11 Op-Amp Applications

CHAPTER OBJECTIVES

- Learn about constant gain, summing, and buffering amplifiers
- Understand how an active filter works
- Describe different types of controlled sources

11.1 CONSTANT-GAIN MULTIPLIER

One of the most common op-amp circuits is the inverting constant-gain multiplier, which provides a precise gain or amplification. Figure 11.1 shows a standard circuit connection, with the resulting gain being given by

$$A = -\frac{R_f}{R_1} \tag{11.1}$$

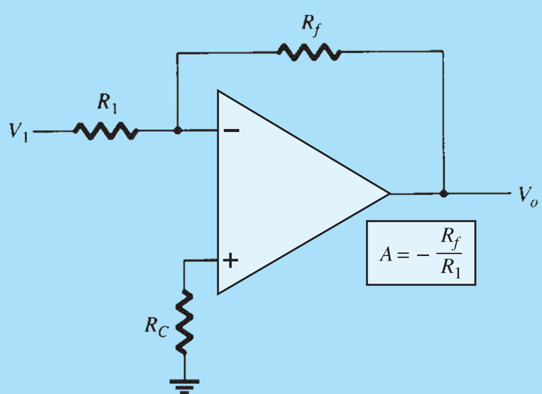

FIG. 11.1
Fixed-gain amplifier.

EXAMPLE 11.1 Determine the output voltage for the circuit of Fig. 11.2 with a sinusoidal input of 2.5 mV.

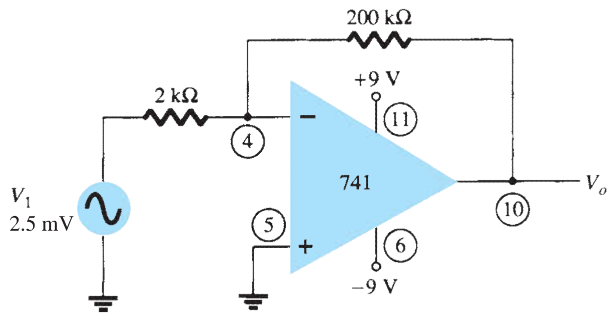

FIG. 11.2
Circuit for Example 11.1.

Solution: The circuit of Fig. 11.2 uses a 741 op-amp to provide a constant or fixed gain, calculated from Eq. (11.1) to be

$$A = -\frac{R_f}{R_1} = -\frac{200\text{ k}\Omega}{2\text{ k}\Omega} = -100$$

The output voltage is then

$$V_o = AV_i = -100(2.5\text{ mV}) = -250\text{ mV} = \mathbf{-0.25\text{ V}}$$

A noninverting constant-gain multiplier is provided by the circuit of Fig. 11.3, with the gain given by

$$A = 1 + \frac{R_f}{R_1} \tag{11.2}$$

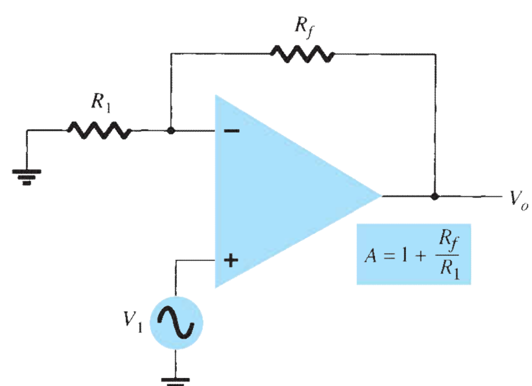

FIG. 11.3
Noninverting fixed-gain amplifier.

EXAMPLE 11.2 Calculate the output voltage from the circuit of Fig. 11.4 for an input of 120 μV.

Solution: The gain of the op-amp circuit is calculated using Eq. (11.2) to be

$$A = 1 + \frac{R_f}{R_1} = 1 + \frac{240\text{ k}\Omega}{2.4\text{ k}\Omega} = 1 + 100 = 101$$

The output voltage is then

$$V_o = AV_i = 101(120\ \mu\text{V}) = \mathbf{12.12\text{ mV}}$$

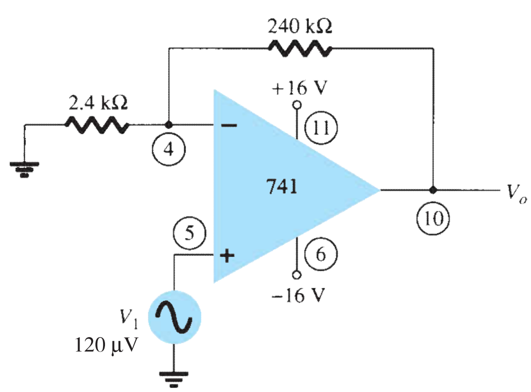

FIG. 11.4
Circuit for Example 11.2.

Multiple-Stage Gains

When a number of stages are connected in series, the overall gain is the product of the individual stage gains. Figure 11.5 shows a connection of three stages. The first stage is connected to provide noninverting gain as given by Eq. (11.1). The next two stages provide an inverting gain given by Eq. (11.1). The overall circuit gain is then noninverting and is calculated by

$$A = A_1 A_2 A_3$$

where $A_1 = 1 + R_f/R_1$, $A_2 = -R_f/R_2$, and $A_3 = -R_f/R_3$.

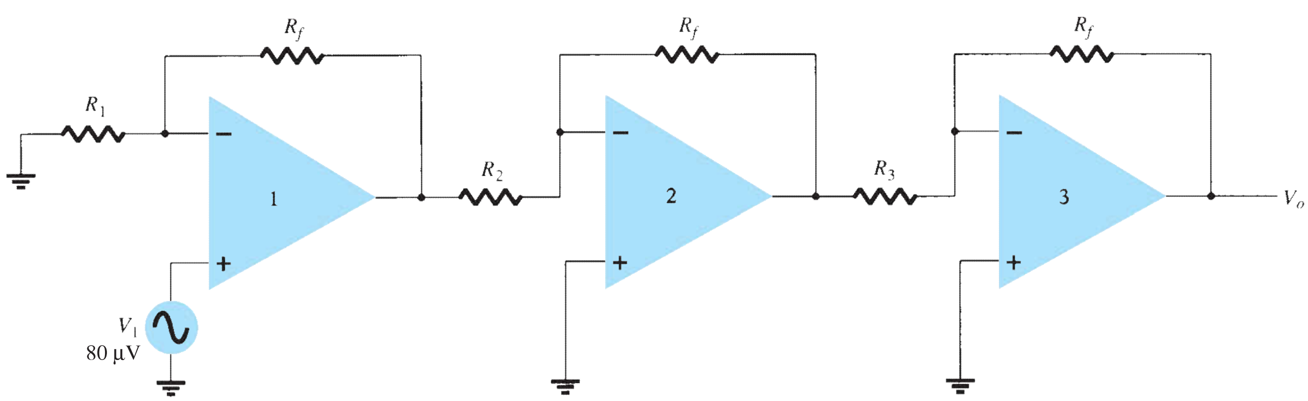

FIG. 11.5
Constant-gain connection with multiple stages.

EXAMPLE 11.3 Calculate the output voltage using the circuit of Fig. 11.5 for resistor components of value $R_f = 470\text{ k}\Omega$, $R_1 = 4.3\text{ k}\Omega$, $R_2 = 33\text{ k}\Omega$, and $R_3 = 33\text{ k}\Omega$ for an input of 80 μV.

Solution: The amplifier gain is calculated to be

$$A = A_1 A_2 A_3 = \left(1 + \frac{R_f}{R_1}\right)\left(-\frac{R_f}{R_2}\right)\left(-\frac{R_f}{R_3}\right)$$

$$= \left(1 + \frac{470\text{ k}\Omega}{4.3\text{ k}\Omega}\right)\left(-\frac{470\text{ k}\Omega}{33\text{ k}\Omega}\right)\left(-\frac{470\text{ k}\Omega}{33\text{ k}\Omega}\right)$$

$$= (110.3)(-14.2)(-14.2) = 22.2 \times 10^3$$

so that

$$V_o = AV_i = 22.2 \times 10^3 (80\ \mu\text{V}) = \mathbf{1.78\ V}$$

EXAMPLE 11.4 Show the connection of an LM124 quad op-amp as a three-stage amplifier with gains of +10, −18, and −27. Use a 270-kΩ feedback resistor for all three circuits. What output voltage will result for an input of 150 μV?

Solution: For the gain of +10,

$$A_1 = 1 + \frac{R_f}{R_1} = +10$$

$$\frac{R_f}{R_1} = 10 - 1 = 9$$

$$R_1 = \frac{R_f}{9} = \frac{270\text{ k}\Omega}{9} = 30\text{ k}\Omega$$

For the gain of −18,

$$A_2 = -\frac{R_f}{R_2} = -18$$

$$R_2 = \frac{R_f}{18} = \frac{270\text{ k}\Omega}{18} = 15\text{ k}\Omega$$

For the gain of −27,

$$A_3 = -\frac{R_f}{R_3} = -27$$

$$R_3 = \frac{R_f}{27} = \frac{270\text{ k}\Omega}{27} = 10\text{ k}\Omega$$

The circuit showing the pin connections and all components used is given in Fig. 11.6. For an input of $V_1 = 150\ \mu$V, the output voltage is

$$V_o = A_1A_2A_3V_1 = (10)(-18)(-27)(150\ \mu\text{V}) = 4860(150\ \mu\text{V})$$
$$= \mathbf{0.729\ V}$$

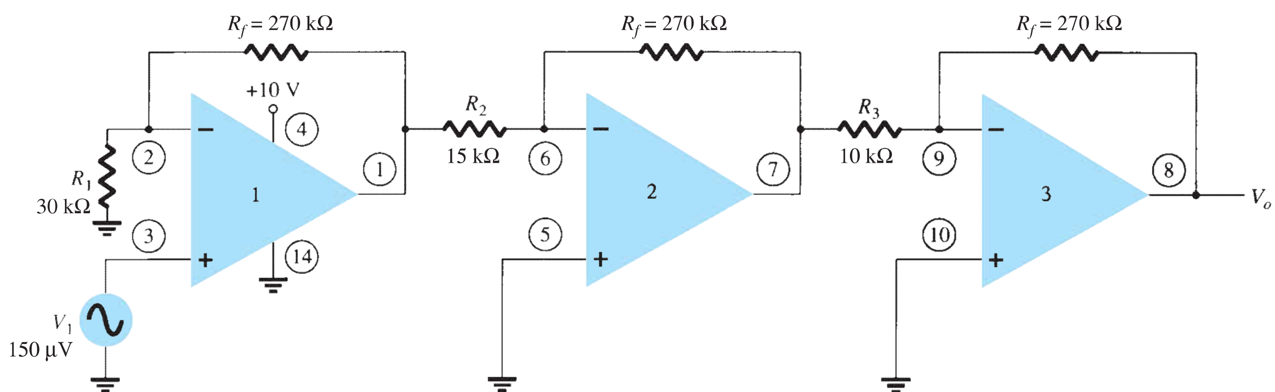

FIG. 11.6
Circuit for Example 11.4 (using LM124).

A number of op-amp stages could also be used to provide separate gains, as demonstrated in the next example.

EXAMPLE 11.5 Show the connection of three op-amp stages using an LM348 IC to provide outputs that are 10, 20, and 50 times larger than the input. Use a feedback resistor of $R_f = 500\text{ k}\Omega$ in all stages.

Solution: The resistor component for each stage is calculated to be

$$R_1 = -\frac{R_f}{A_1} = -\frac{500\text{ k}\Omega}{-10} = 50\text{ k}\Omega$$

$$R_2 = -\frac{R_f}{A_2} = -\frac{500\text{ k}\Omega}{-20} = 25\text{ k}\Omega$$

$$R_3 = -\frac{R_f}{A_3} = -\frac{500\text{ k}\Omega}{-50} = 10\text{ k}\Omega$$

The resulting circuit is drawn in Fig. 11.7.

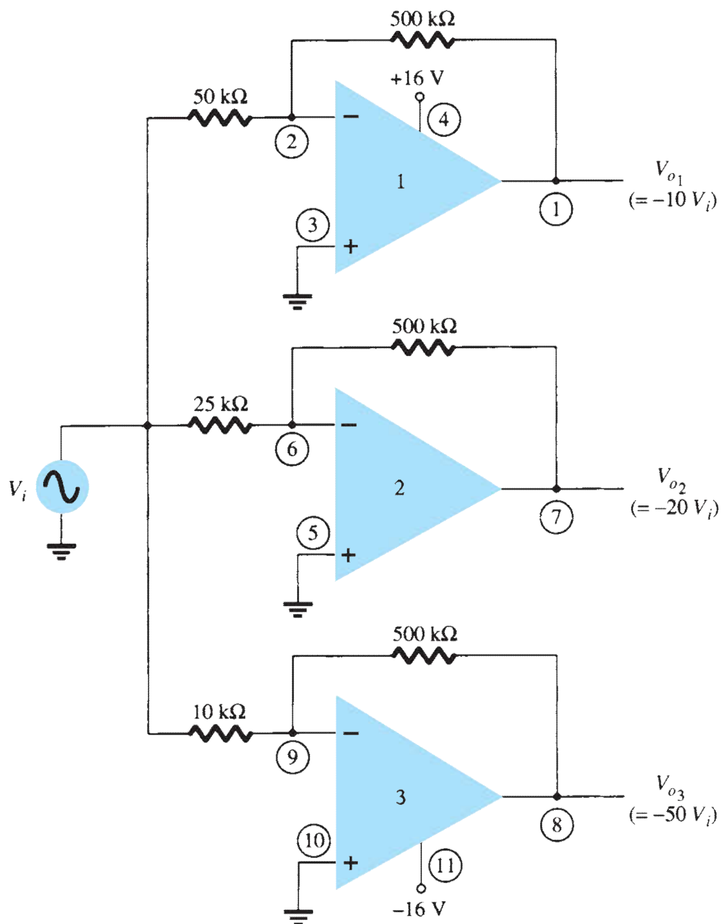

FIG. 11.7
Circuit for Example 11.5 (using LM348).

11.2 VOLTAGE SUMMING

Another popular use of an op-amp is as a summing amplifier. Figure 11.8 shows the connection, with the output being the sum of the three inputs, each multiplied by a different gain. The output voltage is

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right) \tag{11.3}$$

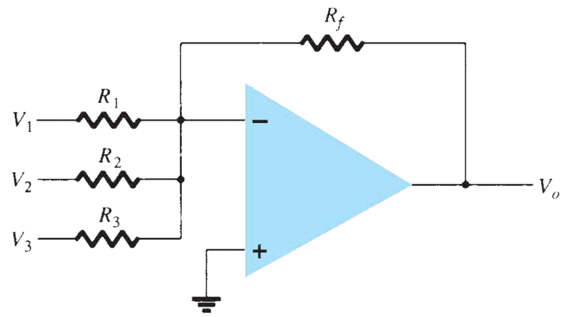

FIG. 11.8
Summing amplifier.

EXAMPLE 11.6 Calculate the output voltage for the circuit of Fig. 11.9. The inputs are $V_1 = 50$ mV sin(1000t) and $V_2 = 10$ mV sin(3000t).

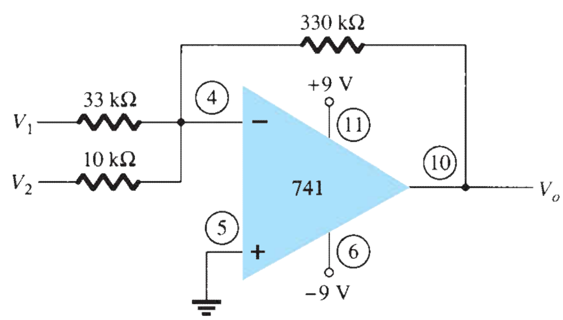

FIG. 11.9
Circuit for Example 11.6.

Solution: The output voltage is

$$V_o = -\left(\frac{330\text{ k}\Omega}{33\text{ k}\Omega}V_1 + \frac{330\text{ k}\Omega}{10\text{ k}\Omega}V_2\right) = -(10\,V_1 + 33\,V_2)$$

$$= -[10(50\text{ mV})\sin(1000t) + 33(10\text{ mV})\sin(3000t)]$$

$$= \mathbf{-[0.5\sin(1000t) + 0.33\sin(3000t)]}$$

Voltage Subtraction

Two signals can be subtracted from one another in a number of ways. Figure 11.10 shows two op-amp stages used to provide subtraction of input signals. The resulting output is given by

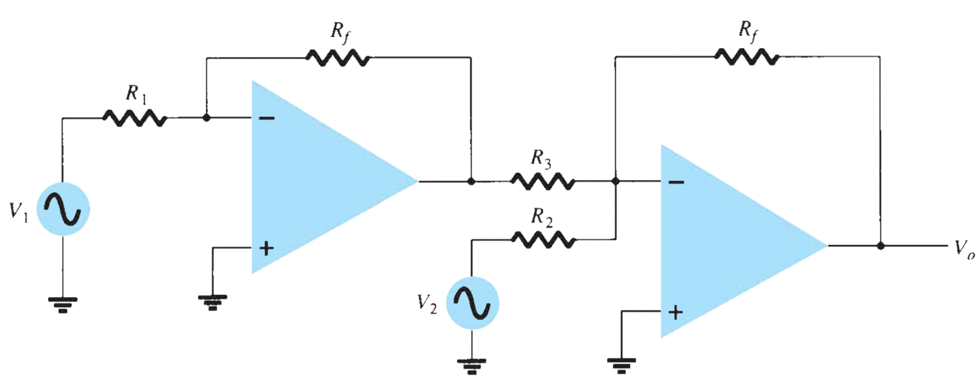

FIG. 11.10
Circuit for subtracting two signals.

$$V_o = -\left[\frac{R_f}{R_3}\left(-\frac{R_f}{R_1}V_1\right) + \frac{R_f}{R_2}V_2\right]$$

$$\boxed{V_o = -\left(\frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}\frac{R_f}{R_1}V_1\right)} \quad \textbf{(11.4)}$$

EXAMPLE 11.7 Determine the output for the circuit of Fig. 11.10 with components $R_f = 1\,\text{M}\Omega$, $R_1 = 100\,\text{k}\Omega$, $R_2 = 50\,\text{k}\Omega$, and $R_3 = 500\,\text{k}\Omega$.

Solution: The output voltage is calculated to be

$$V_o = -\left(\frac{1\,\text{M}\Omega}{50\,\text{k}\Omega}V_2 - \frac{1\,\text{M}\Omega}{500\,\text{k}\Omega}\frac{1\,\text{M}\Omega}{100\,\text{k}\Omega}V_1\right) = -(20\,V_2 - 20\,V_1) = \mathbf{-20(V_2 - V_1)}$$

The output is seen to be the difference of V_2 and V_1 multiplied by a gain factor of -20.

Another connection to provide subtraction of two signals is shown in Fig. 11.11. This connection uses only one op-amp stage to provide subtracting two input signals. Using superposition, we can show the output to be

$$\boxed{V_o = \frac{R_3}{R_1 + R_3}\frac{R_2 + R_4}{R_2}V_1 - \frac{R_4}{R_2}V_2} \quad \textbf{(11.5)}$$

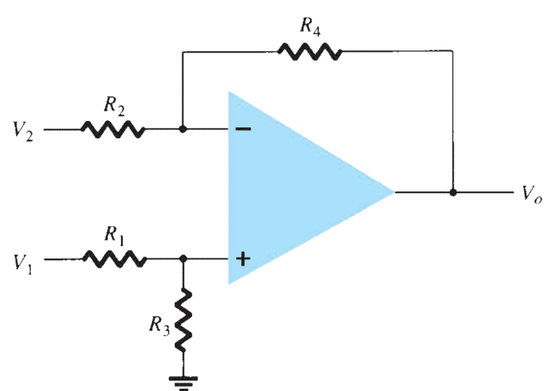

FIG. 11.11
Subtraction circuit.

EXAMPLE 11.8 Determine the output voltage for the circuit of Fig. 11.12.

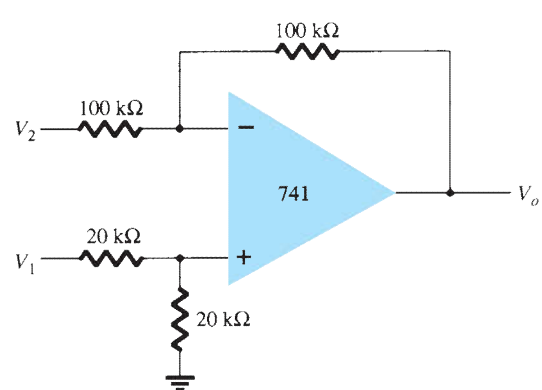

FIG. 11.12
Circuit for Example 11.8.

Solution: The resulting output voltage can be expressed as

$$V_o = \left(\frac{20\text{ k}\Omega}{20\text{ k}\Omega + 20\text{ k}\Omega}\right)\left(\frac{100\text{ k}\Omega + 100\text{ k}\Omega}{100\text{ k}\Omega}\right)V_1 - \frac{100\text{ k}\Omega}{100\text{ k}\Omega}V_2$$

$$= V_1 - V_2$$

The resulting output voltage is seen to be the difference of the two input voltages.

11.3 VOLTAGE BUFFER

A voltage buffer circuit provides a means of isolating an input signal from a load by using a stage having unity voltage gain, with no phase or polarity inversion, and acting as an ideal circuit with very high input impedance and low output impedance. Figure 11.13 shows an op-amp connected to provide this buffer amplifier operation. The output voltage is determined by

$$V_o = V_1 \tag{11.6}$$

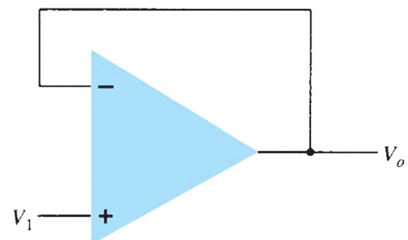

FIG. 11.13
Unity-gain (buffer) amplifier.

Figure 11.14 shows how an input signal can be provided to two separate outputs. The advantage of this connection is that the load connected across one output has no (or little) effect on the other output. In effect, the outputs are buffered or isolated from each other.

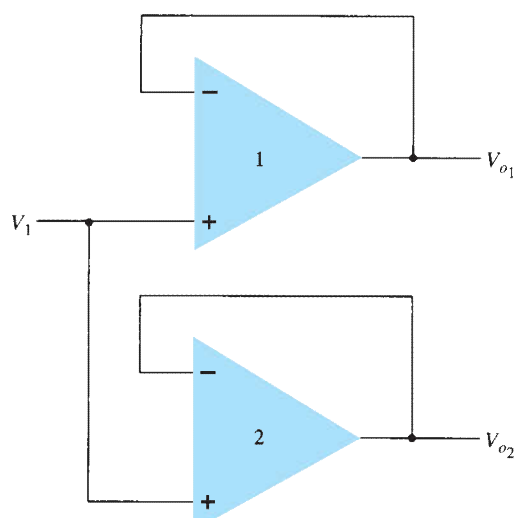

FIG. 11.14
Use of buffer amplifier to provide output signals.