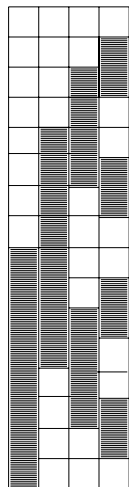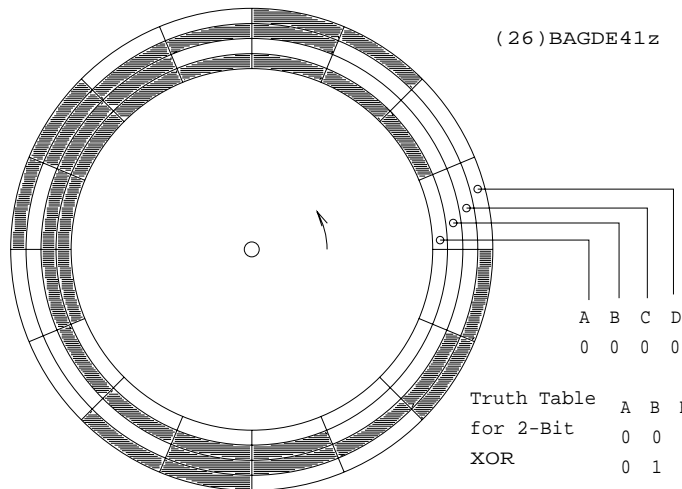4-Bit Absolute Gray Coded Angular Displacement Encoder
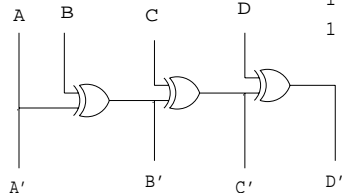
ABCD
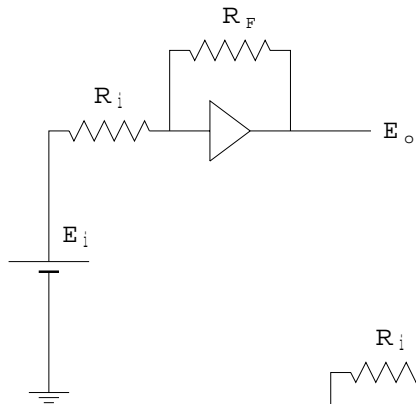

Linear

Displacement

(26)BAGDE41z

A B C D
0 0 0 0

Truth Table
for 2-Bit
XOR

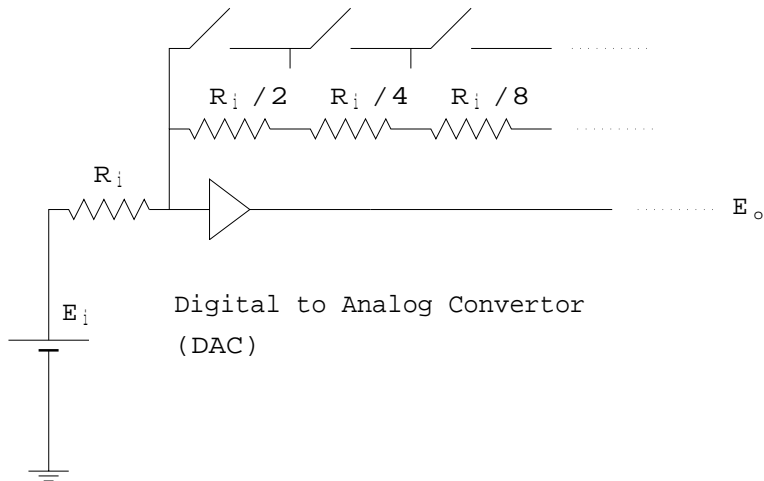| A	B	B'
0	0	0
0	1	1
1	0	1
1	1	0

Logic Circuit to
Decode Gray to
Straight 4-Bit
Binary

A   B   C   D

A'   B'   C'   D'

Basic Operational Amplifier

$$E_o = E_i R_F / R_i$$

Digital to Analog Convertor (DAC)

(26)ADAC42b

+

Basic Operational Amplifier

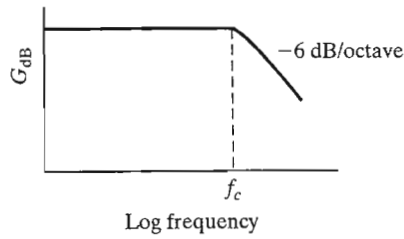$$E_o = E_i R_F / R_i$$

R_F

R_i

E_o

E_i

$R_i/2 \quad R_i/4 \quad R_i/8$

R_i

E_o

E_i

Digital to Analog Convertor
(DAC)

E_{REF}

COMPARATORS
"1" OR "0" FOR $V_{IN} > \frac{1}{2} E_{REF}$

$3R$ $\frac{13}{16}$

7
"0"

$2R$ $\frac{11}{16}$

6
"0"

QUANTUM-TO-GRAY-CODE CONVERSION

LEVEL	0	1	2	3	4	5	6	7
MSB	0	0	0	0	1	1	1	1
BIT 2	0	0	1	1	1	1	0	0
BIT 3	0	1	1	0	0	1	1	0

$2R$ $\frac{9}{16}$

5
"1"

$2R$ $\frac{7}{16}$

4
"1"

MSB

$2R$ $\frac{5}{16}$

3
"0"

BIT 2

$2R$ $\frac{3}{16}$

2
"1"

$2R$ $\frac{1}{16}$

1
"1"

BIT 3

R

V_{IN}
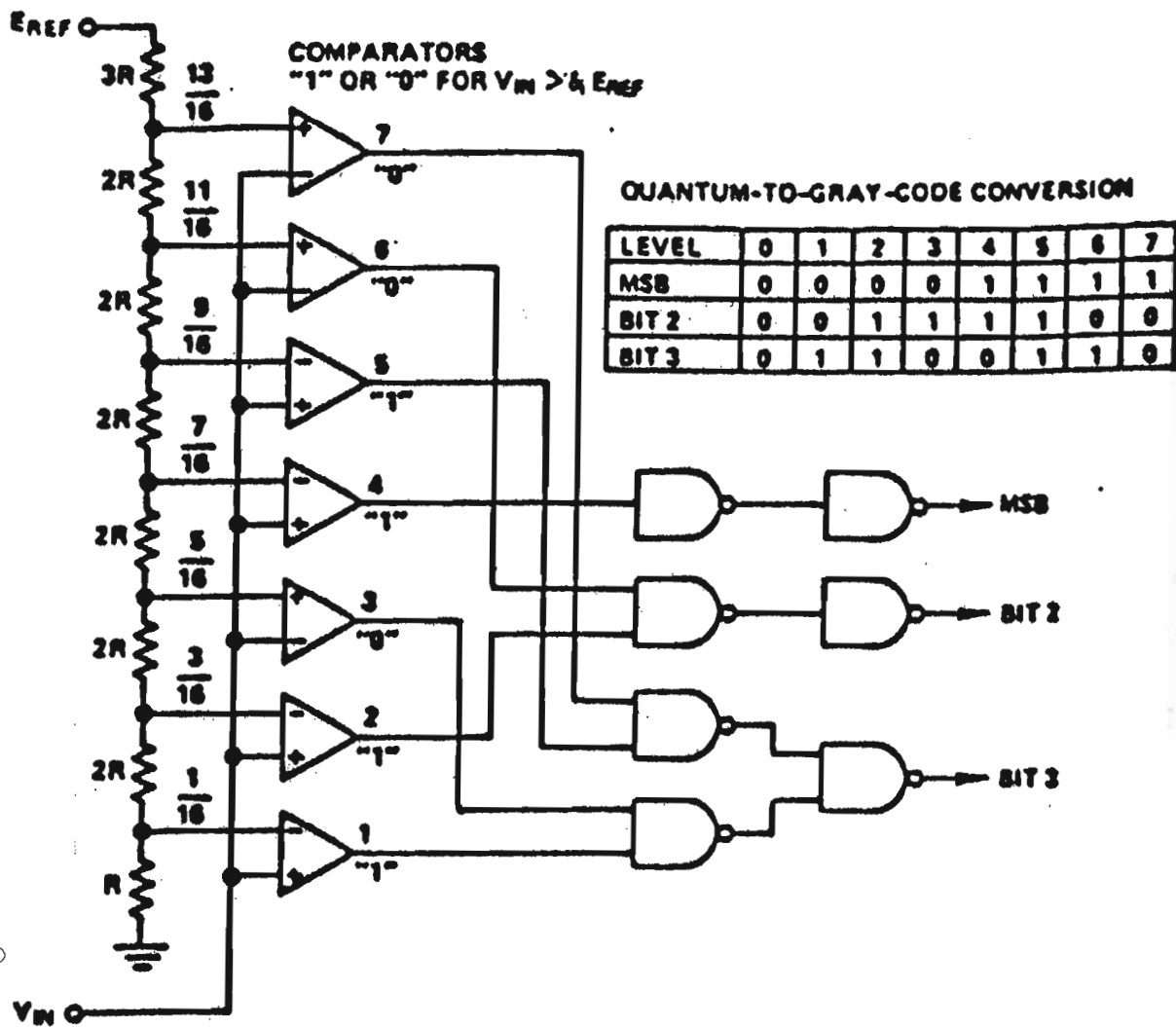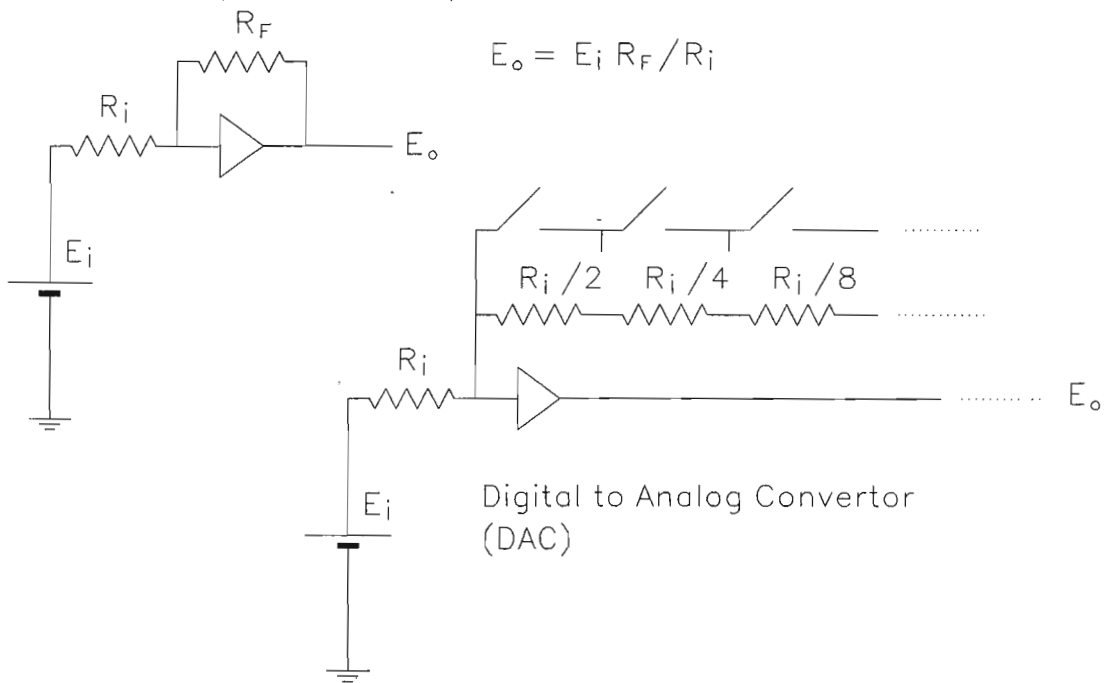
(26)ADAC42b

FIGURE 3.12

Frequency response of op-amp amplifier.

3.15

$$f_c = \frac{GPB}{G}$$

$$\phi = -\tan^{-1}\frac{f}{f_c}$$

3.16

$$GBP_{inv} = \frac{R_2}{R_1 + R_2}\,GBP_{noninv}$$

$$(3.18)$$

$$G = \left(1 + 2\frac{R_2}{R_G}\right)\left(\frac{R_2}{R_3}\right)$$
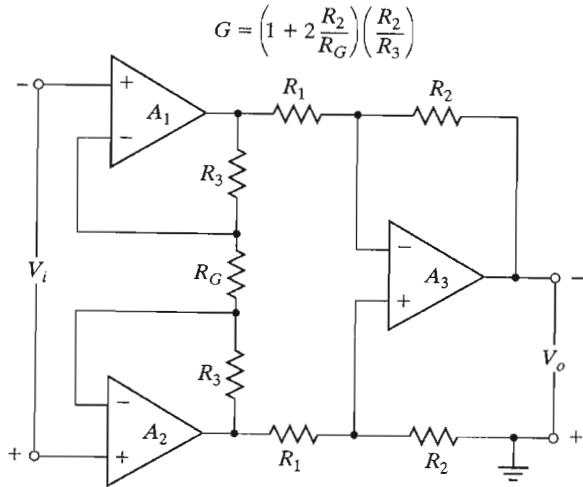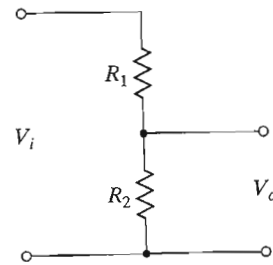
FIGURE 3.14

True differential input instrument amplifier.
(From Franco, 2002.)

$$V_o = V_i\frac{R_2}{R_1 + R_2}$$

$$(3.19)$$

FIGURE 3.15

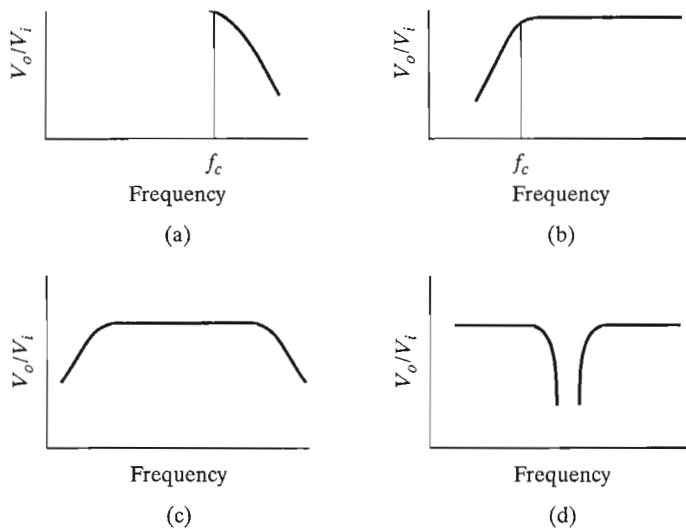Attenuation using dividing network.

$$G = \frac{1}{\sqrt{1 + (f/f_c)^{2n}}}$$

FIGURE 3.16

Categories of electrical filters: (a) lowpass; (b) highpass; (c) bandpass;
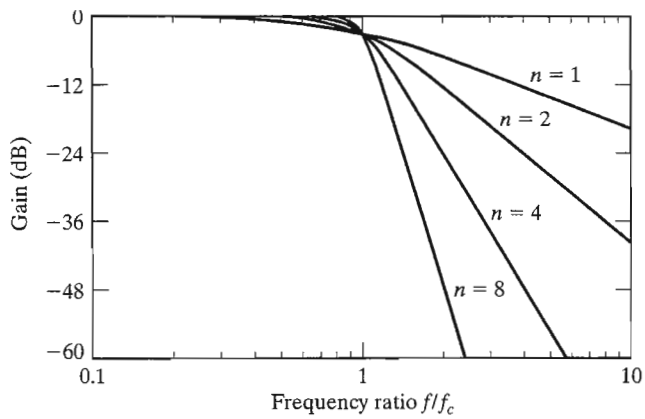(d) bandstop.

FIGURE 3.17

Gain of lowpass Butterworth filters as a function of order and frequency.
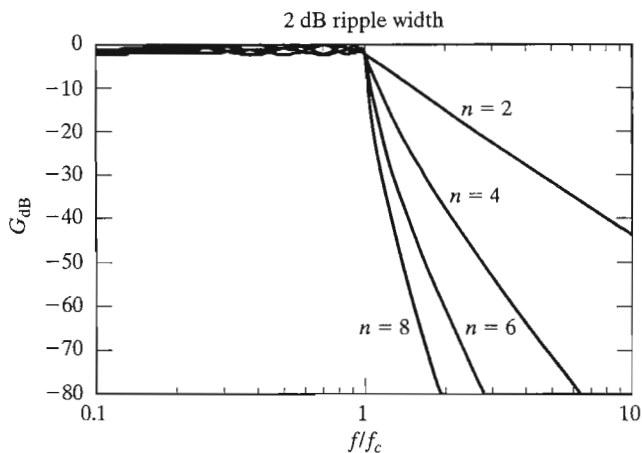

FIGURE 3.18

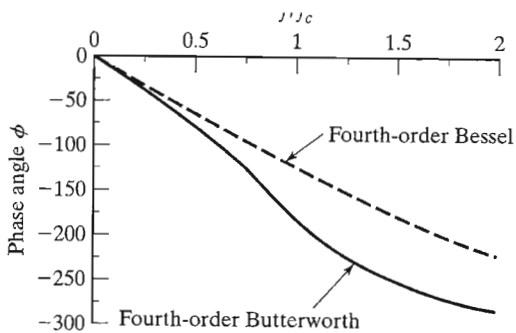Gain of lowpass Chebyshev filters as a function of order and frequency.

FIGURE 3.19

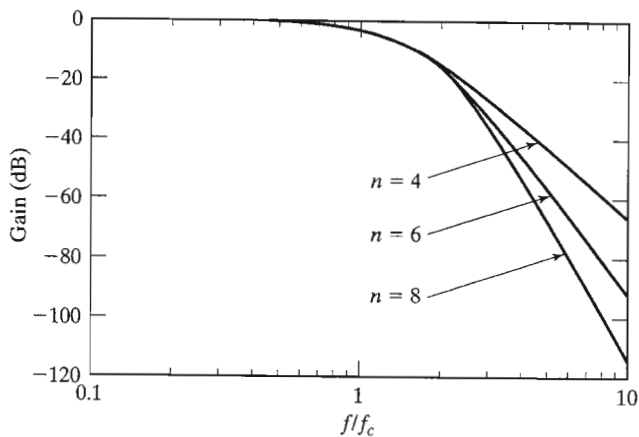Comparison of Butterworth and Bessel phase-angle variation with frequency.

FIGURE 3.20

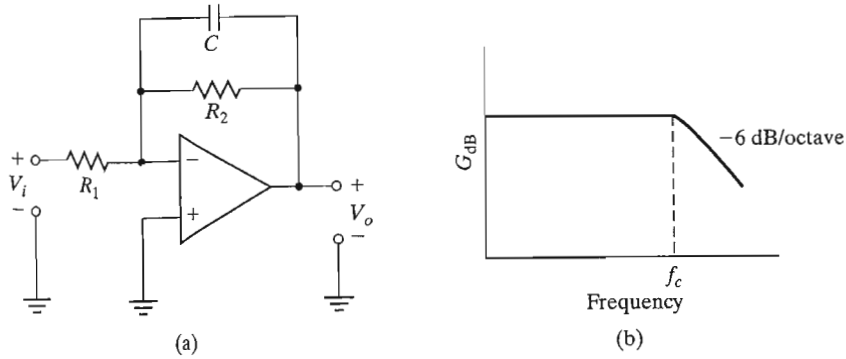Gain of lowpass Bessel filters as a function of order and frequency.

FIGURE 3.21

Lowpass Butterworth filter using op-amp: (a) op-amp circuit; (b) frequency response.

To determine the frequency response, we will use ac circuit analysis to examine the behavior of the circuit when a single-frequency sinusoidal signal is input. This input signal takes the form $V_{mi}\,e^{j2\pi ft}$, where V_{mi} is the sine-wave amplitude and f is the frequency. In deriving Eq. (3.17), the expression for the gain on an inverting amplifier, we used resistances R_1 and R_2 in the feedback loop. If instead we had used complex impedances Z_1 and Z_2, the resulting equation for gain G would have been

$$G = -\frac{Z_2}{Z_1} \tag{3.21}$$

We can apply this equation to the filter in Figure 3.21(a). Z_2 consists of C and R_2 in parallel. Since the impedance of a capacitor is $1/j2\pi fC$, the value of Z_2 is found to be

$$Z_2 = \frac{1}{\left(\dfrac{1}{R_2}\right) + j2\pi fC} = \frac{R_2}{1 + j2\pi fCR_2} \tag{3.22}$$

Z_1 is simply R_1, so the expression for G, Eq. (3.21), becomes

$$G = -\frac{1}{R_1}\frac{R_2}{1 + j2\pi fCR_2} = G_o\frac{1}{1 + j2\pi fCR_2} = \frac{V_o}{V_i} \tag{3.23}$$

where G_o, the low-frequency gain $(-R_2/R_1)$, is the same as that of the simple inverting amplifier (without the presence of capacitor C). It should be noted that the gain G is represented by a complex number.

If we take the absolute value of the terms in Eq. (3.23), we obtain the following expression:

$$\left|\frac{G}{G_o}\right| = \left|\frac{1}{1 + j2\pi fCR_2}\right| = \frac{1}{\sqrt{1 + (2\pi fCR_2)^2}} \tag{3.24}$$

The corner frequency, f_c, for a Butterworth filter is defined as the frequency where the magnitude of the gain is reduced 3 dB from its low-frequency value, G_o. Equation (3.2) shows that 3 dB corresponds to a reduction in gain, G, by a fraction equal to 0.707. Substituting the value $G = 0.707G_o$ into Eq. (3.24) gives

$$\left|\frac{0.707G_o}{G_o}\right| = 0.707 = \frac{1}{\sqrt{1 + (2\pi fCR_2)^2}} \tag{3.25}$$

This can be solved for the corner frequency f_c:

$$f_c = \frac{1}{2\pi CR_2} \tag{3.26}$$

It should be noted that the corner frequency for a lowpass filter computed by Eq. (3.26) cannot be any higher than the cutoff frequency for the inverting amplifier itself.

Equation (3.24) can be used to determine the roll-off rate as frequency becomes high relative to the corner frequency. At high frequencies, $2\pi fCR_2$ is large compared to 1, and Eq. (3.25) reduces to

$$\left|\frac{G}{G_o}\right| = \frac{1}{2\pi fCR_2} \tag{3.27}$$

This shows that if the frequency is doubled (a change of 1 octave), the gain will be reduced by a factor of 1/2. Based on Eq. (3.2), a reduction in gain G by 1/2 corresponds to -6 dB. Thus the roll-off is 6 dB per octave.

Equations (3.23) and (3.26) can be combined to give an expression for gain in terms of f_c:

$$G = \frac{V_o}{V_i} = G_o \frac{1}{1 + j(f/f_c)} \tag{3.28}$$

Equation (3.28) can be used to evaluate the phase angle of V_o relative to V_i. The phase of V_o relative to V_i is then the phase of $1/[1 + j(f/f_c)]$:

$$\phi = \tan^{-1}\frac{-f}{f_c} = -\tan^{-1}\frac{f}{f_c} \tag{3.29}$$

While Eq. (3.16) has the same form as Eq. (3.29), Eq. (3.16) results from characteristics of the op-amp itself, whereas Eq. (3.29) is a consequence of the capacitor in the feedback loop.
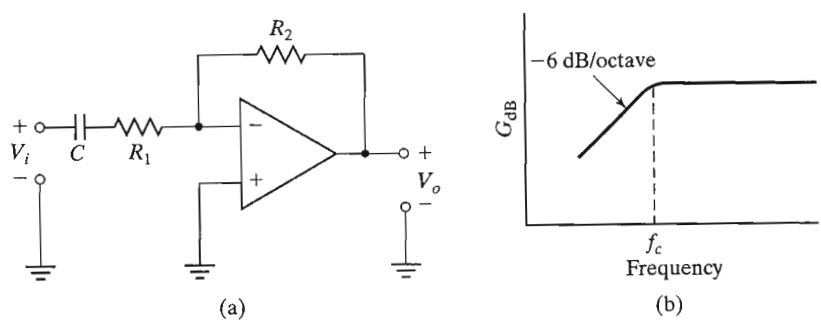
FIGURE 3.22

First-order Butterworth highpass filter using an op-amp: (a) op-amp circuit;
(b) frequency response.

Figure 3.22 shows an op-amp circuit and frequency response for a first-order
high-pass Butterworth filter. The formula for the cutoff frequency, which can be de-
rived in a manner similar to that for the low-pass filter, is given by

$$f_c = \frac{1}{2\pi R_1 C} \tag{3.30}$$

It should also be noted that highpass filters using op-amps are in fact bandpass filters
since the filter amplifier also has a high-frequency cutoff.

Figure 3.23 shows an op-amp circuit and frequency response for a first-order But-
terworth bandpass filter. The upper and lower cutoff frequencies for the bandpass filter
are given by

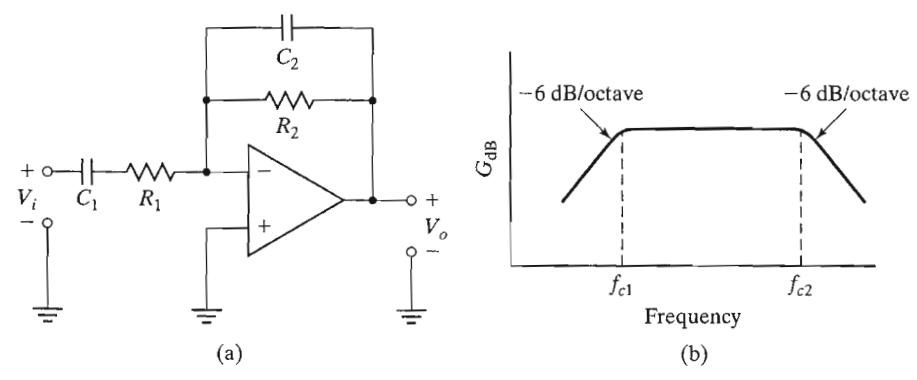$$f_{c1} = \frac{1}{2\pi R_1 C_1} \qquad f_{c2} = \frac{1}{2\pi R_2 C_2} \tag{3.31}$$

FIGURE 3.23

Bandpass filter using op-amp: (a) op-amp circuit; (b) frequency response.

$$V_o(t) = -\frac{1}{RC} \int_0^t V_i(t) \, dt + V_o(0) \qquad (3.32)$$
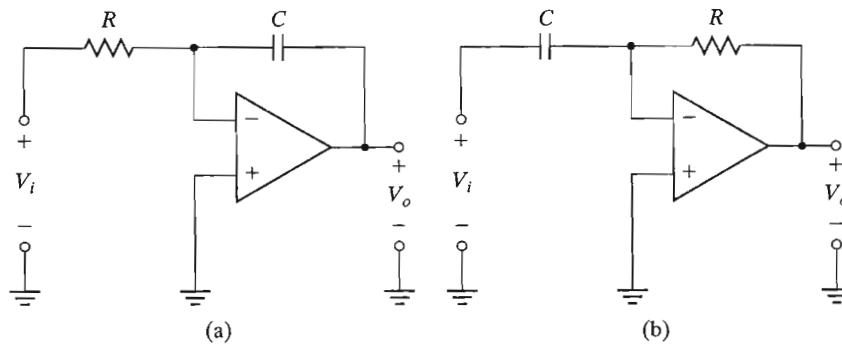

FIGURE 3.24

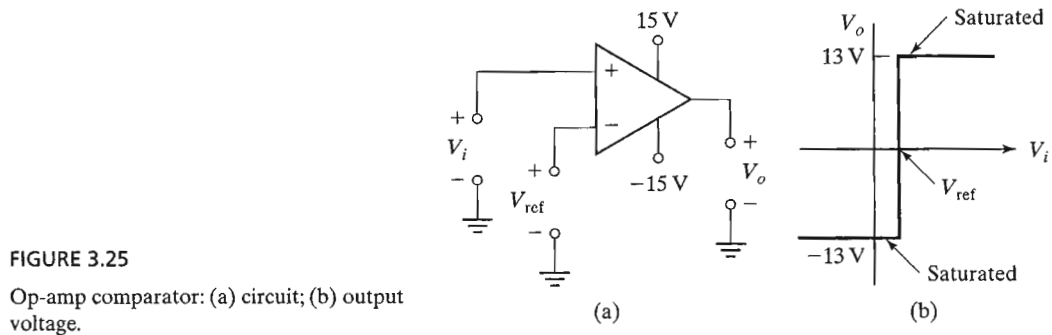Op-amp circuits for (a) integration and (b) differentiation.

FIGURE 3.25

Op-amp comparator: (a) circuit; (b) output voltage.

For the differentiator circuit shown in Figure 3.24(b), the output voltage is the time derivative of the input voltage:

$$V_o(t) = -RC \frac{dV_i(t)}{dt} \qquad (3.33)$$