Pole A circuit containing one resistor and one capacitor that contributes −20 dB/decade to a filter's roll-off rate.

Roll-off The rate of decrease in gain, below or above the critical frequencies of a filter.

KEY FORMULAS

15–1	$BW = f_c$	Low-pass bandwidth
15–2	$BW = f_{c2} - f_{c1}$	Filter bandwidth of a band-pass filter
15–3	$f_0 = \sqrt{f_{c1}f_{c2}}$	Center frequency of a band-pass filter
15–4	$Q = \dfrac{f_0}{BW}$	Quality factor of a band-pass filter
15–5	$DF = 2 - \dfrac{R_1}{R_2}$	Damping factor
15–6	$A_{cl(NI)} = \dfrac{R_1}{R_2} + 1$	Closed-loop voltage gain
15–7	$f_c = \dfrac{1}{2\pi\sqrt{R_A R_B C_A C_B}}$	Critical frequency for a second-order Sallen-Key filter
15–8	$f_0 = \dfrac{1}{2\pi C}\sqrt{\dfrac{R_1 + R_3}{R_1 R_2 R_3}}$	Center frequency of a multiple-feedback filter
15–9	$A_0 = \dfrac{R_2}{2R_1}$	Gain of a multiple-feedback filter

TRUE/FALSE QUIZ

Answers can be found at www.pearsonhighered.com/floyd.

1. The response of a filter can be identified by its passband.
2. A filter pole is the cutoff frequency of a filter.
3. A single-pole filter has one *RC* circuit.
4. A single-pole filter produces a roll-off of −25 dB/decade.
5. A low-pass filter can pass a dc voltage.
6. A high-pass filter passes any frequency above dc.
7. The critical frequency of a filter depends only on *R* and *C* values.
8. The band-pass filter has two critical frequencies.
9. The quality factor of a band-pass filter is the ratio of bandwidth to the center frequency.
10. The higher the *Q*, the narrower the bandwidth of a band-pass filter.
11. The Butterworth characteristic provides a flat response in the passband.
12. Filters with a Chebyshev response have a slow roll-off.
13. A Chebyshev response has ripples in the passband.
14. Bessel filters are useful in filtering pulse waveforms.
15. The order of a filter is the number of poles it contains.
16. A Sallen-Key filter is also known as a VCVS filter.
17. Multiple feedback is used in low-pass filters.
18. A state-variable filter uses differentiators.
19. A band-stop filter rejects certain frequencies.
20. Filter response can be measured using a sweep generator.

for the figures in this set of questions plz refer to the text book (Floyd)

CIRCUIT-ACTION QUIZ

Answers can be found at www.pearsonhighered.com/floyd.

1. If the critical frequency of a low-pass filter is increased, the bandwidth will
   (a) increase **(b)** decrease **(c)** not change
2. If the critical frequency of a high-pass filter is increased, the bandwidth will
   (a) increase **(b)** decrease **(c)** not change
3. If the Q of a band-pass filter is increased, the bandwidth will
   (a) increase **(b)** decrease **(c)** not change
4. If the value of C_A and C_B in Figure 15–11 are increased by the same amount, the critical frequency will
   (a) increase **(b)** decrease **(c)** not change
5. If the the value of R_2 in Figure 15–11 is increased, the bandwidth will
   (a) increase **(b)** decrease **(c)** not change
6. If two filters like the one in Figure 15–15 are cascaded, the roll-off rate of the frequency response will
   (a) increase **(b)** decrease **(c)** not change
7. If the value of R_2 in Figure 15–19 is decreased, the Q will
   (a) increase **(b)** decrease **(c)** not change
8. If the capacitors in Figure 15–19 are changed to 0.022 μF, the center frequency will
   (a) increase **(b)** decrease **(c)** not change

SELF-TEST

Answers can be found at www.pearsonhighered.com/floyd.

Section 15–1

1. The term *pole* in filter terminology refers to
   (a) a high-gain op-amp **(b)** one complete active filter
   (c) a single *RC* circuit **(d)** the feedback circuit
2. A single resistor and a single capacitor can be connected to form a filter with a roll-off rate of
   (a) −20 dB/decade **(b)** −40 dB/decade
   (c) −6 dB/octave **(d)** answers (a) and (c)
3. A band-pass response has
   (a) two critical frequencies **(b)** one critical frequency
   (c) a flat curve in the passband **(d)** a wide bandwidth
4. The lowest frequency passed by a low-pass filter is
   (a) 1 Hz **(b)** 0 Hz **(c)** 10 Hz **(d)** dependent on the critical frequency
5. The quality factor (Q) of a band-pass filter depends on
   (a) the critical frequencies **(b)** only the bandwidth
   (c) the center frequency and the bandwidth **(d)** only the center frequency

Section 15–2

6. ~~The damping factor of an active filter determines~~
   ~~**(a)** the voltage gain~~ ~~**(b)** the critical frequency~~
   ~~**(c)** the response characteristic~~ ~~**(d)** the roll-off rate~~
7. A maximally flat frequency response is known as
   (a) Chebyshev **(b)** Butterworth **(c)** Bessel **(d)** Colpitts
8. ~~The damping factor of a filter is set by~~
   ~~**(a)** the negative feedback circuit~~ ~~**(b)** the positive feedback circuit~~
   ~~**(c)** the frequency-selective circuit~~ ~~**(d)** the gain of the op-amp~~
9. ~~The number of poles in a filter affect the~~
   (a) voltage gain **(b)** bandwidth
   (c) center frequency **(d)** roll-off rate

Section 15–3

10. Sallen-Key low-pass filters are

(a) single-pole filters **(b)** second-order filters

(c) Butterworth filters **(d)** band-pass filters

11. When low-pass filters are cascaded, the roll-off rate

(a) increases **(b)** decreases **(c)** does not change

Section 15–4

12. In a high-pass filter, the roll-off occurs

(a) above the critical frequency **(b)** below the critical frequency

(c) during the mid range **(d)** at the center frequency

13. A two-pole Sallen-Key high-pass filter contains

(a) one capacitor and two resistors **(b)** two capacitors and two resistors

(c) a feedback circuit **(d)** answers (b) and (c)

Section 15–5

14. When a low-pass and a high-pass filter are cascaded to get a band-pass filter, the critical frequency of the low-pass filter must be

(a) equal to the critical frequency of the high-pass filter

(b) less than the critical frequency of the high-pass filter

(c) greater than the critical frequency of the high-pass filter

15. A state-variable filter consists of

(a) one op-amp with multiple-feedback paths

(b) a summing amplifier and two integrators

(c) a summing amplifier and two differentiators

(d) three Butterworth stages

Section 15–6

16. When the gain of a filter is minimum at its center frequency, it is

(a) a band-pass filter **(b)** a band-stop filter

(c) a notch filter **(d)** answers (b) and (c)

PROBLEMS

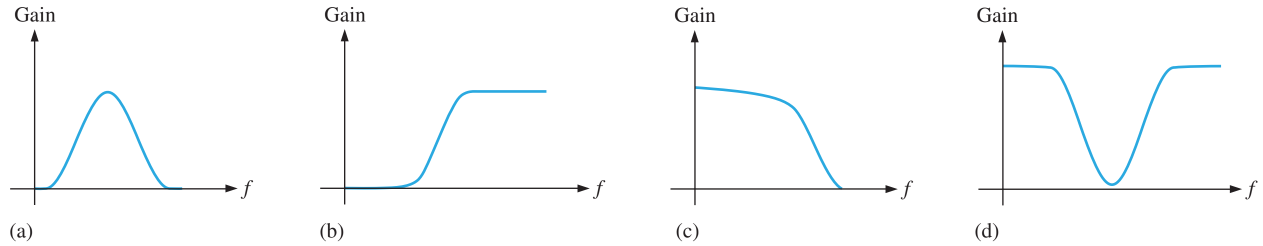
Answers to all odd-numbered problems are at the end of the book.

BASIC PROBLEMS

Section 15–1

Basic Filter Responses

1. Identify each type of filter response (low-pass, high-pass, band-pass, or band-stop) in Figure 15–42.



▲ FIGURE 15–42

2. A certain low-pass filter has a critical frequency of 800 Hz. What is its bandwidth?

3. A single-pole high-pass filter has a frequency-selective circuit with $R = 2.2\ \text{k}\Omega$ and $C = 0.0015\ \mu\text{F}$. What is the critical frequency? Can you determine the bandwidth from the available information?

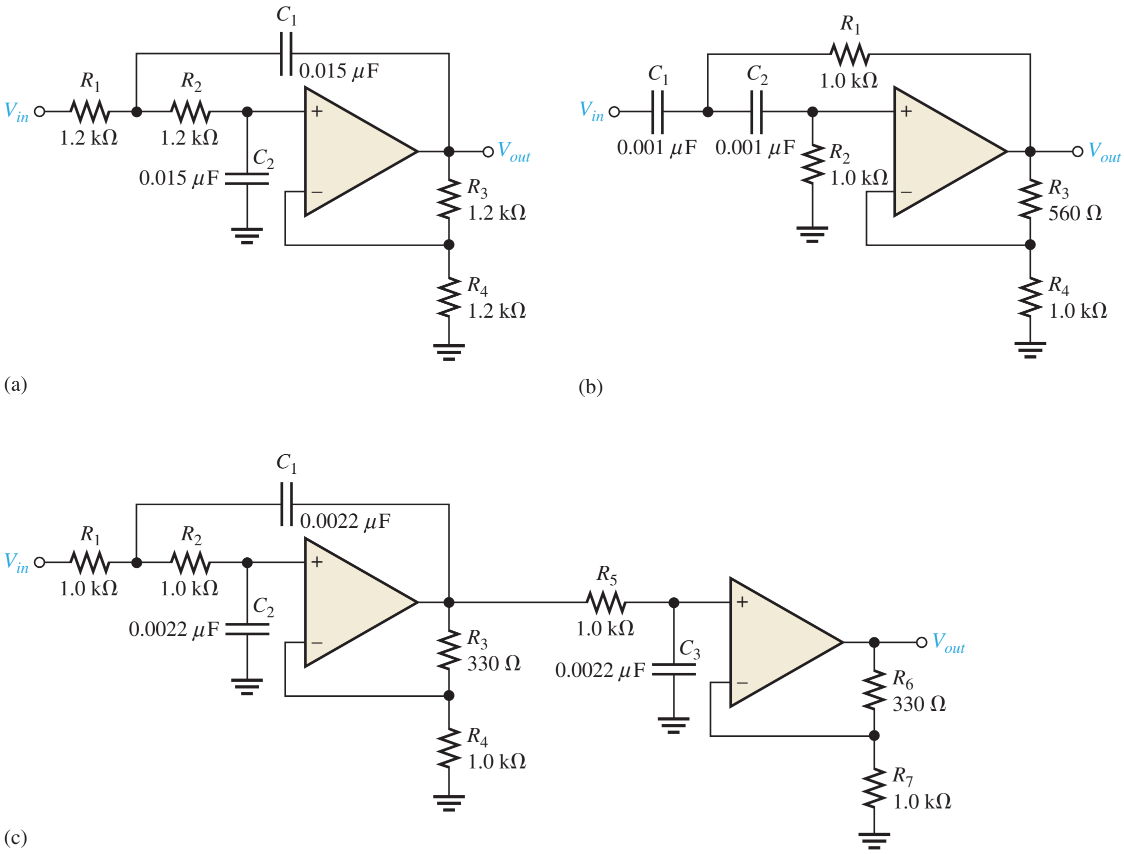
4. What is the roll-off rate of the filter described in Problem 3?

5. What is the bandwidth of a band-pass filter whose critical frequencies are 3.2 kHz and 3.9 kHz? What is the Q of this filter?

6. What is the center frequency of a filter with a Q of 15 and a bandwidth of 1 kHz?

Section 15–2 Filter Response Characteristics

7. What is the damping factor in each active filter shown in Figure 15–43? Which filters are approximately optimized for a Butterworth response characteristic?

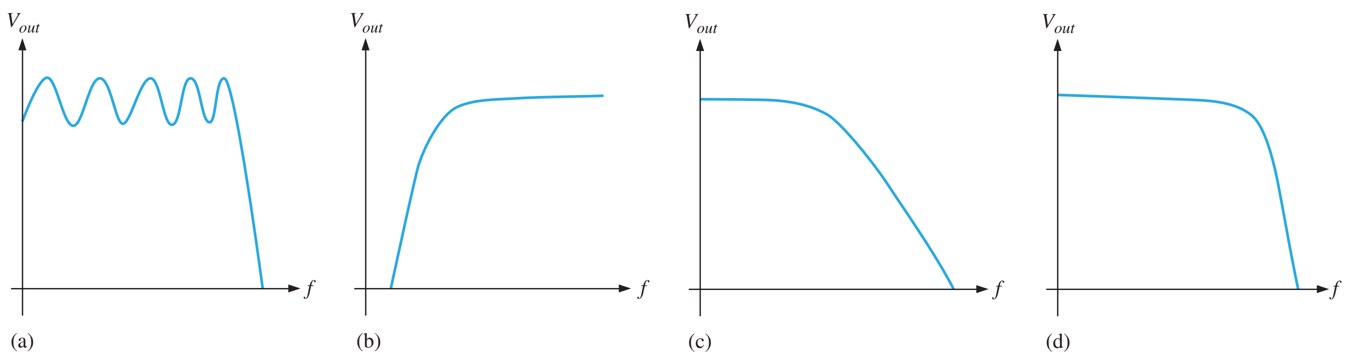


▲ **FIGURE 15–43**

Multisim file circuits are identified with a logo and are in the Problems folder on the companion website. Filenames correspond to figure numbers (e.g., F15-43).

8. For the filters in Figure 15–43 that do not have a Butterworth response, specify the changes necessary to convert them to Butterworth responses. (Use nearest standard values.)

9. Response curves for second-order filters are shown in Figure 15–44. Identify each as Butterworth. Chebyshev, or Bessel.



▲ **FIGURE 15–44**

Section 15–3 Active Low-Pass Filters

10. Is the four-pole filter in Figure 15–45 approximately optimized for a Butterworth response? What is the roll-off rate?

11. Determine the critical frequency in Figure 15–45.

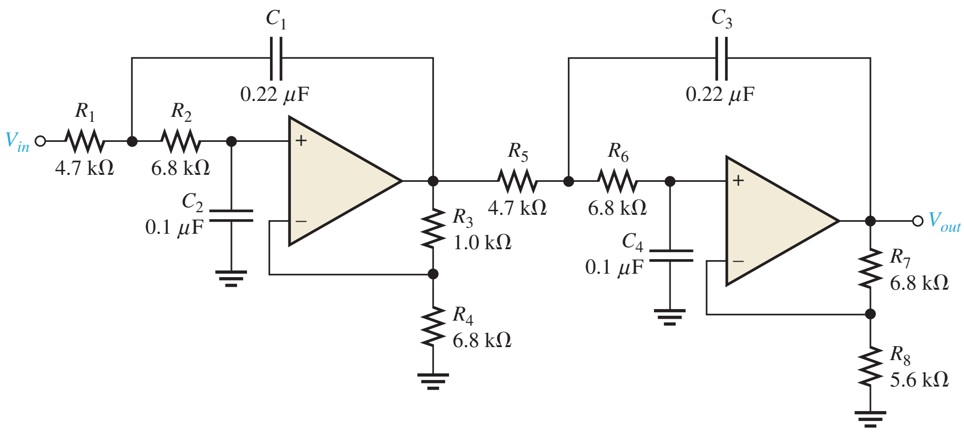
12. Without changing the response curve, adjust the component values in the filter of Figure 15–45 to make it an equal-value filter. Select $C = 0.22\ \mu F$ for both stages.

13. Modify the filter in Figure 15–45 to increase the roll-off rate to -120 dB/decade while maintaining an approximate Butterworth response.

14. Using a block diagram format, show how to implement the following roll-off rates using single-pole and two-pole low-pass filters with Butterworth responses.

(a) -40 dB/decade **(b)** -20 dB/decade
(c) -60 dB/decade **(d)** -100 dB/decade
(e) -120 dB/decade

▶ **FIGURE 15–45**



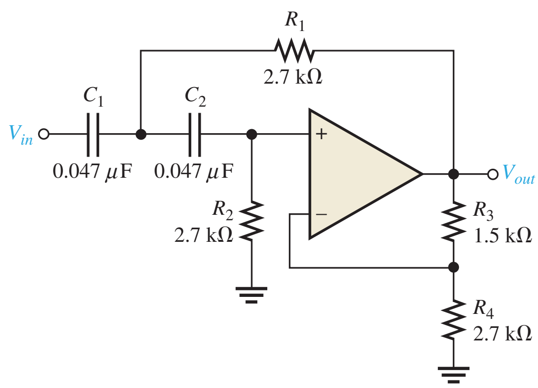
Section 15–4 Active High-Pass Filters

15. Convert the filter in Problem 12 to a high-pass with the same critical frequency and response characteristic.

16. Make the necessary circuit modification to reduce by half the critical frequency in Problem 15.

17. For the filter in Figure 15–46, **(a)** how would you increase the critical frequency? (b) How would you increase the gain?

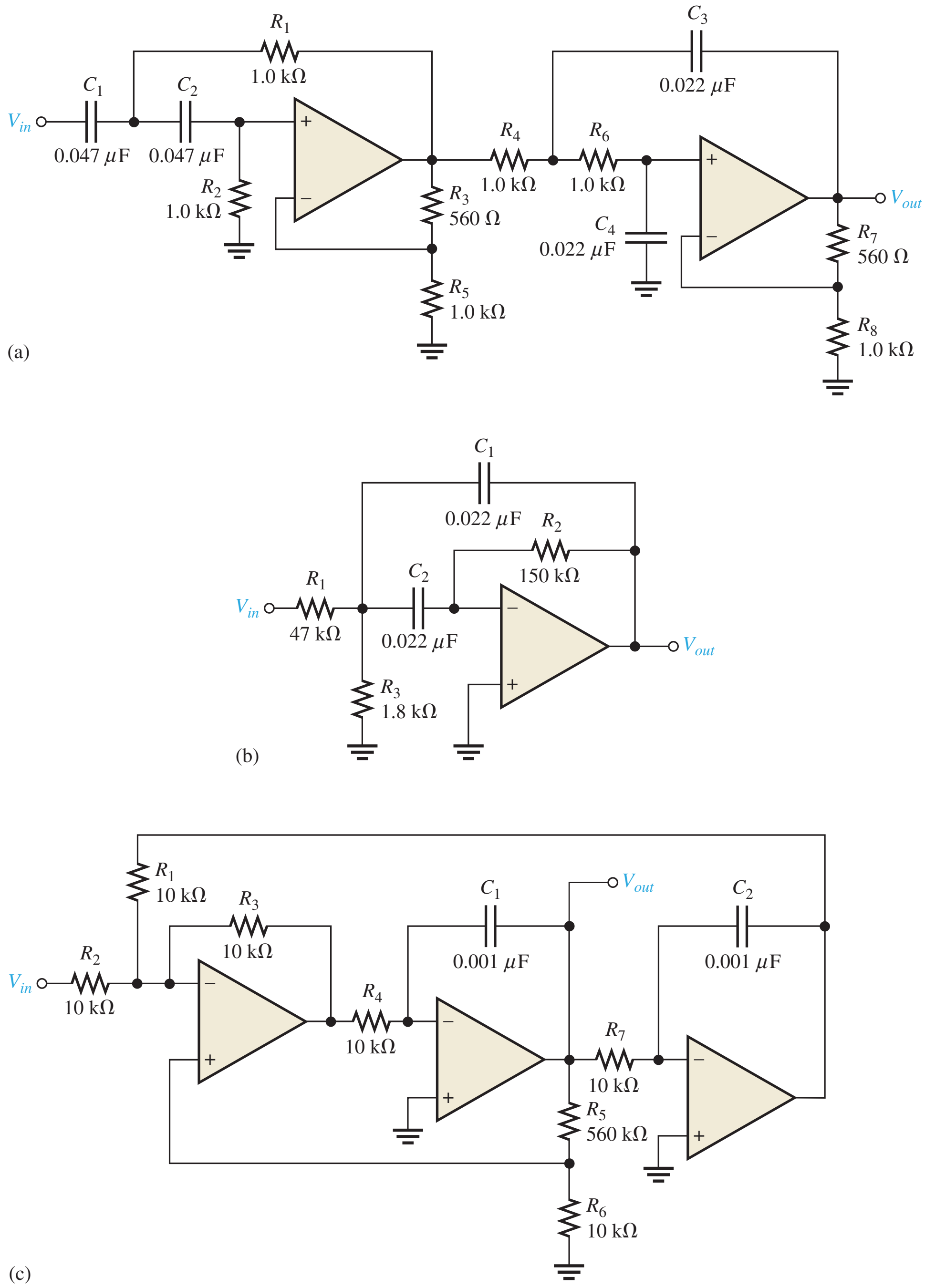
▶ **FIGURE 15–46**



Section 15–5 Active Band-Pass Filters

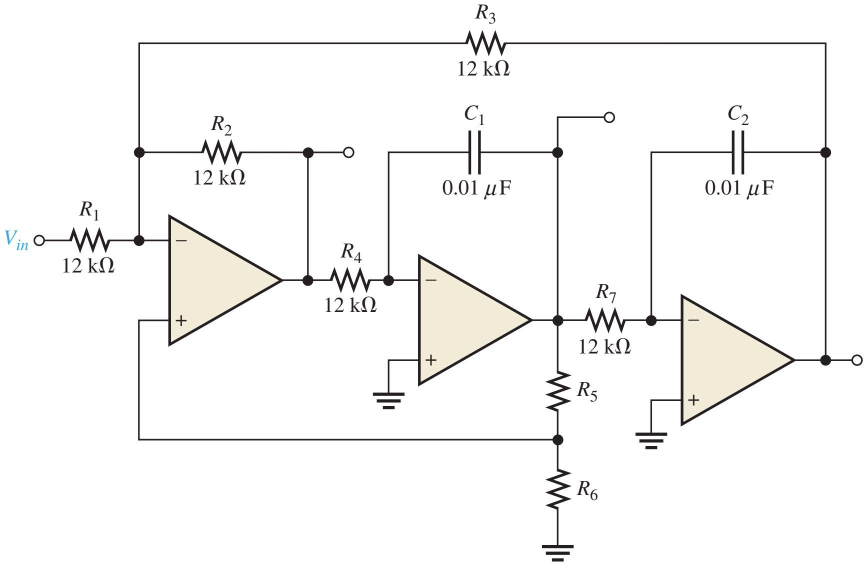
18. Identify each band-pass filter configuration in Figure 15–47.

19. Determine the center frequency and bandwidth for each filter in Figure 15–47.



▲ FIGURE 15–47

▶ FIGURE 15–48



20. Optimize the state-variable filter in Figure 15–48 for $Q = 50$. What bandwidth is achieved?

Section 15–6

Active Band-Stop Filters

21. Show how to make a notch (band-stop) filter using the basic circuit in Figure 15–48.

22. Modify the band-stop filter in Problem 21 for a center frequency of 120 Hz.

~~MULTISIM TROUBLESHOOTING PROBLEMS~~

~~These file circuits are in the Troubleshooting Problems folder on the companion website.~~

~~**23.** Open file TSP15-23 and determine the fault.~~

~~**24.** Open file TSP15-24 and determine the fault.~~

~~**25.** Open file TSP15-25 and determine the fault.~~

~~**26.** Open file TSP15-26 and determine the fault.~~

~~**27.** Open file TSP15-27 and determine the fault.~~

~~**28.** Open file TSP15-28 and determine the fault.~~

~~**29.** Open file TSP15-29 and determine the fault.~~

~~**30.** Open file TSP15-30 and determine the fault.~~

~~**31.** Open file TSP15-31 and determine the fault.~~

KEY TERMS

Key terms and other bold terms in the chapter are defined in the end-of-book glossary.

Closed-loop voltage gain (A_{cl}) The voltage gain of an op-amp with external feedback.

CMRR Common-mode rejection ratio; the ratio of open-loop gain to common-mode gain; a measure of an op-amp's ability to reject common-mode signals.

Common mode A condition characterized by the presence of the same signal on both op-amp inputs.

Differential amplifier A type of amplifier with two inputs and two outputs that is used as the input stage of an op-amp.

Differential mode A mode of op-amp operation in which two opposite-polarity signal voltages are applied to the two inputs (double-ended) or in which a signal is applied to one input and ground to the other input (single-ended).

Gain-bandwidth product A constant parameter which is always equal to the frequency at which the op-amp's open-loop gain is unity (1).

Inverting amplifier An op-amp closed-loop configuration in which the input signal is applied to the inverting input.

Negative feedback The process of returning a portion of the output signal to the input of an amplifier such that it is out of phase with the input signal.

Noninverting amplifier An op-amp closed-loop configuration in which the input signal is applied to the noninverting input.

Open-loop voltage gain (A_{ol}) The voltage gain of an op-amp without external feedback.

Operational amplifier (op-amp) A type of amplifier that has very high voltage gain, very high input impedance, very low output impedance, and good rejection of common-mode signals.

Phase shift The relative angular displacement of a time-varying function relative to a reference.

Slew rate The rate of change of the output voltage of an op-amp in response to a step input.

Voltage-follower A closed-loop, noninverting op-amp with a voltage gain of 1.

KEY FORMULAS

Op-Amp Input Modes and Parameters

12–1	$\text{CMRR} = \dfrac{A_{ol}}{A_{cm}}$	Common-mode rejection ratio
12–2	$\text{CMRR} = 20\log\left(\dfrac{A_{ol}}{A_{cm}}\right)$	Common-mode rejection ratio (dB)
12–3	$I_{BIAS} = \dfrac{I_1 + I_2}{2}$	Input bias current
12–4	$I_{OS} = \lvert I_1 - I_2 \rvert$	Input offset current
12–5	$V_{OS} = I_{OS}R_{in}$	Offset voltage
12–6	$V_{OUT(error)} = A_v I_{OS} R_{in}$	Output error voltage
12–7	$\text{Slew rate} = \dfrac{\Delta V_{out}}{\Delta t}$	Slew rate

Op-Amp Configurations

12–8	$A_{cl(NI)} = 1 + \dfrac{R_f}{R_i}$	Voltage gain (noninverting)
12–9	$A_{cl(VF)} = 1$	Voltage gain (voltage-follower)
12–10	$A_{cl(I)} = -\dfrac{R_f}{R_i}$	Voltage gain (inverting)

Op-Amp Impedances

12–11	$Z_{in(NI)} = (1 + A_{ol}B)Z_{in}$	Input impedance (noninverting)
12–12	$Z_{out(NI)} = \frac{Z_{out}}{1 + A_{ol}B}$	Output impedance (noninverting)
12–13	$Z_{in(VF)} = (1 + A_{ol})Z_{in}$	Input impedance (voltage-follower)
12–14	$Z_{out(VF)} = \frac{Z_{out}}{1 + A_{ol}}$	Output impedance (voltage-follower)
12–15	$Z_{in(I)} \cong R_i$	Input impedance (inverting)
12–16	$Z_{out(I)} = \frac{Z_{out}}{1 + A_{ol}B}$	Output impedance (inverting)

Op-Amp Frequency Responses

12–17	$BW = f_{cu}$	Op-amp bandwidth
12–18	$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1 + f^2/f_c^2}}$	*RC* attenuation
12–19	$A_{ol} = \frac{A_{ol(mid)}}{\sqrt{1 + f^2/f_c^2}}$	Open-loop voltage gain
12–20	$\theta = -\tan^{-1}\left(\frac{f}{f_c}\right)$	*RC* phase shift
12–21	$f_{c(cl)} = f_{c(ol)}(1 + BA_{ol(mid)})$	Closed-loop critical frequency
12–22	$BW_{cl} = BW_{ol}(1 + BA_{ol(mid)})$	Closed-loop bandwidth
12–23	$f_T = A_{cl}f_{c(cl)}$	Unity-gain bandwidth

TRUE/FALSE QUIZ

Answers can be found at www.pearsonhighered.com/floyd.

1. An ideal op-amp has an infinite input impedance.
2. An ideal op-amp has a very high output impedance.
3. The op-amp can operate in both the differential mode or the common mode.
4. Common-mode rejection means that a signal appearing on both inputs is effectively cancelled.
5. CMRR stands for common-mode rejection reference.
6. Slew rate determines how fast the output can change in response to a step input.
7. Negative feedback reduces the gain of an op-amp from its open-loop value.
8. Negative feedback reduces the bandwidth of an op-amp from its open-loop value.
9. A noninverting amplifier uses negative feedback.
10. The gain of a voltage-follower is very high.
11. Negative feedback affects the input and output impedances of an op-amp.
12. A compensated op-amp has a gain roll-off of −20 dB/decade above the critical frequency.
13. The gain-bandwidth product equals the unity-gain frequency.
14. If the feedback resistor in an inverting amplifier opens, the gain becomes zero.

CIRCUIT-ACTION QUIZ

Answers can be found at www.pearsonhighered.com/floyd.

1. If R_f is decreased in the circuit of Figure 12–18, the voltage gain will
   (a) increase **(b)** decrease **(c)** not change
2. If $V_{in} = 1$ mV and R_f opens in the circuit of Figure 12–18, the output voltage will
   (a) increase **(b)** decrease **(c)** not change

3. If R_i is increased in the circuit of Figure 12–18, the voltage gain will
   (a) increase (b) decrease (c) not change
4. If 10 mV are applied to the input to the op-amp circuit of Figure 12–22 and R_f is increased, the output voltage will
   (a) increase (b) decrease (c) not change
5. In Figure 12–28, if R_f is changed from 100 kΩ to 68 kΩ, the feedback attenuation will
   (a) increase (b) decrease (c) not change
6. If the closed-loop gain in Figure 12–43(a) is increased by increasing the value of R_f, the closed-loop bandwidth will
   (a) increase (b) decrease (c) not change
7. If R_f is changed to 470 kΩ and R_i is changed to 10 kΩ in Figure 12–43(b), the closed-loop bandwidth will
   (a) increase (b) decrease (c) not change
8. If R_i in Figure 12–43(b) opens, the output voltage will
   (a) increase (b) decrease (c) not change

SELF-TEST

Answers can be found at www.pearsonhighered.com/floyd.

Section 12–1

1. An integrated circuit (IC) op-amp has
   (a) two inputs and two outputs (b) one input and one output
   (c) two inputs and one output
2. Which of the following characteristics does not necessarily apply to an op-amp?
   (a) High gain (b) Low power
   (c) High input impedance (d) Low output impedance
3. A differential amplifier
   (a) is part of an op-amp (b) has one input and one output
   (c) has two outputs (d) answers (a) and (c)

Section 12–2

4. When an op-amp is operated in the single-ended differential mode,
   (a) the output is grounded
   (b) one input is grounded and a signal is applied to the other
   (c) both inputs are connected together
   (d) the output is not inverted
5. In the double-ended differential mode,
   (a) a signal is applied between the two inputs (b) the gain is 1
   (c) the outputs are different amplitudes (d) only one supply voltage is used
6. In the common mode,
   (a) both inputs are grounded (b) the outputs are connected together
   (c) an identical signal appears on both inputs (d) the output signals are in-phase
7. Common-mode gain is
   (a) very high (b) very low
   (c) always unity (d) unpredictable
8. If $A_{ol} = 3500$ and $A_{cm} = 0.35$, the CMRR is
   (a) 1225 (b) 10,000
   (c) 80 dB (d) answers (b) and (c)
9. With zero volts on both inputs, an op-amp ideally should have an output equal to
   (a) the positive supply voltage (b) the negative supply voltage
   (c) zero (d) the CMRR

10. Of the values listed, the most realistic value for open-loop gain of an op-amp is

(a) 1 **(b)** 2000 **(c)** 80 dB **(d)** 100,000

11. A certain op-amp has bias currents of 50 μA and 49.3 μA. The input offset current is

(a) 700 nA **(b)** 99.3 μA **(c)** 49.7 μA **(d)** none of these

12. The output of a particular op-amp increases 8 V in 12 μs. The slew rate is

(a) 96 V/μs **(b)** 0.67 V/μs **(c)** 1.5 V/μs **(d)** none of these

Section 12–3

13. The purpose of offset nulling is to

(a) reduce the gain **(b)** equalize the input signals

(c) zero the output error voltage **(d)** answers (b) and (c)

14. The use of negative feedback

(a) reduces the voltage gain of an op-amp **(b)** makes the op-amp oscillate

(c) makes linear operation possible **(d)** answers (a) and (c)

Section 12–4

15. For an op-amp with negative feedback, the output is

(a) equal to the input

(b) increased

(c) fed back to the inverting input

(d) fed back to the noninverting input

16. A certain noninverting amplifier has an R_i of 1.0 kΩ and an R_f of 100 kΩ. The closed-loop gain is

(a) 100,000 **(b)** 1000 **(c)** 101 **(d)** 100

17. If the feedback resistor in Question 16 is open, the voltage gain

(a) increases **(b)** decreases **(c)** is not affected **(d)** depends on R_i

18. A certain inverting amplifier has a closed-loop gain of 25. The op-amp has an open-loop gain of 100,000. If another op-amp with an open-loop gain of 200,000 is substituted in the configuration, the closed-loop gain

(a) doubles **(b)** drops to 12.5 **(c)** remains at 25 **(d)** increases slightly

19. A voltage-follower

(a) has a gain of 1 **(b)** is noninverting

(c) has no feedback resistor **(d)** has all of these

Section 12–5

20. Negative feedback

(a) increases the input and output impedances

(b) increases the input impedance and the bandwidth

(c) decreases the output impedance and the bandwidth

(d) does not affect impedances or bandwidth

Section 12–6

21. Bias current compensation

(a) reduces gain **(b)** reduces output error voltage

(c) increases bandwidth **(d)** has no effect

Section 12–7

22. The midrange open-loop gain of an op-amp

(a) extends from the lower critical frequency to the upper critical frequency

(b) extends from 0 Hz to the upper critical frequency

(c) rolls off at 20 dB/decade beginning at 0 Hz

(d) answers (b) and (c)

23. The frequency at which the open-loop gain is equal to 1 is called

(a) the upper critical frequency **(b)** the cutoff frequency

(c) the notch frequency **(d)** the unity-gain frequency

24. Phase shift through an op-amp is caused by

(a) the internal *RC* circuits **(b)** the external *RC* circuits

(c) the gain roll-off **(d)** negative feedback

25. Each *RC* circuit in an op-amp

(a) causes the gain to roll off at −6 dB/octave

(b) causes the gain to roll off at −20 dB/decade

(c) reduces the midrange gain by 3 dB

(d) answers (a) and (b)

26. If a certain op-amp has a midrange open-loop gain of 200,000 and a unity-gain frequency of 5 MHz, the gain-bandwidth product is

(a) 200,000 Hz **(b)** 5,000,000 Hz

(c) 1×10^{12} Hz **(d)** not determinable from the information

Section 12–8

27. The bandwidth of an ac amplifier having a lower critical frequency of 1 kHz and an upper critical frequency of 10 kHz is

(a) 1 kHz **(b)** 9 kHz **(c)** 10 kHz **(d)** 11 kHz

28. The bandwidth of a dc amplifier having an upper critical frequency of 100 kHz is

(a) 100 kHz **(b)** unknown **(c)** infinity **(d)** 0 kHz

29. When negative feedback is used, the gain-bandwidth product of an op-amp

(a) increases **(b)** decreases **(c)** stays the same **(d)** fluctuates

30. If a certain op-amp has a closed-loop gain of 20 and an upper critical frequency of 10 MHz, the gain-bandwidth product is

(a) 200 MHz **(b)** 10 MHz **(c)** the unity-gain frequency **(d)** answers (a) and (c)

PROBLEMS

Answers to all odd-numbered problems are at the end of the book.

BASIC PROBLEMS

Section 12–1

Introduction to Operational Amplifiers

1. Compare a practical op-amp to an ideal op-amp.
2. Two IC op-amps are available to you. Their characteristics are listed below. Choose the one you think is more desirable.

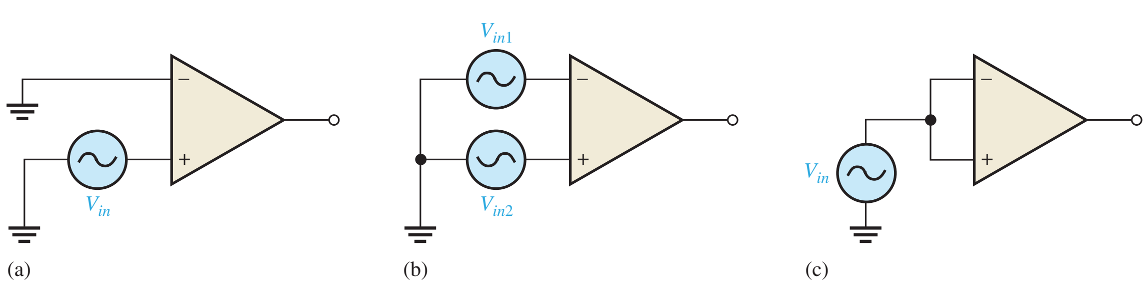
   Op-amp 1: $Z_{in} = 5\text{ M}\Omega, Z_{out} = 100\Omega, A_{ol} = 50{,}000$

   Op-amp 2: $Z_{in} = 10\text{ M}\Omega, Z_{out} = 75\ \Omega, A_{ol} = 150{,}000$

Section 12–2

Op-Amp Input Modes and Parameters

3. Identify the type of input mode for each op-amp in Figure 12–60.
4. A certain op-amp has a CMRR of 250,000. Convert this to decibels.
5. The open-loop gain of a certain op-amp is 175,000. Its common-mode gain is 0.18. Determine the CMRR in decibels.
6. An op-amp datasheet specifies a CMRR of 300,000 and an A_{ol} of 90,000. What is the common-mode gain?
7. Determine the bias current, I_{BIAS}, given that the input currents to an op-amp are 8.3 μA and 7.9 μA.



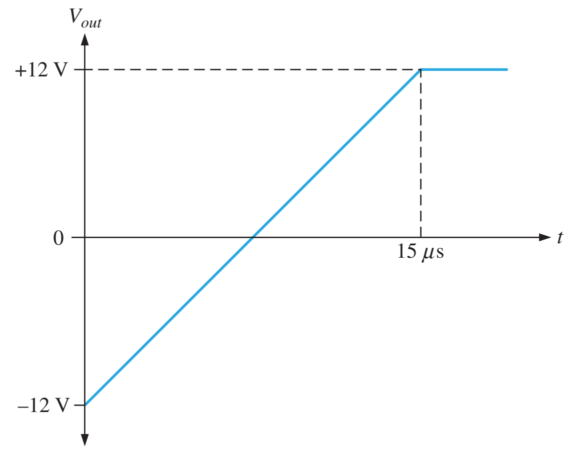
▲ FIGURE 12–60

8. Distinguish between input bias current and input offset current, and then calculate the input offset current in Problem 7.

9. Figure 12–61 shows the output voltage of an op-amp in response to a step input. What is the slew rate?

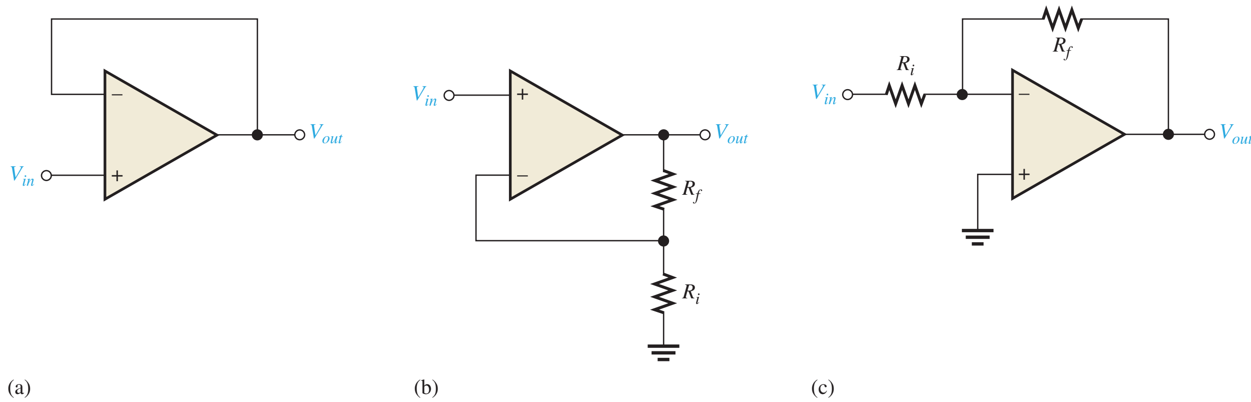
10. How long does it take the output voltage of an op-amp to go from −10 V to +10 V if the slew rate is 0.5 V/μS?

▶ FIGURE 12–61



Section 12–4 Op-Amps with Negative Feedback

11. Identify each of the op-amp configurations in Figure 12–62.



▲ FIGURE 12–62

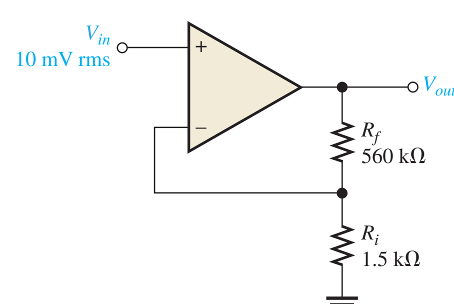
12. A noninverting amplifier has an R_i of 1.0 kΩ and an R_f of 100 kΩ. Determine V_f and B if V_{out} = 5 V.

13. For the amplifier in Figure 12–63, determine the following:

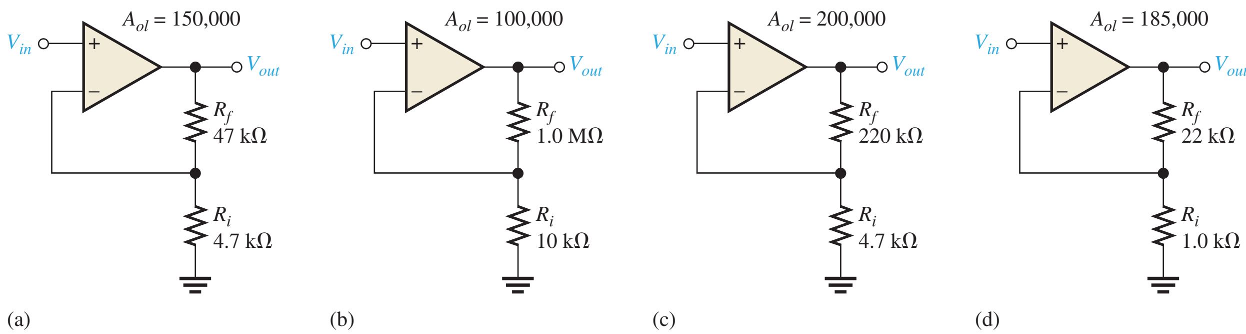
(a) $A_{cl(\mathrm{NI})}$ **(b)** V_{out} **(c)** V_f

▶ FIGURE 12–63

Multisim file circuits are identified with a logo and are in the Problems folder on the companion website. Filenames correspond to figure numbers (e.g., F12-63).

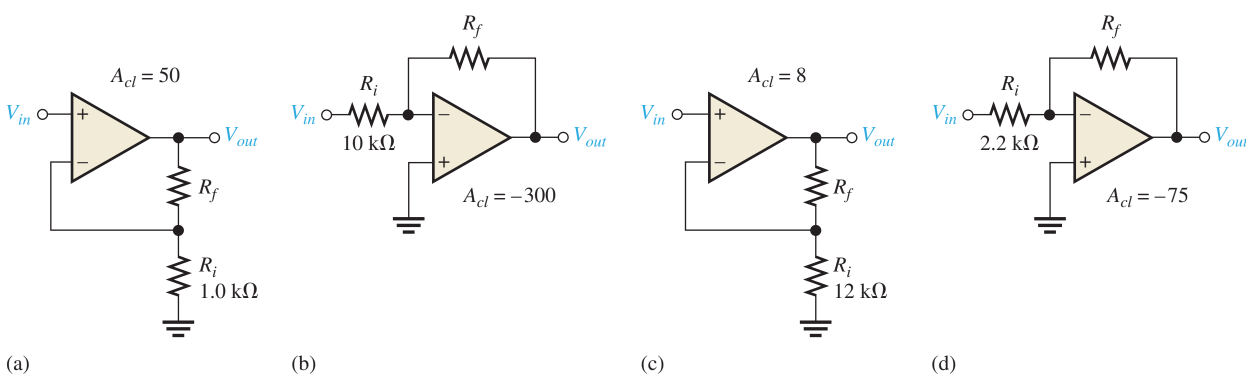


14. Determine the closed-loop gain of each amplifier in Figure 12–64.



▲ FIGURE 12–64

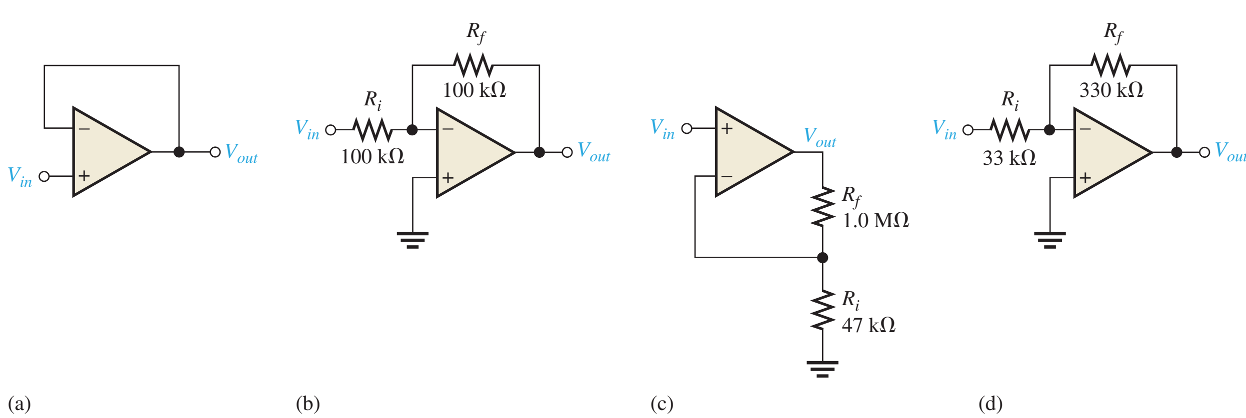
15. Find the value of R_f that will produce the indicated closed-loop gain in each amplifier in Figure 12–65.



▲ FIGURE 12–65

16. Find the gain of each amplifier in Figure 12–66.

17. If a signal voltage of 10 mV rms is applied to each amplifier in Figure 12–66, what are the output voltages and what is their phase relationship with inputs?

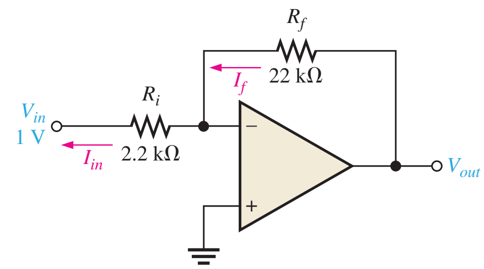


▲ FIGURE 12–66

18. Determine the approximate values for each of the following quantities in Figure 12–67.

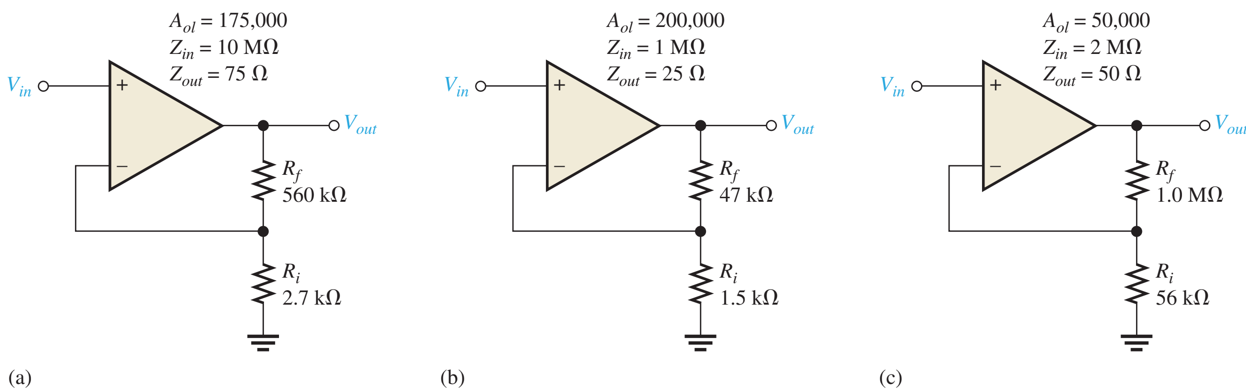
(a) I_{in} **(b)** I_f **(c)** V_{out} **(d)** closed-loop gain

▶ FIGURE 12–67



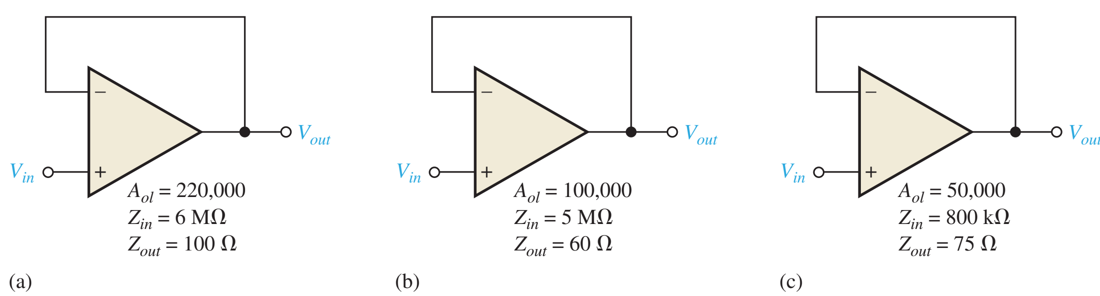
Section 12–5 Effects of Negative Feedback on Op-Amp Impedances

19. Determine the input and output impedances for each amplifier configuration in Figure 12–68.



▲ FIGURE 12–68

20. Repeat Problem 19 for each circuit in Figure 12–69.



▲ FIGURE 12–69

21. Repeat Problem 19 for each circuit in Figure 12–70.

Section 12–6 Bias Current and Offset Voltage

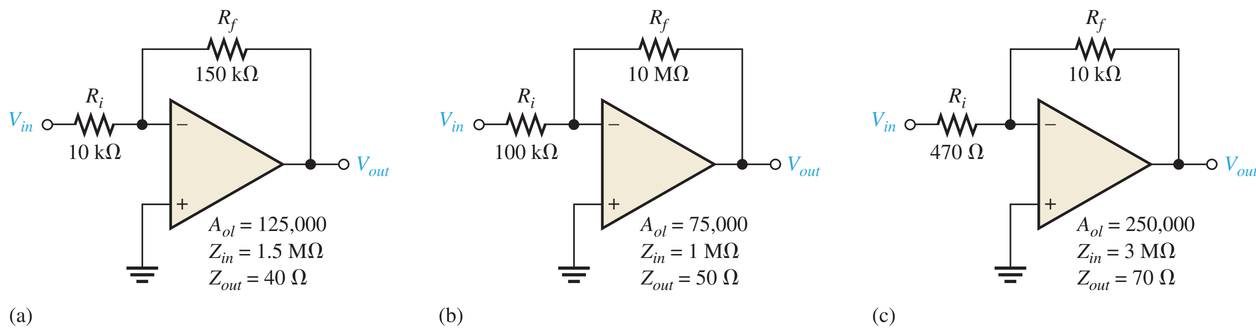
22. A voltage-follower is driven by a voltage source with a source resistance of 75 Ω.

(a) What value of compensating resistor is required for bias current, and where should the resistor be placed?

(b) If the two input currents after compensation are 42 μA and 40 μA, what is the output error voltage?

23. Determine the compensating resistor value for each amplifier configuration in Figure 12–68, and indicate the placement of the resistor.

24. A particular op-amp voltage-follower has an input offset voltage of 2 nV. What is the output error voltage?



▲ **FIGURE 12–70**

For Problem 21.

25. What is the input offset voltage of an op-amp if a dc output voltage of 35 mV is measured when the input voltage is zero? The op-amp's open-loop gain is specified to be 200,000.

Section 12–7 Open-Loop Frequency and Phase Responses

26. The midrange open-loop gain of a certain op-amp is 120 dB. Negative feedback reduces this gain by 50 dB. What is the closed-loop gain?

27. The upper critical frequency of an op-amp's open-loop response is 200 Hz. If the midrange gain is 175,000, what is the ideal gain at 200 Hz? What is the actual gain? What is the op-amp's open-loop bandwidth?

28. An *RC* lag circuit has a critical frequency of 5 kHz. If the resistance value is 1.0 kΩ, what is X_C when $f = 3$ kHz?

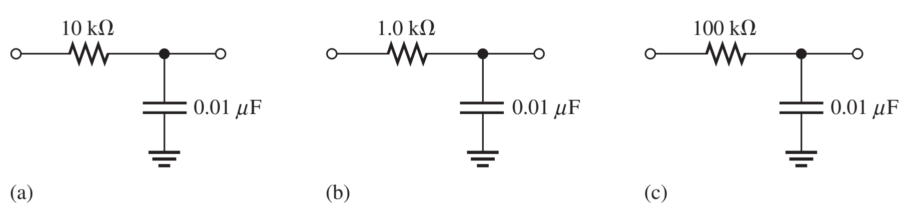
29. Determine the attenuation of an *RC* lag circuit with $f_c = 12$ kHz for each of the following frequencies.

(a) 1 kHz **(b)** 5 kHz **(c)** 12 kHz **(d)** 20 kHz **(e)** 100 kHz

30. The midrange open-loop gain of a certain op-amp is 80,000. If the open-loop critical frequency is 1 kHz, what is the open-loop gain at each of the following frequencies?

(a) 100 Hz **(b)** 1 kHz **(c)** 10 kHz **(d)** 1 MHz

31. Determine the phase shift through each circuit in Figure 12–71 at a frequency of 2 kHz.



▲ **FIGURE 12–71**

32. An *RC* lag circuit has a critical frequency of 8.5 kHz. Determine the phase shift for each frequency and plot a graph of its phase angle versus frequency.

(a) 100 Hz **(b)** 400 Hz **(c)** 850 Hz **(d)** 8.5 kHz **(e)** 25 kHz **(f)** 85 kHz

33. A certain op-amp has three internal amplifier stages with midrange gains of 30 dB, 40 dB, and 20 dB. Each stage also has a critical frequency associated with it as follows: $f_{c1} = 600$ Hz, $f_{c2} = 50$ kHz, and $f_{c3} = 200$ kHz.

(a) What is the midrange open-loop gain of the op-amp, expressed in dB?

(b) What is the total phase shift through the amplifier, including inversion, when the signal frequency is 10 kHz?

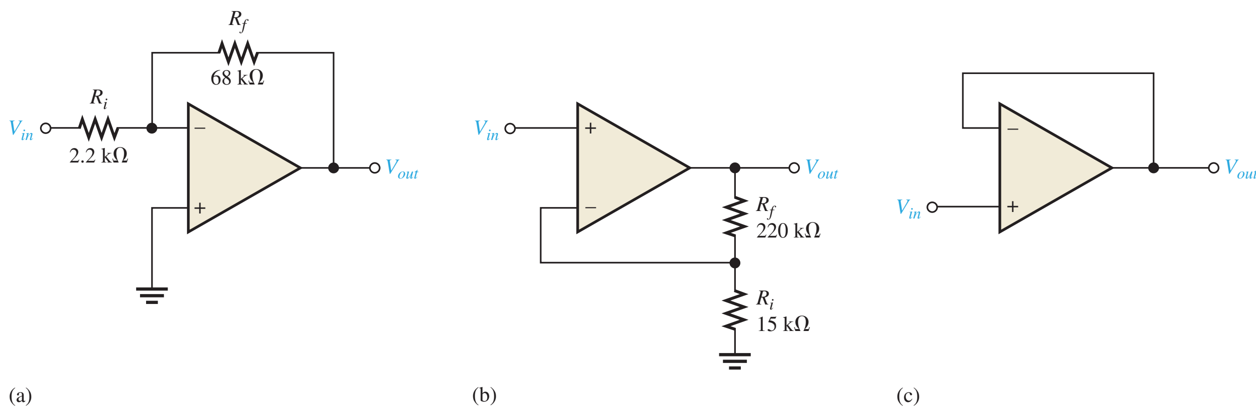
34. What is the gain roll-off rate in Problem 33 between the following frequencies?

(a) 0 Hz and 600 Hz **(b)** 600 Hz and 50 kHz

(c) 50 kHz and 200 kHz **(d)** 200 kHz and 1 MHz

Section 12–8 Closed-Loop Frequency Response

35. Determine the midrange gain in dB of each amplifier in Figure 12–72. Are these open-loop or closed-loop gains?



▲ FIGURE 12–72

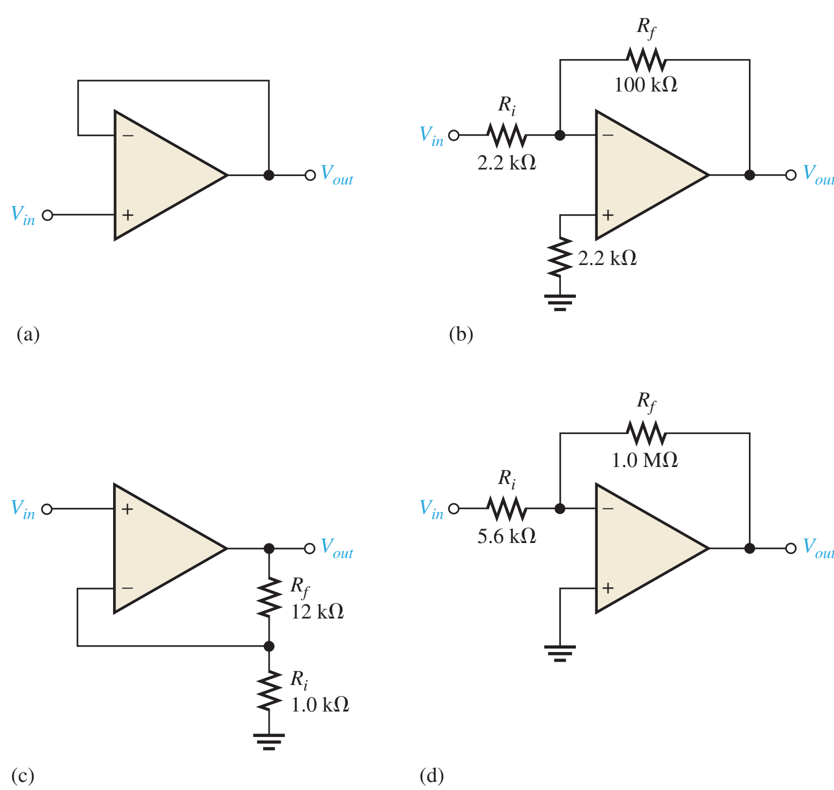
36. A certain amplifier has an open-loop gain in midrange of 180,000 and an open-loop critical frequency of 1500 Hz. If the attenuation of the feedback path is 0.015, what is the closed-loop bandwidth?

37. Given that $f_{c(ol)} = 750$ Hz, $A_{ol} = 89$ dB, and $f_{c(cl)} = 5.5$ kHz, determine the closed-loop gain in decibels.

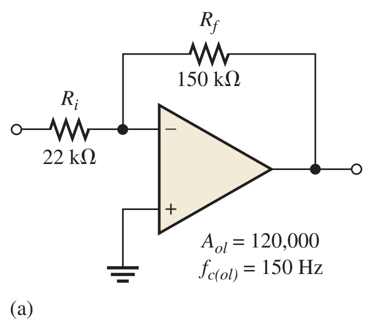
38. What is the unity-gain bandwidth in Problem 37?

39. For each amplifier in Figure 12–73, determine the closed-loop gain and bandwidth. The op-amps in each circuit exhibit an open-loop gain of 125 dB and a unity-gain bandwidth of 2.8 MHz.

▶ FIGURE 12–73



40. Which of the amplifiers in Figure 12–74 has the smaller bandwidth?



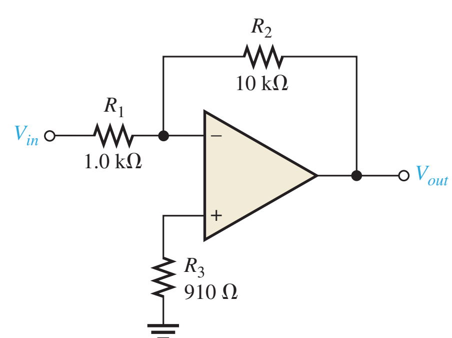
▲ FIGURE 12–74

Section 12–9 **Troubleshooting**

41. Determine the most likely fault(s) for each of the following symptoms in Figure 12–75 with a 100 mV signal applied.

(a) No output signal.

(b) Output severely clipped on both positive and negative swings.



▲ FIGURE 12–75

42. Determine the effect on the output if the circuit in Figure 12–75 has the following fault (one fault at a time).

(a) Output pin is shorted to the inverting input.

(b) R_3 is open.

(c) R_3 is 10 kΩ instead of 910 Ω.

(d) R_1 and R_2 are swapped.

SELF-TEST

Answers can be found at www.pearsonhighered.com/floyd.

Section 16–1

1. An oscillator differs from an amplifier because the oscillator

(a) has more gain **(b)** requires no input signal

(c) requires no dc supply **(d)** always has the same output

Section 16–2

2. One condition for oscillation is

(a) a phase shift around the feedback loop of 180°

(b) a gain around the feedback loop of one-third

(c) a phase shift around the feedback loop of 0°

(d) a gain around the feedback loop of less than 1

3. A second condition for oscillation is

(a) no gain around the feedback loop

(b) a gain of 1 around the feedback loop

(c) the attenuation of the feedback circuit must be one-third

(d) the feedback circuit must be capacitive

4. In a certain oscillator, $A_v = 50$. The attenuation of the feedback circuit must be

(a) 1 **(b)** 0.01 **(c)** 10 **(d)** 0.02

5. For an oscillator to properly start, the gain around the feedback loop must initially be

(a) 1 **(b)** less than 1 **(c)** greater than 1 **(d)** equal to B

Section 16–3

6. Wien-bridge oscillators are based on

(a) positive feedback **(b)** negative feedback

(c) the piezoelectric effect **(d)** high gain

7. In a Wien-bridge oscillator, if the resistances in the positive feedback circuit are decreased, the frequency

(a) decreases **(b)** increases **(c)** remains the same

8. The Wien-bridge oscillator's positive feedback circuit is

(a) an *RL* circuit **(b)** an *LC* circuit

(c) a voltage divider **(d)** a lead-lag circuit

9. A phase-shift oscillator has

(a) three *RC* circuits **(b)** three *LC* circuits

(c) a T-type circuit **(d)** a π-type circuit

Section 16–4

10. Colpitts, Clapp, and Hartley are names that refer to

(a) types of *RC* oscillators **(b)** inventors of the transistor

(c) types of *LC* oscillators **(d)** types of filters

11. The main feature of a crystal oscillator is

(a) economy **(b)** reliability **(c)** stability **(d)** high frequency

PROBLEMS

Answers to odd-numbered problems are at the end of the book.

BASIC PROBLEMS

Section 16–1 The Oscillator

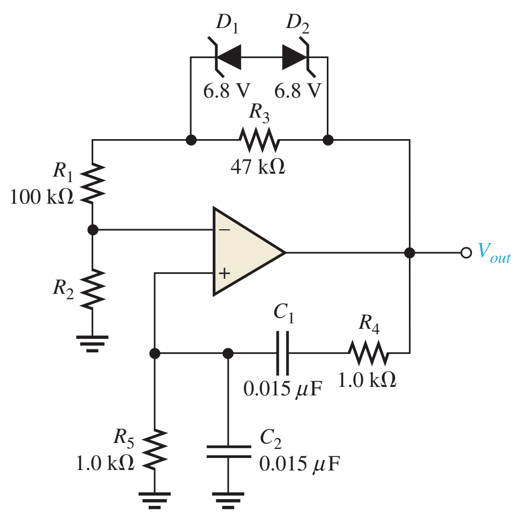
1. What type of input is required for an oscillator?
2. What are the basic components of an oscillator circuit?

Section 16–2 Feedback Oscillators

3. If the voltage gain of the amplifier portion of an oscillator is 75, what must be the attenuation of the feedback circuit to sustain the oscillation?
4. Generally describe the change required in the oscillator of Problem 3 in order for oscillation to begin when the power is initially turned on.

Section 16–3 Oscillators with *RC* Feedback Circuits

5. A certain lead-lag circuit has a resonant frequency of 3.5 kHz. What is the rms output voltage if an input signal with a frequency equal to f_r and with an rms value of 2.2 V is applied to the input?
6. Calculate the resonant frequency of a lead-lag circuit with the following values: $R_1 = R_2 = 6.2\ \text{k}\Omega$, and $C_1 = C_2 = 0.02\ \mu\text{F}$.
7. Determine the necessary value of R_2 in Figure 16–57 so that the circuit will oscillate. Neglect the forward resistance of the zener diodes. (*Hint:* The total gain of the circuit must be 3 when the zener diodes are conducting.)
8. Explain the purpose of R_3 in Figure 16–57.

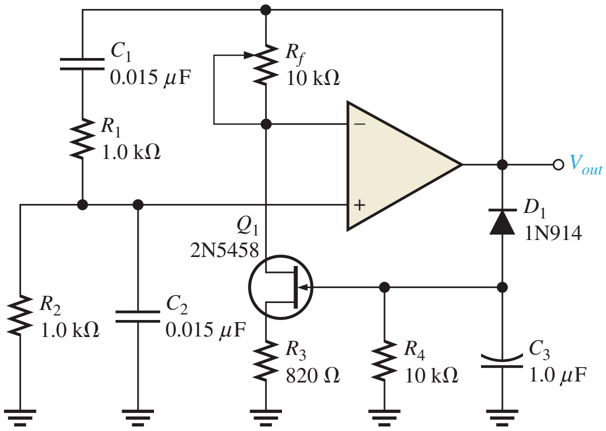


▲ FIGURE 16–57

9. For the Wien-bridge oscillator in Figure 16–58, calculate the setting for R_f, assuming the internal drain-source resistance, r'_{ds}, of the JFET is 350 Ω when oscillations are stable.
10. Find the frequency of oscillation for the Wien-bridge oscillator in Figure 16–58.

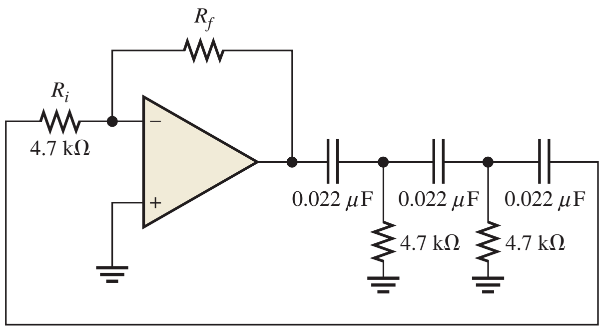
▶ FIGURE 16–58

Multisim file circuits are identified with a logo and are in the Problems folder on the companion website. Filenames correspond to figure numbers (e.g., F16-58).



11. What value of R_f is required in Figure 16–59? What is f_r?

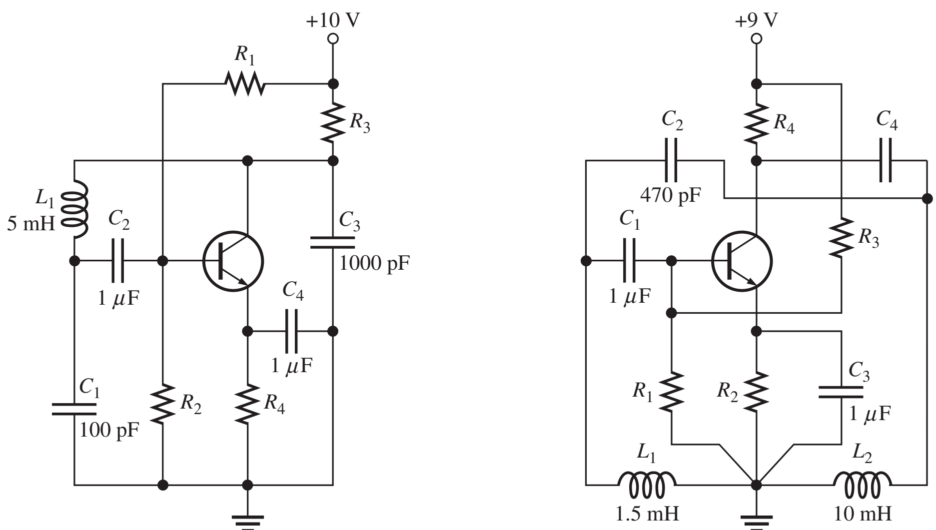
▶ FIGURE 16–59



Section 16–4 Oscillators with *LC* Feedback Circuits

12. Calculate the frequency of oscillation for each circuit in Figure 16–60 and identify the type of oscillator. Assume $Q > 10$ in each case.

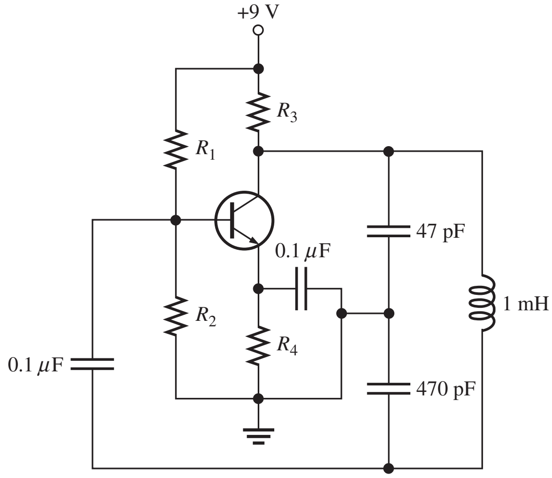
▶ FIGURE 16–60



(a) (b)

13. Determine what the gain of the amplifier stage must be in Figure 16–61 in order to have sustained oscillation.

▶ FIGURE 16–61



Section 16–5 Relaxation Oscillators

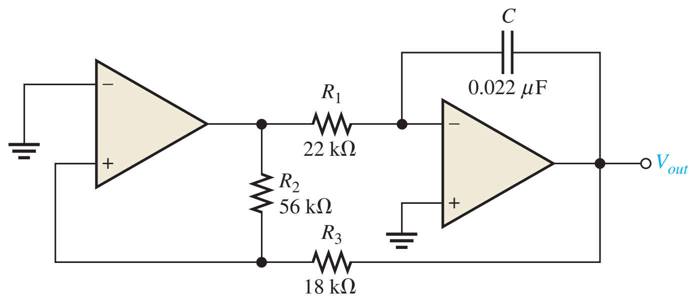
14. What type of signal does the circuit in Figure 16–62 produce? Determine the frequency of the output.

15. Show how to change the frequency of oscillation in Figure 16–62 to 10 kHz.

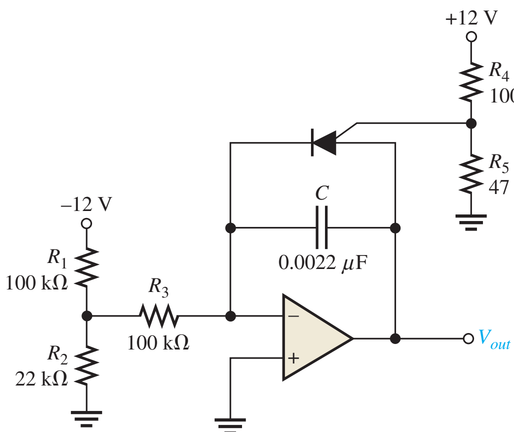
16. Determine the amplitude and frequency of the output voltage in Figure 16–63. Use 1 V as the forward PUT voltage.

17. Modify the sawtooth generator in Figure 16–63 so that its peak-to-peak output is 4 V.

▶ FIGURE 16–62



▶ FIGURE 16–63



18. A certain sawtooth generator has the following parameter values: $V_{IN} = 3$ V, $R = 4.7$ kΩ, $C = 0.001$ μF. Determine its peak-to-peak output voltage if the period is 10 μs.