Digital to Analog converters:-

A digital to analog converter is an electronic device or circuit that converts digital data (binary code) into a corresponding analog voltage or current.

It translates numbers (0 and 1) from a computer or microcontroller into continuous signals that can drive analog devices such as speakers, motors or displays.

Need of D/A converters:-

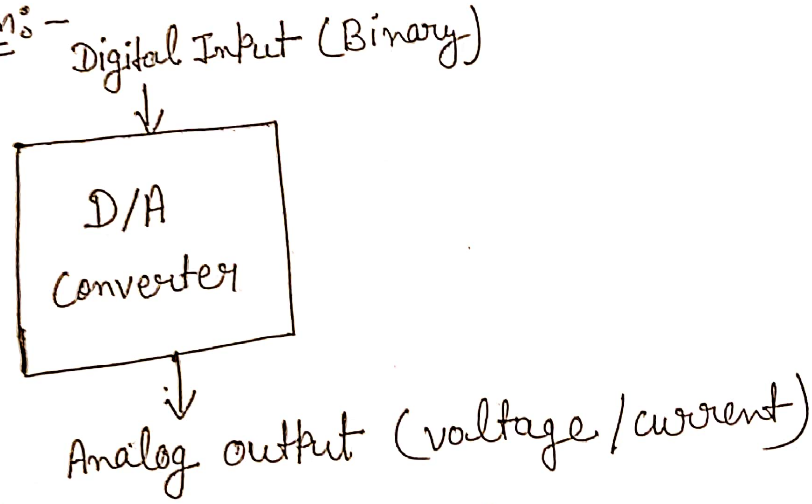
Modern electronic systems are mostly digital - computers, microcontrollers all process digital data.

However, the real world is analog - temperature, sound, light and motion are continuous quantities.

Hence, a D/A converter is needed to convert the digital output of a system into an analog signal to:-

1. Drive analog devices (like speakers or motors)
2. Control real world parameters
3. Reconstruct waveforms from digital data.

Block Diagram:-



Working principle:-

A D/A converter works on the principle of weighted summation of binary inputs. Each bit in the digital input has a specific weight based on its position.

For an n-bit D/A converter:-

$$V_{out} = V_{ref} \times \frac{D}{2^n - 1}$$

where, V_{out} = analog output voltage
V_{ref} = Reference voltage
D = Decimal value of binary input
n = number of bits.

Ex:- If $n = 3$, $V_{ref} = 8V$ input = 101 (Decimal = 5)

$$V_{out} = V_{ref} \times \frac{D}{2^n - 1}$$

$$V_{out} = 8 \times \frac{5}{2^3 - 1} = 8 \times \frac{5}{8 - 1} = \frac{8 \times 5}{7}$$

$$\Rightarrow \frac{40}{7} = 5.71\,V$$

Types of D/A converters :-

① Weighted resistor converter :-

A weighted resistor D/A converter is a type of digital to analog converter that converts a binary digital signal into an analog output voltage using a network of resistors with values weighted according to the binary bit significance. It is also called a binary weighted resistor DAC.

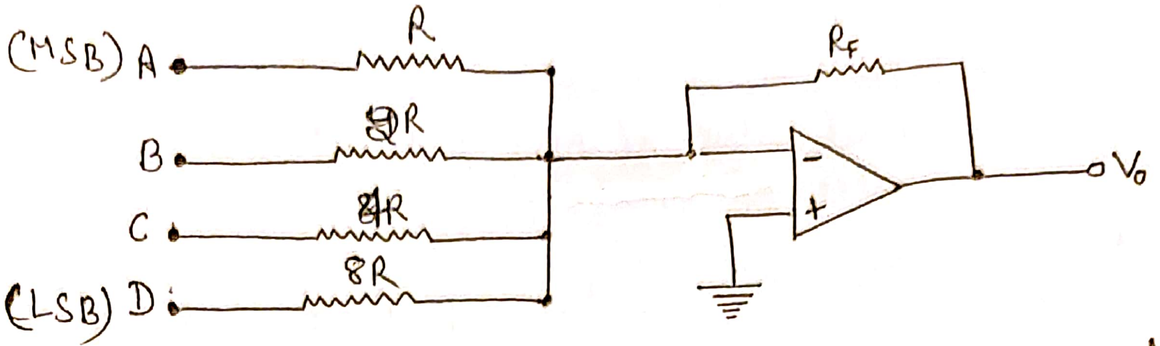
Basic concept :-

This is a simple methods where each bit signal is connected with weighted resistor.

The MSB input is connected with lowest resistor and as we move forward towards to LSB the resistance value is made twice of previous resistor.

The purpose of increasing the resistor value is to pass minimum current through LSB resistance while maximum current through MSB resistance.

The network connected in this method is also known as "Variable resistor network".



(4-bit weighted Resistor D/A converter with op-amp)

Note:-

Op-amp means operational Amplifier.

We know that for summing amplifier is used so the output valtage of the D/A converter is :-

$$V_{out} = -R_F \left[\frac{V_A}{R_A} + \frac{V_B}{R_B} + \frac{V_c}{R_c} + \frac{V_D}{R_D} \right]$$

Now, In this circuit $R_F = R$.

$$V_o = -R \left[\frac{A}{R} + \frac{B}{2R} + \frac{C}{4R} + \frac{D}{8R} \right]$$

Now, Put $R = 1$,

$$V_o = -\left[\frac{A}{1} + \frac{B}{2} + \frac{C}{4} + \frac{D}{8} \right]$$

$$V_o = -\left[\frac{A}{2^0} + \frac{B}{2^1} + \frac{C}{2^2} + \frac{D}{2^3} \right]$$

This is the formula of weighted resistor.

Now, take two voltage level :-

0 = 0V

1 = 4V

Case:-1 when input ABCD = 0000

$$V_o = -R\left[\frac{0}{R} + \frac{0}{2R} + \frac{0}{4R} + \frac{0}{8R}\right] = 0$$

$$\boxed{V_o = 0V}$$

Case:-2 when input ABCD = 0001

[0 = 0V
1 = 4V]

$$V_o = -R\left[\frac{0}{R} + \frac{0}{2R} + \frac{0}{4R} + \frac{4}{8R}\right]$$

$$V_o = -R \times \frac{4}{8R} = -\frac{4}{8} = -0.5V$$

$$\boxed{V_o = -0.5V}$$

Case:-3 When input ABCD = 0010

$$V_o = -R\left[\frac{0}{R} + \frac{0}{2R} + \frac{4}{4R} + \frac{0}{8R}\right]$$

$$V_o = -R \times \frac{4}{4R} = -1$$

$$\boxed{V_o = -1V}$$

Case:-4 When input ABCD = 0011

$$V_o = -R\left[\frac{0}{R} + \frac{0}{2R} + \frac{4}{4R} + \frac{4}{8R}\right]$$

$$V_o = -R\left[\frac{1}{R} + \frac{1}{2R}\right]$$

$$V_o = -R \times \frac{1}{R}\left[1 + \frac{1}{2}\right]$$

$$V_o = -\frac{3}{2} = -1.5$$

$$\boxed{V_o = -1.5V}$$

In this way, we can convert all 16 possible (binary) digital inputs into analog outputs.

Advantages :-

1. Simple and easy to understand.
2. Fast conversion speed
3. Good accuracy for low bit systems.

Disadvantages :-

1. It requires a wide range of resistor values (R, 2R, 4R.....).
2. Difficult to maintain precision for high bit systems.
3. Not suitable for IC implementation.

② R-2R Ladder D/A converter :—

An R-2R Ladder D/A converter is a digital to analog converter that converts a binary digital input into an analog voltage using only two resistor values — R and 2R.

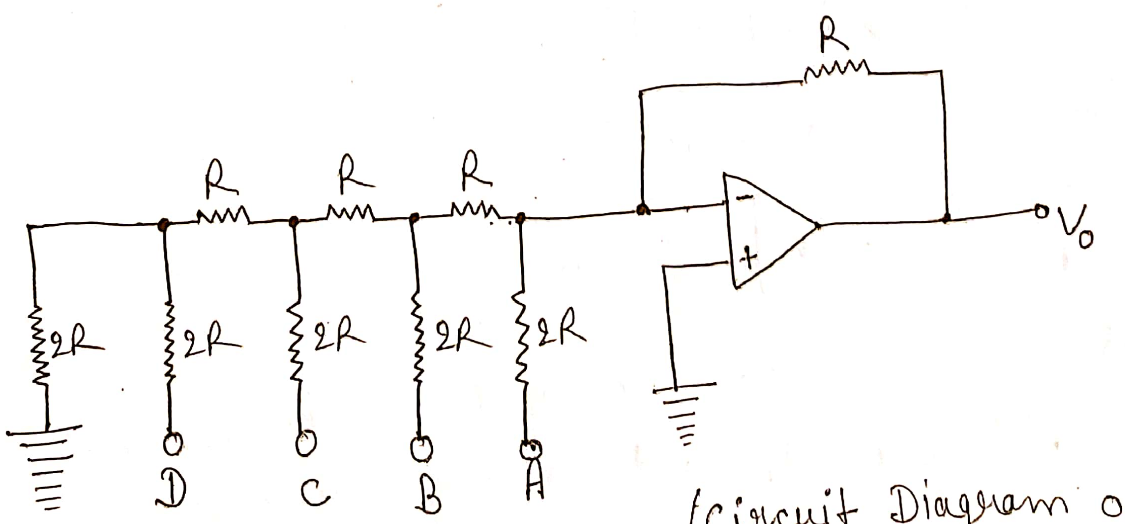
It overcomes the main problem of the weighted resistor DAC which required many resistors of very different values (R, 2R, 4R, 8R, ...).

By using only two resistor values the R-2R DAC achieves:- high accuracy, easy fabrication and stable performance.

Basic concept :-

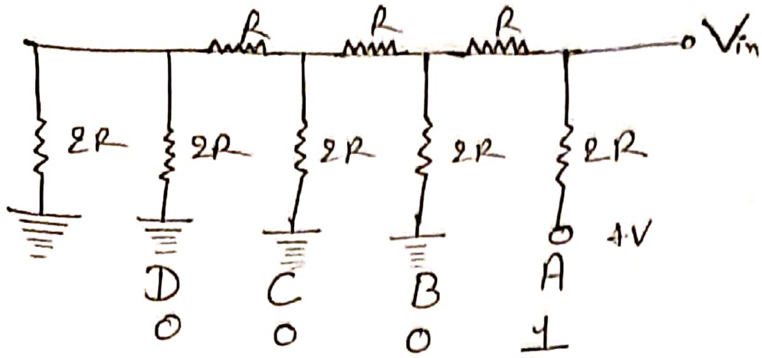
R-2R ladder is a resistive network. It contains only two resistor values R and 2R.

It has op-amp as a scaling circuit. MSB input towards right and LSB input with left of the circuit.

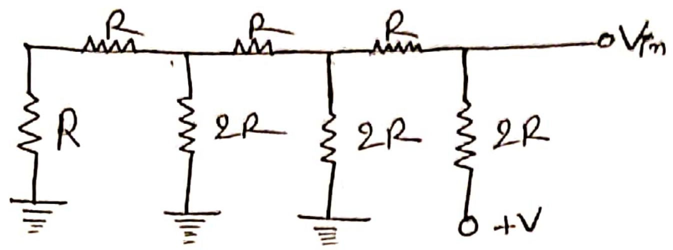


(Circuit Diagram of R-2R Ladder D/A converter)

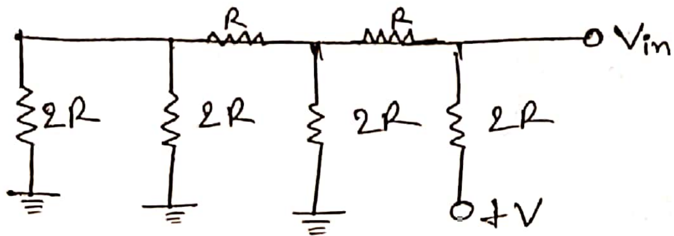
Suppose digital input is ABCD = 1000



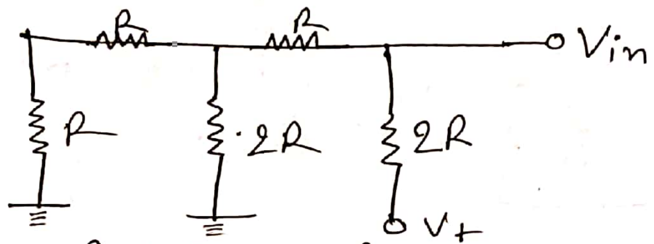
$2R \parallel 2R = R$



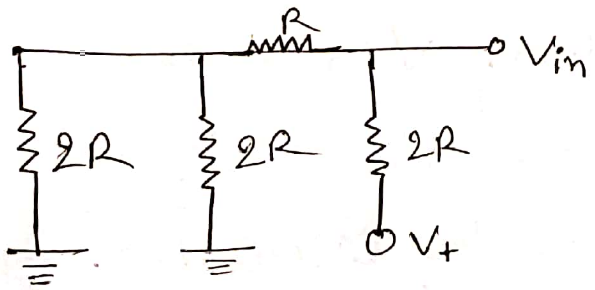
$R + R = 2R$



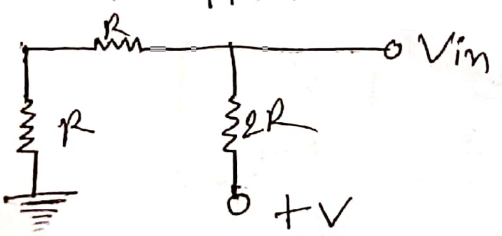
$2R \parallel 2R = R$



$R + R = 2R$

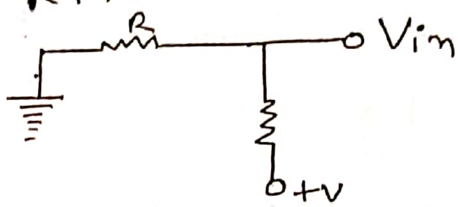


$2R \parallel 2R = R$



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$= \frac{1}{2R} + \frac{1}{2R}$$
$$= \frac{2}{2R} = \frac{1}{R}$$
$$\frac{1}{R_D} = \frac{1}{R}$$
$$\boxed{R_D = R}$$

$R + R = 2R$



By voltage divider,

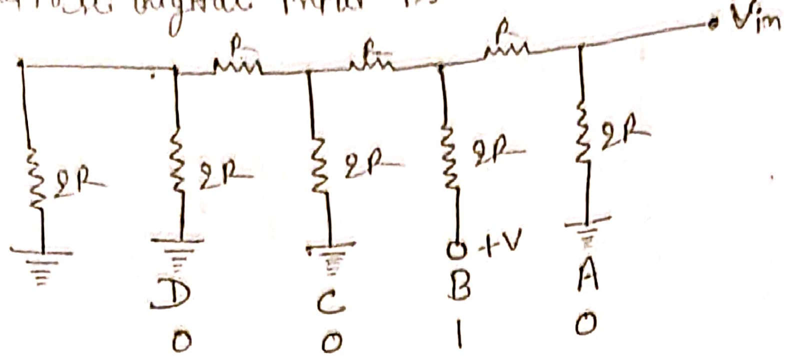
$$V_{in} = \frac{V \times 2R}{2R + 2R}$$

$$V_{in} = \frac{V \times \cancel{2R}}{\cancel{4R}_{2}}$$

$$\boxed{V_{in} = \frac{V}{2}}$$

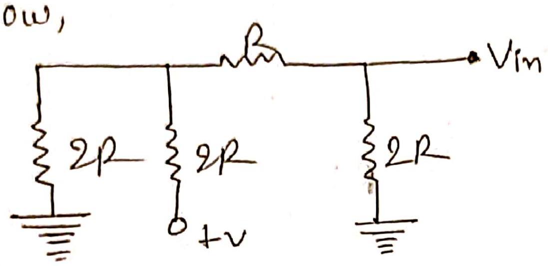
Now, when ABCD = 1000, then $V_{in} = \frac{V}{2}$.

Suppose digital input is ABCD = 0100



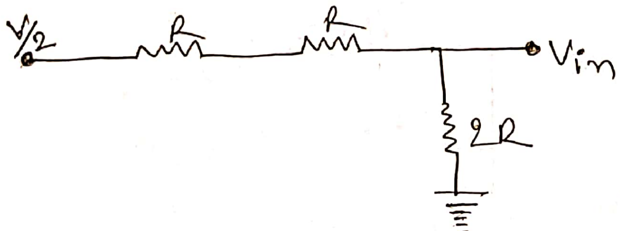
After solving,

Now,



Voltage divider

$$V_{in} = \frac{V \times 2R}{2R+2R} = \frac{V \times 2R}{4R\ 2} = \frac{V}{2}$$



$$V_{in} = \frac{V \times 2R}{2\ 4R} \Rightarrow \boxed{V_{in} = \frac{V}{4}}$$

when ABCD = 0100, then $V_{in} = \frac{V}{4}$

Similarly,

When ABCD = 0010, then $V_{in} = V/8$

When ABCD = 0001, then $V_{in} = \frac{V}{16}$

The output of D/A converter can be calculated by using summing amplifier equation.

$$V_o = -R_F \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4} \right]$$

$$V_o = -R_F\left[\frac{A}{2R} + \frac{B}{4R} + \frac{C}{8R} + \frac{D}{16R}\right]$$

Since, $V_1 = \frac{A}{2}$, $V_2 = \frac{B}{4}$, $V_3 = \frac{C}{8}$, $V_4 = \frac{D}{16}$, $R_F = R$

$$V_o = -\frac{R}{R}\left[\frac{A}{2} + \frac{B}{4} + \frac{C}{8} + \frac{D}{16}\right]$$

$$\boxed{V_o = -\left[\frac{A}{2^1} + \frac{B}{2^2} + \frac{C}{2^3} + \frac{D}{2^4}\right]}$$

This is the formula for R-2R Ladder D/A converter

Ex:-

① If input ABCD = 0000

$$V_o = -\left[\frac{0}{2} + \frac{0}{4} + \frac{0}{8} + \frac{0}{16}\right]$$

$$\boxed{V_o = 0}$$

② If input ABCD = 0001

$$V_o = -\left[\frac{0}{2} + \frac{0}{4} + \frac{0}{8} + \frac{1}{16}\right] = -0.625$$

$$\boxed{V_o = -0.625}$$

③ If input ABCD = 0010

$$V_o = -\left[\frac{0}{2} + \frac{0}{4} + \frac{1}{8} + \frac{0}{16}\right] = -1.25$$

$$\boxed{V_o = -1.25}$$

④ If input ABCD = 0011

$$V_o = -\left[\frac{0}{2} + \frac{0}{4} + \frac{1}{8} + \frac{1}{16}\right] = -1.845$$

$$\boxed{V_o = -1.845}$$

Advantages :-

1. It uses only two resistor values (R and 2R)
2. High Accuracy
3. Good linearity
4. Easy to expand to higher bits

Disadvantages :-

1. Slightly more complex structure than weighted resistor DAC.
2. Requires precise matching of R and 2R resistors for best performance.
3. Output is inverted.

Specifications for D/A converters :-

- These specifications determine how accurate, fast and reliable a DAC is in converting digital data into an analog signal.

1. Resolution :-

The resolution of a DAC is the smallest change in analog output that corresponds to a one-bit change in the digital input.
It depends on the number of bits (n) of the DAC.

$$\text{Resolution} = \frac{V_{ref}}{2^n - 1}$$

2. Accuracy :-

Accuracy is how close the actual analog circuit output is to its ideal value for a given digital input.

3. Linearity :-

(a) Differential Non-Linearity :- It measures difference between actual step size and ideal step size.

(b) Integral Non-Linearity :- It measures the maximum deviation of actual output from a straight line ideal output over the entire range.

(4) Setting time :-
Setting time is the time taken by the DAC output to reach and stay within a specified error band of its final value after a change in digital input.

(5) Temperature sensitivity :-
The variation in DAC performance due to changes in temperature.

Examples of D/A converters ICs :-

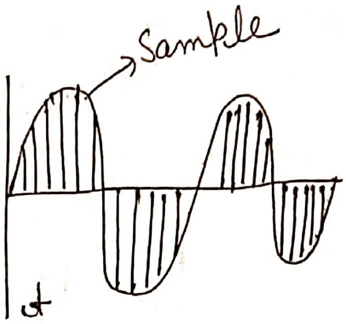
DAC ICs are integrated circuits that perform digital to analog conversion internally, using architectures like R-2R ladder, weighted resistor.

IC Name	Type	Resolution	Key Features
DAC0808	8-bit Binary weighted	8-bit	• Uses R-2R Ladder • Fast response • Requires op-amp
MC1408/ MC1508	8-bit	8-bit	• High speed current output
AD7524	8-bit, R-2R Ladder	8-bit	• Low cost • Voltage output • Simple interface
AD558	8-bit, Voltage output DAC	8-bit	• Internal reference • Single 5V supply • Fast settling
MAX541	12 bit /14bit R-2R	12-14 bit	• High Precision • Rail to rail output • Low noise

Sample and hold circuit :-

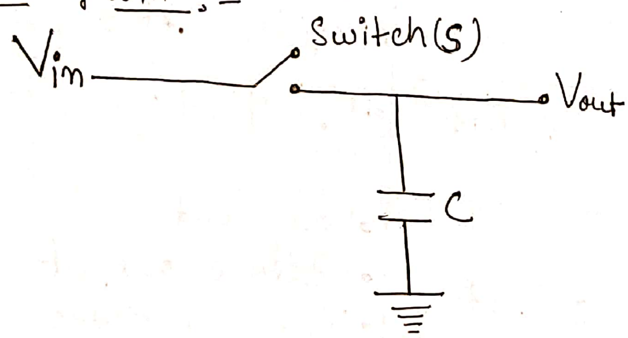
The sample and hold circuit is an electronic circuit which creates the samples of voltage given to it as input and after these, it holds these samples for definite time.
A sample and hold circuit is an essential component in data conversion system, especially before analog to digital converters.

Sample :- Taking an instantaneous snapshot of an analog's voltage at a specific moment in time.



Hold :- Hold is keeping or storing the sampled analog voltage constant for a certain period of time.

Circuit Diagram :-

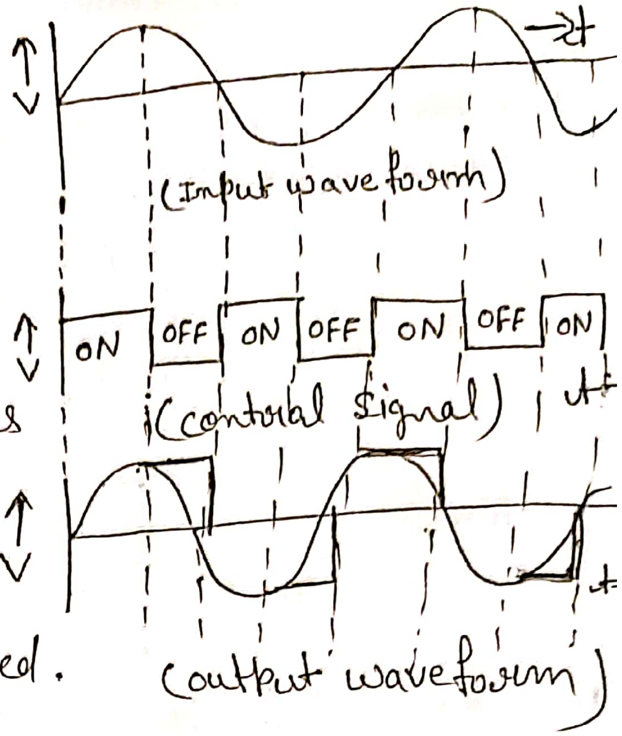


Sampling time :- The time during which the circuit generates the sample of the input signal is called sampling time.

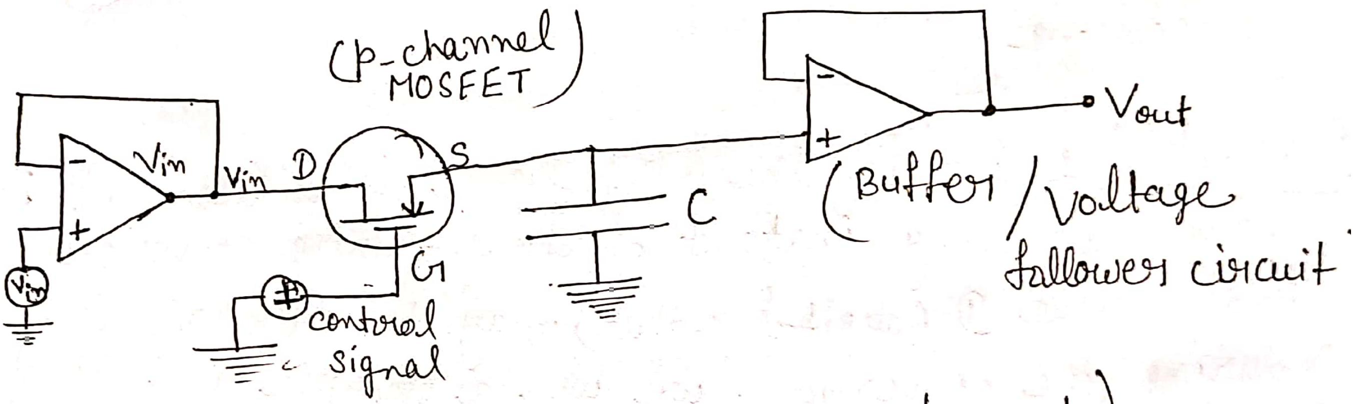
Holding time :- The time during which the circuit holds the sampled value is called holding time.

Sampling time is generally between 1 μs to 14 μs while the holding time can assume any value as required in the application.

Working:- The sample and hold circuit consist of a combination of switch and a capacitor such that when the switch is closed then the capacitor charges to the given input voltage and when the switch is open, the capacitor has no path to get discharge, hence it holds the input voltage for a certain period of time until the switch is again closed.



Capacitor is the heart of sample and hold circuit because capacitor charges to peak value when the switch is closed and holds the sampled voltage when the switch is open.



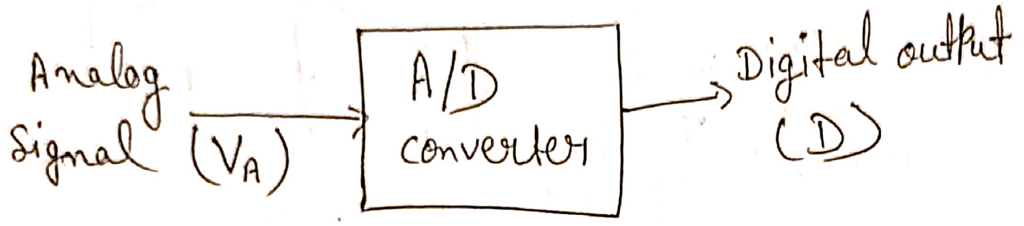
(Sample and Hold circuit using op-amp).

Applications:-

1. Analog to digital conversion
2. In digital oscilloscopes
3. Data Acquisition systems
4. Communication systems
5. Sampled data systems

Analog to digital converters :-

An analog to digital converter is an electronic device or circuit that converts a continuous (analog) signal into a discrete (digital) signal.
It takes an analog input voltage or current and produces a binary output that represents the amplitude of the input signal.

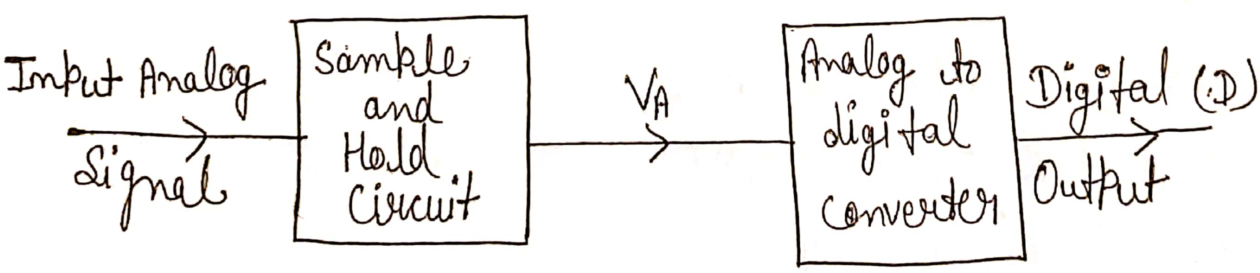


Working principle :-

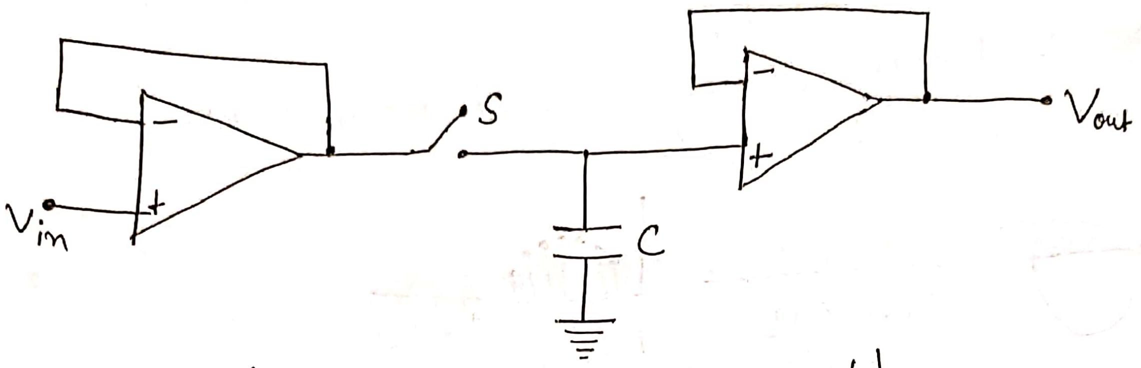
There are three basic working principles :-

1. Sampling
2. Quantization
3. Encoding

① **Sampling :-** If the input signal is sinusoidal i.e., changes at every instant of time during conversion, final value D (digital output) may be erroneous. So during the conversion, we use a sample and hold circuit to sample the input voltage and hold it to a constant value.



The sample and hold circuit consists of a switch and a capacitor and two voltage follower op-amps. When the switch is closed, the capacitor charges upto input voltage V_{in} and when the switch is opened, the capacitor holds that voltage until the switch is closed again. Thus output voltage remains measurably constant.



(Hold and sample circuit)

But how fast we should sample the input voltage decided by Nyquist theorem.

Nyquist Theorem:-
A band limited analogue signal that has been sampled can be perfectly reconstructed from an infinite sequence of samples if the sampling rate f_s exceeds $2f_{max}$ samples per second where f_{max} is the highest frequency in the original signal.

Band limited: $\{f_{min}, f_{max}\}$:- All the frequencies of input signal lie in this range.

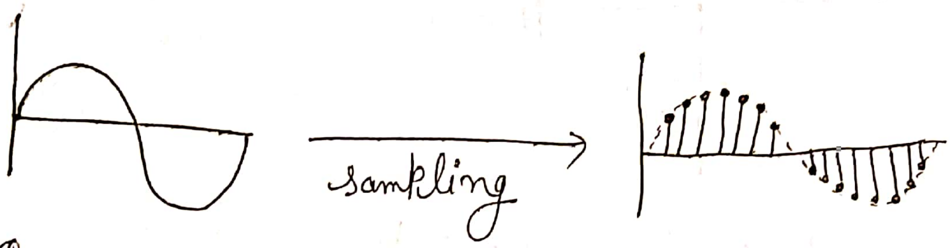
Sampling rate:- $(f_s > 2f_{max})$:- Only then we can reconstruct the original signal.

Aliasing Error:- If the analog signal is sampled at rate $f_s < 2f_{max}$, then the constructed signal will be different from the original analog signal and this error in the original signal is called aliasing error.

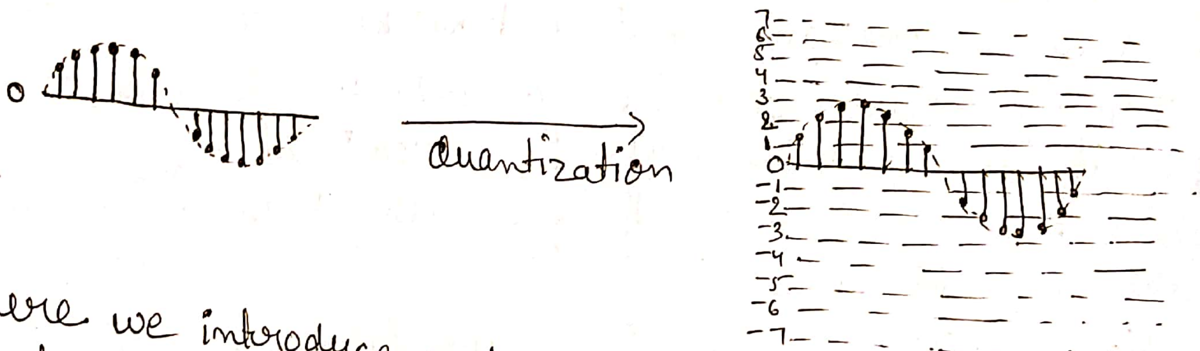
There is one another postulate that must be considered here to reconstruct the original signal from the sampled value.

Valvano Postulate :- If f_{max} is the largest frequency component of analog signal, then we must sample more than 10 times f_{max}, in order to reconstruct the original signal from sampled signal when plotted on a voltage versus time graph.

For example :- 1000 Hz signal sampled at 2000 Hz



② Quantization :- The process of assigning a sampled signal a value from the discrete set of value is called quantization. (nearest possible integers)



Here we introduce a term called "resolution" which represents how much the quantised value is close to the actual value. It is generally defined in terms of number of bits.

Thus "Resolution" defines the minimum change in the input signal that can be detected.

$$\text{Resolution} = \frac{\text{Full Scale range}}{2^{(\text{no. of bits})}} = \frac{V_{max} - V_{min}}{2^n} = \frac{V_{ref}}{2^n}$$

where n = no. of bits.

2^n = no. of discrete levels of quantization.

Ex:- If $n = 2$ (no. of bits)

Then $2^2 = 4$ (discrete levels of quantization)

If $n = 3$ (no. of bits)

Then $2^3 = 8$ (discrete levels of quantization)

If full scale range / V_{ref} is 10 V for a given ADC, $n=3$ then,

$$\text{resolution} = \frac{10V}{2^3} = \frac{10}{8} = 1.25V$$

i.e, An ADC can detect a minimum voltage charge of 1.25 V but not less than 1.25 V

If $V_{ref} = 1V$ for a given ADC for $n = 3$, then

$$\text{resolution} = \frac{1V}{2^3} = \frac{1}{8} = 0.125V$$

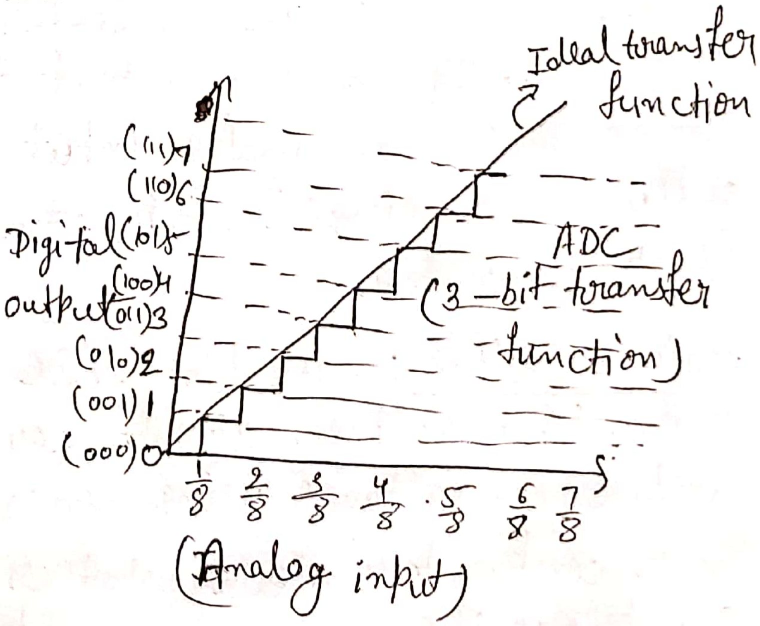
i.e, an ADC can detect a minimum voltage change of 0.125 V but not less than 0.125 V.

If $V_{ref} = 10V$ for a given ADC for $n = 8$, then

$$\text{resolution} = \frac{10V}{2^8} = 0.039V$$

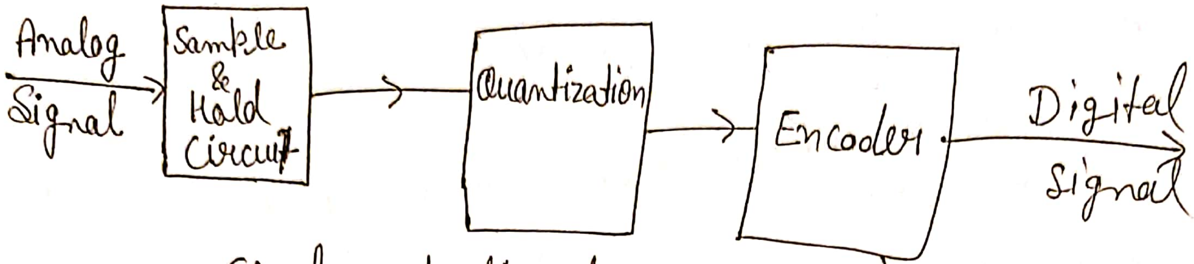
Thus by decreasing the full scale range / V_{ref} and by increase the no. of bits we can increase the resolution.

Therefore, Quantization error $= -\frac{1}{2}LSB = -0.5 LSB$



③ Encoding :- The last process is encoding in which the quantised values are converted into digital binary numbers i.e., in the form of 0 & 1.

Thus the whole process of conversion of an analog signal into a digital signal may be expressed as :-



(Analog to digital converter)

Applications of A/D converter :-

1. In digital signal processing
2. Data Acquisition Systems
3. Communication systems
4. Control Systems
5. In medical instruments

Parallel comparator A/D converter :-

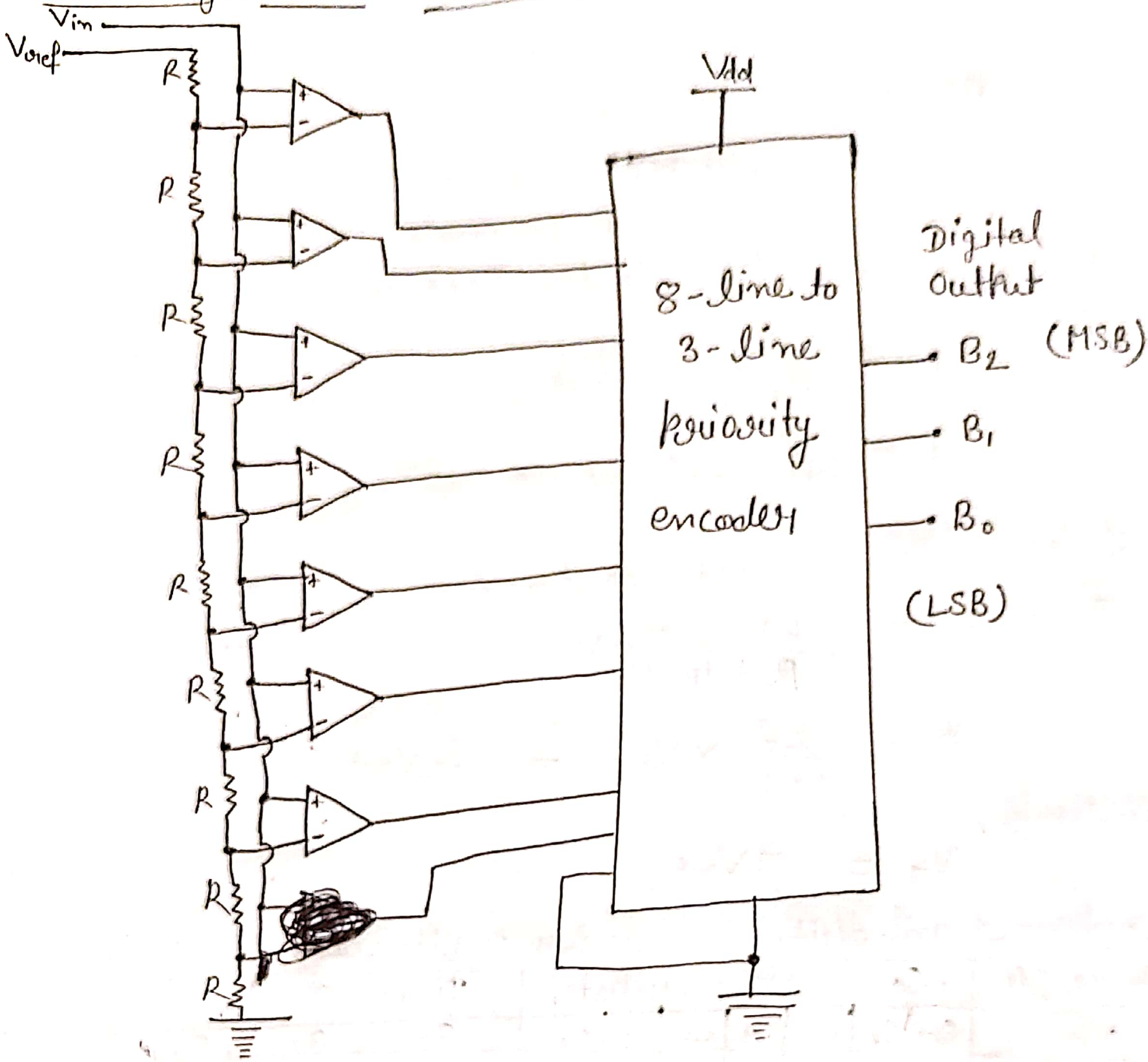
A Parallel comparator A/D converter is also known as a Flash A/D converter. It is the fastest type of analog to digital converter. It converts an analog input voltage directly into a digital output in a single step. That's why it is called a flash converter.

Basic Principle :- An flash ADC works by comparing the analog input voltage simultaneously with a number of reference voltages using comparators.

Each comparator tells whether the input voltage is above or below its reference voltage.

The combined outputs of all comparators are then encoded into a digital binary number.

Block Diagram :- Circuit Diagram



(Parallel A/D / Flash ADC)

Working :-

⇒ It consist $(2^n - 1)$ comparators.
⇒ It consist 2^n matched resistors.
⇒ Analog signal applied to non-inverting terminal.
⇒ Reference voltage applied to inverting terminal.

3-bit flash A/D converter :-

$n = 3$

no. of comparators $= 2^n - 1 = 7$

no. of Resistance $= 2^n = 2^3 = 8$

if $V_{in} > V_R$ = output of comparator $= 1$

if $V_{in} > V_R$ = output of comparator $= 0$

if V_{in} is the voltage to the first comparator.

Then,

$$V_1 = \frac{R}{R + 7R} \times V_{ref}$$

$$V_i = \frac{R}{R(1+7)} \times V_{ref} = \frac{V_{ref}}{8}$$

if V_2 is the voltage to the second comparator.

Then,

$$V_2 = \left[\frac{R+R}{R + 7R}\right] \times V_{ref}$$

$$V_2 = \frac{2R}{8R} \times V_{ref} = \frac{2}{8} V_{ref}$$

Similarly,

$$V_7 = \frac{7 V_{ref}}{8}$$

Comparator and digital output for 3-bit flash ADC :-

Analog I/P V_{in}	Comparator output							Digital O/P		
	C_7	C_6	C_5	C_4	C_3	C_2	C_1	B_2	B_1	B_0
0	0	0	0	0	0	0	0	0	0	0
$V/8$	0	0	0	0	0	0	1	0	0	1
$2V/8$	0	0	0	0	0	1	1	0	1	0
$3V/8$	0	0	0	0	1	1	1	0	1	1
$4V/8$	0	0	0	1	1	1	1	1	0	0
$5V/8$	0	0	1	1	1	1	1	1	0	1
$6V/8$	0	1	1	1	1	1	1	1	1	0
$7V/8$	1	1	1	1	1	1	1	1	1	1

Advantanges :-

① It is fastest ADC converter.

② Construction is simple and easy.

③ Suitable for large bandwidth application.

Disadvantages :-

① It is high power consumption.

② Limited resalution

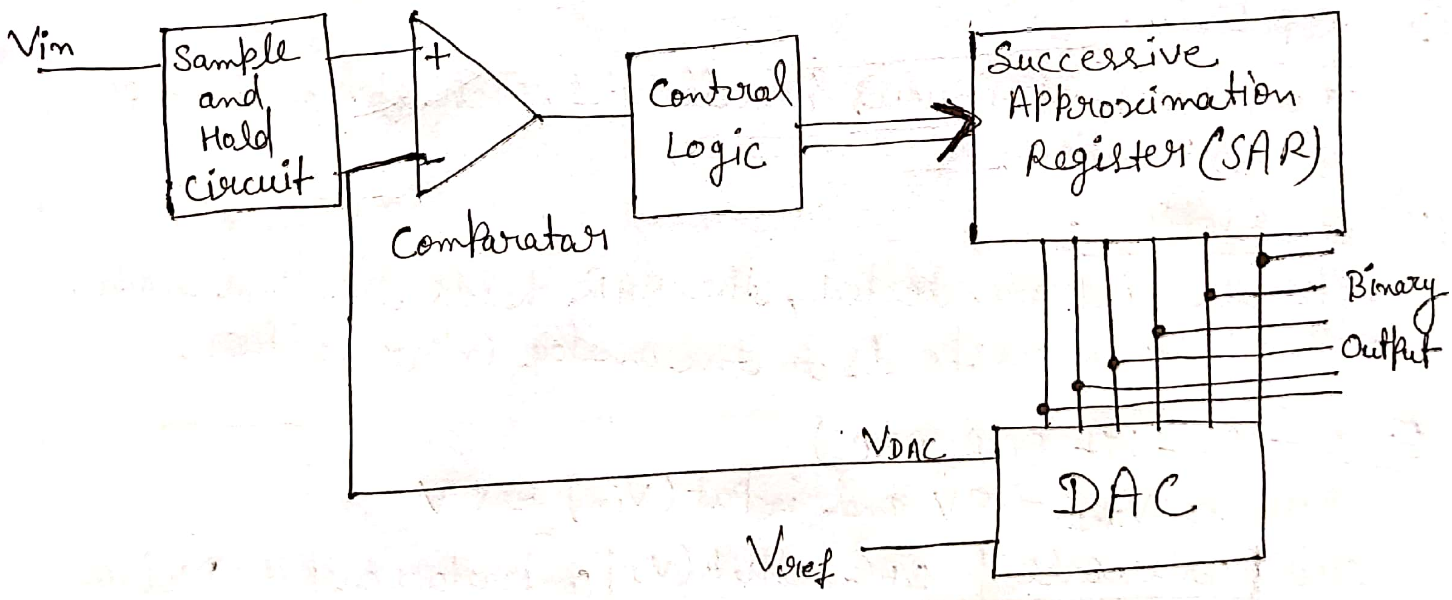
③ Large die area (2^n-1) comparator

④ component matching (resistor and comparator).

Successive Approximation A/D converter :-

Successive approximation analog to digital converter is one of the most commonly used types of ADC due to its speed and accuracy. It converts an analog input signal into a digital output using a binary search algorithm.

Block Diagram :-



(Successive Approximation A/D converter)

Main component :-

It is consist of :-

① Sample and Hold circuit
② Comparator
③ Successive Approximation Register (SAR)
④ Digital to analog converter (DAC)

Working :-

① **Initialization :-** The SAR is cleared and begins the conversion by setting the most significant bit (MSB) to 1.

② **Step by step approximation :-**

(i) The DAC converts the current SAR digital value to an analog voltage.
(ii) The comparator compares this DAC output with the input analog voltage.
(iii) If the DAC output is less than the input voltage, the bit remains 1.
(iv) If the DAC output is greater than the input voltage → the bit is cleared (0).
(v) Then the SAR moves to the next lower bit.

③ **Repetition :-**

This process continuous for all bits, each step refines the approximation.

④ **Completion :-**

After all bits are tested, the SAR holds the final digital output that corresponds to the analog input voltage.

Ex :- (4-bit SAR ADC)

Assume $V_{ref} = 8V$ and input $(V_{in}) = 5V$.

Step	Trial Code	DAC output (V)	Comparator output	Decision
1	1000	4.0	$V_{in} > V_{DAC}$	Keep bit 1
2	1100	6.0	$V_{in} < V_{DAC}$	Clear bit 2
3	1010	5.0	$V_{in} = V_{DAC}$	Keep bit 3
4	1010	5.0	—	Final output

Digital output = 1010
Equivalent decimal value = 10
Analog value (10/16) × 8V = 5V

Advantage :-

1. High speed compared to Integrating ADCs.
2. Good accuracy and resolution.
3. Simple and efficient digital logic.
4. Moderate hardware complexity.

Disadvantage :-

1. Requires a high precision DAC.
2. Comparator offset errors can affect accuracy.

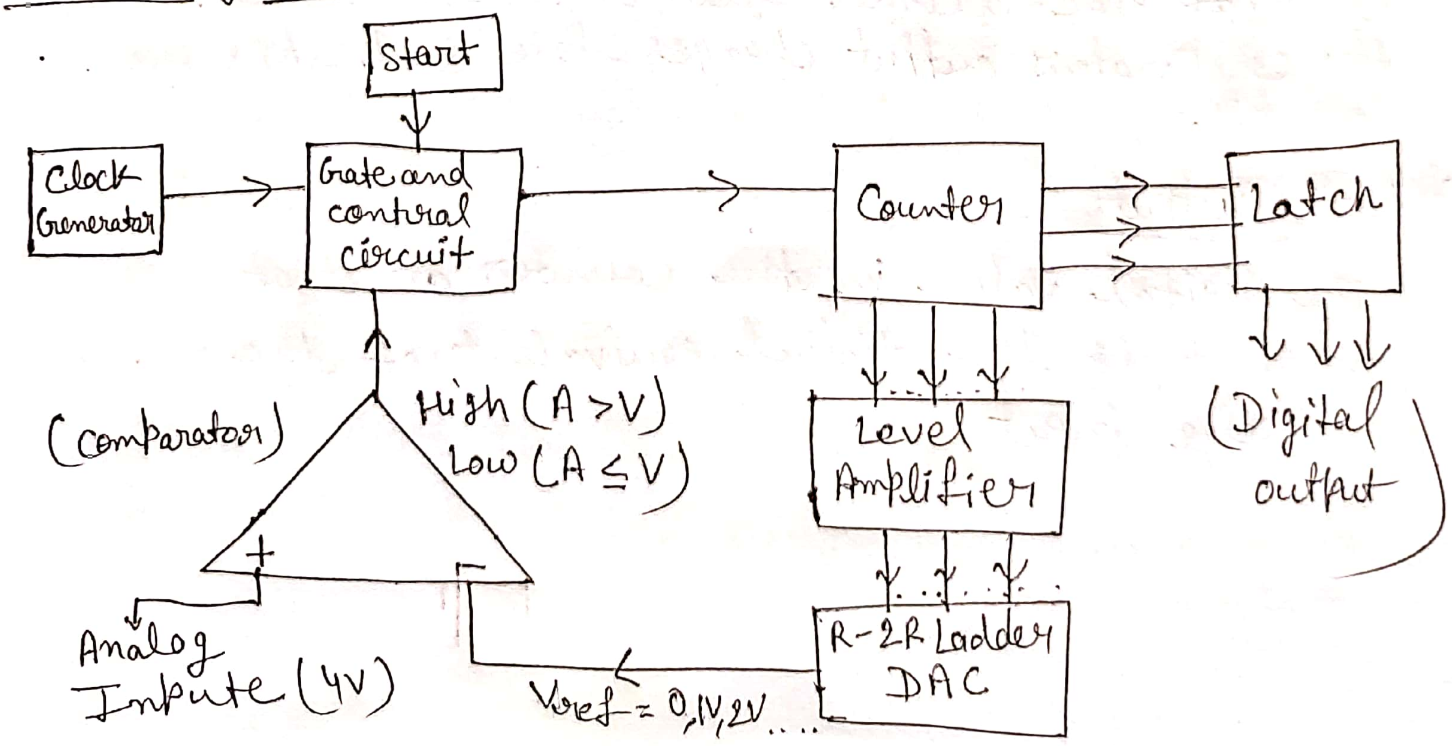
Application :-

1. Digital oscilloscopes.
2. Data Acquisition systems.
3. Digital voltmeters.

Counting A/D converter :-

Counting A/D converter is also known as counter type ADC. A counter type ADC produces a digital output which is approximately equal to analog input by using counter operation internally.

Block Diagram :-



Components :-

① **Sample and hold circuit** :- It captures and holds the analog input voltage steady during conversion.

② **Comparator** :- It compares the input analog voltage (V_{in}) with the DAC output voltage (V_{DAC}).

③ **Digital counter** :- It generates a digital count that increases step by step from 0 upward.

④ **Digital to analog converter** :- It converts the counter's digital output into an analog voltage (V_{DAC})

Working :-

Step:-1 :- **Start conversion** :-

⇒ The counter is reset to zero (000...0).
⇒ The DAC output (V_{DAC}) is initially 0V.

Step:2 **Counting process** :-

⇒ The counter starts counting upward (binary count).
⇒ For each count, the DAC converts the count value into an analog voltage.
⇒ V_{DAC} increases step by step like a staircase.

Step:-3 :- **Comparison** :-

⇒ The comparator continuously compares V_{in} and V_{DAC}.
⇒ When V_{DAC} becomes equal to or just exceeds V_{in}, the comparator output changes state and stops the counter.

Step:-4 **Output** :-

The digital value in the counter at that moment is the digital equivalent of the analog input

Ex:- Assume,
Reference voltage (V_{ref}) = 8 V
input Vin = 5 V
3-bit ADC => 2^3 = 8 steps

Counter output	DAC output (V)	Comparator output	Action
000	0.0	Low	Count
001	1.0	Low	count
010	2.0	Low	count
011	3.0	Low	Count
100	4.0	Low	count
101	5.0	High	Stop

Digital output = 101
Equivalent Decimal = 5
Analog output (5/8) x 8 = 5 V

Advantages:-
① Simple to design and understand
② Requires fewer components
③ Good accuracy for slow signals.

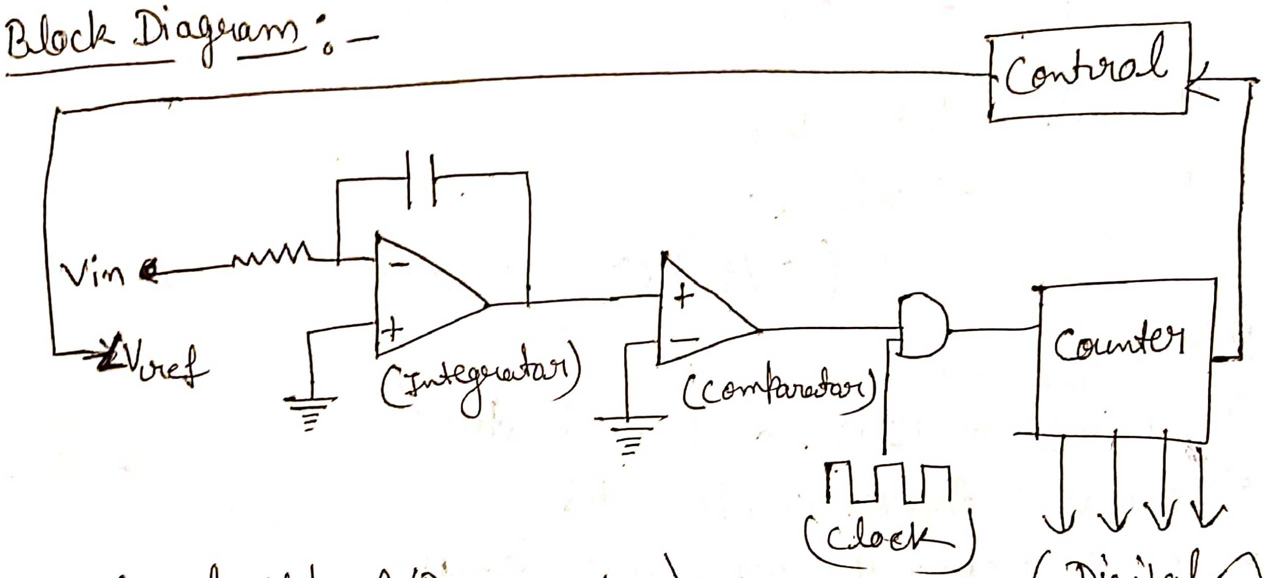
Disadvantages:-
① Slow conversion speed
② Not suitable for high speed or rapidly changing signals.

Applications:-
① Low speed instruments like digital panel meters.
② Slow changing signals measurement
③ Educational and demonstration circuits.

Dual Slope A/D converter :-

Dual slope ADC is also known as an integrating ADC.
It is a highly accurate type of analog to digital converter commonly used in digital multimeters and precision instruments.
It converts an analog voltage into a digital value by integrating (summing over time) the input voltage and then de-integrating it using a known reference voltage.

Block Diagram :-



(Dual slope A/D converter)

Components :-

① Integrator (Op-Amp with capacitor) :- It integrates (sums) the input voltage over time to produce a ramp signal.

② Comparator :- It detects when the integrator output returns to zero.

③ Control logic & Counter :- Controls timing and counts clock pulses during integration and de-integration.

④ Reference voltage (Vref)

Working :-

The conversion occurs in two phases :-

① Integration (Input phase) :-

The input analog voltage Vin is applied to the integrator for a fixed time period (T_1).

The integrator output ramps upward or downward depending on the polarity of Vin.

The output at the end of this phase is :-

$$V_{out} = \frac{-V_{in} \times T_1}{RC}$$

② De-Integration (Reference Phase) :-

After T_1, the input is disconnected and a refference voltage V_{Ref} is applied.

The integrator now ramps back toward zero at a constant rate.

The time (T_2) taken for the output to return to zero is measured by a counter.

Since, the slope is constant,

$$T_2 = \frac{V_{in} \times T_1}{V_{Ref}}$$

Hence, T_2 is directly proportional to Vin

$$\boxed{T_2 \propto V_{in}}$$

Mathematical relation :-

$$\boxed{V_{in} = V_{Ref} \times \frac{T_2}{T_1}}$$

Advantages :-

① High accuracy
② Excellent noise rejection
③ Stable and precise due to averaging effect.
④ Ideal for slowly varying signals.

Disadvantages :-

① Slow conversion rate
② Not suitable for high speed applications.

Applications :-

① Digital multimeters
② Precision measuring instruments
③ Industrial and laboratory equipment.

Specifications of A/D converters :-

① Resolution :- The number of bits in the digital output of the ADC. It indicates how many discrete levels the analog input range is divided into.

Formula :- No. of levels $= 2^n$

Ex :- An 8-bit ADC has $2^8 = 256$ levels.

② Accuracy :- The degree to which the digital output matches the actual analog input

③ Conversion time :- The time required by the ADC to complete one conversion cycle.

Unit :- Microsecond (μs) or nanosecond (ns).

④ Sampling rate :- The number of samples taken per second from the analog signal.

Symbol :- f_s

Unit :- SPS (Sample per second) or Hertz (Hz)

(5) Quantization error :- The difference between the actual analog input and its nearest digital level representation.

Quantization error = $\pm \frac{1}{2}$ LSB

Examples of A/D converter ICs :-

IC Name	Type	Input voltage	Features	Resolution
(1) ADC0804	8-bit (SAR)	0-5 V	• Single channel input • Requires external clock or RC network	8 bit (256 steps)
(2) ADC0808/ ADC0809	8-bit (SAR)	0-5 V	• Built in 8 channel analog multiplexer • TTL compatible digital outputs	8-bit
(3) ADC 1008	10-bit (SAR)	0-10 V	• High resolution • multiplexer input options	10 bit
(4) ADC0820	8-bit (SAR)	0-5 V	• On-chip sample and hold circuit	8-bit
(5). TLC5540	Flash	0-5 V	• Used in video and very high speed.	8-bit