3. Current is the rate of charge flow past a given point in a given direction.

$$i = \frac{dq}{dt}$$

4. Voltage is the energy required to move 1 C of charge from a reference point (−) to another point (+).

$$v_{ab} = \frac{dw}{dq}$$

5. Power is the energy supplied or absorbed per unit time. It is also the product of voltage and current.

$$p = \frac{dw}{dt} = vi$$

6. According to the passive sign convention, power assumes a positive sign when the current enters the positive polarity of the voltage across an element.
7. An ideal voltage source produces a specific potential difference across its terminals regardless of what is connected to it. An ideal current source produces a specific current through its terminals regardless of what is connected to it.
8. Voltage and current sources can be dependent or independent. A dependent source is one whose value depends on some other circuit variable.
9. Two areas of application of the concepts covered in this chapter are the TV picture tube and electricity billing procedure.

Review Questions

1.1 One millivolt is one millionth of a volt.

(a) True (b) False

1.2 The prefix *micro* stands for:

(a) 10^6 (b) 10^3 (c) 10^{-3} (d) 10^{-6}

1.3 The voltage 2,000,000 V can be expressed in powers of 10 as:

(a) 2 mV (b) 2 kV (c) 2 MV (d) 2 GV

1.4 A charge of 2 C flowing past a given point each second is a current of 2 A.

(a) True (b) False

1.5 The unit of current is:

(a) coulomb (b) ampere
(c) volt (d) joule

1.6 Voltage is measured in:

(a) watts (b) amperes
(c) volts (d) joules per second

1.7 A 4-A current charging a dielectric material will accumulate a charge of 24 C after 6 s.

(a) True (b) False

1.8 The voltage across a 1.1-kW toaster that produces a current of 10 A is:

(a) 11 kV (b) 1100 V (c) 110 V (d) 11 V

1.9 Which of these is not an electrical quantity?

(a) charge (b) time (c) voltage
(d) current (e) power

1.10 The dependent source in Fig. 1.22 is:

(a) voltage-controlled current source
(b) voltage-controlled voltage source
(c) current-controlled voltage source
(d) current-controlled current source

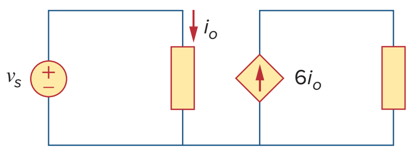


Figure 1.22
For Review Question 1.10.

Answers: 1.1b, 1.2d, 1.3c, 1.4a, 1.5b, 1.6c, 1.7a, 1.8c, 1.9b, 1.10d.

Problems

Section 1.3 Charge and Current

1.1 How much charge is represented by these number of electrons?

(a) 6.482×10^{17}

(b) 1.24×10^{18}

(c) 2.46×10^{19}

(d) 1.628×10^{20}

1.2 Determine the current flowing through an element if the charge flow is given by

(a) $q(t) = (3)$ mC

(b) $q(t) = (4t^2 + 20t - 4)$ C

(c) $q(t) = (15e^{-3t} - 2e^{-18t})$ nC

(d) $q(t) = 5t^2(3t^3 + 4)$ pC

(e) $q(t) = 2e^{-3t} \sin(20\pi t)$ μC

1.3 Find the charge $q(t)$ flowing through a device if the current is:

(a) $i(t) = 3$ A, $q(0) = 1$ C

(b) $i(t) = (2t + 5)$ mA, $q(0) = 0$

(c) $i(t) = 20\cos(10t + \pi/6)$ μA, $q(0) = 2\,\mu$C

(d) $i(t) = 10e^{-30t}\sin 40t$ A, $q(0) = 0$

1.4 A total charge of 300 C flows past a given cross section of a conductor in 30 seconds. What is the value of the current?

1.5 Determine the total charge transferred over the time interval of $0 \leq t \leq 10$ s when $i(t) = \frac{1}{2}t$ A.

1.6 The charge entering a certain element is shown in Fig. 1.23. Find the current at:

(a) $t = 1$ ms (b) $t = 6$ ms (c) $t = 10$ ms

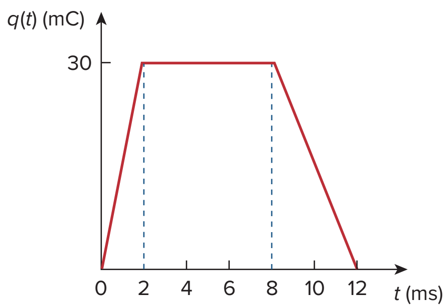


Figure 1.23
For Prob. 1.6.

1.7 The charge flowing in a wire is plotted in Fig. 1.24. Sketch the corresponding current.

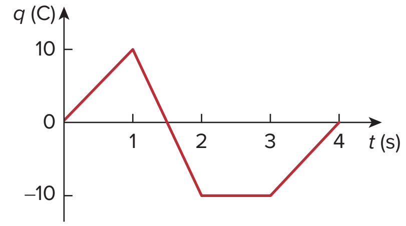


Figure 1.24
For Prob. 1.7.

1.8 The current flowing past a point in a device is shown in Fig. 1.25. Calculate the total charge through the point.

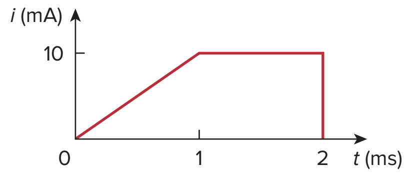


Figure 1.25
For Prob. 1.8.

1.9 The current through an element is shown in Fig. 1.26. Determine the total charge that passed through the element at:

(a) $t = 1$ s (b) $t = 3$ s (c) $t = 5$ s

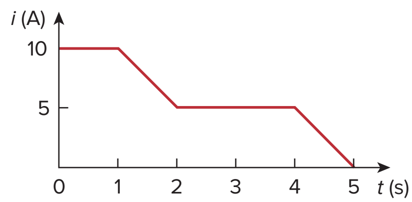


Figure 1.26
For Prob. 1.9.

Sections 1.4 and 1.5 Voltage, Power, and Energy

1.10 A lightning bolt with 10 kA strikes an object for 15 μs. How much charge is deposited on the object?

1.11 A rechargeable flashlight battery is capable of delivering 90 mA for about 12 h. How much charge can it release at that rate? If its terminal voltage is 1.5 V, how much energy can the battery deliver?

1.12 If the current flowing through an element is given by

$$i(t) = \begin{cases} 3t\text{A}, & 0 \leqq t < 6 \text{ s} \\ 18\text{A}, & 6 \leqq t < 10 \text{ s} \\ -12\text{A}, & 10 \leqq t < 15 \text{ s} \\ 0, & t \geqq 15 \text{ s} \end{cases}$$

Plot the charge stored in the element over $0 < t < 20$ s.

1.13 The charge entering the positive terminal of an element is

$$q = 5 \sin 4\pi t \text{ mC}$$

while the voltage across the element (plus to minus) is

$$v = 3 \cos 4\pi t \text{ V}$$

(a) Find the power delivered to the element at $t = 0.3$ s.

(b) Calculate the energy delivered to the element between 0 and 0.6 s.

1.14 The voltage $v(t)$ across a device and the current $i(t)$ through it are

$$v(t) = 20 \sin (4t) \text{ V and } i(t) = 10(1 + e^{-2t}) \text{ mA}$$

Calculate:

(a) the total charge in the device at $t = 1$ *s*, $q(0) = 0$.

(b) the power consumed by the device at $t = 1$ s.

1.15 The current entering the positive terminal of a device is $i(t) = 6e^{-2t}$ mA and the voltage across the device is $v(t) = 10di/dt$V.

(a) Find the charge delivered to the device between $t = 0$ and $t = 2$ s.

(b) Calculate the power absorbed.

(c) Determine the energy absorbed in 3 s.

Section 1.6 Circuit Elements

1.16 Figure 1.27 shows the current through and the voltage across an element.

(a) Sketch the power delivered to the element for $t > 0$.

(b) Fnd the total energy absorbed by the element for the period of $0 < t < 4$s.

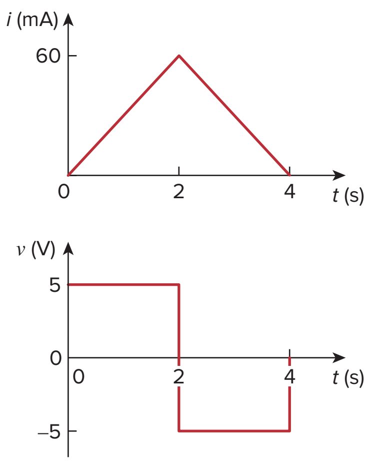


Figure 1.27
For Prob. 1.16.

1.17 Figure 1.28 shows a circuit with four elements, $p_1 = 60$ W absorbed, $p_3 = -145$ W absorbed, and $p_4 = 75$ W absorbed. How many watts does element 2 absorb?

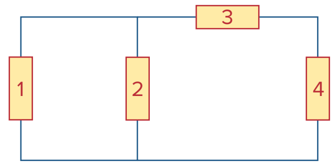


Figure 1.28
For Prob. 1.17.

1.18 Find the power absorbed by each of the elements in Fig. 1.29.

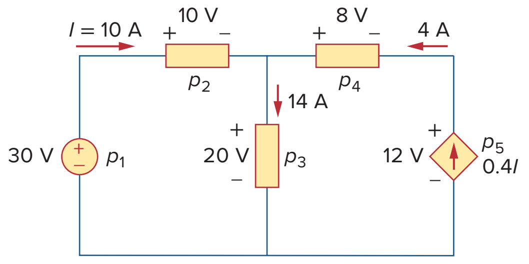


Figure 1.29
For Prob. 1.18.

1.19 Find I and the power absorbed by each element in the network of Fig. 1.30.

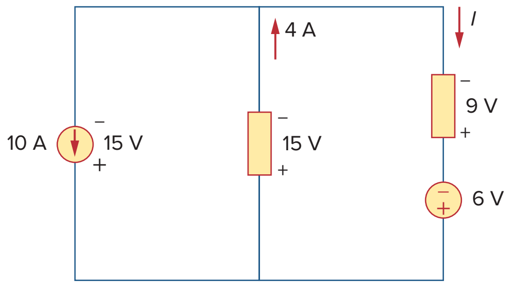


Figure 1.30
For Prob. 1.19.

1.20 Find V_o and the power absorbed by each element in the circuit of Fig. 1.31.

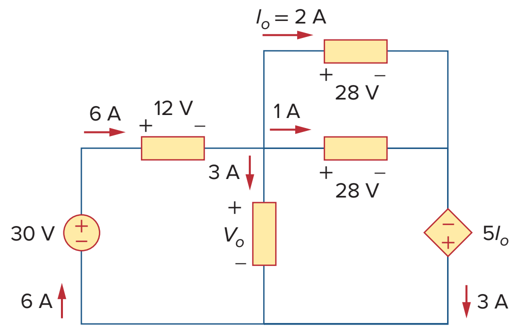


Figure 1.31
For Prob. 1.20.

Section 1.7 Applications

1.21 A 60-W incandescent bulb operates at 120 V. How many electrons and coulombs flow through the bulb in one day?

1.22 A lightning bolt strikes an airplane with 40 kA for 1.7 ms. How many coulombs of charge are deposited on the plane?

1.23 A 1.8-kW electric heater takes 15 min to boil a quantity of water. If this is done once a day and power costs 10 cents/kWh, what is the cost of its operation for 30 days?

1.24 A utility company charges 8.2 cents/kWh. If a consumer operates a 60-W light bulb continuously for one day, how much is the consumer charged?

1.25 A 1.2-kW toaster takes roughly 4 minutes to heat four slices of bread. Find the cost of operating the toaster twice per day for 2 weeks (14 days). Assume energy costs 9 cents/kWh.

1.26 A cell phone battery is rated at 3.85 V and can store 10.78 watt-hours of energy.

(a) How much average current can it deliver over a period of 3 hours if it is fully discharged at the end of that time?

(b) How much average power is delivered in part (a)?

(c) What is the ampere-hour rating of the battery?

1.27 A constant current of 3 A for 4 hours is required to charge an automotive battery. If the terminal voltage is $10 + t/2$V, where t is in hours,

(a) how much charge is transported as a result of the charging?

(b) how much energy is expended?

(c) how much does the charging cost? Assume electricity costs 9 cents/kWh.

1.28 A 150-W incandescent outdoor lamp is connected to a 120-V source and is left burning continuously for an average of 12 hours per day. Determine:

(a) the current through the lamp when it is lit.

(b) the cost of operating the light for one non-leap year if electricity costs 9.5 cents per kWh.

1.29 An electric stove with four burners and an oven is used in preparing a meal as follows.

Burner 1: 20 minutes Burner 2: 40 minutes

Burner 3: 15 minutes Burner 4: 45 minutes

Oven: 30 minutes

If each b urner is rated at 1.2 kW and the o ven at 1.8 kW, and electricity costs 12 cents per kWh, calculate the cost of electricity used in preparing the meal.

1.30 Reliant Energy (the electric company in Houston, Texas) charges customers as follows:

Monthly charge \$6

First 250 kWh @ \$0.02/kWh

All additional kWh @ \$0.07/kWh

If a customer uses 2,436 kWh in one month, ho w much will Reliant Energy charge?

1.31 In a household, a business is run for an average of 6 h/day. The total power consumed by the computer and its printer is 230 W. In addition, a 75-W light runs during the same 6 h. If their utility charges 11.75 cents per kWh, how much do the owners pay every 30 days?

Comprehensive Problems

1.32 A telephone wire has a current of 20μA flowing through it. How long does it take for a charge of 15 C to pass through the wire?

1.33 A lightning bolt carried a current of 2 kA and lasted for 3 ms. How many coulombs of charge were contained in the lightning bolt?

1.34 Figure 1.32 shows the power consumption of a certain household in 1 day. Calculate:

(a) the total energy consumed in kWh,

(b) the average power over the total 24 hour period.

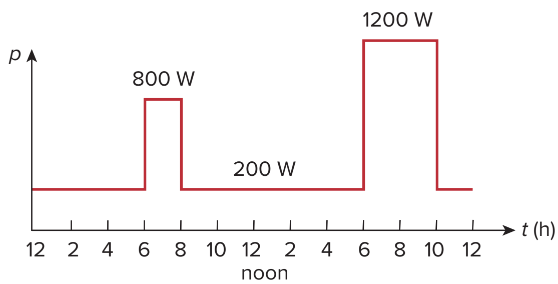


Figure 1.32
For Prob. 1.34.

1.35 The graph in Fig. 1.33 represents the power drawn by an industrial plant between 8:00 and 8:30 a.m. Calculate the total energy in MWh consumed by the plant.

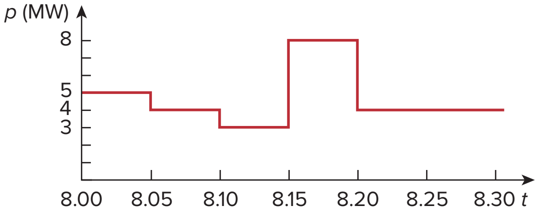


Figure 1.33
For Prob. 1.35.

1.36 A battery can be rated in ampere-hours (Ah) or watt hours (Wh). The ampere hours can be obtained from the watt hours by dividing watt hours by a nominal voltage of 12 V. If an automobile battery is rated at 20 Ah:

(a) What is the maximum current that can be supplied for 15 minutes?

(b) How many days will it last if it is discharged at a rate of 2 mA?

1.37 A total of 2 MJ are delivered to an automobile battery (assume 12 V) giving it an additional charge. How much is that additional charge? Express your answer in ampere-hours.

1.38 How much energy does a 10-hp motor deliver in 30 minutes? Assume that 1 horsepower = 746 W.

1.39 A 600-W TV receiver is turned on for 4 h with nobody watching it. If electricity costs 10 cents/kWh, how much money is wasted?

10. The voltage division principle for two resistors in series is

$$v_1 = \frac{R_1}{R_1 + R_2} v, \qquad v_2 = \frac{R_2}{R_1 + R_2} v$$

11. The current division principle for two resistors in parallel is

$$i_1 = \frac{R_2}{R_1 + R_2} i, \qquad i_2 = \frac{R_1}{R_1 + R_2} i$$

12. The formulas for a delta-to-wye transformation are

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}, \qquad R_2 = \frac{R_c R_a}{R_a + R_b + R_c}$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$

13. The formulas for a wye-to-delta transformation are

$$R_a = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}, \qquad R_b = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$$

$$R_c = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$

14. The basic laws covered in this chapter can be applied to the problems of electrical lighting and design of dc meters.

Review Questions

2.1 The reciprocal of resistance is:

(a) voltage (b) current
(c) conductance (d) coulombs

2.2 An electric heater draws 10 A from a 120-V line. The resistance of the heater is:

(a) 1200 Ω (b) 120 Ω
(c) 12 Ω (d) 1.2 Ω

2.3 The voltage drop across a 1.5-kW toaster that draws 12 A of current is:

(a) 18 kV (b) 125 V
(c) 120 V (d) 10.42 V

2.4 The maximum current that a 2W, 80 kΩ resistor can safely conduct is:

(a) 160 kA (b) 40 kA
(c) 5 mA (d) 25 μA

2.5 A network has 12 branches and 8 independent loops. How many nodes are there in the network?

(a) 19 (b) 17 (c) 5 (d) 4

2.6 The current I in the circuit of Fig. 2.63 is:

(a) −0.8 A (b) −0.2 A
(c) 0.2 A (d) 0.8 A

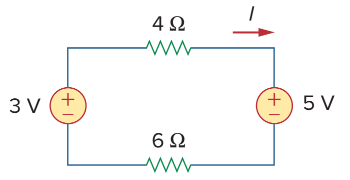


Figure 2.63
For Review Question 2.6.

2.7 The current I_o of Fig. 2.64 is:

(a) −4 A (b) −2 A (c) 4 A (d) 16 A

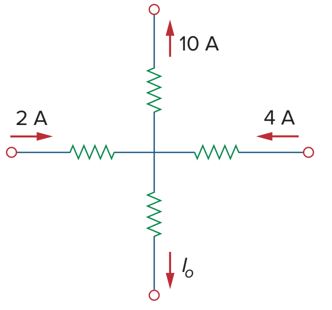


Figure 2.64
For Review Question 2.7.

2.8 In the circuit in Fig. 2.65, V is:

(a) 30 V (b) 14 V (c) 10 V (d) 6 V

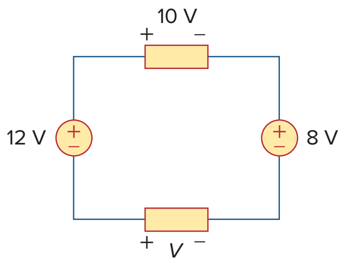


Figure 2.65
For Review Question 2.8.

2.9 Which of the circuits in Fig. 2.66 will give you $V_{ab} = 7$ V?

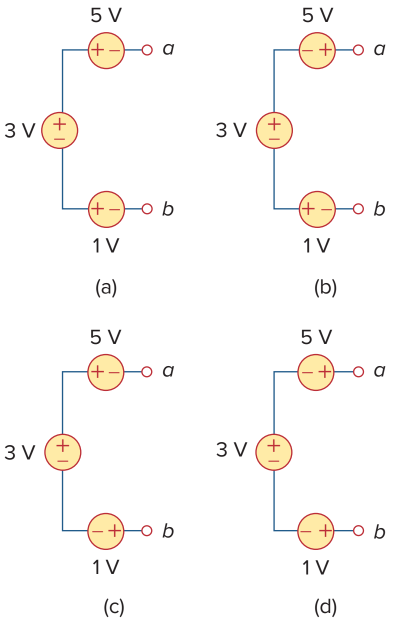


Figure 2.66
For Review Question 2.9.

2.10 In the circuit of Fig. 2.67, a decrease in R_3 leads to a decrease of, select all that apply:

(a) current through R_3

(b) voltage across R_3

(c) voltage across R_1

(d) power dissipated in R_2

(e) none of the above

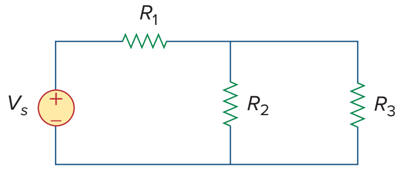


Figure 2.67
For Review Question 2.10.

Answers: 2.1c, 2.2c, 2.3b, 2.4c, 2.5c, 2.6b, 2.7a, 2.8d, 2.9d, 2.10b, d.

Problems

Section 2.2 Ohm's Law

2.1 Design a problem, complete with a solution, to help students to better understand Ohm's law. Use at least two resistors and one voltage source. Hint, you could use both resistors at once or one at a time, it is up to you. Be creative.

2.2 Find the hot resistance of a light bulb rated 60 W, 120 V.

2.3 A bar of silicon is 4 cm long with a circular cross section. If the resistance of the bar is 240 Ω at room temperature, what is the cross-sectional radius of the bar?

2.4 (a) Calculate current i in Fig. 2.68 when the switch is in position 1.
(b) Find the current when the switch is in position 2.

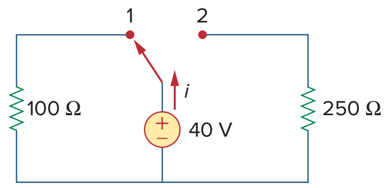


Figure 2.68
For Prob. 2.4.

Section 2.3 Nodes, Branches, and Loops

2.5 For the network graph in Fig. 2.69, find the number of nodes, branches, and loops.

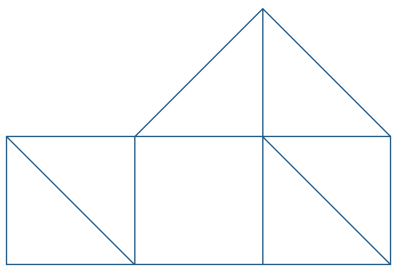


Figure 2.69
For Prob. 2.5.

2.6 In the network graph shown in Fig. 2.70, determine the number of branches and nodes.

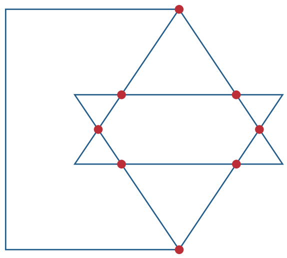


Figure 2.70
For Prob. 2.6.

2.7 Determine the number of branches and nodes in the circuit of Fig. 2.71.

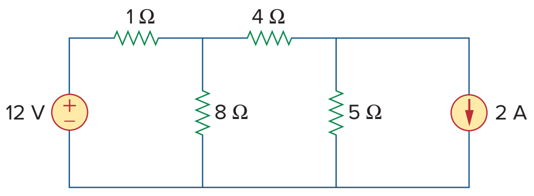


Figure 2.71
For Prob. 2.7.

Section 2.4 Kirchhoff's Laws

2.8 Design a problem, complete with a solution, to help other students better understand Kirchhoff's Current Law. Design the problem by specifying values of i_a, i_b, and i_c, shown in Fig. 2.72, and asking them to solve for values of i_1, i_2, and i_3. Be careful to specify realistic currents.

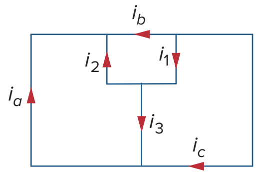


Figure 2.72
For Prob. 2.8.

2.9 Find i_1, i_2, and i_3 in Fig. 2.73.

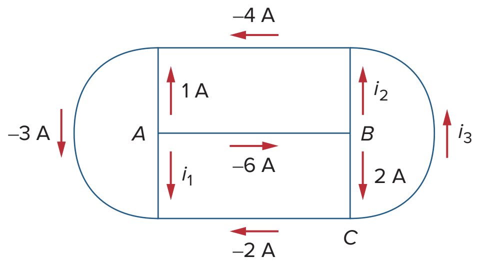


Figure 2.73
For Prob. 2.9.

2.10 Determine i_1 and i_2 in the circuit of Fig. 2.74.

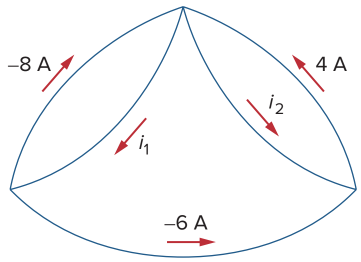


Figure 2.74
For Prob. 2.10.

2.11 In the circuit of Fig. 2.75, calculate V_1 and V_2.

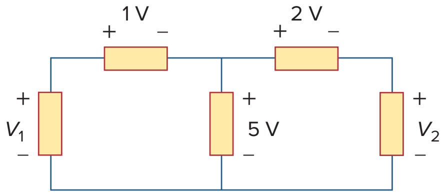


Figure 2.75
For Prob. 2.11.

2.12 In the circuit in Fig. 2.76, obtain v_1, v_2, and v_3.

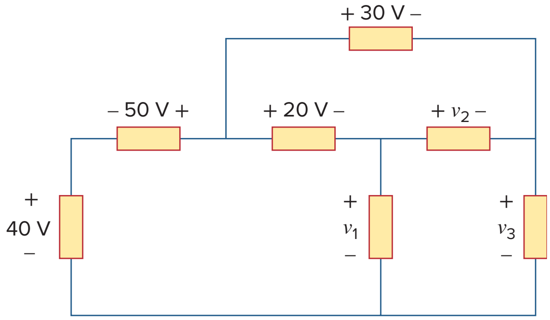


Figure 2.76
For Prob. 2.12.

2.13 For the circuit in Fig. 2.77, use KCL to find the branch currents I_1 to I_4.

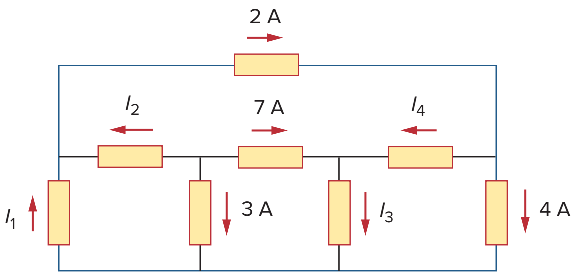


Figure 2.77
For Prob. 2.13.

2.14 Given the circuit in Fig. 2.78, use KVL to find the branch voltages V_1 to V_4.

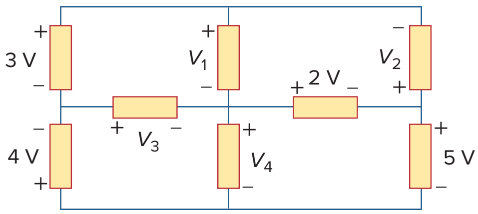


Figure 2.78
For Prob. 2.14.

2.15 Calculate v and i_x in the circuit of Fig. 2.79.

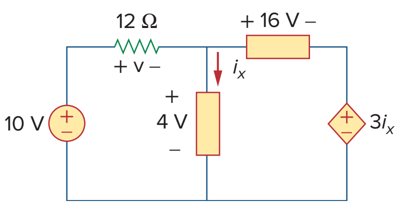


Figure 2.79
For Prob. 2.15.

2.16 Determine V_o in the circuit in Fig. 2.80.

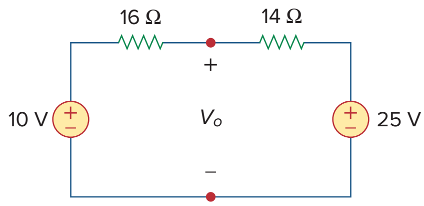


Figure 2.80
For Prob. 2.16.

2.17 Obtain v_1 through v_3 in the circuit of Fig. 2.81.

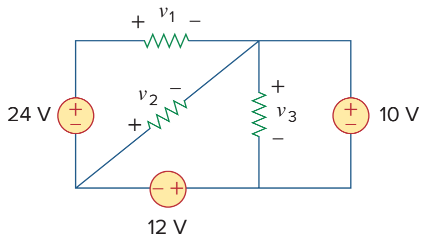


Figure 2.81
For Prob. 2.17.

2.18 Find I and V in the circuit of Fig. 2.82.

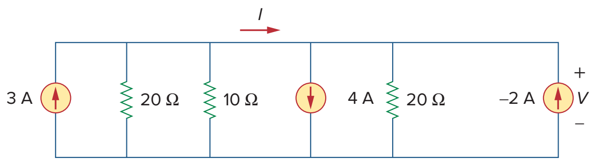


Figure 2.82
For Prob. 2.18.

2.19 From the circuit in Fig. 2.83, find I, the power dissipated by the resistor, and the power supplied by each source.

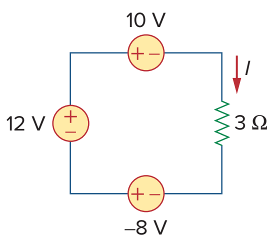


Figure 2.83
For Prob. 2.19.

2.20 Determine i_o in the circuit of Fig. 2.84.

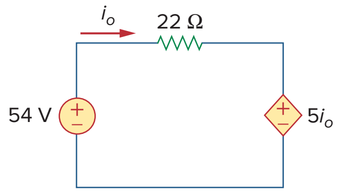


Figure 2.84
For Prob. 2.20.

2.21 Find V_x in the circuit of Fig. 2.85.

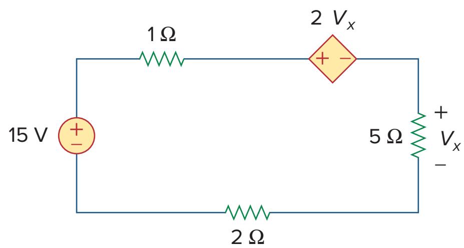


Figure 2.85
For Prob. 2.21.

2.22 Find V_o in the circuit in Fig. 2.86 and the power absorbed by the dependent source.

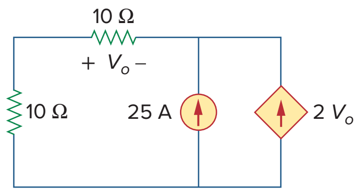


Figure 2.86
For Prob. 2.22.

2.23 In the circuit shown in Fig. 2.87, determine V_x and the power absorbed by the 60-Ω resistor.

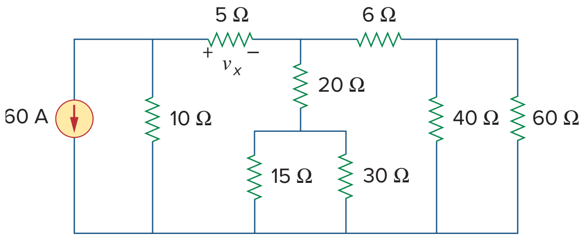


Figure 2.87
For Prob. 2.23.

2.24 For the circuit in Fig. 2.88, find V_o/V_s in terms of α, R_1, R_2, R_3, and R_4. If $R_1 = R_2 = R_3 = R_4$, what value of α will produce $|V_o/V_s| = 10$?

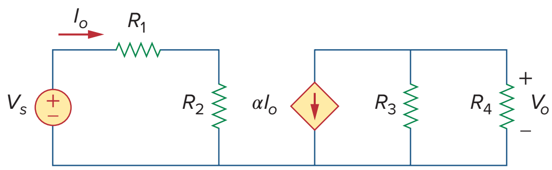


Figure 2.88
For Prob. 2.24.

2.25 For the network in Fig. 2.89, find the current, voltage, and power associated with the 20-kΩ resistor.

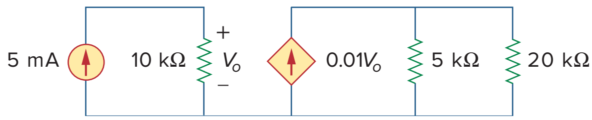


Figure 2.89
For Prob. 2.25.

Sections 2.5 and 2.6 Series and Parallel Resistors

2.26 For the circuit in Fig. 2.90, $i_o = 3$ A. Calculate i_x and the total power absorbed by the entire circuit.

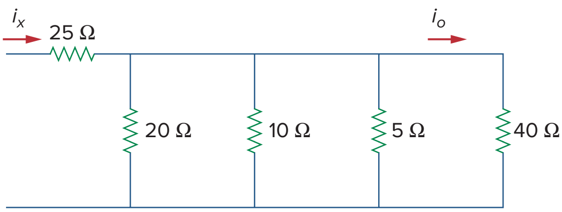


Figure 2.90
For Prob. 2.26.

2.27 Calculate I_o in the circuit of Fig. 2.91.

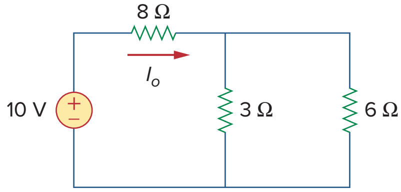


Figure 2.91
For Prob. 2.27.

2.28 Design a problem, using Fig. 2.92, to help other students better understand series and parallel circuits.

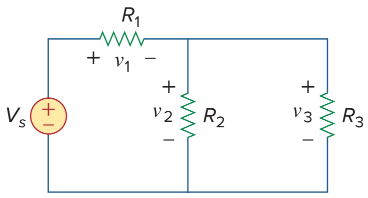


Figure 2.92
For Prob. 2.28.

2.29 All resistors (R) in Fig. 2.93 are 10 Ω each. Find R_{eq}.

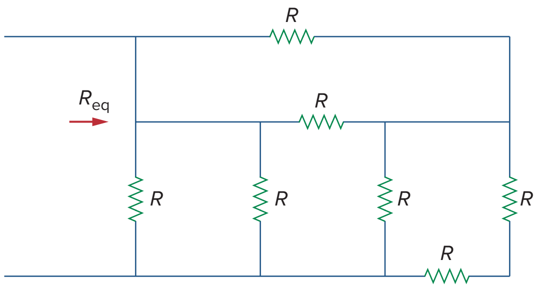


Figure 2.93
For Prob. 2.29.

2.30 Find R_{eq} for the circuit in Fig. 2.94.

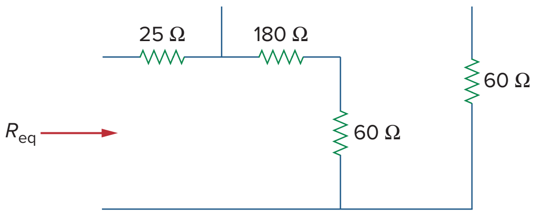


Figure 2.94
For Prob. 2.30.

2.31 For the circuit in Fig. 2.95, determine i_1 to i_5.

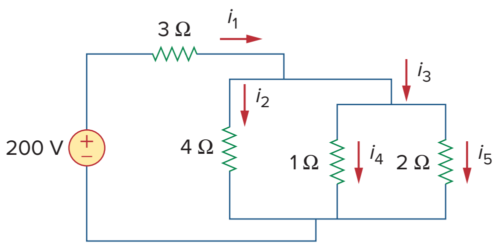


Figure 2.95
For Prob. 2.31.

2.32 Find i_1 through i_4 in the circuit in Fig. 2.96.

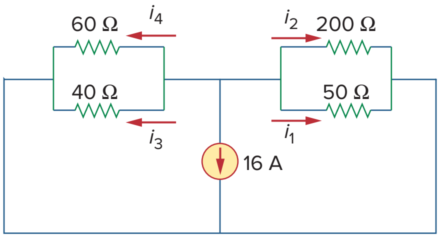


Figure 2.96
For Prob. 2.32.

2.33 Obtain v and i in the circuit of Fig. 2.97.

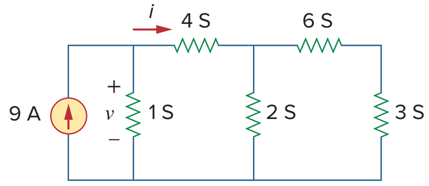


Figure 2.97
For Prob. 2.33.

2.34 Using series/parallel resistance combination, find the equivalent resistance seen by the source in the circuit of Fig. 2.98. Find the overall absorbed power by the resistor network.

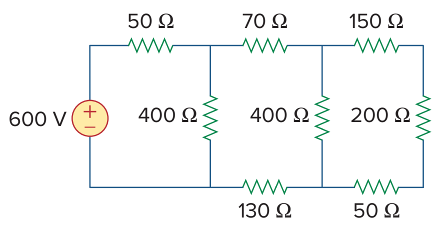


Figure 2.98
For Prob. 2.34.

2.35 Calculate V_o and I_o in the circuit of Fig. 2.99.

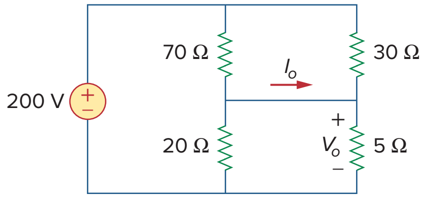


Figure 2.99
For Prob. 2.35.

2.36 Find i and V_o in the circuit of Fig. 2.100.

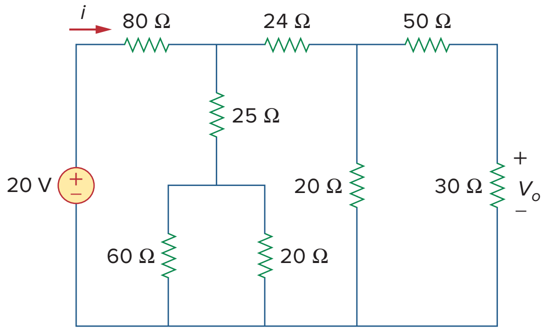


Figure 2.100
For Prob. 2.36.

2.37 Given the circuit in Fig. 2.101 and that the resistance, R_{eq}, looking into the circuit from the left is equal to 100 Ω, determine the value of R_1.

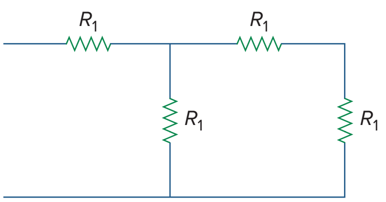


Figure 2.101
For Prob. 2.37.

2.38 Find R_{eq} and i_o in the circuit of Fig. 2.102.

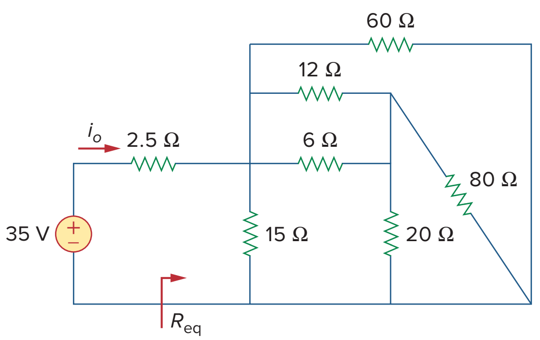


Figure 2.102
For Prob. 2.38.

2.39 Evaluate R_{eq} looking into each set of terminals for each of the circuits shown in Fig. 2.103.

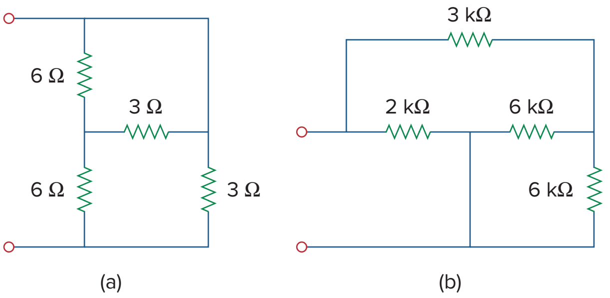


Figure 2.103
For Prob. 2.39.

2.40 For the ladder network in Fig. 2.104, find I and R_{eq}.

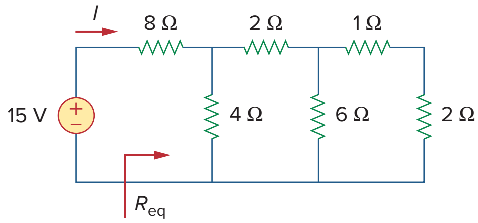


Figure 2.104
For Prob. 2.40.

2.41 If $R_{eq} = 50\ \Omega$ in the circuit of Fig. 2.105, find R.

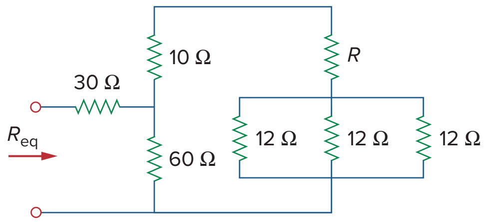
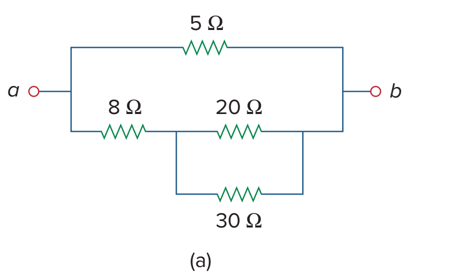


Figure 2.105
For Prob. 2.41.

2.42 Reduce each of the circuits in Fig. 2.106 to a single resistor at terminals a-b.



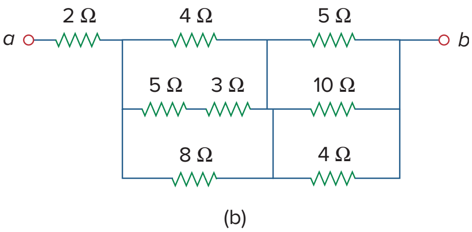


Figure 2.106
For Prob. 2.42.

2.43 Calculate the equivalent resistance R_{ab} at terminals *a-b* for each of the circuits in Fig. 2.107.

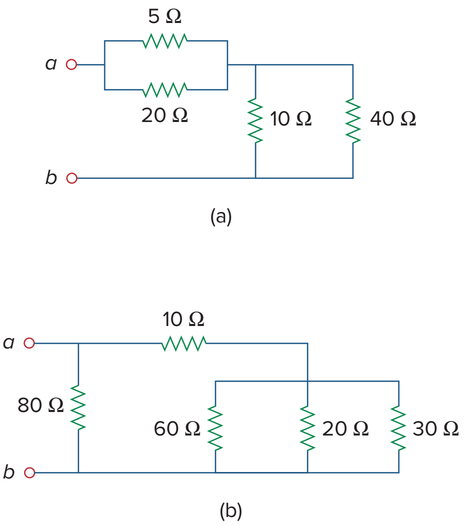


Figure 2.107
For Prob. 2.43.

2.44 For the circuits in Fig. 2.108, obtain the equivalent resistance at terminals *a-b*.

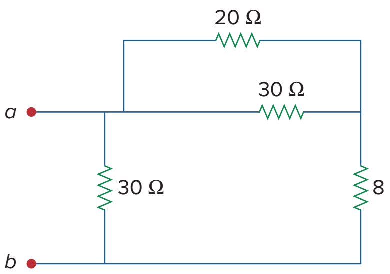


Figure 2.108
For Prob. 2.44.

2.45 Find the equivalent resistance at terminals *a-b* of each circuit in Fig. 2.109.

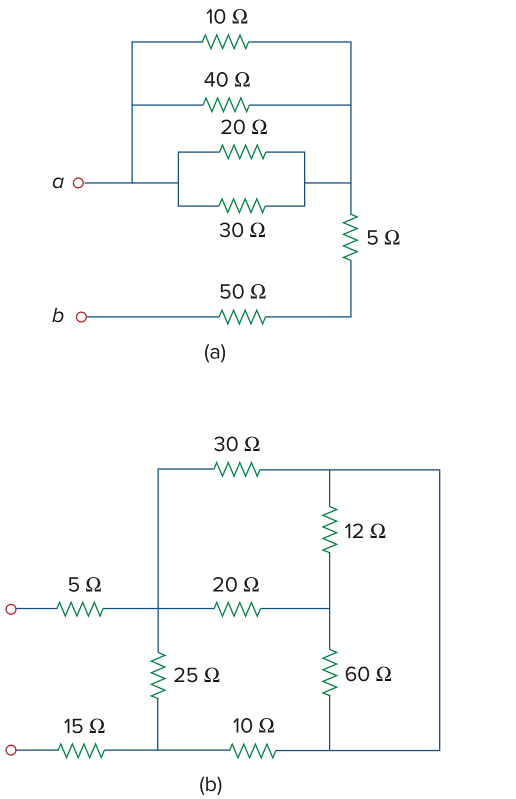


Figure 2.109
For Prob. 2.45.

2.46 Find *I* in the circuit of Fig. 2.110.

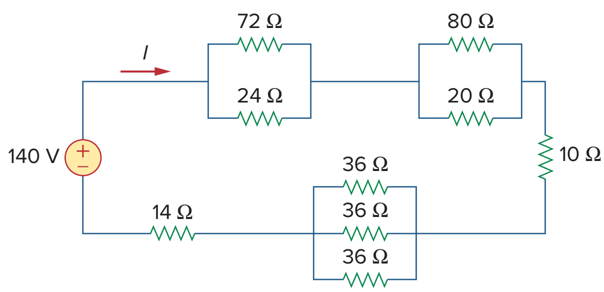


Figure 2.110
For Prob. 2.46.

2.47 Find the equivalent resistance R_{ab} in the circuit of Fig. 2.111.

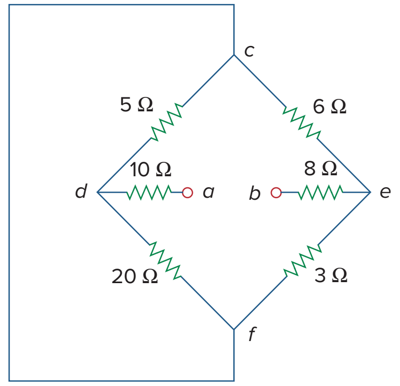


Figure 2.111
For Prob. 2.47.

Section 2.7 Wye-Delta Transformations

2.48 Convert the circuits in Fig. 2.112 from Y to Δ.

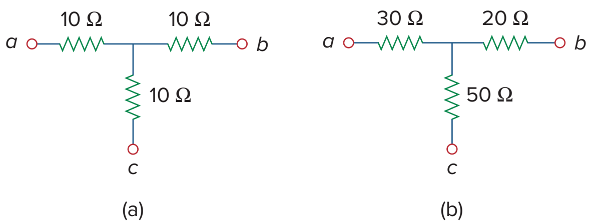


Figure 2.112
For Prob. 2.48.

2.49 Transform the circuits in Fig. 2.113 from Δ to Y.

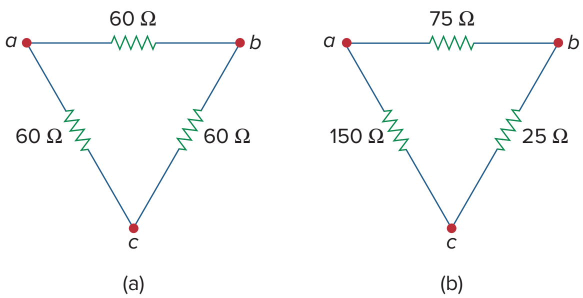


Figure 2.113
For Prob. 2.49.

2.50 Design a problem to help other students better understand wye-delta transformations using Fig. 2.114.

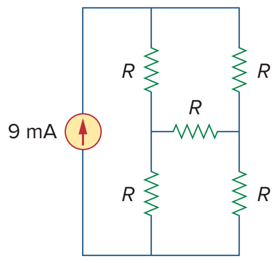


Figure 2.114
For Prob. 2.50.

2.51 Obtain the equivalent resistance at the terminals *a-b* for each of the circuits in Fig. 2.115.

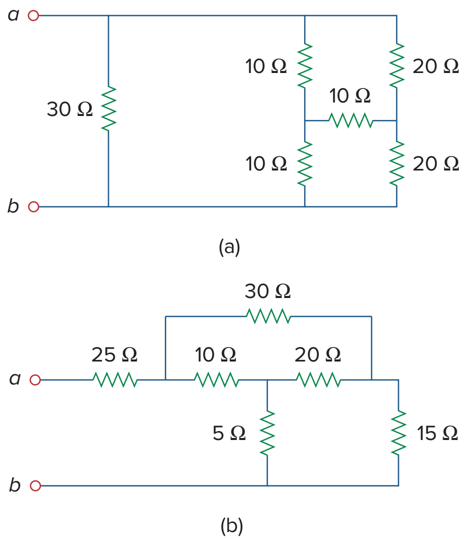


Figure 2.115
For Prob. 2.51.

***2.52** For the circuit shown in Fig. 2.116, find the equivalent resistance. All resistors are 3Ω.

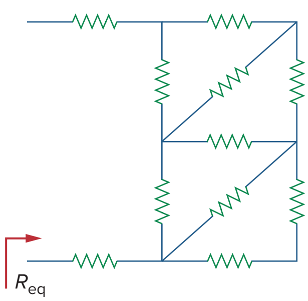


Figure 2.116
For Prob. 2.52.

* An asterisk indicates a challenging problem.

***2.53** Obtain the equivalent resistance R_{ab} in each of the circuits of Fig. 2.117. In (b), all resistors have a value of 30 Ω.

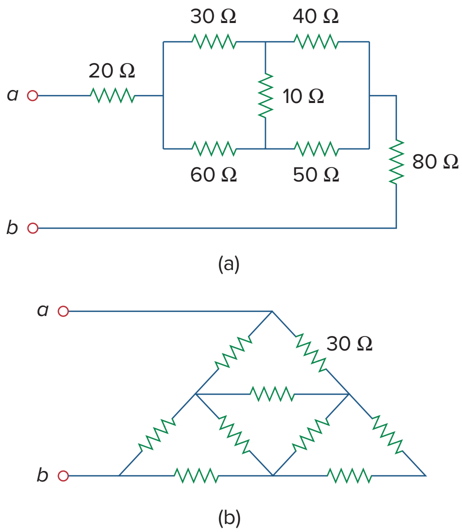


Figure 2.117
For Prob. 2.53.

2.54 Consider the circuit in Fig. 2.118. Find the equivalent resistance at terminals: (a) *a-b*, (b) *c-d*.

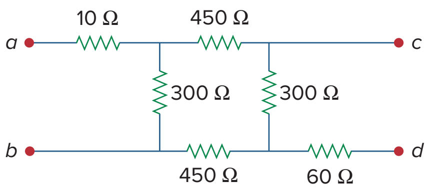


Figure 2.118
For Prob. 2.54.

2.55 Calculate I_o in the circuit of Fig. 2.119.

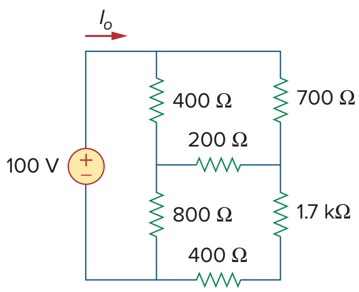


Figure 2.119
For Prob. 2.55.

2.56 Determine V in the circuit of Fig. 2.120.

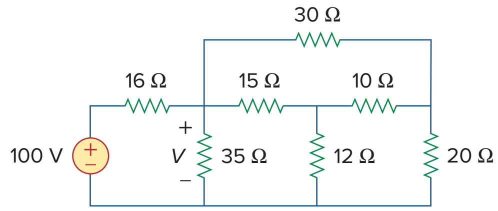


Figure 2.120
For Prob. 2.56.

***2.57** Find R_{eq} and I in the circuit of Fig. 2.121.

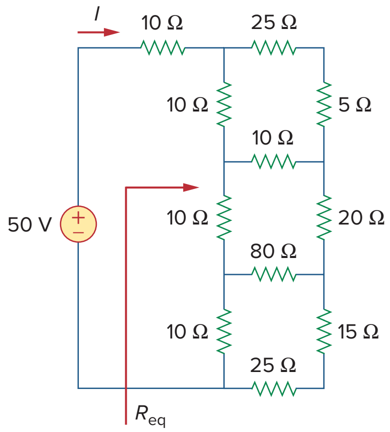


Figure 2.121
For Prob. 2.57.

Section 2.8 Applications

2.58 The 150 W light bulb in Fig. 2.122 is rated at 110 volts. Calculate the value of V_s to make the light bulb operate at its rated conditions.

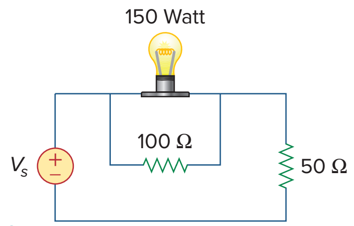


Figure 2.122
For Prob. 2.58.

2.59 An enterprising young man travels to Europe carrying three light bulbs he had purchased in North America. The light bulbs he has are a 100-W light bulb, a 60-W light bulb, and a 40-W light bulb. Each light bulb is rated at 110 V. He wishes to connect these to a 220-V system that is found in Europe. For reasons we are not sure of, he connects the 40-W light bulb in series with a parallel combination of the 60-W light bulb and the 100-W light bulb as shown in Fig. 2.123. How much power is actually being delivered to each light bulb? What does he see when he first turns on the light bulbs?

Is there a better way to connect these light bulbs in order to have them work more effectively?

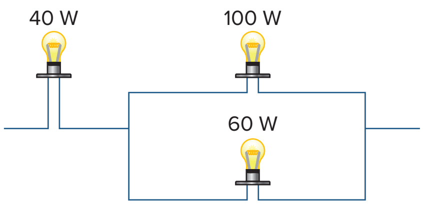


Figure 2.123
For Prob. 2.59.

2.60 If the three bulbs of Prob. 2.59 are connected in parallel to the 120-V source, calculate the current through each bulb.

2.61 As a design engineer, you are asked to design a lighting system consisting of a 70-W power supply and two light bulbs as shown in Fig. 2.124. You must select the two bulbs from the following three available bulbs.

$R_1 = 80\ \Omega$, cost = \$0.60 (standard size)
$R_2 = 90\ \Omega$, cost = \$0.90 (standard size)
$R_3 = 100\ \Omega$, cost = \$0.75 (nonstandard size)

The system should be designed for minimum cost such that I lies within the range $I = 1.2\text{ A} \pm 5$ percent.

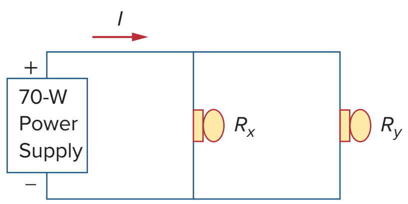


Figure 2.124
For Prob. 2.61.

2.62 A three-wire system supplies two loads A and B as shown in Fig. 2.125. Load A consists of a motor drawing a current of 8 A, while load B is a PC drawing 2 A. Assuming 10 h/day of use for 365 days and 6 cents/kWh, calculate the annual energy cost of the system.

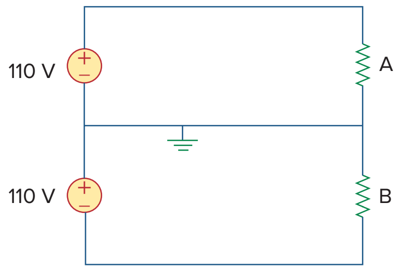


Figure 2.125

2.63 If an ammeter with an internal resistance of 100 Ω and a current capacity of 2 mA is to measure 5 A, determine the value of the resistance needed. Calculate the power dissipated in the shunt resistor.

2.64 The potentiometer (adjustable resistor) R_x in Fig. 2.126 is to be designed to adjust current i_x from 10 mA to 1 A. Calculate the values of R and R_x to achieve this.

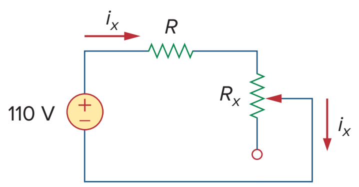


Figure 2.126
For Prob. 2.64.

2.65 Design a circuit that uses a d'Arsonval meter (with an internal resistance of 2 kΩ that requires a current of 5 mA to cause the meter to deflect full scale) to build a voltmeter to read values of voltages up to 100 volts.

2.66 A 20-kΩ/V voltmeter reads 10 V full scale.

(a) What series resistance is required to make the meter read 50 V full scale?

(b) What power will the series resistor dissipate when the meter reads full scale?

2.67 (a) Obtain the voltage V_o in the circuit of Fig. 2.127(a).

(b) Determine the voltage V_o' measured when a voltmeter with 6-kΩ internal resistance is connected as shown in Fig. 2.127(b).

(c) The finite resistance of the meter introduces an error into the measurement. Calculate the percent error as

$$\left| \frac{V_o - V_o'}{V_o} \right| \times 100\ \%$$

(d) Find the percent error if the internal resistance were 36 kΩ.

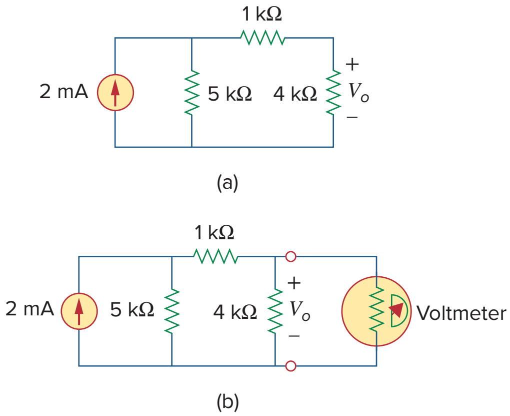


Figure 2.127
For Prob. 2.67.

2.68 (a) Find the current I in the circuit of Fig. 2.128(a).
(b) An ammeter with an internal resistance of 1 Ω is inserted in the network to measure I' as shown in Fig. 2.128(b). What is I'?
(c) Calculate the percent error introduced by the meter as

$$\left| \frac{I - I'}{I} \right| \times 100\%$$

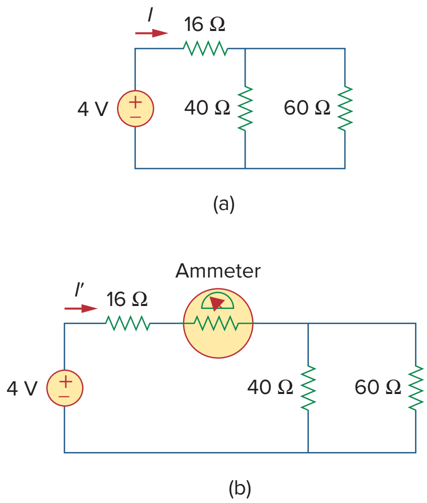


Figure 2.128
For Prob. 2.68.

2.69 A voltmeter is used to measure V_o in the circuit in Fig. 2.129. The voltmeter model consists of an ideal voltmeter in parallel with a 250-kΩ resistor. Let $V_s = 95$ V, $R_s = 25$ kΩ, and $R_1 = 40$ kΩ. Calculate V_o with and without the voltmeter when

(a) $R_2 = 5$ kΩ (b) $R_2 = 25$ kΩ

(c) $R_2 = 250$ kΩ

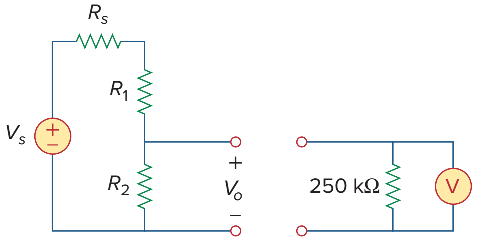


Figure 2.129
For Prob. 2.69.

2.70 (a) Consider the Wheatstone bridge shown in Fig. 2.130. Calculate v_a, v_b, and v_{ab}.

(b) Rework part (a) if the ground is placed at a instead of o.

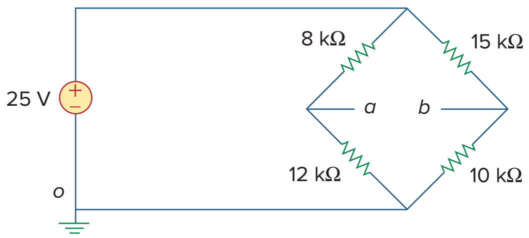


Figure 2.130
For Prob. 2.70.

2.71 Figure 2.131 represents a model of a solar photovoltaic panel. Given that $V_s = 95$ V, $R_1 = 25$ Ω, and $i_L = 2$ A, find R_L.

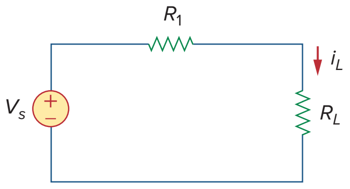


Figure 2.131
For Prob. 2.71.

2.72 Find V_o in the two-way power divider circuit in Fig. 2.132.

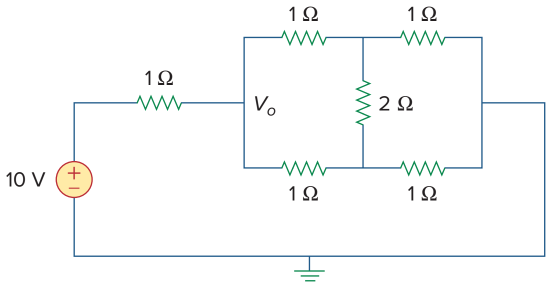


Figure 2.132
For Prob. 2.72.

2.73 An ammeter model consists of an ideal ammeter in series with a 20-Ω resistor. It is connected with a current source and an unknown resistor R_x as shown in Fig. 2.133. The ammeter reading is noted. When a potentiometer R is added and adjusted until the ammeter reading drops to one half its previous reading, then $R = 65\ \Omega$. What is the value of R_x?

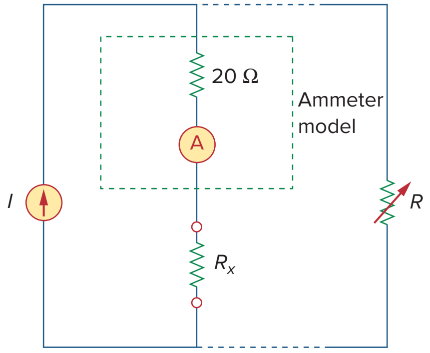


Figure 2.133
For Prob. 2.73.

2.74 The circuit in Fig. 2.134 is to control the speed of a motor such that the motor draws currents 5 A, 3 A, and 1 A when the switch is at high, medium, and low positions, respectively. The motor can be modeled as a load resistance of 20 mΩ. Determine the series dropping resistances R_1, R_2, and R_3.

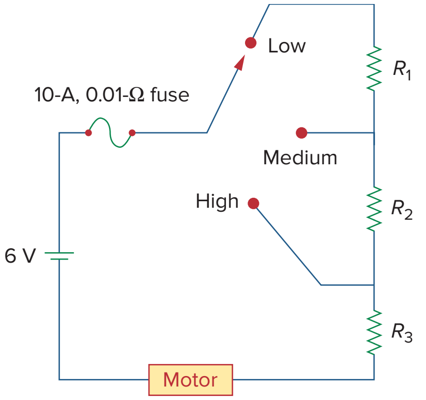


Figure 2.134
For Prob. 2.74.

2.75 Find R_{ab} in the four-way power divider circuit in Fig. 2.135. Assume each $R = 4\ \Omega$.

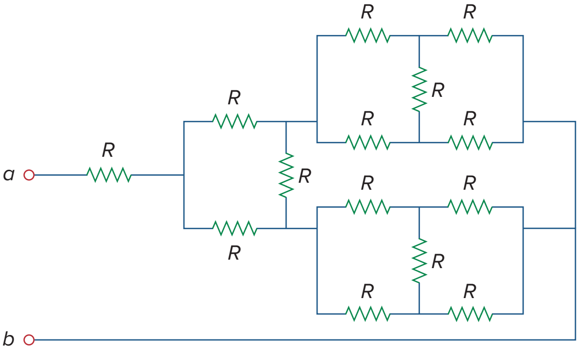


Figure 2.135
For Prob. 2.75.

Comprehensive Problems

2.76 Repeat Prob. 2.75 for the eight-way divider shown in Fig. 2.136.

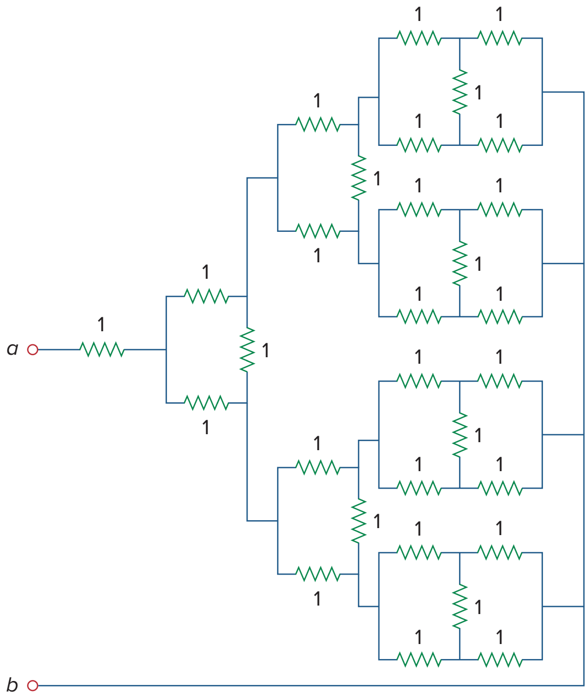


Figure 2.136
For Prob. 2.76.

2.77 Suppose your circuit laboratory has the following standard commercially available resistors in large quantities:

1.8 Ω   20 Ω   300 Ω   24 kΩ   56 kΩ

Using series and parallel combinations and a minimum number of available resistors, how would you obtain the following resistances for an electronic circuit design?

(a) 5 Ω   (b) 311.8 Ω
(c) 40 kΩ   (d) 52.32 kΩ

2.78 In the circuit in Fig. 2.137, the wiper divides the potentiometer resistance between αR and $(1-\alpha)R$, $0 \le \alpha \le 1$. Find v_o / v_s.

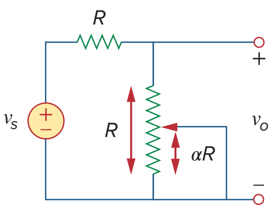


Figure 2.137
For Prob. 2.78.

2.79 An electric pencil sharpener rated 240 mW, 6 V is connected to a 9-V battery as shown in Fig. 2.138. Calculate the value of the series-dropping resistor R_x needed to power the sharpener.

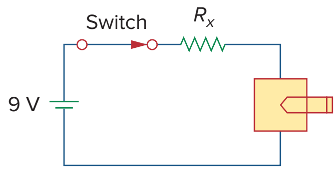


Figure 2.138
For Prob. 2.79.

2.80 A loudspeaker is connected to an amplifier as shown in Fig. 2.139. If a 10-Ω loudspeaker draws the maximum power of 12 W from the amplifier, determine the maximum power a 4-Ω loudspeaker will draw.

Figure 2.139
For Prob. 2.80.

2.81 For a specific application, the circuit shown in Fig. 2.140 was designed so that $I_L = 83.33$ mA and that $R_{in} = 5$ kΩ. What are the values of R_1 and R_2?

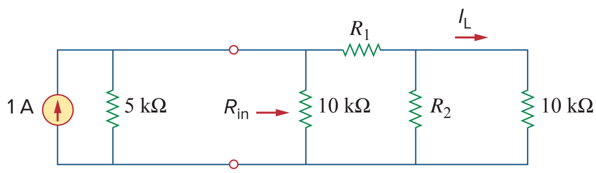


Figure 2.140
For Prob. 2.81.

2.82 The pin diagram of a resistance array is shown in Fig. 2.141. Find the equivalent resistance between the following:

(a) 1 and 2
(b) 1 and 3
(c) 1 and 4

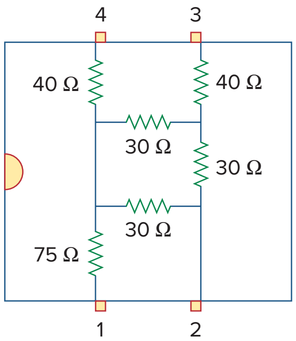


Figure 2.141
For Prob. 2.82.

2.83 Two delicate devices are rated as shown in Fig. 2.142. Find the values of the resistors R_1 and R_2 needed to power the devices using a 36-V battery.

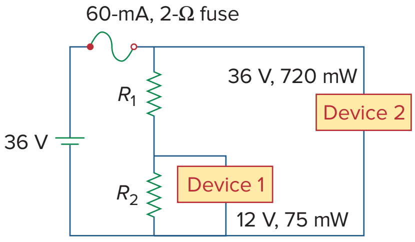


Figure 2.142
For Prob. 2.83.

3.7 In the circuit of Fig. 3.49, current i_1 is:

(a) 4 A (b) 3 A (c) 2 A (d) 1 A

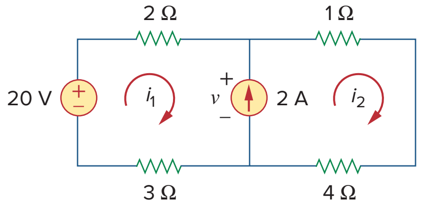


Figure 3.49
For Review Questions 3.7 and 3.8.

3.8 The voltage v across the current source in the circuit of Fig. 3.49 is:

(a) 20 V (b) 15 V (c) 10 V (d) 5 V

3.9 The *PSpice* part name for a current-controlled voltage source is:

(a) EX (b) FX (c) HX (d) GX

3.10 Which of the following statements are not true of the pseudocomponent IPROBE:

(a) It must be connected in series.
(b) It plots the branch current.
(c) It displays the current through the branch in which it is connected.
(d) It can be used to display voltage by connecting it in parallel.
(e) It is used only for dc analysis.
(f) It does not correspond to a particular circuit element.

Answers: 3.1a, 3.2c, 3.3a, 3.4c, 3.5c, 3.6a, 3.7d, 3.8b, 3.9c, 3.10b,d.

Problems

Sections 3.2 and 3.3 Nodal Analysis

3.1 Using Fig. 3.50, design a problem to help other students better understand nodal analysis.

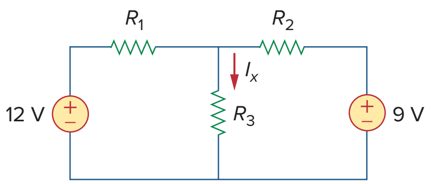


Figure 3.50
For Prob. 3.1 and Prob. 3.39.

3.2 For the circuit in Fig. 3.51, obtain v_1 and v_2.

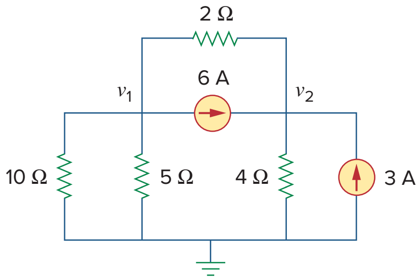


Figure 3.51
For Prob. 3.2.

3.3 Find the currents I_1 through I_4 and the voltage v_o in the circuit of Fig. 3.52.

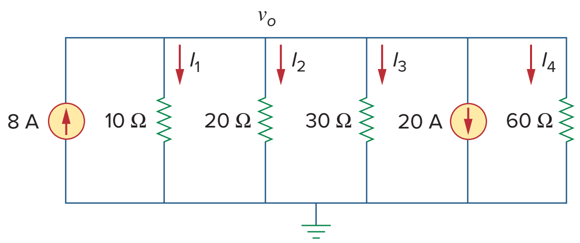


Figure 3.52
For Prob. 3.3.

3.4 Given the circuit in Fig. 3.53, calculate the currents i_1 through i_4.

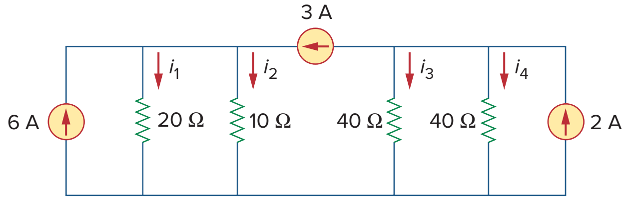


Figure 3.53
For Prob. 3.4.

3.5 Obtain v_o in the circuit of Fig. 3.54.

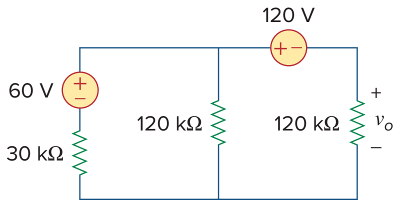


Figure 3.54
For Prob. 3.5.

3.6 Solve for V_1 in the circuit of Fig. 3.55 using nodal analysis.

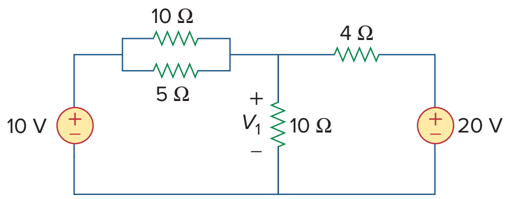


Figure 3.55
For Prob. 3.6.

3.7 Apply nodal analysis to solve for V_x in the circuit of Fig. 3.56.

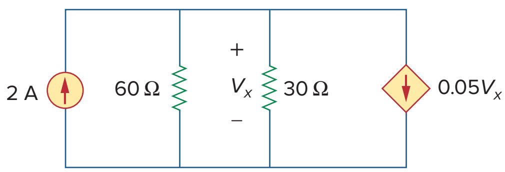


Figure 3.56
For Prob. 3.7.

3.8 Using nodal analysis, find v_o in the circuit of Fig. 3.57.

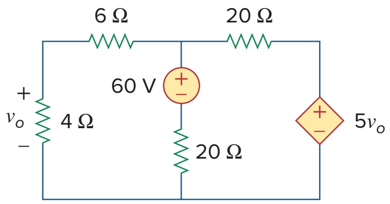


Figure 3.57
For Prob. 3.8 and Prob. 3.37.

3.9 Determine I_b in the circuit in Fig. 3.58 using nodal analysis.

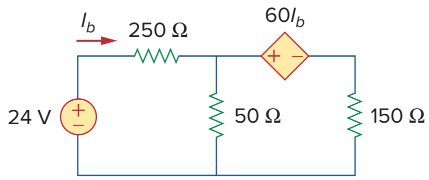


Figure 3.58
For Prob. 3.9.

3.10 Find I_o in the circuit of Fig. 3.59.

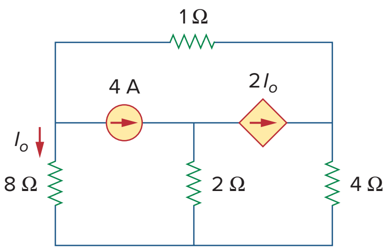


Figure 3.59
For Prob. 3.10.

3.11 Find V_o and the power dissipated in all the resistors in the circuit of Fig. 3.60.

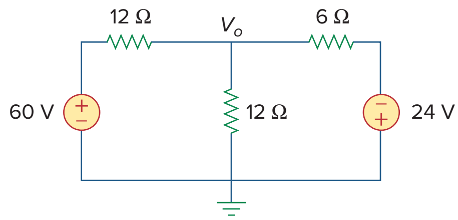


Figure 3.60
For Prob. 3.11.

3.12 Using nodal analysis, determine V_o in the circuit in Fig. 3.61.

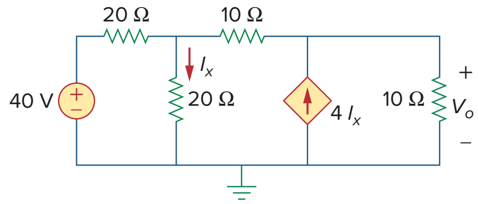


Figure 3.61
For Prob. 3.12.

3.13 Calculate v_1 and v_2 in the circuit of Fig. 3.62 using nodal analysis.

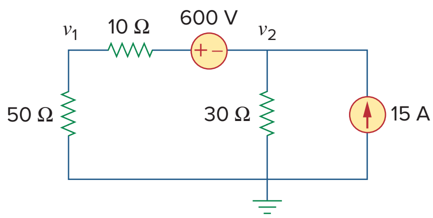


Figure 3.62
For Prob. 3.13.

3.14 Using nodal analysis, find v_o in the circuit of Fig. 3.63.

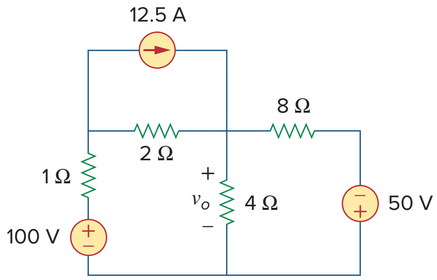


Figure 3.63
For Prob. 3.14.

3.15 Apply nodal analysis to find i_o and the power dissipated in each resistor in the circuit of Fig. 3.64.

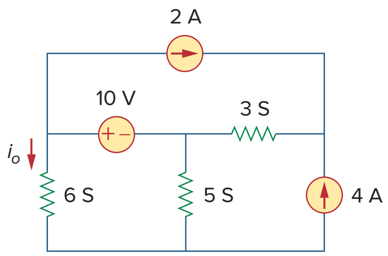


Figure 3.64
For Prob. 3.15.

3.16 Determine voltages v_1 through v_3 in the circuit of Fig. 3.65 using nodal analysis.

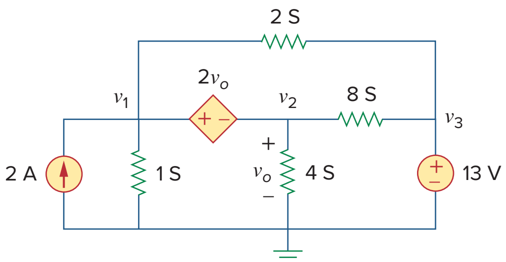


Figure 3.65
For Prob. 3.16.

3.17 Using nodal analysis, find current i_o in the circuit of Fig. 3.66.

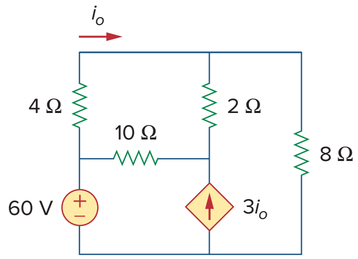


Figure 3.66
For Prob. 3.17.

3.18 Determine the node voltages in the circuit in Fig. 3.67 using nodal analysis.

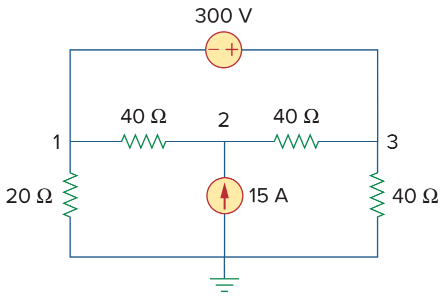


Figure 3.67
For Prob. 3.18.

3.19 Use nodal analysis to find v_1, v_2, and v_3 in the circuit of Fig. 3.68.

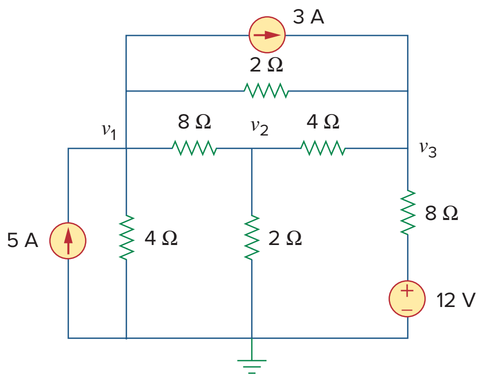


Figure 3.68
For Prob. 3.19.

3.20 For the circuit in Fig. 3.69, find v_1, v_2, and v_3 using nodal analysis.

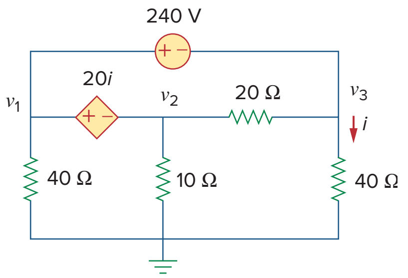


Figure 3.69
For Prob. 3.20.

3.21 For the circuit in Fig. 3.70, find v_1 and v_2 using nodal analysis.

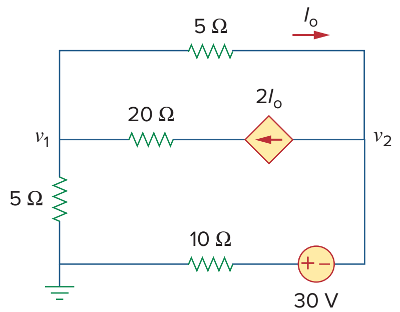


Figure 3.70
For Prob. 3.21.

3.22 Determine v_1 and v_2 in the circuit of Fig. 3.71.

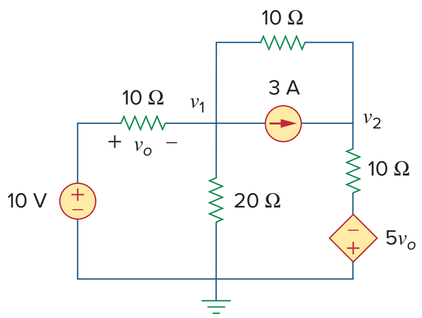


Figure 3.71
For Prob. 3.22.

3.23 Use nodal analysis to find V_o in the circuit of Fig. 3.72.

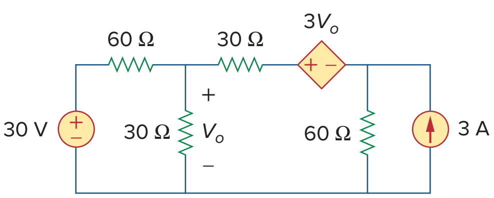


Figure 3.72
For Prob. 3.23.

3.24 Use nodal analysis and *MATLAB* to find V_o in the circuit of Fig. 3.73.

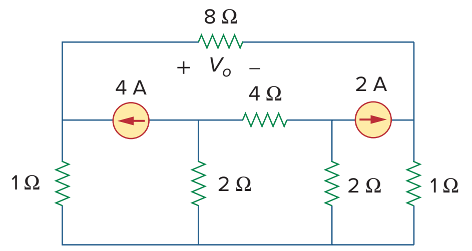


Figure 3.73
For Prob. 3.24.

3.25 Use nodal analysis along with *MATLAB* to determine the node voltages in Fig. 3.74.

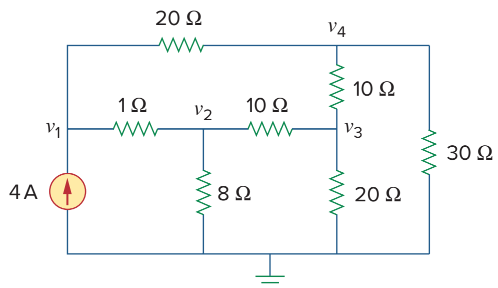


Figure 3.74
For Prob. 3.25.

3.26 Calculate the node voltages v_1, v_2, and v_3 in the circuit of Fig. 3.75.

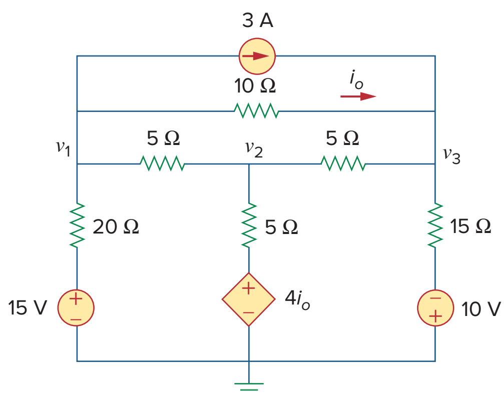


Figure 3.75
For Prob. 3.26.

***3.27** Use nodal analysis to determine voltages v_1, v_2, and v_3 in the circuit of Fig. 3.76.

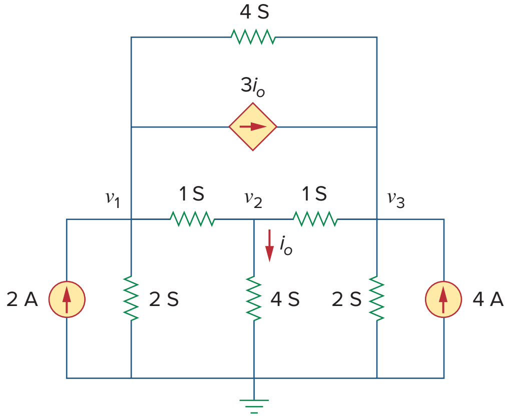


Figure 3.76
For Prob. 3.27.

***3.28** Use *MATLAB* to find the voltages at nodes *a*, *b*, *c*, and *d* in the circuit of Fig. 3.77.

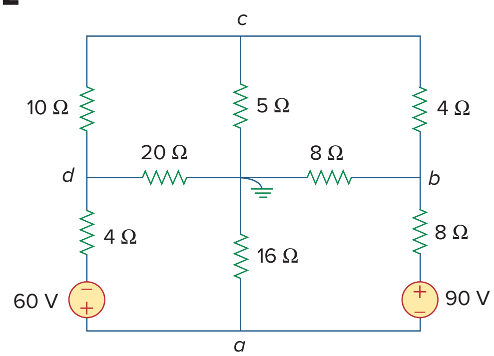


Figure 3.77
For Prob. 3.28.

3.29 Use *MATLAB* to solve for the node voltages in the circuit of Fig. 3.78.

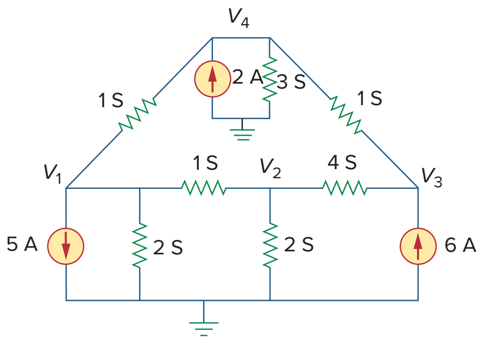


Figure 3.78
For Prob. 3.29.

* An asterisk indicates a challenging problem.

3.30 Using nodal analysis, find v_o and i_o in the circuit of Fig. 3.79.

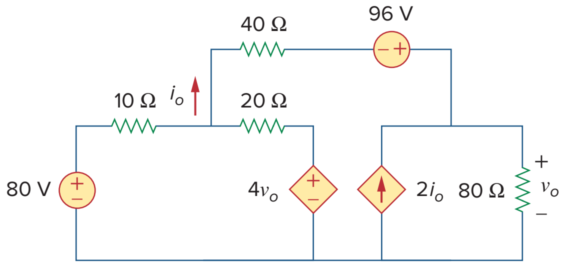


Figure 3.79
For Prob. 3.30.

3.31 Find the node voltages for the circuit in Fig. 3.80.

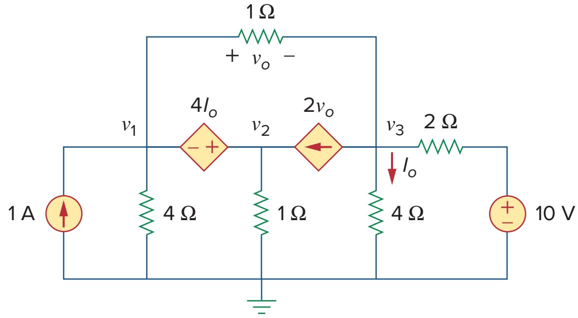


Figure 3.80
For Prob. 3.31.

3.32 Obtain the node voltages v_1, v_2, and v_3 in the circuit of Fig. 3.81.

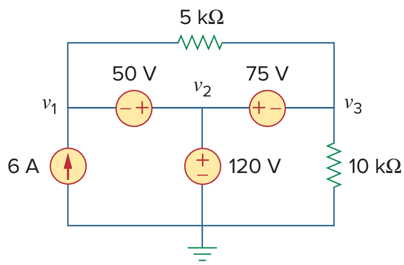
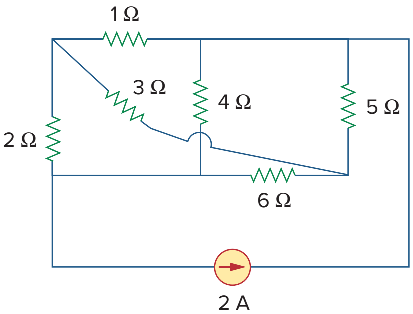


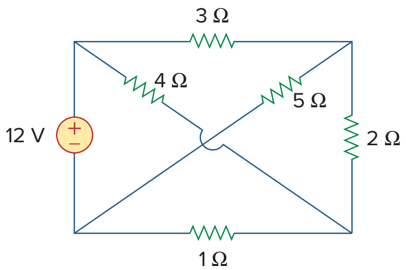
Figure 3.81
For Prob. 3.32.

Sections 3.4 and 3.5 Mesh Analysis

3.33 Which of the circuits in Fig. 3.82 is planar? For the planar circuit, redraw the circuits with no crossing branches.



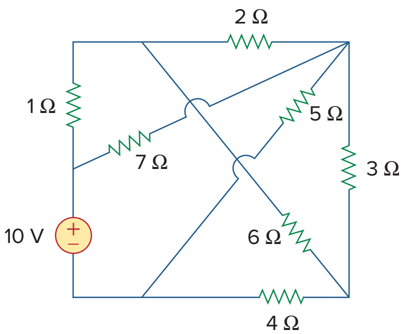
(a)



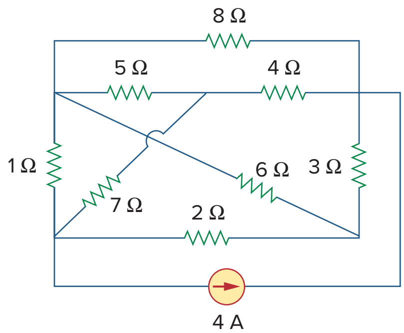
(b)

Figure 3.82
For Prob. 3.33.

3.34 Determine which of the circuits in Fig. 3.83 is planar and redraw it with no crossing branches.



(a)



(b)

Figure 3.83
For Prob. 3.34.

3.35 Rework Prob. 3.5 using mesh analysis.

3.36 Use mesh analysis to obtain i_a, i_b, and i_c in the circuit in Fig. 3.84.

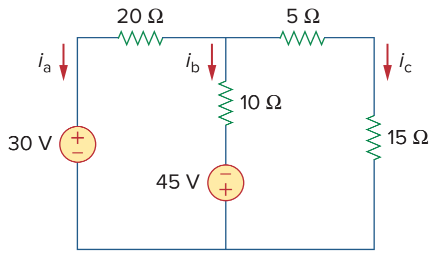


Figure 3.84
For Prob. 3.36.

3.37 Solve Prob. 3.8 using mesh analysis.

3.38 Apply mesh analysis to the circuit in Fig. 3.85 and obtain I_o.
ML

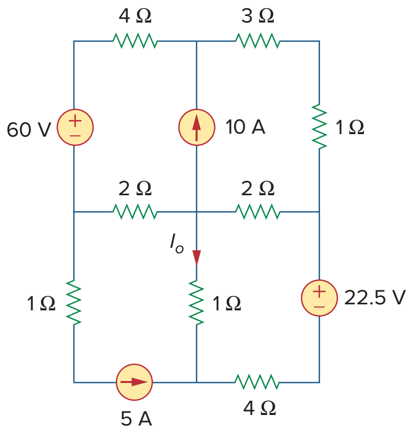


Figure 3.85
For Prob. 3.38.

3.39 Using Fig. 3.50 from Prob. 3.1, design a problem to help other students better understand mesh analysis.

3.40 For the bridge network in Fig. 3.86, find i_o using mesh analysis.

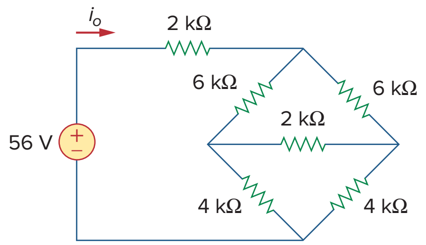


Figure 3.86
For Prob. 3.40.

3.41 Apply mesh analysis to find i in Fig. 3.87.

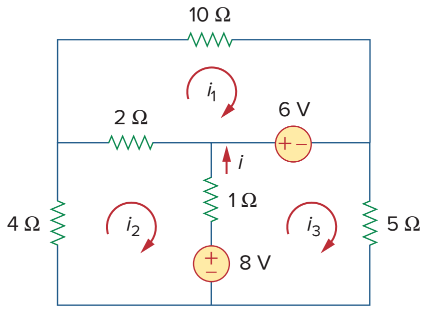


Figure 3.87
For Prob. 3.41.

3.42 Using Fig. 3.88, design a problem to help students better understand mesh analysis using matrices.

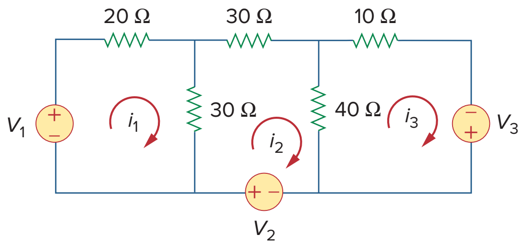


Figure 3.88
For Prob. 3.42.

3.43 Use mesh analysis to find v_{ab} and i_o in the circuit of Fig. 3.89.

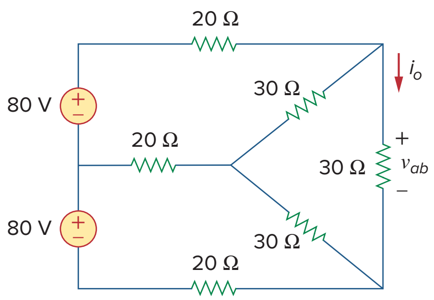


Figure 3.89
For Prob. 3.43.

3.44 Use mesh analysis to obtain i_o in the circuit of Fig. 3.90.

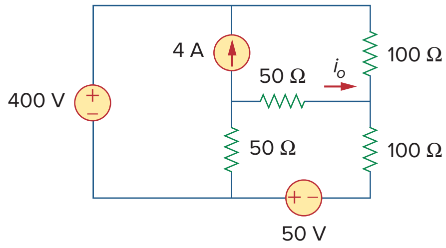


Figure 3.90
For Prob. 3.44.

3.45 Find current i in the circuit of Fig. 3.91.

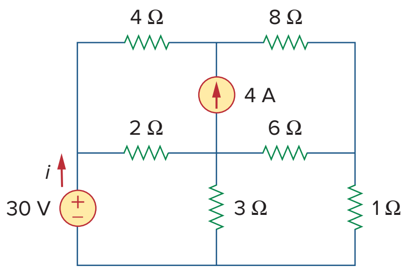


Figure 3.91
For Prob. 3.45.

3.46 Calculate the mesh currents i_1 and i_2 in Fig. 3.92.

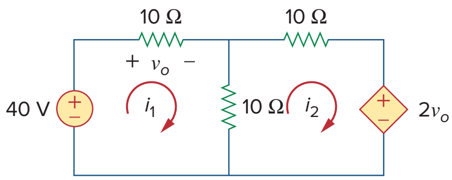


Figure 3.92
For Prob. 3.46.

3.47 Rework Prob. 3.19 using mesh analysis.

3.48 Determine the current through the 10-kΩ resistor in the circuit of Fig. 3.93 using mesh analysis.

ML

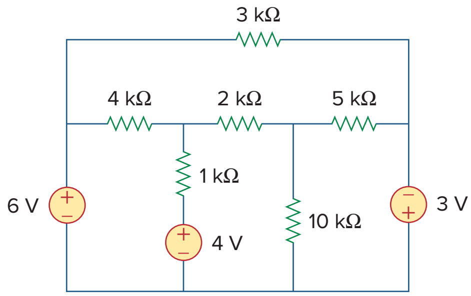


Figure 3.93
For Prob. 3.48.

3.49 Find v_o and i_o in the circuit of Fig. 3.94.

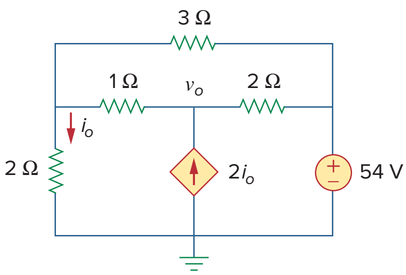


Figure 3.94
For Prob. 3.49.

3.50 Use mesh analysis to find the current i_o in the circuit of Fig. 3.95.

ML

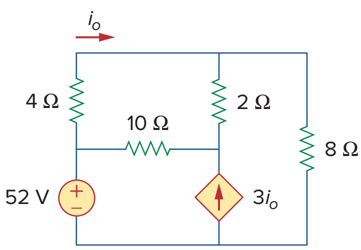


Figure 3.95
For Prob. 3.50.

3.51 Apply mesh analysis to find v_o in the circuit of Fig. 3.96.

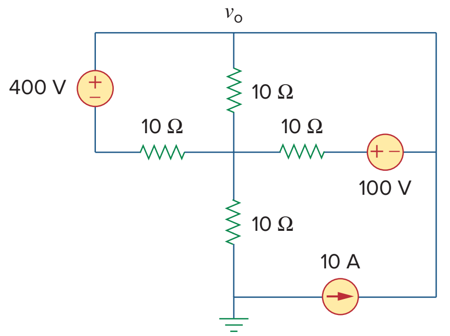


Figure 3.96
For Prob. 3.51.

3.52 Use mesh analysis to find i_1, i_2, and i_3 in the circuit of Fig. 3.97.

ML

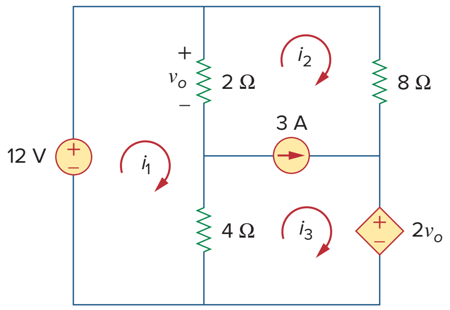


Figure 3.97
For Prob. 3.52.

3.53 Find the mesh currents in the circuit of Fig. 3.98 using *MATLAB*.

ML

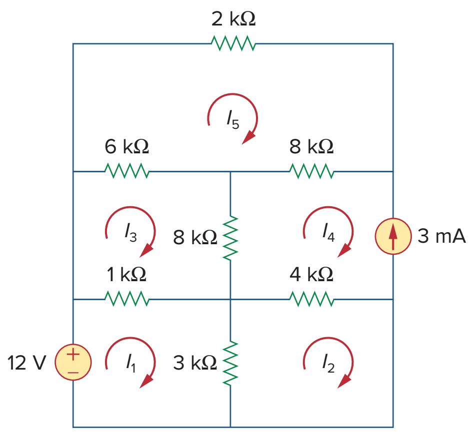


Figure 3.98
For Prob. 3.53.

3.54 Find the mesh currents i_1, i_2, and i_3 in the circuit in Fig. 3.99.

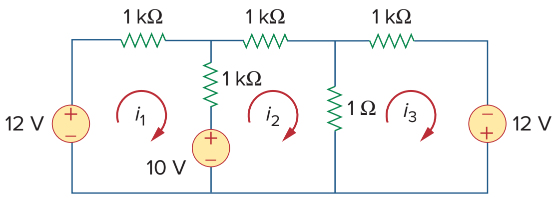


Figure 3.99
For Prob. 3.54.

***3.55** In the circuit of Fig. 3.100, solve for I_1, I_2, and I_3.

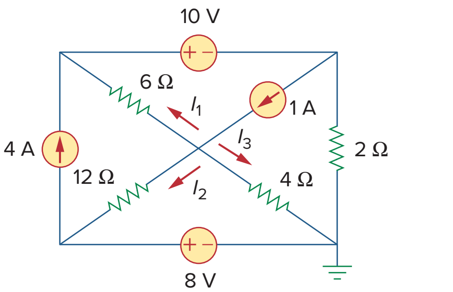


Figure 3.100
For Prob. 3.55.

3.56 Determine v_1 and v_2 in the circuit of Fig. 3.101.

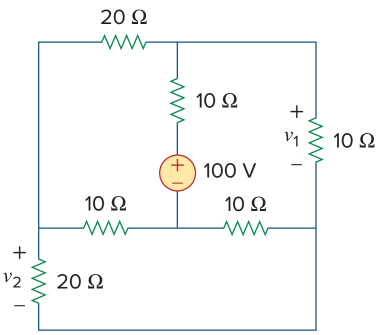


Figure 3.101
For Prob. 3.56.

3.57 In the circuit of Fig. 3.102, find the values of R, V_1, and V_2 given that $i_o = 15$ mA.

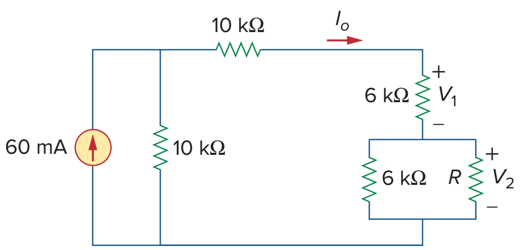


Figure 3.102
For Prob. 3.57.

3.58 Find i_1, i_2, and i_3 in the circuit of Fig. 3.103.

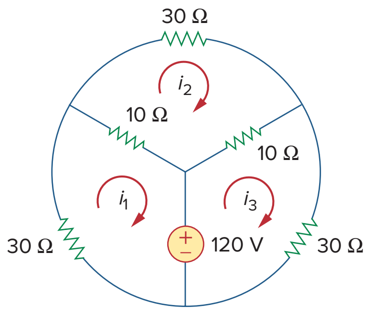


Figure 3.103
For Prob. 3.58.

3.59 Rework Prob. 3.30 using mesh analysis.

3.60 Calculate the power dissipated in each resistor in the circuit of Fig. 3.104.

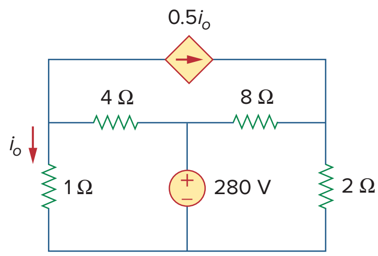


Figure 3.104
For Prob. 3.60.

3.61 Calculate the current gain i_o/i_s in the circuit of Fig. 3.105.

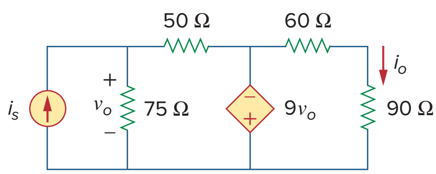


Figure 3.105
For Prob. 3.61.

3.62 Find the mesh currents i_1, i_2, and i_3 in the network of Fig. 3.106.

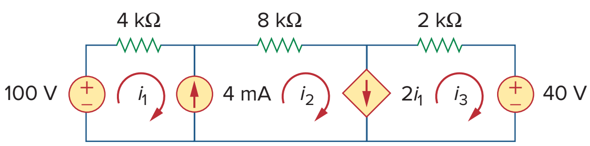


Figure 3.106
For Prob. 3.62.

3.63 Find v_x and i_x in the circuit shown in Fig. 3.107.

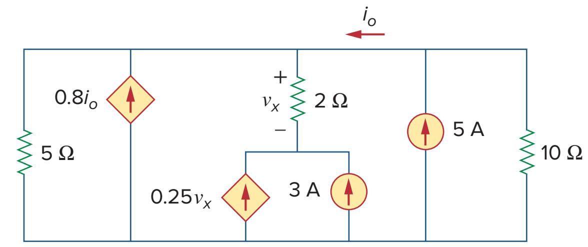


Figure 3.107
For Prob. 3.63.

3.64 Find v_o and i_o in the circuit of Fig. 3.108.

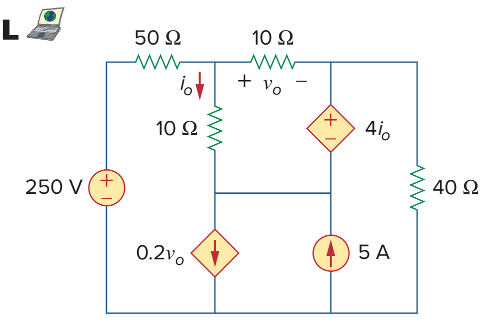


Figure 3.108
For Prob. 3.64.

3.65 Use *MATLAB* to solve for the mesh currents in the circuit of Fig. 3.109.

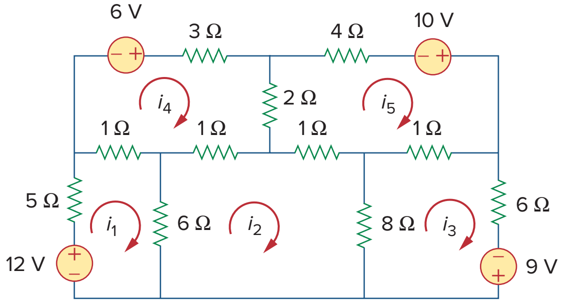


Figure 3.109
For Prob. 3.65.

3.66 Write a set of mesh equations for the circuit in Fig. 3.110. Use *MATLAB* to determine the mesh currents.

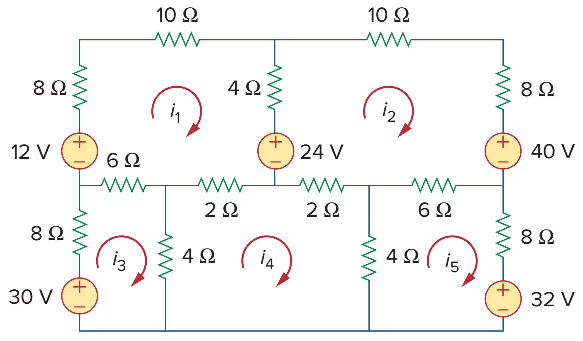


Figure 3.110
For Prob. 3.66.

Section 3.6 Nodal and Mesh Analyses by Inspection

3.67 Obtain the node-voltage equations for the circuit in Fig. 3.111 by inspection. Then solve for V_o.

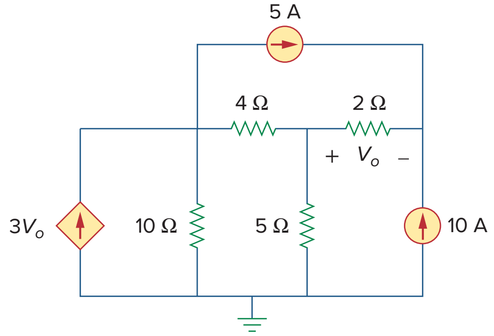


Figure 3.111
For Prob. 3.67.

3.68 Using Fig. 3.112, design a problem, to solve for V_o, to help other students better understand nodal analysis. Try your best to come up with values to make the calculations easier.

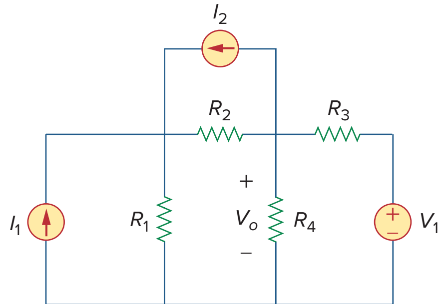


Figure 3.112
For Prob. 3.68.

3.69 For the circuit shown in Fig. 3.113, write the node-voltage equations by inspection.

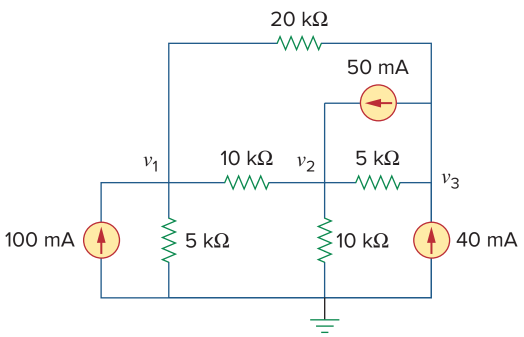


Figure 3.113
For Prob. 3.69.

3.70 Write the node-voltage equations by inspection and then determine values of V_1 and V_2 in the circuit of Fig. 3.114.

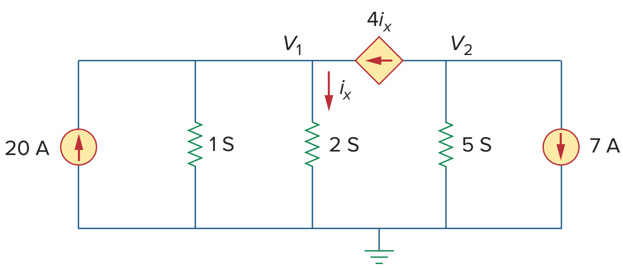


Figure 3.114
For Prob. 3.70.

3.71 Write the mesh-current equations for the circuit in Fig. 3.115. Next, determine the values of i_1, i_2, and i_3.

ML

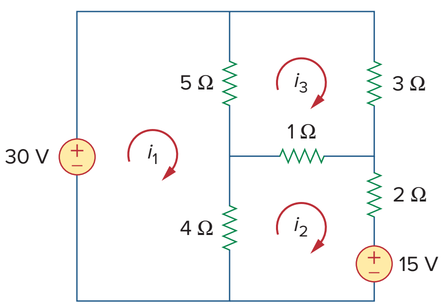


Figure 3.115
For Prob. 3.71.

3.72 By inspection, write the mesh-current equations for the circuit in Fig. 3.116.

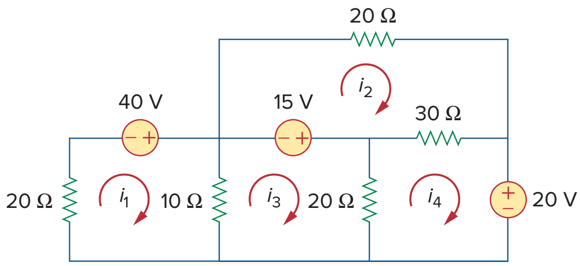


Figure 3.116
For Prob. 3.72.

3.73 Write the mesh-current equations for the circuit in Fig. 3.117.

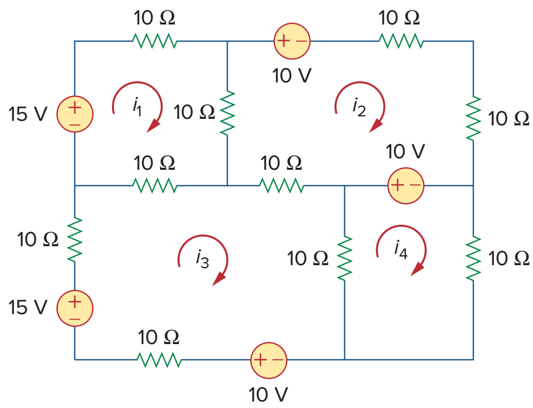


Figure 3.117
For Prob. 3.73.

3.74 By inspection, obtain the mesh-current equations for the circuit in Fig. 3.118.

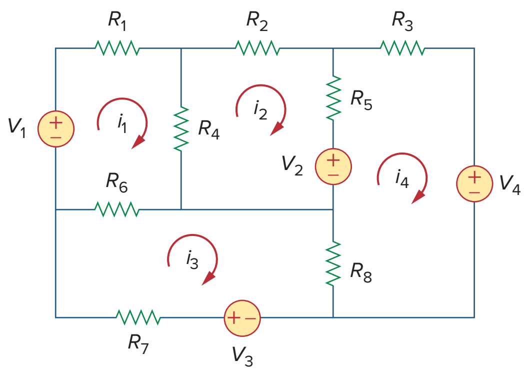


Figure 3.118
For Prob. 3.74.

Section 3.8 Circuit Analysis with *PSpice* or *MultiSim*

3.75 Use *PSpice* or *MultiSim* to solve Prob. 3.58.

3.76 Use *PSpice* or *MultiSim* to solve Prob. 3.27.

3.77 Solve for V_1 and V_2 in the circuit of Fig. 3.119 using *PSpice* or *MultiSim*.

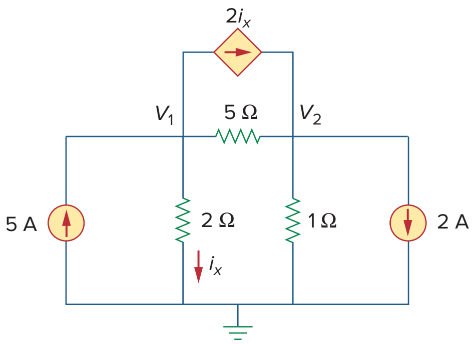


Figure 3.119
For Prob. 3.77.

3.78 Solve Prob. 3.20 using *PSpice* or *MultiSim*.

3.79 Rework Prob. 3.28 using *PSpice* or *MultiSim*.

3.80 Find the nodal voltages v_1 through v_4 in the circuit of Fig. 3.120 using *PSpice* or *MultiSim*.

ML

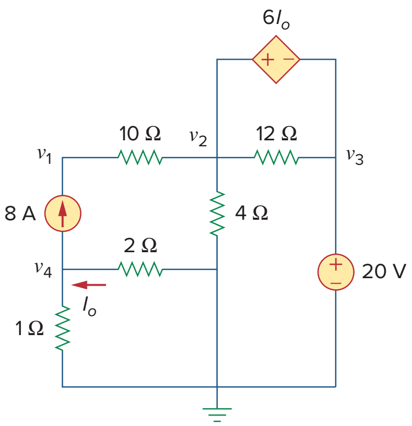


Figure 3.120
For Prob. 3.80.

3.81 Use *PSpice* or *MultiSim* to solve the problem in Example 3.4.

3.82 If the Schematics Netlist for a network is as follows, draw the network.

```
R_R1    1   2   2K
R_R2    2   0   4K
R_R3    3   0   8K
R_R4    3   4   6K
R_R5    1   3   3K
V_VS    4   0   DC      100
I_IS    0   1   DC      4
F_F1    1   3   VF_F1   2
VF_F1   5   0   0V
E_E1    3   2   1       3     3
```

3.83 The following program is the Schematics Netlist of a particular circuit. Draw the circuit and determine the voltage at node 2.

```
R_R1   1   2   20
R_R2   2   0   50
R_R3   2   3   70
R_R4   3   0   30
V_VS   1   0   20V
I_IS   2   0   DC    2A
```

Section 3.9 Applications

3.84 Calculate v_o and I_o in the circuit of Fig. 3.121.

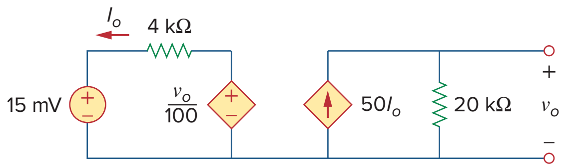


Figure 3.121
For Prob. 3.84.

3.85 An audio amplifier with a resistance of 9 Ω supplies power to a speaker. What should be the resistance of the speaker for maximum power to be delivered?

3.86 For the simplified transistor circuit of Fig. 3.122, calculate the voltage v_o.

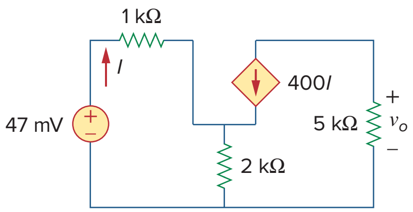


Figure 3.122
For Prob. 3.86.

3.87 For the circuit in Fig. 3.123, find the gain v_o/v_s.

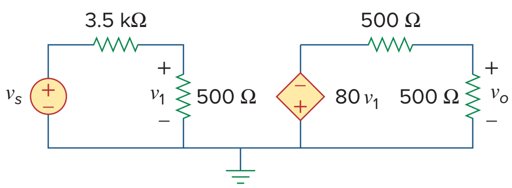


Figure 3.123
For Prob. 3.87.

*3.88 Determine the gain v_o/v_s of the transistor amplifier circuit in Fig. 3.124.

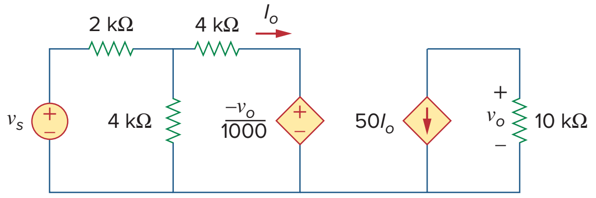


Figure 3.124
For Prob. 3.88.

3.89 For the transistor circuit shown in Fig. 3.125, find I_B and V_{CE}. Let $\beta = 100$, and $V_{BE} = 0.7$ V.

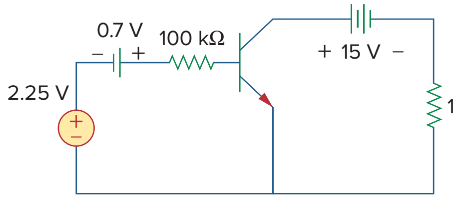


Figure 3.125
For Prob. 3.89.

3.90 Calculate v_s for the transistor in Fig. 3.126 given that $v_o = 6$ V, $\beta = 90$, $V_{BE} = 0.7$ V.

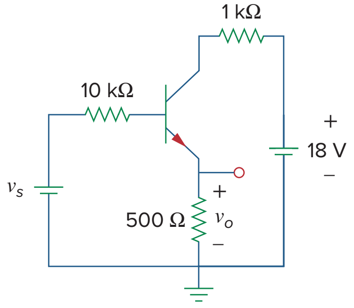


Figure 3.126
For Prob. 3.90.

3.91 For the transistor circuit of Fig. 3.127, find I_B, V_{CE}, and v_o. Take $\beta = 150$, $V_{BE} = 0.7$ V.

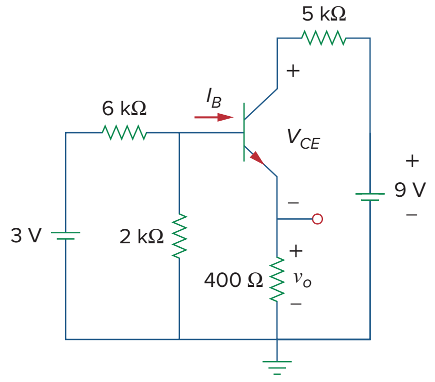


Figure 3.127
For Prob. 3.91.

3.92 Using Fig. 3.128, design a problem to help other students better understand transistors. Make sure you use reasonable numbers!

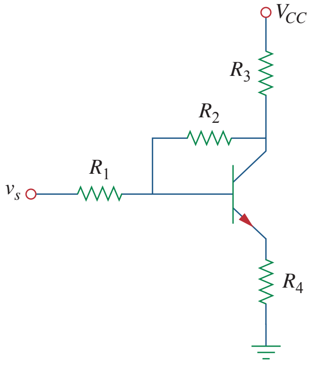


Figure 3.128
For Prob. 3.92.

Comprehensive Problem

*3.93 Rework Example 3.11 with hand calculation.

6. For a given Thevenin equivalent circuit, maximum power transfer occurs when $R_L = R_{Th}$; that is, when the load resistance is equal to the Thevenin resistance.
7. The maximum power transfer theorem states that the maximum power is delivered by a source to the load R_L when R_L is equal to R_{Th}, the Thevenin resistance at the terminals of the load.
8. *PSpice* can be used to verify the circuit theorems covered in this chapter.
9. Source modeling and resistance measurement using the Wheatstone bridge provide applications for Thevenin's theorem.

Review Questions

4.1 The current through a branch in a linear network is 2 A when the input source voltage is 10 V. If the voltage is reduced to 1 V and the polarity is reversed, the current through the branch is:

(a) – 2 A (b) – 0.2 A (c) 0.2 A
(d) 2 A (e) 20 A

4.2 For superposition, it is not required that only one independent source be considered at a time; any number of independent sources may be considered simultaneously.

(a) True (b) False

4.3 The superposition principle applies to power calculation.

(a) True (b) False

4.4 Refer to Fig. 4.67. The Thevenin resistance at terminals *a* and *b* is:

(a) 25 Ω (b) 20 Ω
(c) 5 Ω (d) 4 Ω

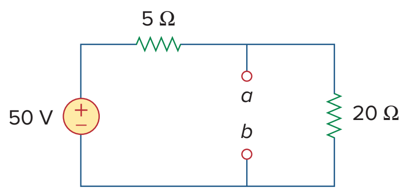


Figure 4.67
For Review Questions 4.4 to 4.6.

4.5 The Thevenin voltage across terminals *a* and *b* of the circuit in Fig. 4.67 is:

(a) 50 V (b) 40 V
(c) 20 V (d) 10 V

4.6 The Norton current at terminals *a* and *b* of the circuit in Fig. 4.67 is:

(a) 10 A (b) 2.5 A
(c) 2 A (d) 0 A

4.7 The Norton resistance R_N is exactly equal to the Thevenin resistance R_{Th}.

(a) True (b) False

4.8 Which pair of circuits in Fig. 4.68 are equivalent?

(a) a and b (b) b and d
(c) a and c (d) c and d

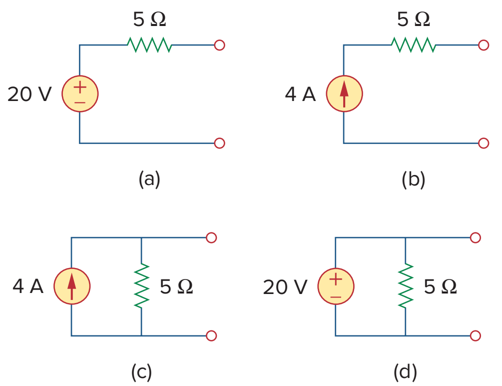


Figure 4.68
For Review Question 4.8.

4.9 A load is connected to a network. At the terminals to which the load is connected, $R_{Th} = 10\ \Omega$ and $V_{Th} = 40$ V. The maximum possible power supplied to the load is:

(a) 160 W (b) 80 W
(c) 40 W (d) 1 W

4.10 The source is supplying the maximum power to the load when the load resistance equals the source resistance.

(a) True (b) False

Answers: 4.1b, 4.2a, 4.3b, 4.4d, 4.5b, 4.6a, 4.7a, 4.8c, 4.9c, 4.10a.

Problems

Section 4.2 Linearity Property

4.1 Calculate the current i_o in the circuit of Fig. 4.69. What value of input voltage is necessary to make i_o equal to 5 amps?

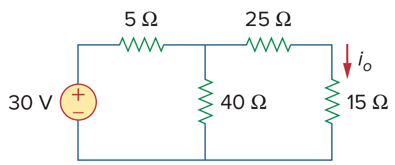


Figure 4.69
For Prob. 4.1.

4.2 Using Fig. 4.70, design a problem to help other students better understand linearity.

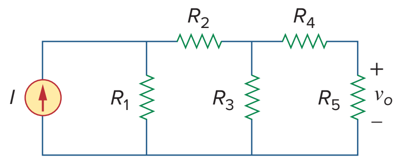


Figure 4.70
For Prob. 4.2.

4.3 (a) In the circuit of Fig. 4.71, calculate v_o and i_o when $v_s = 1$ V.

(b) Find v_o and i_o when $v_s = 10$ V.

(c) What are v_o and i_o when each of the 1-Ω resistors is replaced by a 10-Ω resistor and $v_s = 10$ V?

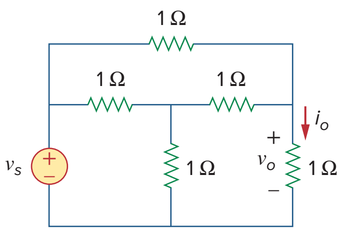


Figure 4.71
For Prob. 4.3.

4.4 Use linearity to determine i_o in the circuit of Fig. 4.72.

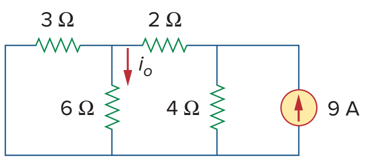


Figure 4.72
For Prob. 4.4.

4.5 For the circuit in Fig. 4.73, assume $v_o = 1$ V, and use linearity to find the actual value of v_o.

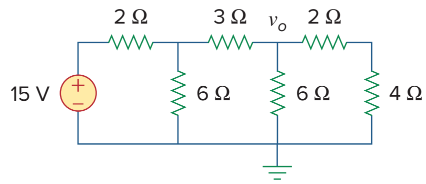


Figure 4.73
For Prob. 4.5.

4.6 For the linear circuit shown in Fig. 4.74, use linearity to complete the following table.

Experiment	V_s	V_o
1	12 V	4 V
2		16 V
3	1 V	
4		−2 V

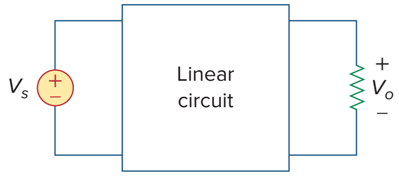


Figure 4.74
For Prob. 4.6.

4.7 Use linearity and the assumption that $V_o = 1$ V to find the actual value of V_o in Fig. 4.75.

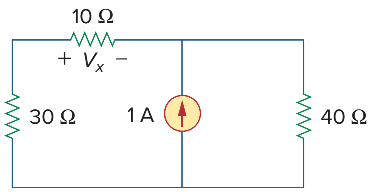


Figure 4.75
For Prob. 4.7.

Section 4.3 Superposition

4.8 Using superposition, find V_o in the circuit of Fig. 4.76. Check with *PSpice or MultiSim*.

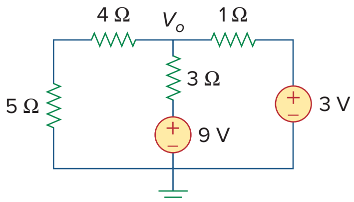


Figure 4.76
For Prob. 4.8.

4.9 Given that $I = 6$ amps when $V_s = 160$ volts and $I_s = -10$ amps and $I = 5$ amp when $V_s = 200$ volts and $I_s = 0$, use superposition and linearity to determine the value of I when $V_s = 120$ volts and $I_s = 5$ amps.

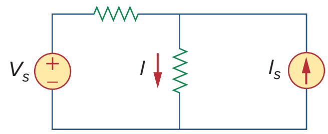


Figure 4.77
For Prob. 4.9.

4.10 Using Fig. 4.78, design a problem to help other students better understand superposition. Note, the letter k is a gain you can specify to make the problem easier to solve but must not be zero.

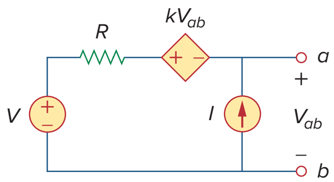


Figure 4.78
For Prob. 4.10.

4.11 Use the superposition principle to find i_o and v_o in the circuit of Fig. 4.79.

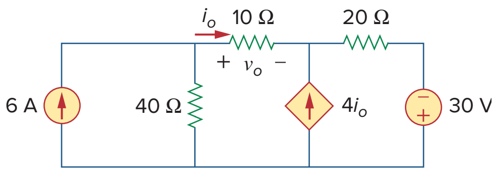


Figure 4.79
For Prob. 4.11.

4.12 Determine v_o in the circuit of Fig. 4.80 using the superposition principle.

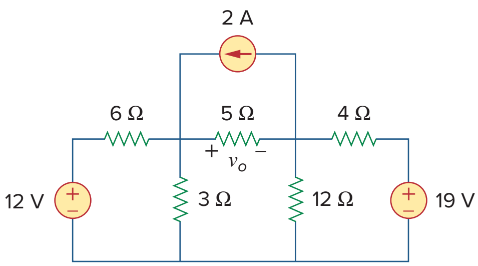


Figure 4.80
For Prob. 4.12.

4.13 Use superposition to find v_o in the circuit of Fig. 4.81.

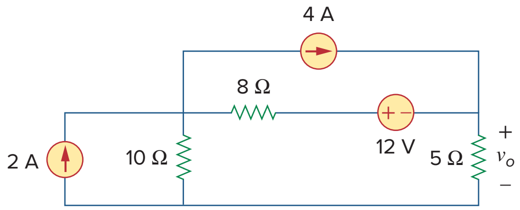


Figure 4.81
For Prob. 4.13.

4.14 Apply the superposition principle to find v_o in the circuit of Fig. 4.82.

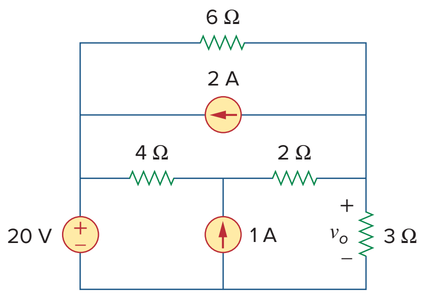


Figure 4.82
For Prob. 4.14.

4.15 For the circuit in Fig. 4.83, use superposition to find i. Calculate the power delivered to the 3-Ω resistor.

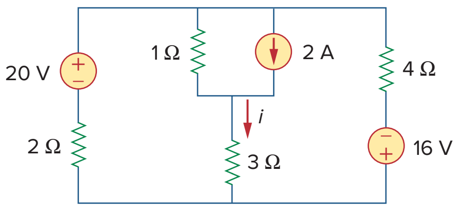


Figure 4.83
For Probs. 4.15 and 4.56.

4.16 Given the circuit in Fig. 4.84, use superposition to obtain i_o.

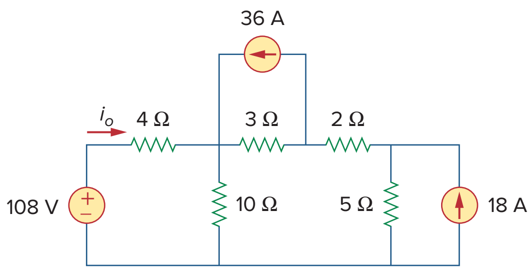


Figure 4.84
For Prob. 4.16.

4.17 Use superposition to obtain v_x in the circuit of Fig. 4.85. Check your result using *PSpice or MultiSim*.

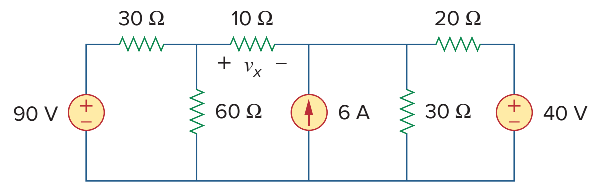


Figure 4.85
For Prob. 4.17.

4.18 Use superposition to find V_o in the circuit of Fig. 4.86.

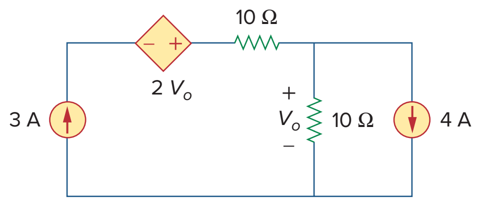


Figure 4.86
For Prob. 4.18.

4.19 Use superposition to solve for v_x in the circuit of Fig. 4.87.

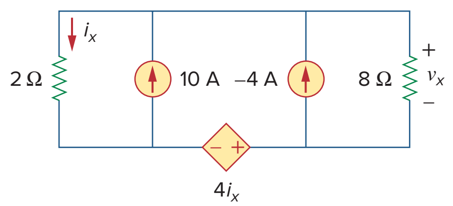


Figure 4.87
For Prob. 4.19.

Section 4.4 Source Transformation

4.20 Use source transformation to reduce the circuit between terminals *a* and *b* shown in Fig. 4.88 to a single voltage source in series with a single resistor.

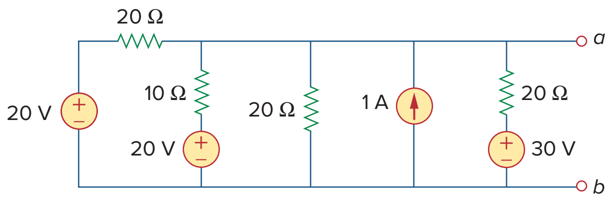


Figure 4.88
For Prob. 4.20.

4.21 Using Fig. 4.89, design a problem to help other students better understand source transformation.

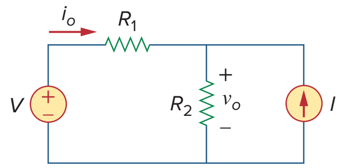


Figure 4.89
For Prob. 4.21.

4.22 For the circuit in Fig. 4.90, use source transformation to find *i*.

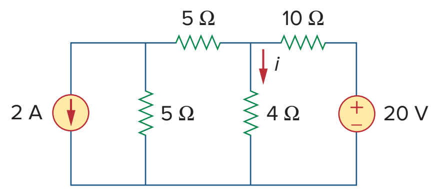


Figure 4.90
For Prob. 4.22.

4.23 Referring to Fig. 4.91, use source transformation to determine the current and power absorbed by the 8-Ω resistor.

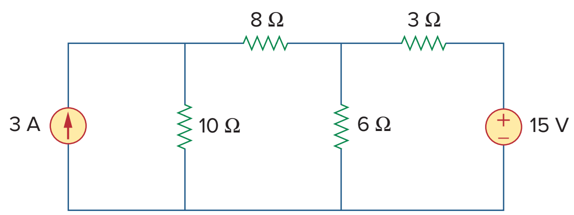


Figure 4.91
For Prob. 4.23.

4.24 Use source transformation to find the voltage V_x in the circuit of Fig. 4.92.

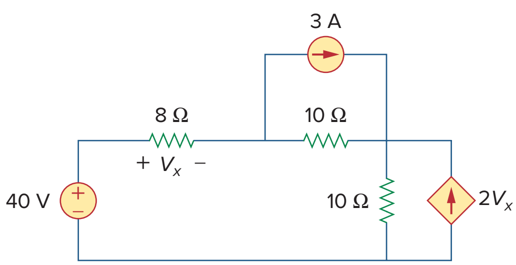


Figure 4.92
For Prob. 4.24.

4.25 Obtain v_o in the circuit of Fig. 4.93 using source transformation. Check your result using *PSpice or MultiSim*.

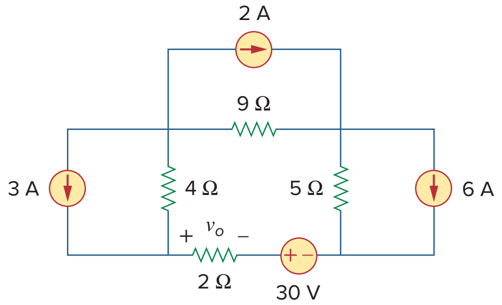


Figure 4.93
For Prob. 4.25.

4.26 Use source transformation to find i_o in the circuit of Fig. 4.94.

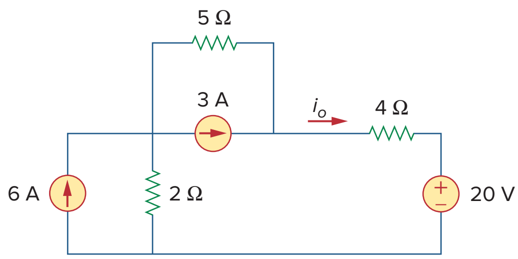


Figure 4.94
For Prob. 4.26.

4.27 Apply source transformation to find v_x in the circuit of Fig. 4.95.

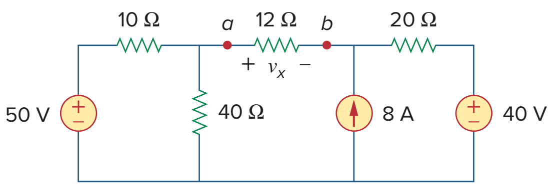


Figure 4.95
For Probs. 4.27 and 4.40.

4.28 Use source transformation to find I_o in Fig. 4.96.

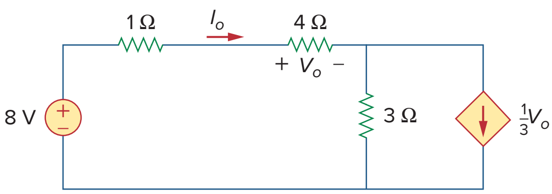


Figure 4.96
For Prob. 4.28.

4.29 Use source transformation to find v_o in the circuit of Fig. 4.97.

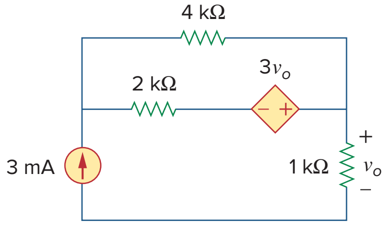


Figure 4.97
For Prob. 4.29.

4.30 Use source transformation on the circuit shown in Fig 4.98 to find i_x.

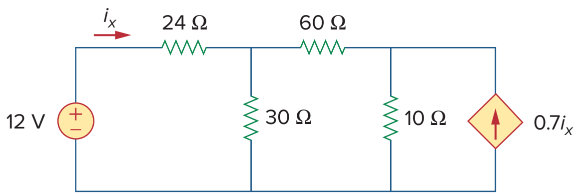


Figure 4.98
For Prob. 4.30.

4.31 Determine v_x in the circuit of Fig. 4.99 using source transformation.

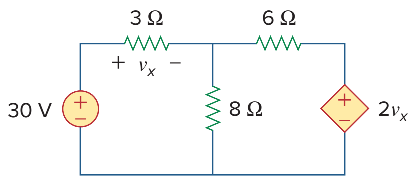


Figure 4.99
For Prob. 4.31.

4.32 Use source transformation to find i_x in the circuit of Fig. 4.100.

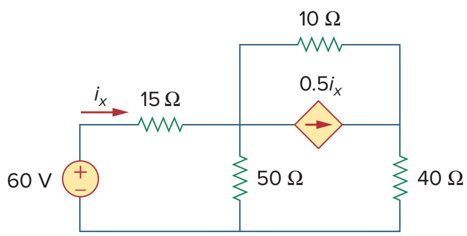


Figure 4.100
For Prob. 4.32.

Sections 4.5 and 4.6 Thevenin's and Norton's Theorems

4.33 Determine the Thevenin equivalent circuit, shown in Fig. 4.101, as seen by the 7-ohm resistor.
Then calculate the current flowing through the 7-ohm resistor.

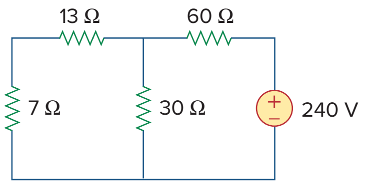


Figure 4.101
For Prob. 4.33.

4.34 Using Fig. 4.102, design a problem that will help other students better understand Thevenin equivalent circuits.

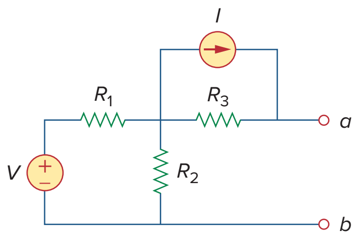


Figure 4.102
For Probs. 4.34 and 4.49.

4.35 Use Thevenin's theorem to find v_o in Prob. 4.12.

4.36 Solve for the current i in the circuit of Fig. 4.103 using Thevenin's theorem. (*Hint:* Find the Thevenin equivalent seen by the 12-Ω resistor.)

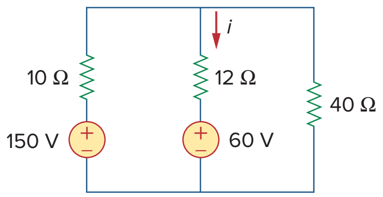


Figure 4.103
For Prob. 4.36.

4.37 Find the Norton equivalent with respect to terminals *a-b* in the circuit shown in Fig. 4.104.

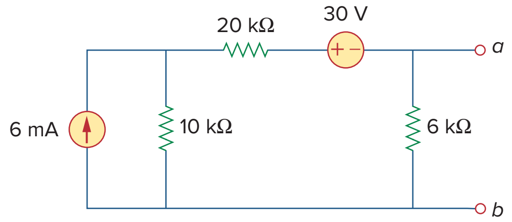


Figure 4.104
For Prob. 4.37.

4.38 Apply Thevenin's theorem to find V_o in the circuit of Fig. 4.105.

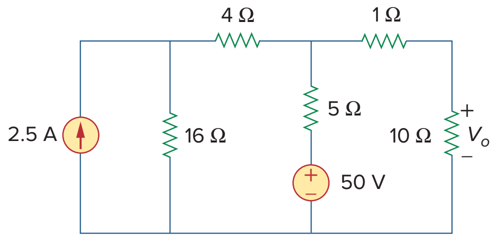


Figure 4.105
For Prob. 4.38.

4.39 Obtain the Thevenin equivalent at terminals *a-b* of the circuit shown in Fig. 4.106.

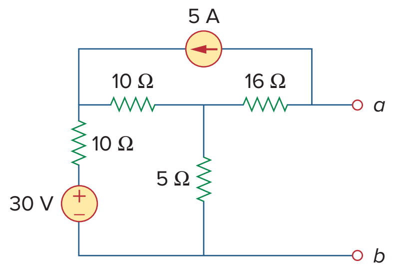


Figure 4.106
For Prob. 4.39.

4.40 Find the Thevenin equivalent at terminals *a-b* of the circuit in Fig. 4.107.

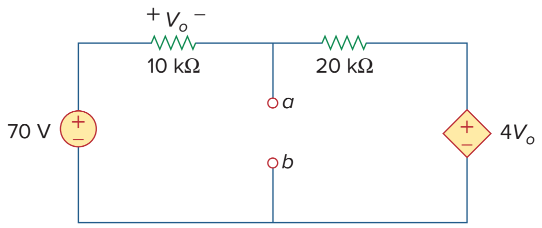


Figure 4.107
For Prob. 4.40.

4.41 Find the Thevenin and Norton equivalents at terminals *a-b* of the circuit shown in Fig. 4.108.

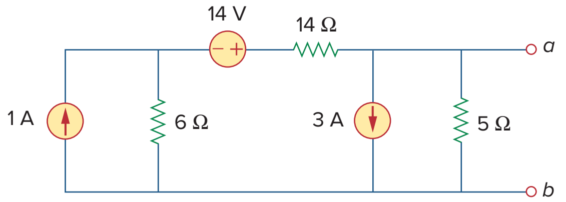


Figure 4.108
For Prob. 4.41.

***4.42** For the circuit in Fig. 4.109, find the Thevenin equivalent between terminals *a* and *b*.

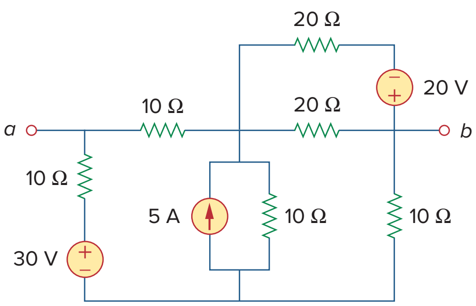


Figure 4.109
For Prob. 4.42.

4.43 Find the Thevenin equivalent looking into terminals *a-b* of the circuit in Fig. 4.110 and solve for i_x.

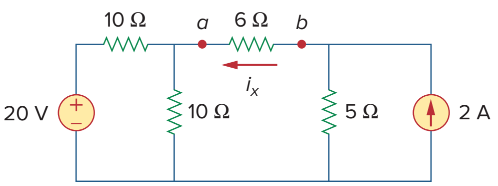


Figure 4.110
For Prob. 4.43.

4.44 For the circuit in Fig. 4.111, obtain the Thevenin equivalent as seen from terminals:

(a) *a-b* (b) *b-c*

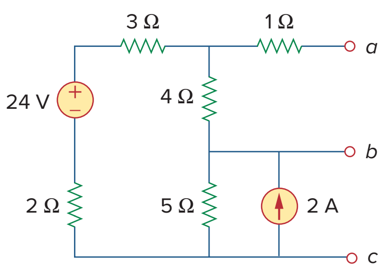


Figure 4.111
For Prob. 4.44.

* An asterisk indicates a challenging problem.

4.45 Find the Thevenin equivalent of the circuit in Fig. 4.112 as seen by looking into terminals *a* and *b*.

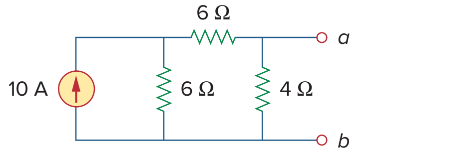


Figure 4.112
For Prob. 4.45.

4.46 Using Fig. 4.113, design a problem to help other students better understand Norton equivalent circuits.

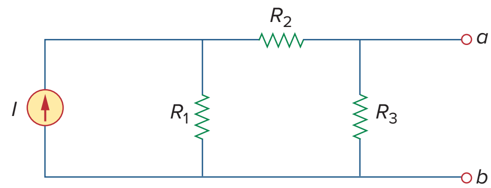


Figure 4.113
For Prob. 4.46.

4.47 Obtain the Thevenin and Norton equivalent circuits of the circuit in Fig. 4.114 with respect to terminals *a* and *b*.

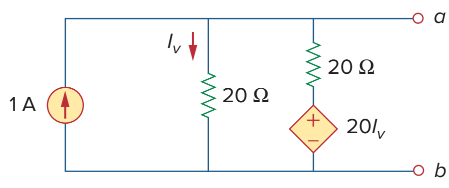


Figure 4.114
For Prob. 4.47.

4.48 Determine the Norton equivalent at terminals *a-b* for the circuit in Fig. 4.115.

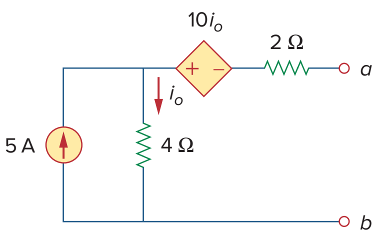


Figure 4.115
For Prob. 4.48.

4.49 Find the Norton equivalent looking into terminals *a-b* of the circuit in Fig. 4.102. Let $V = 40$ V, $I = 3$ A, $R_1 = 10\ \Omega$, $R_2 = 40\ \Omega$, and $R_3 = 20\ \Omega$.

4.50 Obtain the Norton equivalent of the circuit in Fig. 4.116 to the left of terminals *a-b*. Use the result to find current *i*.

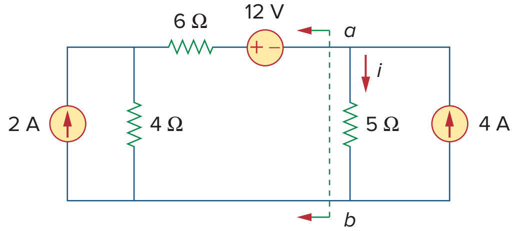


Figure 4.116
For Prob. 4.50.

4.51 Given the circuit in Fig. 4.117, obtain the Norton equivalent as viewed from terminals:

(a) *a-b* (b) *c-d*

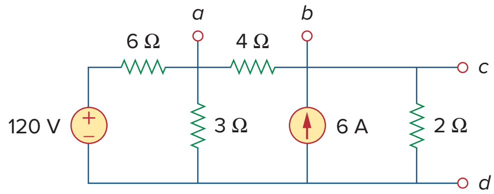


Figure 4.117
For Prob. 4.51.

4.52 For the transistor model in Fig. 4.118, obtain the Thevenin equivalent at terminals *a-b*.

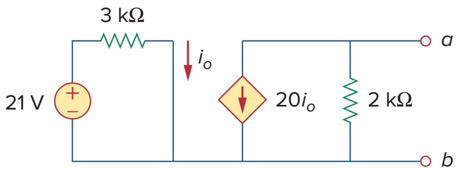


Figure 4.118
For Prob. 4.52.

4.53 Find the Norton equivalent at terminals *a-b* of the circuit in Fig. 4.119.

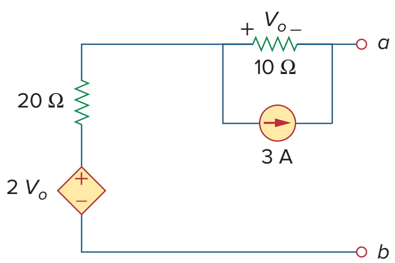


Figure 4.119
For Prob. 4.53.

4.54 Find the Thevenin equivalent between terminals *a-b* of the circuit in Fig. 4.120.

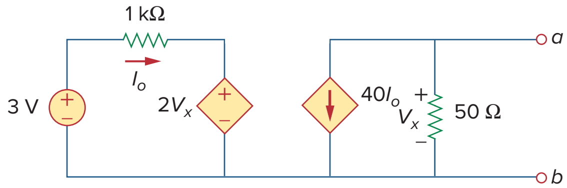


Figure 4.120
For Prob. 4.54.

***4.55** Obtain the Norton equivalent at terminals *a-b* of the circuit in Fig. 4.121.

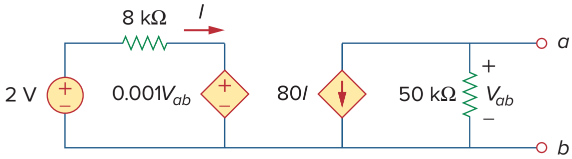


Figure 4.121
For Prob. 4.55.

4.56 Use Norton's theorem to find V_o in the circuit of Fig. 4.122.

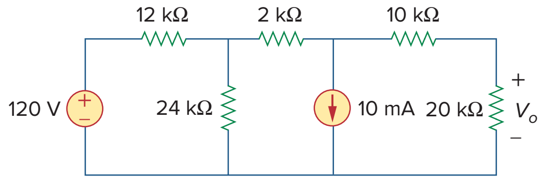


Figure 4.122
For Prob. 4.56.

4.57 Obtain the Thevenin and Norton equivalent circuits at terminals *a-b* for the circuit in Fig. 4.123.

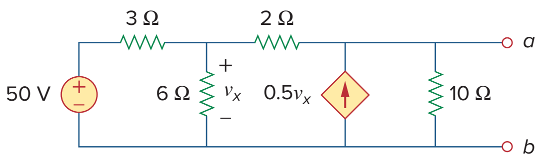


Figure 4.123
For Probs. 4.57 and 4.79.

4.58 The network in Fig. 4.124 models a bipolar transistor common-emitter amplifier connected to a load. Find the Thevenin resistance seen by the load.

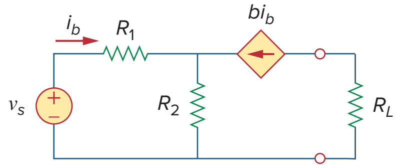


Figure 4.124
For Prob. 4.58.

4.59 Determine the Thevenin and Norton equivalents at terminals *a-b* of the circuit in Fig. 4.125.

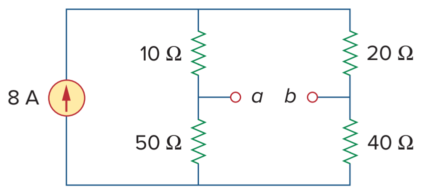


Figure 4.125
For Probs. 4.59 and 4.80.

***4.60** For the circuit in Fig. 4.126, find the Thevenin and Norton equivalent circuits at terminals *a-b*.

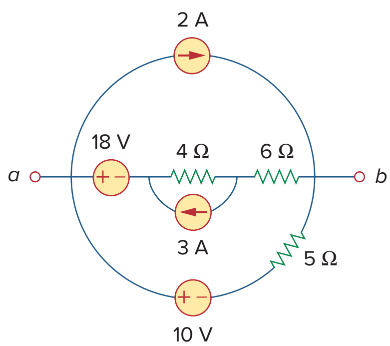


Figure 4.126
For Probs. 4.60 and 4.81.

***4.61** Obtain the Thevenin and Norton equivalent circuits at terminals *a-b* of the circuit in Fig. 4.127.

ML

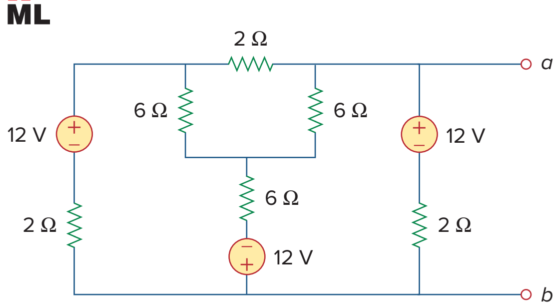


Figure 4.127
For Prob. 4.61.

***4.62** Find the Thevenin equivalent of the circuit in Fig. 4.128.

ML

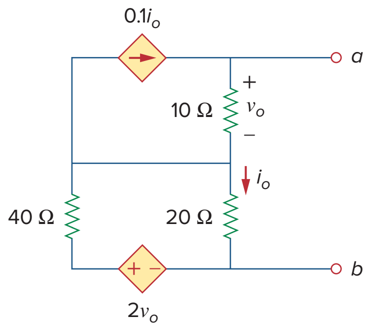


Figure 4.128
For Prob. 4.62.

4.63 Find the Norton equivalent for the circuit in Fig. 4.129.

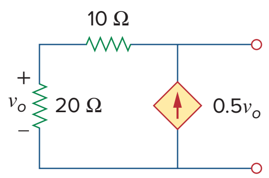


Figure 4.129
For Prob. 4.63.

4.64 Obtain the Thevenin equivalent seen at terminals *a-b* of the circuit in Fig. 4.130.

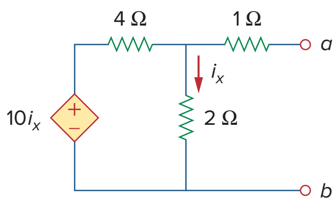


Figure 4.130
For Prob. 4.64.

4.65 For the circuit shown in Fig. 4.131, determine the relationship between V_o and I_o.

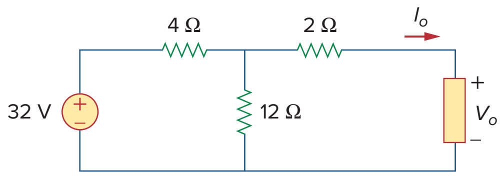


Figure 4.131
For Prob. 4.65.

Section 4.8 Maximum Power Transfer

4.66 Find the maximum power that can be delivered to the resistor R in the circuit of Fig. 4.132.

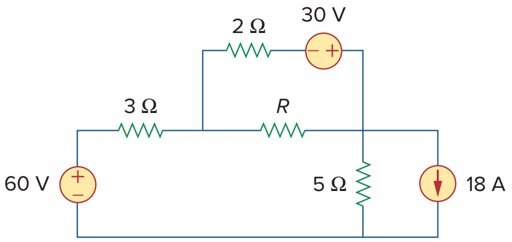


Figure 4.132
For Prob. 4.66.

4.67 The variable resistor R in Fig. 4.133 is adjusted until it absorbs the maximum power from the circuit.
(a) Calculate the value of R for maximum power.
(b) Determine the maximum power absorbed by R.

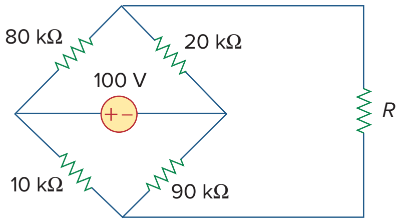


Figure 4.133
For Prob. 4.67.

***4.68** Consider the 30-Ω resistor in Fig. 4.134. First compute the Thevenin equivalent circuit as seen by the 30-Ω resistor. Compute the value of R that results in Thevenin equivalent resistance equal to the 30-Ω resistance and then calculate power delivered to the 30-Ω resistor. Now let $R = 0\ \Omega$, 110 Ω, and ∞, calculate the power delivered to the 30-Ω resistor in each case. What can you say about the value of R that will result in the maximum power that can be delivered to the 30-Ω resistor?

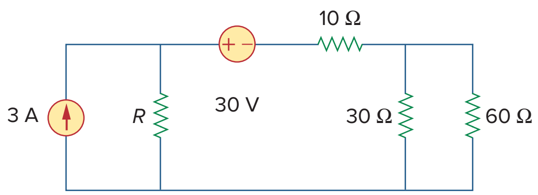


Figure 4.134
For Prob. 4.68.

4.69 Find the maximum power transferred to resistor R in the circuit of Fig. 4.135.

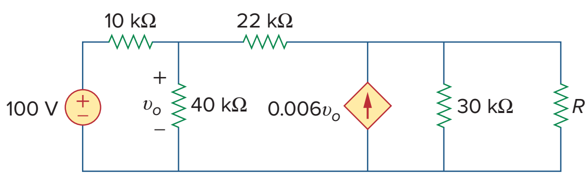


Figure 4.135
For Prob. 4.69.

4.70 Determine the maximum power delivered to the variable resistor R shown in the circuit of Fig. 4.136.

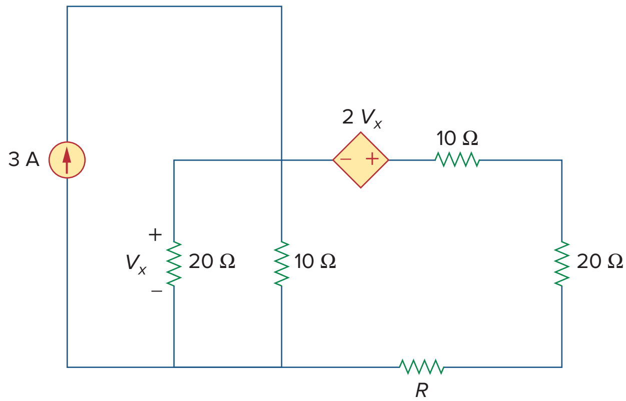


Figure 4.136
For Prob. 4.70.

4.71 For the circuit in Fig. 4.137, what resistor connected across terminals a-b will absorb maximum power from the circuit? What is that power?

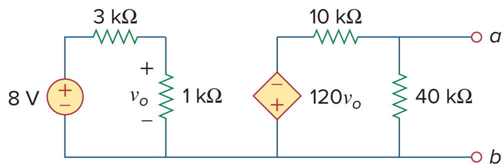


Figure 4.137
For Prob. 4.71.

4.72 (a) For the circuit in Fig. 4.138, obtain the Thevenin equivalent at terminals a-b.
(b) Calculate the current in $R_L = 13\ \Omega$.
(c) Find R_L for maximum power deliverable to R_L.
(d) Determine that maximum power.

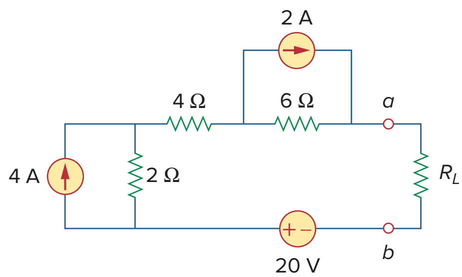


Figure 4.138
For Prob. 4.72.

4.73 Determine the maximum power that can be delivered to the variable resistor R in the circuit of Fig. 4.139.

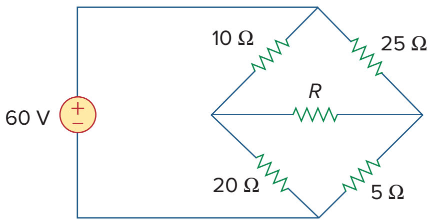


Figure 4.139
For Prob. 4.73.

4.74 For the bridge circuit shown in Fig. 4.140, find the load R_L for maximum power transfer and the maximum power absorbed by the load.

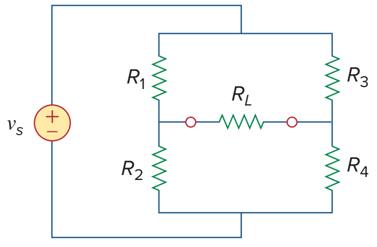


Figure 4.140
For Prob. 4.74.

***4.75** For the circuit in Fig. 4.141, determine the value of R such that the maximum power delivered to the load is 12 mW.

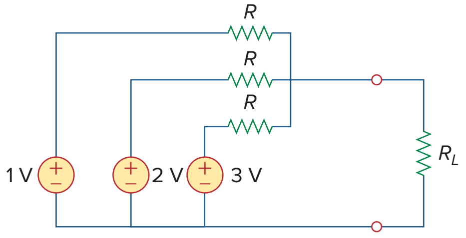


Figure 4.141
For Prob. 4.75.

Section 4.9 Verifying Circuit Theorems with *PSpice*

4.76 Solve Prob. 4.34 using *PSpice or MultiSim*. Let $V = 40$ V, $I = 3$ A, $R_1 = 10\ \Omega$, $R_2 = 40\ \Omega$, and $R_3 = 20\ \Omega$.

4.77 Use *PSpice or MultiSim* to solve Prob. 4.44.

4.78 Use *PSpice or MultiSim* to solve Prob. 4.52.

4.79 Obtain the Thevenin equivalent of the circuit in Fig. 4.123 using *PSpice or MultiSim*.

4.80 Use *PSpice or MultiSim* to find the Thevenin equivalent circuit at terminals *a-b* of the circuit in Fig. 4.125.

4.81 For the circuit in Fig. 4.126, use *PSpice or MultiSim* to find the Thevenin equivalent at terminals *a-b*.

Section 4.10 Applications

4.82 An automobile battery has an open circuit voltage of 14.7 V which drops to 12 V when connected to two 65-W headlights. What is the resistance of the headlights and the value of the internal resistance of the battery?

4.83 The following results were obtained from measurements taken between the two terminals of a resistive network.

Terminal Voltage	72 V	0 V
Terminal Current	0 A	9 A

Find the Thevenin equivalent of the network.

4.84 When connected to a 4- Ω resistor, a battery has a terminal voltage of 10.8 V but produces 12 V on an open circuit. Determine the Thevenin equivalent circuit for the battery.

4.85 The Thevenin equivalent at terminals *a-b* of the linear network shown in Fig. 4.142 is to be determined by measurement. When a 10-kΩ resistor is connected to terminals *a-b*, the voltage V_{ab} is measured as 20 V. When a 30-kΩ resistor is connected to the terminals, V_{ab} is measured as 40 V. Determine: (a) the Thevenin equivalent at terminals *a-b*, (b) V_{ab} when a 20-kΩ resistor is connected to terminals *a-b*.

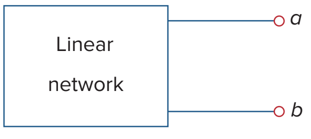


Figure 4.142
For Prob. 4.85.

4.86 A black box with a circuit in it is connected to a variable resistor. An ideal ammeter (with zero resistance) and an ideal voltmeter (with infinite resistance) are used to measure current and voltage as shown in Fig. 4.143. The results are shown in the table on the next page.

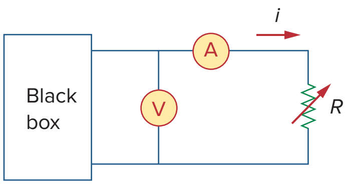


Figure 4.143
For Prob. 4.86.

(a) Find i when $R = 12\ \Omega$.

(b) Determine the maximum power from the box.

$R(\Omega)$	V(V)	i(A)
2	6	3
8	16	2
14	21	1.5

4.87 A transducer is modeled with a current source I_s and a parallel resistance R_s. The current at the terminals of the source is measured to be 9.975 mA when an ammeter with an internal resistance of 20 Ω is used.

(a) If adding a 2-kΩ resistor across the source terminals causes the ammeter reading to fall to 9.876 mA, calculate I_s and R_s.

(b) What will the ammeter reading be if the resistance between the source terminals is changed to 4 kΩ?

4.88 Consider the circuit in Fig. 4.144. An ammeter with internal resistance R_i is inserted between A and B to measure I_o. Determine the reading of the ammeter if: (a) $R_i = 500\ \Omega$, (b) $R_i = 0\ \Omega$. (*Hint:* Find the Thevenin equivalent circuit at terminals a-b.)

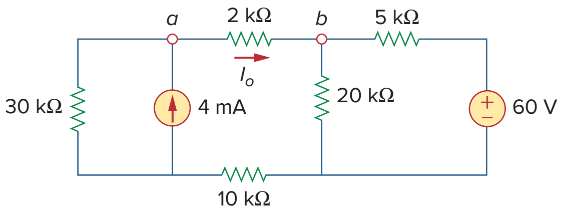


Figure 4.144
For Prob. 4.88.

4.89 Consider the circuit in Fig. 4.145. (a) Replace the resistor R_L by a zero resistance ammeter and determine the ammeter reading. (b) To verify the reciprocity theorem, interchange the ammeter and the 12-V source and determine the ammeter reading again.

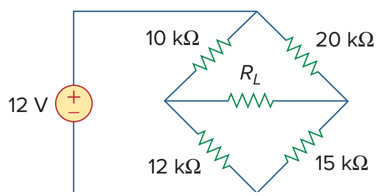


Figure 4.145
For Prob. 4.89.

4.90 The Wheatstone bridge circuit shown in Fig. 4.146 is used to measure the resistance of a strain gauge. The adjustable resistor has a linear taper with a maximum value of 100 Ω. If the resistance of the strain gauge is found to be 42.6 Ω, what fraction of the full slider travel is the slider when the bridge is balanced?

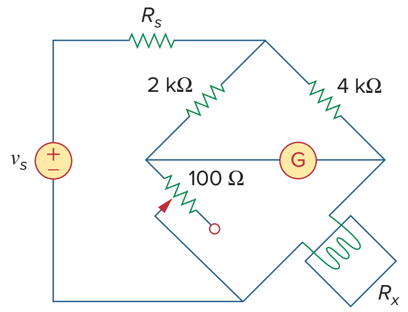


Figure 4.146
For Prob. 4.90.

4.91 (a) In the Wheatstone bridge circuit of Fig. 4.147 select the values of R_a and R_b such that the bridge can measure R_x in the range of 0–25 Ω.

(b) Repeat for the range of 0–250 Ω.

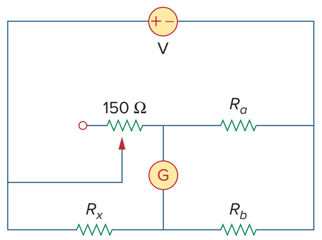


Figure 4.147
For Prob. 4.91.

***4.92** Consider the bridge circuit of Fig. 4.148. Is the bridge balanced? If the 10-kΩ resistor is replaced by an 18-kΩ resistor, what resistor connected between terminals a-b absorbs the maximum power? What is this power?

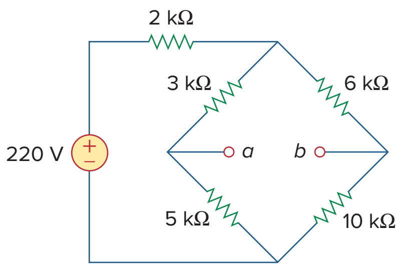


Figure 4.148
For Prob. 4.92.

Comprehensive Problems

4.93 The circuit in Fig. 4.149 models a common-emitter transistor amplifier. Find i_x using source transformation.

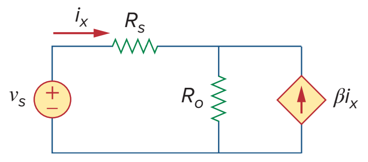


Figure 4.149
For Prob. 4.93.

4.94 An attenuator is an interface circuit that reduces the voltage level without changing the output resistance.

(a) By specifying R_s and R_p of the interface circuit in Fig. 4.150, design an attenuator that will meet the following requirements:

$$\frac{V_o}{V_g} = 0.125, \qquad R_{eq} = R_{Th} = R_g = 100\ \Omega$$

(b) Using the interface designed in part (a), calculate the current through a load of $R_L = 50\ \Omega$ when $V_g = 12$ V.

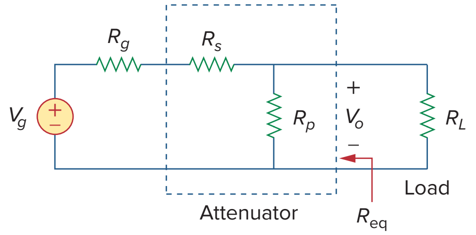


Figure 4.150
For Prob. 4.94.

***4.95** A dc voltmeter with a sensitivity of 10 kΩ/V is used to find the Thevenin equivalent of a linear network. Readings on two scales are as follows:

(a) 0–10 V scale: 8 V (b) 0–50 V scale: 10 V

Obtain the Thevenin voltage and the Thevenin resistance of the network.

***4.96** A resistance array is connected to a load resistor R and a 9-V battery as shown in Fig. 4.151.

(a) Find the value of R such that $V_o = 1.8$ V.

(b) Calculate the value of R that will draw the maximum current. What is the maximum current?

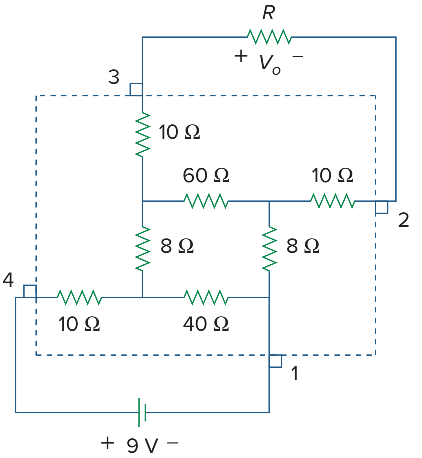


Figure 4.151
For Prob. 4.96.

4.97 A common-emitter amplifier circuit is shown in Fig. 4.152. Obtain the Thevenin equivalent to the left of points *B* and *E*.

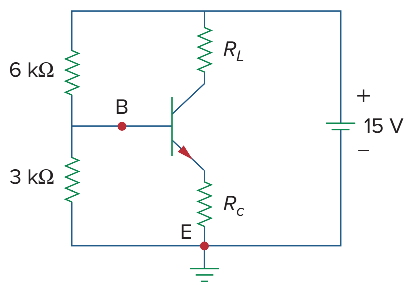


Figure 4.152
For Prob. 4.97.

***4.98** For Practice Prob. 4.18, determine the current through the 40-Ω resistor and the power dissipated by the resistor.

Review Questions

5.1 The two input terminals of an op amp are labeled as:

(a) high and low.
(b) positive and negative.
(c) inverting and noninverting.
(d) differential and nondifferential.

5.2 For an ideal op amp, which of the following statements are not true?

(a) The differential voltage across the input terminals is zero.
(b) The current into the input terminals is zero.
(c) The current from the output terminal is zero.
(d) The input resistance is zero.
(e) The output resistance is zero.

5.3 For the circuit in Fig. 5.40, voltage v_o is:

(a) −6 V (b) −5 V
(c) −1.2 V (d) −0.2 V

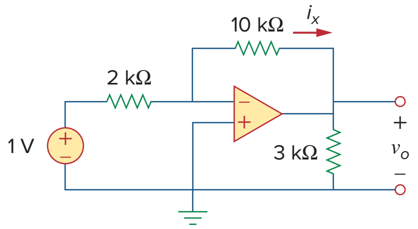


Figure 5.40
For Review Questions 5.3 and 5.4.

5.4 For the circuit in Fig. 5.40, current i_x is:

(a) 600 μA (b) 500 μA
(c) 200 μA (d) 1/12 μA

5.5 If $v_s = 0$ in the circuit of Fig. 5.41, current i_o is:

(a) −10 μA (b) −2.5 μA
(c) 10/12 μA (d) 10/14 μA

5.6 If $v_s = 8$ mV in the circuit of Fig. 5.41, the output voltage is:

(a) −44 mV (b) −8 mV
(c) 4 mV (d) 7 mV

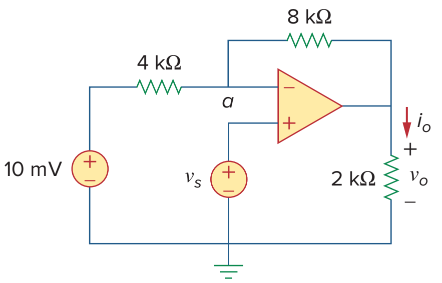


Figure 5.41
For Review Questions 5.5, 5.6, and 5.7.

5.7 Refer to Fig. 5.41. If $v_s = 8$ mV, voltage v_a is:

(a) −8 mV (b) 0 mV
(c) 10/3 mV (d) 8 mV

5.8 The power absorbed by the 4-kΩ resistor in Fig. 5.42 is:

(a) 9 mW (b) 4 mW
(c) 2 mW (d) 1 mW

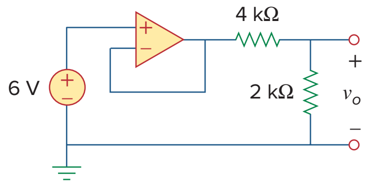


Figure 5.42
For Review Questions 5.8.

5.9 Which of these amplifiers is used in a digital-to-analog converter?

(a) noninverter
(b) voltage follower
(c) summer
(d) difference amplifier

5.10 Difference amplifiers are used in (please check all that apply):

(a) instrumentation amplifiers
(b) voltage followers
(c) voltage regulators
(d) buffers
(e) summing amplifiers
(f) subtracting amplifiers

Answers: 5.1c, 5.2c,d, 5.3b, 5.4b, 5.5a, 5.6c, 5.7d, 5.8b, 5.9c, 5.10a, f.

Problems

Section 5.2 Operational Amplifiers

5.1 The equivalent model of a certain op amp is shown in Fig. 5.43. Determine:

(a) the input resistance
(b) the output resistance
(c) the voltage gain in dB

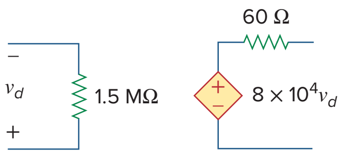


Figure 5.43
For Prob. 5.1.

5.2 The open-loop gain of an op amp is 50,000. Calculate the output voltage when there are inputs of $+10\ \mu$V on the inverting terminal and $+20\ \mu$V on the noninverting terminal.

5.3 Determine the voltage input to the inverting terminal of an op amp when $-40\ \mu$V is applied to the non-inverting terminal and the output through an open-loop gain of 150,000 is 15 V.

5.4 The output voltage of an op amp is -4 V when the noninverting input is 1 mV. If the open-loop gain of the op amp is 2×10^6, what is the inverting input?

5.5 For the op amp circuit of Fig. 5.44, the op amp has an open-loop gain of 100,000, an input resistance of 10 kΩ, and an output resistance of 100 Ω. Find the voltage gain v_o/v_i using the nonideal model of the op amp.

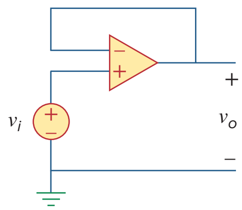


Figure 5.44
For Prob. 5.5.

5.6 Using the same parameters for the 741 op amp in Example 5.1, find v_o in the op amp circuit of Fig. 5.45.

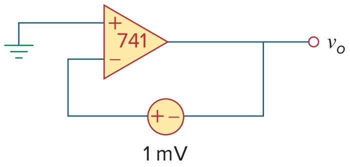


Figure 5.45
For Prob. 5.6.

5.7 The op amp in Fig. 5.46 has $R_i = 100$ kΩ, $R_o = 100$ Ω, $A = 100{,}000$. Find the differential voltage v_d and the output voltage v_o.

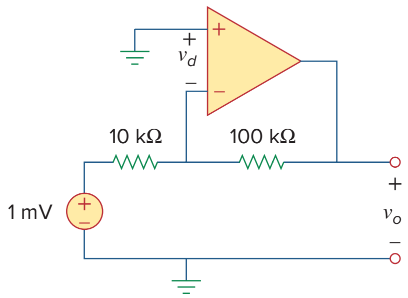


Figure 5.46
For Prob. 5.7.

Section 5.3 Ideal Op Amp

5.8 Obtain v_o for each of the op amp circuits in Fig. 5.47.

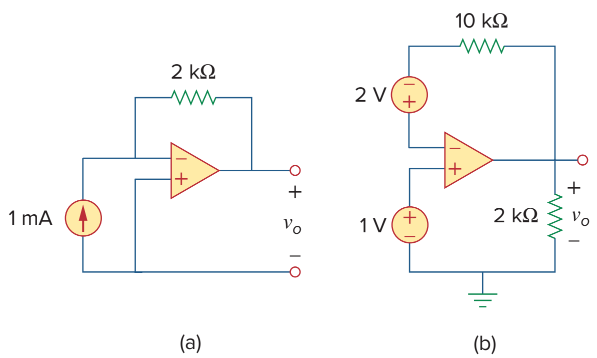


Figure 5.47
For Prob. 5.8.

5.9 Determine v_o for each of the op amp circuits in Fig. 5.48.

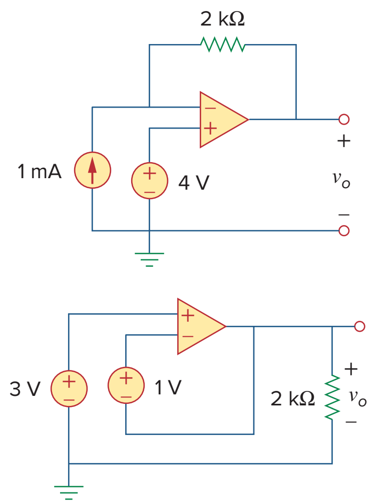


Figure 5.48
For Prob. 5.9.

5.10 Find the gain v_o/v_s of the circuit in Fig. 5.49.

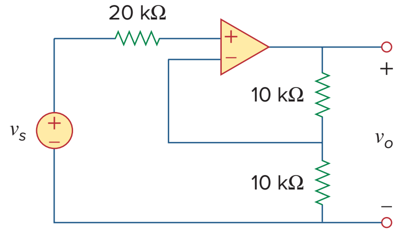


Figure 5.49
For Prob. 5.10.

5.11 Using Fig. 5.50, design a problem to help other students better understand how ideal op amps work.
e2d

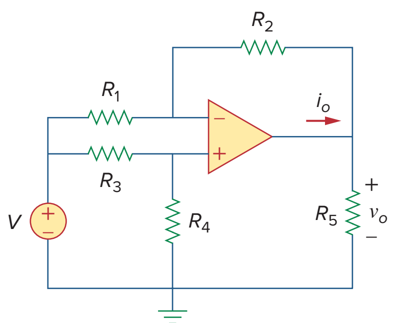


Figure 5.50
For Prob. 5.11.

5.12 Calculate the voltage ratio v_o/v_s for the op amp circuit of Fig. 5.51. Assume that the op amp is ideal.

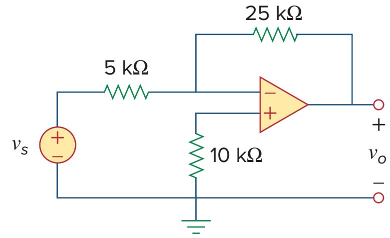


Figure 5.51
For Prob. 5.12.

5.13 Find v_o and i_o in the circuit of Fig. 5.52.

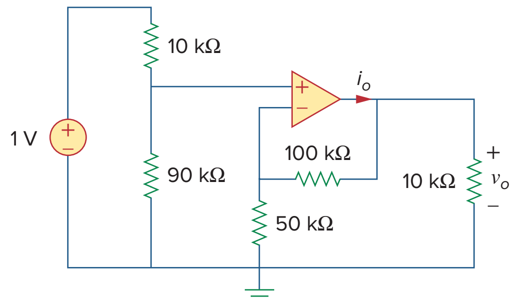


Figure 5.52
For Prob. 5.13.

5.14 Determine the output voltage v_o in the circuit of Fig. 5.53.

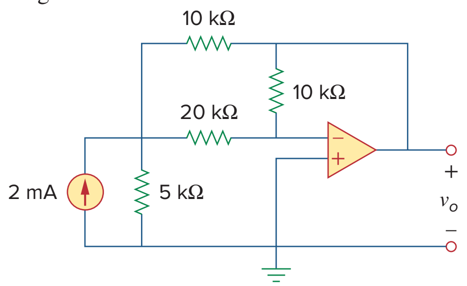


Figure 5.53
For Prob. 5.14.

Section 5.4 Inverting Amplifier

5.15 (a) Determine the ratio v_o/i_s in the op amp circuit of Fig. 5.54.

(b) Evaluate the ratio for $R_1 = 20$ kΩ, $R_2 = 25$ kΩ, $R_3 = 40$ kΩ.

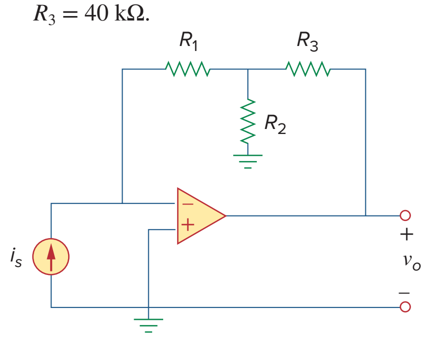


Figure 5.54
For Prob. 5.15.

5.16 Using Fig. 5.55, design a problem to help students better understand inverting op amps.

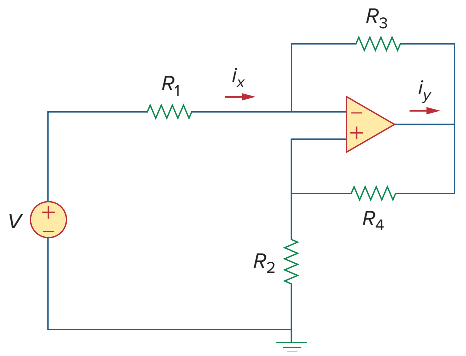


Figure 5.55
For Prob. 5.16.

5.17 Calculate the gain v_o/v_i when the switch in Fig. 5.56 is in:

(a) position 1 (b) position 2 (c) position 3.

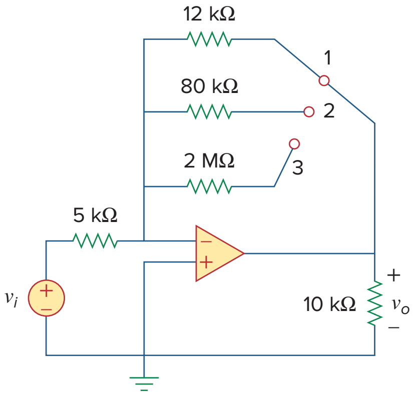


Figure 5.56
For Prob. 5.17.

***5.18** For the circuit shown in Figure 5.57, solve for the Thevenin equivalent circuit looking into terminals A and B.

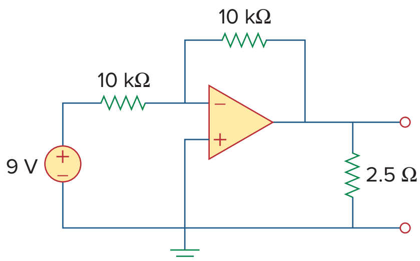


Figure 5.57
For Prob. 5.18.

5.19 Determine i_o in the circuit of Fig. 5.58.

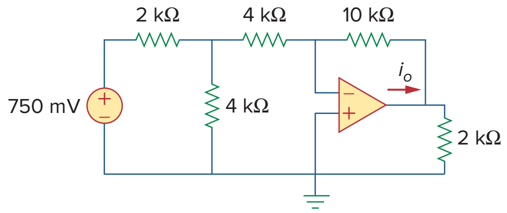


Figure 5.58
For Prob. 5.19.

5.20 In the circuit of Fig. 5.59, calculate v_o of $v_s = 2$ V.

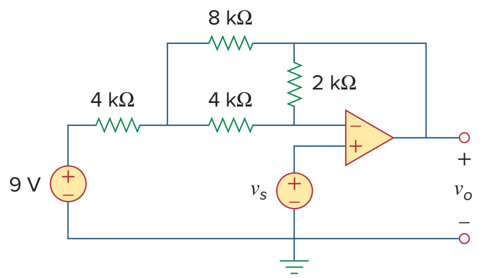


Figure 5.59
For Prob. 5.20.

5.21 Calculate v_o in the op amp circuit of Fig. 5.60.

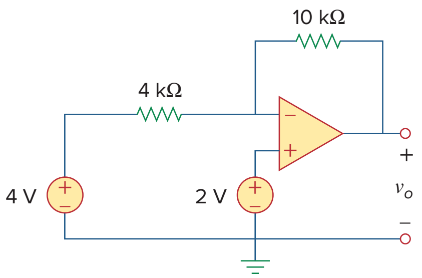


Figure 5.60
For Prob. 5.21.

5.22 Design an inverting amplifier with a gain of −15.

5.23 For the op amp circuit in Fig. 5.61, find the voltage gain v_o/v_s.

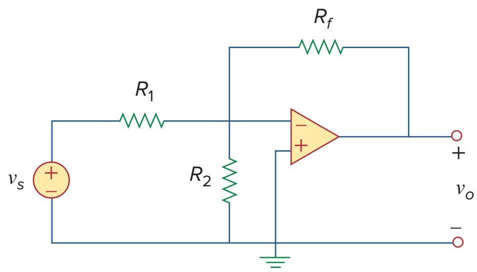


Figure 5.61
For Prob. 5.23.

* An asterisk indicates a challenging problem.

5.24 In the circuit shown in Fig. 5.62, find k in the voltage transfer function $v_o = kv_s$.

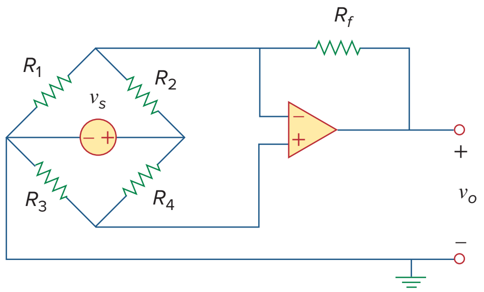


Figure 5.62
For Prob. 5.24.

Section 5.5 Noninverting Amplifier

5.25 Calculate v_o in the op amp circuit of Fig. 5.63.

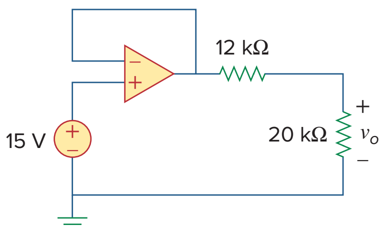


Figure 5.63
For Prob. 5.25.

5.26 Using Fig. 5.64, design a problem to help other students better understand noninverting op amps.

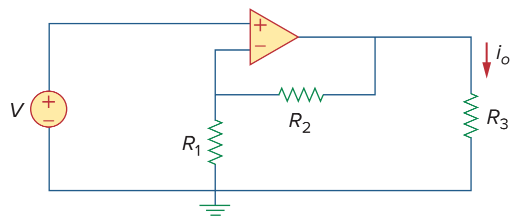


Figure 5.64
For Prob. 5.26.

5.27 Find v_o in the op amp circuit of Fig. 5.65.

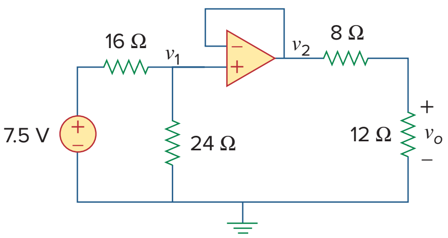


Figure 5.65
For Prob. 5.27.

5.28 Find i_o in the op amp circuit of Fig. 5.66.

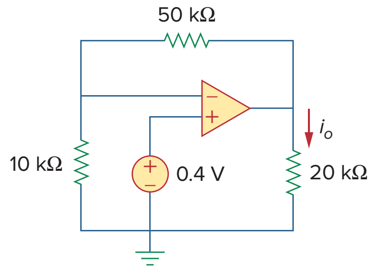


Figure 5.66
For Prob. 5.28.

5.29 Determine the voltage gain v_o/v_i of the op amp circuit in Fig. 5.67.

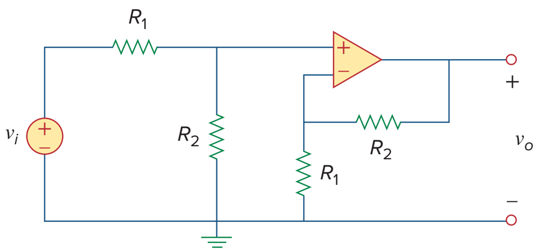


Figure 5.67
For Prob. 5.29.

5.30 In the circuit shown in Fig. 5.68, find i_x and the power absorbed by the 20-kΩ resistor.

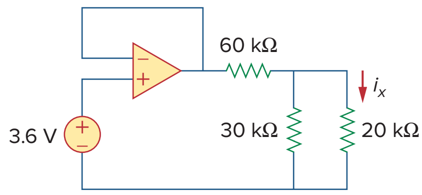


Figure 5.68
For Prob. 5.30.

5.31 For the circuit in Fig. 5.69, find i_x.

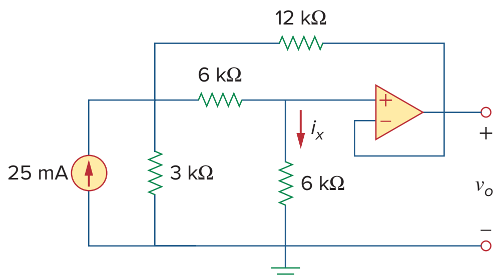


Figure 5.69
For Prob. 5.31.

5.32 Calculate i_x and v_o in the circuit of Fig. 5.70. Find the power dissipated by the 60-kΩ resistor.

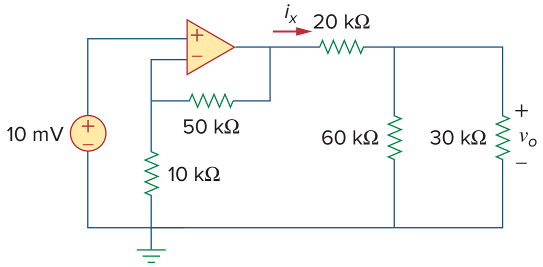


Figure 5.70
For Prob. 5.32.

5.33 Refer to the op amp circuit in Fig. 5.71. Calculate i_x and the power absorbed by the 3-kΩ resistor.

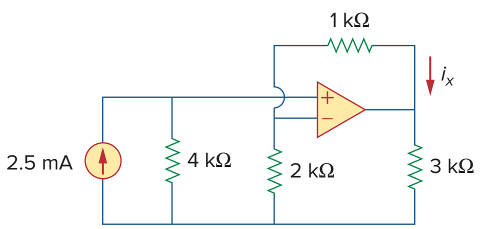


Figure 5.71
For Prob. 5.33.

5.34 Given the op amp circuit shown in Fig. 5.72, express v_o in terms of v_1 and v_2.

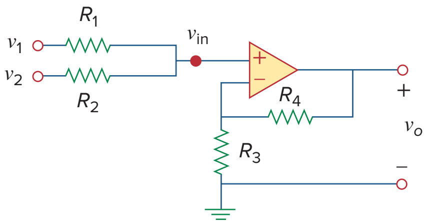


Figure 5.72
For Prob. 5.34.

5.35 Design a noninverting amplifier with a gain of 7.5.

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5.36 For the circuit shown in Fig. 5.73, find the Thevenin equivalent at terminals *a*-*b*. (*Hint:* To find R_{Th}, apply a current source i_o and calculate v_o.)

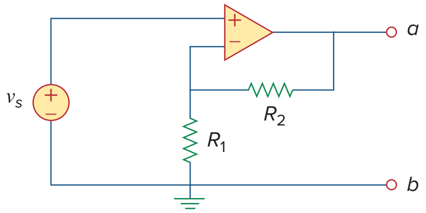

Figure 5.73
For Prob. 5.36.

Section 5.6 Summing Amplifier

5.37 Determine the output of the summing amplifier in Fig. 5.74.

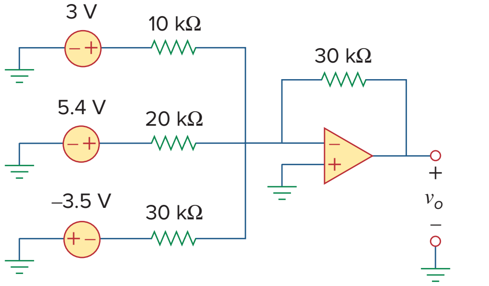

Figure 5.74
For Prob. 5.37.

5.38 Using Fig. 5.75, design a problem to help other students better understand summing amplifiers.

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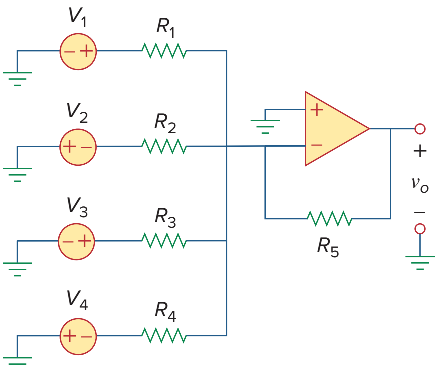


Figure 5.75
For Prob. 5.38.

5.39 For the op amp circuit in Fig. 5.76, determine the value of v_2 in order to make $v_o = -16.5$ V.

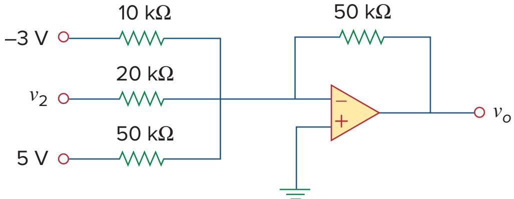


Figure 5.76
For Prob. 5.39.

5.40 Referring to the circuit shown in Fig. 5.77, determine V_o in terms of V_1 and V_2.

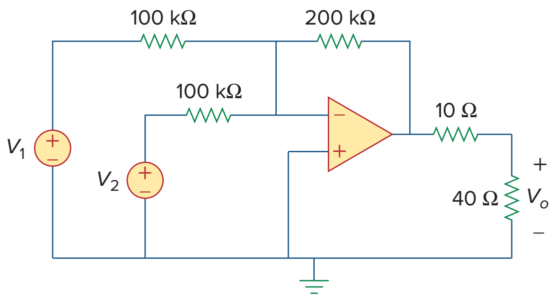


Figure 5.77
For Prob. 5.40.

5.41 An *averaging amplifier* is a summer that provides an output equal to the average of the inputs. By using proper input and feedback resistor values, one can get

$$-v_{\text{out}} = \frac{1}{4}(v_1 + v_2 + v_3 + v_4)$$

Using a feedback resistor of 10 kΩ, design an averaging amplifier with four inputs.

5.42 The feedback resistor of a three-input averaging summing amplifier is 50 kΩ. What are the values of R_1, R_2, and R_3?

5.43 The feedback resistor of a five-input averaging summing amplifier is 40 kΩ. What are the values of R_1, R_2, R_3, R_4, and R_5?

5.44 Show that the output voltage v_o of the circuit in Fig. 5.78 is

$$v_o = \frac{(R_3 + R_4)}{R_3(R_1 + R_2)}(R_2 v_1 + R_1 v_2)$$

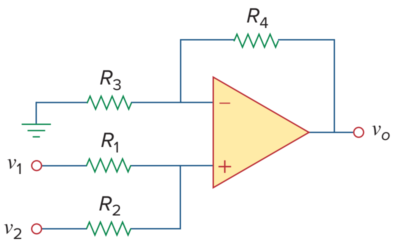


Figure 5.78
For Prob. 5.44.

5.45 Design an op amp circuit to perform the following operation:

$$v_o = 3.5v_1 - 2.5v_2$$

All resistances must be ≤ 100 kΩ.

5.46 Using only two op amps, design a circuit to solve

$$-v_{\text{out}} = \frac{v_3 - v_1}{5} + \frac{v_1 - v_2}{2}$$

Section 5.7 Difference Amplifier

5.47 The circuit in Fig. 5.79 is for a difference amplifier. Find v_o given that $v_1 = 1$ V and $v_2 = 2$ V.

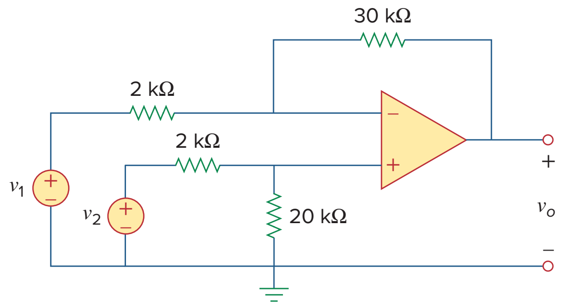


Figure 5.79
For Prob. 5.47.

5.48 The circuit in Fig. 5.80 is a differential amplifier driven by a bridge. Find v_o.

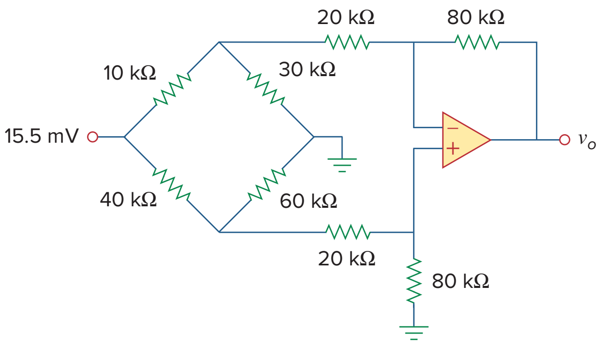


Figure 5.80
For Prob. 5.48.

5.49 Design a difference amplifier to have a gain of 4 and a common-mode input resistance of 20 kΩ at each input.

5.50 Design a circuit to amplify the difference between two inputs by 2.5.

(a) Use only one op amp.

(b) Use two op amps.

5.51 Using two op amps, design a subtractor.

***5.52** Design an op amp circuit such that

$$v_o = 4v_1 + 6v_2 - 3v_3 - 5v_4$$

Let all the resistors be in the range of 20 to 200 kΩ.

***5.53** The ordinary difference amplifier for fixed-gain operation is shown in Fig. 5.81(a). It is simple and reliable unless gain is made variable. One way of providing gain adjustment without losing simplicity and accuracy is to use the circuit in Fig. 5.81(b). Another way is to use the circuit in Fig. 5.81(c). Show that:

(a) for the circuit in Fig. 5.81(a),

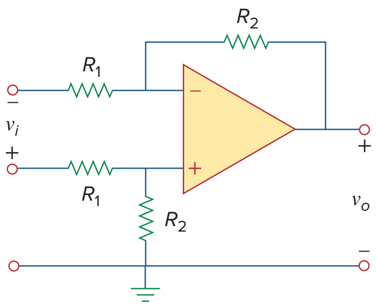
$$\frac{v_o}{v_i} = \frac{R_2}{R_1}$$

(b) for the circuit in Fig. 5.81(b),

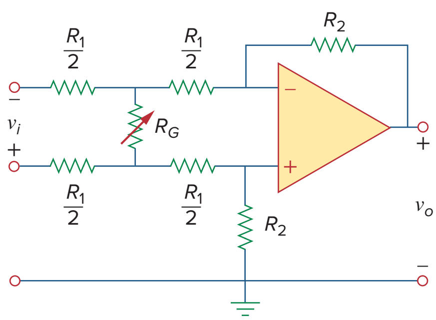
$$\frac{v_o}{v_i} = \frac{R_2}{R_1}\frac{1}{1 + \dfrac{R_1}{2R_G}}$$

(c) for the circuit in Fig. 5.81(c),

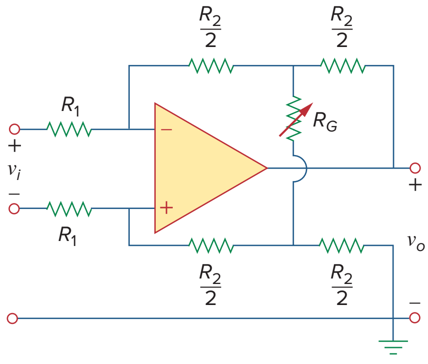
$$\frac{v_o}{v_i} = \frac{R_2}{R_1}\left(1 + \frac{R_2}{2R_G}\right)$$



(a)



(b)



(c)

Figure 5.81
For Prob. 5.53.

Section 5.8 Cascaded Op Amp Circuits

5.54 Determine the voltage transfer ratio v_o/v_s in the op amp circuit of Fig. 5.82, where R = 10 kΩ.

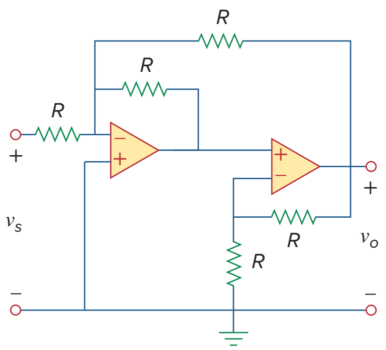


Figure 5.82
For Prob. 5.54.

5.55 In a certain electronic device, a three-stage amplifier is desired, whose overall voltage gain is 42 dB. The individual voltage gains of the first two stages are to be equal, while the gain of the third is to be one-fourth of each of the first two. Calculate the voltage gain of each.

5.56 Using Fig. 5.83, design a problem to help other students better understand cascaded op amps.

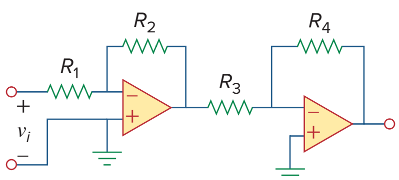


Figure 5.83
For Prob. 5.56.

5.57 Find v_o in the op amp circuit of Fig. 5.84.

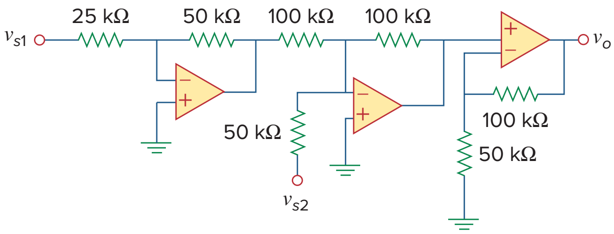


Figure 5.84
For Prob. 5.57.

5.58 Calculate i_o in the op amp circuit of Fig. 5.85.

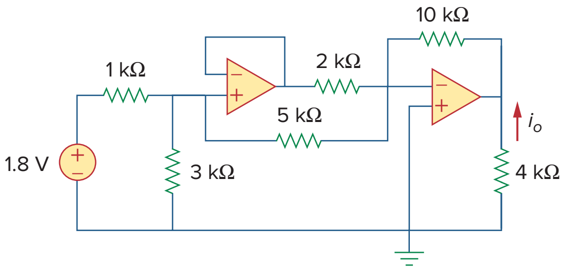


Figure 5.85
For Prob. 5.58.

5.59 In the op amp circuit of Fig. 5.86, determine the voltage gain v_o/v_s. Take $R = 10$ kΩ.

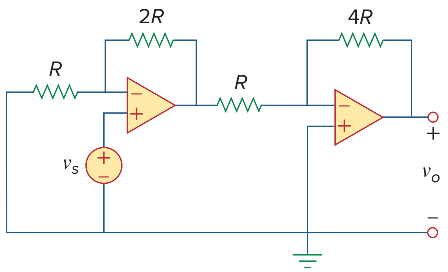


Figure 5.86
For Prob. 5.59.

5.60 Calculate v_o/v_i in the op amp circuit of Fig. 5.87.

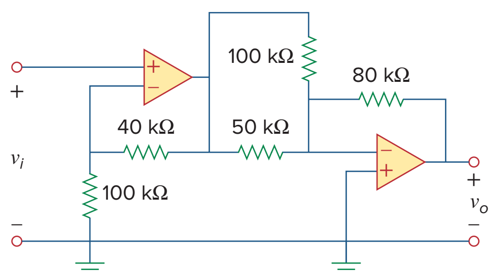


Figure 5.87
For Prob. 5.60.

5.61 Determine v_o in the circuit of Fig. 5.88.

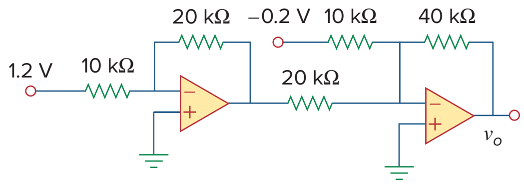


Figure 5.88
For Prob. 5.61.

5.62 Obtain the closed-loop voltage gain v_o/v_i of the circuit in Fig. 5.89.

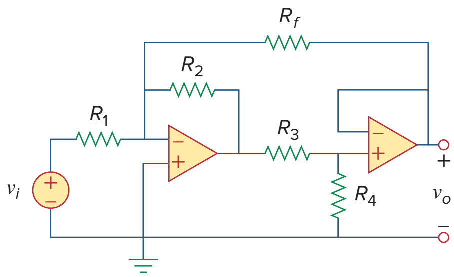


Figure 5.89
For Prob. 5.62.

5.63 Determine the gain v_o/v_i of the circuit in Fig. 5.90.

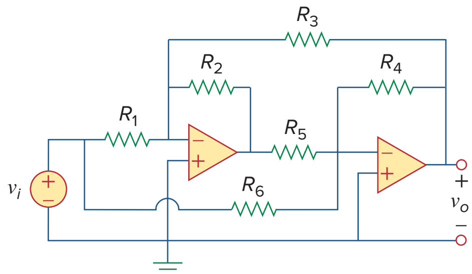


Figure 5.90
For Prob. 5.63.

5.64 For the op amp circuit shown in Fig. 5.91, find v_o/v_s.

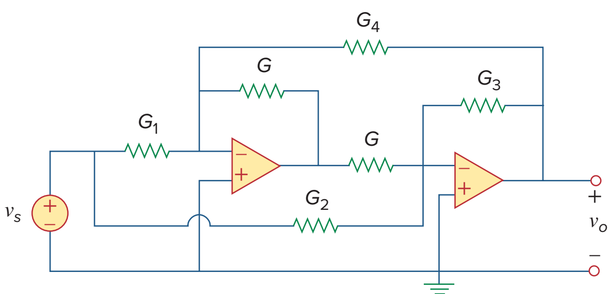


Figure 5.91
For Prob. 5.64.

5.65 Find v_o in the op amp circuit of Fig. 5.92.

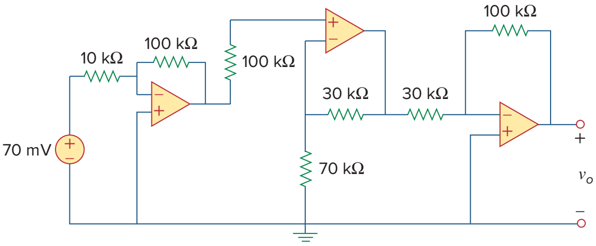


Figure 5.92
For Prob. 5.65.

5.66 For the circuit in Fig. 5.93, find v_o.

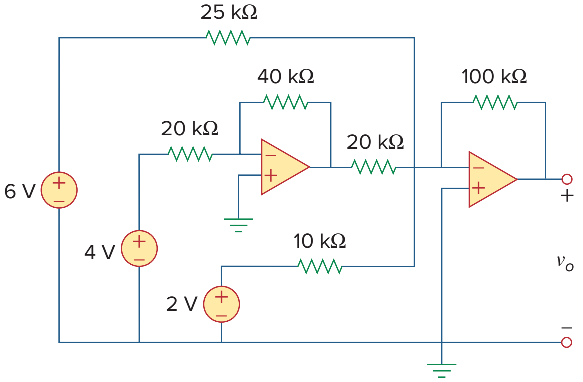


Figure 5.93
For Prob. 5.66.

5.67 Obtain the output v_o in the circuit of Fig. 5.94.

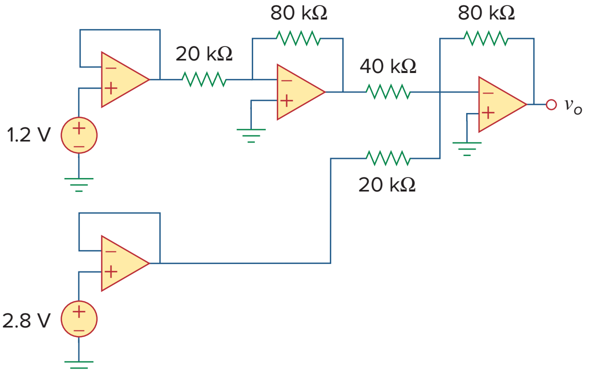


Figure 5.94
For Prob. 5.67.

5.68 Find v_o in the circuit of Fig. 5.95, assuming that $R_f = \infty$ (open circuit).

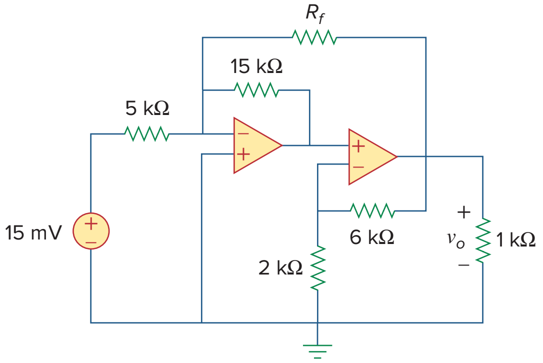


Figure 5.95
For Probs. 5.68 and 5.69.

5.69 Repeat the previous problem if $R_f = 10$ kΩ.

5.70 Determine v_o in the op amp circuit of Fig. 5.96.

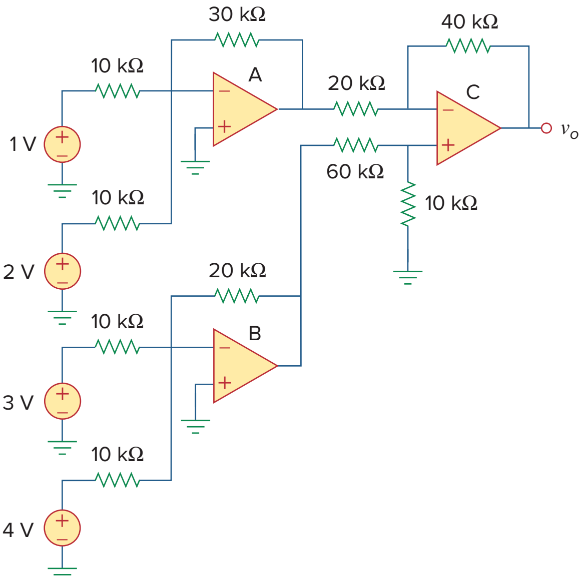


Figure 5.96
For Prob. 5.70.

5.71 Determine v_o in the op amp circuit of Fig. 5.97.

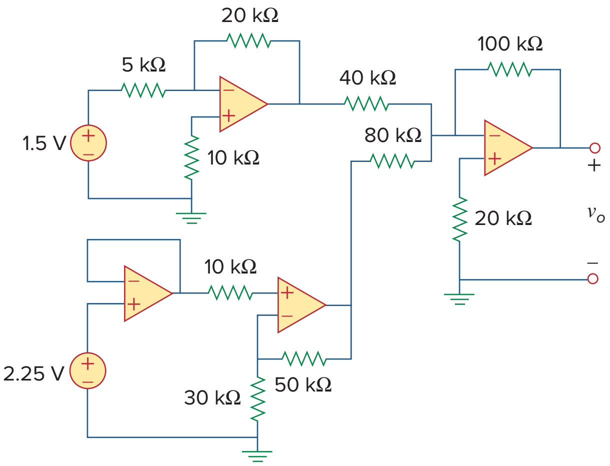


Figure 5.97
For Prob. 5.71.

5.72 Find the load voltage v_L in the circuit of Fig. 5.98.

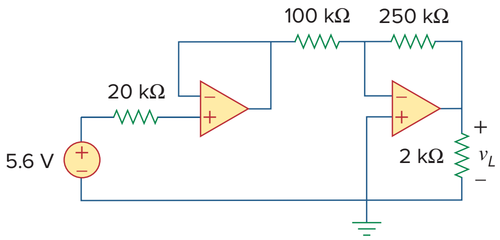


Figure 5.98
For Prob. 5.72.

5.73 Determine the load voltage v_L in the circuit of Fig. 5.99.

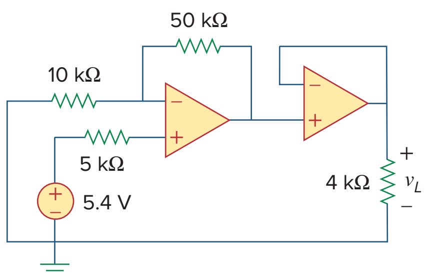


Figure 5.99
For Prob. 5.73.

5.74 Find i_o in the op amp circuit of Fig. 5.100.

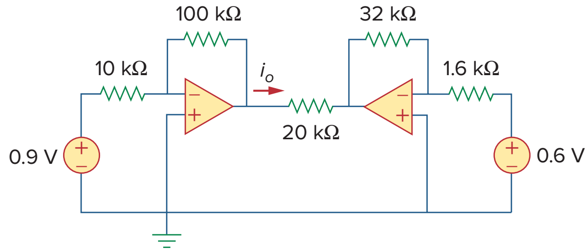


Figure 5.100
For Prob. 5.74.

Section 5.9 Op Amp Circuit Analysis with *PSpice*

5.75 Rework Example 5.11 using the nonideal op amp LM324 instead of uA741.

5.76 Solve Prob. 5.19 using *PSpice* or *MultiSim* and op amp uA741.

5.77 Solve Prob. 5.48 using *PSpice* or *MultiSim* and op amp LM324.

5.78 Use *PSpice* or *MultiSim* to obtain v_o in the circuit of Fig. 5.101.

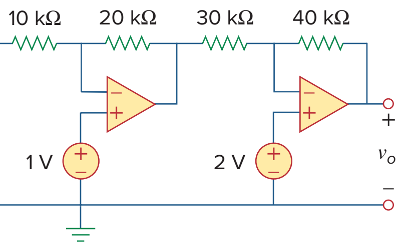


Figure 5.101
For Prob. 5.78.

5.79 Determine v_o in the op amp circuit of Fig. 5.102, using *PSpice* or *MultiSim*.

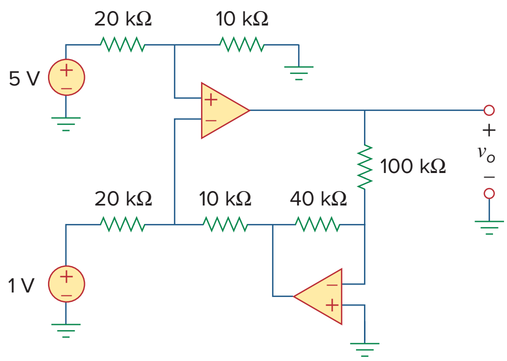


Figure 5.102
For Prob. 5.79.

5.80 Use *PSpice* or *MultiSim* to solve Prob. 5.70.

5.81 Use *PSpice* or *MultiSim* to verify the results in Example 5.9. Assume nonideal op amps LM324.

Section 5.10 Applications

5.82 A four-bit DAC covers a voltage range of 0 to 10 V. Calculate the resolution of the DAC in volts per discrete binary step.

5.83 Design a six-bit digital-to-analog converter.

(a) If $|V_o| = 1.1875$ V is desired, what should $[V_1V_2V_3V_4V_5V_6]$ be?
(b) Calculate $|V_o|$ if $[V_1V_2V_3V_4V_5V_6] = [011011]$.
(c) What is the maximum value $|V_o|$ can assume?

***5.84** A four-bit *R-2R ladder* DAC is presented in Fig. 5.103.

(a) Show that the output voltage is given by

$$-V_o = R_f\left(\frac{V_1}{2R} + \frac{V_2}{4R} + \frac{V_3}{8R} + \frac{V_4}{16R}\right)$$

(b) If $R_f = 12$ kΩ and $R = 10$ kΩ, find $|V_o|$ for $[V_1V_2V_3V_4] = [1011]$ and $[V_1V_2V_3V_4] = [0101]$.

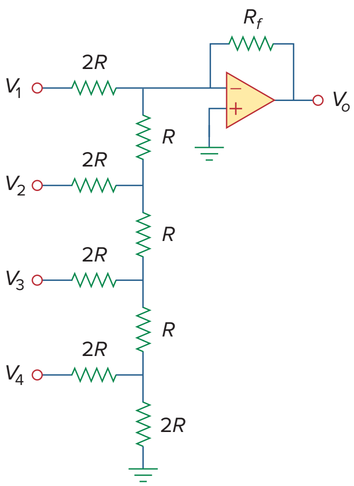


Figure 5.103
For Prob. 5.84.

5.85 In the op amp circuit of Fig. 5.104, find the value of R so that the power absorbed by the 10-kΩ resistor is 10 mW. Determine the power gain.

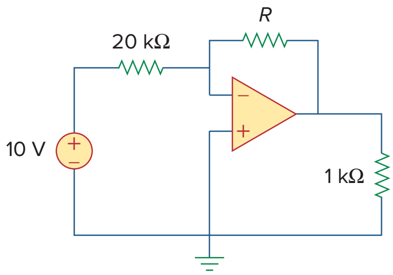


Figure 5.104
For Prob. 5.85.

5.86 Design a voltage controlled ideal current source (within the operating limits of the op amp) where the output current is equal to 200 $v_s(t)$ μA.

5.87 Figure 5.105 displays a two-op-amp instrumentation amplifier. Derive an expression for v_o in terms of v_1 and v_2. How can this amplifier be used as a subtractor?

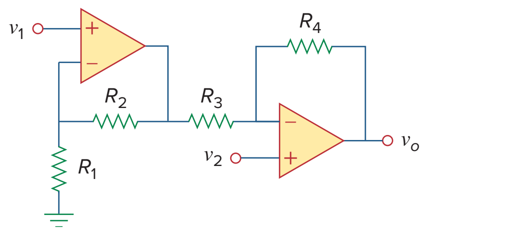


Figure 5.105
For Prob. 5.87.

***5.88** Figure 5.106 shows an instrumentation amplifier driven by a bridge. Obtain the gain v_o/v_i of the amplifier.

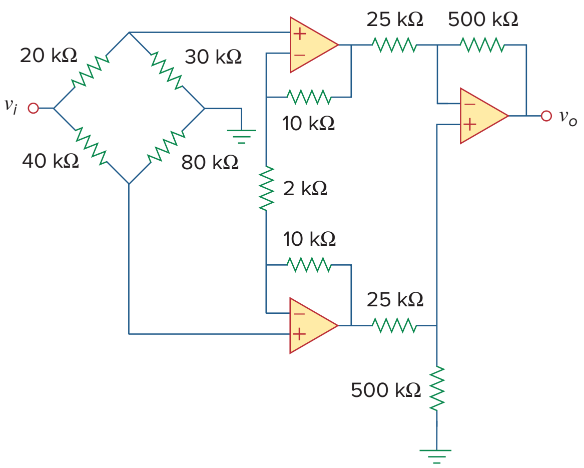


Figure 5.106
For Prob. 5.88.

Comprehensive Problems

5.89 Design a circuit that provides a relationship between output voltage v_o and input voltage v_s such that $v_o = 12v_s - 10$. Two op amps, a 6-V battery, and several resistors are available.

5.90 The op amp circuit in Fig. 5.107 is a *current amplifier*. Find the current gain i_o/i_s of the amplifier.

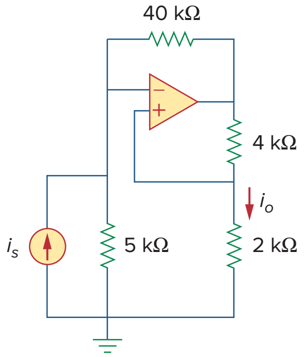


Figure 5.107
For Prob. 5.90.

5.91 A noninverting current amplifier is portrayed in Fig. 5.108. Calculate the gain i_o/i_s. Take $R_1 = 8$ kΩ and $R_2 = 1$ kΩ.

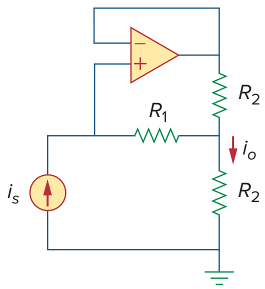


Figure 5.108
For Prob. 5.91.

5.92 Refer to the *bridge amplifier* shown in Fig. 5.109. Determine the voltage gain v_o/v_i.

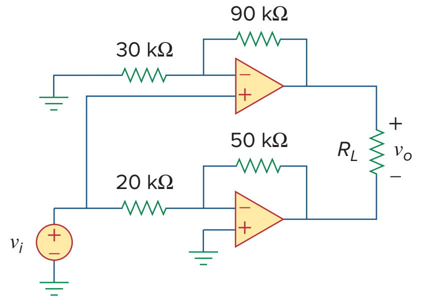


Figure 5.109
For Prob. 5.92.

***5.93** A voltage-to-current converter is shown in Fig. 5.110, which means that $i_L = Av_i$ if $R_1R_2 = R_3R_4$. Find the constant term A.

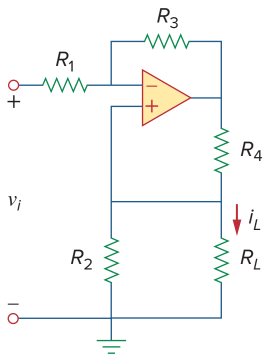


Figure 5.110
For Prob. 5.93.

2. The voltage across a capacitor is directly proportional to the time integral of the current through it.

$$v = \frac{1}{C}\int_{-\infty}^{t} i\, d\tau = \frac{1}{C}\int_{t_0}^{t} i\, d\tau + v(t_0)$$

The voltage across a capacitor cannot change instantly.
3. Capacitors in series and in parallel are combined in the same way as conductances.
4. The voltage across an inductor is directly proportional to the time rate of change of the current through it.

$$v = L\frac{di}{dt}$$

The voltage across the inductor is zero unless the current is changing. Thus, an inductor acts like a short circuit to a dc source.
5. The current through an inductor is directly proportional to the time integral of the voltage across it.

$$i = \frac{1}{L}\int_{-\infty}^{t} v\, d\tau = \frac{1}{L}\int_{t_0}^{t} v\, d\tau + i(t_0)$$

The current through an inductor cannot change instantly.
6. Inductors in series and in parallel are combined in the same way resistors in series and in parallel are combined.
7. At any given time t, the energy stored in a capacitor is $\frac{1}{2}Cv^2$, while the energy stored in an inductor is $\frac{1}{2}Li^2$.
8. Three application circuits, the integrator, the differentiator, and the analog computer, can be realized using resistors, capacitors, and op amps.

Review Questions

6.1 What charge is on a 5-F capacitor when it is connected across a 120-V source?

(a) 600 C (b) 300 C
(c) 24 C (d) 12 C

6.2 Capacitance is measured in:

(a) coulombs (b) joules
(c) henrys (d) farads

6.3 When the total charge in a capacitor is doubled, the energy stored:

(a) remains the same (b) is halved
(c) is doubled (d) is quadrupled

6.4 Can the voltage waveform in Fig. 6.42 be associated with a real capacitor?

(a) Yes (b) No

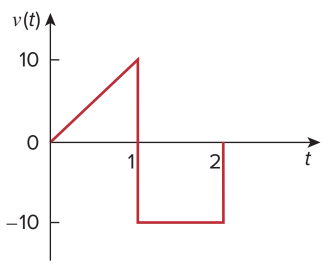


Figure 6.42
For Review Question 6.4.

6.5 The total capacitance of two 40-mF series-connected capacitors in parallel with a 4-mF capacitor is:

(a) 3.8 mF (b) 5 mF (c) 24 mF
(d) 44 mF (e) 84 mF

6.6 In Fig. 6.43, if $i = \cos 4t$ and $v = \sin 4t$, the element is:

(a) a resistor (b) a capacitor (c) an inductor

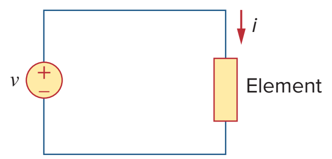


Figure 6.43
For Review Question 6.6.

6.7 A 5-H inductor changes its current by 3 A in 0.2 s. The voltage produced at the terminals of the inductor is:

(a) 75 V (b) 8.888 V
(c) 3 V (d) 1.2 V

6.8 If the current through a 10-mH inductor increases from zero to 2 A, how much energy is stored in the inductor?

(a) 40 mJ (b) 20 mJ
(c) 10 mJ (d) 5 mJ

6.9 Inductors in parallel can be combined just like resistors in parallel.

(a) True (b) False

6.10 For the circuit in Fig. 6.44, the voltage divider formula is:

(a) $v_1 = \dfrac{L_1 + L_2}{L_1} v_s$ (b) $v_1 = \dfrac{L_1 + L_2}{L_2} v_s$

(c) $v_1 = \dfrac{L_2}{L_1 + L_2} v_s$ (d) $v_1 = \dfrac{L_1}{L_1 + L_2} v_s$

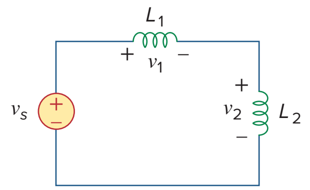


Figure 6.44
For Review Question 6.10.

Answers: 6.1a, 6.2d, 6.3d, 6.4b, 6.5c, 6.6b, 6.7a, 6.8b, 6.9a, 6.10d.

Problems

Section 6.2 Capacitors

6.1 If the voltage across a 7.5-F capacitor is $2te^{-3t}$ V, find the current and the power.

6.2 A 50-μF capacitor has energy $w(t) = 10 \cos^2 377t$ J. Determine the current through the capacitor.

6.3 Design a problem to help other students better understand how capacitors work.

6.4 A voltage across a capacitor is equal to $[2 - 2\cos(4t)]$ V and the current flowing through it is equal to $2 \sin(4t)$ μA. Determine the value of the capacitance. Calculate the power being stored by the capacitor.

6.5 The voltage across a 4-μF capacitor is shown in Fig. 6.45. Find the current waveform.

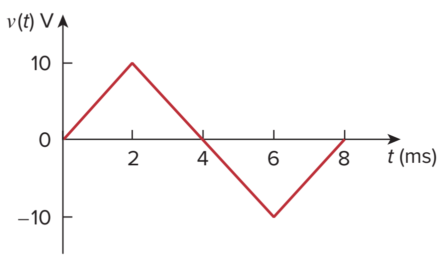


Figure 6.45
For Prob. 6.5.

6.6 The voltage waveform in Fig. 6.46 is applied across a 55-μF capacitor. Draw the current waveform through it.

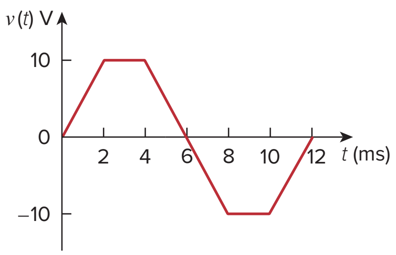


Figure 6.46
For Prob. 6.6.

6.7 At $t = 0$, the voltage across a 25-mF capacitor is 10 V. Calculate the voltage across the capacitor for $t > 0$ when current $5t$ mA flows through it.

6.8 A 4-mF capacitor has the terminal voltage

$$v = \begin{cases} 50 \text{ V}, & t \le 0 \\ Ae^{-100t} + Be^{-600t} \text{ V}, & t \ge 0 \end{cases}$$

If the capacitor has an initial current of 2 A, find:

(a) the constants A and B,
(b) the energy stored in the capacitor at $t = 0$,
(c) the capacitor current for $t > 0$.

6.9 The current through a 0.5-F capacitor is $6(1 - e^{-t})$ A. Determine the voltage and power at $t = 2$ s. Assume $v(0) = 0$.

6.10 The voltage across a 5-mF capacitor is shown in Fig. 6.47. Determine the current through the capacitor.

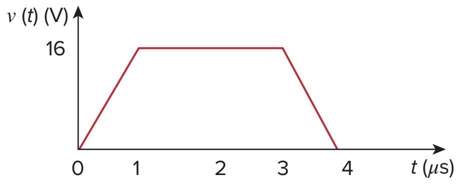


Figure 6.47
For Prob. 6.10.

6.11 A 4-mF capacitor has the current waveform shown in Fig. 6.48. Assuming that $v(0) = 10$ V, sketch the voltage waveform $v(t)$.

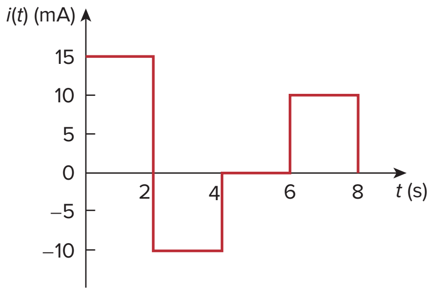


Figure 6.48
For Prob. 6.11.

6.12 A voltage of $45e^{-2000t}$ V appears across a parallel combination of a 100-mF capacitor and a 12-Ω resistor. Calculate the power absorbed by the parallel combination.

6.13 Find the voltage across the capacitors in the circuit of Fig. 6.49 under dc conditions.

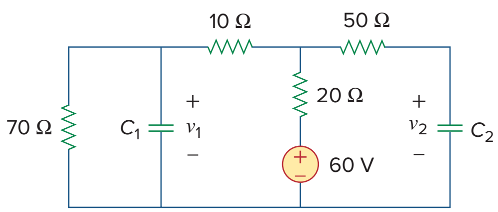


Figure 6.49
For Prob. 6.13.

Section 6.3 Series and Parallel Capacitors

6.14 Series-connected 20- and 60-pF capacitors are placed in parallel with series-connected 30- and 70-pF capacitors. Determine the equivalent capacitance.

6.15 Two capacitors (25 and 75 μF) are connected to a 100-V source. Find the energy stored in each capacitor if they are connected in:

(a) parallel (b) series

6.16 The equivalent capacitance at terminals a-b in the circuit of Fig. 6.50 is 20 μF. Calculate the value of C.

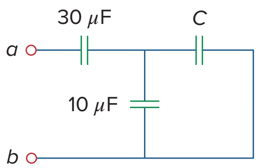


Figure 6.50
For Prob. 6.16.

6.17 Determine the equivalent capacitance for each of the circuits of Fig. 6.51.

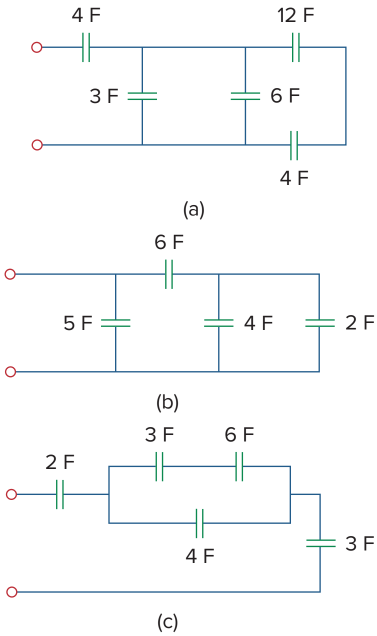


Figure 6.51
For Prob. 6.17.

6.18 Find C_{eq} in the circuit of Fig. 6.52 if all capacitors are 4 μF.

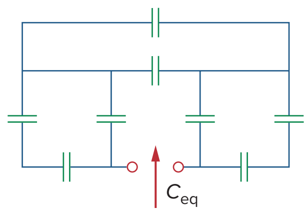


Figure 6.52
For Prob. 6.18.

6.19 Find the equivalent capacitance between terminals a and b in the circuit of Fig. 6.53. All capacitances are in μF.

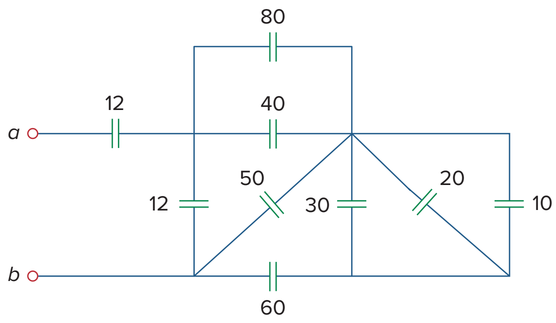


Figure 6.53
For Prob. 6.19.

6.20 Find the equivalent capacitance at terminals a-b of the circuit in Fig. 6.54.

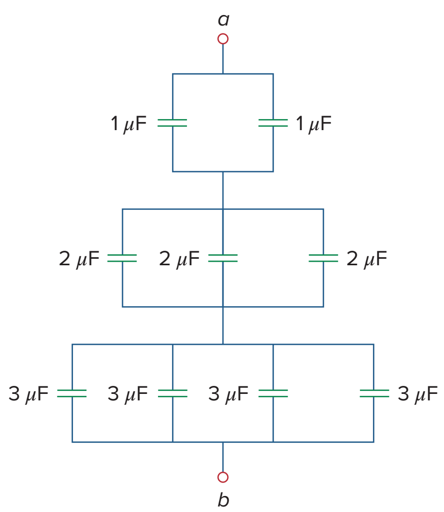


Figure 6.54
For Prob. 6.20.

6.21 Determine the equivalent capacitance at terminals a-b of the circuit in Fig. 6.55.

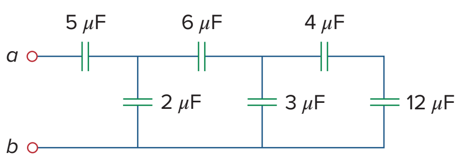


Figure 6.55
For Prob. 6.21.

6.22 Obtain the equivalent capacitance of the circuit in Fig. 6.56.

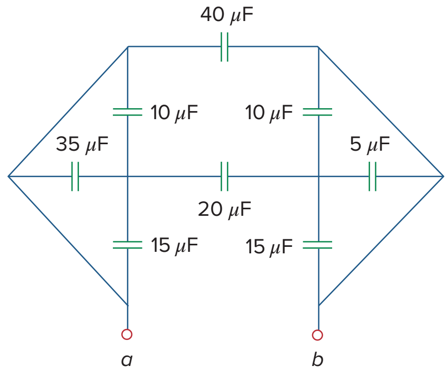


Figure 6.56
For Prob. 6.22.

6.23 Using Fig. 6.57, design a problem that will help other students better understand how capacitors work together when connected in series and in parallel.

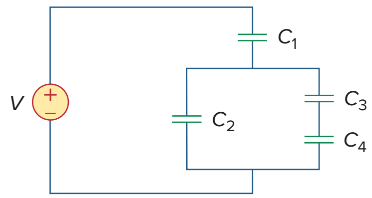


Figure 6.57
For Prob. 6.23.

6.24 In the circuit shown in Fig. 6.58 assume that the capacitors were initially uncharged and that the current source has been connected to the circuit long enough for all the capacitors to reach steady state (no current flowing through the capacitors). Determine the voltage across each capacitor and the energy stored in each.

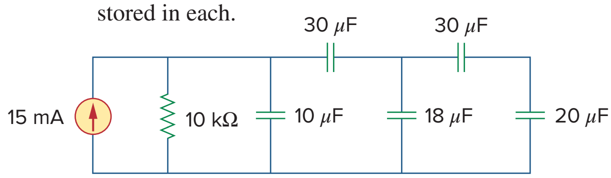


Figure 6.58
For Prob. 6.24.

6.25 (a) Show that the voltage-division rule for two capacitors in series as in Fig. 6.59(a) is

$$v_1 = \frac{C_2}{C_1 + C_2} v_s, \qquad v_2 = \frac{C_1}{C_1 + C_2} v_s$$

assuming that the initial conditions are zero.

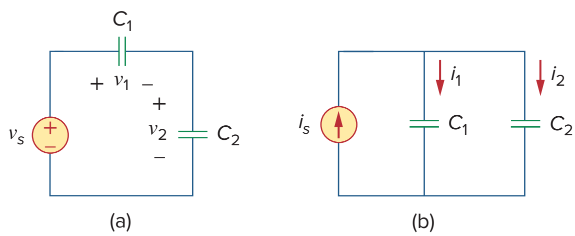


Figure 6.59
For Prob. 6.25.

(b) For two capacitors in parallel as in Fig. 6.59(b), show that the current-division rule is

$$i_1 = \frac{C_1}{C_1 + C_2} i_s, \qquad i_2 = \frac{C_2}{C_1 + C_2} i_s$$

assuming that the initial conditions are zero.

6.26 Three capacitors, $C_1 = 5\ \mu$F, $C_2 = 10\ \mu$F, and $C_3 = 20\ \mu$F, are connected in parallel across a 200-V source. Determine:

(a) the total capacitance,
(b) the charge on each capacitor,
(c) the total energy stored in the parallel combination.

6.27 Given that four 10-μF capacitors can be connected in series and in parallel, find the minimum and maximum values that can be obtained by such series/parallel combinations.

***6.28** Obtain the equivalent capacitance of the network shown in Fig. 6.60.

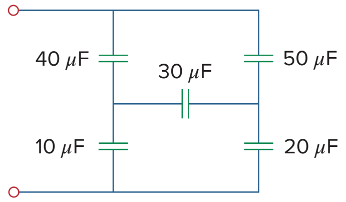


Figure 6.60
For Prob. 6.28.

6.29 Determine C_{eq} for each circuit in Fig. 6.61.

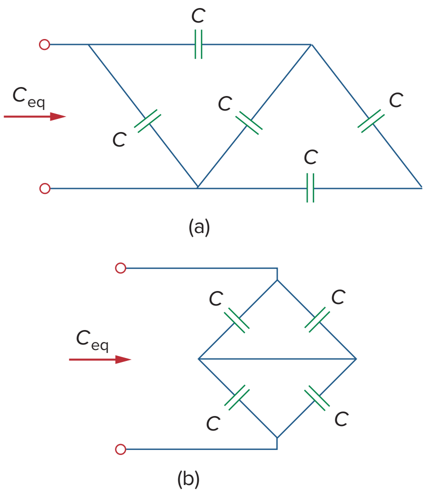


Figure 6.61
For Prob. 6.29.

6.30 Assuming that the capacitors are initially uncharged, find $v_o(t)$ in the circuit of Fig. 6.62.

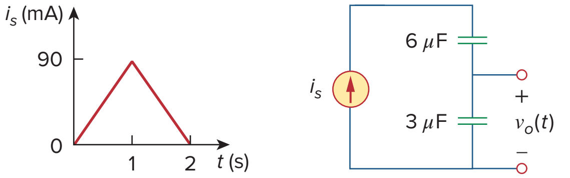


Figure 6.62
For Prob. 6.30.

6.31 If $v(0) = 0$, find $v(t)$, $i_1(t)$, and $i_2(t)$ in the circuit of Fig. 6.63.

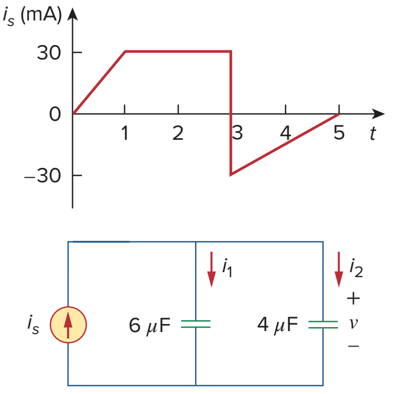


Figure 6.63
For Prob. 6.31.

6.32 In the circuit in Fig. 6.64, let $i_s = 4.5e^{-2t}$ mA and the voltage across each capacitor is equal to zero at $t = 0$. Determine v_1 and v_2 and the energy stored in each capacitor for all $t > 0$.

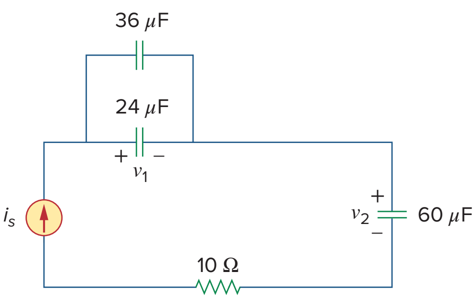


Figure 6.64
For Prob. 6.32.

* An asterisk indicates a challenging problem.

6.33 Obtain the Thevenin equivalent at the terminals, a-b, of the circuit shown in Fig. 6.65. Please note that Thevenin equivalent circuits do not generally exist for circuits involving capacitors and resistors. This is a special case where the Thevenin equivalent circuit does exist.

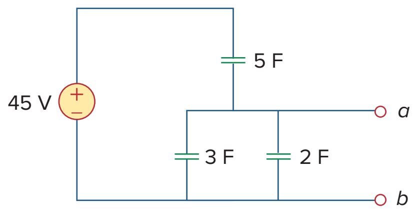


Figure 6.65
For Prob. 6.33.

Section 6.4 Inductors

6.34 The current through a 25-mH inductor is $10e^{-t/2}$ A. Find the voltage and the power at $t = 3$ s.

6.35 An inductor has a linear change in current from 100 mA to 200 mA in 2 ms and induces a voltage of 160 mV. Calculate the value of the inductor.

6.36 Design a problem to help other students better understand how inductors work.

6.37 The current through a 12-mH inductor is $4 \sin 100t$ A. Find the voltage, and the energy stored at $t = \frac{\pi}{200}$ s.

6.38 The current through a 40-mH inductor is

$$i(t) = \begin{cases} 0, & t < 0 \\ te^{-2t}\text{ A}, & t > 0 \end{cases}$$

Find the voltage $v(t)$.

6.39 The voltage across a 50-mH inductor is given by

$$v(t) = [5e^{-2t} + 2t + 4]\text{ V} \qquad \text{for } t > 0.$$

Determine the current $i(t)$ through the inductor. Assume that $i(0) = 0$ A.

6.40 The current through a 5-mH inductor is shown in Fig. 6.66. Determine the voltage across the inductor at $t = 1$, 3, and 5 ms.

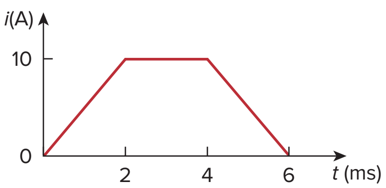


Figure 6.66
For Prob. 6.40.

6.41 The voltage across a 2-H inductor is $20(1 - e^{-2t})$ V. If the initial current through the inductor is 0.3 A, find the current and the energy stored in the inductor at $t = 1$ s.

6.42 If the voltage waveform in Fig. 6.67 is applied across the terminals of a 5-H inductor, calculate the current through the inductor. Assume $i(0) = -1$ A.

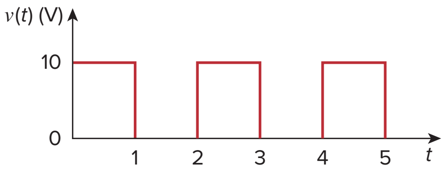


Figure 6.67
For Prob. 6.42.

6.43 The current in a 150-mH inductor increases from 0 to 60 mA (steady state). How much energy is stored in the inductor?

***6.44** A 100-mH inductor is connected in parallel with a 2-kΩ resistor. The current through the inductor is $i(t) = 35e^{-400t}$ mA. (a) Find the voltage v_L across the inductor. (b) Find the voltage v_R across the resistor. (c) Does $v_R(t) + v_L(t) = 0$? (d) Calculate the energy stored in the inductor at $t = 0$.

6.45 If the voltage waveform in Fig. 6.68 is applied to a 25-mH inductor, find the inductor current $i(t)$ for $0 < t < 2$ seconds. Assume $i(0) = 0$.

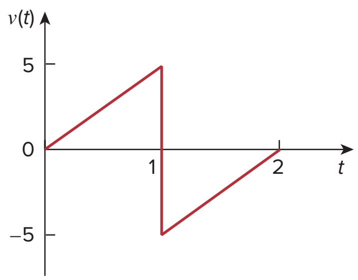


Figure 6.68
For Prob. 6.45.

6.46 Find v_C, i_L, and the energy stored in the capacitor and inductor in the circuit of Fig. 6.69 under dc conditions.

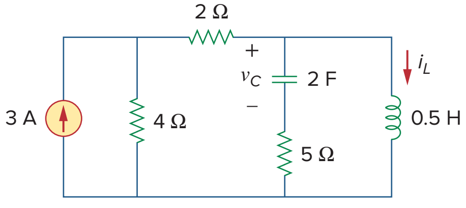


Figure 6.69
For Prob. 6.46.

6.47 For the circuit in Fig. 6.70, calculate the value of R that will make the energy stored in the capacitor the same as that stored in the inductor under dc conditions.

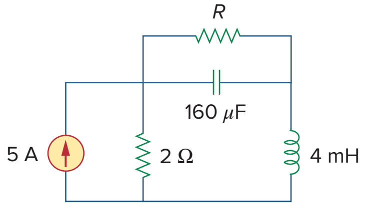


Figure 6.70
For Prob. 6.47.

6.48 Under steady-state dc conditions, find i and v in the circuit in Fig. 6.71.

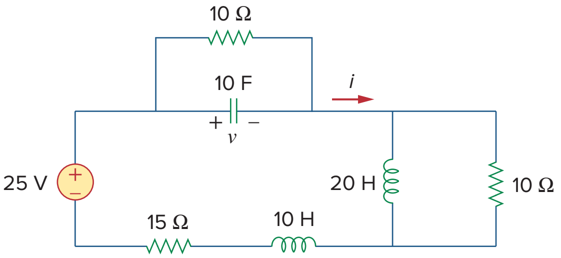


Figure 6.71
For Prob. 6.48.

Section 6.5 Series and Parallel Inductors

6.49 Find the equivalent inductance of the circuit in Fig. 6.72. Assume all inductors are 40 mH.

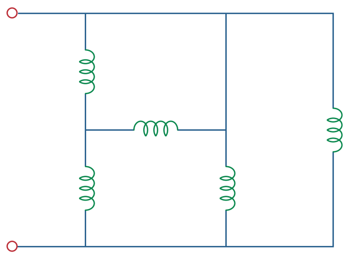


Figure 6.72
For Prob. 6.49.

6.50 An energy-storage network consists of series-connected 16- and 14-mH inductors in parallel with series-connected 24- and 36-mH inductors. Calculate the equivalent inductance.

6.51 Determine L_{eq} at terminals a-b of the circuit in Fig. 6.73.

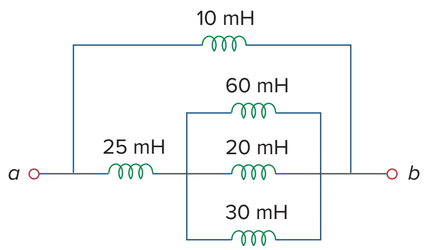


Figure 6.73
For Prob. 6.51.

6.52 Using Fig. 6.74, design a problem to help other students better understand how inductors behave when connected in series and when connected in parallel.

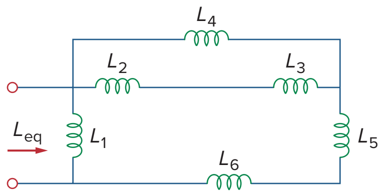


Figure 6.74
For Prob. 6.52.

6.53 Find L_{eq} at the terminals of the circuit in Fig. 6.75.

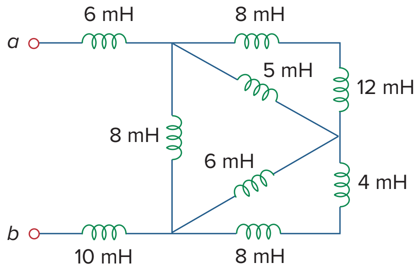


Figure 6.75
For Prob. 6.53.

6.54 Find the equivalent inductance looking into the terminals of the circuit in Fig. 6.76.

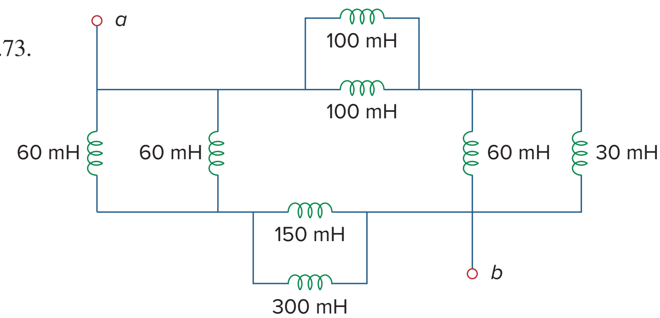


Figure 6.76
For Prob. 6.54.

6.55 Find L_{eq} in each of the circuits in Fig. 6.77.

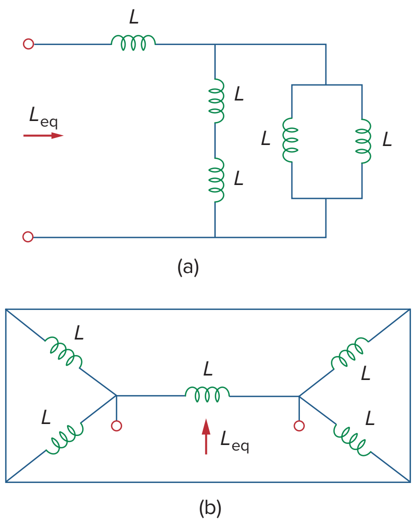


Figure 6.77
For Prob. 6.55.

6.56 Find L_{eq} in the circuit of Fig. 6.78.

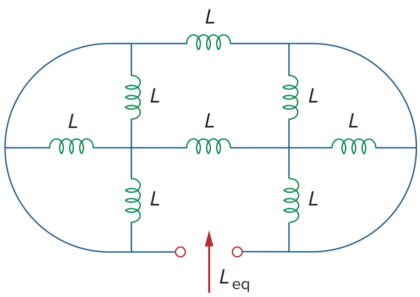


Figure 6.78
For Prob. 6.56.

***6.57** Determine L_{eq} that may be used to represent the inductive network of Fig. 6.79 at the terminals.

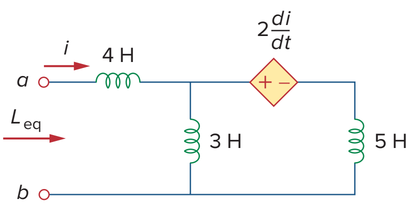


Figure 6.79
For Prob. 6.57.

6.58 The current waveform in Fig. 6.80 flows through a 3-H inductor. Sketch the voltage across the inductor over the interval $0 < t < 6$ s.

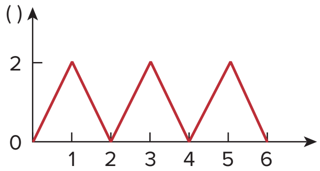


Figure 6.80
For Prob. 6.58.

6.59 (a) For two inductors in series as in Fig. 6.81(a), show that the voltage division principle is

$$v_1 = \frac{L_1}{L_1 + L_2} v_s, \qquad v_2 = \frac{L_2}{L_1 + L_2} v_s$$

assuming that the initial conditions are zero.

(b) For two inductors in parallel as in Fig. 6.81(b), show that the current-division principle is

$$i_1 = \frac{L_2}{L_1 + L_2} i_s, \qquad i_2 = \frac{L_1}{L_1 + L_2} i_s$$

assuming that the initial conditions are zero.

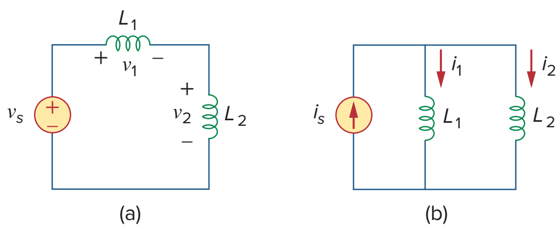


Figure 6.81
For Prob. 6.59.

6.60 In the circuit of Fig. 6.82, $i_o(0) = 2$ A. Determine $i_o(t)$ and $v_o(t)$ for $t > 0$.

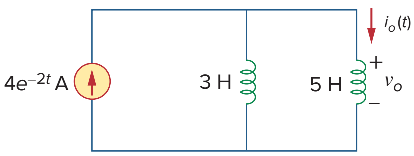


Figure 6.82
For Prob. 6.60.

6.61 Consider the circuit in Fig. 6.83. Find: (a) L_{eq}, $i_1(t)$, and $i_2(t)$ if $i_s = 3e^{-t}$ mA, (b) $v_o(t)$, (c) energy stored in the 20-mH inductor at $t = 1$ s.

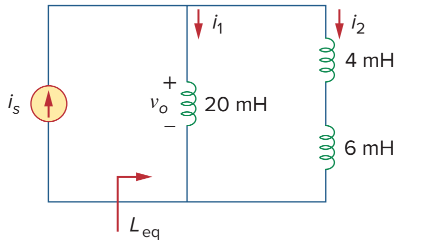


Figure 6.83
For Prob. 6.61.

6.62 Consider the circuit in Fig. 6.84. Given that $v(t) = 12e^{-3t}$ mV for $t > 0$ and $i_1(0) = -30$ mA, find: (a) $i_2(0)$, (b) $i_1(t)$ and $i_2(t)$.

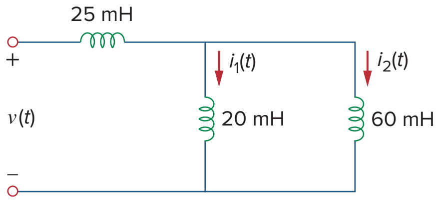


Figure 6.84
For Prob. 6.62.

6.63 In the circuit of Fig. 6.85, sketch v_o.

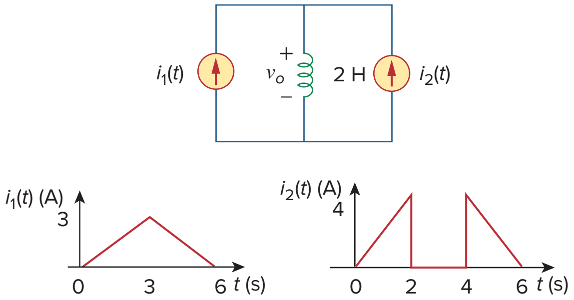


Figure 6.85
For Prob. 6.63.

6.64 The switch in Fig. 6.86 has been in position A for a long time. At $t = 0$, the switch moves from position A to B. The switch is a make-before-break type so that there is no interruption in the inductor current. Find:

(a) $i(t)$ for $t > 0$,
(b) v *just after* the switch has been moved to position B,
(c) $v(t)$ long after the switch is in position B.

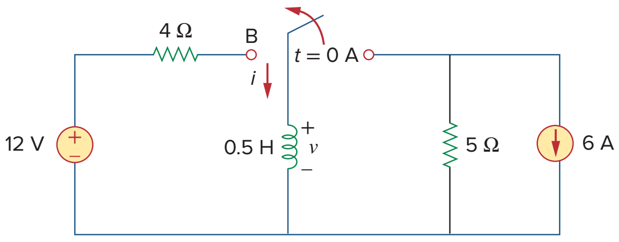


Figure 6.86
For Prob. 6.64.

6.65 The inductors in Fig. 6.87 are initially charged and are connected to the black box at $t = 0$. If $i_1(0) = 4$ A, $i_2(0) = -2$ A, and $v(t) = 50e^{-200t}$ mV, $t \geq 0$, find:

(a) the energy initially stored in each inductor,
(b) the total energy delivered to the black box from $t = 0$ to $t = \infty$,
(c) $i_1(t)$ and $i_2(t)$, $t \geq 0$,
(d) $i(t)$, $t \geq 0$.

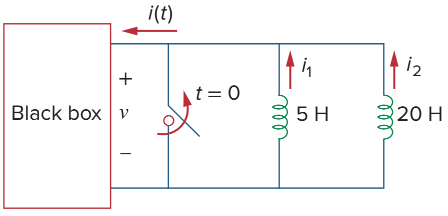


Figure 6.87
For Prob. 6.65.

6.66 The current $i(t)$ through a 20-mH inductor is equal, in magnitude, to the voltage across it for all values of time. If $i(0) = 2$ A, find $i(t)$.

Section 6.6 Applications

6.67 An op amp integrator has $R = 50$ kΩ and $C = 0.04$ μF. If the input voltage is $v_i = 10 \sin 50t$ mV, obtain the output voltage. Assume that at t equal to zero, the output is equal to zero.

6.68 A 6-V dc voltage is applied to an integrator with $R = 50\ \text{k}\Omega$, $C = 100\ \mu\text{F}$ at $t = 0$. How long will it take for the op amp to saturate if the saturation voltages are $+12$ V and -12 V? Assume that the initial capacitor voltage was zero.

6.69 An op amp integrator with $R = 4\ \text{M}\Omega$ and $C = 1\ \mu\text{F}$ has the input waveform shown in Fig. 6.88. Plot the output waveform.

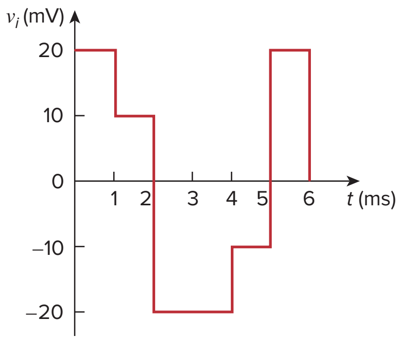


Figure 6.88
For Prob. 6.69.

6.70 Using a single op amp, a capacitor, and resistors of 100 kΩ or less, design a circuit to implement

$$v_o = -2 \int_0^t v_i(\tau)\, d\tau$$

Assume $v_o = 0$ at $t = 0$.

6.71 Show how you would use a single op amp to generate

$$v_o = -\int_0^t (v_1 + 4v_2 + 10v_3)\, d\tau$$

If the inte grating capacitor is $C = 5\ \mu\text{F}$, obtain the other component values.

6.72 At $t = 1.5$ ms, calculate v_o due to the cascaded integrators in Fig. 6.89. Assume that the integrators are reset to 0 V at $t = 0$.

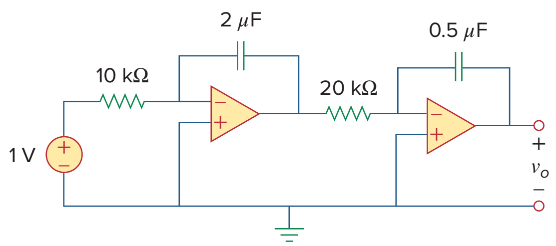


Figure 6.89
For Prob. 6.72.

6.73 Show that the circuit in Fig. 6.90 is a noninverting integrator.

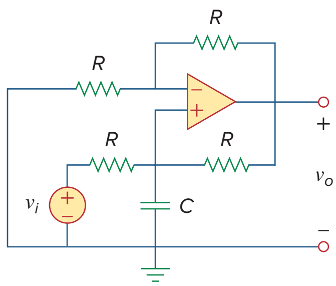


Figure 6.90
For Prob. 6.73.

6.74 The triangular waveform in Fig. 6.91(a) is applied to the input of the op amp differentiator in Fig. 6.91(b). Plot the output.

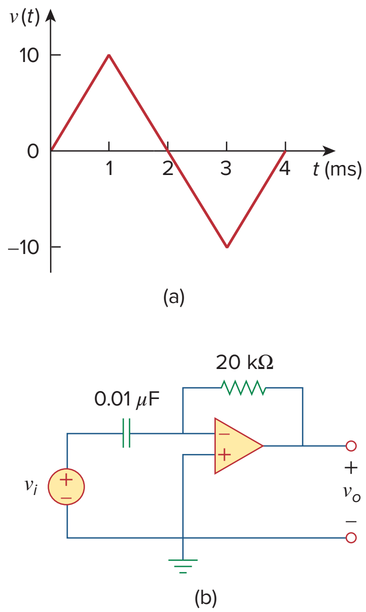


Figure 6.91
For Prob. 6.74.

6.75 An op amp differentiator has $R = 250\ \text{k}\Omega$ and $C = 10\ \mu\text{F}$. The input voltage is a ramp $r(t) = 7t$ mV. Find the output voltage.

6.76 A voltage waveform has the following characteristics: a positive slope of 20 V/s for 5 ms followed by a negative slope of 10 V/s for 10 ms. If the waveform is applied to a differentiator with $R = 50\ \text{k}\Omega$, $C = 10\ \mu\text{F}$, sketch the output voltage waveform.

***6.77** The output v_o of the op amp circuit in Fig. 6.92(a) is shown in Fig. 6.92(b). Let $R_i = R_f = 1\ \text{M}\Omega$ and $C = 1\ \mu\text{F}$. Determine the input voltage waveform and sketch it.

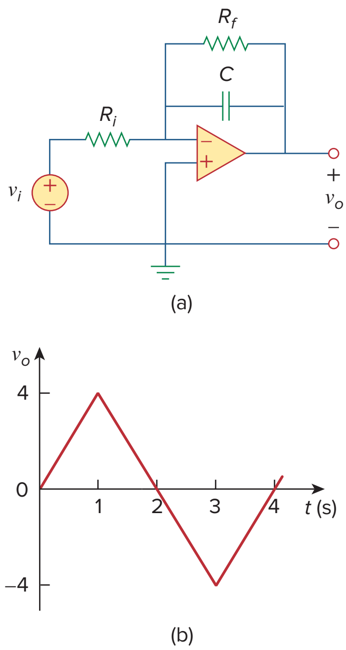


Figure 6.92
For Prob. 6.77.

6.78 Design an analog computer to simulate

$$\frac{d^2v_o}{dt^2} + 2\frac{dv_o}{dt} + v_o = 10 \sin 2t$$

where $v_0(0) = -6$ V and $v_0'(0) = 0$.

6.79 Design an analog computer circuit to solve for $v(t)$, given the following equation and a value for $f(t)$ and that $v(0) = 0$ V.

$$(dv(t)/dt) + 3vt = ftdt$$

6.80 Figure 6.93 presents an analog computer designed to solve a differential equation. Assuming $f(t)$ is known, set up the equation for $f(t)$.

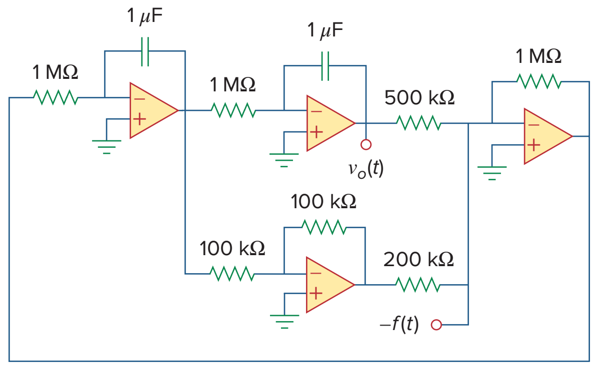


Figure 6.93
For Prob. 6.80.

6.81 Design an analog computer to simulate the following equation to solve for $v(t)$ (assume the initial conditions are zero):

$$(d^3v(t)/dt^3) + 3(dv(t)/dt) = 4f(t)$$

6.82 Design an op amp circuit such that

$$v_o = 10v_s + 2\int v_s dt$$

where v_s and v_o are the input voltage and output voltage, respectively.

Comprehensive Problems

6.83 Your laboratory has available a large number of 5-μF capacitors rated at 150 V. To design a capacitor bank of 10 μF rated at 600 V, how many 5-μF capacitors are needed and how would you connect them?

6.84 An 8-mH inductor is used in a fusion power experiment. If the current through the inductor is $i(t) = 10 \cos^2(\pi t)$ mA, for all $t > 0$ s, find the power being delivered to the inductor and the energy stored in it at $t = 0.5$ s.

4. The singularity functions include the unit step, the unit ramp function, and the unit impulse functions. The unit step function $u(t)$ is

$$u(t) = \begin{cases} 0, & t < 0 \\ 1, & t > 0 \end{cases}$$

The unit impulse function is

$$\delta(t) = \begin{cases} 0, & t < 0 \\ \text{Undefined}, & t = 0 \\ 0, & t > 0 \end{cases}$$

The unit ramp function is

$$r(t) = \begin{cases} 0, & t \leq 0 \\ t, & t \geq 0 \end{cases}$$

5. The steady-state response is the behavior of the circuit after an independent source has been applied for a long time. The transient response is the component of the complete response that dies out with time.
6. The total or complete response consists of the steady-state response and the transient response.
7. The step response is the response of the circuit to a sudden application of a dc current or voltage. Finding the step response of a first-order circuit requires the initial value $x(0^+)$, the final value $x(\infty)$, and the time constant τ. With these three items, we obtain the step response as

$$x(t) = x(\infty) + [x(0^+) - x(\infty)]e^{-t/\tau}$$

A more general form of this equation is

$$x(t) = x(\infty) + [x(t_0^+) - x(\infty)]e^{-(t-t_0)/\tau}$$

Or we may write it as

$$\text{Instantaneous value} = \text{Final} + [\text{Initial} - \text{Final}]e^{-(t-t_0)/\tau}$$

8. *PSpice* is very useful for obtaining the transient response of a circuit.
9. Four practical applications of *RC* and *RL* circuits are: a delay circuit, a photoflash unit, a relay circuit, and an automobile ignition circuit.

Review Questions

7.1 An *RC* circuit has $R = 2\ \Omega$ and $C = 4$ F. The time constant is:

(a) 0.5 s (b) 2 s (c) 4 s
(d) 8 s 15 s

7.2 The time constant for an *RL* circuit with $R = 2\ \Omega$ and $L = 4$ H is:

(a) 0.5 s (b) 2 s (c) 4 s
(d) 8 s 15 s

7.3 A capacitor in an *RC* circuit with $R = 2\ \Omega$ and $C = 4$ F is being charged. The time required for the capacitor voltage to reach 63.2 percent of its steady-state value is:

(a) 2 s (b) 4 s (c) 8 s
(d) 16 s none of the above

7.4 An *RL* circuit has $R = 2\ \Omega$ and $L = 4$ H. The time needed for the inductor current to reach 40 percent of its steady-state value is:

(a) 0.5 s (b) 1 s (c) 2 s
(d) 4 s none of the above

7.5 In the circuit of Fig. 7.79, the capacitor voltage just before $t = 0$ is:

(a) 10 V (b) 7 V (c) 6 V
(d) 4 V 0 V

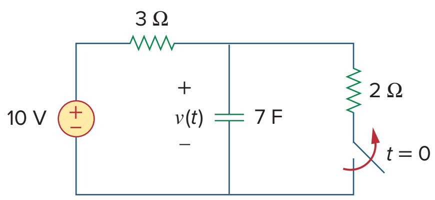


Figure 7.79
For Review Questions 7.5 and 7.6.

7.6 In the circuit in Fig. 7.79, $v(\infty)$ is:

(a) 10 V (b) 7 V (c) 6 V
(d) 4 V 0 V

7.7 For the circuit in Fig. 7.80, the inductor current just before $t = 0$ is:

(a) 8 A (b) 6 A (c) 4 A
(d) 2 A 0 A

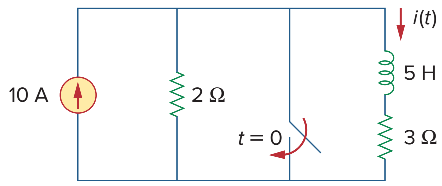


Figure 7.80
For Review Questions 7.7 and 7.8.

7.8 In the circuit of Fig. 7.80, $i(\infty)$ is:

(a) 10 A (b) 6 A (c) 4 A
(d) 2 A 0 A

7.9 If v_s changes from 2 V to 4 V at $t = 0$, we may express v_s as:

(a) $\delta(t)$ V (b) $2u(t)$ V
(c) $2u(-t) + 4u(t)$ V (d) $2 + 2u(t)$ V
$4u(t) - 2$ V

7.10 The pulse in Fig. 7.116(a) can be expressed in terms of singularity functions as:

(a) $2u(t) + 2u(t-1)$ V (b) $2u(t) - 2u(t-1)$ V
(c) $2u(t) - 4u(t-1)$ V (d) $2u(t) + 4u(t-1)$ V

Answers: 7.1d, 7.2b, 7.3c, 7.4b, 7.5d, 7.6a, 7.7c, 7.8e, 7.9c,d, 7.10b.

Problems

Section 7.2 The Source-Free *RC* Circuit

7.1 In the circuit shown in Fig. 7.81

$$v(t) = 56e^{-200t}\,\text{V}, \quad t > 0$$

$$i(t) = 8e^{-200t}\,\text{mA}, \quad t > 0$$

(a) Find the values of R and C.

(b) Calculate the time constant τ.

(c) Determine the time required for the voltage to decay half its initial value at $t = 0$.

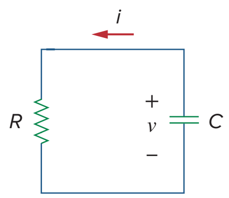


Figure 7.81
For Prob. 7.1.

7.2 Find the time constant for the *RC* circuit in Fig. 7.82.

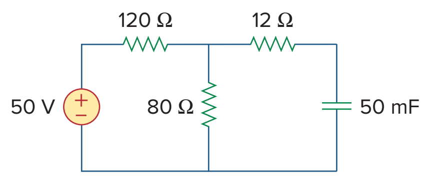


Figure 7.82
For Prob. 7.2.

7.3 Determine the time constant for the circuit in Fig. 7.83.

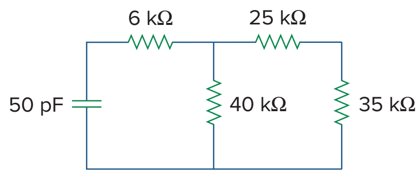


Figure 7.83
For Prob. 7.3.

7.4 The switch in Fig. 7.84 has been in position A for a long time. Assume the switch moves instantaneously from A to B at $t = 0$. Find v for $t > 0$.

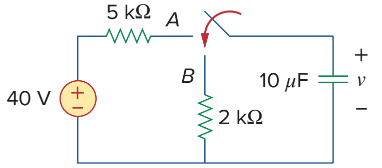


Figure 7.84
For Prob. 7.4.

7.5 Using Fig. 7.85, design a problem to help other students better understand source-free RC circuits.

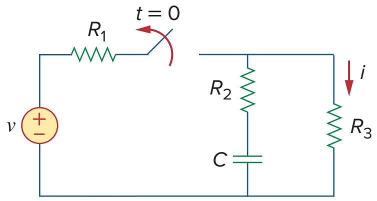


Figure 7.85
For Prob. 7.5.

7.6 The switch in Fig. 7.86 has been closed for a long time, and it opens at $t = 0$. Find $v(t)$ for $t \geq 0$.

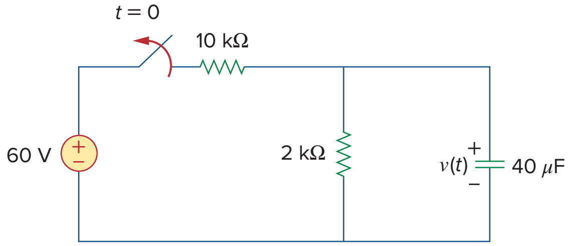


Figure 7.86
For Prob. 7.6.

7.7 Assuming that the switch in Fig. 7.87 has been in position A for a long time and is moved to position B at $t = 0$, Then at $t = 1$ second, the switch moves from B to C. Find $v_C(t)$ for $t \geq 0$.

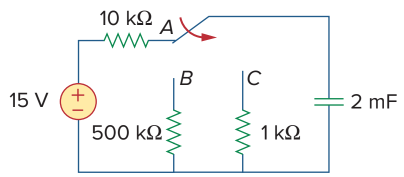


Figure 7.87
For Prob. 7.7.

7.8 For the circuit in Fig. 7.88, if

$$v = 10e^{-4t} \text{ V} \quad \text{and} \quad i = 0.2e^{-4t} \text{ A}, \quad t > 0$$

(a) Find R and C.
(b) Determine the time constant.
(c) Calculate the initial energy in the capacitor.
(d) Obtain the time it takes to dissipate 50 percent of the initial energy.

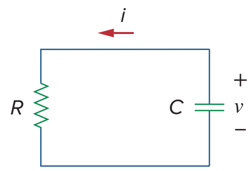


Figure 7.88
For Prob. 7.8.

7.9 The switch in Fig. 7.89 opens at $t = 0$. Find v_o for $t > 0$.

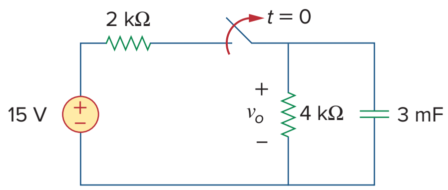


Figure 7.89
For Prob. 7.9.

7.10 For the circuit in Fig. 7.90, find $v_o(t)$ for $t > 0$. Determine the time necessary for the capacitor voltage to decay to one-third of its value at $t = 0$.

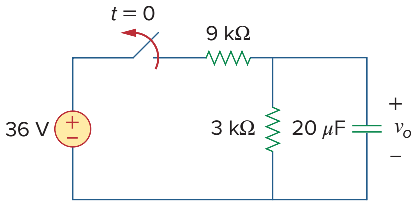


Figure 7.90
For Prob. 7.10.

Section 7.3 The Source-Free RL Circuit

7.11 For the circuit in Fig. 7.91, find i_o for $t > 0$.

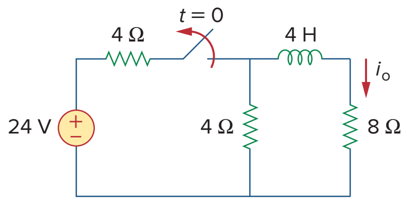


Figure 7.91
For Prob. 7.11.

7.12 Using Fig. 7.92, design a problem to help other students better understand source-free *RL* circuits.

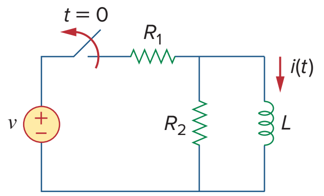


Figure 7.92
For Prob. 7.12.

7.13 In the circuit of Fig. 7.93,

$$v(t) = 80e^{-10^3 t}\,\text{V}, \quad t > 0$$

$$i(t) = 5e^{-10^3 t}\,\text{mA}, \quad t > 0$$

(a) Find R, L, and τ.

(b) Calculate the energy dissipated in the resistance for $0 < t < 0.5$ ms.

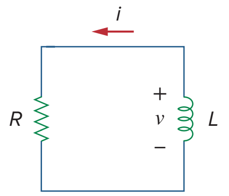


Figure 7.93
For Prob. 7.13.

7.14 Calculate the time constant of the circuit in Fig. 7.94.

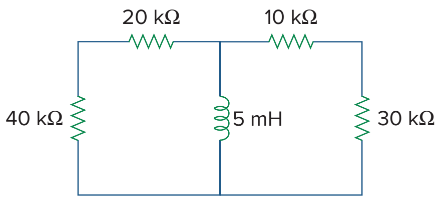


Figure 7.94
For Prob. 7.14.

7.15 Find the time constant for each of the circuits in Fig. 7.95.

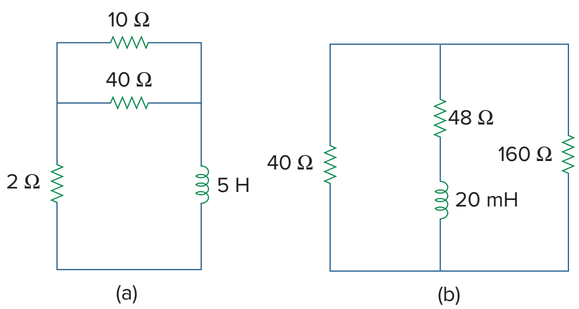


Figure 7.95
For Prob. 7.15.

7.16 Determine the time constant for each of the circuits in Fig. 7.96.

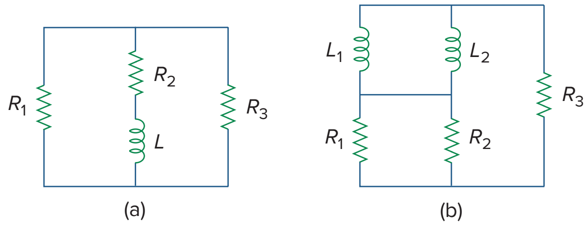


Figure 7.96
For Prob. 7.16.

7.17 Consider the circuit of Fig. 7.97. Find $v_o(t)$ if $i(0) = 15$ A and $v(t) = 0$.

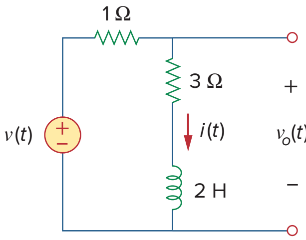


Figure 7.97
For Prob. 7.17.

7.18 For the circuit in Fig. 7.98, determine $v_o(t)$ when $i(0) = 5$ A and $v(t) = 0$.

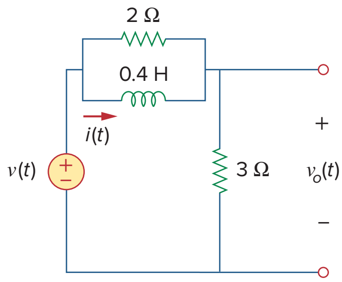


Figure 7.98
For Prob. 7.18.

7.19 In the circuit of Fig. 7.99, find $i(t)$ for $t > 0$ if $i(0) = 5$ A.

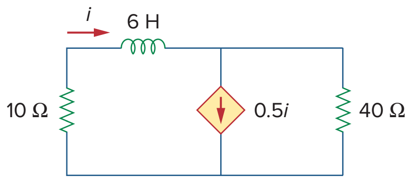


Figure 7.99
For Prob. 7.19.

7.20 For the circuit in Fig. 7.100,

$$v = 90e^{-50t}\,\text{V}$$

and

$$i = 30e^{-50t}\,\text{A}, \qquad t > 0$$

(a) Find L and R.
(b) Determine the time constant.
(c) Calculate the initial energy in the inductor.
(d) What fraction of the initial energy is dissipated in 10 ms?

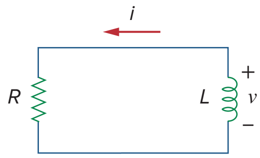


Figure 7.100
For Prob. 7.20.

7.21 In the circuit of Fig. 7.101, find the value of R for which the steady-state energy stored in the inductor will be 2 J.

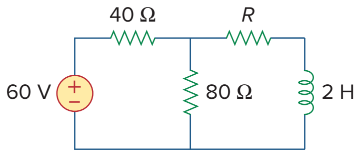


Figure 7.101
For Prob. 7.21.

7.22 Find $i(t)$ and $v(t)$ for $t > 0$ in the circuit of Fig. 7.102 if $i(0) = 10$ A.

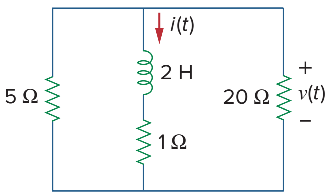


Figure 7.102
For Prob. 7.22.

7.23 Consider the circuit in Fig. 7.103. Given that $v_o(0) = 10$ V, find v_o and v_x for $t > 0$.

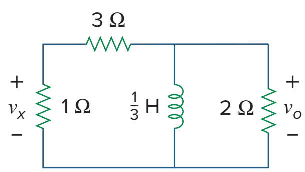


Figure 7.103
For Prob. 7.23.

Section 7.4 Singularity Functions

7.24 Express the following signals in terms of singularity functions.

(a) $v(t) = \begin{cases} 0, & t < 0 \\ -5, & t > 0 \end{cases}$

(b) $i(t) = \begin{cases} 0, & t < 1 \\ -10, & 1 < t < 3 \\ 10, & 3 < t < 5 \\ 0, & t > 5 \end{cases}$

(c) $x(t) = \begin{cases} t - 1, & 1 < t < 2 \\ 1, & 2 < t < 3 \\ 4 - t, & 3 < t < 4 \\ 0, & \text{Otherwise} \end{cases}$

(d) $y(t) = \begin{cases} 2, & t < 0 \\ -5, & 0 < t < 1 \\ 0, & t > 1 \end{cases}$

7.25 Design a problem to help other students better understand singularity functions.

7.26 Express the signals in Fig. 7.104 in terms of singularity functions.

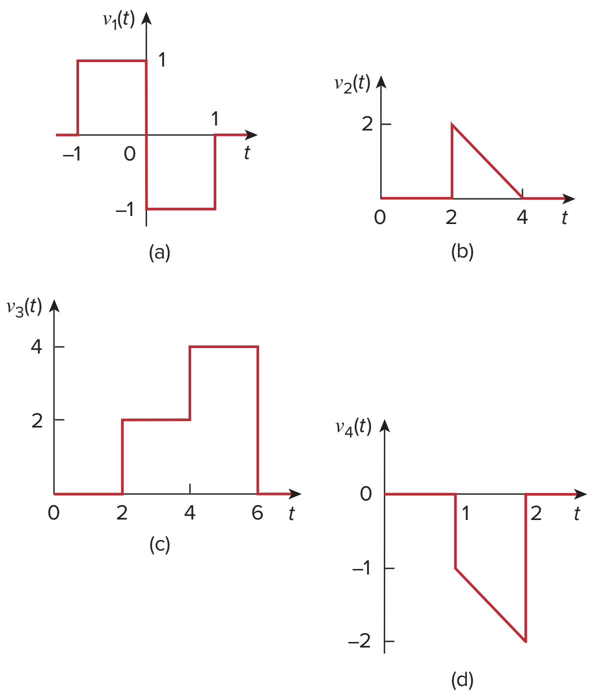


Figure 7.104
For Prob. 7.26.

7.27 Express $v(t)$ in Fig. 7.105 in terms of step functions.

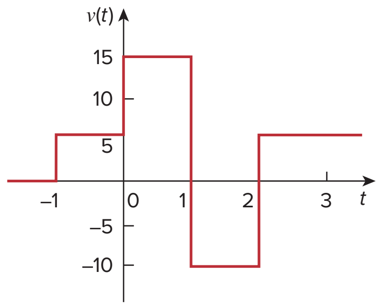


Figure 7.105
For Prob. 7.27.

7.28 Sketch the waveform represented by

$$i(t) = [r(t) - r(t-1) - u(t-2) - r(t-2) + r(t-3) + u(t)(t-4)] \text{ A}$$

7.29 Sketch the following functions:

(a) $x(t) = 10e^{-t}u(t-1)$,

(b) $y(t) = 10e^{-(t-1)}u(t)$,

(c) $z(t) = \cos 4t\delta(t-1)$

7.30 Evaluate the following integrals involving the impulse functions:

(a) $\int_{-\infty}^{\infty} 4t^2\delta(t-1)dt$

(b) $\int_{-\infty}^{\infty} 4t^2 \cos 2\pi t\delta(t-0.5)dt$

7.31 Evaluate the following integrals:

(a) $\int_{-\infty}^{\infty} e^{-4t^2}\delta(t-2)dt$

(b) $\int_{-\infty}^{\infty} [5\delta(t) + e^{-t}\delta(t) + \cos 2\pi t\delta(t)]dt$

7.32 Evaluate the following integrals:

(a) $\int_{1}^{t} u(\lambda)d\lambda$

(b) $\int_{0}^{4} r(t-1)dt$

(c) $\int_{1}^{5} (t-6)^2\delta(t-2)dt$

7.33 The voltage across a 10-mH inductor is $45\delta(t-2)$mV. Find the inductor current, assuming that the inductor is initially uncharged.

7.34 Evaluate the following derivatives:

(a) $\frac{d}{dt}[u(t-1)u(t+1)]$

(b) $\frac{d}{dt}[r(t-6)u(t-2)]$

(c) $\frac{d}{dt}[\sin 4tu(t-3)]$

7.35 Find the solution to the following differential equations:

(a) $\frac{dv}{dt} + 2v = 0, \qquad v(0) = -1 \text{ V}$

(b) $2\frac{di}{dt} - 3i = 0, \qquad i(0) = 2$

7.36 Solve for v in the following differential equations, subject to the stated initial condition.

(a) $dv/dt + v = u(t), \qquad v(0) = 0$

(b) $2\, dv/dt - v = 3u(t), \qquad v(0) = -6$

7.37 A circuit is described by

$$4\frac{dv}{dt} + v = 10$$

(a) What is the time constant of the circuit?

(b) What is $v(\infty)$, the final value of v?

(c) If $v(0) = 2$, find $v(t)$ for $t \geq 0$.

7.38 A circuit is described by

$$\frac{di}{dt} + 3i = 2u(t)$$

Find $i(t)$ for $t > 0$ given that $i(0) = 0$.

Section 7.5 Step Response of an *RC* Circuit

7.39 Calculate the capacitor voltage for $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.106.

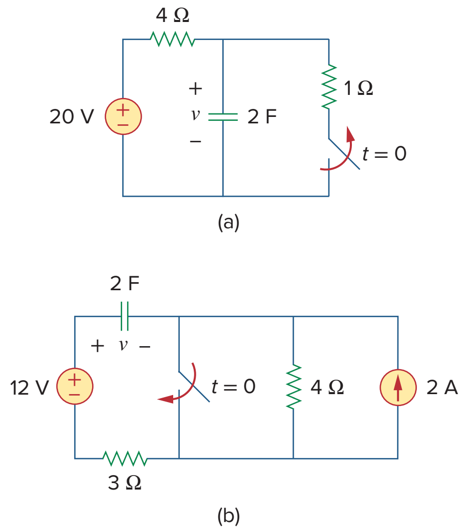


Figure 7.106
For Prob. 7.39.

7.40 Find the capacitor voltage for $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.107.

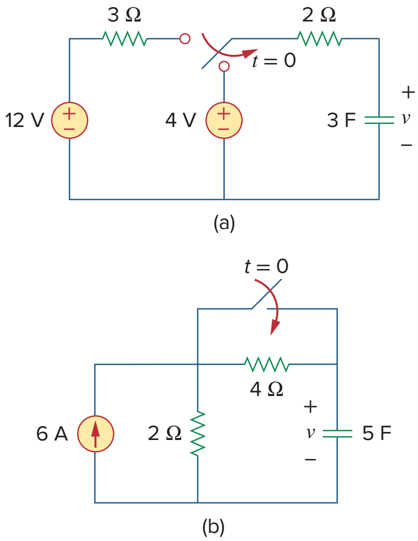


Figure 7.107
For Prob. 7.40.

7.41 Using Fig. 7.108, design a problem to help other students better understand the step response of an *RC* circuit.

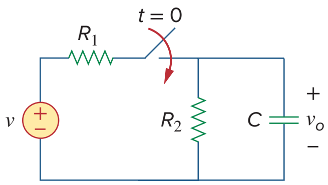


Figure 7.108
For Prob. 7.41.

7.42 (a) If the switch in Fig. 7.109 has been open for a long time and is closed at $t = 0$, find $v_o(t)$.

(b) Suppose that the switch has been closed for a long time and is opened at $t = 0$. Find $v_o(t)$.

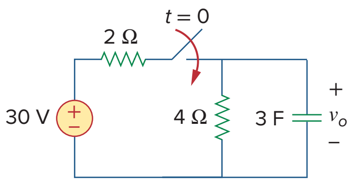


Figure 7.109
For Prob. 7.42.

7.43 Consider the circuit in Fig. 7.110. Find $i(t)$ for $t < 0$ and $t > 0$.

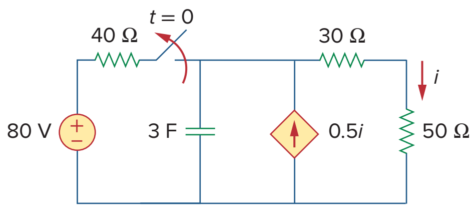


Figure 7.110
For Prob. 7.43.

7.44 The switch in Fig. 7.111 has been in position *a* for a long time. At $t = 0$, it moves to position *b*. Calculate $i(t)$ for all $t > 0$.

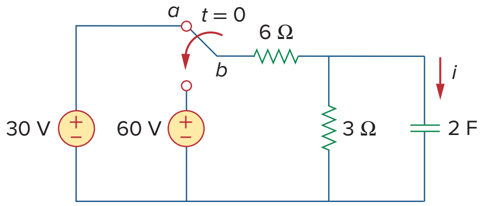


Figure 7.111
For Prob. 7.44.

7.45 Find v_o in the circuit of Fig. 7.112 when $v_s = 30u(t)$ V. Assume that $v_o(0) = 5$ V.

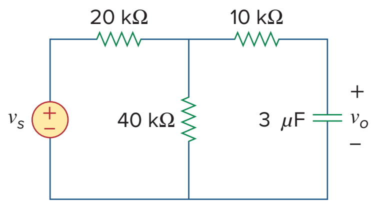


Figure 7.112
For Prob. 7.45.

7.46 For the circuit in Fig. 7.113, $i_s(t) = 5u(t)$. Find $v(t)$.

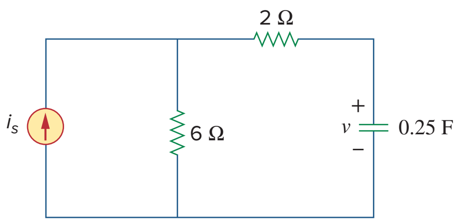


Figure 7.113
For Prob. 7.46.

7.47 Determine $v(t)$ for $t > 0$ in the circuit of Fig. 7.114 if $v(0) = 0$.

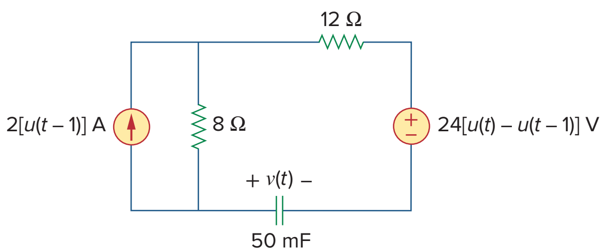


Figure 7.114
For Prob. 7.47.

7.48 Find $v(t)$ and $i(t)$ in the circuit of Fig. 7.115.

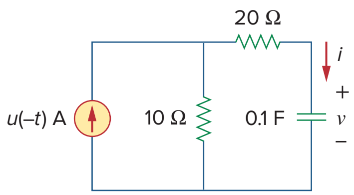


Figure 7.115
For Prob. 7.48.

7.49 If the waveform in Fig. 7.116(a) is applied to the circuit of Fig. 7.116(b), find $v(t)$. Assume $v(0) = 0$.

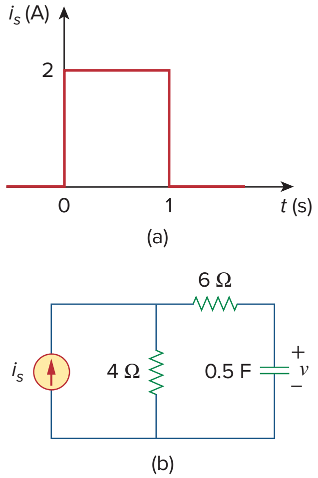


Figure 7.116
For Prob. 7.49 and Review Question 7.10.

***7.50** In the circuit of Fig. 7.117, find i_x for $t > 0$. Let $R_1 = R_2 = 1$ kΩ, $R_3 = 2$ kΩ, and $C = 0.25$ mF.

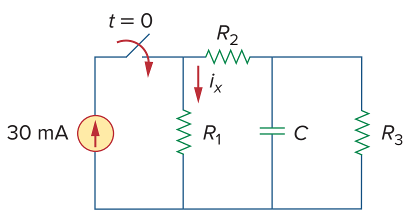


Figure 7.117
For Prob. 7.50.

Section 7.6 Step Response of an *RL* Circuit

7.51 Rather than applying the shortcut technique used in Section 7.6, use KVL to obtain Eq. (7.60).

7.52 Using Fig. 7.118, design a problem to help other students better understand the step response of an *RL* circuit.

* An asterisk indicates a challenging problem.

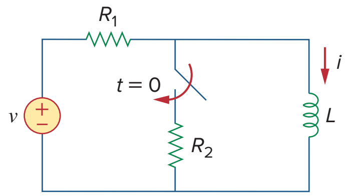


Figure 7.118
For Prob. 7.52.

7.53 Determine the inductor current $i(t)$ for both $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.119.

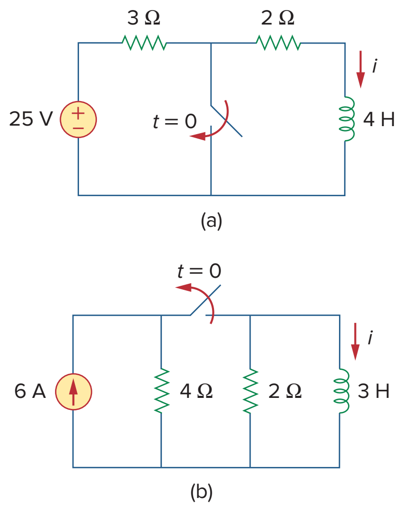


Figure 7.119
For Prob. 7.53.

7.54 Obtain the inductor current for both $t < 0$ and $t > 0$ in each of the circuits in Fig. 7.120.

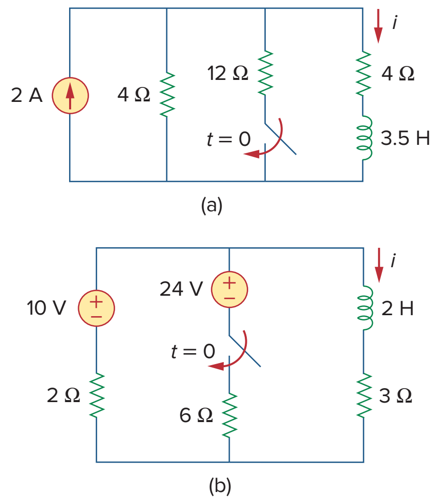


Figure 7.120
For Prob. 7.54.

7.55 Find $v(t)$ for $t < 0$ and $t > 0$ in the circuit of Fig. 7.121.

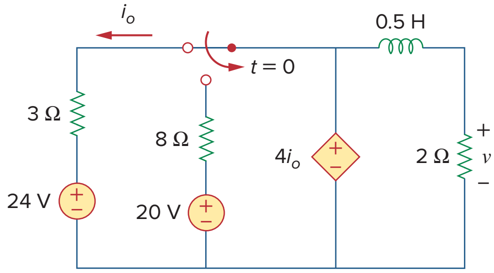


Figure 7.121
For Prob. 7.55.

7.56 For the network shown in Fig. 7.122, find $v(t)$ for $t > 0$.

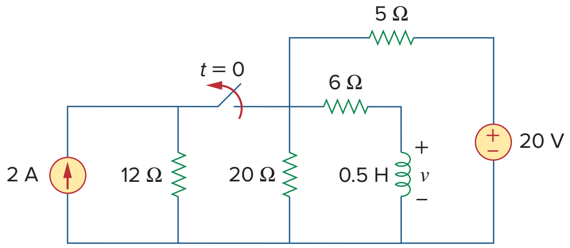


Figure 7.122
For Prob. 7.56.

***7.57** Find $i_1(t)$ and $i_2(t)$ for $t > 0$ in the circuit of Fig. 7.123.

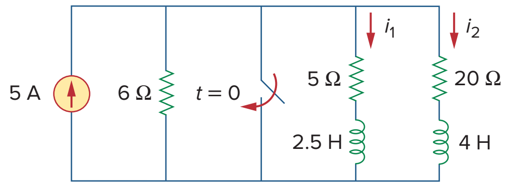


Figure 7.123
For Prob. 7.57.

7.58 Rework Prob. 7.17 if $i(0) = 10$ A and $v(t) = 20u(t)$ V.

7.59 Determine the step response $v_o(t)$ to $i_s = 6u(t)$ A in the circuit of Fig. 7.124.

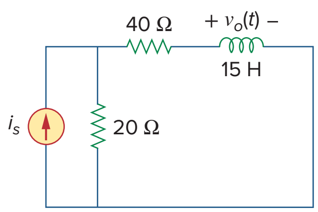


Figure 7.124
For Prob. 7.59.

7.60 Find $v(t)$ for $t > 0$ in the circuit of Fig. 7.125 if the initial current in the inductor is zero.

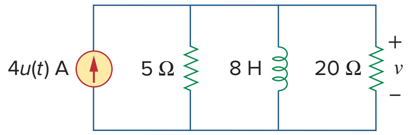


Figure 7.125
For Prob. 7.60.

7.61 In the circuit in Fig. 7.126, i_s changes from 5 A to 10 A at $t = 0$; that is, $i_s = 5u(-t) + 10u(t)$. Find v and i.

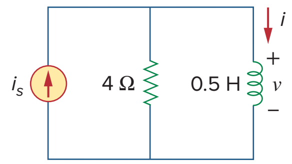


Figure 7.126
For Prob. 7.61.

7.62 For the circuit in Fig. 7.127, calculate $i(t)$ if $i(0) = 0$.

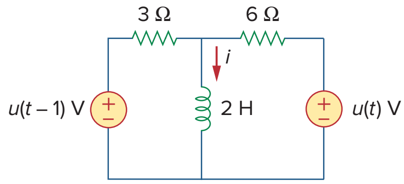


Figure 7.127
For Prob. 7.62.

7.63 Obtain $v(t)$ and $i(t)$ in the circuit of Fig. 7.128.

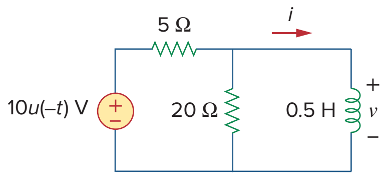


Figure 7.128
For Prob. 7.63.

7.64 Determine the value of $i_L(t)$ and the total energy dissipated by the circuit from $t = 0$ sec to $t = \infty$ sec. The value of $i_{in}(t)$ is equal to $[6 - 6u(t)]$ A.

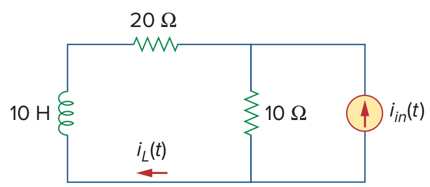


Figure 7.129
For Prob. 7.64.

7.65 If the input pulse in Fig. 7.130(a) is applied to the circuit in Fig. 7.130(b), determine the response $i(t)$.

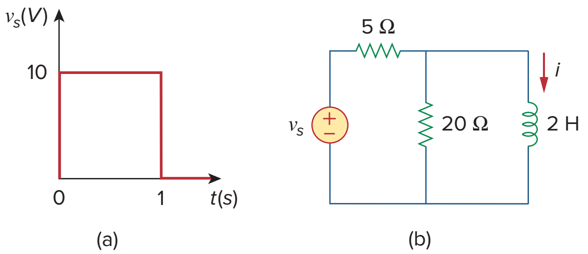


Figure 7.130
For Prob. 7.65.

Section 7.7 First-order Op Amp Circuits

7.66 Using Fig. 7.131, design a problem to help other students better understand first-order op amp circuits.

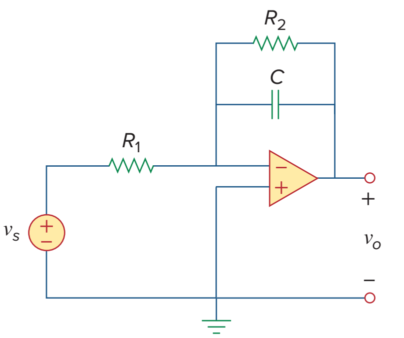


Figure 7.131
For Prob. 7.66.

7.67 If $v(0) = 10$ V, find $v_o(t)$ for $t > 0$ in the op amp circuit in Fig. 7.132. Let $R = 100$ kΩ and $C = 20$ μF.

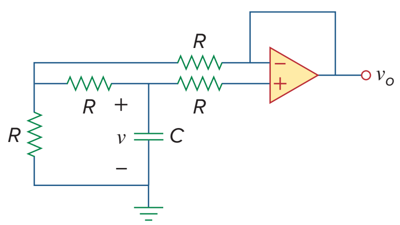


Figure 7.132
For Prob. 7.67.

7.68 Obtain v_o for $t > 0$ in the circuit of Fig. 7.133.

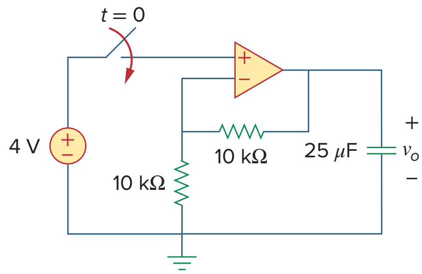


Figure 7.133
For Prob. 7.68.

7.69 For the op amp circuit in Fig. 7.134, find $v_o(t)$ for $t > 0$.

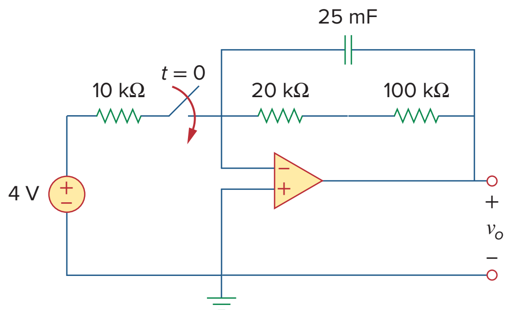


Figure 7.134
For Prob. 7.69.

7.70 Determine v_o for $t > 0$ when $v_s = 20$ mV in the op amp circuit of Fig. 7.135.

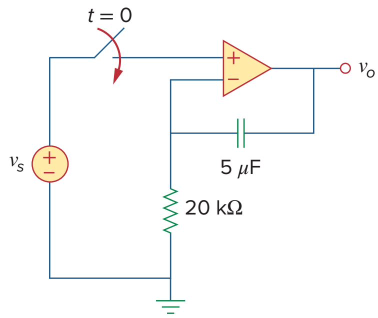


Figure 7.135
For Prob. 7.70.

7.71 For the op amp circuit in Fig. 7.136, suppose $v_s = 10u(t)$ V. Find $v(t)$ for $t > 0$.

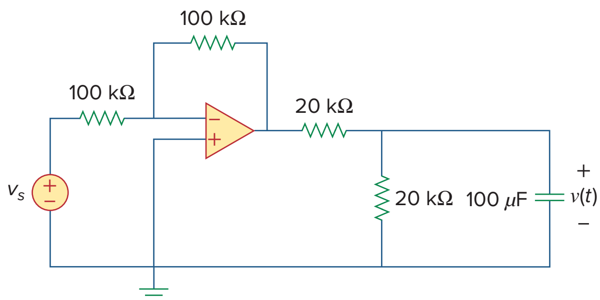


Figure 7.136
For Prob. 7.71.

7.72 Find i_o in the op amp circuit in Fig. 7.137. Assume that $v(0) = -2$ V, $R = 10$ kΩ, and $C = 10$ μF.

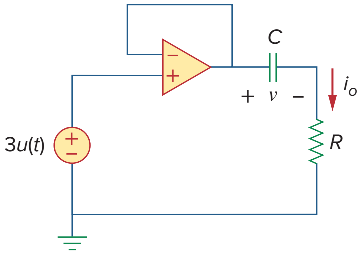


Figure 7.137
For Prob. 7.72.

7.73 For the op amp circuit of Fig. 7.138, let $R_1 = 10$ kΩ, $R_f = 30$ kΩ, $C = 20$ μF, and $v(0) = 1$ V. Find v_0.

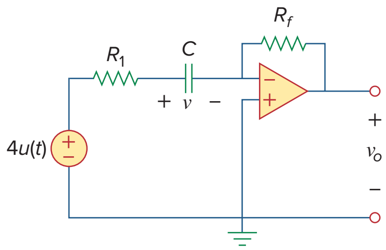


Figure 7.138
For Prob. 7.73.

7.74 Determine $v_o(t)$ for $t > 0$ in the circuit of Fig. 7.139. Let $i_s = 10u(t)$ μA and assume that the capacitor is initially uncharged.

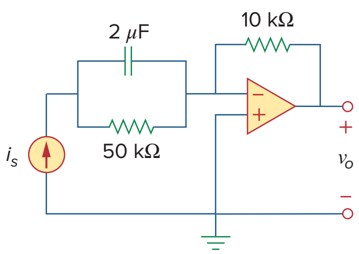


Figure 7.139
For Prob. 7.74.

7.75 In the circuit of Fig. 7.140, find v_o and i_o, given that $v_s = 10[1 - e^{-t}]u(t)$ V.

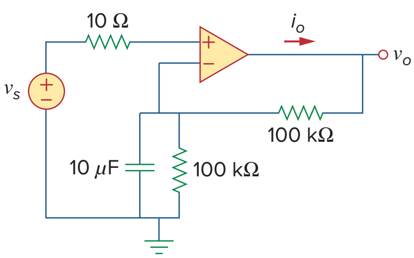


Figure 7.140
For Prob. 7.75.

Section 7.8 Transient Analysis with *PSpice*

7.76 Repeat Prob. 7.49 using *PSpice or MultiSim*.

7.77 The switch in Fig. 7.141 opens at $t = 0$. Use *PSpice or MultiSim* to determine $v(t)$ for $t > 0$.

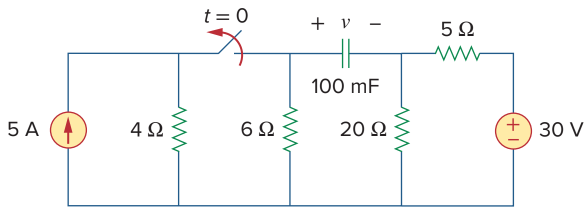


Figure 7.141
For Prob. 7.77.

7.78 The switch in Fig. 7.142 moves from position a to b at $t = 0$. Use *PSpice or MultiSim* to find $i(t)$ for $t > 0$.

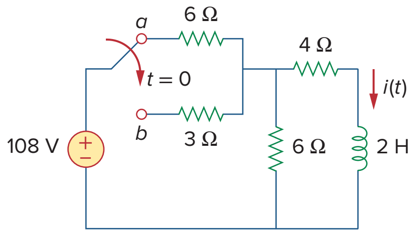


Figure 7.142
For Prob. 7.78.

7.79 In the circuit of Fig. 7.143, determine $i_o(t)$.

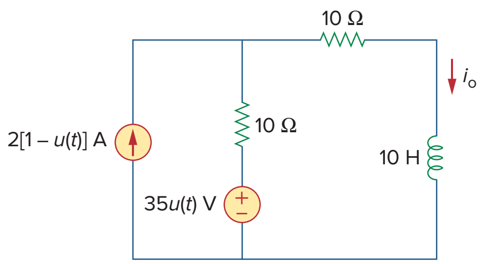


Figure 7.143
For Prob. 7.79.

7.80 In the circuit of Fig. 7.144, find the value of i_o for all values of $0 < t$.

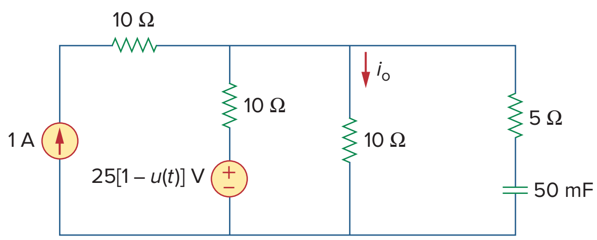


Figure 7.144
For Prob. 7.80.

7.81 Repeat Prob. 7.65 using *PSpice or MultiSim*.

Section 7.9 Applications

7.82 In designing a signal-switching circuit, it was found that a 100-μF capacitor was needed for a time constant of 3 ms. What value resistor is necessary for the circuit?

7.83 An *RC* circuit consists of a series connection of a 120-V source, a switch, a 34-MΩ resistor, and a 15-μF capacitor. The circuit is used in estimating the speed of a horse running a 4-km racetrack. The switch closes when the horse begins and opens when the horse crosses the finish line. Assuming that the capacitor charges to 85.6 V, calculate the speed of the horse.

7.84 A capacitor with a value of 10 mF has a leakage resistance of 2 MΩ. How long does it take the voltage across the capacitor to decay to 40% of the initial voltage to which the capacitor is charged? Assume that the capacitor is charged and then set aside by itself.

7.85 A simple relaxation oscillator circuit is shown in Fig. 7.145. The neon lamp fires when its voltage reaches 75 V and turns off when its voltage drops to 30 V. Its resistance is 120 Ω when on and infinitely high when off.

(a) For how long is the lamp on each time the capacitor discharges?
(b) What is the time interval between light flashes?

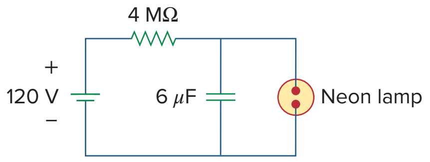


Figure 7.145
For Prob. 7.85.

7.86 Figure 7.146 shows a circuit for setting the length of time voltage is applied to the electrodes of a welding machine. The time is taken as how long it takes the capacitor to charge from 0 to 8 V. What is the time range covered by the variable resistor?

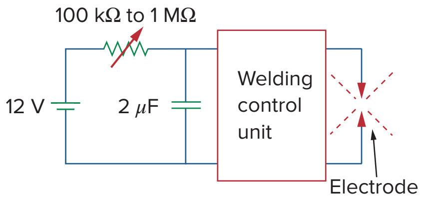


Figure 7.146
For Prob. 7.86.

7.87 A 120-V dc generator energizes a motor whose coil has an inductance of 50 H and a resistance of 100 Ω. A field discharge resistor of 400 Ω is connected in parallel with the motor to avoid damage to the motor, as shown in Fig. 7.147. The system is at steady state. Find the current through the discharge resistor 100 ms after the breaker is tripped.

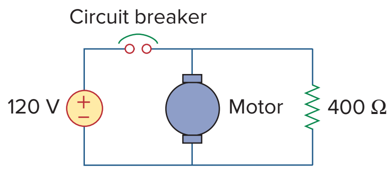


Figure 7.147
For Prob. 7.87.

Comprehensive Problems

7.88 The circuit in Fig. 7.148(a) can be designed as an approximate differentiator or an integrator, depending on whether the output is taken across the resistor or the capacitor, and also on the time constant $\tau = RC$ of the circuit and the width T of the input pulse in Fig. 7.148(b). The circuit is a differentiator if $\tau \ll T$, say $\tau < 0.1T$, or an integrator if $\tau \gg T$, say $\tau > 10T$.

(a) What is the minimum pulse width that will allow a differentiator output to appear across the capacitor?
(b) If the output is to be an integrated form of the input, what is the maximum value the pulse width can assume?

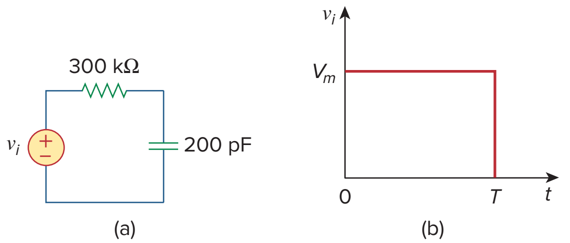


Figure 7.148
For Prob. 7.88.

7.89 An *RL* circuit may be used as a differentiator if the output is taken across the inductor and $\tau \ll T$ (say $\tau < 0.1T$), where T is the width of the input pulse. If R is fixed at 200 kΩ, determine the maximum value of L required to differentiate a pulse with $T = 10\ \mu$s.

7.90 An attenuator probe employed with oscilloscopes was designed to reduce the magnitude of the input voltage v_i by a factor of 10. As shown in Fig. 7.149, the oscilloscope has internal resistance R_s and capacitance C_s, while the probe has an internal resistance R_p. If R_p is fixed at 6 MΩ, find R_s and C_s for the circuit to have a time constant of 15 μs.

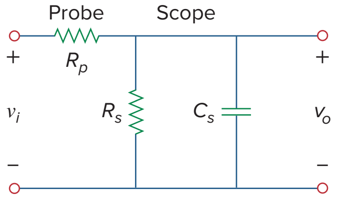


Figure 7.149
For Prob. 7.90.

7.91 The circuit in Fig. 7.150 is used by a biology student to study "frog kick." She noticed that the frog kicked a little when the switch was closed but kicked violently for 5 s when the switch was opened. Model the frog as a resistor and calculate its resistance. Assume that it takes 10 mA for the frog to kick violently.

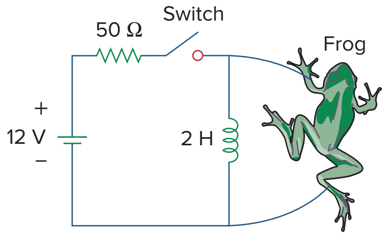


Figure 7.150
For Prob. 7.91.

7.92 To move a spot of a cathode-ray tube across the screen requires a linear increase in the voltage across the deflection plates, as shown in Fig. 7.151. Given that the capacitance of the plates is 4 nF, sketch the current flowing through the plates.

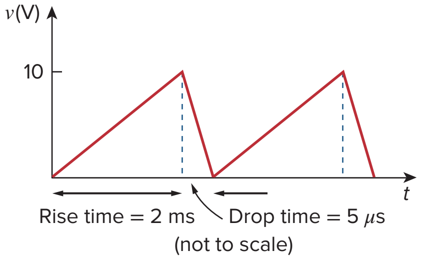


Figure 7.151
For Prob. 7.92.

$s^2 + 2\alpha s + \omega_0^2 = 0$, where α is the neper frequency and ω_0 is the undamped natural frequency. For a series circuit, $\alpha = R/2L$, for a parallel circuit $\alpha = 1/2RC$, and for both cases $\omega_0 = 1/\sqrt{LC}$.

3. If there are no independent sources in the circuit after switching (or sudden change), we regard the circuit as source-free. The complete solution is the natural response.
4. The natural response of an *RLC* circuit is overdamped, underdamped, or critically damped, depending on the roots of the characteristic equation. The response is critically damped when the roots are equal ($s_1 = s_2$ or $\alpha = \omega_0$), overdamped when the roots are real and unequal ($s_1 \neq s_2$ or $\alpha > \omega_0$), or underdamped when the roots are complex conjugate ($s_1 = s_2^*$ or $\alpha < \omega_0$).
5. If independent sources are present in the circuit after switching, the complete response is the sum of the transient response and the steady-state response.
6. *PSpice* is used to analyze *RLC* circuits in the same way as for *RC* or *RL* circuits.
7. Two circuits are dual if the mesh equations that describe one circuit have the same form as the nodal equations that describe the other The analysis of one circuit gives the analysis of its dual circuit.
8. The automobile ignition circuit and the smoothing circuit are typical applications of the material covered in this chapter.

Review Questions

8.1 For the circuit in Fig. 8.58, the capacitor voltage at $t = 0^-$ (just before the switch is closed) is:

(a) 0 V (b) 4 V (c) 8 V (d) 12 V

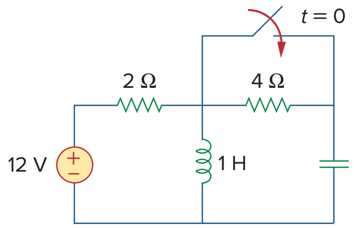


Figure 8.58
For Review Questions 8.1 and 8.2.

8.2 For the circuit in Fig. 8.58, the initial inductor current (at $t = 0$) is:

(a) 0 A (b) 2 A (c) 6 A (d) 12 A

8.3 When a step input is applied to a second-order circuit, the final values of the circuit variables are found by:

(a) Replacing capacitors with closed circuits and inductors with open circuits.
(b) Replacing capacitors with open circuits and inductors with closed circuits.
(c) Doing neither of the above.

8.4 If the roots of the characteristic equation of an *RLC* circuit are -2 and -3, the response is:

(a) $(A \cos 2t + B \sin 2t)e^{-3t}$
(b) $(A + 2Bt)e^{-3t}$
(c) $Ae^{-2t} + Bte^{-3t}$
(d) $Ae^{-2t} + Be^{-3t}$

where A and B are constants.

8.5 In a series *RLC* circuit, setting $R = 0$ will produce:

(a) an overdamped response
(b) a critically damped response
(c) an underdamped response
(d) an undamped response
(e) none of the above

8.6 A parallel *RLC* circuit has $L = 2$ H and $C = 0.25$ F. The value of R that will produce a unity neper frequency is:

(a) 0.5 Ω (b) 1 Ω (c) 2 Ω (d) 4 Ω

8.7 Refer to the series *RLC* circuit in Fig. 8.59. What kind of response will it produce?

(a) overdamped
(b) underdamped
(c) critically damped
(d) none of the above

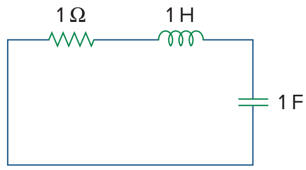


Figure 8.59
For Review Question 8.7.

8.8 Consider the parallel *RLC* circuit in Fig. 8.60. What type of response will it produce?

(a) overdamped
(b) underdamped
(c) critically damped
(d) none of the above

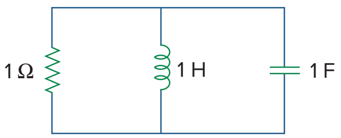


Figure 8.60
For Review Question 8.8.

8.9 Match the circuits in Fig. 8.61 with the following items:

(i) first-order circuit
(ii) second-order series circuit
(iii) second-order parallel circuit
(iv) none of the above

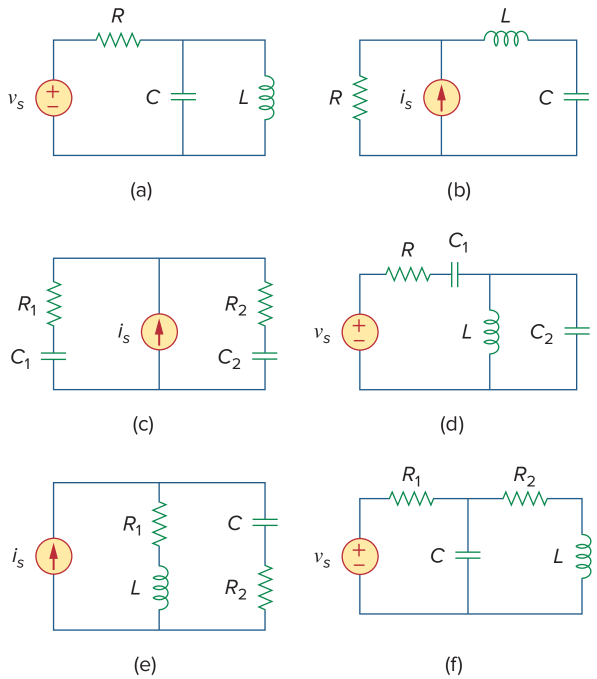


Figure 8.61
For Review Question 8.9.

8.10 In an electric circuit, the dual of resistance is:

(a) conductance (b) inductance
(c) capacitance (d) open circuit
(e) short circuit

Answers: 8.1a, 8.2c, 8.3b, 8.4d, 8.5d, 8.6c, 8.7b, 8.8b, 8.9 (i)-c, (ii)-b, e, (iii)-a, (iv)-d, f, 8.10a.

Problems

Section 8.2 Finding Initial and Final Values

8.1 For the circuit in Fig. 8.62, find:

(a) $i(0^+)$ and $v(0^+)$,
(b) $di(0^+)/dt$ and $dv(0^+)/dt$,
(c) $i(\infty)$ and $v(\infty)$.

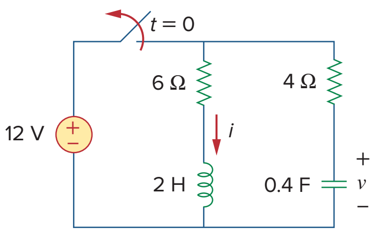


Figure 8.62
For Prob. 8.1.

8.2 **e2d** Using Fig. 8.63, design a problem to help other students better understand finding initial and final values.

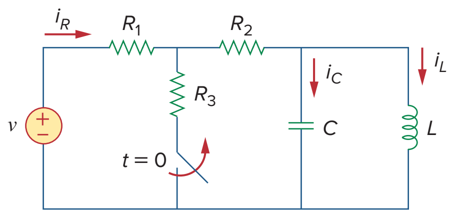


Figure 8.63
For Prob. 8.2.

8.3 Refer to the circuit shown in Fig. 8.64. Calculate:

(a) $i_L(0^+)$, $v_C(0^+)$, and $v_R(0^+)$,
(b) $di_L(0^+)/dt$, $dv_C(0^+)/dt$, and $dv_R(0^+)/dt$,
(c) $i_L(\infty)$, $v_C(\infty)$, and $v_R(\infty)$.

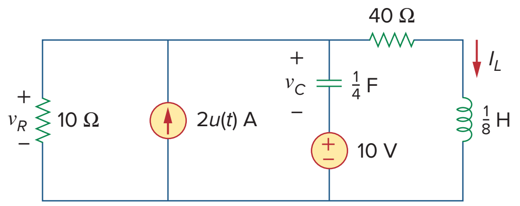


Figure 8.64
For Prob. 8.3.

8.4 In the circuit of Fig. 8.65, find:

(a) $v(0^+)$ and $i(0^+)$,
(b) $dv(0^+)/dt$ and $di(0^+)/dt$,
(c) $v(\infty)$ and $i(\infty)$.

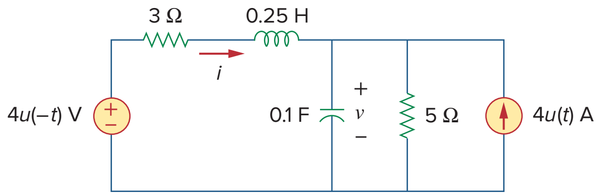


Figure 8.65
For Prob. 8.4.

8.5 Refer to the circuit in Fig. 8.66. Determine:

(a) $i(0^+)$ and $v(0^+)$,
(b) $di/(0^+)dt$ and $dv(0^+)/dt$,
(c) $i(\infty)$ and $v(\infty)$.

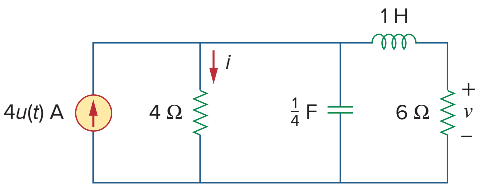


Figure 8.66
For Prob. 8.5.

8.6 In the circuit of Fig. 8.67, find:

(a) $v_R(0^+)$ and $v_L(0^+)$,
(b) $dv_R(0^+)/dt$ and $dv_L(0^+)/dt$,
(c) $v_R(\infty)$ and $v_L(\infty)$.

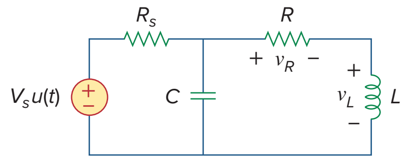


Figure 8.67
For Prob. 8.6.

Section 8.3 Source-Free Series *RLC* Circuit

8.7 A series *RLC* circuit has $R = 20$ kΩ, $L = 0.2$ mH, and $C = 5\ \mu$F. What type of damping is exhibited by the circuit?

8.8 Design a problem to help other students better understand source-free *RLC* circuits.

8.9 The current in an *RLC* circuit is described by

$$\frac{d^2i}{dt^2} + 10\frac{di}{dt} + 25i = 0$$

If $i(0) = 10$ A and $di(0)/dt = 0$, find $i(t)$ for $t > 0$.

8.10 The differential equation that describes the current in an *RLC* network is

$$3\frac{d^2i}{dt^2} + 15\frac{di}{dt} + 12i = 0$$

Given that $i(0) = 0$, $di(0)/dt = 6$ mA/s, obtain $i(t)$.

8.11 The natural response of an *RLC* circuit is described by the differential equation

$$\frac{d^2v}{dt^2} + 2\frac{dv}{dt} + v = 0$$

for which the initial conditions are $v(0) = 10$ V and $dv(0)/dt = 0$. Solve for $v(t)$.

8.12 If $R = 50$ Ω, $L = 1.5$ H, what value of C will make an *RLC* series circuit:

(a) overdamped,
(b) critically damped,
(c) underdamped?

8.13 For the circuit in Fig. 8.68, calculate the value of R needed to have a critically damped response.

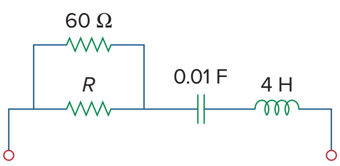


Figure 8.68
For Prob. 8.13.

8.14 The switch in Fig. 8.69 moves from position A to position B at $t = 0$ (please note that the switch must connect to point B before it breaks the connection at A, a make-before-break switch). Let $v(0) = 0$, find $v(t)$ for $t > 0$.

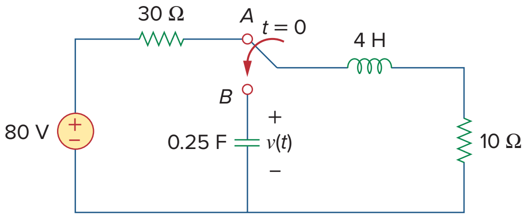


Figure 8.69
For Prob. 8.14.

8.15 The responses of a series *RLC* circuit are

$$v_C(t) = 30 - 10e^{-20t} + 30e^{-10t} \text{ V}$$
$$i_L(t) = 40e^{-20t} - 60e^{-10t} \text{ mA}$$

where v_C and i_L are the capacitor voltage and inductor current, respectively. Determine the values of R, L, and C.

8.16 Find $i(t)$ for $t > 0$ in the circuit of Fig. 8.70.

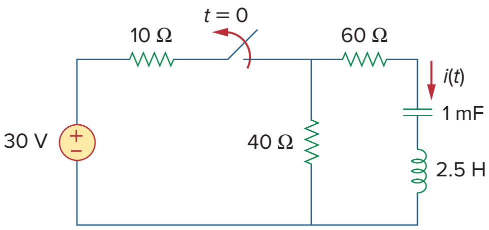


Figure 8.70
For Prob. 8.16.

8.17 In the circuit of Fig. 8.71, the switch instantaneously moves from position A to B at $t = 0$. Find $v(t)$ for all $t \geq 0$.

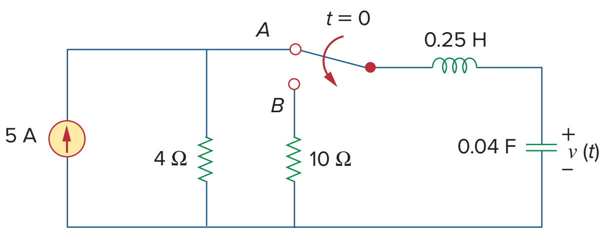


Figure 8.71
For Prob. 8.17.

8.18 Find the voltage across the capacitor as a function of time for $t > 0$ for the circuit in Fig. 8.72. Assume steady-state conditions exist at $t = 0^-$.

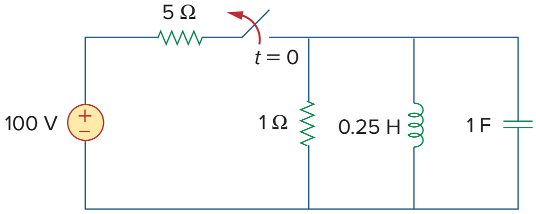


Figure 8.72
For Prob. 8.18.

8.19 Obtain $v(t)$ for $t > 0$ in the circuit of Fig. 8.73.

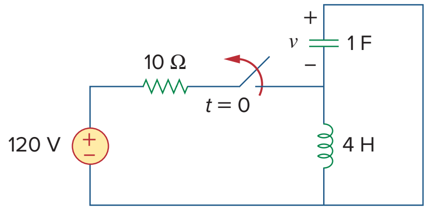


Figure 8.73
For Prob. 8.19.

8.20 The switch in the circuit of Fig. 8.74 has been closed for a long time but is opened at $t = 0$. Determine $i(t)$ for $t > 0$.

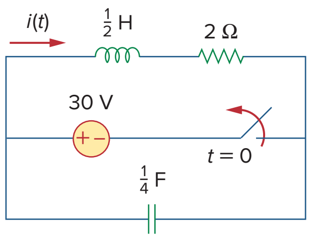


Figure 8.74
For Prob. 8.20.

***8.21** Calculate $v(t)$ for $t > 0$ in the circuit of Fig. 8.75.

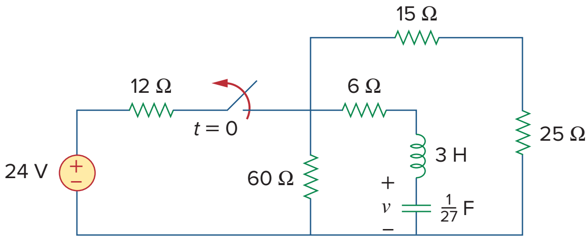


Figure 8.75
For Prob. 8.21.

* An asterisk indicates a challenging problem.

Section 8.4 Source-Free Parallel *RLC* Circuit

8.22 Assuming $R = 2\ \text{k}\Omega$, design a parallel *RLC* circuit that has the characteristic equation

$$s^2 + 100s + 10^6 = 0.$$

8.23 For the network in Fig. 8.76, what value of C is needed to make the response underdamped with unity neper frequency ($\alpha = 1$)?

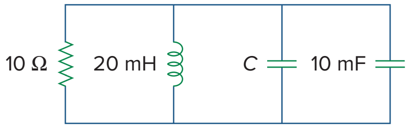


Figure 8.76
For Prob. 8.23.

8.24 The switch in Fig. 8.77 moves from position A to position *B* at $t = 0$ (please note that the switch must connect to point *B* before it breaks the connection at *A*, a make-before-break switch). Determine $i(t)$ for $t > 0$.

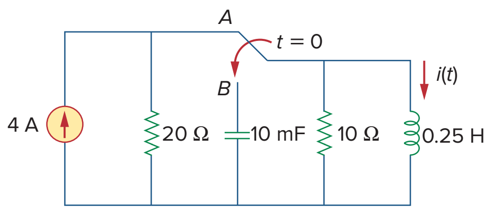


Figure 8.77
For Prob. 8.24.

8.25 Using Fig. 8.78, design a problem to help other students better understand source-free *RLC* circuits.

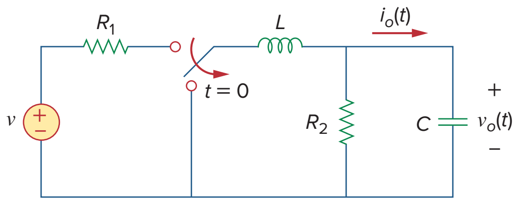


Figure 8.78
For Prob. 8.25.

Section 8.5 Step Response of a Series *RLC* Circuit

8.26 The step response of an *RLC* circuit is given by

$$\frac{d^2i}{dt^2} + 2\frac{di}{dt} + 5i = 10$$

Given that $i(0) = 2$ and $di(0)/dt = 4$, solve for $i(t)$.

8.27 A branch voltage in an *RLC* circuit is described by

$$\frac{d^2v}{dt^2} + 4\frac{dv}{dt} + 8v = 24$$

If the initial conditions are $v(0) = 0 = dv(0)/dt$, find $v(t)$.

8.28 A series *RLC* circuit is described by

$$L\frac{d^2i}{dt^2} + R\frac{di}{dt} + \frac{i}{C} = 10$$

Find the response when $L = 0.5$ H, $R = 4\ \Omega$, and $C = 0.2$ F. Let $i(0) = 1$, $di(0)/dt = 0$.

8.29 Solve the following differential equations subject to the specified initial conditions

(a) $d^2v/dt^2 + 4v = 12$, $v(0) = 0$, $dv(0)/dt = 2$
(b) $d^2i/dt^2 + 5\,di/dt + 4i = 8$, $i(0) = -1$, $di(0)/dt = 0$
(c) $d^2v/dt^2 + 2\,dv/dt + v = 3$, $v(0) = 5$, $dv(0)/dt = 1$
(d) $d^2i/dt^2 + 2\,di/dt + 5i = 10$, $i(0) = 4$, $di(0)/dt = -2$

8.30 The step responses of a series *RLC* circuit are

$$v_C = 40 - 10e^{-2000t} - 10e^{-4000t}\ \text{V}, \qquad t > 0$$
$$i_L(t) = 3e^{-2000t} + 6e^{-4000t}\ \text{mA}, \qquad t > 0$$

(a) Find C. (b) Determine what type of damping is exhibited by the circuit.

8.31 Consider the circuit in Fig. 8.79. Find $v_L(0^+)$ and $v_C(0^+)$.

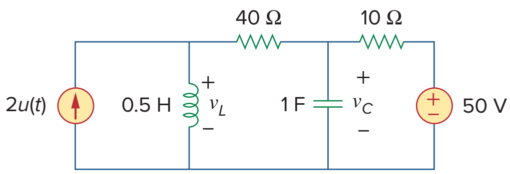


Figure 8.79
For Prob. 8.31.

8.32 For the circuit in Fig. 8.80, find $v(t)$ for $t > 0$.

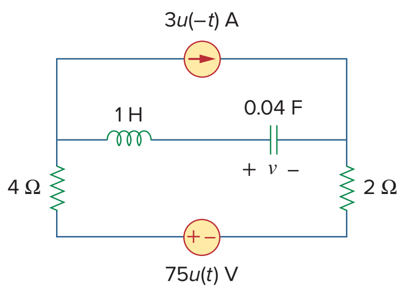


Figure 8.80
For Prob. 8.32.

8.33 Find $v(t)$ for $t > 0$ in the circuit of Fig. 8.81.

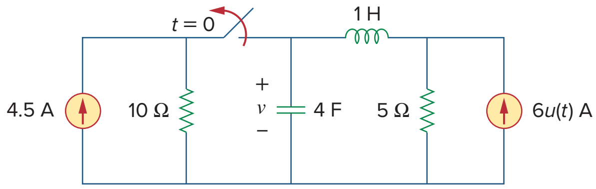


Figure 8.81
For Prob. 8.33.

8.34 Calculate $i(t)$ for $t > 0$ in the circuit of Fig. 8.82.

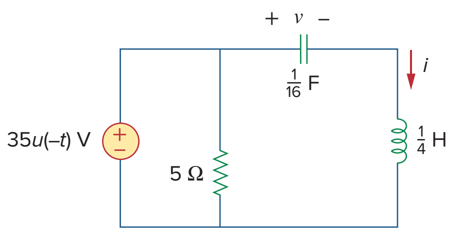


Figure 8.82
For Prob. 8.34.

8.35 Using Fig. 8.83, design a problem to help other students better understand the step response of series *RLC* circuits.

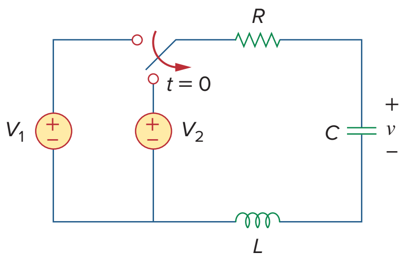


Figure 8.83
For Prob. 8.35.

8.36 Obtain $v(t)$ and $i(t)$ for $t > 0$ in the circuit of Fig. 8.84.

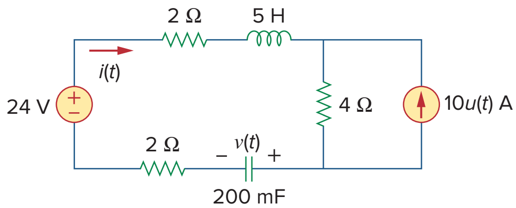


Figure 8.84
For Prob. 8.36.

***8.37** For the network in Fig. 8.85, solve for $i(t)$ for $t > 0$.

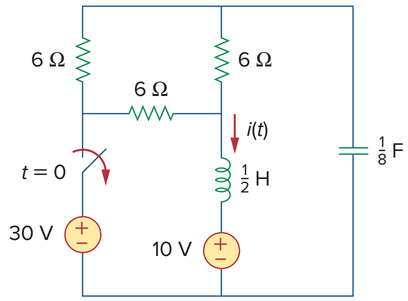


Figure 8.85
For Prob. 8.37.

8.38 Refer to the circuit in Fig. 8.86. Calculate $i(t)$ for $t > 0$.

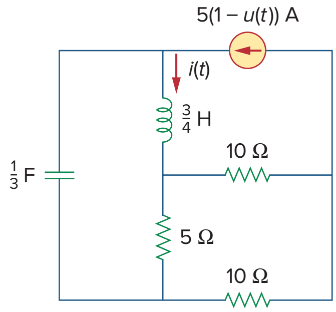


Figure 8.86
For Prob. 8.38.

8.39 Determine $v(t)$ for $t > 0$ in the circuit of Fig. 8.87.

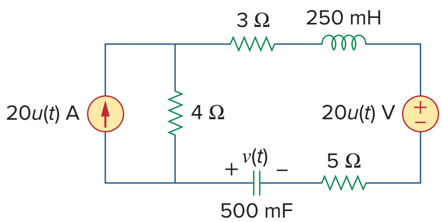


Figure 8.87
For Prob. 8.39.

8.40 The switch in the circuit of Fig. 8.88 is moved from position a to b at $t = 0$. Assume that the voltage across the capacitor is equal to zero at $t = 0$ and that the switch is a make before break switch. Determine $i(t)$ for all $t > 0$.

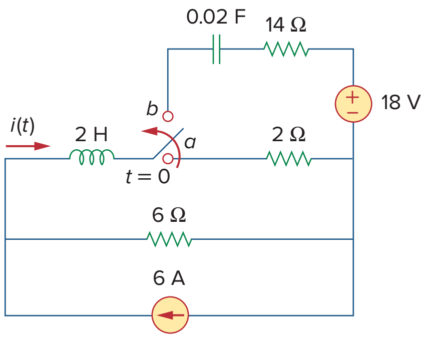


Figure 8.88
For Prob. 8.40.

***8.41** For the network in Fig. 8.89, find $i(t)$ for $t > 0$.

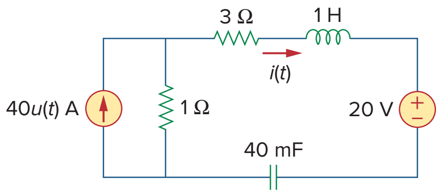


Figure 8.89
For Prob. 8.41.

***8.42** Given the network in Fig. 8.90, find $v(t)$ for $t > 0$.

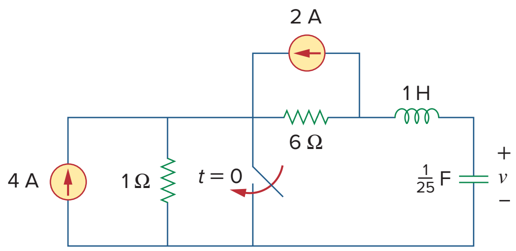


Figure 8.90
For Prob. 8.42.

8.43 The switch in Fig. 8.91 is opened at $t = 0$ after the circuit has reached steady state. Choose R and C such that $\alpha = 8$ Np/s and $\omega_d = 30$ rad/s.

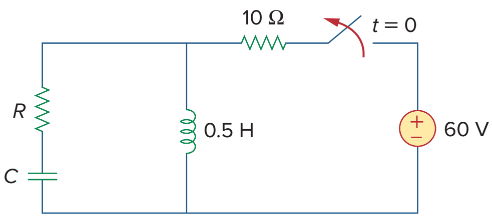


Figure 8.91
For Prob. 8.43.

8.44 A series RLC circuit has the following parameters: $R = 1$ kΩ, $L = 1$ H, and $C = 10$ nF. What type of damping does this circuit exhibit?

Section 8.6 Step Response of a Parallel *RLC* Circuit

8.45 In the circuit of Fig. 8.92, find $v(t)$ and $i(t)$ for $t > 0$.

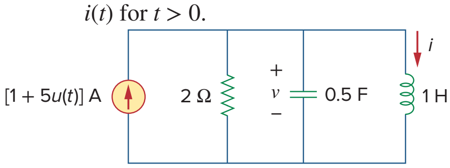


Figure 8.92
For Prob. 8.45.

8.46 Using Fig. 8.93, design a problem to help other students better understand the step response of a parallel RLC circuit.

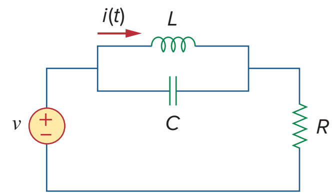


Figure 8.93
For Prob. 8.46.

8.47 Find the output voltage $v_o(t)$ in the circuit of Fig. 8.94.

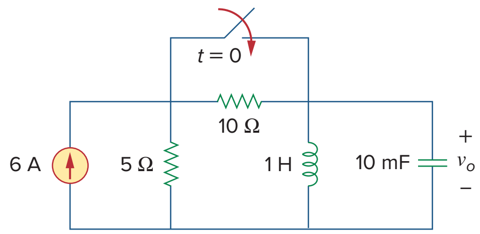


Figure 8.94
For Prob. 8.47.

8.48 Given the circuit in Fig. 8.95, find $i(t)$ and $v(t)$ for $t > 0$.

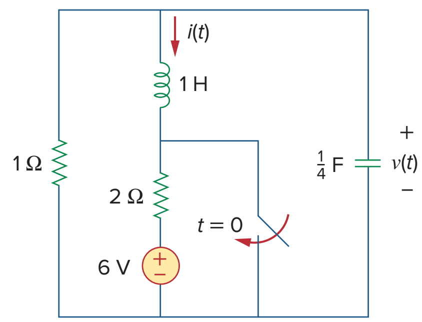


Figure 8.95
For Prob. 8.48.

8.49 Determine $i(t)$ for $t > 0$ in the circuit of Fig. 8.96.

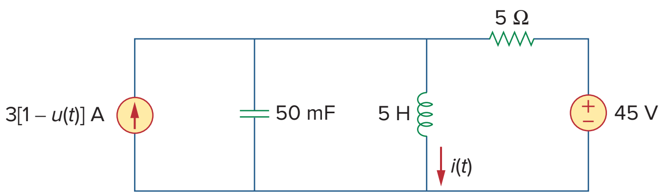


Figure 8.96
For Prob. 8.49.

8.50 For the circuit in Fig. 8.97, find $i(t)$ for $t > 0$.

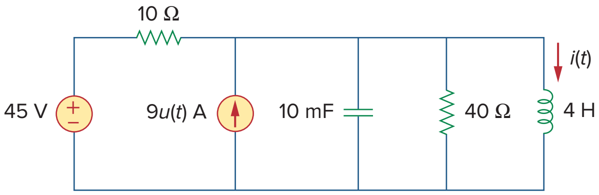


Figure 8.97
For Prob. 8.50.

8.51 Find $v(t)$ for $t > 0$ in the circuit of Fig. 8.98.

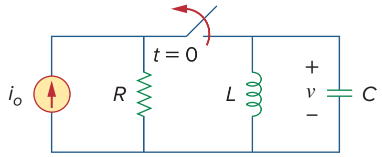


Figure 8.98
For Prob. 8.51.

8.52 The step response of a parallel *RLC* circuit is

$$v = 10 + 20e^{-300t}(\cos 400t - 2\sin 400t)\text{ V}, \qquad t \geq 0$$

when the inductor is 25 mH. Find R and C.

Section 8.7 General Second-Order Circuits

8.53 After being open for a day, the switch in the circuit of Fig. 8.99 is closed at $t = 0$. Find the differential equation describing $i(t)$, $t > 0$.

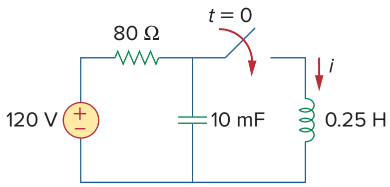


Figure 8.99
For Prob. 8.53.

8.54 Using Fig. 8.100, design a problem to help other students better understand general second-order circuits.

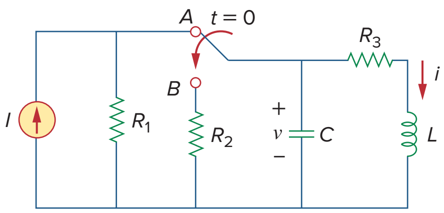


Figure 8.100
For Prob. 8.54.

8.55 For the circuit in Fig. 8.101, find $v(t)$ for $t > 0$. Assume that $i(0^+) = 2$ A.

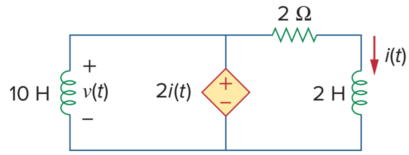


Figure 8.101
For Prob. 8.55.

8.56 In the circuit of Fig. 8.102, find $i(t)$ for $t > 0$.

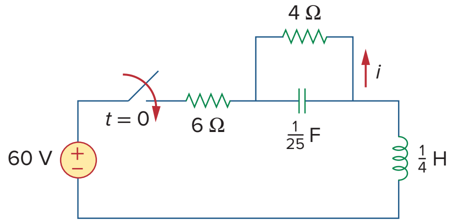


Figure 8.102
For Prob. 8.56.

8.57 Given the circuit shown in Fig. 8.103, determine the characteristic equation of the circuit and the values for $i(t)$ and $v(t)$ for all $t > 0$.

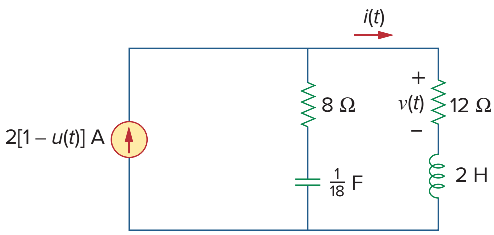


Figure 8.103
For Prob. 8.57.

8.58 In the circuit of Fig. 8.104, the switch has been in position 1 for a long time but moved to position 2 at $t = 0$. Find:

(a) $v(0^+)$, $dv(0^+)/dt$,
(b) $v(t)$ for $t \geq 0$.

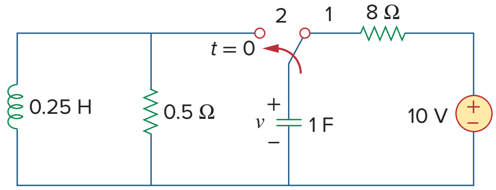


Figure 8.104
For Prob. 8.58.

8.59 The switch in Fig. 8.105 has been in position 1 for $t < 0$. At $t = 0$, it is moved from position 1 to the top of the capacitor at $t = 0$. Please note that the switch is a make before break switch, it stays in contact with position 1 until it makes contact with the top of the capacitor and then breaks the contact at position 1. Given that the initial voltage across the capacitor is equal to zero, determine $v(t)$.

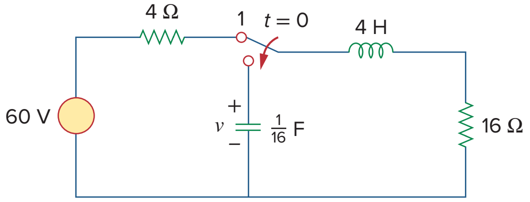


Figure 8.105
For Prob. 8.59.

8.60 Obtain i_1 and i_2 for $t > 0$ in the circuit of Fig. 8.106.

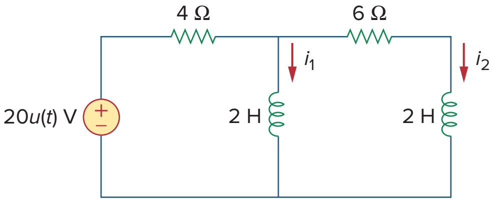


Figure 8.106
For Prob. 8.60.

8.61 For the circuit in Prob. 8.5, find i and v for $t > 0$.

8.62 Find the response $v_R(t)$ for $t > 0$ in the circuit of Fig. 8.107. Let $R = 8\ \Omega$, $L = 2$ H, and $C = 125$ mF.

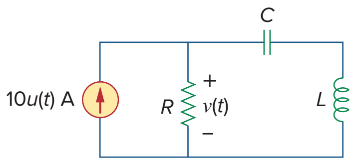


Figure 8.107
For Prob. 8.62.

Section 8.8 Second-Order Op Amp Circuits

8.63 For the op amp circuit in Fig. 8.108, find the differential equation for $i(t)$.

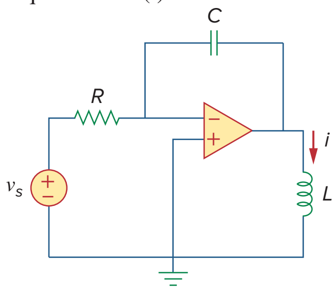


Figure 8.108
For Prob. 8.63.

8.64 Using Fig. 8.109, design a problem to help other students better understand second-order op amp circuits.

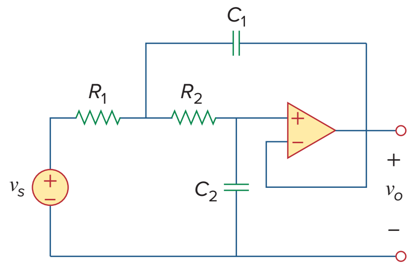


Figure 8.109
For Prob. 8.64.

8.65 Determine the differential equation for the op amp circuit in Fig. 8.110. If $v_1(0^+) = 2$ V and $v_2(0^+) = 0$ V, find v_o for $t > 0$. Let $R = 100\ \text{k}\Omega$ and $C = 1\ \mu$F.

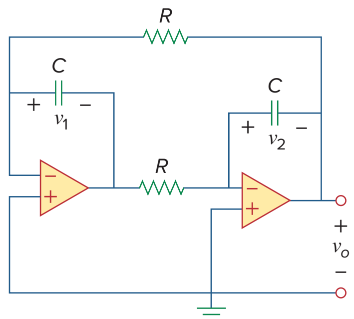


Figure 8.110
For Prob. 8.65.

8.66 Obtain the differential equations for $v_o(t)$ in the op amp circuit of Fig. 8.111.

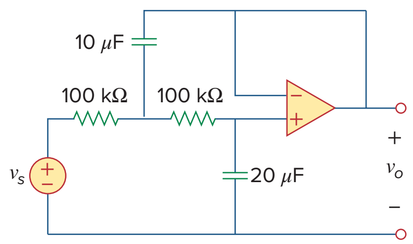


Figure 8.111
For Prob. 8.66.

***8.67** In the op amp circuit of Fig. 8.112, determine $v_o(t)$ for $t > 0$. Let $v_{in} = u(t)$ V, $R_1 = R_2 = 10$ kΩ, $C_1 = C_2 = 100\ \mu$F.

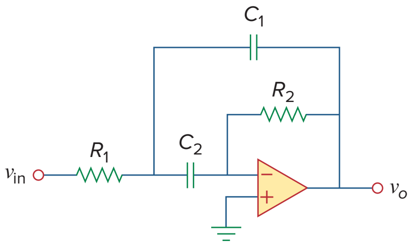


Figure 8.112
For Prob. 8.67.

Section 8.9 *PSpice* Analysis of *RLC* Circuit

8.68 For the step function $v_s = u(t)$, use *PSpice* or *MultiSim* to find the response $v(t)$ for $0 < t < 6$ s in the circuit of Fig. 8.113.

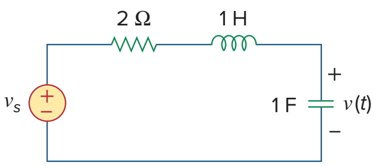


Figure 8.113
For Prob. 8.68.

8.69 Given the source-free circuit in Fig. 8.114, use *PSpice* or *MultiSim* to get $i(t)$ for $0 < t < 20$ s. Take $v(0) = 30$ V and $i(0) = 2$ A.

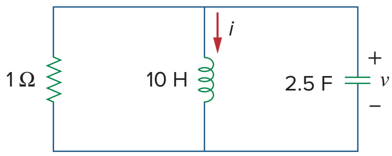


Figure 8.114
For Prob. 8.69.

8.70 For the circuit in Fig. 8.115, use *PSpice* or *MultiSim* to obtain $v(t)$ for $0 < t < 4$ s. Assume that the capacitor voltage and inductor current at $t = 0$ are both zero.

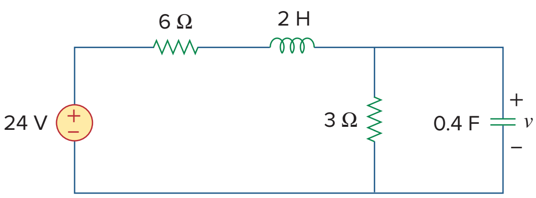


Figure 8.115
For Prob. 8.70.

8.71 Obtain $v(t)$ for $0 < t < 4$ s in the circuit of Fig. 8.116 using *PSpice* or *MultiSim*.

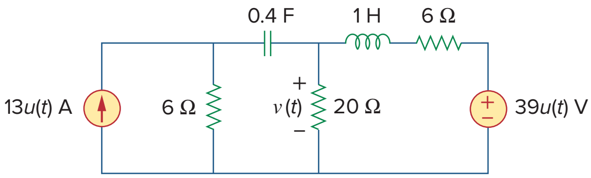


Figure 8.116
For Prob. 8.71.

8.72 The switch in Fig. 8.117 has been in position 1 for a long time. At $t = 0$, it is switched to position 2. Use *PSpice* or *MultiSim* to find $i(t)$ for $0 < t < 0.2$ s.

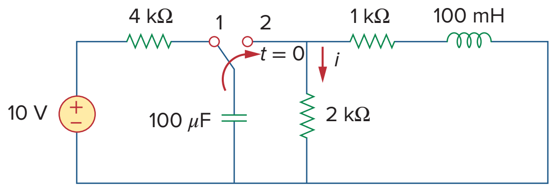


Figure 8.117
For Prob. 8.72.

8.73 Design a problem, to be solved using *PSpice* or *MultiSim*, to help other students better understand source-free *RLC* circuits.

Section 8.10 Duality

8.74 Draw the dual of the circuit shown in Fig. 8.118.

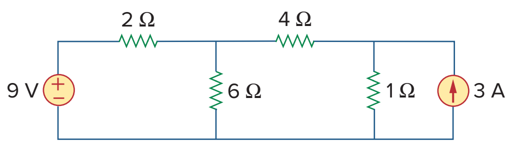


Figure 8.118
For Prob. 8.74.

8.75 Obtain the dual of the circuit in Fig. 8.119.

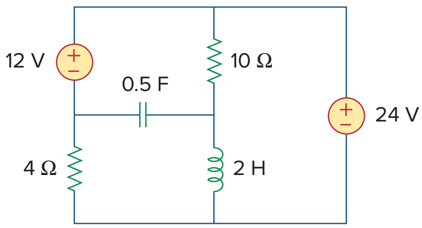


Figure 8.119
For Prob. 8.75.

8.76 Find the dual of the circuit in Fig. 8.120.

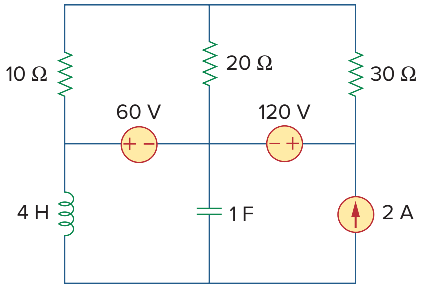


Figure 8.120
For Prob. 8.76.

8.77 Draw the dual of the circuit in Fig. 8.121.

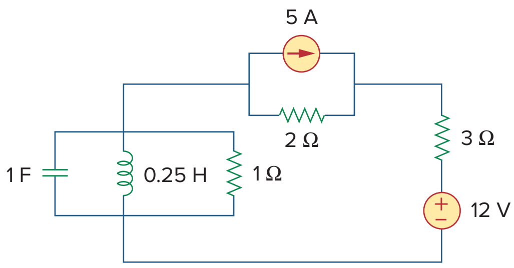


Figure 8.121
For Prob. 8.77.

Section 8.11 Applications

8.78 An automobile airbag igniter is modeled by the circuit in Fig. 8.122. Determine the time it takes the voltage across the igniter to reach its first peak after switching from A to B. Let $R = 3\ \Omega$, $C = 1/30$ F, and $L = 60$ mH.

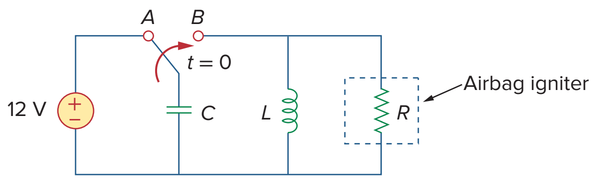


Figure 8.122
For Prob. 8.78.

8.79 A load is modeled as a 100-mH inductor in parallel with a 12-Ω resistor. A capacitor is needed to be connected to the load so that the network is critically damped at 60 Hz. Calculate the size of the capacitor.

Comprehensive Problems

8.80 A mechanical system is modeled by a series *RLC* circuit. It is desired to produce an overdamped response with time constants 0.1 and 0.5 ms. If a series 50-kΩ resistor is used, find the values of L and C.

8.81 An oscillogram can be adequately modeled by a second-order system in the form of a parallel *RLC* circuit. It is desired to give an underdamped voltage across a 200-Ω resistor. If the damped frequency is 4 kHz and the time constant of the envelope is 0.25 s, find the necessary values of L and C.

8.82 The circuit in Fig. 8.123 is the electrical analog of body functions used in medical schools to study convulsions. The analog is as follows:

C_1 = Volume of fluid in a drug
C_2 = Volume of blood stream in a specified region
R_1 = Resistance in the passage of the drug from the input to the blood stream
R_2 = Resistance of the excretion mechanism, such as kidney, etc.
v_0 = Initial concentration of the drug dosage
$v(t)$ = Percentage of the drug in the blood stream

Find $v(t)$ for $t > 0$ given that $C_1 = 0.5\ \mu$F, $C_2 = 5\ \mu$F, $R_1 = 5$ MΩ, $R_2 = 2.5$ MΩ, and $v_0 = 60u(t)$ V.

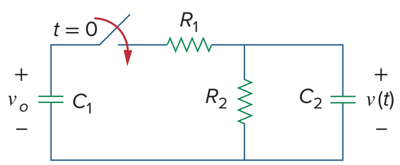


Figure 8.123
For Prob. 8.82.

8.83 Figure 8.124 shows a typical tunnel-diode oscillator circuit. The diode is modeled as a nonlinear resistor with $i_D = f(v_D)$, i.e., the diode current is a nonlinear function of the voltage across the diode. Derive the differential equation for the circuit in terms of v and i_D.

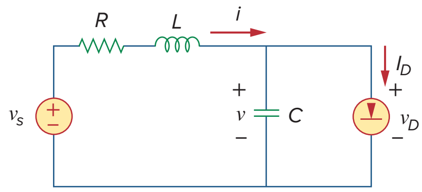


Figure 8.124
For Prob. 8.83.

7. The techniques of voltage/current division, series/parallel combination of impedance/admittance, circuit reduction, and Y-Δ transformation all apply to ac circuit analysis.
8. AC circuits are applied in phase-shifters and bridges.

Review Questions

9.1 Which of the following is *not* a right way to express the sinusoid $A \cos \omega t$?

(a) $A \cos 2\pi f t$ (b) $A \cos(2\pi t/T)$
(c) $A \cos \omega(t - T)$ (d) $A \sin(\omega t - 90°)$

9.2 A function that repeats itself after fixed intervals is said to be:

(a) a phasor (b) harmonic
(c) periodic (d) reactive

9.3 Which of these frequencies has the shorter period?

(a) 1 krad/s (b) 1 kHz

9.4 If $v_1 = 30 \sin(\omega t + 10°)$ and $v_2 = 20 \sin(\omega t + 50°)$, which of these statements are true?

(a) v_1 leads v_2 (b) v_2 leads v_1
(c) v_2 lags v_1 (d) v_1 lags v_2
(e) v_1 and v_2 are in phase

9.5 The voltage across an inductor leads the current through it by 90°.

(a) True (b) False

9.6 The imaginary part of impedance is called:

(a) resistance (b) admittance
(c) susceptance (d) conductance
(e) reactance

9.7 The impedance of a capacitor increases with increasing frequency.

(a) True (b) False

9.8 At what frequency will the output voltage $v_o(t)$ in Fig. 9.39 be equal to the input voltage $v(t)$?

(a) 0 rad/s (b) 1 rad/s (c) 4 rad/s
(d) ∞ rad/s (e) none of the above

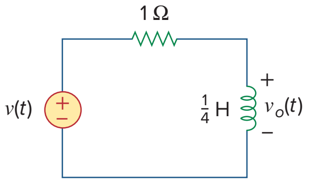


Figure 9.39
For Review Question 9.8.

9.9 A series RC circuit has $|V_R| = 12$ V and $|V_C| = 5$ V. The magnitude of the supply voltage is:

(a) −7 V (b) 7 V (c) 13 V (d) 17 V

9.10 A series RCL circuit has $R = 30\ \Omega$, $X_C = 50\ \Omega$, and $X_L = 90\ \Omega$. The impedance of the circuit is:

(a) $30 + j140\ \Omega$ (b) $30 + j40\ \Omega$
(c) $30 - j40\ \Omega$ (d) $-30 - j40\ \Omega$
(e) $-30 + j40\ \Omega$

Answers: 9.1d, 9.2c, 9.3b, 9.4b,d, 9.5a, 9.6e, 9.7b, 9.8d, 9.9c, 9.10b.

Problems

Section 9.2 Sinusoids

9.1 Given the sinusoidal voltage $v(t) = 50 \cos(30t + 10°)$ V, find: (a) the amplitude V_m, (b) the period T, (c) the frequency f, and (d) $v(t)$ at $t = 10$ ms.

9.2 A current source in a linear circuit has

$$i_s = 15 \cos(25\pi t + 25°) \text{ A}$$

(a) What is the amplitude of the current?
(b) What is the angular frequency?
(c) Find the frequency of the current.
(d) Calculate i_s at $t = 2$ ms.

9.3 Express the following functions in cosine form:

(a) $10 \sin(\omega t + 30°)$ (b) $-9 \sin(8t)$
(c) $-20 \sin(\omega t + 45°)$

9.4 Design a problem to help other students better understand sinusoids.

9.5 Given $v_1 = 45 \sin(\omega t + 30°)$ V and $v_2 = 50 \cos(\omega t - 30°)$ V, determine the phase angle between the two sinusoids and which one lags the other.

9.6 For the following pairs of sinusoids, determine which one leads and by how much.

(a) $v(t) = 10 \cos(4t - 60°)$ and $i(t) = 4 \sin(4t + 50°)$

(b) $v_1(t) = 4 \cos(377t + 10°)$ and $v_2(t) = -20 \cos 377t$

(c) $x(t) = 13 \cos 2t + 5 \sin 2t$ and $y(t) = 15 \cos(2t - 11.8°)$

Section 9.3 Phasors

9.7 If $f(\phi) = \cos\phi + j \sin\phi$, show that $f(\phi) = e^{j\phi}$.

9.8 Calculate these complex numbers and express your results in rectangular form:

(a) $\dfrac{60\angle 45°}{7.5 - j10} + j2$

(b) $\dfrac{32\angle -20°}{(6 - j8)(4 + j2)} + \dfrac{20}{-10 + j24}$

(c) $20 + (16\angle -50°)(5 + j12)$

9.9 Evaluate the following complex numbers and leave your results in polar form:

(a) $5\angle 30° \left(6 - j8 + \dfrac{3\angle 60°}{2 + j}\right)$

(b) $\dfrac{(10\angle 60°)(35\angle -50°)}{(2 + j6) - (5 + j)}$

9.10 Design a problem to help other students better understand phasors.

9.11 Find the phasors corresponding to the following signals:

(a) $v(t) = 21 \cos(4t - 15°)$V

(b) $i(t) = -8 \sin(10t + 70°)$ mA

(c) $v(t) = 120 \sin(10t - 50°)$ V

(d) $i(t) = -60 \cos(30t + 10°)$ mA

9.12 Let $\mathbf{X} = 4\angle 40°$ and $\mathbf{Y} = 20\angle -30°$. Evaluate the following quantities and express your results in polar form:

(a) $(\mathbf{X} + \mathbf{Y})\mathbf{X}^*$

(b) $(\mathbf{X} - \mathbf{Y})^*$

(c) $(\mathbf{X} + \mathbf{Y})/\mathbf{X}$

9.13 Evaluate the following complex numbers:

(a) $\dfrac{2 + j3}{1 - j6} + \dfrac{7 - j8}{-5 + j11}$

(b) $\dfrac{(5\angle 10°)(10\angle -40°)}{(4\angle -80°)(-6\angle 50°)}$

(c) $\begin{vmatrix} 2 + j3 & -j2 \\ -j2 & 8 - j5 \end{vmatrix}$

9.14 Simplify the following expressions:

(a) $\dfrac{(5 - j6) - (2 + j8)}{(-3 + j4)(5 - j) + (4 - j6)}$

(b) $\dfrac{(240\angle 75° + 160\angle -30°)(60 - j80)}{(67 + j84)(20\angle 32°)}$

(c) $\left(\dfrac{10 + j20}{3 + j4}\right)^2 \sqrt{(10 + j5)(16 - j20)}$

9.15 Evaluate these determinants:

(a) $\begin{vmatrix} 10 + j6 & 2 - j3 \\ -5 & -1 + j \end{vmatrix}$

(b) $\begin{vmatrix} 20\angle -30° & -4\angle -10° \\ 16\angle 0° & 3\angle 40° \end{vmatrix}$

(c) $\begin{vmatrix} 1 - j & -j & 0 \\ j & 1 & -j \\ 1 & j & 1 + j \end{vmatrix}$

9.16 Transform the following sinusoids to phasors:

(a) $-20 \cos(4t + 135°)$ (b) $8 \sin(20t + 30°)$

(c) $20 \cos(2t) + 15 \sin(2t)$

9.17 Two voltages v_1 and v_2 appear in series so that their sum is $v = v_1 + v_2$. If $v_1 = 10 \cos(50t - \pi/3)$ V and $v_2 = 12 \cos(50t + 30°)$ V, find v.

9.18 Obtain the sinusoids corresponding to each of the following phasors:

(a) $\mathbf{V}_1 = 60\angle 15°$ V, $\omega = 1$

(b) $\mathbf{V}_2 = 6 + j8$ V, $\omega = 40$

(c) $\mathbf{I}_1 = 2.8e^{-j\pi/3}$ A, $\omega = 377$

(d) $\mathbf{I}_2 = -0.5 - j1.2$ A, $\omega = 10^3$

9.19 Using phasors, find:

(a) $3 \cos(20t + 10°) - 5 \cos(20t - 30°)$

(b) $40 \sin 50t + 30 \cos(50t - 45°)$

(c) $20 \sin 400t + 10 \cos(400t + 60°) - 5 \sin(400t - 20°)$

9.20 A linear network has a current input $7.5 \cos(10t + 30°)$ A and a voltage output $120 \cos(10t + 75°)$ V. Determine the associated impedance.

9.21 Simplify the following:

(a) $f(t) = 5\cos(2t + 15°) - 4\sin(2t - 30°)$

(b) $g(t) = 8\sin t + 4\cos(t + 50°)$

(c) $h(t) = \int_0^t (10\cos 40t + 50\sin 40t)\,dt$

9.22 An alternating voltage is given by $v(t) = 55\cos(5t + 45°)$ V. Use phasors to find

$$10v(t) + 4\frac{dv}{dt} - 2\int_{-\infty}^{t} v(t)\,dt$$

Assume that the value of the integral is zero at $t = -\infty$.

9.23 Apply phasor analysis to evaluate the following:

(a) $v = [110\sin(20t + 30°) + 220\cos(20t - 90°)]$ V

(b) $i = [30\cos(5t + 60°) - 20\sin(5t + 60°)]$ A

9.24 Find $v(t)$ in the following integrodifferential equations using the phasor approach:

(a) $v(t) + \int v\,dt = 10\cos t$

(b) $\frac{dv}{dt} + 5v(t) + 4\int v\,dt = 20\sin(4t + 10°)$

9.25 Using phasors, determine $i(t)$ in the following equations:

(a) $2\frac{di}{dt} + 3i(t) = 4\cos(2t - 45°)$

(b) $10\int i\,dt + \frac{di}{dt} + 6i(t) = 5\cos(5t + 22°)$ A

9.26 The loop equation for a series *RLC* circuit gives

$$\frac{di}{dt} + 2i + \int_{-\infty}^{t} i\,dt = \cos 2t \text{ A}$$

Assuming that the value of the integral at $t = -\infty$ is zero, find $i(t)$ using the phasor method.

9.27 A parallel *RLC* circuit has the node equation

$$\frac{dv}{dt} + 50v + 100\int v\,dt = 110\cos(377t - 10°) \text{ V}$$

Determine $v(t)$ using the phasor method. You may assume that the value of the integral at $t = -\infty$ is zero.

Section 9.4 Phasor Relationships for Circuit Elements

9.28 Determine the current that flows through an 20-Ω resistor connected to a voltage source $v_s = 120\cos(377t + 37°)$ V.

9.29 Given that $v_c(0) = 2\cos(155°)$ V, what is the instantaneous voltage across a 2-μF capacitor when the current through it is $i = 4\sin(10^6 t + 25°)$ A?

9.30 A voltage $v(t) = 100\cos(60t + 20°)$ V is applied to a parallel combination of a 40-kΩ resistor and a 50-μF capacitor. Find the steady-state currents through the resistor and the capacitor.

9.31 A series *RLC* circuit has $R = 80$ Ω, $L = 240$ mH, and $C = 5$ mF. If the input voltage is $v(t) = 115\cos 2t$, find the current flowing through the circuit.

9.32 Using Fig. 9.40, design a problem to help other students better understand phasor relationships for circuit elements.

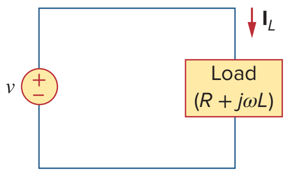


Figure 9.40
For Prob. 9.32.

9.33 A series *RL* circuit is connected to a 220-V ac source. If the voltage across the resistor is 170 V, find the voltage across the inductor.

9.34 What value of ω will cause the forced response, v_o, in Fig. 9.41 to be zero?

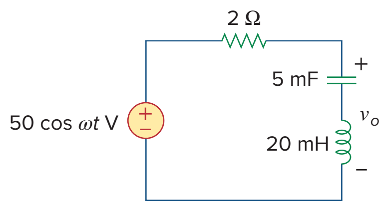


Figure 9.41
For Prob. 9.34.

Section 9.5 Impedance and Admittance

9.35 Find the steady-state current i in the circuit of Fig. 9.42, when $v_s(t) = 115\cos 200t$ V.

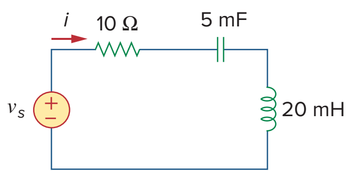


Figure 9.42
For Prob. 9.35.

9.36 Using Fig. 9.43, design a problem to help other students better understand impedance.

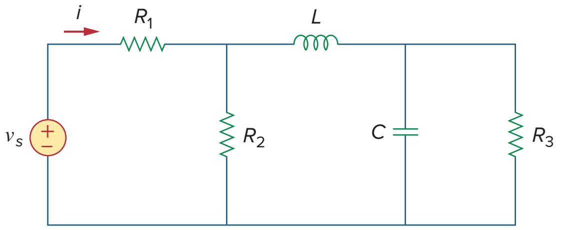


Figure 9.43
For Prob. 9.36.

9.37 Determine the admittance **Y** for the circuit in Fig. 9.44.

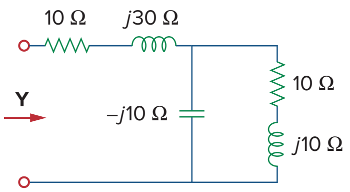


Figure 9.44
For Prob. 9.37.

9.38 Using Fig. 9.45, design a problem to help other students better understand admittance.

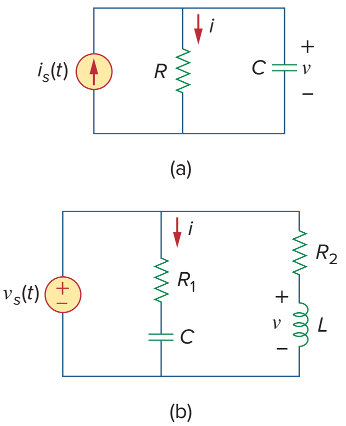


Figure 9.45
For Prob. 9.38.

9.39 For the circuit shown in Fig. 9.46, find Z_{eq} and use that to find current **I**. Let $\omega = 10$ rad/s.

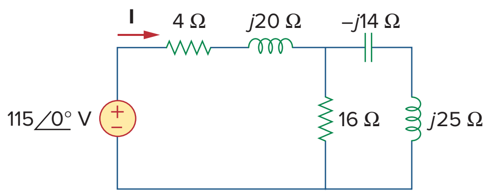


Figure 9.46
For Prob. 9.39.

9.40 In the circuit of Fig. 9.47, find i_o when:

(a) $\omega = 1$ rad/s (b) $\omega = 5$ rad/s
(c) $\omega = 10$ rad/s

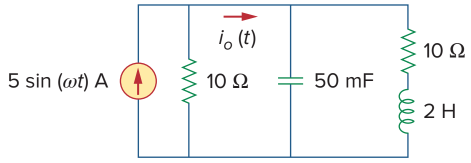


Figure 9.47
For Prob. 9.40.

9.41 Find $v(t)$ in the *RLC* circuit of Fig. 9.48.

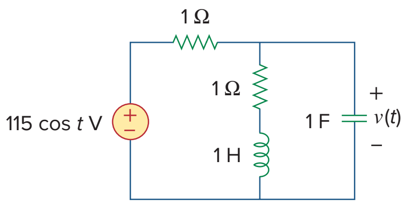


Figure 9.48
For Prob. 9.41.

9.42 Calculate $v_o(t)$ in the circuit of Fig. 9.49.

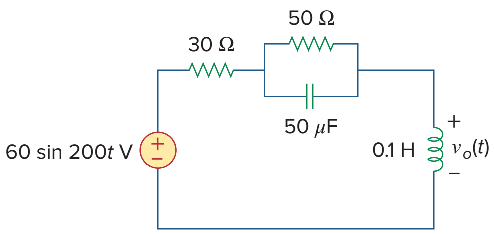


Figure 9.49
For Prob. 9.42.

9.43 Find current $\mathbf{I}_o$ in the circuit shown in Fig. 9.50.

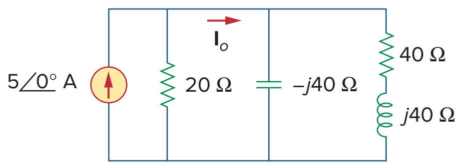


Figure 9.50
For Prob. 9.43.

9.44 Calculate $i(t)$ in the circuit of Fig. 9.51.

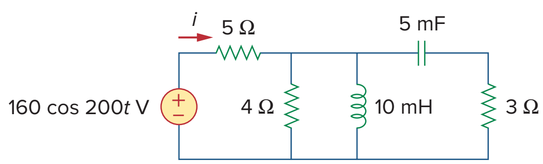


Figure 9.51
For prob. 9.44.

9.45 Find current $\mathbf{I}_o$ in the network of Fig. 9.52.

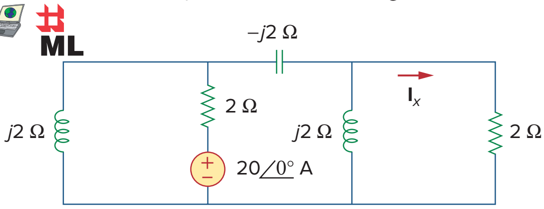


Figure 9.52
For Prob. 9.45.

9.46 If $v_s = 100 \sin(10t + 18^\circ)$ V in the circuit of Fig. 9.53, find i_o.

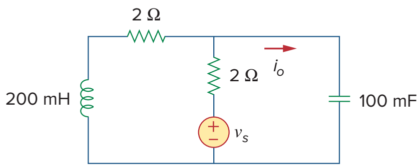


Figure 9.53
For Prob. 9.46.

9.47 In the circuit of Fig. 9.54, determine the value of $i_s(t)$.

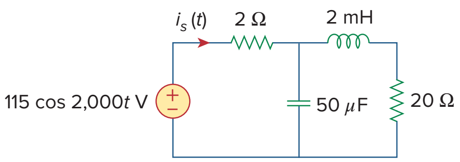


Figure 9.54
For Prob. 9.47.

9.48 Given that $v_s(t) = 20 \sin(100t - 40^\circ)$ in Fig. 9.55, determine $i_x(t)$.

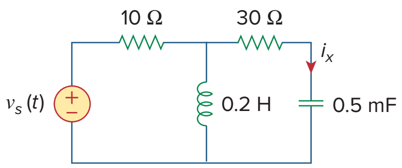


Figure 9.55
For Prob. 9.48.

9.49 Find $v_s(t)$ in the circuit of Fig. 9.56 if the current i_x through the 1-Ω resistor is $8 \sin 200t$ A.

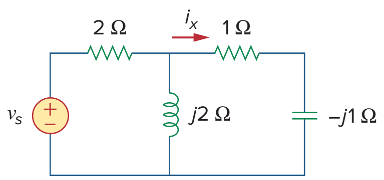


Figure 9.56
For Prob. 9.49.

9.50 Determine v_x in the circuit of Fig. 9.57. Let $i_s(t) = 5 \cos(100t + 40^\circ)$ A.

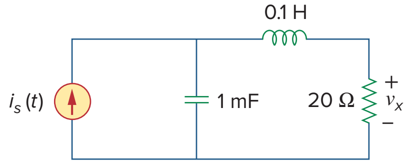


Figure 9.57
For Prob. 9.50.

9.51 If the voltage v_o across the 2-Ω resistor in the circuit of Fig. 9.58 is $90 \cos 2t$ V, obtain i_s.

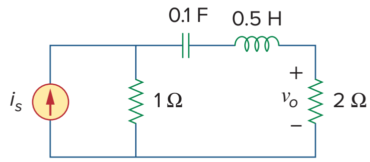


Figure 9.58
For Prob. 9.51.

9.52 If $\mathbf{V}_o = 8\underline{/30^\circ}$ V in the circuit of Fig. 9.59, find $\mathbf{I}_s$.

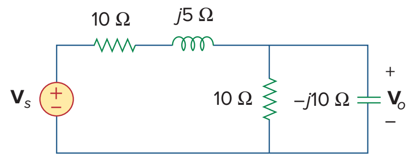


Figure 9.59
For Prob. 9.52.

9.53 Find $\mathbf{I}_o$ in the circuit of Fig. 9.60.

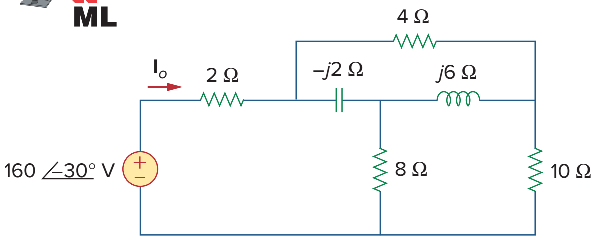


Figure 9.60
For Prob. 9.53.

9.54 In the circuit of Fig. 9.61, find $\mathbf{V}_s$ if $\mathbf{I}_o = 30\underline{/0^\circ}$ A.

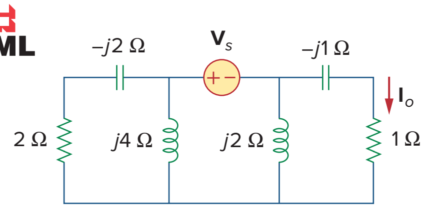


Figure 9.61
For Prob. 9.54.

***9.55** Find **Z** in the network of Fig. 9.62, given that $\mathbf{V}_o = 4\underline{/0^\circ}$ V.

ML

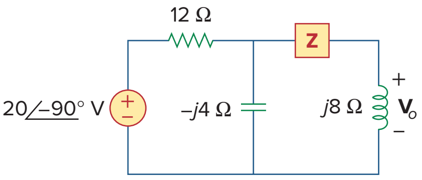


Figure 9.62
For Prob. 9.55.

Section 9.7 Impedance Combinations

9.56 At $\omega = 377$ rad/s, find the input impedance of the circuit shown in Fig. 9.63.

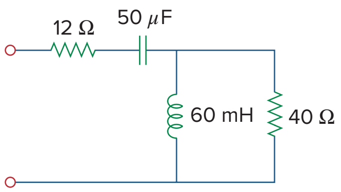


Figure 9.63
For Prob. 9.56.

9.57 At $\omega = 1$ rad/s, obtain the input admittance in the circuit of Fig. 9.64.

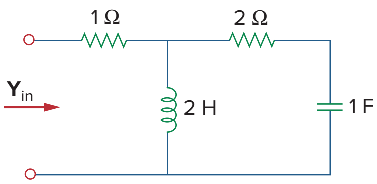


Figure 9.64
For Prob. 9.57.

9.58 Using Fig. 9.65, design a problem to help other students better understand impedance combinations.

e2d

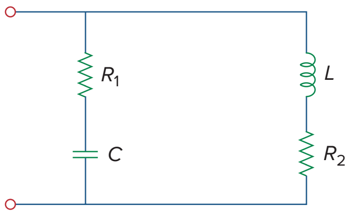


Figure 9.65
For Prob. 9.58.

* An asterisk indicates a challenging problem.

9.59 For the network in Fig. 9.66, find $\mathbf{Z}_{in}$. Let $\omega =$ 100 rad/s.

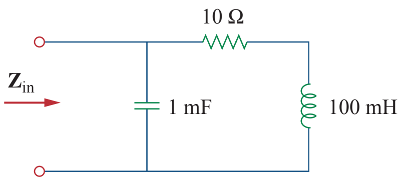


Figure 9.66
For Prob. 9.59.

9.60 Obtain $\mathbf{Z}_{in}$ for the circuit in Fig. 9.67.

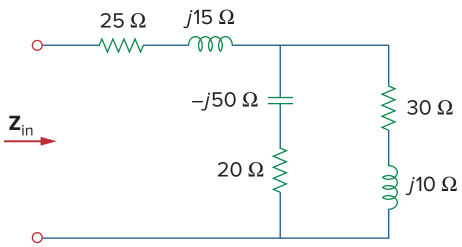


Figure 9.67
For Prob. 9.60.

9.61 Find $\mathbf{Z}_{eq}$ in the circuit of Fig. 9.68.

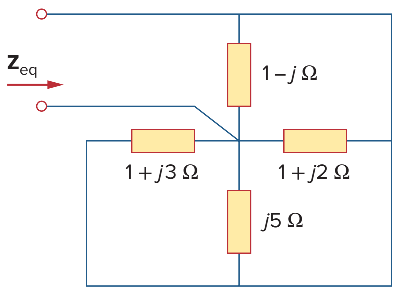


Figure 9.68
For Prob. 9.61.

9.62 For the circuit in Fig. 9.69, find the input impedance $\mathbf{Z}_{in}$ at 10 krad/s.

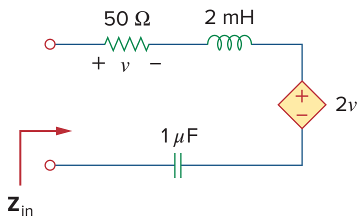


Figure 9.69
For Prob. 9.62.

9.63 For the circuit in Fig. 9.70, find the value of $\mathbf{Z}_T$.

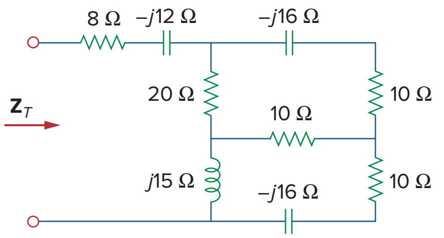


Figure 9.70
For Prob. 9.63.

9.64 Find $\mathbf{Z}_T$ and $\mathbf{V}_o$ in the circuit in Fig. 9.71. Let the value of the inductance equal $j20\ \Omega$.

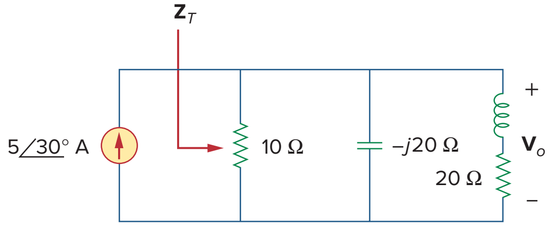


Figure 9.71
For Prob. 9.64.

9.65 Determine $\mathbf{Z}_T$ and $\mathbf{I}$ for the circuit in Fig. 9.72.

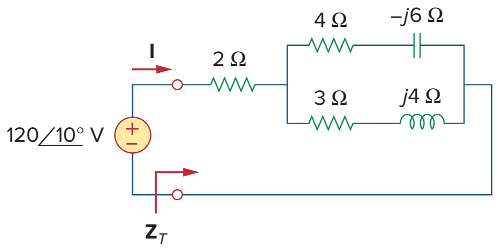


Figure 9.72
For Prob. 9.65.

9.66 For the circuit in Fig. 9.73, calculate $\mathbf{Z}_T$ and $\mathbf{V}_{ab}$.

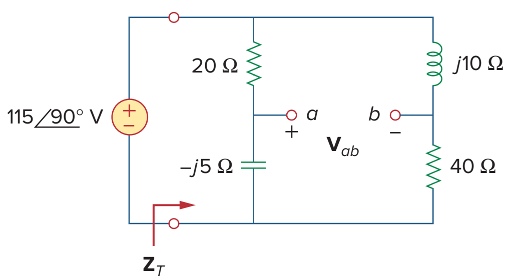


Figure 9.73
For Prob. 9.66.

9.67 At $\omega = 10^3$ rad/s, find the input admittance of each of the circuits in Fig. 9.74.

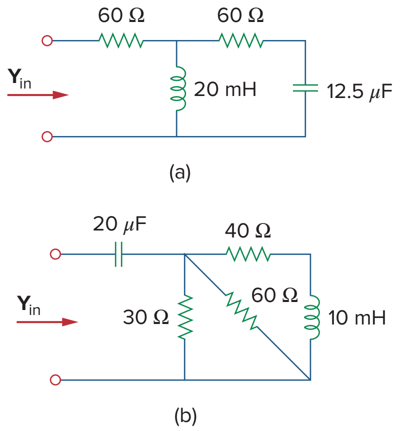


Figure 9.74
For Prob. 9.67.

9.68 Determine $\mathbf{Y}_{eq}$ for the circuit in Fig. 9.75.

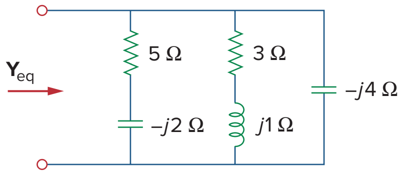


Figure 9.75
For Prob. 9.68.

9.69 Find the equivalent admittance $\mathbf{Y}_{eq}$ of the circuit in Fig. 9.76.

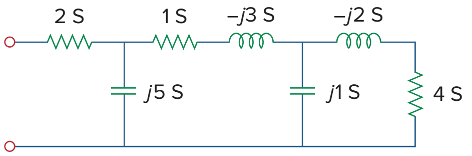


Figure 9.76
For Prob. 9.69.

9.70 Find the equivalent impedance of the circuit in Fig. 9.77.

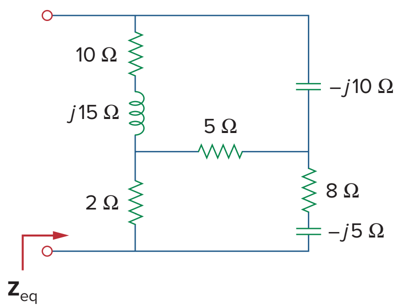


Figure 9.77
For Prob. 9.70.

9.71 Obtain the equivalent impedance of the circuit in Fig. 9.78.

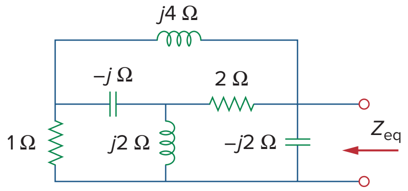


Figure 9.78
For Prob. 9.71.

9.72 Calculate the value of $\mathbf{Z}_{ab}$ in the network of Fig. 9.79.

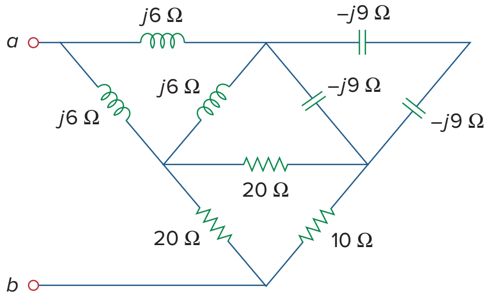


Figure 9.79
For Prob. 9.72.

9.73 Determine the equivalent impedance of the circuit in Fig. 9.80.

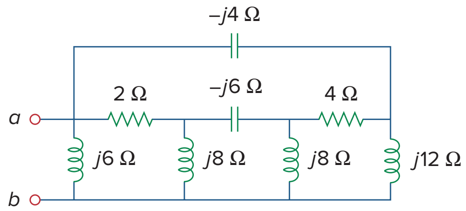


Figure 9.80
For Prob. 9.73.

Section 9.8 Applications

9.74 Design an *RL* circuit to provide a 90° leading phase shift.

9.75 Design a circuit that will transform a sinusoidal voltage input to a cosinusoidal voltage output.

9.76 For the following pairs of signals, determine if v_1 leads or lags v_2 and by how much.

(a) $v_1 = 10\cos(5t - 20°)$, $\quad v_2 = 8\sin 5t$

(b) $v_1 = 19\cos(2t + 90°)$, $\quad v_2 = 6\sin 2t$

(c) $v_1 = -4\cos 10t$, $\quad v_2 = 15\sin 10t$

9.77 Refer to the *RC* circuit in Fig. 9.81.

(a) Calculate the phase shift at 2 MHz.
(b) Find the frequency where the phase shift is 45°.

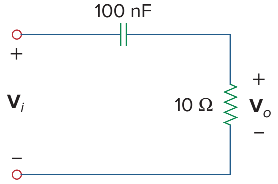


Figure 9.81
For Prob. 9.77.

9.78 A coil with impedance $8 + j6\ \Omega$ is connected in series with a capacitive reactance X. The series combination is connected in parallel with a resistor R. Given that the equivalent impedance of the resulting circuit is $5\angle 0°\ \Omega$, find the value of R and X.

9.79 (a) Calculate the phase shift of the circuit in Fig. 9.82.
(b) State whether the phase shift is leading or lagging (output with respect to input).
(c) Determine the magnitude of the output when the input is 120 V.

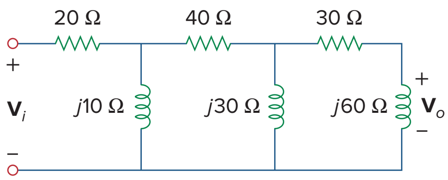


Figure 9.82
For Prob. 9.79.

9.80 Consider the phase-shifting circuit in Fig. 9.83. Let $\mathbf{V}_i = 120$ V operating at 60 Hz. Find:

(a) $\mathbf{V}_o$ when R is maximum
(b) $\mathbf{V}_o$ when R is minimum
(c) the value of R that will produce a phase shift of 45°

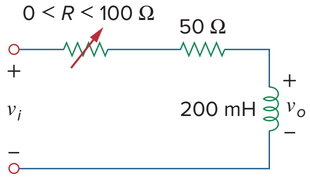


Figure 9.83
For Prob. 9.80.

9.81 The ac bridge in Fig. 9.37 is balanced when $R_1 = 400\ \Omega$, $R_2 = 600\ \Omega$, $R_3 = 1.2\ \text{k}\Omega$, and $C_2 = 0.3\ \mu\text{F}$. Find R_x and C_x. Assume R_2 and C_2 are in series.

9.82 A capacitance bridge balances when $R_1 = 100\ \Omega$, $R_2 = 2\ \text{k}\Omega$, and $C_s = 40\ \mu\text{F}$. What is C_x, the capacitance of the capacitor under test?

9.83 An inductive bridge balances when $R_1 = 1.2\ \text{k}\Omega$, $R_2 = 500\ \Omega$, and $L_s = 250$ mH. What is the value of L_x, the inductance of the inductor under test?

9.84 The ac bridge shown in Fig. 9.84 is known as a *Maxwell bridge* and is used for accurate measurement of inductance and resistance of a coil in terms of a standard capacitance C_s. Show that when the bridge is balanced,

$$L_x = R_2 R_3 C_s \qquad \text{and} \qquad R_x = \frac{R_2}{R_1} R_3$$

Find L_x and R_x for $R_1 = 40\text{ k}\Omega$, $R_2 = 1.6\text{ k}\Omega$, $R_3 = 4\text{ k}\Omega$, and $C_s = 0.45\ \mu\text{F}$.

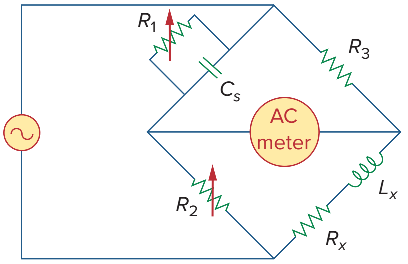


Figure 9.84
Maxwell bridge; For Prob. 9.84.

9.85 The ac bridge circuit of Fig. 9.85 is called a *Wien bridge*. It is used for measuring the frequency of a source. Show that when the bridge is balanced,

$$f = \frac{1}{2\pi\sqrt{R_2 R_4 C_2 C_4}}$$

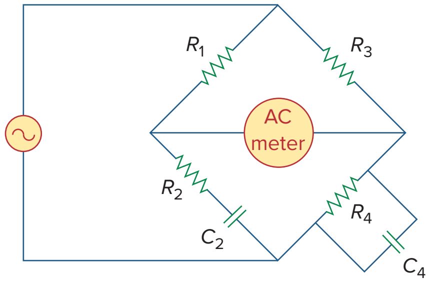


Figure 9.85
Wien bridge; For Prob. 9.85.

Comprehensive Problems

9.86 The circuit shown in Fig. 9.86 is used in a television receiver. What is the total impedance of this circuit?

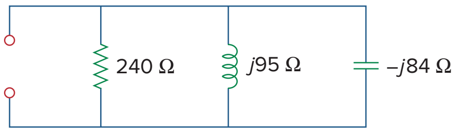


Figure 9.86
For Prob. 9.86.

9.87 The network in Fig. 9.87 is part of the schematic describing an industrial electronic sensing device. What is the total impedance of the circuit at 4 kHz?

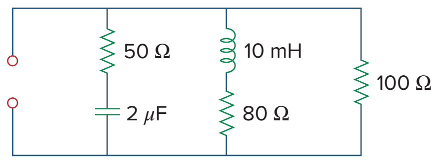


Figure 9.87
For Prob. 9.87.

9.88 A series audio circuit is shown in Fig. 9.88.

(a) What is the impedance of the circuit?

(b) If the frequency were halved, what would be the impedance of the circuit?

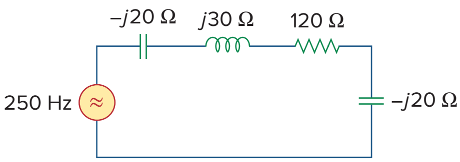


Figure 9.88
For Prob. 9.88.

9.89 An industrial load is modeled as a series combination of an inductor and a resistance as shown in Fig. 9.89. Calculate the value of a capacitor C across the series combination so that the net impedance is resistive at a frequency of 2 kHz.

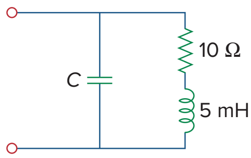


Figure 9.89
For Prob. 9.89.

9.90 An industrial coil is modeled as a series combination of an inductance L and resistance R, as shown in Fig. 9.90. Since an ac voltmeter measures only the magnitude of a sinusoid, the following measurements are taken at 60 Hz when the circuit operates in the steady state:

$$|\mathbf{V}_s| = 145 \text{ V}, \qquad |\mathbf{V}_1| = 50 \text{ V}, \qquad |\mathbf{V}_o| = 110 \text{ V}$$

Use these measurements to determine the values of L and R.

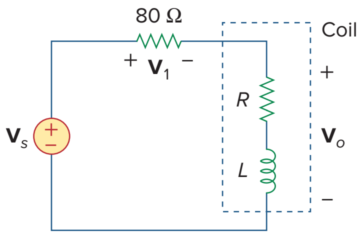


Figure 9.90
For Prob. 9.90.

9.91 Figure 9.91 shows a series combination of an inductance and a resistance. If it is desired to connect a capacitor in parallel with the series combination such that the net impedance is resistive at 10 kHz, what is the required value of C?

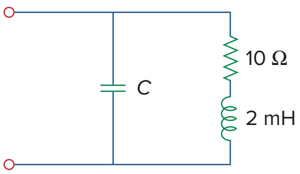


Figure 9.91
For Prob. 9.91.

9.92 A transmission line has a series impedance of $\mathbf{Z} = 100\underline{/75^\circ}\ \Omega$ and a shunt admittance of $\mathbf{Y} = 450\underline{/48^\circ}\ \mu\text{S}$. Find: (a) the characteristic impedance $\mathbf{Z}_o = \sqrt{\mathbf{Z}/\mathbf{Y}}$, (b) the propagation constant $\gamma = \sqrt{\mathbf{ZY}}$.

9.93 A power transmission system is modeled as shown in Fig. 9.92. Given the source voltage and circuit elements

$\mathbf{V}_s = 115\underline{/0^\circ}$ V,	source impedance
$\mathbf{Z}_s = (1 + j0.5)\ \Omega$,	line impedance
$\mathbf{Z}_\ell = (0.4 + j0.3)\ \Omega$,	and load impedance
$\mathbf{Z}_L = (23.2 + j18.9)\ \Omega$,	find the load current $\mathbf{I}_L$.

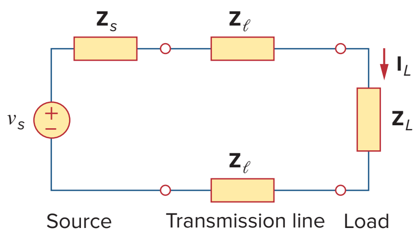


Figure 9.92
For Prob. 9.93.

Practice Problem 10.16

In the Wien-bridge oscillator circuit in Fig. 10.42, let $R_1 = R_2 = 2.5\ \text{k}\Omega$, $C_1 = C_2 = 1$ nF. Determine the frequency f_o of the oscillator.

Answer: 63.66 kHz.

10.10 Summary

1. We apply nodal and mesh analysis to ac circuits by applying KCL and KVL to the phasor form of the circuits.
2. In solving for the steady-state response of a circuit that has independent sources with different frequencies, each independent source *must* be considered separately. The most natural approach to analyzing such circuits is to apply the superposition theorem. A separate phasor circuit for each frequency *must* be solved independently, and the corresponding response should be obtained in the time domain. The overall response is the sum of the time domain responses of all the individual phasor circuits.
3. The concept of source transformation is also applicable in the frequency domain.
4. The Thevenin equivalent of an ac circuit consists of a voltage source $\mathbf{V}_{\text{Th}}$ in series with the Thevenin impedance $\mathbf{Z}_{\text{Th}}$.
5. The Norton equivalent of an ac circuit consists of a current source $\mathbf{I}_N$ in parallel with the Norton impedance $\mathbf{Z}_N (= \mathbf{Z}_{\text{Th}})$.
6. *PSpice* is a simple and powerful tool for solving ac circuit problems. It relieves us of the tedious task of working with the complex numbers involved in steady-state analysis.
7. The capacitance multiplier and the ac oscillator provide two typical applications for the concepts presented in this chapter. A capacitance multiplier is an op amp circuit used in producing a multiple of a physical capacitance. An oscillator is a device that uses a dc input to generate an ac output.

Review Questions

10.1 The voltage $\mathbf{V}_o$ across the capacitor in Fig. 10.43 is:

(a) $5\angle 0^\circ$ V (b) $7.071\angle 45^\circ$ V

(c) $7.071\angle -45^\circ$ V (d) $5\angle -45^\circ$ V

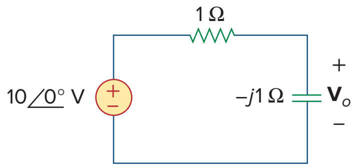


Figure 10.43
For Review Question 10.1.

10.2 The value of the current $\mathbf{I}_o$ in the circuit of Fig. 10.44 is:

(a) $4\angle 0^\circ$ A (b) $2.4\angle -90^\circ$ A

(c) $0.6\angle 0^\circ$ A (d) -1 A

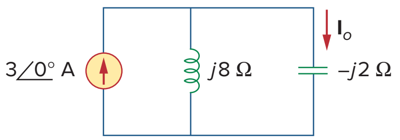


Figure 10.44
For Review Question 10.2.

10.3 Using nodal analysis, the value of $\mathbf{V}_o$ in the circuit of Fig. 10.45 is:

(a) −24 V (b) −8 V
(c) 8 V (d) 24 V

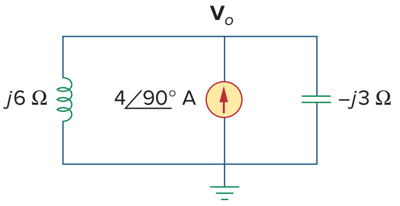


Figure 10.45
For Review Question 10.3.

10.4 In the circuit of Fig. 10.46, current $i(t)$ is:

(a) 10 cos t A (b) 10 sin t A (c) 5 cos t A
(d) 5 sin t A (e) 4.472 cos(t − 63.43°) A

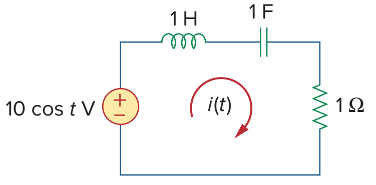


Figure 10.46
For Review Question 10.4.

10.5 Refer to the circuit in Fig. 10.47 and observe that the two sources do not have the same frequency. The current $i_x(t)$ can be obtained by:

(a) source transformation
(b) the superposition theorem
(c) *PSpice*

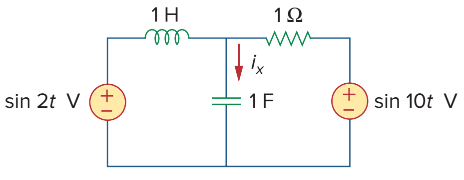


Figure 10.47
For Review Question 10.5.

10.6 For the circuit in Fig. 10.48, the Thevenin impedance at terminals *a-b* is:

(a) 1 Ω (b) 0.5 − j0.5 Ω
(c) 0.5 + j0.5 Ω (d) 1 + j2 Ω
(e) 1 − j2 Ω

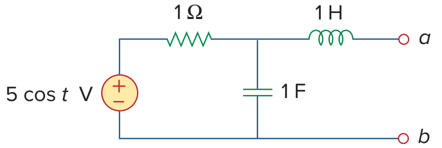


Figure 10.48
For Review Questions 10.6 and 10.7.

10.7 In the circuit of Fig. 10.48, the Thevenin voltage at terminals *a-b* is:

(a) $3.535\angle -45°$ V (b) $3.535\angle 45°$ V
(c) $7.071\angle -45°$ V (d) $7.071\angle 45°$ V

10.8 Refer to the circuit in Fig. 10.49. The Norton equivalent impedance at terminals *a-b* is:

(a) −j4 Ω (b) −j2 Ω
(c) j2 Ω (d) j4 Ω

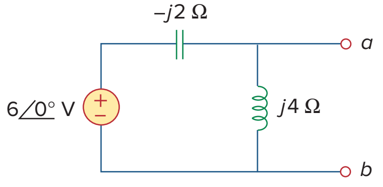


Figure 10.49
For Review Questions 10.8 and 10.9.

10.9 The Norton current at terminals *a-b* in the circuit of Fig. 10.49 is:

(a) $1\angle 0°$ A (b) $1.5\angle -90°$ A
(c) $1.5\angle 90°$ A (d) $3\angle 90°$ A

10.10 *PSpice* can handle a circuit with two independent sources of different frequencies.

(a) True (b) False

Answers: 10.1c, 10.2a, 10.3d, 10.4a, 10.5b, 10.6c, 10.7a, 10.8a, 10.9d, 10.10b.

Problems

Section 10.2 Nodal Analysis

10.1 Determine i in the circuit of Fig. 10.50.

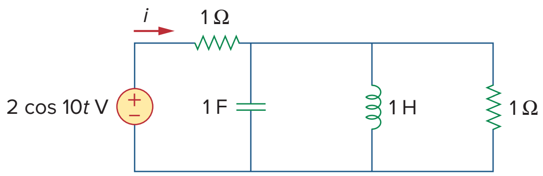


Figure 10.50
For Prob. 10.1.

10.2 Using Fig. 10.51, design a problem to help other students better understand nodal analysis.

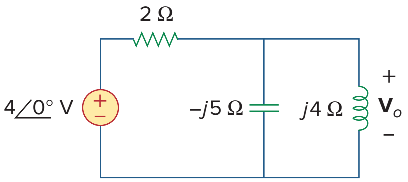


Figure 10.51
For Prob. 10.2.

10.3 Determine v_o in the circuit of Fig. 10.52.

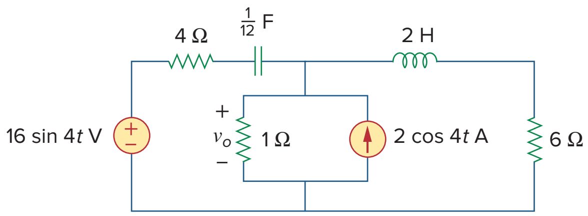


Figure 10.52
For Prob. 10.3.

10.4 Compute $v_o(t)$ in the circuit of Fig. 10.53.

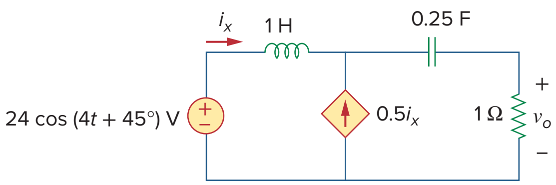


Figure 10.53
For Prob. 10.4.

10.5 Find i_o in the circuit of Fig. 10.54.

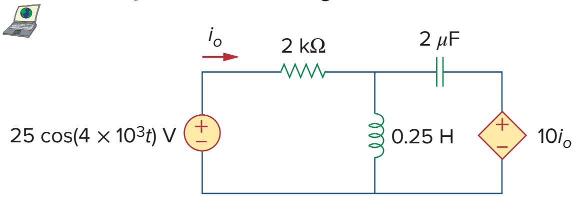


Figure 10.54
For Prob. 10.5.

10.6 Determine $\mathbf{V}_x$ in Fig. 10.55.

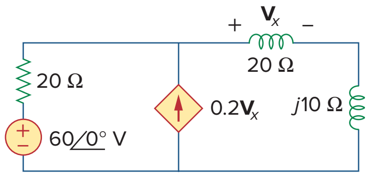


Figure 10.55
For Prob. 10.6.

10.7 Use nodal analysis to find $\mathbf{V}$ in the circuit of Fig. 10.56.

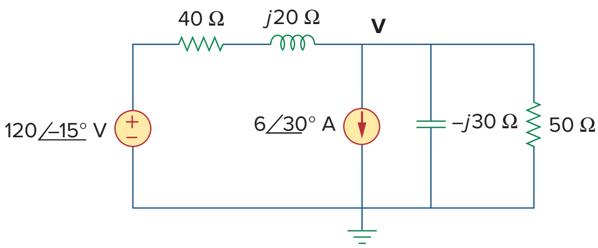


Figure 10.56
For Prob. 10.7.

10.8 Use nodal analysis to find current i_o in the circuit of Fig. 10.57. Let $i_s = 6\cos(200t + 15°)$ A.

ML

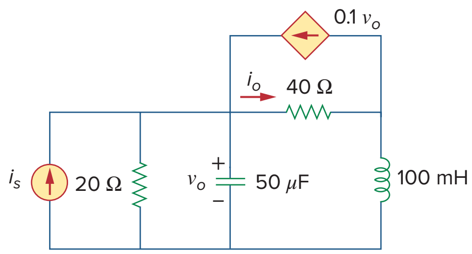


Figure 10.57
For Prob. 10.8.

10.9 Use nodal analysis to find v_o in the circuit of Fig. 10.58.

ML

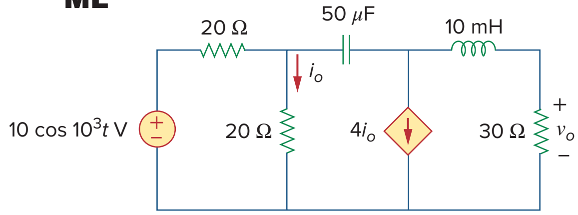


Figure 10.58
For Prob. 10.9.

10.10 Use nodal analysis to find v_o in the circuit of Fig. 10.59. Let $\omega = 2$ krad/s.

ML

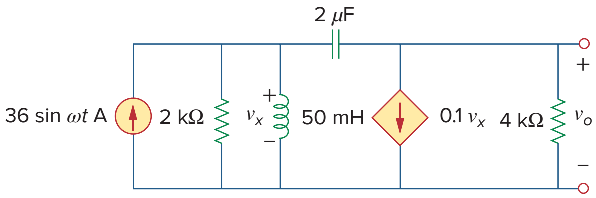


Figure 10.59
For Prob. 10.10.

10.11 Using nodal analysis, find $i_o(t)$ in the circuit in Fig. 10.60.

ML

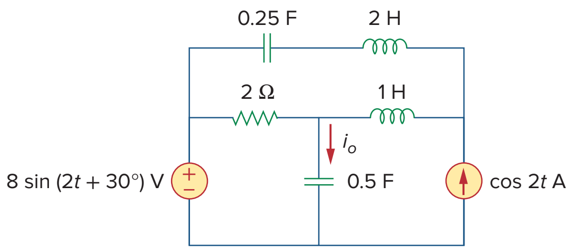


Figure 10.60
For Prob. 10.11.

10.12 Using Fig. 10.61, design a problem to help other students better understand nodal analysis.

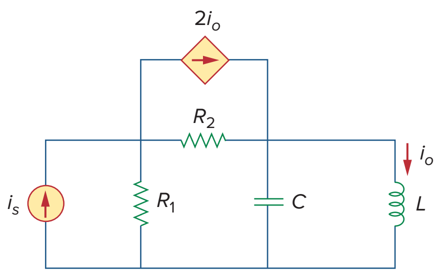


Figure 10.61
For Prob. 10.12.

10.13 Determine $\mathbf{V}_x$ in the circuit of Fig. 10.62 using any method of your choice.

ML

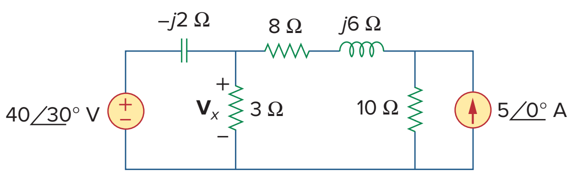


Figure 10.62
For Prob. 10.13.

10.14 Calculate the voltage at nodes 1 and 2 in the circuit of Fig. 10.63 using nodal analysis.

ML

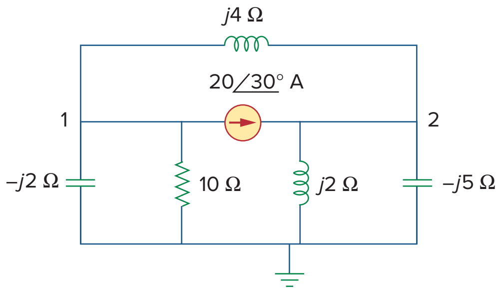


Figure 10.63
For Prob. 10.14.

10.15 Solve for the current **I** in the circuit of Fig. 10.64 using nodal analysis.

ML

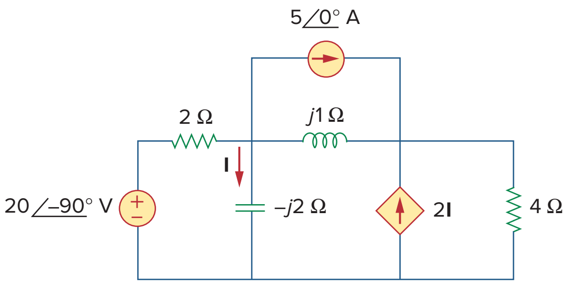


Figure 10.64
For Prob. 10.15.

10.16 Use nodal analysis to find $\mathbf{V}_x$ in the circuit shown in Fig. 10.65.

ML

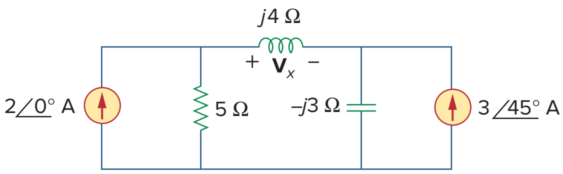


Figure 10.65
For Prob. 10.16.

10.17 By nodal analysis, obtain current $\mathbf{I}_o$ in the circuit of Fig. 10.66.

ML

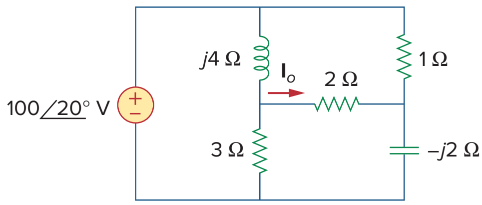


Figure 10.66
For Prob. 10.17.

10.18 Use nodal analysis to obtain $\mathbf{V}_o$ in the circuit of Fig. 10.67 below.

ML

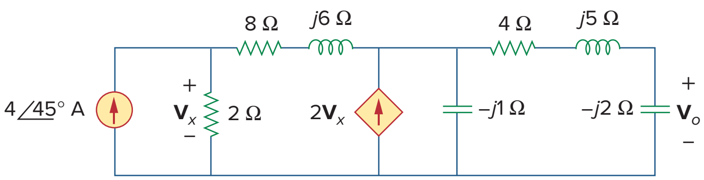


Figure 10.67
For Prob. 10.18.

10.19 Obtain $\mathbf{V}_o$ in Fig. 10.68 using nodal analysis.

ML

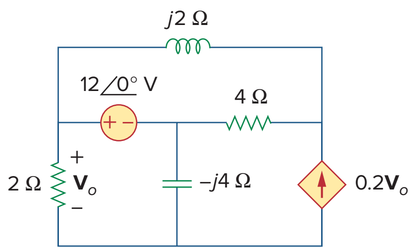


Figure 10.68
For Prob. 10.19.

10.20 Refer to Fig. 10.69. If $v_s(t) = V_m \sin \omega t$ and $v_o(t) = A \sin(\omega t + \phi)$, derive the expressions for A and ϕ.

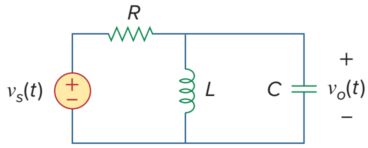


Figure 10.69
For Prob. 10.20.

10.21 For each of the circuits in Fig. 10.70, find $\mathbf{V}_o/\mathbf{V}_i$ for $\omega = 0$, $\omega \to \infty$, and $\omega^2 = 1/LC$.

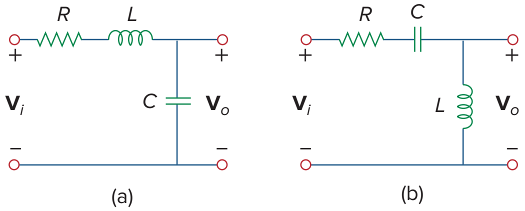


Figure 10.70
For Prob. 10.21.

10.22 For the circuit in Fig. 10.71, determine $\mathbf{V}_o/\mathbf{V}_s$.

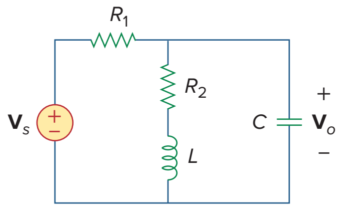


Figure 10.71
For Prob. 10.22.

10.23 Using nodal analysis obtain $\mathbf{V}$ in the circuit of Fig. 10.72.

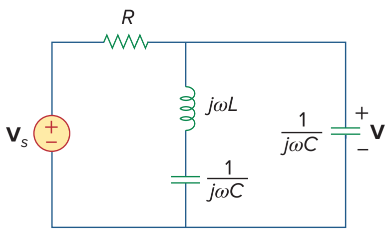


Figure 10.72
For Prob. 10.23.

Section 10.3 Mesh Analysis

10.24 Design a problem to help other students better understand mesh analysis.

10.25 Solve for i_o in Fig. 10.73 using mesh analysis.

ML

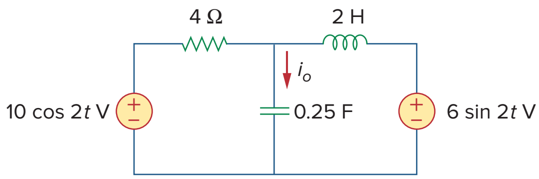


Figure 10.73
For Prob. 10.25.

10.26 Use mesh analysis to find current i_o in the circuit of Fig. 10.74.

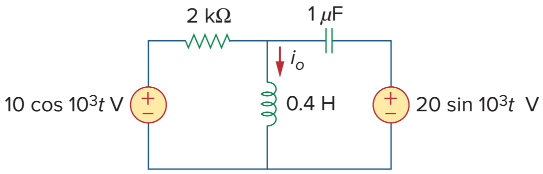


Figure 10.74
For Prob. 10.26.

10.27 Using mesh analysis, find $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 10.75.

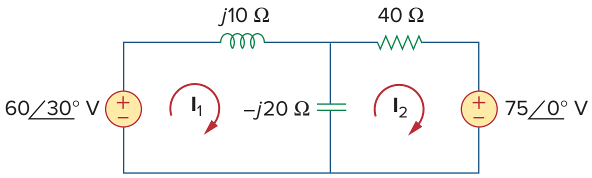


Figure 10.75
For Prob. 10.27.

10.28 In the circuit of Fig. 10.76, determine the mesh currents i_1 and i_2. Let $v_1 = 10 \cos 4t$ V and $v_2 = 20 \cos(4t - 30°)$ V.

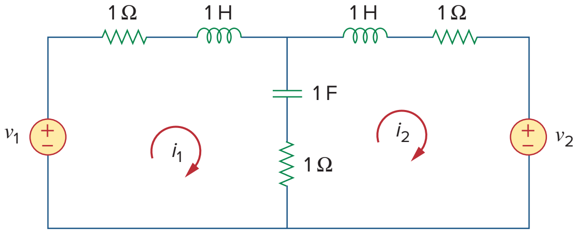


Figure 10.76
For Prob. 10.28.

10.29 Using Fig. 10.77, design a problem to help other students better understand mesh analysis.

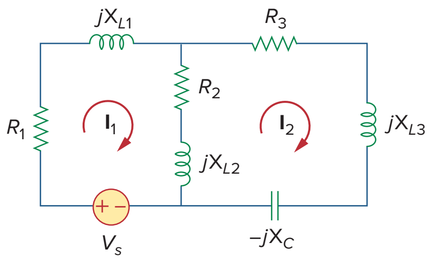


Figure 10.77
For Prob. 10.29.

10.30 Use mesh analysis to find v_o in the circuit of Fig. 10.78. Let $v_{s1} = 120 \cos(100t + 90°)$ V, $v_{s2} = 80 \cos 100t$ V.

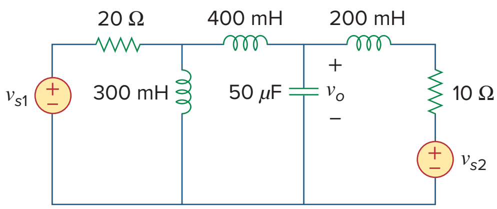


Figure 10.78
For Prob. 10.30.

10.31 Use mesh analysis to determine current $\mathbf{I}_o$ in the circuit of Fig. 10.79 below.

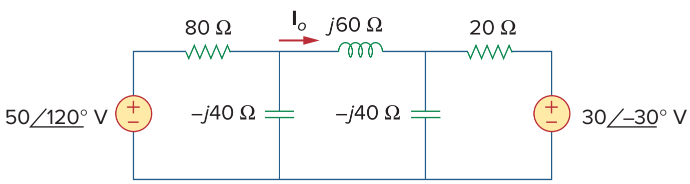


Figure 10.79
For Prob. 10.31.

10.32 Determine $\mathbf{V}_o$ and $\mathbf{I}_o$ in the circuit of Fig. 10.80 using mesh analysis.

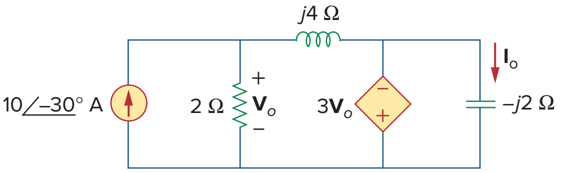


Figure 10.80
For Prob. 10.32.

10.33 Compute **I** in Prob. 10.15 using mesh analysis.

10.34 Use mesh analysis to find $\mathbf{I}_o$ in Fig. 10.28 (for Example 10.10).

10.35 Calculate $\mathbf{I}_o$ in Fig. 10.30 (for Practice Prob. 10.10) using mesh analysis.

10.36 Compute $\mathbf{V}_o$ in the circuit of Fig. 10.81 using mesh analysis.

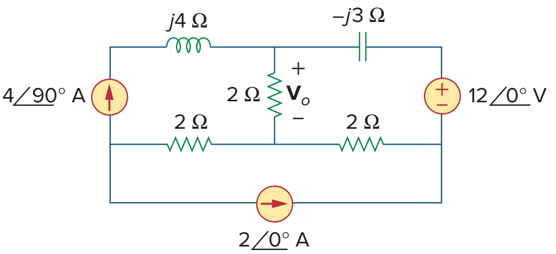


Figure 10.81
For Prob. 10.36.

10.37 Use mesh analysis to find currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 10.82.

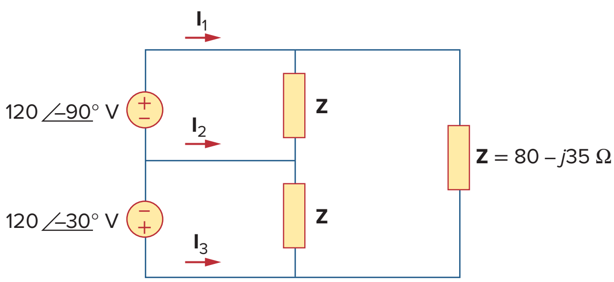


Figure 10.82
For Prob. 10.37.

10.38 Using mesh analysis, obtain $\mathbf{I}_o$ in the circuit shown in Fig. 10.83.

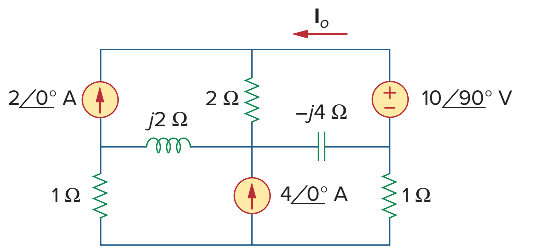


Figure 10.83
For Prob. 10.38.

10.39 Find $\mathbf{I}_1$, $\mathbf{I}_2$, $\mathbf{I}_3$, and $\mathbf{I}_x$ in the circuit of Fig. 10.84.

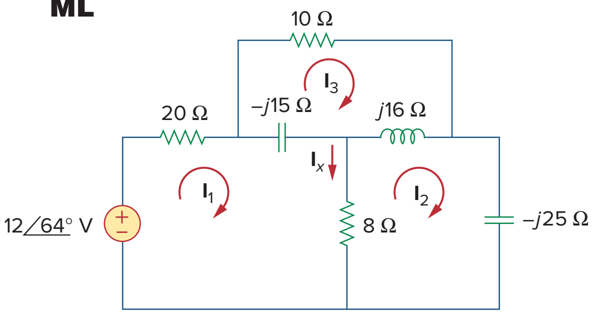


Figure 10.84
For Prob. 10.39.

Section 10.4 Superposition Theorem

10.40 Find i_o in the circuit shown in Fig. 10.85 using superposition.

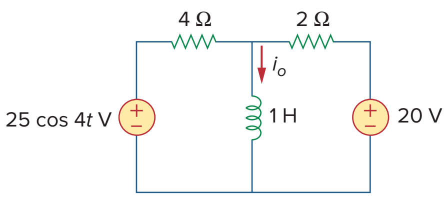


Figure 10.85
For Prob. 10.40.

10.41 Find v_o for the circuit in Fig. 10.86, assuming that $i_s(t) = 2 \sin (2t) + 3 \cos (4t)$ A.

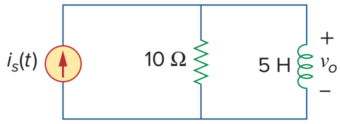


Figure 10.86
For Prob. 10.41.

10.42 Using Fig. 10.87, design a problem to help other students better understand the superposition theorem.

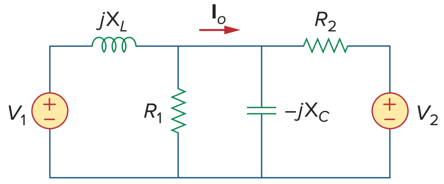


Figure 10.87
For Prob. 10.42.

10.43 Using the superposition principle, find i_x in the circuit of Fig. 10.88.

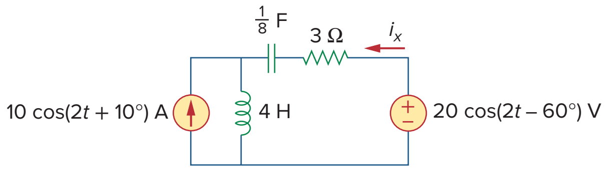


Figure 10.88
For Prob. 10.43.

10.44 Use the superposition principle to obtain v_x in the circuit of Fig. 10.89. Let $v_s = 50 \sin 2t$ V and $i_s = 12 \cos(6t + 10°)$ A.

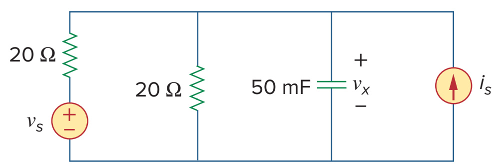


Figure 10.89
For Prob. 10.44.

10.45 Use superposition to find $i(t)$ in the circuit of Fig. 10.90.

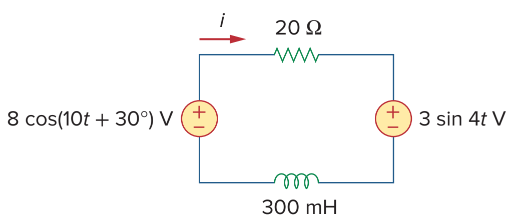


Figure 10.90
For Prob. 10.45.

10.46 Solve for $v_o(t)$ in the circuit of Fig. 10.91 using the superposition principle.

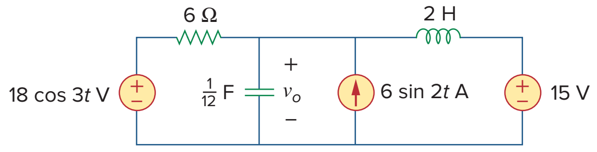


Figure 10.91
For Prob. 10.46.

10.47 Determine i_o in the circuit of Fig. 10.92, using the superposition principle.

ML

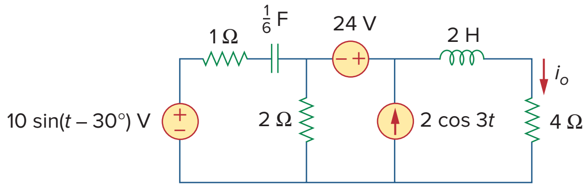


Figure 10.92
For Prob. 10.47.

10.48 Find i_o in the circuit of Fig. 10.93 using superposition.

ML

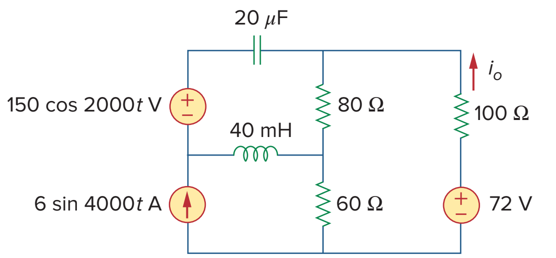


Figure 10.93
For Prob. 10.48.

Section 10.5 Source Transformation

10.49 Using source transformation, find i in the circuit of Fig. 10.94.

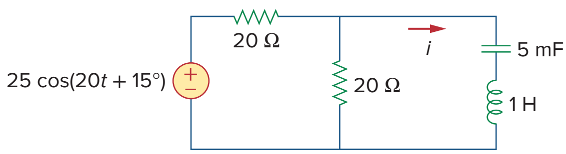


Figure 10.94
For Prob. 10.49.

10.50 Using Fig. 10.95, design a problem to help other students understand source transformation.

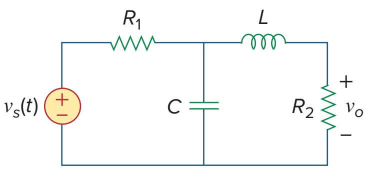


Figure 10.95
For Prob. 10.50.

10.51 Use source transformation to find $\mathbf{I}_o$ in the circuit of Prob. 10.42.

10.52 Use the method of source transformation to find $\mathbf{I}_x$ in the circuit of Fig. 10.96.

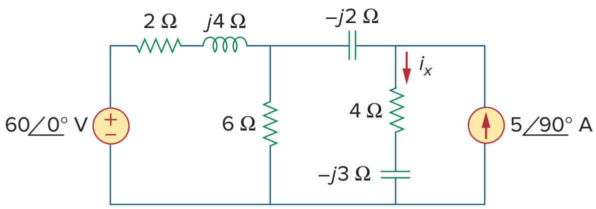


Figure 10.96
For Prob. 10.52.

10.53 Use the concept of source transformation to find $\mathbf{V}_o$ in the circuit of Fig. 10.97.

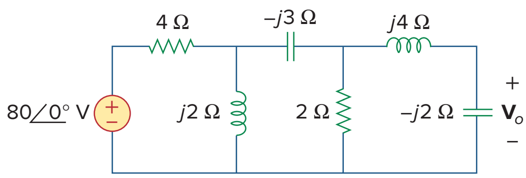
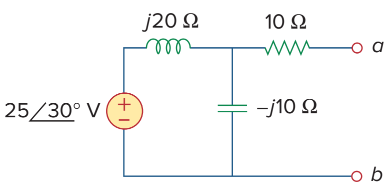


Figure 10.97
For Prob. 10.53.

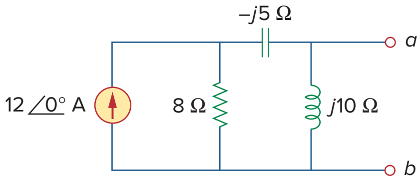
10.54 Rework Prob. 10.7 using source transformation.

Section 10.6 Thevenin and Norton Equivalent Circuits

10.55 Find the Thevenin and Norton equivalent circuits at terminals *a-b* for each of the circuits in Fig. 10.98.



(a)



(b)

Figure 10.98
For Prob. 10.55.

10.56 For each of the circuits in Fig. 10.99, obtain Thevenin and Norton equivalent circuits at terminals *a-b*.

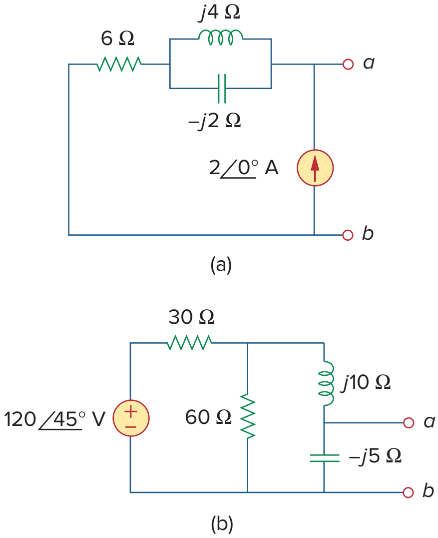


Figure 10.99
For Prob. 10.56.

10.57 Using Fig. 10.100, design a problem to help other students better understand Thevenin and Norton equivalent circuits.

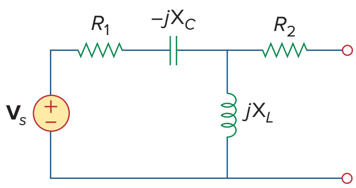


Figure 10.100
For Prob. 10.57.

10.58 For the circuit depicted in Fig. 10.101, find the Thevenin equivalent circuit at terminals *a-b*.

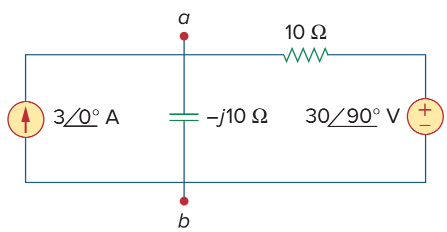


Figure 10.101
For Prob. 10.58.

10.59 Calculate the output impedance of the circuit shown in Fig. 10.102.

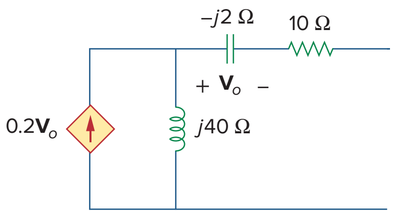


Figure 10.102
For Prob. 10.59.

10.60 Find the Thevenin equivalent of the circuit in Fig. 10.103 as seen from:

(a) terminals *a-b* (b) terminals *c-d*

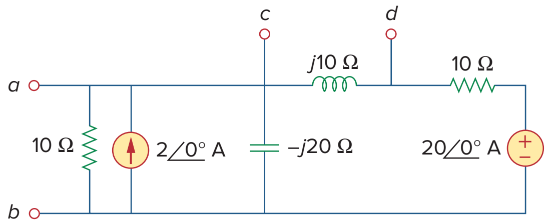


Figure 10.103
For Prob. 10.60.

10.61 Find the Thevenin equivalent at terminals *a-b* of the circuit in Fig. 10.104.

ML

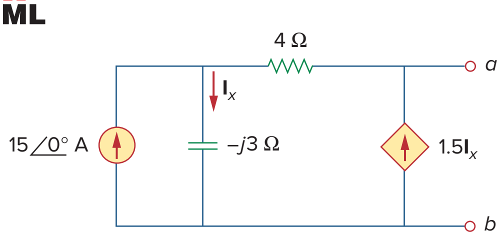


Figure 10.104
For Prob. 10.61.

10.62 Using Thevenin's theorem, find v_o in the circuit of Fig. 10.105.

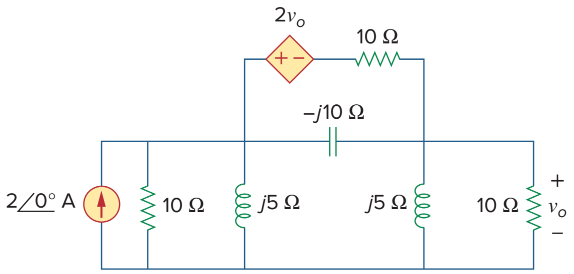


Figure 10.105
For Prob. 10.62.

10.63 Obtain the Norton equivalent of the circuit depicted in Fig. 10.106 at terminals *a-b*.

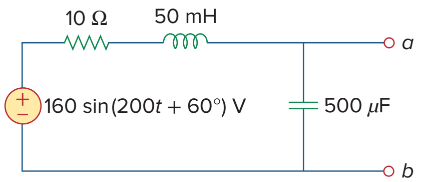


Figure 10.106
For Prob. 10.63.

10.64 For the circuit shown in Fig. 10.107, find the Norton equivalent circuit at terminals *a-b*.

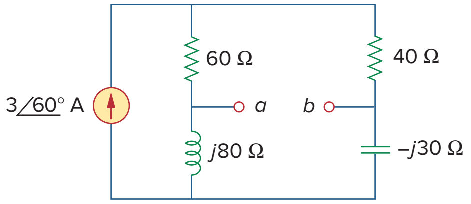


Figure 10.107
For Prob. 10.64.

10.65 Using Fig. 10.108, design a problem to help other students better understand Norton's theorem.

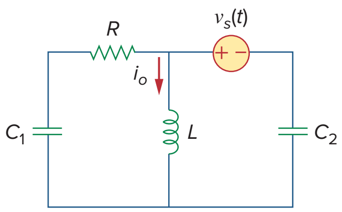


Figure 10.108
For Prob. 10.65.

10.66 At terminals *a-b*, obtain Thevenin and Norton equivalent circuits for the network depicted in Fig. 10.109. Take $\omega = 10$ rad/s.

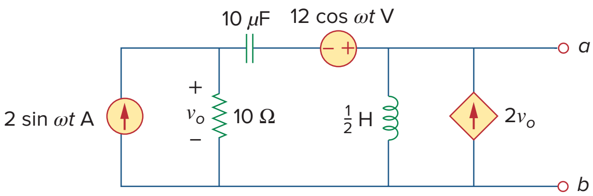


Figure 10.109
For Prob. 10.66.

10.67 Find the Thevenin and Norton equivalent circuits at terminals *a-b* in the circuit of Fig. 10.110.

ML

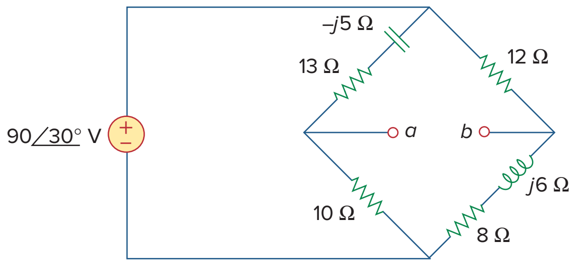


Figure 10.110
For Prob. 10.67.

10.68 Find the Thevenin equivalent at terminals *a-b* in the circuit of Fig. 10.111.

ML

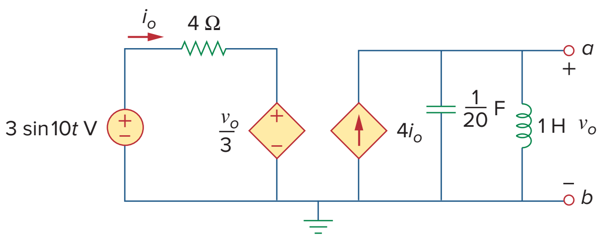


Figure 10.111
For Prob. 10.68.

Section 10.7 Op Amp AC Circuits

10.69 For the integrator shown in Fig. 10.112, obtain $\mathbf{V}_o/\mathbf{V}_s$. Find $v_o(t)$ when $v_s(t) = \mathbf{V}_m \sin \omega t$ and $\omega = 1/RC$.

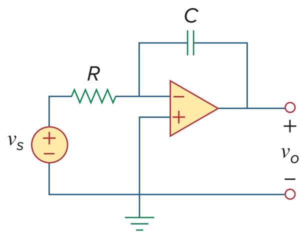


Figure 10.112
For Prob. 10.69.

10.70 Using Fig. 10.113, design a problem to help other students better understand op amps in AC circuits.

e2d

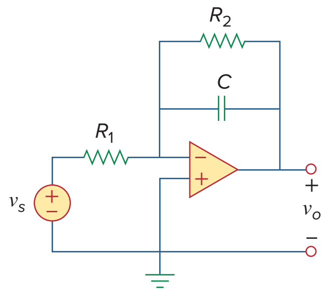


Figure 10.113
For Prob. 10.70.

10.71 Find v_o in the op amp circuit of Fig. 10.114.

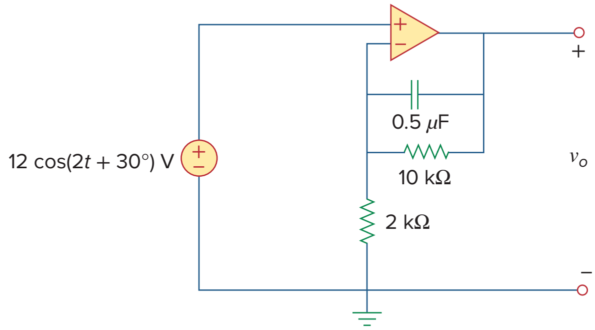


Figure 10.114
For Prob. 10.71.

10.72 Compute $i_o(t)$ in the op amp circuit in Fig. 10.115 if $v_s = 4\cos(10^4 t)$ V.

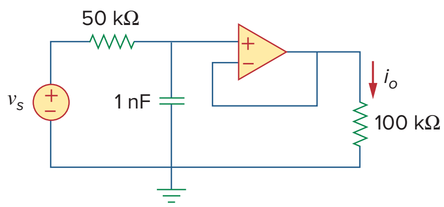


Figure 10.115
For Prob. 10.72.

10.73 If the input impedance is defined as $\mathbf{Z}_{\text{in}} = \mathbf{V}_s/\mathbf{I}_s$, find the input impedance of the op amp circuit in Fig. 10.116 when $R_1 = 10\ \text{k}\Omega$, $R_2 = 20\ \text{k}\Omega$, $C_1 = 10$ nF, $C_2 = 20$ nF, and $\omega = 5000$ rad/s.

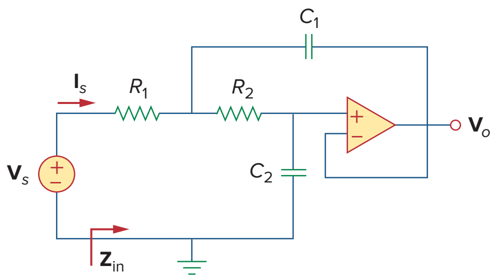


Figure 10.116
For Prob. 10.73.

10.74 Evaluate the voltage gain $\mathbf{A}_v = \mathbf{V}_o/\mathbf{V}_s$ in the op amp circuit of Fig. 10.117. Find $\mathbf{A}_v$ at $\omega = 0$, $\omega \to \infty$, $\omega = 1/R_1C_1$, and $\omega = 1/R_2C_2$.

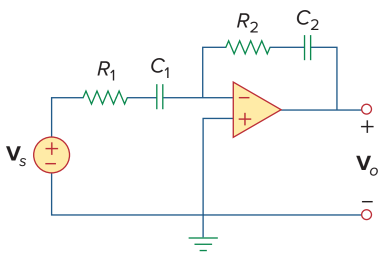


Figure 10.117
For Prob. 10.74.

10.75 In the op amp circuit of Fig. 10.118, find the closed-loop gain and phase shift of the output voltage with respect to the input voltage if $C_1 = C_2 = 1$ nF, $R_1 = R_2 = 100$ kΩ, $R_3 = 20$ kΩ, $R_4 = 40$ kΩ, and $\omega = 2000$ rad/s.

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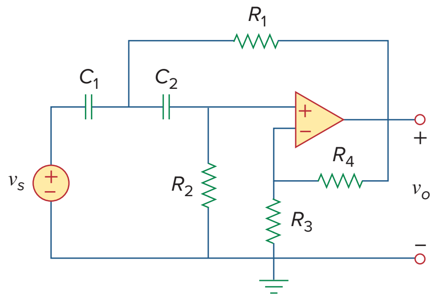

Figure 10.118
For Prob. 10.75.

10.76 Determine $\mathbf{V}_o$ and $\mathbf{I}_o$ in the op amp circuit of Fig. 10.119.

ML

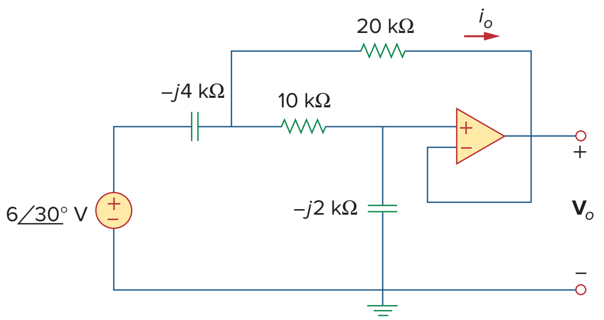

Figure 10.119
For Prob. 10.76.

10.77 Compute the closed-loop gain $\mathbf{V}_o/\mathbf{V}_s$ for the op amp circuit of Fig. 10.120.

ML

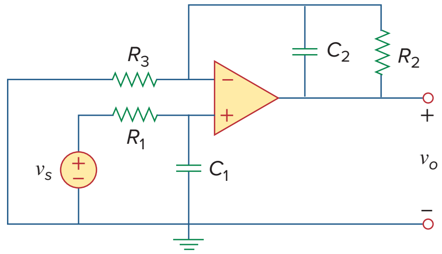

Figure 10.120
For Prob. 10.77.

10.78 Determine $v_o(t)$ in the op amp circuit in Fig. 10.121 below.

ML

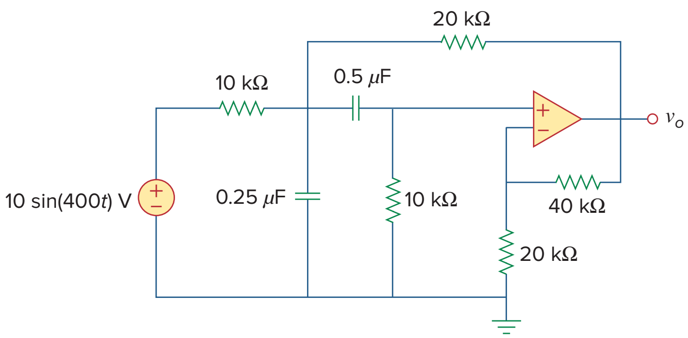

Figure 10.121
For Prob. 10.78.

10.79 For the op amp circuit in Fig. 10.122, obtain $\mathbf{V}_o$.

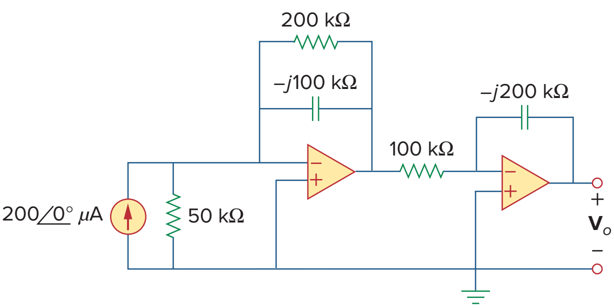

Figure 10.122
For Prob. 10.79.

10.80 Obtain $v_o(t)$ for the op amp circuit in Fig. 10.123 if $v_s = 12\cos(1000t - 60°)$ V.

ML

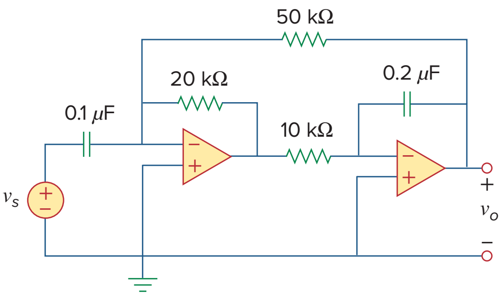

Figure 10.123
For Prob. 10.80.

Section 10.8 AC Analysis Using *PSpice*

10.81 Use *PSpice or MultiSim* to determine $\mathbf{V}_o$ in the circuit of Fig. 10.124. Assume $\omega = 1$ rad/s.

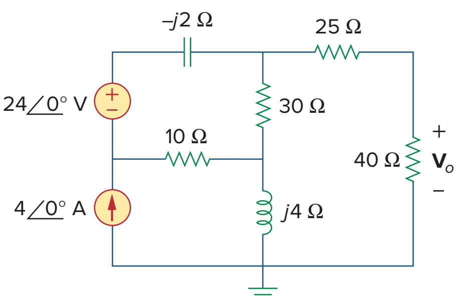

Figure 10.124
For Prob. 10.81.

10.82 Solve Prob. 10.19 using *PSpice or MultiSim*.

10.83 Use *PSpice or MultiSim* to find $v_o(t)$ in the circuit of Fig. 10.125. Let $i_s = 2\cos(10^3 t)$ A.

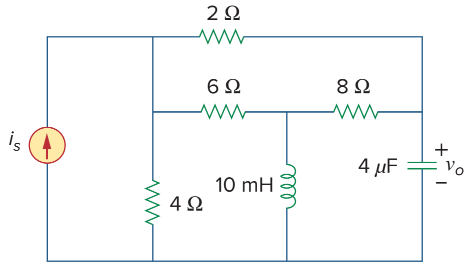

Figure 10.125
For Prob. 10.83.

10.84 Obtain $\mathbf{V}_o$ in the circuit of Fig. 10.126 using *PSpice or MultiSim*.

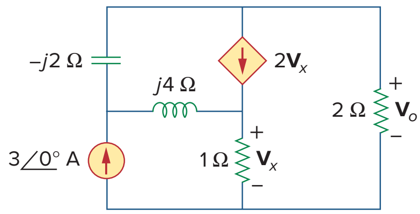

Figure 10.126
For Prob. 10.84.

10.85 Using Fig. 10.127, design a problem to help other students better understand performing AC analysis with *PSpice or MultiSim*.

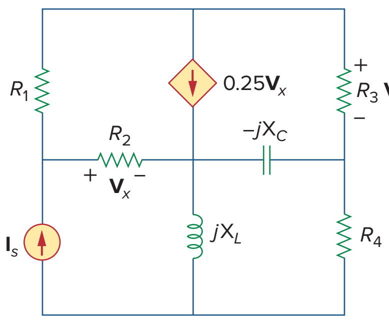

Figure 10.127
For Prob. 10.85.

10.86 Use *PSpice or MultiSim* to find $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_3$ in the network of Fig. 10.128.

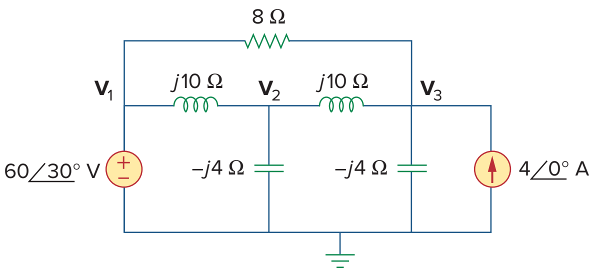

Figure 10.128
For Prob. 10.86.

10.87 Determine $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_3$ in the circuit of Fig. 10.129 using *PSpice or MultiSim*.

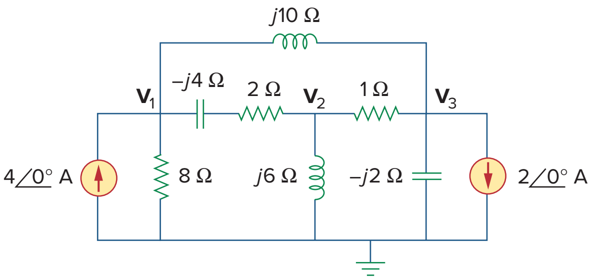

Figure 10.129
For Prob. 10.87.

10.88 Use *PSpice or MultiSim* to find v_o and i_o in the circuit of Fig. 10.130 below.

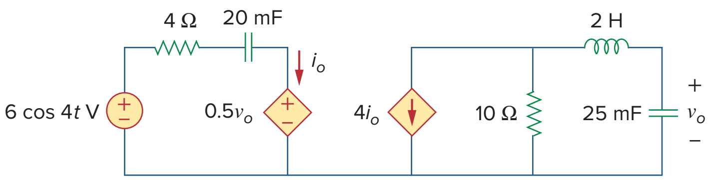

Figure 10.130
For Prob. 10.88.

10.90 Figure 10.132 shows a Wien-bridge network. Show that the frequency at which the phase shift between the input and output signals is zero is $f = \frac{1}{2\pi} RC$, and that the necessary gain is $\mathbf{A}_v = \mathbf{V}_o/\mathbf{V}_i = 3$ at that frequency.

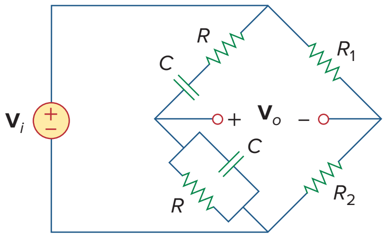

Figure 10.132
For Prob. 10.90.

Section 10.9 Applications

10.89 The op amp circuit in Fig. 10.131 is called an *inductance simulator*. Show that the input impedance is given by

$$\mathbf{Z}_{in} = \frac{\mathbf{V}_{in}}{\mathbf{I}_{in}} = j\omega L_{eq}$$

where

$$L_{eq} = \frac{R_1 R_3 R_4}{R_2 C}$$

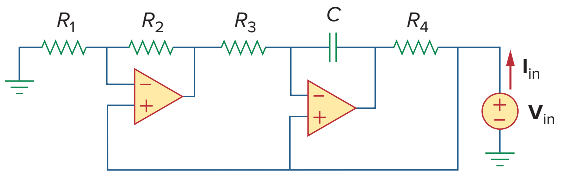

Figure 10.131
For Prob. 10.89.

10.91 Consider the oscillator in Fig. 10.133.

(a) Determine the oscillation frequency.
(b) Obtain the minimum value of R for which oscillation takes place.

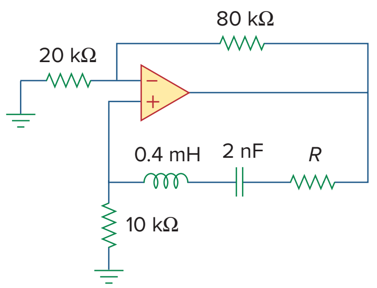

Figure 10.133
For Prob. 10.91.

10.92 The oscillator circuit in Fig. 10.134 uses an ideal op amp.

(a) Calculate the minimum value of R_o that will cause oscillation to occur.

(b) Find the frequency of oscillation.

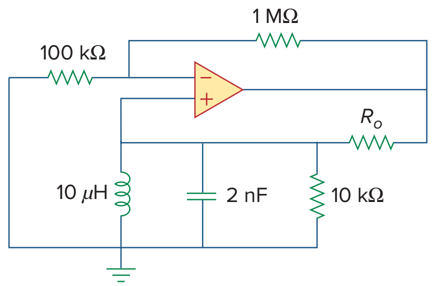

Figure 10.134
For Prob. 10.92.

10.93 Figure 10.135 shows a *Colpitts oscillator*. Show that the oscillation frequency is

$$f_o = \frac{1}{2\pi\sqrt{LC_T}}$$

where $C_T = C_1C_2/(C_1 + C_2)$. Assume $R_i \gg X_{C_2}$.

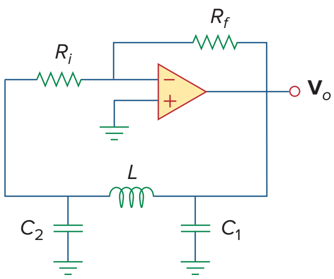

Figure 10.135
A Colpitts oscillator; for Prob. 10.93.

(*Hint:* Set the imaginary part of the impedance in the feedback circuit equal to zero.)

10.94 Design a Colpitts oscillator that will operate at 50 kHz.

10.95 Figure 10.136 shows a *Hartley oscillator*. Show that the frequency of oscillation is

$$f_o = \frac{1}{2\pi\sqrt{C(L_1 + L_2)}}$$

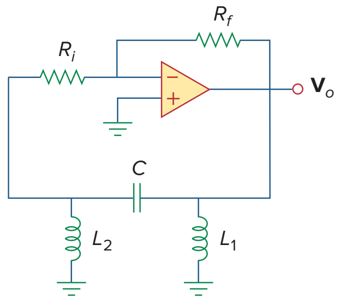

Figure 10.136
A Hartley oscillator; for Prob. 10.95.

10.96 Refer to the oscillator in Fig. 10.137.

(a) Show that

$$\frac{\mathbf{V}_2}{\mathbf{V}_o} = \frac{1}{3 + j(\omega L/R - R/\omega L)}$$

(b) Determine the oscillation frequency f_o.

(c) Obtain the relationship between R_1 and R_2 in order for oscillation to occur.

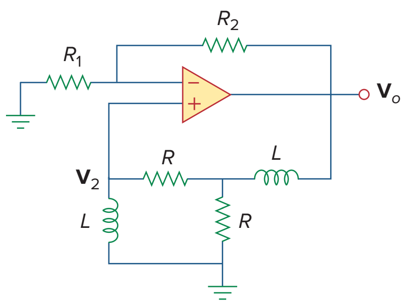

Figure 10.137
For Prob. 10.96.

Review Questions

11.1 The average power absorbed by an inductor is zero.

(a) True (b) False

11.2 The Thevenin impedance of a network seen from the load terminals is $80 + j55\ \Omega$. For maximum power transfer, the load impedance must be:

(a) $-80 + j55\ \Omega$ (b) $-80 - j55\ \Omega$
(c) $80 - j55\ \Omega$ (d) $80 + j55\ \Omega$

11.3 The amplitude of the voltage available in the 60-Hz, 120-V power outlet in your home is:

(a) 110 V (b) 120 V
(c) 170 V (d) 210 V

11.4 If the load impedance is $20 - j20$, the power factor is

(a) $\angle -45^\circ$ (b) 0 (c) 1
(d) 0.7071 (e) none of these

11.5 A quantity that contains all the power information in a given load is the

(a) power factor (b) apparent power
(c) average power (d) reactive power
(e) complex power

11.6 Reactive power is measured in:

(a) watts (b) VA
(c) VAR (d) none of these

11.7 In the power triangle shown in Fig. 11.34(a), the reactive power is:

(a) 1000 VAR leading (b) 1000 VAR lagging
(c) 866 VAR leading (d) 866 VAR lagging

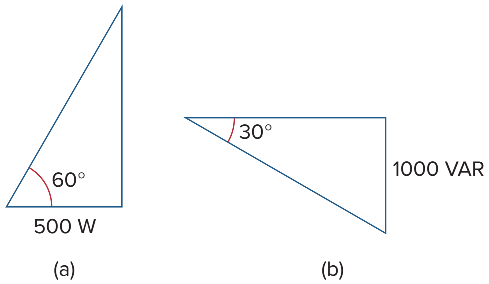

Figure 11.34
For Review Questions 11.7 and 11.8.

11.8 For the power triangle in Fig. 11.34(b), the apparent power is:

(a) 2000 VA (b) 1000 VAR
(c) 866 VAR (d) 500 VAR

11.9 A source is connected to three loads $\mathbf{Z}_1$, $\mathbf{Z}_2$, and $\mathbf{Z}_3$ in parallel. Which of these is not true?

(a) $P = P_1 + P_2 + P_3$ (b) $Q = Q_1 + Q_2 + Q_3$
(c) $S = S_1 + S_2 + S_3$ (d) $\mathbf{S} = \mathbf{S}_1 + \mathbf{S}_2 + \mathbf{S}_3$

11.10 The instrument for measuring average power is the:

(a) voltmeter (b) ammeter
(c) wattmeter (d) varmeter
(e) kilowatt-hour meter

Answers: 11.1a, 11.2c, 11.3c, 11.4d, 11.5e, 11.6c, 11.7d, 11.8a, 11.9c, 11.10c.

Problems[1]

Section 11.2 Instantaneous and Average Power

11.1 If $v(t) = 160 \cos 50t$ V and $i(t) = -33 \sin (50t - 30^\circ)$A, calculate the instantaneous power and the average power.

11.2 Given the circuit in Fig. 11.35, find the average power supplied or absorbed by each element.

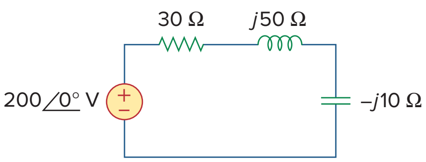

Figure 11.35
For Prob. 11.2.

11.3 A load consists of a 60-Ω resistor in parallel with a 90-μF capacitor. If the load is connected to a voltage source $v_s(t) = 160 \cos 2000t$, find the average power delivered to the load.

11.4 Using Fig. 11.36, design a problem to help other students better understand instantaneous and average power.

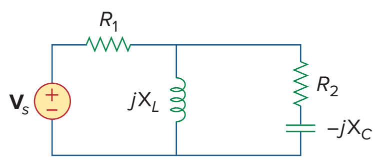

Figure 11.36
For Prob. 11.4.

[1] Starting with problem 11.22, unless otherwise specified, assume that all values of currents and voltages are rms.

11.5 ssuming that $v_s = 8\cos(2t - 40°)$ V in the circuit of Fig. 11.37, find the average power delivered to each of the passive elements.

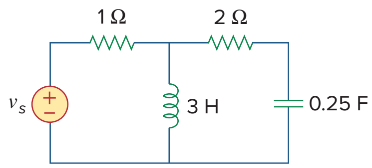

Figure 11.37
For Prob. 11.5.

11.6 For the circuit in Fig. 11.38, $i_s = 6\cos 10^3 t$ A. Find the average power absorbed by the 50-Ω resistor.

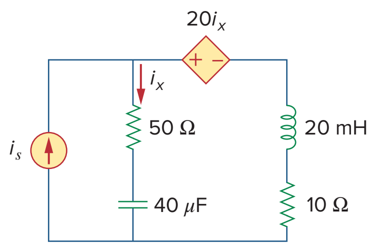

Figure 11.38
For Prob. 11.6.

11.7 Given the circuit of Fig. 11.39, find the average power absorbed by the 10-Ω resistor.

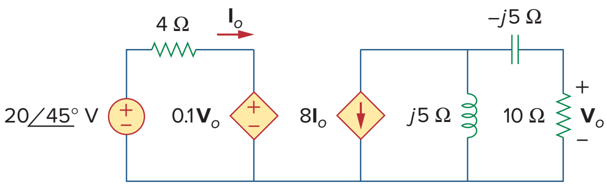

Figure 11.39
For Prob. 11.7.

11.8 In the circuit of Fig. 11.40, determine the average power absorbed by the 40-Ω resistor.

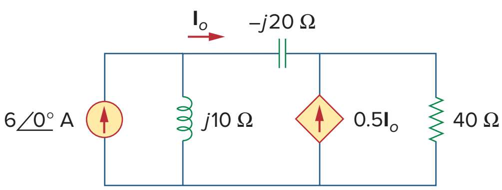

Figure 11.40
For Prob. 11.8.

11.9 For the op amp circuit in Fig. 11.41, $\mathbf{V}_s = 2\angle 30°$ V. Find the average power absorbed by the 20-kΩ resistor.

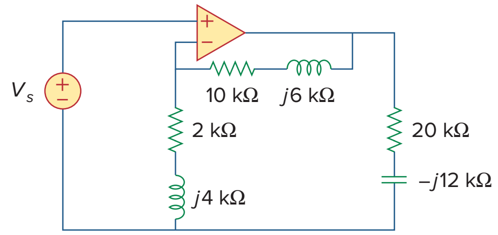

Figure 11.41
For Prob. 11.9.

11.10 In the op amp circuit in Fig. 11.42, find the total average power absorbed by the resistors.

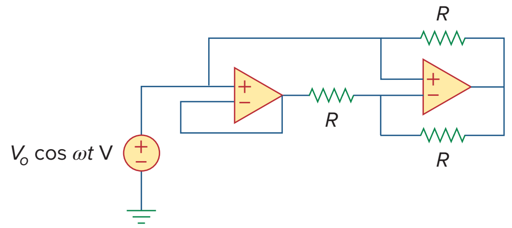

Figure 11.42
For Prob. 11.10.

11.11 For the network in Fig. 11.43, assume that the port impedance is

$$\mathbf{Z}_{ab} = \frac{R}{\sqrt{1 + \omega^2 R^2 C^2}} \angle -\tan^{-1}\omega RC$$

Find the average power consumed by the network when $R = 10$ kΩ, $C = 200$ nF, and $i = 33\sin(377t + 22°)$ mA.

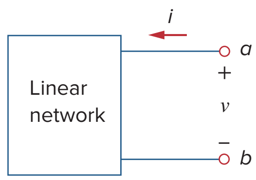

Figure 11.43
For Prob. 11.11.

Section 11.3 Maximum Average Power Transfer

11.12 For the circuit shown in Fig. 11.44, determine the load impedance $\mathbf{Z}_L$ for maximum power transfer (to $\mathbf{Z}_L$). Calculate the maximum power absorbed by the load.

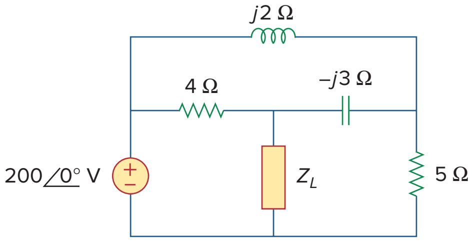

Figure 11.44
For Prob. 11.12.

11.13 The Thevenin impedance of a source is $\mathbf{Z}_{Th} = 120 + j60\ \Omega$, while the peak Thevenin voltage is $\mathbf{V}_{Th} = 165 + j0$ V. Determine the maximum available average power from the source.

11.14 e2d Using Fig. 11.45, design a problem to help other students better understand maximum average power transfer to a load $\boldsymbol{Z}$.

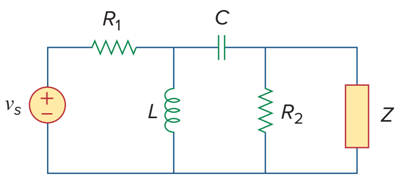

Figure 11.45
For Prob. 11.14.

11.15 In the circuit of Fig. 11.46, find the value of $\mathbf{Z}_L$ that will absorb the maximum power and the value of the maximum power.

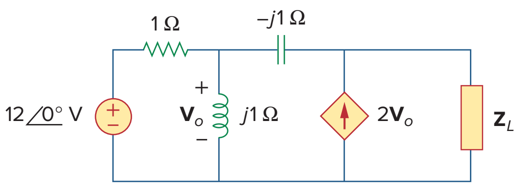

Figure 11.46
For Prob. 11.15.

11.16 For the circuit in Fig. 11.47, find the value of $\mathbf{Z}_L$ that will receive the maximum power from the circuit. Then calculate the power delivered to the load $\mathbf{Z}_L$.

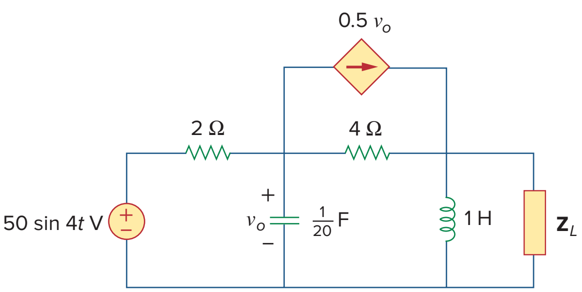

Figure 11.47
For Prob. 11.16.

11.17 Calculate the value of $\mathbf{Z}_L$ in the circuit of Fig. 11.48 in order for $\mathbf{Z}_L$ to receive maximum average power. What is the maximum average power received by $\mathbf{Z}_L$?

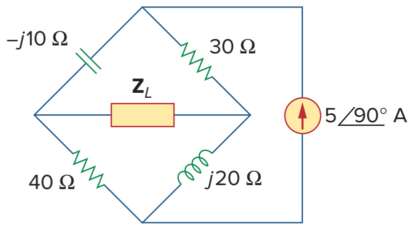

Figure 11.48
For Prob. 11.17.

11.18 Find the value of $\mathbf{Z}_L$ in the circuit of Fig. 11.49 for maximum power transfer.

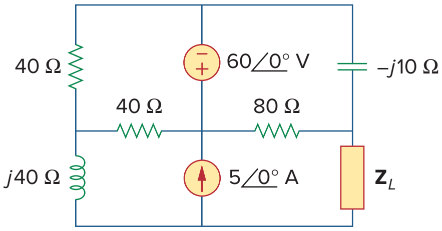

Figure 11.49
For Prob. 11.18.

11.19 The variable resistor R in the circuit of Fig. 11.50 is adjusted until it absorbs the maximum average power. Find R and the maximum average power absorbed.

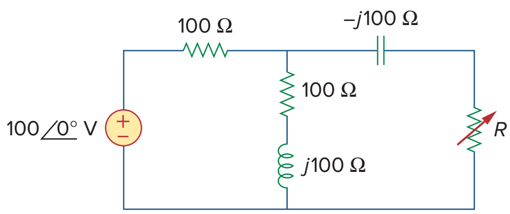

Figure 11.50
For Prob. 11.19.

11.20 The load resistance R_L in Fig. 11.51 is adjusted until it absorbs the maximum average power. Calculate the value of R_L and the maximum average power.

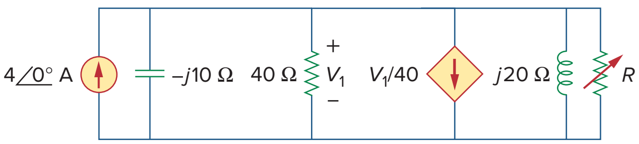

Figure 11.51
For Prob. 11.20.

11.21 Assuming that the load impedance is to be purely resistive, what load should be connected to terminals *a*-*b* of the circuits in Fig. 11.52 so that the maximum power is transferred to the load?

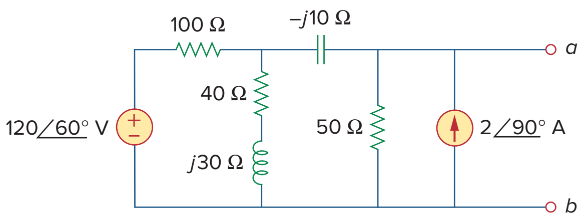

Figure 11.52
For Prob. 11.21.

Section 11.4 Effective or RMS Value

11.22 Find the rms value of the offset sine wave shown in Fig. 11.53.

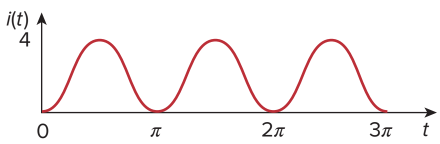

Figure 11.53
For Prob. 11.22.

11.23 Using Fig. 11.54, design a problem to help other students better understand how to find the rms value of a waveshape.

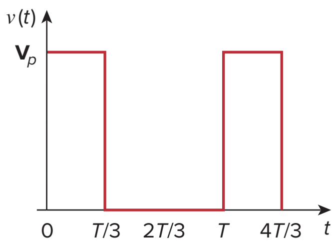

Figure 11.54
For Prob. 11.23.

11.24 Determine the rms value of the waveform in Fig. 11.55.

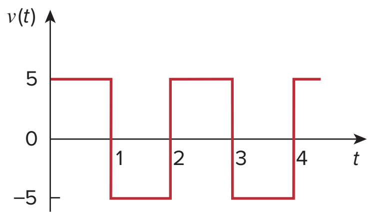

Figure 11.55
For Prob. 11.24.

11.25 Find the rms value of the signal shown in Fig. 11.56.

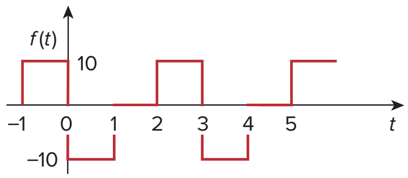

Figure 11.56
For Prob. 11.25.

11.26 Find the effective value of the voltage waveform in Fig. 11.57.

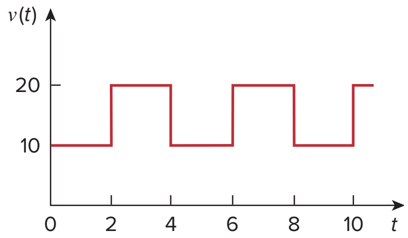

Figure 11.57
For Prob. 11.26.

11.27 Calculate the rms value of the current waveform of Fig. 11.58.

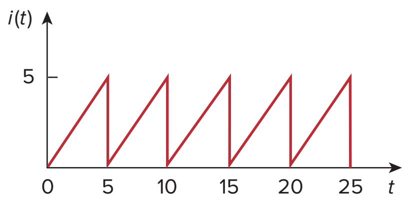

Figure 11.58
For Prob. 11.27.

11.28 Find the rms value of the voltage waveform of Fig. 11.59 as well as the average power absorbed by a 2-Ω resistor when the voltage is applied across the resistor.

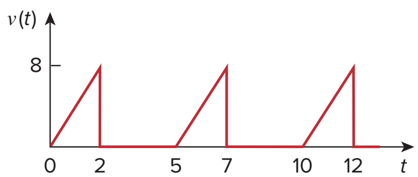

Figure 11.59
For Prob. 11.28.

11.29 Calculate the effective value of the current waveform in Fig. 11.60 and the average power delivered to a 12-Ω resistor when the current runs through the resistor.

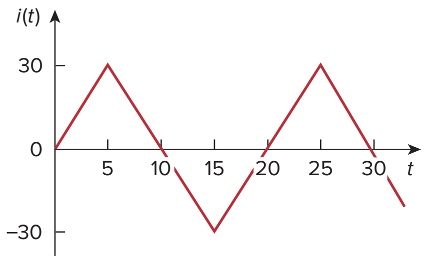

Figure 11.60
For Prob. 11.29.

11.30 Compute the rms value of the waveform depicted in Fig. 11.61.

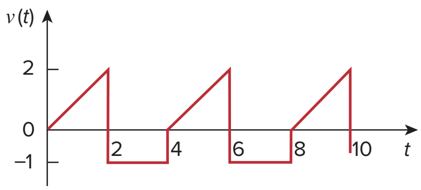

Figure 11.61
For Prob. 11.30.

11.31 Find the rms value of the signal shown in Fig. 11.62.

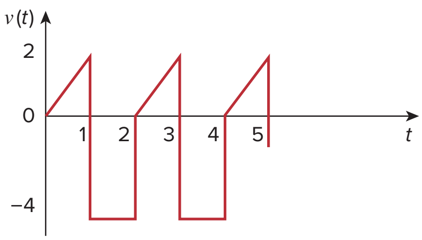

Figure 11.62
For Prob. 11.31.

11.32 Obtain the rms value of the current waveform shown in Fig. 11.63.

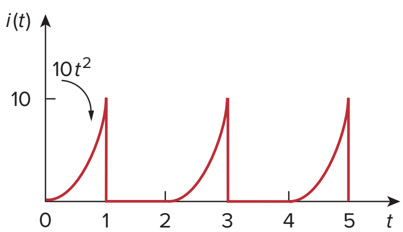

Figure 11.63
For Prob. 11.32.

11.33 Determine the rms value for the waveform in Fig. 11.64.

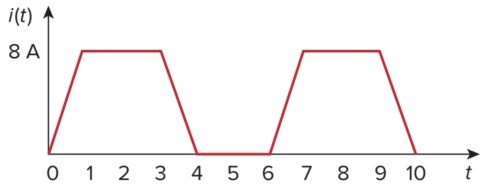

Figure 11.64
For Prob. 11.33.

11.34 Find the effective value of $f(t)$ defined in Fig. 11.65.

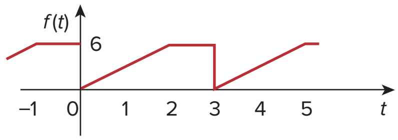

Figure 11.65
For Prob. 11.34.

11.35 One cycle of a periodic voltage waveform is depicted in Fig. 11.66. Find the effective value of the voltage. Note that the cycle starts at $t = 0$ and ends at $t = 6$ s.

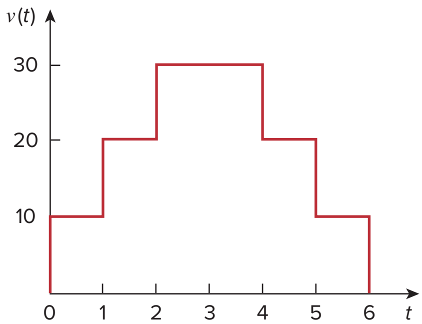

Figure 11.66
For Prob. 11.35.

11.36 Calculate the rms value for each of the following functions:

(a) $i(t) = 10$ A (b) $v(t) = 4 + 3 \cos 5t$ V
(c) $i(t) = 8 - 6 \sin 2t$ A (d) $v(t) = 5 \sin t + 4 \cos t$ V

11.37 Design a problem to help other students better understand how to determine the rms value of the sum of multiple currents.

Section 11.5 Apparent Power and Power Factor

11.38 For the power system in Fig. 11.67, find: (a) the average power, (b) the reactive power, (c) the power factor. Note that 440 V is an rms value.

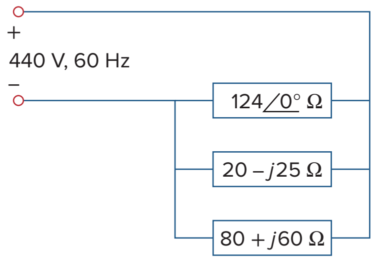

Figure 11.67
For Prob. 11.38.

11.39 An ac motor with impedance $\mathbf{Z}_L = 2 + j1.2\ \Omega$ is supplied by a 220-V, 60-Hz source. (a) Find pf, P, and Q. (b) Determine the capacitor required to be connected in parallel with the motor so that the power factor is corrected to unity.

11.40 Design a problem to help other students better understand apparent power and power factor.

11.41 Obtain the power factor for each of the circuits in Fig. 11.68. Specify each power factor as leading or lagging.

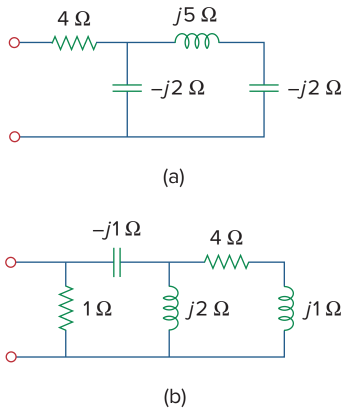

Figure 11.68
For Prob. 11.41.

Section 11.6 Complex Power

11.42 A 110-V rms, 60-Hz source is applied to a load impedance $\mathbf{Z}$. The apparent power entering the load is 120 VA at a power factor of 0.707 lagging.

(a) Calculate the complex power.
(b) Find the rms current supplied to the load.
(c) Determine $\mathbf{Z}$.
(d) Assuming that $\mathbf{Z} = R + j\omega L$, find the values of R and L.

11.43 Design a problem to help other students understand complex power.

11.44 Find the complex power delivered by v_s to the network in Fig. 11.69. Let $v_s = 100 \cos 2000t$ V.

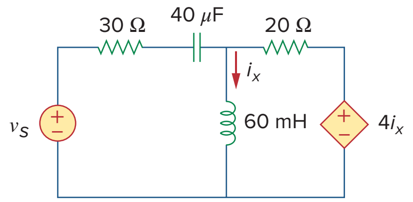

Figure 11.69
For Prob. 11.44.

11.45 The voltage across a load and the current through it are given by

$$v(t) = 20 + 60 \cos 100t \text{ V}$$
$$i(t) = 1 - 0.5 \sin 100t \text{ A}$$

Find:

(a) the rms values of the voltage and of the current
(b) the average power dissipated in the load

11.46 For the following voltage and current phasors, calculate the complex power, apparent power, real power, and reactive power. Specify whether the pf is leading or lagging.

(a) $\mathbf{V} = 220\underline{/30^\circ}$ V rms, $I = 0.5\underline{/60^\circ}$ A rms
(b) $\mathbf{V} = 250\underline{/-10^\circ}$ V rms,
$\mathbf{I} = 6.2\underline{/-25^\circ}$ A rms
(c) $\mathbf{V} = 120\underline{/0^\circ}$ V rms, $\mathbf{I} = 2.4\underline{/-15^\circ}$ A rms
(d) $\mathbf{V} = 160\underline{/45^\circ}$ V rms, $\mathbf{I} = 8.5\underline{/90^\circ}$ A rms

11.47 For each of the following cases, find the complex power, the average power, and the reactive power:

(a) $v(t) = 169.7 \sin(377t + 45^\circ)$ V,
$i(t) = 5.657 \sin(377t)$ A
(b) $v(t) = 339.4 \sin(377t + 90^\circ)$ V,
$i(t) = 5.657 \sin(377t + 45^\circ)$ A
(c) $\mathbf{V} = 900\underline{/90^\circ}$ V rms, $\mathbf{Z} = 75\underline{/45^\circ}\ \Omega$
(d) $\mathbf{I} = 100\underline{/60^\circ}$ A rms, $\mathbf{Z} = 50\underline{/60^\circ}\ \Omega$

11.48 Determine the complex power for the following cases:

(a) $P = 269$ W, $Q = 150$ VAR (capacitive)
(b) $Q = 2000$ VAR, pf $= 0.9$ (leading)
(c) $S = 600$ VA, $Q = 450$ VAR (inductive)
(d) $V_{\text{rms}} = 220$ V, $P = 1$ kW,
$|\mathbf{Z}| = 40\ \Omega$ (inductive)

11.49 Find the complex power for the following cases:

(a) $P = 4$ kW, pf $= 0.86$ (lagging)
(b) $S = 2$ kVA, $P = 1.6$ kW (capacitive)
(c) $\mathbf{V}_{\text{rms}} = 208\underline{/20^\circ}$ V, $\mathbf{I}_{\text{rms}} = 6.5\underline{/-50^\circ}$ A
(d) $\mathbf{V}_{\text{rms}} = 120\underline{/30^\circ}$ V, $\mathbf{Z} = 40 + j60\ \Omega$

11.50 Obtain the overall impedance for the following cases:

(a) $P = 1000$ W, pf $= 0.8$ (leading), $V_{\text{rms}} = 220$ V
(b) $P = 1500$ W, $Q = 2000$ VAR (inductive), $I_{\text{rms}} = 12$ A
(c) $\mathbf{S} = 4500\underline{/60^\circ}$ VA, $\mathbf{V} = 120\underline{/45^\circ}$ V

11.51 For the entire circuit in Fig. 11.70, calculate:

(a) the power factor
(b) the average power delivered by the source
(c) the reactive power
(d) the apparent power
(e) the complex power

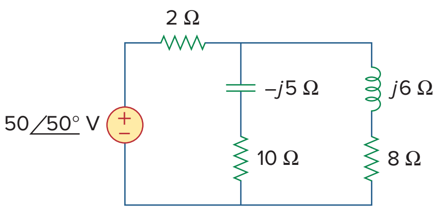

Figure 11.70
For Prob. 11.51.

11.52 In the circuit of Fig. 11.71, device *A* receives 2 kW at 0.8 pf lagging, device *B* receives 3 kVA at 0.4 pf leading, while device *C* is inductive and consumes 1 kW and receives 500 VAR.

(a) Determine the power factor of the entire system.
(b) Find **I** given that $\mathbf{V}_s = 120\underline{/45^\circ}$ V rms.

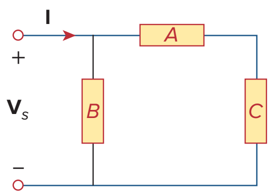

Figure 11.71
For Prob. 11.52.

11.53 In the circuit of Fig. 11.72, load *A* receives 4 kVA at 0.8 pf leading. Load *B* receives 2.4 kVA at 0.6 pf lagging. Box *C* is an inductive load that consumes 1 kW and receives 500 VAR.

(a) Determine **I**.
(b) Calculate the power factor of the combination.

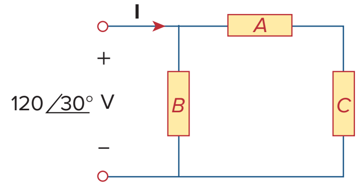

Figure 11.72
For Prob. 11.53.

Section 11.7 Conservation of AC Power

11.54 For the network in Fig. 11.73, find the complex power absorbed by each element.

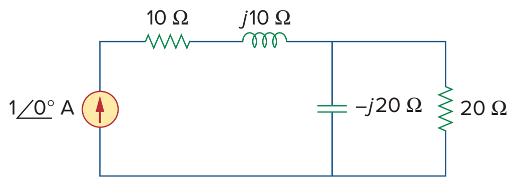

Figure 11.73
For Prob. 11.54.

11.55 Using Fig. 11.74, design a problem to help other students better understand the conservation of AC power.

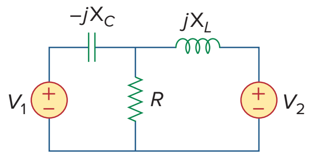

Figure 11.74
For Prob. 11.55.

11.56 Obtain the complex power delivered by the source in the circuit of Fig. 11.75.

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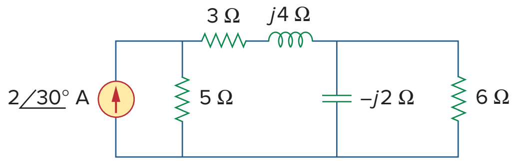

Figure 11.75
For Prob. 11.56.

11.57 For the circuit in Fig. 11.76, find the average, reactive, and complex power delivered by the dependent current source.

ML

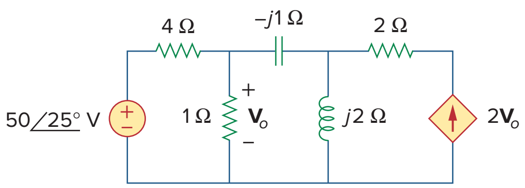

Figure 11.76
For Prob. 11.57.

11.58 Obtain the complex power delivered to the 10-kΩ resistor in Fig. 11.77 below.

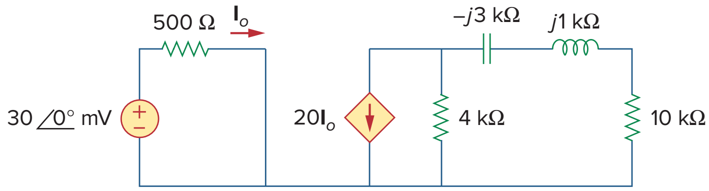

Figure 11.77
For Prob. 11.58.

11.59 Calculate the reactive power in the inductor and capacitor in the circuit of Fig. 11.78.

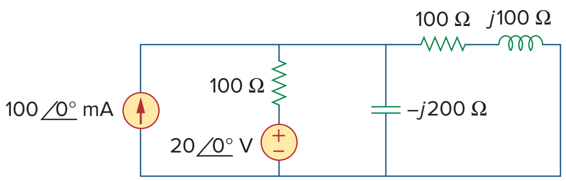

Figure 11.78
For Prob. 11.59.

11.60 For the circuit in Fig. 11.79, find $\mathbf{V}_o$ and the input power factor.

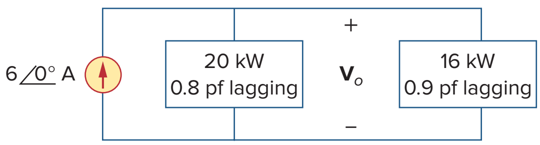

Figure 11.79
For Prob. 11.60.

11.61 Given the circuit in Fig. 11.80, find I_o and the overall complex power supplied.

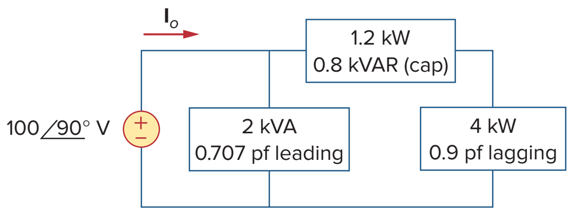

Figure 11.80
For Prob. 11.61.

11.62 For the circuit in Fig. 11.81, find $\mathbf{V}_s$.

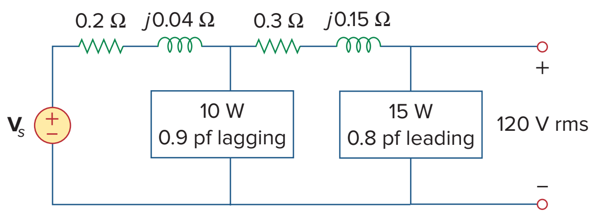

Figure 11.81
For Prob. 11.62.

11.63 Find $\mathbf{I}_o$ in the circuit of Fig. 11.82.

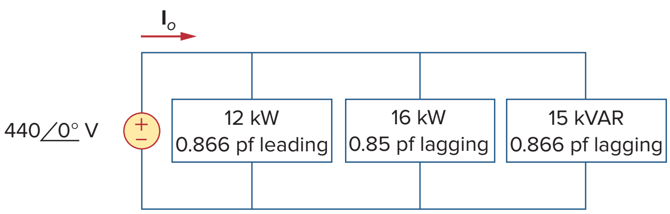

Figure 11.82
For Prob. 11.63.

11.64 Determine $\mathbf{I}_s$ in the circuit of Fig. 11.83, if the voltage source supplies 6 kW and 1.2 kVAR (leading).

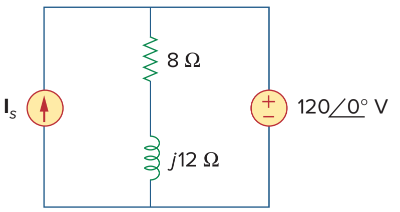

Figure 11.83
For Prob. 11.64.

11.65 In the op amp circuit of Fig. 11.84, $v_s = 4 \cos 10^4 t$ V. Find the average power delivered to the 50-kΩ resistor.

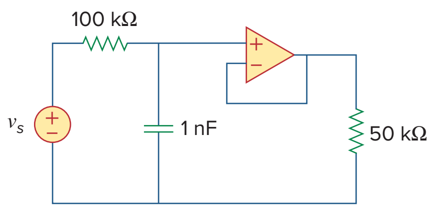

Figure 11.84
For Prob. 11.65.

11.66 Obtain the average power absorbed by the 10-Ω resistor in the op amp circuit in Fig. 11.85.

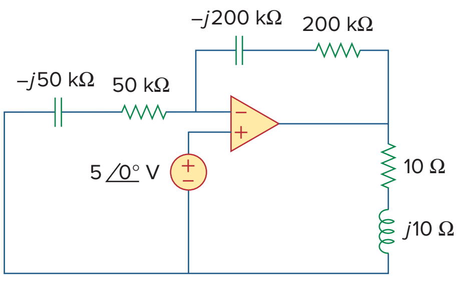

Figure 11.85
For Prob. 11.66.

11.67 For the op amp circuit in Fig. 11.86, calculate:

(a) the complex power delivered by the voltage source

(b) the average power dissipated in the 10-Ω resistor

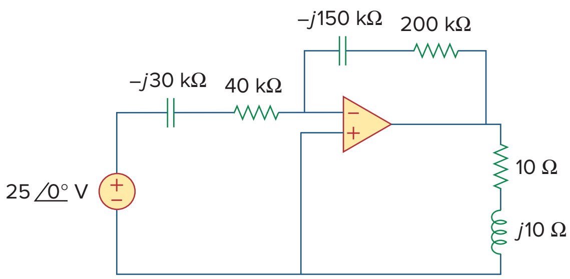

Figure 11.86
For Prob. 11.67.

11.68 Compute the complex power supplied by the current source in the series *RLC* circuit in Fig. 11.87.

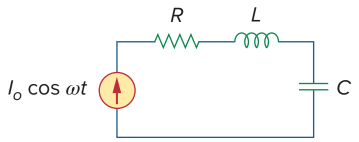

Figure 11.87
For Prob. 11.68.

Section 11.8 Power Factor Correction

11.69 Refer to the circuit shown in Fig. 11.88.

(a) What is the power factor?

(b) What is the average power dissipated?

(c) What is the value of the capacitance that will give a unity power factor when connected to the load?

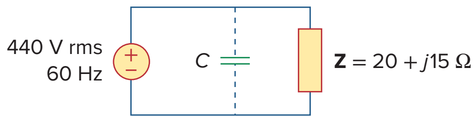

Figure 11.88
For Prob. 11.69.

11.70 Design a problem to help other students better understand power factor correction.

11.71 Three loads are connected in parallel to a $120\angle 0°$ V rms source. Load 1 absorbs 60 kVAR at pf = 0.85 lagging, load 2 absorbs 90 kW and 50 kVAR leading, and load 3 absorbs 100 kW at pf = 1. (a) Find the equivalent impedance. (b) Calculate the power factor of the parallel combination. (c) Determine the current supplied by the source.

11.72 Two loads connected in parallel draw a total of 2.4 kW at 0.8 pf lagging from a 120-V rms, 60-Hz line. One load absorbs 1.5 kW at a 0.707 pf lagging. Determine: (a) the pf of the second load, (b) the parallel element required to correct the pf to 0.9 lagging for the two loads.

11.73 A 240-V rms 60-Hz supply serves a load that is 10 kW (resistive), 15 kVAR (capacitive), and 22 kVAR (inductive). Find:

(a) the apparent power
(b) the current drawn from the supply
(c) the kVAR rating and capacitance required to improve the power factor to 0.96 lagging
(d) the current drawn from the supply under the new power-factor conditions

11.74 A 120-V rms 60-Hz source supplies two loads connected in parallel, as shown in Fig. 11.89.

(a) Find the power factor of the parallel combination.

(b) Calculate the value of the capacitance connected in parallel that will raise the power factor to unity.

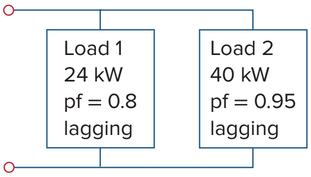

Figure 11.89
For Prob. 11.74.

11.75 Consider the power system shown in Fig. 11.90. Calculate:

(a) the total complex power

(b) the power factor

(c) the parallel capacitance necessary to establish a unity power factor

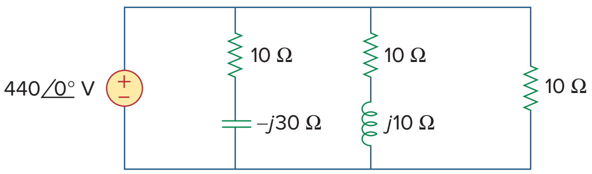

Figure 11.90
For Prob. 11.75.

Section 11.9 Applications

11.76 Obtain the wattmeter reading of the circuit in Fig. 11.91.

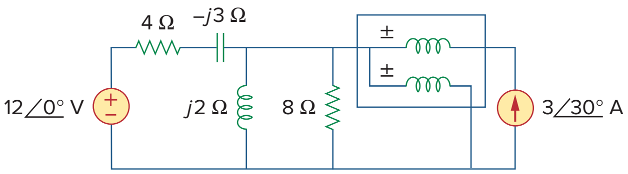

Figure 11.91
For Prob. 11.76.

11.77 What is the reading of the wattmeter in the network of Fig. 11.92?

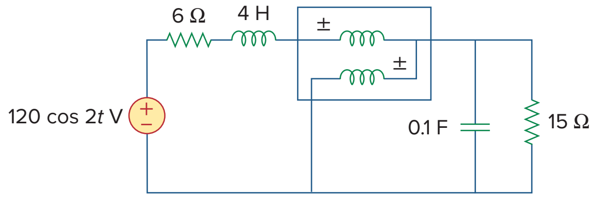

Figure 11.92
For Prob. 11.77.

11.78 Find the wattmeter reading of the circuit shown in Fig. 11.93.

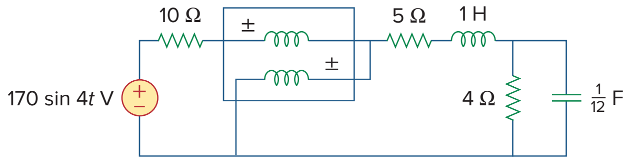

Figure 11.93
For Prob. 11.78.

11.79 Determine the wattmeter reading of the circuit in Fig. 11.94.

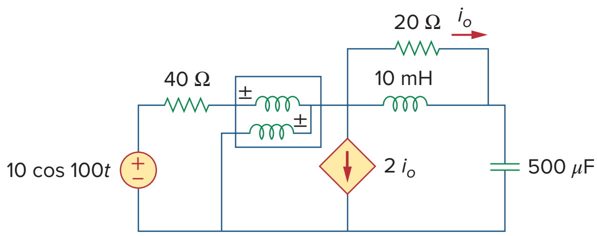

Figure 11.94
For Prob. 11.79.

11.80 The circuit of Fig. 11.95 portrays a wattmeter connected into an ac network.

(a) Find the magnitude of the load current.

(b) Calculate the wattmeter reading.

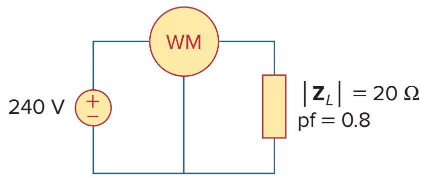

Figure 11.95
For Prob. 11.80.

11.81 Design a problem to help other students better understand how to correct power factor to values other than unity.

11.82 A 240-V rms 60-Hz source supplies a parallel combination of a 5-kW heater and a 30-kVA induction motor whose power factor is 0.82. Determine:

(a) the system apparent power

(b) the system reactive power

(c) the kVA rating of a capacitor required to adjust the system power factor to 0.9 lagging

(d) the value of the capacitor required

11.83 Oscilloscope measurements indicate that the peak voltage across a load and the peak current through it are, respectively, $210\angle 60^\circ$ V and $8\angle 25^\circ$ A. Determine:

(a) the real power

(b) the apparent power

(c) the reactive power

(d) the power factor

11.84 A consumer has an annual consumption of 1200 MWh with a maximum demand of 2.4 MVA. The maximum demand charge is $30 per kVA per annum, and the energy charge per kWh is 4 cents.

(a) Determine the annual cost of energy.

(b) Calculate the charge per kWh with a flat-rate tariff if the revenue to the utility company is to remain the same as for the two-part tariff.

11.85 A regular household system of a single-phase three-wire circuit allows the operation of both 120-V and 240-V, 60-Hz appliances. The household circuit is modeled as shown in Fig. 11.96. Calculate:

(a) the currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_n$

(b) the total complex power supplied

(c) the overall power factor of the circuit

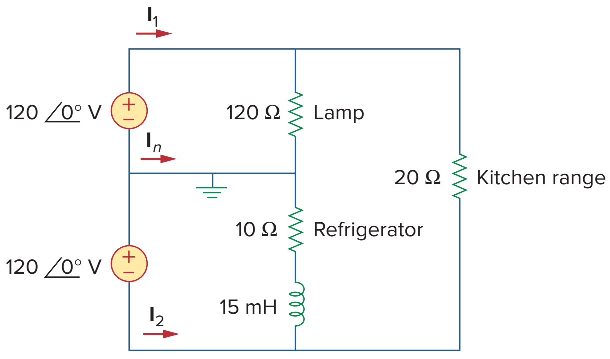

Figure 11.96
For Prob. 11.85.

Comprehensive Problems

11.86 A transmitter delivers maximum power to an antenna when the antenna is adjusted to represent a load of 75-Ω resistance in series with an inductance of 4 μH. If the transmitter operates at 4.12 MHz, find its internal impedance.

11.87 In a TV transmitter, a series circuit has an impedance of 3 kΩ and a total current of 50 mA. If the voltage across the resistor is 80 V, what is the power factor of the circuit?

11.88 A certain electronic circuit is connected to a 110-V ac line. The root-mean-square value of the current drawn is 2 A, with a phase angle of 55°.

(a) Find the true power drawn by the circuit.

(b) Calculate the apparent power.

11.89 An industrial heater has a nameplate that reads: 210 V 60 Hz 12 kVA 0.78 pf lagging
Determine:

(a) the apparent and the complex power

(b) the impedance of the heater

***11.90** A 2000-kW turbine-generator of 0.85 power factor operates at the rated load. An additional load of 300 kW at 0.8 power factor is added. What kVAR of capacitors is required to operate the turbine-generator but keep it from being overloaded?

11.91 The nameplate of an electric motor has the following information:

Line voltage: 220 V rms
Line current: 15 A rms
Line frequency: 60 Hz
Power: 2700 W

Determine the power factor (lagging) of the motor. Find the value of the capacitance C that must be connected across the motor to raise the pf to unity.

11.92 As shown in Fig. 11.97, a 550-V feeder line supplies an industrial plant consisting of a motor drawing 90 kW at 0.8 pf (inductive), a capacitor with a rating of 20 kVAR, and lighting drawing 10 kW.

(a) Calculate the total reactive power and apparent power absorbed by the plant.

(b) Determine the overall pf.

(c) Find the magnitude of the current in the feeder line.

* An asterisk indicates a challenging problem.

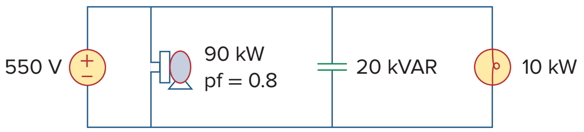

Figure 11.97
For Prob. 11.92.

11.93 A factory has the following four major loads:

- A motor rated at 5 hp, 0.8 pf lagging (1hp = 0.7457 kW).
- A heater rated at 1.2 kW, 1.0 pf.
- Ten 120-W lightbulbs.
- A synchronous motor rated at 1.6 kVAR, 0.6 pf leading.

(a) Calculate the total real and reactive power.

(b) Find the overall power factor.

11.94 A 1-MVA substation operates at full load at 0.7 power factor. It is desired to improve the power factor to 0.95 by installing capacitors. Assume that new substation and distribution facilities cost \$120 per kVA installed, and capacitors cost \$30 per kVA installed.

(a) Calculate the cost of capacitors needed.

(b) Find the savings in substation capacity released.

(c) Are capacitors economical for releasing the amount of substation capacity?

1.95 A coupling capacitor is used to block dc current from an amplifier as shown in Fig. 11.98(a). The amplifier and the capacitor act as the source, while the speaker is the load as in Fig. 11.98(b).

(a) At what frequency is maximum power transferred to the speaker?

(b) If $V_s = 4.6$ V rms, how much power is delivered to the speaker at that frequency?

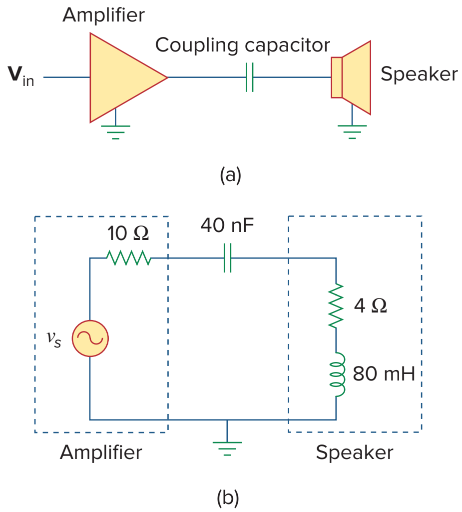

Figure 11.98
For Prob. 11.95.

1.96 A power amplifier has an output impedance of $40 + j8\ \Omega$. It produces a no-load output voltage of 146 V at 300 Hz.

(a) Determine the impedance of the load that achieves maximum power transfer.

(b) Calculate the load power under this matching condition.

1.97 A power transmission system is modeled as shown in Fig. 11.99. If $\mathbf{V}_s = 440\underline{/0^\circ}$ rms, find the average power absorbed by the load.

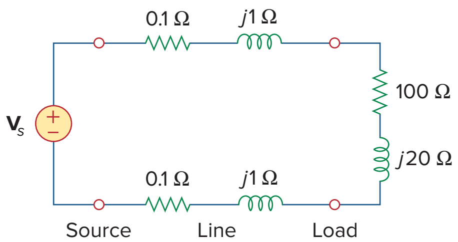

Figure 11.99
For Prob. 11.97.

12.11 Summary

1. The phase sequence is the order in which the phase voltages of a three-phase generator occur with respect to time. In an *abc* sequence of balanced source voltages, $\mathbf{V}_{an}$ leads $\mathbf{V}_{bn}$ by 120°, which in turn leads $\mathbf{V}_{cn}$ by 120°. In an *acb* sequence of balanced voltages, $\mathbf{V}_{an}$ leads $\mathbf{V}_{cn}$ by 120°, which in turn leads $\mathbf{V}_{bn}$ by 120°.
2. A balanced wye- or delta-connected load is one in which the three-phase impedances are equal.
3. The easiest way to analyze a balanced three-phase circuit is to transform both the source and the load to a Y-Y system and then analyze the single-phase equivalent circuit. Table 12.1 presents a summary of the formulas for phase currents and voltages and line currents and voltages for the four possible configurations.
4. The line current I_L is the current flowing from the generator to the load in each transmission line in a three-phase system. The line voltage V_L is the voltage between each pair of lines, excluding the neutral line if it exists. The phase current I_p is the current flowing through each phase in a three-phase load. The phase voltage V_p is the voltage of each phase. For a wye-connected load,

$$V_L = \sqrt{3}V_p \qquad \text{and} \qquad I_L = I_p$$

   For a delta-connected load,

$$V_L = V_p \qquad \text{and} \qquad I_L = \sqrt{3}I_p$$

5. The total instantaneous power in a balanced three-phase system is constant and equal to the average power.
6. The total complex power absorbed by a balanced three-phase Y-connected or Δ-connected load is

$$\mathbf{S} = P + jQ = \sqrt{3}V_L I_L \underline{/\theta}$$

   where θ is the angle of the load impedances.
7. An unbalanced three-phase system can be analyzed using nodal or mesh analysis.
8. *PSpice* is used to analyze three-phase circuits in the same way as it is used for analyzing single-phase circuits.
9. The total real power is measured in three-phase systems using either the three-wattmeter method or the two-wattmeter method.
10. Residential wiring uses a 120/240-V, single-phase, three-wire system.

Review Questions

12.1 What is the phase sequence of a three-phase motor for which $\mathbf{V}_{AN} = 220\underline{/-100°}$ V and $\mathbf{V}_{BN} = 220\underline{/140°}$ V?

(a) *abc* (b) *acb*

12.2 If in an *acb* phase sequence, $V_{an} = 100\underline{/-20°}$, then $\mathbf{V}_{cn}$ is:

(a) $100\underline{/-140°}$ (b) $100\underline{/100°}$
(c) $100\underline{/-50°}$ (d) $100\underline{/10°}$

12.3 Which of these is not a required condition for a balanced system:

(a) $|\mathbf{V}_{an}| = |\mathbf{V}_{bn}| = |\mathbf{V}_{cn}|$
(b) $\mathbf{I}_a + \mathbf{I}_b + \mathbf{I}_c = 0$
(c) $V_{an} + V_{bn} + V_{cn} = 0$
(d) Source voltages are 120° out of phase with each other.
(e) Load impedances for the three phases are equal.

12.4 In a Y-connected load, the line current and phase current are equal.

(a) True (b) False

12.5 In a Δ-connected load, the line current and phase current are equal.

(a) True (b) False

12.6 In a Y-Y system, a line voltage of 220 V produces a phase voltage of:

(a) 381 V (b) 311 V (c) 220 V
(d) 156 V (e) 127 V

12.7 In a Δ-Δ system, a phase voltage of 100 V produces a line voltage of:

(a) 58 V (b) 71 V (c) 100 V
(d) 173 V (e) 141 V

12.8 When a Y-connected load is supplied by voltages in *abc* phase sequence, the line voltages lag the corresponding phase voltages by 30°.

(a) True (b) False

12.9 In a balanced three-phase circuit, the total instantaneous power is equal to the average power.

(a) True (b) False

12.10 The total power supplied to a balanced Δ-load is found in the same way as for a balanced Y-load.

(a) True (b) False

Answers: 12.1a, 12.2a, 12.3c, 12.4a, 12.5b,12.6e, 12.7c, 12.8b, 12.9a, 12.10a.

Problems[1]

Section 12.2 Balanced Three-Phase Voltages

12.1 If $\mathbf{V}_{ab} = 400$ V in a balanced Y-connected three-phase generator, find the phase voltages, assuming the phase sequence is:

(*a*) *abc* (*b*) *acb*

12.2 What is the phase sequence of a balanced three-phase circuit for which $\mathbf{V}_{an} = 120\underline{/30^\circ}$ V and $\mathbf{V}_{cn} = 120\underline{/-90^\circ}$ V? Find $\mathbf{V}_{bn}$.

12.3 Given a balanced Y-connected three-phase generator with a line-to-line voltage of $\mathbf{V}_{ab} = 100\underline{/45^\circ}$ V and $\mathbf{V}_{bc} = 100\underline{/165^\circ}$ V, determine the phase sequence and the value of $\mathbf{V}_{ca}$.

12.4 A three-phase system with *abc* sequence and $V_L = 440$ V feeds a Y-connected load with $Z_L = 40\underline{/30^\circ}$ Ω. Find the line currents.

12.5 For a Y-connected load, the time-domain expressions for three line-to-neutral voltages at the terminals are:

$$v_{AN} = 120\cos(\omega t + 32^\circ)\text{ V}$$
$$v_{BN} = 120\cos(\omega t - 88^\circ)\text{ V}$$
$$v_{CN} = 120\cos(\omega t + 152^\circ)\text{ V}$$

Write the time-domain expressions for the line-to-line voltages v_{AB}, v_{BC}, and v_{CA}.

Section 12.3 Balanced Wye-Wye Connection

12.6 Using Fig. 12.41, design a problem to help other **e2d** students better understand balanced wye-wye connected circuits.

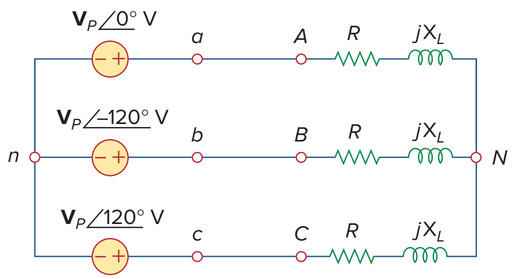

Figure 12.41
For Prob. 12.6.

12.7 Obtain the line currents in the three-phase circuit of Fig. 12.42 on the next page.

12.8 In a balanced three-phase Y-Y system, the source is an *acb* sequence of voltages and $\mathbf{V}_{cn} = 120\underline{/35^\circ}$ V rms. The line impedance per phase is $(1 + j2)$ Ω, while the per-phase impedance of the load is $(11 + j14)$ Ω. Calculate the line currents and the load voltages.

12.9 A balanced Y-Y four-wire system has phase voltages

$$\mathbf{V}_{an} = 120\underline{/0^\circ}, \qquad \mathbf{V}_{bn} = 120\underline{/-120^\circ}$$
$$\mathbf{V}_{cn} = 120\underline{/120^\circ}\text{ V}$$

The load impedance per phase is $19 + j13$ Ω, and the line impedance per phase is $1 + j2$ Ω. Solve for the line currents and neutral current.

[1] Remember that unless stated otherwise, all given voltages and currents are rms values.

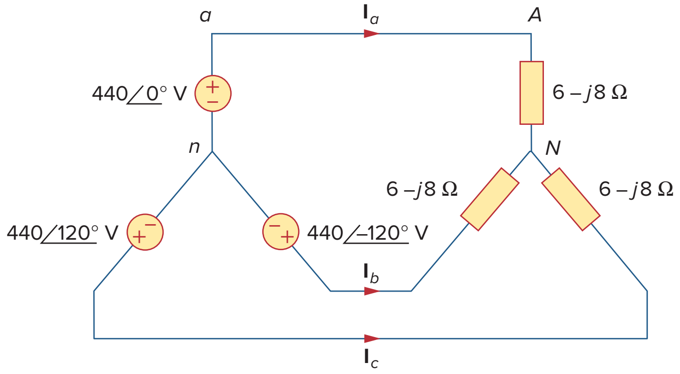

Figure 12.42
For Prob. 12.7.

12.10 For the circuit in Fig. 12.43, determine the current in the neutral line.

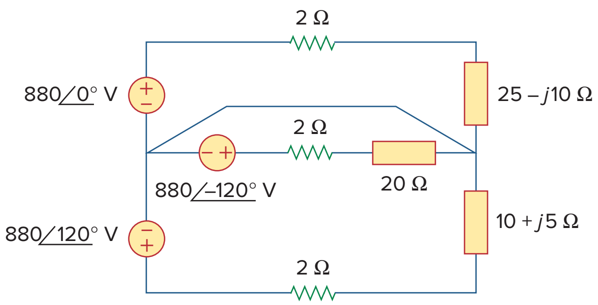

Figure 12.43
For Prob. 12.10.

Section 12.4 Balanced Wye-Delta Connection

12.11 In the Y-Δ system shown in Fig. 12.44, the source is a positive sequence with $\mathbf{V}_{an} = 440\angle 0^\circ$ V and phase impedance $\mathbf{Z}_p = 2 - j3\ \Omega$. Calculate the line voltage $\mathbf{V}_L$ and the line current $\mathbf{I}_L$.

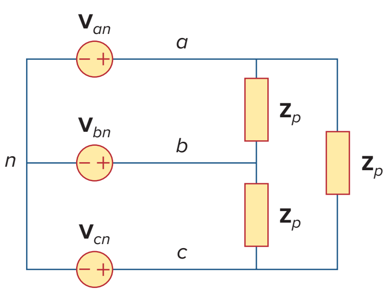

Figure 12.44
For Prob. 12.11.

12.12 Using Fig. 12.45, design a problem to help other students better understand wye-delta connected circuits.

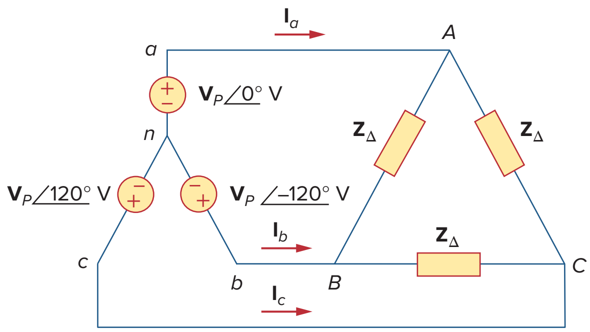

Figure 12.45
For Prob. 12.12.

12.13 In the balanced three-phase Y-Δ system in Fig. 12.46, find the line current I_L and the average power delivered to the load.

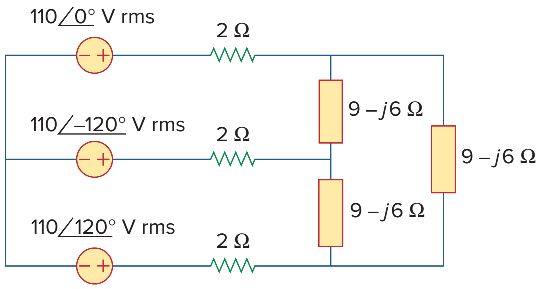

Figure 12.46
For Prob. 12.13.

12.14 Obtain the line currents in the three-phase circuit of Fig. 12.47 on the next page.

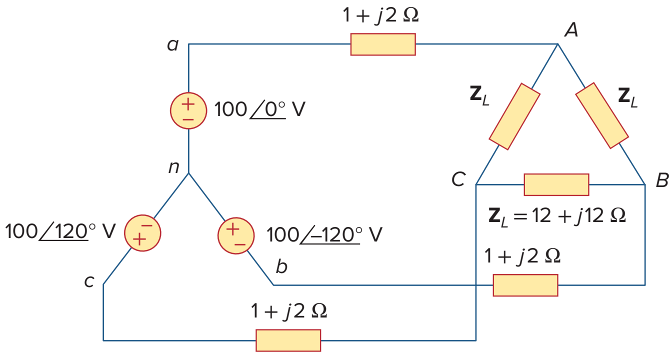

Figure 12.47
For Prob. 12.14.

12.15 The circuit in Fig. 12.48 is excited by a balanced three-phase source with a line voltage of 210 V. If $\mathbf{Z}_l = 1 + j1\ \Omega$, $\mathbf{Z}_\Delta = 24 - j30\ \Omega$, and $\mathbf{Z}_Y = 12 + j5\ \Omega$, determine the magnitude of the line current of the combined loads.

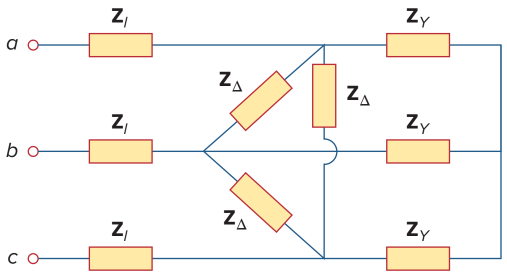

Figure 12.48
For Prob. 12.15.

12.16 A balanced delta-connected load has a phase current $\mathbf{I}_{AC} = 5\underline{/-30^\circ}$ A.

(a) Determine the three line currents assuming that the circuit operates in the positive phase sequence.

(b) Calculate the load impedance if the line voltage is $\mathbf{V}_{AB} = 440\underline{/0^\circ}$ V.

12.17 A positive sequence wye-connected source where $\mathbf{V}_{an} = 120\underline{/90^\circ}$ V, is connected to a delta-connected load where $\mathbf{Z}_L = (60 + j45)\ \Omega$. Determine the line currents.

12.18 If $\mathbf{V}_{an} = 220\underline{/60^\circ}$ V in the network of Fig. 12.49, find the load phase currents $\mathbf{I}_{AB}$, $\mathbf{I}_{BC}$, and $\mathbf{I}_{CA}$.

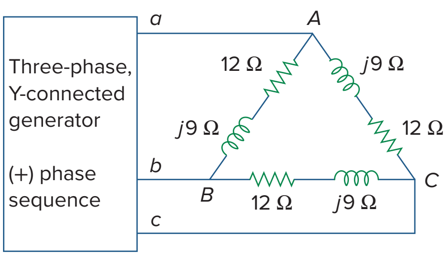

Figure 12.49
For Prob. 12.18.

Section 12.5 Balanced Delta-Delta Connection

12.19 For the Δ-Δ circuit of Fig. 12.50, calculate the phase and line currents.

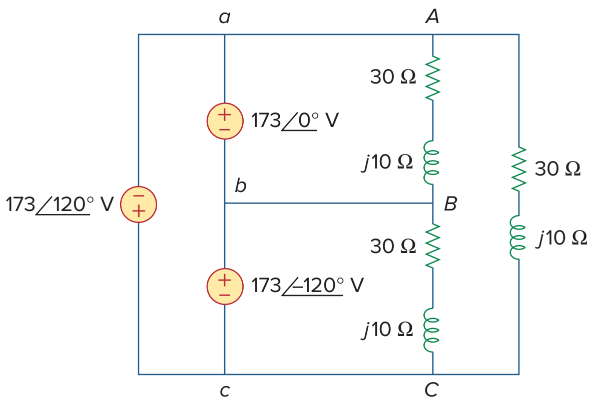

Figure 12.50
For Prob. 12.19.

12.20 Using Fig. 12.51, design a problem to help other students better understand balanced delta-delta connected circuits.

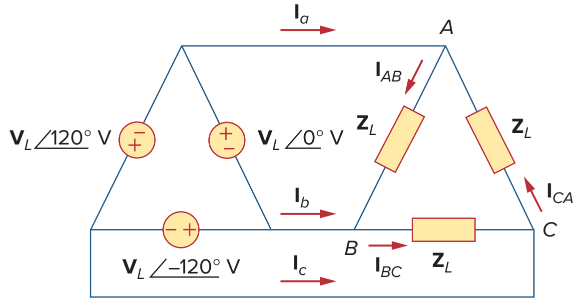

Figure 12.51
For Prob. 12.20.

12.21 Three 440-V generators form a delta-connected source that is connected to a balanced delta-connected load of $Z_L = (8.66 + j5)\ \Omega$ per phase as shown in Fig. 12.52. Determine the value of I_{BC} and I_{aA}. What is the pf of the load?

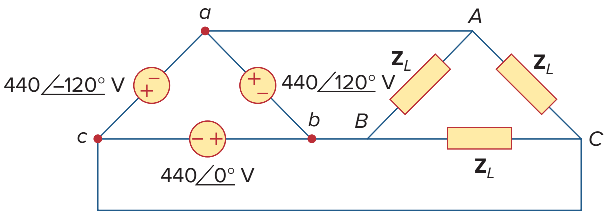

Figure 12.52
For Prob. 12.21.

12.22 Find the line currents I_{aA}, I_{bB}, and I_{cC} in the three-phase network of Fig. 12.53. Take $\mathbf{Z}_L = (114 + j87)\ \Omega$ and $\mathbf{Z}_l = (2 + j)\ \Omega$.

12.23 A balanced delta connected source is connected to a balanced delta connected load where $Z_L = (80 + j60)\ \Omega$ and $Z_l = (2 + j)\ \Omega$. Given that the load voltages are $\mathbf{V}_{AB} = 100\angle{0°}$ V, $\mathbf{V}_{BC} = 100\angle{120°}$ V, and $\mathbf{V}_{CA} = 100\angle{-120°}$ V. Calculate the source voltages $\mathbf{V}_{ab}$, $\mathbf{V}_{bc}$, and $\mathbf{V}_{ca}$.

12.24 A balanced delta-connected source has phase voltage $\mathbf{V}_{ab} = 880\angle{30°}$ V and a positive phase sequence. If this is connected to a balanced delta-connected load, find the line and phase currents. Take the load impedance per phase as $60\angle{30°}\ \Omega$ and line impedance per phase as $1 + j1\ \Omega$.

Section 12.6 Balanced Delta-Wye Connection

12.25 In the circuit of Fig. 12.54, if $\mathbf{V}_{ab} = 440\angle{10°}$, $\mathbf{V}_{bc} = 440\angle{-110°}$, $\mathbf{V}_{ca} = 440\angle{130°}$ V, find the line currents.

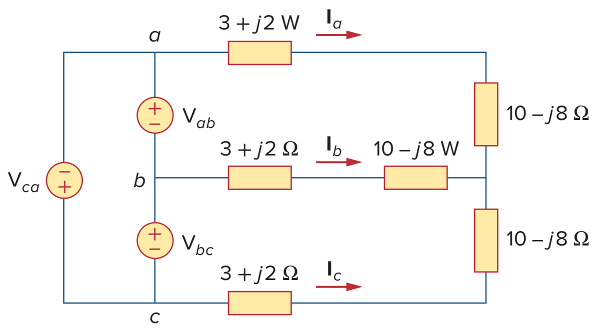

Figure 12.54
For Prob. 12.25.

12.26 Using Fig. 12.55, design a problem to help other students better understand balanced delta connected sources delivering power to balanced wye connected loads.

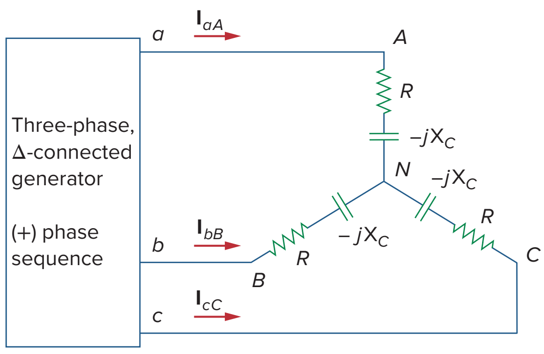

Figure 12.55
For Prob. 12.26.

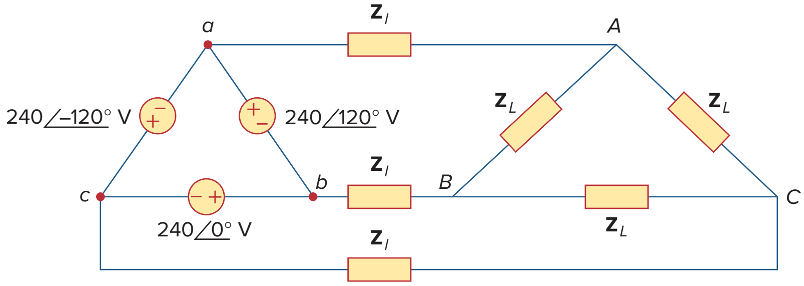

Figure 12.53
For Prob. 12.22.

12.27 A Δ-connected source supplies power to a Y-connected load in a three-phase balanced system. Given that the line impedance is $2 + j1\ \Omega$ per phase while the load impedance is $6 + j4\ \Omega$ per phase, find the magnitude of the line voltage at the load. Assume the source phase voltage $\mathbf{V}_{ab} = 208\underline{/0^\circ}$ V rms.

12.28 The line-to-line voltages in a Y-load have a magnitude of 880 V and are in the positive sequence at 60 Hz. If the loads are balanced with $Z_1 = Z_2 = Z_3 = 25\underline{/30^\circ}$, find all line currents and phase voltages.

Section 12.7 Power in a Balanced System

12.29 A balanced three-phase Y-Δ system has $\mathbf{V}_{an} = 240\underline{/0^\circ}$ V rms and $\mathbf{Z}_\Delta = 51 + j45\ \Omega$. If the line impedance per phase is $0.4 + j1.2\ \Omega$, find the total complex power delivered to the load.

12.30 In Fig. 12.56, the rms value of the line voltage is 208 V. Find the average power delivered to the load.

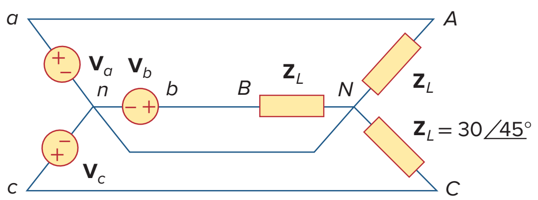

Figure 12.56
For Prob. 12.30.

12.31 A balanced delta-connected load is supplied by a 60-Hz three-phase source with a line voltage of 480 V. Each load phase draws 24 kW at a lagging power factor of 0.8. Find:

(a) the load impedance per phase
(b) the line current
(c) the value of capacitance needed to be connected in parallel with each load phase to minimize the current from the source

12.32 Design a problem to help other students better understand power in a balanced three-phase system.

12.33 A three-phase source delivers 4.8 kVA to a wye-connected load with a phase voltage of 208 V and a power factor of 0.9 lagging. Calculate the source line current and the source line voltage.

12.34 A balanced wye-connected load with a phase impedance of $10 - j16\ \Omega$ is connected to a balanced three-phase generator with a line voltage of 220 V. Determine the line current and the complex power absorbed by the load.

12.35 Three equal impedances, $60 + j30\ \Omega$ each, are delta-connected to a 230-V rms, three-phase circuit. Another three equal impedances, $40 + j10\ \Omega$ each, are wye-connected across the same circuit at the same points. Determine:

(a) the line current

(b) the total complex power supplied to the two loads

(c) the power factor of the two loads combined

12.36 A 4200-V, three-phase transmission line has an impedance of $4 + j\ \Omega$ per phase. If it supplies a load of 1 MVA at 0.75 power factor (lagging), find:

(a) the complex power

(b) the power loss in the line

(c) the voltage at the sending end

12.37 The total power measured in a three-phase system feeding a balanced wye-connected load is 12 kW at a power factor of 0.6 leading. If the line voltage is 440 V, calculate the line current I_L and the load impedance $\mathbf{Z}_Y$.

12.38 Given the circuit in Fig. 12.57 below, find the total complex power absorbed by the load.

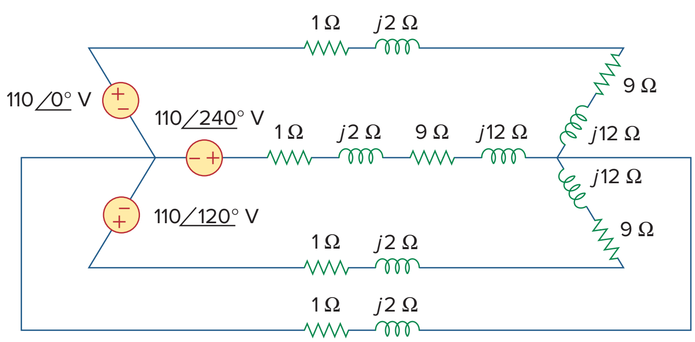

Figure 12.57
For Prob. 12.38.

12.39 Find the real power absorbed by the load in Fig. 12.58.

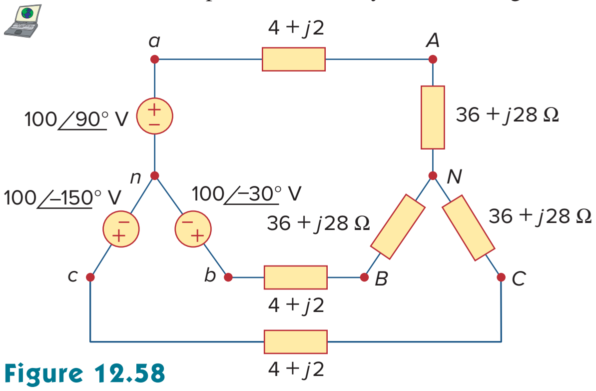

Figure 12.58
For Prob. 12.39.

12.40 For the three-phase circuit in Fig. 12.59, find the average power absorbed by the delta-connected load with $\mathbf{Z}_\Delta = 21 + j24\ \Omega$.

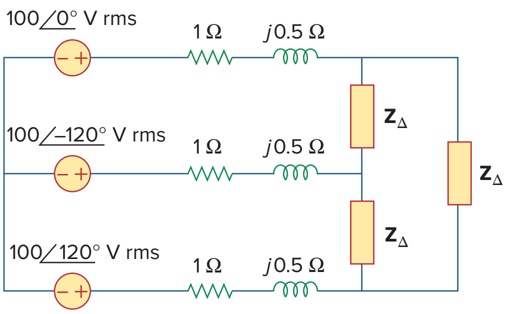

Figure 12.59
For Prob. 12.40.

12.41 A balanced delta-connected load draws 5 kW at a power factor of 0.8 lagging. If the three-phase system has an effective line voltage of 400 V, find the line current.

12.42 A balanced three-phase generator delivers 7.2 kW to a wye-connected load with impedance $30 - j40\ \Omega$ per phase. Find the line current I_L and the line voltage V_L.

12.43 Refer to Fig. 12.48. Obtain the complex power absorbed by the combined loads.

12.44 A three-phase line has an impedance of $1 + j3\ \Omega$ per phase. The line feeds a balanced delta-connected load, which absorbs a total complex power of $12 + j5$ kVA. If the line voltage at the load end has a magnitude of 240 V, calculate the magnitude of the line voltage at the source end and the source power factor.

12.45 A balanced wye-connected load is connected to the generator by a balanced transmission line with an impedance of $0.5 + j2\ \Omega$ per phase. If the load is rated at 450 kW, 0.708 power factor lagging, 440-V line voltage, find the line voltage at the generator.

12.46 A three-phase load consists of three 100-Ω resistors that can be wye- or delta-connected. Determine which connection will absorb the most average power from a three-phase source with a line voltage of 110 V. Assume zero line impedance.

12.47 The following three parallel-connected three-phase loads are fed by a balanced three-phase source:

Load 1: 250 kVA, 0.8 pf lagging
Load 2: 300 kVA, 0.95 pf leading
Load 3: 450 kVA, unity pf

If the line voltage is 13.8 kV, calculate the line current and the power factor of the source. Assume that the line impedance is zero.

12.48 A balanced, positive-sequence wye-connected source has $\mathbf{V}_{an} = 240\angle 0°$ V rms and supplies an unbalanced delta-connected load via a transmission line with impedance $2 + j3\ \Omega$ per phase.

(a) Calculate the line currents if $\mathbf{Z}_{AB} = 40 + j15\ \Omega$, $\mathbf{Z}_{BC} = 60\ \Omega$, $\mathbf{Z}_{CA} = 18 - j12\ \Omega$.
(b) Find the complex power supplied by the source.

12.49 Each phase load consists of a 20-Ω resistor and a 10-Ω inductive reactance. With a line voltage of 480 V rms, calculate the average power taken by the load if:

(a) the three-phase loads are delta-connected
(b) the loads are wye-connected

12.50 A balanced three-phase source with $\mathbf{V}_L = 240$ V rms is supplying 8 kVA at 0.6 power factor lagging to two wye-connected parallel loads. If one load draws 3 kW at unity power factor, calculate the impedance per phase of the second load.

Section 12.8 Unbalanced Three-Phase Systems

ML

12.51 Consider the wye-delta system shown in Fig. 12.60. Let $\mathbf{Z}_1 = 100\ \Omega$, $\mathbf{Z}_2 = j100\ \Omega$, and $\mathbf{Z}_3 = -j100\ \Omega$. Determine the phase currents, $\mathbf{I}_{AB}$, $\mathbf{I}_{BC}$, and $\mathbf{I}_{CA}$, and the line currents, $\mathbf{I}_{aA}$, $\mathbf{I}_{bB}$, and $\mathbf{I}_{cC}$.

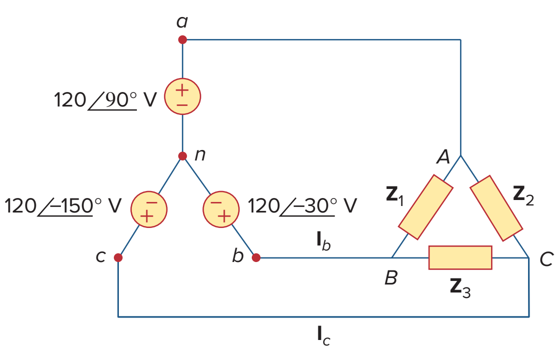

Figure 12.60
For Prob. 12.51.

12.52 A four-wire wye-wye circuit has

$$\mathbf{V}_{an} = 220\underline{/120^\circ}, \qquad \mathbf{V}_{bn} = 220\underline{/0^\circ}$$
$$\mathbf{V}_{cn} = 220\underline{/-120^\circ}\ \text{V}$$

If the impedances are

$$\mathbf{Z}_{AN} = 20\underline{/60^\circ}, \qquad \mathbf{Z}_{BN} = 30\underline{/0^\circ}$$
$$\mathbf{Z}_{cn} = 40\underline{/30^\circ}\ \Omega$$

find the current in the neutral line.

12.53 Using Fig. 12.61, design a problem that will help other students better understand unbalanced three-phase systems.

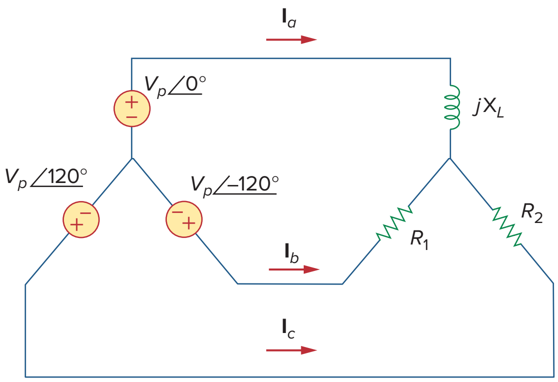

Figure 12.61
For Prob. 12.53.

12.54 A balanced three-phase Y-source with $V_P =$ 880 V rms drives a Y-connected three-phase load with phase impedance $\mathbf{Z}_A = 80\ \Omega$, $\mathbf{Z}_B = 60 + j90\ \Omega$, and $\mathbf{Z}_C = j80\ \Omega$. Calculate the line currents and total complex power delivered to the load. Assume that the neutrals are connected.

12.55 A three-phase supply, with the line-to-line voltage of 240 V rms, has the unbalanced load as shown in Fig. 12.62. Find the line currents and the total complex power delivered to the load.

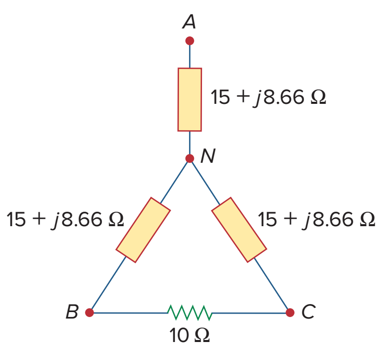

Figure 12.62
For Prob. 12.55.

12.56 Using Fig. 12.63, design a problem to help other students to better understand unbalanced three-phase systems.

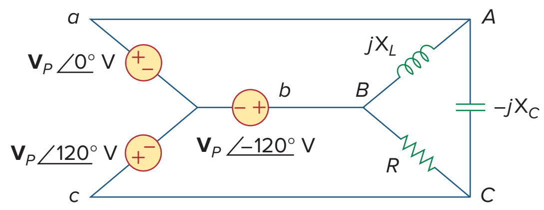

Figure 12.63
For Prob. 12.56.

12.57 Determine the line currents for the three-phase circuit of Fig. 12.64. Let $\mathbf{V}_a = 220\underline{/0^\circ}$, $\mathbf{V}_b = 220\underline{/-120^\circ}$, $\mathbf{V}_c = 220\underline{/120^\circ}$ V.

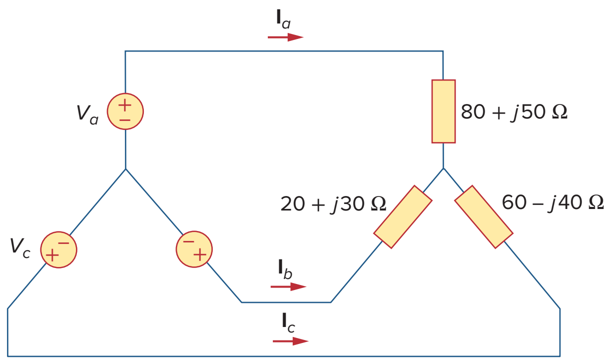

Figure 12.64
For Prob. 12.57.

Section 12.9 *PSpice* for Three-Phase Circuits

12.58 Solve Prob. 12.10 using *PSpice or MultiSim*.

12.59 The source in Fig. 12.65 is balanced and exhibits a positive phase sequence. If $f = 60$ Hz, use *PSpice or MultiSim* to find $\mathbf{V}_{AN}$, $\mathbf{V}_{BN}$, and $\mathbf{V}_{CN}$.

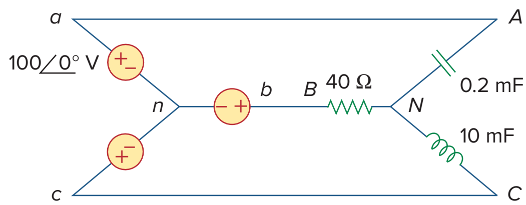

Figure 12.65
For Prob. 12.59.

12.60 Use *PSpice or MultiSim* to determine $\mathbf{I}_o$ in the single-phase, three-wire circuit of Fig. 12.66. Let $\mathbf{Z}_1 = 15 - j10\ \Omega$, $\mathbf{Z}_2 = 30 + j20\ \Omega$, and $\mathbf{Z}_3 = 12 + j5\ \Omega$.

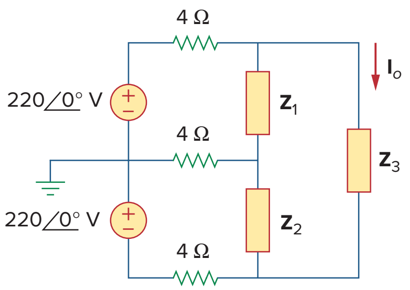

Figure 12.66
For Prob. 12.60.

12.61 Given the circuit in Fig. 12.67, use *PSpice or MultiSim* to determine currents $\mathbf{I}_{aA}$ and voltage $\mathbf{V}_{BN}$.

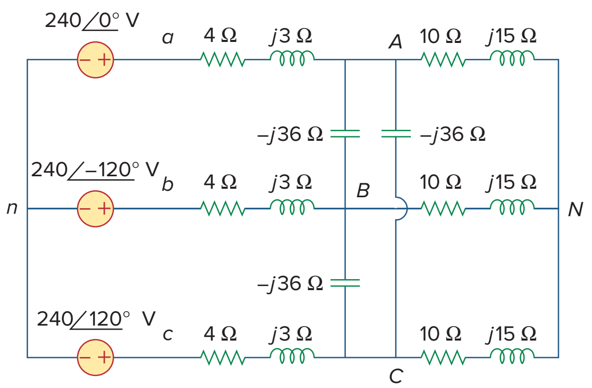

Figure 12.67
For Prob. 12.61.

12.62 Using Fig. 12.68, design a problem to help other students better understand how to use *PSpice or MultiSim* to analyze three-phase circuits.

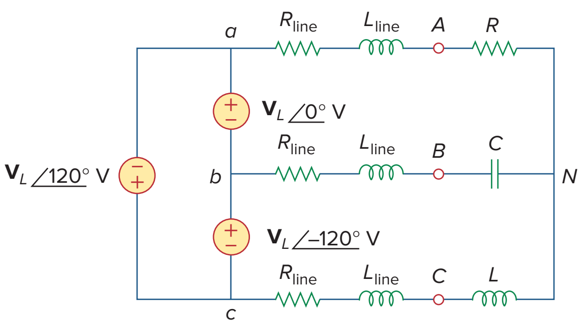

Figure 12.68
For Prob. 12.62.

12.63 Use *PSpice or MultiSim* to find currents $\mathbf{I}_{aA}$ and $\mathbf{I}_{AC}$ in the unbalanced three-phase system shown in Fig. 12.69. Let

$$\mathbf{Z}_l = 2 + j, \qquad \mathbf{Z}_1 = 40 + j20\ \Omega,$$
$$\mathbf{Z}_2 = 50 - j30\ \Omega, \qquad \mathbf{Z}_3 = 25\ \Omega$$

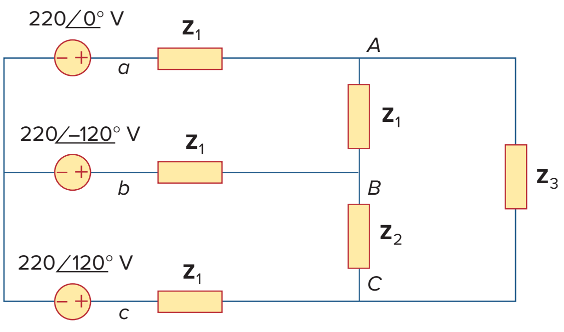

Figure 12.69
For Prob. 12.63.

12.64 For the circuit in Fig. 12.58, use *PSpice or MultiSim* to find the line currents and the phase currents.

12.65 A balanced three-phase circuit is shown in Fig. 12.70 on the next page. Use *PSpice or MultiSim* to find the line currents $\mathbf{I}_{aA}$, $\mathbf{I}_{bB}$, and $\mathbf{I}_{cC}$.

Section 12.10 Applications

12.66 A three-phase, four-wire system operating with a 480-V line voltage is shown in Fig. 12.71. The source voltages are balanced. The power absorbed by the resistive wye-connected load is measured by the three-wattmeter method. Calculate:

(a) the voltage to neutral

(b) the currents $\mathbf{I}_1$, $\mathbf{I}_2$, $\mathbf{I}_3$, and $\mathbf{I}_n$

(c) the readings of the wattmeters

(d) the total power absorbed by the load

***12.67** As shown in Fig. 12.72, a three-phase four-wire line with a phase voltage of 120 V rms and positive phase sequence supplies a balanced motor load at 260 kVA at 0.85 pf lagging. The motor load is connected to the three main lines marked *a, b,* and *c*. In addition, incandescent lamps (unity pf) are connected as follows: 24 kW from line *c* to the neutral, 15 kW from line b to the neutral, and 9 kW from line *c* to the neutral.

(a) If three wattmeters are arranged to measure the power in each line, calculate the reading of each meter.

(b) Find the magnitude of the current in the neutral line.

* An asterisk indicates a challenging problem.

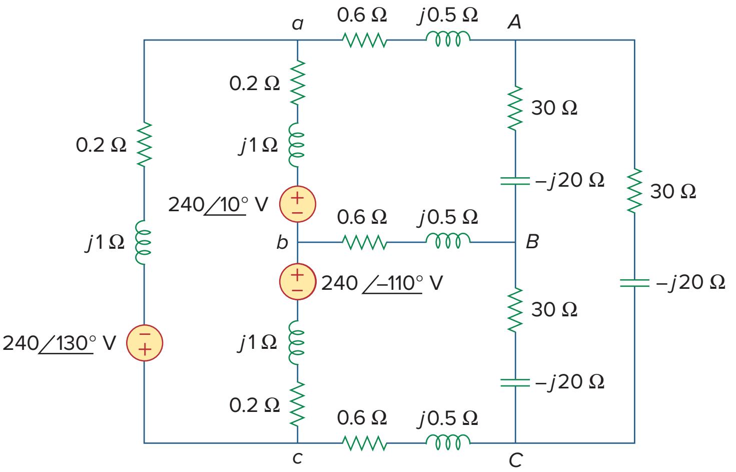

Figure 12.70
For Prob. 12.65.

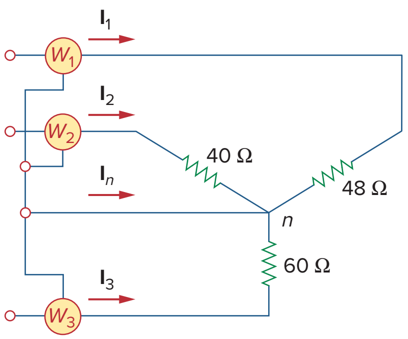

Figure 12.71
For Prob. 12.66.

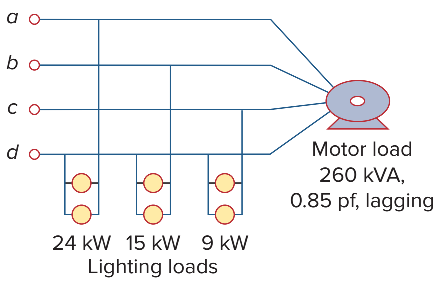

Figure 12.72
For Prob. 12.67.

12.68 Meter readings for a three-phase wye-connected alternator supplying power to a motor indicate that the line voltages are 330 V, the line currents are 8.4 A, and the total line power is 4.5 kW. Find:

(a) the load in VA

(b) the load pf

(c) the phase current

(d) the phase voltage

12.69 A certain store contains three balanced three-phase loads. The three loads are:

Load 1: 16 kVA at 0.85 pf lagging
Load 2: 12 kVA at 0.6 pf lagging
Load 3: 8 kW at unity pf

The line voltage at the load is 208 V rms at 60 Hz, and the line impedance is $0.4 + j0.8\ \Omega$. Determine the line current and the complex power delivered to the loads.

12.70 The two-wattmeter method gives $P_1 = 1200$ W and $P_2 = -400$ W for a three-phase motor running on a 240-V line. Assume that the motor load is wye-connected and that it draws a line current of 6 A. Calculate the pf of the motor and its phase impedance.

12.71 In Fig. 12.73, two wattmeters are properly connected to the unbalanced load supplied by a balanced source such that $\mathbf{V}_{ab} = 208\underline{/0^\circ}$ V with positive phase sequence.

(a) Determine the reading of each wattmeter.

(b) Calculate the total apparent power absorbed by the load.

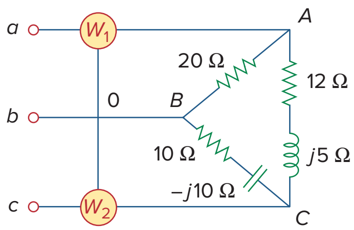

Figure 12.73
For Prob. 12.71.

12.72 If wattmeters W_1 and W_2 are properly connected respectively between lines a and b and lines b and c to measure the power absorbed by the delta-connected load in Fig. 12.44, predict their readings.

12.73 For the circuit displayed in Fig. 12.74, find the wattmeter readings.

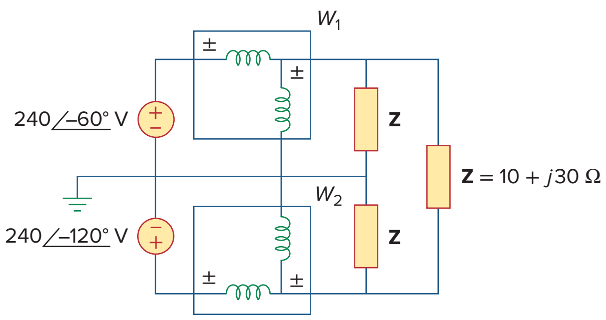

Figure 12.74
For Prob. 12.73.

12.74 Predict the wattmeter readings for the circuit in Fig. 12.75.

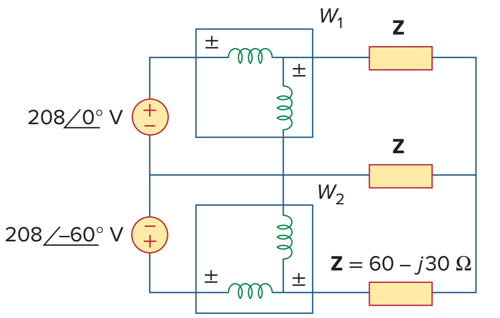

Figure 12.75
For Prob. 12.74.

12.75 A man has a body resistance of 600 Ω. How much current flows through his ungrounded body:

(a) when he touches the terminals of a 12-V autobattery?

(b) when he sticks his finger into a 120-V light socket?

12.76 Show that the I^2R losses will be higher for a 120-V appliance than for a 240-V appliance if both have the same power rating.

Comprehensive Problems

12.77 A three-phase generator supplied 10 kVA at a power factor of 0.85 lagging. If 7,500 W are delivered to the load and line losses are 160 W per phase, what are the losses in the generator?

12.78 A three-phase 440-V, 51-kW, 60-kVA inductive load operates at 60 Hz and is wye-connected. It is desired to correct the power factor to 0.95 lagging. What value of capacitor should be placed in parallel with each load impedance?

12.79 A balanced three-phase generator has an *abc* phase sequence with phase voltage $\mathbf{V}_{an} = 554.3\underline{/0^\circ}$ V. The generator feeds an induction motor which may be represented by a balanced Y-connected load with an impedance of $12 + j5$ Ω per phase. Find the line currents and the load voltages. Assume a line impedance of 2 Ω per phase.

12.80 A balanced three-phase source furnishes power to the following three loads:

Load 1: 6 kVA at 0.83 pf lagging

Load 2: unknown

Load 3: 8 kW at 0.7071 pf leading

If the line current is 84.6 A rms, the line voltage at the load is 208 V rms, and the combined load has a 0.8 pf lagging, determine the unknown load.

12.81 A professional center is supplied by a balanced three-phase source. The center has four balanced three-phase loads as follows:

Load 1: 150 kVA at 0.8 pf leading

Load 2: 100 kW at unity pf

Load 3: 200 kVA at 0.6 pf lagging

Load 4: 80 kW and 95 kVAR (inductive)

If the line impedance is $0.02 + j0.05$ Ω per phase and the line voltage at the loads is 480 V, find the magnitude of the line voltage at the source.

12.82 A balanced three-phase system has a distribution wire with impedance $2 + j6$ Ω per phase. The system supplies two three-phase loads that are connected in parallel. The first is a balanced wye-connected load that absorbs 400 kVA at a power factor of 0.8 lagging. The second load is a balanced delta-connected load with impedance of $10 + j8$ Ω per phase. If the magnitude of the line voltage at the loads is 2400 V rms, calculate the magnitude of the line voltage at the source and the total complex power supplied to the two loads.

12.83 A commercially available three-phase inductive motor operates at a full load of 120 hp (1 hp = 746 W) at 95 percent efficiency at a lagging power factor of 0.707. The motor is connected in parallel to a 80-kW balanced three-phase heater at unity power factor. If the magnitude of the line voltage is 480 V rms, calculate the line current.

*12.84 Figure 12.76 displays a three-phase delta-connected motor load which is connected to a line voltage of 440 V and draws 4 kVA at a power factor of 72 percent lagging. In addition, a single 1.8 kVAR capacitor is connected between lines *a* and *b*, while a 800-W lighting load is connected between line *c* and neutral. Assuming the *abc* sequence and taking $\mathbf{V}_{an} = V_p\angle 0°$, find the magnitude and phase angle of currents $\mathbf{I}_a$, $\mathbf{I}_b$, $\mathbf{I}_c$, and $\mathbf{I}_n$.

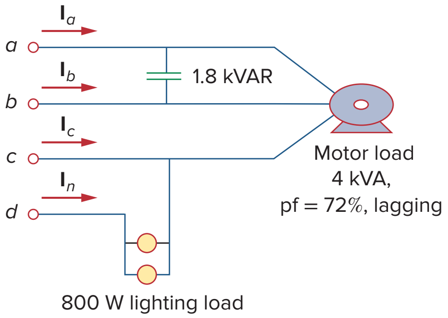

Figure 12.76
For Prob. 12.84.

12.85 Design a three-phase heater with suitable symmetric loads using wye-connected pure resistance. Assume that the heater is supplied by a 240-V line voltage and is to give 27 kW of heat.

12.86 For the single-phase three-wire system in Fig. 12.77, find currents $\mathbf{I}_{aA}$, $\mathbf{I}_{bB}$, and $\mathbf{I}_{nN}$.

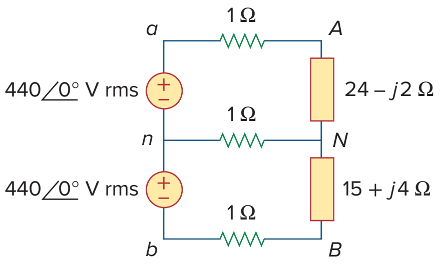

Figure 12.77
For Prob. 12.86.

12.87 Consider the single-phase three-wire system shown in Fig. 12.78. Find the current in the neutral wire and the complex power supplied by each source. Take $\mathbf{V}_s$ as a $220\angle 0°$-V, 60-Hz source.

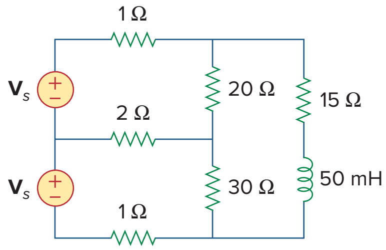

Figure 12.78
For Prob. 12.87.

Review Questions

13.1 Refer to the two magnetically coupled coils of Fig. 13.69(a). The polarity of the mutual voltage is:

(a) Positive (b) Negative

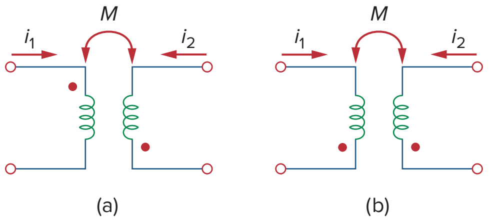

Figure 13.69
For Review Questions 13.1 and 13.2.

13.2 For the two magnetically coupled coils of Fig. 13.69(b), the polarity of the mutual voltage is:

(a) Positive (b) Negative

13.3 The coefficient of coupling for two coils having $L_1 = 2$ H, $L_2 = 8$ H, $M = 3$ H is:

(a) 0.1875 (b) 0.75
(c) 1.333 (d) 5.333

13.4 A transformer is used in stepping down or stepping up:

(a) dc voltages (b) ac voltages
(c) both dc and ac voltages

13.5 The ideal transformer in Fig. 13.70(a) has $N_2/N_1 = 10$. The ratio V_2/V_1 is:

(a) 10 (b) 0.1 (c) −0.1 (d) −10

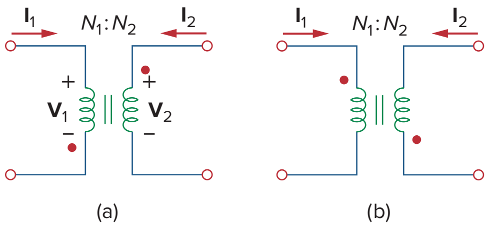

Figure 13.70
For Review Questions 13.5 and 13.6.

13.6 For the ideal transformer in Fig. 13.70(b), $N_2/N_1 = 10$. The ratio i_2/I_1 is:

(a) 10 (b) 0.1 (c) −0.1 (d) −10

13.7 A three-winding transformer is connected as portrayed in Fig. 13.71(a). The value of the output voltage V_o is:

(a) 10 (b) 6 (c) −6 (d) −10

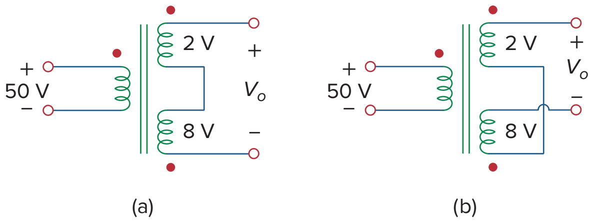

Figure 13.71
For Review Questions 13.7 and 13.8.

13.8 If the three-winding transformer is connected as in Fig. 13.71(b), the value of the output voltage V_o is:

(a) 10 (b) 6 (c) −6 (d) −10

13.9 In order to match a source with internal impedance of 500 Ω to a 15-Ω load, what is needed is:

(a) step-up linear transformer
(b) step-down linear transformer
(c) step-up ideal transformer
(d) step-down ideal transformer
(e) autotransformer

13.10 Which of these transformers can be used as an isolation device?

(a) linear transformer (b) ideal transformer
(c) autotransformer (d) all of the above

Answers: 13.1b, 13.2a, 13.3b, 13.4b, 13.5d, 13.6b, 13.7c, 13.8a, 13.9d, 13.10b.

Problems[1]

Section 13.2 Mutual Inductance

13.1 For the three coupled coils in Fig. 13.72, calculate the total inductance.

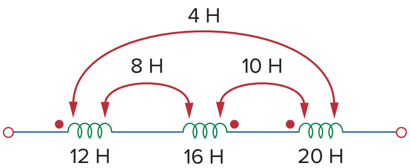

Figure 13.72
For Prob. 13.1.

13.2 Using Fig. 13.73, design a problem to help other students better understand mutual inductance.

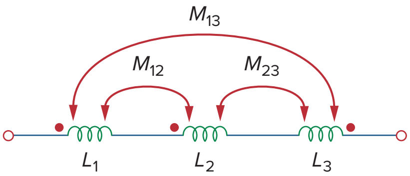

Figure 13.73
For Prob. 13.2.

13.3 Two coils connected in series-aiding fashion have a total inductance of 500 mH. When connected in a series-opposing configuration, the coils have a total inductance of 300 mH. If the inductance of one coil (L_1) is three times the other, find L_1, L_2, and M. What is the coupling coefficient?

13.4 (a) For the coupled coils in Fig. 13.74(a), show that

$$L_{eq} = L_1 + L_2 + 2M$$

(b) For the coupled coils in Fig. 13.74(b), show that

$$L_{eq} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$$

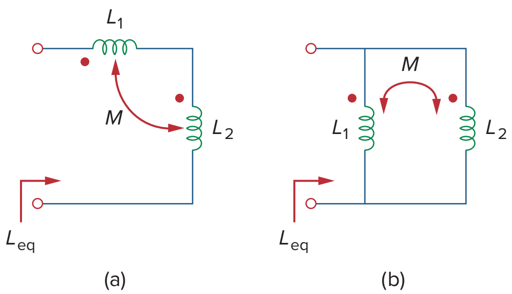

Figure 13.74
For Prob. 13.4.

13.5 Two coils are mutually coupled, with $L_1 = 50$ mH, $L_2 = 120$ mH, and $k = 0.5$. Calculate the maximum possible equivalent inductance if:

(a) the two coils are connected in series
(b) the coils are connected in parallel

13.6 Given the circuit shown in Fig. 13.75, determine the value of $\mathbf{V}_1$ and $\mathbf{I}_2$.

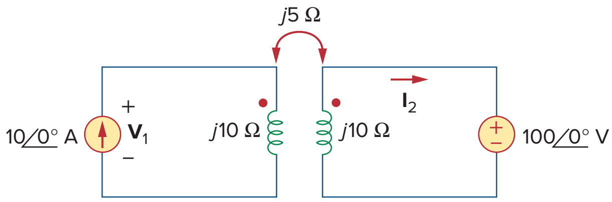

Figure 13.75
For Prob. 13.6.

13.7 For the circuit in Fig. 13.76, find $\mathbf{V}_o$.

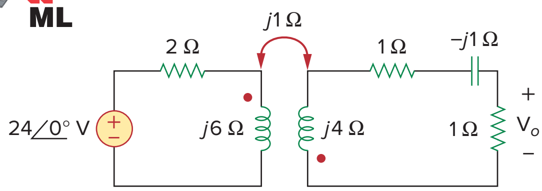

Figure 13.76
For Prob. 13.7.

13.8 Find $v(t)$ for the circuit in Fig. 13.77.

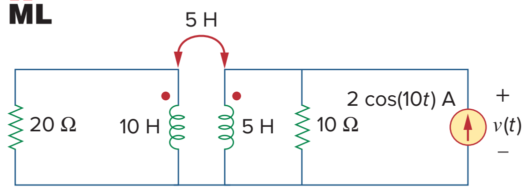

Figure 13.77
For Prob. 13.8.

13.9 Find $\mathbf{V}_x$ in the network shown in Fig. 13.78.

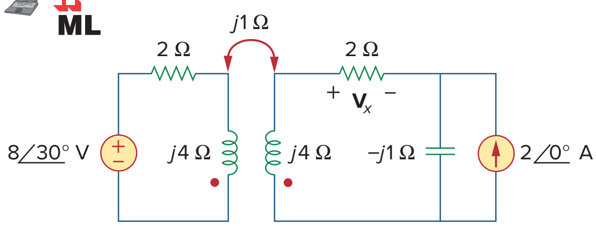

Figure 13.78
For Prob. 13.9.

[1] Remember, unless otherwise specified, assume all values of currents and voltages are rms.

13.10 Find v_o in the circuit of Fig. 13.79.

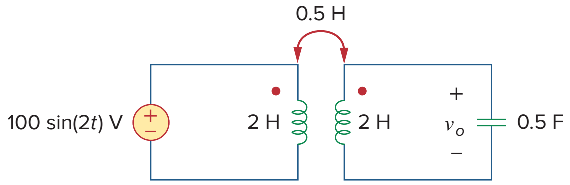

Figure 13.79
For Prob. 13.10.

13.11 Use mesh analysis to find i_x in Fig. 13.80, where

$$i_s = 4\cos(600t) \text{ A} \quad \text{and} \quad v_s = 110\cos(600t + 30°)$$

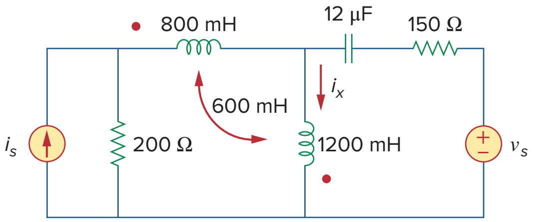

Figure 13.80
For Prob. 13.11.

13.12 Determine the equivalent L_{eq} in the circuit of Fig. 13.81.

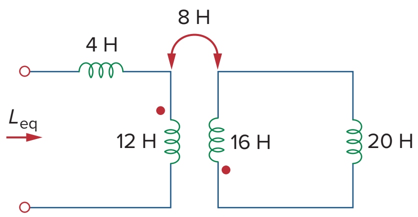

Figure 13.81
For Prob. 13.12.

13.13 For the circuit in Fig. 13.82, determine the impedance seen by the source.

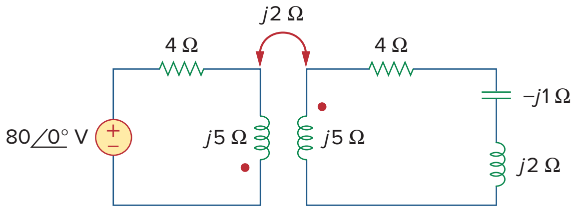

Figure 13.82
For Prob. 13.13.

13.14 Obtain the Thevenin equivalent circuit for the circuit in Fig. 13.83 at terminals *a-b*.

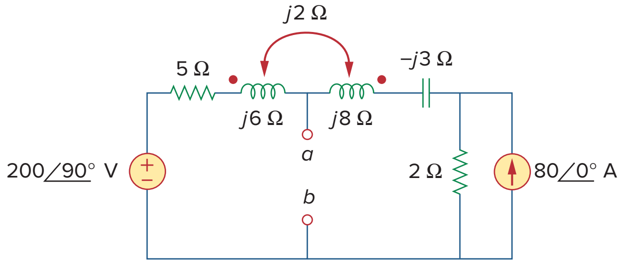

Figure 13.83
For Prob. 13.14.

13.15 Find the Norton equivalent for the circuit in Fig. 13.84 at terminals *a-b*.

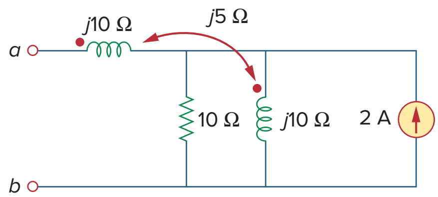

Figure 13.84
For Prob. 13.15.

13.16 Obtain the Norton equivalent at terminals *a-b* of the circuit in Fig. 13.85.

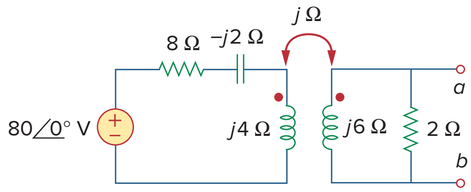

Figure 13.85
For Prob. 13.16.

13.17 In the circuit of Fig. 13.86, Z_L is a 15-mH inductor having an impedance of $j40\ \Omega$. Determine Z_{in} when $k = 0.6$.

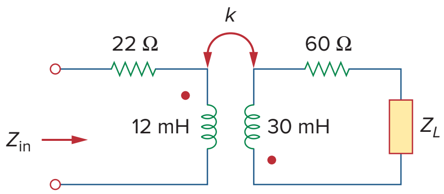

Figure 13.86
For Prob. 13.17.

13.18 Find the Thevenin equivalent to the left of the load Z in the circuit of Fig. 13.87.

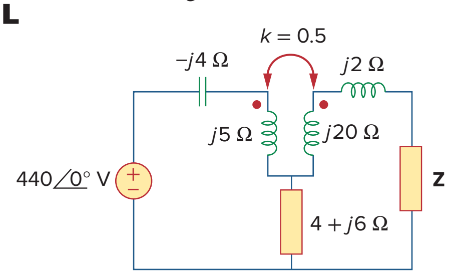

Figure 13.87
For Prob. 13.18.

13.19 Determine an equivalent T-section that can be used to replace the transformer in Fig. 13.88.

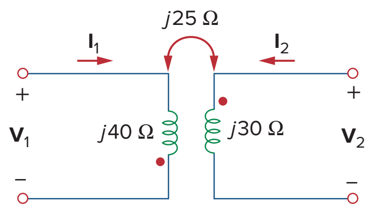

Figure 13.88
For Prob. 13.19.

Section 13.3 Energy in a Coupled Circuit

13.20 Determine currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.89. Find the energy stored in the coupled coils at $t = 2$ ms. Take $\omega = 1{,}000$ rad/s.

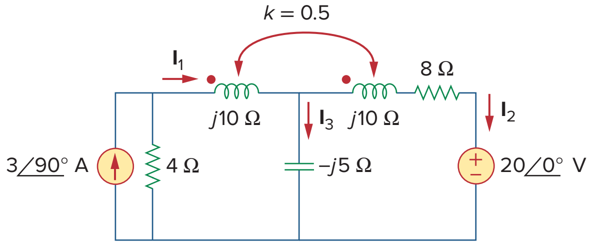

Figure 13.89
For Prob. 13.20.

13.21 Using Fig. 13.90, design a problem to help other students better understand energy in a coupled circuit.

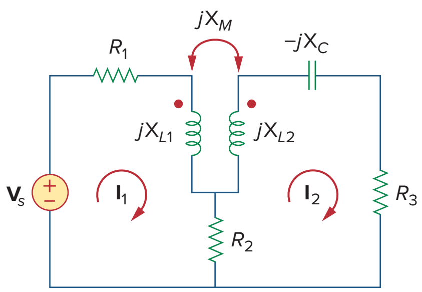

Figure 13.90
For Prob. 13.21.

***13.22** Find current $\mathbf{I}_o$ in the circuit of Fig. 13.91.

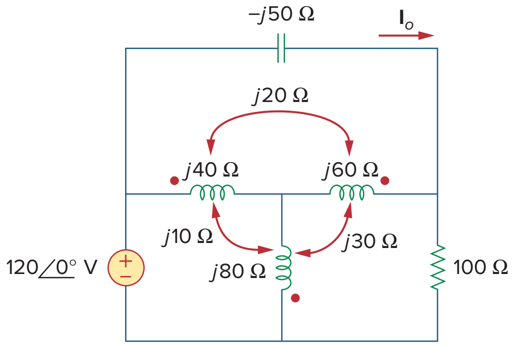

Figure 13.91
For Prob. 13.22.

13.23 Let $i_s = 5\cos(100t)$ A. Calculate the voltage across the capacitor, v_c. Also calculate the value of the energy stored in the coupled coils at $t = 2.5\pi$ ms.

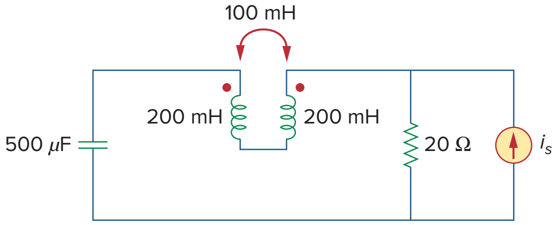

Figure 13.92
For Prob. 13.23.

13.24 In the circuit of Fig. 13.93,

(a) find the coupling coefficient,
(b) calculate v_o,
(c) determine the energy stored in the coupled inductors at $t = 2$ s.

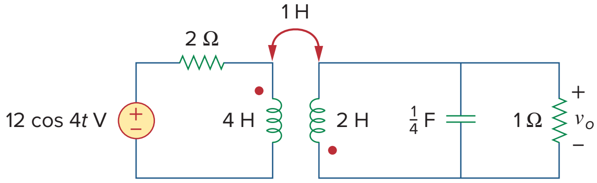

Figure 13.93
For Prob. 13.24.

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*An asterisk indicates a challenging problem.

13.25 For the network in Fig. 13.94, find $\mathbf{Z}_{ab}$ and $\mathbf{I}_o$.

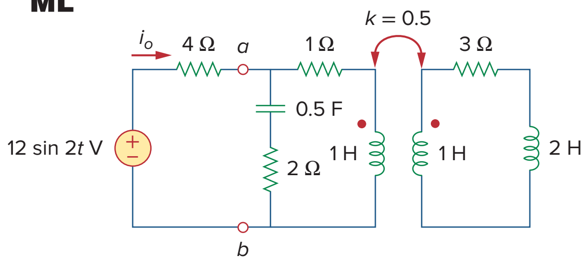


Figure 13.94
For Prob. 13.25.

13.26 Find $\mathbf{I}_o$ in the circuit of Fig. 13.95. Switch the dot on the winding on the right and calculate $\mathbf{I}_o$ again.

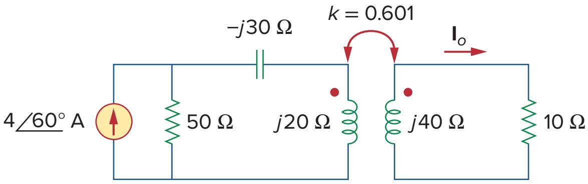


Figure 13.95
For Prob. 13.26.

13.27 Find the average power delivered to the 50-Ω resistor in the circuit of Fig. 13.96.

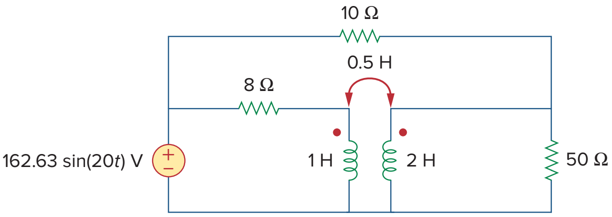


Figure 13.96
For Prob. 13.27.

***13.28** In the circuit of Fig. 13.97, find the value of X that will give maximum power transfer to the 20-Ω load.

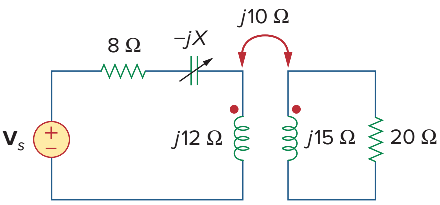


Figure 13.97
For Prob. 13.28.

Section 13.4 Linear Transformers

13.29 In the circuit of Fig. 13.98, find the value of the coupling coefficient k that will make the 10-Ω resistor dissipate 1.28 kW. For this value of k, find the energy stored in the coupled coils at $t = 1.5$ s.

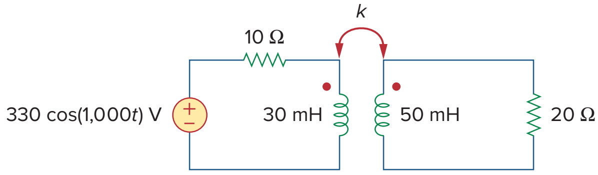


Figure 13.98
For Prob. 13.29.

13.30 (a) Find the input impedance of the circuit in Fig. 13.99 using the concept of reflected impedance.
(b) Obtain the input impedance by replacing the linear transformer by its T equivalent.

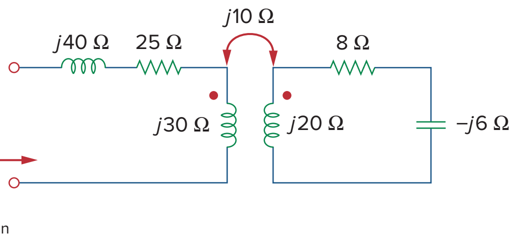


Figure 13.99
For Prob. 13.30.

13.31 Using Fig. 13.100, design a problem to help other students better understand linear transformers and how to find T-equivalent and Π-equivalent circuits.

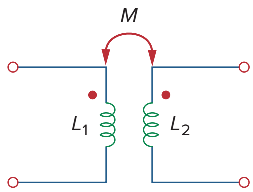


Figure 13.100
For Prob. 13.31.

***13.32** Two linear transformers are cascaded as shown in Fig. 13.101. Show that

$$\mathbf{Z}_{in} = \frac{\omega^2 R(L_a^2 + L_a L_b - M_a^2) + j\omega^3(L_a^2 L_b + L_a L_b^2 - L_a M_b^2 - L_b M_a^2)}{\omega^2(L_a L_b + L_b^2 - M_b^2) - j\omega R(L_a + L_b)}$$

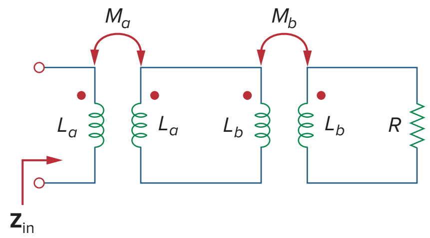


Figure 13.101
For Prob. 13.32.

13.33 Determine the input impedance of the air-core transformer circuit of Fig. 13.102.

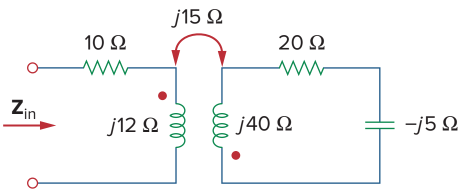


Figure 13.102
For Prob. 13.33.

13.34 Using Fig. 13.103, design a problem to help other students better understand how to find the input impedance of circuits with transformers.

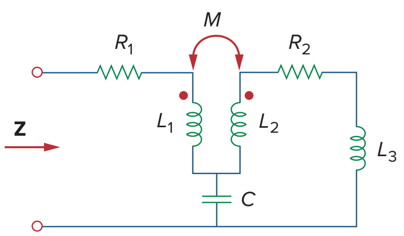


Figure 13.103
For Prob. 13.34.

* **13.35** Find currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.104.

Section 13.5 Ideal Transformers

13.36 As done in Fig. 13.32, obtain the relationships between terminal voltages and currents for each of the ideal transformers in Fig. 13.105.

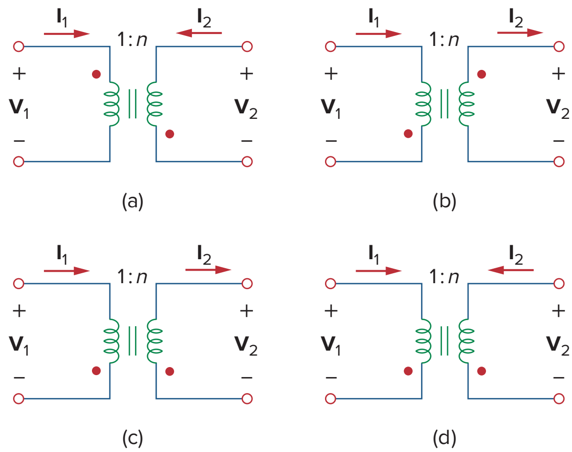


Figure 13.105
For Prob. 13.36.

13.37 A 240/2,400-V rms step-up ideal transformer delivers 50 kW to a resistive load. Calculate:

(a) the turns ratio
(b) the primary current
(c) the secondary current

13.38 Design a problem to help other students better understand ideal transformers.

13.39 A 1,200/240-V rms transformer has impedance $60\angle{-30^\circ}$ Ω on the high-voltage side. If the transformer is connected to a $0.8\angle{10^\circ}$-Ω load on the low-voltage side, determine the primary and secondary currents when the transformer is connected to 1,200 V rms.

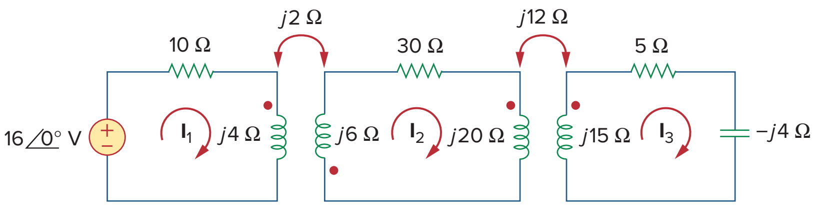


Figure 13.104
For Prob. 13.35.

13.40 The primary of an ideal transformer with a turns ratio of 5 is connected to a voltage source with Thevenin parameters $v_{Th} = 10 \cos 2000t$ V and $R_{Th} = 100\ \Omega$. Determine the average power delivered to a 200-Ω load connected across the secondary winding.

13.41 Given $I_2 = 2$ A, determine the value of I_s in Fig. 13.106.
ML

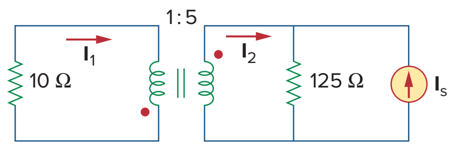


Figure 13.106
For Prob. 13.41.

13.42 For the circuit in Fig. 13.107, determine the power absorbed by the 2-Ω resistor. Assume the 120 V is an rms value.
ML

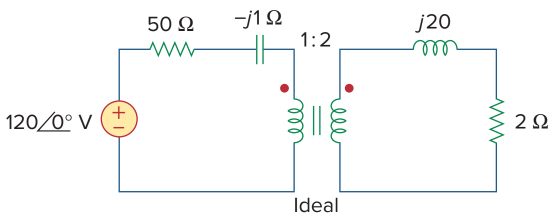


Figure 13.107
For Prob. 13.42.

13.43 Obtain $\mathbf{V}_1$ and $\mathbf{V}_2$ in the ideal transformer circuit of Fig. 13.108.
ML

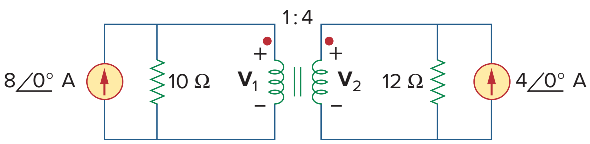


Figure 13.108
For Prob. 13.43.

***13.44** In the ideal transformer circuit of Fig. 13.109, find $i_1(t)$ and $i_2(t)$.

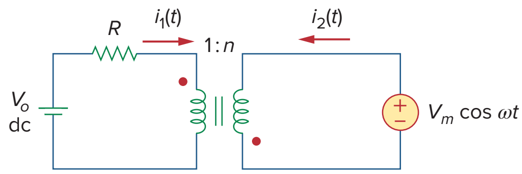


Figure 13.109
For Prob. 13.44.

13.45 For the circuit shown in Fig. 13.110, find the value of the average power absorbed by the 8-Ω resistor.
ML

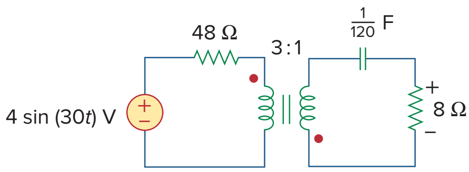


Figure 13.110
For Prob. 13.45.

13.46 (a) Find $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 13.111 below.
(b) Switch the dot on one of the windings. Find $\mathbf{I}_1$ and $\mathbf{I}_2$ again.
ML

13.47 Find $v(t)$ for the circuit in Fig. 13.112.
ML

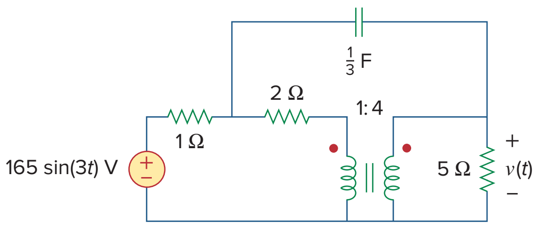


Figure 13.112
For Prob. 13.47.

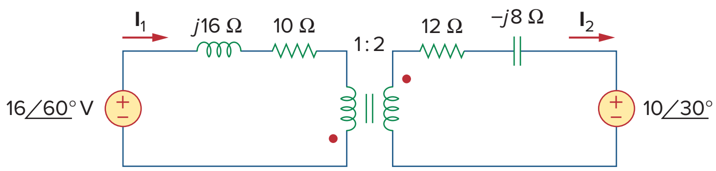


Figure 13.111
For Prob. 13.46.

13.48 Using Fig. 13.113, design a problem to help other students better understand how ideal transformers work.

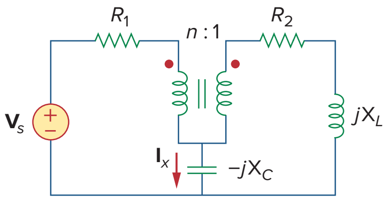


Figure 13.113
For Prob. 13.48.

13.49 Find current i_x in the ideal transformer circuit shown in Fig. 13.114.

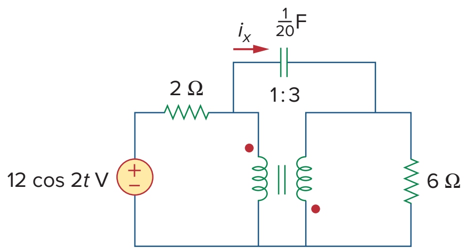


Figure 13.114
For Prob. 13.49.

13.50 Calculate the input impedance for the network in Fig. 13.115.

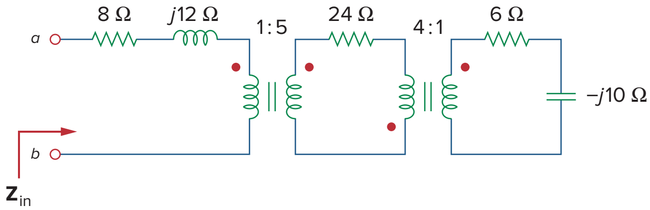


Figure 13.115
For Prob. 13.50.

13.51 Use the concept of reflected impedance to find the input impedance and current $\mathbf{I}_1$ in Fig. 13.116.

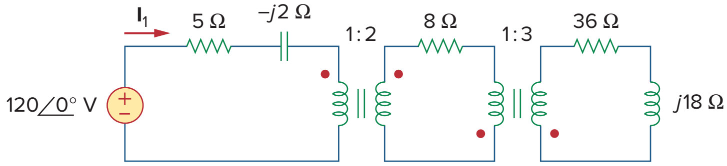


Figure 13.116
For Prob. 13.51.

13.52 For the circuit in Fig. 13.117, determine the turns ratio n that will cause maximum average power transfer to the load. Calculate that maximum average power.

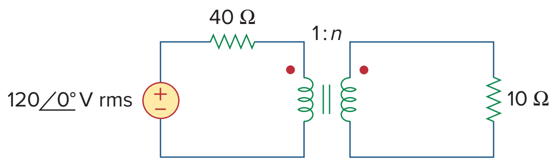


Figure 13.117
For Prob. 13.52.

13.53 Refer to the network in Fig. 13.118.

(a) Find n for maximum power supplied to the 200-Ω load.

(b) Determine the power in the 200-Ω load if $n = 10$.

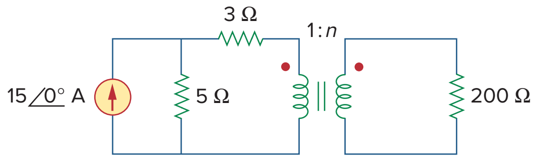


Figure 13.118
For Prob. 13.53.

13.54 A transformer is used to match an amplifier with an 8-Ω load as shown in Fig. 13.119. The Thevenin equivalent of the amplifier is: $V_{Th} = 10$ V, $Z_{Th} = 128$ Ω.

(a) Find the required turns ratio for maximum energy power transfer.
(b) Determine the primary and secondary currents.
(c) Calculate the primary and secondary voltages.

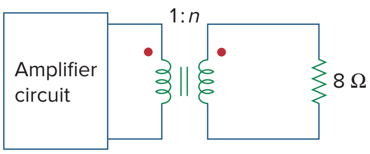


Figure 13.119
For Prob. 13.54.

13.55 For the circuit in Fig. 13.120, calculate the equivalent resistance.

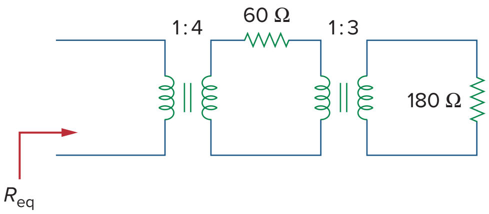


Figure 13.120
For Prob. 13.55.

13.56 Find the power absorbed by the 100-Ω resistor in the ideal transformer circuit of Fig. 13.121.

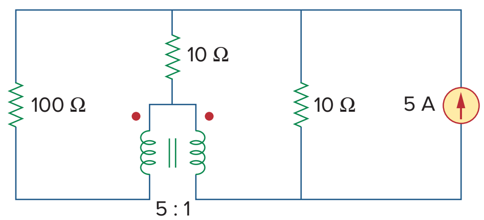


Figure 13.121
For Prob. 13.56.

13.57 For the ideal transformer circuit of Fig. 13.122 below, find:

(a) $\mathbf{I}_1$ and $\mathbf{I}_2$,
(b) $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_o$,
(c) the complex power supplied by the source.

13.58 Determine the average power absorbed by each resistor in the circuit of Fig. 13.123.

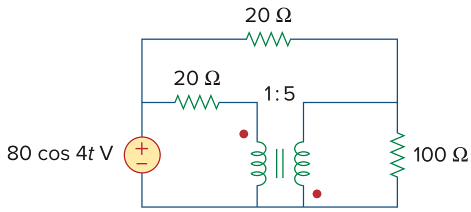


Figure 13.123
For Prob. 13.58.

13.59 In the circuit of Fig. 13.124, let $v_s = 165 \sin(1{,}000t)$ V. Find the average power delivered to each resistor.

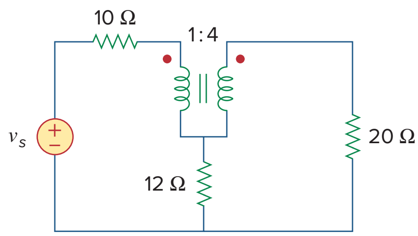


Figure 13.124
For Prob. 13.59.

13.60 Refer to the circuit in Fig. 13.125 on the following page.

(a) Find currents $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$.
(b) Find the power dissipated in the 40-Ω resistor.

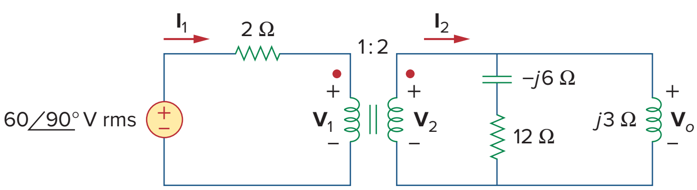


Figure 13.122
For Prob. 13.57.

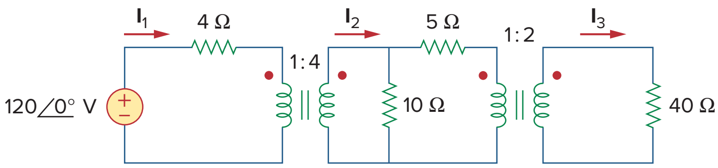


Figure 13.125
For Prob. 13.60.

***13.61** For the circuit in Fig. 13.126, find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{V}_o$.

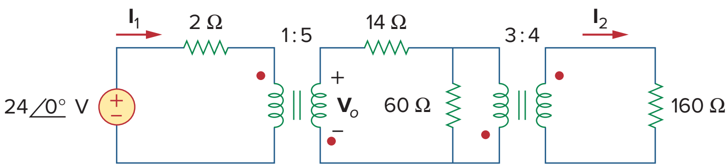


Figure 13.126
For Prob. 13.61.

13.62 For the network in Fig. 13.127, find:

(a) the complex power supplied by the source,
(b) the average power delivered to the 18-Ω resistor.

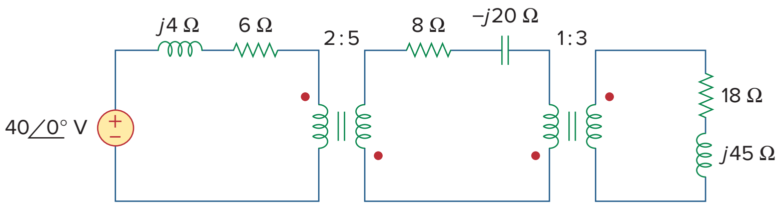


Figure 13.127
For Prob. 13.62.

13.63 Find the mesh currents in the circuit of Fig. 13.128

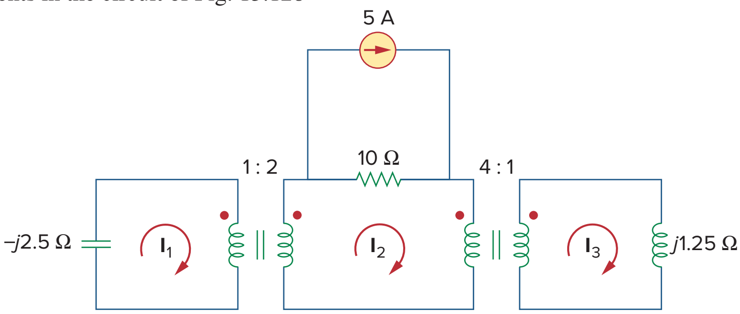


Figure 13.128
For Prob. 13.63.

13.64 For the circuit in Fig. 13.129, find the turns ratio so that the maximum power is delivered to the 30-kΩ resistor.

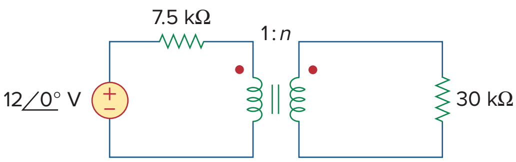


Figure 13.129
For Prob. 13.64.

***13.65** Calculate the average power dissipated by the 20-Ω resistor in Fig. 13.130.

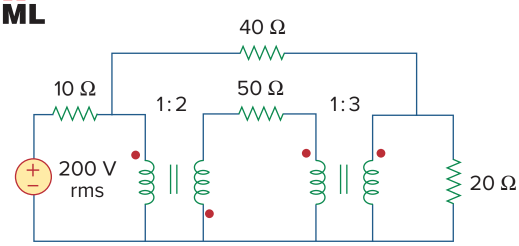


Figure 13.130
For Prob. 13.65.

Section 13.6 Ideal Autotransformers

13.66 Design a problem to help other students better understand how the ideal autotransformer works.

13.67 An autotransformer with a 40 percent tap is supplied by an 880-V, 60-Hz source and is used for step-down operation. A 5-kVA load operating at unity power factor is connected to the secondary terminals. Find:

(a) the secondary voltage,
(b) the secondary current,
(c) the primary current.

13.68 In the ideal autotransformer of Fig. 13.131, calculate $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_o$. Find the average power delivered to the load.

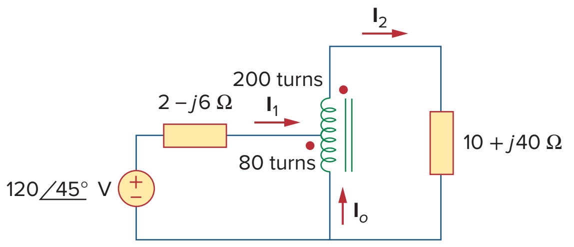


Figure 13.131
For Prob. 13.68.

***13.69** In the circuit of Fig. 13.131, $N_1 = 190$ turns and $N_2 = 10$ turns. Determine the Thevenin equivalent circuit looking into terminals *a* and *b*. What would be the value of $\mathbf{Z}_L$ that would absorb maximum power from the circuit?

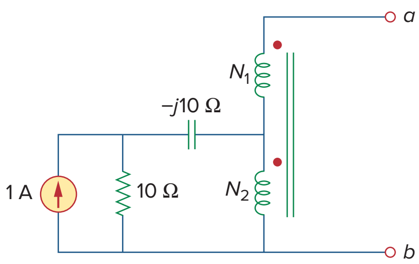


Figure 13.132
For Prob. 13.69.

13.70 In the ideal transformer circuit shown in Fig. 13.133, determine the average power delivered to the load.

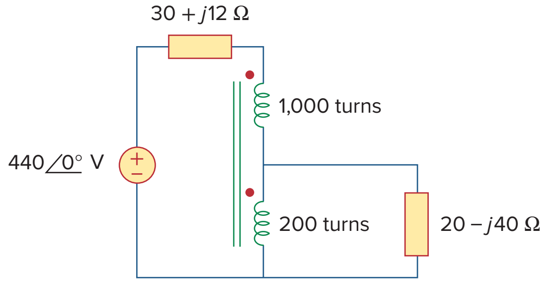


Figure 13.133
For Prob. 13.70.

13.71 When individuals travel, their electrical appliances need to have converters to match the voltages required by their appliances to the local voltage available to power their appliances. Today these converters use power electronics to convert voltages. In the past these converters were autotransformers. The autotransformer shown in Fig. 13.134 is used to convert 115 to 220 V. What is the value of the turns? If the maximum current available from the 115 V source is 15 A, what will be the maximum current available for the 220-V appliance?

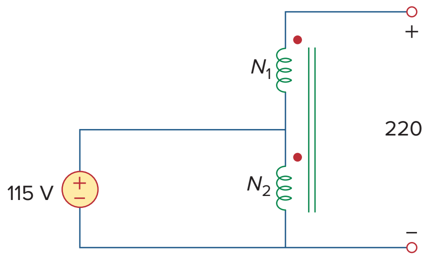


Figure 13.134
For Prob. 13.71.

Section 13.7 Three-Phase Transformers

13.72 In order to meet an emergency, three single-phase transformers with 12,470/7,200 V rms are connected in Δ-Y to form a three-phase transformer which is fed by a 12,470-V transmission line. If the transformer supplies 60 MVA to a load, find:

(a) the turns ratio for each transformer,
(b) the currents in the primary and secondary windings of the transformer,
(c) the incoming and outgoing transmission line currents.

13.73 Figure 13.135 on the next page shows a three-phase transformer that supplies a Y-connected load.

(a) Identify the transformer connection.
(b) Calculate currents $\mathbf{I}_2$ and $\mathbf{I}_c$.
(c) Find the average power absorbed by the load.

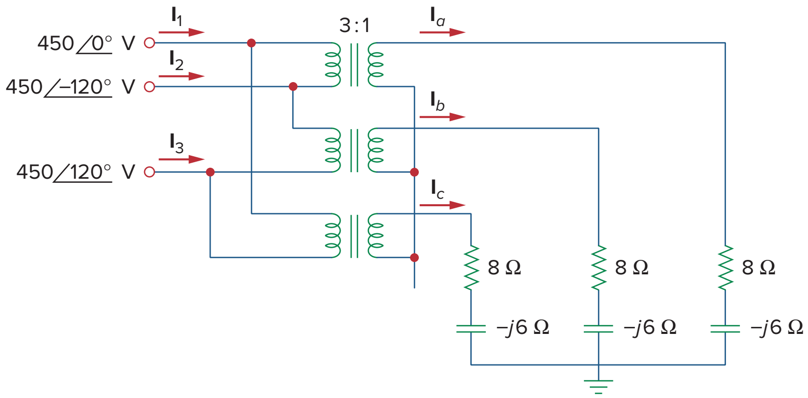


Figure 13.135
For Prob. 13.73.

13.74 Consider the three-phase transformer shown in Fig. 13.136. The primary is fed by a three-phase source with line voltage of 2.4 kV rms, while the secondary supplies a three-phase 120-kW balanced load at pf of 0.8. Determine:

(a) the type of transformer connections,
(b) the values of I_{LS} and I_{PS},
(c) the values of I_{LP} and I_{PP},
(d) the kVA rating of each phase of the transformer.

13.75 A balanced three-phase transformer bank with the Δ-Y connection depicted in Fig. 13.137 is used to step down line voltages from 4,500 V rms to 900 V rms. If the transformer feeds a 120-kVA load, find:

(a) the turns ratio for the transformer,
(b) the line currents at the primary and secondary sides.

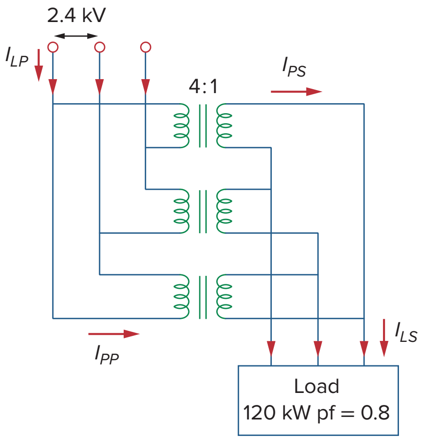


Figure 13.136
For Prob. 13.74.

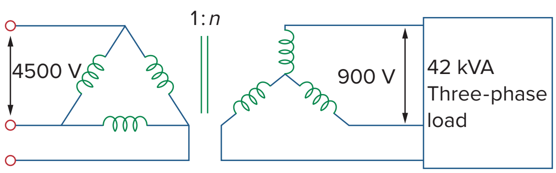


Figure 13.137
For Prob. 13.75.

13.76 **e2d** Using Fig. 13.138, design a problem to help other students better understand a Y-Δ, three-phase transformer and how they work.

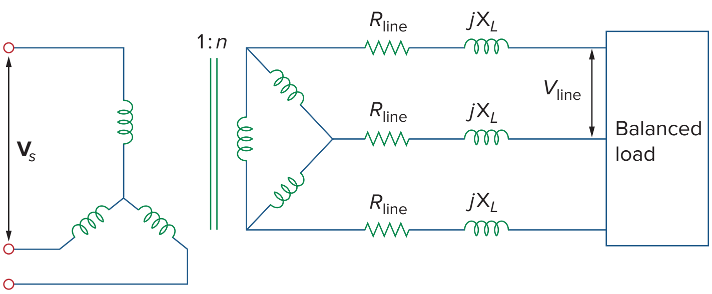


Figure 13.138
For Prob. 13.76.

13.77 The three-phase system of a town distributes power with a line voltage of 13.2 kV. A pole transformer connected to single wire and ground steps down the high-voltage wire to 120 V rms and serves a house as shown in Fig. 13.139.

(a) Calculate the turns ratio of the pole transformer to get 120 V.

(b) Determine how much current a 100-W lamp connected to the 120-V hot line draws from the high-voltage line.

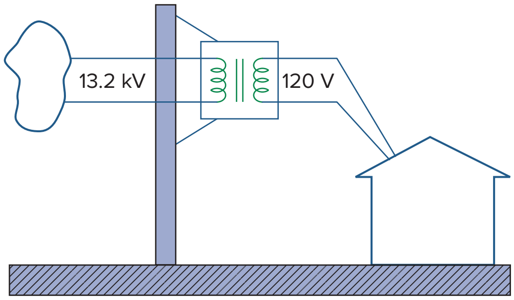


Figure 13.139
For Prob. 13.77.

Section 13.8 *PSpice* Analysis of Magnetically Coupled Circuits

13.78 Use *PSpice* or *MultiSim* to determine the mesh currents in the circuit of Fig. 13.140. Take $\omega = 1$ rad/s. Use $k = 0.5$ when solving this problem.

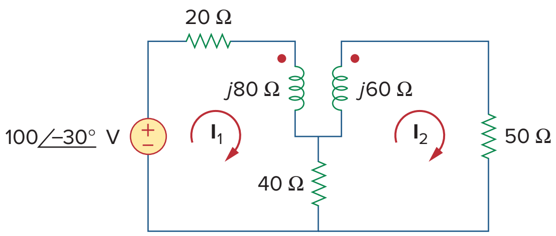


Figure 13.140
For Prob. 13.78.

13.79 Use *PSpice* or *MultiSim* to find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.141.

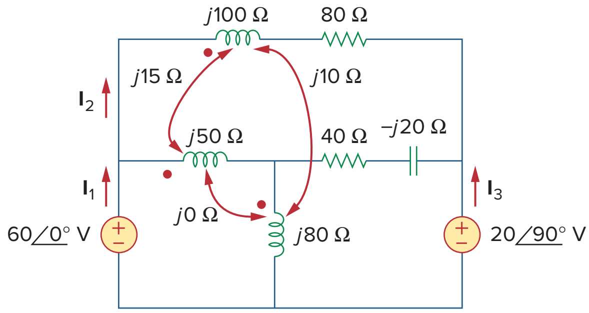


Figure 13.141
For Prob. 13.79.

13.80 Rework Prob. 13.22 using *PSpice* or *Multisim*.

13.81 Use *PSpice* or *MultiSim* to find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit of Fig. 13.142.

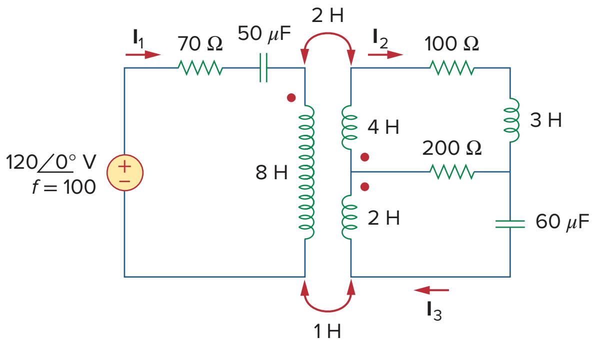


Figure 13.142
For Prob. 13.81.

13.82 Use *PSpice* or *MultiSim* to find $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{I}_o$ in the circuit of Fig. 13.143.

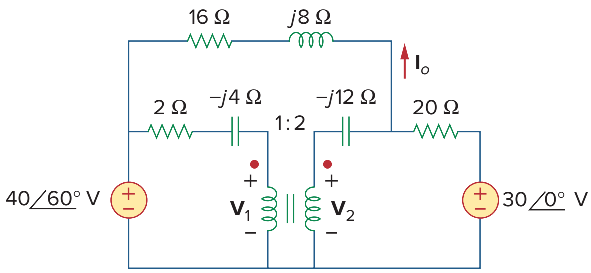


Figure 13.143
For Prob. 13.82.

13.83 Find $\mathbf{I}_x$ and $\mathbf{V}_x$ in the circuit of Fig. 13.144 using *PSpice* or *MultiSim*.

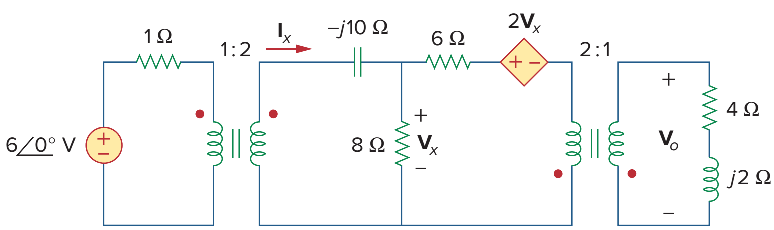


Figure 13.144
For Prob. 13.83.

13.84 Determine $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the ideal transformer circuit of Fig. 13.145 using *PSpice* or *MultiSim*.

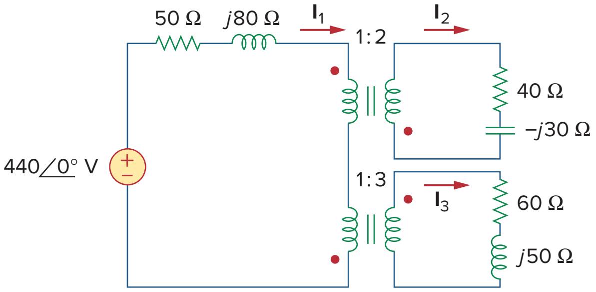


Figure 13.145
For Prob. 13.84.

Section 13.9 Applications

13.85 A stereo amplifier circuit with an output impedance of 7.2 kΩ is to be matched to a speaker with an input impedance of 8 Ω by a transformer whose primary side has 3,000 turns. Calculate the number of turns required on the secondary side.

13.86 A transformer having 2,400 turns on the primary and 48 turns on the secondary is used as an impedance-matching device. What is the reflected value of a 3-Ω load connected to the secondary?

13.87 A radio receiver has an input resistance of 300 Ω. When it is connected directly to an antenna system with a characteristic impedance of 75 Ω, an impedance mismatch occurs. By inserting an impedance-matching transformer ahead of the receiver, maximum power can be realized. Calculate the required turns ratio.

13.88 A step-down power transformer with a turns ratio of $n = 0.1$ supplies 12.6 V rms to a resistive load. If the primary current is 2.5 A rms, how much power is delivered to the load?

13.89 A 240/120-V rms power transformer is rated at 10 kVA. Determine the turns ratio, the primary current, and the secondary current.

13.90 A 4-kVA, 2,400/240-V rms transformer has 250 turns on the primary side. Calculate:

(a) the turns ratio,
(b) the number of turns on the secondary side,
(c) the primary and secondary currents.

13.91 A 25,000/240-V rms distribution transformer has a primary current rating of 75 A.

(a) Find the transformer kVA rating.
(b) Calculate the secondary current.

13.92 A 4,800-V rms transmission line feeds a distribution transformer with 1,200 turns on the primary and 28 turns on the secondary. When a 10-Ω load is connected across the secondary, find:

(a) the secondary voltage,
(b) the primary and secondary currents,
(c) the power supplied to the load.

Comprehensive Problems

13.93 A four-winding transformer (Fig. 13.146) is often used in equipment (e.g., PCs, VCRs) that may be operated from either 110 or 220 V. This makes the equipment suitable for both domestic and foreign use. Show which connections are necessary to provide:

(a) an output of 14 V with an input of 110 V,
(b) an output of 50 V with an input of 220 V.

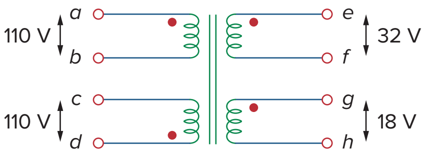


Figure 13.146
For Prob. 13.93.

***13.94** A 440/110-V ideal transformer can be connected to become a 550/440-V ideal autotransformer. There are four possible connections, two of which are wrong. Find the output voltage of:

(a) a wrong connection,
(b) the right connection.

13.95 Ten bulbs in parallel are supplied by a 7,200/120-V transformer as shown in Fig. 13.147, where the bulbs are modeled by the 144-Ω resistors. Find:

(a) the turns ratio n,
(b) the current through the primary winding.

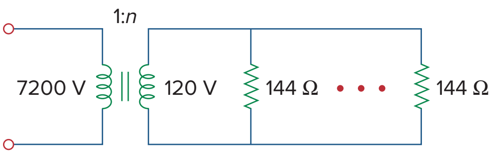


Figure 13.147
For Prob. 13.95.

range ($\omega_1 < \omega < \omega_2$). A band-stop filter passes only signals whose frequencies are outside a prescribed range ($\omega_1 > \omega > \omega_2$).

12. Scaling is the process whereby unrealistic element values are magnitude-scaled by a factor K_m and/or frequency-scaled by a factor K_f to produce realistic values.

$$R' = K_m R, \qquad L' = \frac{K_m}{K_f} L, \qquad C' = \frac{1}{K_m K_f} C$$

13. *PSpice* can be used to obtain the frequency response of a circuit if a frequency range for the response and the desired number of points within the range are specified in the AC Sweep.
14. The radio receiver—one practical application of resonant circuits—employs a band-pass resonant circuit to tune in one frequency among all the broadcast signals picked up by the antenna.
15. The touch-tone telephone and the crossover network are two typical applications of filters. The touch-tone telephone system employs filters to separate tones of different frequencies to activate electronic switches. The crossover network separates signals in different frequency ranges so that they can be delivered to different devices such as tweeters and woofers in a loudspeaker system.

Review Questions

14.1 A zero of the transfer function

$$H(s) = \frac{10(s+1)}{(s+2)(s+3)}$$

is at

(a) 10 (b) -1 (c) -2 (d) -3

14.2 On the Bode magnitude plot, the slope of $1/(5 + j\omega)^2$ for large values of ω is

(a) 20 dB/decade (b) 40 dB/decade
(c) -40 dB/decade (d) -20 dB/decade

14.3 On the Bode phase plot for $0.5 < \omega < 50$, the slope of $[1 + j10\omega - \omega^2/25]^2$ is

(a) 45°/decade (b) 90°/decade
(c) 135°/decade (d) 180°/decade

14.4 How much inductance is needed to resonate at 5 kHz with a capacitance of 12 nF?

(a) 2,652 H (b) 11.844 H
(c) 3.333 H (d) 84.43 mH

14.5 The difference between the half-power frequencies is called the:

(a) quality factor (b) resonant frequency
(c) bandwidth (d) cutoff frequency

14.6 In a series *RLC* circuit, which of these quality factors has the steepest magnitude response curve near resonance?

(a) $Q = 20$ (b) $Q = 12$
(c) $Q = 8$ (d) $Q = 4$

14.7 In a parallel *RLC* circuit, the bandwidth B is directly proportional to R.

(a) True (b) False

14.8 When the elements of an *RLC* circuit are both magnitude-scaled and frequency-scaled, which quality is unaffected?

(a) resistor (b) resonant frequency
(c) bandwidth (d) quality factor

14.9 What kind of filter can be used to select a signal of one particular radio station?

(a) low-pass (b) high-pass
(c) band-pass (d) band-stop

14.10 A voltage source supplies a signal of constant amplitude, from 0 to 40 kHz, to an RC low-pass filter. A load resistor, connected in parallel across the capacitor, experiences the maximum voltage at:

(a) dc (b) 10 kHz
(c) 20 kHz (d) 40 kHz

Answers: 14.1b, 14.2c, 14.3d, 14.4d, 14.5c, 14.6a, 14.7b, 14.8d, 14.9c, 14.10a.

Problems

Section 14.2 Transfer Function

14.1 Find the transfer function I_o/I_i of the RL circuit in Fig. 14.68. Express it using $\omega_0 = R/L$.

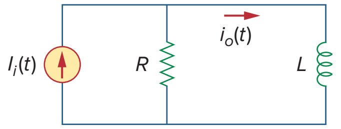


Figure 14.68
For Prob. 14.1.

14.2 Using Fig. 14.69, design a problem to help other students better understand how to determine transfer functions.

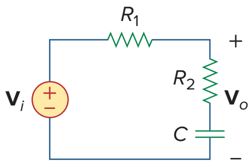


Figure 14.69
For Prob. 14.2.

14.3 For the circuit shown in Fig. 14.70, find $\mathbf{H}(s) = \mathbf{V}_o(s)/\mathbf{I}_i(s)$.

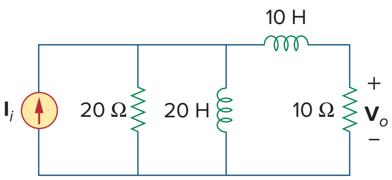


Figure 14.70
For Prob. 14.3.

14.4 Find the transfer function $\mathbf{H}(s) = \mathbf{V}_o/\mathbf{V}_i$ of the circuit shown in Fig. 14.71.

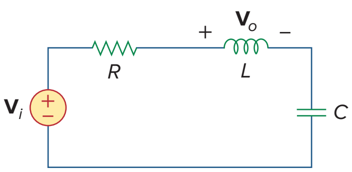


Figure 14.71
For Prob. 14.4.

14.5 For the circuit shown in Fig. 14.72, find $\mathbf{H}(s) = \mathbf{V}_o/\mathbf{I}_s$.

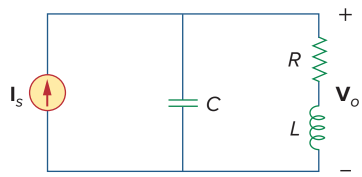


Figure 14.72
For Prob. 14.5.

14.6 For the circuit shown in Fig. 14.73, find $\mathbf{H}(s) = \mathbf{V}_o(s)/\mathbf{V}_s(s)$.

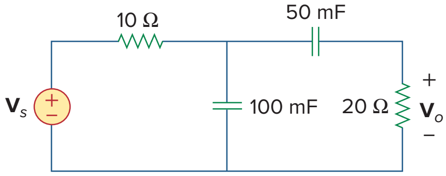


Figure 14.73
For Prob. 14.6.

Section 14.3 The Decibel Scale

14.7 Calculate $|\mathbf{H}(\omega)|$ if H_{dB} equals

(a) 0.1 dB (b) −5 dB (c) 215 dB

14.8 Design a problem to help other students calculate the magnitude in dB and phase in degrees of a variety of transfer functions at a single value of ω.

Section 14.4 Bode Plots

14.9 A ladder network has a voltage gain of

$$\mathbf{H}(\omega) = \frac{10}{(1 + j\omega)(10 + j\omega)}$$

Sketch the Bode plots for the gain.

14.10 Design a problem to help other students better understand how to determine the Bode magnitude and phase plots of a given transfer function in terms of $j\omega$.

14.11 Sketch the Bode plots for

$$\mathbf{H}(\omega) = \frac{0.2(10 + j\omega)}{j\omega(2 + j\omega)}$$

14.12 A transfer function is given by

$$T(s) = \frac{100(s + 10)}{s(s + 10)}$$

Sketch the magnitude and phase Bode plots.

14.13 Construct the Bode plots for

$$G(s) = \frac{0.1(s + 1)}{s^2(s + 10)}, \qquad s = j\omega$$

14.14 Draw the Bode plots for

$$\mathbf{H}(\omega) = \frac{250(j\omega + 1)}{j\omega(-\omega^2 + 10\,j\omega + 25)}$$

14.15 Construct the Bode magnitude and phase plots for

$$H(s) = \frac{2(s + 1)}{(s + 2)(s + 10)}, \qquad s = j\omega$$

14.16 Sketch Bode magnitude and phase plots for

$$H(s) = \frac{1.6}{s(s^2 + s + 16)}, \qquad s = j\omega$$

14.17 Sketch the Bode plots for

$$G(s) = \frac{s}{(s + 2)^2(s + 1)}, \qquad s = j\omega$$

14.18 A linear network has this transfer function

ML

$$H(s) = \frac{7s^2 + s + 4}{s^3 + 8s^2 + 14s + 5}, \qquad s = j\omega$$

Use *MATLAB* or equivalent to plot the magnitude and phase (in degrees) of the transfer function. Take $0.1 < \omega < 10$ rad/s.

14.19 Sketch the asymptotic Bode plots of the magnitude and phase for

$$H(s) = \frac{80s}{(s + 10)(s + 20)(s + 40)}, \qquad s = j\omega$$

14.20 Design a more complex problem than given in Prob. 14.10, to help other students better understand how to determine the Bode magnitude and phase plots of a given transfer function in terms of $j\omega$. Include at least a second order repeated root.

14.21 Sketch the magnitude Bode plot for

$$H(s) = \frac{10s(s + 20)}{(s + 1)(s^2 + 60s + 400)}, \qquad s = j\omega$$

14.22 Find the transfer function $\mathbf{H}(\omega)$ with the Bode magnitude plot shown in Fig. 14.74.

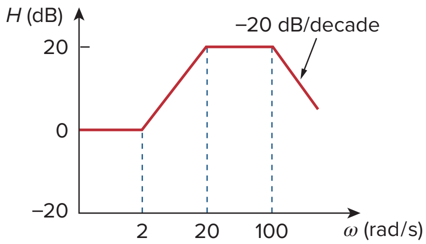


Figure 14.74
For Prob. 14.22.

14.23 The Bode magnitude plot of $\mathbf{H}(\omega)$ is shown in Fig. 14.75. Find $\mathbf{H}(\omega)$.

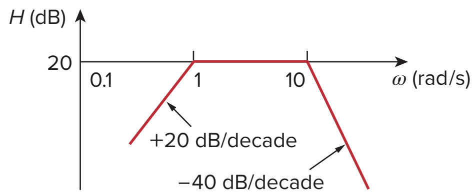


Figure 14.75
For Prob. 14.23.

14.24 The magnitude plot in Fig. 14.76 represents the transfer function of a preamplifier. Find $H(s)$.

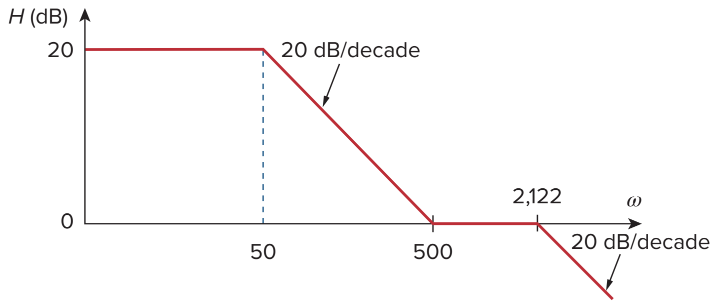


Figure 14.76
For Prob. 14.24.

Section 14.5 Series Resonance

14.25 A series *RLC* network has $R = 2$ kΩ, $L = 40$ mH, and $C = 1\ \mu$F. Calculate the impedance at resonance and at one-fourth, one-half, twice, and four times the resonant frequency.

14.26 e2d Design a problem to help other students better understand ω_0, Q, and B at resonance in series *RLC* circuits.

14.27 e2d Design a series *RLC* resonant circuit with $\omega_0 =$ 40 rad/s and $B = 10$ rad/s.

14.28 Design a series *RLC* circuit with $B = 20$ rad/s and $\omega_0 = 1{,}000$ rad/s. Find the circuit's Q. Let $R = 10\ \Omega$.

14.29 Let $v_s = 20\cos(at)$ V in the circuit of Fig. 14.77. Find ω_0, Q, and B, as seen by the capacitor.

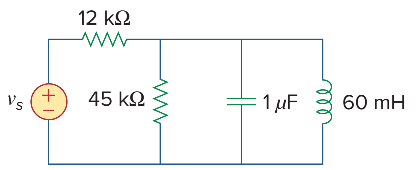


Figure 14.77
For Prob. 14.29.

14.30 A circuit consisting of a coil with inductance 10 mH and resistance 20 Ω is connected in series with a capacitor and a generator with an rms voltage of 120 V. Find:

(a) the value of the capacitance that will cause the circuit to be in resonance at 15 kHz

(b) the current through the coil at resonance

(c) the Q of the circuit

Section 14.6 Parallel Resonance

14.31 e2d Design a parallel resonant *RLC* circuit with $\omega_0 = 100$ krad/s and a bandwidth of 10 krad/s. Additionally what is the value of Q?

14.32 e2d Design a problem to help other students better understand the quality factor, the resonant frequency, and bandwidth of a parallel *RLC* circuit.

14.33 A parallel resonant circuit with a bandwidth of 40 krad/s and the half-power frequencies are $\omega_1 =$ 4.98 Mrad/s and $\omega_2 = 5.02$ Mrad/s, calculate the quality factor and resonant frequency.

14.34 A parallel *RLC* circuit has $R = 100$ kΩ, $L =$ 100 mH, and a $C = 10\ \mu$F. Determine the value of Q, the resonant frequency, and the bandwidth. If $R = 200$ kΩ, how does that affect the values of Q, resonant frequency, and the bandwidth?

14.35 A parallel *RLC* circuit has $R = 10$ kΩ, $L = 100$ mH, and a resonant frequency of 200 krad/s. Calculate the value of C, the value of the quality factor, and the bandwidth.

14.36 It is expected that a parallel *RLC* resonant circuit has a midband admittance of 25×10^{-3} S, quality factor of 120, and a resonant frequency of 200 krad/s. Calculate the values of R, L, and C. Find the bandwidth and the half-power frequencies.

14.37 Rework Prob. 14.25 if the elements are connected in parallel.

14.38 Find the resonant frequency of the circuit in Fig. 14.78.

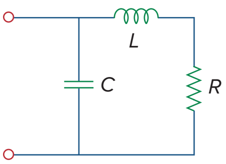


Figure 14.78
For Prob. 14.38.

14.39 For the "tank" circuit in Fig. 14.79, find the resonant frequency.

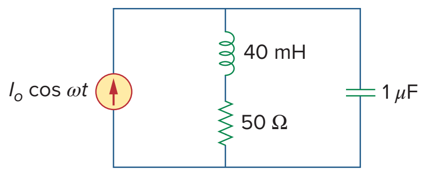


Figure 14.79
For Probs. 14.39, 14.71, and 14.91.

14.40 A parallel resonance circuit has a resistance of 2 kΩ and half-power frequencies of 86 kHz and 90 kHz. Determine:

(a) the capacitance

(b) the inductance

(c) the resonant frequency

(d) the bandwidth

(e) the quality factor

14.41 e2d Using Fig. 14.80, design a problem to help other students better understand the quality factor, the resonant frequency, and bandwidth of *RLC* circuits.

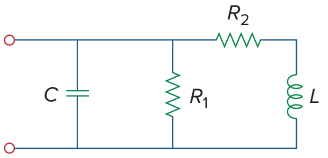


Figure 14.80
For Prob. 14.41.

14.42 For the circuits in Fig. 14.81, find the resonant frequency ω_0, the quality factor Q, and the bandwidth B.

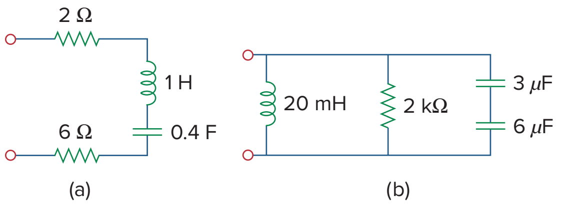


Figure 14.81
For Prob. 14.42.

14.43 Calculate the resonant frequency of each of the circuits in Fig. 14.82.

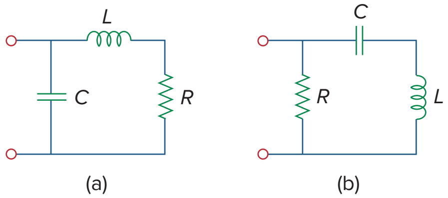


Figure 14.82
For Prob. 14.43.

***14.44** For the circuit in Fig. 14.83, find:

(a) the resonant frequency ω_0

(b) $\mathbf{Z}_{in}(\omega_0)$

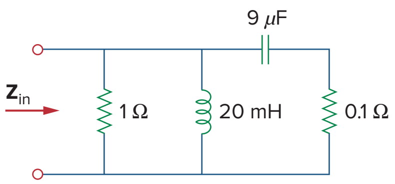


Figure 14.83
For Prob. 14.44.

14.45 For the circuit shown in Fig. 14.84, find ω_0, B, and Q, as seen by the voltage across the inductor.

* An asterisk indicates a challenging problem.

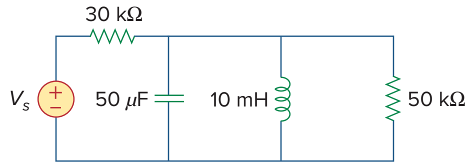


Figure 14.84
For Prob. 14.45.

14.46 For the network illustrated in Fig. 14.85, find

(a) the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o(\omega)/\mathbf{I}(\omega)$,

(b) the magnitude of $\mathbf{H}$ at $\omega_0 = 1$ rad/s.

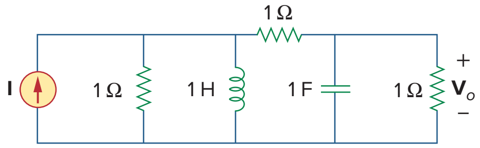


Figure 14.85
For Probs. 14.46, 14.78, and 14.92.

Section 14.7 Passive Filters

14.47 Show that a series LR circuit is a low-pass filter if the output is taken across the resistor. Calculate the corner frequency f_c if $L = 2$ mH and $R = 10$ kΩ.

14.48 Find the transfer function $\mathbf{V}_o/\mathbf{V}_s$ of the circuit in Fig. 14.86. Show that the circuit is a low-pass filter.

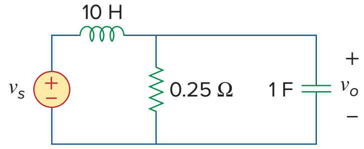


Figure 14.86
For Prob. 14.48.

14.49 Design a problem to help other students better understand low-pass filters described by transfer functions.

14.50 Determine what type of filter is in Fig. 14.87. Calculate the corner frequency f_c.

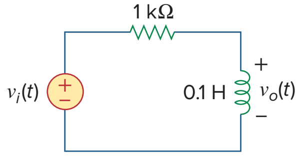


Figure 14.87
For Prob. 14.50.

14.51 Design an *RL* low-pass filter that uses a 40-mH coil and has a cutoff frequency of 5 kHz.

14.52 Design a problem to help other students better understand passive high-pass filters.

14.53 Design a series *RLC* type band-pass filter with cutoff frequencies of 10 kHz and 11 kHz. Assuming $C = 80$ pF, find R, L, and Q.

14.54 Design a passive band-stop filter with $\omega_0 = 10$ rad/s and $Q = 20$.

14.55 Determine the range of frequencies that will be passed by a series *RLC* band-pass filter with $R = 10\ \Omega$, $L = 25$ mH, and $C = 0.4\ \mu$F. Find the quality factor.

14.56 (a) Show that for a band-pass filter,

$$\mathbf{H}(s) = \frac{sB}{s^2 + sB + \omega_0^2}, \qquad s = j\omega$$

where B = bandwidth of the filter and ω_0 is the center frequency.

(b) Similarly, show that for a band-stop filter,

$$\mathbf{H}(s) = \frac{s^2 + \omega_0^2}{s^2 + sB + \omega_0^2}, \qquad s = j\omega$$

14.57 Determine the center frequency and bandwidth of the band-pass filters in Fig. 14.88.

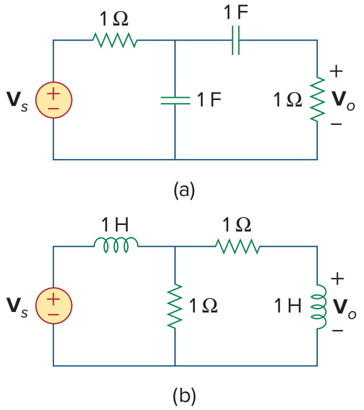


Figure 14.88
For Prob. 14.57.

14.58 The circuit parameters for a series *RLC* band-stop filter are $R = 250\ \Omega$, $L = 1$ mH, $C = 40$ pF. Calculate:

(a) the center frequency

(b) the half-power frequencies

(c) the quality factor

14.59 Find the bandwidth and center frequency of the band-stop filter of Fig. 14.89.

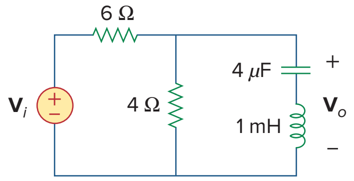


Figure 14.89
For Prob. 14.59.

Section 14.8 Active Filters

14.60 Obtain the transfer function of a high-pass filter with a passband gain of 100 and a cutoff frequency of 40 rad/s.

14.61 Find the transfer function for each of the active filters in Fig. 14.90.

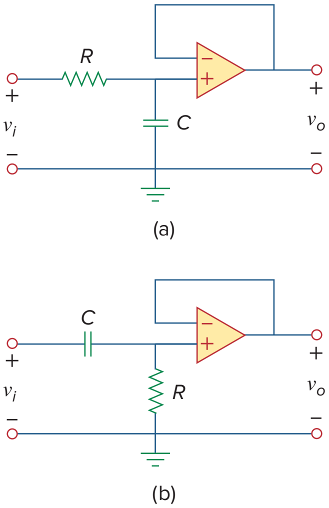


Figure 14.90
For Probs. 14.61 and 14.62.

14.62 The filter in Fig. 14.90(b) has a 3-dB cutoff frequency at 1 kHz. If its input is connected to a 120-mV variable frequency signal, find the output voltage at:

(a) 200 Hz (b) 2 kHz (c) 10 kHz

14.63 Design an active first-order high-pass filter with

$$\mathbf{H}(s) = -\frac{100s}{s + 10}, \qquad s = j\omega$$

Use a 1-μF capacitor.

14.64 Obtain the transfer function of the active filter in Fig. 14.91 on the next page. What kind of filter is it?

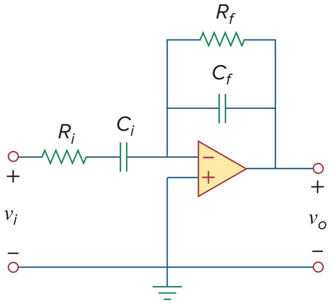


Figure 14.91
For Prob. 14.64.

14.65 A high-pass filter is shown in Fig. 14.92. Show that the transfer function is

$$\mathbf{H}(\omega) = \left(1 + \frac{R_f}{R_i}\right)\frac{j\omega RC}{1 + j\omega RC}$$

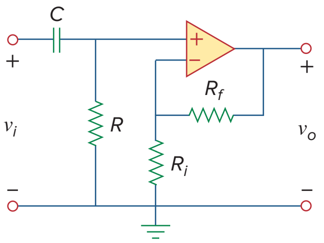


Figure 14.92
For Prob. 14.65.

14.66 A "general" first-order filter is shown in Fig. 14.93.

(a) Show that the transfer function is

$$\mathbf{H}(s) = \frac{R_4}{R_3 + R_4} \times \frac{s + (1/R_1C)[R_1/R_2 - R_3/R_4]}{s + 1/R_2C},$$

$s = j\omega$

(b) What condition must be satisfied for the circuit to operate as a high-pass filter?

(c) What condition must be satisfied for the circuit to operate as a low-pass filter?

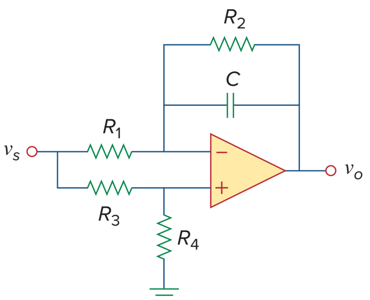


Figure 14.93
For Prob. 14.66.

14.67 Design an active low-pass filter with dc gain of 0.25 and a corner frequency of 500 Hz.

14.68 Design a problem to help other students better understand the design of active high-pass filters when specifying a high-frequency gain and a corner frequency.

14.69 Design the filter in Fig. 14.94 to meet the following requirements:

(a) It must attenuate a signal at 2 kHz by 3 dB compared with its value at 10 MHz.

(b) It must provide a steady-state output of $v_o(t) = 10\sin(2\pi \times 10^8 t + 180°)$ V for an input $v_s(t) = 4\sin(2\pi \times 10^8 t)$ V.

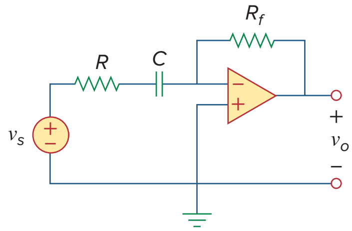


Figure 14.94
For Prob. 14.69.

***14.70** A second-order active filter known as a Butterworth filter is shown in Fig. 14.95.

(a) Find the transfer function $\mathbf{V}_o/\mathbf{V}_i$.

(b) Show that it is a low-pass filter.

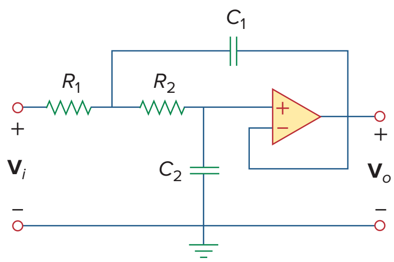


Figure 14.95
For Prob. 14.70.

Section 14.9 Scaling

14.71 Use magnitude and frequency scaling on the circuit of Fig. 14.79 to obtain an equivalent circuit in which the inductor and capacitor have magnitude 1 H and 1 F respectively.

14.72 Design a problem to help other students better understand magnitude and frequency scaling.

14.73 Calculate the values of R, L, and C that will result in $R = 12$ kΩ, $L = 40$ μH, and $C = 300$ nF respectively when magnitude-scaled by 800 and frequency-scaled by 1000.

14.74 A circuit has $R_1 = 3\ \Omega$, $R_2 = 10\ \Omega$, $L = 2\text{H}$, and $C = 1/10$ F. After the circuit is magnitude-scaled by 100 and frequency-scaled by 10^6, find the new values of the circuit elements.

14.75 In an *RLC* circuit, $R = 20\ \Omega$, $L = 4$ H, and $C = 1$ F. The circuit is magnitude-scaled by 10 and frequency-scaled by 10^5. Calculate the new values of the elements.

14.76 Given a parallel *RLC* circuit with $R = 5\ \text{k}\Omega$, $L = 10$ mH, and $C = 20\ \mu$F, if the circuit is magnitude-scaled by $K_m = 500$ and frequency-scaled by $K_f = 10^5$, find the resulting values of R, L, and C.

14.77 A series *RLC* circuit has $R = 10\ \Omega$, $\omega_0 = 40$ rad/s, and $B = 5$ rad/s. Find L and C when the circuit is scaled:

(a) in magnitude by a factor of 600,

(b) in frequency by a factor of 1,000,

(c) in magnitude by a factor of 400 and in frequency by a factor of 10^5.

14.78 Redesign the circuit in Fig. 14.85 so that all resistive elements are scaled by a factor of 1,000 and all frequency-sensitive elements are frequency-scaled by a factor of 10^4.

***14.79** Refer to the network in Fig. 14.96.

(a) Find $\mathbf{Z}_{\text{in}}(s)$.

(b) Scale the elements by $K_m = 10$ and $K_f = 100$. Find $\mathbf{Z}_{\text{in}}(s)$ and ω_0.

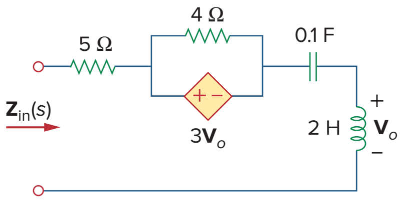


Figure 14.96
For Prob. 14.79.

14.80 (a) For the circuit in Fig. 14.97, draw the new circuit after it has been scaled by $K_m = 200$ and $K_f = 10^4$.

(b) Obtain the Thevenin equivalent impedance at terminals *a-b* of the scaled circuit at $\omega = 10^4$ rad/s.

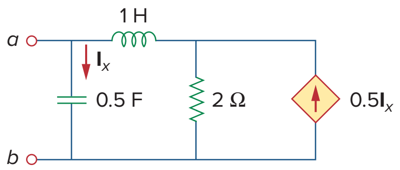


Figure 14.97
For Prob. 14.80.

14.81 The circuit shown in Fig. 14.98 has the impedance

$$Z(s) = \frac{1{,}000(s+1)}{(s+1+j50)(s+1-j50)}, \qquad s = j\omega$$

Find:

(a) the values of R, L, C, and G

(b) the element values that will raise the resonant frequency by a factor of 10^3 by frequency scaling

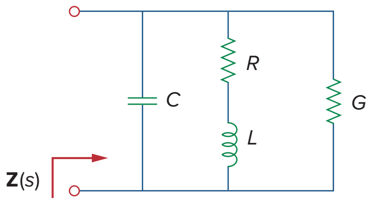


Figure 14.98
For Prob. 14.81.

14.82 Scale the low-pass active filter in Fig. 14.99 so that its corner frequency increases from 1 rad/s to 200 rad/s. Use a 1-μF capacitor.

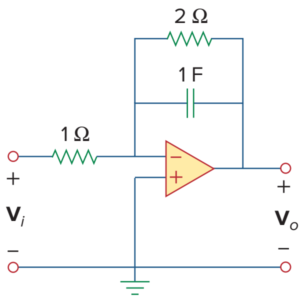


Figure 14.99
For Prob. 14.82.

14.83 The op amp circuit in Fig. 14.100 is to be magnitude-scaled by 100 and frequency-scaled by 10^5. Find the resulting element values.

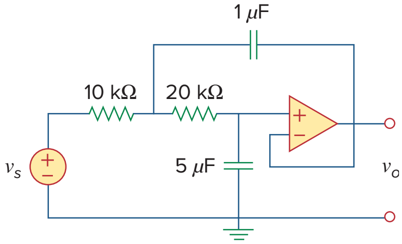


Figure 14.100
For Prob. 14.83.

Section 14.10 Frequency Response Using *PSpice*

14.84 Using *PSpice or MultiSim,* obtain the frequency response of the circuit in Fig. 14.101 on the next page.

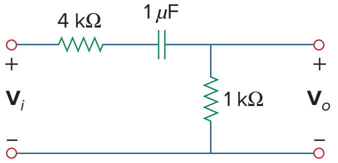


Figure 14.101
For Prob. 14.84.

14.85 Use *PSpice or MultiSim* to obtain the magnitude and phase plots of $\mathbf{V}_o/\mathbf{I}_s$ of the circuit in Fig. 14.102.

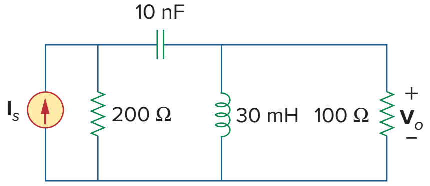


Figure 14.102
For Prob. 14.85.

14.86 **e⊿d** Using Fig. 14.103, design a problem to help other students better understand how to use *PSpice* to obtain the frequency response (magnitude and phase of I) in electrical circuits.

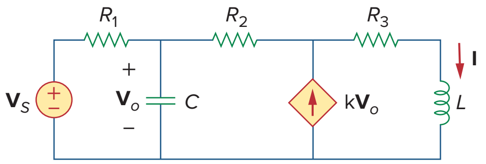


Figure 14.103
For Prob. 14.86.

14.87 In the interval $0.1 < f < 100$ Hz, plot the response of the network in Fig. 14.104. Classify this filter and obtain ω_0.

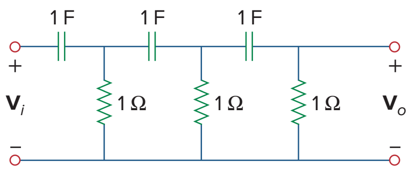


Figure 14.104
For Prob. 14.87.

14.88 Use *PSpice or MultiSim* to generate the magnitude and phase Bode plots of $\mathbf{V}_o$ in the circuit of Fig. 14.105.

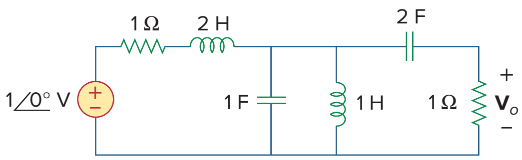


Figure 14.105
For Prob. 14.88.

14.89 Obtain the magnitude plot of the response $\mathbf{V}_o$ in the network of Fig. 14.106 for the frequency interval $100 < f < 1{,}000$ Hz.

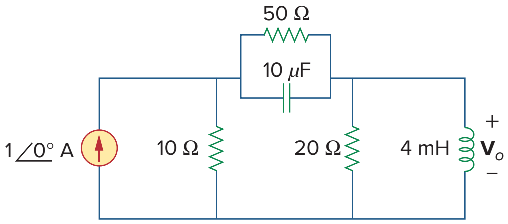


Figure 14.106
For Prob. 14.89.

14.90 Obtain the frequency response of the circuit in Fig. 14.40 (see Practice Problem 14.10). Take $R_1 = R_2 = 100\ \Omega$, $L = 2$ mH. Use $1 < f < 100{,}000$ Hz.

14.91 For the "tank" circuit of Fig. 14.79, obtain the frequency response (voltage across the capacitor) using *PSpice or MultiSim*. Determine the resonant frequency of the circuit.

14.92 Using *PSpice or MultiSim*, plot the magnitude of the frequency response of the circuit in Fig. 14.85.

Section 14.12 Applications

14.93 For the phase shifter circuit shown in Fig. 14.107, find $\mathbf{H} = V_o/V_s$.

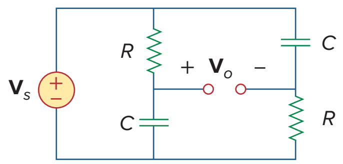


Figure 14.107
For Prob. 14.93.

14.94 **e⊿d** For an emergency situation, an engineer needs to make an *RC* high-pass filter. He has one 10-pF capacitor, one 30-pF capacitor, one 1.8-kΩ resistor, and one 3.3-kΩ resistor available. Find the greatest cutoff frequency possible using these elements.

14.95 **e⊿d** A series-tuned antenna circuit consists of a variable capacitor (40 pF to 360 pF) and a 240-μH antenna coil that has a dc resistance of 12 Ω.

(a) Find the frequency range of radio signals to which the radio is tunable.

(b) Determine the value of Q at each end of the frequency range.

14.96 The crossover circuit in Fig. 14.108 is a low-pass filter that is connected to a woofer. Find the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o(\omega)/\mathbf{V}_i(\omega)$.

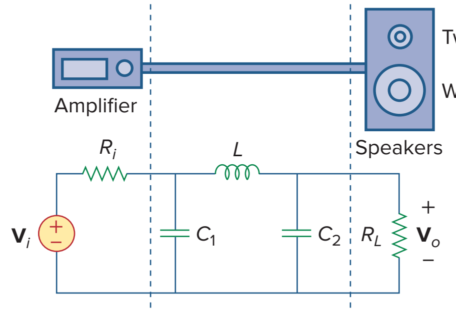


Figure 14.108
For Prob. 14.96.

14.97 The crossover circuit in Fig. 14.109 is a high-pass filter that is connected to a tweeter. Determine the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o(\omega)/\mathbf{V}_i(\omega)$.

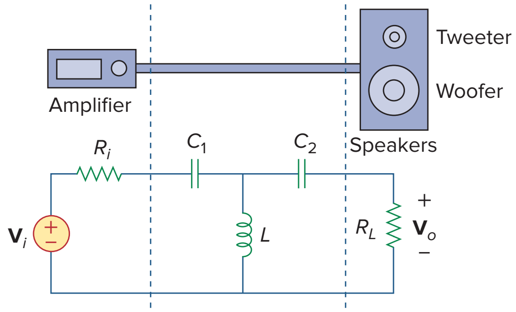


Figure 14.109
For Prob. 14.97.

Comprehensive Problems

14.98 A certain electronic test circuit produced a resonant curve with half-power points at 432 Hz and 454 Hz. If $Q = 20$, what is the resonant frequency of the circuit?

14.99 In an electronic device, a series circuit is employed that has a resistance of 100 Ω, a capacitive reactance of 5 kΩ, and an inductive reactance of 300 Ω when used at 2 MHz. Find the resonant frequency and bandwidth of the circuit.

14.100 In a certain application, a simple *RC* low-pass filter is designed to reduce high frequency noise. If the desired corner frequency is 20 kHz and $C = 0.5\ \mu$F, find the value of R.

14.101 In an amplifier circuit, a simple *RC* high-pass filter is needed to block the dc component while passing the time-varying component. If the desired rolloff frequency is 15 Hz and $C = 10\ \mu$F, find the value of R.

14.102 Practical *RC* filter design should allow for source and load resistances as shown in Fig. 14.110. Let $R = 4$ kΩ and $C = 40$-nF. Obtain the cutoff frequency when:

(a) $R_s = 0$, $R_L = \infty$,

(b) $R_s = 1$ kΩ, $R_L = 5$ kΩ.

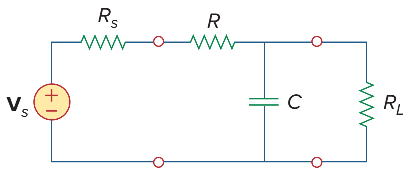


Figure 14.110
For Prob. 14.102.

14.103 The *RC* circuit in Fig. 14.111 is used for a lead compensator in a system design. Obtain the transfer function of the circuit.

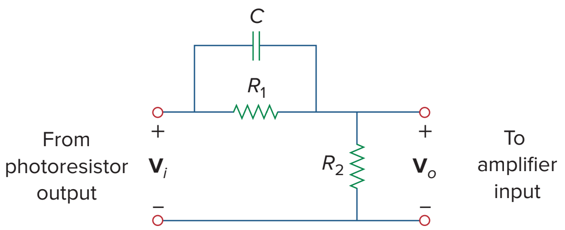


Figure 14.111
For Prob. 14.103.

14.104 A low-quality-factor, double-tuned band-pass filter is shown in Fig. 14.112. Use *PSpice or MultiSim* to generate the magnitude plot of $\mathbf{V}_o(\omega)$.

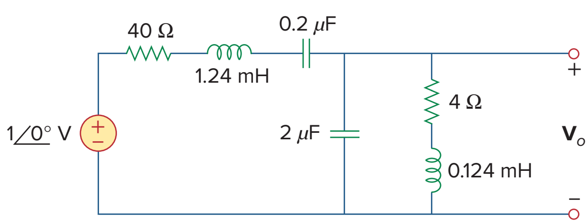


Figure 14.112
For Prob. 14.104.

Review Questions

19.1 For the single-element two-port network in Fig. 19.64(a), $\mathbf{z}_{11}$ is:

(a) 0 (b) 5 (c) 10
(d) 20 (e) undefined

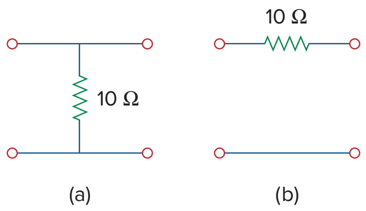


Figure 19.64
For Review Questions.

19.2 For the single-element two-port network in Fig. 19.64(b), $\mathbf{z}_{11}$ is:

(a) 0 (b) 5 (c) 10
(d) 20 (e) undefined

19.3 For the single-element two-port network in Fig. 19.64(a), $\mathbf{y}_{11}$ is:

(a) 0 (b) 5 (c) 10
(d) 20 (e) undefined

19.4 For the single-element two-port network in Fig. 19.64(b), $\mathbf{h}_{21}$ is:

(a) −0.1 (b) −1 (c) 0
(d) 10 (e) undefined

19.5 For the single-element two-port network in Fig. 19.64(a), **B** is:

(a) 0 (b) 5 (c) 10
(d) 20 (e) undefined

19.6 For the single-element two-port network in Fig. 19.64(b), **B** is:

(a) 0 (b) 5 (c) 10
(d) 20 (e) undefined

19.7 When port 1 of a two-port circuit is short-circuited, $\mathbf{I}_1 = 4\mathbf{I}_2$ and $\mathbf{V}_2 = 0.25\mathbf{I}_2$. Which of the following is true?

(a) $y_{11} = 4$ (b) $y_{12} = 16$
(c) $y_{21} = 16$ (d) $y_{22} = 0.25$

19.8 A two-port is described by the following equations:

$$\mathbf{V}_1 = 50\mathbf{I}_1 + 10\mathbf{I}_2$$
$$\mathbf{V}_2 = 30\mathbf{I}_1 + 20\mathbf{I}_2$$

Which of the following is *not* true?

(a) $\mathbf{z}_{12} = 10$ (b) $\mathbf{y}_{12} = -0.0143$
(c) $\mathbf{h}_{12} = 0.5$ (d) $\mathbf{A} = 50$

19.9 If a two-port is reciprocal, which of the following is *not* true?

(a) $\mathbf{z}_{21} = \mathbf{z}_{12}$ (b) $\mathbf{y}_{21} = \mathbf{y}_{12}$
(c) $\mathbf{h}_{21} = \mathbf{h}_{12}$ (d) $AD = BC + 1$

19.10 If the two single-element two-port networks in Fig. 19.64 are cascaded, then **D** is:

(a) 0 (b) 0.1 (c) 2
(d) 10 (e) undefined

Answers: 19.1c, 19.2e , 19.3e , 19.4b, 19.5a, 19.6c, 19.7b, 19.8d, 19.9c, 19.10c.

Problems

Section 19.2 Impedance Parameters

19.1 Obtain the z parameters for the network in Fig. 19.65.

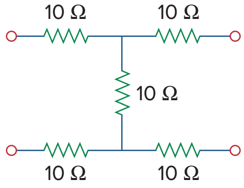


Figure 19.65
For Probs. 19.1 and 19.28.

*__19.2__ Find the impedance parameter equivalent of the network in Fig. 19.66.

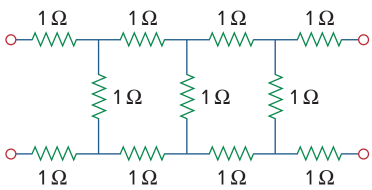


Figure 19.66
For Prob. 19.2.

* An asterisk indicates a challenging problem.

19.3 Find the z parameters of the circuit in Fig. 19.67.

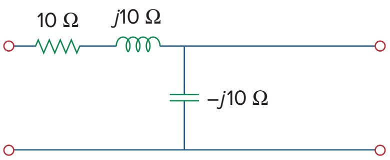


Figure 19.67
For Prob. 19.3.

19.4 Using Fig. 19.68, design a problem to help other students better understand how to determine z parameters from an electrical circuit.

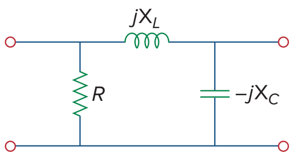


Figure 19.68
For Prob. 19.4.

19.5 Obtain the z parameters for the network in Fig. 19.69 as functions of s.

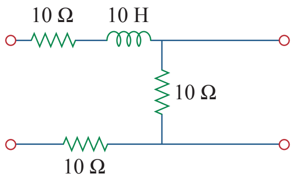


Figure 19.69
For Prob. 19.5.

19.6 Compute the z parameters of the circuit in Fig. 19.70.

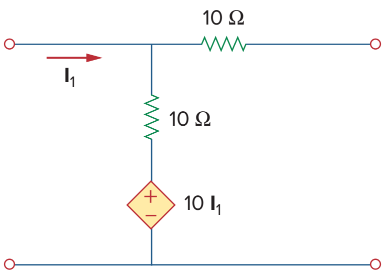


Figure 19.70
For Prob. 19.6 and 19.73.

19.7 Calculate the z parameters of the circuit in Fig. 19.71 as functions of s.

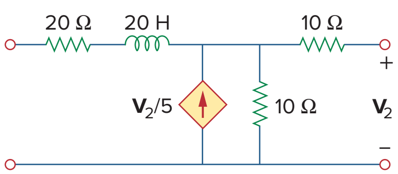


Figure 19.71
For Prob. 19.7 and 19.80.

19.8 Find the z parameters of the two-port in Fig. 19.72.

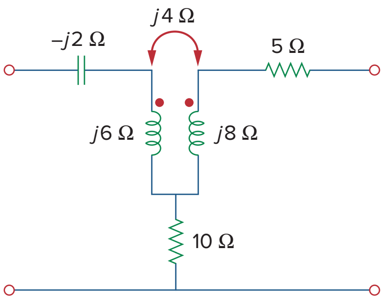


Figure 19.72
For Prob. 19.8.

19.9 The y parameters of a network are:

$$\mathbf{Y} = [\mathbf{y}] = \begin{bmatrix} 0.5 & -0.2 \\ -0.2 & 0.4 \end{bmatrix} S$$

Determine the z parameters for the network.

19.10 Construct a two-port that realizes each of the following z parameters.

(a) $[\mathbf{z}] = \begin{bmatrix} 25 & 20 \\ 5 & 10 \end{bmatrix} \Omega$

(b) $[\mathbf{z}] = \begin{bmatrix} 1 + \frac{3}{s} & \frac{1}{s} \\ \frac{1}{s} & 2s + \frac{1}{s} \end{bmatrix} \Omega$

19.11 Determine a two-port network that is represented by the following z parameters:

$$[\mathbf{z}] = \begin{bmatrix} 6 + j3 & 5 - j2 \\ 5 - j2 & 8 - j \end{bmatrix} \Omega$$

19.12 For the circuit shown in Fig. 19.73, let

$$[\mathbf{z}] = \begin{bmatrix} 10 & -6 \\ -4 & 12 \end{bmatrix} \Omega$$

Find I_1, I_2, V_1, and V_2.

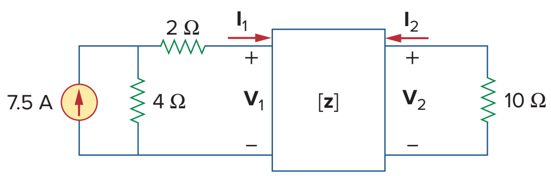


Figure 19.73
For Prob. 19.12.

19.13 Determine the average power delivered to $Z_L = 5 + j4$ in the network of Fig. 19.74. *Note:* The voltage is rms.

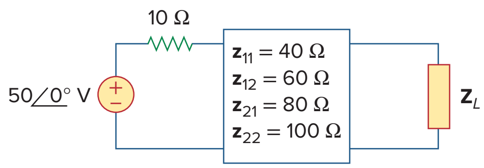


Figure 19.74
For Prob. 19.13.

19.14 For the two-port network shown in Fig. 19.75, show that at the output terminals,

$$\mathbf{Z}_{\text{Th}} = \mathbf{z}_{22} - \frac{\mathbf{z}_{12}\mathbf{z}_{21}}{\mathbf{z}_{11} + \mathbf{Z}_s}$$

and

$$\mathbf{V}_{\text{Th}} = \frac{\mathbf{z}_{21}}{\mathbf{z}_{11} + \mathbf{Z}_s}\mathbf{V}_s$$

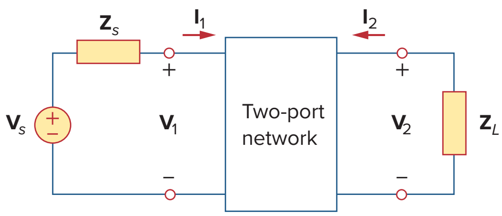


Figure 19.75
For Probs. 19.14 and 19.41.

19.15 For the two-port circuit in Fig. 19.76,

$$[\mathbf{z}] = \begin{bmatrix} 40 & 60 \\ 80 & 120 \end{bmatrix} \Omega$$

(a) Find $\mathbf{Z}_L$ for maximum power transfer to the load.

(b) Calculate the maximum power delivered to the load.

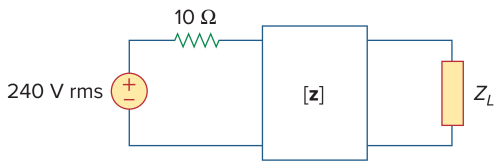


Figure 19.76
For Prob. 19.15.

19.16 For the circuit in Fig. 19.77, at $\omega = 2$ rad/s, $\mathbf{z}_{11} = 10\ \Omega$, $\mathbf{z}_{12} = \mathbf{z}_{21} = j6\ \Omega$, $\mathbf{z}_{22} = 4\ \Omega$. Obtain the Thevenin equivalent circuit at terminals *a*-*b* and calculate v_o.

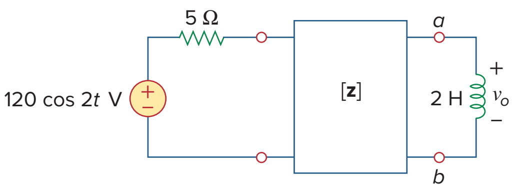


Figure 19.77
For Prob. 19.16.

Section 19.3 Admittance Parameters

*__19.17__ Determine the *z* and *y* parameters for the circuit in Fig. 19.78.

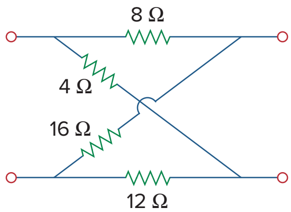


Figure 19.78
For Prob. 19.17.

19.18 Calculate the *y* parameters for the two-port in Fig. 19.79.

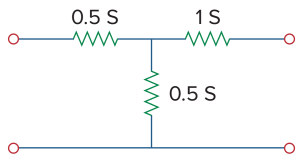


Figure 19.79
For Probs. 19.18 and 19.37.

19.19 e⊘d Using Fig. 19.80, design a problem to help other students better understand how to find *y* parameters in the *s*-domain.

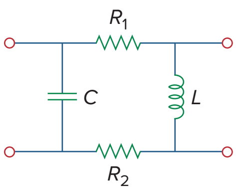


Figure 19.80
For Prob. 19.19.

19.20 Find the *y* parameters for the circuit in Fig. 19.81.

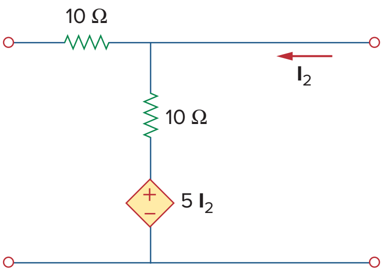


Figure 19.81
For Prob. 19.20.

19.21 Obtain the admittance parameter equivalent circuit of the two-port in Fig. 19.82.

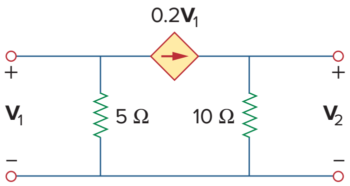


Figure 19.82
For Prob. 19.21.

19.22 Obtain the y parameters of the two-port network in Fig. 19.83.

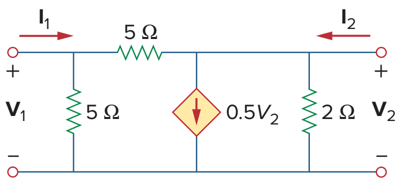


Figure 19.83
For Prob. 19.22.

19.23 (a) Find the y parameters of the two-port in Fig. 19.84.

(b) Determine $\mathbf{V}_2(s)$ for $v_s = 2u(t)$ V.

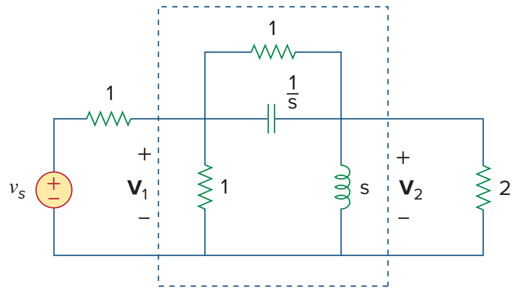


Figure 19.84
For Prob. 19.23.

19.24 Find the resistive circuit that represents these y parameters:

$$[\mathbf{y}] = \begin{bmatrix} \frac{1}{2} & -\frac{1}{4} \\ -\frac{1}{4} & \frac{3}{8} \end{bmatrix} \text{S}$$

19.25 Draw the two-port network that has the following y parameters:

$$[\mathbf{y}] = \begin{bmatrix} 1 & -0.5 \\ -0.5 & 1.5 \end{bmatrix} \text{S}$$

19.26 Calculate $[\mathbf{y}]$ for the two-port in Fig. 19.85.

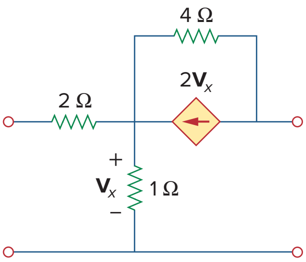


Figure 19.85
For Prob. 19.26.

19.27 Find the y parameters for the circuit in Fig. 19.86.

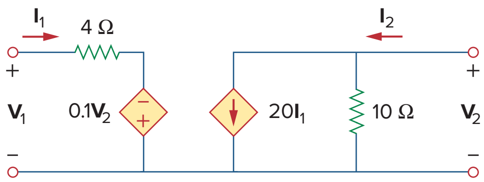


Figure 19.86
For Prob. 19.27.

19.28 In the circuit of Fig. 19.65, the input port is connected to a 1-A current source and the right hand side of the circuit is left open ($I_2 = 0$). Calculate the power absorbed by the circuit by using the y parameters. Confirm your result by direct circuit analysis.

19.29 In the bridge circuit of Fig. 19.87, $I_1 = 20$ A and $I_2 = -8$ A.

(a) Find V_1 and V_2 using y parameters.

(b) Confirm the results in part (a) by direct circuit analysis.

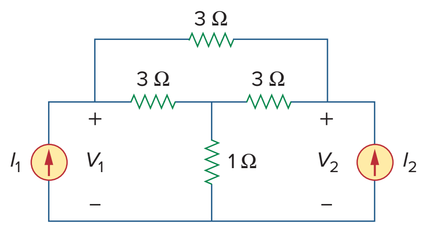


Figure 19.87
For Prob. 19.29.

Section 19.4 Hybrid Parameters

19.30 Find the h parameters for the networks in Fig. 19.88.

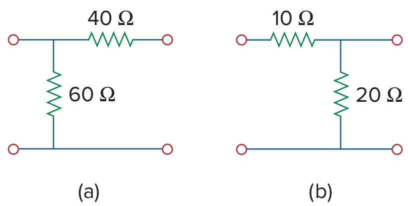


Figure 19.88
For Prob. 19.30.

19.31 Determine the hybrid parameters for the network in Fig. 19.89.

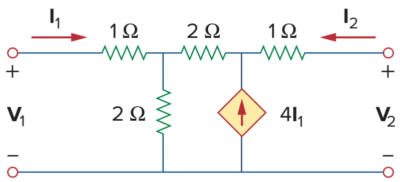


Figure 19.89
For Prob. 19.31.

19.32 Using Fig. 19.90, design a problem to help other students better understand how to find the h and g parameters for a circuit in the s-domain.

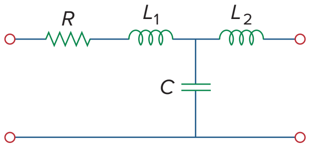


Figure 19.90
For Prob. 19.32.

19.33 Obtain the h parameters for the two-port of Fig. 19.91.

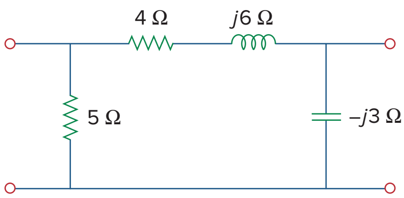


Figure 19.91
For Prob. 19.33.

19.34 Obtain the h and g parameters of the two-port in Fig. 19.92.

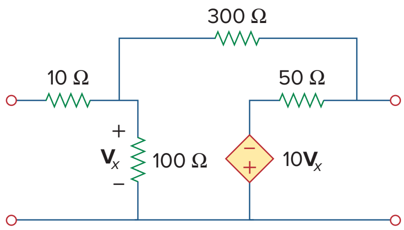


Figure 19.92
For Prob. 19.34.

19.35 Determine the h parameters for the network in Fig. 19.93.

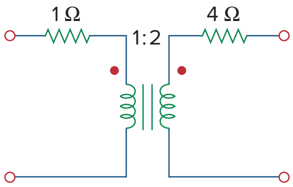


Figure 19.93
For Prob. 19.35.

19.36 For the two-port in Fig. 19.94,

$$[\mathbf{h}] = \begin{bmatrix} 16\ \Omega & 3 \\ -2 & 0.01\ \text{S} \end{bmatrix}$$

Find:

(a) V_2/V_1 (b) I_2/I_1
(c) I_1/V_1 (d) V_2/I_1

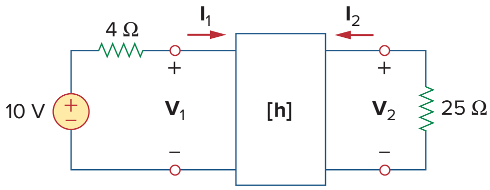


Figure 19.94
For Prob. 19.36.

19.37 The input port of the circuit in Fig. 19.79 is connected to a 10-V dc voltage source while the output port is terminated by a 5-Ω resistor. Find the voltage across the 5-Ω resistor by using h parameters of the circuit. Confirm your result by using direct circuit analysis.

19.38 The h parameters of the two-port of Fig. 19.95 are:

$$[\mathbf{h}] = \begin{bmatrix} 600\ \Omega & 0.04 \\ 30 & 2\ \text{mS} \end{bmatrix}$$

Given the $Z_s = 2\ \text{k}\Omega$ and $Z_L = 400\ \Omega$, find Z_{in} and Z_{out}.

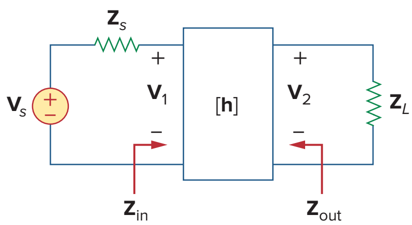


Figure 19.95
For Prob. 19.38.

19.39 Obtain the g parameters for the wye circuit of Fig. 19.96.

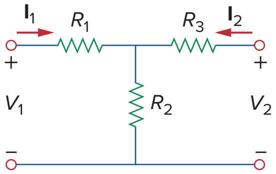


Figure 19.96
For Prob. 19.39.

19.40 Using Fig. 19.97, design a problem to help other students better understand how to find g parameters in an ac circuit.

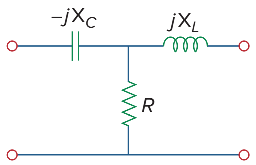


Figure 19.97
For Prob. 19.40.

19.41 For the two-port in Fig. 19.75, show that

$$\frac{\mathbf{I}_2}{\mathbf{I}_1} = \frac{-\mathbf{g}_{21}}{\mathbf{g}_{11}\mathbf{Z}_L + \Delta_g}$$

$$\frac{\mathbf{V}_2}{\mathbf{V}_s} = \frac{\mathbf{g}_{21}\mathbf{Z}_L}{(1 + \mathbf{g}_{11}\mathbf{Z}_s)(\mathbf{g}_{22} + \mathbf{Z}_L) - \mathbf{g}_{21}\mathbf{g}_{12}\mathbf{Z}_s}$$

where Δ_g is the determinant of [**g**] matrix.

19.42 The h parameters of a two-port device are given by

$$\mathbf{h}_{11} = 600\ \Omega, \qquad \mathbf{h}_{12} = 10^{-3}, \qquad \mathbf{h}_{21} = 120,$$
$$\mathbf{h}_{22} = 2 \times 10^{-6}\ \text{S}$$

Draw a circuit model of the device including the value of each element.

Section 19.5 Transmission Parameters

19.43 Find the transmission parameters for the single-element two-port networks in Fig. 19.98.

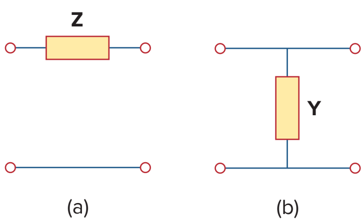


Figure 19.98
For Prob. 19.43.

19.44 Using Fig. 19.99, design a problem to help other students better understand how to find the transmission parameters of an ac circuit.

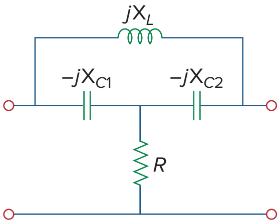


Figure 19.99
For Prob. 19.44.

19.45 Find the **ABCD** parameters for the circuit in Fig. 19.100.

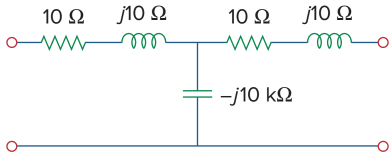


Figure 19.100
For Prob. 19.45.

19.46 Find the transmission parameters for the circuit in Fig. 19.101.

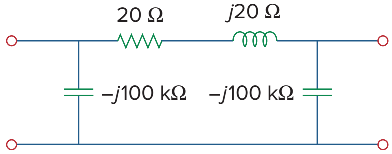


Figure 19.101
For Prob. 19.46.

19.47 Obtain the **ABCD** parameters for the network in Fig. 19.102.

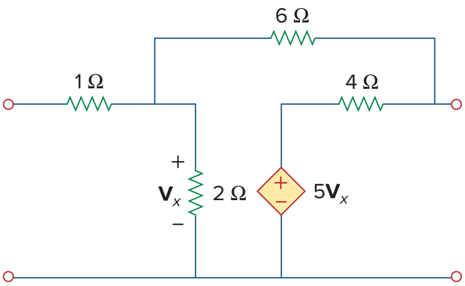


Figure 19.102
For Prob. 19.47

19.48 For a two-port, let $\mathbf{A} = 4$, $\mathbf{B} = 30\ \Omega$, $\mathbf{C} = 0.1$ S, and $\mathbf{D} = 1.5$. Calculate the input impedance $\mathbf{Z}_{in} = \mathbf{V}_1/\mathbf{I}_1$, when:

(a) the output terminals are short-circuited,

(b) the output port is open-circuited,

(c) the output port is terminated by a 10-Ω load.

19.49 Using impedances in the s-domain, obtain the transmission parameters for the circuit in Fig. 19.103.

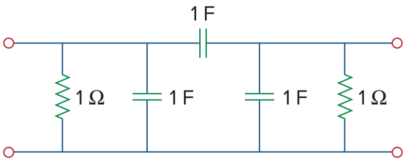


Figure 19.103
For Prob. 19.49.

19.50 Derive the s-domain expression for the t parameters of the circuit in Fig. 19.104.

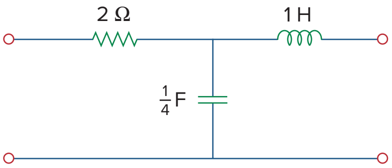


Figure 19.104
For Prob. 19.50.

19.51 Obtain the t parameters for the network in Fig. 19.105.

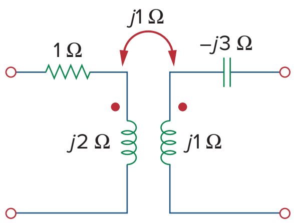


Figure 19.105
For Prob. 19.51.

Section 19.6 Relationships Between Parameters

19.52 (a) For the T network in Fig. 19.106, show that the h parameters are:

$$\mathbf{h}_{11} = R_1 + \frac{R_2R_3}{R_1 + R_3}, \qquad \mathbf{h}_{12} = \frac{R_2}{R_2 + R_3}$$

$$\mathbf{h}_{21} = -\frac{R_2}{R_2 + R_3}, \qquad h_{22} = \frac{1}{R_2 + R_3}$$

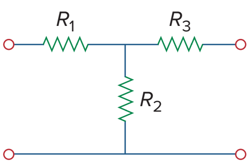


Figure 19.106
For Prob. 19.52.

(b) For the same network, show that the transmission parameters are:

$$\mathbf{A} = 1 + \frac{R_1}{R_2}, \qquad \mathbf{B} = R_3 + \frac{R_1}{R_2}(R_2 + R_3)$$

$$\mathbf{C} = \frac{1}{R_2}, \qquad \mathbf{D} = 1 + \frac{R_3}{R_2}$$

19.53 Through derivation, express the z parameters in terms of the **ABCD** parameters.

19.54 Show that the transmission parameters of a two-port may be obtained from the y parameters as:

$$\mathbf{A} = -\frac{\mathbf{y}_{22}}{\mathbf{y}_{21}}, \qquad \mathbf{B} = -\frac{1}{\mathbf{y}_{21}}$$

$$\mathbf{C} = -\frac{\Delta_y}{\mathbf{y}_{21}}, \qquad \mathbf{D} = -\frac{\mathbf{y}_{11}}{\mathbf{y}_{21}}$$

19.55 Prove that the g parameters can be obtained from the z parameters as

$$\mathbf{g}_{11} = \frac{1}{\mathbf{z}_{11}}, \qquad \mathbf{g}_{12} = -\frac{\mathbf{z}_{12}}{\mathbf{z}_{11}}$$

$$\mathbf{g}_{21} = \frac{\mathbf{z}_{21}}{\mathbf{z}_{11}}, \qquad \mathbf{g}_{22} = \frac{\Delta_z}{\mathbf{z}_{11}}$$

19.56 For the network of Fig. 19.107, obtain $\mathbf{V_o}/\mathbf{V_s}$.

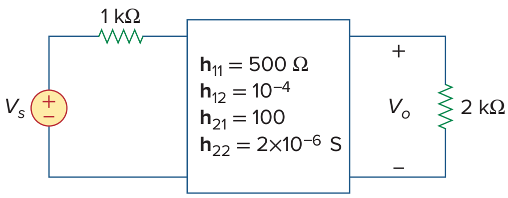


Figure 19.107
For Prob. 19.56.

19.57 Given the transmission parameters

$$[\mathbf{T}] = \begin{bmatrix} 3 & 20 \\ 1 & 7 \end{bmatrix}$$

obtain the other five two-port parameters.

19.58 Design a problem to help other students better understand how to develop the y parameters and transmission parameters, given equations in terms of the hybrid parameters.

19.59 Given that

$$[\mathbf{g}] = \begin{bmatrix} 0.06\text{ S} & -0.4 \\ 0.2 & 2\ \Omega \end{bmatrix}$$

determine:

(a) [**z**] (b) [**y**] (c) [**h**] (d) [**T**]

19.60 Design a T network necessary to realize the following z parameters at $\omega = 10^6$ rad/s.

$$[\mathbf{z}] = \begin{bmatrix} 4 + j3 & 3 \\ 2 & 5 - j \end{bmatrix} \text{k}\Omega$$

19.61 For the bridge circuit in Fig. 19.108, obtain:

(a) the z parameters
(b) the h parameters
(c) the transmission parameters

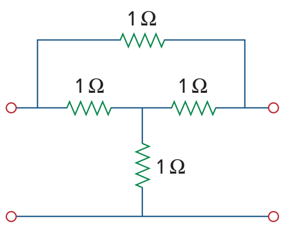


Figure 19.108
For Prob. 19.61.

19.62 Find the z parameters of the op amp circuit in Fig. 19.109. Obtain the transmission parameters.

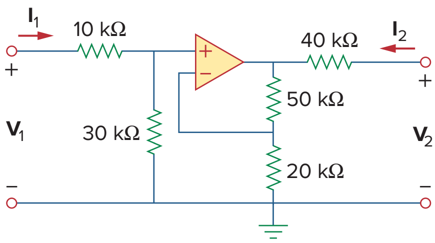


Figure 19.109
For Prob. 19.62.

19.63 Determine the z parameters of the two-port in Fig. 19.110.

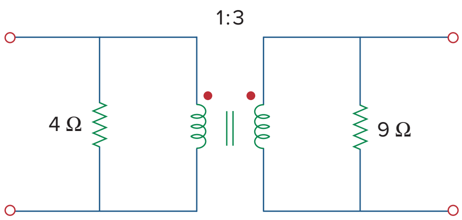


Figure 19.110
For Prob. 19.63.

19.64 Determine the y parameters at $\omega = 1{,}000$ rad/s for the op amp circuit in Fig. 19.111. Find the corresponding h parameters.

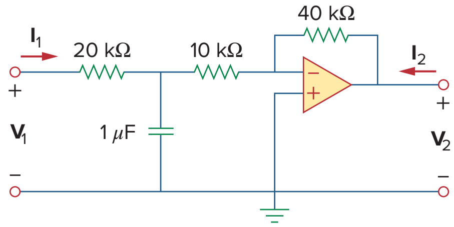


Figure 19.111
For Prob. 19.64.

Section 19.7 Interconnection of Networks

19.65 What is the y parameter presentation of the circuit in Fig. 19.112?

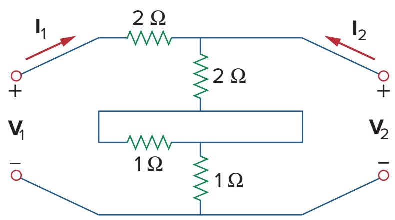


Figure 19.112
For Prob. 19.65.

19.66 In the two-port of Fig. 19.113, let $\mathbf{y}_{12} = \mathbf{y}_{21} = 0$, $\mathbf{y}_{11} = 2$ mS, and $\mathbf{y}_{22} = 10$ mS. Find $\mathbf{V}_o/\mathbf{V}_s$.

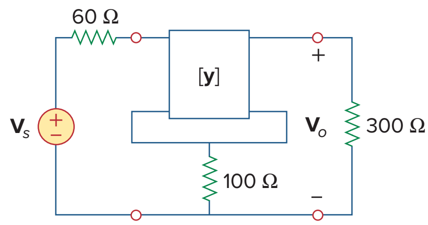


Figure 19.113
For Prob. 19.66.

19.67 If three copies of the circuit in Fig. 19.114 are connected in parallel, find the overall transmission parameters.

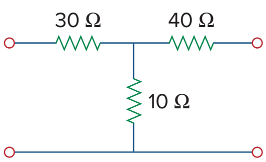


Figure 19.114
For Prob. 19.67.

19.68 Obtain the h parameters for the network in Fig. 19.115.

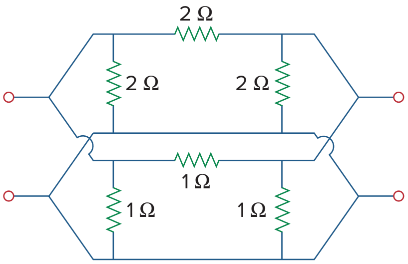


Figure 19.115
For Prob. 19.68.

*__19.69__ The circuit in Fig. 19.116 may be regarded as two two-ports connected in parallel. Obtain the y parameters as functions of s.

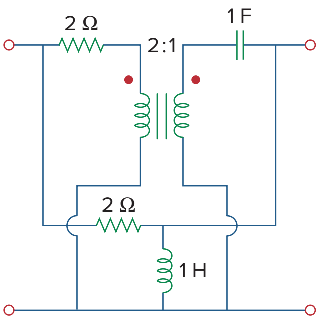


Figure 19.116
For Prob. 19.69.

*__19.70__ For the parallel-series connection of the two two-ports in Fig. 19.117, find the g parameters.

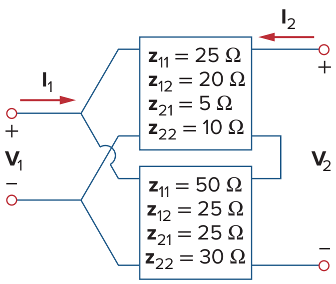


Figure 19.117
For Prob. 19.70.

*__19.71__ Determine the z parameters for the network in Fig. 19.118.

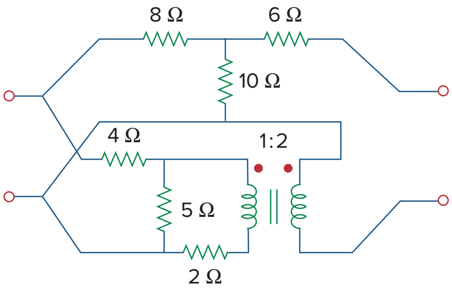


Figure 19.118
For Prob. 19.71.

*__19.72__ A series-parallel connection of two two-ports is shown in Fig. 19.119. Determine the z parameter representation of the network.

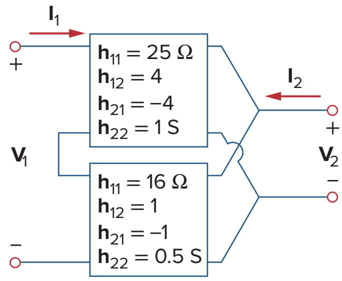


Figure 19.119
For Prob. 19.72.

19.73 Three copies of the circuit shown in Fig. 19.70 are connected in cascade. Determine the z parameters.

*__19.74__ Determine the **ABCD** parameters of the circuit in Fig. 19.120 as functions of s. (*Hint:* Partition the circuit into subcircuits and cascade them using the results of Prob. 19.43.)

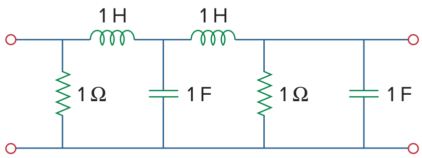


Figure 19.120
For Prob. 19.74.

*__19.75__ For the individual two-ports shown in Fig. 19.121 where,

$$[\mathbf{z}_a] = \begin{bmatrix} 8 & 6 \\ 4 & 5 \end{bmatrix} \Omega \quad [\mathbf{y}_b] = \begin{bmatrix} 8 & -4 \\ 2 & 10 \end{bmatrix} \text{S}$$

(a) Determine the y parameters of the overall two-port.
(b) Find the voltage ratio $\mathbf{V}_o/\mathbf{V}_i$ when $\mathbf{Z}_L = 2\ \Omega$.

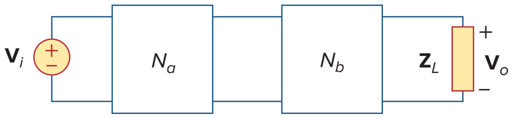


Figure 19.121
For Prob. 19.75.

Section 19.8 Computing Two-Port Parameters Using *PSpice*

19.76 Use *PSpice* or *MultiSim* to obtain the z parameters of the network in Fig. 19.122.

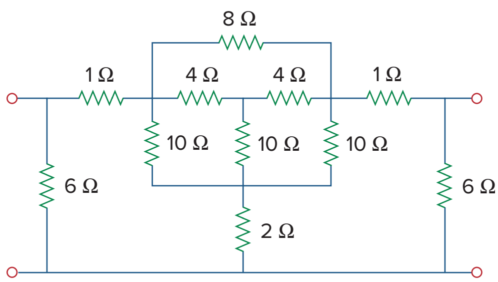


Figure 19.122
For Prob. 19.76.

19.77 Using *PSpice* or *MultiSim,* find the h parameters of the network in Fig. 19.123. Take $\omega = 1$ rad/s.

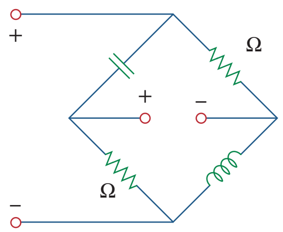


Figure 19.123
For Prob. 19.77.

19.78 Obtain the h parameters at $\omega = 4$ rad/s for the circuit in Fig. 19.124 using *PSpice* or *MultiSim.*

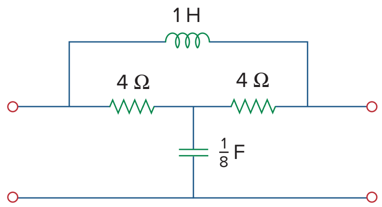


Figure 19.124
For Prob. 19.78.

19.79 Use *PSpice* or *MultiSim* to determine the z parameters of the circuit in Fig. 19.125. Take $\omega = 2$ rad/s.

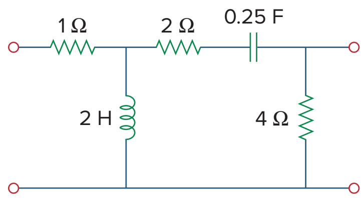


Figure 19.125
For Prob. 19.79.

19.80 Use *PSpice* or *MultiSim* to find the z parameters of the circuit in Fig. 19.71.

19.81 Repeat Prob. 19.26 using *PSpice* or *MultiSim.*

19.82 Use *PSpice* or *MultiSim* to rework Prob. 19.31.

19.83 Rework Prob. 19.47 using *PSpice* or *MultiSim.*

19.84 Using *PSpice* or *MultiSim,* find the transmission parameters for the network in Fig. 19.126.

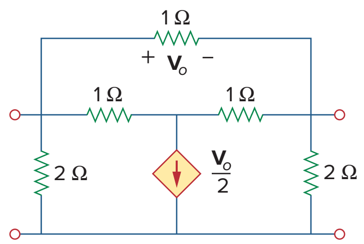


Figure 19.126
For Prob. 19.84.

19.85 At $\omega = 1$ rad/s, find the transmission parameters of the network in Fig. 19.127 using *PSpice* or *MultiSim.*

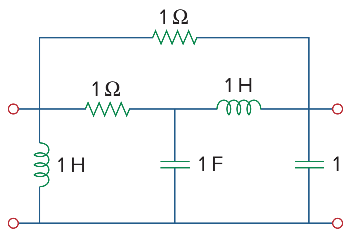


Figure 19.127
For Prob. 19.85.

19.86 Obtain the g parameters for the network in Fig. 19.128 using *PSpice* or *MultiSim.*

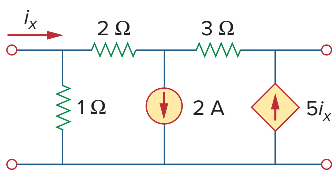


Figure 19.128
For Prob. 19.86.

19.87 For the circuit shown in Fig. 19.129, use *PSpice* or *MultiSim* to obtain the t parameters. Assume $\omega = 1$ rad/s.

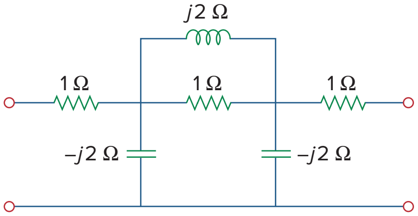


Figure 19.129
For Prob. 19.87.

Section 19.9 Applications

19.88 Using the y parameters, derive formulas for Z_{in}, Z_{out}, A_i, and A_v for the common-emitter transistor circuit.

19.89 A transistor has the following parameters in a common-emitter circuit:

$$h_{ie} = 2{,}640\ \Omega, \qquad h_{re} = 2.6 \times 10^{-4}$$
$$h_{fe} = 72, \qquad h_{oe} = 16\ \mu\text{S}, \qquad R_L = 100\ \text{k}\Omega$$

What is the voltage amplification of the transistor? How many decibels gain is this?

19.90 A transistor with

e⊿d

$$h_{fe} = 120, \qquad h_{ie} = 2\ \text{k}\Omega$$
$$h_{re} = 10^{-4}, \qquad h_{oe} = 20\ \mu\text{S}$$

is used for a CE amplifier to provide an input resistance of 1.5 kΩ.

(a) Determine the necessary load resistance R_L.
(b) Calculate A_v, A_i, and Z_{out} if the amplifier is driven by a 4-mV source having an internal resistance of 600 Ω.
(c) Find the voltage across the load.

19.91 For the transistor network of Fig. 19.130,

$$h_{fe} = 80, \qquad h_{ie} = 1.2\ \text{k}\Omega$$
$$h_{re} = 1.5 \times 10^{-4}, \qquad h_{oe} = 20\ \mu\text{S}$$

Determine the following:

(a) voltage gain $A_v = V_o/V_s$,
(b) current gain $A_i = I_o/I_i$,
(c) input impedance Z_{in},
(d) output impedance Z_{out}.

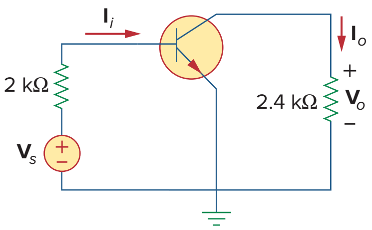


Figure 19.130
For Prob. 19.91.

*__19.92__ Determine A_v, A_i, Z_{in}, and Z_{out} for the amplifier shown in Fig. 19.131. Assume that

$$h_{ie} = 4\ \text{k}\Omega, \qquad h_{re} = 10^{-4}$$
$$h_{fe} = 100, \qquad h_{oe} = 30\ \mu\text{S}$$

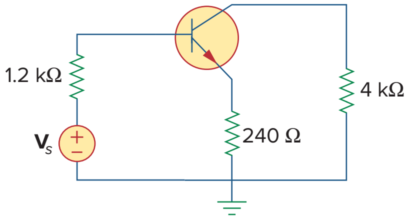


Figure 19.131
For Prob. 19.92.

*__19.93__ Calculate A_v, A_i, Z_{in}, and Z_{out} for the transistor network in Fig. 19.132. Assume that

$$h_{ie} = 2\ \text{k}\Omega, \qquad h_{re} = 2.5 \times 10^{-4}$$
$$h_{fe} = 150, \qquad h_{oe} = 10\ \mu\text{S}$$

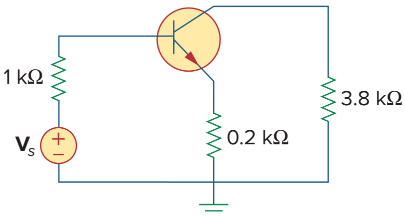


Figure 19.132
For Prob. 19.93.

19.94 A transistor in its common-emitter mode is specified by

e⊿d

$$[\mathbf{h}] = \begin{bmatrix} 200\ \Omega & 0 \\ 100 & 10^{-6}\ \text{S} \end{bmatrix}$$

Two such identical transistors are connected in cascade to form a two-stage amplifier used at audio frequencies. If the amplifier is terminated by a 4-kΩ resistor, calculate the overall A_v and Z_{in}.

19.95 Realize an LC ladder network such that

$$y_{22} = \frac{s^3 + 5s}{s^4 + 10s^2 + 8}$$

19.96 Design an LC ladder network to realize a low-pass filter with transfer function

e⊿d

$$H(s) = \frac{1}{s^4 + 2.613s^3 + 3.414s^2 + 2.613s + 1}$$

19.97 Synthesize the transfer function

e⊿d

$$H(s) = \frac{V_o}{V_s} = \frac{s^3}{s^3 + 6s + 12s + 24}$$

using the LC ladder network in Fig. 19.133.

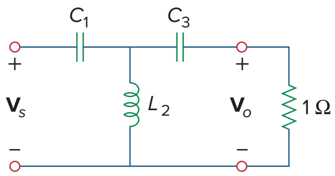


Figure 19.133
For Prob. 19.97.

19.98 A two-stage amplifier in Fig. 19.134 contains two identical stages with

$$[\mathbf{h}] = \begin{bmatrix} 2\text{ k}\Omega & 0.004 \\ 200 & 500\,\mu\text{S} \end{bmatrix}$$

If $\mathbf{Z}_L = 20$ kΩ, find the required value of $\mathbf{V}_s$ to produce $\mathbf{V}_o = 16$ V.

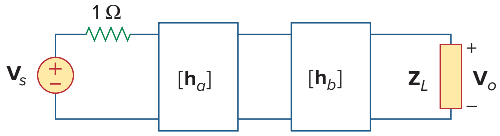
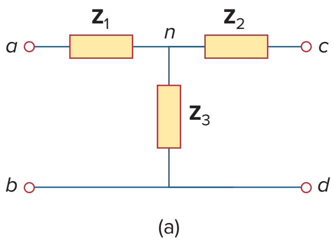


Figure 19.134
For Prob. 19.98.

Comprehensive Problem

19.99 Assume that the two circuits in Fig. 19.135 are equivalent. The parameters of the two circuits must be equal. Using this factor and the z parameters, derive Eqs. (9.67) and (9.68).



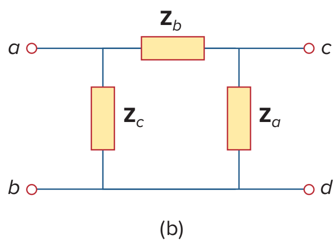


Figure 19.135
For Prob. 19.99.