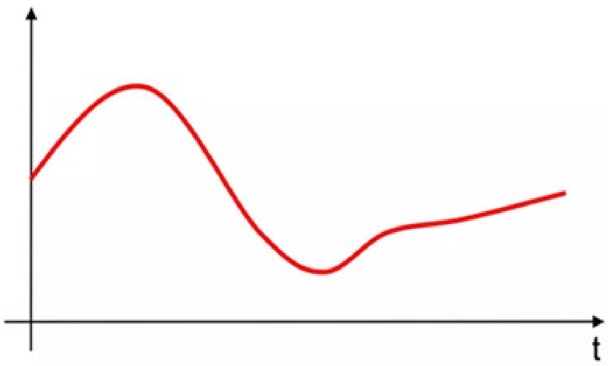
Module-2-ADC-DAC

Signal Types

Analog Signals

- Any continuous signal that a time varying variable of the signal is a representation of some other time varying quantity
  - Measures one quantity in terms of some other quantity
  - Examples
    - Speedometer needle as function of speed
    - Radio volume as function of knob movement



Analog to Digital Converter

- An electronic integrated circuit which converts a signal from analog (continuous) to digital (discrete) form
- Provides a link between the analog world of transducers and the digital world of signal processing and data handling
- ADC are used virtually everywhere where an analog signal has to be processed, stored, or transported in digital form
  - Microphones
  - Strain Gages
  - Thermocouple
  - Digital Multimeters

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ADC Process

Quantizing

- Separating the input signal into a discrete states with K increments
- $K=2^N$
  - N is the number of bits of the ADC
- Analog quantization size
  - $Q=(V_{max}-V_{min})/2^N$
  - Q is the Resolution

Encoding

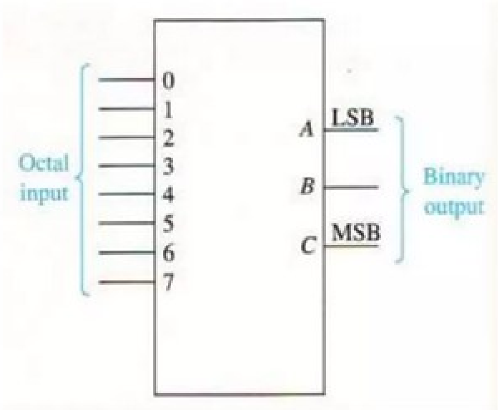
- Assigning a unique digital code to each state for input into the microprocessor

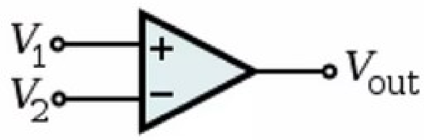
ADC – Flash ADC

- Also known as Parallel ADC
- A n-bit flash ADC uses 2^{n-1} comparators and a encoder logic.
- Advantage: the fastest type of ADC.
- Disadvantages: limited resolution, expensive, large power consumption and low accuracy.
- Applications: Data acquisition, satellite communication, radar processing, sampling oscilloscope and high density disk drives.

Flash ADC

- Elements
  - Encoder – *Converts output of comparators to binary*
  - Comparators

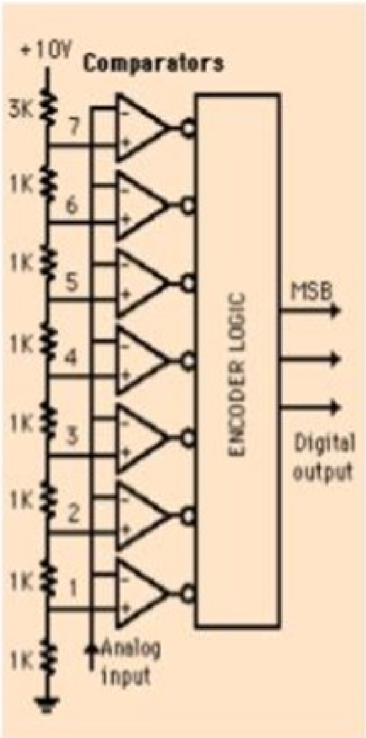




$$V_{\text{out}} = \begin{cases} V_{S+} & V_1 > V_2 \\ V_{S-} & V_1 < V_2 \end{cases}$$

Flash - ADC

3-bit flash ADC



Comparator Input Range(V)	Comparator Output							Encoder Output
	A	B	C	D	E	F	G	
<1	0	0	0	0	0	0	0	000
>1 – 2	1	0	0	0	0	0	0	001
>2 – 3	1	1	0	0	0	0	0	010
>3 – 4	1	1	1	0	0	0	0	011
>4 – 5	1	1	1	1	0	0	0	100
>5 – 6	1	1	1	1	1	0	0	101
>6 – 7	1	1	1	1	1	1	0	110
>7	1	1	1	1	1	1	1	111

Flash – ADC Example

- Algorithm
  - V_{in} value lies between two comparators
  - Resolution $\Delta V = \frac{V_{ref}}{2^N}$;
  - N= Encoder Output bits
  - Comparators => 2^N-1

  - Example: V_{ref} 8V, Encoder 3-bit
    - Resolution $\Delta V = \frac{8}{2^3}$ = 1.0V
    - Comparators 2^3-1=7

Flash – ADC Example

V_{in} = 5.5V, V_{ref}= 8V

V_{in} lies in between V_{comp5} & V_{comp6}

$V_{comp5} = V_{ref}*5/8 = 5V$

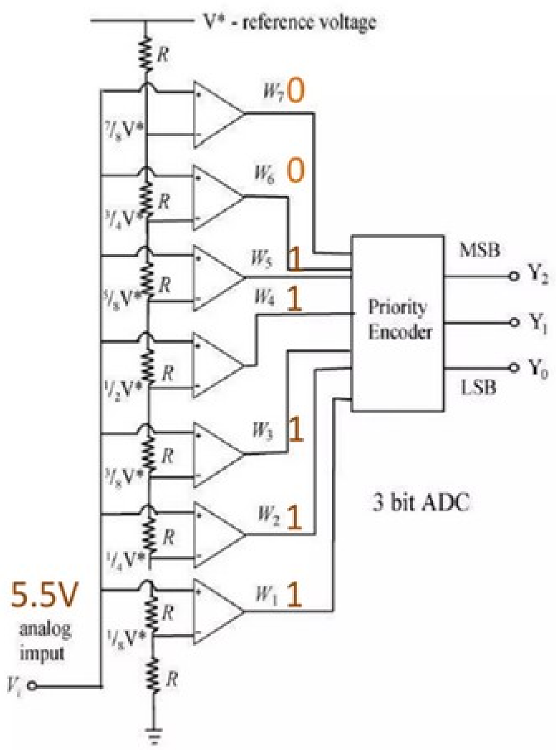
$V_{comp6} = V_{ref}*6/8 = 6V$

Comparator 1 - 5 => output **1**

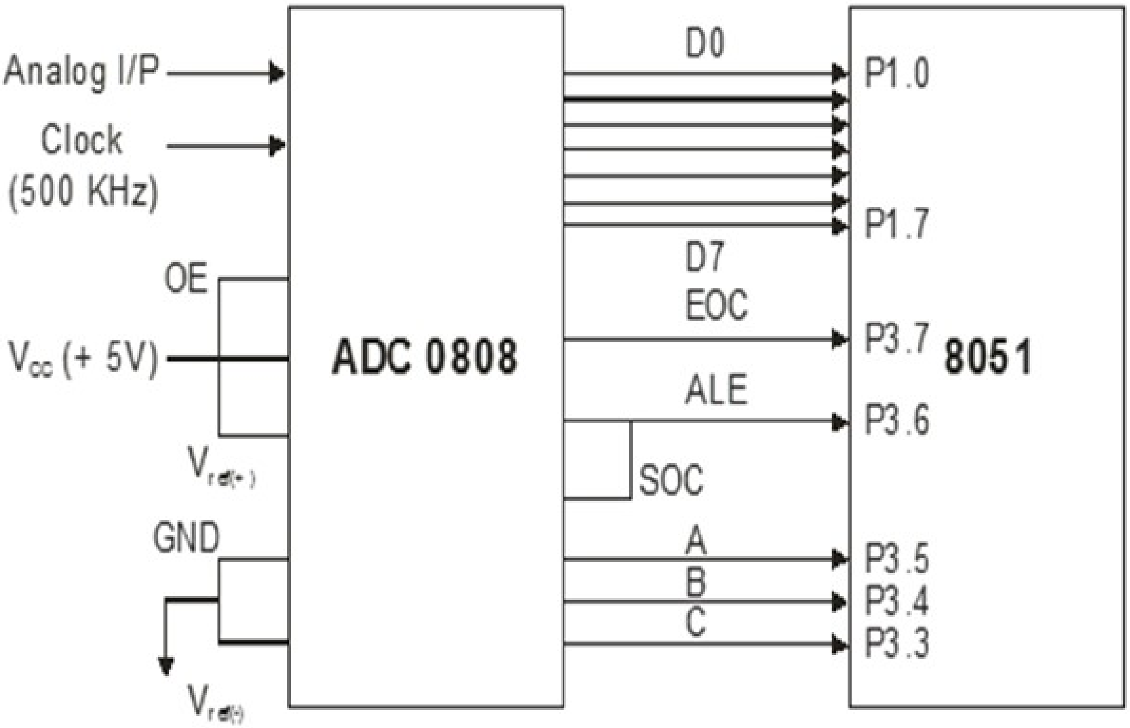
Comparator 6 - 7 => output **0**

Encoder Octal Input = sum(0011111) = 5

Encoder Binary Output = 1 0 1



ADC interfacing with 8051



Flash – ADC . . . Pros and Cons

Pros

- Fastest (in the order of nano seconds)
- Simple operational theory
- Speed is limited only by gate and comparator propagation delay

Cons

- Each additional bit of resolution requires twice the number of comparators
- Expensive
- Prone to produce glitches in the output

Application of ADC

In the modern world of growing technology, we are dependent on digital devices. These digital devices operate on the digital signal. But not every quantity is in digital form instead they are in analog form. So an ADC is used for converting analog signals into digital signals. The **applications** of ADC are limitless. Some of these **applications** given below:

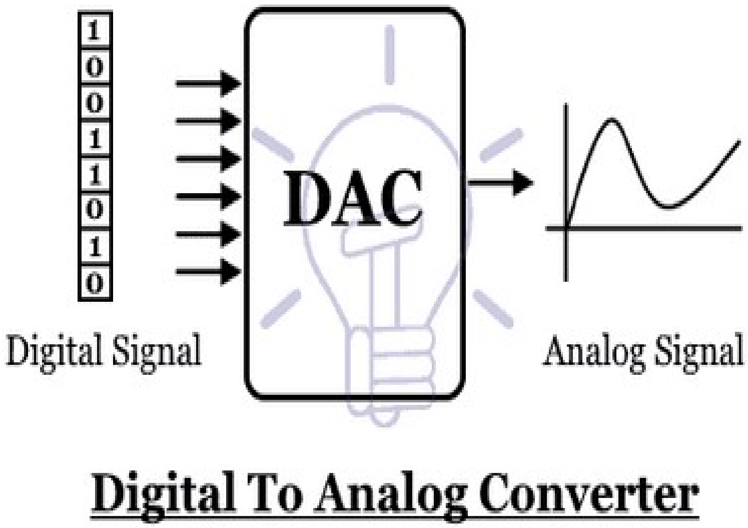
- **Cell phones** operate on the digital voice signal. Originally the voice is in analog form, which is converted through ADC before feeding to the cell phone transmitter.
- **Images** and **videos** captured using camera is stored in any digital device, is also converted into digital form using ADC.
- Medical Imaging like **x-ray** & **MRI** also uses **ADC** to convert images into Digital form before modification. They are then modified for better understanding.
- Music from the **cassette** is also converted into the digital form such as **CDs** and **thumb drives** using **ADC** converters.
- **Digital Oscilloscope** also contains **ADC** for converting Analog signal into a digital signal for display purposes & different other features.
- **Air conditioner** contains **temperature sensors** for maintaining the room temperature. This temperature is converted into digital form using ADC so that onboard controller can read & adjust the cooling effect.

In today's modern world almost every device has become the **digital version** of itself & they need to have ADC in it. Because it has to operate in digital domain which can be only acquired using **analog to digital converter (ADC)**.

What is DAC (Digital to Analog Converter)?

Digital to analog converter is an electronic circuit that converts any digital signal (such as binary signal) into an analog signal (voltage or current).

The digital signal such as the binary signal exist in the form of bits & it is the combination of 1's & 0's (or High & low voltage levels). The DAC converts these bits into an analog voltage or current.



The DAC has several digital inputs & a single analog output.

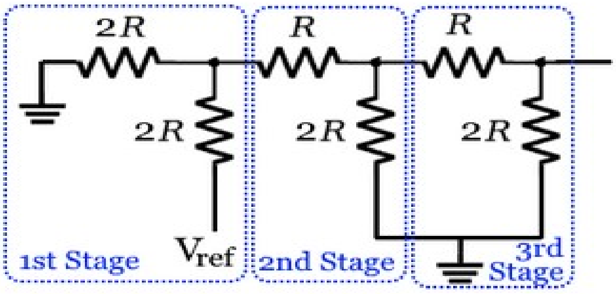
- ***Related Post:* *Analog to Digital Converter (ADC) – Block Diagram, Factors & Applications***

Need of DAC

The information exist in real world is in analog form. Why we convert them into digital form in the first place if we want to convert them back? The processing speed of a digital computer is very fast & can compute or process any data in a matter of micro seconds. It conserves time & helps in processing complex data according to our need. But we cannot understand the digital data in real world.

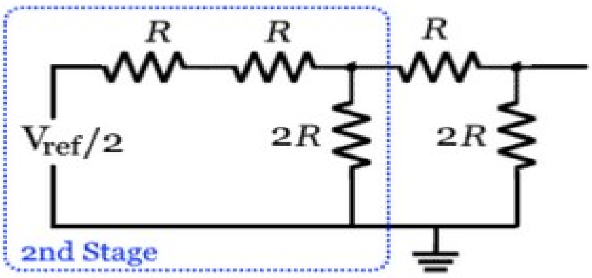
Let's assume a 3 bit DAC using R-2R ladder network.

$B_2B_1B_0$ are the 3 bits of the binary input. When $B_0 = 1$, B_1 & $B_2 = 0$. Then the equivalent circuit would be;



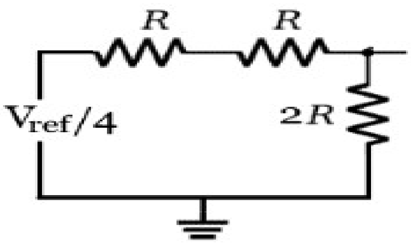
Replacing the 1st stage with its V_{th} & R_{th};

$$V_{th} = V_{ref}/2 \text{ \& } R_{th} = R$$



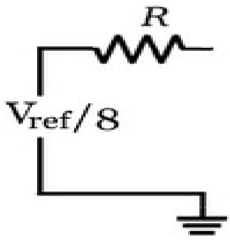
Now the 2nd stage V_{th} & R_{th};

$$V_{th} = V_{ref}/4 \text{ \& } R_{th} = R$$



Now the 3rd stage Vth & R_{th}

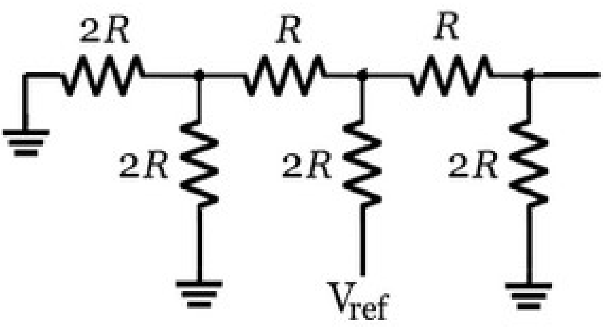
$$V_{th} = V_{ref}/8 \text{ \& } R_{th} = R$$



So the output voltage in this case would become

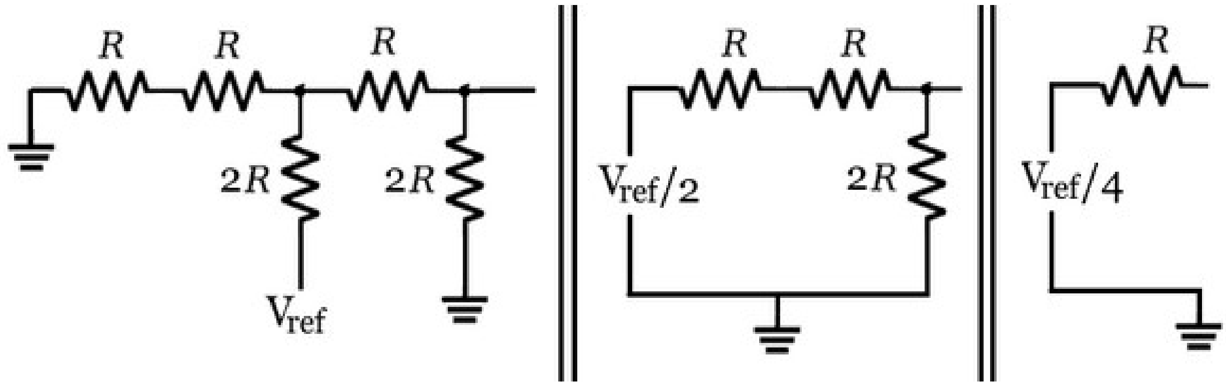
$$V_{out} = -V_{th}\ (R_f/R) = -(V_{ref}/8)\ (R/R) = -(V_{ref}/8)$$

When B_1 = 1, B_0 & B_2 = 0. Then the equivalent circuit would be;

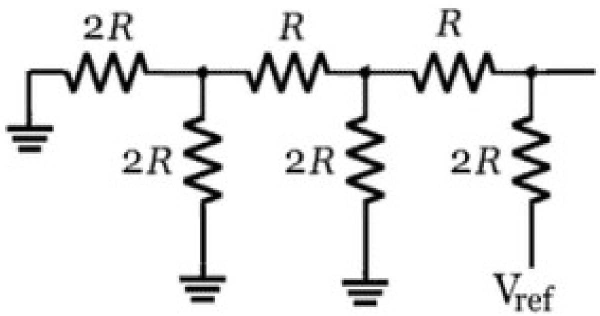


Applying the same process the output voltage will be

$$V_{out} = -(V_{ref}/4)$$

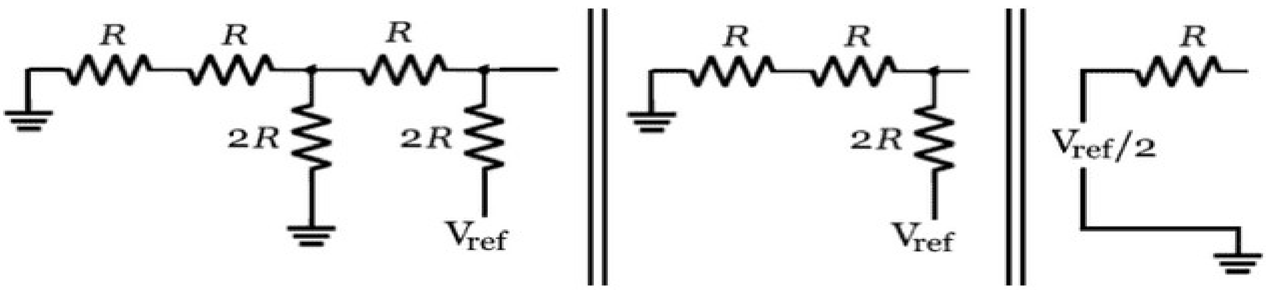


When B_2 = 1, B_0 & B_1 = 0. Then the equivalent circuit would be;



Applying the same process the output voltage will be

$$V_{out} = -(V_{ref}/2)$$



As we know the output of the opamp is the sum of individual inputs where each bit is

$$V_{out} = -\{ B_0 (V_{ref}/8) + B_1 (V_{ref}/4) + B_2 (V_{ref}/2)\}$$

$$V_{out} = - V_{ref} \{ B_0(1/8) + B_1 (1/4) + B_2 (1/2)\}$$

$$V_{out} = - V_{ref} \{ B_0(1/2^3) + B_1 (1/2^2) + B_2 (1/2^1)\}$$

We can generalize this formula for an N bit binary number as;

$$V_{out} = - V_{ref} \{B_0(1/2^N) + B_1(1/2^{N-1}) + B_2(1/2^{N-2}) +\ldots+ B_{N-2}(1/2^2) + B_{N-1}(1/2^1)\}$$

Example:

Convert a binary number of 10110 into an analog output where the v_{ref} = 12v

The number of bit N = 5

$$V_{out} = - V_{ref} \{B_0(1/2^N) + B_1(1/2^{N-1}) + B_2(1/2^{N-2}) +\ldots+ B_{N-2}(1/2^2) + B_{N-1}(1/2^1)\}$$

$$V_{out} = - V_{ref} \{B_0(1/2^5) + B_1(1/2^4) + B_2(1/2^3) + B_3(1/2^2) + B_4(1/2^1)\}$$

$$V_{out} = - (12) \{(0)(1/2^5) + (1)(1/2^4) + (1)(1/2^3) + (0)(1/2^2) + (1)(1/2^1)\}$$

$$V_{out} = - (12) \{(1/2^4) + (1/2^3) + (1/2^1)\}$$

$$V_{out} = - (12) \{(1/16) + (1/8) + (1/2)\}$$

$$V_{out} = - 8.25 \text{ v}$$

Advantages of R-2R Ladder DAC;

- Uses only two types of resistors
- Easiliy scalable to any number of bits
- Output impedance is always R

Resolution & Step Size of Digital to Analog Converter

Resolution & step size of a DAC plays important role in the precision & accuracy of the analog output.

Resolution of DAC

Resolution is the number of possible output levels a DAC can produce. It depends on the number of input bits.

$$\text{Resolution} = 2^n$$

The resolution of an n-bit DAC is 2^n. For example, a 4-bit DAC has resolution of 2^4 or 16 output levels.

Step Size of a DAC

The step size of a DAC is the smallest change in the analog output & it is the difference between two consecutive output voltage levels.

The step size can be calculated by dividing the range (maximum output voltage) or V_{ref} by 2^n where n is the number of bits.

$$\text{Step size} = \text{Range} / 2^n$$

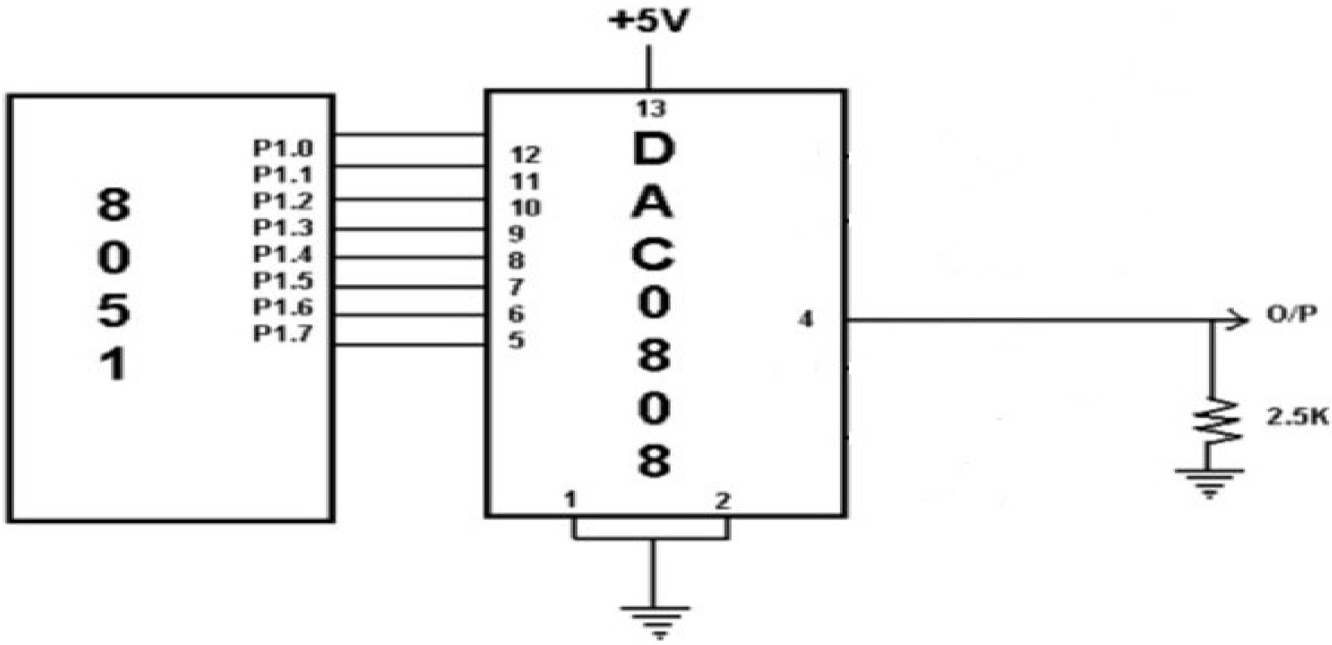
For example, the step size of a 4 bit DAC with range of 5v is;

$$\text{Step size} = 5/2^4 = 5/16 = 0.3125\text{v}$$

The step size of this DAC is 0.3125. So for a single bit increment, its analog output will increase by 0.3125 v.

Increasing the resolution of a DAC decreases the step size & generates a smooth analog wave with much more accuracy.

DAC interfacing with 8051



Applications of DAC

Digital to analog converters are used in various applications to convert a digitally processed signal into an analog signal. Some of the various applications of a DAC are given below;

Audio:

The audio signal is analog in nature but it is converted using ADC (analog to digital converter) into digital format to edit & store in storage devices in various digital formats such as mp3, wav etc. The audio amplifier or the sound card in a system contains DAC that converts the audio signal stored in digital device into an analog signal. The signal can be modified by the amplifier by varying its gain (volume), bass, treble etc. & then converted into analog signal because the speaker cannot support a digital signal.

Video:

Digital video players utilize DAC to play any digital video using an analog monitor. These video players convert the digital signal from the digital source file into an analog signal.

A digital video player has digital video ports such as DVI or HDMI. But if it has any analog output ports (composite port of yellow color), it contains a DAC whose job is to convert the video file into analog signal.

Motor Control

One of the most important components in controlling a motor using a digital device such as a microcontroller is a DAC.

In various electronics projects, motor is embedded with a microcontroller. The microcontroller generates a digital signal to vary the speed of the motor which is converted into an analog signal using a **DAC (Digital to Analog Converter)**.