

Electrical Science-2 (15B11EC211)

Unit-3

Operational Amplifier and Filters

Lecture-2

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- Non-inverting op-amp with problem
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Non-inverting Amplifier

- Non-inverting amplifier: The input voltage v_i is applied directly at the non-inverting input terminal, and resistor R_1 is connected between the ground and the inverting terminal.
- A non-inverting amplifier is an op amp circuit designed to provide a positive voltage gain.

Applying KCL at node V_1

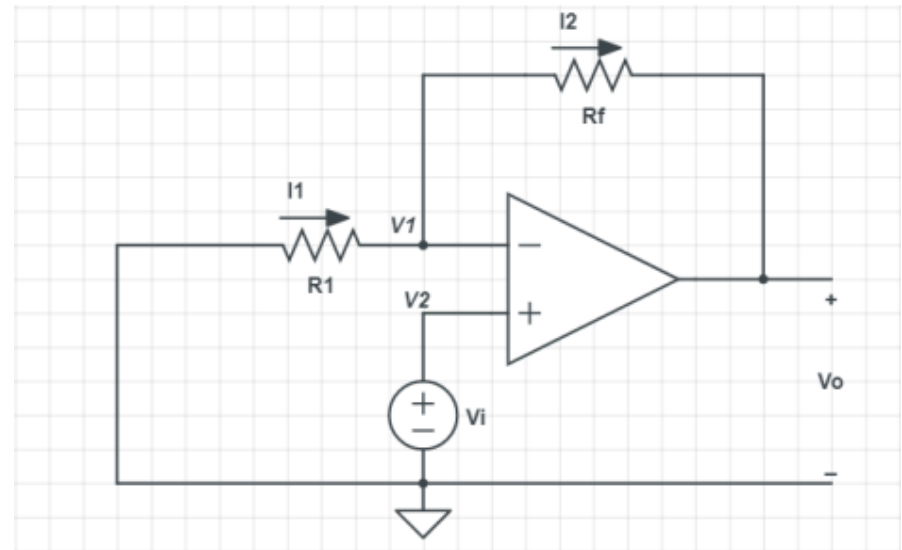
$$I_1 = I_2$$

$$\frac{0 - V_1}{R_1} = \frac{V_1 - V_o}{R_f}$$

But $V_1 = V_2 = V_i$ for an ideal op amp, since the noninverting terminal is grounded. Hence,

$$-\frac{V_i}{R_1} = \frac{V_i - V_o}{R_f}$$

$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_i$$



Problem

Q1. Calculate the output voltage of the given figure.

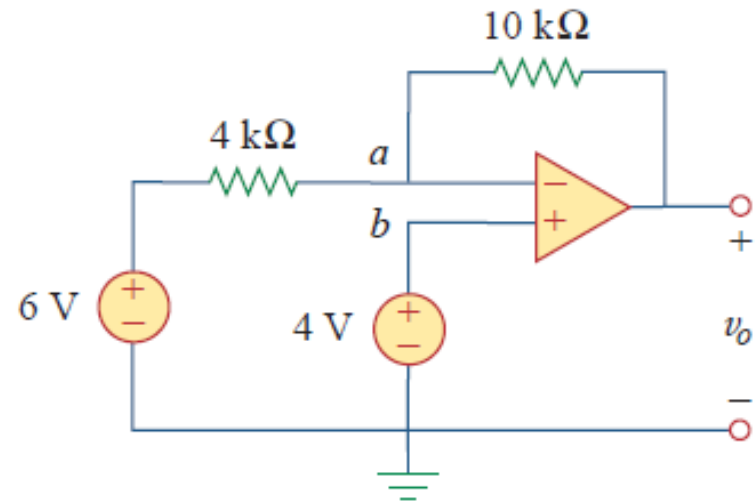
Sol: Applying KCL at Node 'a'

$$\frac{6 - v_a}{4} = \frac{v_a - v_o}{10}$$

$$\text{But, } v_a = v_b = 4V$$

$$\frac{6 - 4}{4} = \frac{4 - v_o}{10}$$

$$v_o = -1V$$



Summing Amplifier

- Summing amplifier: A summing amplifier is an op amp circuit that combines several inputs and produces an output that is the weighted sum of the inputs.

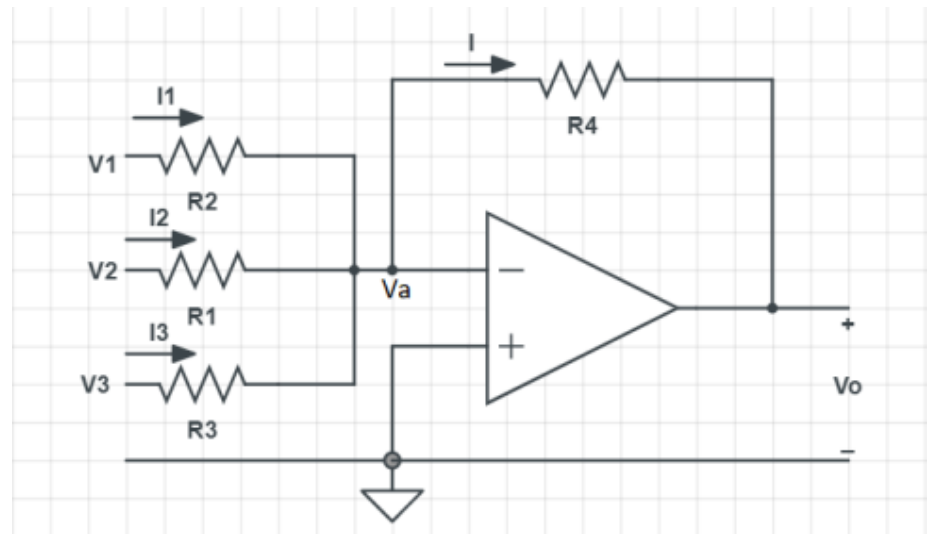
Applying KCL at node V_a

$$I_1 + I_2 + I_3 = I$$

$$\frac{V_1 - V_a}{R_2} + \frac{V_2 - V_a}{R_1} + \frac{V_3 - V_a}{R_3} = \frac{V_a - V_o}{R_4}$$

Note, $V_a = 0$ for an ideal op amp, since the noninverting terminal is grounded. Hence,

$$V_o = -\left(\frac{R_4}{R_2}V_1 + \frac{R_4}{R_1}V_2 + \frac{R_4}{R_3}V_3\right)$$



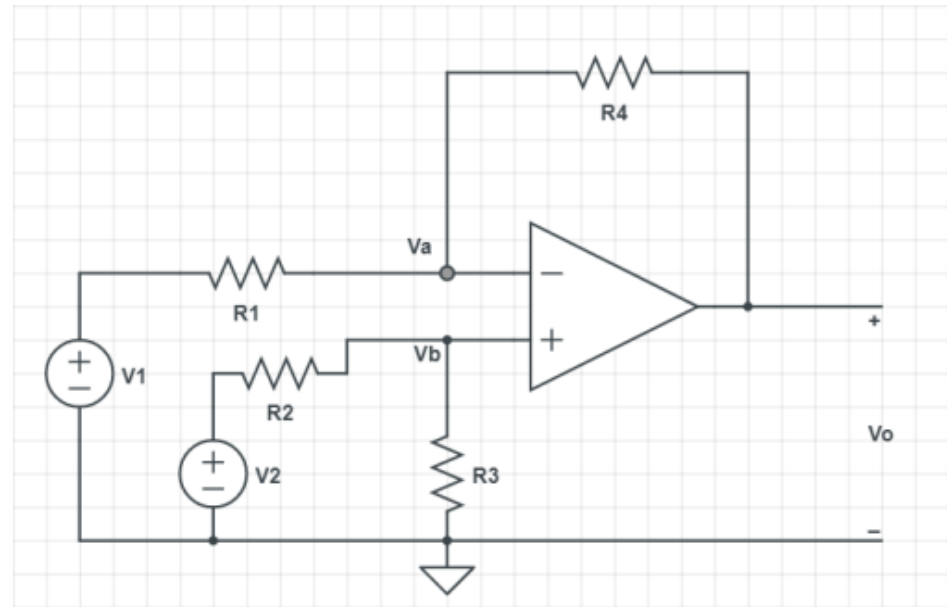
Difference Amplifier

- Difference amplifier: A difference amplifier is a device that amplifies the difference between two inputs but rejects any signals common to the two inputs.

Applying KCL at node V_a

$$\frac{V_1 - V_a}{R_1} = \frac{V_a - V_o}{R_4}$$

$$V_o = \frac{R_4}{R_1} + 1 \quad V_a - \frac{R_4}{R_1} V_1$$



Contd...

Applying KCL at node V_b

$$\frac{V_2 - V_b}{R_2} = \frac{V_b - 0}{R_3}$$

$$V_b = \frac{R_3}{R_3 + R_2} V_2$$

Note, $V_a = V_b$

$$V_o = \frac{R_4}{R_1} + 1 \cdot \frac{R_3}{R_3 + R_2} V_2 - \frac{R_4}{R_1} V_1$$

Since a difference amplifier must reject a signal common to the amplifier must have the property that $V_o = 0$ when $V_1 = V_2$.

This property exists when

$$\frac{R_1}{R_4} = \frac{R_2}{R_3}$$

If $R_1 = R_4$ and $R_2 = R_3$, the difference amplifier becomes a subtractor, with the output

$$V_o = V_1 - V_2$$

Integrator

- Integrator: An integrator is an op amp circuit whose output is proportional to the integral of the input signal

Applying KCL at node a

$$I_r = I_c$$

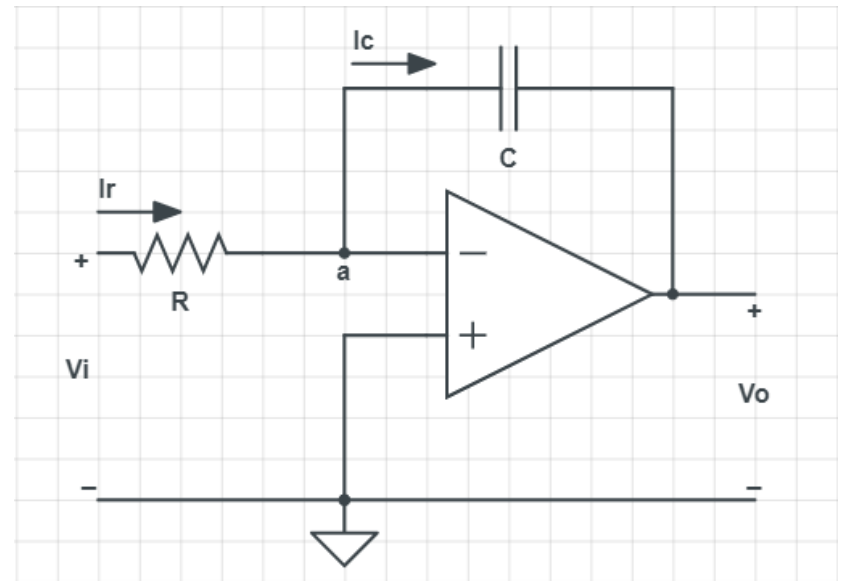
Note, At node a the voltage is 0

$$\frac{V_i - 0}{R} = -C \frac{dV_o}{dt}$$

$$dV_o = -\frac{1}{RC} V_i dt$$

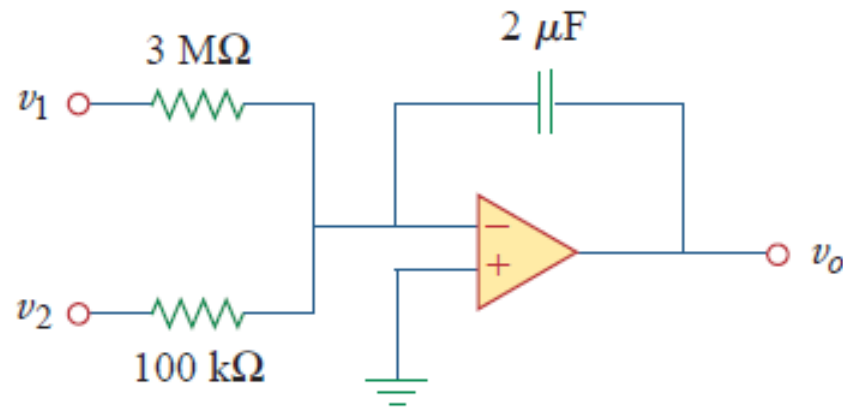
Integrating both side

$$V_o = -\frac{1}{RC} \int_0^t V_i(t) dt$$



Problem

Q2. If $v_1 = 10\cos 2t \text{ mV}$ and $v_2 = 0.5t \text{ mV}$, find v_o in the op amp circuit as shown in Figure. Assume that the voltage across the capacitor is initially zero.



Contd...

Sol: This is summer integrator

$$v_o = -\frac{1}{R_1 C} \int v_1 dt - \frac{1}{R_2 C} \int v_2 dt$$

$$v_o = \frac{1}{3 \times 10^6 \times 2 \times 10^{-6}} \int_0^t 10 \cos 2t \, dt \\ - \frac{1}{100 \times 10^3 \times 2 \times 10^{-6}} \int_0^t 0.5 t \, dt$$

$$v_o = -\frac{1}{6} \frac{10}{2} \sin 2t - \frac{1}{0.2} \frac{0.5 t^2}{2}$$

$$v_o = -0.833 \sin 2t - 1.25 t^2$$

Differentiator

- Differentiator: A differentiator is an op amp circuit whose output is proportional to the rate of change of the input signal.

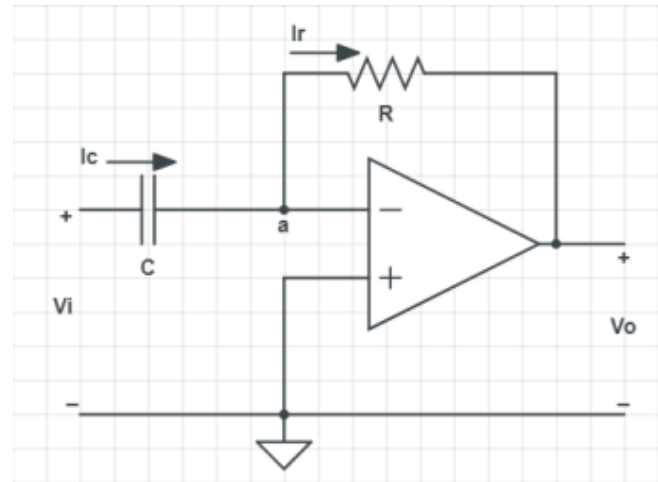
Applying KCL at node a

$$I_c = I_r$$

Note, At node a the voltage is 0

$$C \frac{d(V_i - 0)}{dt} = \frac{0 - V_o}{R}$$

$$V_o = -RC \frac{dV_i}{dt}$$



showing that the output is the derivative of the inp

Introduction to Filters

Introduction to Filter

- A filter is a circuit that is designed to pass signals with desired frequencies and reject or attenuate others.
- An electric filter can be used to eliminate unwanted constituents, such as electrical noise, from an electrical signal.
- Filters are the circuits used in radio and TV receivers to allow us to select one desired signal out of a multitude of broadcast signals in the environment.
- There are mainly two types of filters:
 1. Passive filters
 2. Active Filters

Introduction to Filter

- **Passive filters:** The filters constructed using passive elements like inductors, capacitors, and resistors are called passive filters.
- **Active filters:** The filters developed using active *elements* (such as transistors and op amps) in addition to passive elements R , L , and C , are called active filter.
- The active filters are usually constructed without inductors (only op amps, resistors, and capacitors) because inductors are relatively large and heavy.

Types of Filters

- There are four types of filters whether passive or active:
 1. Lowpass
 2. Highpass
 3. Bandpass
 4. Bandstop
- A lowpass filter passes low frequencies and stops high frequencies, as shown

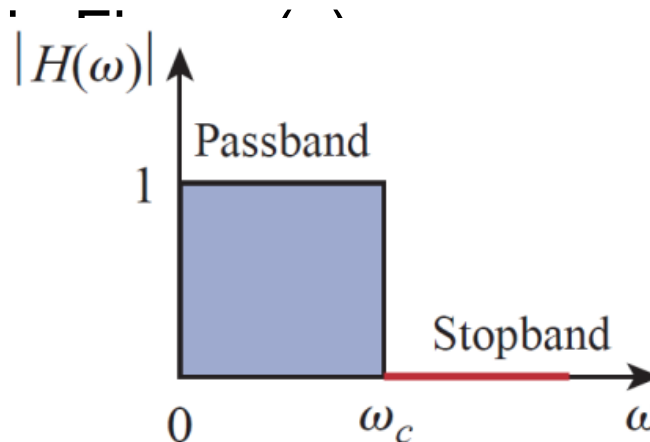


Figure (a)

Types of Filters

- A highpass filter passes high frequencies and rejects low frequencies, as shown in Figure (b).

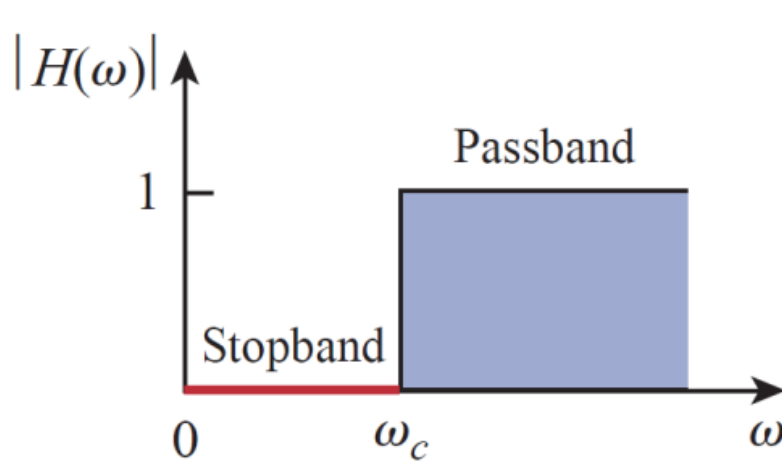


Figure (b)

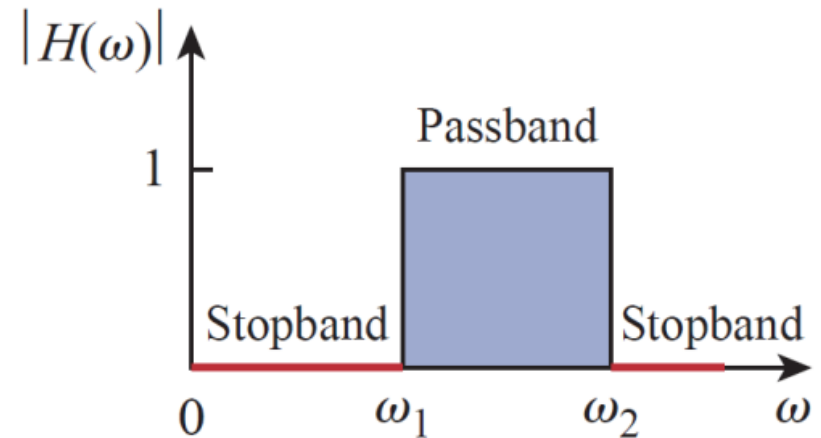


Figure (C)

- A bandpass filter passes frequencies within a frequency band and blocks or attenuates frequencies outside the band, as shown in Figure (C).

Types of Filters

- A bandstop filter passes frequencies outside a frequency band and blocks or attenuates frequencies within the band, as shown in Figure (d).

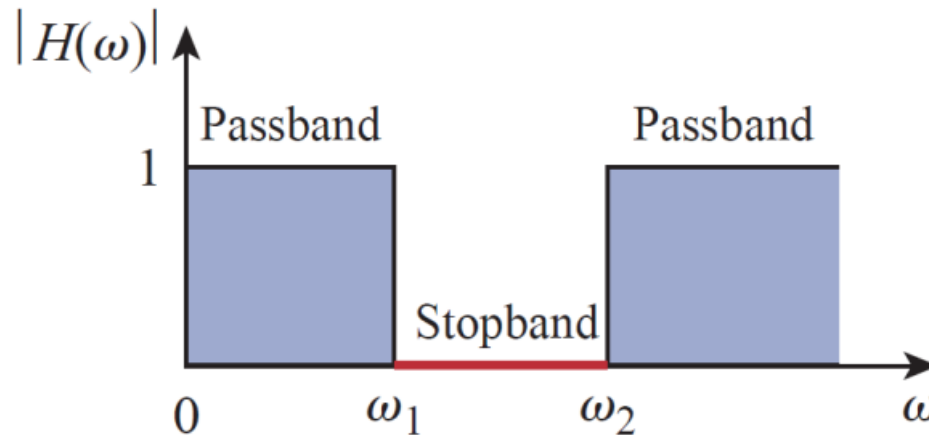


Figure (d)

Order of Filter

- The order, n of a filter is the number of reactive elements (if all are contributing.)
- Order of the filter means the maximum number of delay elements used in the filter circuit.
- A first order filter would have one capacitor or one inductor, that affects the filter's frequency response.
- A second order filter would have two capacitors or two inductors, or one capacitor and one inductor, that affects the filter's frequency response.
- There is a trade-off involving the order of the filter. The higher the order, the more accurately the filter frequency response approximates the frequency response of an ideal filter; that's good.
- The higher the filter order, the more complicated the circuit required to build the filter; that's not good.

Reference

1. Charles K. Alexander and Matthew N. O. Sadiku, “Fundamentals of Electric Circuits”, Chapter 19, 4th ed, Mcgraw Hill, 2009
2. Ramakant A. Gayakwad, “Op-Amps and Linear Integrated Circuits”, 4th edition, Pearson, 2000
3. R.C. Dorf and J. A. Svoboda, “Introduction to Electric Circuits”, 9th ed, John Wiley & Sons, 2013