Digital To Analog Converter (DAC)

Digital to analog converter is used to convert digital quantity into analog quantity. DAC converter produces an output current of voltage proportional to digital quantity (binary word) applied to its input. Today microcomputers are widely used for industrial control. The output of the microcomputer is a digital quantity. In many applications the digital output of the microcomputer has to be converted into analog quantity which is used for the control of relay, small motor, actuator e.t.c. In communication system digital transmission is faster and convenient but the digital signals have to be converted back to analog signals at the receiving terminal. DAC converters are also used as a part of the circuitry of several ADC converters.

There are several ways of making a digital to analog converter. Some of them are given as under.

1. Binary weighted resistor DAC
2. R-2R Ladder network
3. Serial DAC converter
4. BCD DAC
5. Bipolar DAC

Binary weighted Resistor DAC

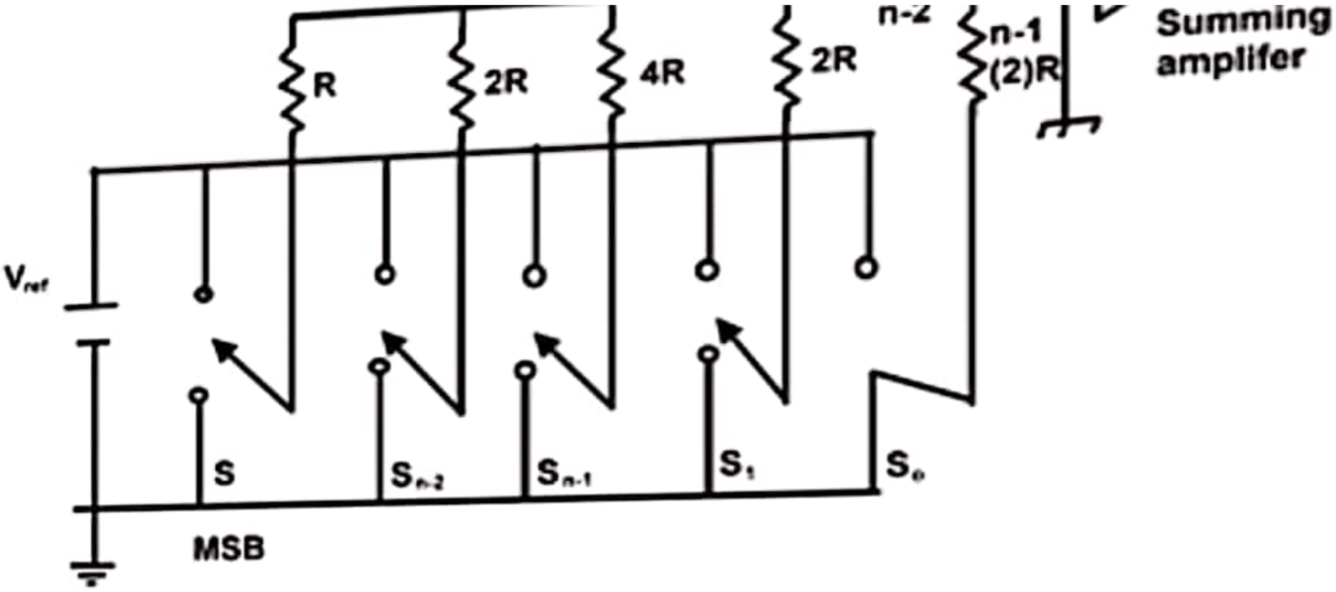

Figure 1: A Binary weighted D/A Converter

Figure 1: Binary Weighted DAC

It consists of the following four major components.

1. n switches one for each bit applied to the input
2. a weighted resistor ladder network ...

summation of the conductance connected to the mode".

Mathematically we can write

$$V_o = \frac{\frac{V_1}{R} + \frac{V_2}{2R} + \frac{V_3}{4R} + \cdots \frac{V_n}{(2^{n-1})R}}{\left[\frac{1}{R} + \frac{1}{2R} + \frac{1}{4R} + \cdots \frac{1}{(2^{n-1})R}\right]}$$

Assume that the resistor R_1, R_2, R_3 .... R_n are binary

$R_n = (2^{n-1})\ R$

$$V_o = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]}$$

A Resistor Ladder Network, can delivers a binary number say number of n bits.

$$N = a_{n-1}\ {}^{n} \overline{z}^{1} + a_{n-2}\ {}^{n} \overline{z}^{2} + \cdots a_1 2^1 + a_0 2^0$$

Or

$$= \sum_{i=0}^{n-1} a_i\ .z^i\ , where\ a_i = \{0,1\}$$

Each bit controls a switch s_i that is connected to V_{ref}.

of the respective input. But the resistor in the MSB position has the value R, the next has the value 2R etc. The resistor of the LSB have the value of (2^{n-1}) R.

The current flowing in the summing amplifier is

$$I = \frac{a_{n-1}V_R}{} + \frac{a_{n-2}V_R}{} + \dots \frac{a_1V_R}{}$$

Above relation shows that output voltage of the D/A converter is proportional to a number represented by the switch that are connected to V_R i.e. $a_i = 1$

Maximum current will flow when all a_i coefficient are 1, i.e.

$$I_{max} = \frac{V_R}{(2)^{n-1}R}(2^n - 1)$$

When all the bits of digital word have value of 1, then the output current of D/A converter is termed the full scale output current and is an important design parameter.

On the other hand, if all switches are open i.e. all a_i coefficients are zero, then the output voltage (current) is zero.

The maximum output voltage $V_o = -R_iI$ depends on the feedback resistor R_f. As, the operational amplifier is

Advantages

As only one resistor is used per it in the resistor network, thus it is an economical D/A converter.

Disadvantages / Limitations

1. Resistors used in the network have a wide range of values, so it is very difficult to ensure the absolute accuracy and stability of all the resistors.
2. It is very difficult to match the temperature coefficients of all the resistors. This factor is specially important in D/A converters operation over a wide temperature range.
3. When n is so large, the resistance corresponding to LBS can assume a large value, which may be comparable with the input resistance of the amplifier. This leads to erroneous results.
4. As the switches represent finite impedance that are connected in series with the weighted resistors and their magnitudes and variations have to be taken in to account in a D/A converter design.

R-2R Ladder Network

In case of weighted resistor DAC requires a wide range of resistance values and switches for each bit position if high accuracy conversion is required. A digital to analog converter with an R-2R ladder network as shown in figure 2 eliminates these complications at the expense of an additional resistor for each bit.

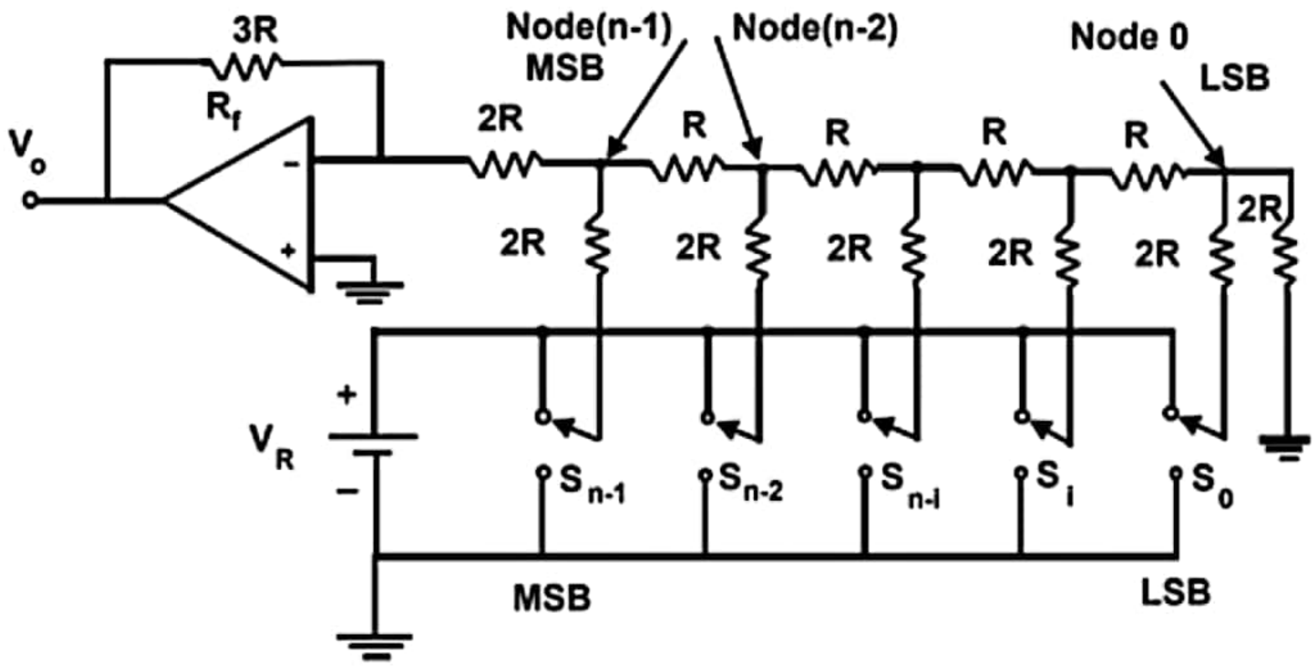

Figure 2: DAC Employing R-2R Ladder Network

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The operation of R-2R ladder DAC is easily explained considering the weights of the different bits one at a time. This can be followed by superposition to construct analog output corresponding any digital input word. Let only the MSB is turned ON in the first case, and all other bits are OFF, a simplified equivalent circuit can be drawn as shown in figure 3.

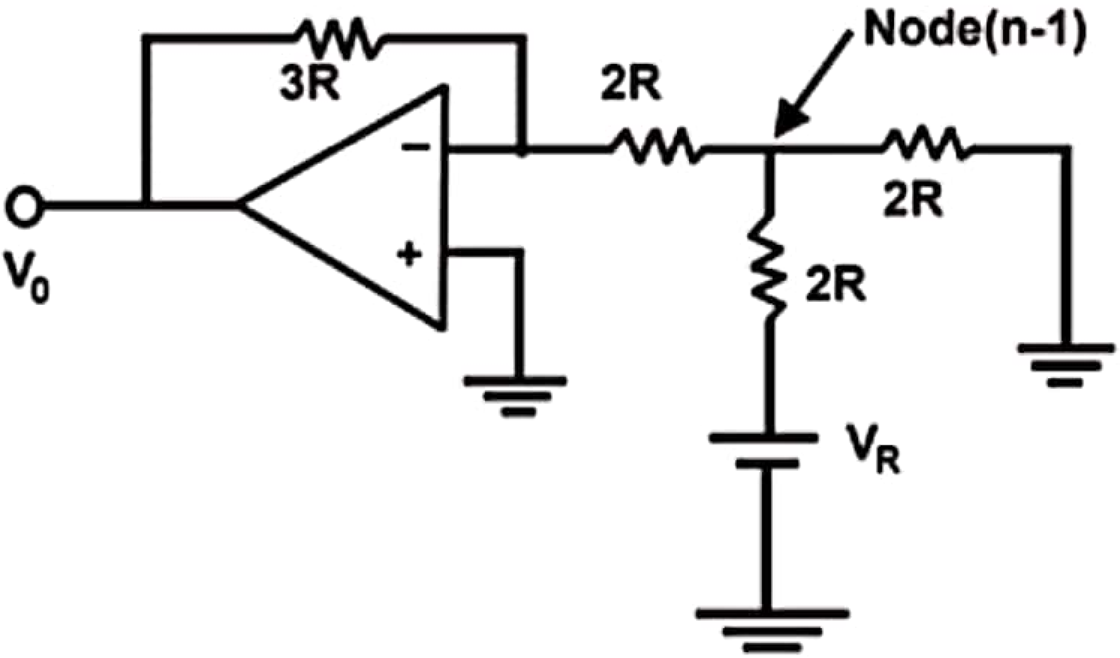

Figure 3: Equivalent Circuit for R-2R ladder network, when MSB is ON and all other are OFF

The equivalent circuit with only switch S_{n-2} connected to the reference voltage is shown in figure 4.

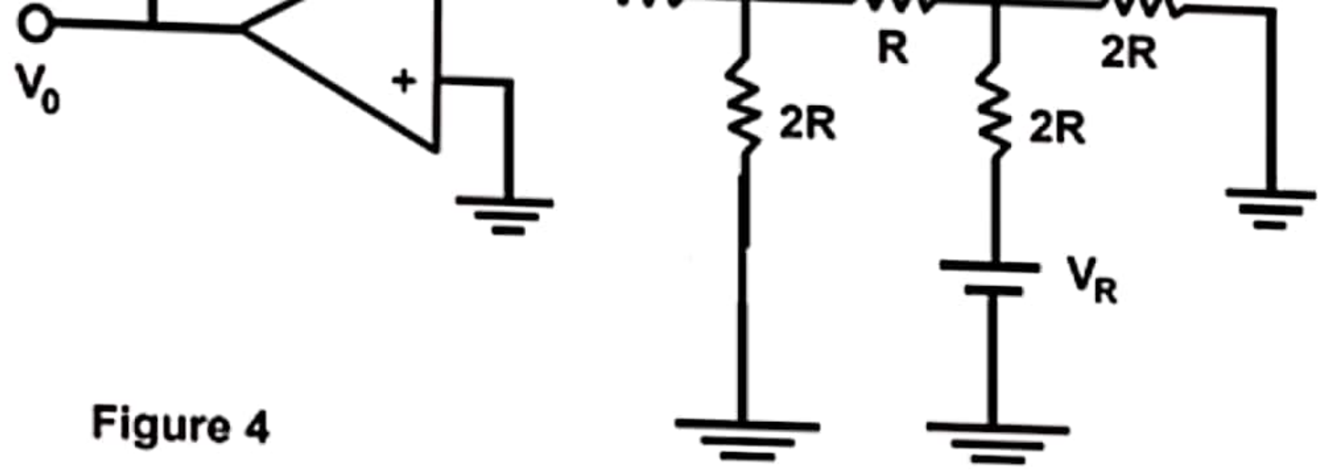

Figure 4

By using principle of superposition all contributions are summed up and the resultant output is

$V_o = V_R [a_{n-1} 2^{n-1} + a_{n-2} 2^{n-2} + \ldots\ldots\ldots\ldots a_1 2^{-(n-1)} + a_o 2^{-n}]$

$V_o = V_R 2^{-n} [a_{n-1} 2^{n-1} + a_{n-2} 2^{n-2} + \ldots\ldots\ldots\ldots a_1 2^{+1} + a_o 2^{o}]$

$$= -V_R 2^{-n} \sum_{i=0}^{n-1} a_i 2^i ; where\ a_i \in \{0,1\}$$

Note that a_i depends on whether th *i*the switch is at 0 or at V_R. Thus the output of the DAC is proportional to the sum of the weights represented by thosee switches that are connected to V_R and the ratio of resistors in the R-2R ladder network.

operational amplifier is taken as 3R, the corresponding output voltage du to the MSB alone is

$$V_o = (V_R / 3)(-3R / 2R)$$

$$= -V_R / 2$$

Let next switch S_{n-2} at V_R with all other switches at

Advantages

1. Only two values of resistors are used; R and 2R.
2. The actual value used for R is relatively less important as long as extremely large values, where stray capacitance enter the picture, are not employs only ratio of resistor values is critical.
3. R-2R ladder network are available in monolithic chips,. These are laser trimmed to be within 0.01% of the desired ratios.
4. The staircase voltage is more likely to be monotonic as the effect of the MSB resistor is not many times grater than that for LSB resistor.

From the name itself it is clear that it is a converter which converts the analog (continuously variable) signal to digital signal. This is really an electronic integrated circuit which directly converts the continuous form of signal to discrete form. It can be expressed as A/D or A-to-D or A-D or ADC. The input (analog) to this system can have any value in a range and are directly measured. But for output (digital) of an N-bit A/D converter, it should have only 2^N discrete values. This **A/D converter** is a linkage between the analog (linear) world of transducers and discreet world of processing the signal and handling the data. The digital to analog converter (DAC) carry out the inverse function of the ADC. The schematic representation of ADC is shown below.

Figure 1

ADC Process

There are mainly two steps involves in the process of conversion. They are

- Sampling and Holding
- Quantizing and Encoding

The whole ADC conversion process is shown in figure 2.

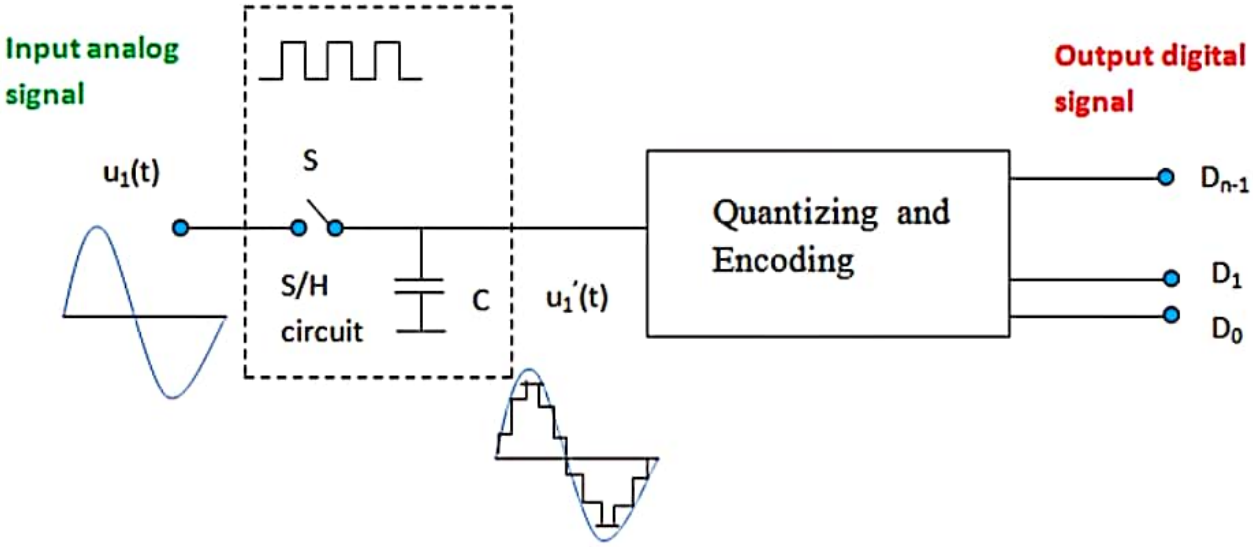

Figure 2

Sampling and Holding

In the process of Sample and hold (S/H), the continuous signal will gets sampled and freeze (hold) the value at a steady level for a particular least period of time. It is done to remove variations in input signal which can alter the conversion process and thereby increases the accuracy. The minimum sampling rate has to be two times the maximum data frequency of the

Quantizing and Encoding

For understanding quantizing, we can first go through the term Resolution used in ADC. It is the smallest variation in analog signal that will result in a variation in the digital output. This actually represents the quantization error.

$$Resolution, \Delta V = \frac{V_r}{2^N}$$

V → Reference voltage range

2^N → Number of states

N → Number of bits in digital output

Quantizing: It is the process in which the reference signal is partitioned into several elow.

Analog signal		
7.5	7	7Δ=7V
6.5	6	6Δ=6V
5.5	5	5Δ=5V

3 →	$3\Delta = 3V$ →	011
2 →	$2\Delta = 2V$ →	010
1 →	$1\Delta = 1V$ →	001
0 →	$0\Delta = 0V$ →	000

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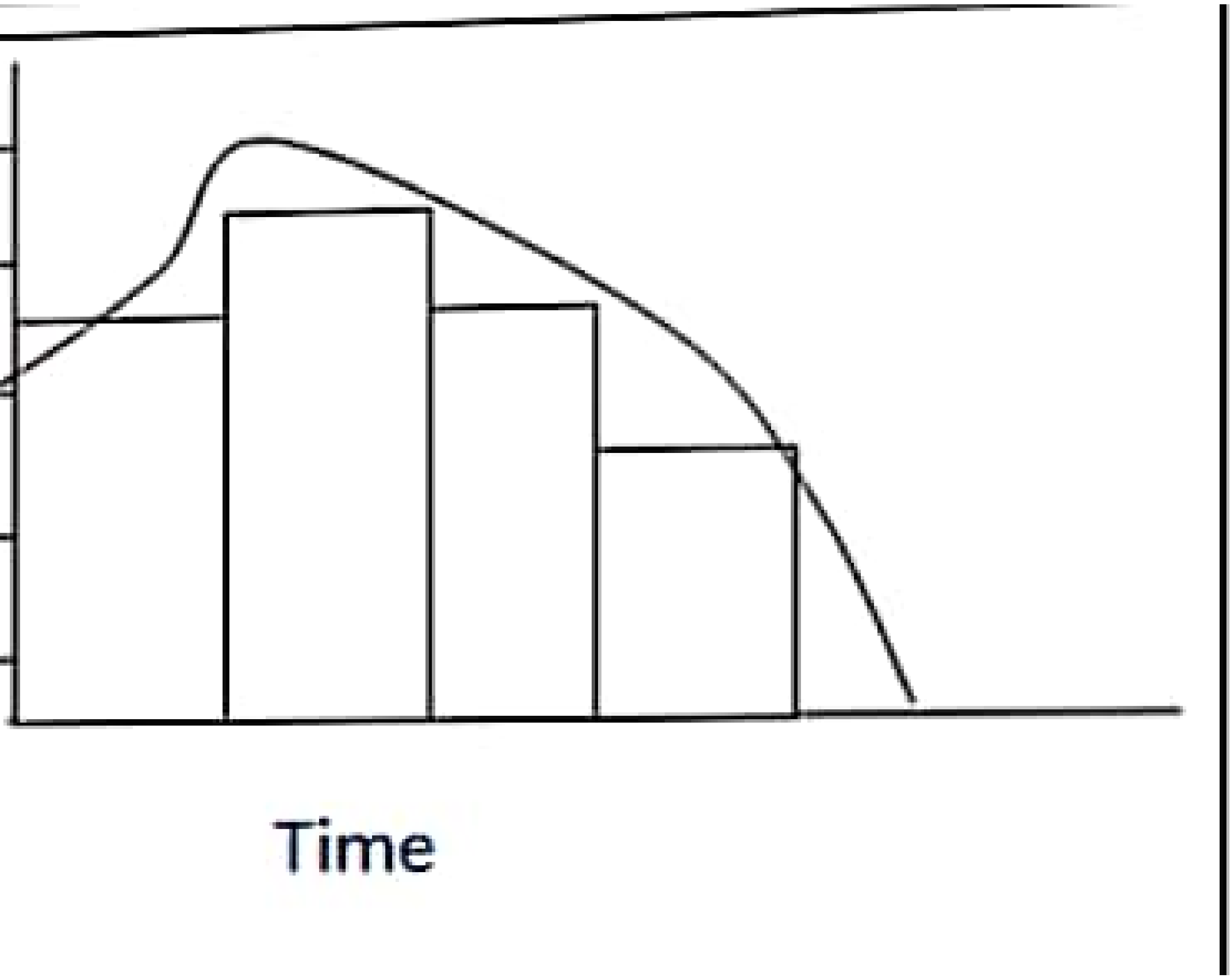
Time

- **Dual Slope ADC:** It have high accuracy but very slow in operation.
- **Pipeline ADC:** It is same as that of two step Flash ADC.
- **Delta-Sigma ADC:** It has high resolution but slow due to over sampling.
- **Flash ADC:** It is the fastest ADC but very expensive.
- **Other:** Staircase ramp, Voltage-to-Frequency, Switched capacitor, tracking, Charge balancing, and resolver.

Application of ADC

- Used together with the transducer.
- Used in computer to convert the analog signal to digital signal.
- Used in cell phones.
- Used in microcontrollers.
- Used in digital signal processing.

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- Used in microcontrollers.
- Used in digital signal processing.
- Used in digital storage oscilloscopes.
- Used in scientific instruments.
- Used in music reproduction technology etc.