times 20$$

$$I_{ref} = \frac{10}{20} mA = 0.5\,mA$$

Now,

$$I_{out_2} = I_{ref} \times (1 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 1 \times 2^0)$$

$$= 0.5\,mA \times (29)_{10}$$

$$\boxed{I_{out_2} = 14.5\,mA}$$

eg:- (3) What is the largest value of o/p voltage from an 8-bit DAC that produces 1 V for a digital i/p of $(00110010)_2$?

Soln. :-

$$(00110010)_2 = 1 \times 2^5 + 1 \times 2^4 + 1 \times 2^1 = (50)_{10}$$

A/c to question :- $1\,V = V_{ref} \times 50$

$$\therefore V_{ref} = \frac{1}{50} = 20\,mV$$

And, largest o/p will occur for largest i/p i.e $(11111111)_2$ for 8-bit.

$$(V_{out})_{max} = 20\,mV \times (255)_{10}$$

$$V_{out} = 5.10\,V$$

Resolution :-

→ Resolution of D/A converter is defined as the smallest change that can occur in the analog o/p as a result of the change in the digital i/p.

- The resolution is always ~~the~~ equal to the weight of the LSB and is also referred as step size.

→ Input weights :-

D (MSB)	C	B	A (LSB)	Vout (V)
0	0	0	1	1
0	0	1	0	2
0	1	0	0	4
1	0	0	0	8

1 → A has weight of 1V
2 → B " " " 2V
4 → C " " " 4V
8 → D " " " 8V.

Ily, if 5-bit D/A converter produces Vout = 0.2 for digital i/p of 00001.

then, (0.2) V is the weight of LSB here.

And weights of other bits will be 0.4, 0.8, ~~0~~1.6 & 3.2 respectively.

And, Vout for $(11111)_2$ = 3.2 + 1.6 + 0.8 + 0.4 + 0.2
= 6.2 V

⇒ Here, resolution (step size) is same as proportionality factor or reference voltage or current

% resolution :-

$$\% \text{ resolution} = \frac{\text{Step size}}{\text{full scale vo(f.s)}} \times 100\%$$

eg:- for 4-bit i/p ; full-scale is $(1111)_2$ = 15 V

and ~~Step~~ if step-size is 1 V

then, $\% \text{ resolution} = \frac{1V}{15V} \times 100\% = 6.67\%$

eg:- A 10-bit DAC has a step size of 10mV. Determine the full-scale output voltage and % resolution.

Soln:-

For 10-bit full scale i/p voltage = $2^{10} - 1 = 1023$

ie 1023 steps of 10mV each.

$\therefore$ Full-scale o/p voltage = $1023 \times 10mV$

$= 1023 \times 0.01$

$= 10.23 V.$

$\% \text{ resolution} = \frac{10mV}{10.23V} \times 100\%$

$= 0.09 \simeq 0.1\%$ ✓

☆ % resolution can also be calculated as:-

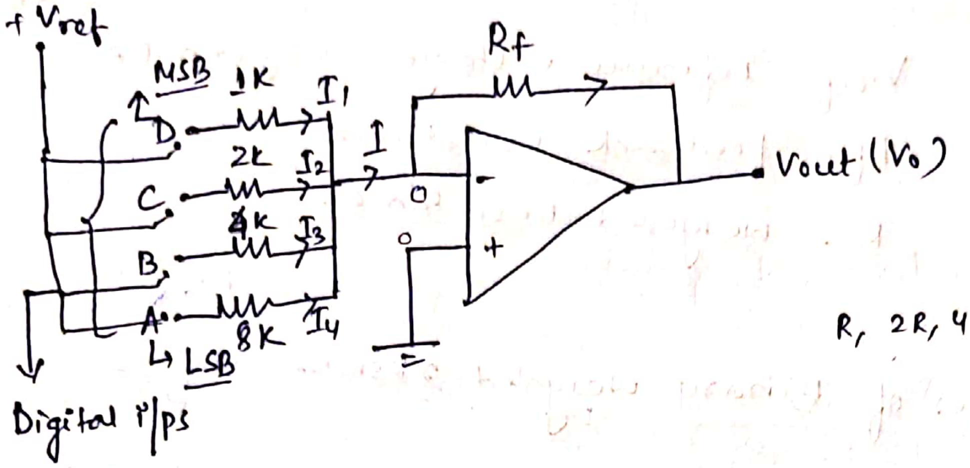
$\% \text{ resolution} = \frac{1}{\text{total no. of steps}} \times 100\%$

Here, $\% \text{ res} = \frac{1}{2^{10}-1} \times 100$

$\% \text{ res} = 0.09 \simeq 0.1\%$ ✓

D/A converter circuitry:-

1. Binary weighted resistor DAC:-



R, 2R, 4R, 8R

→ This is basic circuit for 4-bit DAC. i/ps A, B, C, D are binary i/ps which is applied to opamp. opamp is employed here as summing amplifier.

Analysis :-

$$\frac{0 - V_0}{R_f} = I \Rightarrow V_0 = -I R_f$$

$$I = I_1 + I_2 + I_3 + I_4$$

$$I_1 = \frac{V_{ref}}{R} \times b_0 \qquad I_2 = \frac{V_{ref}}{2R} \times b_1 \qquad I_3 = \frac{V_r}{4R} \times b_2$$

$$I_4 = \frac{V_r}{8R} \times b_3$$

and

$$V_0 = -I R_f$$

$$= -R_f \left[I_1 + I_2 + I_3 + I_4 \right]$$

$$= -R_f \left[\frac{V_r}{R} \underset{MSB}{b_0} + \frac{V_r}{2R} b_1 + \frac{V_r}{4R} b_2 + \frac{V_r}{8R} \underset{LSB}{b_3} \right]$$

$$V_0 = -\frac{V_r R_f}{R} \left[\frac{b_0}{2^0} + \frac{b_1}{2^1} + \frac{b_2}{2^2} + \frac{b_3}{2^3} \right]$$

∴ general formulat becomes:-

$$V_0 = -\frac{V_{ref}\, R_f}{R}\left[\frac{b_0}{2^0} + \frac{b_1}{2^1} + \cdots \frac{b_n}{2^{n-1}}\right]$$

where, V_{ref} = reference voltage for given DAC.
R_f = feedback resistance.
R = weighted resistance.

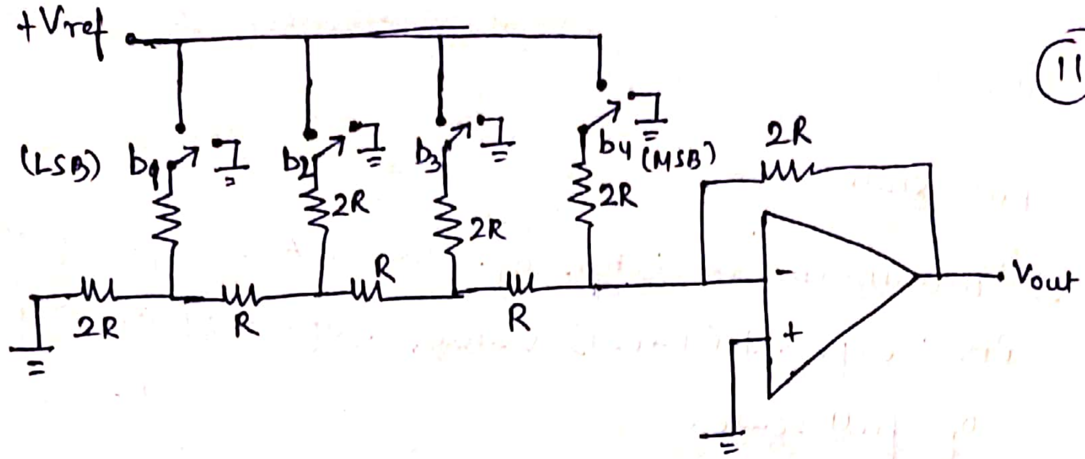
Disadvantages of Binary weighted resistor DAC:-

1. The difference b/w the resistance values corresponding to LSB and MSB will increase as the no. of bits present in the i/p increases.

2. It is difficult to design more accurate and high value of resistors as the digital i/p increases.

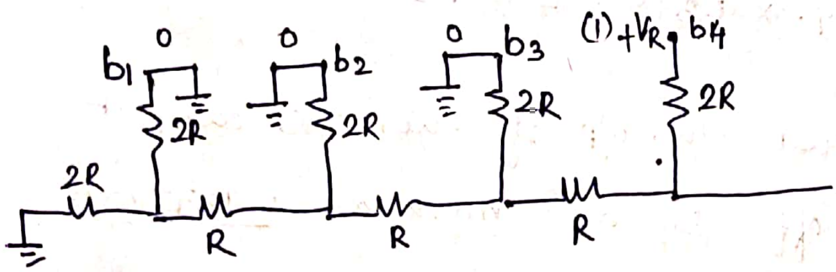
2. R/2R ladder DAC :-

- This DAC will overcome the drawbacks of above DAC as only two values of resistors will be used (R and 2R).



- The binary i/ps control the states of switches.

for example if we take $(1000)_2$ as digital i/p then, R-2R ladder becomes:-



Here,

$$V_o = -\frac{R_f}{R} \times V_{ref} \left[\frac{b_1}{2^4} + \frac{b_2}{2^3} + \frac{b_3}{2^2} + \frac{b_4}{2^1} \right]$$

or,

$$V_o = -\frac{R_f}{R} \times V_{ref} \left[\frac{b_1}{2^n} + \frac{b_2}{2^{n-1}} + \cdots + \frac{b_n}{2^1} \right]$$

Accuracy:-

1. Full scale error:-

- maximum deviation of the DAC's o/p from its expected (ideal) value, expressed as a % of full scale.

For example, assume that DAC has a accuracy of $\pm 0.01\%$ f.s. and if the full scale value is 9.375V.

then,

$$\pm 0.01\% \times 9.375 = \pm 0.9375 \text{ mV}$$

which means that the o/p of this DAC can, at any time, be off by as much as 0.9375 mV. from its expected o/p.

2. Linearity error:

- maximum deviation in the step size from the ideal step size.

For example, the DAC has an expected step size of 0.625V. If this DAC has a linearity error of ± 0.01 f.s., this would mean that the actual step size could be off by as much as

$$\pm 0.01 \times 9.375 = 0.9375 \text{ mV}$$