Analog to Digital converters and Digital to Analog Converters

All the real world quantities are analog in nature. We can represent these quantities electrically as analog signals. An **analog signal** is a time varying signal that has any number of values (variations) for a given time slot.

In contrast to this, a **digital signal** varies suddenly from one level to another level and will have only finite number of values (variations) for a given time slot.

This chapter discusses about the types of data converters and their specifications.

Types of Data Converters

The electronic circuits, which can be operated with analog signals are called as analog circuits. Similarly, the electronic circuits, which can be operated with digital signals are called as digital circuits. A data converter is an electronic circuit that converts data of one form to another.

There are two **types of data converters** −

- Analog to Digital Converter
- Digital to Analog Converter

If we want to connect the output of an analog circuit as an input of a digital circuit, then we have to place an interfacing circuit between them. This interfacing circuit that converts the analog signal into digital signal is called as **Analog to Digital Converter**.

Similarly, if we want to connect the output of a digital circuit as an input of an analog circuit, then we have to place an interfacing circuit between them. This interfacing circuit that converts the digital signal into an analog signal is called as **Digital to Analog Converter**.

Note that some Analog to Digital Converters may require Digital to Analog Converter as an internal block for their operation.

Specifications

The following are the **specifications** that are related to data conversions −

- Resolution
- Conversion Time

Resolution

Resolution is the **minimum amount of change** needed in an analog input voltage for it to be represented in binary (digital) output. It depends on the number of bits that are used in the digital output.

Mathematically, resolution can be represented as

$$Resolution = \frac{V_{FS}}{2^N - 1}$$

where, V_{FS} - is the full scale input voltage or maximum analog input voltage,

'N' is the number of bits that are present in the digital output.

Conversion Time

The amount of time required for a data converter in order to convert the data (information) of one form into its equivalent data in other form is called as **conversion time**. Since we have two types of data converters, there are two types of conversion times as follows

- Analog to Digital Conversion time
- Digital to Analog Conversion time

The amount of time required for an Analog to Digital Converter (ADC) to convert the analog input voltage into its equivalent binary (digital) output is called as **Analog to Digital conversion time**. It depends on the number of bits that are used in the digital output.

The amount of time required for a Digital to Analog Converter (DAC) to convert the binary (digital) input into its equivalent analog output voltage is called as **Digital to Analog conversion time**. It depends on the number of bits that are present in the binary (digital) input.

A **Digital to Analog Converter (DAC)** converts a digital input signal into an analog output signal. The digital signal is represented with a binary code, which is a combination of bits 0 and 1.

A Digital to Analog Converter (DAC) consists of a number of binary inputs and a single output. In general, the **number of binary inputs** of a DAC will be a power of two.

Types of DACs

There are **two types** of DACs

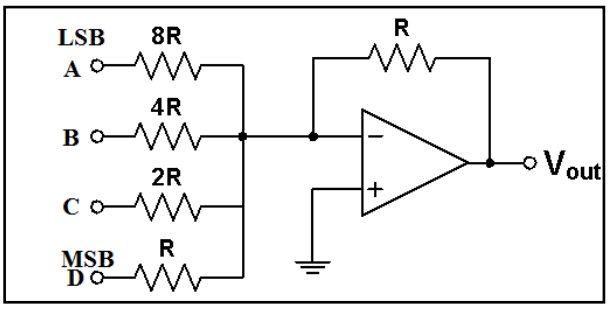
- Weighted Resistor DAC
- R-2R Ladder DAC

This section discusses about these two types of DACs in detail −

Weighted Resistor DAC

A weighted resistor DAC produces an analog output, which is almost equal to the digital (binary) input by using **binary weighted resistors** in the inverting adder circuit. In short, a binary weighted resistor DAC is called as weighted resistor DAC.

The **circuit diagram** of a 4-bit binary weighted resistor DAC is shown in the following figure –



The circuit diagram of D/A converter is summing amplifier with four digital inputs DCBA with D is MSB and weighted resistor R while A is LSB with weighted resistor 8R. The output voltage of D / A converter is given by,

$$V_0 = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4}\right)$$

$$V_0 = -R \left(\frac{D}{R} + \frac{C}{2R} + \frac{B}{4R} + \frac{A}{8R}\right)$$

$$V_0 = -\left(\frac{V_1}{2^0} + \frac{V_2}{2^1} + \frac{V_3}{2^2} + \frac{V_4}{2^3}\right)$$

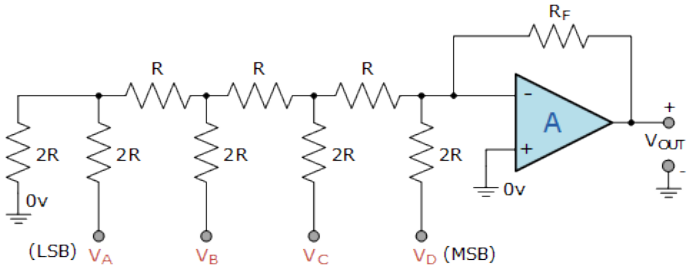
Where, D = V_1, C =V_2, B = V_3, A = V_4

Drawbacks

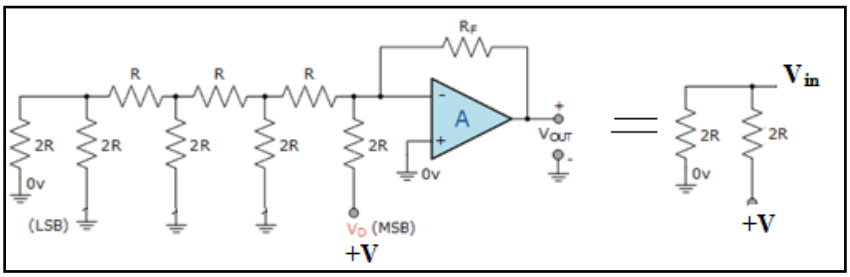
1. Each resistor has different value which is exactly half of the previous one. Such precision resistors may not available.
2. It requires wide range of resistors from $R\ to\ (2^n - 1)R$ for n bit
3. Each resistor has to handle different currents.
4. It may not possible to get low tolerance resistors.
5. Temperature change causes change in resistance, which affect the output.
6. Difficult to fabricate with integrated circuits techniques.

R-2R ladder network

R-2R ladder is a resistive network contains only two resistors value R and 2R. It has OP-AMP as a scaling circuit and MSB towards right and LSB input with left of the circuit.



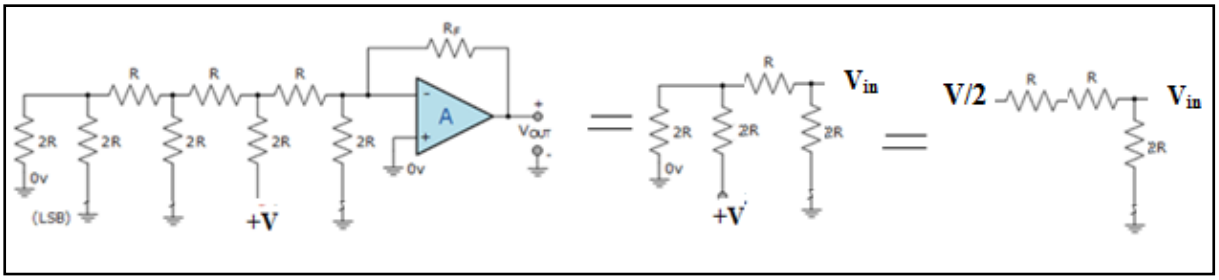
Suppose digital input is DCBA = 1000 then equivalent circuit becomes,



$$V_{in} = I \; x \; 2R$$

$$V_{in} = \frac{V \; x2R}{4R} = \frac{V}{2}$$

Suppose digital input is DCBA = 0100 then equivalent circuit becomes,



$$V_{in} = \frac{V/_2 \; x2R}{4R} = \frac{V}{4}$$

When DCBA = 0010 then V_{in} = V / 8

When DCBA = 0001 then V_{in} = V / 16

The output of complete D/A converter is calculated by summing amplifier

$$V_0 = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4}\right)$$

$$V_0 = -R \left(\frac{D}{2R} + \frac{C}{4R} + \frac{B}{8R} + \frac{A}{16R}\right)$$

$$V_0 = -\left(\frac{V_1}{2^1} + \frac{V_2}{2^2} + \frac{V_3}{2^3} + \frac{V_4}{2^4}\right)$$

Analog to Digital converter

The method of conversion of an analog voltage into an equivalent digital number is known as analog to digital converter.

Types of ADCs

There arefour **types** of ADCs

- Simultaneous ADC (Flash type ADC)
- Counter type ADC
- Successive Approximation type ADC

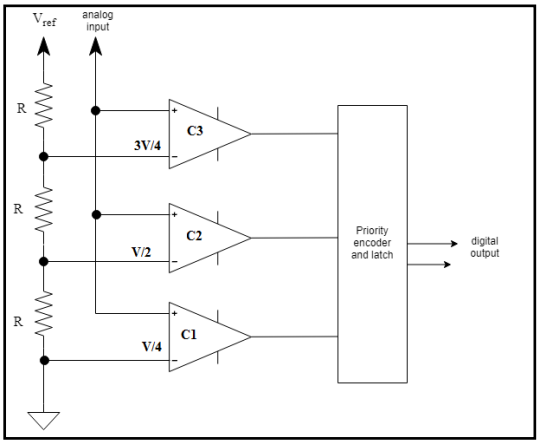
- Dual slope ADC

Simultaneous ADC (Flash type ADC)

Also called the parallel A/D converter, this circuit is the simplest to understand. It is formed of a series of comparators, each one comparing the input signal to a unique reference voltage. The comparator outputs connect to the inputs of a priority encoder circuit, which then produces a binary output.

V_{ref} is a stable reference voltage provided by a precision voltage regulator as part of the converter circuit, not shown in the schematic. As the analog input voltage exceeds the reference voltage at each comparator, the comparator outputs will sequentially saturate to a high state. The priority encoder generates a binary number based on the highest-order active input, ignoring all other active inputs.

To construct n bit A / D converter $(2^n) - 1$ comparators are essential. Figure shows 2 bit A /D converter. The circuit consist of voltage divider network, 3 comparators and 3 line to 2 line priority encoder. At each node of the resistive network the comparison voltage is available. Since all the resistors are of equal value the voltage levels available at nodes are equally divided between reference voltage and ground. The purpose of the circuit is to compare analog voltage with each of node voltage.



Analog input voltage	C3	C2	C1	Digital output	
$0\ to\ {}^{V}/_{4}$	0	0	0	0	1
$> {}^{V}/_{4}\ to\ {}^{V}/_{2}$	0	0	1	0	1
$> {}^{V}/_{2}\ to\ {}^{3V}/_{4}$	0	1	1	1	0
$> {}^{3V}/_{4}\ to\ V$	0	1	1	1	1

When input is between $0\ to\ {}^{V}/_{4}$ then the output is C3C2C1 = 000

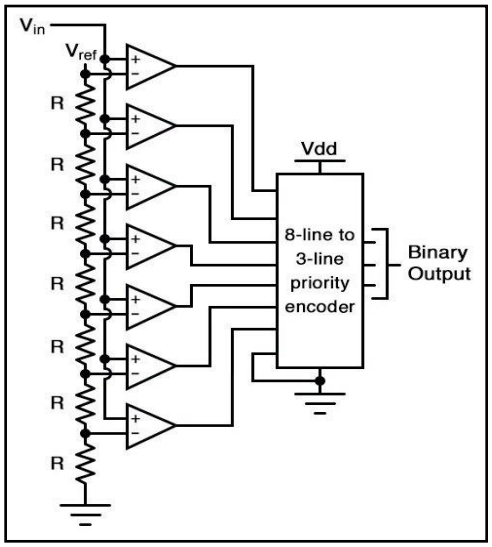
When input is between $> {}^{V}/_{4}\ to\ {}^{V}/_{2}$ then the output is C3C2C1 = 001

When input is between $> {}^{V}/_{2}\ to\ {}^{3V}/_{4}$ then the output is C3C2C1 = 011

When input is between $> {}^{3V}/_{4}$ *to* V then the output is C3C2C1 = 111

Advantage – High speed as data conversion takes place simultaneously hence called flash type ADC

Disadvantage – It requires more comparators and is very difficult to construct with discrete circuits.



Counter type A/D converter

A **counter type ADC** produces a digital output, which is approximately equal to the analog input by using counter operation internally.

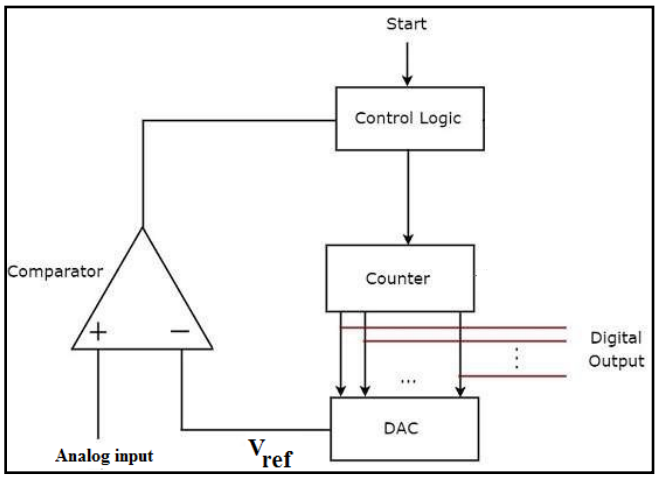
The **block diagram** of a counter type ADC 4 blocks: Counter, DAC, Comparator and Control logic.

The **working** of a counter type ADC is as follows −

- The **control logic** resets the counter and enables the clock signal generator in order to send the clock pulses to the counter, when it received the start commanding signal.
- The **counter** gets incremented by one for every clock pulse and its value will be in binary (digital) format. This output of the counter is applied as an input of DAC.
- **DAC** converts the received binary (digital) input, which is the output of counter, into an analog output. Comparator compares this analog value, V_{ref} with the external analog input value V_i.
- The **output of comparator** will be **'1'** as long as V_i is greater than V_{ref}. The operations mentioned in above two steps will be continued as long as the control logic receives '1' from the output of comparator.
- The **output of comparator** will be **'0'** when V_i is less than or equal to V_{ref}. So, the control logic receives '0' from the output of comparator. Then, the control logic

disables the clock signal generator so that it doesn't send any clock pulse to the counter.

- At this instant, the output of the counter will be displayed as the **digital output**. It is almost equivalent to the corresponding external analog input value V_i.



Advantage and Disadvantages –

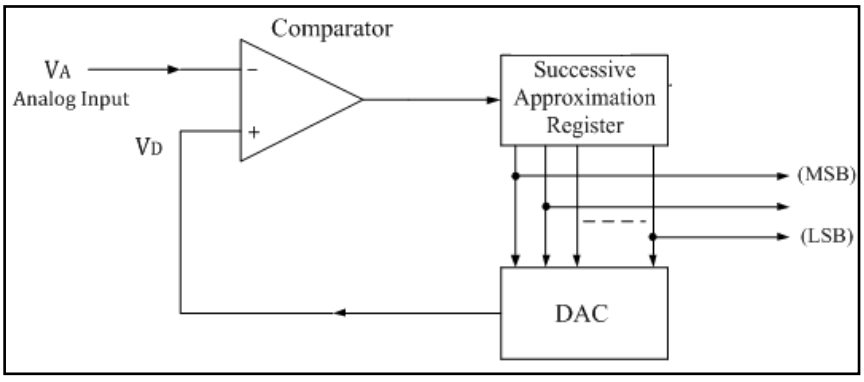
1. Good method of conversion to high resolution
2. Method is simple than simultaneous ADC

The main drawback is long conversion time because counter always start from 000 and advances through each count.

successive approximation type ADC

A **successive approximation type ADC** produces a digital output, which is approximately equal to the analog input by using successive approximation technique internally.

The **block diagram** of a successive approximation ADC is shown in the following figure

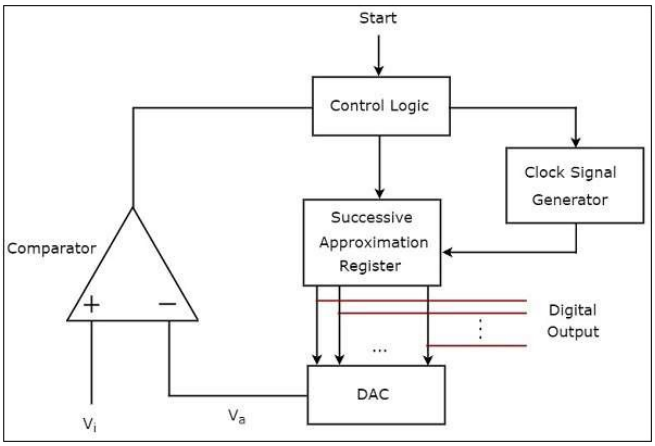


Successive Approximation type ADC is the most widely used and popular ADC method. The conversion time is maintained constant in successive approximation type ADC, and is proportional to the number of bits in the digital output, unlike the counter and continuous type A/D converters. The basic principle of this type of A/D converter is that the unknown analog input voltage is approximated against an n-bit digital value by trying one bit at a

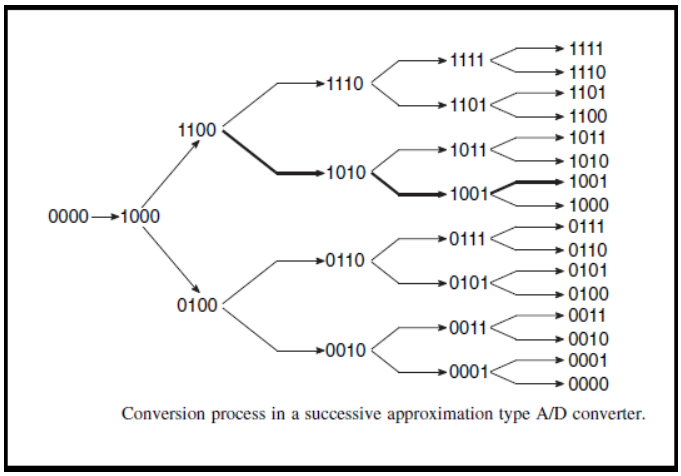
time, beginning with the MSB. The principle of successive approximation process for a 3-bit conversion is explained here. This type of ADC operates by successively dividing the voltage range by half, as explained in the following steps.

(1) The MSB is initially set to 1 with the remaining two bits set as 00. The digital equivalent voltage is compared with the unknown analog input voltage

(2) If the analog input voltage is higher than the digital equivalent voltage, the MSB is retained as 1 and the second MSB is set to 1. Otherwise, the MSB is set to 0 and the second MSB is set to 1. Comparison is made as given in step (1) to decide whether to retain or reset the second MSB.



This type of A/D converter is widely used in digital voltmeters, for interfacing analog signals with computers because of its high speed and better resolution.



Conversion process in a successive approximation type A/D converter.