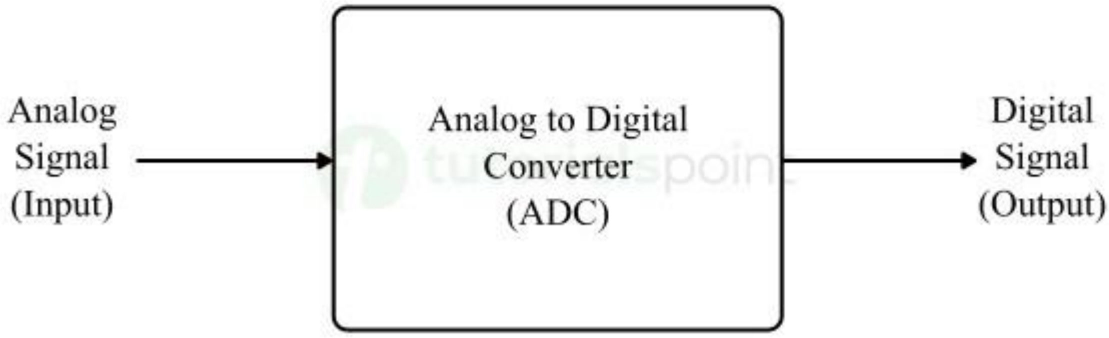
ANALOG TO DIGITAL CONVERTER

An **analog-to-digital converter**, also known as **ADC**, is a digital circuit used to convert analog signals into digital format.The conversion of analog signals into digital format is crucial for their processing with the help of digital systems like microprocessors, microcontrollers, digital signal processors (DSPs), etc. Therefore, ADCs are important components in several digital systems like computers and other digital devices.

What is an Analog to Digital Converter?

An analog to digital converter is a digital circuit designed to perform conversion of analog signals into digital data format. It is also known ADC. Analog to digital converters are essential components in digital systems like computers, data processors, digital communication systems, etc.



From this figure, it is clear that the input to an analog to digital converter is an analog or natural signal and the output is a digital or discrete time signal. The analog to digital converter serves as an interface between external environment and a digital system.

Working of Analog to Digital Converter

The working of an analog to digital converter involves the processes explained below −

Inputting Analog Signal

An analog to digital converter takes an analog signal as input. The analog signal could be a voltage, current, temperature, pressure, or any other physical quantity that changes continuously with time.

Sampling

At this stage, the analog to digital converter samples the input analog signal at regular intervals of time. These time intervals are defined in terms of sampling rate.

In the sampling process, the analog signal that varies continuously over time is measured at discrete instants of time to collect discrete values of the signal.

Quantization

Quantization is a process of assigning a digital or discrete value to each sampled value of the analog signal. In the process of quantization, the range of all possible analog values is divided into a finite number of discrete digital values.

Encoding

Encoding is a process of converting the quantized digital values into their equivalent binary numbers. These encoded binary numbers represent the sampled analog values in the digital format.

The resolution, accuracy, and precision of the analog to digital converter is determined by the number of bits used for encoding.

Outputting Digital Signal

At the end, the analog to digital converter produces a digital signal as output. This output digital signal can be processed, stored, or transmitted by digital systems.

Performance Factors of Analog to Digital Converters

The performance of an analog to digital converter can be evaluated using several different factors. The following two are the most important −

Signal-to-Noise Ratio (SNR) of ADC

The Signal-to-Noise Ratio (SNR) of an analog to digital converter is defined as the measure of ability of the converter to differentiate between the desired signal and unwanted noise signal.

Mathematically, the SNR of an analog to digital converter is expressed as the ratio of the power of the electrical signal (that represents the useful information) to the power of the noise signal (that represents the unwanted disturbances).

In practice, the SNR is expressed in decibels (dB) and the formula for calculating the SNR of an ADC is given below,

$$\text{SNR of ADC} = 10 \times \log(\text{ElectricalSignalPower}/\text{NoiseSignalPower})$$

From this expression, it is clear that a higher SNR represents better performance of the analog to digital converter. In other words, an analog to digital converter having a high SNR distinguishes the electrical signal from the noise signal more clearly. Therefore, it is desirable that the analog to digital converter have a high SNR so that it can accurately capture and digitalize smaller analog signals even in the presence of noise signals.

Bandwidth of Analog to Digital Converter

The bandwidth of an analog to digital converter is nothing but the range of frequencies that it can sample and digitalize accurately. The sampling rate of the analog to digital converter determines its bandwidth. Where, the sampling rate is defined as the number of samples of the analog signal taken per second.

According to the Nyquist-Shannon sampling theorem, the maximum sampling rate of an analog to digital converter should be at least double of the maximum frequency component present in the input analog signal. It is an important factor to avoid misidentification of the signal that can introduce distortion or error in sampling.

Types of Analog-to-Digital Converters

In digital electronics, different types of analog-to-digital converters (ADCs) are designed to fulfil the requirements of different applications.Some of common types of analog-to-digital converters include the following –

- Flash ADC
- Successive Approximation Register ADC

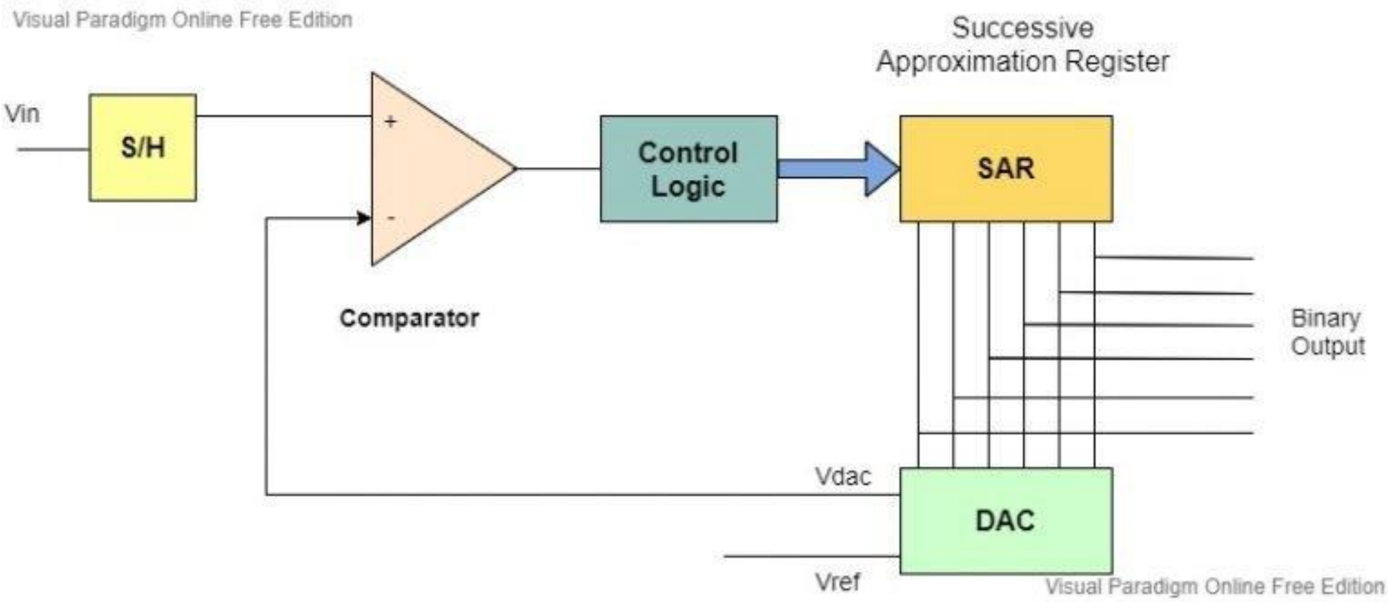
Flash ADC

Flash ADC, also known as **Direct ADC**, is the fastest ADC available. This type of ADC has sampling rates of the order of gigahertz. The flash ADCs offer such high speeds because they use a bank of comparators that can operate in parallel, each for a certain voltage range.

However, the flash ADCs are relatively larger in size and costlier than other types of ADCs. Also, they consume relatively more power. In the case of a flash ADC, if "n bits" is resolution of the ADC, then it requires (2^n – 1) comparators in its bank. For example, a flash ADC having 8-bit resolution requires ($2^8 - 1 = 255$) comparators.

The flash analog-to-digital converters are mainly used in digitization of video signals or fast signals in optical storage.

Successive Approximation Register ADC



The Successive Approximation Register Analog to Digital Converter, abbreviated as SAR ADC, is a type of analog to digital converter that uses a series of comparisons to determine each bit of the digital output.

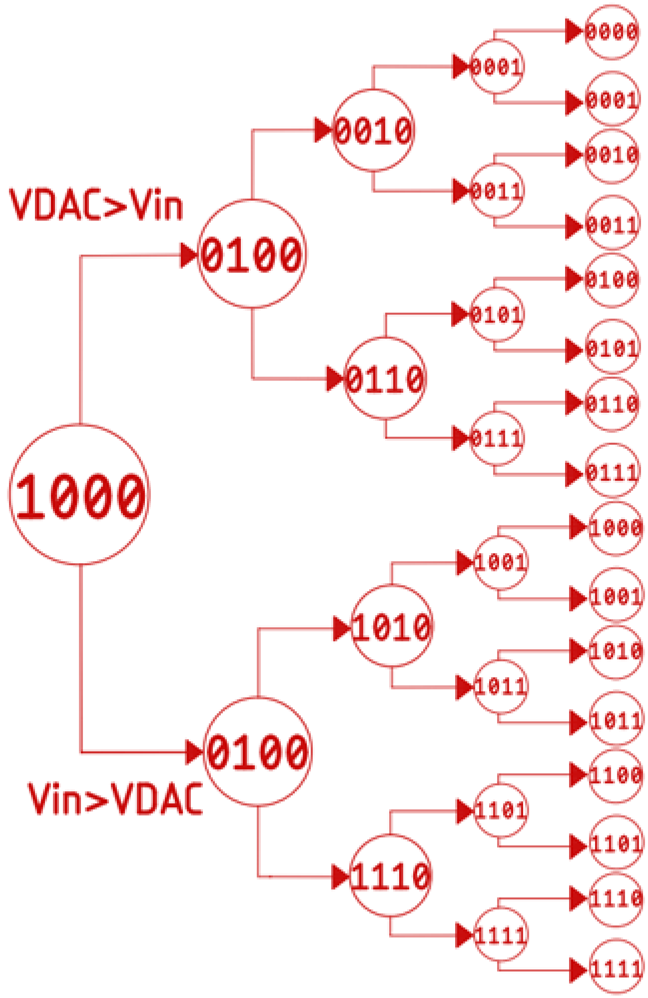
The SAR ADC starts working by initializing its internal approximation registers. Then, it takes a sample of the input analog signal and stores it steady until the conversion process completes.

After that a binary search algorithm is utilized to perform approximation of the input signal. This process starts by setting the most significant bit (MSB) of the output digital signal to the highest value and compares this value with the sampled input analog signal.

In the next step, the SAR ADC compares the sampled input analog signal with the output of an internal digital-to-analog converter that produces a signal proportional to the current approximation of the input signal.

Depending on results of the comparison, the SAR ADC successively changes the value of each bit in the digital output until the desired output is obtained. Once all bits of the digital output have been determined, the SAR converter completes the conversion process. The digital output obtained represents the digital approximation of the sampled input analog signal.

The SAR analog-to-digital converters are commonly used in various applications, such as consumer electronics, medical instruments, data acquisition systems, etc.



Applications of Analog to Digital Converter

Analog-to-digital converters (ADCs) are used in various industries and fields where analog signals have to be processed, analyzed, or transmitted using digital systems like computers. Some common applications of analog to digital converters are listed below −

- In the field of digital signal processing, ADCs are used for converting analog signals obtained from sensors, microphones, or other analog devices into digital format for processing them using digital processors.

- In audio processing applications, ADCs are used to convert analog audio signals into digital format for storage, manipulation, and transmission in digital systems.
- ADCs are essential components in various **data acquisition systems** used in the field of scientific research, industrial automation, and instrumentation.
- In communication systems, ADCs are used to convert analog audio or video signals into digital format for transmission over communication channels.
- ADCs are used in **radio receivers** for digitization of received radio frequency (RF) signals.
- ADCs play an important role in several **medical equipment and healthcare systems** for converting various analog bio-signals and physiological parameters like heart rate, blood pressure, oxygen saturation, EEG signals, etc. into digital format to process them using digital systems.
- In **automotive electronics**, ADCs are used to convert analog signals received from sensors measuring parameters such as temperature, torque, speed, etc. into digital format for driver assistance and vehicle diagnostics.
- ADCs are also used in a wide range of consumer electronic devices such as smartphones, tablets, laptops, entertainment equipment, etc.

DIGITAL TO ANALOG CONVERTERS

The block diagram of DAC is shown in the following figure −

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.

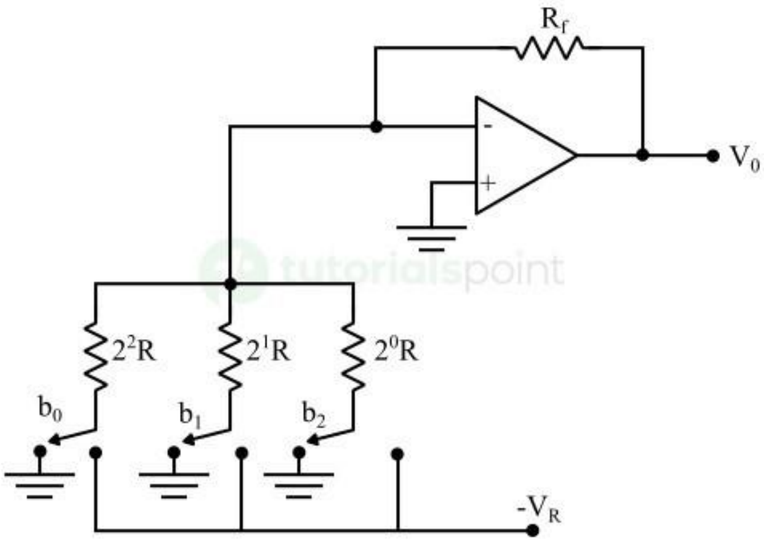
Types of Digital to Analog Converters

Depending on the construction and structure, there are two types of digital to analog converters, they are −

- Weighted Resistor DAC
- R-2R Ladder DAC

  - ## 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 3-bit binary weighted resistor DAC is shown in the following figure −



The bits of a binary number can have only one of the two values. i.e., either 0 or 1. Let the 3-bit binary input is $b_2b_1b_0$. Here, the bits b_2 and b_0 denote the Most Significant Bit (MSB) and Least Significant Bit (LSB) respectively.

The digital switches shown in the above figure will be connected to ground, when the corresponding input bits are equal to '0'. Similarly, the digital switches shown in the above figure will be connected to the negative reference voltage, $-V_R$ when the corresponding input bits are equal to '1'.In the above circuit, the non-inverting input terminal of an op-amp is connected to ground. That means zero volts is applied at the non-inverting input terminal of op-amp.According to the virtual short concept, the voltage at the inverting input terminal of op-amp is same as that of the voltage present at its non-inverting input terminal. So, the voltage at the inverting input terminal's node will be zero volts.

$$\therefore V_o = -IR_f$$

$$\therefore V_o = -[I_1 + I_2 + I_3 + \dots\dots\dots\dots + I_n]R_f$$

$$\therefore V_o = -\left[B_1 \frac{V_R}{2^1 R} + B_2 \frac{V_R}{2^2 R} + B_3 \frac{V_R}{2^3 R} + \dots\dots + B_n \frac{V}{2^n}\right.$$

$$V_o = -\frac{R_f}{R} V_R[B_1.2^{-1} + B_2.2^{-2} + B_3..2^{-3} + \dots\dots\dots + B_n..2^{-}$$

$$If\, R_f = R$$

$$\therefore V_o = -V_R[B_1.2^{-1} + B_2.2^{-2} + B_3..2^{-3} + \dots\dots\dots + B_n..2^{-n}]$$

Disadvantages of Weighted Resistor DAC

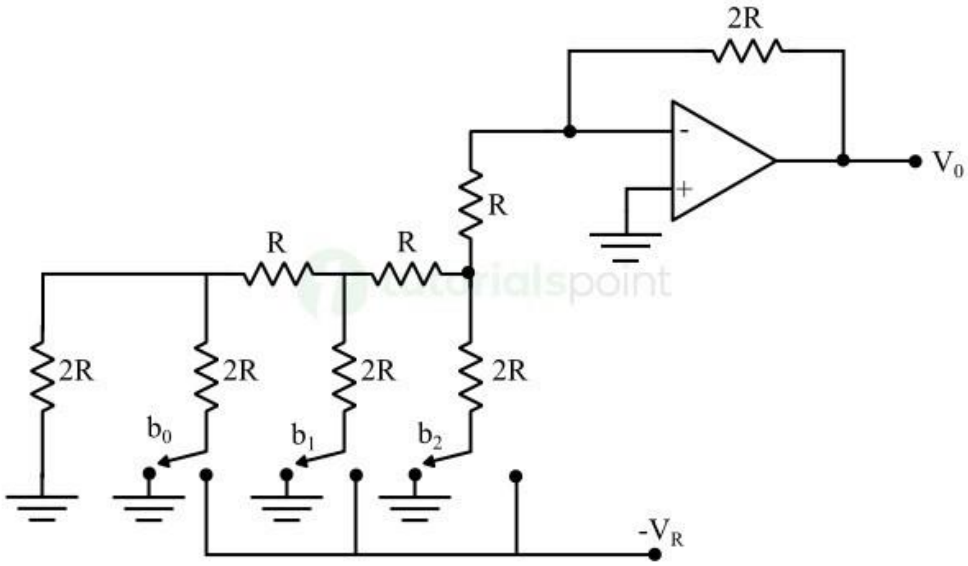
The disadvantages of the binary weighted resistor DAC are as follows −

- The difference between the resistance values corresponding to LSB & MSB will increase as the number of bits present in the digital input increases.
- It is difficult to design more accurate resistors as the number of bits present in the digital input increases.

R-2R Ladder DAC

The R-2R Ladder DAC overcomes the disadvantages of a binary weighted resistor DAC. As the name suggests, R-2R Ladder DAC produces an analog output, which is almost equal to the digital (binary) input by using a R-2R ladder network in the inverting adder circuit.

The circuit diagram of a 3-bit R-2R Ladder DAC is shown in the following figure −



The bits of a binary number can have only one of the two values. i.e., either 0 or 1. Let the 3-bit binary input is $b_2b_1b_0$. Here, the bits b_2 and b_0 denote the Most Significant Bit (MSB) and Least Significant Bit (LSB) respectively.

The digital switches shown in the above figure will be connected to ground, when the corresponding input bits are equal to '0'. Similarly, the digital switches shown in above figure will be connected to the negative reference voltage, $-V_R$ when the corresponding input bits are equal to '1'.

It is difficult to get the generalized output voltage equation of a R-2R Ladder DAC. But we can find the analog output voltage values of R-2R Ladder DAC for individual binary input combinations easily.

Advantages of R-2R Ladder DAC

The advantages of a R-2R Ladder DAC are as follows −

- R-2R Ladder DAC contains only two values of resistor: R and 2R. So, it is easy to select and design more accurate resistors.
- If a greater number of bits are present in the digital input, then we have to include required number of R-2R sections additionally.

Due to the above advantages, R-2R Ladder DAC is preferable over binary weighted resistor DAC.

Applications of Digital to Analog Converters

Digital to analog converters are widely used in a variety of applications in the field of digital electronics. The main function of a digital to analog converter is to convert a digital signal into analog format.

The following are some common devices and systems in which the digital to analog converters are used −

- Audio amplifiers and playback systems
- Video encoder systems
- Data acquisition systems
- Calibration of testing and measuring instruments
- Motor control circuits
- Digital signal processors
- Telecommunication systems, etc