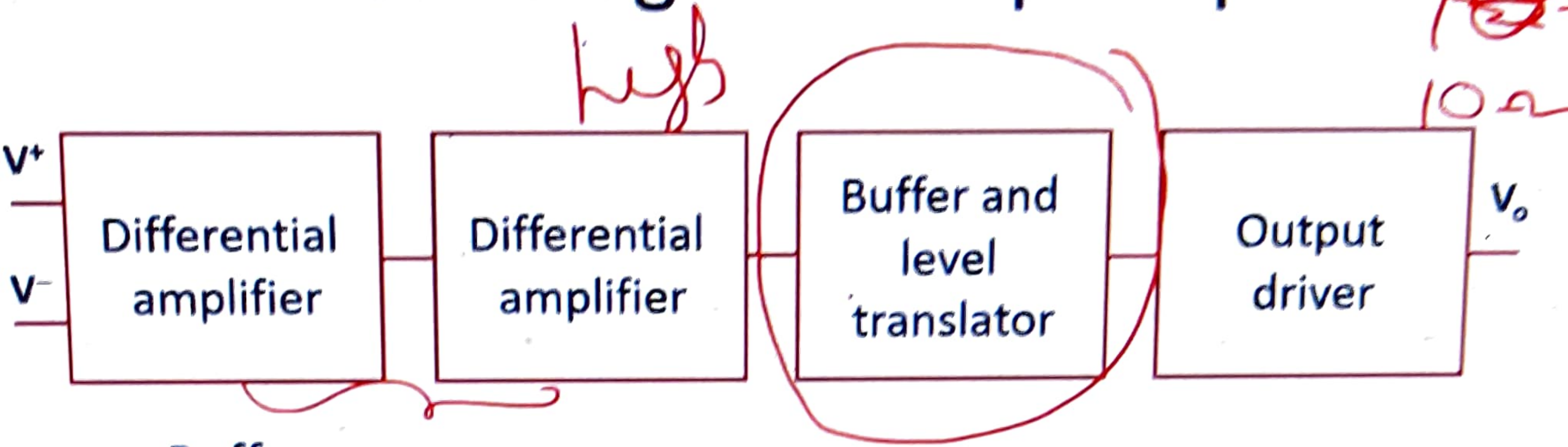
Block diagram of op-amp

1KΩ



- Buffer
  - Emitter follower
  - Very high input impedance, to prevent loading to the amplifier
- Level shifter
  - Adjusts DC voltages so that output voltage is zero for zero input voltage

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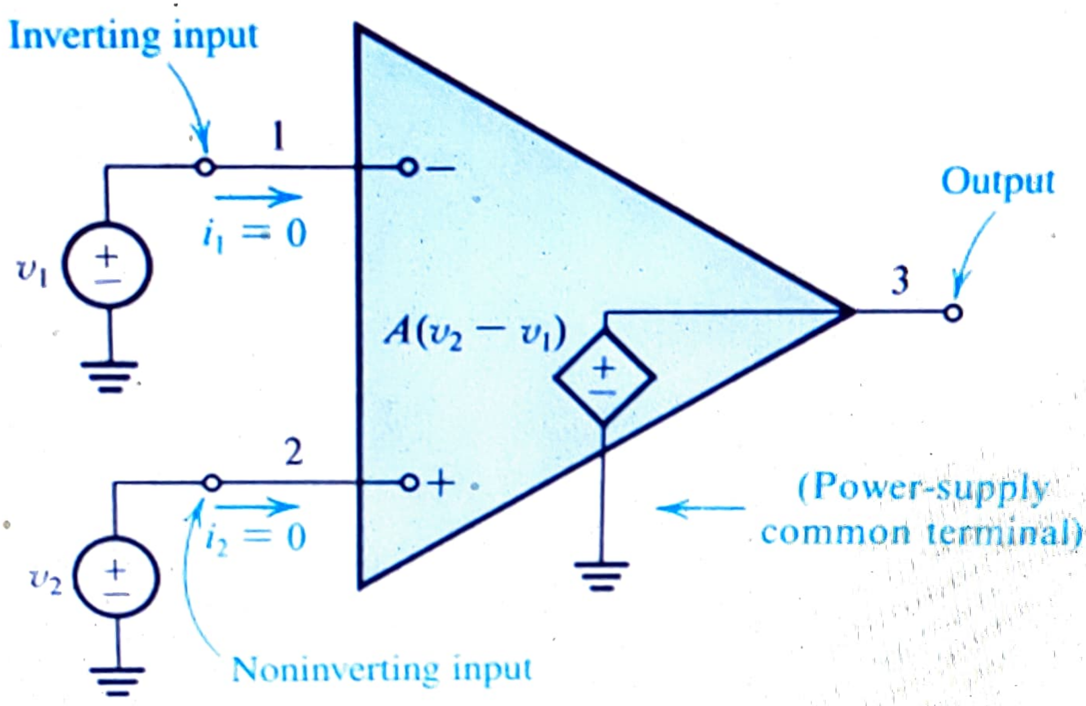
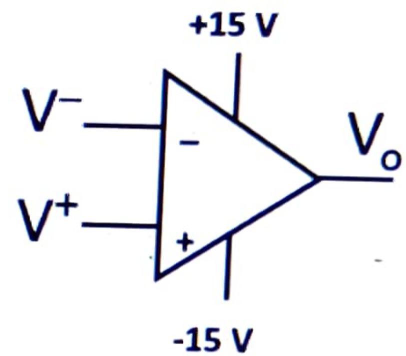
Equivalent circuit of the ideal op-am
(VCVS model of op-amp)



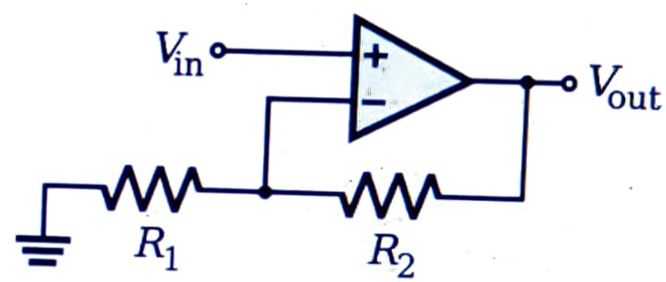
etails

Operations of op-amp

- **Open loop**
  - Output is driven into saturation
  - Comparator
  - Zero crossing detector

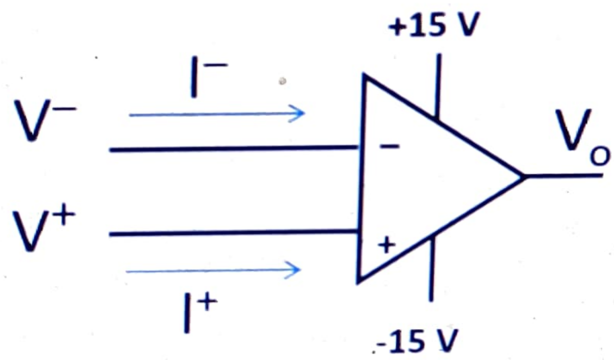


- **Closed loop**
  - Negative feed back
  - Linear output range



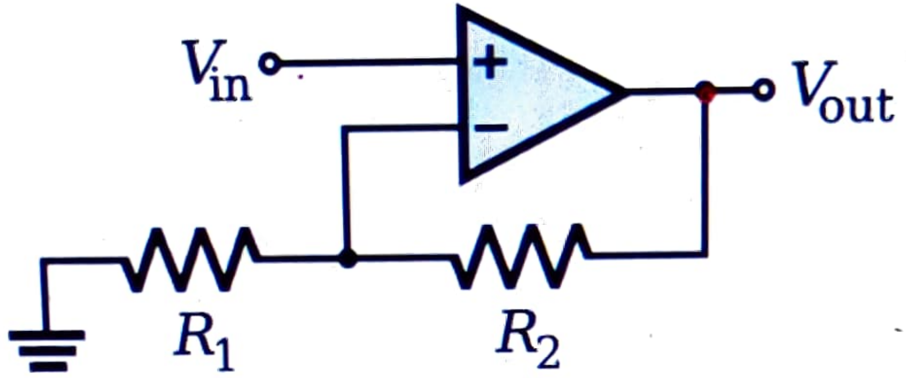
Analysis of op-amp

- Assumptions
  - Current entering the op-amp terminals is zero, $\mathbf{I^+ = I^- = 0}$
  - Difference voltage is zero, $\mathbf{V^+ - V^- = 0}$



Non-inverting op-amp

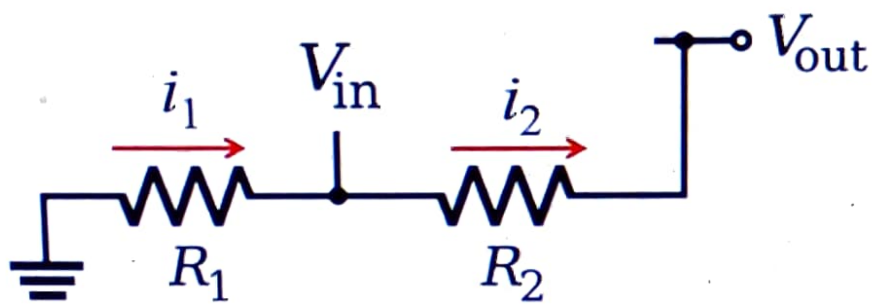
negative feed back



$$i_1 = i_2$$

$$\frac{0 - V_{in}}{R_1} = \frac{V_{in} - V_{out}}{R_2}$$

$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$



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KCL

$i_1 = i + i_2$

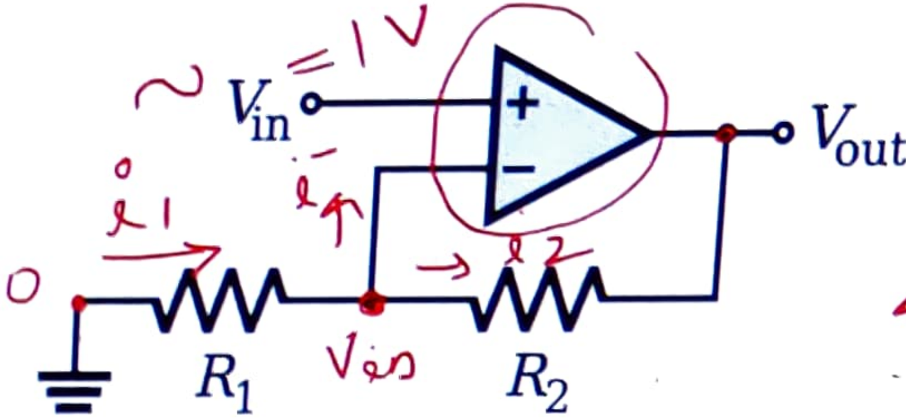
$i_1 = 0 + i_2$

$i_1 = i_2$

Non-inverting op-amp

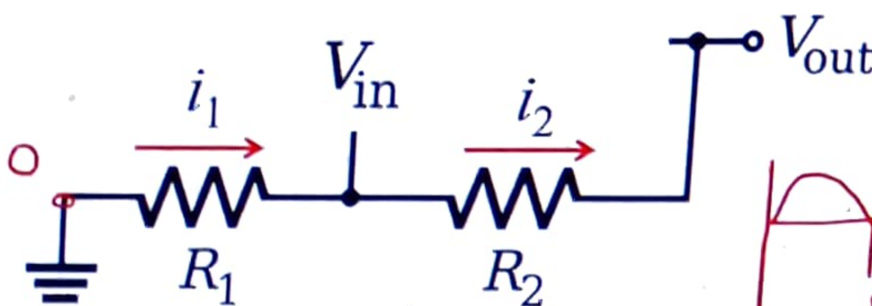
$i_1 = i_2 \longrightarrow i_1 = i_2$

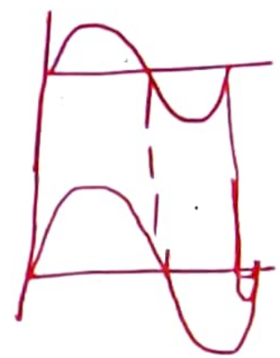
$$\frac{0 - V_{in}}{R_1} = \frac{V_{in} - V_{out}}{R_2}$$



$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

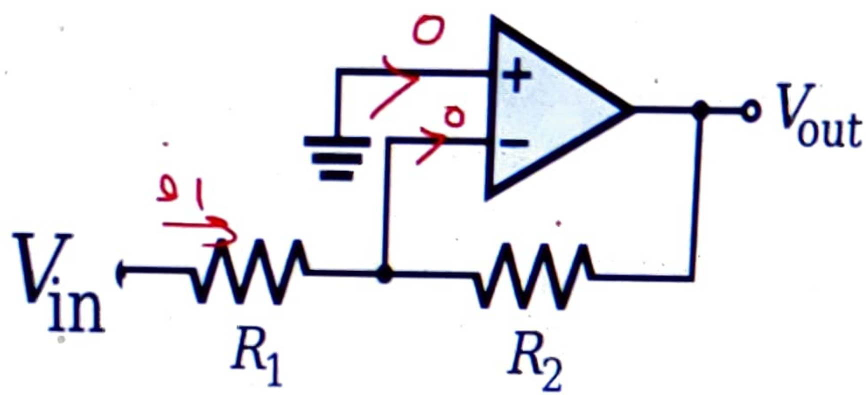
$V_{out} = K\,V_{in}$



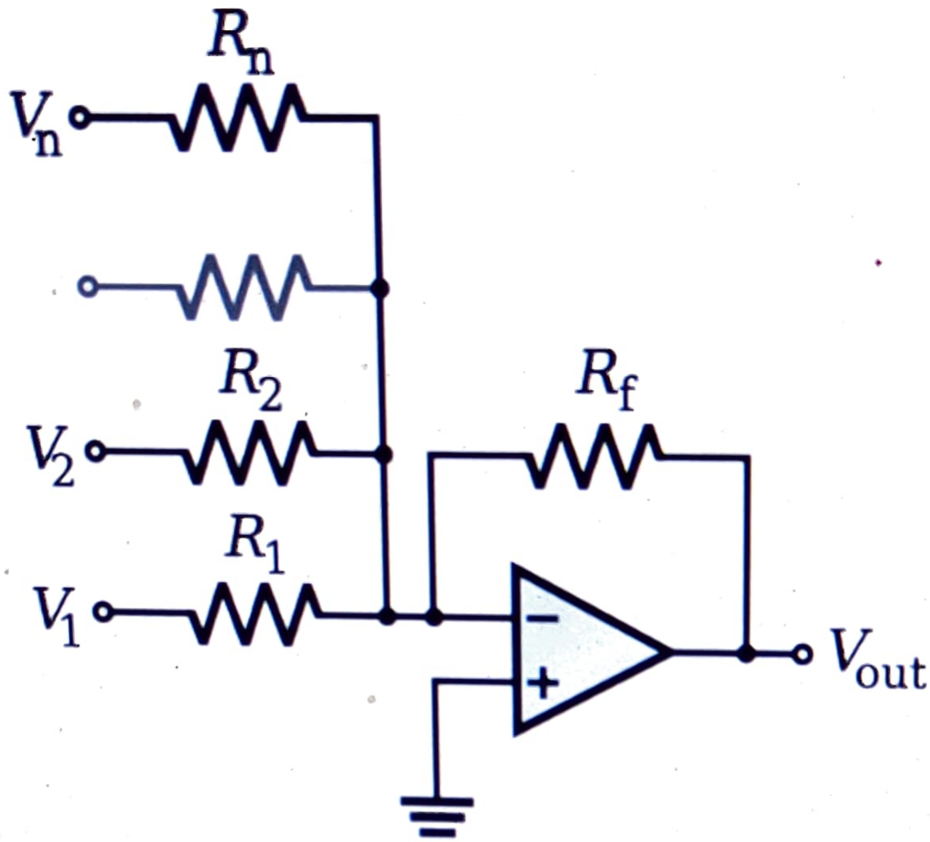


Inverting op-amp

$$V_{out} = -\frac{R_2}{R_1} V_{in}$$



Inverting summing amplifier



$$V_{out} = -\left(\frac{R_f}{R_1} + \frac{R_f}{R_2} + \dots\dots\dots\dots + \frac{R_f}{R_n}\right)V_{in}$$

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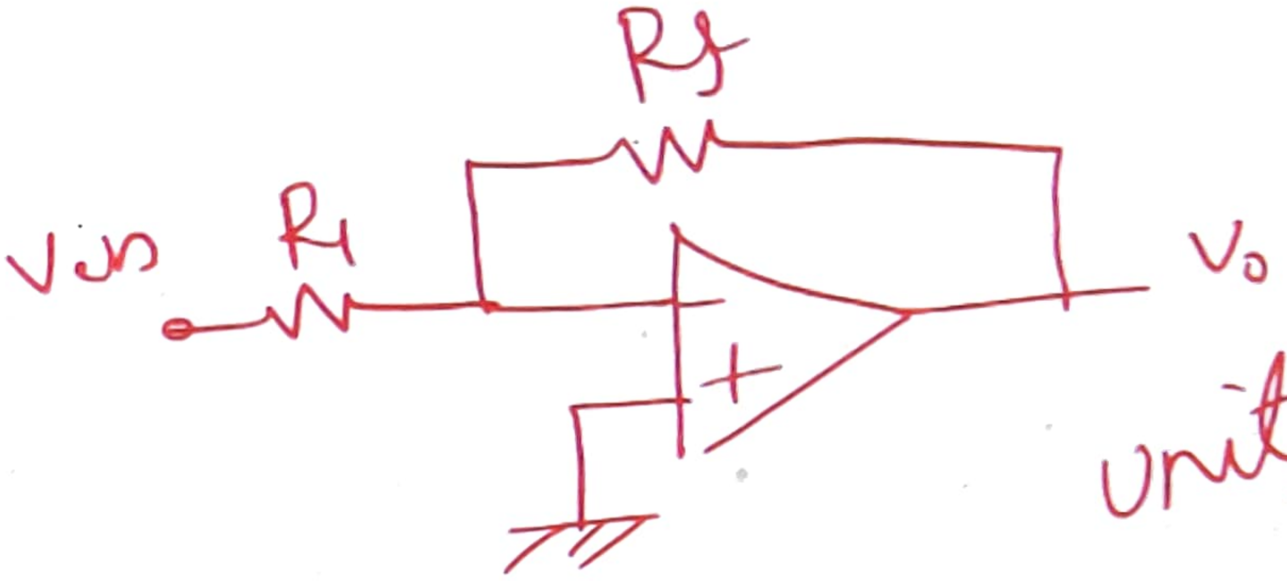
Design an inverting op-amp with gain of 1

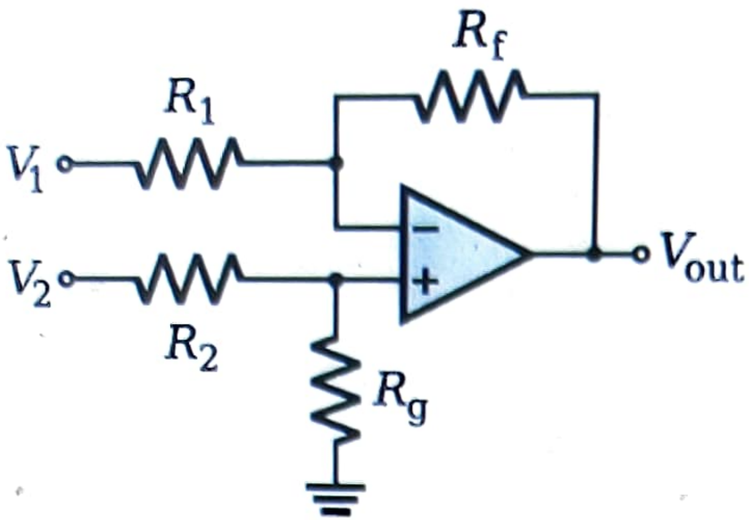


unity gain

$$V_o = -\left(\frac{R_f}{R_1}\right) V_{in}$$

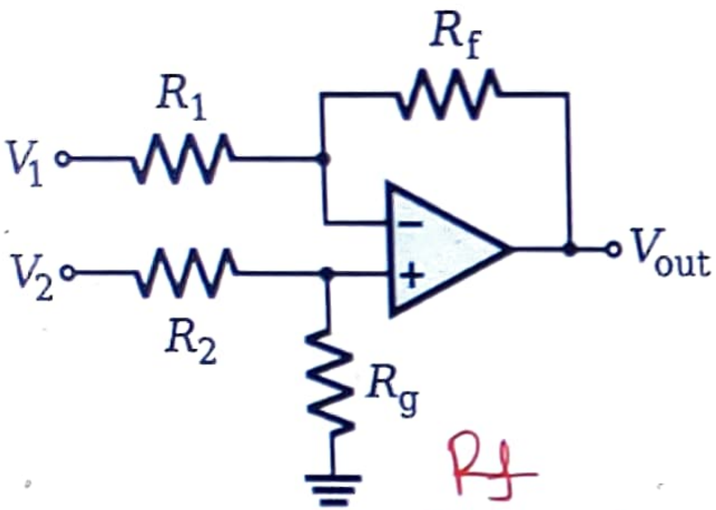
gain = 1

$$V_o = -V_{in}$$



Difference amplifier

Difference amplifier



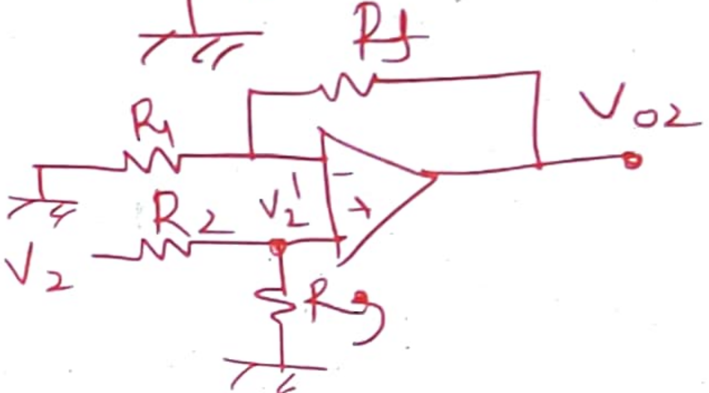
Superposition → take only one source at a time

(1) $V_{out} = V_{01} + V_{02}$

$= -[A] + [B]$

$=$

$$V_{01} = -\frac{R_f}{R_1} V_1$$



$$V_{02} = \left(1 + \frac{R_f}{R_g}\right) V_2'$$

$$V_2' = \left(\frac{R_g}{R_2 + R_g}\right) V_2$$