Problems

Section 1.2

1.1 There are approximately 520 million passenger vehicles registered in the United States. Assume that the battery in an average vehicle stores 480 watt-hours (Wh) of energy. Estimate (in gigawatt-hours) the total energy stored in US passenger vehicles.

1.2 Each frame of a movie file is played at a resolution of 960×640 picture elements (pixels). Each pixel requires 4 bytes of memory. Videos are displayed at the rate of 40 frames per second. If the size of this file is 64 gigabytes, find its length.

1.3 The 8 gigabyte ($1 \text{ GB} = 2^{30}$ bytes) flash memory chip for an MP3 player is 10 mm by 20 mm by 2 mm. This memory chip holds 15,000 photos.

a) How many photos fit into a cube whose sides are 2 mm?

b) How many bytes of memory are stored in a cube whose sides are 100 μm?

1.4 The line described in Assessment Problem 1.7 is 900 mi in length. The line contains two conductors, each weighing 2526 lb per 1000 ft. How many kilograms of conductor are in the line?

1.5 A 40-inch monitor contains 4800×2160 picture elements, or pixels. Each pixel is represented in 32 bits of memory. A byte of memory is 8 bits.

a) How many megabytes (MB) of memory are required to store the information displayed on the monitor?

b) To display a video on the monitor, the image must be refreshed 30 times per second. How many terabytes (TB) of memory are required to store a 2 hr video?

c) For the video described in part (a), how fast must the image data in memory be moved to the monitor? Express your answer in gigabits per second (Gb/s).

1.6 Some species of bamboo can grow (250 mm/day). Assume individual cells in the plant are 10 μm long.

a) How long, on average, does it take a bamboo stalk to grow 1 cell length?

b) How many cell lengths are added in one week, on average?

Section 1.4

1.7 There is no charge at the upper terminal of the element in Fig. 1.5 for $t < 0$. At $t = 0$ a current of $125e^{-2500t}$ mA enters the upper terminal.

a) Derive the expression for the charge that accumulates at the upper terminal for $t > 0$.

b) Find the total charge that accumulates at the upper terminal.

c) If the current is stopped at $t = 0.5$ ms, how much charge has accumulated at the upper terminal?

1.8 The current entering the upper terminal of Fig. 1.5 is

$$i = 24 \cos 4000t \text{ A}$$

Assume the charge at the upper terminal is zero at the instant the current is passing through its maximum value. Find the expression for $q(t)$.

1.9 The current at the terminals of the element in Fig. 1.5 is

$$i = 0, \qquad t < 0;$$

$$i = 40te^{-500t} \text{ A}, \qquad t \geq 0.$$

a) Find the expression for the charge accumulating at the upper terminal.

b) Find the charge that has accumulated at $t = 1$ ms.

1.10 In electronic circuits it is not unusual to encounter currents in the microampere range. Assume a 35 μA current, due to the flow of electrons. What is the average number of electrons per second that flow past a fixed reference cross section that is perpendicular to the direction of flow?

1.11 How much energy is imparted to an electron as it flows through a 1.5 V battery from the positive to the negative terminals? Express your answer in joules.

Sections 1.5–1.6

1.12 The references for the voltage and current at the terminals of a circuit element are as shown in Fig. 1.6(d). The numerical values for v and i are -20 V and 5 A.

a) Calculate the power at the terminals and state whether the power is being absorbed or delivered by the element in the box.

b) Given that the current is due to electron flow, state whether the electrons are entering or leaving terminal 2.

c) Do the electrons gain or lose energy as they pass through the element in the box?

1.13 Repeat Problem 1.12 with a voltage of −60 V.

1.14 Two electric circuits, represented by boxes A and B, are connected as shown in Fig. P1.14. The reference direction for the current i in the interconnection and the reference polarity for the voltage v across the interconnection are as shown in the figure. For each of the following sets of numerical values, calculate the power in the interconnection and state whether the power is flowing from A to B or vice versa.

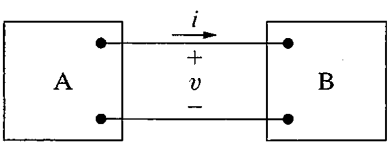
a) $i = 8$ A, $v = 40$ V

b) $i = -2$A, $v = -10$ V

c) $i = 2$A, $v = -50$ V

d) $i = -10$ A, $v = 20$ V

Figure P1.14

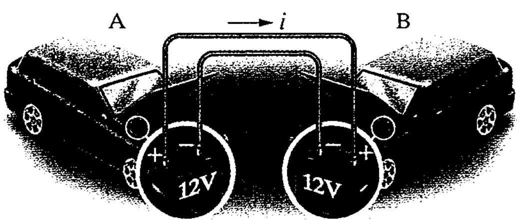


1.15 When a car has a dead battery, it can often be started by connecting the battery from another car across its terminals. The positive terminals are connected together as are the negative terminals. The connection is illustrated in Fig. P1.15. Assume the current i in Fig. P1.15 is measured and found to be 40 A.

a) Which car has the dead battery?

b) If this connection is maintained for 1.5 min, how much energy is transferred to the dead battery?

Figure P1.15



1.16 The manufacturer of a 1.5 V D flashlight battery says that the battery will deliver 9 mA for 40 continuous hours. During that time the voltage will drop from 1.5 V to 1.0 V. Assume the drop in voltage is linear with time. How much energy does the battery deliver in this 40 h interval?

1.17 One 12 V battery supplies 100 mA to a boom box. How much energy does the battery supply in 4 h?

1.18 The voltage and current at the terminals of the circuit elements in Fig 1.5 are zero for $t < 0$. For $t \geq 0$, they are

$$v = 3e^{-50t}\text{ V},$$
$$i = 5e^{-50t}\text{ mA}.$$

a) Calculate the power supplied to the element at 5 ms.

b) Calculate the total energy delivered to the circuit element.

1.19 PSPICE MULTISIM The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$. For $t \geq 0$ they are

$$v = 75 - 75e^{-1000t}\text{ V},$$
$$i = 50e^{-1000t}\text{mA}.$$

a) Find the maximum value of the power delivered to the circuit.

b) Find the total energy delivered to the element.

1.20 The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$. For $t \geq 0$ they are

$$v = 50e^{-1600t} - 50e^{-400t}\text{ V},$$
$$i = 5e^{-1600t} - 5e^{-400t}\text{ mA}.$$

a) Find the power at $t = 625\ \mu$s.

b) How much energy is delivered to the circuit element between 0 and 625 μs?

c) Find the total energy delivered to the element.

1.21 PSPICE MULTISIM The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$. For $t \geq 0$, they are

$$v = (1600t + 1)e^{-800t}\text{ V},\quad t \geq 0;$$
$$i = 50e^{-800t}\text{ mA},\quad t \geq 0.$$

a) Find the time when the power delivered to the circuit element is maximum.

b) Find the maximum value of p in milliwatts.

c) Find the total energy delivered to the circuit element in microjoules.

1.22 The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$. For $t \geq 0$, they are
PSPICE MULTISIM

$$v = (4000t + 3.2)e^{-1200t}\ \text{V},$$
$$i = (160t + 0.26)e^{-1200t}\ \text{A}.$$

a) At what instant of time is the maximum power delivered to the element?

b) Find the maximum power in watts.

c) Find the total energy delivered to the element in microjoules.

1.23 The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$ and $t > 50$ s. In the interval between 0 and 50 s, the expressions are
PSPICE MULTISIM

$$v = t(1 - 0.030t)\ \text{V}, \quad 0 < t < 50\ \text{s};$$
$$i = 4 - 0.3t\ \text{A}, \quad 0 < t < 50\ \text{s}.$$

a) At what instant of time is the maximum power delivered to the element?

b) What is the power at the time found in part (a)?

c) At what instant of time is the power being extracted from the circuit element the maximum?

d) What is the power at the time found in part (c)?

e) Calculate the net energy delivered to the circuit at 0, 10, 20, 30, 40 and 50 s.

1.24 The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$. For $t \geq 0$, they are
PSPICE MULTISIM

$$v = 500e^{-120t} \sin 250t\ \text{V},$$
$$i = 6e^{-150t} \sin 250t\ \text{A}.$$

a) Find the power absorbed by the element at $t = 20$ ms.

b) Find the total energy absorbed by the element.

1.25 The voltage and current at the terminals of the circuit element in Fig. 1.5 are
PSPICE MULTISIM

$$v = 260 \cos 850\pi t\ \text{V}, \quad i = 9 \sin 850\pi t\ \text{A}.$$

a) Find the maximum value of the power being delivered to the element.

b) Find the maximum value of the power being extracted from the element.

c) Find the average value of p in the interval $0 \leq t \leq 3$ ms.

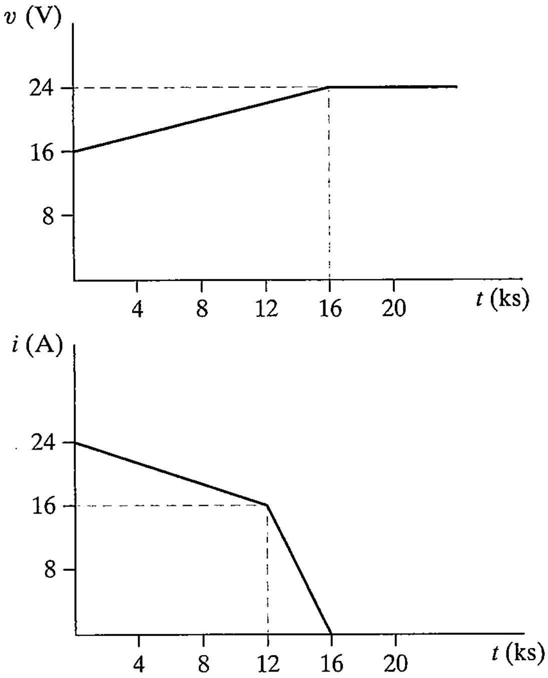
d) Find the average value of p in the interval $0 \leq t \leq 16.525$ ms.

1.26 The voltage and current at the terminals of an automobile battery during a charge cycle are shown in Fig. P1.26.

a) Calculate the total charge transferred to the battery.

b) Calculate the total energy transferred to the battery.

Figure P1.26

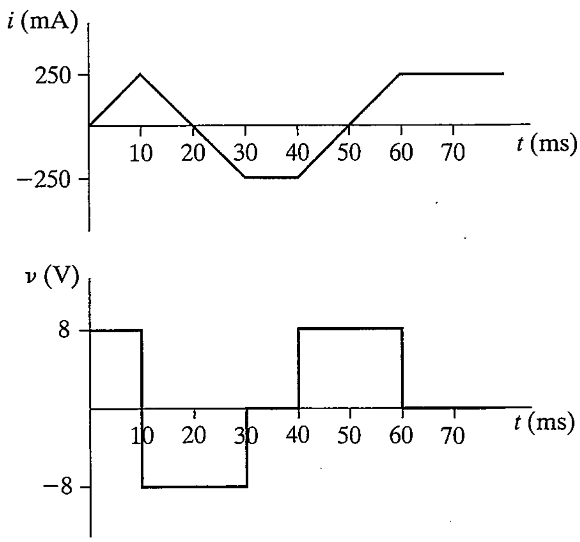


1.27 The voltage and current at the terminals of the circuit element in Fig. 1.5 are shown in Fig. P1.27.

a) Sketch the power versus t plot for $0 \leq t \leq 80$ ms.

b) Calculate the energy delivered to the circuit element at $t = 10$, 30, and 80 ms.

Figure P1.27



1.28 An industrial battery is charged over a period of several hours at a constant voltage of 120 V. Initially, the current is 20 mA and increases linearly to 30 mA in 10 ks. From 10 ks to 20 ks, the current is constant at 30 mA. From 20 ks to 30 ks the current decreases linearly to 10 mA. At 30 ks the power is disconnected from the battery.

a) Sketch the current from $t = 0$ to $t = 30$ ks.

b) Sketch the power delivered to the battery from $t = 0$ to $t = 30$ ks.

c) Using the sketch of the power, find the total energy delivered to the battery.

1.29 The numerical values for the currents and voltages in the circuit in Fig. P1.29 are given in Table P1.29. Find the total power developed in the circuit.

Figure P1.29

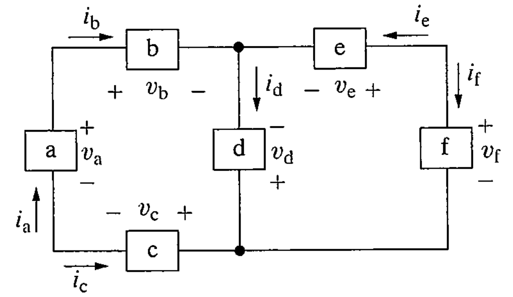


TABLE P1.29

Element	Voltage (V)	Current (mA)
a	40	−4
b	−24	−4
c	−16	4
d	−80	−1.5
e	40	2.5
f	120	−2.5

1.30 The numerical values of the voltages and currents in the interconnection seen in Fig. P1.30 are given in Table P1.30. Does the interconnection satisfy the power check?

Figure P1.30

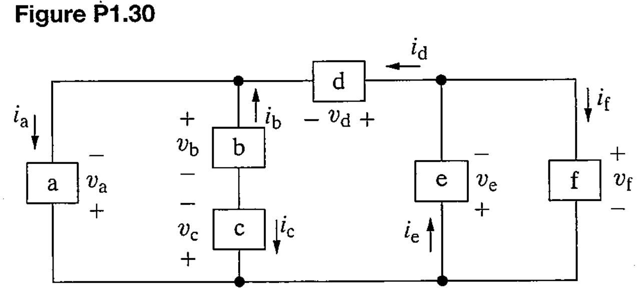


TABLE P1.30

Element	Voltage (kV)	Current (mA)
a	−3	−250
b	4	−400
c	1	400
d	1	150
e	−4	200
f	4	50

1.31 Assume you are an engineer in charge of a project and one of your subordinate engineers reports that the interconnection in Fig. P1.31 does not pass the power check. The data for the interconnection are given in Table P1.31.

a) Is the subordinate correct? Explain your answer.

b) If the subordinate is correct, can you find the error in the data?

Figure P1.31

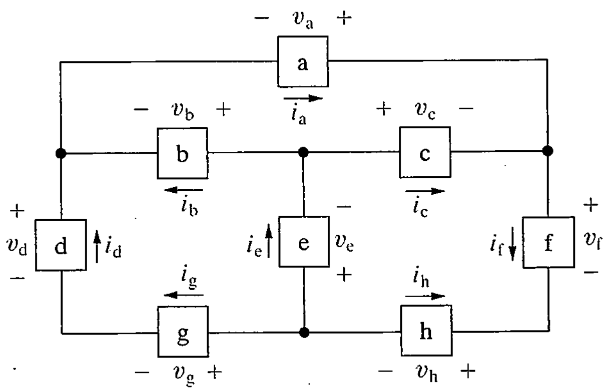


TABLE P1.31

Element	Voltage (V)	Current (A)
a	46.16	6.0
b	14.16	4.72
c	−32.0	−6.4
d	22.0	1.28
e	−33.6	−1.68
f	66.0	0.4
g	2.56	1.28
g	−0.4	0.4

1.32 The voltage and power values for each of the elements shown in Fig. P1.32 are given in Table P1.32.

a) Show that the interconnection of the elements satisfies the power check.

b) Find the value of the current through each of the elements using the values of power and voltage and the current directions shown in the figure.

1.33 The current and power for each of the interconnected elements in Fig. P1.33 is measured. The values are listed in Table P1.33.

a) Show that the interconnection satisfies the power check.

b) Identify the elements that absorb power.

c) Find the voltage for each of the elements in the interconnection, using the values of power and current and the voltage polarities shown in the figure.

Figure P1.32

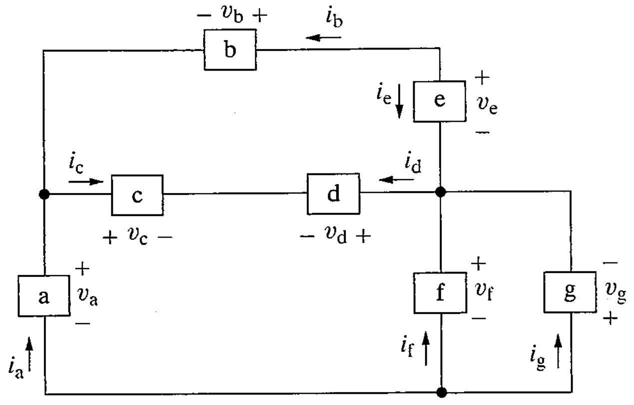


Figure P1.33

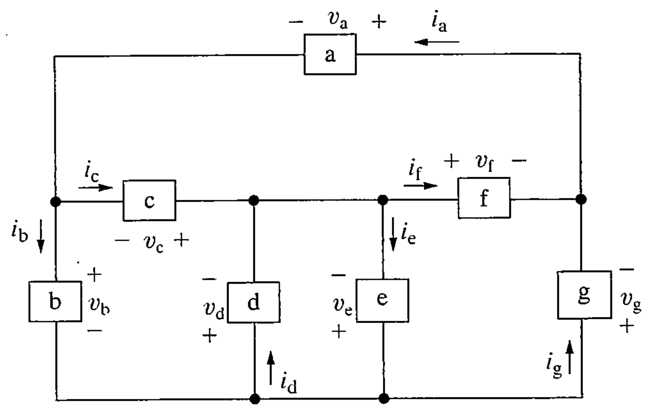


TABLE P1.32

Element	Power (kW)	Voltage (V)
a	0.6 supplied	400
b	0.05 supplied	−100
c	0.4 absorbed	200
d	0.6 supplied	300
e	0.1 absorbed	−200
f	2.0 absorbed	500
g	1.25 supplied	−500

TABLE P1.33

Element	Power (mW)	Current (mA)
a	175	25
b	375	75
c	150	−50
d	−320	40
e	160	20
f	120	−30
g	−660	55

1.34 PRACTICAL PERSPECTIVE Show that the power balances for the circuit shown in Fig. 1.7, using the voltage and current values given in Table 1.5, with the value of the current for component d changed to −1 A.

1.35 PRACTICAL PERSPECTIVE Suppose there is no power lost in the wires used to distribute power in a typical home.

a) Create a new model for the power distribution circuit by modifying the circuit shown in Fig 1.7. Use the same names, voltage polarities, and current directions for the components that remain in this modified model.

b) The following voltages and currents are calculated for the components:

$$v_a = 120\text{ V} \qquad i_a = -10\text{ A}$$
$$v_b = 120\text{ V} \qquad i_b = 10\text{ A}$$
$$v_f = -120\text{ V} \qquad i_f = 3\text{ A}$$
$$v_g = 120\text{ V}$$
$$v_h = -240\text{ V} \qquad i_h = -7\text{ A}$$

If the power in this modified model balances, what is the value of the current in component g?

Summary

- The circuit elements introduced in this chapter are voltage sources, current sources, and resistors:
  - An **ideal voltage source** maintains a prescribed voltage regardless of the current in the source. An **ideal current source** maintains a prescribed current regardless of the voltage across the source. Voltage and current sources are either **independent**, that is, not influenced by any other current or voltage in the circuit, or **dependent**, that is, determined by some other current or voltage in the circuit. (See pages 56 and 57.)
  - A **resistor** constrains its voltage and current to be proportional to each other. The value of the proportional constant relating voltage and current in a resistor is called its **resistance** and is measured in ohms. (See page 60.)
- **Ohm's law** establishes the proportionality of voltage and current in a resistor. Specifically,

$$v = iR$$

if the current flow in the resistor is in the direction of the voltage drop across it, or

$$v = -iR$$

if the current flow in the resistor is in the direction of the voltage rise across it. (See page 60.)

- By combining the equation for power, $p = vi$, with Ohm's law, we can determine the power absorbed by a resistor:

$$p = i^2R = v^2/R.$$

(See pages 61–62.)

- Circuits have nodes and closed paths. A **node** is a point where two or more circuit elements join. When just two elements connect to form a node, they are said to be **in series**. A **closed path** is a loop traced through connecting elements, starting and ending at the same node and encountering intermediate nodes only once each. (See pages 67–68.)
- The voltages and currents of interconnected circuit elements obey Kirchhoff's laws:
  - **Kirchhoff's current law** states that the algebraic sum of all the currents at any node in a circuit equals zero. (See page 67.)
  - **Kirchhoff's voltage law** states that the algebraic sum of all the voltages around any closed path in a circuit equals zero. (See page 68.)
- A circuit is solved when the voltage across and the current in every element have been determined. By combining an understanding of independent and dependent sources, Ohm's law, and Kirchhoff's laws, we can solve many simple circuits.

Problems

Section 2.1

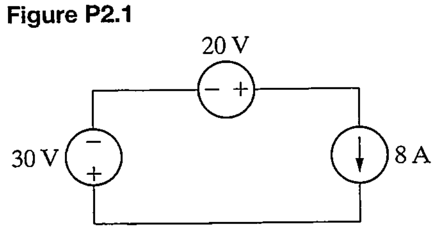
2.1 a) Is the interconnection of an ideal source in the circuit in Fig. P2.1 valid? Explain.

b) Identify which sources are developing power and which sources are absorbing power.

c) Verify that the total power developed in the circuit equals the total power absorbed.

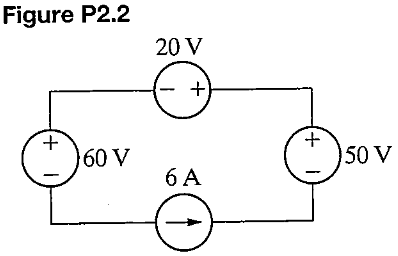
d) Repeat (a)–(c), reversing the polarity of the 30 V source.

Figure P2.1



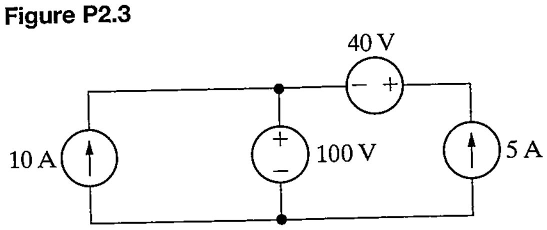
2.2 If the interconnection in Fig. P2.2 is valid, find the total power developed in the circuit. If the interconnection is not valid, explain why.

Figure P2.2



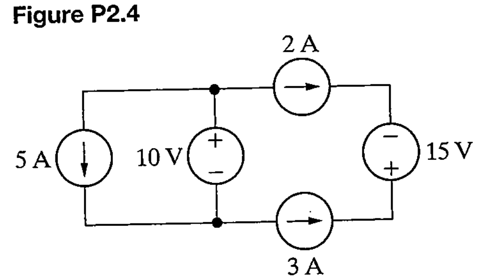
2.3 If the interconnection in Fig. P2.3 is valid, find the power developed by the current sources. If the interconnection is not valid, explain why.

Figure P2.3



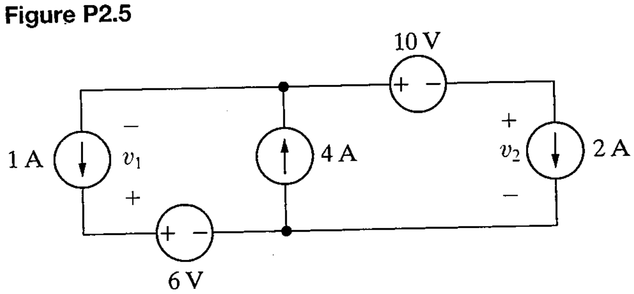
2.4 If the interconnection in Fig. P2.4 is valid, find the power developed by the voltage sources. If the interconnection is not valid, explain why.

Figure P2.4



2.5 The interconnection of ideal sources can lead to an indeterminate solution. With this thought in mind, explain why the solutions for v_1 and v_2 in the circuit in Fig. P2.5 are not unique.

Figure P2.5

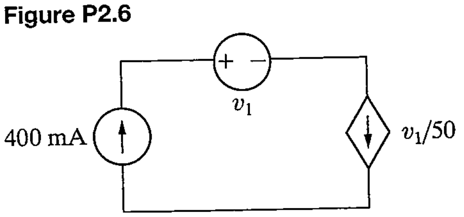


2.6 Consider the interconnection shown in Fig. P2.6.

a) What value of v_1 is required to make this a valid interconnection?

b) For this value of v_1, find the power associated with the voltage source.

Figure P2.6



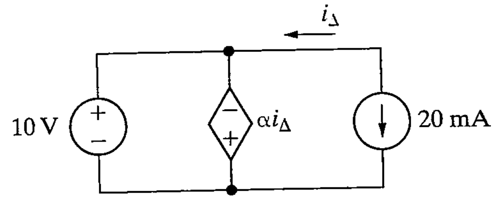
2.7 Consider the interconnection shown in Fig. P2.7.

a) What value of α is required to make this a valid interconnection?

b) For this value of α, find the power associated with the current source.

c) Is the current source supplying or absorbing power?

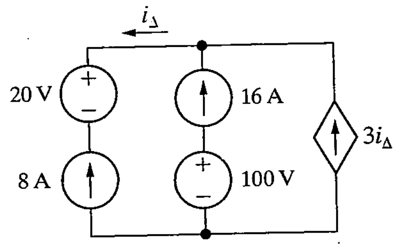
Figure P2.7



2.8 a) Is the interconnection in Fig. P2.8 valid? Explain.

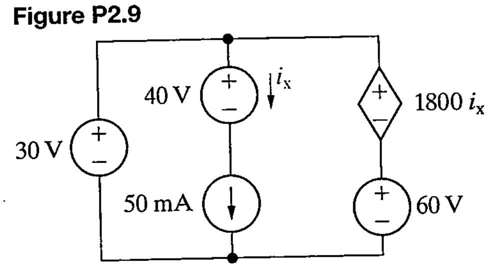
b) Can you find the total energy developed in the circuit? Explain.

Figure P2.8



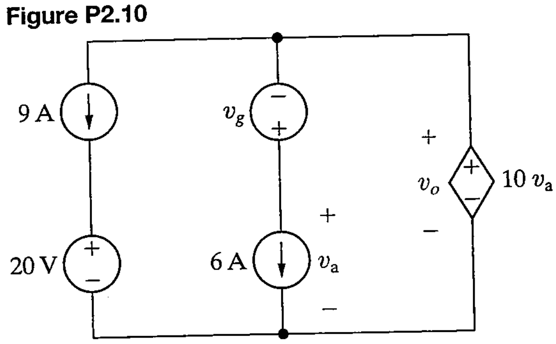
2.9 If the interconnection in Fig. P2.9 is valid, find the total power developed in the circuit. If the interconnection is not valid, explain why.

Figure P2.9



2.10 Find the total power developed in the circuit in Fig. P2.10 if $v_o = 10$ V.

Figure P2.10



Section 2.2–2.3

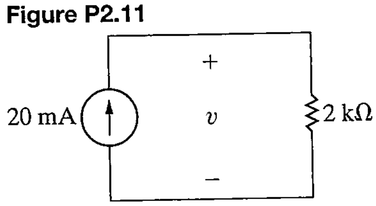
2.11 For the circuit shown in Fig. P2.11

a) Find v.

b) Find the power absorbed by the resistor.

c) Reverse the direction of the current source and repeat parts (a) and (b).

Figure P2.11



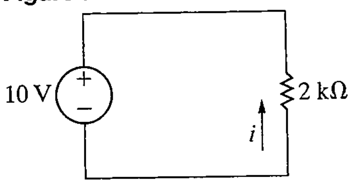
2.12 For the circuit shown in Fig. P2.12

a) Find i.

b) Find the power supplied by the voltage source.

c) Reverse the polarity of the voltage source and repeat parts (a) and (b).

Figure P2.12

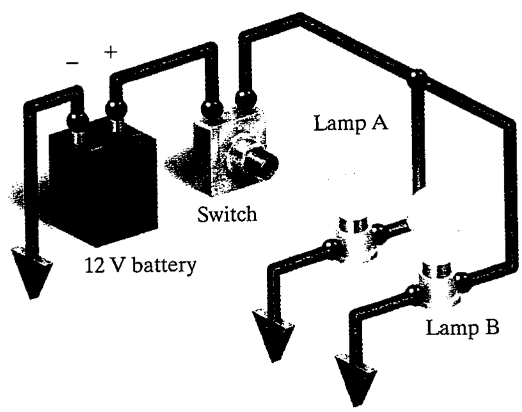


2.13 A pair of automotive headlamps is connected to a 12 V battery via the arrangement shown in Fig. P2.13. In the figure, the triangular symbol ▼ is used to indicate that the terminal is connected directly to the metal frame of the car.

a) Construct a circuit model using resistors and an independent voltage source.

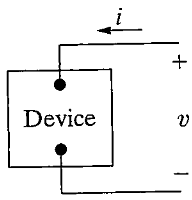
b) Identify the correspondence between the ideal circuit element and the symbol component that it represents.

Figure P2.13



2.14 The terminal voltage and terminal current were measured on the device shown in Fig. P2.14(a). The values of v and i are given in the table of Fig. P2.14(b). Use the values in the table to construct a circuit model for the device consisting of a single resistor from Appendix H.

Figure P2.14



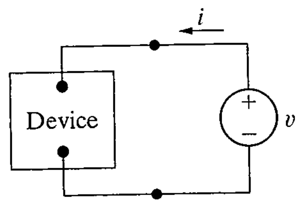
(a)

i (mA)	v (V)
−10	−120
−5	−60
5	60
10	120
15	180

(b)

2.15 A variety of voltage source values were applied to the device shown in Fig. P2.15(a). The power absorbed by the device for each value of voltage is recorded in the table given in Fig. P2.15(b). Use the values in the table to construct a circuit model for the device consisting of a single resistor from Appendix H.

Figure P2.15



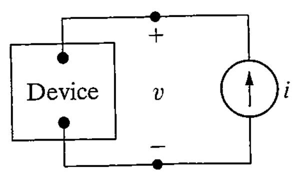
(a)

v (V)	p (mW)
−8	640
−4	160
4	160
8	640
12	1440
16	2560

(b)

2.16 A variety of current source values were applied to the device shown in Fig. P2.16(a). The power absorbed by the device for each value of current is recorded in the table given in Fig. P2.16(b). Use the values in the table to construct a circuit model for the device consisting of a single resistor from Appendix H.

Figure P2.16



(a)

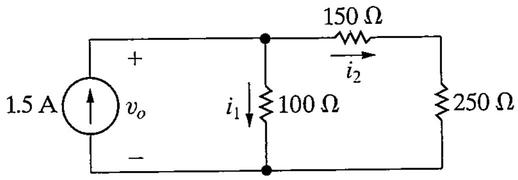
i (mA)	p (mW)
0.5	12.5
1.0	50
1.5	112.5
2.0	200
2.5	312.5
3.0	450

(b)

Section 2.4

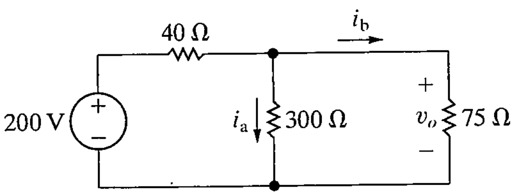
2.17 PSPICE MULTISIM
a) Find the currents i_1 and i_2 in the circuit in Fig. P2.17.
b) Find the voltage v_o.
c) Verify that the total power developed equals the total power dissipated.

Figure P2.17



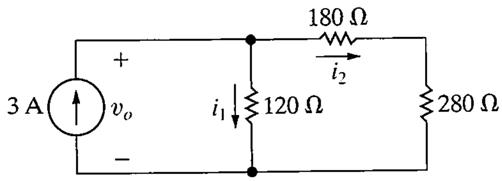
2.18 PSPICE MULTISIM
Given the circuit shown in Fig. P2.18, find
a) the value of i_a,
b) the value of i_b,
c) the value of v_o,
d) the power dissipated in each resistor,
e) the power delivered by the 200 V source.

Figure P2.18



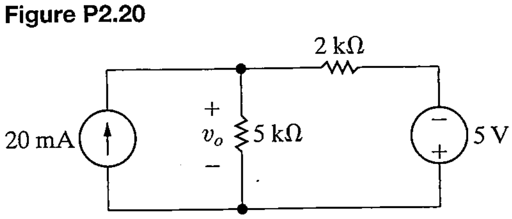
2.19 PSPICE MULTISIM
a) Find the currents i_1 and i_2 in the circuit in Fig. P2.19.
b) Find the voltage v_o.
c) Verify that the total power developed equals the total power dissipated.

Figure P2.19



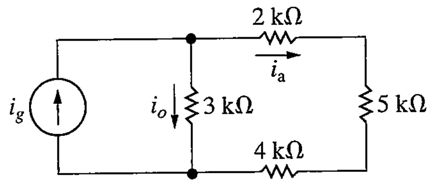
2.20 Consider the circuit shown in Fig. P2.20.
a) Find v_o using Kirchoff's laws and Ohm's law.
b) Test the solution for v_o by verifying that the total power supplied equals the total power absorbed.

Figure P2.20



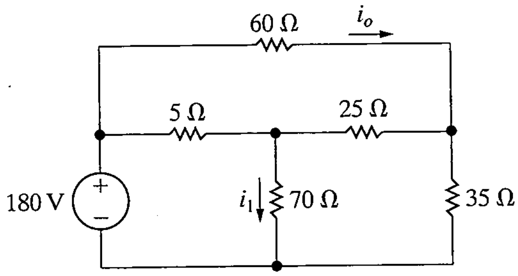
2.21 PSPICE MULTISIM
The current i_a in the circuit shown in Fig. P2.21 is 2 mA. Find (a) i_o; (b) i_g; and (c) the power delivered by the independent current sources.

Figure P2.21



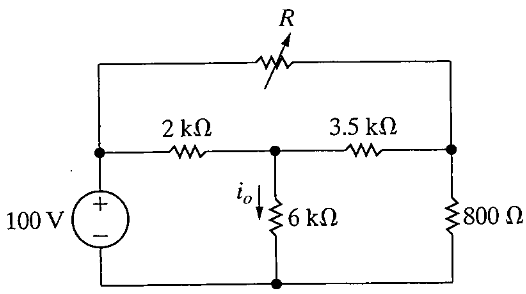
2.22 PSPICE MULTISIM
The current i_o in the circuit in Fig. P2.22 is 2 A.
a) Find i_1.
b) Find the power dissipated in each resistor.
c) Verify that the total power dissipated in the circuit equals the power developed by the 180 V source.

Figure P2.22



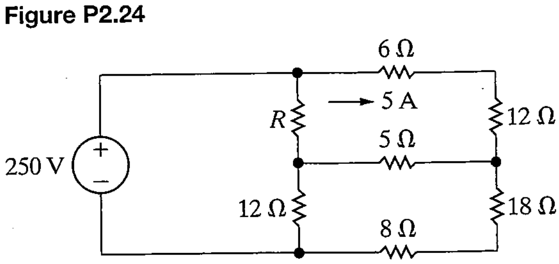
2.23 PSPICE MULTISIM
The variable resistor R in the circuit in Fig. P2.23 is adjusted until i_0 equals 20 mA. Find the value of R.

Figure P2.23



2.24 PSPICE MULTISIM
For the circuit shown in Fig. P2.24, find (a) R and (b) the power supplied by the 250 V source.

Figure P2.24



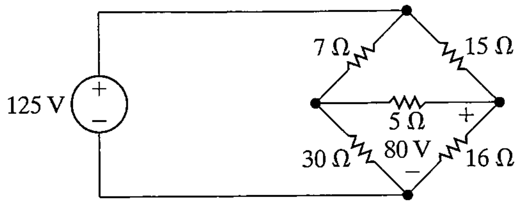
2.25 PSPICE MULTISIM The voltage across the 16 Ω resistor in the circuit in Fig. P2.25 is 80 V, positive at the upper terminal.

a) Find the power dissipated in each resistor.

b) Find the power supplied by the 125 V ideal voltage source.

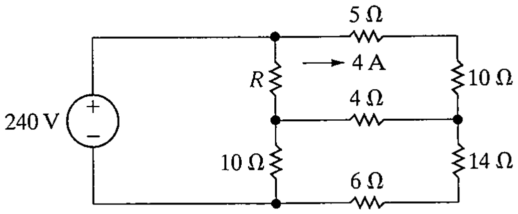
c) Verify that the power supplied equals the total power dissipated.

Figure P2.25



2.26 PSPICE MULTISIM For the circuit shown in Fig. P2.26, find (a) R and (b) the power supplied by the 240 V source.

Figure P2.26

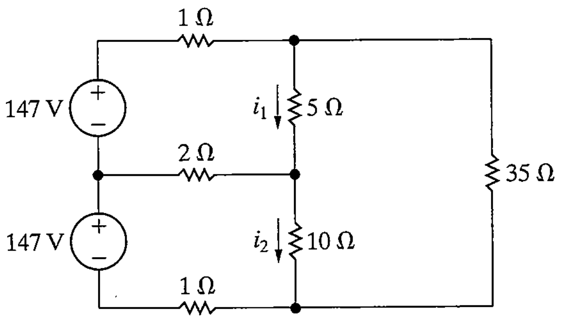


2.27 The currents i_1 and i_2 in the circuit in Fig. P2.27 are 21 A and 14 A, respectively.

a) Find the power supplied by each voltage source.

b) Show that the total power supplied equals the total power dissipated in the resistors.

Figure P2.27

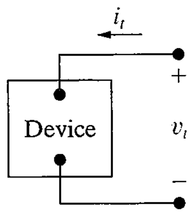


2.28 The voltage and current were measured at the terminals of the device shown in Fig. P2.28(a). The results are tabulated in Fig. P2.28(b).

a) Construct a circuit model for this device using an ideal voltage source in series with a resistor.

b) Use the model to predict the value of i_t when v_t is zero.

Figure P2.28



(a)

v_t (V)	i_t (A)
50	0
66	2
82	4
98	6
114	8
130	10

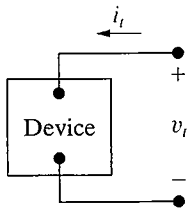
(b)

2.29 The voltage and current were measured at the terminals of the device shown in Fig. P2.29(a). The results are tabulated in Fig. P2.29(b).

a) Construct a circuit model for this device using an ideal current source in parallel with a resistor.

b) Use the model to predict the amount of power the device will deliver to a 20 Ω resistor.

Figure P2.29



(a)

v_t (V)	i_t (A)
50	0
65	3
80	6
95	9
110	12

(b)

2.30 The table in Fig. P2.30(a) gives the relationship between the terminal current and voltage of the practical constant current source shown in Fig. P2.30(b).

a) Plot i_s versus v_s.

b) Construct a circuit model of this current source that is valid for $0 \leq v_s \leq 75$ V, based on the equation of the line plotted in (a).

c) Use your circuit model to predict the current delivered to a 2.5 kΩ resistor.

d) Use your circuit model to predict the open-circuit voltage of the current source.

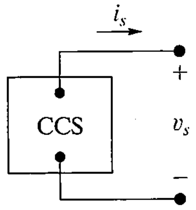
e) What is the actual open-circuit voltage?

f) Explain why the answers to (d) and (e) are not the same.

Figure P2.30

i_s (mA)	v_s (V)
20.0	0
17.5	25
15.0	50
12.5	75
9.0	100
4.0	125
0.0	140

(a)



(b)

2.31 The table in Fig. P2.31(a) gives the relationship between the terminal voltage and current of the practical constant voltage source shown in Fig. P2.31(b).

a) Plot v_s versus i_s.

b) Construct a circuit model of the practical source that is valid for $0 \le i_s \le 24$ mA, based on the equation of the line plotted in (a). (Use an ideal voltage source in series with an ideal resistor.)

c) Use your circuit model to predict the current delivered to a 1 kΩ resistor connected to the terminals of the practical source.

d) Use your circuit model to predict the current delivered to a short circuit connected to the terminals of the practical source.

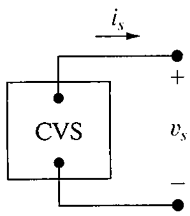
e) What is the actual short-circuit current?

f) Explain why the answers to (d) and (e) are not the same.

Figure P2.31

v_s (V)	i_s (mA)
24	0
22	8
20	16
18	24
15	32
10	40
0	48

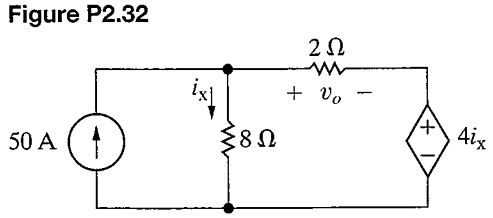
(a)



(b)

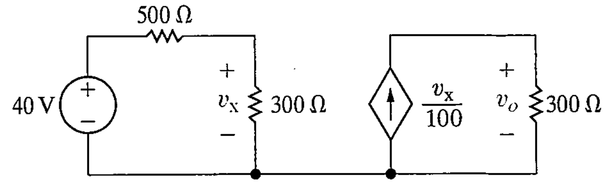
2.32 For the circuit shown in Fig. P2.32, find v_o and the total power supplied in the circuit.

Figure P2.32



2.33 For the circuit shown in Fig. P2.33, find v_o and the total power absorbed in the circuit.

Figure P2.33

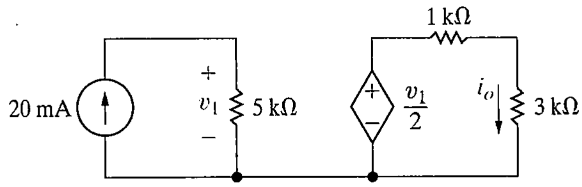


2.34 Consider the circuit shown in Fig. P2.34.

a) Find i_o.

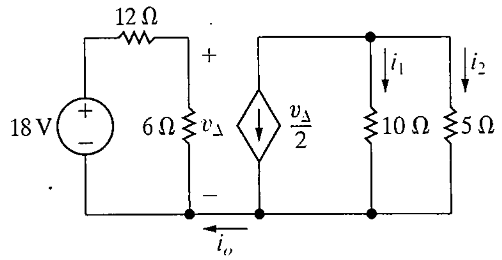
b) Verify the value of i_o by showing that the power generated in the circuit equals the power absorbed in the circuit.

Figure P2.34



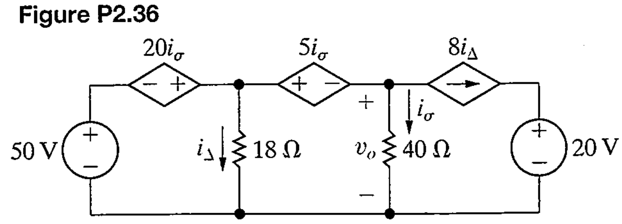
2.35 Find (a) i_o, (b) i_1, and (c) i_2 in the circuit in Fig. P2.35.
PSPICE
MULTISIM

Figure P2.35



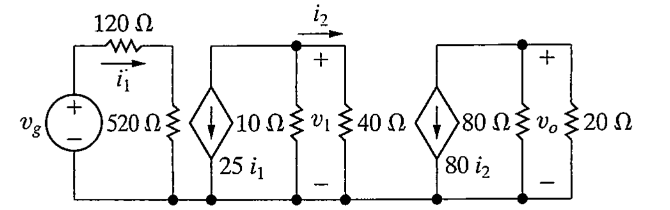
2.36 For the circuit shown in Fig. P2.36, calculate (a) i_Δ and v_o and (b) show that the power developed equals the power absorbed.

Figure P2.36



2.37 Find v_1 and v_g in the circuit shown in Fig. P2.37 when v_o equals 10 V. (*Hint:* Start at the right end of the circuit and work back toward v_g.)

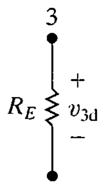
Figure P2.37



2.38 Derive Eq. 2.21. *Hint:* Use Eqs. (3) and (4) from Example 2.12 to express i_E as a function of i_B. Solve Eq. (2) for i_2 and substitute the result into both Eqs. (5) and (6). Solve the "new" Eq. (6) for i_1 and substitute this result into the "new" Eq. (5). Replace i_E in the "new" Eq. (5) and solve for i_B. Note that because i_{CC} appears only in Eq. (1), the solution for i_B involves the manipulation of only five equations.

2.39 PSPICE MULTISIM For the circuit shown in Fig. 2.24, $R_1 = 40$ kΩ, $R_2 = 60$ kΩ, $R_C = 750$ Ω, $R_E = 120$ Ω, $V_{CC} = 10$ V, $V_0 = 600$ mV, and $\beta = 49$. Calculate i_B, i_C, i_E, v_{3d}, v_{bd}, i_2, i_1, v_{ab}, i_{CC}, and v_{13}. (*Note:* In the double subscript notation on voltage variables, the first subscript is positive with respect to the second subscript. See Fig. P2.39.)

Figure P2.39



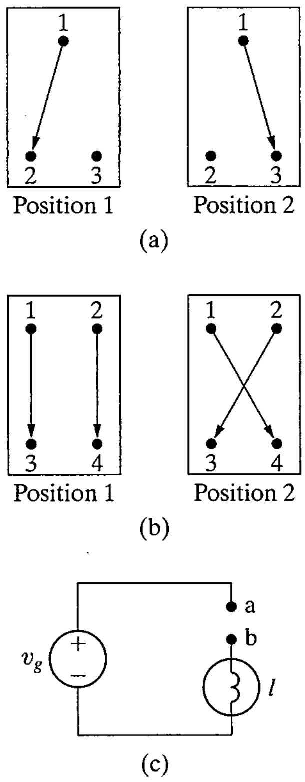
Sections 2.1–2.5

2.40 PSPICE MULTISIM It is often desirable in designing an electric wiring system to be able to control a single appliance from two or more locations, for example, to control a lighting fixture from both the top and bottom of a stairwell. In home wiring systems, this type of control is implemented with three-way and four-way switches. A three-way switch is a three-terminal, two-position switch, and a four-way switch is a four-terminal, two-position switch. The switches are shown schematically in Fig. P2.40(a), which illustrates a three-way switch, and P2.40(b), which illustrates a four-way switch.

a) Show how two three-way switches can be connected between a and b in the circuit in Fig. P2.40(c) so that the lamp l can be turned ON or OFF from two locations.

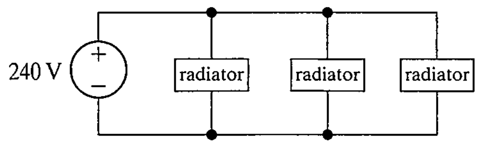
b) If the lamp (appliance) is to be controlled from more than two locations, four-way switches are used in conjunction with two three-way switches. One four-way switch is required for each location in excess of two. Show how one four-way switch plus two three-way switches can be connected between a and b in Fig. P2.40(c) to control the lamp from three locations. (*Hint:* The four-way switch is placed between the three-way switches.)

Figure P2.40



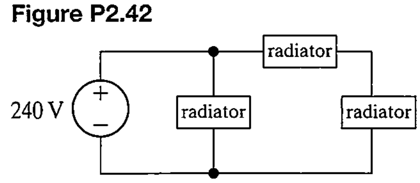
2.41 PRACTICAL PERSPECTIVE Suppose you want to add a third radiator to your garage that is identical to the two radiators you have already installed. All three radiators can be modeled by 48 Ω resistors. Using the wiring diagram shown in Fig. P2.41, calculate the total power for the three radiators.

Figure P2.41



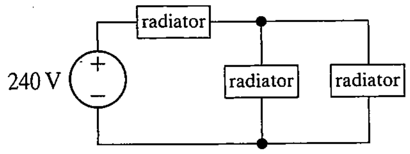
2.42 PRACTICAL PERSPECTIVE Repeat Problem 2.41 using the wiring diagram shown in Fig. P2.42. Compare the total radiator power in this configuration with the total radiator power in the configuration shown in Fig. P2.41.

Figure P2.42



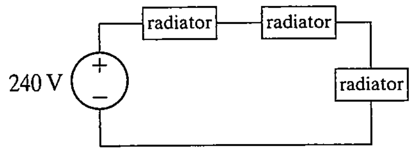
2.43 PRACTICAL PERSPECTIVE Repeat Problem 2.41 using the wiring diagram shown in Fig. P2.43. Compare the total radiator power in this configuration with the total radiator power in the configuration shown in Fig. P2.41.

Figure P2.43



2.44 PRACTICAL PERSPECTIVE Repeat Problem 2.41 using the wiring diagram shown in Fig. P2.44. Compare the total radiator power in this configuration with the total radiator power in the configuration shown in Fig. P2.41.

Figure P2.44



where i_j is the current through the resistance R_j and i is the current into the parallel-connected resistances whose equivalent resistance is R_{eq}. (See page 97.)

- A **voltmeter** measures voltage and must be placed in parallel with the voltage being measured. An ideal voltmeter has infinite internal resistance and thus does not alter the voltage being measured. (See page 98.)
- An **ammeter** measures current and must be placed in series with the current being measured. An ideal ammeter has zero internal resistance and thus does not alter the current being measured. (See page 98.)
- **Digital meters** and **analog meters** have internal resistance, which influences the value of the circuit variable being measured. Meters based on the d'Arsonval meter movement deliberately include internal resistance as a way to limit the current in the movement's coil. (See pages 99–101.)
- The **Wheatstone bridge** circuit is used to make precise measurements of a resistor's value using four resistors, a dc voltage source, and a galvanometer. A Wheatstone bridge is balanced when the resistors obey Eq. 3.11, resulting in a galvanometer reading of 0 A. (See pages 101–102.)
- A circuit with three resistors connected in a Δ configuration (or a π configuration) can be transformed into an equivalent circuit in which the three resistors are Y connected (or T connected). The Δ-to-Y transformation is given by Eqs. 3.15–3.17; the Y-to-Δ transformation is given by Eqs. 3.18–3.20. (See pages 103–105.)

Problems

Sections 3.1–3.2

3.1 a) Show that the solution of the circuit in Fig. 3.11 (see Example 3.1) satisfies Kirchhoff's current law at junctions x and y.
PSPICE
MULTISIM
b) Show that the solution of the circuit in Fig. 3.11 satisfies Kirchhoff's voltage law around every closed loop.

3.2 a) Find the power dissipated in each resistor in the circuit shown in Fig. 3.11.
PSPICE
MULTISIM
b) Find the power delivered by the 120 V source.
c) Show that the power delivered equals the power dissipated.

3.3 For each of the circuits shown in Fig. P3.3:
a) Identify the resistors connected in series.
b) Simplify the circuit by replacing the series-connected resistors with equivalent resistors.

3.4 For each of the circuits shown in Fig. P3.4:
a) Identify the resistors connected in parallel.
b) Simplify the circuit by replacing the parallel-connected resistors with equivalent resistors.

Figure P3.3

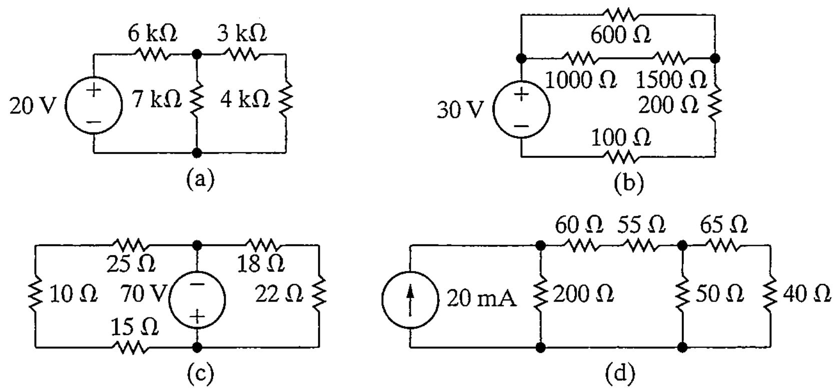
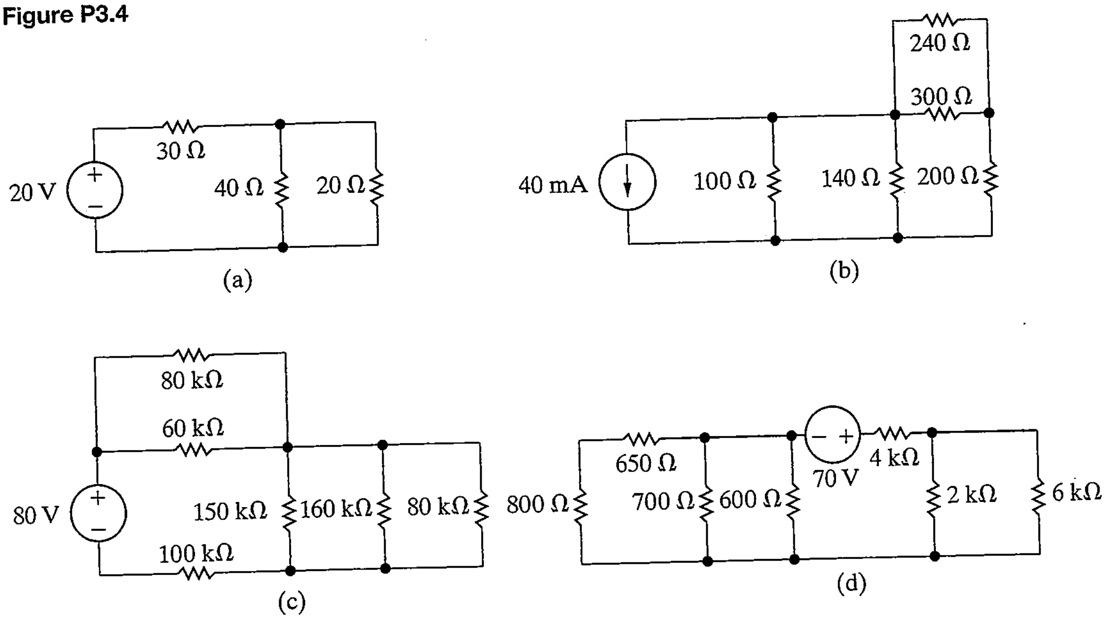


Figure P3.4



3.5 For each of the circuits shown in Fig. P3.3:

a) Find the equivalent resistance seen by the source.

b) Find the power developed by the source.

3.6 For each of the circuits shown in Fig. P3.4:

a) Find the equivalent resistance seen by the source.

b) Find the power developed by the source.

3.7 PSPICE MULTISIM a) In the circuits in Fig. P3.7(a)–(d), find the equivalent resistance seen by the source.

b) For each circuit find the power delivered by the source.

3.8 PSPICE MULTISIM Find the equivalent resistance R_{ab} for each of the circuits in Fig. P3.8.

Figure P3.7

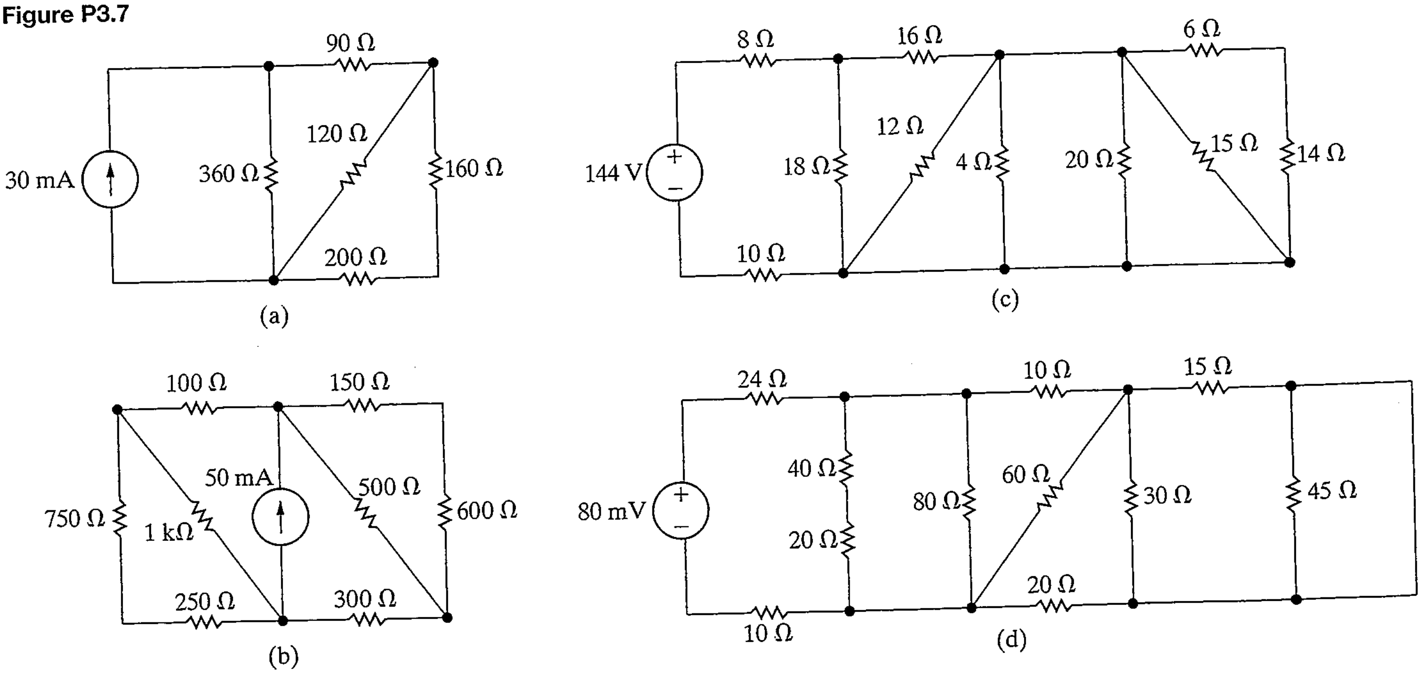
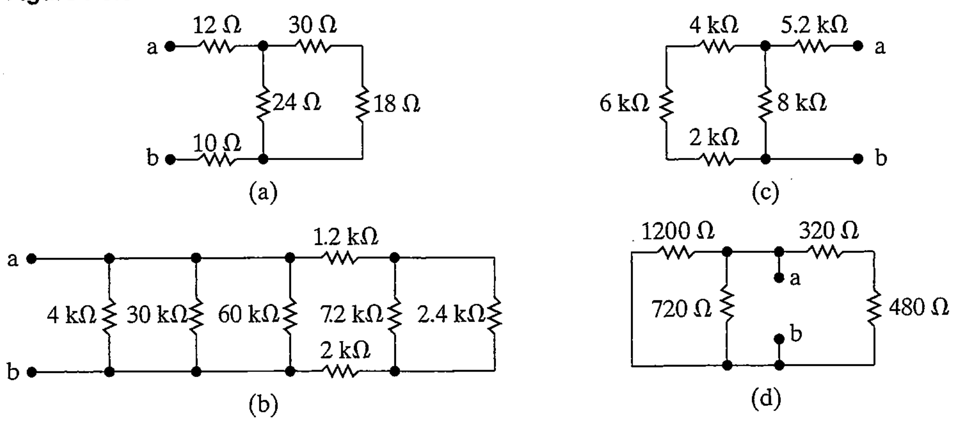


Figure P3.8



3.9 Find the equivalent resistance R_{ab} for each of the circuits in Fig. P3.9.
PSPICE
MULTISIM

3.10 a) Find an expression for the equivalent resistance of three resistors of value R in series.

b) Find an expression for the equivalent resistance of m resistors of value R in series.

c) Using the results of (a), design a resistive network with an equivalent resistance of 4.5 kΩ using three resistors with the same value from Appendix H.

d) Using the results of (b), design a resistive network with an equivalent resistance of 6.6 kΩ using a minimum number of identical resistors from Appendix H.

3.11 a) Find an expression for the equivalent resistance of two resistors of value R in parallel.

b) Find an expression for the equivalent resistance of n resistors of value R in parallel.

c) Using the results of (a), design a resistive network with an equivalent resistance of 5 kΩ using two resistors with the same value from Appendix H.

d) Using the results of (b), design a resistive network with an equivalent resistance of 4 kΩ using a minimum number of identical resistors from Appendix H.

Sections 3.3

3.12 a) Calculate the output voltage v_o for the voltage-divider circuit shown in Fig. P3.12.
DESIGN PROBLEM
PSPICE
MULTISIM

b) Calculate the net current flowing through the circuit.

c) Calculate the total power of this circuit in the absence of R_1, if the existing voltage source is replaced by a similar source of 100 V.

Figure P3.9

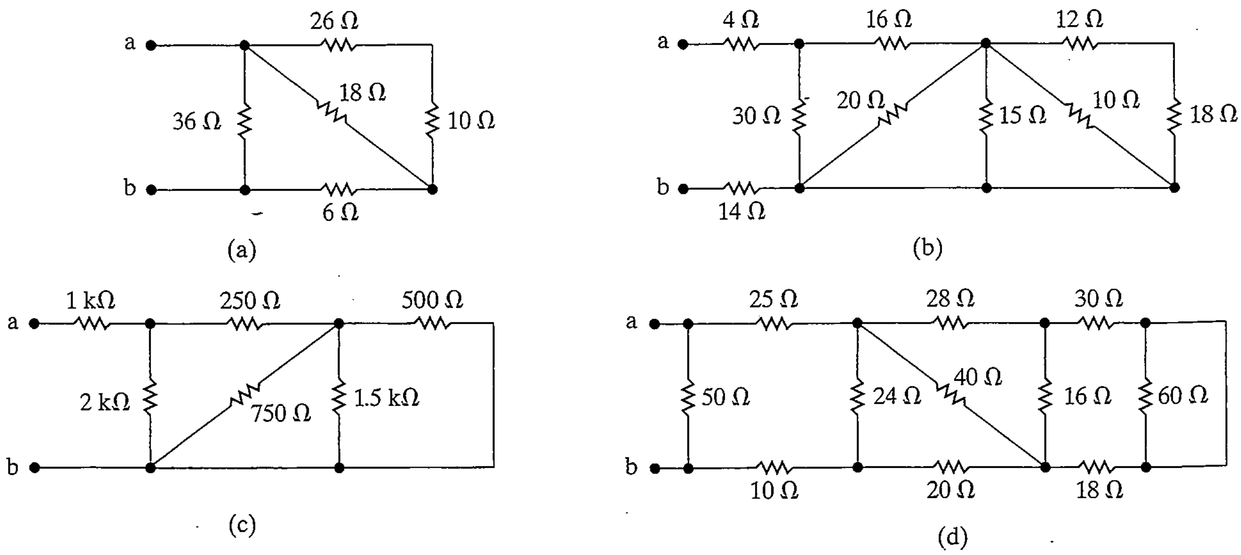
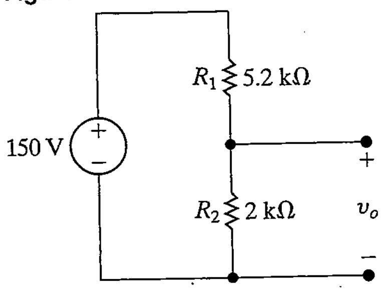


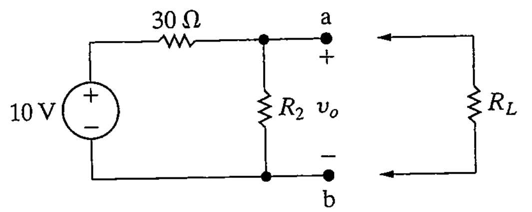
Figure P3.12



3.13 In the voltage-divider circuit shown in Fig. P3.13, find the voltage v_o for $R_2 = 10\ \Omega$. Also find the output voltage when $R_L = 30\ \text{k}\Omega$ is connected across the terminals a and b.

PSPICE MULTISIM

Figure P3.13

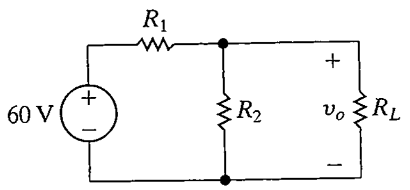


3.14 The no-load voltage in the voltage-divider circuit shown in Fig. P3.14 is 15 V. The smallest load resistor that is ever connected to the divider is 3.6 kΩ. When the divider is loaded, v_o is not to drop below 14 V.

a) Design the divider circuit to meet the specifications just mentioned. Specify the numerical values of R_1 and R_2.

b) Assume the power ratings of commercially available resistors are 1, 2, 3 and 4 W. What power rating would you specify?

Figure P3.14

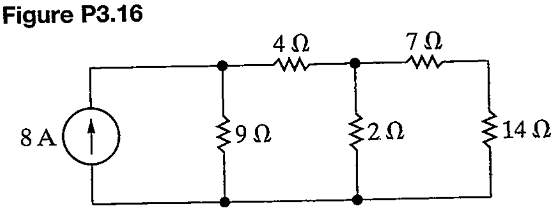


3.15 Assume the voltage divider in Fig. P3.14 has been constructed from 3 W resistors. What is the smallest resistors from Appendix H that can be used as R_L before one of the resistors in the divider is operating at its dissipation limit?

3.16 Find the output voltage across the 14 Ω resistor in the circuit shown in Fig. P3.16.

PSPICE MULTISIM

Figure P3.16



3.17 For the current divider circuit in Fig. P3.17 calculate

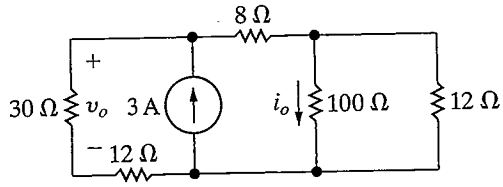
PSPICE MULTISIM

a) the current in the 8 Ω resistor,

b) the voltage across the 30 Ω resistor, and

c) the power dissipated in the 100 Ω resistor.

Figure P3.17

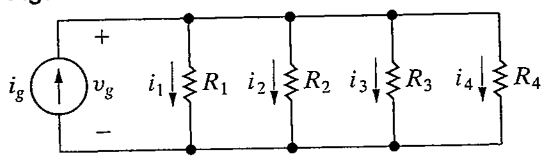


3.18 Specify the resistors in the current-divider circuit in Fig. P3.18 to meet the following design criteria:

$$i_g = 100\ \text{mA};\ v_g = 25\ \text{V};\ i_1 = 0.6 i_2;$$

$$i_3 = 2 i_2;\ \text{and}\ i_4 = 4 i_1.$$

Figure P3.18

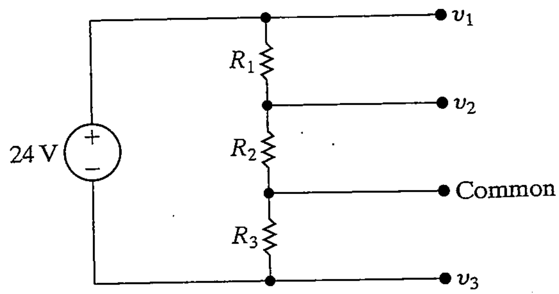


3.19 There is often a need to produce more than one voltage using a voltage divider. For example, the memory components of many personal computers require voltages of −12 V, 5 V, and +12 V, all with respect to a common reference terminal. Select the values of R_1, R_2, and R_3 in the circuit in Fig. P3.19 to meet the following design requirements:

a) The total power supplied to the divider circuit by the 24 V source is 100 W when the divider is unloaded.

b) The three voltages, all measured with respect to the common reference terminal, are $v_1 = 12$ V, $v_2 = 5$ V, and $v_3 = -12$ V.

Figure P3.19



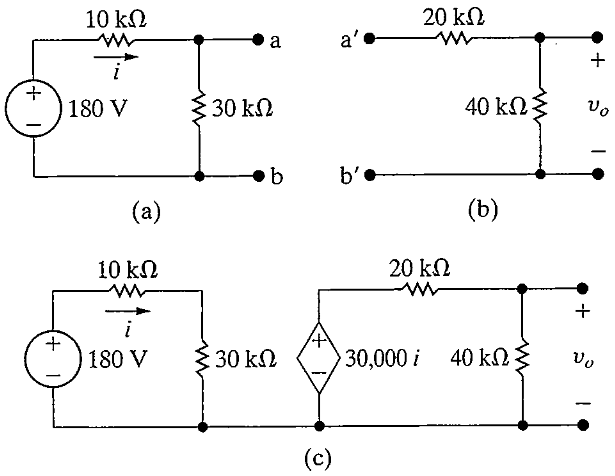
3.20 PSPICE MULTISIM

a) The voltage divider in Fig. P3.20(a) is loaded with the voltage divider shown in Fig. P3.20(b); that is, a is connected to a′, and b is connected to b′. Find v_o.

b) Now assume the voltage divider in Fig. P3.20(b) is connected to the voltage divider in Fig. P3.20(a) by means of a current-controlled voltage source as shown in Fig. P3.20(c). Find v_o.

c) What effect does adding the dependent-voltage source have on the operation of the voltage divider that is connected to the 180 V source?

Figure P3.20



3.21 DESIGN PROBLEM

A voltage divider like that in Fig. 3.19 is to be designed so that $v_o = kv_s$ at no load ($R_L = \infty$) and $v_o = \alpha v_s$ at full load ($R_L = R_o$). Note that by definition $\alpha < k < 1$.

a) Show that

$$R_1 = \frac{k - \alpha}{\alpha k} R_o$$

and

$$R_2 = \frac{k - \alpha}{\alpha(1 - k)} R_o.$$

b) Specify the numerical values of R_1 and R_2 if $k = 0.85$, $\alpha = 0.80$, and $R_o = 34$ kΩ.

c) If $v_s = 60$ V, specify the maximum power that will be dissipated in R_1 and R_2.

d) Assume the load resistor is accidentally short circuited. How much power is dissipated in R_1 and R_2?

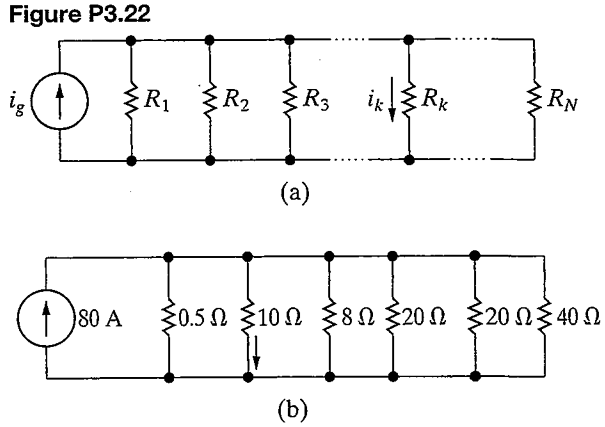
3.22 PSPICE MULTISIM

a) Show that the current in the kth branch of the circuit in Fig. P3.22(a) is equal to the source current i_g times the conductance of the kth branch divided by the sum of the conductances, that is,

$$i_k = \frac{i_g G_k}{G_1 + G_2 + G_3 + \cdots + G_k + \cdots + G_N}.$$

b) Use the result derived in (a) to calculate the current in the 10 Ω resistor in the circuit in Fig. P3.22(b).

Figure P3.22



Sections 3.4

3.23 Look at the circuit in Fig. P3.3(a).

a) Find the net output voltage across the 7 kΩ and 4 kΩ resistors, positive at the top.

b) Use the result from part (a) and find the current flowing through the 4 kΩ resistor.

3.24 Look at the circuit in Fig. P3.1(d).

a) Use current division to find the current in the 50 Ω resistor from left to right.

b) Use the result from part (a) and current division to find the current in the 70 Ω resistor from top to bottom.

3.25 Look at the circuit in Fig. P3.7(a).

a) Use current division to find the current in the 120 Ω resistor from top to bottom.

b) Using your result from (a), find the voltage drop across the 120 Ω resistor, positive at the top.

c) Starting with your result from (b), use voltage division to find the voltage across the 200 Ω resistor, positive on the right.

d) Using your result from (c), find the current in the 200 Ω resistor from left to right.

e) Starting with your result from (d), use current division to find the current in the 90 Ω resistor from left to right.

3.26 Attach a 450 mA current source between the terminals a–b in Fig. P3.6(a), with the current arrow pointing up.

a) Use current division to find the current in the 36 Ω resistor from top to bottom.

b) Use the result from part (a) to find the voltage across the 36 Ω resistor, positive at the top.

c) Use the result from part (b) and voltage division to find the voltage across the 18 Ω resistor, positive at the top.

d) Use the result from part (c) and voltage division to find the voltage across the 10 Ω resistor, positive at the top.

3.27 Attach a 10 V voltage source between the terminals a–b in Fig. P3.9(b), with the positive terminal at the top.

a) Use voltage division to find the voltage across the 4 Ω resistor, positive at the top.

b) Use the result from part (a) to find the current in the 4 Ω resistor from left to right.

c) Use the result from part (b) and current division to find the current in the 16 Ω resistor from left to right.

d) Use the result from part (c) and current division to find the current in the 10 Ω resistor from top to bottom.

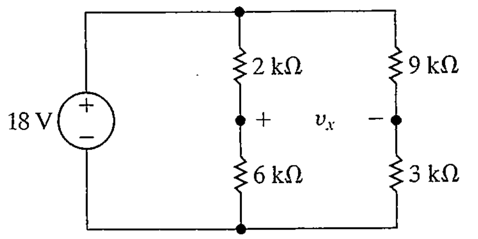
e) Use the result from part (d) to find the voltage across the 10 Ω resistor, positive at the top.

f) Use the result from part (e) and voltage division to find the voltage across the 18 Ω resistor, positive at the top.

3.28 PSPICE MULTISIM a) Find the voltage v_x in the circuit in Fig. P3.28 using voltage and/or current division.

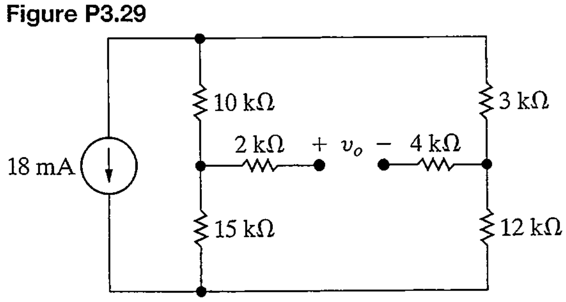
b) Replace the 18 V source with a general voltage source equal to V_s. Assume V_s is positive at the upper terminal. Find v_x as a function of V_s.

Figure P3.28



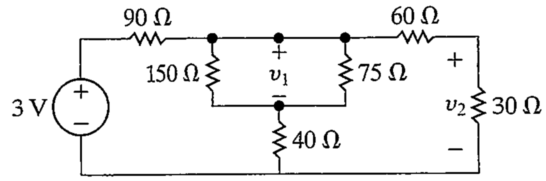
3.29 PSPICE MULTISIM Find v_o in the circuit in Fig. P3.29 using voltage and/or current division.

Figure P3.29



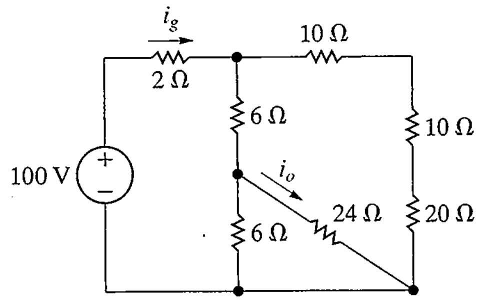
3.30 PSPICE MULTISIM Find v_1 and v_2 in the circuit in Fig. P3.30 using voltage and/or current division.

Figure P3.30



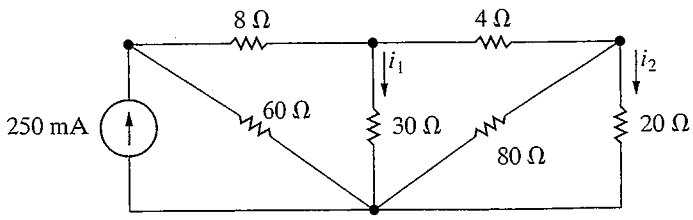
3.31 For the circuit in Fig. P3.31, find i_g and then use current division to find i_o.

Figure P3.31



3.32 PSPICE MULTISIM For the circuit in Fig. P3.32, calculate i_1 and i_2 using current division.

Figure P3.32



Sections 3.5

3.33 A d'Arsonval ammeter is shown in Fig. P3.33.

a) Calculate the value of the shunt resistor, R_A, to give a full-scale current reading of 5 A.

b) How much resistance is added to a circuit when the 5 A ammeter in part (a) is inserted to measure current?

c) Calculate the value of the shunt resistor, R_A, to give a full-scale current reading of 100 mA.

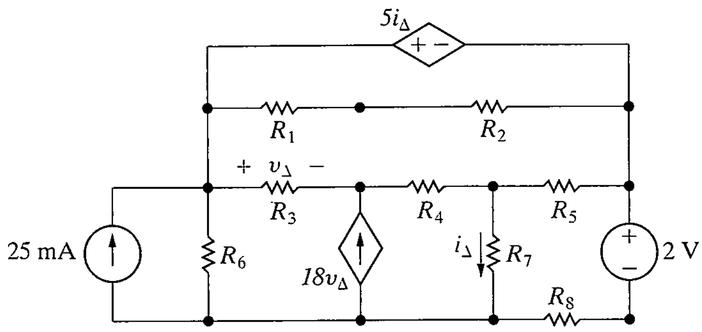
d) How much resistance is added to a circuit when the 100 mA ammeter in part (c) is inserted to measure current?

Problems

Section 4.1

4.1 For the circuit shown in Fig. P4.1, state the numerical value of the number of (a) branches, (b) branches where the current is unknown, (c) essential branches, (d) essential branches where the current is unknown, (e) nodes, (f) essential nodes, and (g) meshes.

Figure P4.1



4.2 a) If only the essential nodes and branches are identified in the circuit in Fig. P4.1, how many simultaneous equations are needed to describe the circuit?

b) How many of these equations can be derived using Kirchhoff's current law?

c) How many must be derived using Kirchhoff's voltage law?

d) What two meshes should be avoided in applying the voltage law?

4.3 Assume the voltage v_s in the circuit in Fig. P4.3 is known. The resistors $R_1 - R_7$ are also known.

a) How many unknown currents are there?

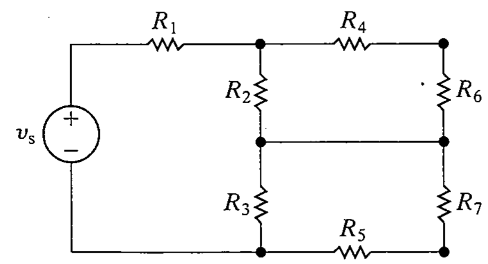
b) How many independent equations can be written using Kirchhoff's current law (KCL)?

c) Write an independent set of KCL equations.

d) How many independent equations can be derived from Kirchhoff's voltage law (KVL)?

e) Write a set of independent KVL equations.

Figure P4.3



4.4 A current leaving a node is defined as positive.

a) Sum the currents at each essential node in the circuit shown in Fig. P4.3.

b) Show that any one of the equations in (a) can be derived from the remaining three equations.

4.5 Look at the circuit in Fig. 4.4.

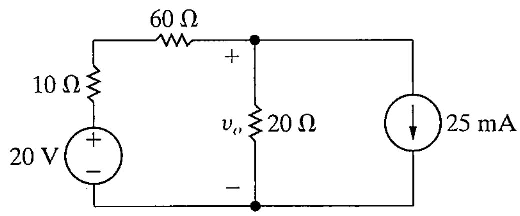
a) Write the KCL equation at the essential node labeled g.

b) Show that the KCL equation in part (a) can be derived from the KCL equations at nodes b, c, and e (see Example 4.2).

Section 4.2

4.6 PSPICE MULTISIM Use the node-voltage method to find v_o in the circuit in Fig. P4.6.

Figure P4.6



4.7 PSPICE MULTISIM a) Find the power developed by the 40 mA current source in the circuit in Fig. P4.6.

b) Find the power developed by the 25 V voltage source in the circuit in Fig. P4.6.

c) Verify that the total power developed equals the total power dissipated.

4.8 PSPICE MULTISIM A 100 Ω resistor is connected in series with the 40 mA current source in the circuit in Fig. P4.6.

a) Find v_o.

b) Find the power developed by the 40 mA current source.

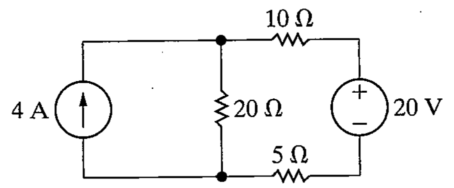
c) Find the power developed by the 25 V voltage source.

d) Verify that the total power developed equals the total power dissipated.

e) What effect will any finite resistance connected in series with the 40 mA current source have on the value of v_o?

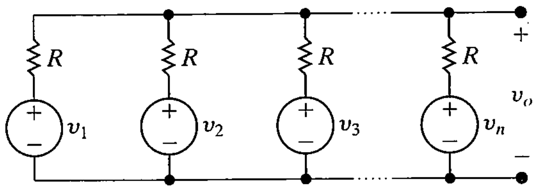
4.9 PSPICE MULTISIM Use the node-voltage method to find how much power the 4 A source extracts from the circuit in Fig. P4.9.

Figure P4.9



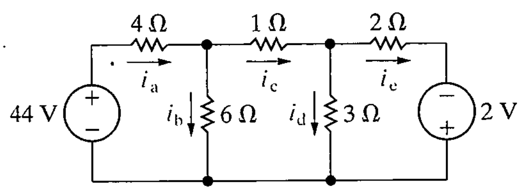
4.10 PSPICE MULTISIM
a) Use the node-voltage method to show that the output voltage v_o in the circuit in Fig. P4.10 is equal to the average value of the source voltages.
b) Find v_o if $v_1 = 120$ V, $v_2 = 60$ V, and $v_3 = -30$ V.

Figure P4.10



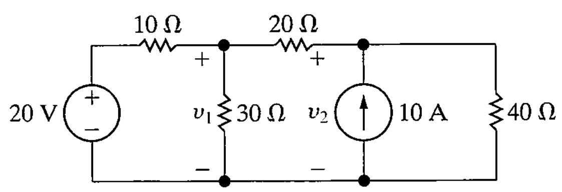
4.11 PSPICE MULTISIM
a) Use the node-voltage method to find the branch currents $i_a - i_e$ in the circuit shown in Fig. P4.11.
b) Find the total power developed in the circuit.

Figure P4.11



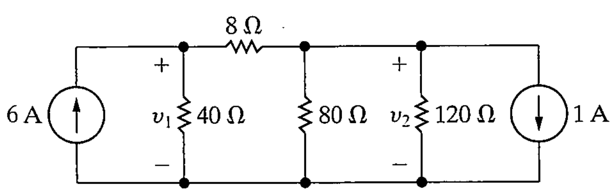
4.12 PSPICE MULTISIM
Use the node-voltage method to find v_1 and v_2 in the circuit in Fig. P4.12.

Figure P4.12



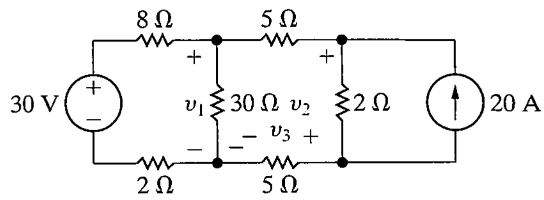
4.13 PSPICE MULTISIM
Use the node-voltage method to find v_1 and v_2 in the circuit shown in Fig. P4.13.

Figure P4.13



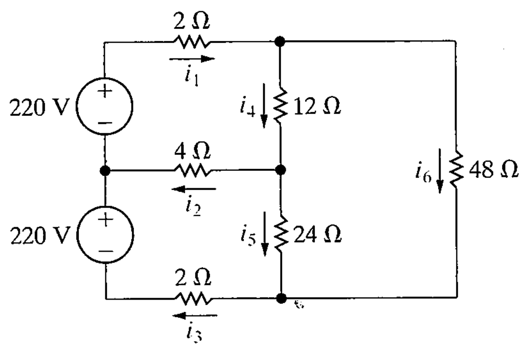
4.14 PSPICE MULTISIM
a) Use the node-voltage method to find v_1, v_2, and v_3 in the circuit in Fig. P4.14.
b) How much power does the 30 V voltage source deliver to the circuit?

Figure P4.14



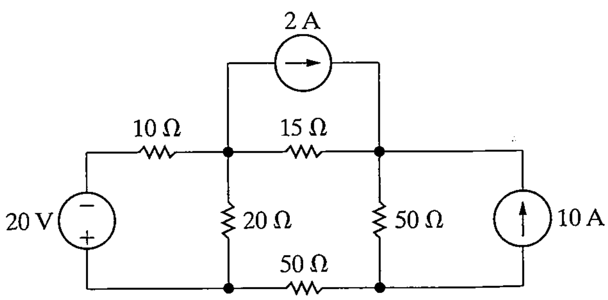
4.15 PSPICE MULTISIM
The circuit shown in Fig. P4.15 is a dc model of a residential power distribution circuit.
a) Use the mesh-current method to find the branch currents $i_1 - i_6$.
b) Test your solution for the branch currents by showing that the total power dissipated equals the total power developed.

Figure P4.15



4.16 PSPICE MULTISIM
Use the mesh-current method to find the total power dissipated in the circuit in Fig. P4.16.

Figure P4.16

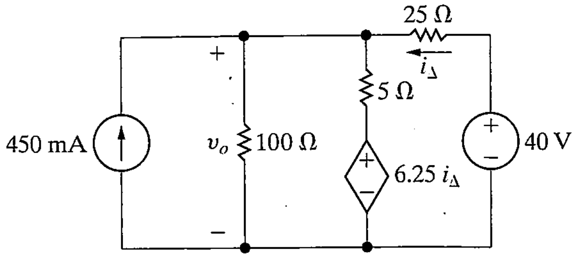


Section 4.3

4.17 PSPICE MULTISIM
a) Use the node-voltage method to find v_o in the circuit in Fig. P4.17.
b) Find the power absorbed by the dependent source.

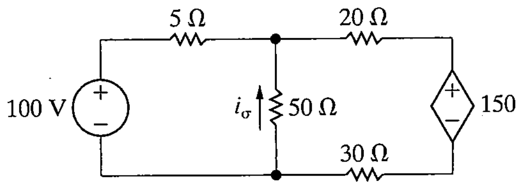
c) Find the total power developed by the independent sources.

Figure P4.17



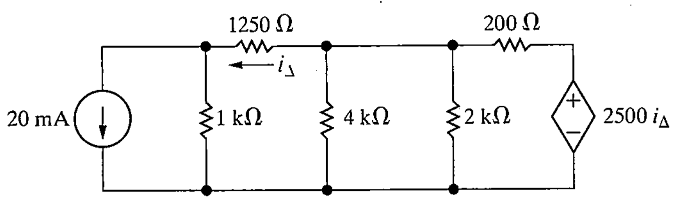
4.18 Use the mesh-current method to calculate the power delivered by the dependent voltage source in the circuit in Fig. P4.18.
PSPICE MULTISIM

Figure P4.18



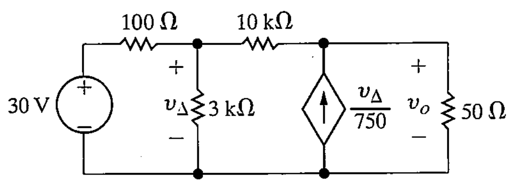
4.19 a) Use the node-voltage method to find the total power developed in the circuit in Fig. P4.19.
PSPICE MULTISIM
b) Check your answer by finding the total power absorbed in the circuit.

Figure P4.19



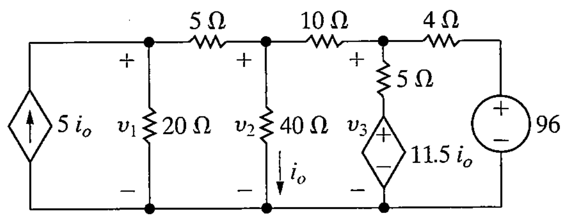
4.20 a) Use the node-voltage method to find v_o for the circuit in Fig. P4.20.
b) Find the total power supplied in the circuit.

Figure P4.20



4.21 a) Find the node voltages v_1, v_2, and v_3 in the circuit in Fig. P4.21.
PSPICE MULTISIM
b) Find the total power dissipated in the circuit.

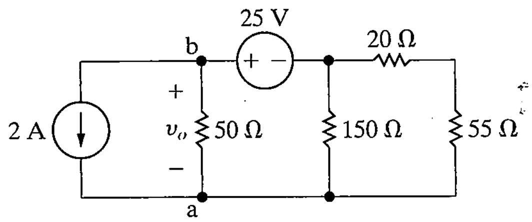
Figure P4.21



Section 4.4

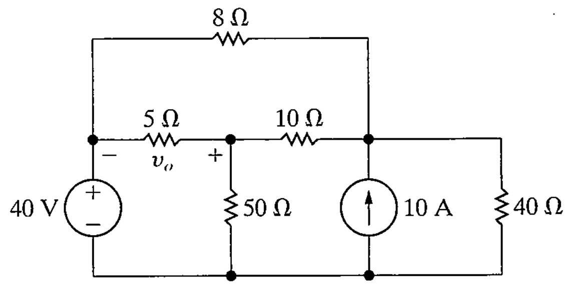
4.22 a) Use the node-voltage method to find v_o and the power delivered by the 2 A current source in the circuit in Fig. P4.22. Use node a as the reference node.
PSPICE MULTISIM
b) Repeat part (a), but use node b as the reference node.
c) Compare the choice of reference node in (a) and (b) Which is better, and why?

Figure P4.22



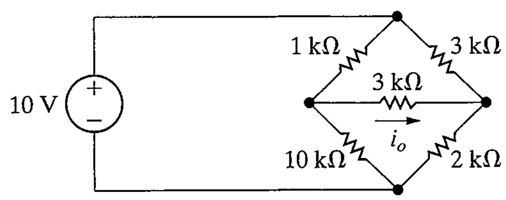
4.23 Use the node-voltage method to find the value of v_o in the circuit in Fig. P4.23.
PSPICE MULTISIM

Figure P4.23



4.24 Use the mesh-current method to find i_o in the circuit in Fig. P4.24.
PSPICE MULTISIM

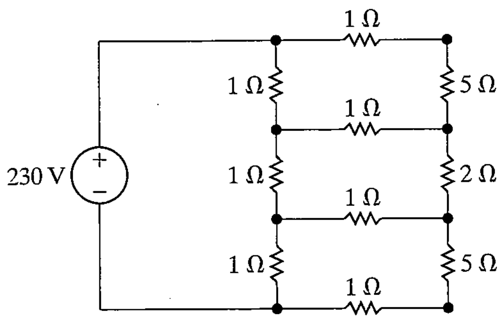
Figure P4.24



4.25 a) Use the node-voltage method to find the power dissipated in the 2 Ω resistor in the circuit in Fig. P4.25.

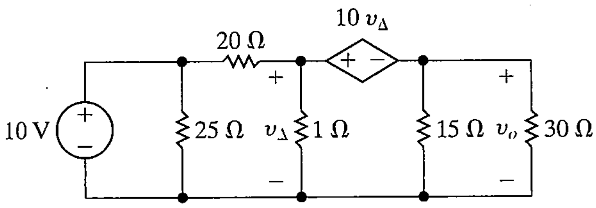
b) Find the power supplied by the 230 V source.

Figure P4.25



4.26 Use the node-voltage method to find v_o in the circuit in Fig. P4.26.

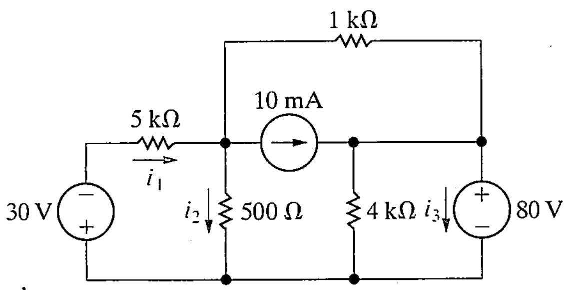
Figure P4.26



4.27 a) Use the node-voltage method to find the branch currents i_1, i_2, and i_3 in the circuit in Fig. P4.27.

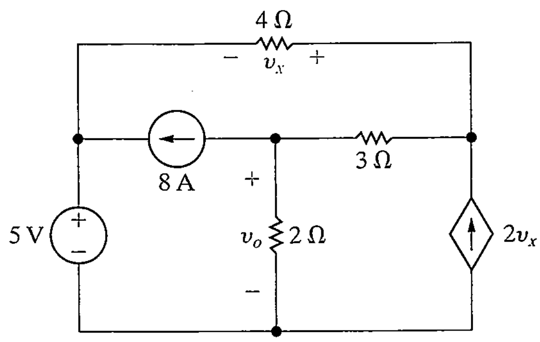
b) Check your solution for i_1, i_2, and i_3 by showing that the power dissipated in the circuit equals the power developed.

Figure P4.27



4.28 Use mesh-current method to find the power developed in the voltage source in the circuit in Fig. P4.28.

Figure P4.28



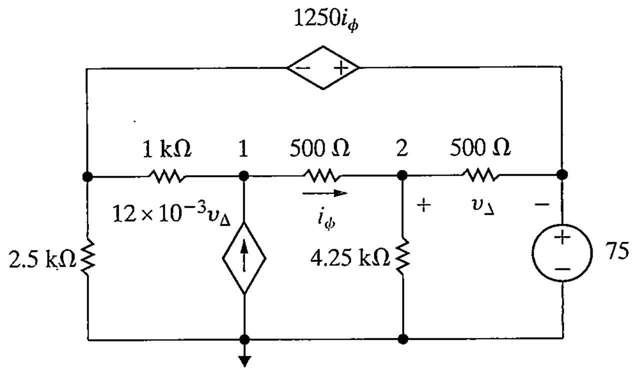
4.29 Assume you are a project engineer and one of your staff is assigned to analyze the circuit shown in Fig. P4.29. The reference node and node numbers given on the figure were assigned by the analyst. Her solution gives the values of v_1 and v_2 as 105 V and 85 V, respectively.

a) What values did the analyst use for the left-most and right-most node voltages when writing KCL equations at nodes 1 and 2?

b) Use the values supplied by the analyst to calculate the total power developed in the circuit and the total power dissipated in the circuit.

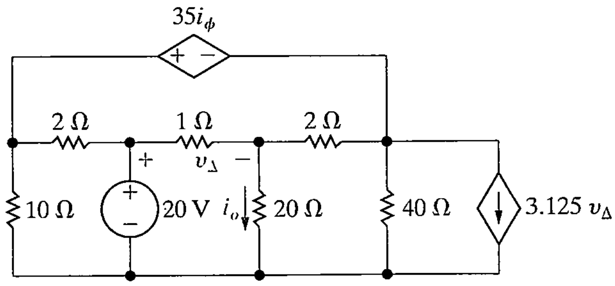
c) Do you agree with the solution submitted by the analyst?

Figure P4.29



4.30 Use the node-voltage method to find the power developed by the 20 V source in the circuit in Fig. P4.30.

Figure P4.30

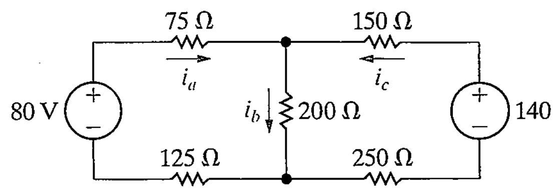


4.31 Show that when Eqs. 4.13, 4.14, and 4.16 are solved for i_B, the result is identical to Eq. 2.21.

4.32 PSPICE MULTISIM a) Use the mesh-current method to find the branch currents i_a, i_b, and i_c in the circuit in Fig. P4.32.

b) Repeat (a) if the polarity of the 140 V source is reversed.

Figure P4.32



Section 4.5

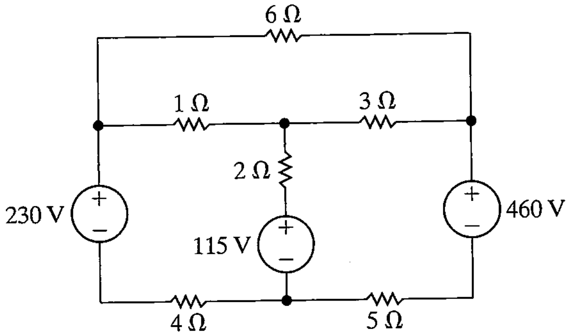
4.33 Solve Problem 4.11 using the mesh-current method.

4.34 Solve Problem 4.15 using the mesh-current method.

4.35 Solve Problem 4.25 using the mesh-current method.

4.36 a) Use the mesh-current method to find the total power developed in the circuit in Fig. P4.36.
PSPICE MULTISIM
b) Check your answer by showing that the total power developed equals the total power dissipated.

Figure P4.36



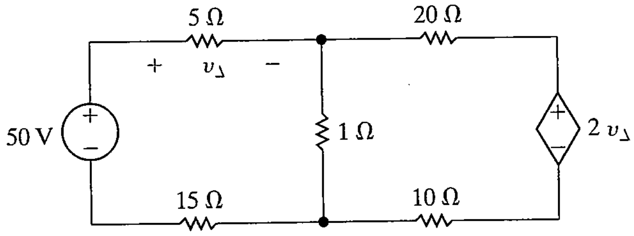
4.37 Solve Problem 4.24 using the mesh-current method.

Section 4.6

4.38 Solve Problem 4.18 using the mesh-current method.

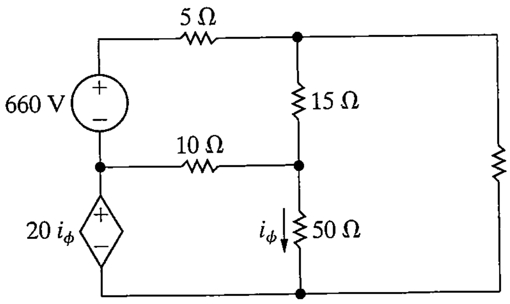
4.39 Use the mesh-current method to find the power dissipated in the 10 Ω resistor in the circuit in Fig. P4.39.
PSPICE MULTISIM

Figure P4.39



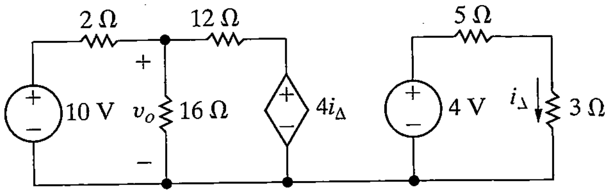
4.40 Use the mesh-current method to find the power delivered by the dependent voltage source in the circuit seen in Fig. P4.40.
PSPICE MULTISIM

Figure P4.40



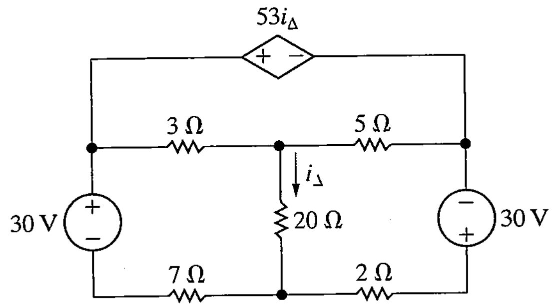
4.41 a) Use the mesh-current method to find v_o in the circuit in Fig. P4.41.
PSPICE MULTISIM
b) Find the power delivered by the dependent source.

Figure P4.41



4.42 Use the mesh-current method to find the power developed in the dependent voltage source in the circuit in Fig. P4.42.
PSPICE MULTISIM

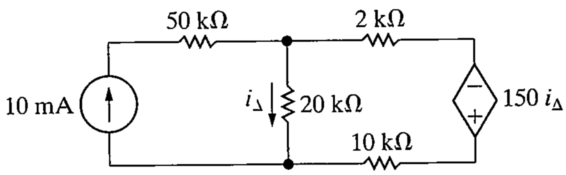
Figure P4.42



Section 4.7

4.43 a) Use the mesh-current method to solve for i_Δ in the circuit in Fig. P4.43.
PSPICE MULTISIM
b) Find the power delivered by the independent current source.
c) Find the power delivered by the dependent voltage source.

Figure P4.43

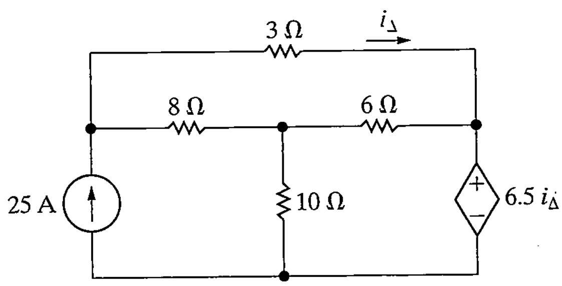


4.44 Solve Problem 4.13 using the mesh-current method.

4.45 Solve Problem 4.21 using the node-voltage method.

4.46 Use the mesh-current method to find the total power developed in the circuit in Fig. P4.46.
PSPICE MULTISIM

Figure P4.46

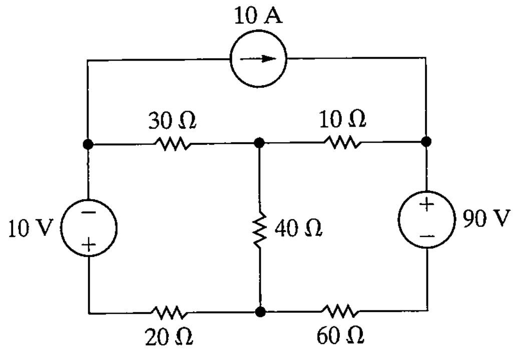


4.47 a) Use the node-voltage method to find how much power the 5 A current source delivers to the circuit in Fig. P4.47.

b) Find the total power delivered to the circuit.

c) Check your calculations by showing that the total power developed in the circuit equals the total power dissipated

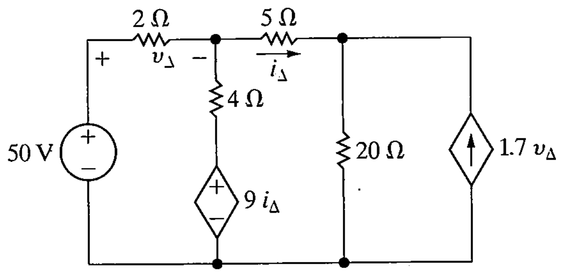
Figure P4.47



4.48 PSPICE MULTISIM a) Use the mesh-current method to determine which sources in the circuit in Fig. P4.48 are generating power.

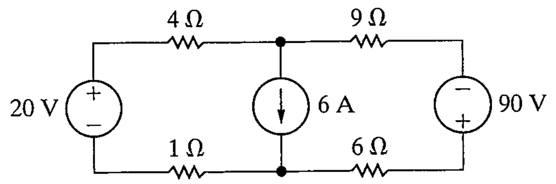
b) Find the total power dissipated in the circuit.

Figure P4.48



4.49 PSPICE MULTISIM Use the mesh-current method to find the total power dissipated in the circuit in Fig. P4.49.

Figure P4.49



4.50 a) Assume the 20 V source in the circuit in Fig. P4.49 is changed to 60 V. Find the total power dissipated in the circuit.

b) Repeat (a) with the 6 A current source replaced by a short circuit.

c) Explain why the answers to (a) and (b) are the same.

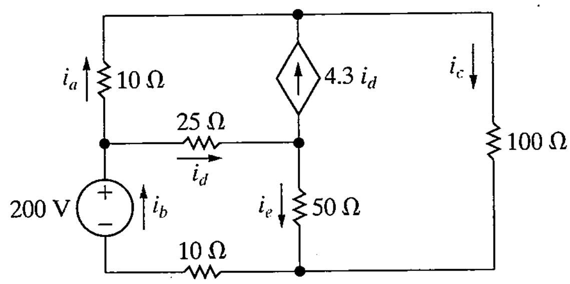
d) Now assume you wish to change the value of the 90 V source, instead of the 20 V source, in the circuit in Fig. P4.49 to get the same power dissipated by the current source that you found in (a) and (b). Use the results in part (c) to calculate the new value of this voltage source.

4.51 Solve Problem 4.27 using the mesh-current method.

4.52 PSPICE MULTISIM a) Use the mesh-current method to find the branch currents in $i_a - i_e$ in the circuit in Fig. P4.52.

b) Check your solution by showing that the total power developed in the circuit equals the total power dissipated.

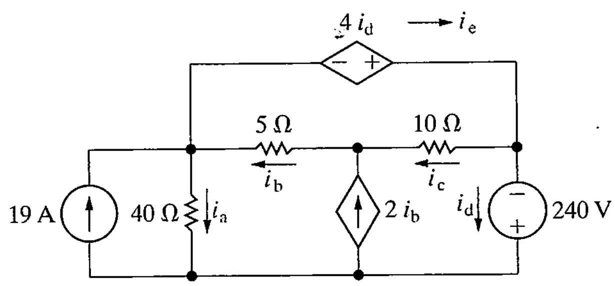
Figure P4.52



4.53 PSPICE MULTISIM a) Find the branch currents $i_a - i_e$ for the circuit shown in Fig. P4.53.

b) Check your answers by showing that the total power generated equals the total power dissipated.

Figure P4.53



Section 4.8

4.54 Assume you have been asked to find the power dissipated in the horizontal 1 kΩ resistor in the circuit in Fig. P4.54.

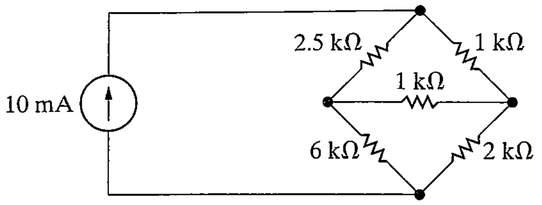
a) Which method of circuit analysis would you recommend? Explain why.

b) Use your recommended method of analysis to find the power dissipated in the horizontal 1 kΩ resistor.

c) Would you change your recommendation if the problem had been to find the power developed by the 10 mA current source? Explain.

d) Find the power delivered by the 10 mA current source.

Figure P4.54



4.55 A 4 kΩ resistor is placed in parallel with the 10 mA current source in the circuit in Fig. P4.56. Assume you have been asked to calculate the power developed by the current source.

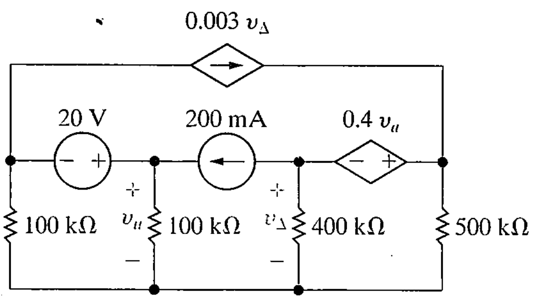
a) Which method of circuit analysis would you recommend? Explain why.

b) Find the power developed by the current source.

4.56 a) Would you use the node-voltage or mesh-current method to find the power absorbed by the 20 V source in the circuit in Fig. P4.56? Explain your choice.

b) Use the method you selected in (a) to find the power.

Figure P4.56

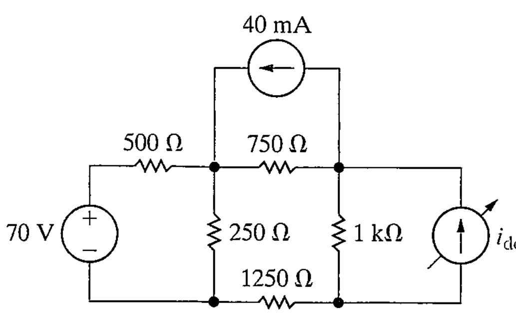


4.57 PSPICE MULTISIM The variable dc current source in the circuit in Fig. P4.57 is adjusted so that the power developed by the 40 mA current source is zero. You want to find the value of i_{dc}.

a) Would you use the node-voltage or mesh-current method to find i_{dc}? Explain your choice.

b) Use the method selected in (a) to find i_{dc}.

Figure P4.57



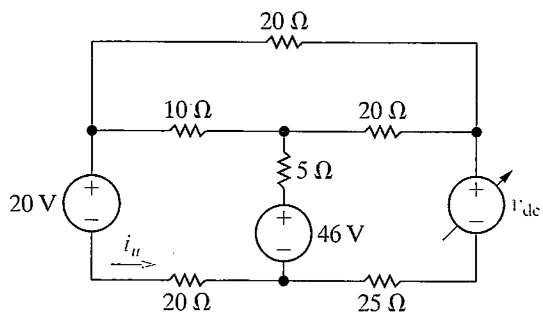
4.58 PSPICE MULTISIM The variable dc voltage source in the circuit in Fig. P4.58 is adjusted so that i_o is zero.

a) Would you use the node-voltage or mesh-current method to find v_{dc}? Explain your choice.

b) Find the value of v_{dc}, using the method selected in (a).

c) Check your solution by showing the power developed equals the power dissipated.

Figure P4.58

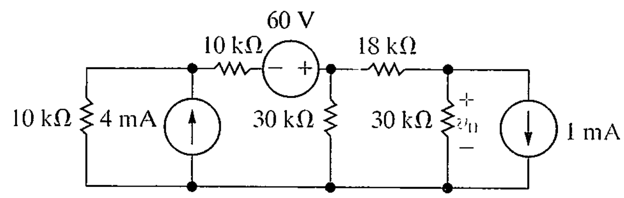


Section 4.9

4.59 a) Make a series of source transformations to find the voltage v_0 in the circuit in Fig. P4.59.

b) Verify your solution using the mesh-current method.

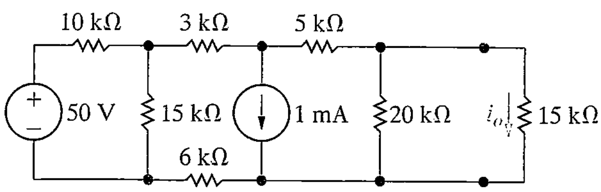
Figure P4.59



4.60 PSPICE MULTISIM a) Find the current i_o in the circuit in Fig. P4.60 by making a succession of appropriate source transformations.

b) Using the result obtained in (a), work back through the circuit to find the power developed by the 50 V source.

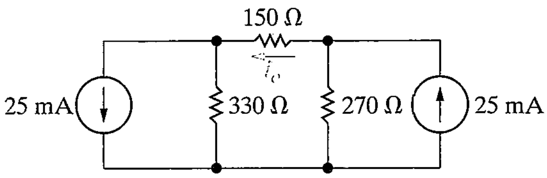
Figure P4.60



4.61 PSPICE MULTISIM a) Use source transformations to find the current i_o in the circuit in Fig. P4.61.

b) Verify your solution by using the node-voltage method to find i_o.

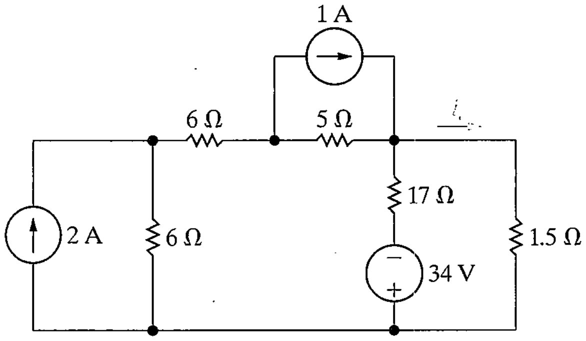
Figure P4.61



4.62 a) Use a series of source transformations to find i_o in the circuit in Fig. P4.62.

b) Verify your solution by using the mesh-current method to find i_o.

Figure P4.62



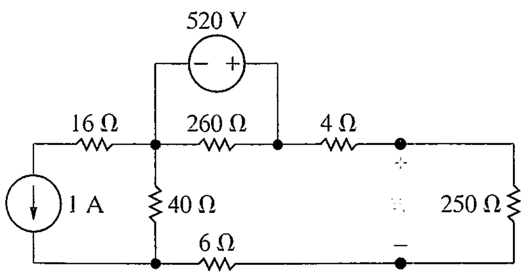
4.63 a) Use source transformations to find v_o in the circuit in Fig. P4.63.

b) Find the power developed by the 520 V source.

c) Find the power developed by the 1 A current source.

d) Verify that the total power developed equals the total power dissipated.

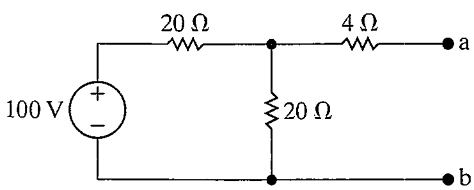
Figure P4.63



Section 4.10

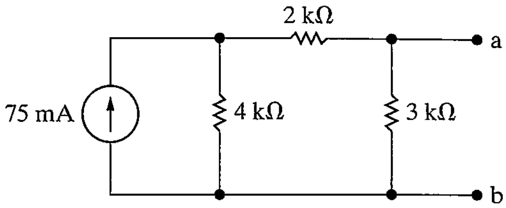
4.64 Find the Norton equivalent with respect to the terminals a and b for the circuit in Fig. P4.64.

Figure P4.64



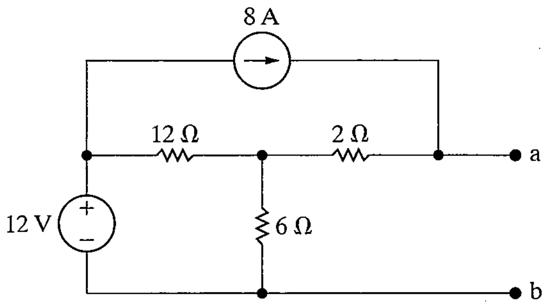
4.65 Find the Norton equivalent with respect to the terminals a, b for the circuit in Fig. P4.65.

Figure P4.65



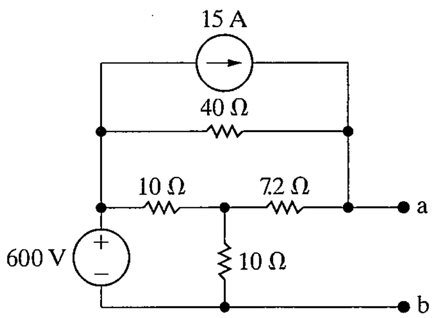
4.66 Find the Norton equivalent with respect to the terminals a, b for the circuit in Fig. P4.66.

Figure P4.66



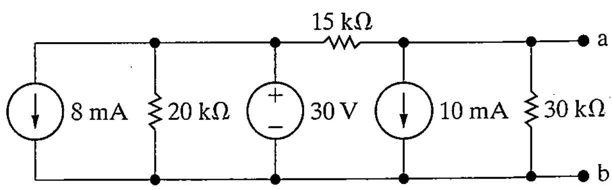
4.67 Find the Norton equivalent with respect to the terminals a and b for the circuit in Fig. P4.67.

Figure P4.67



4.68 Find the Norton equivalent with respect to the terminals a, b in the circuit in Fig. P4.68.

Figure P4.68



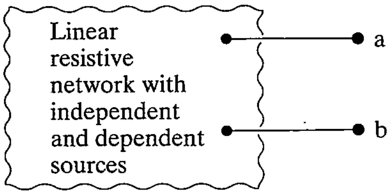
4.69 A Thévenin equivalent can also be determined from measurements made at the pair of terminals of interest. Assume the following measurements were made at the terminals a,b in the circuit in Fig. P4.69.

When a 20 Ω resistor is connected to the terminals a, b, the voltage v_{ab} is measured and found to be 100 V.

When a 50 Ω resistor is connected to the terminals a, b, the voltage is measured and found to be 200 V.

Find the Thévenin equivalent of the network with respect to the terminals a, b.

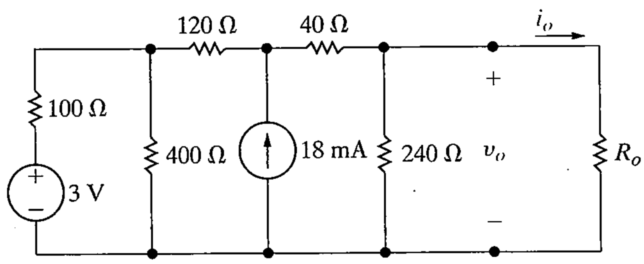
Figure P4.69



4.70 An automobile battery, when connected to a car radio, provides 12.5 V to the radio. When connected to a set of headlights, it provides 11.7 V to the headlights. Assume the radio can be modeled as a 6.25 Ω resistor and the headlights can be modeled as a 0.65 Ω resistor. What are the Thévenin and Norton equivalents for the battery?

4.71 Determine i_o and v_o in the circuit shown in Fig. P4.71 when R_o is a resistor from Appendix H such that $100\ \Omega \leq R_o < 200\ \Omega$.
PSPICE
MULTISIM

Figure P4.71

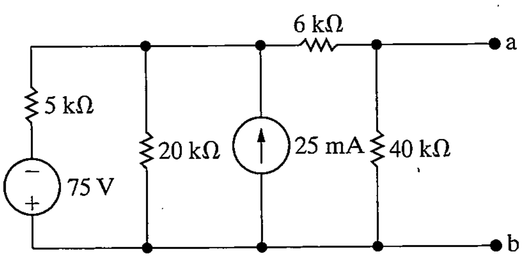


4.72 A voltmeter with a resistance of 85.5 kΩ is used to measure the voltage v_{ab} in the circuit in Fig. P4.72.

a) What is the voltmeter reading?

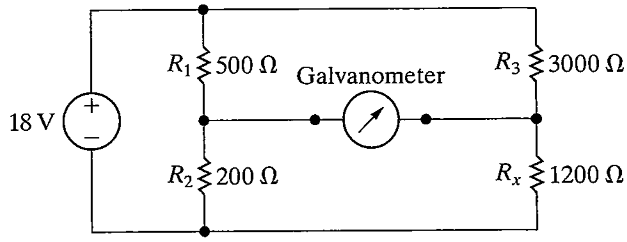
b) What is the percentage of error in the voltmeter reading if the percentage of error is defined as [(measured − actual)/actual] × 100?

Figure P4.72



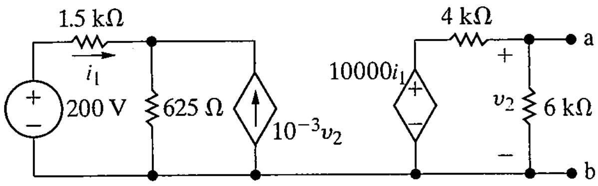
4.73 The Wheatstone bridge in the circuit shown in Fig. P4.73 is balanced when R_3 equals 3000 Ω. If the galvanometer has a resistance of 50 Ω, how much current will the galvanometer detect, when the bridge is unbalanced by setting R_3 to 3003 Ω? (*Hint:* Find the Thévenin equivalent with respect to the galvanometer terminals when R_3 = 3003 Ω. Note that once we have found this Thévenin equivalent, it is easy to find the amount of unbalanced current in the galvanometer branch for different galvanometer movements.)
PSPICE
MULTISIM

Figure P4.73



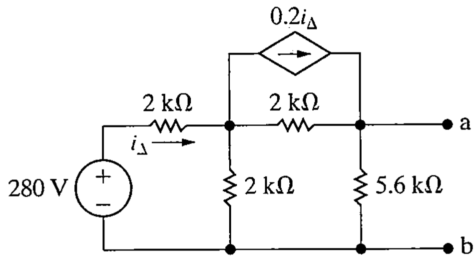
4.74 Determine the Thévenin equivalent with respect to the terminals a, b for the circuit shown in Fig. P4.74.

Figure P4.74



4.75 Find the Norton equivalent with respect to the terminals a, b for the circuit seen in Fig. P4.75.
PSPICE
MULTISIM

Figure P4.75

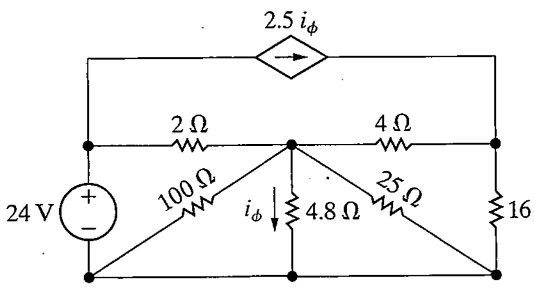


4.76 When an ammeter is used to measure the current i_ϕ in the circuit shown in Fig. P4.76, it reads 6 A.
PSPICE
MULTISIM

a) What is the resistance of the ammeter?

b) What is the percentage of error in the current measurement?

Figure P4.76



Section 4.11

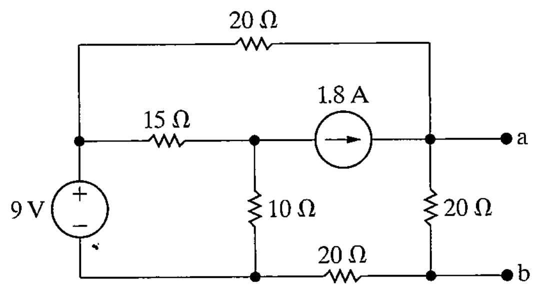
4.77 a) Find the Thévenin equivalent resistance with respect to the terminals a, b in the circuit in Fig. P4.64 without finding either the open circuit voltage or the short circuit current.

b) Find the Norton equivalent resistance with respect to the terminals a, b in the circuit in Fig. P4.66 without finding either the open circuit voltage or the short circuit current.

4.78 a) Find the Thévenin equivalent with respect to the terminals a, b for the circuit in Fig. P4.78 by finding the open-circuit voltage and short-circuit current.

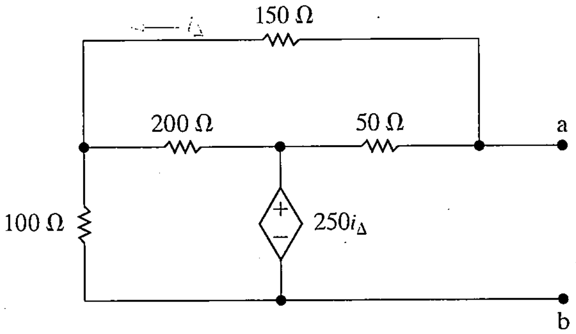
b) Solve for the Thévenin resistance by removing the independent sources. Compare your result to the Thévenin resistance found in (a).

Figure P4.78



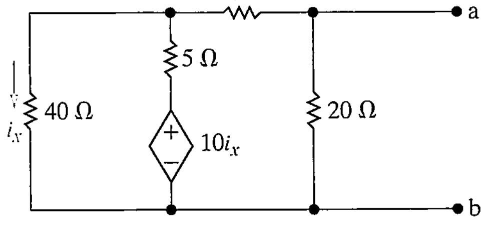
4.79 Find the Thévenin equivalent with respect to the terminals a,b in the circuit in Fig. P4.79.

Figure P4.79



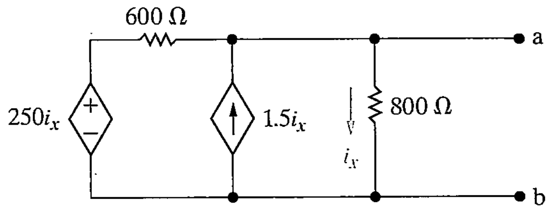
4.80 Find the Thévenin equivalent with respect to the terminals a, b in the circuit in Fig. P4.80.

Figure P4.80



4.81 Find the Thévenin equivalent with respect to the terminals a and b for the circuit in Fig. P4.81.

Figure P4.81



Section 4.12

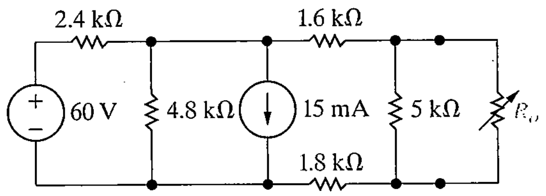
4.82 The variable resistor in the circuit in Fig. P4.82 is adjusted for maximum power transfer to R_o.

a) Find the value of R_o.

b) Find the maximum power that can be delivered to R_o.

c) Find a resistor in Appendix H closest to the value in part (a). How much power is delivered to this resistor?

Figure P4.82



4.83 What percentage of the total power developed in the circuit in Fig. P4.82 is delivered to R_o when R_o is set for maximum power transfer?

4.84 a) Calculate the power delivered for each value of R_o used in Problem 4.71.

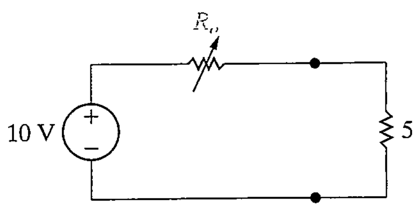
b) Plot the power delivered to R_o versus the resistance R_o.

c) At what value of R_o is the power delivered to R_o a maximum?

4.85 a) Find the value of the variable resistor R_o in the circuit in Fig. P4.85 that will result in maximum power dissipation in the 5 Ω resistor. (*Hint:* Hasty conclusions could be hazardous to your career.)

b) What is the maximum power that can be delivered to the 5 Ω resistor?

Figure P4.85



4.86 A variable resistor R_o is connected across the terminals a, b in the circuit in Fig. P4.75. The variable resistor is adjusted until maximum power is transferred to R_o.
PSPICE
MULTISIM

a) Find the value of R_o.

b) Find the maximum power delivered to R_o.

c) Find the percentage of the total power developed in the circuit that is delivered to R_o.

d) Find the resistor from Appendix H closest in value to the R_o. from part (a).

e) Find the percentage of the total power developed in the circuit that is delivered to the resistor in part (d).

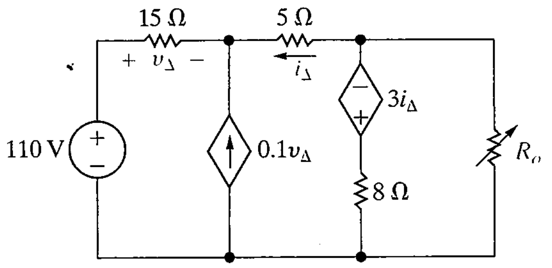
4.87 The variable resistor (R_o) in the circuit in Fig. P4.87 is adjusted until it absorbs maximum power from the circuit.
PSPICE
MULTISIM

a) Find the value of R_o.

b) Find the maximum power.

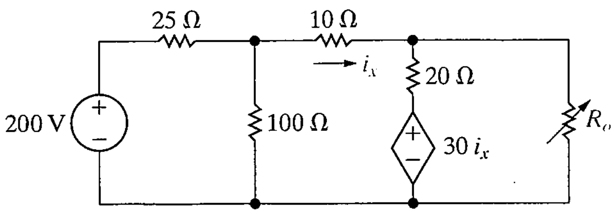
c) Find the percentage of the total power developed in the circuit that is delivered to R_o.

Figure P4.87



4.88 The variable resistor (R_o) in the circuit in Fig. P4.88 is adjusted until the power dissipated in the resistor is 250 W. Find the values of R_o that satisfy this condition.
PSPICE
MULTISIM

Figure P4.88



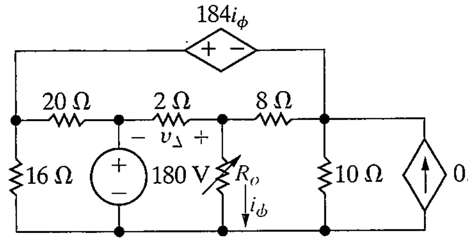
4.89 The variable resistor in the circuit in Fig. P4.89 is adjusted for maximum power transfer to R_o.
PSPICE
MULTISIM

a) Find the numerical value of R_o.

b) Find the maximum power delivered to R_o.

c) How much power does the 180 V source deliver to the circuit when R_o is adjusted to the value found in (a)?

Figure P4.89

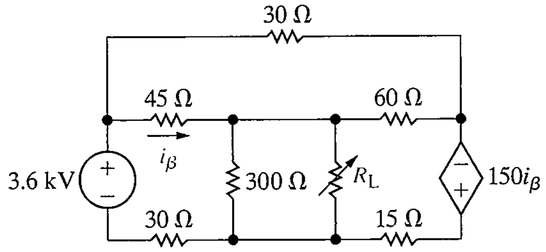


4.90 The variable resistor (R_L) in the circuit in Fig. P4.90 is adjusted for maximum power transfer to R_L.
PSPICE
MULTISIM

a) Find the numerical value of R_L.

b) Find the maximum power transferred to R_L.

Figure P4.90



4.91 The variable resistor (R_o) in the circuit in Fig. P4.91 is adjusted for maximum power transfer to R_o.
PSPICE
MULTISIM

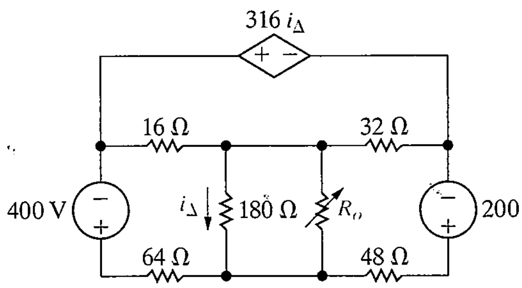
a) Find the value of R_o.

b) Find the maximum power that can be delivered to R_o.

c) What percentage of the total power developed in the circuit is delivered to R_o found in part(a)?

d) If R_o is selected from Appendix H, which resistor value will result in the greatest amount of power delivered to R_o?

Figure P4.91

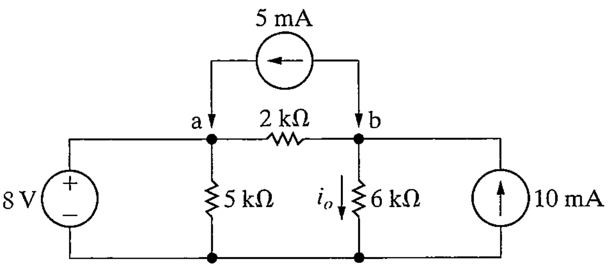


Section 4.13

4.92 a) In the circuit in Fig. P4.92, before the 5 mA current source is attached to the terminals a,b, the current i_o is calculated and found to be 3.5 mA. Use superposition to find the value of i_o after the current source is attached.
PSPICE
MULTISIM

b) Verify your solution by finding i_o when all three sources are acting simultaneously.

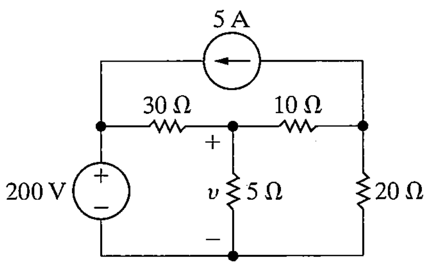
Figure P4.92



4.93 a) Use the principle of superposition to find the voltage across the 20 Ω resistor in the circuit of Fig. P4.93.
PSPICE MULTISIM

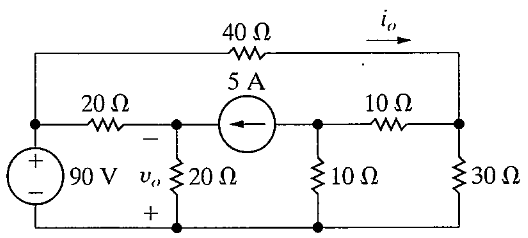
b) Find the power dissipated in the 20 Ω resistor.

Figure P4.93



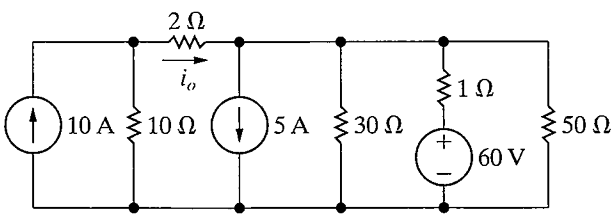
4.94 Using the principle of superposition, find the voltage across the 30 Ω resistor in the circuit in Fig. P4.94.

Figure P4.94



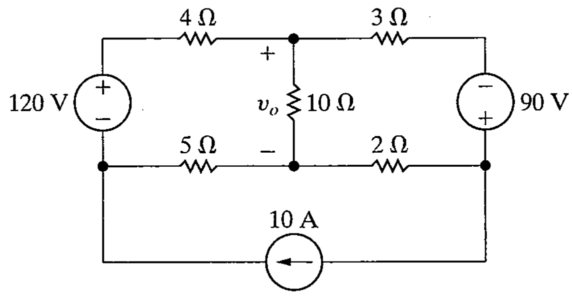
4.95 Using the principle of superposition, find the current through the 50 Ω resistor in the circuit shown in Fig. P4.95.
PSPICE MULTISIM

Figure P4.95



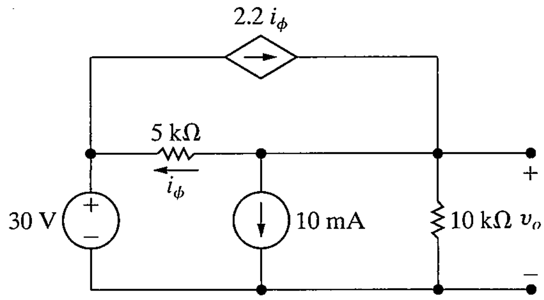
4.96 Using the principle of superposition, find the current through the 10 Ω resistor in the circuit in Fig. P4.96.
PSPICE MULTISIM

Figure P4.96



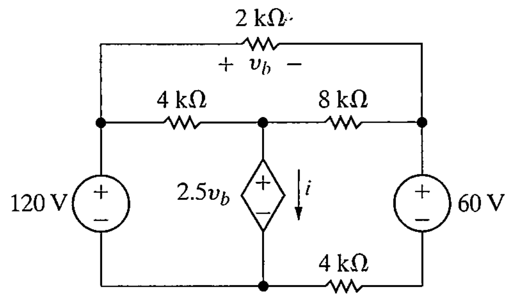
4.97 Use the principle of superposition and find the voltage across the 10 kΩ resistor in the circuit in Fig. P4.97.
PSPICE MULTISIM

Figure P4.97



4.98 Use the principle of superposition to find the current i in the circuit of Fig. P4.98.
PSPICE MULTISIM

Figure P4.98



Sections 4.1–4.13

4.99 Assume your supervisor has asked you to determine the power developed by the 50 V source in the circuit in Fig. P4.99. Before calculating the power developed by the 50 V source, the supervisor asks you to submit a proposal describing how you plan to attack the problem. Furthermore, he asks you to explain why you have chosen your proposed method of solution.

a) Describe your plan of attack, explaining your reasoning.

b) Use the method you have outlined in (a) to find the power developed by the 50 V source.

- A difference amplifier is an op amp circuit producing an output voltage that is a scaled replica of the input voltage difference. (See page 190.)

- The two voltage inputs to a difference amplifier can be used to calculate the common mode and difference mode voltage inputs, v_{cm} and v_{dm}. The output from the difference amplifier can be written in the form

$$v_o = A_{cm}v_{cm} + A_{dm}v_{dm},$$

where A_{cm} is the common mode gain and A_{dm} is the differential mode gain. (See page 192.)

- In an ideal difference amplifier, $A_{cm} = 0$. To measure how nearly ideal a difference amplifier is, we use the common mode rejection ratio:

$$\text{CMRR} = \left|\frac{A_{dm}}{A_{cm}}\right|.$$

An ideal difference amplifier has an infinite CMRR. (See page 194.)

- We considered both a simple, ideal op amp model and a more realistic model in this chapter. The differences between the two models are as follows:

Simplified Model	**More Realistic Model**
Infinite input resistance	Finite input resistance
Infinite open-loop gain	Finite open-loop gain
Zero output resistance	Nonzero output resistance

(See page 195.)

Problems

Sections 5.1–5.2

5.1 The op amp in the circuit in Fig. P5.1 is ideal.

PSPICE MULTISIM

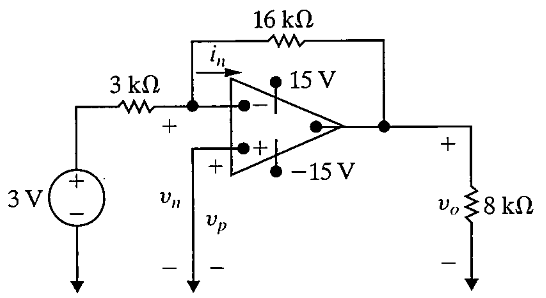
a) Label the 5 op amp terminals with their names.

b) What ideal op amp constraint determines the value of i_n? What is this value?

c) What ideal op amp constraint determines the value of $(v_p - v_n)$? What is this value?

d) Calculate v_o.

Figure P5.1



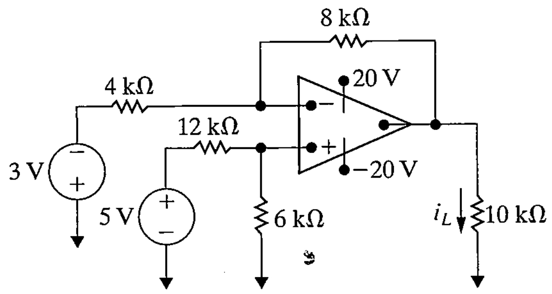
5.2 a) Replace the 3 V source in the circuit Fig. P5.1 and calculate v_o for each of the following source values: −5 V, −7 V, 5 V, 7 V.

b) Specify the range of voltage source values that will not cause the op amp to saturate.

5.3 Find i_L (in milliamperes) in the circuit in Fig. P5.3.

PSPICE MULTISIM

Figure P5.3



5.4 The op amp in the circuit in Fig. P5.4 is ideal.

PSPICE MULTISIM

a) Calculate v_o if $v_a = 2$ V and $v_b = 1$ V.

b) Calculate v_o if $v_a = -1$ V and $v_b = 0$ V.

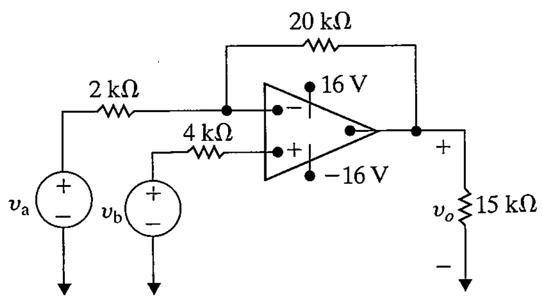
c) Calculate v_o if $v_a = 3$ V and $v_b = 3.5$ V.

d) Calculate v_o if $v_a = -2$ V and $v_b = 1$ V.

e) Calculate v_o if $v_a = 4$ V and $v_b = 0$ V.

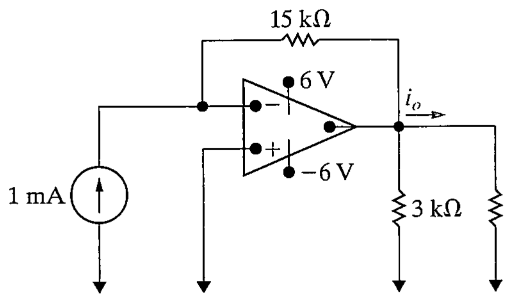
f) If $v_b = 3$ V, specify the range of v_a such that the amplifier does not saturate.

Figure P5.4



5.5 Find v_o in the circuit in Fig. P5.5.
PSPICE MULTISIM

Figure P5.5



5.6 The op amp in the circuit in Fig. P5.6 is ideal. Calculate the following:
PSPICE MULTISIM

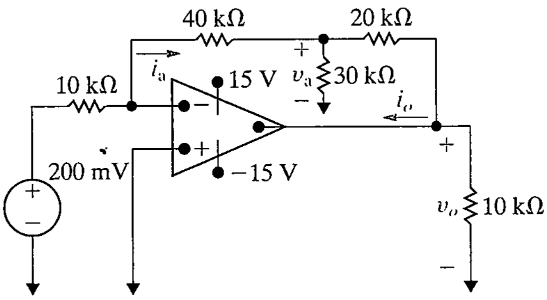
a) i_a

b) v_a

c) v_o

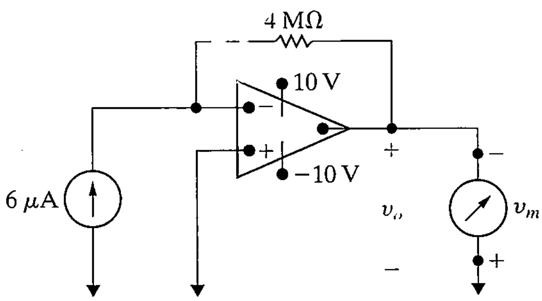
d) i_o

Figure P5.6



5.7 A voltmeter with a full-scale reading of 20 V is used to measure the output voltage in the circuit in Fig. P5.7. What is the reading of the voltmeter? Assume the op amp is ideal.
PSPICE MULTISIM

Figure P5.7



Section 5.3

5.8 a) Design an inverting amplifier with a gain of 6. Use an ideal op amp, a 20 kΩ resistor in the feedback path, and ±15 V power supplies.

b) Using your design from part (a), determine the range of input voltages that will keep the op amp in its linear operating region.

c) Suppose you wish to amplify a 4 V signal, using your design from part (a) with a variable feedback resistor. What is the largest value of feedback resistance that keeps the op amp in its linear operation region? Using this resistor value, what is the new gain of the inverting amplifier?

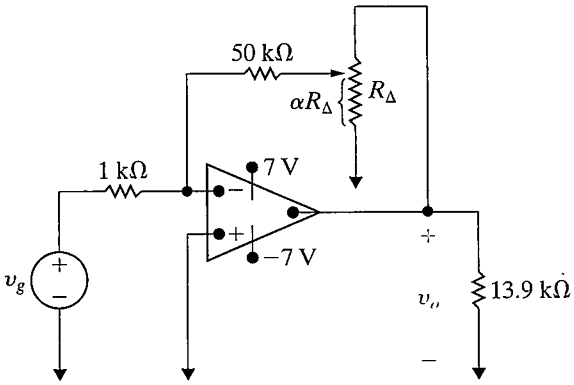
5.9 a) Design an inverting amplifier with a gain of 2.5, using an ideal op amp. Use a set of identical resistors from Appendix H.
DESIGN PROBLEM

b) If you wish to amplify signals between −2 V and +3 V using the circuit you designed in part (a), what are the smallest power supply voltages you can use?

5.10 a) The op amp in the circuit shown in Fig. P5.10 is ideal. The adjustable resistor R_Δ has a maximum value of 100 kΩ, and α is restricted to the range of $0.5 \leq \alpha \leq 1$. Calculate the range of v_o if $v_g = 40\,\text{mV}$.

b) If α is not restricted, at what value of α will the op amp saturate?

Figure P5.10

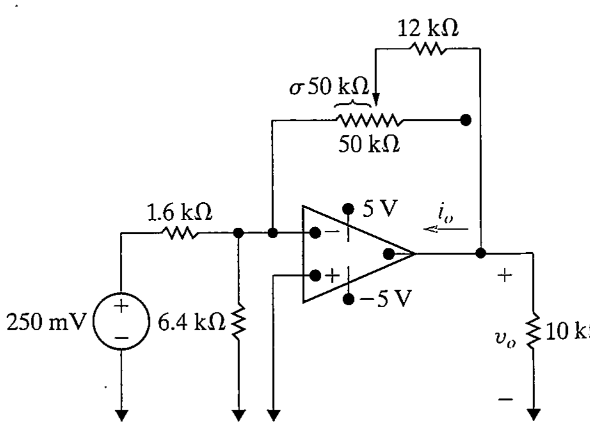


5.11 The op amp in the circuit in Fig. P5.11 is ideal.
PSPICE MULTISIM

a) Find the range of values for σ in which the op amp does not saturate.

b) Find i_o (in microamperes) when $\sigma = 0.272$.

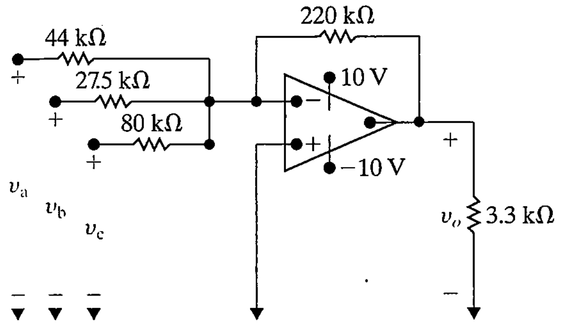
Figure P5.11



Section 5.4

5.12 The op amp in Fig. P5.12 is ideal.
PSPICE MULTISIM
a) What circuit configuration is shown in this figure?
b) Find v_o if $v_a = 1$ V, $v_b = 1.5$ V, and $v_c = -4$ V.
c) The voltages v_a and v_c remain at 1 V and −4 V, respectively. What are the limits on v_b if the op amp operates within its linear region?

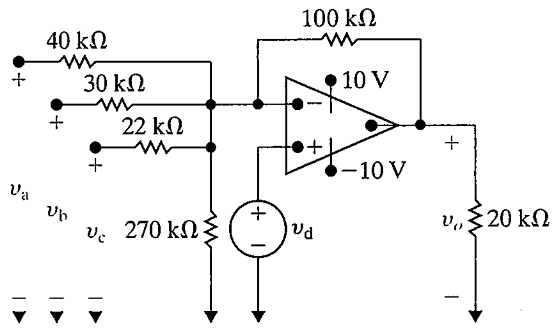
Figure P5.12



5.13 Refer to the circuit in Fig. 5.12, where the op amp is assumed to be ideal. Given that $R_a = 4$ kΩ, $R_b = 5$ kΩ, $R_c = 20$ kΩ, $v_a = 200$ mV, $v_b = 150$ mV, $v_c = 400$ mV, and $V_{CC} = \pm 6$ V, specify the range of R_f for which the op amp operates within its linear region.
PSPICE MULTISIM

5.14 a) The op amp in Fig. P5.14 is ideal. Find v_o if $v_a = 4$ V, $v_b = 8$ V, $v_c = 6$ V, and $v_d = 3$ V.
PSPICE MULTISIM
b) Assume v_a, v_b, and v_d retain their values as given in (a). Specify the range of v_c such that the op amp operates within its linear region.

Figure P5.14



5.15 The 100 kΩ feedback resistor in the circuit in Fig. P5.14 is replaced by a variable resistance R_f. The voltages $v_a - v_d$ have the same values as given in Problem 5.14(a).
PSPICE MULTISIM
a) What value of R_f will cause the op amp to saturate? Note that $0 \leq R_f \leq \infty$.
b) When R_f has a value found in (a), what is the current into the output terminal of the op amp?

5.16 a) Design an inverting-summing amplifier using an 80 kΩ resistor in the feedback path so that

$$v_o = -(10v_a + 4v_b + 6v_c).$$

Use ±12 V power supplies.
b) Suppose $v_a = 4$ V and $v_c = -2$ V. What range of values for v_b will keep the op amp in its linear operating region?

5.17 Design an inverting-summing amplifier so that
DESIGN PROBLEM PSPICE MULTISIM

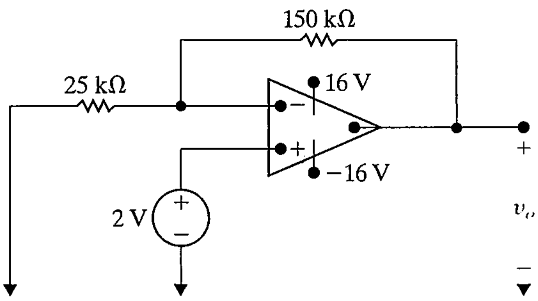
$$v_o = -(8v_a + 4v_b + 10v_c + 6v_d).$$

Start by choosing a feedback resistor (R_f) from Appendix H. Then choose single resistors or construct resistor networks using resistor values in Appendix H to satisfy the design values for R_a, R_b, R_c, and R_d. Draw your final circuit diagram.

Section 5.5

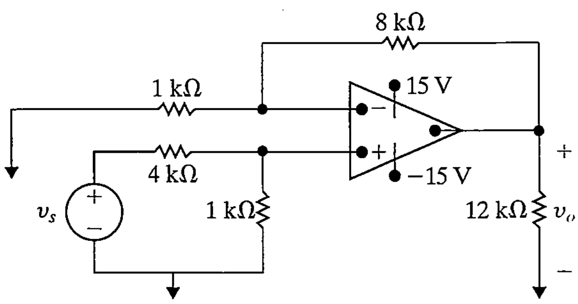
5.18 The op amp in the circuit of Fig. P5.18 is ideal.
PSPICE MULTISIM
a) What op amp circuit configuration is this?
b) Calculate v_o.

Figure P5.18



5.19 The op amp in the circuit of Fig. P5.19 is ideal.
a) What op amp circuit configuration is this?
b) Find v_o in terms of v_s.
c) Find the range of values for v_s so that v_o does not saturate and the op amp remains in its linear region of operation.

Figure P5.19



5.20 The op amp in the circuit shown in Fig. P5.20 is ideal,

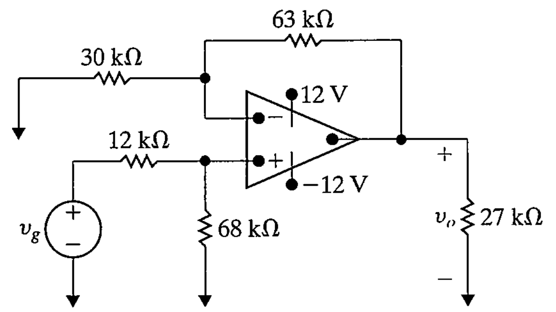
PSPICE MULTISIM

a) Calculate v_o when v_g equals 4 V.

b) Specify the range of values of v_g so that the op amp operates in a linear mode.

c) Assume that v_g equals 2 V and that the 63 kΩ resistor is replaced with a variable resistor. What value of the variable resistor will cause the op amp to saturate?

Figure P5.20



5.21 a) Design an inverting amplifier (see Fig. 5.9) with a gain of 10 using a 100 kΩ resistor in the feedback path. Draw your final circuit diagram.

b) Suppose you wish to amplify the input signals in the range $-3\text{ V} \leq v_s \leq -2\text{ V}$, what are the minimum values of the power supplies that will keep the op amp in its linear operating region?

5.22 a) Design a noninverting amplifier (see Fig. 5.13) with a gain of 2.5. Use resistors from Appendix H. You might need to combine resistors in series and in parallel to get the desired resistance. Draw your final circuit.

b) If you use ±16 V power supplies for the op amp, what range of input values will allow the op amp to stay in its linear operating region?

5.23 The op amp in the circuit of Fig. P5.23 is ideal.

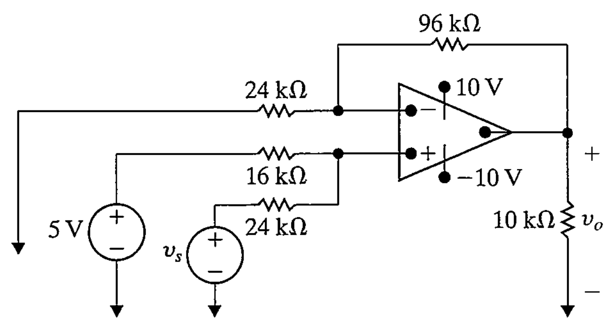
PSPICE MULTISIM

a) What op amp circuit configuration is this?

b) Find v_o in terms of v_s.

c) Find the range of values for v_s such that v_o does not saturate and the op amp remains in its linear region of operation.

Figure P5.23



5.24 The circuit in Fig. P5.24 is a noninverting summing amplifier. Assume the op amp is ideal. Design the circuit so that

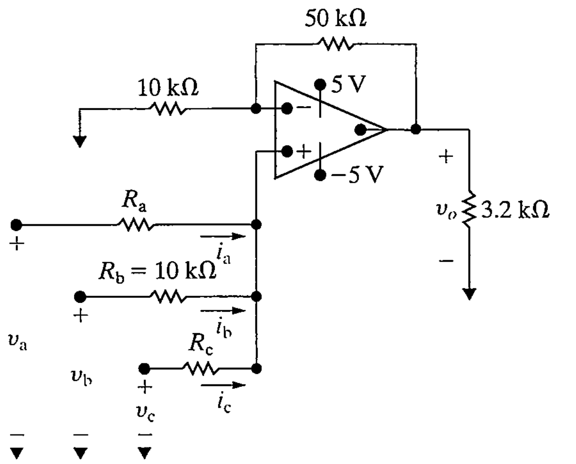
DESIGN PROBLEM PSPICE MULTISIM

$$v_o = 2v_a + 4v_b + v_c.$$

a) Specify the numerical values of R_a and R_c.

b) Calculate i_a, i_b, and i_c (in microamperes) when $v_a = 1$ V, $v_b = 0.2$ V, and $v_c = 0.8$ V.

Figure P5.24



Section 5.6

5.25 a) Using the Ohm's law, derive the output expression of a summing amplifier with two inputs.

b) Solve (a) for three inputs.

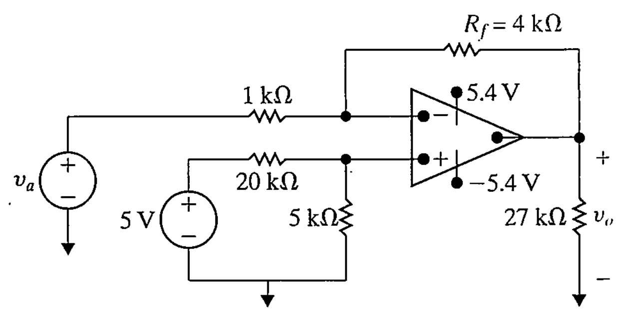
5.26 The op amp in the circuit of Fig. P5.26 is ideal.

a) What op amp circuit configuration is this?

b) Find an expression for the output voltage v_o in terms of the input voltage v_a.

c) Suppose $v_a = 2$ V. What value of R_f will cause the op amp to saturate?

Figure P5.26



5.27 The resistors in the difference amplifier shown in Fig. 5.15 are $R_a = 24$ kΩ, $R_b = 75$ kΩ, $R_c = 130$ kΩ and $R_d = 120$ kΩ. The signal voltages v_a and v_b are 8 and 5 V, respectively, and $V_{CC} = \pm 20$ V.

PSPICE MULTISIM

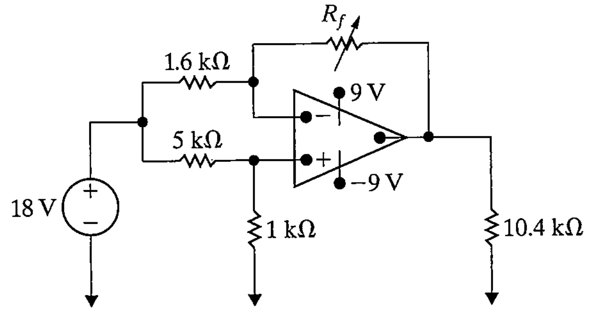
a) Find v_o.

b) What is the resistance seen by the signal source v_a?

c) What is the resistance seen by the signal source v_b?

5.28 The resistor R_f in the circuit in Fig. P5.28 is adjusted until the ideal op amp saturates. Specify R_f in kilohms.

Figure P5.28



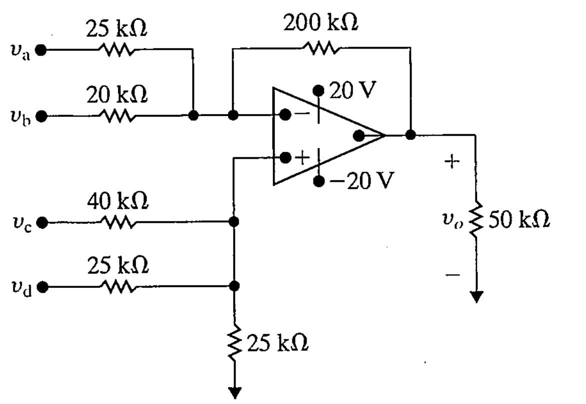
5.29 DESIGN PROBLEM PSPICE MULTISIM Design a difference amplifier (Fig. 5.15) to meet the following criteria: $v_o = 3v_b - 4v_a$. The resistance seen by the signal source v_b is 470 kΩ, and the resistance seen by the signal source v_a is 22 kΩ when the output voltage v_o is zero. Specify the values of R_a, R_b, R_c, and R_d using single resistors or combinations of resistors from Appendix H.

5.30 PSPICE MULTISIM The op amp in the adder-subtractor circuit shown in Fig. P5.30 is ideal.

a) Find the output voltage v_o given $v_a = 2$ V, $v_b = 3$ V, $v_c = 5$ V, and $v_d = 6$ V.

b) For the values given in (a), find v_o if the feedback resistor is replaced with a 100 kΩ resistor.

Figure P5.30

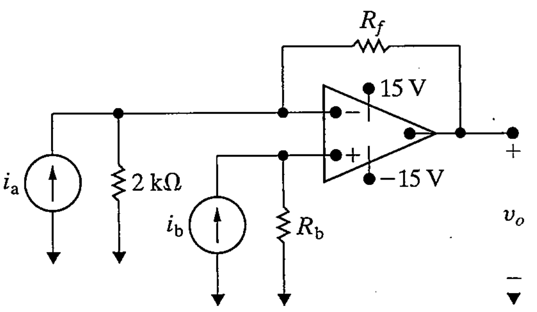


5.31 DESIGN PROBLEM PSPICE MULTISIM Select the values of R_b and R_f in the circuit in Fig. P5.31 so that

$$v_o = 8000(i_b - i_a).$$

Use single resistors or combinations of resistors from Appendix H. The op amp is ideal.

Figure P5.31



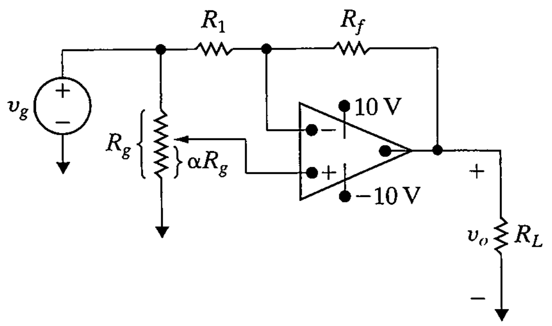
5.32 The op amp in the circuit of Fig. P5.32 is ideal.

a) Plot v_o versus α when $R_f = 4R_1$ and $v_g = 2$ V. Use increments of 0.1 and note by hypothesis that $0 \leq \alpha \leq 1.0$.

b) Write an equation for the straight line you plotted in (a). How are the slope and intercept of the line related to v_g and the ratio R_f/R_1?

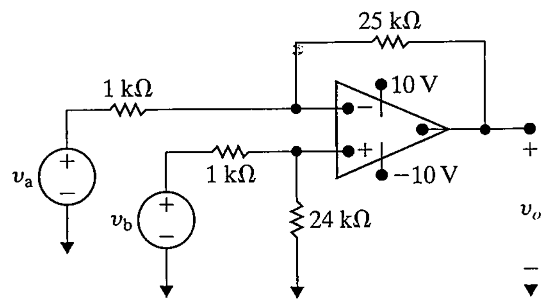
c) Using the results from (b), choose values for v_g and the ratio R_f/R_1 such that $v_o = -6\alpha + 4$.

Figure P5.32



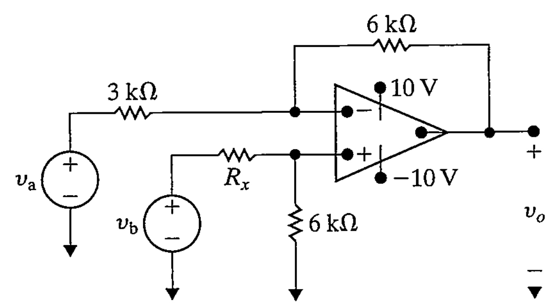
5.33 In the difference amplifier shown in Fig. P5.33, compute (a) the differential mode gain, (b) the common mode gain, and (c) the CMRR.

Figure P5.33



5.34 In the difference amplifier shown in Fig. P5.34, what range of values of R_x yields a CMRR $\geq$ 1500?

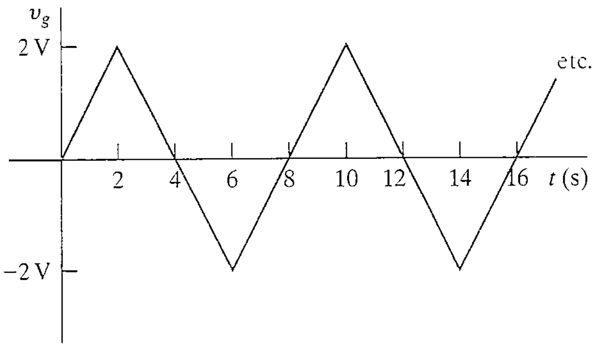
Figure P5.34



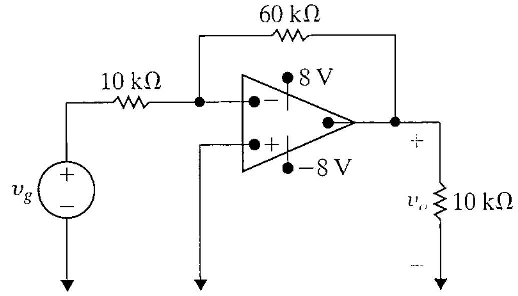
Sections 5.1–5.6

5.35 PSPICE MULTISIM The voltage v_g shown in Fig. P5.35(a) is applied to the inverting amplifier shown in Fig. P5.35(b). Sketch v_o versus t, assuming the op amp is ideal.

Figure P5.35



(a)



(b)

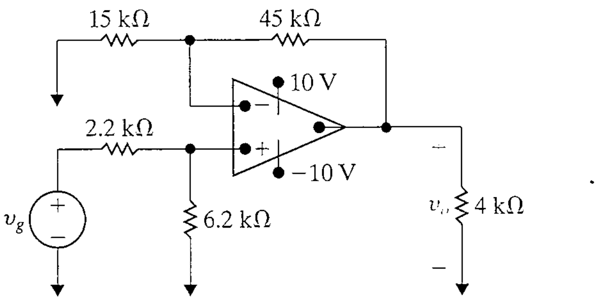
5.36 PSPICE MULTISIM A signal voltage v_g in the circuit shown in Fig. P5.36 is described by the following equations:

$$v_g = 0, \qquad t \leq 0,$$

$$v_g = 5\cos(\pi/4)t \text{ V}, \qquad 0 \leq t \leq \infty.$$

Sketch v_o versus t, assuming the op amp is ideal.

Figure P5.36



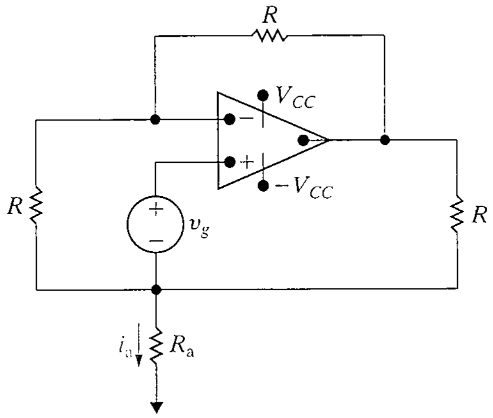
5.37 a) Show that when the ideal op amp in Fig. P5.37 is operating in its linear region,

$$i_a = \frac{3v_g}{R}.$$

b) Show that the ideal op amp will saturate when

$$R_a = \frac{R(\pm V_{CC} - 2v_g)}{3v_g}.$$

Figure P5.37



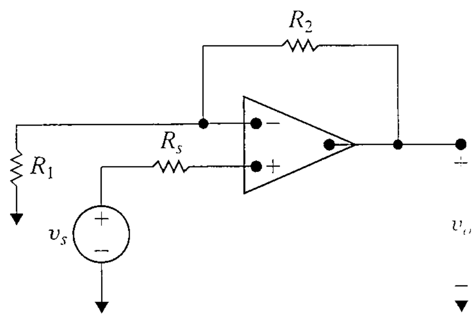
5.38 Assume that the ideal op amp in the circuit seen in Fig. P5.38 is operating in its linear region.

a) Derive the expression for the output voltage.

b) Find the output voltage v_o when $R_1 = 2$ kΩ, $R_2 = 100$ kΩ, $R_s = 10$ kΩ, and $v_s = 4$ V.

c) How does this circuit behave when $R_2 = 0$?

Figure P5.38



5.39 PSPICE MULTISIM The two op amps in the circuit in Fig. P5.39 are ideal. Calculate v_{o1} and v_{o2}.

Problems

Section 6.1

6.1 The current in a 150 μH inductor is known to be

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$$i_L = 25te^{-500t}\,\text{A} \quad \text{for } t \geq 0.$$

a) Find the voltage across the inductor for $t > 0$. (Assume the passive sign convention.)

b) Find the power (in microwatts) at the terminals of the inductor when $t = 5$ ms.

c) Is the inductor absorbing or delivering power at 5 ms?

d) Find the energy (in microjoules) stored in the inductor at 5 ms.

e) Find the maximum energy (in microjoules) stored in the inductor and the time (in milliseconds) when it occurs.

6.2 The triangular current pulse shown in Fig. P6.2 is applied to a 500 mH inductor.

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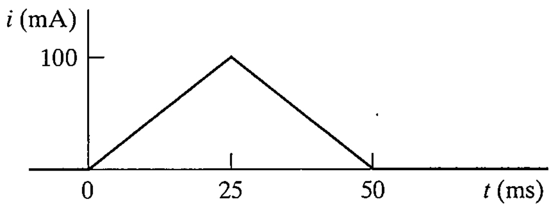
a) Write the expressions that describe $i(t)$ in the four intervals $t < 0$, $0 \leq t \leq 25$ ms, 25 ms $\leq t \leq 50$ ms, and $t > 50$ ms.

b) Derive the expressions for the inductor voltage, power, and energy. Use the passive sign convention.

Figure P6.2



6.3 The current in a 50 mH inductor is known to be

$$i = 120\text{ mA}, \qquad t \leq 0;$$

$$i = A_1e^{-500t} + A_2e^{-2000t}\text{A}, \qquad t \geq 0.$$

The voltage across the inductor (passive sign convention) is 3 V at $t = 0$.

a) Find the expression for the voltage across the inductor for $t > 0$.

b) Find the time, greater than zero, when the power at the terminals of the inductor is zero.

6.4 Assume in Problem 6.3 that the value of the voltage across the inductor at $t = 0$ is -18 V instead of 3 V.

a) Find the numerical expressions for i and v for $t \geq 0$.

b) Specify the time intervals when the inductor is storing energy and the time intervals when the inductor is delivering energy.

c) Show that the total energy extracted from the inductor is equal to the total energy stored.

6.5 The current in a 300 mH inductor is

$$i = 100\text{ mA}, \qquad t \leq 0;$$

$$i = (B_1 \cos 220t + B_2 \sin 220t)e^{-60t}\,\text{A}, \qquad t \geq 0.$$

The voltage across the inductor (passive sign convention) is 5 V at $t = 0$. Calculate the power at the terminals of the inductor at $t = 30$ ms. State whether the inductor is absorbing or delivering power.

6.6 Evaluate the integral

$$\int_0^\infty p\,dt$$

for Example 6.2. Comment on the significance of the result.

6.7 The voltage at the terminals of the 750 μH inductor in Fig. P6.7(a) is shown in Fig. P6.7(b). The inductor current i is known to be zero for $t \leq 0$.

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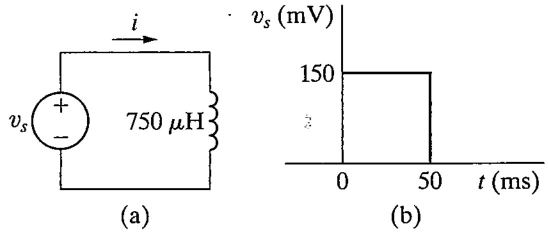
a) Derive the expressions for i for $t \geq 0$.

b) Sketch i versus t for $0 \leq t \leq \infty$.

Figure P6.7



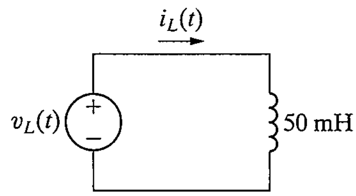
6.8 The current in the 50 mH inductor in Fig. P6.8 is known to be 100 mA for $t < 0$. The inductor voltage for $t \geq 0$ is given by the expression

$$v_L(t) = 2e^{-100t}\,\text{V}, \qquad 0^+ \leq t \leq 100\text{ ms}$$

$$v_L(t) = -2e^{-100(t-0.1)}\,\text{V}, \qquad 100\text{ ms} \leq t < \infty$$

Sketch $v_L(t)$ and $i_L(t)$ for $0 \leq t < \infty$.

Figure P6.8



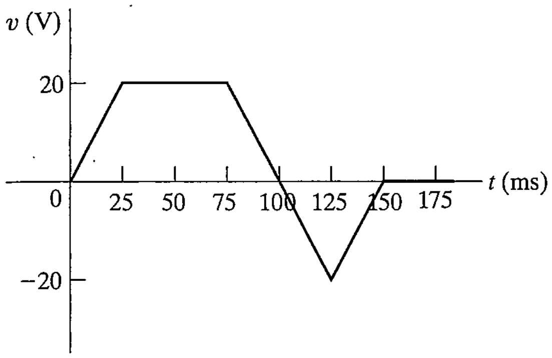
6.9 The current in and the voltage across a 10 H inductor are known to be zero for $t \leq 0$. The voltage across the inductor is given by the graph in Fig. P6.9 for $t \geq 0$.

a) Derive the expression for the current as a function of time in the intervals $0 \le t \le 25$ ms, $25 \text{ ms} \le t \le 75$ ms, $75 \text{ ms} \le t \le 125$ ms, $125 \text{ ms} \le t \le 150$ ms, and $150 \text{ ms} \le t < \infty$.

b) For $t > 0$, what is the current in the inductor when the voltage is zero?

c) Sketch i versus t for $0 \le t < \infty$.

Figure P6.9



6.10 a) Find the inductor current in the circuit in Fig. P6.10 if $v = 20 \cos 80t$ V, L = 100 mH, and $i(0) = 0$ A.

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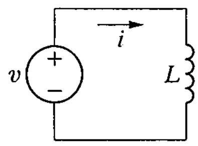
b) Sketch v, i, p, and w versus t. In making these sketches, use the format used in Fig. 6.8. Plot over one complete cycle of the voltage waveform.

c) Describe the subintervals in the time interval between 0 and 8π ms when power is being absorbed by the inductor. Repeat for the subintervals when power is being delivered by the inductor.

Figure P6.10



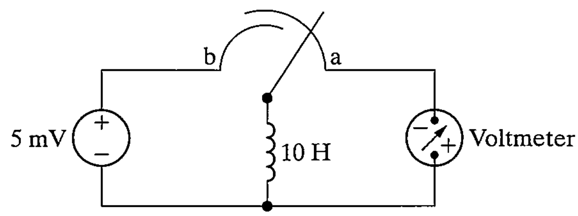
6.11 The current in a 100 mH inductor is known to be −10 A for $t \le 0$ and $(-10 \cos 400t - 15 \sin 400t)e^{-200t}$ A for $t \ge 0$. Assume the passive sign convention.

a) At what instant of time is the voltage across the inductor maximum?

b) What is the maximum voltage?

6.12 In the circuit in Fig. P6.12, there was no energy stored initially in the 10 H inductor when it was placed across the terminals of the voltmeter. At $t = 0$ the inductor was switched instantaneously to position b where it remained for 1.6 s before returning instantaneously to position a. The d'Arsonval voltmeter has a full-scale reading of 20 V and a sensitivity of 1000 Ω/V. What will the reading of the voltmeter be at the instant the switch returns to position a if the inertia of d'Arsonval movement is negligible?

Figure P6.12



Section 6.2

6.13 The voltage across an 8 μF capacitor is known to be

$$v_c = 600te^{-2500t} \text{V} \quad \text{for} \quad t \ge 0.$$

a) Find the current through the capacitor for $t > 0$. Assume the passive sings convention.

b) Find the power at the terminals of the capacitor when $t = 100$ μs.

c) Is the capacitor absorbing or delivering power at $t = 100$ μs.

d) Find the energy stored in the capacitor at $t = 100$ μs.

e) Find the maximum energy stored in the capacitors and the time when the maximum occurs.

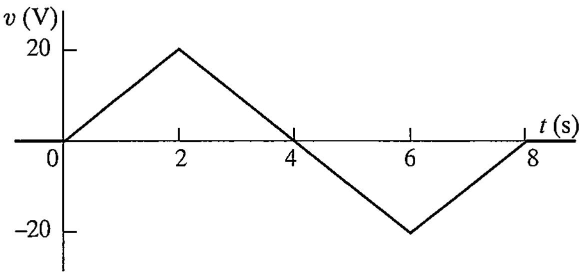
6.14 The triangular voltage pulse shown in Fig. P6.14 is applied to a 200 μF capacitor.

a) Write the expressions that describe $v(t)$ in the five time intervals $t < 0$, $0 \le t \le 2$ s, $2 \text{ s} \le t \le 6$ s, $6 \text{ s} \le t \le 8$ s, and $t > 8$ s.

b) Derive the expressions for the capacitor current, power, and energy for the time intervals in part (a). Use the passive sign convention.

c) Identify the time intervals between 0 and 8 s when power is being delivered by the capacitor. Repeat for the time intervals when power is being absorbed by the capacitor.

Figure P6.14



6.15 The voltage across the terminals of a 10 μF capacitor is

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$$v = \begin{cases} 70 \text{ V}, & t \le 0; \\ (A_1e^{-1400t} + A_2te^{-1400t}) \text{ V}, & t \ge 0. \end{cases}$$

The initial current in the capacitor is 150 mA. Assume the passive sign convention.

a) What is the initial energy stored in the capacitor?

b) Evaluate the coefficients A_1 and A_2.

c) What is the expression for the capacitor current?

6.16 A 100 μF capacitor is subjected to a voltage pulse having a duration of 4 s. The pulse is described by the following equations:

$$v_c(t) = \begin{cases} 5t^3\ \text{V}, & 0 \le t \le 2\ \text{s}; \\ -5(t-4)^3\ \text{V}, & 2\ \text{s} \le t \le 4\text{s}; \\ 0 & \text{elsewhere.} \end{cases}$$

Sketch the current pulse that exists in the capacitor during the 4 s interval.

6.17 PSPICE MULTISIM The voltage at the terminals of the capacitor in Fig. 6.10 is known to be

$$v = \begin{cases} 50\ \text{V}, & t \le 0; \\ 20 + 4e^{-300t}(5\cos 1000t + \sin 1000t)\ \text{V}, & t \ge 0. \end{cases}$$

Assume $C = 125\ \mu$F.

a) Find the current in the capacitor for $t < 0$.

b) Find the current in the capacitor for $t > 0$.

c) Is there any instantaneous change in the voltage across the capacitor at $t = 0$?

d) Is there an instantaneous change in the current in the capacitor at $t = 0$?

e) How much energy (in millijoules) is stored in the capacitor at $t = \infty$?

6.18 The expressions for voltage, power, and energy derived in Example 6.5 involved both integration and manipulation of algebraic expressions. As an engineer, you cannot accept such results on faith alone. That is, you should develop the habit of asking yourself, "Do these results make sense in terms of the known behavior of the circuit they purport to describe?" With these thoughts in mind, test the expressions of Example 6.5 by performing the following checks:

a) Check the expressions to see whether the voltage is continuous in passing from one time interval to the next.

b) Check the power expression in each interval by selecting a time within the interval and seeing whether it gives the same result as the corresponding product of v and i. For example, test at 10 and 30 μs.

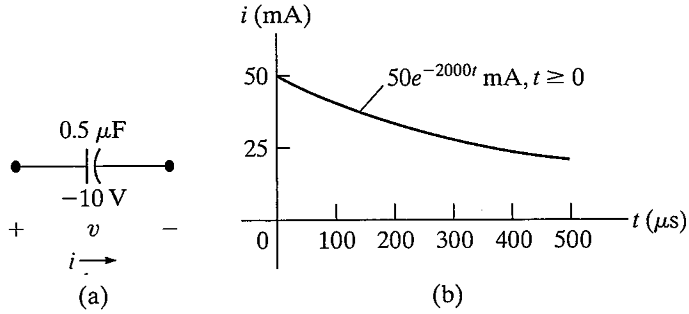
c) Check the energy expression within each interval by selecting a time within the interval and seeing whether the energy equation gives the same result as $\frac{1}{2}Cv^2$. Use 10 and 30 μs as test points.

6.19 The initial voltage on the 0.5 μF capacitor shown in Fig. P6.19(a) is -10 V. The capacitor current has the waveform shown in Fig. P6.19(b).

a) How much energy, in microjoules, is stored in the capacitor at $t = 200\ \mu$s?

b) Repeat (a) for $t = \infty$.

Figure P6.19



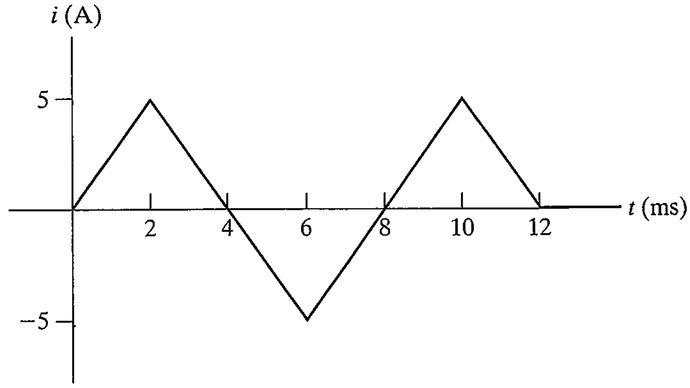
6.20 PSPICE MULTISIM The current shown in Fig. P6.20 is applied to a 3 μF capacitor. The initial voltage on the capacitor is zero.

a) Find the charge on the capacitor at $t = 6$ ms.

b) Find the voltage on the capacitor at $t = 10$ ms.

c) How much energy is stored in the capacitor by this current?

Figure P6.20



6.21 PSPICE MULTISIM The rectangular-shaped current pulse shown in Fig. P6.21 is applied to a 0.1 μF capacitor. The initial voltage on the capacitor is a 15 V drop in the reference direction of the current. Derive the expression for the capacitor voltage for the time intervals in (a)–(d).

a) $0 \le t \le 10\ \mu s$;

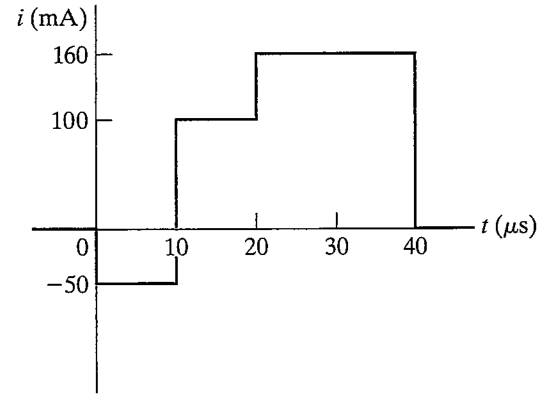
b) $10\ \mu s \le t \le 20\ \mu s$;

c) $20\ \mu s \le t \le 40\ \mu s$

d) $40\ \mu s \le t < \infty$

e) Sketch $v(t)$ over the interval $-10\ \mu s \le t \le 50\ \mu s$.

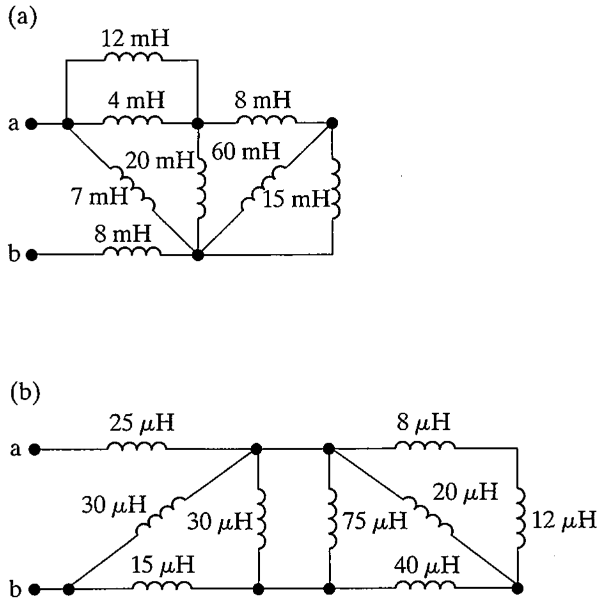
Figure P6.21



Section 6.3

6.22 Assume that the initial energy stored in the inductors of Figs. P6.22(a) and (b) is zero. Find the equivalent inductance with respect to the terminals a, b.

Figure P6.22



6.23 Use realistic inductor values from Appendix H to construct series and parallel combinations of inductors to yield the equivalent inductances specified below. Try to minimize the number of inductors used. Assume that no initial energy is stored in any of the inductors.

a) 8 mH;

b) 45 μH;

c) 180 μH.

6.24 The two parallel inductors in Fig. P6.24 are connected across the terminals of a black box at $t = 0$. The resulting voltage v for $t > 0$ is known to be $64e^{-4t}$ V. It is also known that $i_1(0) = -10$ A and $i_2(0) = 5$ A.

a) Replace the original inductors with an equivalent inductor and find $i(t)$ for $t \ge 0$.

b) Find $i_1(t)$ for $t \ge 0$.

c) Find $i_2(t)$ for $t \ge 0$.

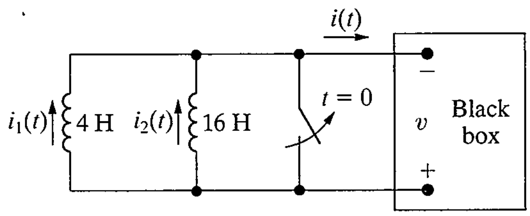
d) How much energy is delivered to the black box in the time interval $0 \le t < \infty$?

e) How much energy was initially stored in the parallel inductors?

f) How much energy is trapped in the ideal inductors?

g) Show that your solutions for i_1 and i_2 agree with the answer obtained in (f).

Figure P6.24



6.25 The three inductors in the circuit in Fig. P6.25 are connected across the terminals of a black box at $t = 0$. The resulting voltage for $t > 0$ is known to be

$$v_o = 500e^{-100t}\ V.$$

If $i_1(0) = -6$ A and $i_2(0) = 1$ A, find

a) $i_o(0)$;

b) $i_o(t)$, $t \ge 0$;

c) $i_1(t)$, $t \ge 0$;

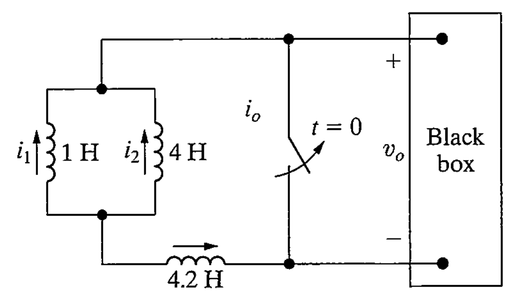
d) $i_2(t)$, $t \ge 0$;

e) the initial energy stored in the three inductors;

f) the total energy delivered to the black box; and

g) the energy trapped in the ideal inductors.

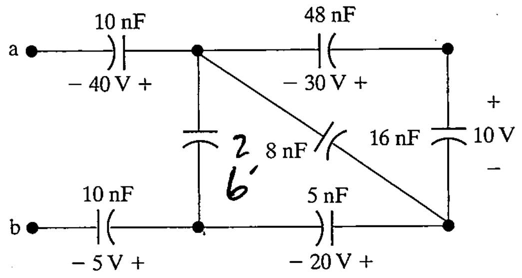
Figure P6.25

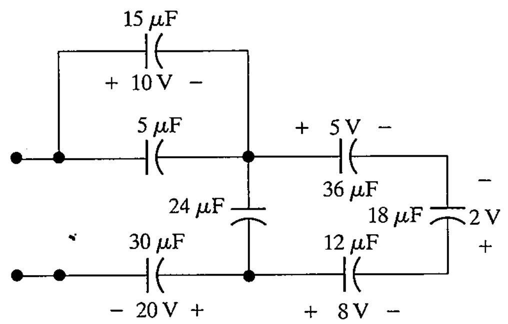


6.26 For the circuit shown in Fig. P6.25, how many milliseconds after the switch is opened is the energy delivered to the black box 80% of the total energy delivered?

6.27 Find the equivalent capacitance with respect to the terminals a, b for the circuits shown in Fig. P6.27.

Figure P6.27





6.28 Use realistic capacitor values from Appendix H to construct series and parallel combinations of capacitors to yield the equivalent capacitances specified below. Try to minimize the number of capacitors used. Assume that no initial energy is stored in any of the capacitors.

a) 480 pF;

b) 600 nF;

c) 120 μF.

6.29 Derive the equivalent circuit for a series connection of ideal capacitors. Assume that each capacitor has its own initial voltage. Denote these initial voltages as $v_1(t_0)$, $v_2(t_0)$, and so on. (*Hint*: Sum the voltages across the string of capacitors, recognizing that the series connection forces the current in each capacitor to be the same.)

6.30 Derive the equivalent circuit for a parallel connection of ideal capacitors. Assume that the initial voltage across the paralleled capacitors is $v(t_0)$. (*Hint*: Sum the currents into the string of capacitors, recognizing that the parallel connection forces the voltage across each capacitor to be the same.)

6.31 The two series-connected capacitors in Fig. P6.31 are connected to the terminals of a black box at $t = 0$. The resulting current $i(t)$ for $t > 0$ is known to be $800e^{-25t}\mu$A.

a) Replace the original capacitors with an equivalent capacitor and find $v_o(t)$ for $t \geq 0$.

b) Find $v_1(t)$ for $t \geq 0$.

c) Find $v_2(t)$ for $t \geq 0$.

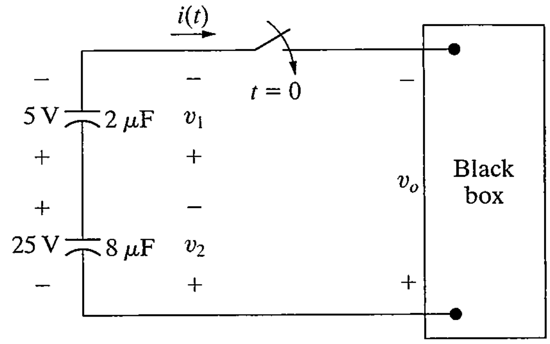
d) How much energy is delivered to the black box in the time interval $0 \leq t < \infty$?

e) How much energy was initially stored in the series capacitors?

f) How much energy is trapped in the ideal capacitors?

g) Show that the solutions for v_1 and v_2 agree with the answer obtained in (f).

Figure P6.31

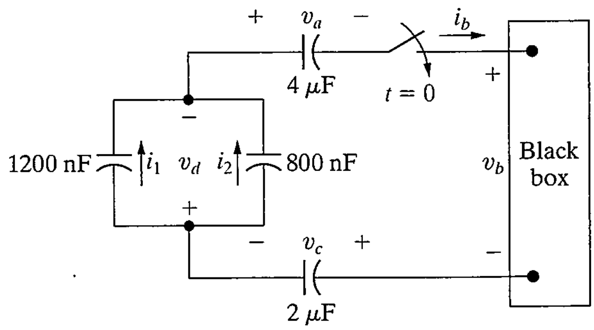


6.32 The four capacitors in the circuit in Fig. P6.32 are connected across the terminals of a black box at $t = 0$. The resulting current i_b for $t > 0$ is known to be

$$i_b = -5e^{-50t}\,\text{mA}.$$

If $v_a(0) = -20$ V, $v_c(0) = -30$ V and $v_d(0) = 250$ V, find the following for $t \geq 0$: (a) $v_b(t)$, (b) $v_a(t)$, (c) $v_c(t)$, (d) $v_d(t)$, (e) $i_1(t)$, and (f) $i_2(t)$.

Figure P6.32



6.33 For the circuit in Fig. P6.32, calculate

a) the initial energy stored in the capacitors;

b) the final energy stored in the capacitors;

Summary

- A first-order circuit may be reduced to a Thévenin (or Norton) equivalent connected to either a single equivalent inductor or capacitor. (See page 248.)

- The **natural response** is the currents and voltages that exist when stored energy is released to a circuit that contains no independent sources. (See page 248.)

- The **time constant** of an *RL* circuit equals the equivalent inductance divided by the Thévenin resistance as viewed from the terminals of the equivalent inductor. (See page 251.)

- The **time constant** of an *RC* circuit equals the equivalent capacitance times the Thévenin resistance as viewed from the terminals of the equivalent capacitor. (See page 257.)

- The **step response** is the currents and voltages that result from abrupt changes in dc sources connected to a circuit. Stored energy may or may not be present at the time the abrupt changes take place. (See page 261.)

- Analysis Method 7.5 can be used to find the solution for the natural and step responses of both *RL* and *RC* circuits:

  Step 1: Identify the variable $x(t)$, which is the quantity that is required to be continuous for all time. This is the inductor current in *RL* circuits and the capacitor voltage in *RC* circuits.

  Step 2: Calculate the initial value X_0, by analyzing the circuit to find $x(t)$ for $t < 0$.

  Step 3: Calculate the time constant, τ, for the circuit by analyzing the circuit for $t \geq 0$ to find the equivalent resistance attached to the inductor or capacitor. For *RL* circuits, $\tau = L/R$, and for *RC* circuits, $\tau = RC$.

  Step 4: Calculate the final value X_f, by analyzing the circuit to find $x(t)$ as $t \to \infty$. If the circuit exhibits a natural response, $X_f = 0$, so no calculation is needed.

  Step 5: Write the equation for $x(t)$ by substituting the initial value X_0, the time constant τ, and the final value X_f, into the expression $x(t) = X_f + (X_0 - X_f)e^{-t/\tau}, t \geq 0$.

  Step 6: Use $x(t)$ to find any other quantities of interest in the circuit. (See page 270.)

- **Sequential switching** in first-order circuits is analyzed by dividing the analysis into time intervals corresponding to specific switch positions. Initial values for a particular interval are determined from the solution corresponding to the immediately preceding interval. (See page 274.)

- An **unbounded response** occurs when the Thévenin resistance is negative, which is possible when the first-order circuit contains dependent sources. (See page 278.)

- An integrating amplifier consists of an ideal op amp, a capacitor in the negative feedback branch, and a resistor in series with the signal source. It outputs the integral of the signal source, within specified limits that avoid saturating the op amp. (See page 280.)

Problems

Section 7.1

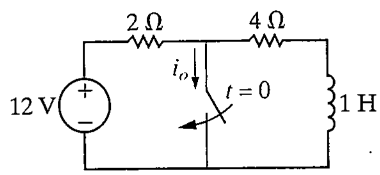
7.1 The switch in the circuit in Fig. P7.1 has been open for a long time. At $t = 0$ the switch is closed.
PSPICE MULTISIM

a) Determine $i_o(0)$ and $i_o(\infty)$.

b) Determine $i_o(t)$ for $t \geq 0$.

c) How many milliseconds after the switch has been closed will i_o equal 5 A?

Figure P7.1

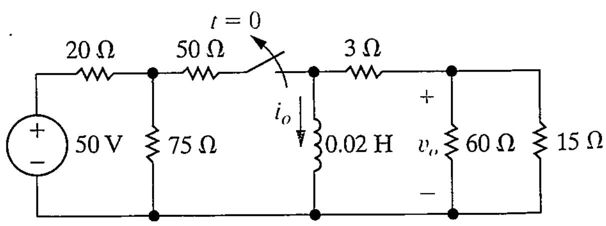


7.2 The switch in the circuit in Fig. P7.2 has been closed for a long time. At $t = 0$ it is opened.
PSPICE MULTISIM

a) Write the expression for $i_o(t)$ for $t \geq 0$.

b) Write the expression for $v_o(t)$ for $t \geq 0^+$.

Figure P7.2



7.3 In the circuit shown in Fig. P7.3, the switch makes contact with position b just before breaking contact with position a. This is known as a make-before-break switch and it ensures that the inductor current is continuous. The interval of time between "making" and "breaking" is assumed to be negligible.

The switch has been in the a position for a long time. At $t = 0$ the switch is thrown from position a to position b.

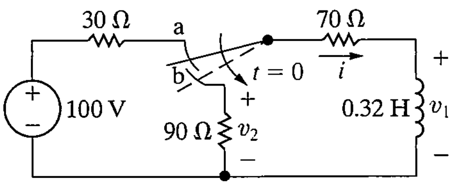
a) Determine the initial current in the inductor.

b) Determine the time constant of the circuit for $t > 0$.

c) Find i, v_1, and v_2 for $t \geq 0$.

d) What percentage of the initial energy stored in the inductor is dissipated in the $90\,\Omega$ resistor 1 ms after the switch is thrown from position a to position b?

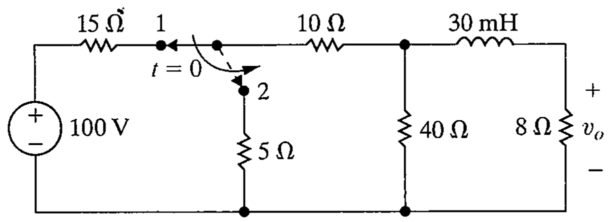
Figure P7.3



7.4 The switch in the circuit in Fig. P7.4 has been in position 1 for a long time. At $t = 0$, the switch moves instantaneously to position 2. Find $v_o(t)$ for $t \geq 0^+$.

PSPICE
MULTISIM

Figure P7.4



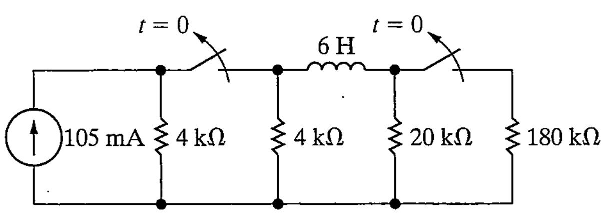
7.5 For the circuit of Fig. P7.4, what percentage of the initial energy stored in the inductor is eventually dissipated in the $8\,\Omega$ resistor?

7.6 The two switches in the circuit seen in Fig. P7.6 are synchronized. The switches have been closed for a long time before opening at $t = 0$.

a) How many microseconds after the switches are open is the energy dissipated in the $4\,k\Omega$ resistor 10% of the initial energy stored in the 6 H inductor?

b) At the time calculated in (a), what percentage of the total energy stored in the inductor has been dissipated?

Figure P7.6

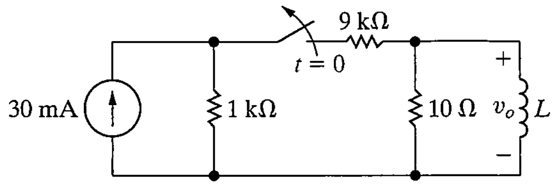


7.7 In the circuit in Fig. P7.7, the switch has been closed for a long time before opening at $t = 0$.

a) Find the value of L so that $v_o(t)$ equals $0.5\, v_o(0^+)$ when $t = 1$ ms.

b) Find the percentage of the stored energy that has been dissipated in the $10\,\Omega$ resistor when $t = 1$ ms.

Figure P7.7



7.8 The switch in the circuit in Fig. P7.8 has been closed for a long time before opening at $t = 0$.

PSPICE
MULTISIM

a) Find $i_1(0^-)$ and $i_2(0^-)$.

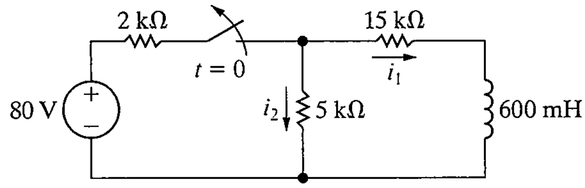
b) Find $i_1(0^+)$ and $i_2(0^+)$.

c) Find $i_1(t)$ for $t \geq 0$.

d) Find $i_2(t)$ for $t \geq 0^+$.

e) Explain why $i_2(0^-) \neq i_2(0^+)$.

Figure P7.8



7.9 The switch shown in Fig. P7.9 has been open for a long time before closing at $t = 0$.

a) Find $i_o(0^-)$, $i_L(0^-)$, and $v_L(0^-)$.

b) Find $i_o(0^+)$, $i_L(0^+)$, and $v_L(0^+)$.

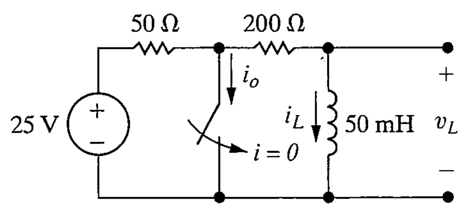
c) Find $i_o(\infty)$, $i_L(\infty)$, and $v_L(\infty)$.

d) Write the expression for $i_L(t)$ for $t \geq 0$.

e) Write the expression for $i_o(t)$ for $t \geq 0^+$.

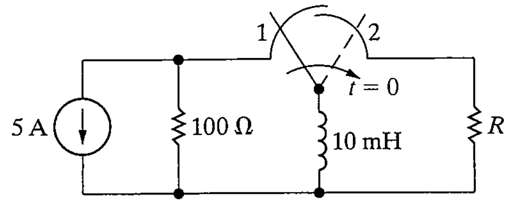
f) Write the expression for $v_L(t)$ for $t \geq 0^+$.

Figure P7.9



7.10 The switch in the circuit seen in Fig. P7.10 has been in position 1 for a long time. At $t = 0$, the switch moves instantaneously to position 2. Find the value of R so that 10% of the initial energy stored in the 10 mH inductor is dissipated in R in $10\,\mu$s.

Figure P7.10



7.11 In the circuit in Fig. P7.10, let I_g represent the dc current source, σ represent the fraction of initial energy stored in the inductor that is dissipated in t_o seconds, and L represent the inductance.

a) Show that

$$R = \frac{L \ln [1/(1 - \sigma)]}{2t_o}.$$

b) Test the expression derived in (a) by using it to find the value of R in Problem 7.10.

7.12 In the circuit in Fig. P7.12, the voltage and current expressions are

$$v = 400e^{-5t}\ \text{V}, \quad t \geq 0^+;$$

$$i = 10e^{-5t}\ \text{A}, \quad t \geq 0.$$

Find

a) R.

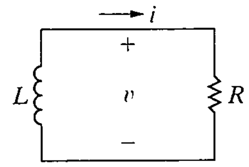
b) τ (in milliseconds).

c) L.

d) the initial energy stored in the inductor.

e) the time (in milliseconds) it takes to dissipate 80% of the initial stored energy.

Figure P7.12



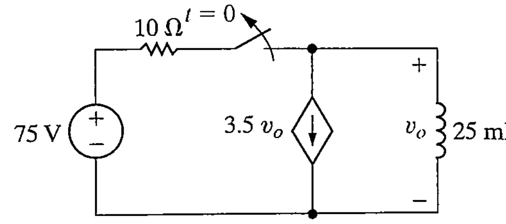
7.13 a) Use component values from Appendix H to create a first-order RL circuit (see Fig. 7.4) with a time constant of 1 ms. Use a single inductor and a network of resistors, if necessary. Draw your circuit.

b) Suppose the inductor you chose in part (a) has an initial current of 10 mA. Write an expression for the current through the inductor for $t \geq 0$.

c) Using your result from part (b), calculate the time at which half of the initial energy stored in the inductor has been dissipated by the resistor.

7.14 A switch in the circuit in Fig. P7.14 has been closed for a long time before opening at $t = 0$. Find $v_o(t)$ for $t \geq 0^+$.
PSPICE
MULTISIM

Figure P7.14



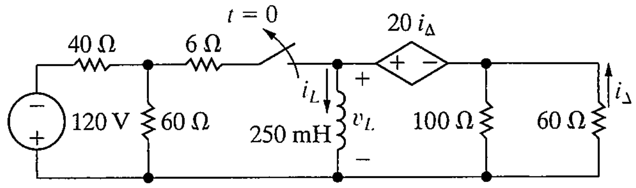
7.15 The switch in Fig. P7.15 has been closed for a long time before opening at $t = 0$. Find

a) $i_L(t)$, $t \geq 0$.

b) $v_L(t)$, $t \geq 0^+$.

c) $i_\Delta(t)$, $t \geq 0^+$.

Figure P7.15



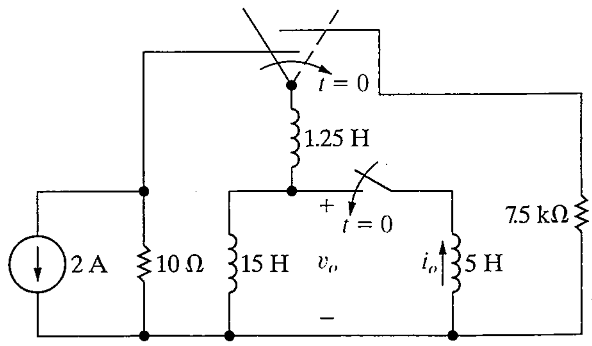
7.16 What percentage of the initial energy stored in the inductor in the circuit in Fig. P7.15 is dissipated by the 60 Ω resistor?

7.17 The two switches shown in the circuit in Fig. P7.17 operate simultaneously. Prior to $t = 0$, each switch has been in its indicated position for a long time. At $t = 0$ the two switches move instantaneously to their new positions. Find

a) $v_o(t)$, $t \geq 0^+$.

b) $i_o(t)$, $t \geq 0$.

Figure P7.17



7.18 For the circuit seen in Fig. P7.17, find

a) the total energy dissipated in the 7.5 k resistor.

b) the energy trapped in the ideal inductors.

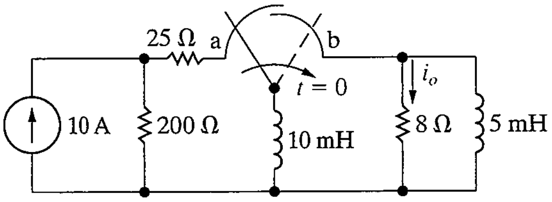
7.19 In the circuit shown in Fig. P7.19, the switch has been in position a for a long time. At $t = 0$, it moves instantaneously from a to b.
PSPICE
MULTISIM

a) Find $i_o(t)$ for $t \geq 0$.

b) What is the total energy delivered to the 8 Ω resistor?

c) How many time constants does it take to deliver 95% of the energy found in (b)?

Figure P7.19



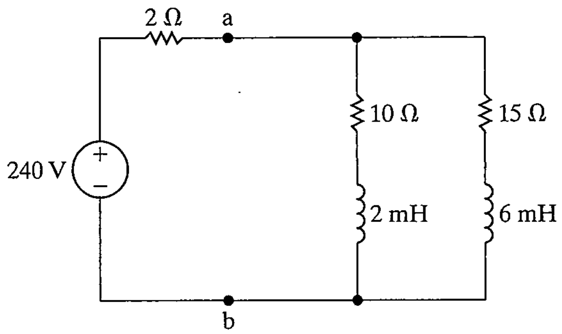
7.20 The 240 V, 2 Ω source in the circuit in Fig. P7.20 is inadvertently short-circuited at its terminals a, b. At the time the fault occurs, the circuit has been in operation for a long time.
PSPICE
MULTISIM

a) What is the initial value of the current i_{ab} in the short-circuit connection between terminals a, b?

b) What is the final value of the current i_{ab}?

c) How many microseconds after the short circuit has occurred is the current in the short equal to 114 A?

Figure P7.20



Section 7.2

7.21 The switch in the circuit in Fig. P7.21 has been in the left position for a long time. At $t = 0$ it moves to the right position and stays there.

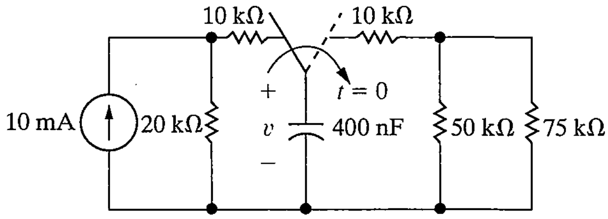
a) Find the initial voltage drop across the capacitor.

b) Find the initial energy stored by the capacitor.

c) Find the time constant of this circuit for $t > 0$.

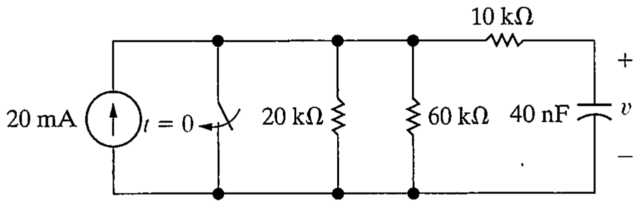
d) Write the expression for the capacitor voltage $v(t)$ for $t \geq 0$.

Figure P7.21



7.22 The switch shown in Fig. P7.22 has been open for a long time before closing at $t = 0$. Write the expression for the capacitor voltage, $v(t)$, for $t \geq 0$.

Figure P7.22

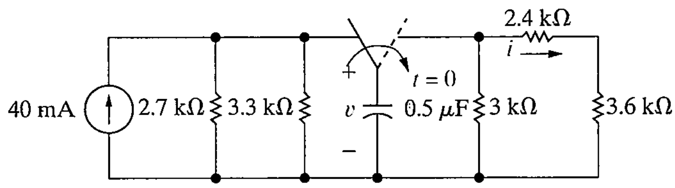


7.23 The switch in the circuit in Fig. P7.23 has been in the left position for a long time. At $t = 0$ it moves to the right position and stays there.

a) Write the expression for the capacitor voltage, $v(t)$, for $t \geq 0$.

b) Write the expression for the current through the 2.4 kΩ resistor, $i(t)$, for $t \geq 0^+$.

Figure P7.23



7.24 What percentage of the initial energy stored in the capacitor in Fig. P7.22 is dissipated by the 3 kΩ resistor 500 μs after the switch is thrown?

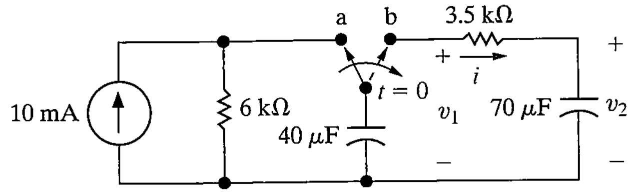
7.25 The switch in the circuit in Fig. P7.25 has been in position a for a long time and $v_2 = 0$ V. At $t = 0$, the switch is thrown to position b. Calculate:

a) i, v_1, and v_2 for $t \geq 0^+$.

b) the energy stored in the 40 μF capacitor at $t = 0$.

c) the energy trapped in the circuit and the total energy dissipated in the 3.5 kΩ resistor if the switch remains in position b indefinitely.

Figure P7.25

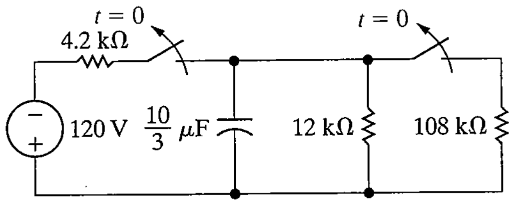


7.26 In the circuit shown in Fig. P7.26, both switches operate together; that is, they either open or close at the same time. The switches are closed a long time before opening at $t = 0$.

a) How many microjoules of energy have been dissipated in the 12 k resistor 12 ms after the switches open?

b) How long does it take to dissipate 75% of the initially stored energy?

Figure P7.26



7.27 The switch in the circuit in Fig. P7.27 is closed at $t = 0$ after being open for a long time.

a) Find $i_1(0^-)$ and $i_2(0^-)$.

b) Find $i_1(0^+)$ and $i_2(0^+)$.

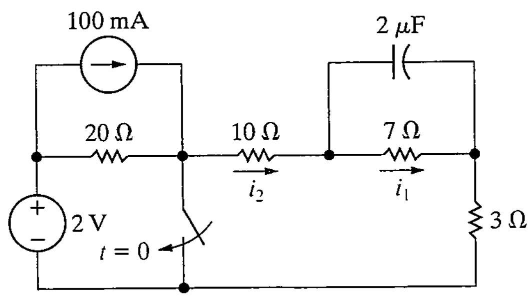
c) Explain why $i_1(0^-) = i_1(0^+)$.

d) Explain why $i_2(0^-) \neq i_2(0^+)$.

e) Find $i_1(t)$ for $t \geq 0$.

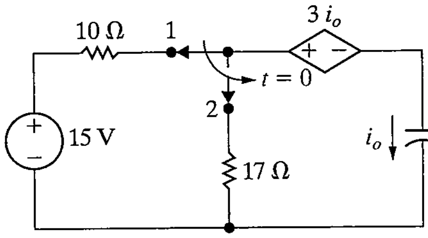
f) Find $i_2(t)$ for $t \geq 0^+$.

Figure P7.27



7.28 The switch in the circuit in Fig. P7.28 has been in position 1 for a long time before moving to position 2 at $t = 0$. Find $i_o(t)$ for $t \geq 0^+$.

Figure P7.28



7.29 In the circuit in Fig. P7.29 the voltage and current expressions are

$$v = 72e^{-500t}\ \text{V}, \quad t \geq 0;$$

$$i = 9e^{-500t}\ \text{mA}, \quad t \geq 0^+.$$

Find

a) R.

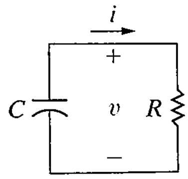
b) C.

c) τ (in milliseconds).

d) the initial energy stored in the capacitor.

e) how many microseconds it takes to dissipate 68% of the initial energy stored in the capacitor.

Figure P7.29



7.30 a) Use component values from Appendix H to create a first-order *RC* circuit (see Fig. 7.13) with a time constant of 50 ms. Use a single capacitor and a network of resistors, if necessary. Draw your circuit.

b) Suppose the capacitor you chose in part (a) has an initial voltage drop of 50 V. Write an expression for the voltage drop across the capacitor for $t \geq 0$.

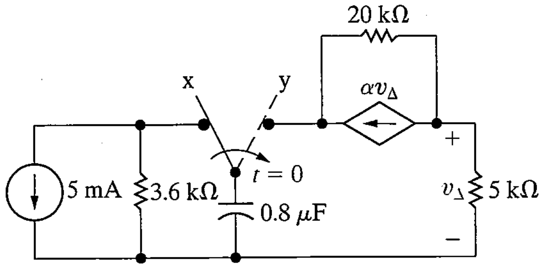
c) Using you result from part (b), calculate the time at which the voltage drop across the capacitor has reached 10 V.

7.31 The switch in the circuit seen in Fig. P7.31 has been in position x for a long time. At $t = 0$, the switch moves instantaneously to position y.

a) Find α so that the time constant for $t > 0$ is 40 ms.

b) For the α found in (a), find v_Δ.

Figure P7.31



7.32 a) In Problem 7.31, how many microjoules of energy are generated by the dependent current source during the time the capacitor discharges to 0 V?

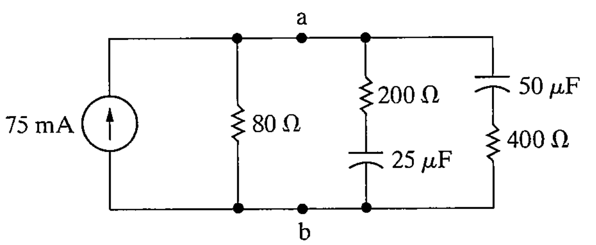
b) Show that for $t \geq 0$ the total energy stored and generated in the capacitive circuit equals the total energy dissipated.

7.33 PSPICE MULTISIM After the circuit in Fig. P7.33 has been in operation for a long time, a screwdriver is inadvertently connected across the terminals a, b. Assume the resistance of the screwdriver is negligible.

a) Find the current in the screwdriver at $t = 0^+$ and $t = \infty$.

b) Derive the expression for the current in the screwdriver for $t \geq 0^+$.

Figure P7.33



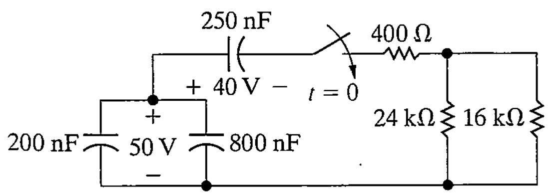
7.34 PSPICE MULTISIM At the time the switch is closed in the circuit in Fig. P7.34, the voltage across the parallel capacitors is 50 V and the voltage on the 250 nF capacitor is 40 V.

a) What percentage of the initial energy stored in the three capacitors is dissipated in the 24 kΩ resistor?

b) Repeat (a) for the 400 Ω and 16 kΩ resistors.

c) What percentage of the initial energy is trapped in the capacitors?

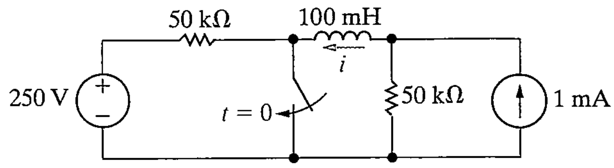
Figure P7.34



Section 7.3

7.35 After the switch in the circuit of Fig. P7.35 has been open for a long time, it is closed at $t = 0$. Calculate (a) the initial value of i; (b) the final value of i; (c) the time constant for $t \geq 0$; and (d) the numerical expression for $i(t)$ when $t \geq 0$.

Figure P7.35

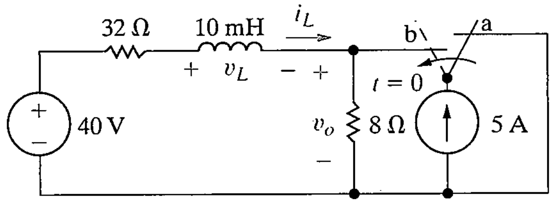


7.36 The switch in the circuit shown in Fig. P7.36 has been in position a for a long time before moving to position b at $t = 0$.

a) Find the numerical expressions for i_L and $v_o(t)$ for $t \geq 0$.

b) Find the numerical values of $v_L(0^+)$ and $v_o(0^+)$.

Figure P7.36

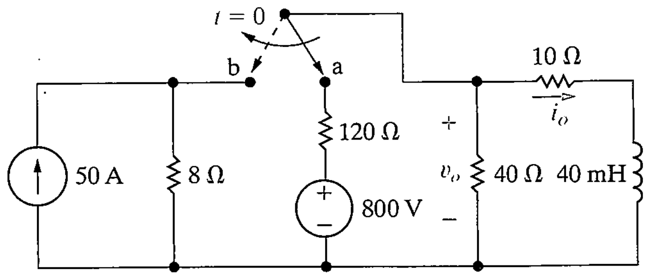


7.37 PSPICE MULTISIM The switch in the circuit shown in Fig. P7.37 has been in position a for a long time. At $t = 0$, the switch moves instantaneously to position b.

a) Find the numerical expression for $i_o(t)$ when $t \geq 0$.

b) Find the numerical expression for $v_o(t)$ for $t \geq 0^+$.

Figure P7.37



7.38 Repeat Problem 7.37 assuming that the switch in the circuit in Fig. P7.37 has been in position b for a long time and then moves to position a at $t = 0$ and stays there.

7.39 The current and voltage at the terminals of the inductor in the circuit in Fig. 7.20 are

$$i(t) = (4 + 4e^{-40t})\text{ A}, \quad t \geq 0;$$
$$v(t) = -80e^{-40t}\text{ V}, \quad t \geq 0^+.$$

a) Specify the numerical values of V_s, R, I_o, and L.

b) How many milliseconds after the switch has been closed does the energy stored in the inductor reach 9 J?

7.40 a) Use component values from Appendix H to create a first-order *RL* circuit (see Fig. 7.20) with a time constant of 8 μs. Use a single inductor and a network of resistors, if necessary. Draw your circuit.

b) Suppose the inductor you chose in part (a) has no initial stored energy. At $t = 0$, a switch connects a voltage source with a value of 25 V in series with the inductor and equivalent resistance. Write an expression for the current through the inductor for $t \geq 0$.

c) Using your result from part (b), calculate the time at which the current through the inductor reaches 75% of its final value.

7.41 The switch in the circuit shown in Fig. P7.41 has been closed for a long time. The switch opens at $t = 0$. For $t \geq 0^+$:

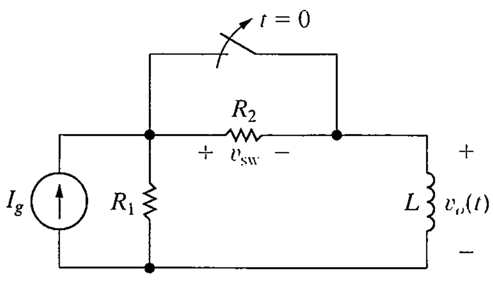
a) Find $v_o(t)$ as a function of I_g, R_1, R_2, and L.

b) Explain what happens to $v_o(t)$ as R_2 gets larger and larger.

c) Find v_{SW} as a function of I_g, R_1, R_2, and L.

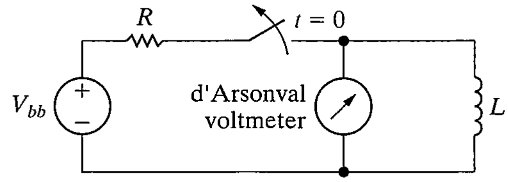
d) Explain what happens to v_{SW} as R_2 gets larger and larger.

Figure P7.41



7.42 The switch in the circuit in Fig. P7.42 has been closed for a long time. A student abruptly opens the switch and reports to her instructor that when the switch opened, an electric arc with noticeable persistence was established across the switch, and at the same time the voltmeter placed across the coil was damaged. On the basis of your analysis of the circuit in Problem 7.41, can you explain to the student why this happened?

Figure P7.42

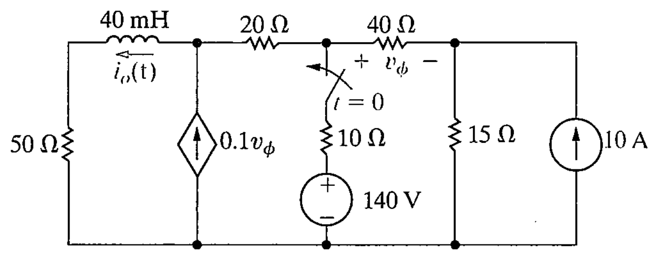


7.43 a) Derive Eq. 7.16 by first converting the Thévenin equivalent in Fig. 7.20 to a Norton equivalent and then summing the currents away from the upper node, using the inductor voltage v as the variable of interest.

b) Use the separation of variables technique to find the solution to Eq. 7.16. Verify that your solution agrees with the solution given in Eq. 7.15.

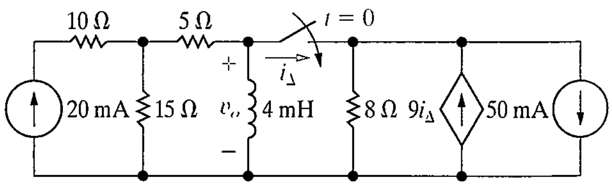
7.44 The switch in the circuit in Fig. P7.44 has been open a long time before closing at $t = 0$. Find $i_o(t)$ for $t \geq 0$.
PSPICE MULTISIM

Figure P7.44



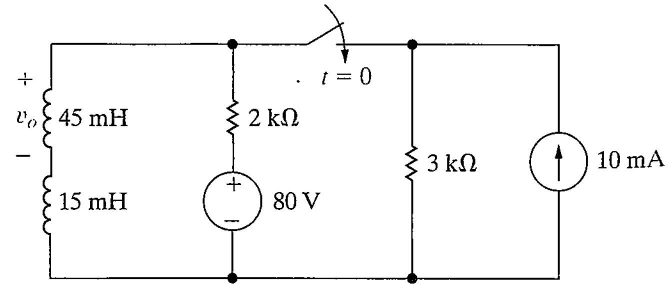
7.45 The switch in the circuit in Fig. P7.45 has been open a long time before closing at $t = 0$. Find $v_o(t)$ for $t \geq 0^+$.
PSPICE MULTISIM

Figure P7.45



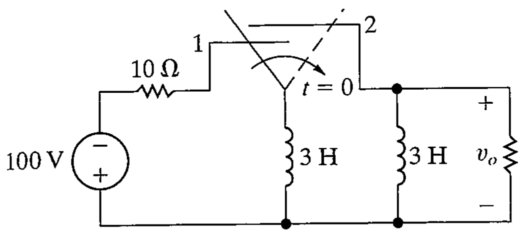
7.46 The switch in the circuit in Fig. P7.46 has been open a long time before closing at $t = 0$. Find $v_o(t)$ for $t \geq 0^+$.
PSPICE MULTISIM

Figure P7.46



7.47 The switch in the circuit in Fig. P7.47 has been in position 1 for a long time. At $t = 0$ it moves instantaneously to position 2. How many milliseconds after the switch moves does v_o equal 100 V?

Figure P7.47



7.48 For the circuit in Fig. P7.46, find (in joules):

a) the total energy dissipated in the 20 Ω resistor,

b) the energy trapped in the inductors, and

c) the initial energy stored in the inductors.

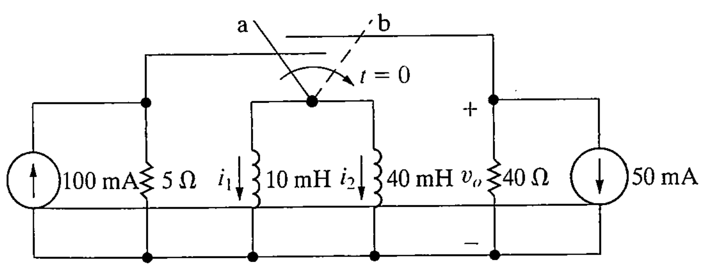
7.49 The make-before-break switch in the circuit of Fig. P7.49 has been in position a for a long time. At $t = 0$, the switch moves instantaneously to position b. Find

a) $v_o(t)$, $t \geq 0^+$.

b) $i_1(t)$, $t \geq 0$.

c) $i_2(t)$, $t \geq 0$.

Figure P7.49

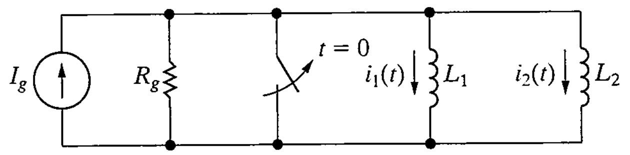


7.50 There is no energy stored in the inductors L_1 and L_2 at the time the switch is opened in the circuit shown in Fig. P7.50.

a) Derive the expressions for the currents $i_1(t)$ and $i_2(t)$ for $t \geq 0$.

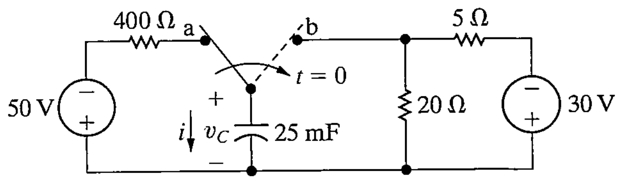
b) Use the expressions derived in (a) to find $i_1(\infty)$ and $i_2(\infty)$.

Figure P7.50



7.51 Assume that the switch in the circuit of Fig. P7.51 has been in position a for a long time and that at $t = 0$ it is moved to position b. Find (a) $v_C(0^+)$; (b) τ for $t > 0$; (c) $v_C(\infty)$; (d) $i(0^+)$; (e) v_C, $t \geq 0$; and (f) i, $t \geq 0^+$.

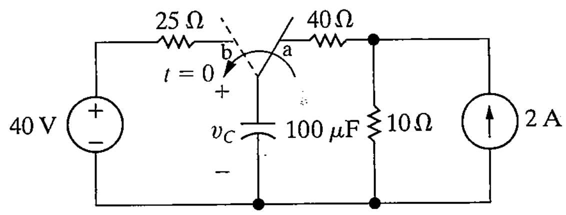
Figure P7.51



7.52 a) The switch in the circuit in Fig. P7.52 has been in position a for a long time. At $t = 0$, the switch moves instantaneously to position b and stays there. Find the initial and final values of the capacitor voltage, the time constant for $t \geq 0$, and the expression for the capacitor voltage for $t \geq 0$.

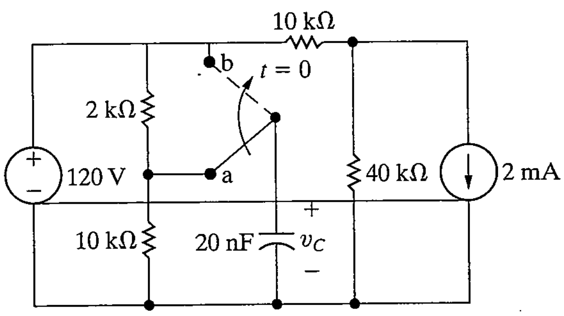
b) Now suppose the switch in the circuit in Fig. P7.52 has been in position b for a long time. At $t = 0$, the switch moves instantaneously to position a and stays there. Find the initial and final values of the capacitor voltage, the time constant for $t \geq 0$, and the expression for the capacitor voltage for $t \geq 0$.

Figure P7.52



7.53 The switch in the circuit of Fig. P7.53 has been in position a for a long time. At $t = 0$ the switch is moved to position b. Calculate (a) the initial voltage on the capacitor; (b) the final voltage on the capacitor; (c) the time constant (in microseconds) for $t = 0$; and (d) the length of time (in microseconds) required for the capacitor voltage to reach zero after the switch is moved to position b.

Figure P7.53

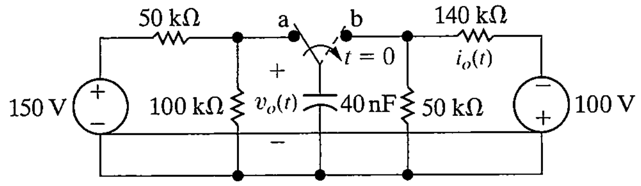


7.54 The switch in the circuit seen in Fig. P7.54 has been in position a for a long time. At $t = 0$, the switch moves instantaneously to position b. For $t \geq 0^+$, find

a) $v_o(t)$.

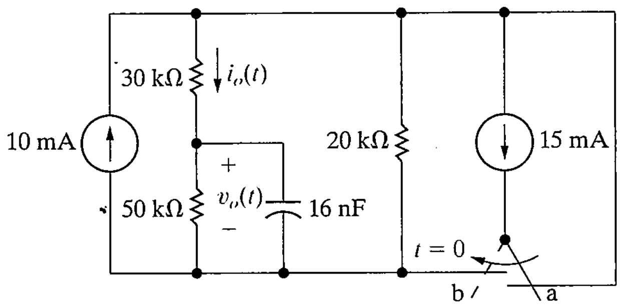
b) $i_o(t)$.

Figure P7.54



7.55 The switch in the circuit seen in Fig. P7.55 has been in position a for a long time. At $t = 0$, the switch moves instantaneously to position b. Find $v_o(t)$ and $i_o(t)$ for $t \geq 0^+$.
PSPICE
MULTISIM

Figure P7.55



7.56 The circuit in Fig. P7.56 has been in operation for a long time. At $t = 0$, the voltage source reverses polarity and the current source drops from 3 mA to 2 mA. Find $v_o(t)$ for $t \geq 0$.
PSPICE
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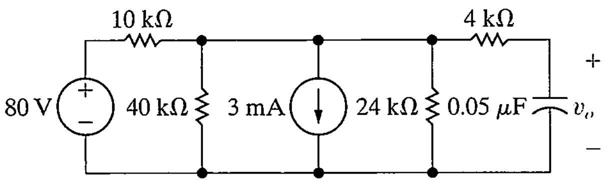
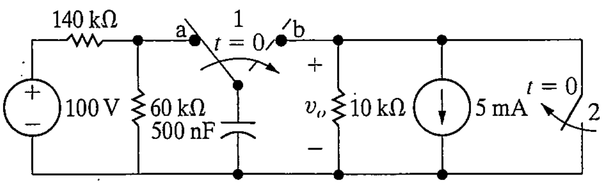
Figure P7.56



7.57 The switch in the circuit in Fig. P7.57 has been in position a for a long time. At $t = 0$, the switch moves instantaneously to position b. At the instant the switch makes contact with terminal b, switch 2 opens. Find $v_o(t)$ for $t \geq 0$.

Figure P7.57



7.58 The current and voltage at the terminals of the capacitor in the circuit in Fig. 7.28 are

$$i(t) = 3e^{-2500t} \text{ mA}, \qquad t \geq 0^+;$$

$$v(t) = (40 - 24e^{-2500t}) \text{ V}, \quad t \geq 0.$$

a) Specify the numerical values of I_s, V_o, R, C, and τ.

b) How many microseconds after the switch has been closed does the energy stored in the capacitor reach 81% of its final value?

7.59 a) Use component values from Appendix H to create a first-order *RC* circuit (see Fig. 7.28) with a time constant of 250 ms. Use a single capacitor and a network of resistors, if necessary. Draw your circuit.

b) Suppose the capacitor you chose in part (a) has an initial voltage drop of 100 V. At $t = 0$, a switch connects a current source with a value of 1 mA in parallel with the capacitor and equivalent resistance. Write an expression for the voltage drop across the capacitor for $t \geq 0$.

c) Using your result from part (b), calculate the time at which the voltage drop across the capicitor reaches 50 V.

7.60 The switch in the circuit shown in Fig. P7.60 opens at $t = 0$ after being closed for a long time. How many milliseconds after the switch opens is the energy stored in the capacitor 36% of its final value?
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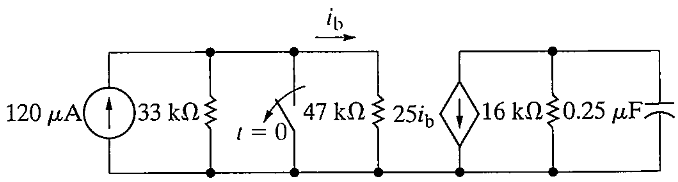
Figure P7.60



7.61 The switch in the circuit shown in Fig. P7.61 has been in the OFF position for a long time. At $t = 0$, the switch moves instantaneously to the ON position. Find $v_o(t)$ for $t \geq 0$.
PSPICE
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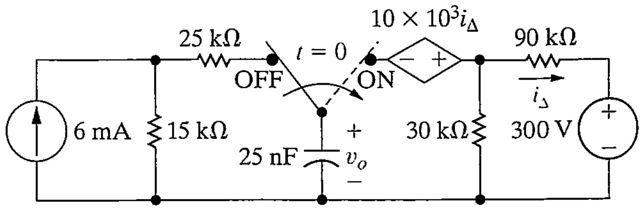
Figure P7.61



7.62 Assume that the switch in the circuit of Fig. P7.61 has been in the ON position for a long time before switching instantaneously to the OFF position at $t = 0$. Find $v_o(t)$ for $t \geq 0$.
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