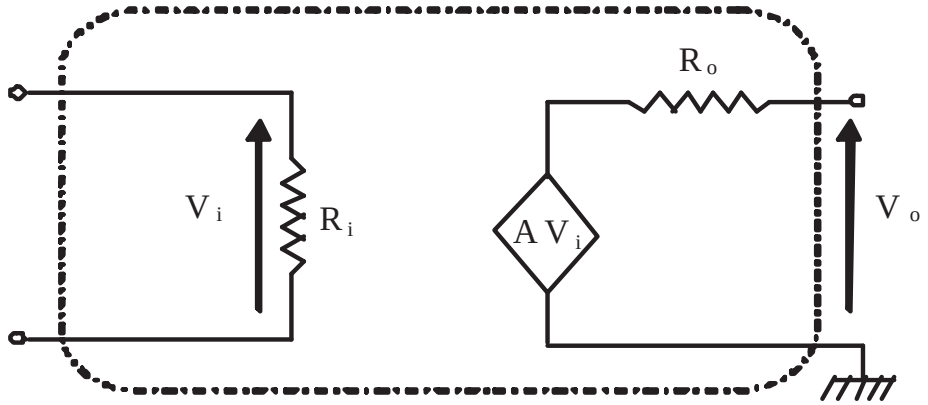
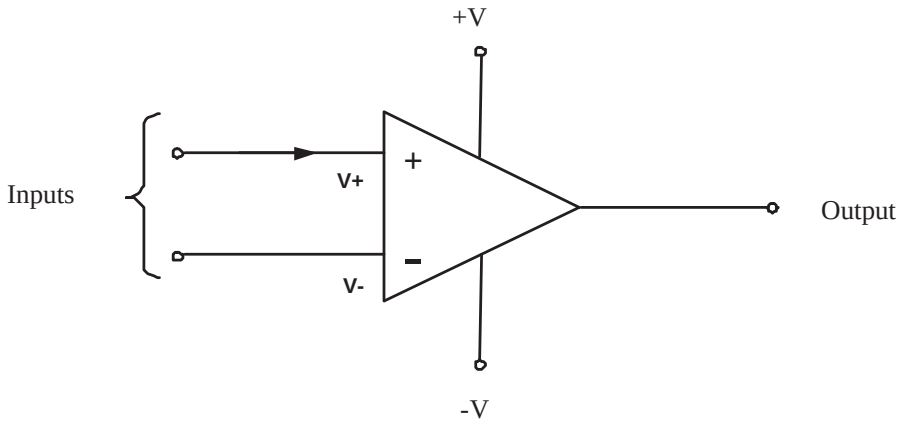
Q3. Calculate the transfer function of the following op-amp circuit and discuss applications

Real Vs. Ideal Op-amp



Parameter	Ideal	Real
R_{in}	∞	$10^6 - 10^{12}\Omega$
R_{out}	0	$100 - 1000\Omega$
$A_d(\text{OL})$	∞	$10^5 - 10^9$
$A_c(\text{OL})$	0	10^{-5}
Slew rate	∞	0.5V/microsecond
Gain-BW product	∞	$1 - 20\text{MHz}$

Golden Rules



- Voltage Rule: $v^+ = v^-$
- Rationale: $v_o = A_d v_i$ is limited; but $A_d \uparrow \infty \Rightarrow v_i \downarrow 0$.
- Current Rule: $i_{\text{in}} = 0$
- Rationale: $R_i = \infty$.

Why Negative Feedback?

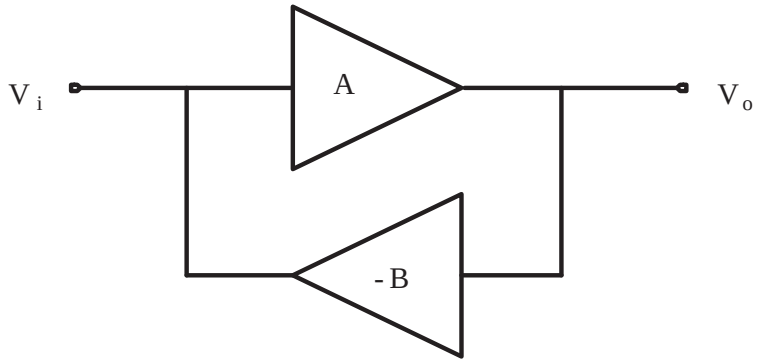


Figure 1: Typical negative feedback

- An op-amp with negative feedback provides the following benefits:
  - Allows to control the voltage gain. For the above circuit, the gain is $\frac{1}{B}$ when $A \approx \infty$.
  - No need to know about the internal characteristics.
  - Extends the useful frequency range.
  - Improves stability (against temperature variations)

The Differential Op-amp: Analysis

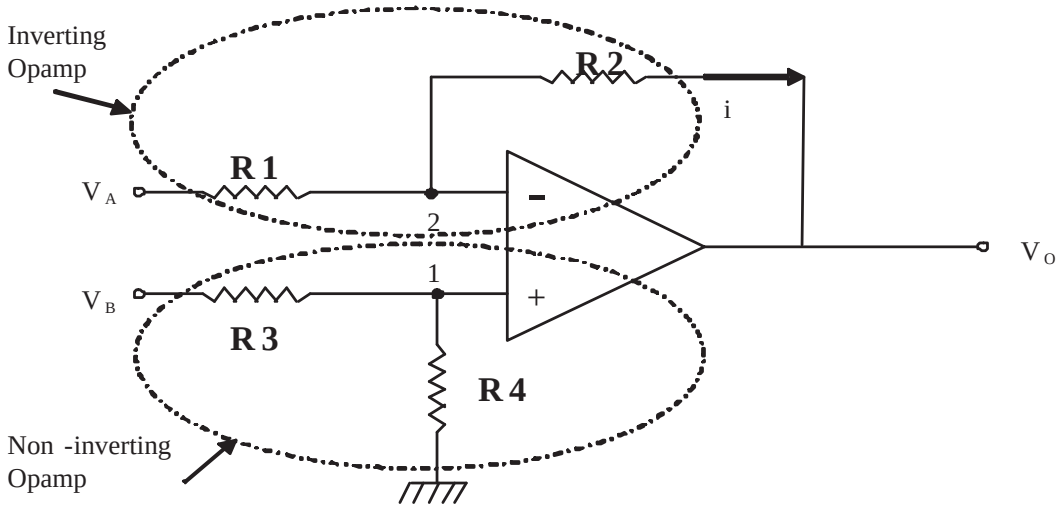


Figure 2: Example

- Compute voltage at the non-inverting terminal

$$v_1 = \frac{R_4}{R_3 + R_4} v_B \tag{1}$$

- From the voltage rule: $v_2 = v_1$.

- Recall the current rule; apply the KCL at node 2 to get

$$\frac{v_A - v_2}{R_1} = \frac{v_2 - v_o}{R_2} \tag{2}$$

- Substituting (1) into (2) yields

$$v_o = \frac{(R_1 + R_2)R_4}{(R_3 + R_4)R_1} v_B - \frac{R_2}{R_1} v_A$$

Key Features

- Set all resistors to be equal $\Rightarrow$ difference op-amp:

$$v_o = (v_B - v_A)$$

- Set $R_1 = R_3$ and $R_2 = R_4 \Rightarrow$ amplified difference:

$$v_o = \frac{R_2}{R_1}(v_B - v_A)$$

Differential signaling

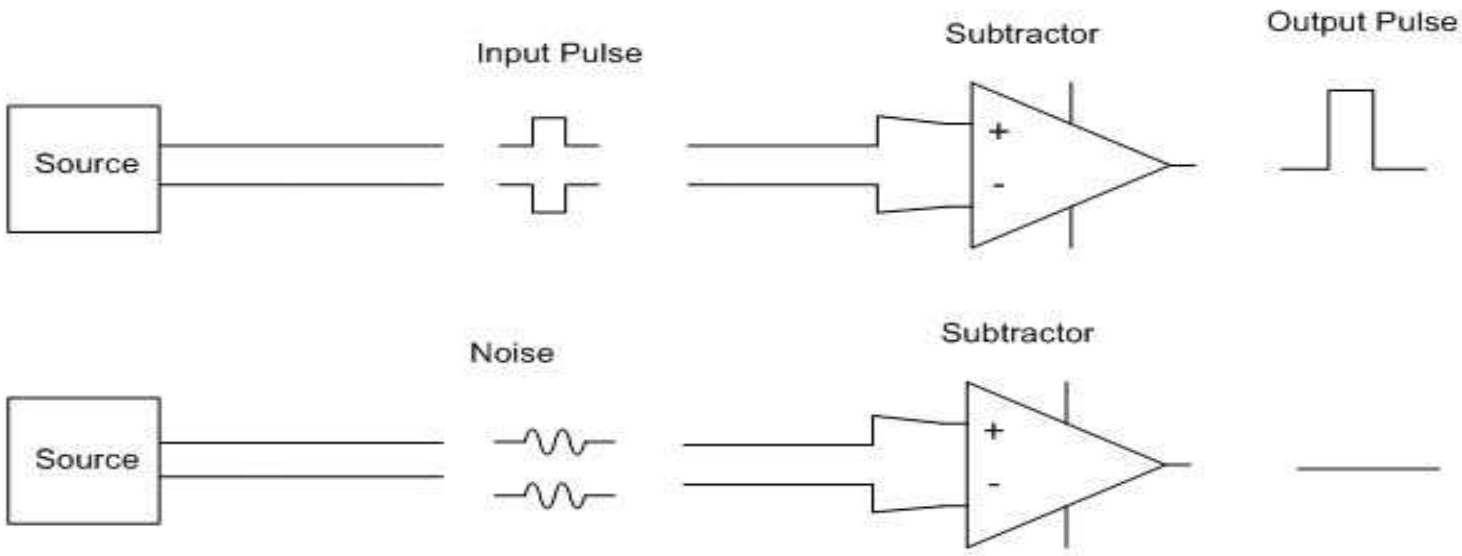


Figure 3: A differential receiver setup

- Input signals can be either analog or digital.
- – Desired input: differential-mode signal
- – Noise: common-mode signal

Differential signaling (cont'd)

- Two basic operations:
  - Amplifying desired small-signal
  - Filtering out noise
- Benefits:
  - Tolerance of ground offsets
  - Suitability for use with low-voltage (<5 volts) electronics
  - Resistance to noise interference(e.g., AC power line, circuit noise).
- Applications:
  - Data transmission (e.g., USB)
  - ECG
  - Thermocouple
  - as a stable comparator module

Comparator

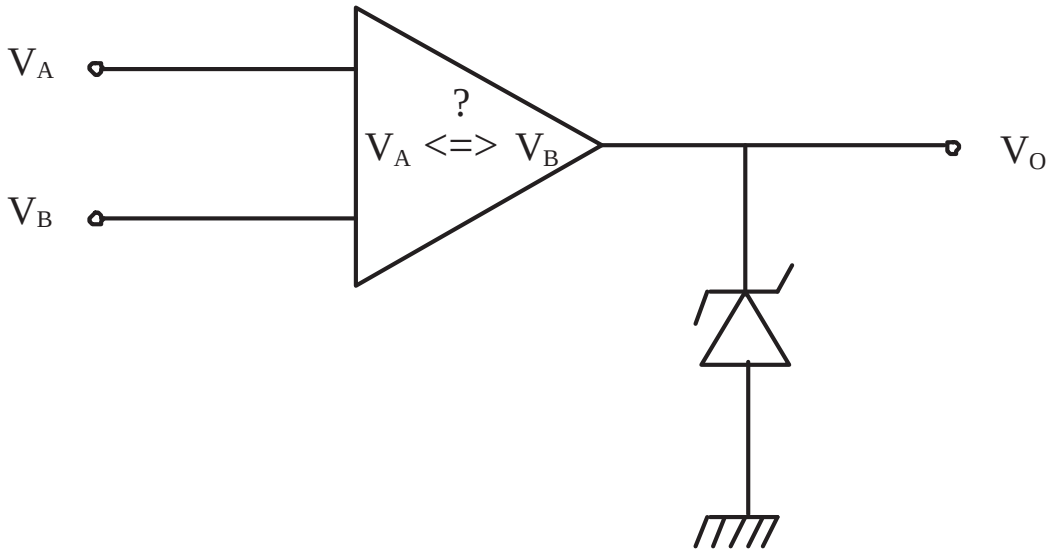


Figure 4: Differential Op-Amp as a Comparator

References

- T. Floyd, *Electronic Devices*, 6th ed., 2002.
- G. Rizzoni, *Principles and applications of electrical engineering*, McGraw Hill, 2004.

Thank you!