LINEAR INTEGRATED CIRCUITS

Summing, Scaling, Averaging Amplifiers & D/A Converter

Outline

- ❑ Inverting Configuration
  - ❑ Summing Amplifier
  - ❑ Scaling or Weighted Amplifier
  - ❑ Average Amplifier
- ❑ Non-inverting Configuration
  - ❑ Summing Amplifier
  - ❑ Scaling or Weighted Amplifier
- ❑ D/A Converter (R-2R Ladder)

Inverting Summing Amplifier

Using Kirchhoff's Current Law flowing through R_F

$$I = I_a + I_b + I_c = \frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c}$$

The output voltage is given as

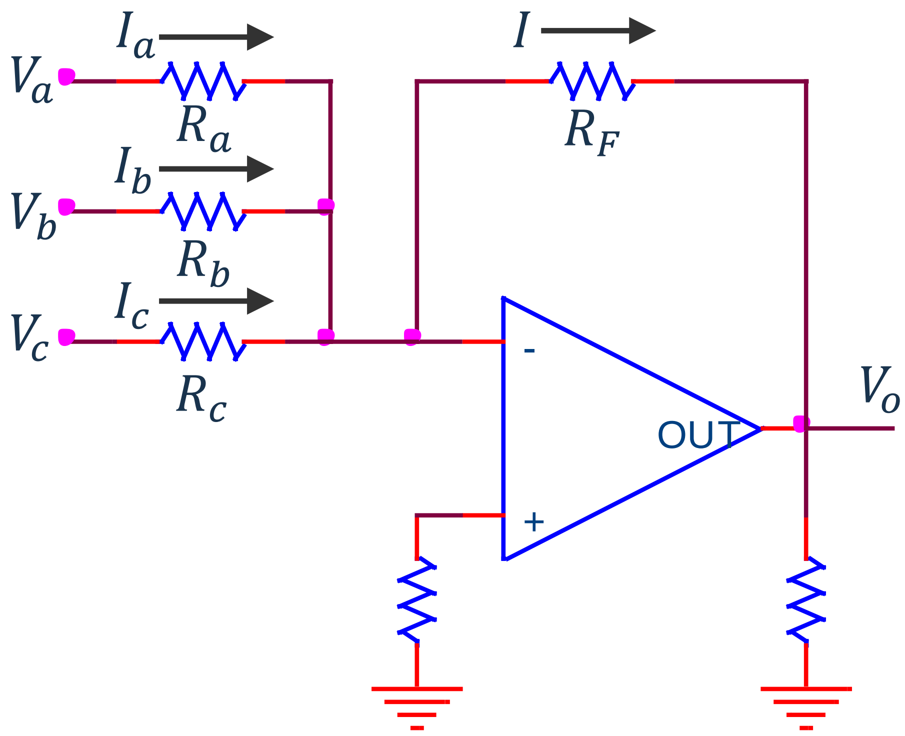
$$V_o = -IR_F = -\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c}\right)R_F \qquad (1)$$

For $R_a = R_b = R_c = R$

$$V_o = -\frac{R_F}{R}(V_a + V_b + V_c) \qquad (2)$$

Further, putting $R_F = R$ in (2)

$$V_o = -(V_a + V_b + V_c)$$



Scaling or Weighted Sum Amplifier

In the given circuit, if $R_a \neq R_b \neq R_c$

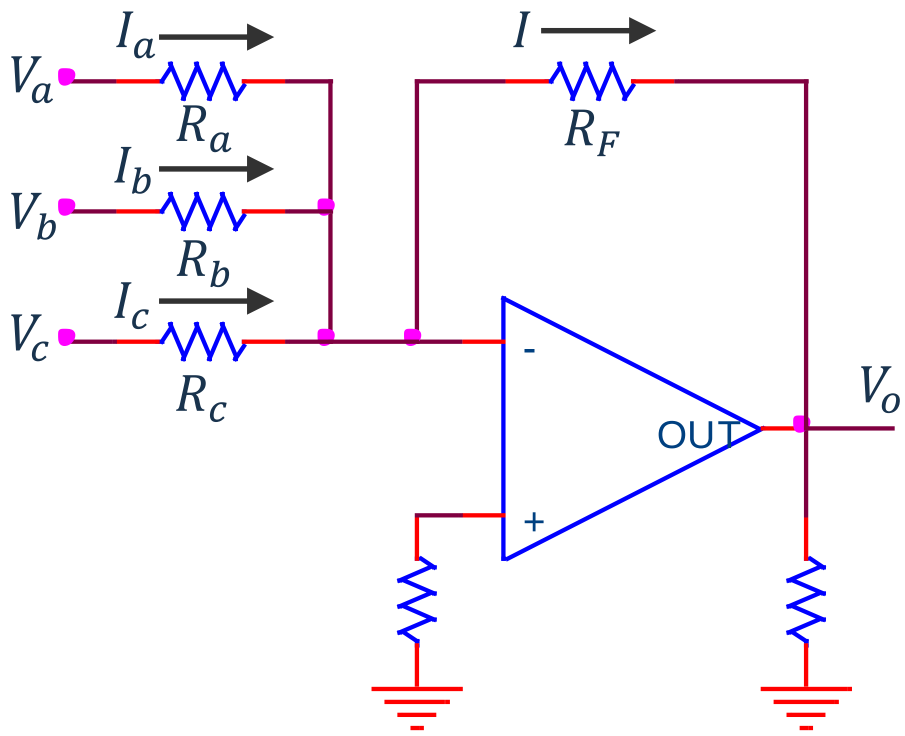
From (1), we get the output voltage is scaled or weighted sum of input voltages

$$V_o = -\left(\frac{R_F}{R_a}V_a + \frac{R_F}{R_b}V_b + \frac{R_F}{R_c}V_c\right)$$

Considering

$$\frac{R_F}{R_a} = 1, \frac{R_F}{R_b} = 2, \text{and } \frac{R_F}{R_c} = 4$$

$$V_o = -(V_a + 2V_b + 4V_c)$$



Averaging Amplifier

Assume $R_a = R_b = R_c = R$ and $\frac{R_F}{R} = \frac{1}{n}$

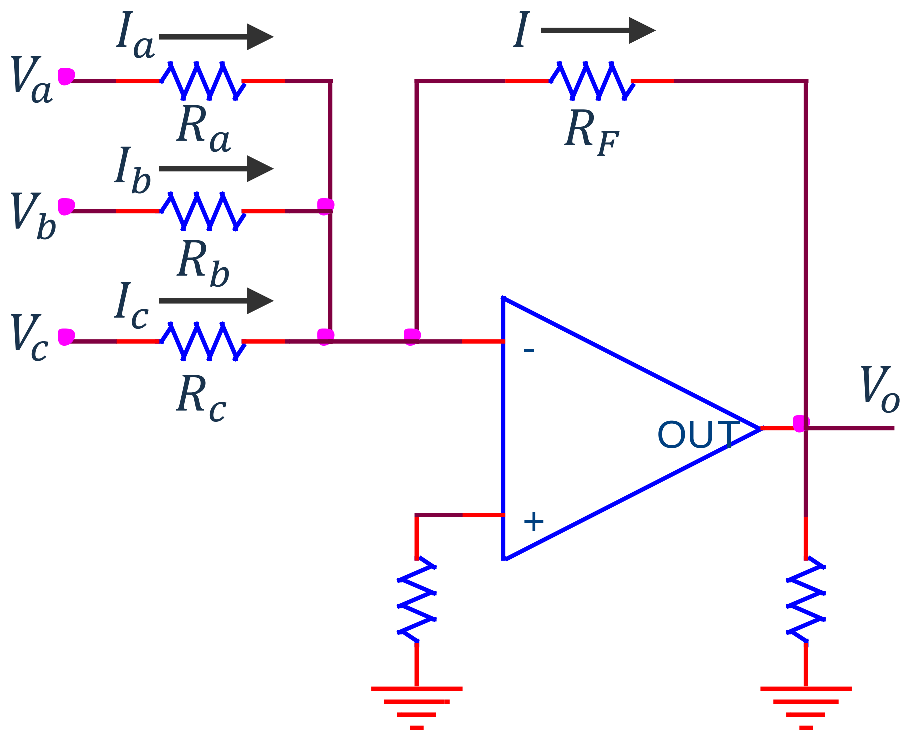
In this circuit for three input voltages

$$\frac{R_F}{R} = \frac{1}{3}$$

From (1)

$$V_o = -\frac{1}{3}(V_a + V_b + V_c)$$

Hence, output voltage is negative average of input voltages.



Non-inverting Summing Amplifier

For simplicity, assume $R_a = R_b = R_c = R$ and determine V_x using Superposition Theorem as

$$V_x = \frac{R/2}{R + R/2} V_a + \frac{R/2}{R + R/2} V_b + \frac{R/2}{R + R/2} V_c$$

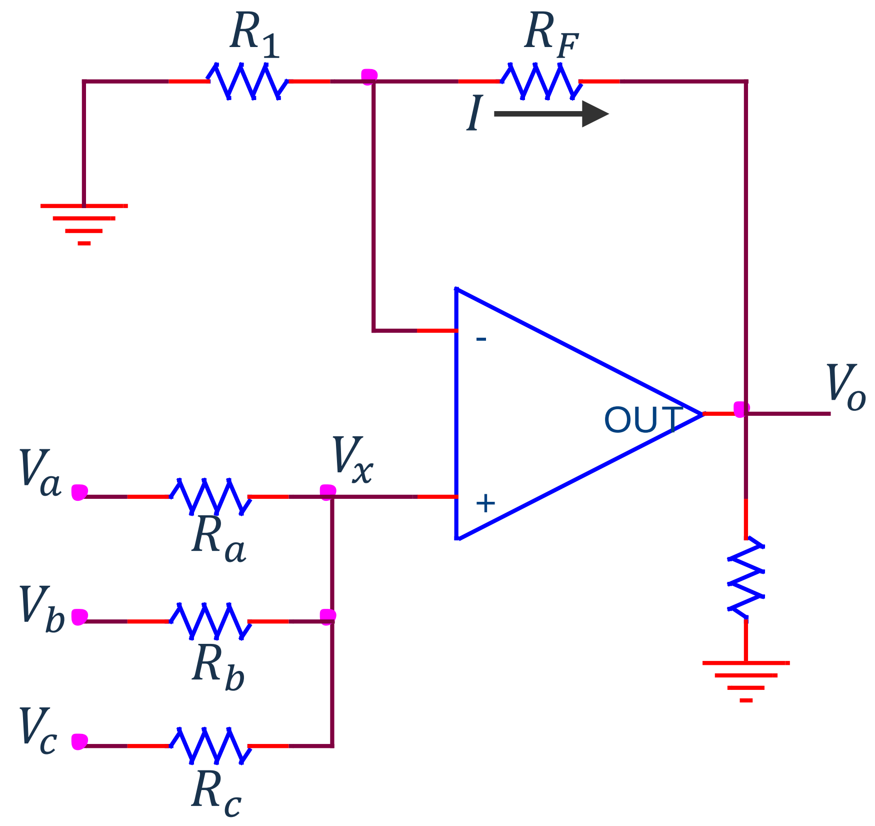
$$V_x = \frac{V_a}{3} + \frac{V_b}{3} + \frac{V_c}{3} = \frac{V_a + V_b + V_c}{3}$$

The output voltage of the given circuit is

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_x = \left(1 + \frac{R_F}{R_1}\right) \frac{(V_a + V_b + V_c)}{3} \qquad (3)$$

If $\left(1 + \frac{R_F}{R_1}\right) = 3$

$$V_o = V_a + V_b + V_c$$



Non-inverting Averaging Circuit

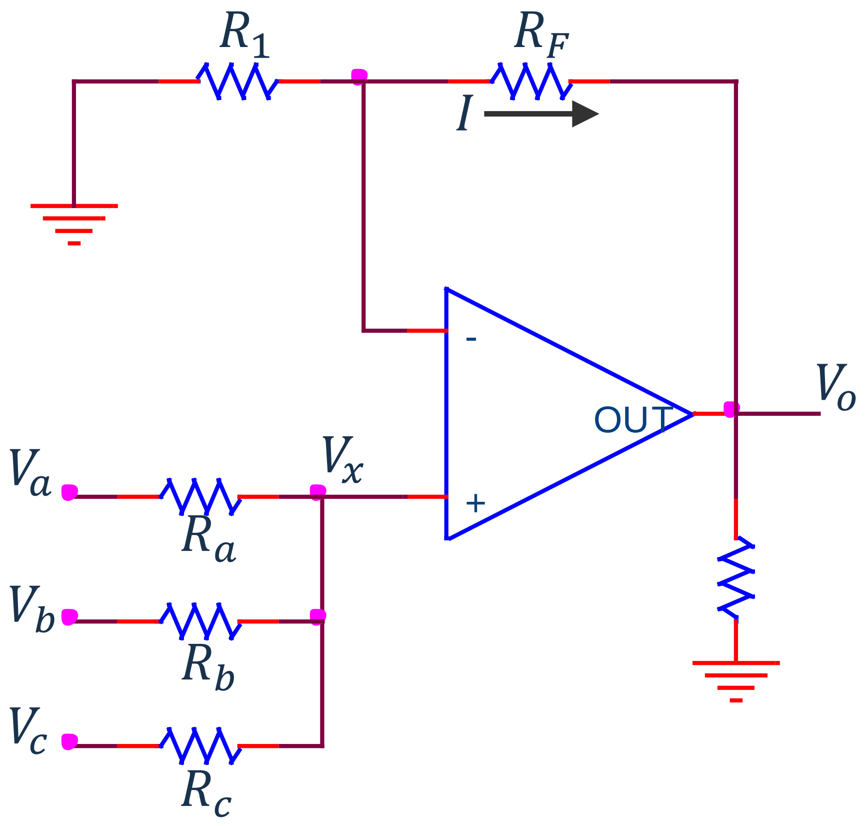
The output voltage of the circuit

$$V_o = \left(1 + \frac{R_F}{R_1}\right)\frac{(V_a + V_b + V_c)}{3}$$

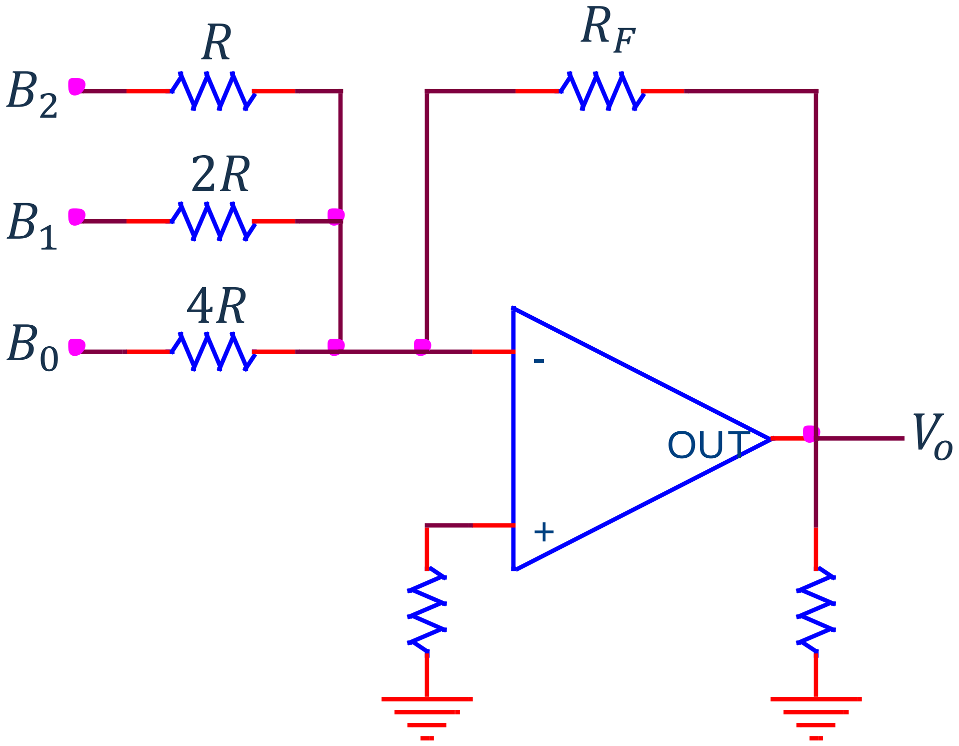
Assume $R_F = 0$,

$$V_o = \frac{1}{3}(V_a + V_b + V_c)$$

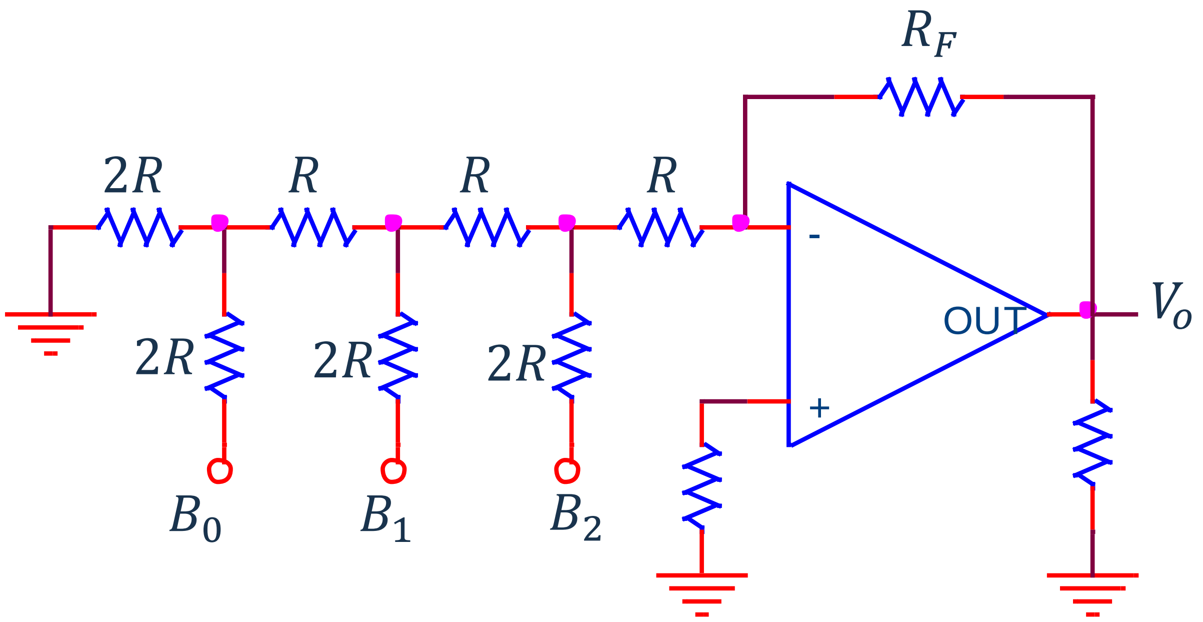
The output voltage is the average of the input voltages.



Weighted-Resistor & R-2R Ladder DAC



Weighted-Resistor DAC



R-2R Ladder DAC

Why R-2R Ladder DAC

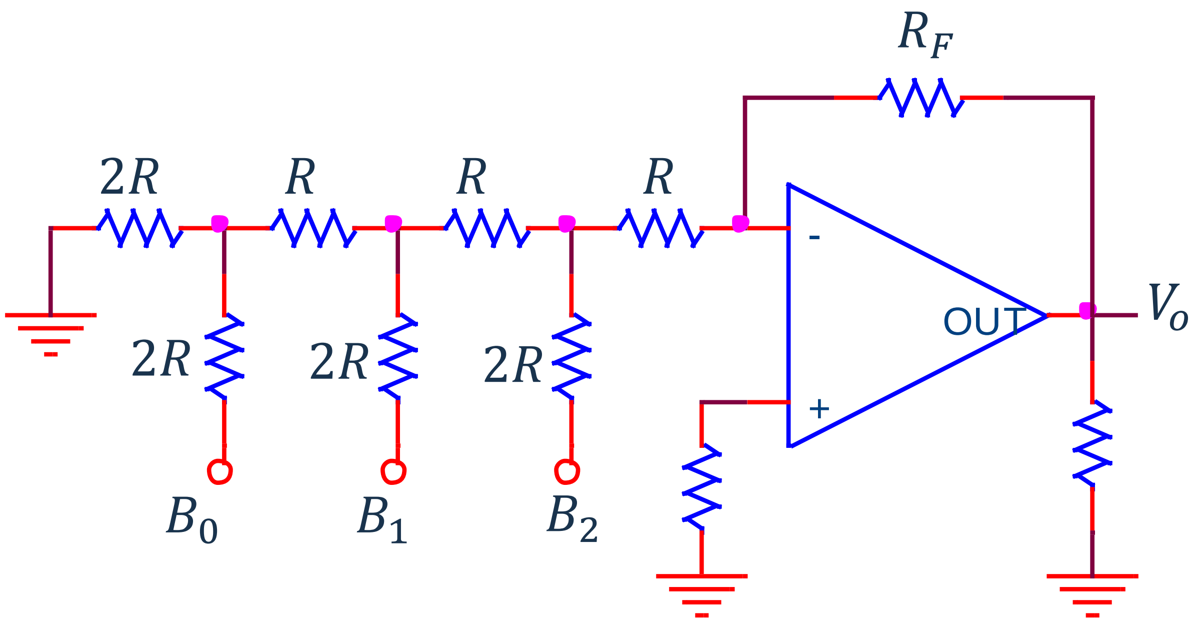
Limitation of weighted-resistors DAC

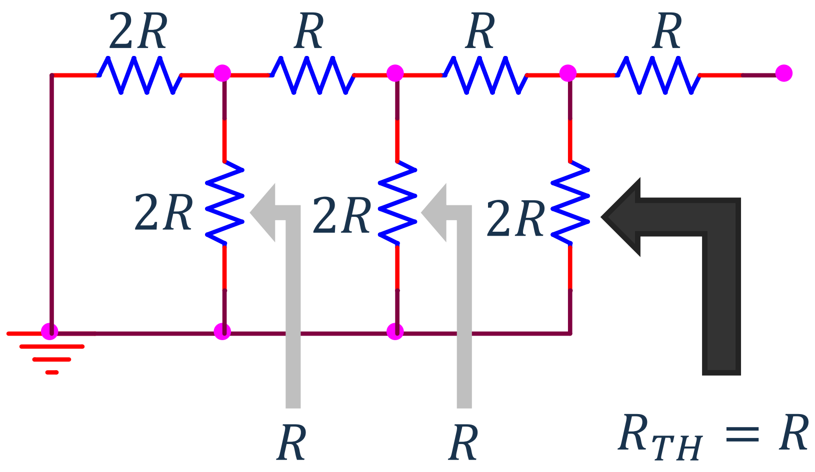
1. Resistor value get doubled with increasing bits
2. Output is erroneous, if resistors are inaccurate

Advantages of R-2R Ladder DAC

1. Only two values resistors are required
2. Easily scalable to any number of bits
3. Total output resistance of the network is R

Thevenin Resistance of R-2R Ladder





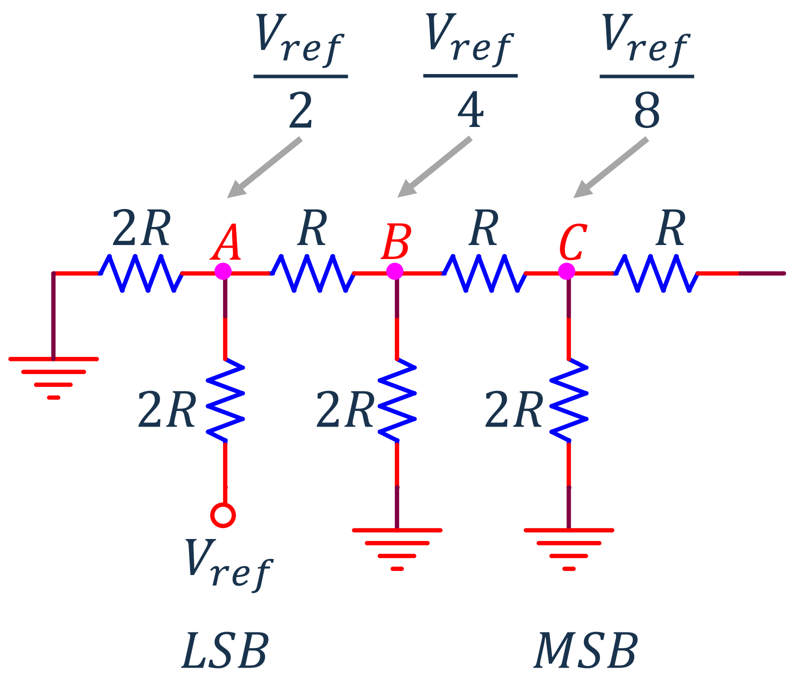
Voltage Analysis

CASE 1: Assume binary input 001

Here 1⇋V_{ref} and 0⇋0V

Voltage at node A, B and C get halved subsequently

$V_A = \frac{V_{ref}}{2}$, $V_B = \frac{V_{ref}}{4}$, and $V_C = \frac{V_{ref}}{8}$



The output voltage of the DAC after OpAmp is

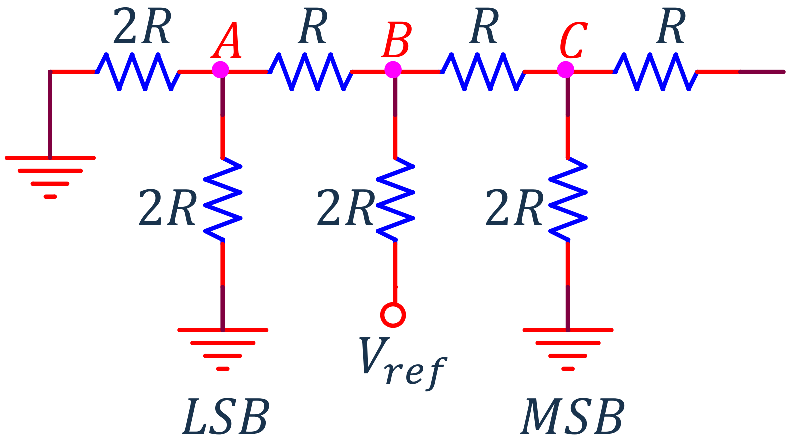
$$V_{001} = -\frac{R_F}{R} V_C = -\frac{R_F}{R}\frac{V_{ref}}{8}$$

For $R_F = R$ and $V_{ref} = 5V$,

$$V_{001} = \frac{5}{8} = -0.625V$$ (Resolution of DAC)

Voltage Analysis

CASE 2: Assume binary input 010

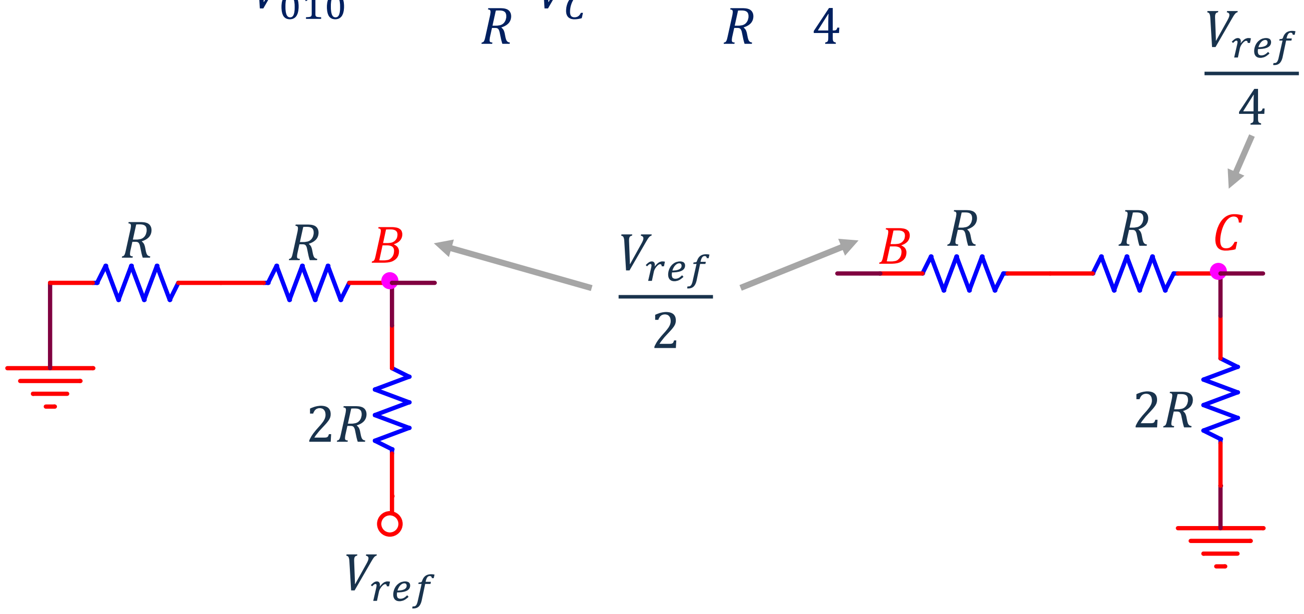


The voltage at node B is given as $V_B = \frac{V_{ref}}{2}$

Voltage at node C is further calculated as $V_C = \frac{V_{ref}}{4}$

The output voltage for 010 binary input

$$V_{010} = -\frac{R_F}{R} V_C = -\frac{R_F}{R}\frac{V_{ref}}{4}$$



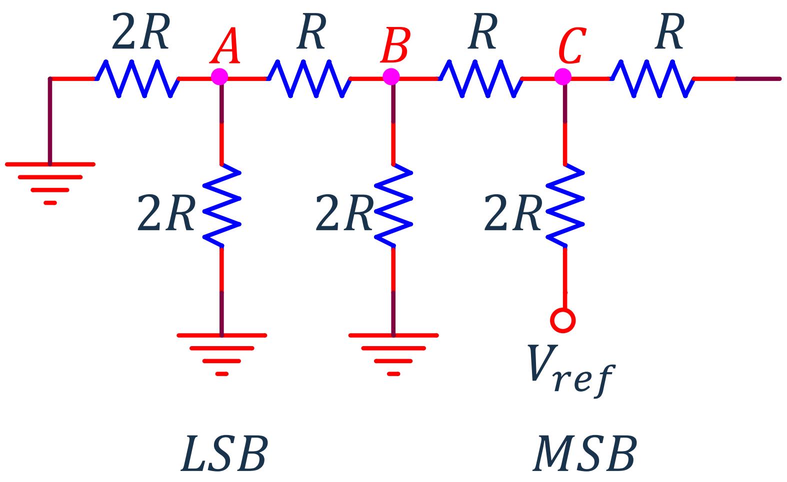
Voltage Analysis

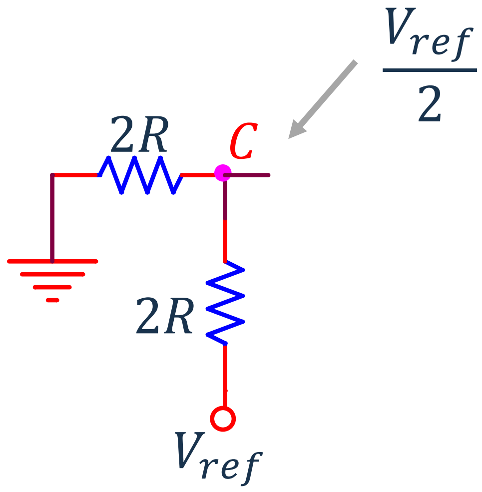
CASE 3: Assume binary input 100

Here 1⇋V_{ref} and 0⇋0V

The output voltage for 100 binary input

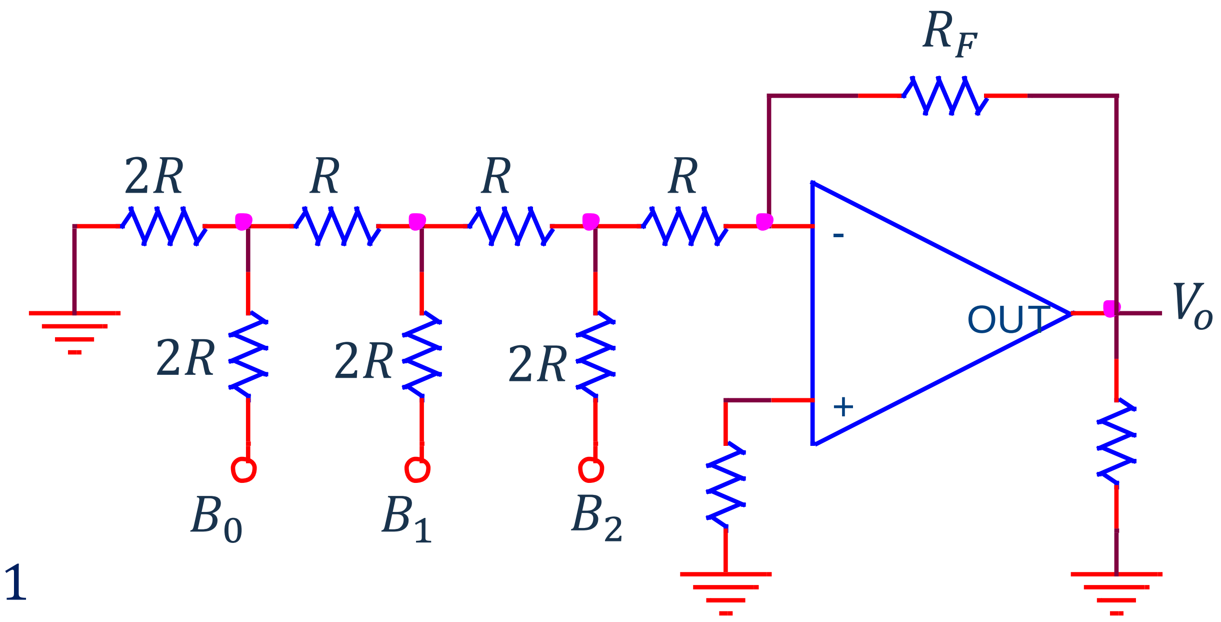
$$V_{100} = -\frac{R_F}{R}V_C = -\frac{R_F}{R}\frac{V_{ref}}{2}$$





Voltage Analysis

Generalized Output Relation



Let's apply Superposition Theorem

The overall output will be

$$V_o = -\frac{R_F}{R}\left(B_0\frac{V_{ref}}{2} + B_1\frac{V_{ref}}{4} + B_2\frac{V_{ref}}{8}\right)$$

Here, $B_2B_1B_0$ is the binary number from 000 to 111

This is scalable to n-bits as

$$V_o = -\frac{R_F}{R}\left(B_0\frac{V_{ref}}{2^1} + B_1\frac{V_{ref}}{2^2} + B_2\frac{V_{ref}}{2^3} + \cdots + +B_{n-1}\frac{V_{ref}}{2^n}\right)$$

Practice Problems

1. Explain working of weighted-resistors summing amplifier.
2. Relate weighted-resistors summing amplifier network with that of R-2R Ladder DAC network.
3. Draw and explain working of Summing, Scaling and Averaging Amplifiers circuits.
4. Draw the transfer characteristics of an ideal 4-bit A/D converter.
5. Describe the working of weighted resistor D/A converter

Thank You