Digital to Analog Convertor and Analog to Digital Convertor

- In an audio amplifier the signal could have a value that was anything from a fraction of a millivolt to several volts; there is no one level that the signal can be assumed to have. The level at the pick-up end of the system is quite different from that at the speaker end. The same is true of any system that uses an analogue input and gives an analogue output.

- A digital signal has only two values, known as logic 0 and logic 1. A system based on these values is termed a binary system; this is the system that all digital computers use. It is only necessary to assign nominal values of voltage to these two binary values and to design the computer circuits so that they are capable of distinguishing between them, a quite easy task for it to do. Naturally, if 0 V is assigned to logic 0 and +5 V is assigned to logic 1 (as is quite usual), we must expect that there will be departures from these values due, for example, to voltage drops in the system, but it is quite easy to allow the two logic levels to have tolerances and still be capable of being distinguished, one from the other.

- The two types of signal are totally incompatible and to make an actual conversion from the analogue to the digital form. The circuit that performs this conversion is known as an **analogue-to-digital converter (ADC).**

- In control systems where a computer is used to control a process, such as the temperature of a furnace, by monitoring the variable (in this case temperature) and generating a signal that is then sent to a controller to maintain the required temperature and the latter will often also need converting because it may well be an analogue device as well, quite unable to respond directly to the digital signal produced by the computer. The device that performs this conversion is known as a **digital-to-analogue converter (DAC).**
- A controller often has to measure a physical quantity, for example temperature, pressure, force, etc. A sensor, often called a transducer, is used to convert this physical quantity into an electrical signal (current or voltage). This electrical signal must then be converted into a binary number so that the digital controller can use it. An analog to digital (A/D) converter (ADC) performs this function.
- **A digital-to-analog (D/A)** converter **(DAC)** is a chip or circuit that converts a digital number into an analog voltage or current. D/As are used to control devices that require a range of control voltages or currents such as electro-acoustic transducers (speakers), some types of variable-speed motors, and many other applications where an analog signal output is required.

Digital to Analog Convertor

- A D/A converter can be visualized as a circuit that adds up a number of voltages under the control of a digital signal. Each voltage can be turned on and off by an electronic switch which is controller by the digital input. The circuit below shows a 3-bit D/A consisting of a summing amplifier fed by three different voltages. Depending on which switches are closed, the output can range from 0 to 7 volts. By using digital signals to control the switches we can build a circuit whose output voltage is proportional to the digital value.

D/A Converter Specifications:

Many different Digital-to-Analog converters are commercially available, both as chips and as subsystems (modules, boards, etc). To select the right D/A converter it is necessary to understand D/A specifications.

DACs can be specifying according to the following parameters:

1. **Interface Type:**

Serial	The output interface is a general serial port.
Parallel	The output interface is a general parallel port.
SPI	The output interface is a serial peripheral interface (SPI) port. SPI was developed by Motorola.
I^2C	Inter-Integrated Circuit (I^2C) bus is a two-wire, low-to-medium speed, communication bus developed by Philips Semiconductors in the early 1980's.
Microwire	MICROWIRE™ is a serial protocol created by National Instruments.

2. **Architecture**

R-2R	Digital-to-analog converters use a resistive ladder network to produce the transfer function of the DAC. Each segment of the ladder consists on a resistor of value R and a resistor of value 2R.
Resistor String	A DAC that uses string of resistors, each of value R, to produce the conversion.
Current-Steering	A type of DAC architecture that uses an internal current source to deliver the output current.
Sigma-Delta	The Sigma-Delta ADC architecture takes a fundamentally different approach from those outlined above. In its most basic form, a sigma-delta converter consists of an integrator, a comparator, and a single-bit DAC. The output of the DAC is subtracted from the input signal. The resulting signal is then integrated, and the integrator output voltage is converted to a single-bit digital output (1 or 0) by the comparator. The resulting bit becomes the input to the DAC, and the DACs output is subtracted from the ADC input signal, etc. This closed-loop process is carried out at a very high "over sampled" rate. The digital data coming from the ADC is a-stream of ones and zeros, and the value of the signal is proportional to the density of digital ones coming from the comparator. This bit stream data is then digitally filtered and decimated to result in a binary-format output.

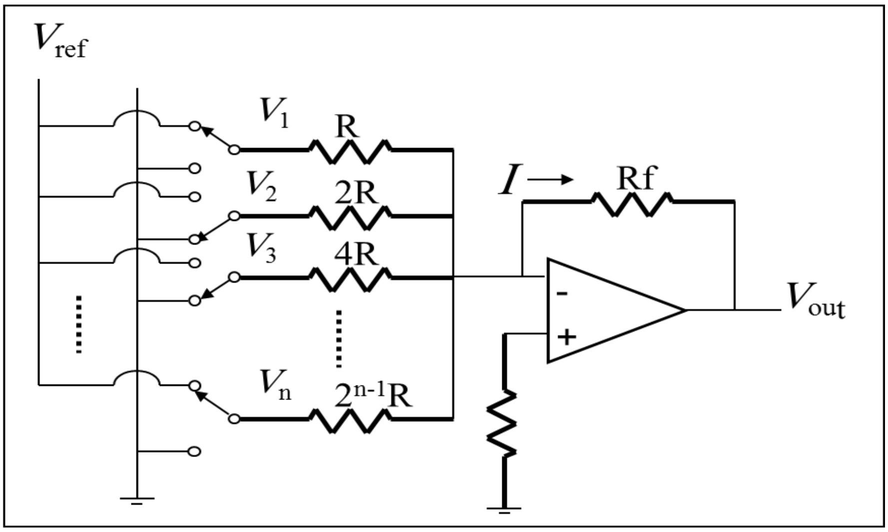
3. **Output Type**

Voltage	The DAC produces a voltage as the analog output.
Current	The DAC produces a current as the analog output.

DAC Types:

1. Binary Weighted Resistor DAC

Binary Weighted Resistor is a variation on the inverting summer Operational amplifier (op-amp) circuit, which is an operational amplifier using negative feedback for controlled gain, with several voltage inputs and one voltage output, as shown in Figure below.



V_1 is most significant bit (MSB).

V_n is least significant bit (LSB).

MSB → LSB

$$V_{out} = -IR_f = -R_f\left(\frac{V_1}{R} + \frac{V_2}{2R} + \frac{V_3}{4R} + \cdots \frac{V_n}{2^{n-1}R}\right)$$

if $R_f = R/2$

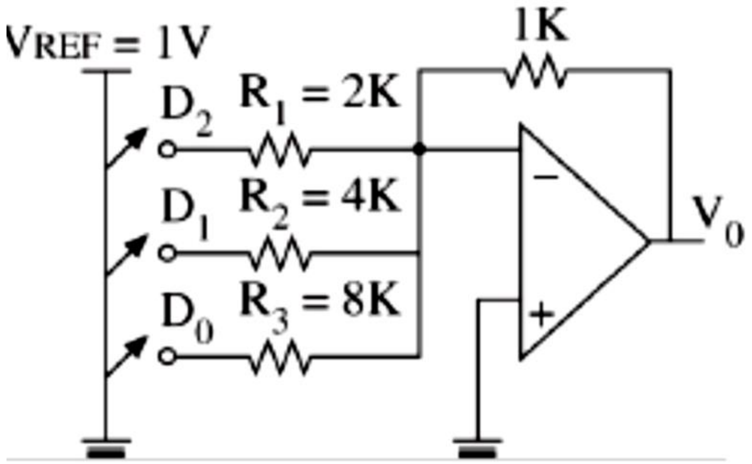
$$V_{out} = -IR_f = -\left(\frac{V_1}{2} + \frac{V_2}{4} + \frac{V_3}{8} + \cdots \frac{V_n}{2^n}\right)$$

For Example, a 4-bit converter yields:

$$V_{out} = -V_{ref}\left(b_3\frac{1}{2} + b_2\frac{1}{4} + b_1\frac{1}{8} + b_0\frac{1}{16}\right)$$

Where b_3 corresponds to Bit-3, b_2 to Bit-2, etc.

EXAMPLE 1: For a 3-bit Binary Weighted Resistor D/A converter circuit, if the reference voltage is 1V, feedback resistor = R/2, with R = 2 KΩ, and if all switches are connected, calculate the output voltage and the output current.



EXAMPLE 2: For a D/A converter, what will be the analog equivalent voltage of 10010001, if the reference voltage is 5 V, and feedback resistor = R/2.

Advantages and Disadvantages of Binary Weighted Resistor:

A. **Advantages:**

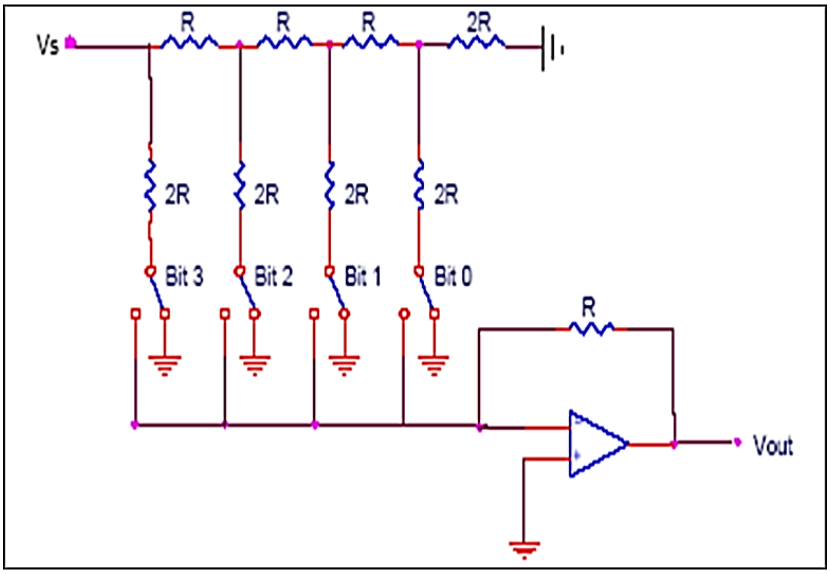
- Fewer Components. So, easy to build for IC's. Thus, simple construction/analysis.
- Fast Conversion.

B. **Disadvantages:**

- Hard to match resistors.
- Requires large range of resistors (2000:1 for 12-bit DAC) with necessary high precision for low resistors. But, large R more susceptible to noise. Thus, it can be expensive. So, it's usually limited to 8-bit resolution.

2. R-2R Ladder DAC

The R-2R Digital to Analog Converter uses only two resistance values R and 2R regardless of the number of bits of the converter compared to the summing amplifier implementation where each bit resistor has a different value, as shown in Figure below.



For a 4-Bit R-2R Ladder:

$$V_{out} = -V_{ref}\left(b_3\frac{1}{2} + b_2\frac{1}{4} + b_1\frac{1}{8} + b_0\frac{1}{16}\right)$$

For general n-Bit R-2R Ladder or Binary Weighted Resister DAC:

$$V_{out} = -V_{ref}\sum_{i=1}^{n} b_{n-i}\frac{1}{2^i}$$

EXAMPLE 3: For a 3-bit R-2R Ladder D/A converter circuit, if the reference voltage is 10 Volts, chart the output voltages for all combinations of binary bits.

Advantages and Disadvantages of R-2R Ladder:

A. Advantages:

- Greater Stability.
- Needs only two values of resistors (R-2R).
- Less reference voltage loading.
- Does not require high precision resistors.

B. Disadvantages:

- More parts. So, it’s harder to construct.
- Lower conversion speed than binary weighted DAC.

3. **Simplified PSpice Simulation** An illustrative circuit design is shown to the right, with the switch arrangements replaced by three square-wave voltage sources used to produce the eight possible binary input voltage combinations.