# CHAPTER 3.
# Signal Conditioning

## 3.1 Signal conditioning

### 3.1.1 Signal conditioning process

- 1. Protection to prevent damage to the next element

- 2. Getting the signal into the right type of signal.
  - Making the signal into a D.C. voltage or current.

- 3. Getting the level of the signal right
  - Amplification

- 4. Eliminating or reducing noise
  - filters

- 5. Signal manipulation
  - Making it a linear function of some variable

## 3.2 The Operational amplifier

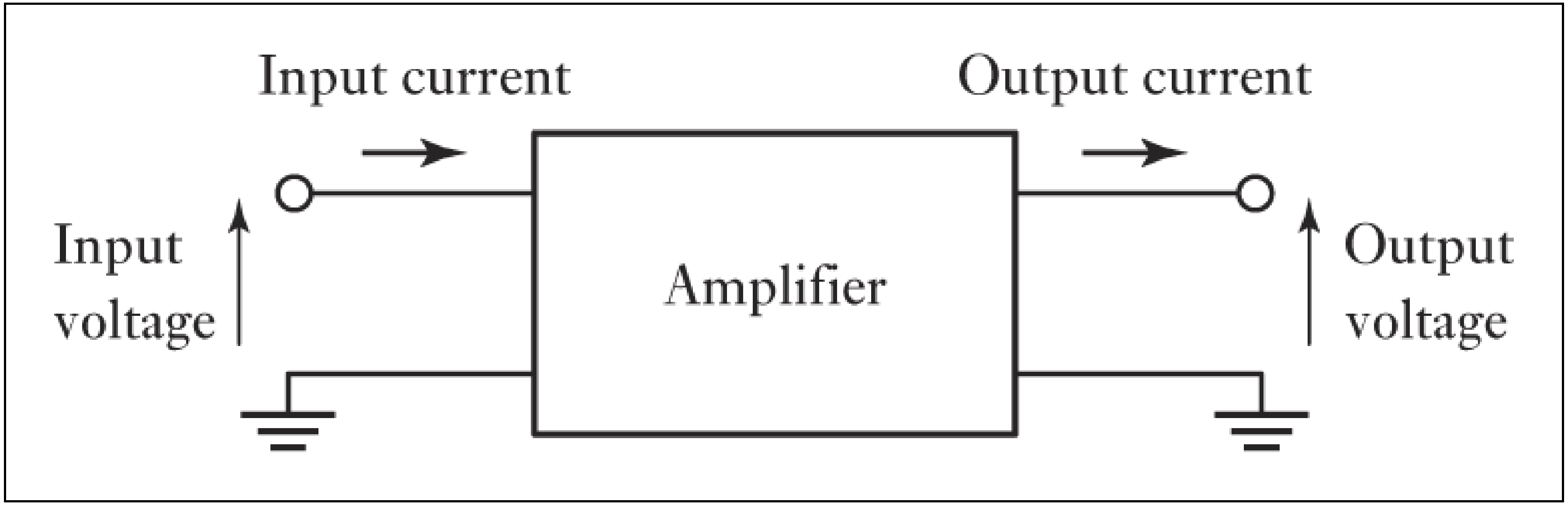



Figure 3.1 Amplifier

## 3.2 The Operational amplifier

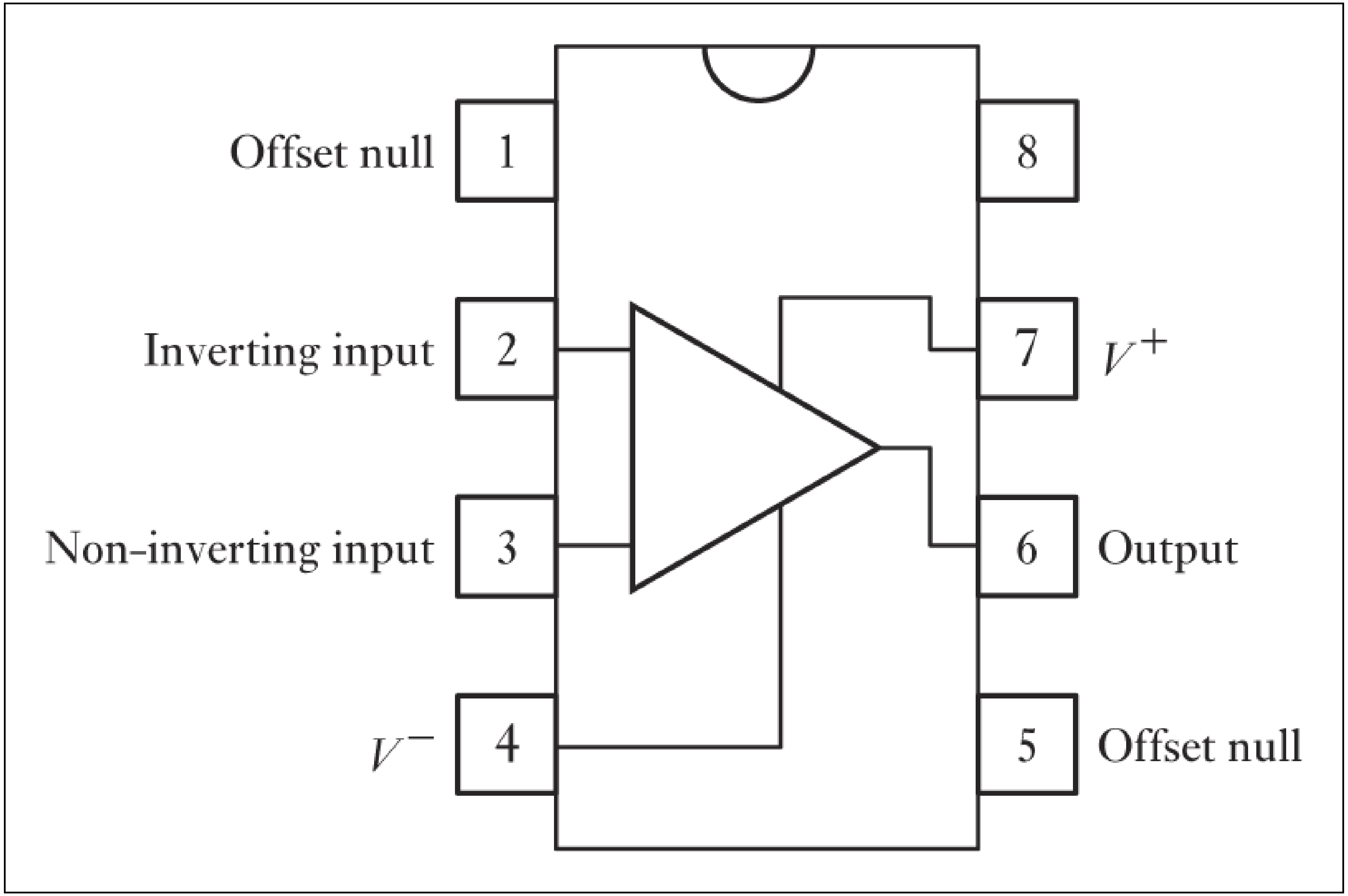



Figure 3.2 Pin connections for a 741-type operational amplifier

### 3.2.1 Inverting amplifier

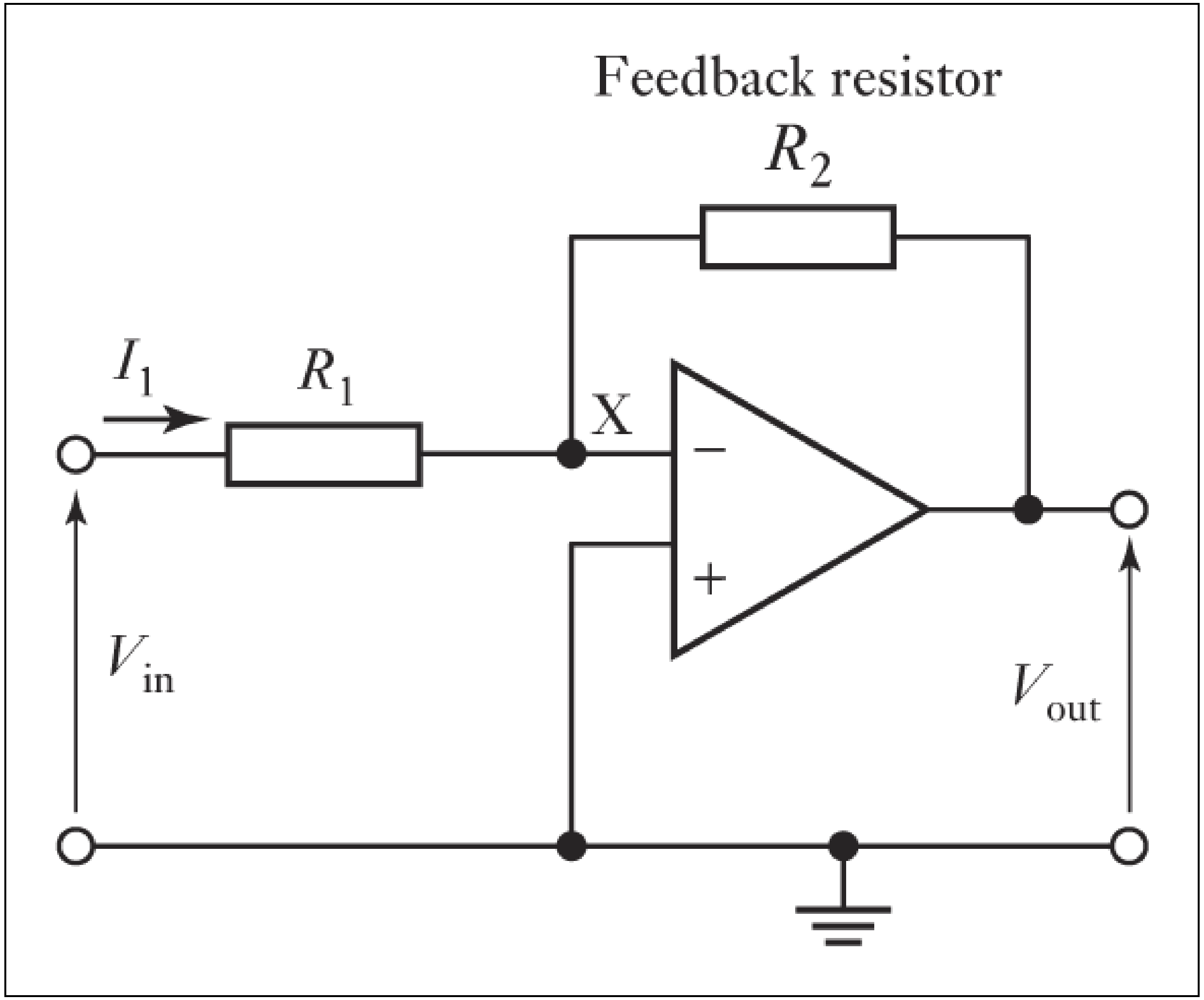



Figure 3.3 Inverting amplifier

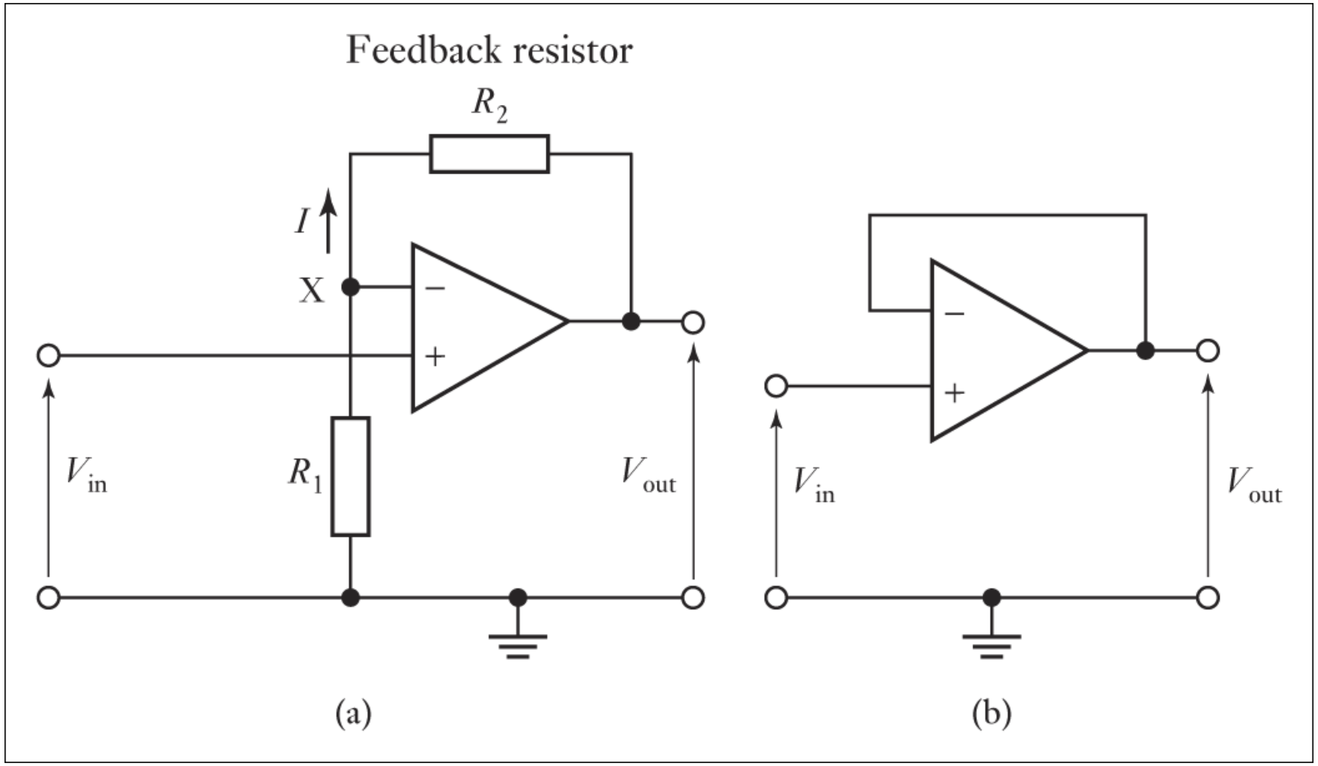
$$V_{in} = I_1 R_1$$

$$-V_{out} = I_1 R_2$$

*Voltage Gain*

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

## 3.2.2 Non-inverting amplifier




$$V_X = \frac{R_1}{R_1 + R_2} V_{out}$$

Figure 3.4 (a) Non-inverting amplifier, (b) voltage follower

$$Voltage\ \ gain = \frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

### 3.2.3 Summing amplifier

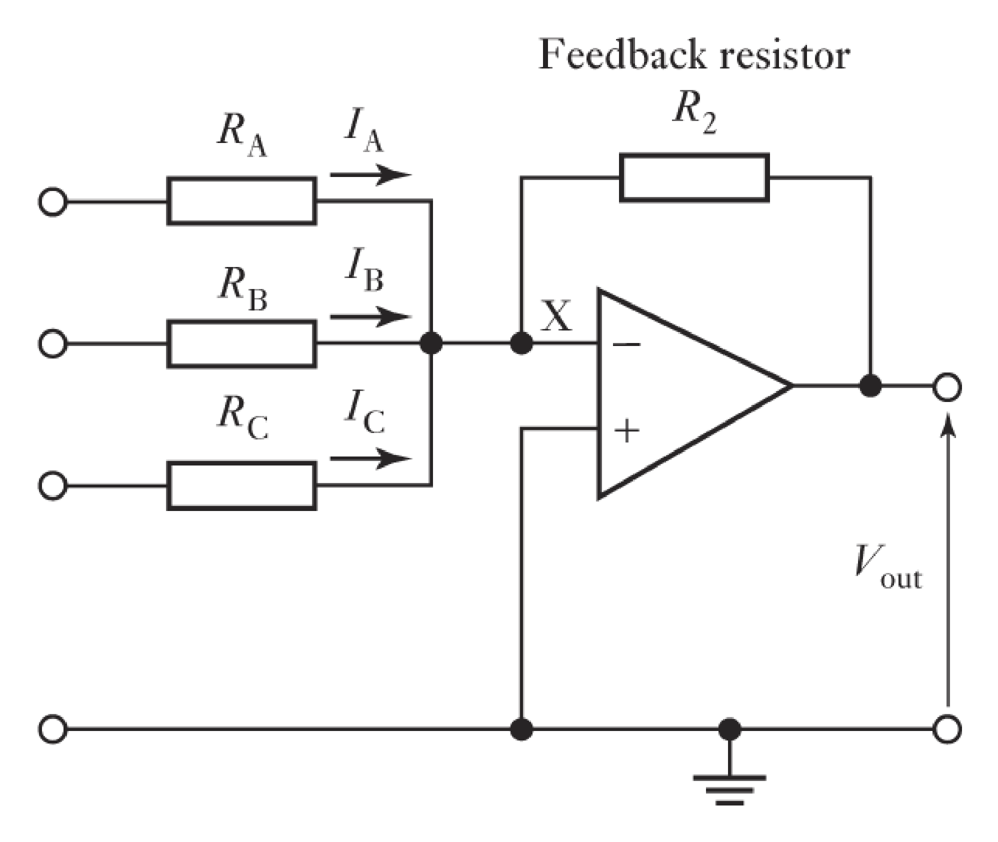



Figure 3.5 Summing amplifier

$$I = I_A + I_B + I_C$$

$$-\frac{V_{out}}{R_2} = \frac{V_A}{R_A} + \frac{V_B}{R_B} + \frac{V_C}{R_C}$$

$$V_{out} = -\left( \frac{R_2}{R_A} V_A + \frac{R_2}{R_B} V_B + \frac{R_2}{R_C} V_C \right)$$

If $R_A = R_B = R_C = R_1$

$$V_{out} = -\frac{R_2}{R_1}\left(V_A + V_B + V_C\right)$$

## 3.2.4 Integrating amplifier

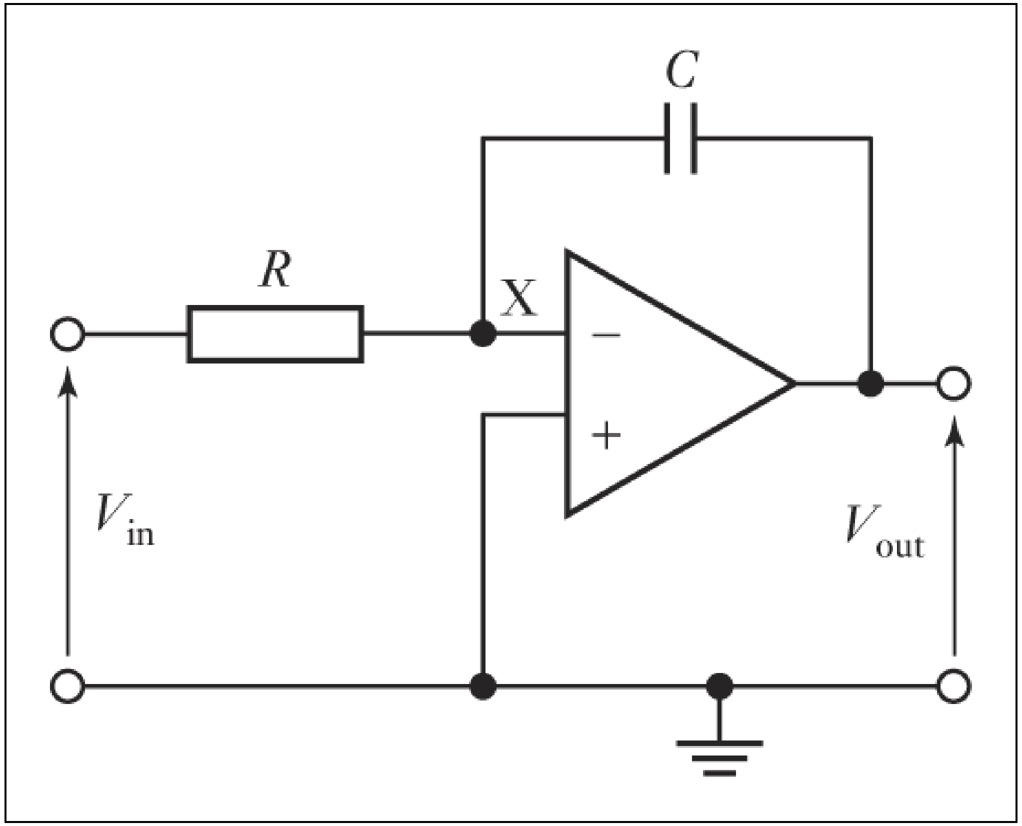



Figure 3.6 Integrating amplifier

$$q = Cv$$

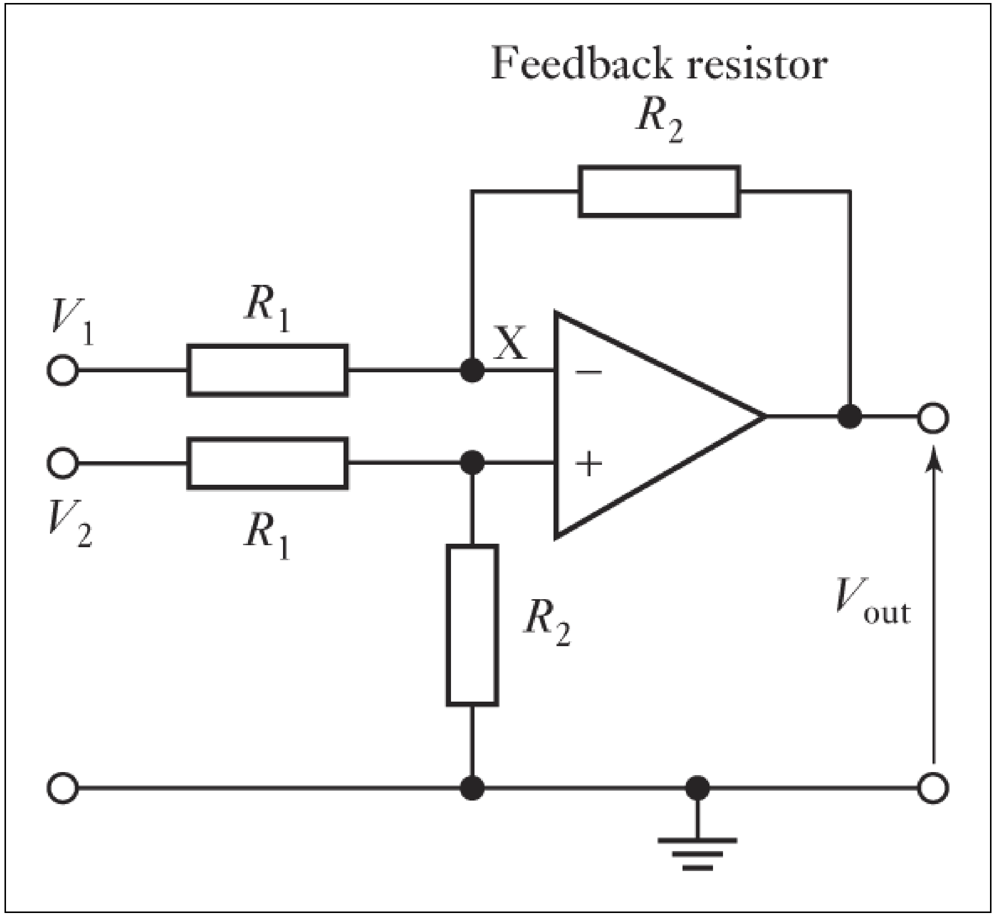
$$i = dq / dt = Cdv / dt$$

$$\frac{v_{in}}{R} = -C\frac{\mathrm{d}v_{out}}{\mathrm{d}t}$$

$$\mathrm{d}v_{out} = -\left(\frac{1}{RC}\right)v_{in}\mathrm{d}t$$

$$v_{out}(t_2) - v_{out}(t_1) = -\frac{1}{RC}\int_{t_1}^{t_2} v_{in}\mathrm{d}t$$

### 3.2.5 Difference amplifier




$$\frac{V_X}{V_2} = \frac{R_2}{R_1 + R_2}$$

$$\frac{V_1 - V_X}{R_1} = \frac{V_X - V_{out}}{R_2}$$

$$\frac{V_{out}}{R_2} = V_X\left(\frac{1}{R_2} + \frac{1}{R_1}\right) - \frac{V_1}{R_1}$$

$$V_{out} = \frac{R_2}{R_1}\left(V_2 - V_1\right)$$

Figure 3.7 Difference amplifier

## 3.2.5 Difference amplifier

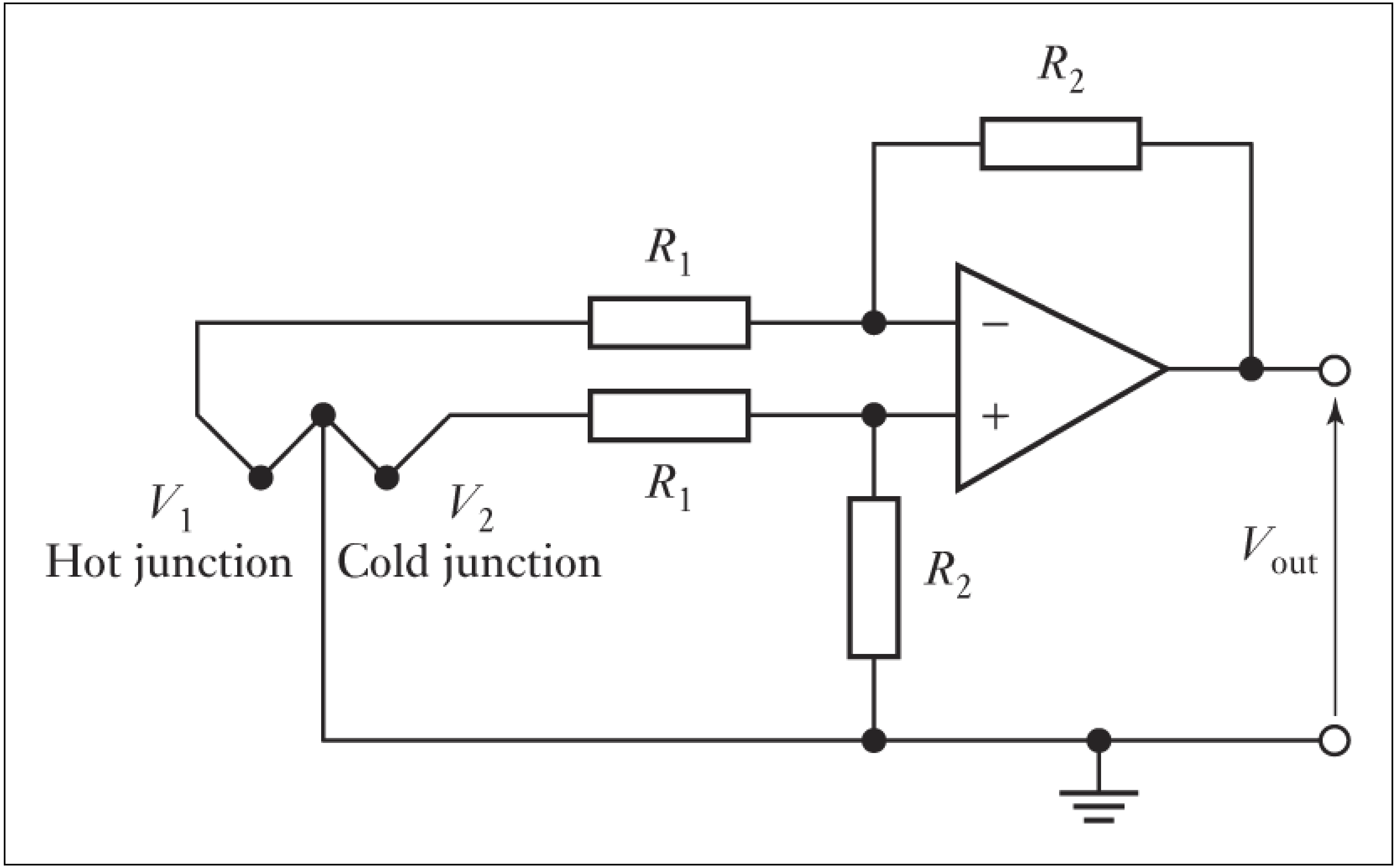



Figure 3.8 Difference amplifier with a thermocouple

### 3.2.5 Difference amplifier

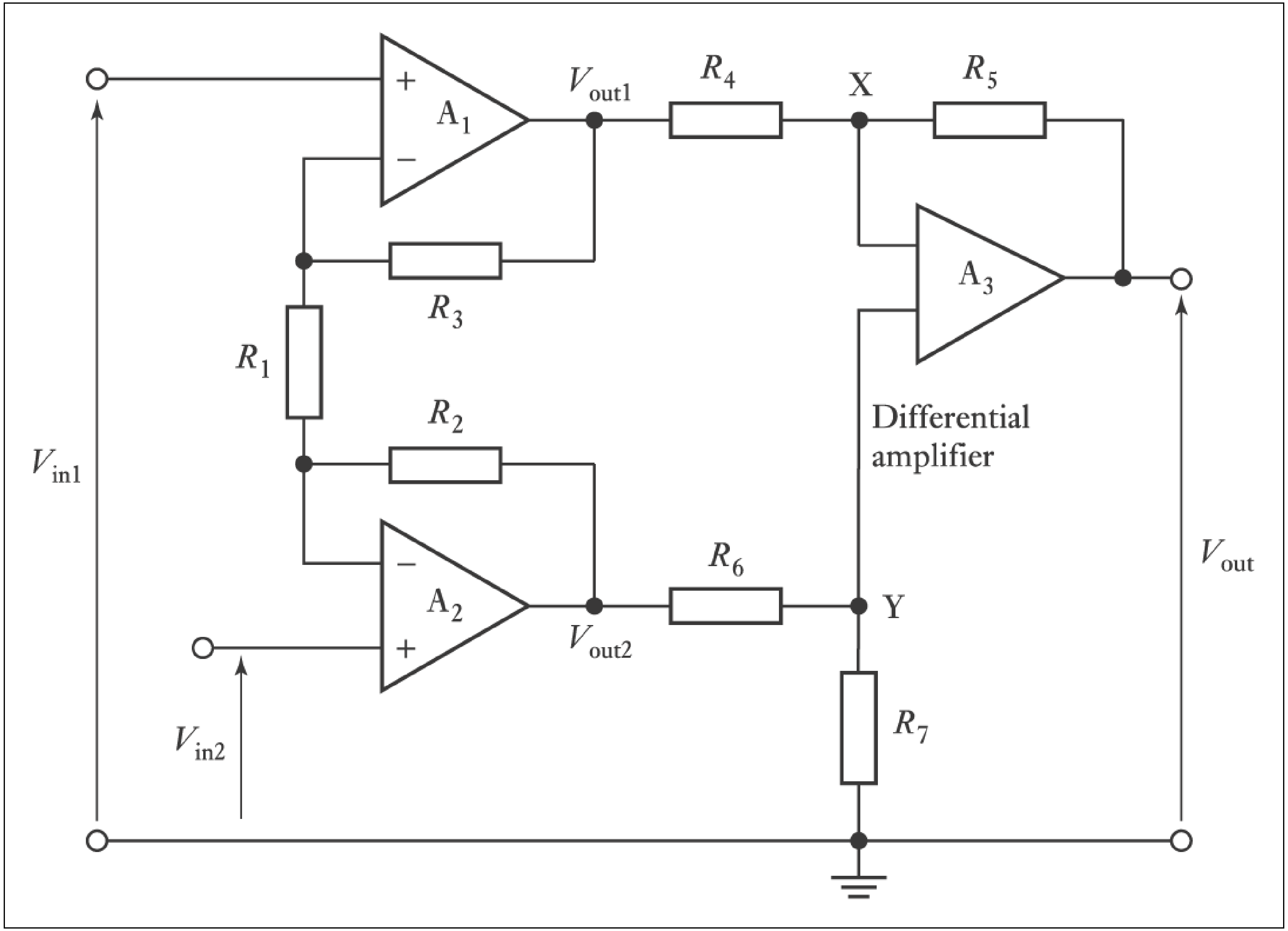
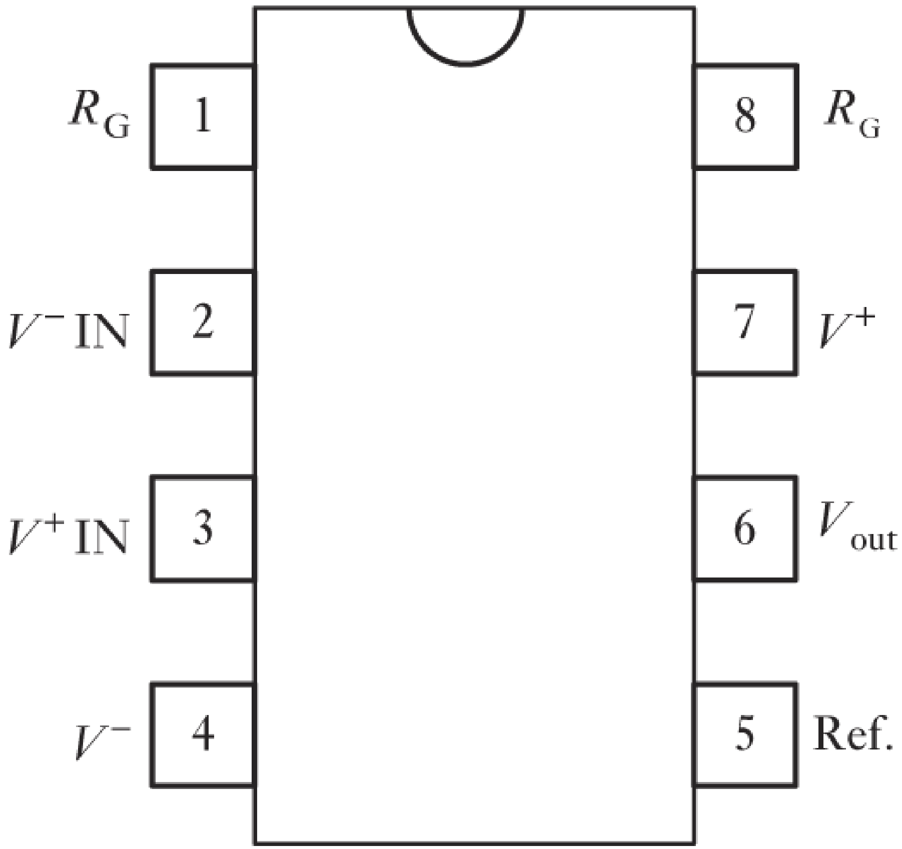



Figure 3.9 Instrumentation amplifier

### 3.2.5 Difference amplifier




Input impedance, differential common mode: $10^{10}$ Ω in parallel with 6 pF

Input common mode range: ±13.5 V

Common mode rejection, $G$ = 1:90 dB, $G$ = 1000:110 dB

Gain range 1 to 10,000

Gain error: 2% maximum

Output voltage: ±13.7 V ($V_s$ = ±15 V)

Figure 3.10 INA114

## 3.2.6 Logarithmic amplifier

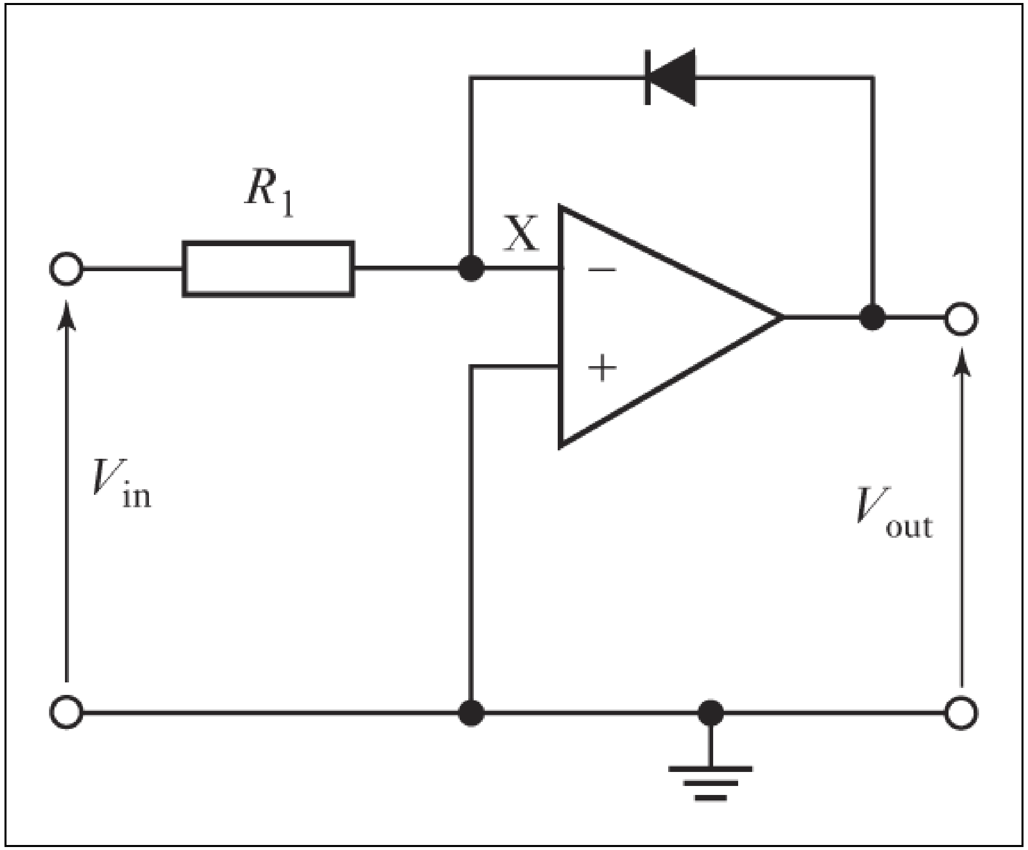



Figure 3.11 Logarithmic amplifier

Diode characteristic

$$V = C \ln I$$

$$V_{out} = -C \ln(V_{in} / R) = K \ln V_{in}$$

If $V_{in} = Ae^{at}$,

$$V_{out} = K \ln V_{in} = K \ln[Ae^{at}]$$
$$= K \ln A + Kat$$

### 3.2.7 Comparator

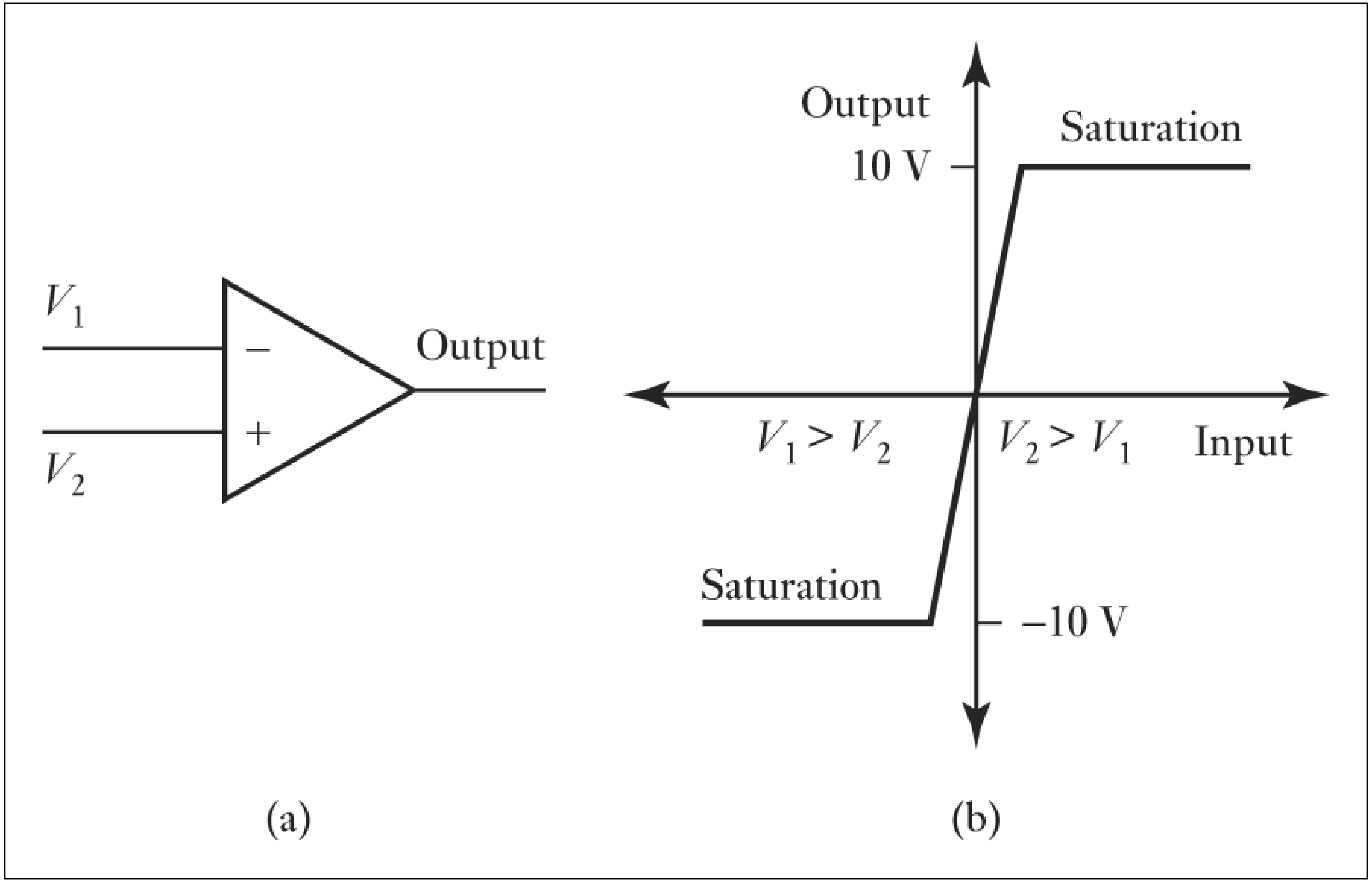



Figure 3.12 Comparator

## 3.2.7 Comparator

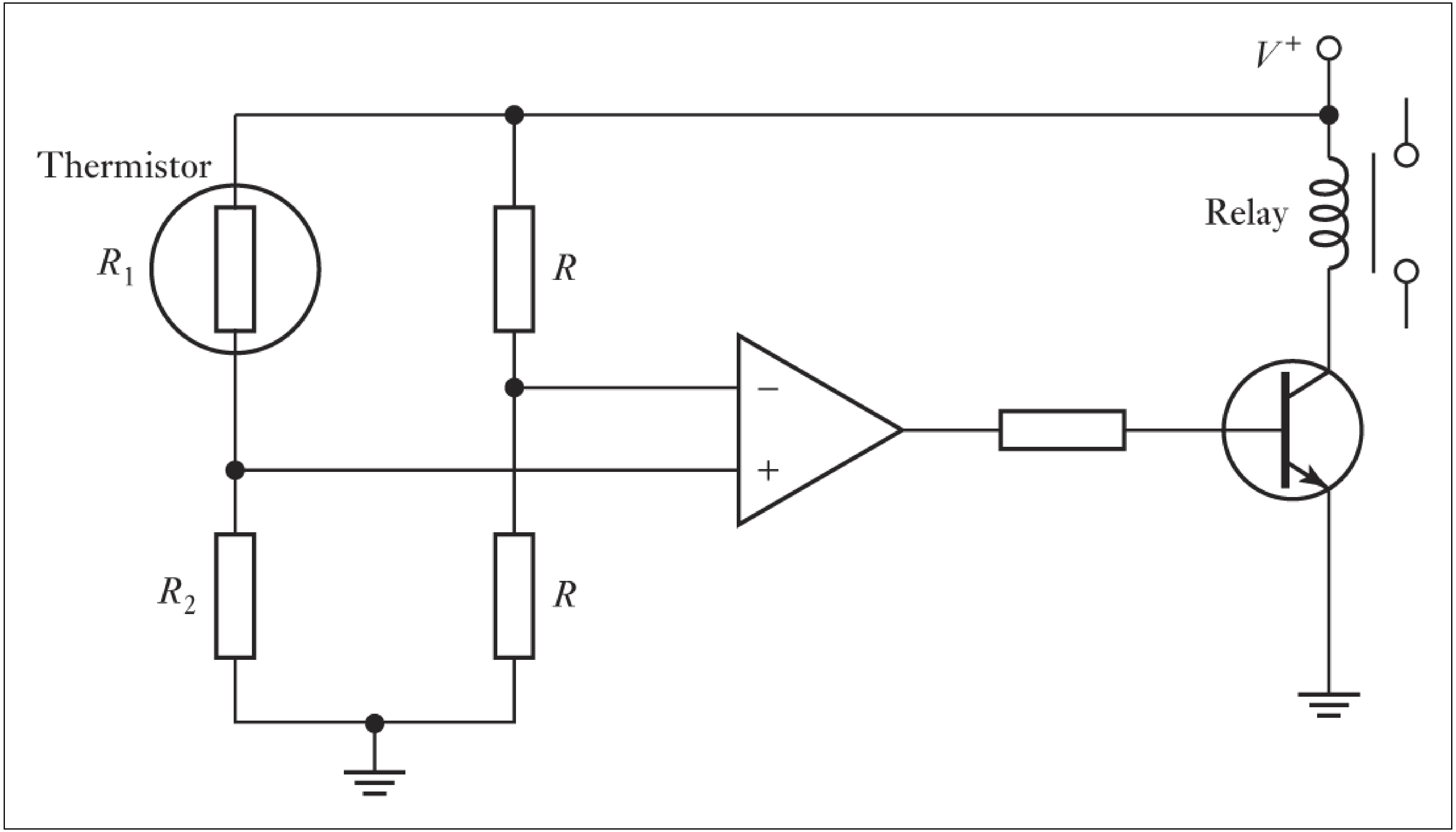



Figure 3.13 Temperature switch circuit

### 3.2.8 Amplifier errors

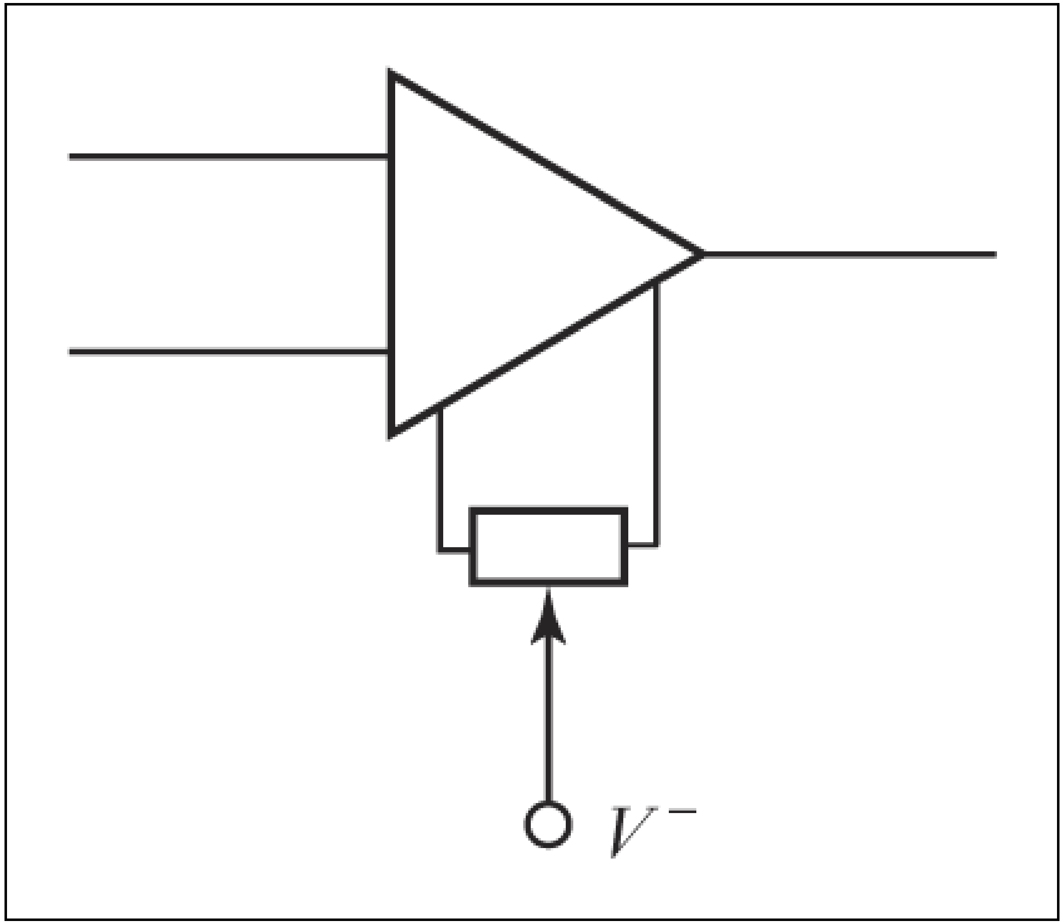



Figure 3.15 Correcting the offset voltage

## 3.3 Protection

- Limit

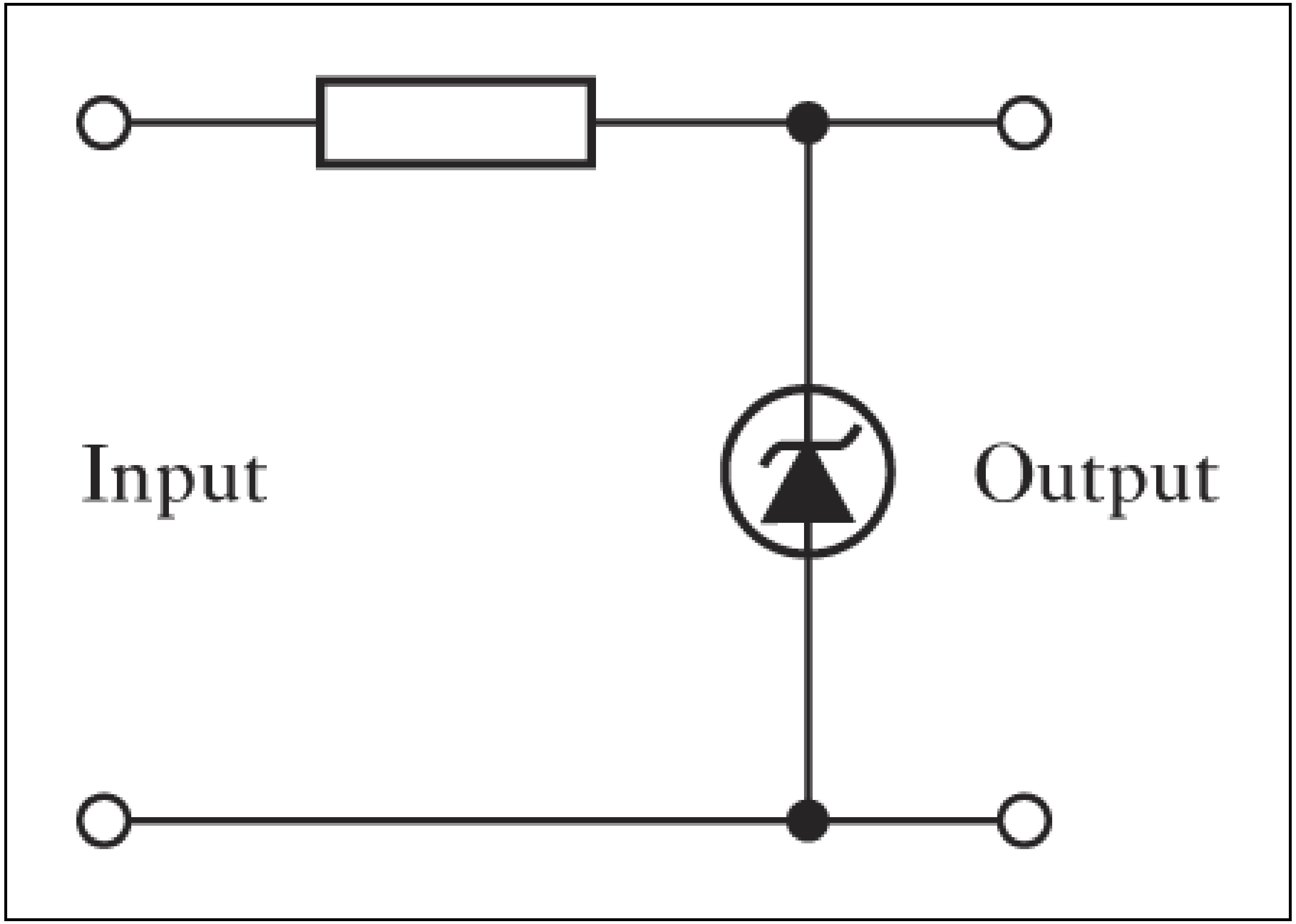



Figure 3.16 Zener diode protection circuit

## 3.3 Protection

- Isolation

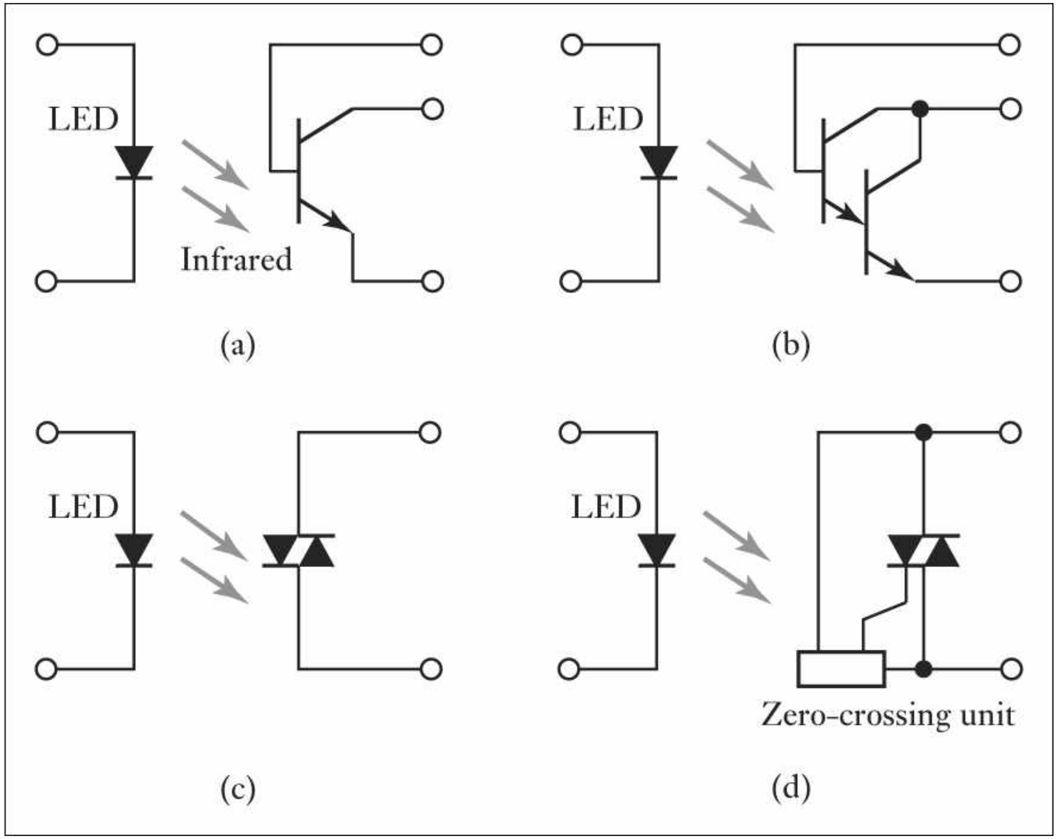



Figure 3.17 Optoisolators: (a) transistor, (b) Darlington, (c) triac, (d) triac with zero-crossing unit

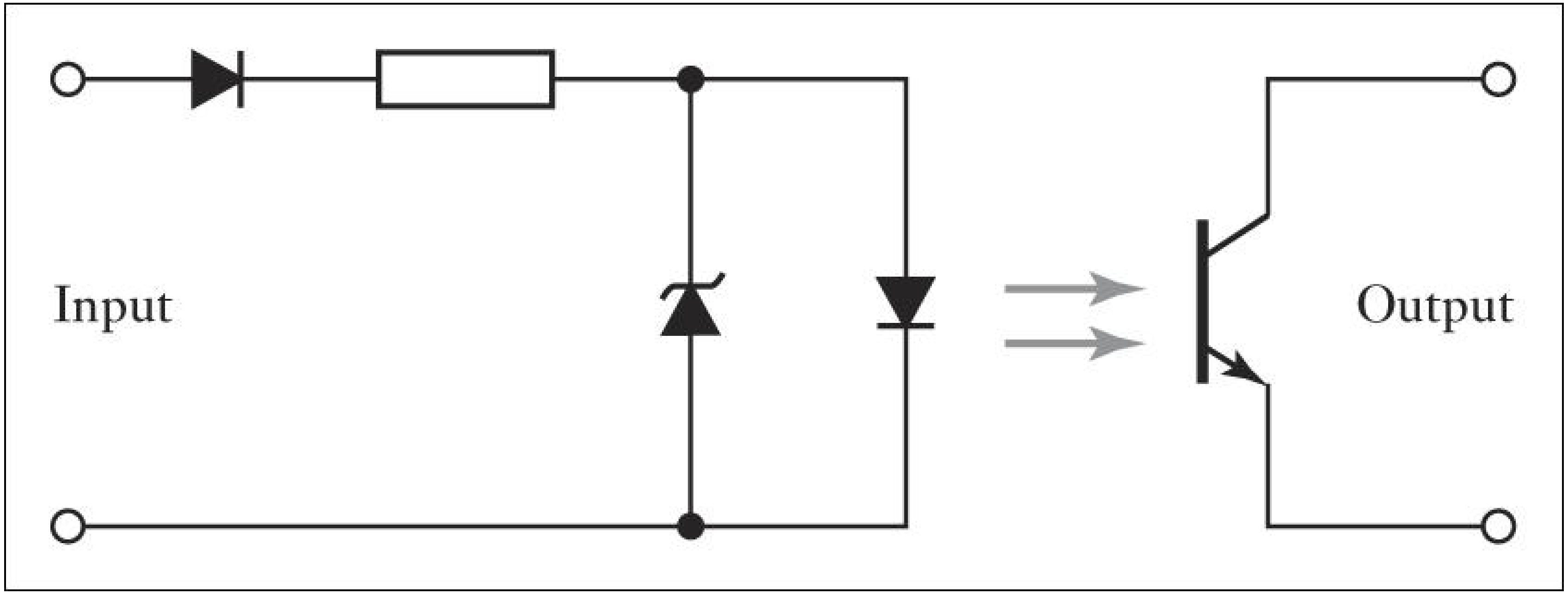



Figure 3.18 Protection circuit

## 3.4 Filtering

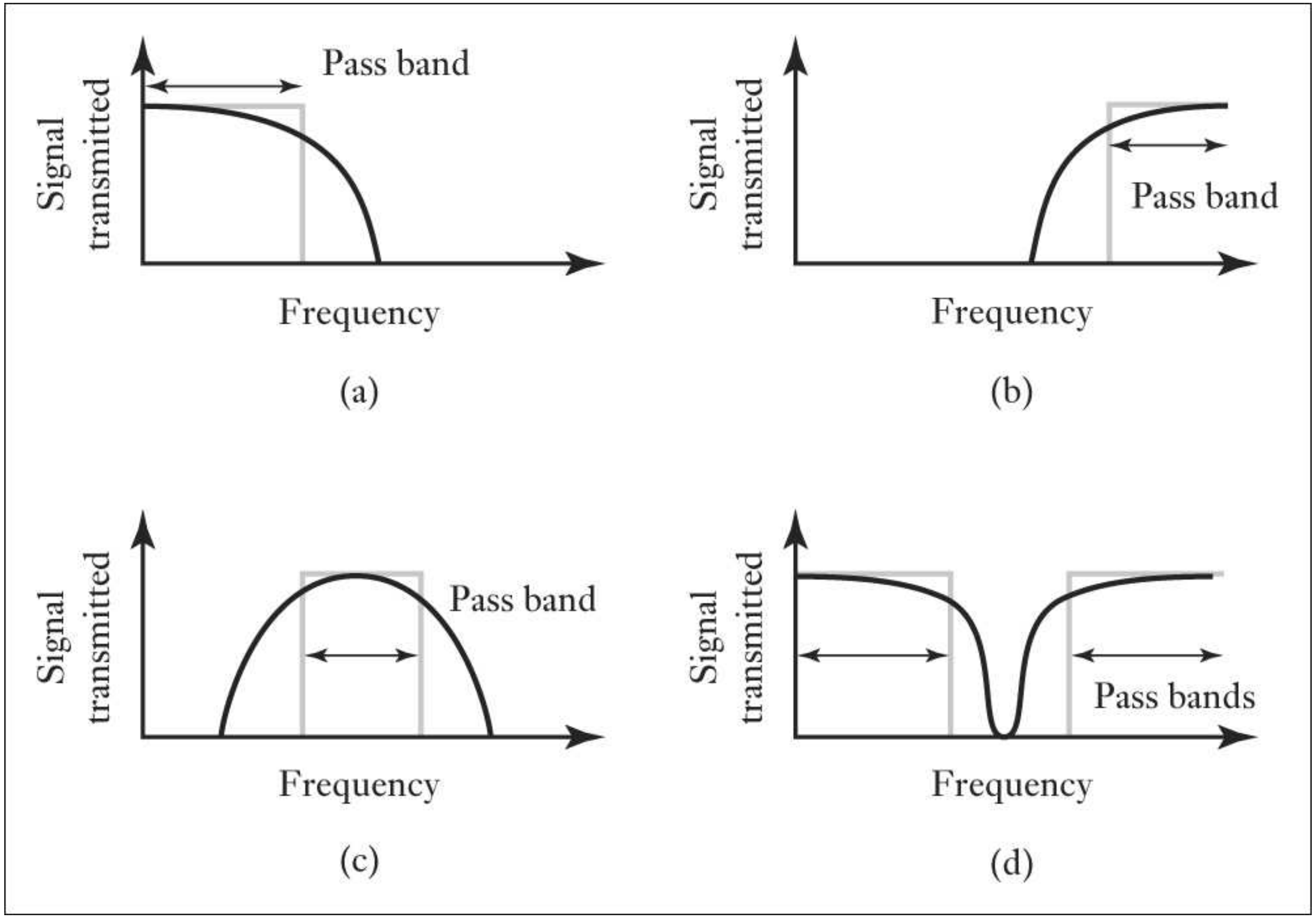



Figure 3.19 Characteristics of ideal filters: (a) low-pass filter, (b) high-pass filter, (c) band-pass filter, (d) band-stop filter

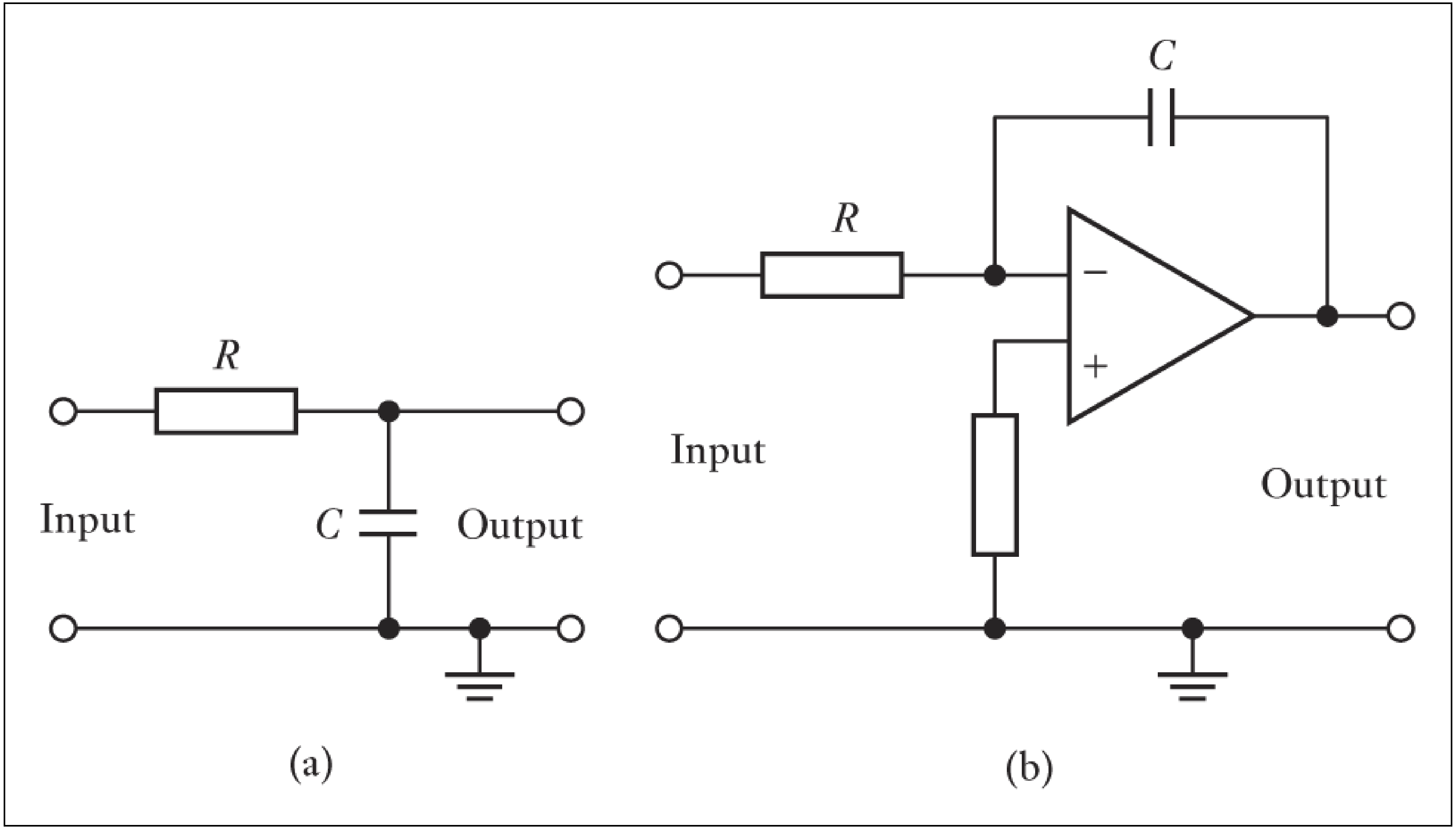



Figure 3.20 Low-pass filter: (a) passive, (b) active using an operational amplifier

## 3.5 Wheatstone bridge

- Balanced $$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

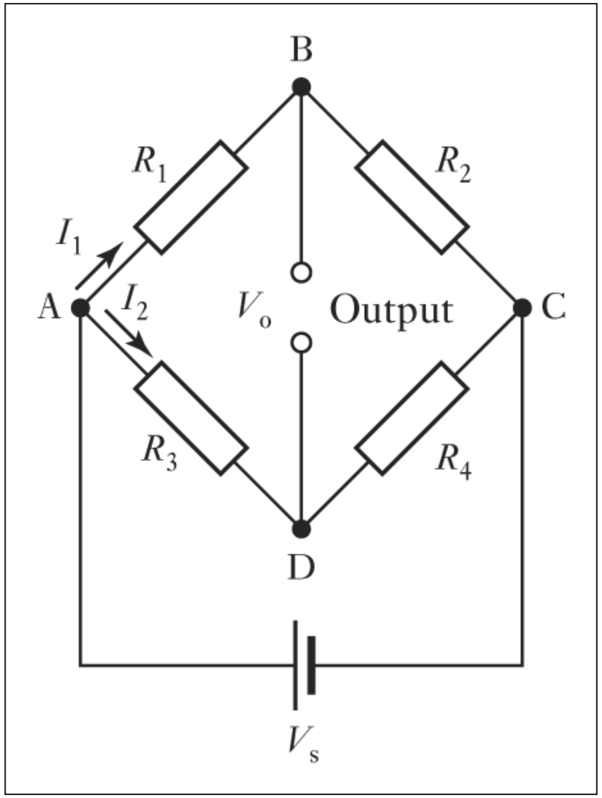



Figure 3.21 Wheatstone bridge

- Output

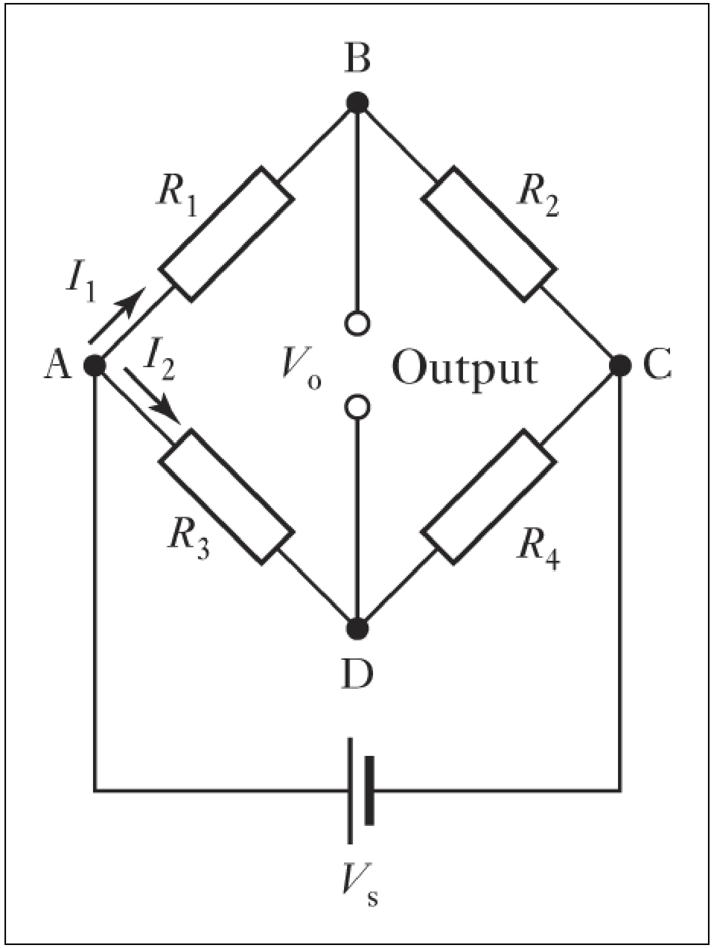
$$V_{AB} = \frac{V_S R_1}{R_1 + R_2}$$

$$V_{AD} = \frac{V_S R_3}{R_3 + R_4}$$

$$V_o = V_{AB} - V_{AD} = V_s \left( \frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4} \right)$$

- Output

$$V_o = V_{AB} - V_{AD} = V_s\left(\frac{R_1}{R_1+R_2} - \frac{R_3}{R_3+R_4}\right)$$




$$V_o + \delta V_o = V_s\left(\frac{R_1+\delta R_1}{R_1+\delta R_1+R_2} - \frac{R_3}{R_3+R_4}\right)$$

$$\left(V_o + \delta V_o\right) - V_o = V_s\left(\frac{R_1+\delta R_1}{R_1+\delta R_1+R_2} - \frac{R_1}{R_1+R_2}\right)$$

$$\delta V_o \approx V_s\left(\frac{\delta R_1}{R_1+R_2}\right)$$

Figure 3.21 Wheatstone bridge

## 3.5.1 Temperature compensation

- 3 lead compensation

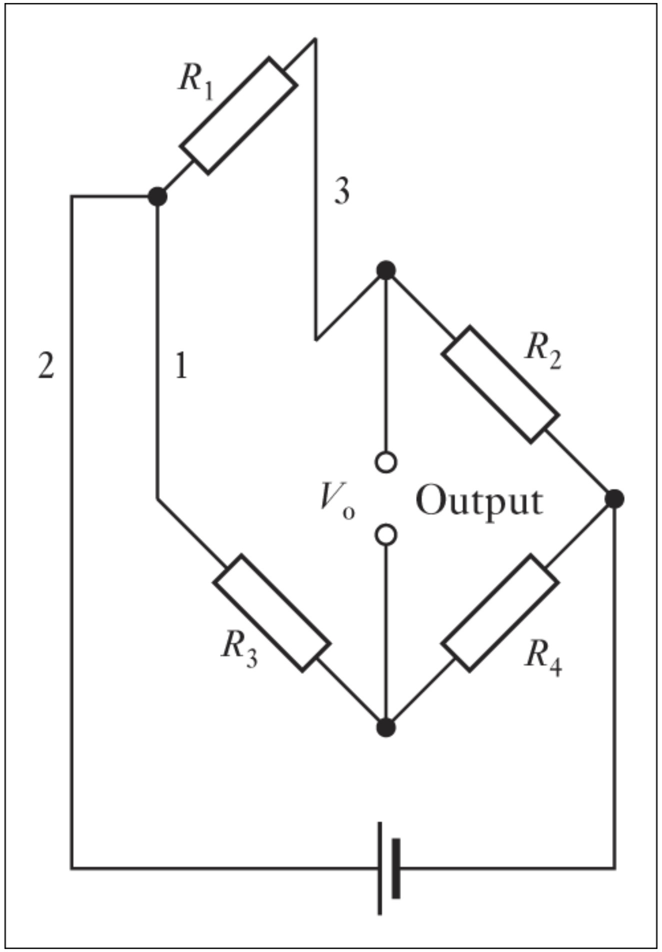



Figure 3.22 Compensation for leads

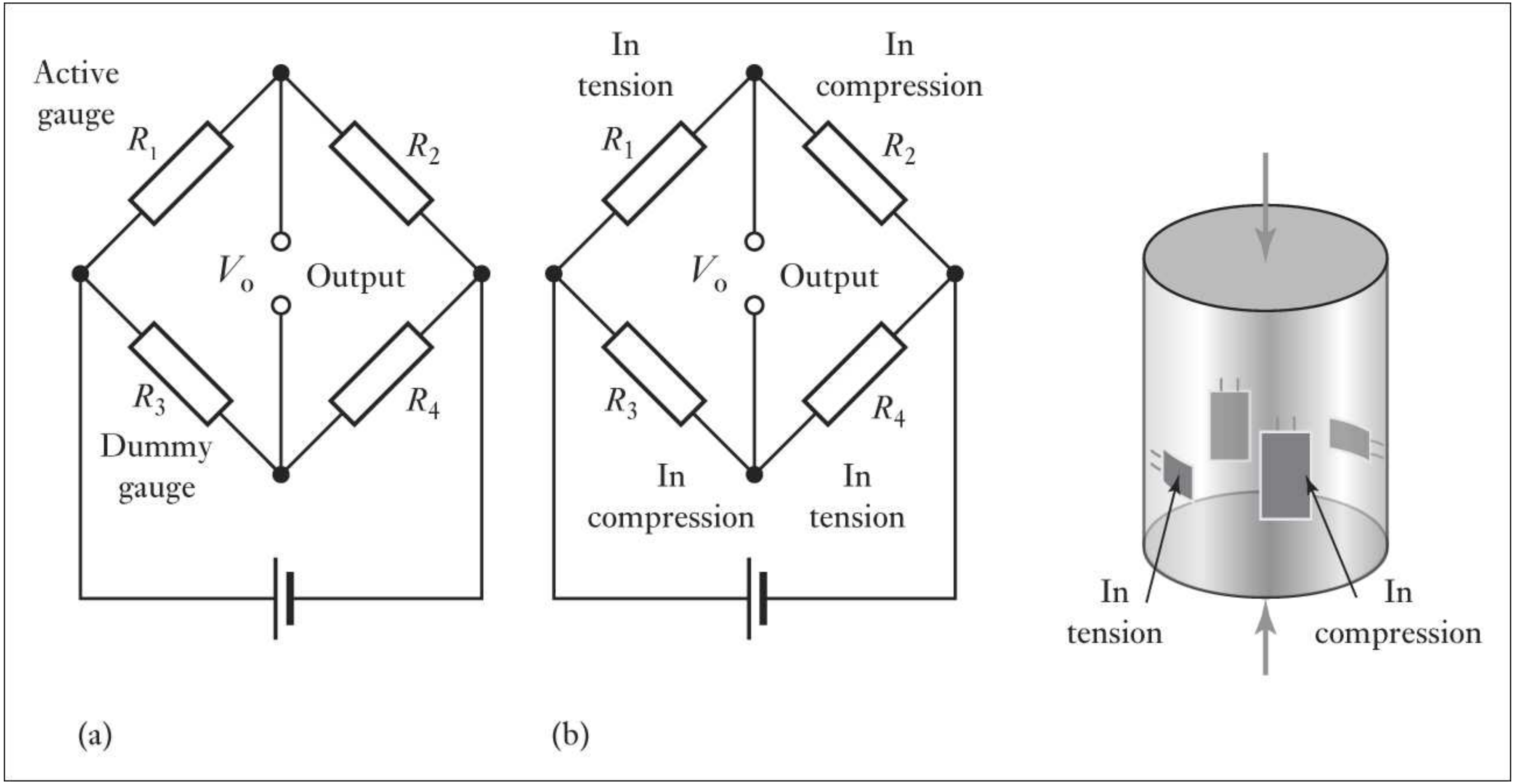



Figure 3.23 Compensation with strain gauges: (a) use of dummy gauge, (b) four active arm bridge

## 3.6 Pulse modulation

- A problem that is often encountered with dealing with the transmission of low-level D.C. signals from sensors is that the gain of an operational amplifier used to amplify them may drift and so the output drifts.

- This problem can be overcome if the signal is a sequence of pulses rather than a continuous-time signal.

## 3.6 Pulse modulation

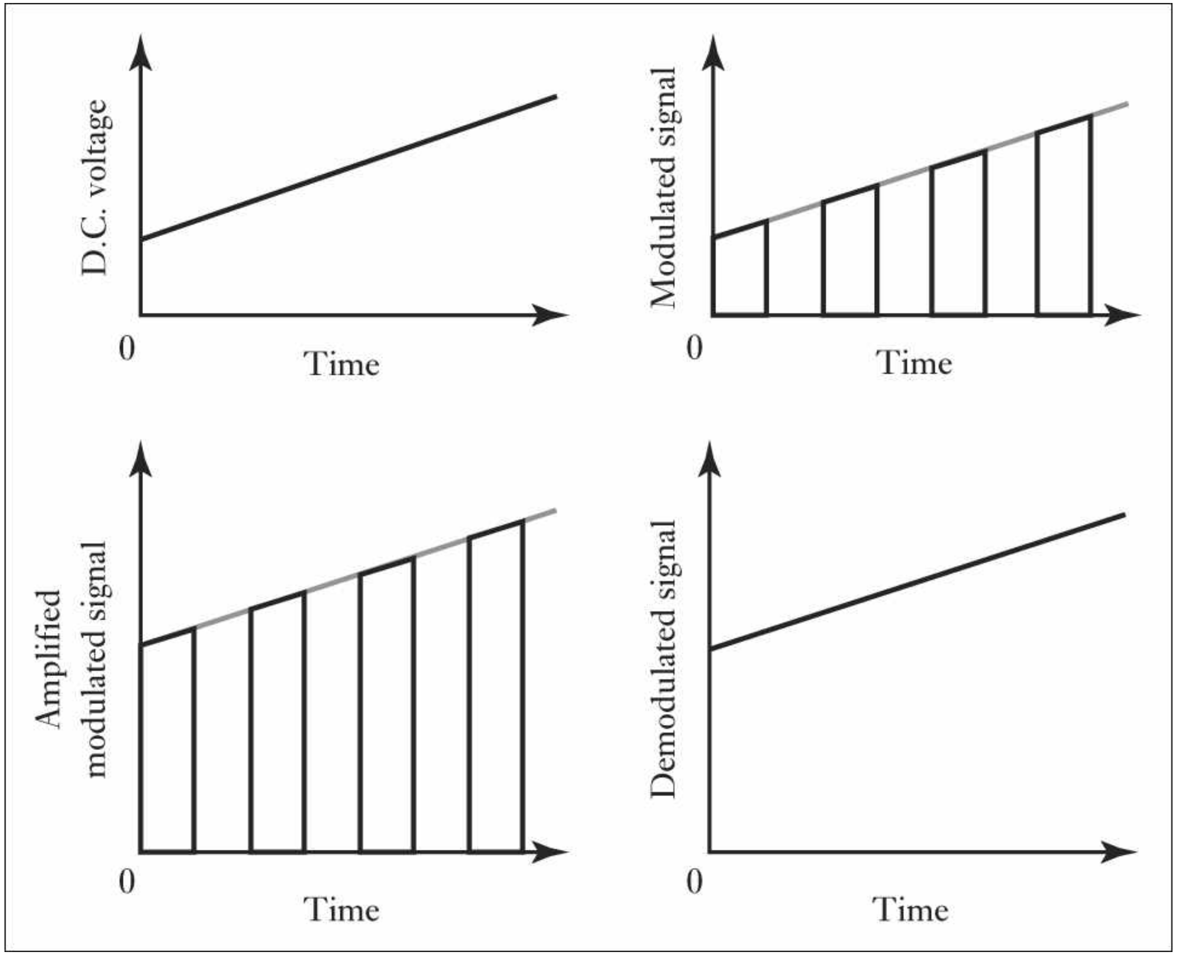



Figure 3.24 Pulse amplitude modulation

## 3.6 Pulse modulation

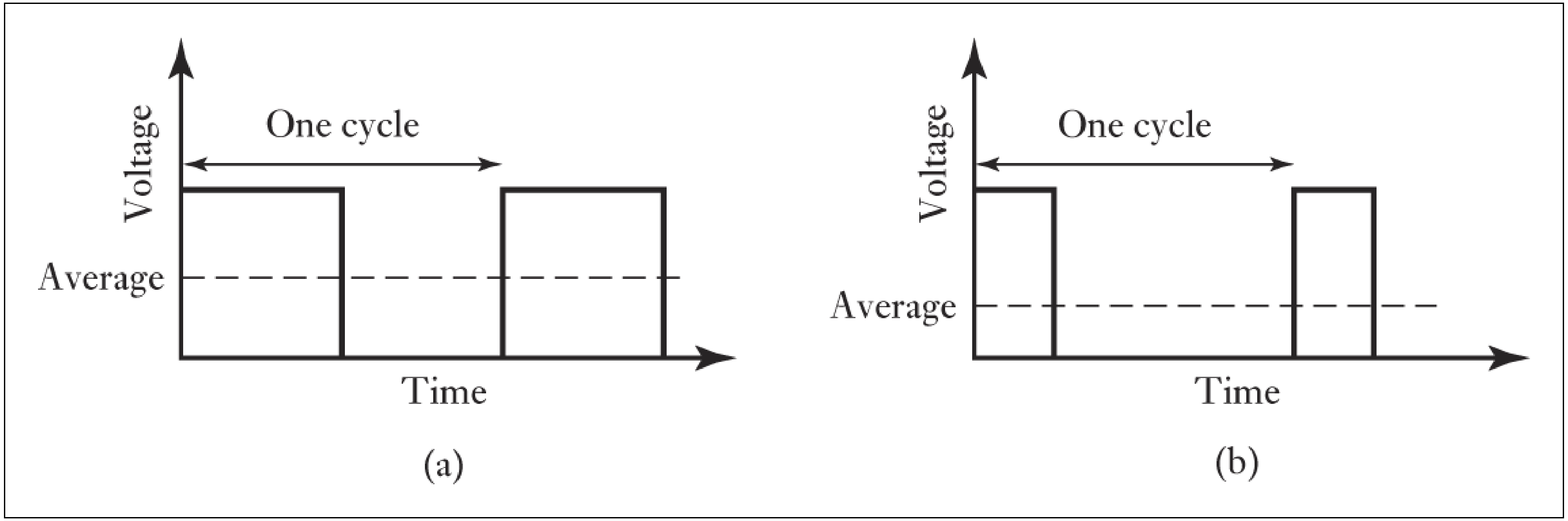



Figure 3.25 PWM for voltage control: (a) duty cycle 50%, (b) duty cycle 25%