ECE 203

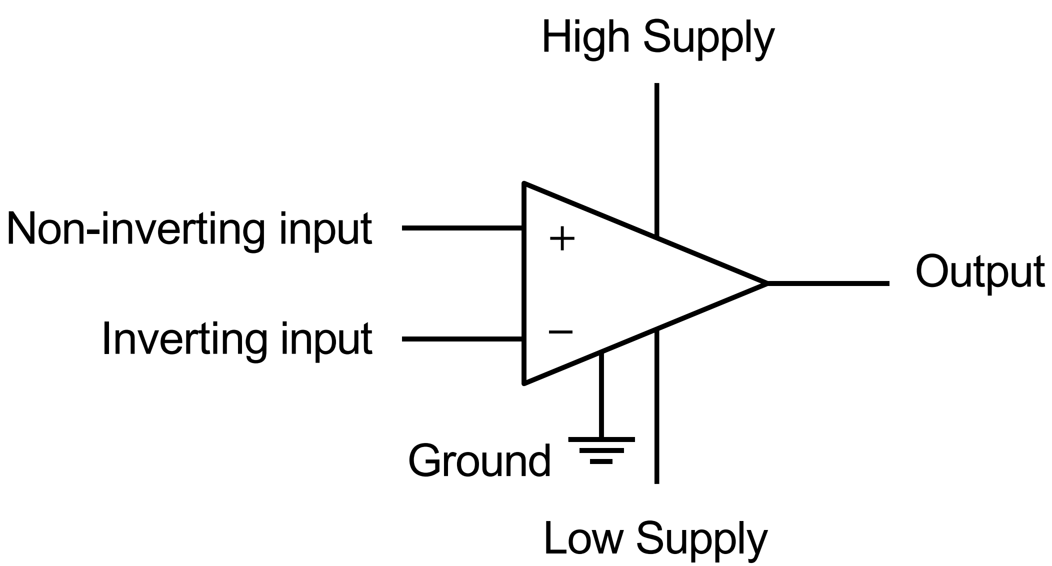
Circuits I

Op-amps

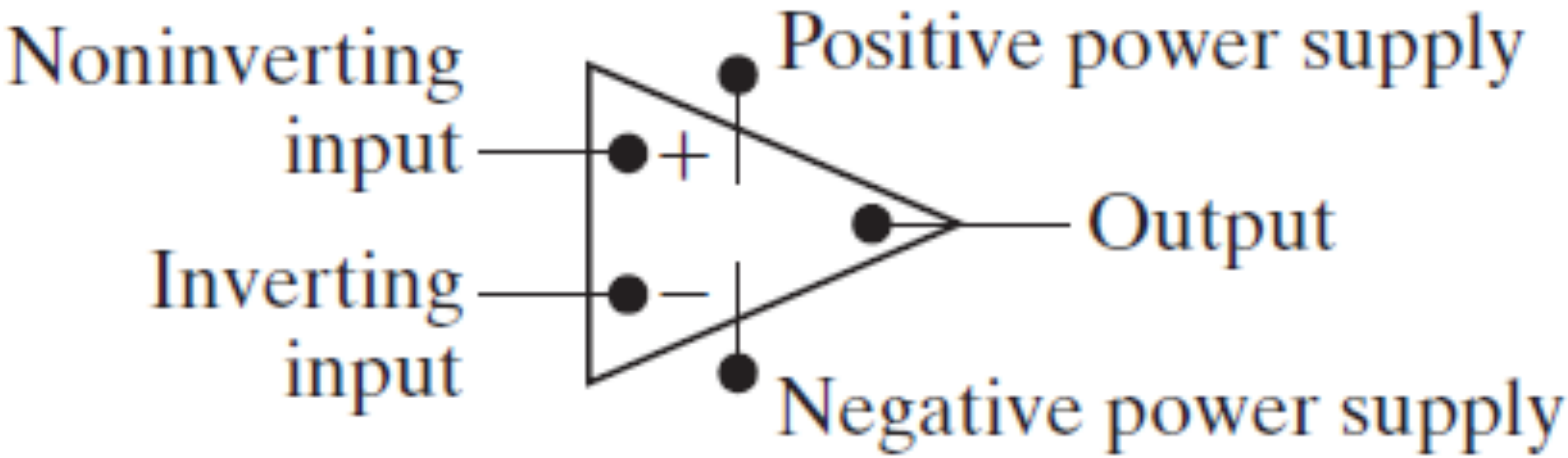
Lecture 5-2

What is an Op-Amp?

- **The Op-Amp is an “active” element with a high gain that is designed to be used with other circuit elements to perform signal processing operations.**
- **It requires power supplies, sometimes a single supply, sometimes positive and negative supplies.**
- **It has two inputs and a single output.**



The Circuit Symbol for Op-Amp



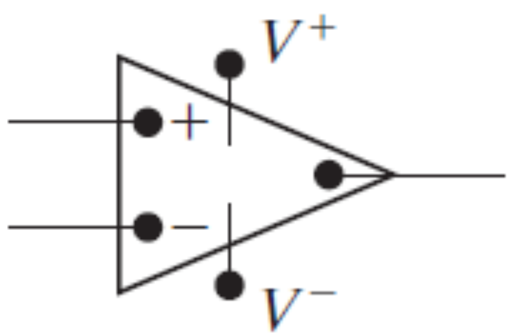
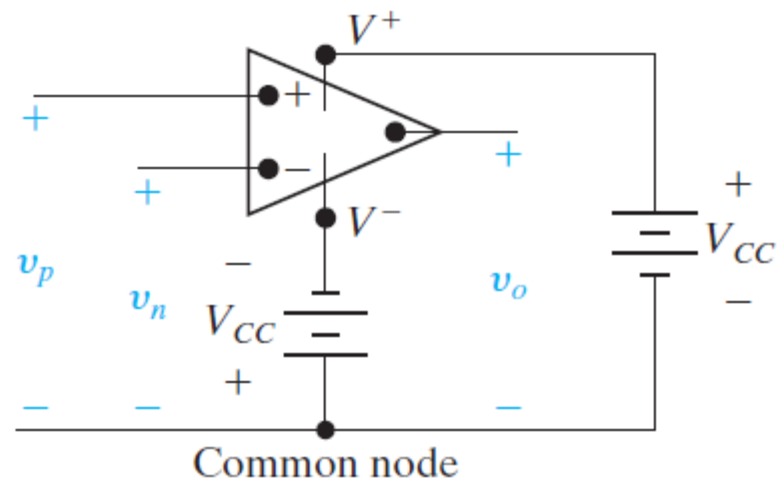


Figure 5.3: A simplified circuit symbol for an op amp.

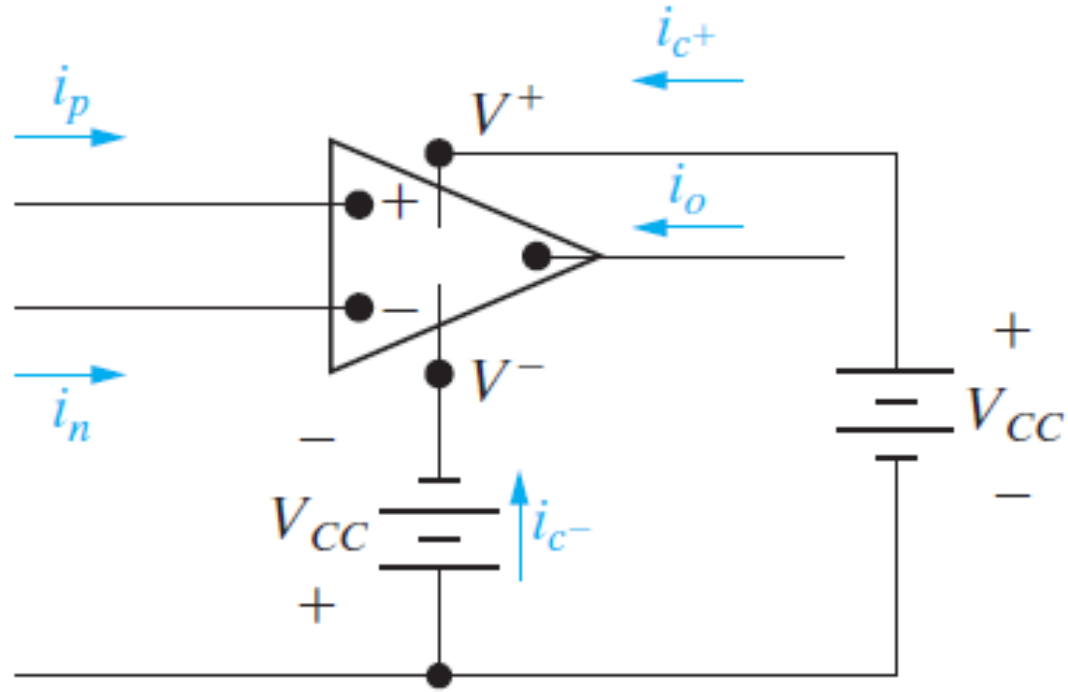
Terminal Voltage Variables

- All voltages are considered as voltage rises from the common node, a convention we also used in the node-voltage analysis method.
- A positive supply voltage (V_{CC}) is connected between V^+ and the common node.
- A negative supply voltage ($-V_{CC}$) is connected between V^- and the common node.
- The voltage between the inverting input terminal and the common node is denoted **v_n**
- The voltage between the noninverting input terminal and the common node is designated as **v_p**
- The voltage between the output terminal and the common node is denoted **v_o**



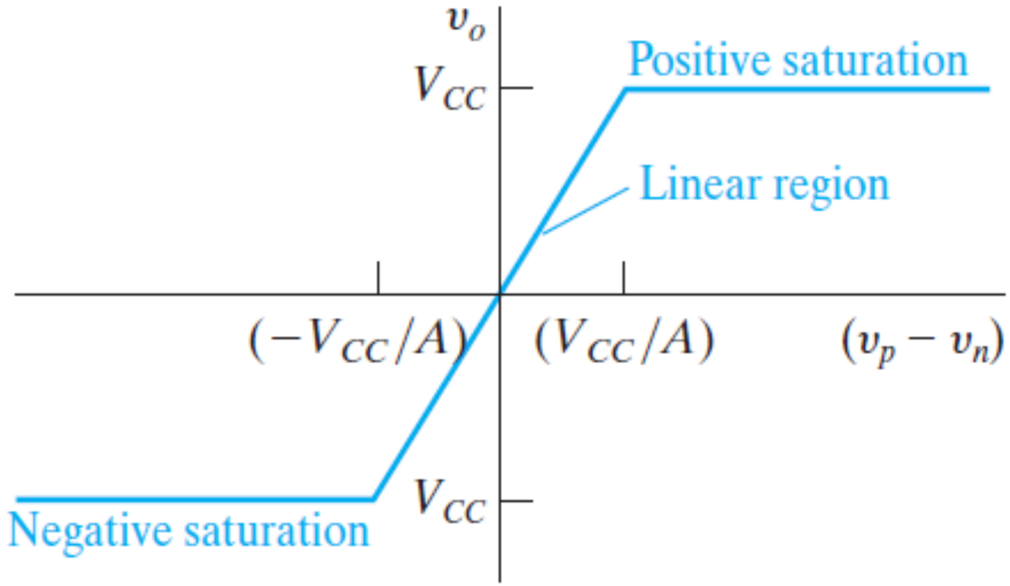
Terminal Current Variables

Current variables with their reference directions, all of which **are into the terminals** of the operational amplifier:



- i_p is the current into the noninverting input terminal
- i_n is the current into the inverting input terminal
- i_o is the current into the output terminal
- i_{c+} is the current into the positive power supply terminal
- I_{c-} is the current into the negative power supply terminal

The voltage transfer characteristic of an op amp.



Op-Amp Circuit Analysis

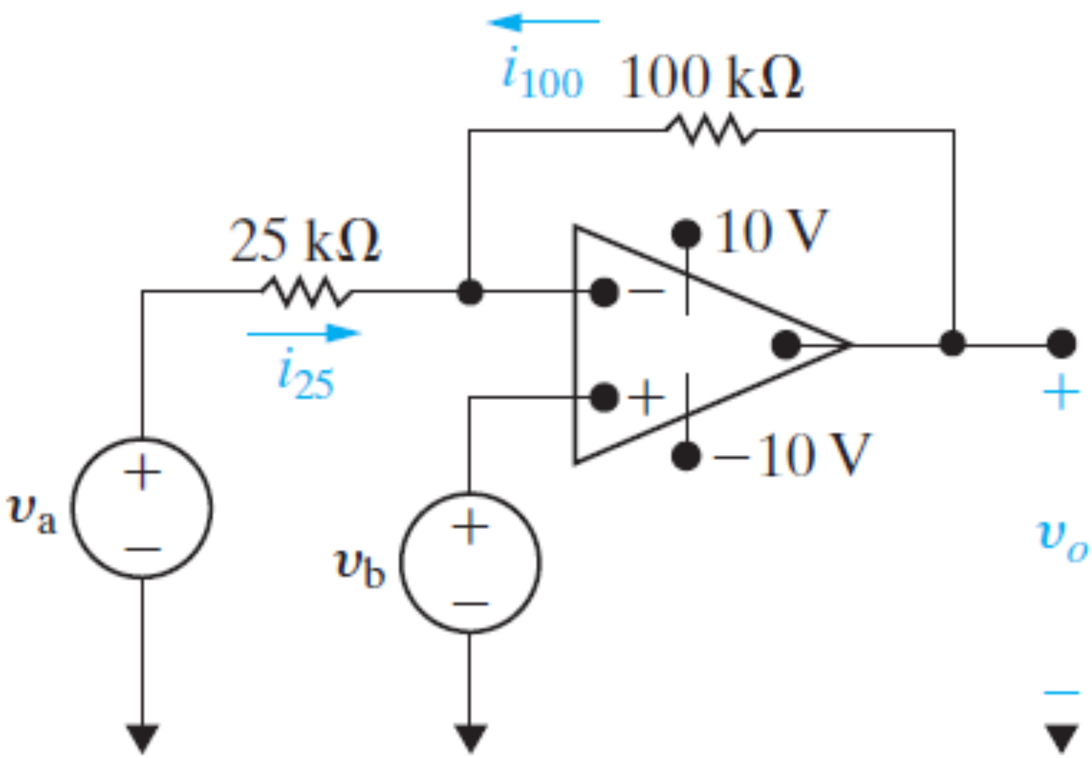
Assumptions (constraints) when in linear operating region:

1) Since gain is infinite, $V^+ = V^-$
2) No current flowing into the V^+ or V^- inputs, $i^+ = i^-$
3) Output resistance is zero

Analyzing a Circuit with an Ideal Op Amp

Step 1: Check for the presence of a negative feedback path; if it exists, we can assume the op amp is operating in its linear region.
Step 2: Write a KCL equation at the inverting input terminal, using the input current constraint (Eq. 5.3), the input voltage and Ohm's law to find the currents.
<u>This equation will usually contain the unknown voltage at the op amp's output terminal.</u>
Step 3: Solve the KCL equation and calculate the voltage at the op amp's output terminal.
Step 4: Compare the voltage at the op amp's output terminal to the power supply voltages to determine whether the op amp is actually in its linear region or whether it has saturated.

Op-Amp Example



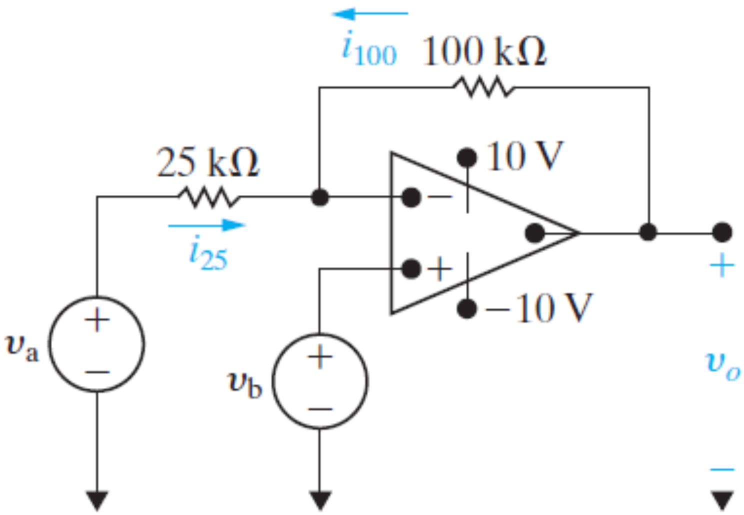
This op amp is ideal.

a. Calculate v_o if $v_a = 1$ V and $v_b = 0$ V.

b. Repeat (a) for $v_a = 1$ V and $v_b = 2$ V.

c. If $v_a = 1.5$ V, specify the range of v_b that avoids amplifier saturation.

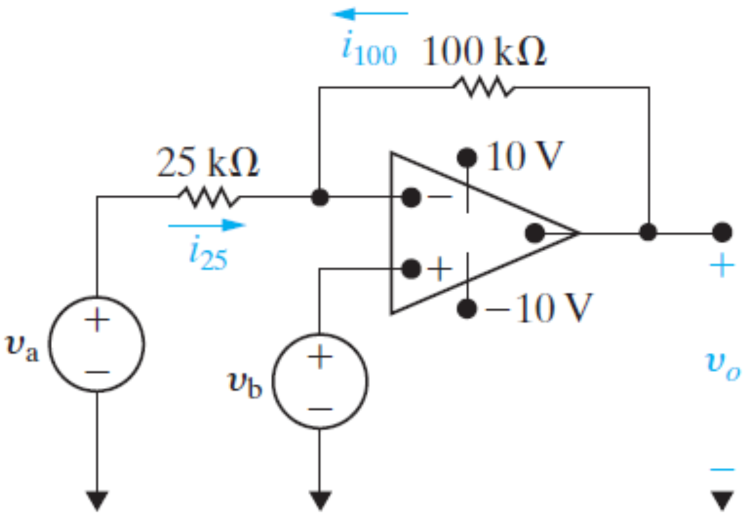
Op-Amp Example



Step 1: Check for the presence of a negative feedback path; if it exists, we can assume the op amp is operating in its linear region.

Step 2: Use nodal analysis. Write a KCL equation at the inverting input terminal, using the input current constraint (Eq. 5.3), the input voltage and Ohm's law to find the currents.
<u>This equation will usually contain the unknown voltage at the op amp's output terminal.</u>

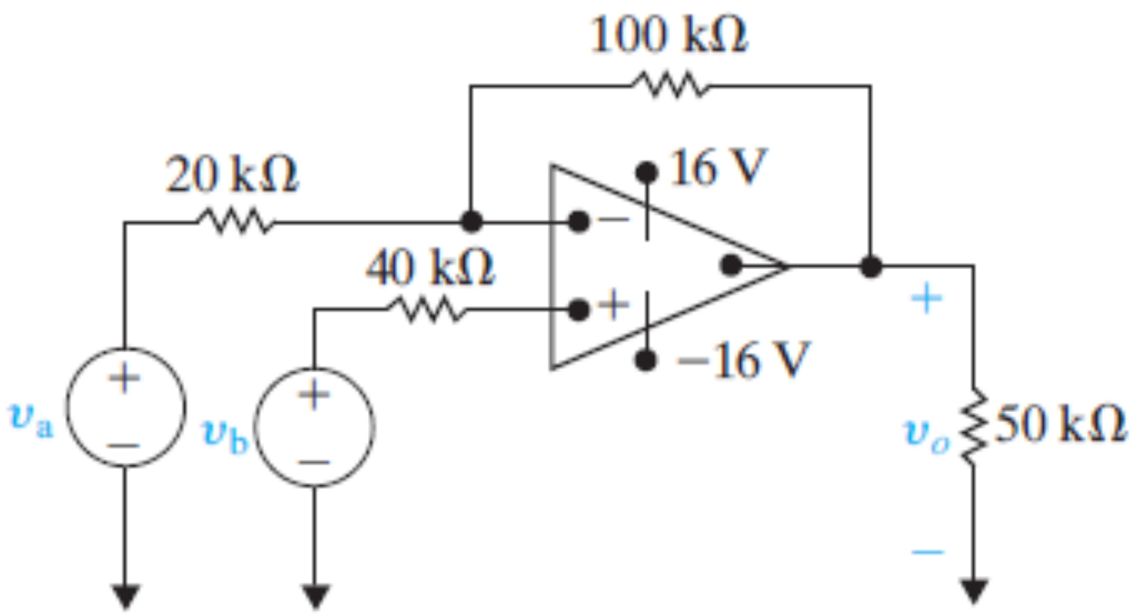
Op-Amp Example



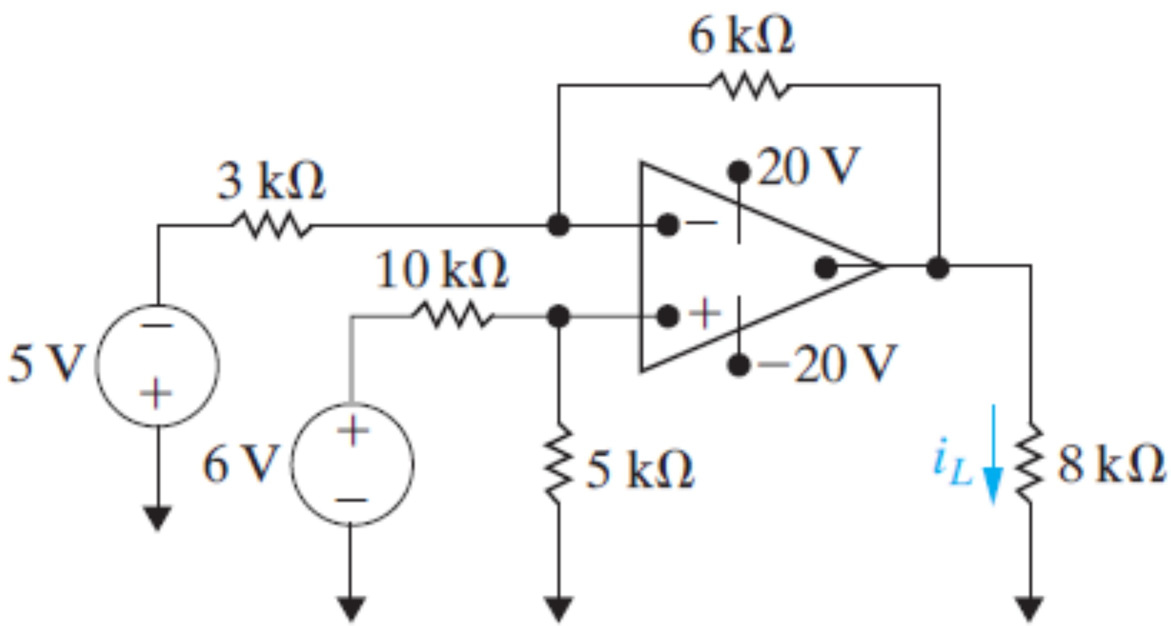
Step 3: Solve the KCL equation and calculate the voltage at the op amp's output terminal.

Step 4: Compare the voltage at the op amp's output terminal to the power supply voltages to determine whether the op amp is actually in its linear region or whether it has saturated.

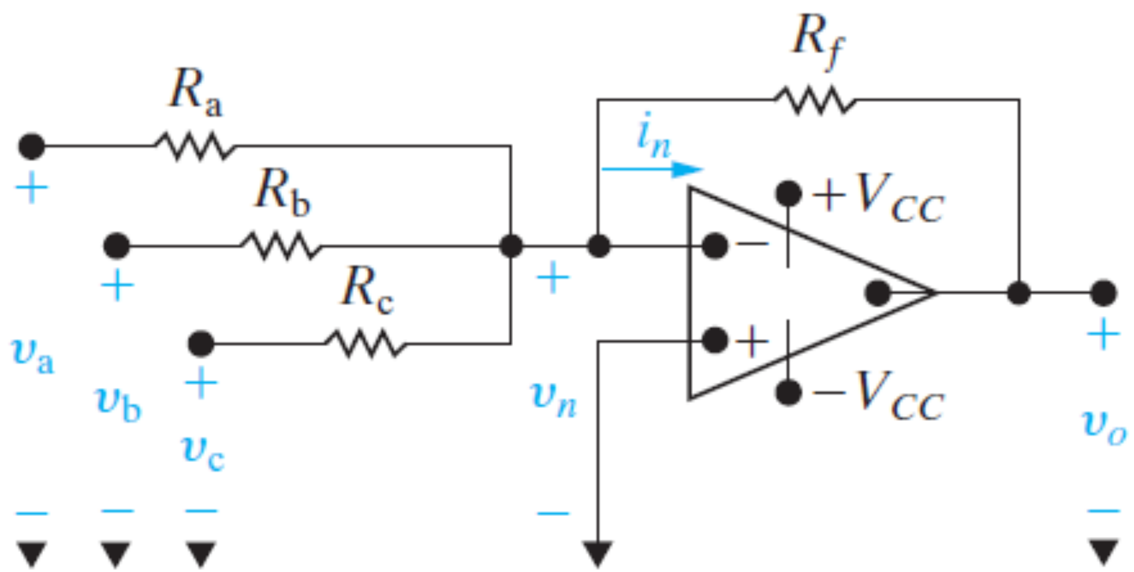
Op-Amp Problem 5.4



Op-Amp Problem 5.6



5.4 Inverting Summing Amplifier



A summing amplifier with three input voltages.

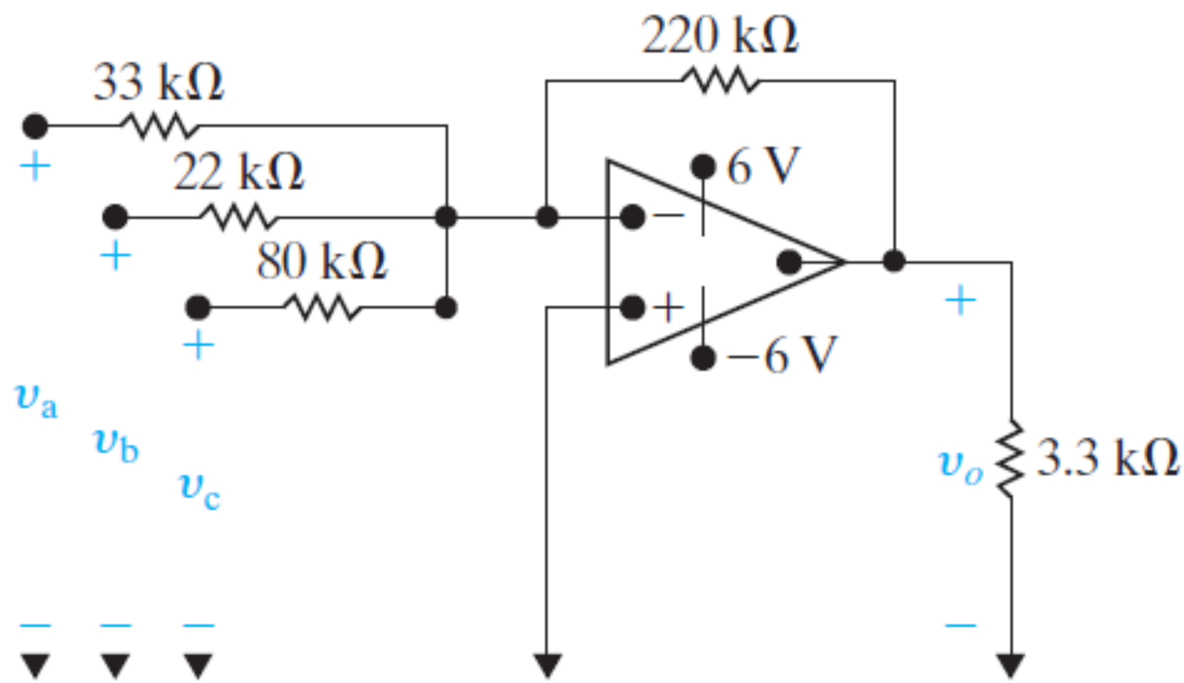
The output voltage of a summing amplifier is an inverted, scaled sum of the voltages applied to the input of the amplifier.

Inverting Summing-Amplifier Equation

(5.6)

$$v_o = -\left(\frac{R_f}{R_a}v_a + \frac{R_f}{R_b}v_b + \frac{R_f}{R_c}v_c\right).$$

Inverting Summing Amplifier
Prob. 5.12

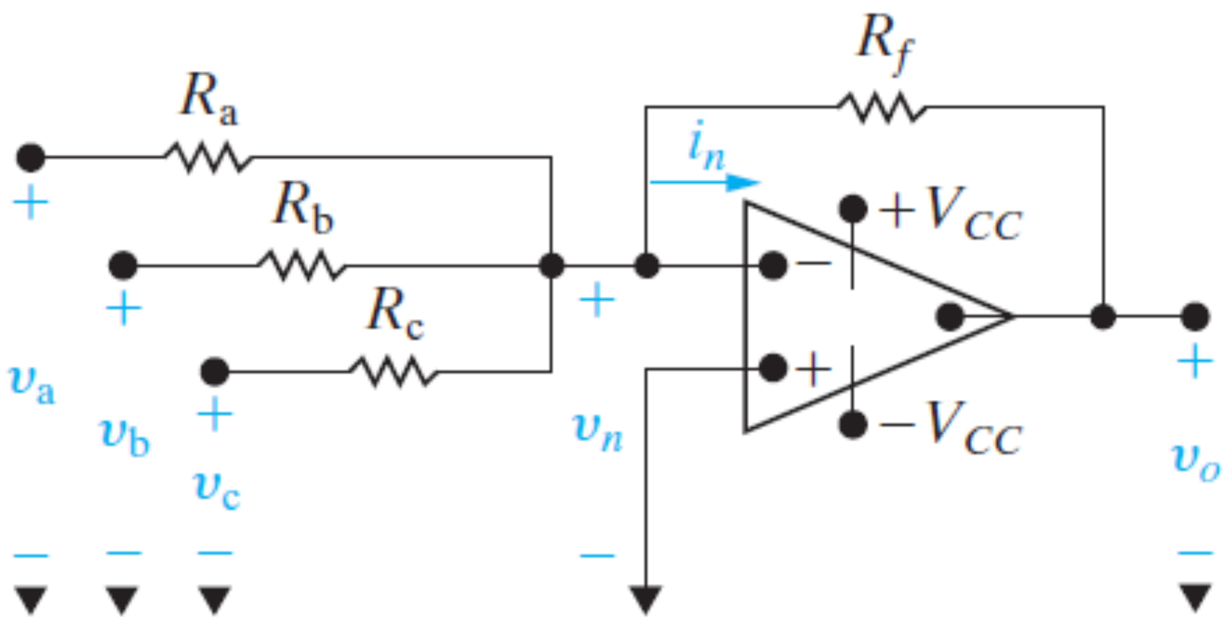


Inverting Summing-Amplifier Equation

(5.6)

$$v_o = -\left(\frac{R_f}{R_a}v_a + \frac{R_f}{R_b}v_b + \frac{R_f}{R_c}v_c\right).$$

Inverting Summing Amplifier
Prob. 5.14

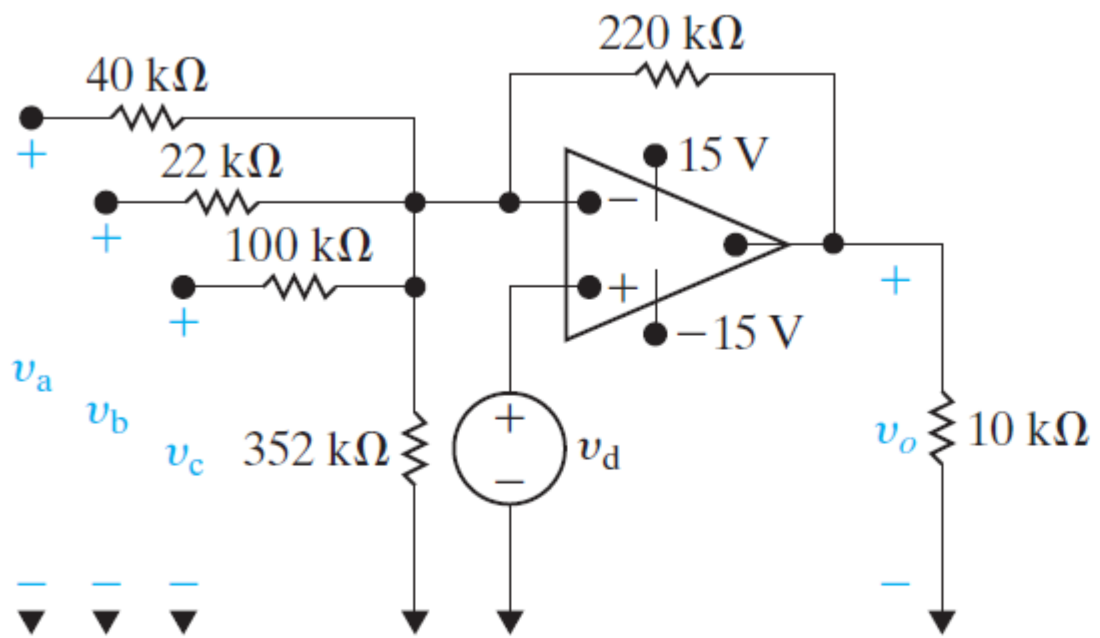


Inverting Summing-Amplifier Equation

(5.6)

$$v_o = -\left(\frac{R_f}{R_a}v_a + \frac{R_f}{R_b}v_b + \frac{R_f}{R_c}v_c\right).$$

Inverting Summing Amplifier
Prob. 5.17

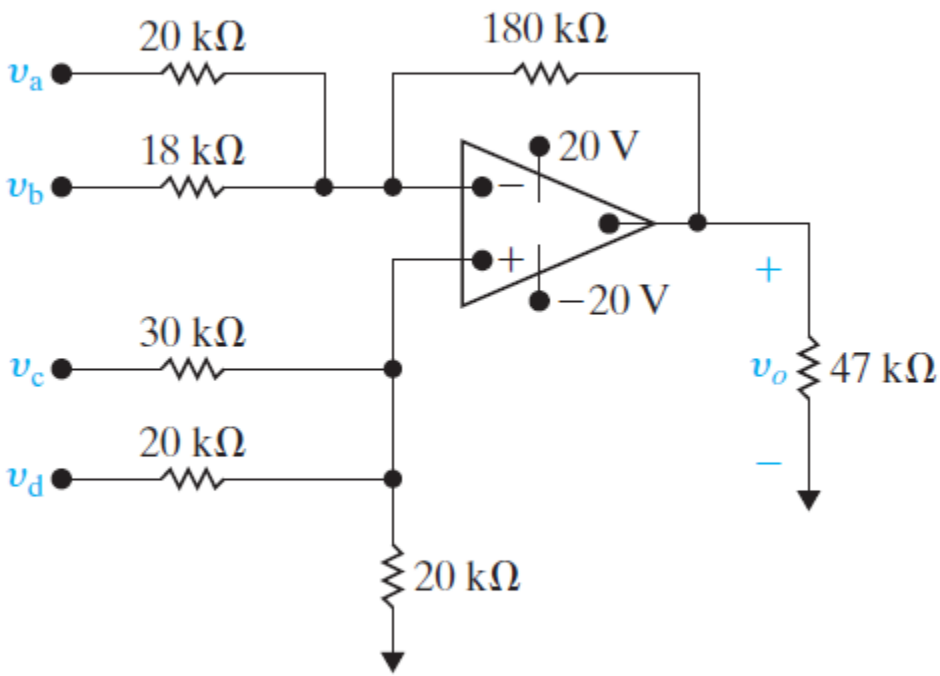


Inverting Summing-Amplifier Equation

(5.6)

$$v_o = -\left(\frac{R_f}{R_a}v_a + \frac{R_f}{R_b}v_b + \frac{R_f}{R_c}v_c\right).$$

5.6 The Difference Amplifier Circuit (Prob. 5.31)



a. Find v_o when $v_a = 1\text{ V}$, $v_b = 2\text{ V}$, $v_c = 3\text{ V}$, and $v_d = 4\text{ V}$.