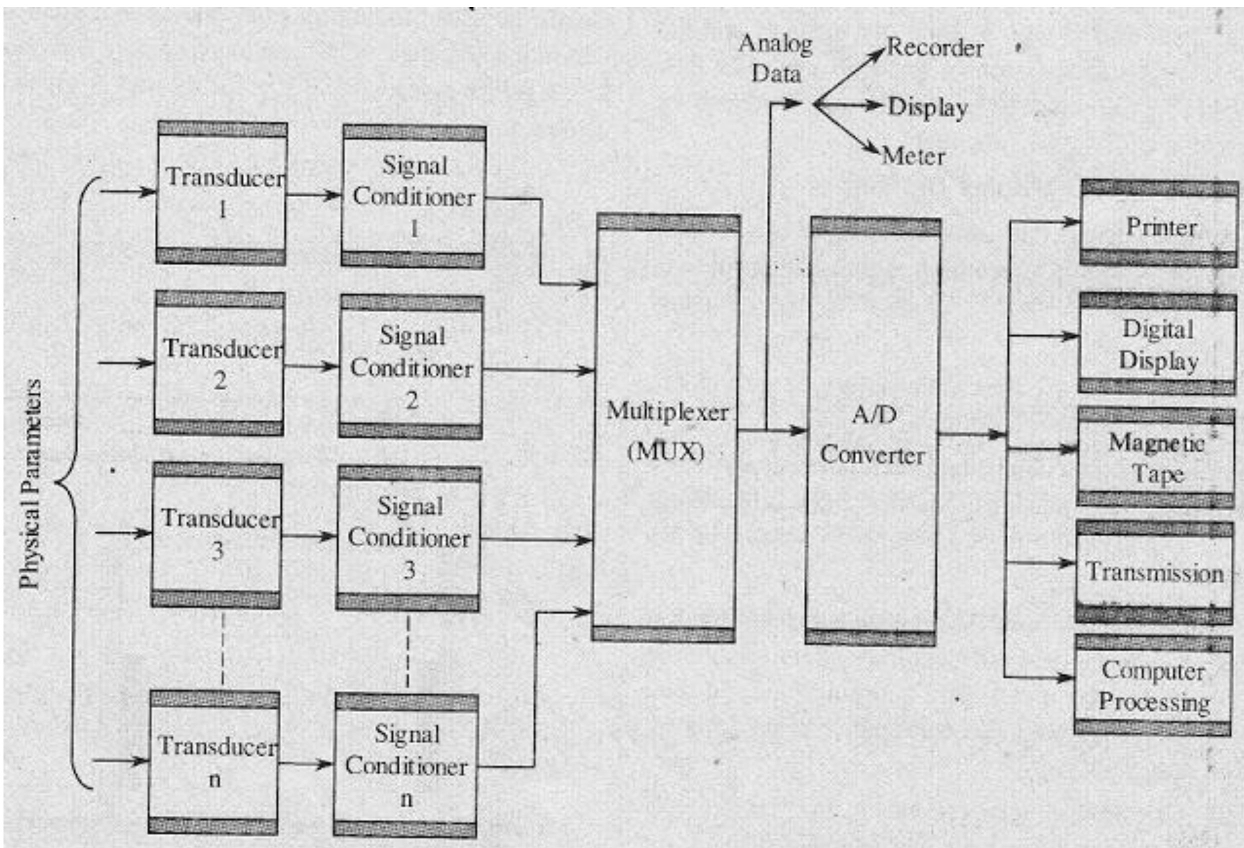
Sensor and instrument-unit 4 notes

Sensor and Instrumentation (Dr. A.P.J. Abdul Kalam Technical University)

UNIT - 4

Data Acquisition:

Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution.

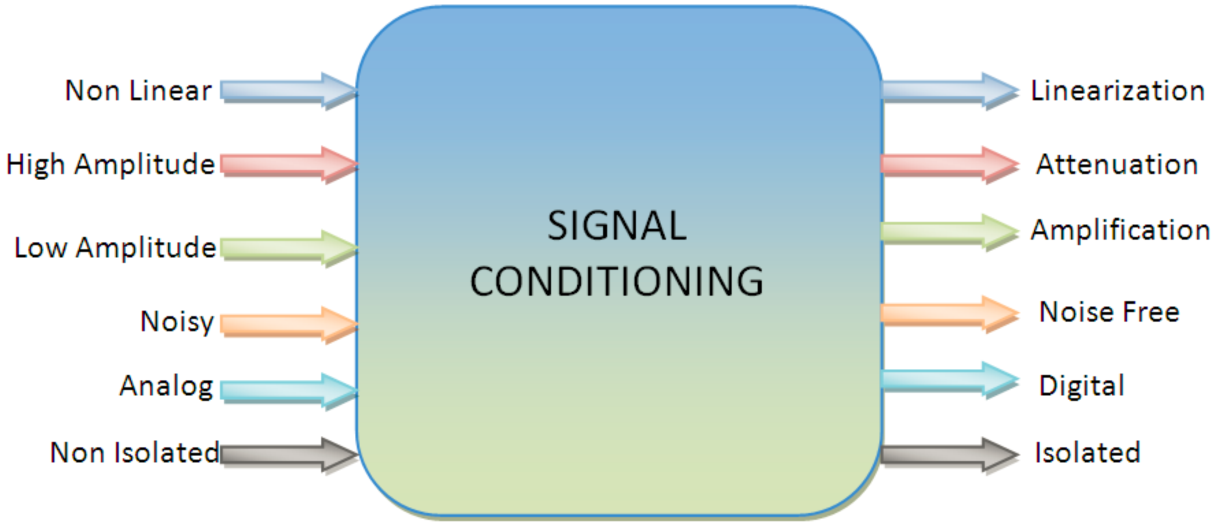


1. Transducer:-

A transducer is used to convert the physical parameters corning from the field into electrical signals or it is used to measure directly the electrical quantities such as resistance, voltage, frequency, etc.

2. Signal Conditioner:-

Usually the output signals of the transducer will be of very low level (weak) signals which cannot be used for further processing. In order to make the signals strong enough to drive the other elements signal conditioners are used such as amplifiers, modifiers, filters etc.



Signal conditioning system enhances the quality of signal coming from a sensor in terms of:

a. Protection

To protect the damage to the next element of mechatronics system such microprocessors from the high current or voltage signals.

b. Right type of signal

To convert the output signal from a transducer into the desired form i.e. voltage / current.

c. Right level of the signal

To amplify or attenuate the signals to a right and acceptable level for the next element.

d. Noise

To eliminate noise from a signal.

e. Manipulation

To manipulate the signal from its nonlinear form to the linear form.

3. Multiplexer:-

The function of the multiplexer is to accept multiple analog inputs (after signal conditioning) and provide a single output sequentially according to the requirements.

4. A/D Converter:-

The analog-to-digital (A/D) converter is generally used to convert the analog data into digital form. The digital data is used for the purpose of easy processing, transmission, digital display and storage. Processing involves various operations on data such as comparison, mathematical manipulations, data is collected, converted into useful form and utilized for various purposes like for control operation and display etc.

The transmission of data in digital form is possible over short distances as well as long distances of and has advantages over transmission in analog form. The data can be stored permanently or temporarily and can be displayed on a CRT or digital panel.

5. Recorders and Display Devices:-

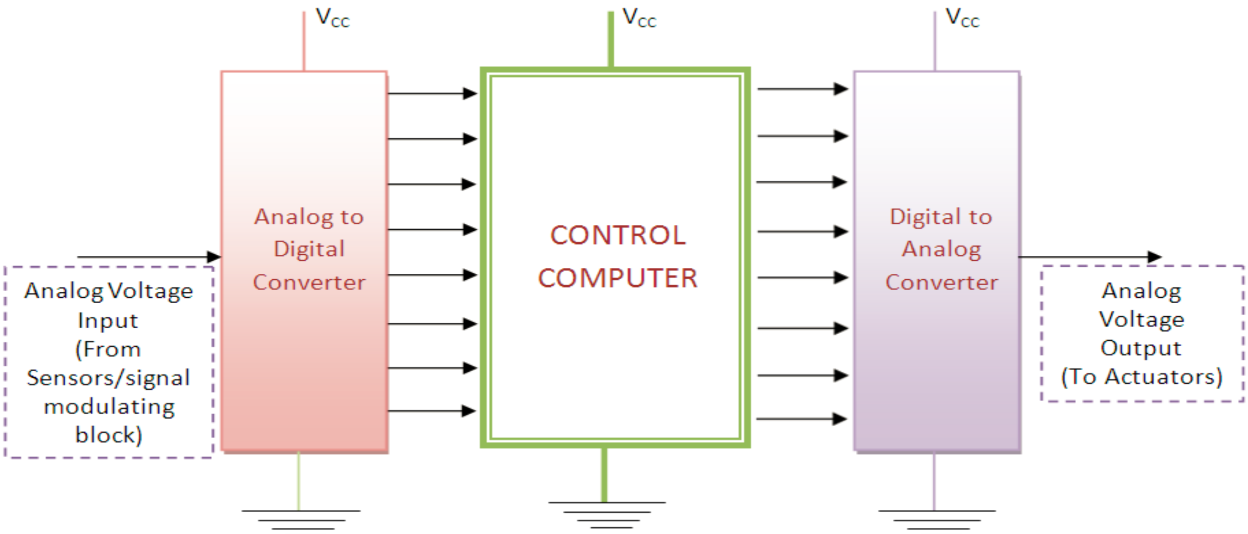
In display devices the data is displayed in a suitable form in order to monitor the input signals. Examples of display devices are oscilloscopes, numerical displays, panel meters, etc.

In order to have either a temporary or permanent record of the useful data recorders are used and analog data can be recorded either graphically or on a magnetic tape. Optical recorders, Ultraviolet recorders, styles-and-ink recorders are some of its examples.

The digital data can be recorded through digital recorders. The digital data is first converted into a suitable form for recording by means of a coupling unit and then recorded on a magnetic tape, punched cards or a perforated paper tape.

DATA CONVERSION DEVICES:

Data Conversion Devices are very important components of a Machine Control Unit (MCU). MCUs are controlled by various computers or microcontrollers which are accepting signals only in Digital Form, while the signals received from signal conditioning module or sensors are generally in analogue form (continuous). Therefore a system is essentially required to convert analog signals into digital form and from digital form to analog form. Figure below shows a typical control system with data conversion devices.



Analog to Digital Converter (ADC)

There are various techniques of converting Analog Signals into Digital signals which are enlisted as follows. However we will be discussing only Successive Approximation ADC and Sigma-delta ADC, detail study of other techniques is out of the scope of the present course.

1. Direct Conversion ADC or Flash ADC

2. Successive Approximation ADC

3. A ramp-compare ADC

4. Wilkinson ADC

5. Integrating ADC

6. Delta-encoded ADC or counter-ramp

7. Pipeline ADC (also called sub ranging quantizer)

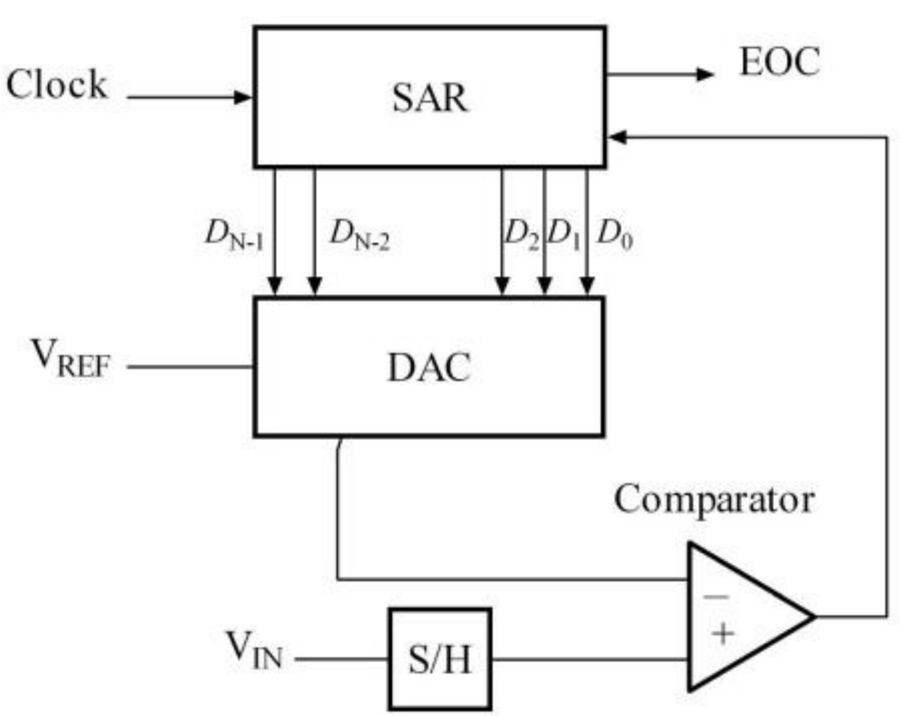
8. Sigma-delta ADC (also known as a delta-sigma ADC)

9. Time-interleaved ADC

Successive Approximation ADC:

A successive approximation ADC is a type of analog-to-digital converter that converts a continuous analog waveform into a discrete digital representation via a binary search through all possible quantization levels before finally converging upon a digital output for each conversion.

Block diagram



Successive Approximation ADC Block Diagram

- DAC = Digital-to-Analog converter
- EOC = end of conversion
- SAR = successive approximation register
- S/H = sample and hold circuit
- V_{in} = input voltage
- V_{ref} = reference voltage

The successive approximation Analog to digital converter circuit typically consists of four chief subcircuits:

1. A sample and hold circuit to acquire the input voltage (Vin).

2. An analog voltage comparator that compares Vin to the output of the internal DAC and outputs the result of the comparison to the successive approximation register (SAR).

3. A successive approximation register sub-circuit designed to supply an approximate digital code of Vin to the internal DAC.

4. An internal reference DAC supplies the comparator with an analog voltage equal to the digital code output of the SARin.

Working:

1. The successive approximation register is initialized so that the most significant bit (MSB) is equal to a digital 1.

2. This code is fed into the DAC, which then supplies the analog equivalent of this digital code (Vref/2) into the comparator circuit for comparison with the sampled input voltage.

3. If this analog voltage exceeds Vin the comparator causes the SAR to reset this bit; otherwise, the bit is left a 1.

4. Then the next bit is set to 1 and the same test is done, continuing this binary search until every bit in the SAR has been tested.

5. The resulting code is the digital approximation of the sampled input voltage and is finally output by the SAR at the end of the conversion (EOC).

Sigma Delta ADC:

One of the more advanced ADC technologies is the so-called delta-sigma, or ΔΣ (using the proper Greek letter notation). In mathematics and physics, the capital Greek letter delta (Δ) represents difference or change, while the capital letter sigma (Σ) represents summation: the adding of multiple terms together. Sometimes this converter is referred to by the same Greek letters in reverse order: sigma-delta, or ΣΔ.

Sigma Delta ADC is widely used in communication system, professional audio system and high precision measurement system. Sigma Delta ADC has characteristics like, high resolution, low cost and low conversion speed.

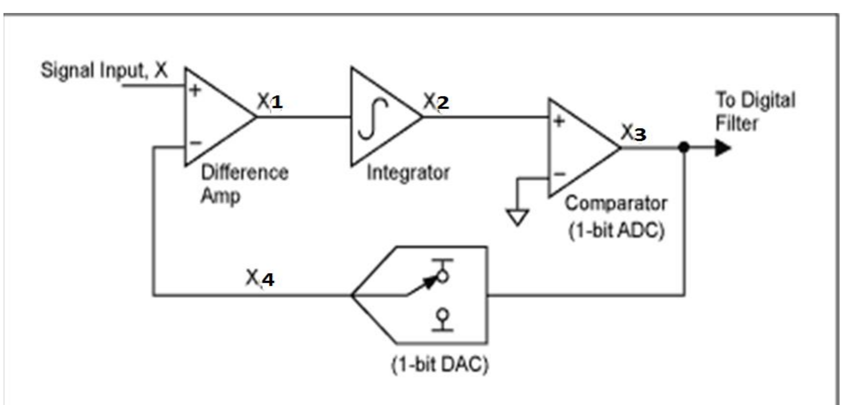
Working Principle:

Whatever is the input is applied on difference amplifier. Another input of the difference amplifier is coming from DAC. The resultant voltage is given to the integrator. Integrator will add the value received from the difference amplifier to the previous value it is having. So the integrator will provide the addition or you can say integrating output.

Next step is a comparator or the 1 bit ADC. Comparator is getting voltage from the integrator and other terminal is grounded. To get 1 at the output of the comparator the positive terminal of the comparator will be at high potential as compared to the negative terminal. If the voltage at the negative terminal is high we will get 0. that means we will get a 1 bit stream of 1 or 0.

If the analog voltage is high then density on 1 will be high and if analog signal is low density of '1' will be low. That means you have given more positive voltage you will get more 1s in digital output. And if you input is more negative you will get more 0s in digital output.

The output of the comparator id given to one bit DAC. If the input of the DAC is 1 it will give +1 as the output whereas if the input of the DAC is 0 it will give -1 as the output. So the loop is continued until we get the final value.



Now $X_1 = X_4 - X$

X_1 is the input to the integrator. The integrator will add the X_1 with the previous value in the integrator.

So $X_2 = X_1 + X_2$(PREVIOUS STAGE let n-1)

If $X_2 > 0$ then $X_3 = 1$

And if $X_3 = 1$ then $X_4 = 1$

If $X_2 < 0$ then $X_3 = 0$

And if $X_3 = 0$ then $X_4 = -1$

This process continues until you get the digital value.

Advantages of Sigma Delta ADC:

1. Sigma Delta ADC is inexpensive since all circuitry within the converter is digital.

2. The output of sigma delta ADC is inherently linear and it has very little differential non linearity.

3. It do not require sample and hold circuit. It is because due to high sampling rate and low precision.

Disadvantages:

1. It is limited to high resolution and very low frequency applications.

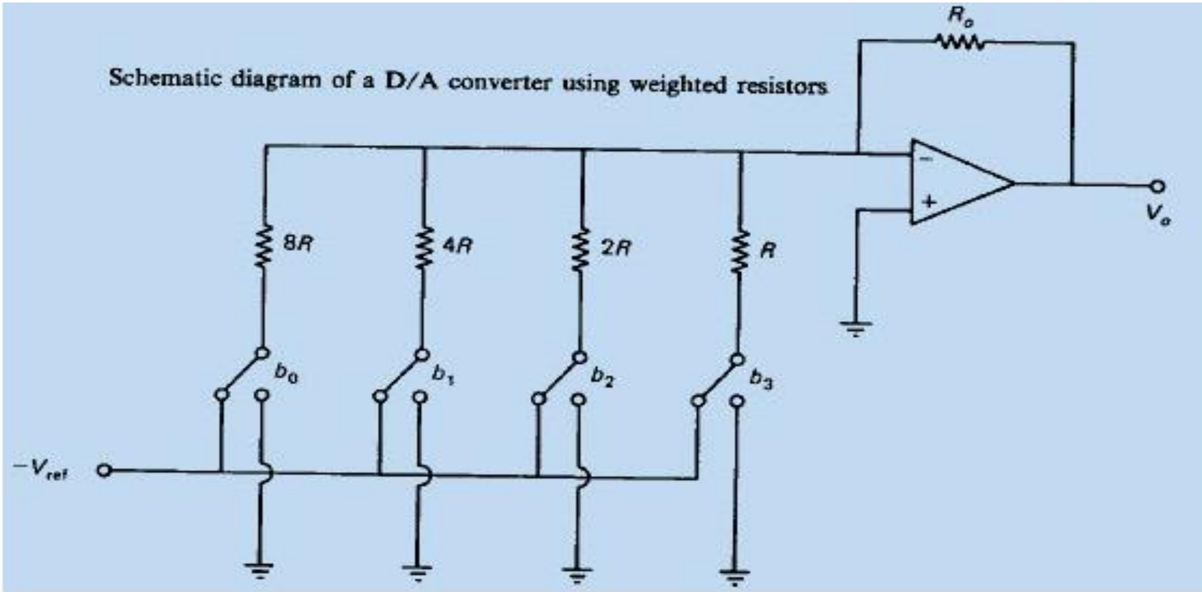
2. It takes quite long time for producing first digital output because of digital filtering and down sampling.

3. It is not possible to use Sigma Delta ADC for multiplexed ac input signals.

Types of DAC:

1. DAC using Weighted Resistors method:

The below shown schematic diagram is DAC using weighted resistors. If the input signals are voltages, the addition of the binary bits can be achieved using the inverting summing amplifier shown in the below figure.



1. The input resistors of the op-amp have their resistance values weighted in a binary format.

2. When the digital input is binary 1, the switch connects the resistor to the reference voltage. When the logic circuit receives binary 0, the switch connects the resistor to ground. All the digital input bits are simultaneously applied to the DAC.

3. The DAC generates analog output voltage corresponding to the given digital data signal.

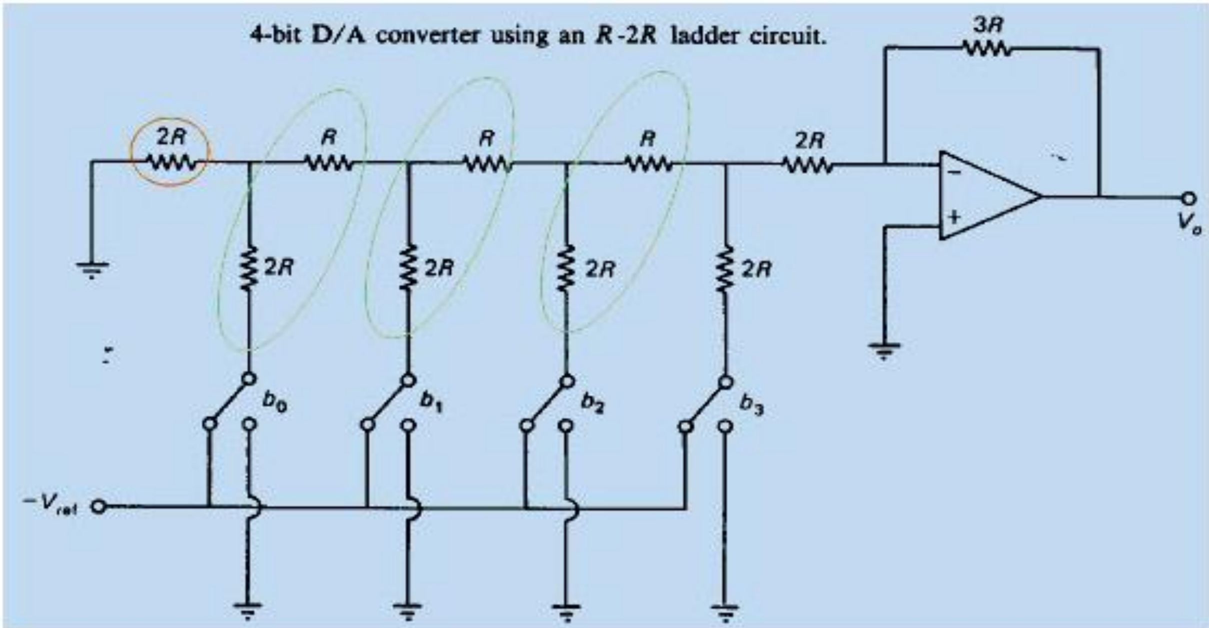
4. For the DAC the given digital voltage is b3 b2 b1 b0 where each bit is a binary value (0 or 1). The output voltage produced at output side is

$$V0=R0/R\ (b3+b2/2+b1/4+b0/8)\ Vref$$

5. As the number of bits is increasing in the digital input voltage, the range of the resistor values becomes large and accordingly, the accuracy becomes poor.

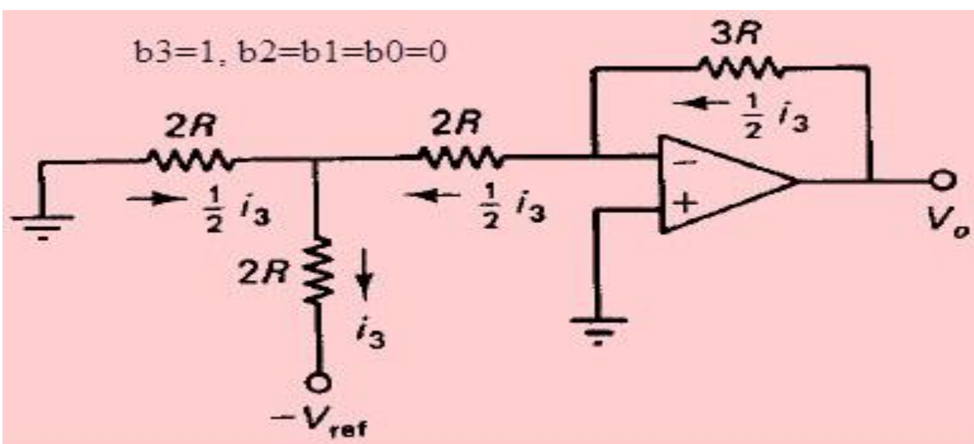
R-2R Ladder Digital to Analog Converter (DAC):

The R-2R ladder DAC constructed as a binary-weighted DAC that uses a repeating cascaded structure of resistor values R and 2R. This improves the precision due to the relative ease of producing equal valued-matched resistors (or current sources).

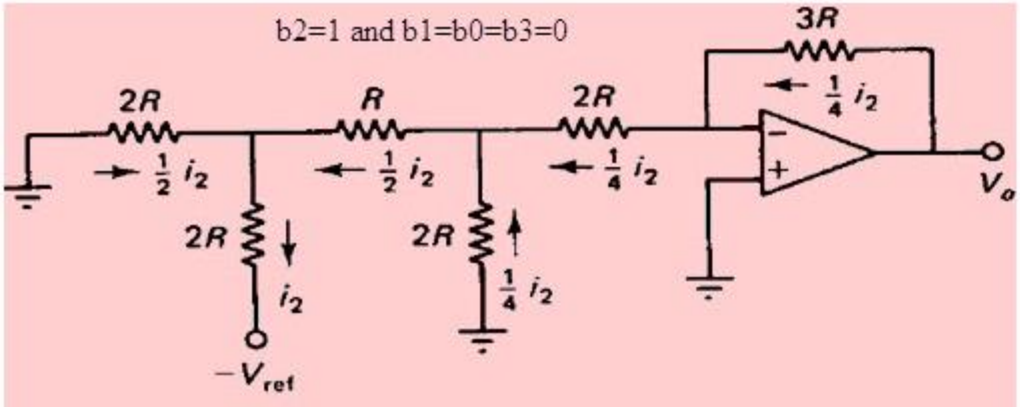


R-2R Ladder Digital to Analog Converter (DAC)

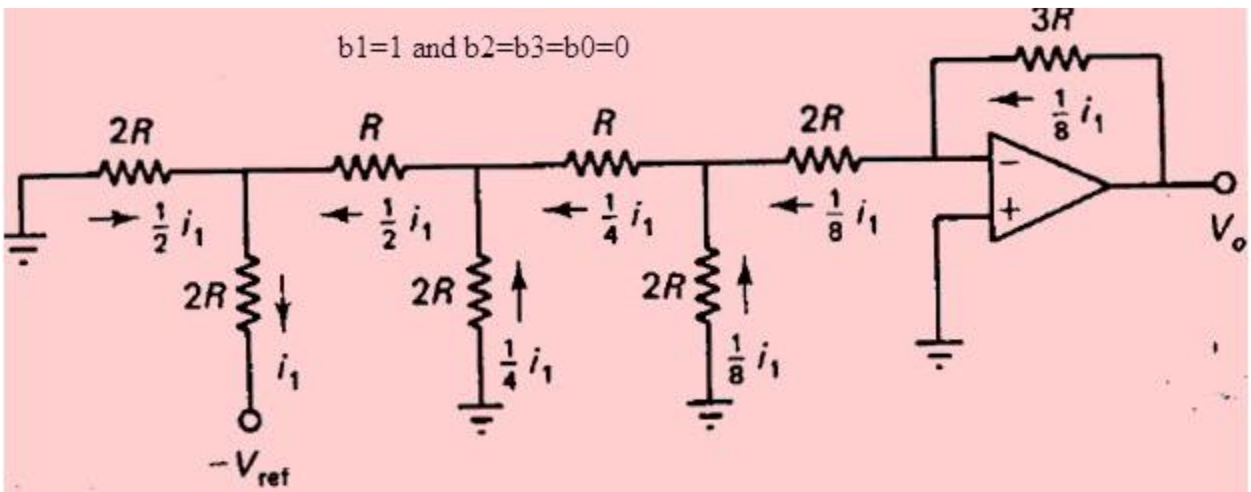
The above figure shows the 4-bit R-2R ladder DAC. In order to achieve high-level accuracy, we have chosen the resistor values as R and 2R. Let the binary value B3 B2 B1 B0, if b3=1, b2=b1=b0=0, then the circuit is shown in the figure below it is a simplified form of the above DAC circuit. The output voltage is V0=3R (i3/2)= Vref/2



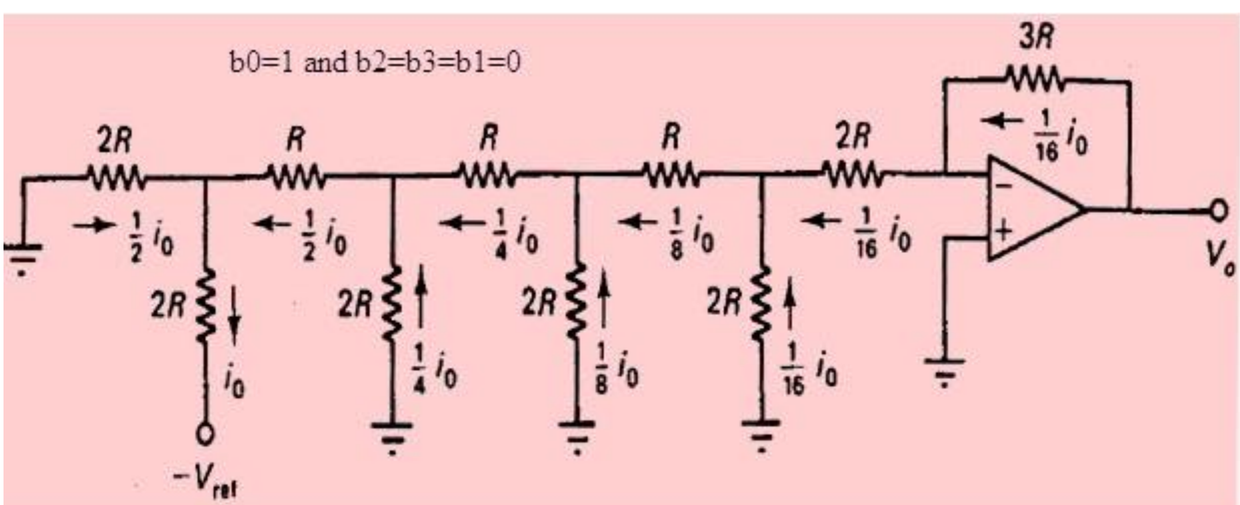
Similarly, If b2=1, and b3=b1=b0=0, then the output voltage is V0=3R(i2/4)=Vref/4 and the circuit is simplified as below



If b1=1 and b2=b3=b0=0, then the circuit shown in the figure below it is a simplified form of the above DAC circuit. The output voltage is V0=3R(i1/8)= Vref/8



Finally, the circuit is shown in below corresponding to the case where b0=1 and b2=b3=b1=0. The output voltage is V0=3R(i0/16) = Vref/16



n this way, we can find that when the input data is b3b2b1b0 (where individual bits are either 0 or 1), then the output voltage is

$$
\begin{aligned}
V_0 &= (\tfrac{1}{2}b_3 + \tfrac{1}{4}b_2 + \tfrac{1}{8}b_1 + \tfrac{1}{16}b_0)V_{\text{ref}} \\
&= \tfrac{1}{2}(b_3 + \tfrac{1}{2}b_2 + \tfrac{1}{4}b_1 + \tfrac{1}{8}b_0)V_{\text{ref}}
\end{aligned}
$$