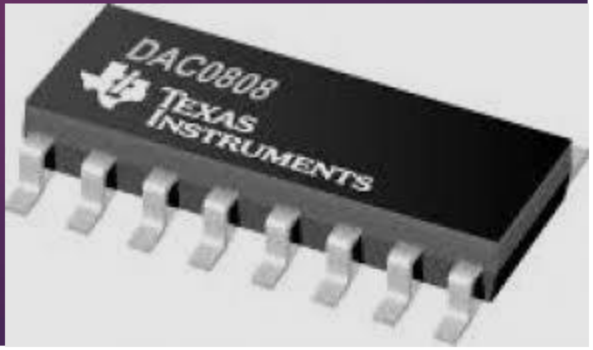
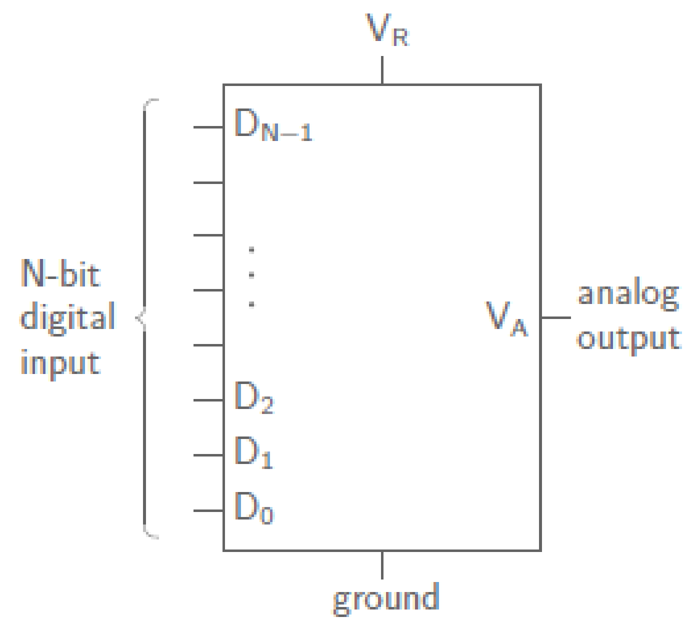
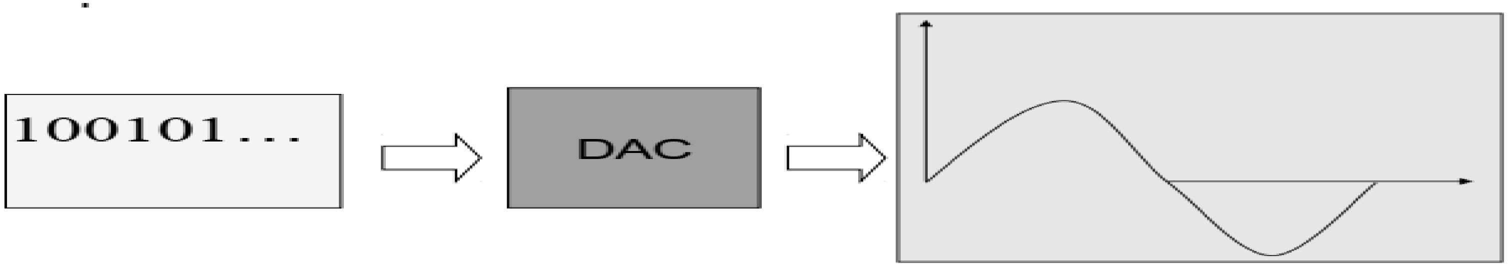
Digital to Analog Converters
(DAC)



Introduction

- Digital to analog converter translates a digital signal into an analog signal to represent a physical quantity.
- A n-bit DAC has n input lines to have 2^n input combination and an analog output line.
- A digital-to-analog converter (DAC) takes a digital code as its input and produces an analog voltage or current as its output.
- This analog output is proportional to the digital input.





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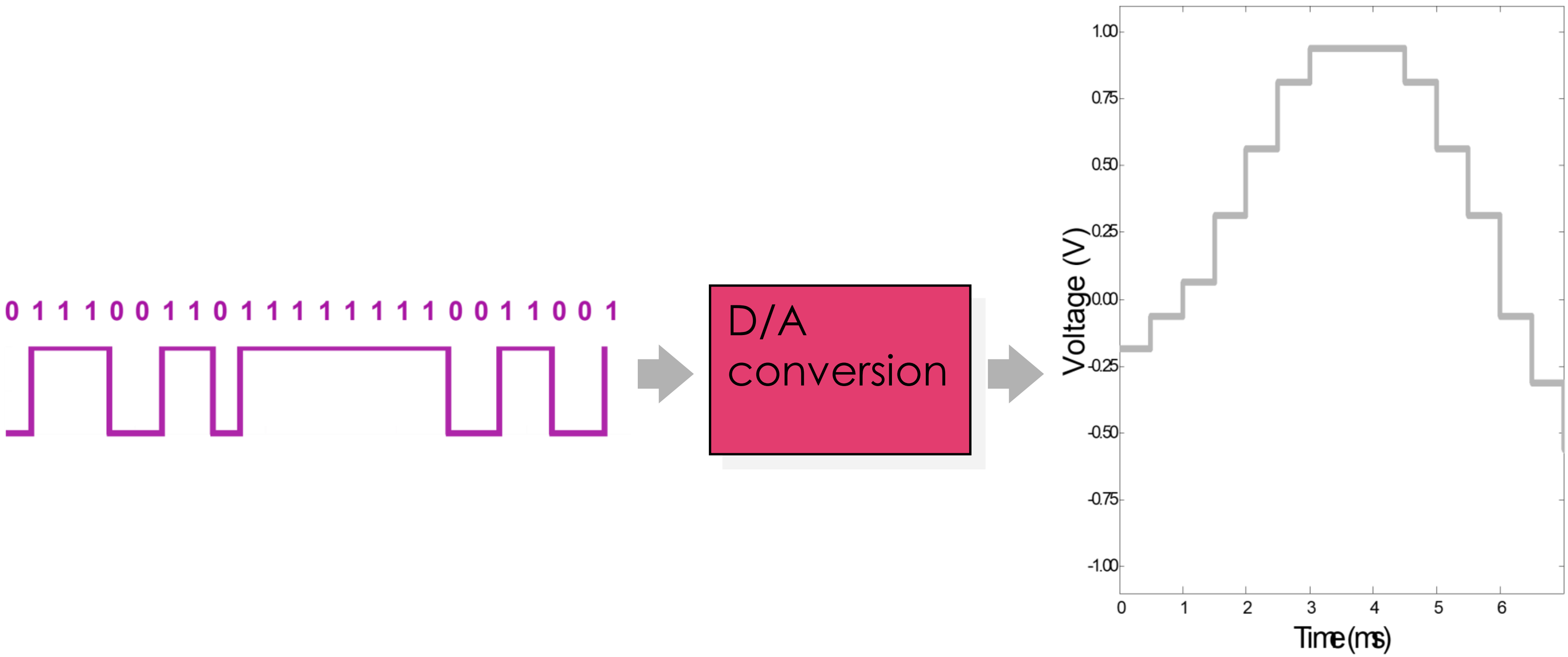
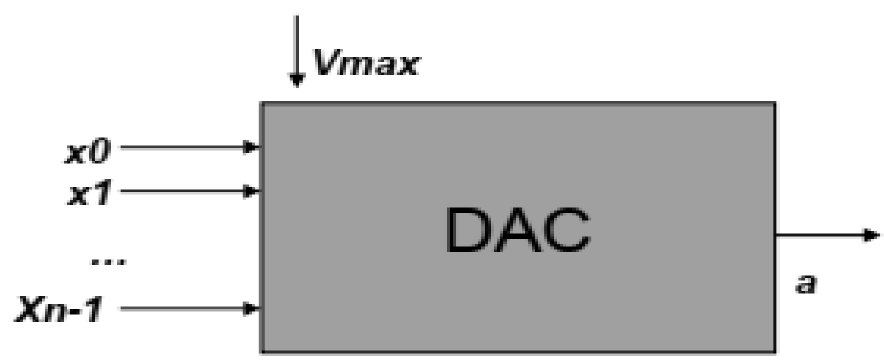

0 1 1 1 0 0 1 1 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0 1
D/A conversion
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
Voltage (V)
0
1
2
3
4
5
6
Time (ms)

Digital to Analog Basic Operation

- The conversion of the digital signal into an analog one is performed by an electronic circuit.
- The input is received in a binary form and the output yielded is in the form of an electrical current or voltage that manifests as an analog presentation.
- The digital data that is being used an input can be produced by an FPGA, or any other microprocessor or microcontroller.
- One of the most commonly seen and used applications of a digital to analog converter is that is music players.
- These devices take in streams and waves of digital data and then convert them into analog audio signals.
- A DAC is defined by certain parameters and its capability pertaining to these specific parameters determines the application they are best suited for. These parameters include resolution and frequency.
- Where the audio output would require a high resolution but low frequency type of converter, a video or visual output will require high frequency and low resolution.

Principle

- Digital to Analog conversion involves transforming the computer's binary output in 0's and 1's (1's typically = 5.0 volts) into an analog representation of the binary data .
- *n* digital inputs for digital encoding
- analog input for *Vmax*
- Analog output



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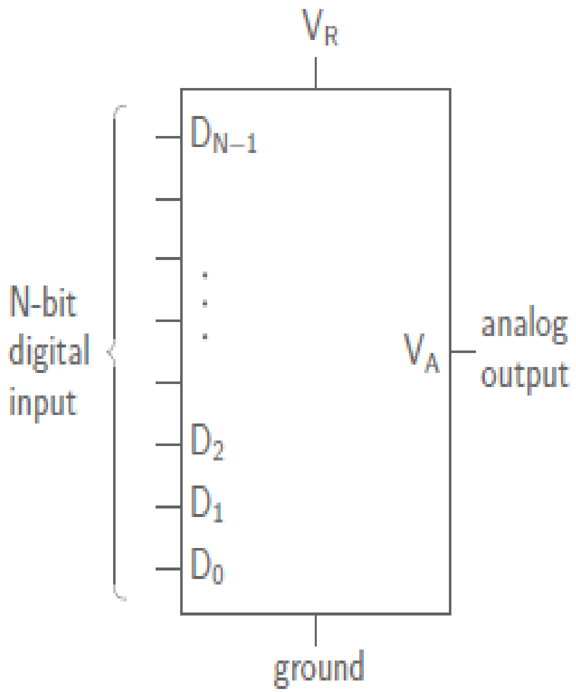
- Digital input Din is defined as n bit digital word such as

  $D_{in}=D_0x2^{-n}+D_1x2^{-(n-1)}+D_2x2^{-n(n-2)}+......D_{n-1}2^{-1}$

- Where D_i is binary digit and equals 1 or 0.
- D_0 is defined as least significant bit and D_{N-1} is most significant bit.
- The analog output signal V_{out} is related to digital input signal.
- D_{in} through analog voltage reference V_{ref}.
- The relation between these three signals is

$$V_{out}=V_{ref}\ x\ D_{in}$$

$$V_{LSB}=V_{ref}/2^n$$



DAC CHARACTERSTICS

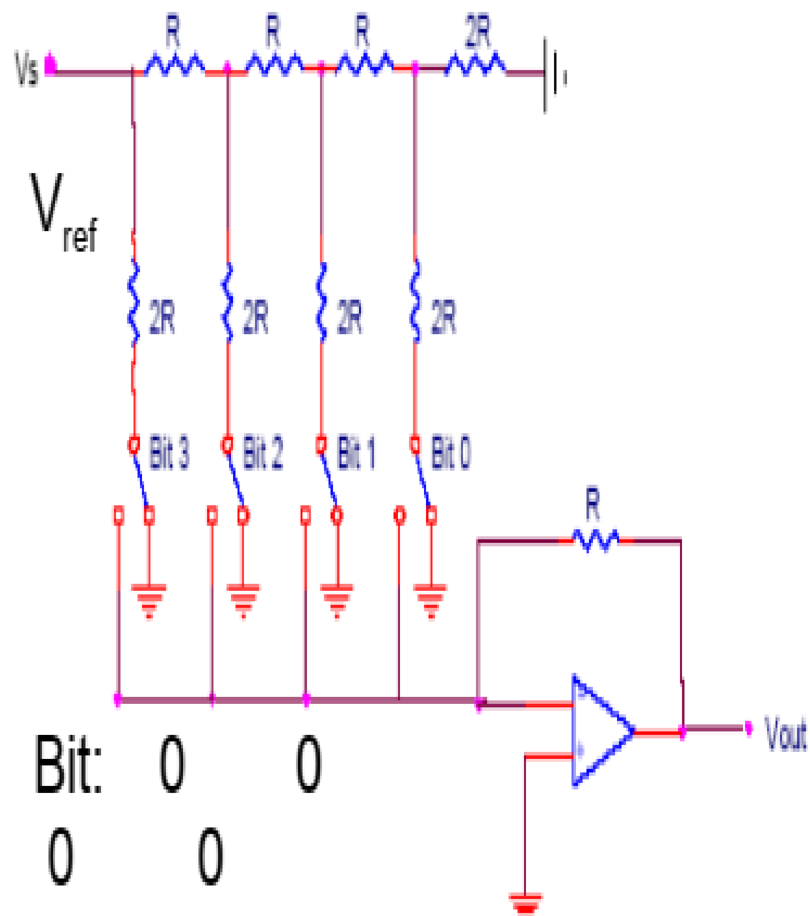
- **Resolution** -Resolution is the amount of variance in output voltage for every change of the LSB in the digital input.
- Just as with ADCs, there are several common ways of specifying a DAC's resolution:
- Number of bits, n , Number of output codes = 2^n, and Number of steps in the output = $2^n - 1$
- **Percentage resolution** = $1 / (2^n - 1)$, expressed as a percentage
- Step size, = $Vref / (2^n - 1)$
- Percentage Resolution=step size/Full scale output
- Example: For 5 bit binary network, if full scale maximum output is 10 Volt, then resolution would be =1/32 *10=0.3125 Volt

Contd..

- Accuracy- is represented in form of full scale error and linearity error.
- Full scale error- is deviation of DAC output from ideal or expected value.
- Linearity error-is maximum deviation in step size of 1 V.
- Offset error-often called 'zero-scale' error, indicates how well the actual transfer function matches the ideal transfer function at a single point.
- Gain error-is difference in slope between ideal DAC output gain and actual gain.

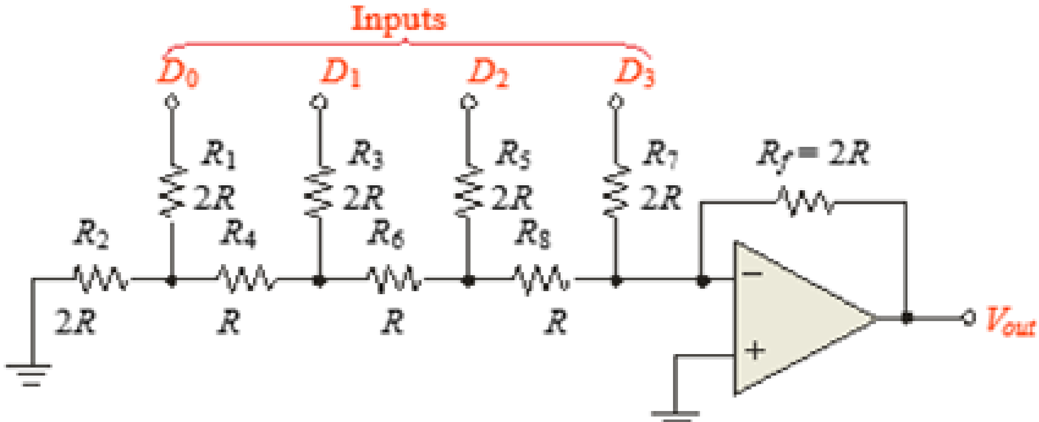
R-2R ladder network

- An enhancement of the binary-weighted resistor DAC is the R-2R ladder network.
- This type of DAC utilizes Thevenin's theorem in arriving at the desired output voltages.
- The R-2R network consists of resistors with only two values - R and 2xR.
- If each input is supplied either 0 volts or reference voltage, the output voltage will be an analog equivalent of the binary value of the three bits.

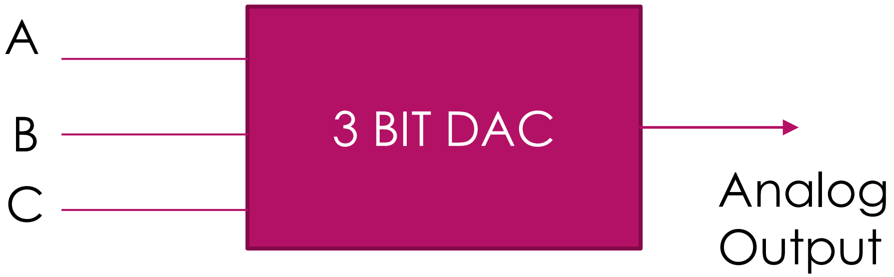


Working

- The *R*-2*R* ladder requires only two values of resistors.
- By calculating a Thevenin equivalent circuit for each input, the output is proportional to the binary weight of inputs that are HIGH.
- Each input that is HIGH contributes to the output: $V_{out} = -\frac{V_S}{2^{n-i}}$
- where V_S = input HIGH level voltage, n = number of bits and i = bit number
- For accuracy, the resistors must be precise ratios, which is easily done in integrated circuits.



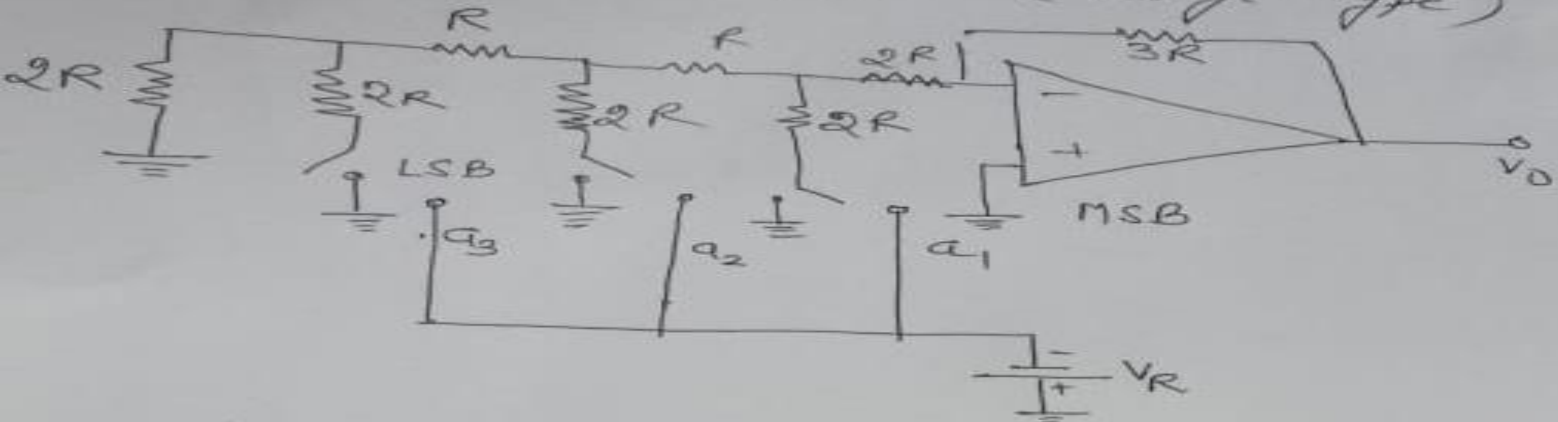
3 BIT DAC



Digital Input			
C	B	A	Analog Output (in Volts)
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

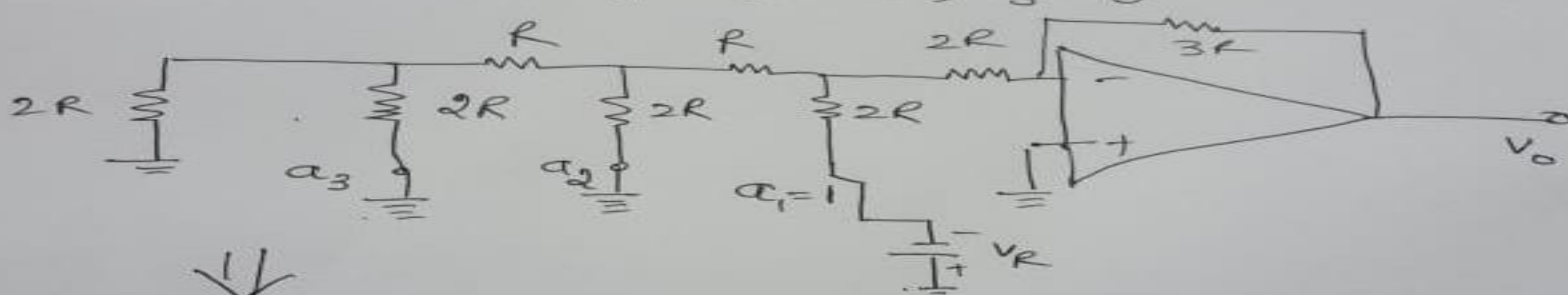
Working

R-2R Ladder DAC (Voltage Type)



let us consider a 3 bit DAC $a_1\ a_2\ a_3$

$100 \rightarrow a_1 = 1,\ a_2 = 0,\ a_3 = 0$



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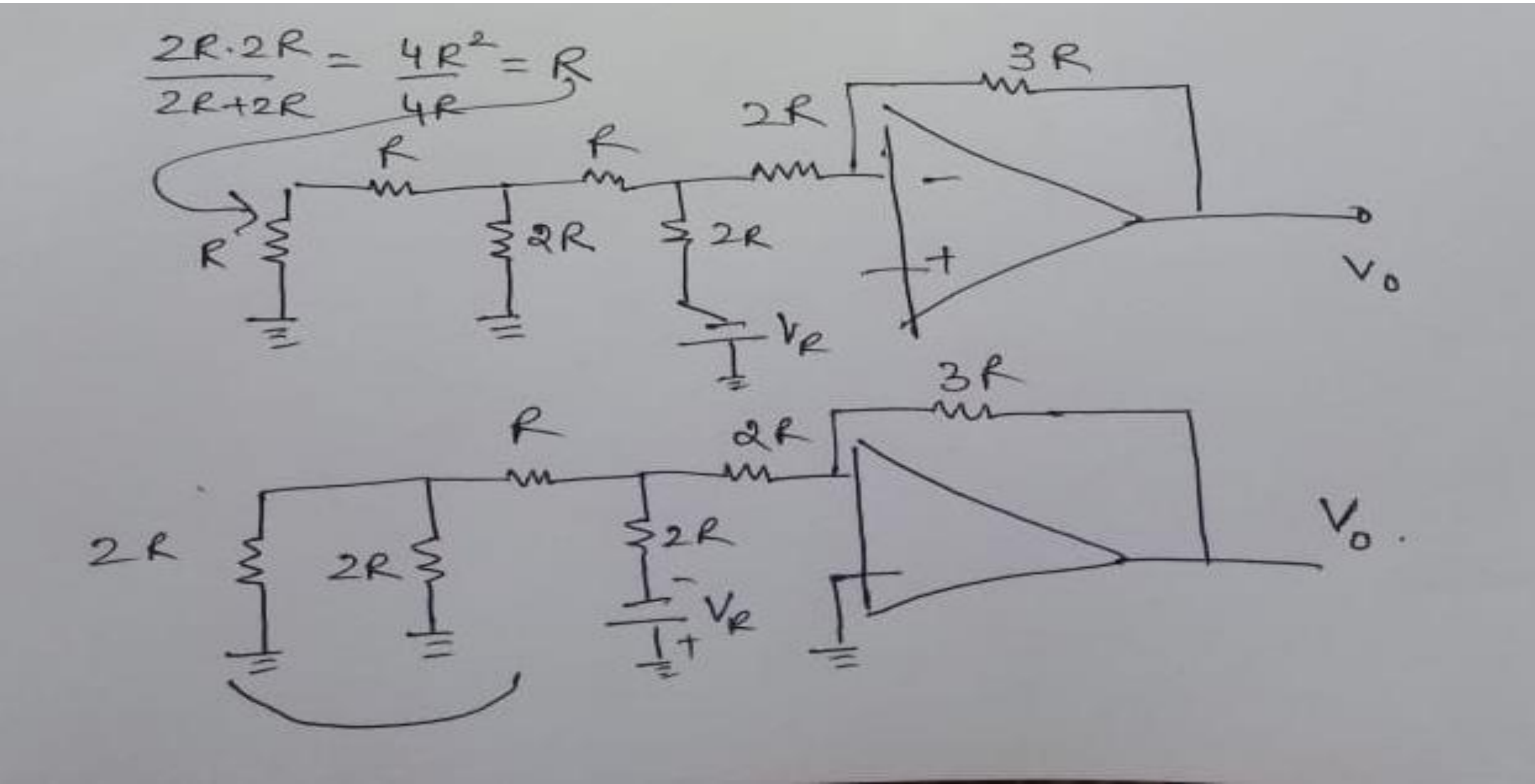
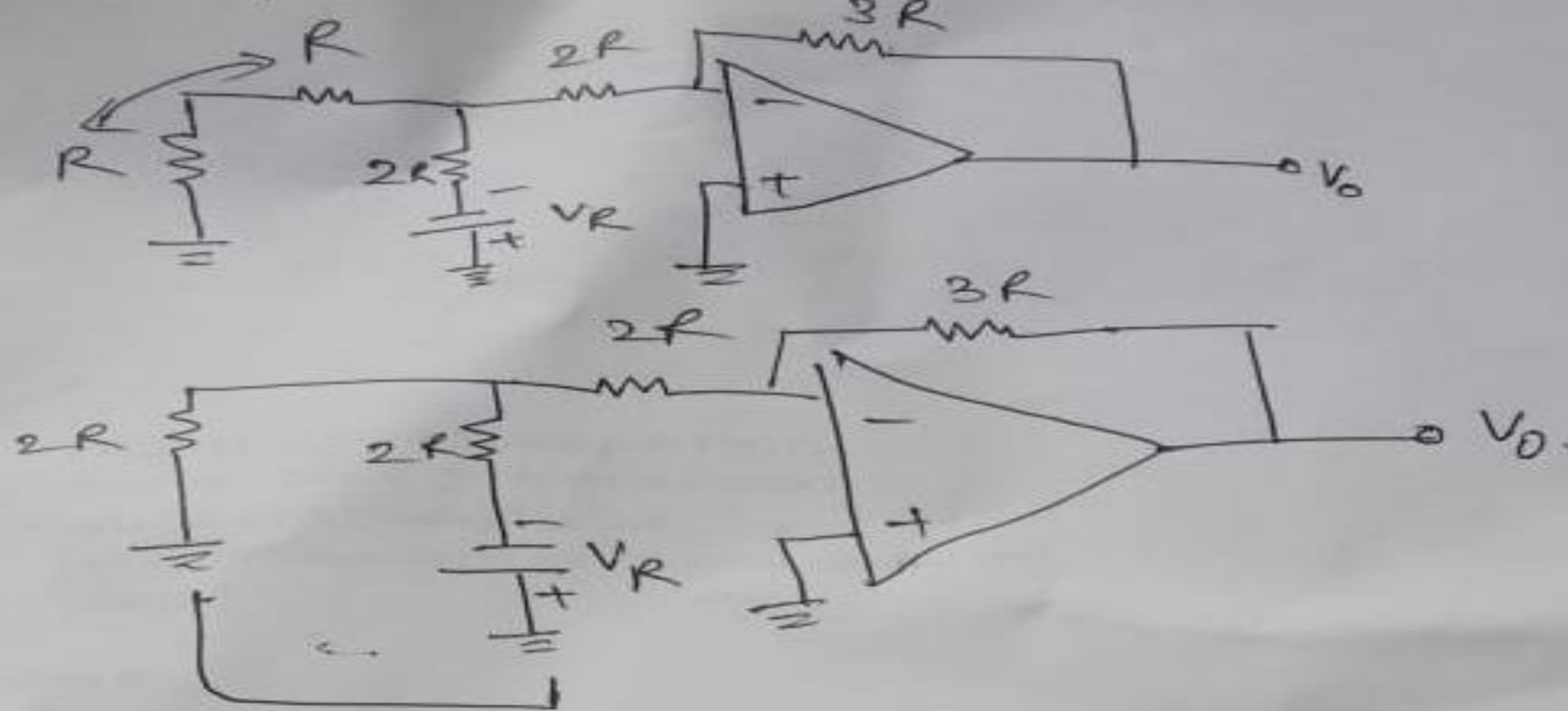


Contd..

$$\frac{2R \cdot 2R}{2R+2R} = \frac{4R^2}{4R} = R$$



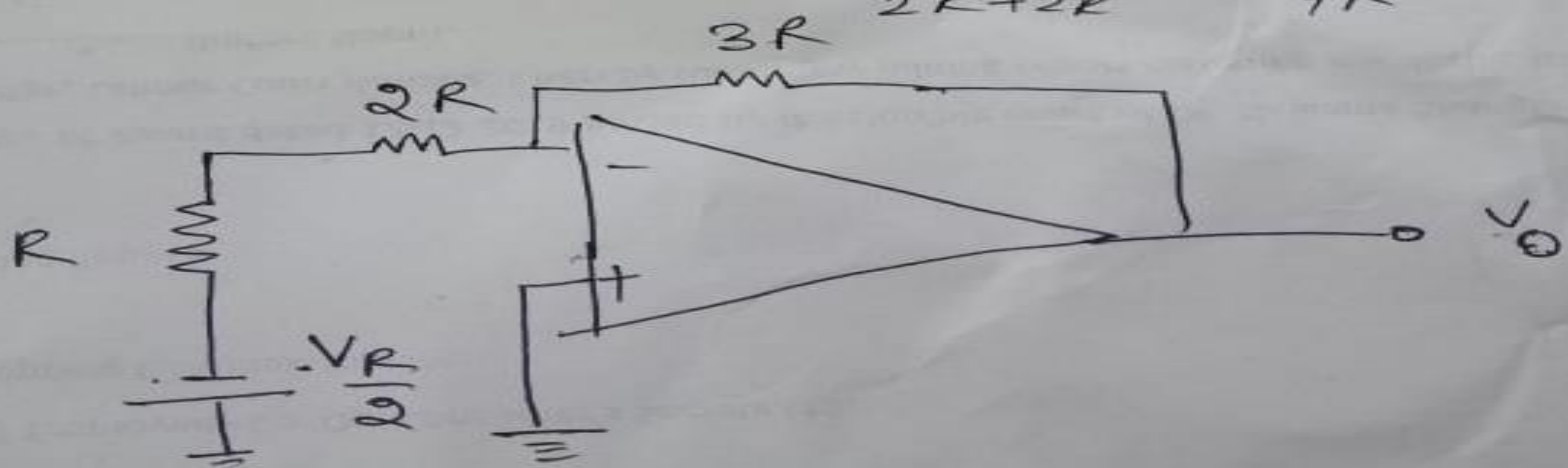
Different voltages

Contd..

$$V_{th} = \frac{(-V_R)\,2R}{2R+2R}$$

$$V_{th} = \frac{-V_R}{2\,\cancel{4R}} \cdot \cancel{2R} = -\frac{V_R}{2}$$

$$R_{th} = \frac{2R \cdot 2R}{2R+2R} = \frac{4R^2}{4R} = R$$



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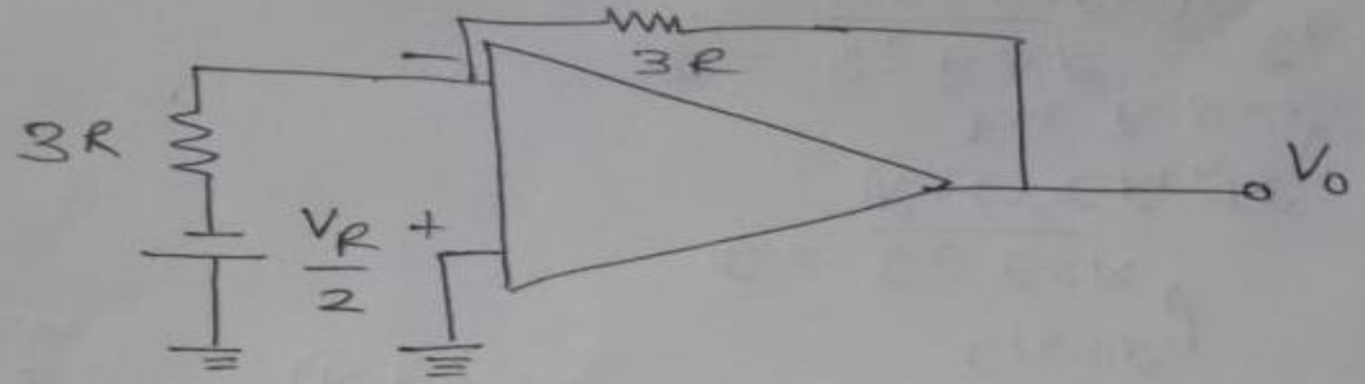
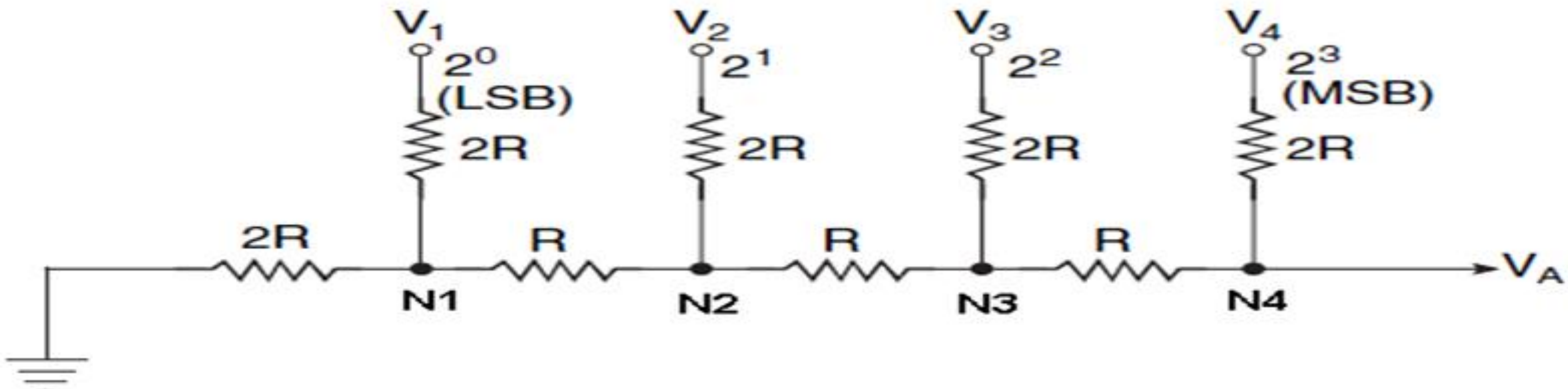
$\Rightarrow$



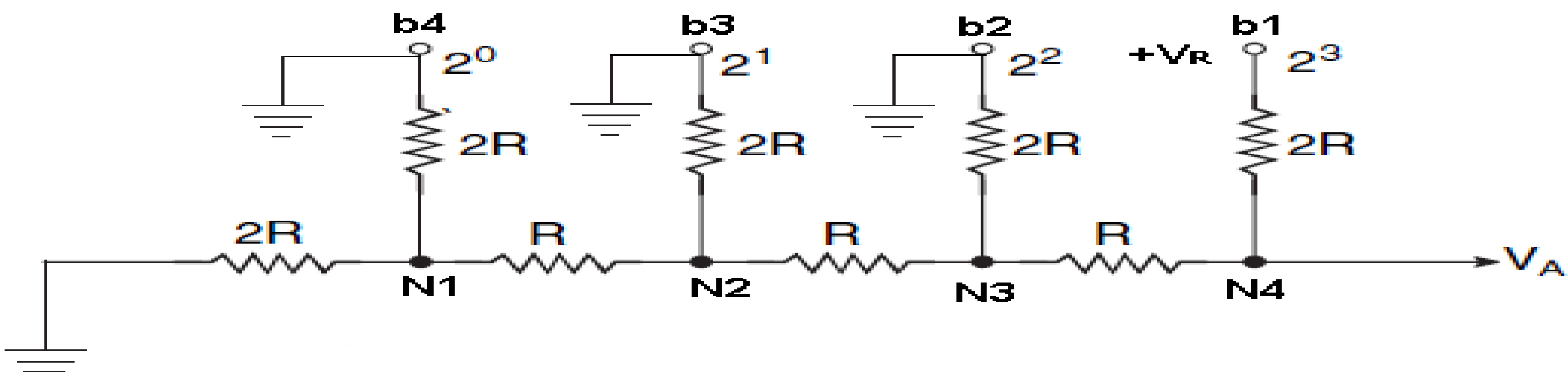
$$V_{out} = \frac{\text{feedback Resistor}}{\text{Input Resistor}} \times \text{input voltage}$$

$$= -\frac{(3R)}{3R}\left(-\frac{V_R}{2}\right) = \frac{V_R}{2}$$

4 Bit DAC

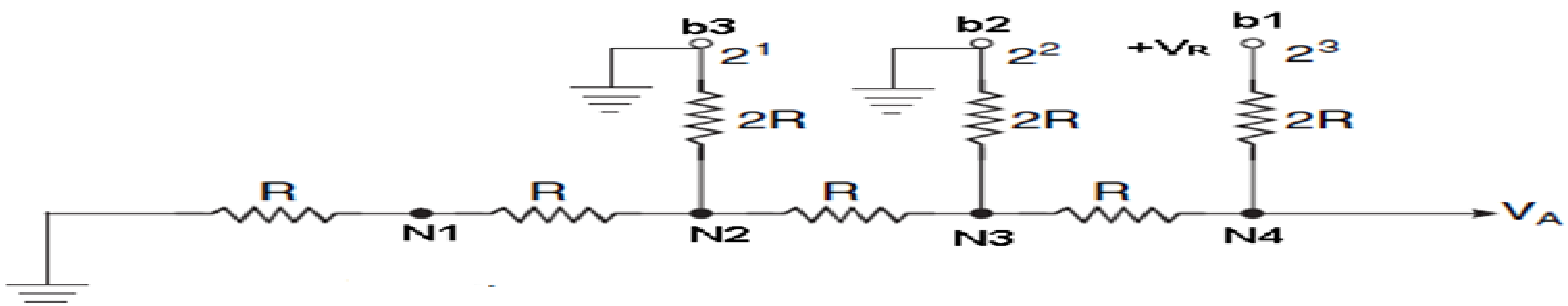


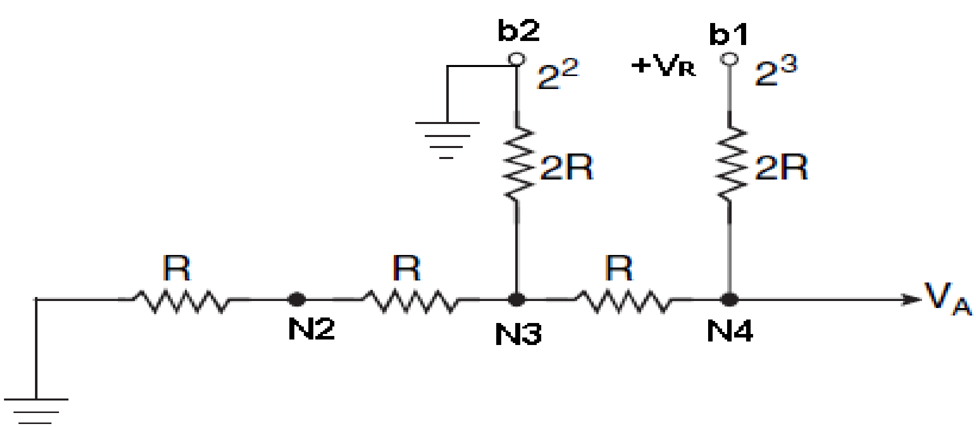
V_1
2^0
(LSB)
V_2
2^1
V_3
2^2
V_4
2^3
(MSB)
2R
2R
2R
2R
2R
R
R
R
N1
N2
N3
N4
V_A

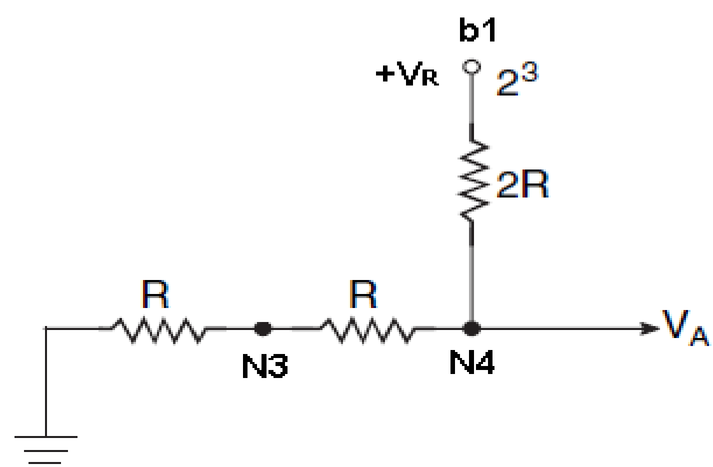


b4
2^0
b3
2^1
b2
2^2
$+V_R$
b1
2^3
2R
2R
2R
2R
2R
R
R
R
N1
N2
N3
N4
V_A

Contd..


b3
2^1
2R
b2
2^2
2R
+VR
b1
2^3
2R
R
R
R
R
N1
N2
N3
N4
VA


b2
2^2
2R
+VR
b1
2^3
2R
R
R
R
N2
N3
N4
VA


b1
+VR
2^3
2R
R
R
N3
N4
VA

Contd,

- Now at N4, calculate the output analog equivalent voltage i.e.
- $V_A = V_R*2R/(R+R+2R)$
- $= V_R/2$
- By using superposition theorem one can find in any n-bit ladder network the output voltage will be
- $V_A = V_R/2^1 + V_R/2^2 + V_R/2^3 + \ldots\ldots + V_R/2^n$

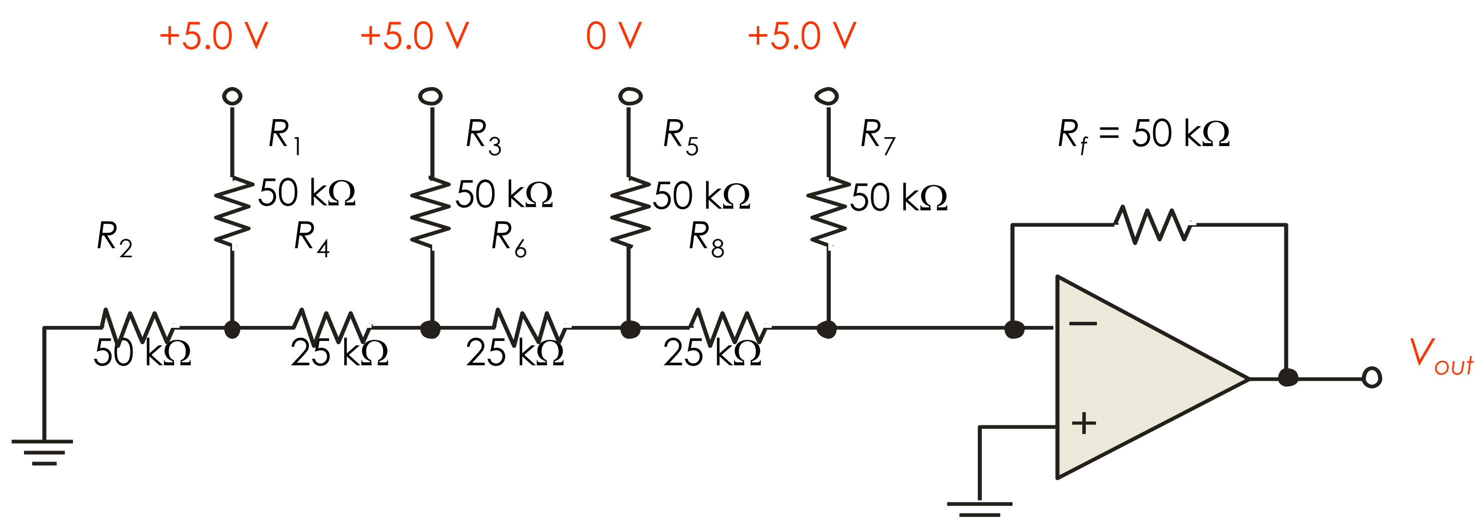
Example:An *R-2R* ladder has a binary input of 1011. If a HIGH = +5.0 V and a LOW = 0 V, what is V_{out}

Apply $V_{out} = -\frac{V_S}{2^{n-i}}$ to all inputs that are HIGH, then sum the results.

$$V_{out}(D_0) = -\frac{5\text{ V}}{2^{4-0}} = -0.3125\text{ V} \quad V_{out}(D_1) = -\frac{5\text{ V}}{2^{4-1}} = -0.625\text{ V}$$

$$V_{out}(D_3) = -\frac{5\text{ V}}{2^{4-3}} = -2.5\text{ V}$$

Applying superposition, V_{out} =-3.43V



Advantages and Disadvantages of R/2R ladder DACs

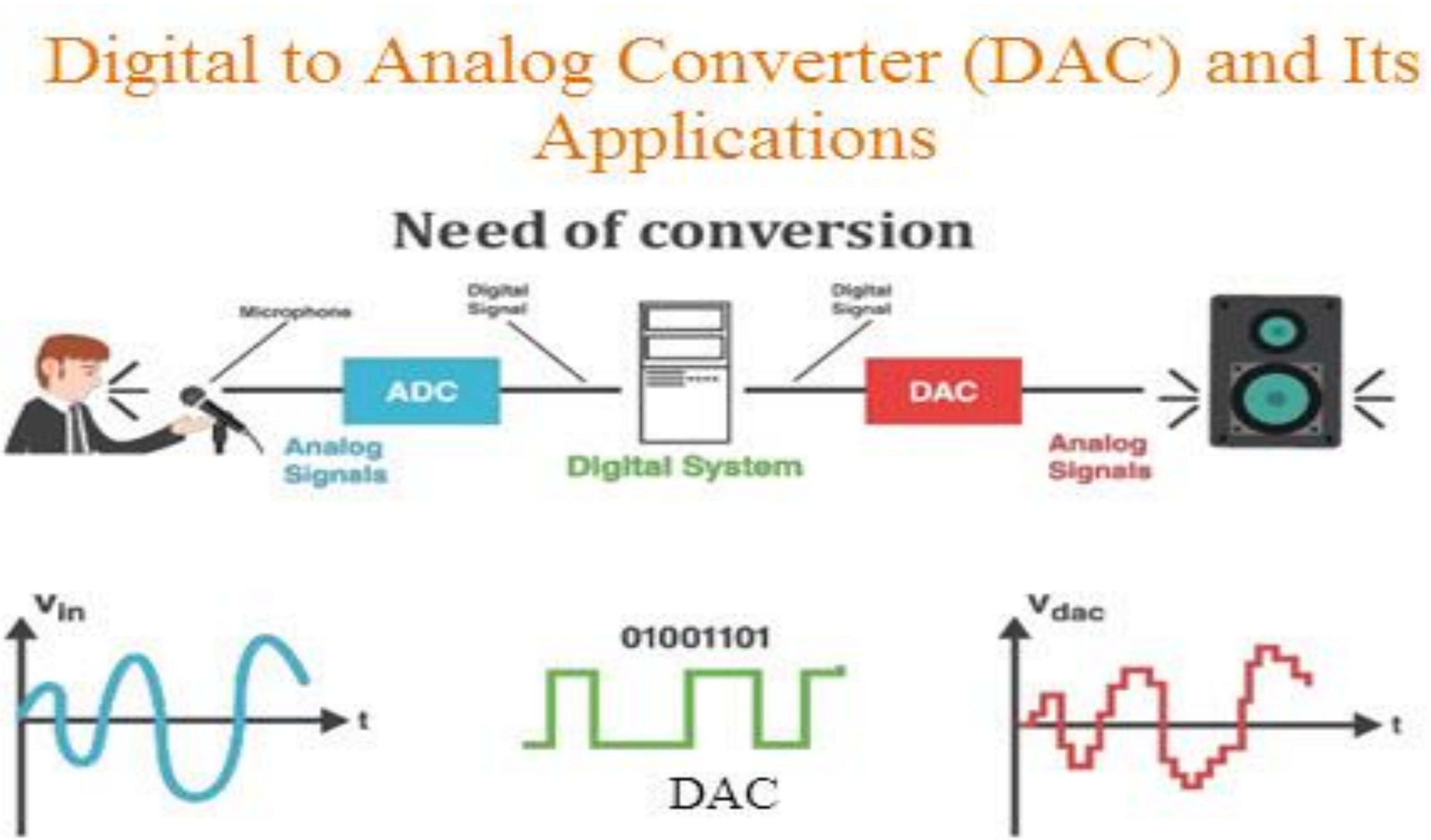
Advantages

- Easier to build accurately as only two precision metal film resistors are required.
- Number of bits can be expanded by adding more sections of same **R/2R** values.
- In inverted **R/2R ladder DAC**, node voltages remain constant with changing input binary words.

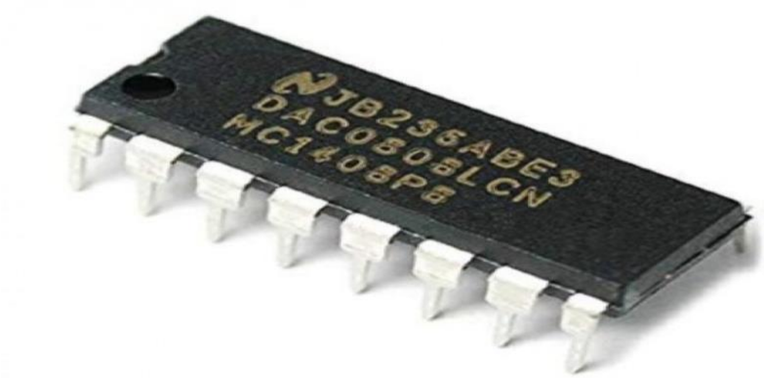
Disadvantages

- Slower conversion rate
- More confusing analysis

Applications



DAC0808



- ❖ Relative Accuracy: ±0.78% error maximum
- ❖ Full Scale Error: ±1 LSB typical
- ❖ Fast Settling Time: 150ns typical
- ❖ Noninverting Digital Inputs are TTL and CMOS Compatible
- ❖ High Speed Multiplying Input Slew Rate: 8mA/µs
- ❖ Power Supply Voltage Range: ±4.5V to ±18V
- ❖ Low Power Consumption: 33 mW @±5V

Thanks