CSE350: Digital Electronics & Pulse Techniques

Lecture 02: DAC

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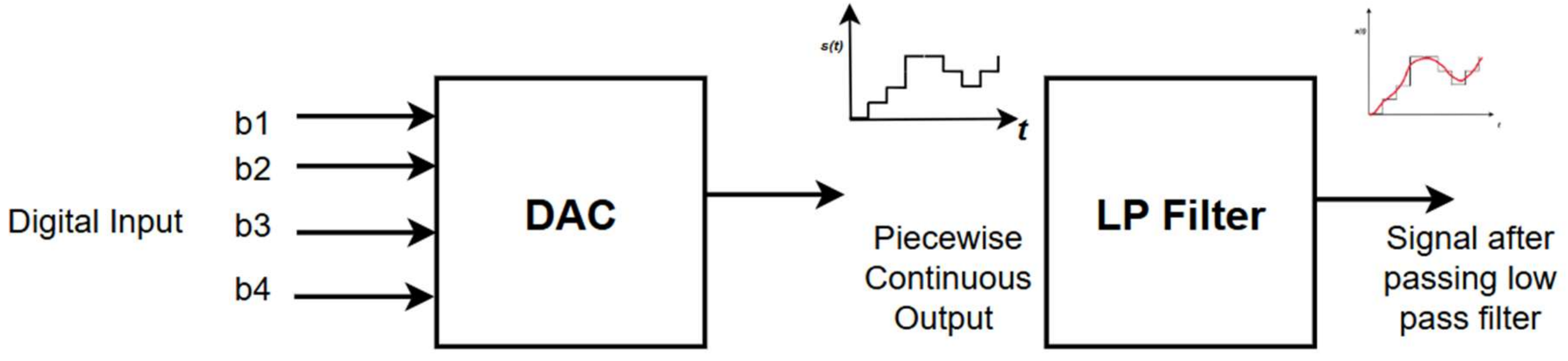
Digital to Analog Converter (DAC)



Binary to Decimal Conversion

Binary Number: $B_3B_2B_1B_0$

Equivalent Decimal Number: $B_3 * 8 + B_2 * 4 + B_1 * 2 + B_0 * 1$

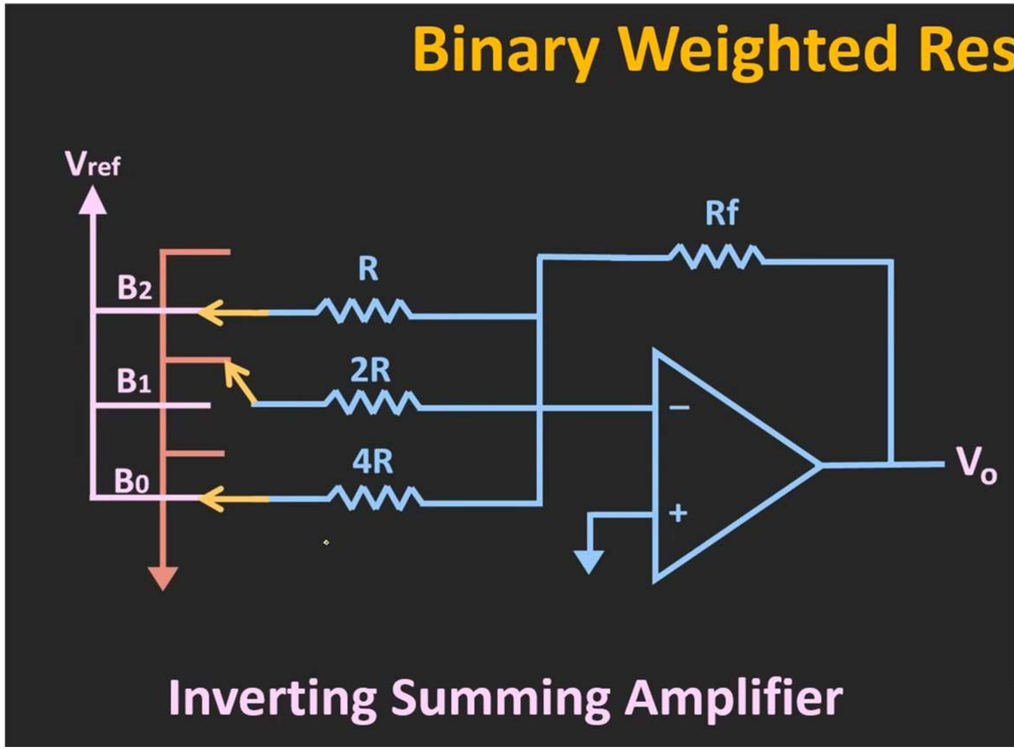
Example : Convert 1001_2 value into a decimal value.

Solve: $1001_2 = 1 * 8 + 0 * 4 + 0 * 2 + 1 * 1 = 9_{10}$

Binary Weighted Resistor DAC

Key features of this circuit,

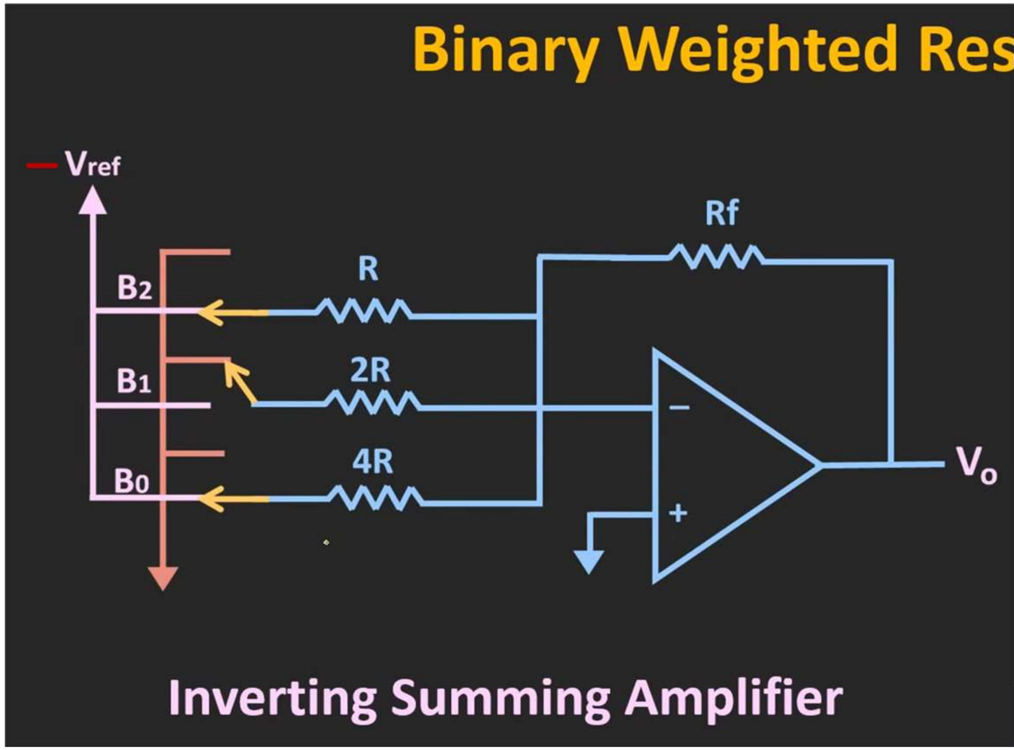
- ➢LSB branch will contain biggest resistor
- ➢MSB branch will contain Smallest resistors
- ➢Output will be positive if the input voltage is negative
- ➢Resistor of adjacent branch will be either double or half
- ➢There are 2^n output level for n bit input.



Binary Weighted Resistor DAC

An inverting adder with a feedback resistor **Rf = R** is used, along with doubling resistors at inverting input terminal. A switch is connected to all branches of input, which may connect to a reference voltage or ground. Since, no current flows through the input terminal of an op-amp and the non-inverting & inverting terminals are virtually shorted, the current towards & voltage at the inverting terminal are both 0.
Let, the current from output to the terminal through Rf is I.
Then,

$$I = \frac{V_o - 0}{R_f} = I_2 + I_1 + I_0$$

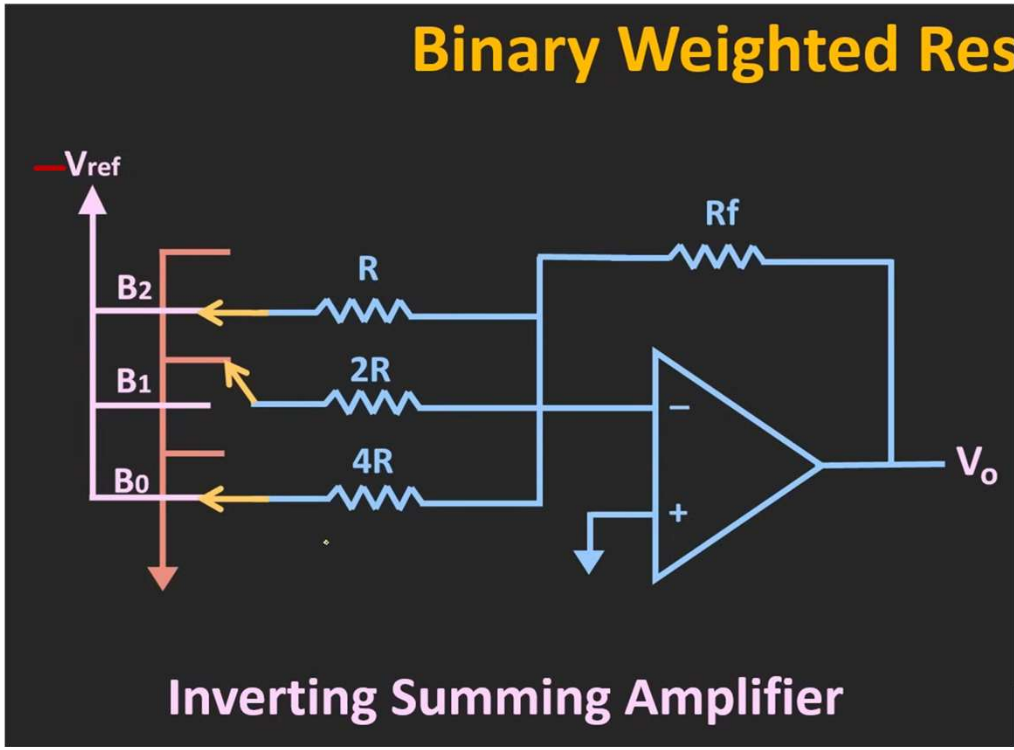


Where, I_2, I_1 & I_0 are the currents through the input branches. When the switches are connected to reference voltage, we can express these currents as,

$$\boxed{I_2 = \frac{0-(-V_{ref})}{R}} \quad \boxed{I_1 = \frac{0-(-V_{ref})}{2R}} \quad \boxed{I_0 = \frac{0-(-V_{ref})}{4R}}$$

When the switches are connected to ground, the currents are 0. The switches are actually implementations of the bits of the digital input signal. These bits if assumed to be B2, B1, B0, then the currents can be expressed for both cases as,

$$\boxed{I_2 = B_2\frac{V_{ref}}{R}} \quad \boxed{I_1 = B_1\frac{V_{ref}}{2R}} \quad \boxed{I_0 = B_0\frac{V_{ref}}{4R}}$$



Applying KCL at inverting terminal,

$$I = \frac{V_o}{R} = I_2 + I_1 + I_0 = V_{ref}(\frac{B_2}{R} + \frac{B_1}{2R} + \frac{B_0}{4R})$$

$$\boxed{V_o = V_{ref}(B_2 + \frac{B_1}{2} + \frac{B_0}{4})}$$

The highest output voltage is,

$$V_o = V_{ref}(1 + \frac{1}{2} + \frac{1}{4}) = V_{ref}\frac{8-1}{4} = V_{ref}\frac{2^n - 1}{2^{n-1}}$$

One of the disadvantages of Binary Weighted Resistors is that, a lot of resistors are used. Hence, fluctuations in their values can cause errors in output voltage. This sensitive nature can be overcome by the R-2R Ladder DAC .

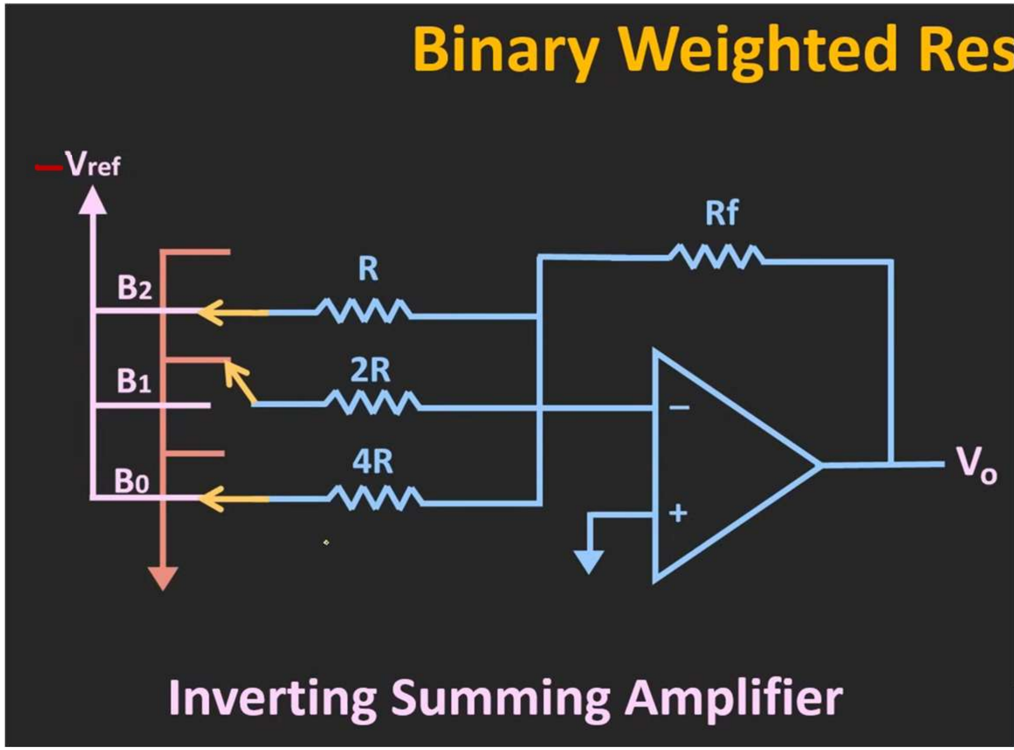
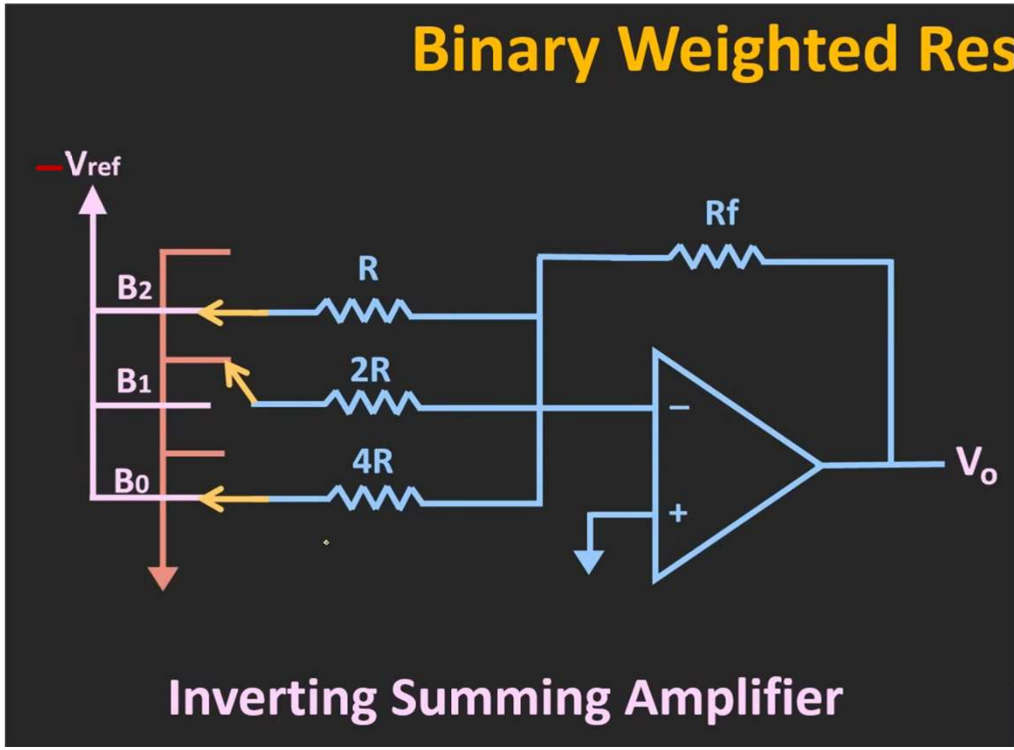


Table: For different input combination. Combination $= 2^3 = 8$,

B0	B1	B2	Vo
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

Suppose,
$V_{REF} = 8\,V$

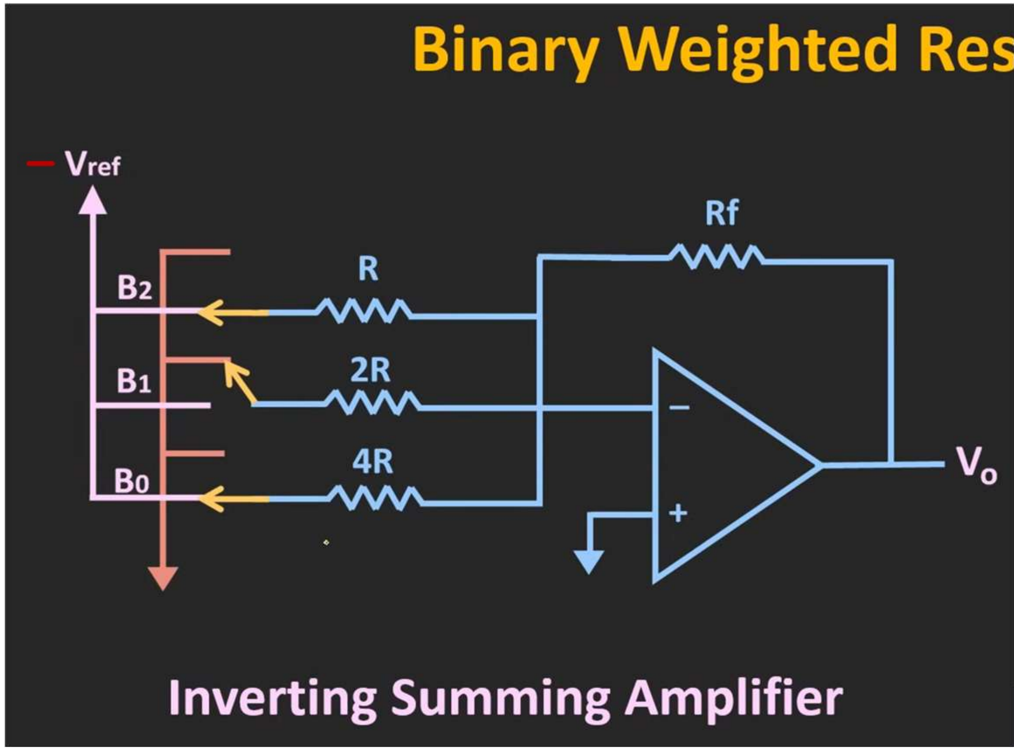


- If $V_{REF} = 8\,V$, what will be the step size ?

Step size is the difference between two adjacent output values or the output value for the LSB bits contribution only. For **0001 input**, output will be the step size.

- If $V_{REF} = 8\,V$, what will be the Max output ?

Max output level can be found for high input at every input. For **1111 input**, output will be max.



General Format for DAC

Binary: DCBA

$$V_o = -R_f\left(\frac{V_D}{R_D} + \frac{V_C}{R_C} + \frac{V_B}{R_B} + \frac{V_A}{R_A}\right)$$

$$R_A > R_B > R_C > R_D \; and \; factor \; of \; 2$$

If we assign,

$R_D = R, then, R_C = 2R, R_B = 4R, R_A = 8R$

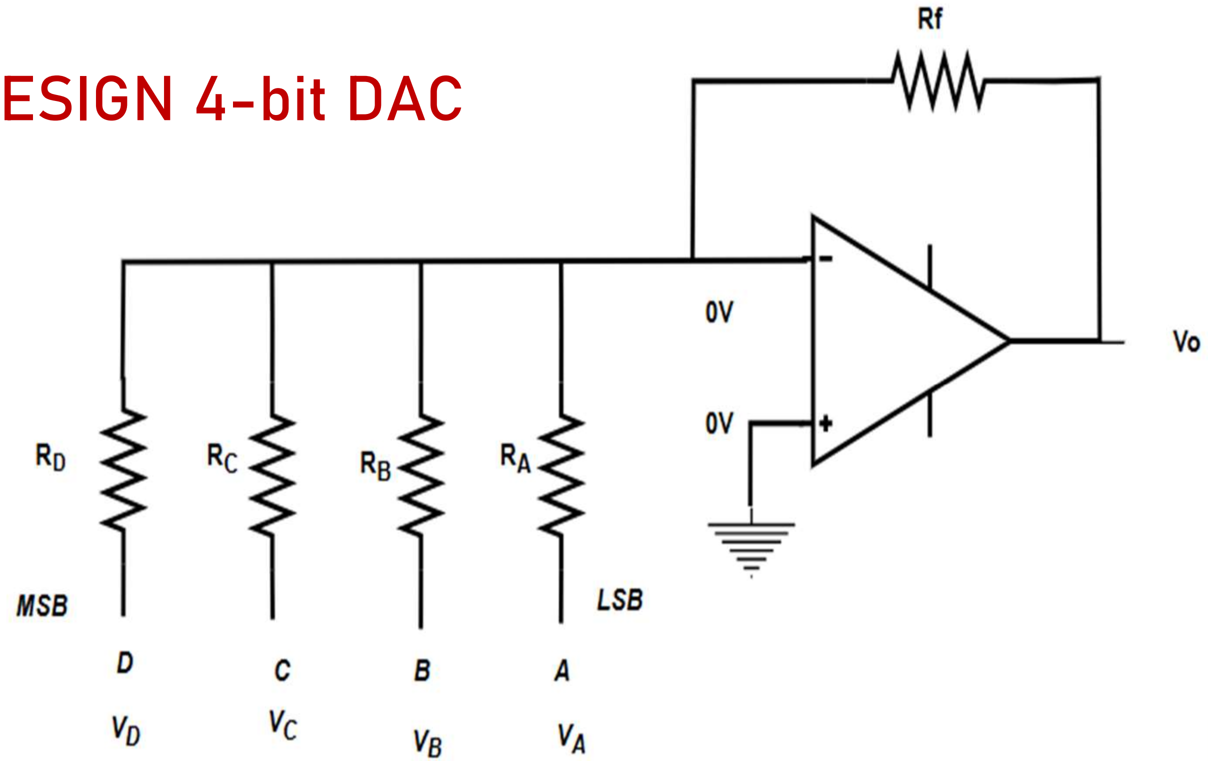
If we assign,

$R_A = R, then, R_B = R/2, R_C = R/4, R_D = R/8$

If we want, positive output, V_{REF} need to be negative.

If we want, negative output, V_{REF} need to be positive.

DESIGN 4-bit DAC



DAC (MSB→ R)

Binary: DCBA

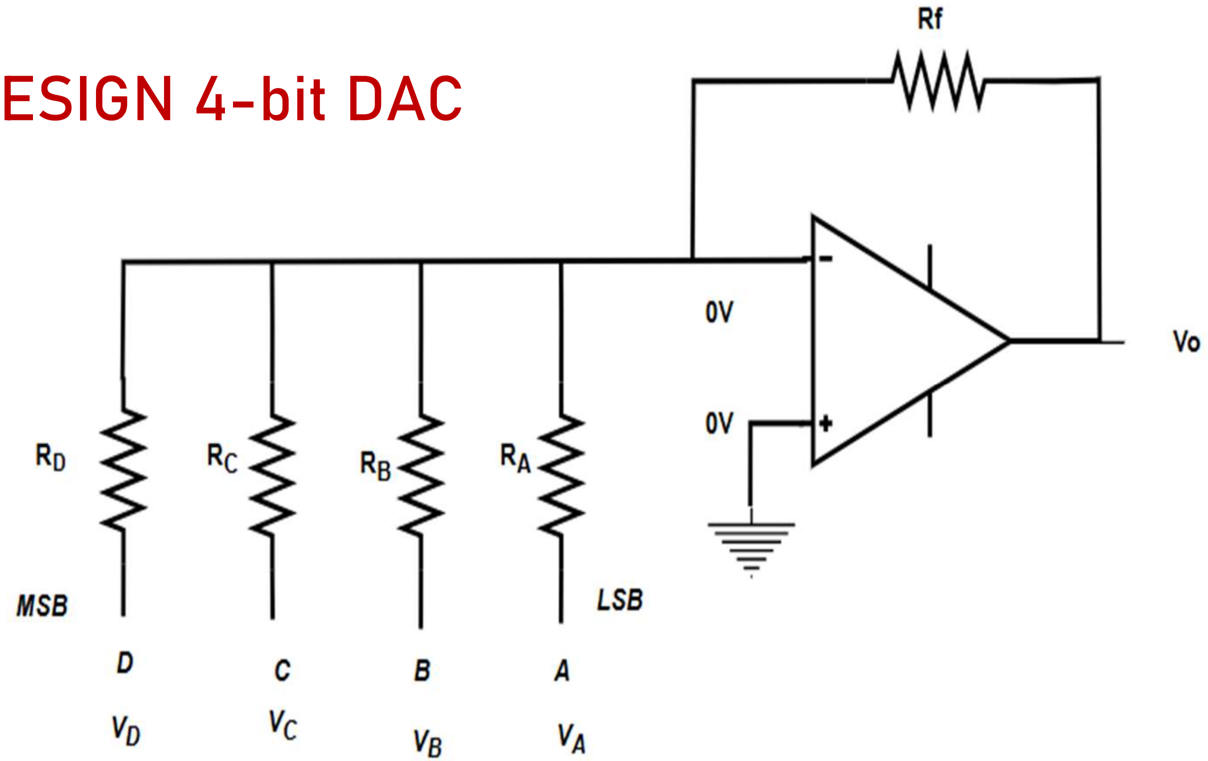
If $V_A = A * V_{REF}, V_B = B \ * V_{REF}$,
$V_C = C \ * V_{REF}$, $V_D = D \ * V_{REF}$

$R_D = R, then, R_C = 2R, R_B = 4R, R_A = 8R$

$$V_o = -\frac{R_f}{R}\left(V_D + \frac{V_C}{2} + \frac{V_B}{4} + \frac{V_A}{8}\right)$$

$$V_o = -\frac{R_f * V_{REF}}{R}\left(D + \frac{C}{2} + \frac{B}{4} + \frac{A}{8}\right)$$

DESIGN 4-bit DAC



DAC (LSB→ R)

Binary: DCBA

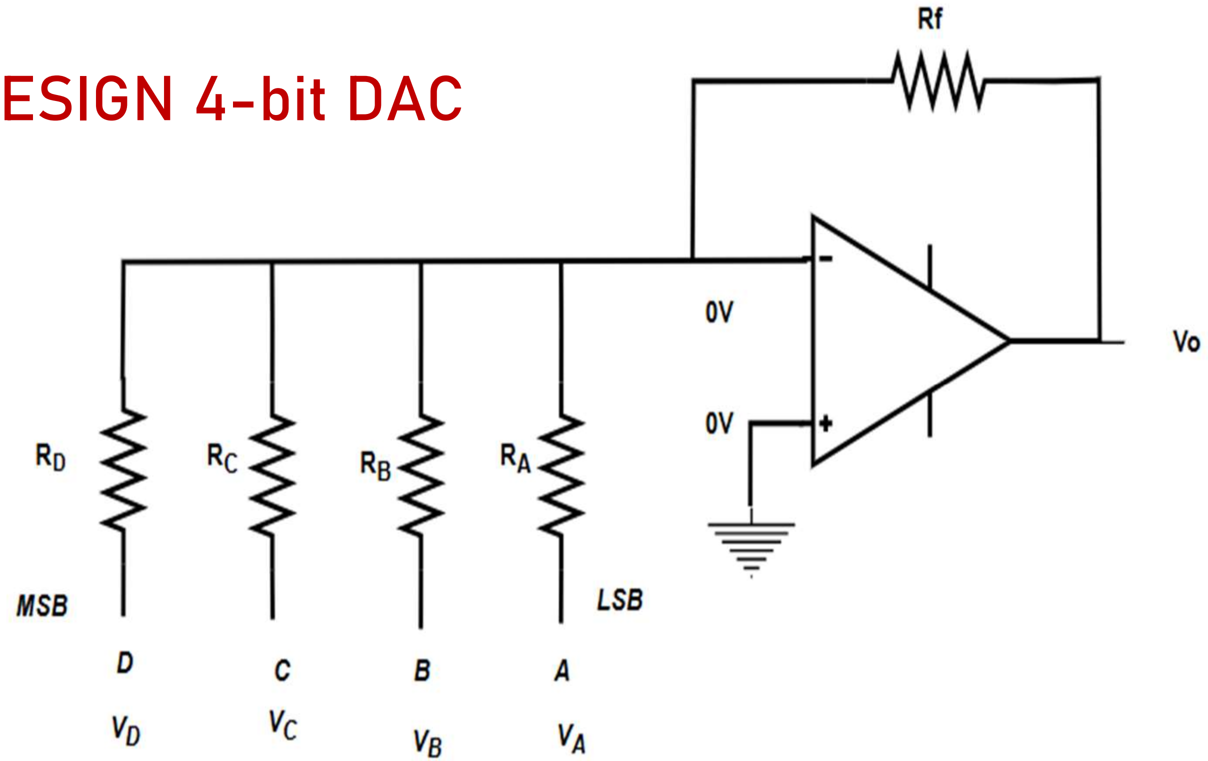
If $V_A = A * V_{REF}, V_B = B * V_{REF}$,
$V_C = C * V_{REF}$, $V_D = D * V_{REF}$

$$R_A = R, R_B = \frac{R}{2}, R_C = \frac{R}{4}, R_D = \frac{R}{8}$$

$$V_o = -\frac{R_f}{R}(8 * V_D + 4 * V_C + 2 * V_B + 1 * V_A)$$

$$V_o = -\frac{R_f * V_{REF}}{R}(8 * D + 4 * C + 2 * B + 1 * A)$$

DESIGN 4-bit DAC



Exercise -

Binary: DCBA

If $R_A = R_F = 10k\Omega$, Find the following parameter for this DAC circuit. Given, $V_{REF} = 0.5\ V, V_H = 30\ V\ and\ V_L = -30\ V$

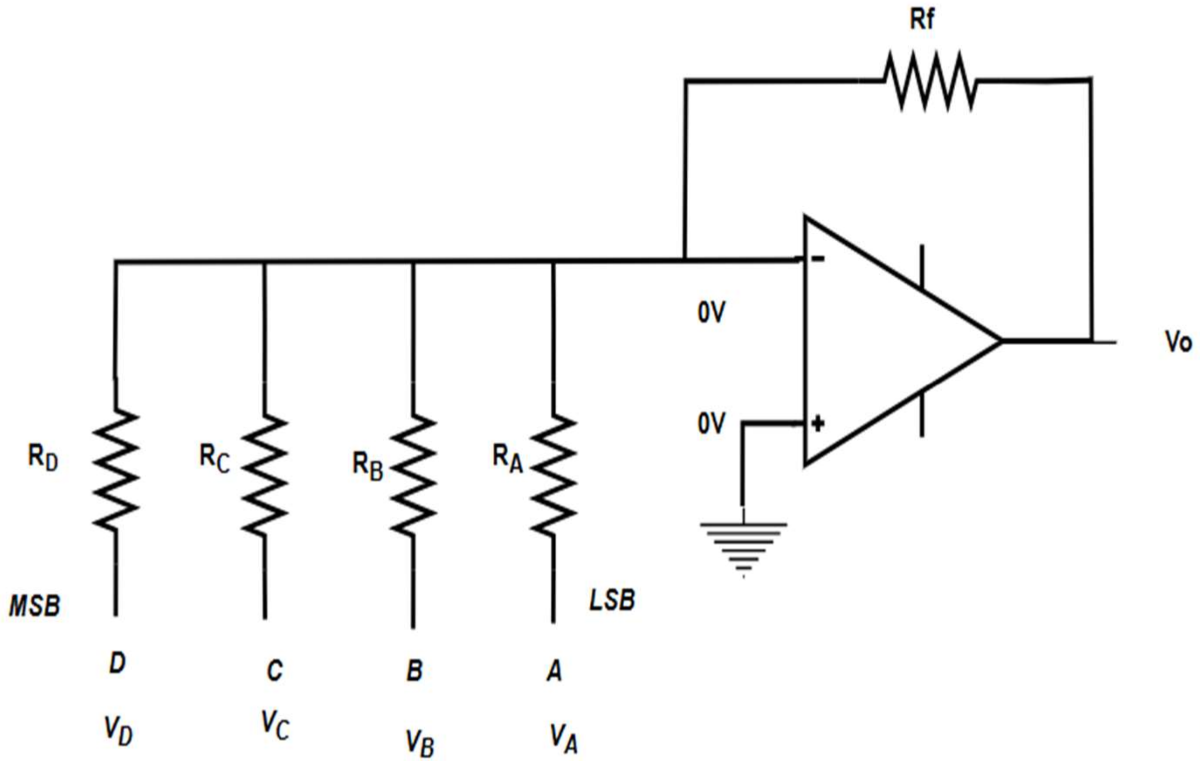
a. Find the value of maximum output.

b. Find the value of the step size.

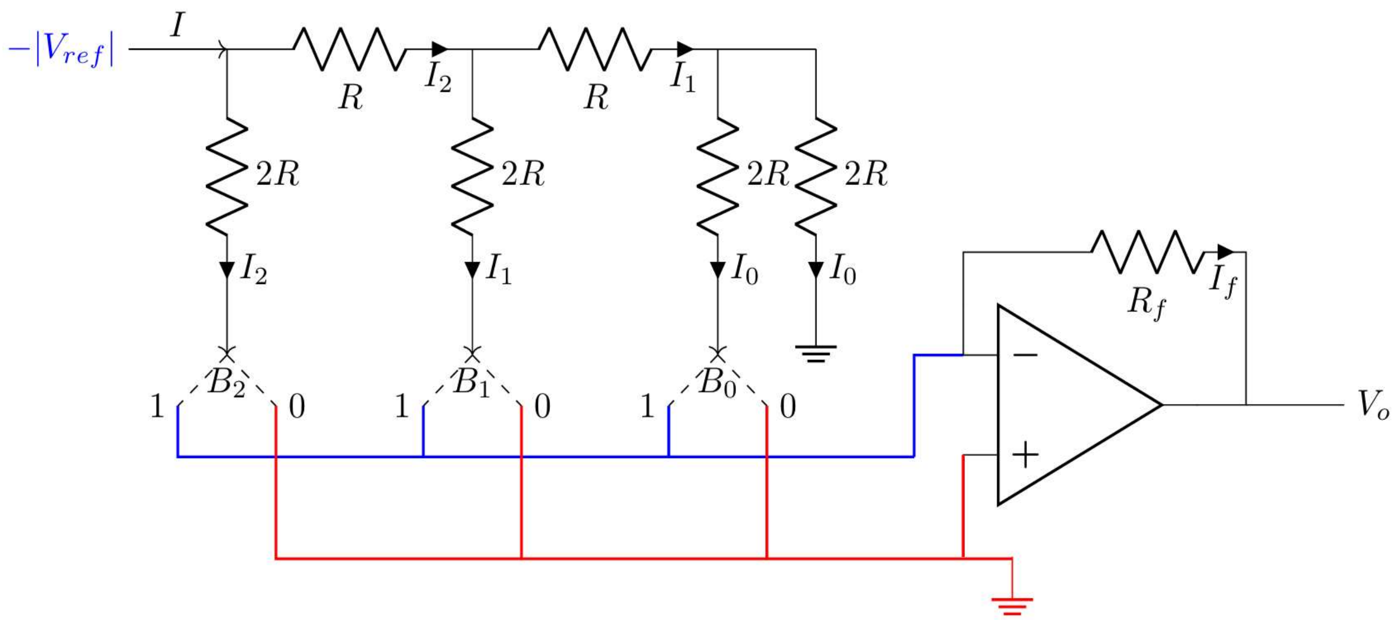
c. Find the value of the 1-LSB change voltage.

d. Find the value of the 1-MSB change voltage.

e. Plot the Output voltage vs input binary.



R2R Ladder DAC: beside is shown a **3-bit R2R ladder DAC**. Here, as we can see, a resistive network of **R & 2R** is used, which has a ladder type structure. The switches connected in 2R branches can either connect to the ground at inverting terminal or that at the non-inverting terminal. In the former case, the current can flow through the feedback resistor 2R. But when the switch connects to non-inverting terminal, it flows to ground.



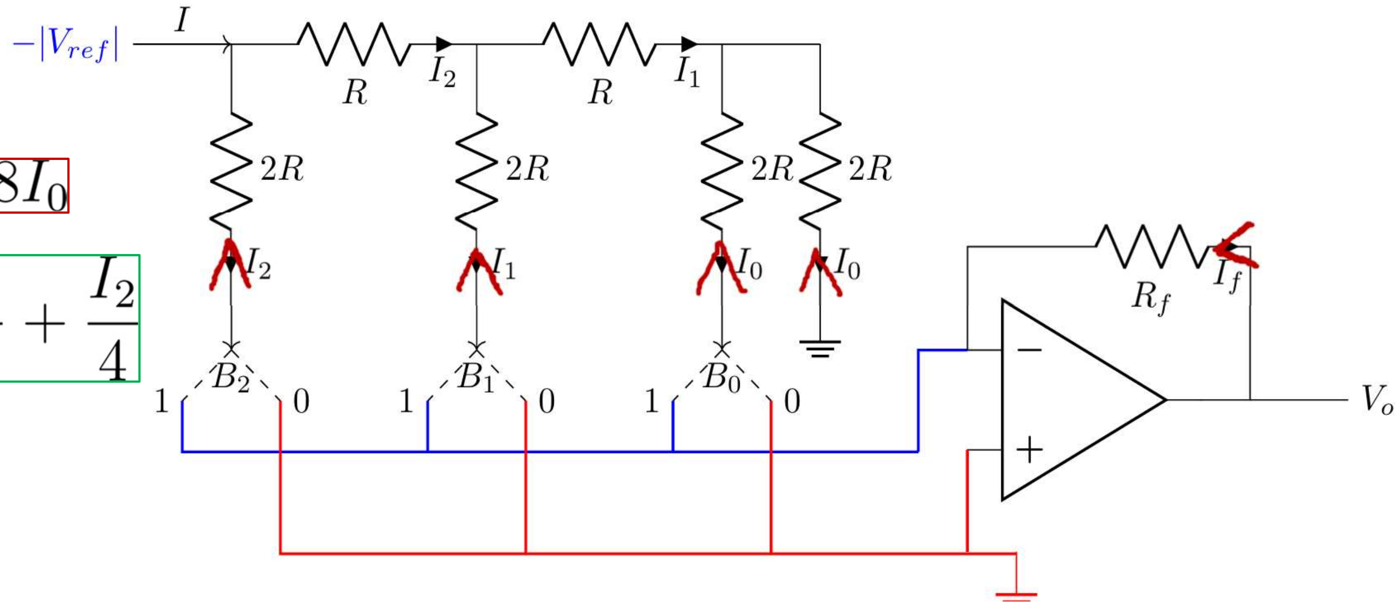
The currents along the branches are marked on the figure. We get,

$$\boxed{I = 2I_2 = 2 * 2I_1 = 2 * 2 * I_0 = 8I_0}$$

So, $\boxed{I_0 = \frac{I_2}{4}}$ $\boxed{I_1 = \frac{I_2}{2}}$ $\boxed{I = I_2 + \frac{I_2}{2} + \frac{I_2}{4}}$

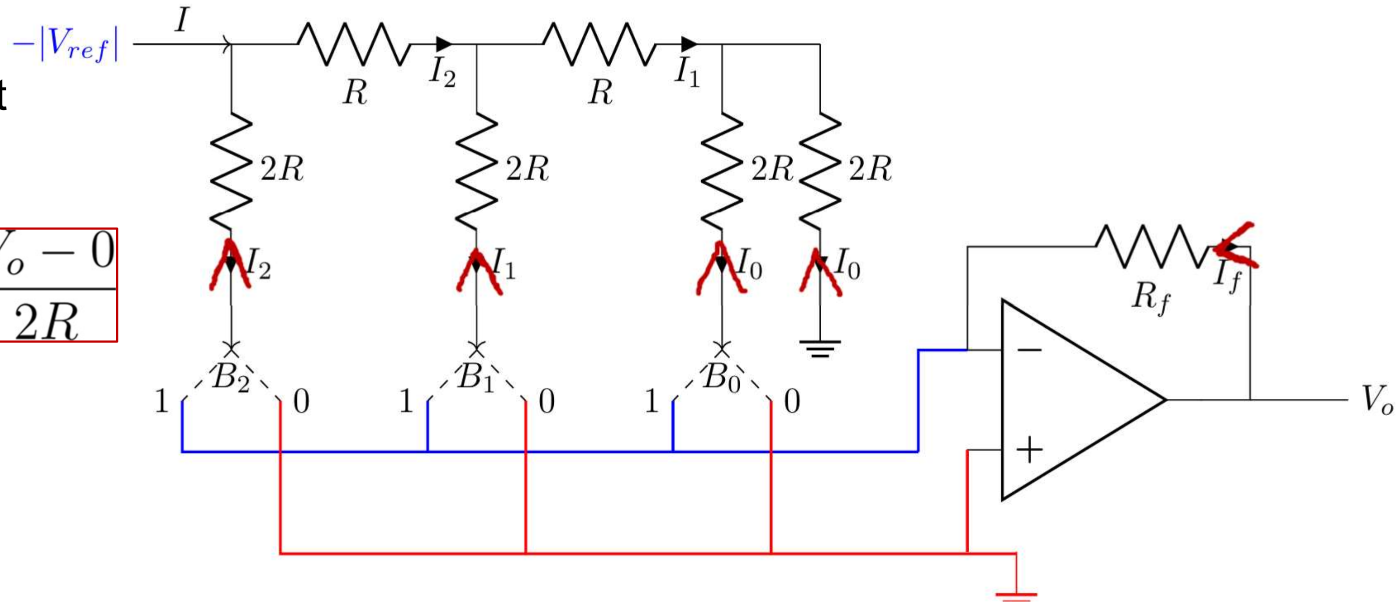
Also,

$$\boxed{I_2 = \frac{0 - (-V_{ref})}{2R} = \frac{V_{ref}}{2R}}$$



Thus, the current through the feedback resistor 2R can be expressed using KCL at inverting terminal,

$$\boxed{I = B_2\frac{V_{ref}}{2R} + B_1\frac{V_{ref}}{4R} + B_0\frac{V_{ref}}{8R} = \frac{V_o - 0}{2R}}$$



So,

$$\boxed{V_o = V_{ref}(B_2 + \frac{B_1}{2} + \frac{B_0}{4})}$$

Exercise -

The figure below shows the input-output characteristics of a converter. The output of the converter is denoted as V_0 and the input as V_{in}. Identify the converter type and the number of bits used by the converter. Further, calculate V_{ref} when RF = 2R.