Chapter 5 Operational amplifier

- The op amp is an electronic unit that behaves like a voltage-controlled voltage source.

- It can also be used in making a voltage- or current-controlled current source. An op amp can sum signals, amplify a signal, integrate it, or differentiate it. The ability of the op amp to perform these mathematical
- operations is the reason it is called an *operational amplifier*. *It is* also the reason for the widespread use of op amps in analog design.
- Op amps are popular in practical circuit designs because they are versatile, inexpensive, easy to use, and fun to work with.

- An op amp is an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation,and integration.

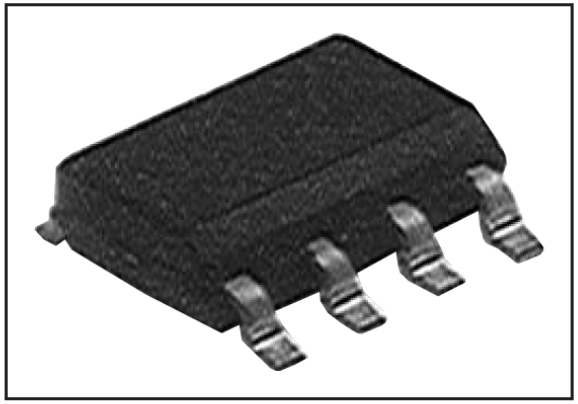


Figure 5.1
A typical operational amplifier.
Courtesy of Tech America.

The pin diagram in Fig. 5.2(a) corresponds to the 741 general-purpose op amp made by Fairchild Semiconductor.

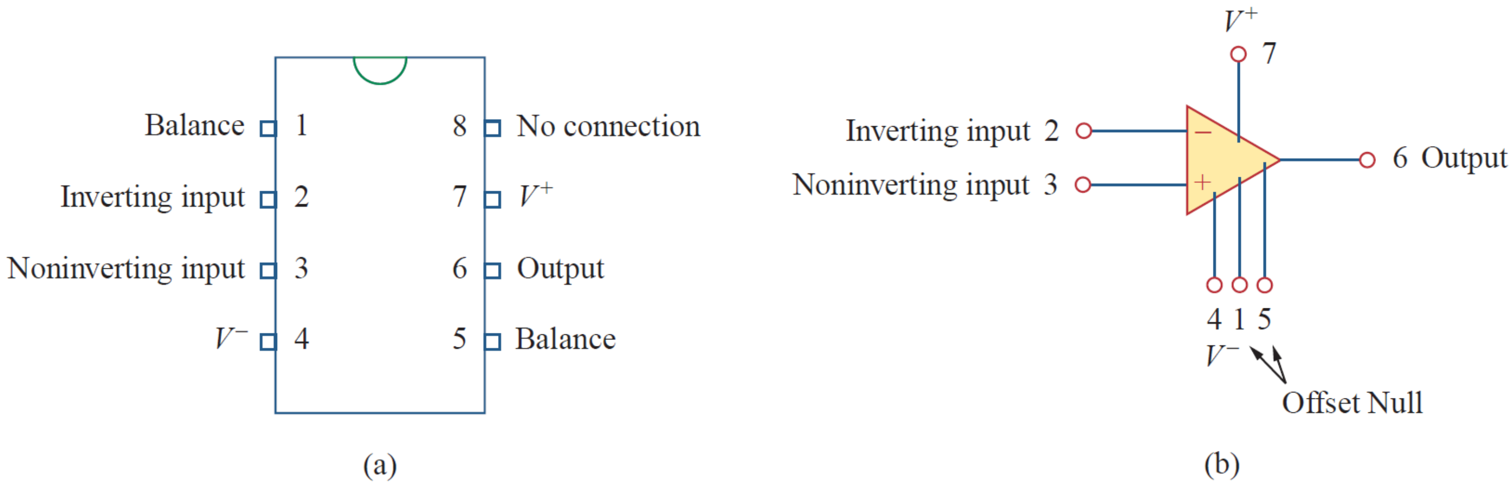


Figure 5.2
A typical op amp: (a) pin configuration, (b) circuit symbol.

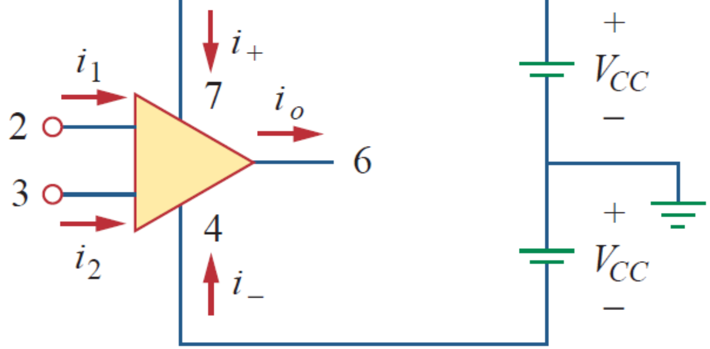


Figure 5.3
Powering the op amp.

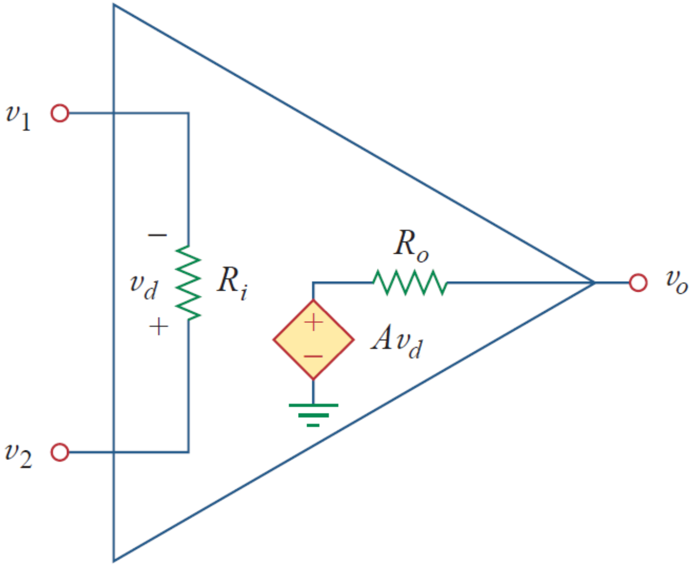


Figure 5.4
The equivalent circuit of the nonideal op amp.

Typical ranges for op amp parameters.

Parameter	Typical range	Ideal values
Open-loop gain, A	10^5 to 10^8	∞
Input resistance, R_i	10^5 to 10^{13} Ω	∞ Ω
Output resistance, R_o	10 to 100 Ω	0 Ω
Supply voltage, V_{CC}	5 to 24 V	

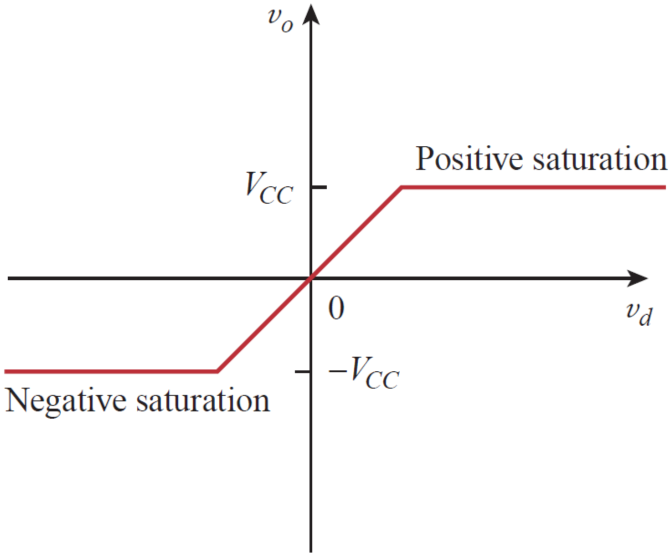


Figure 5.5
Op amp output voltage v_o as a function of the differential input voltage v_d.

Example 5.1

A 741 op amp has an open-loop voltage gain of 2×10^5, input resistance of 2 MΩ, and output resistance of 50 Ω. The op amp is used in the circuit of Fig. 5.6(a). Find the closed-loop gain v_o/v_s. Determine current i when $v_s = 2$ V.

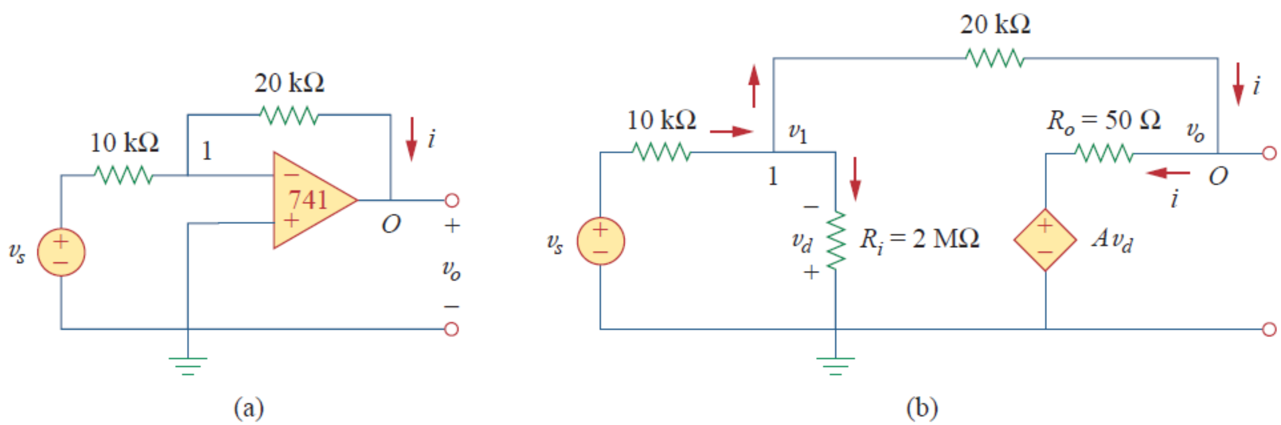
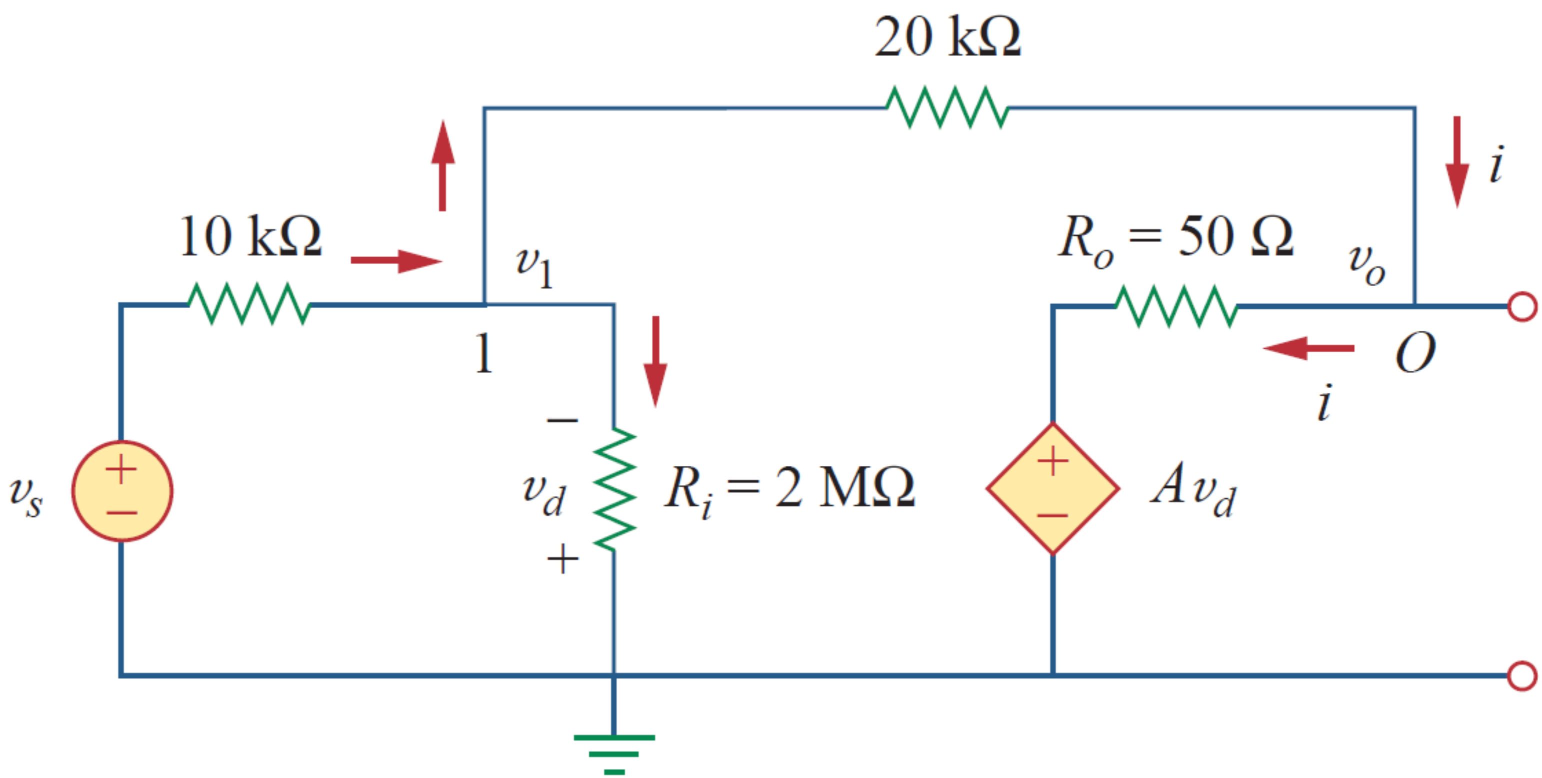


Figure 5.6
For Example 5.1: (a) original circuit, (b) the equivalent circuit.



(b)

Solution:

Using the op amp model in Fig. 5.4, we obtain the equivalent circuit of Fig. 5.6(a) as shown in Fig. 5.6(b). We now solve the circuit in Fig. 5.6(b) by using nodal analysis. At node 1, KCL gives

$$\frac{v_s - v_1}{10 \times 10^3} = \frac{v_1}{2000 \times 10^3} + \frac{v_1 - v_o}{20 \times 10^3}$$

Multiplying through by 2000×10^3, we obtain

$$200v_s = 301v_1 - 100v_o$$

or

$$2v_s \simeq 3v_1 - v_o \quad \Rightarrow \quad v_1 = \frac{2v_s + v_o}{3} \qquad \textbf{(5.1.1)}$$

At node O,

$$\frac{v_1 - v_o}{20 \times 10^3} = \frac{v_o - Av_d}{50}$$

But $v_d = -v_1$ and $A = 200{,}000$. Then

$$v_1 - v_o = 400(v_o + 200{,}000v_1) \qquad \textbf{(5.1.2)}$$

Substituting v_1 from Eq. (5.1.1) into Eq. (5.1.2) gives

$$0 \simeq 26{,}667{,}067v_o + 53{,}333{,}333v_s \quad \Rightarrow \quad \frac{v_o}{v_s} = -1.9999699$$

This is closed-loop gain, because the 20-kΩ feedback resistor closes the loop between the output and input terminals. When $v_s = 2$ V, $v_o = -3.9999398$ V. From Eq. (5.1.1), we obtain $v_1 = 20.066667\ \mu$V. Thus,

$$i = \frac{v_1 - v_o}{20 \times 10^3} = 0.19999 \text{ mA}$$

It is evident that working with a nonideal op amp is tedious, as we are dealing with very large numbers.

5.3 Ideal Op Amp

To facilitate the understanding of op amp circuits, we will assume ideal op amps. An op amp is ideal if it has the following characteristics:

1. Infinite open-loop gain, $A \simeq \infty$.
2. Infinite input resistance, $R_i \simeq \infty$.
3. Zero output resistance, $R_o \simeq 0$.

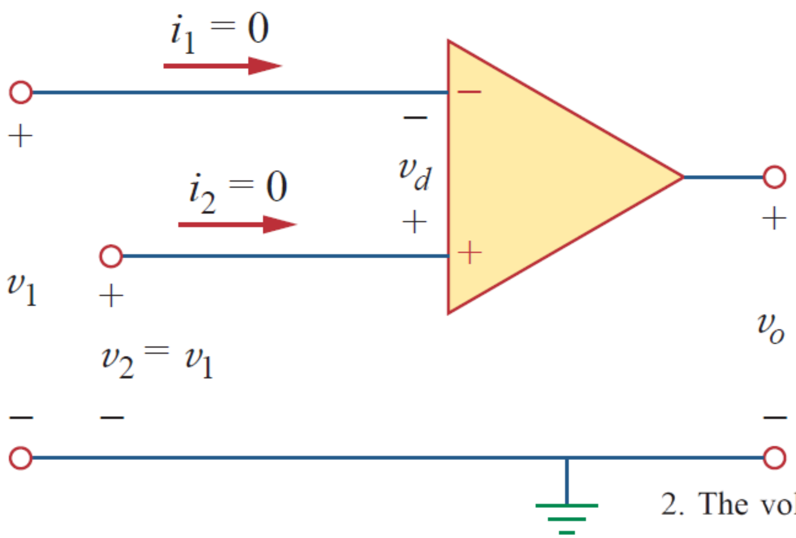


Figure 5.8
Ideal op amp model.

1. The currents into both input terminals are zero:

$$i_1 = 0, \qquad i_2 = 0$$

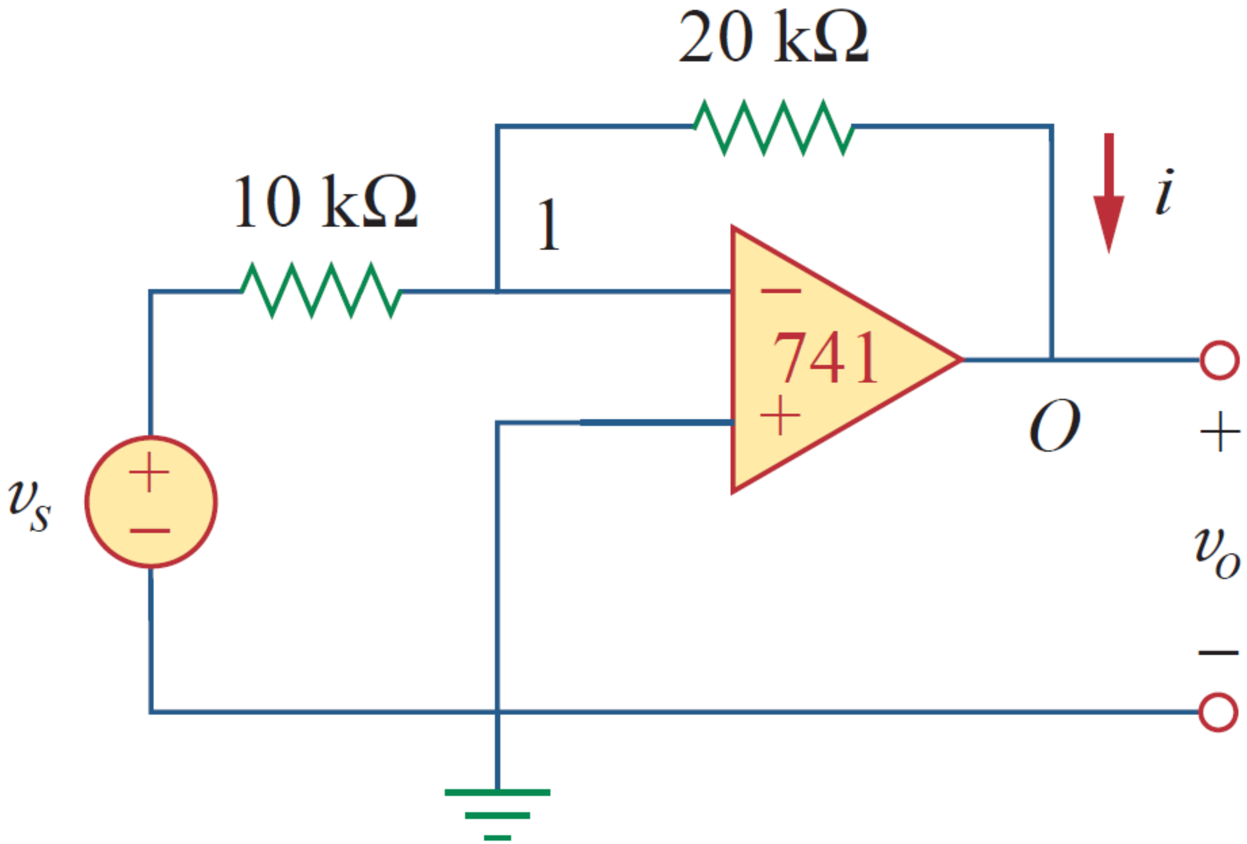
This is due to infinite input resistance. An ir

2. The voltage across the input terminals is equal to zero; i.e.,

$$v_d = v_2 - v_1 = 0 \tag{5.6}$$

or

$$v_1 = v_2 \tag{5.7}$$



(a)

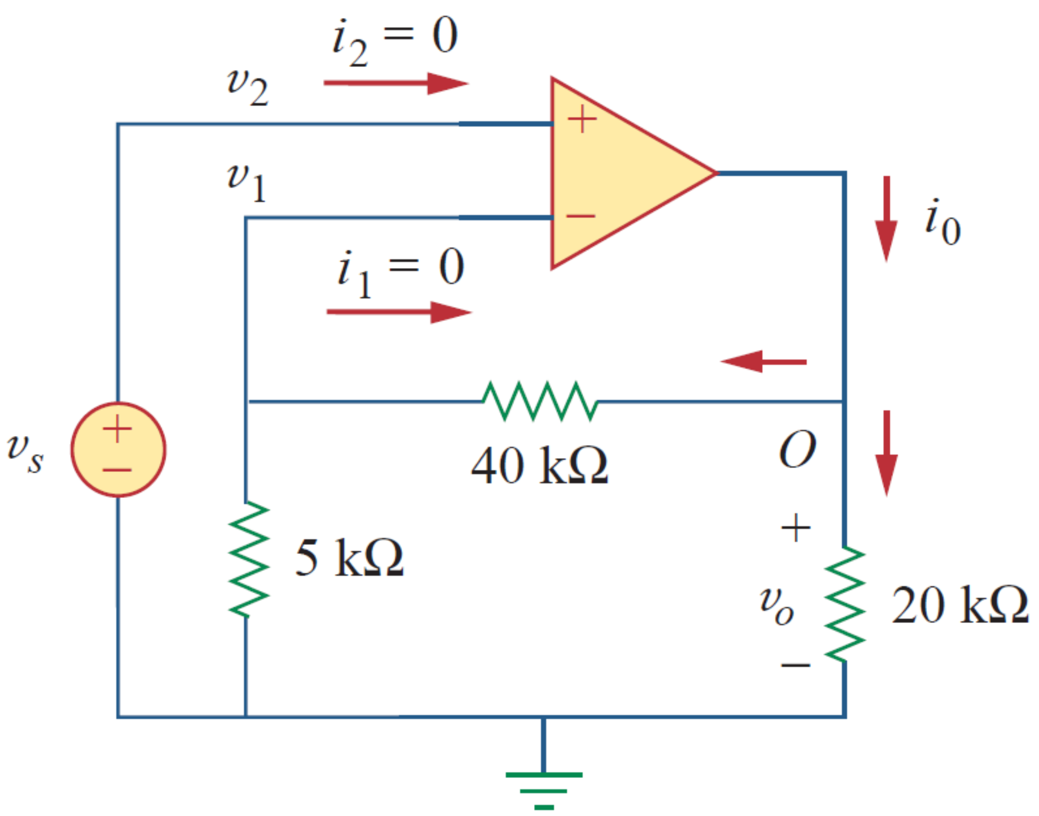


Figure 5.9
For Example 5.2.

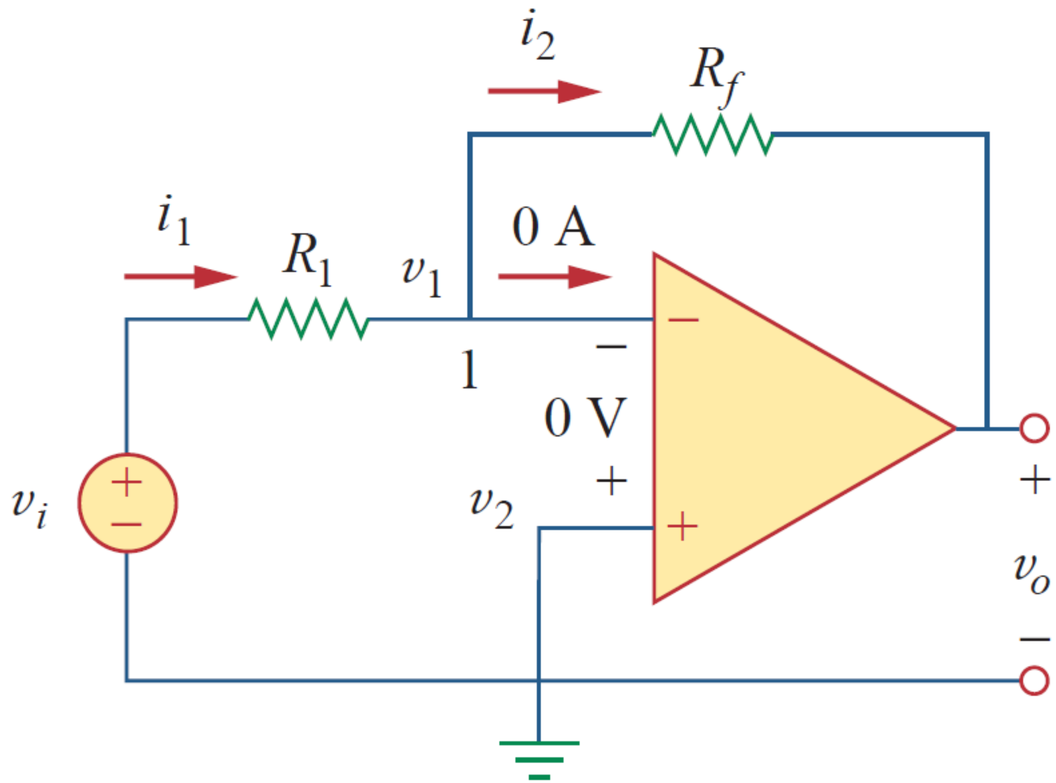


Figure 5.10
The inverting amplifier.

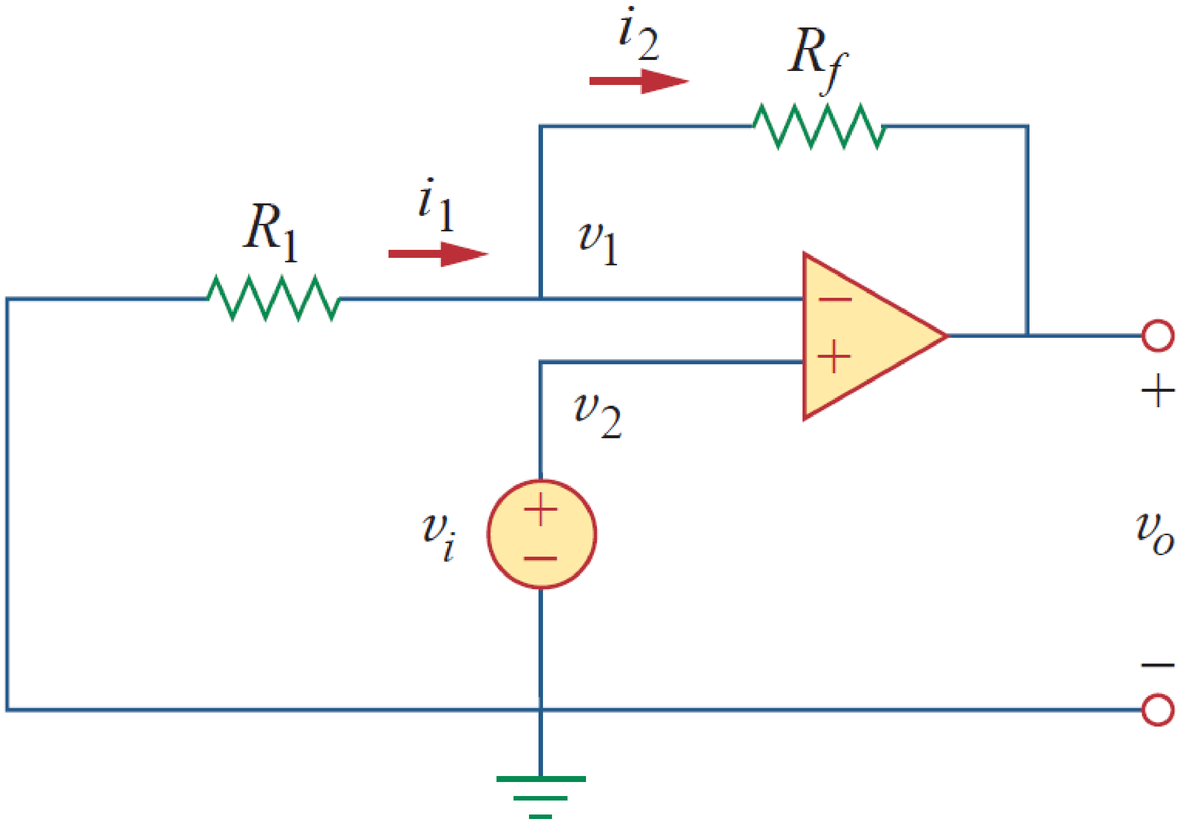


Figure 5.16
The noninverting amplifier.

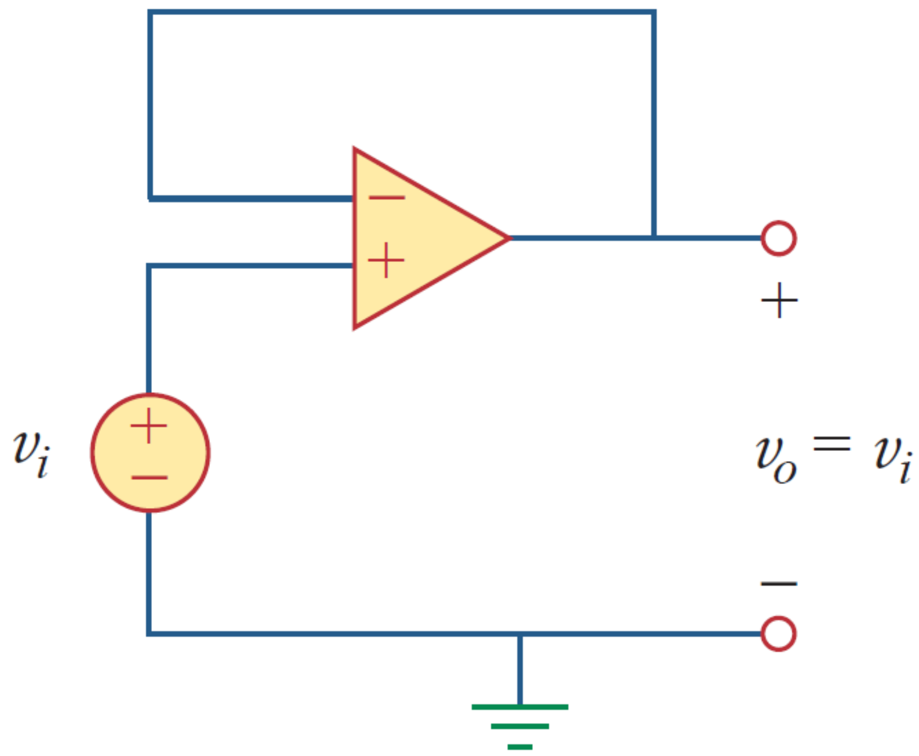


Figure 5.17
The voltage follower.

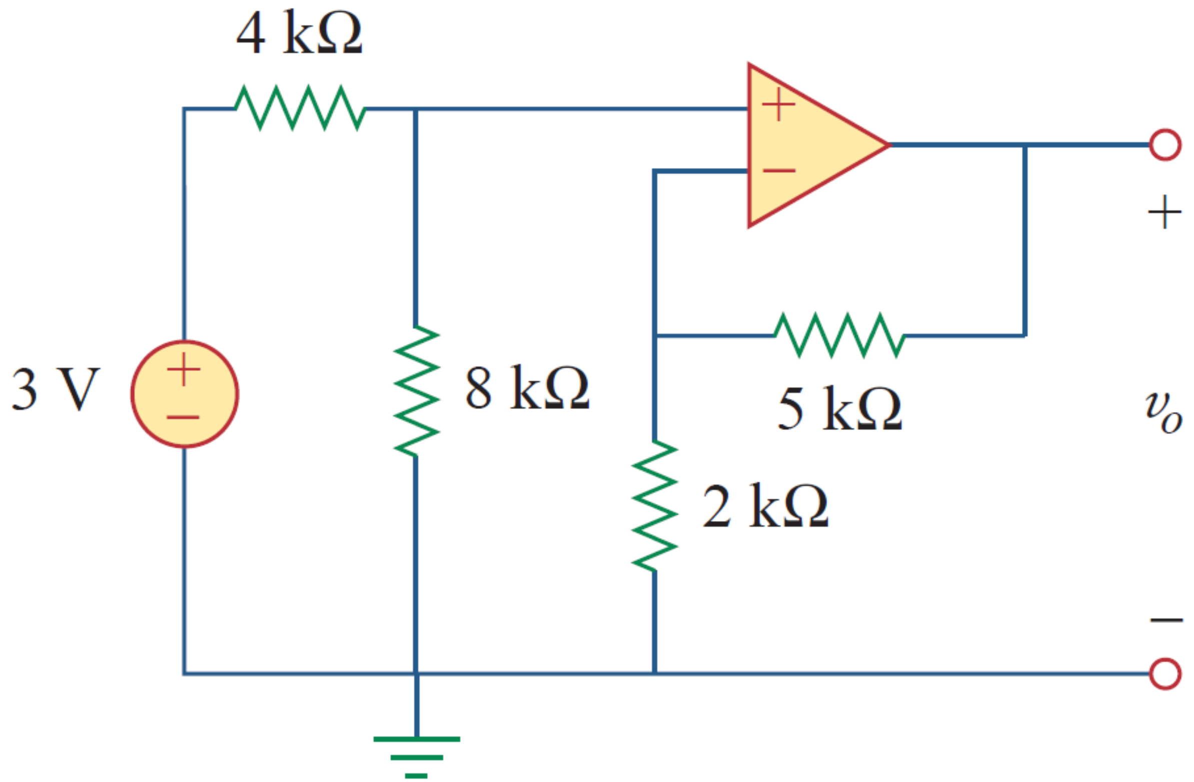


Figure 5.20
For Practice Prob. 5.5.

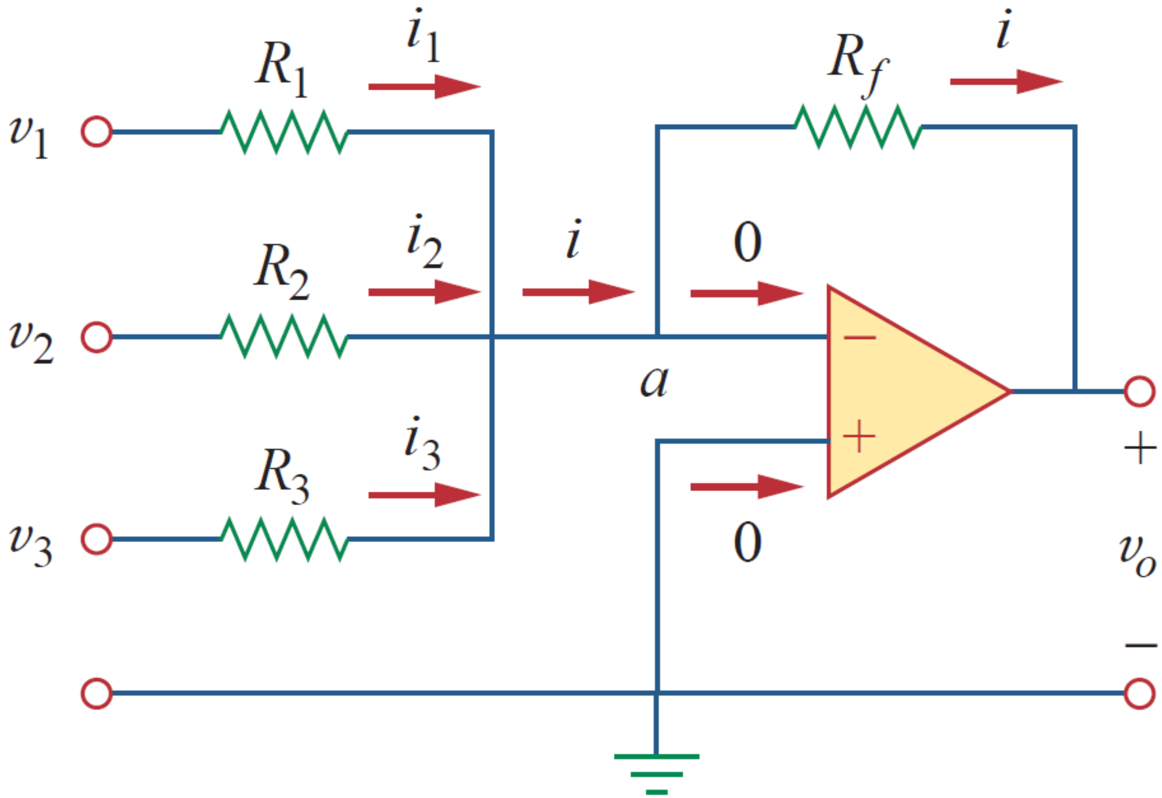


Figure 5.21
The summing amplifier.

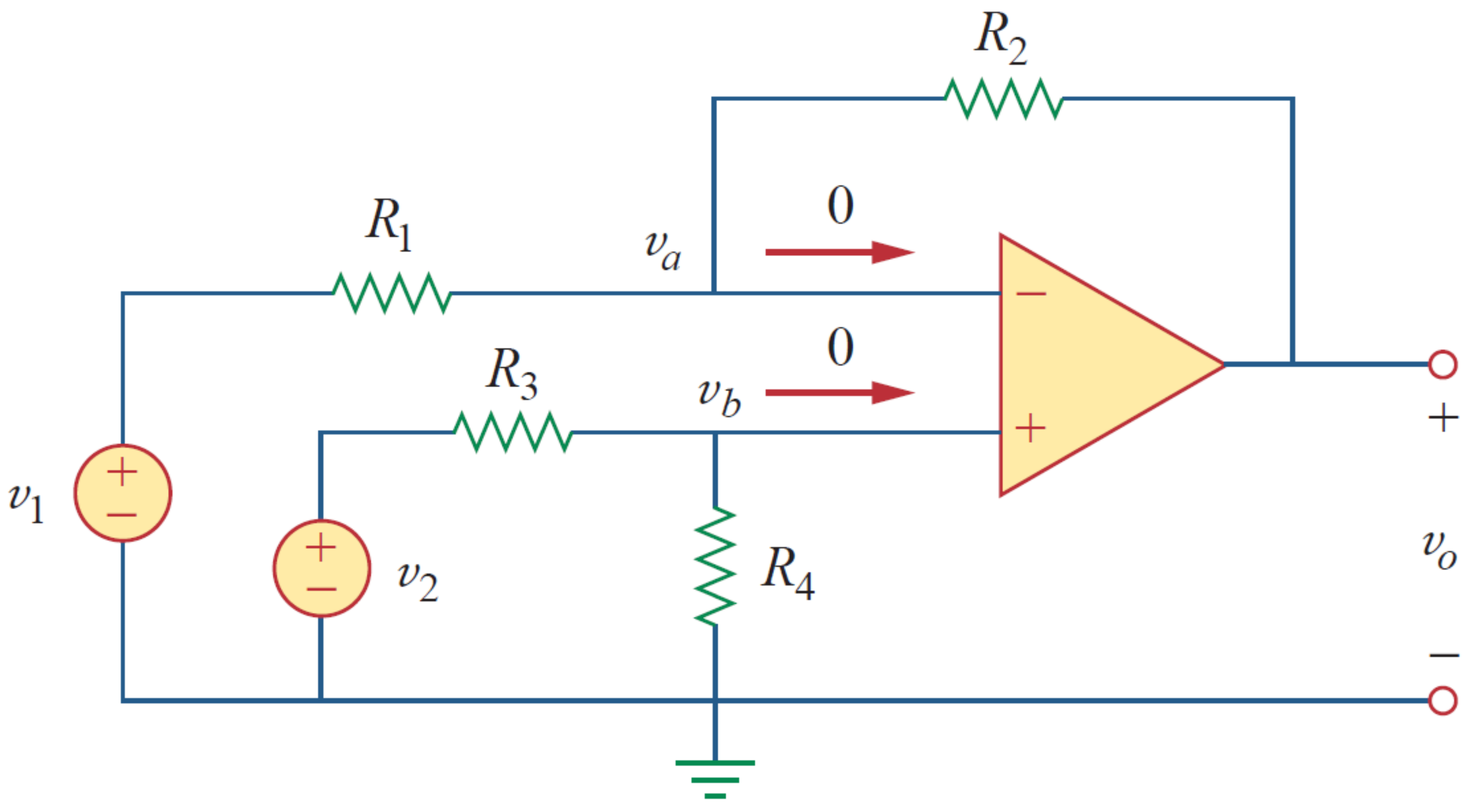


Figure 5.24
Difference amplifier.

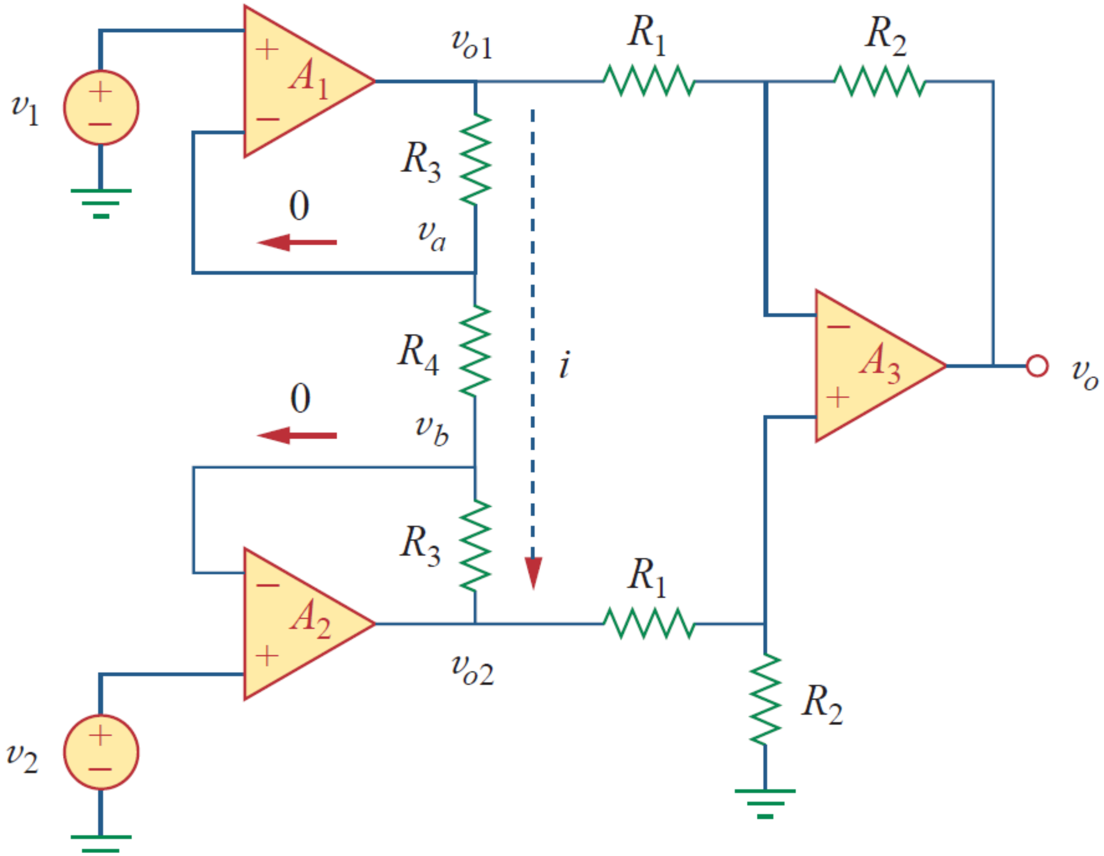


Figure 5.26
Instrumentation amplifier; for Example 5.8.

Obtain i_o in the instrumentation amplifier circuit of Fig. 5.27.

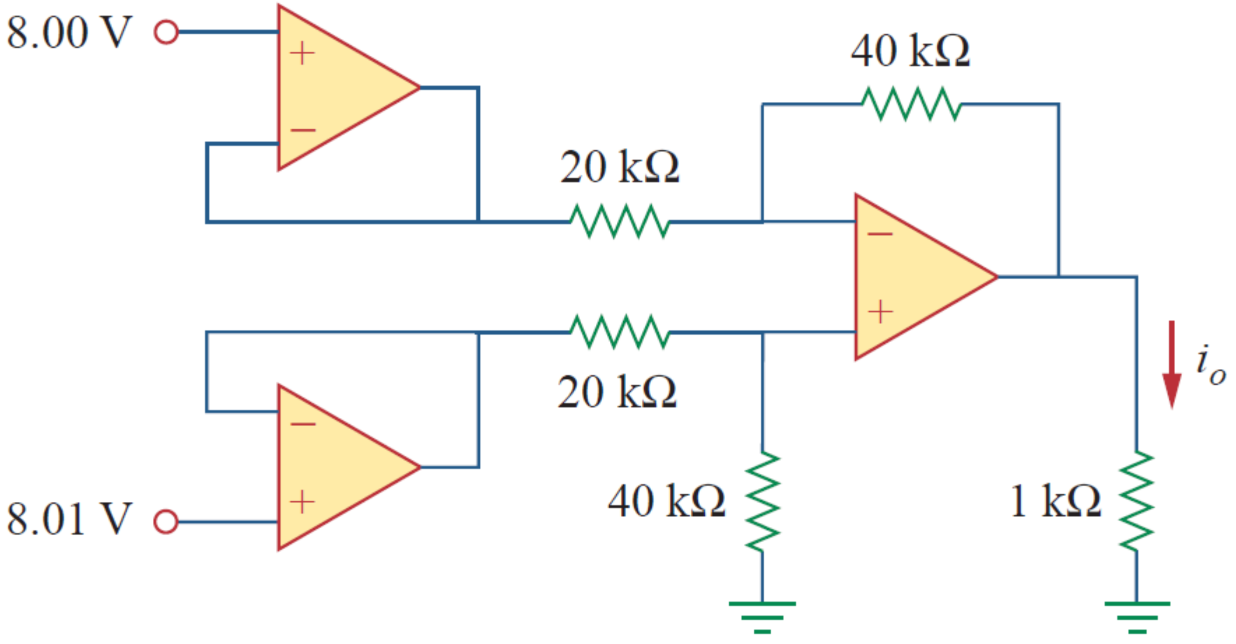


Figure 5.27
Instrumentation amplifier; for Practice Prob. 5.8.