Problems

Sections 3.1–3.2

3.1 For each of the circuits shown,

a) identify the resistors connected in series,

b) simplify the circuit by replacing the series-connected resistors with equivalent resistors.

3.2 For each of the circuits shown in Fig. P3.2,

a) identify the resistors connected in parallel,

b) simplify the circuit by replacing the parallel-connected resistors with equivalent resistors.

3.3 Find the equivalent resistance seen by the source in each of the circuits of Problem 3.1.

3.4 Find the equivalent resistance seen by the source in each of the circuits of Problem 3.2.

3.5 PSPICE MULTISIM Find the equivalent resistance R_{ab} for each of the circuits in Fig. P3.5.

3.6 PSPICE MULTISIM Find the equivalent resistance R_{ab} for each of the circuits in Fig. P3.6.

Figure P3.1

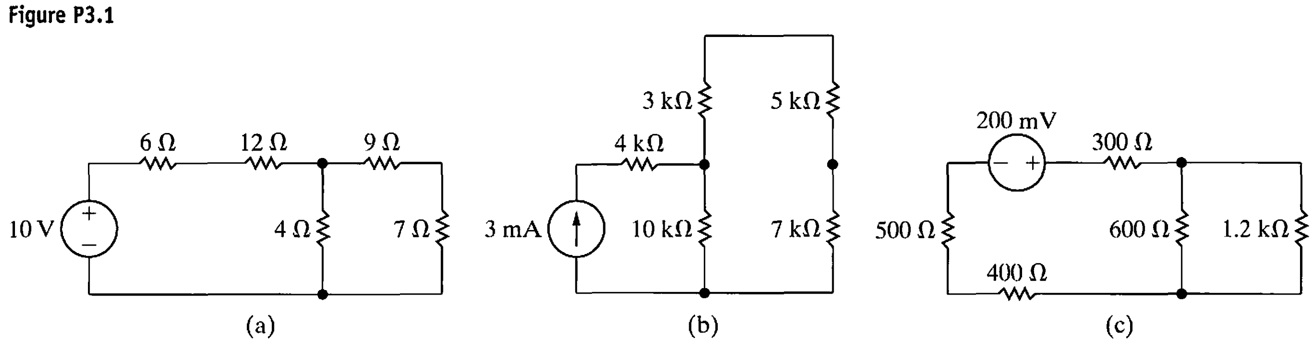


Figure P3.2

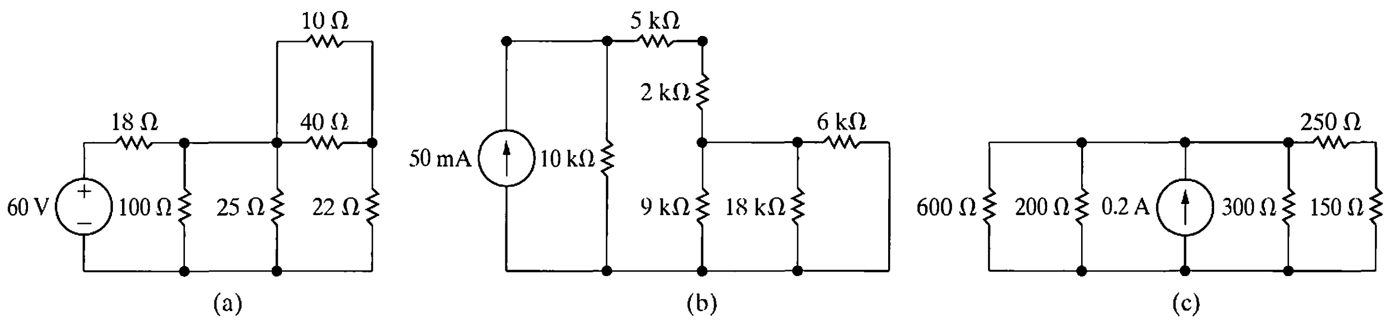


Figure P3.5

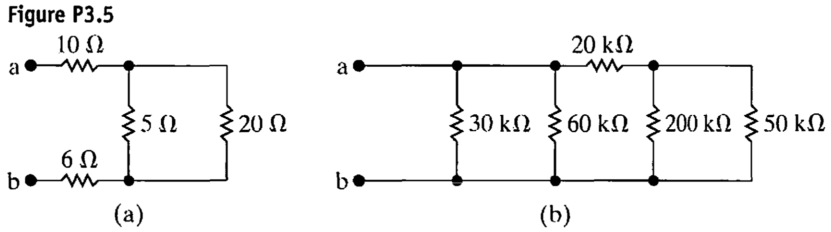
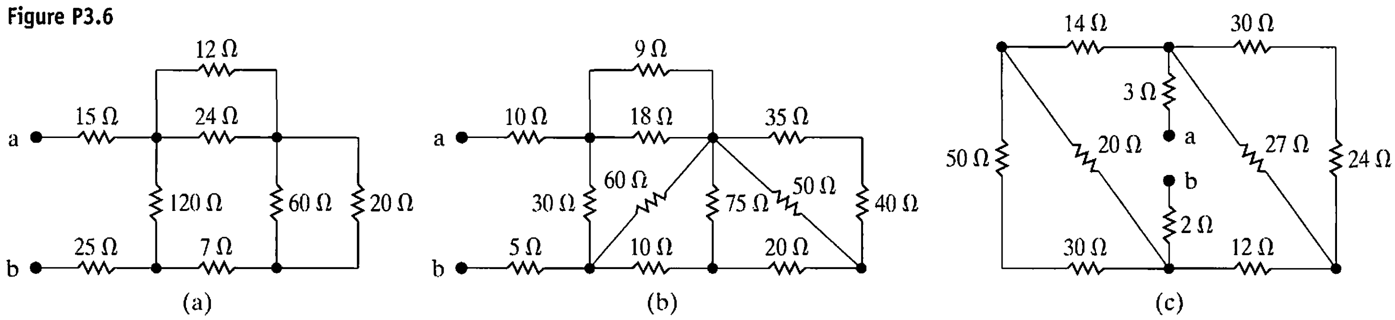


Figure P3.6



3.7 PSPICE MULTISIM
a) In the circuits in Fig. P3.7(a)–(c), find the equivalent resistance R_{ab}.
b) For each circuit find the power delivered by the source.

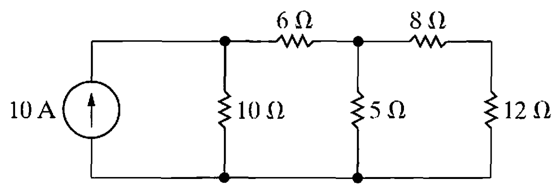
3.8 PSPICE MULTISIM
a) Find the power dissipated in each resistor in the circuit shown in Fig. 3.9.
b) Find the power delivered by the 120 V source.
c) Show that the power delivered equals the power dissipated.

3.9 PSPICE MULTISIM
a) Show that the solution of the circuit in Fig. 3.9 (see Example 3.1) satisfies Kirchhoff's current law at junctions x and y.
b) Show that the solution of the circuit in Fig. 3.9 satisfies Kirchhoff's voltage law around every closed loop.

Sections 3.3–3.4

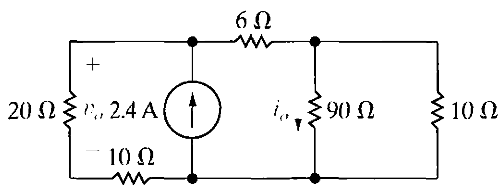
3.10 PSPICE MULTISIM
Find the power dissipated in the 5 Ω resistor in the circuit in Fig. P3.10.

Figure P3.10



3.11 PSPICE MULTISIM
For the circuit in Fig. P3.11 calculate
a) v_o and i_o.
b) the power dissipated in the 6 Ω resistor.
c) the power developed by the current source.

Figure P3.11



3.12
a) Find an expression for the equivalent resistance of two resistors of value R in series.
b) Find an expression for the equivalent resistance of n resistors of value R in series.
c) Using the results of (a), design a resistive network with an equivalent resistance of 3 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.

3.13
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.

3.14 PSPICE MULTISIM
In the voltage-divider circuit shown in Fig. P3.14, the no-load value of v_o is 4 V. When the load resistance R_L is attached across the terminals a and b, v_o drops to 3 V. Find R_L.

Figure P3.14

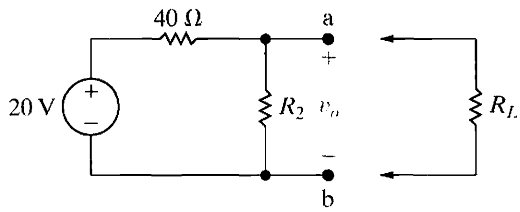
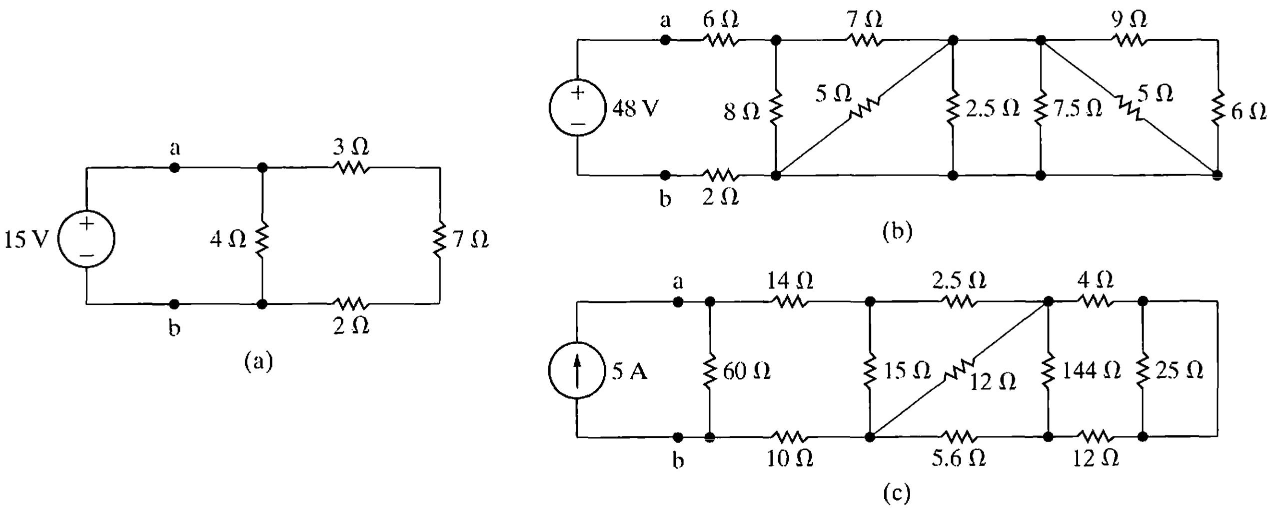


Figure P3.7



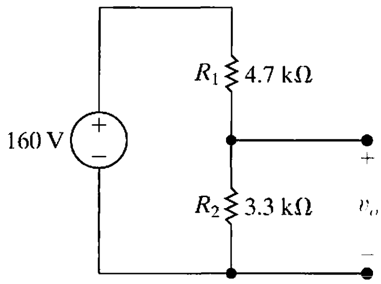
3.15 DESIGN PROBLEM PSPICE MULTISIM

a) Calculate the no-load voltage v_o for the voltage-divider circuit shown in Fig. P3.15.

b) Calculate the power dissipated in R_1 and R_2.

c) Assume that only 0.5 W resistors are available. The no-load voltage is to be the same as in (a). Specify the smallest ohmic values of R_1 and R_2.

Figure P3.15



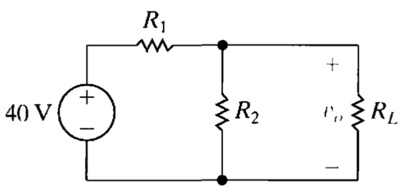
3.16 DESIGN PROBLEM PSPICE MULTISIM

The no-load voltage in the voltage-divider circuit shown in Fig. P3.16 is 8 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 7.5 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 1/16, 1/8, 1/4, 1, and 2 W. What power rating would you specify?

Figure P3.16



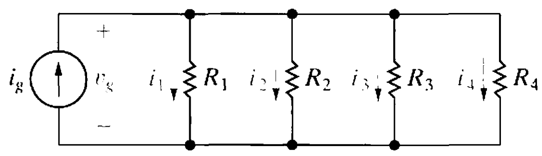
3.17 Assume the voltage divider in Fig. P3.16 has been constructed from 1 W resistors. What is the smallest resistor from Appendix H that can be used as R_L before one of the resistors in the divider is operating at its dissipation limit?

3.18 DESIGN PROBLEM

Specify the resistors in the circuit in Fig. P3.18 to meet the following design criteria:

$$i_g = 1 \text{ mA}; v_g = 1 \text{ V}; i_1 = 2i_2;$$
$$i_2 = 2i_3; \text{and } i_3 = 2i_4.$$

Figure P3.18



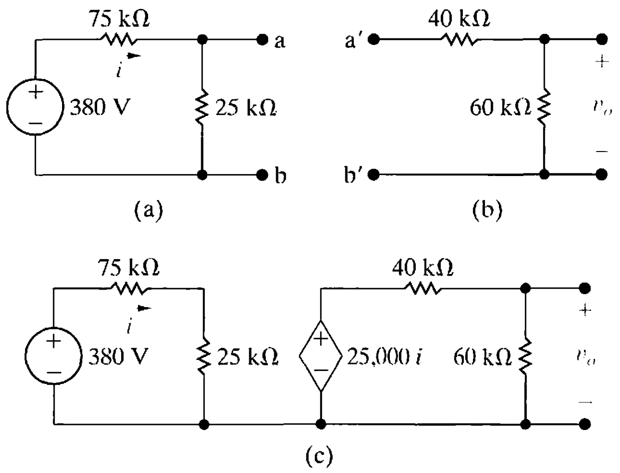
3.19 PSPICE MULTISIM

a) The voltage divider in Fig. P3.19(a) is loaded with the voltage divider shown in Fig. P3.19(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. P3.19(b) is connected to the voltage divider in Fig. P3.19(a) by means of a current-controlled voltage source as shown in Fig. P3.19(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 380 V source?

Figure P3.19



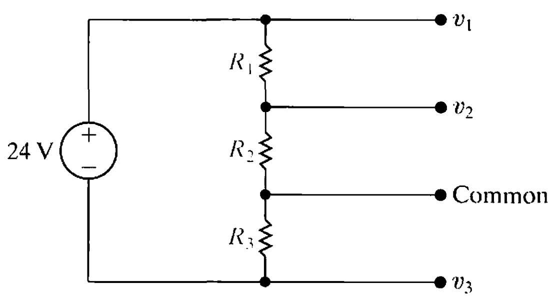
3.20 DESIGN PROBLEM

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. P3.20 to meet the following design requirements:

a) The total power supplied to the divider circuit by the 24 V source is 80 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 P3.20



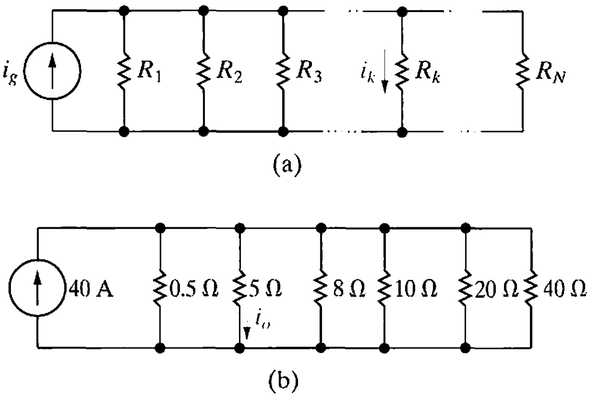
3.21 PSPICE MULTISIM

a) Show that the current in the kth branch of the circuit in Fig. P3.21(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 5 Ω resistor in the circuit in Fig. P3.21(b).

Figure P3.21



3.22 DESIGN PROBLEM A voltage divider like that in Fig. 3.13 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?

3.23 Look at the circuit in Fig. P3.2(a).

a) Use voltage division to find the voltage drop across the 18 Ω resistor, positive at the left.

b) Using your result from (a), find the current flowing in the 18 Ω resistor from left to right.

c) Starting with your result from (b), use current division to find the current in the 25 Ω resistor from top to bottom.

d) Using your result from part (c), find the voltage drop across the 25 Ω resistor, positive at the top.

e) Starting with your result from (d), use voltage division to find the voltage drop across the 10 Ω resistor, positive on the left.

3.24 Look at the circuit in Fig. P3.2(b).

a) Use current division to find the current flowing from top to bottom in the 10 kΩ resistor.

b) Using your result from (a), find the voltage drop across the 10 kΩ resistor, positive at the top.

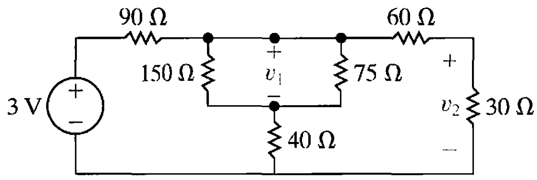
c) Starting with your result from (b), use voltage division to find the voltage drop across the 2 kΩ resistor, positive at the top.

d) Using your result from part (c), find the current through the 2 kΩ resistor from top to bottom.

e) Starting with your result from part (d), use current division to find the current through the 18 kΩ resistor from top to bottom.

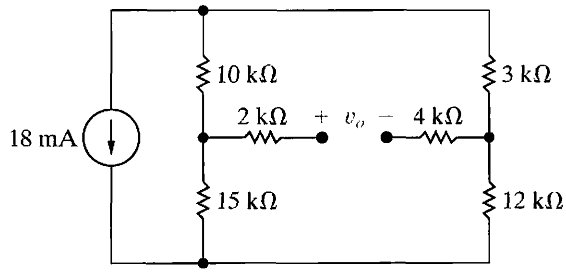
3.25 PSPICE MULTISIM Find v_1 and v_2 in the circuit in Fig. P3.25.

Figure P3.25



3.26 PSPICE MULTISIM Find v_o in the circuit in Fig. P3.26.

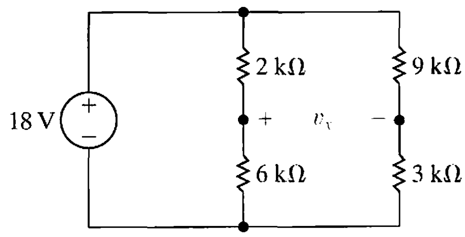
Figure P3.26



3.27 PSPICE MULTISIM a) Find the voltage v_x in the circuit in Fig. P3.27.

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.

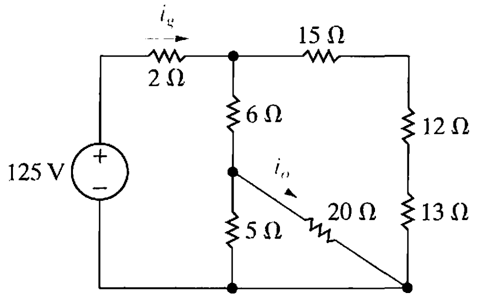
Figure P3.27



3.28 Find i_o and i_g in the circuit in Fig. P3.28.

PSPICE MULTISIM

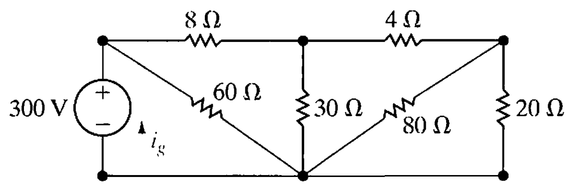
Figure P3.28



3.29 For the circuit in Fig. P3.29, calculate (a) i_g and (b) the power dissipated in the 30 Ω resistor.

PSPICE MULTISIM

Figure P3.29



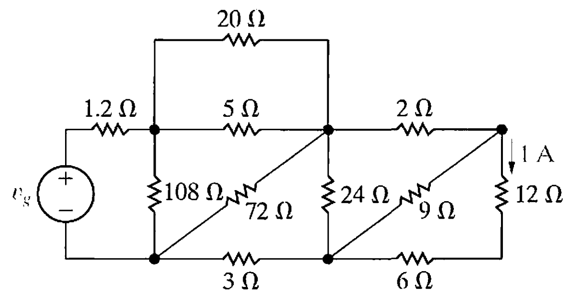
3.30 The current in the 12 Ω resistor in the circuit in Fig. P3.30 is 1 A, as shown.

PSPICE MULTISIM

a) Find v_g.

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

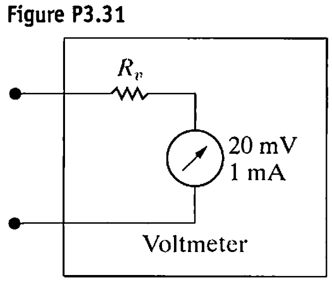
Figure P3.30



Section 3.5

3.31 A d'Arsonval voltmeter is shown in Fig. P3.31. Find the value of R_v for each of the following full-scale readings: (a) 50 V, (b) 5 V, (c) 250 mV, and (d) 25 mV.

Figure P3.31



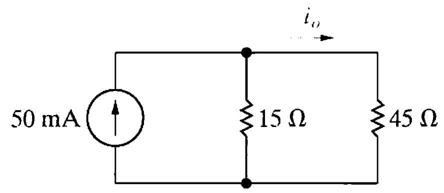
3.32 Suppose the d'Arsonval voltmeter described in Problem 3.31 is used to measure the voltage across the 45 Ω resistor in Fig. P3.32.

a) What will the voltmeter read?

b) Find the percentage of error in the voltmeter reading if

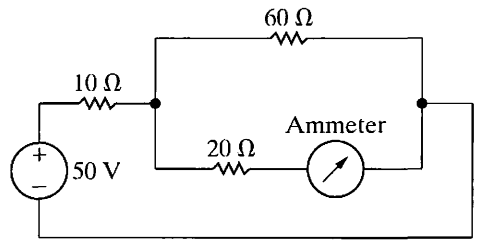
$$\% \text{ error} = \left(\frac{\text{measured value}}{\text{true value}} - 1\right) \times 100.$$

Figure P3.32



3.33 The ammeter in the circuit in Fig. P3.33 has a resistance of 0.1 Ω. Using the definition of the percentage error in a meter reading found in Problem 3.32, what is the percentage of error in the reading of this ammeter?

Figure P3.33



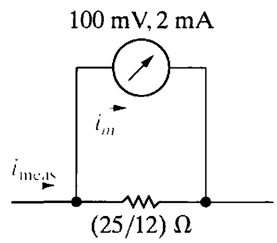
3.34 The ammeter described in Problem 3.33 is used to measure the current i_o in the circuit in Fig. P3.32. What is the percentage of error in the measured value?

3.35 a) Show for the ammeter circuit in Fig. P3.35 that the current in the d'Arsonval movement is always 1/25th of the current being measured.

b) What would the fraction be if the 100 mV, 2 mA movement were used in a 5 A ammeter?

c) Would you expect a uniform scale on a dc d'Arsonval ammeter?

Figure P3.35



3.36 A shunt resistor and a 50 mV, 1 mA d'Arsonval movement are used to build a 5 A ammeter. A resistance of 20 mΩ is placed across the terminals of the ammeter. What is the new full-scale range of the ammeter?

3.37 PSPICE MULTISIM The elements in the circuit in Fig. 2.24 have the following values: $R_1 = 20$ kΩ, $R_2 = 80$ kΩ, $R_C = 0.82$ kΩ, $R_E = 0.2$ kΩ, $V_{CC} = 7.5$ V, $V_0 = 0.6$ V, and $\beta = 39$.

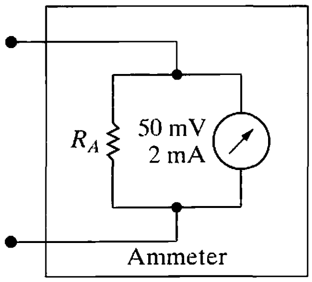
a) Calculate the value of i_B in microamperes.

b) Assume that a digital multimeter, when used as a dc ammeter, has a resistance of 1 kΩ. If the meter is inserted between terminals b and 2 to measure the current i_B, what will the meter read?

c) Using the calculated value of i_B in (a) as the correct value, what is the percentage of error in the measurement?

3.38 DESIGN PROBLEM A d'Arsonval ammeter is shown in Fig. P3.38. Design a set of d'Arsonval ammeters to read the following full-scale current readings: (a) 10 A, (b) 1 A, (c) 50 mA, and (d) 2 mA. Specify the shunt resistor for each ammeter.

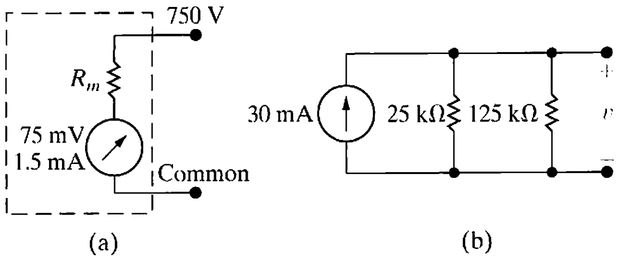
Figure P3.38



3.39 DESIGN PROBLEM A d'Arsonval movement is rated at 1 mA and 50 mV. Assume 0.5 W precision resistors are available to use as shunts. What is the largest full-scale-reading ammeter that can be designed using a single resistor? Explain.

3.40 The voltmeter shown in Fig. P3.40(a) has a full-scale reading of 750 V. The meter movement is rated 75 mV and 1.5 mA. What is the percentage of error in the meter reading if it is used to measure the voltage v in the circuit of Fig. P3.40(b)?

Figure P3.40



3.41 You have been told that the dc voltage of a power supply is about 350 V. When you go to the instrument room to get a dc voltmeter to measure the power supply voltage, you find that there are only two dc voltmeters available. One voltmeter is rated 300 V full scale and has a sensitivity of 900 Ω/V. The other voltmeter is rated 150 V full scale and has a sensitivity of 1200 Ω/V. (*Hint:* you can find the effective resistance of a voltmeter by multiplying its rated full-scale voltage and its sensitivity.)

a) How can you use the two voltmeters to check the power supply voltage?

b) What is the maximum voltage that can be measured?

c) If the power supply voltage is 320 V, what will each voltmeter read?

3.42 Assume that in addition to the two voltmeters described in Problem 3.41, a 50 kΩ precision resistor is also available. The 50 kΩ resistor is connected in series with the series-connected voltmeters. This circuit is then connected across the terminals of the power supply. The reading on the 300 V meter is 205.2 V and the reading on the 150 V meter is 136.8 V. What is the voltage of the power supply?

3.43 The voltage-divider circuit shown in Fig. P3.43 is designed so that the no-load output voltage is 7/9ths of the input voltage. A d'Arsonval voltmeter having a sensitivity of 100 Ω/V and a full-scale rating of 200 V is used to check the operation of the circuit.

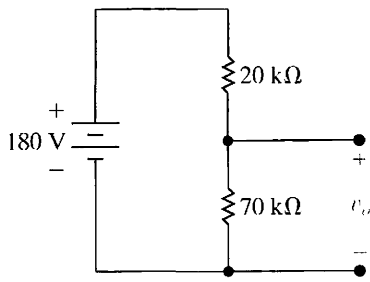
a) What will the voltmeter read if it is placed across the 180 V source?

b) What will the voltmeter read if it is placed across the 70 kΩ resistor?

c) What will the voltmeter read if it is placed across the 20 kΩ resistor?

d) Will the voltmeter readings obtained in parts (b) and (c) add to the reading recorded in part (a)? Explain why or why not.

Figure P3.43

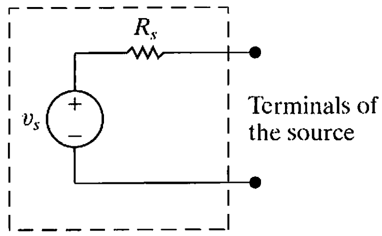


3.44 The circuit model of a dc voltage source is shown in Fig. P3.44. The following voltage measurements are made at the terminals of the source: (1) With the terminals of the source open, the voltage is measured at 50 mV, and (2) with a 15 MΩ resistor connected to the terminals, the voltage is measured at 48.75 mV. All measurements are made with a digital voltmeter that has a meter resistance of 10 MΩ.

a) What is the internal voltage of the source (v_s) in millivolts?

b) What is the internal resistance of the source (R_s) in kilo-ohms?

Figure P3.44

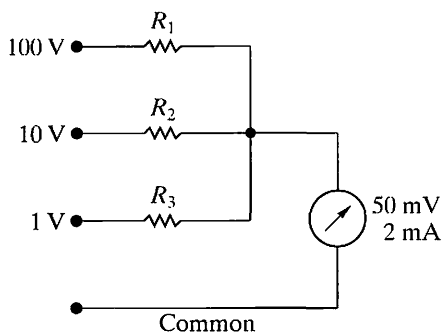


3.45 DESIGN PROBLEM Assume in designing the multirange voltmeter shown in Fig. P3.45 that you ignore the resistance of the meter movement.

a) Specify the values of R_1, R_2, and R_3.

b) For each of the three ranges, calculate the percentage of error that this design strategy produces.

Figure P3.45



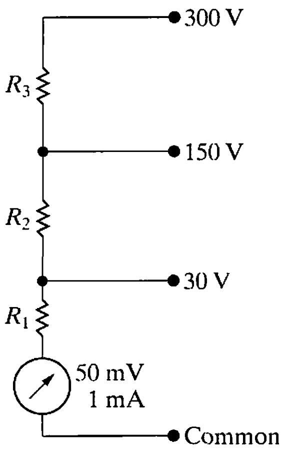
3.46 DESIGN PROBLEM Design a d'Arsonval voltmeter that will have the three voltage ranges shown in Fig. P3.46.

a) Specify the values of R_1, R_2, and R_3.

b) Assume that a 750 kΩ resistor is connected between the 150 V terminal and the common terminal. The voltmeter is then connected to an unknown voltage using the common terminal and the 300 V terminal. The voltmeter reads 288 V. What is the unknown voltage?

c) What is the maximum voltage the voltmeter in (b) can measure?

Figure P3.46

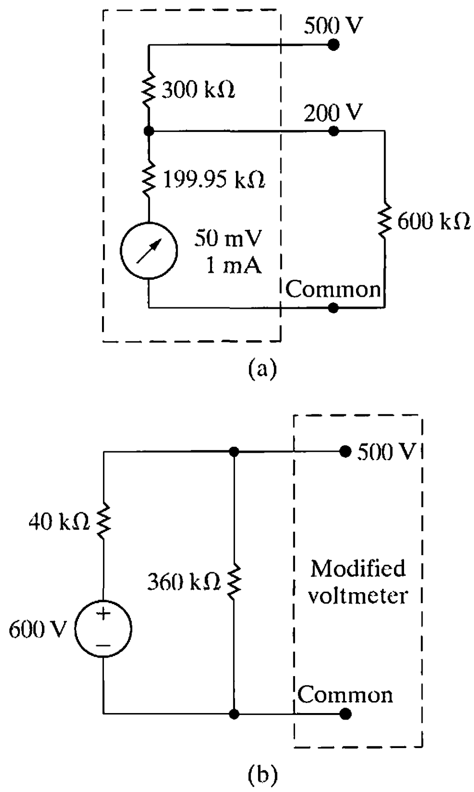


3.47 A 600 kΩ resistor is connected from the 200 V terminal to the common terminal of a dual-scale voltmeter, as shown in Fig. P3.47(a). This modified voltmeter is then used to measure the voltage across the 360 kΩ resistor in the circuit in Fig. P3.47(b).

a) What is the reading on the 500 V scale of the meter?

b) What is the percentage of error in the measured voltage?

Figure P3.47

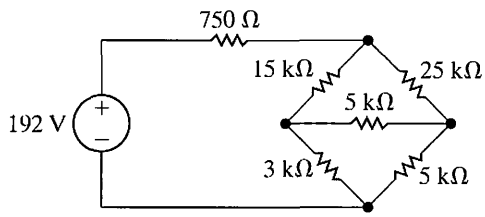


Sections 3.6–3.7

3.48 Assume the ideal voltage source in Fig. 3.26 is replaced by an ideal current source. Show that Eq. 3.33 is still valid.

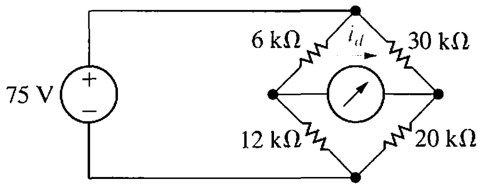
3.49 PSPICE MULTISIM Find the power dissipated in the 3 kΩ resistor in the circuit in Fig. P3.49.

Figure P3.49



3.50 PSPICE MULTISIM Find the detector current i_d in the unbalanced bridge in Fig. P3.50 if the voltage drop across the detector is negligible.

Figure P3.50



3.51 PSPICE MULTISIM The bridge circuit shown in Fig. 3.26 is energized from a 24 V dc source. The bridge is balanced when $R_1 = 500\ \Omega$, $R_2 = 1000\ \Omega$, and $R_3 = 750\ \Omega$.

a) What is the value of R_x?

b) How much current (in milliamperes) does the dc source supply?

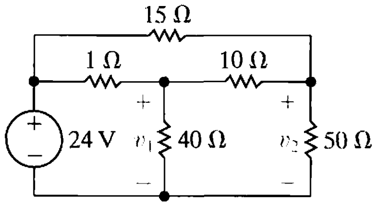
c) Which resistor in the circuit absorbs the most power? How much power does it absorb?

d) Which resistor absorbs the least power? How much power does it absorb?

3.52 PSPICE MULTISIM In the Wheatstone bridge circuit shown in Fig. 3.26, the ratio R_2/R_1 can be set to the following values: 0.001, 0.01, 0.1, 1, 10, 100, and 1000. The resistor R_3 can be varied from 1 to 11,110 Ω, in increments of 1 Ω. An unknown resistor is known to lie between 4 and 5 Ω. What should be the setting of the R_2/R_1 ratio so that the unknown resistor can be measured to four significant figures?

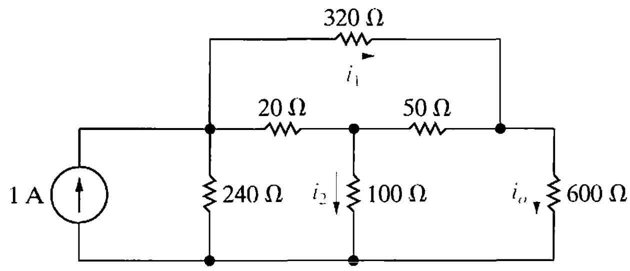
3.53 PSPICE MULTISIM Use a Δ-to-Y transformation to find the voltages v_1 and v_2 in the circuit in Fig. P3.53.

Figure P3.53



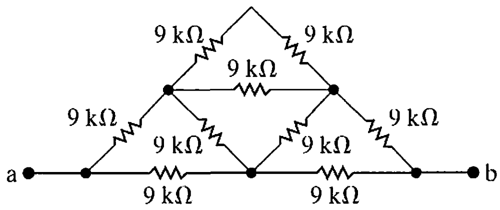
3.54 PSPICE MULTISIM Use a Y-to-Δ transformation to find (a) i_o; (b) i_1; (c) i_2; and (d) the power delivered by the ideal current source in the circuit in Fig. P3.54.

Figure P3.54



3.55 PSPICE MULTISIM Find R_{ab} in the circuit in Fig. P3.55.

Figure P3.55

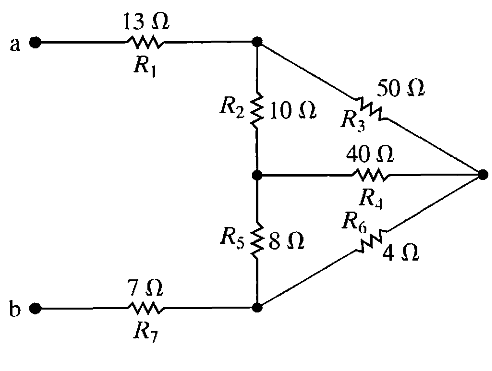


3.56 PSPICE MULTISIM a) Find the equivalent resistance R_{ab} in the circuit in Fig. P3.56 by using a Δ-to-Y transformation involving the resistors R_2, R_3, and R_4.

b) Repeat (a) using a Y-to-Δ transformation involving resistors R_2, R_4, and R_5.

c) Give two additional Δ-to-Y or Y-to-Δ transformations that could be used to find R_{ab}.

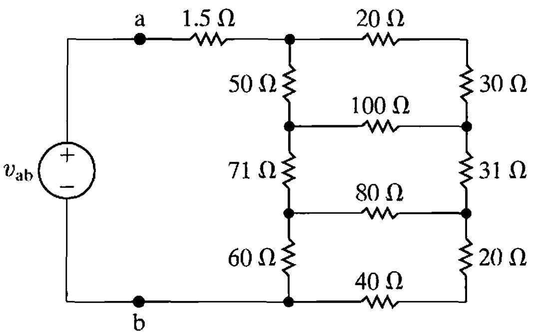
Figure P3.56



3.57 PSPICE MULTISIM a) Find the resistance seen by the ideal voltage source in the circuit in Fig. P3.57.

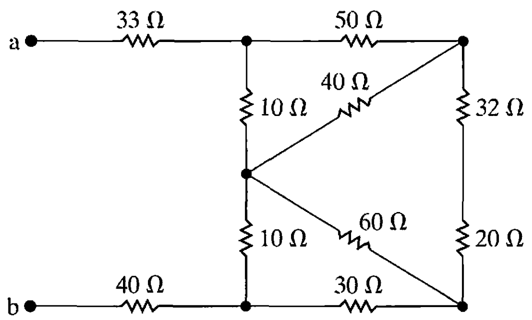
b) If v_{ab} equals 400 V, how much power is dissipated in the 31 Ω resistor?

Figure P3.57



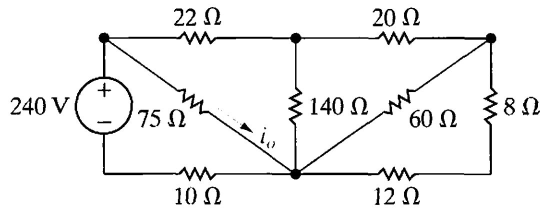
3.58 PSPICE MULTISIM Find the equivalent resistance R_{ab} in the circuit in Fig. P3.58.

Figure P3.58



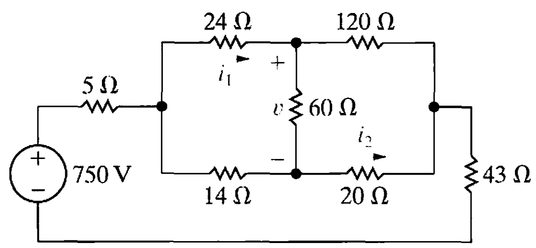
3.59 PSPICE MULTISIM Find i_o and the power dissipated in the 140 Ω resistor in the circuit in Fig. P3.59.

Figure P3.59



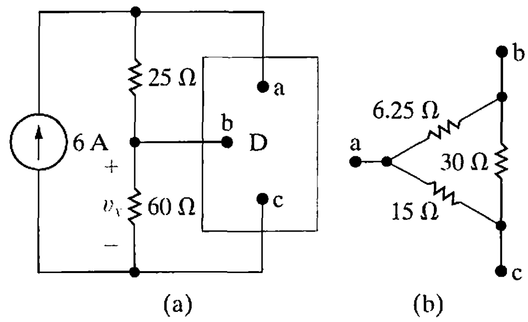
3.60 PSPICE MULTISIM For the circuit shown in Fig. P3.60, find (a) i_1, (b) v, (c) i_2, and (d) the power supplied by the voltage source.

Figure P3.60



3.61 PSPICE MULTISIM In the circuit in Fig. P3.61(a) the device labeled D represents a component that has the equivalent circuit shown in Fig. P3.61(b). The labels on the terminals of D show how the device is connected to the circuit. Find v_x and the power absorbed by the device.

Figure P3.61



3.62 Derive Eqs. 3.44–3.49 from Eqs. 3.41–3.43. The following two hints should help you get started in the right direction:

1) To find R_1 as a function of R_a, R_b, and R_c, first subtract Eq. 3.42 from Eq. 3.43 and then add this result to Eq. 3.41. Use similar manipulations to find R_2 and R_3 as functions of R_a, R_b, and R_c.
2) To find R_b as a function of R_1, R_2, and R_3, take advantage of the derivations obtained by hint (1), namely, Eqs. 3.44–3.46. Note that these equations can be divided to obtain

$$\frac{R_2}{R_3} = \frac{R_c}{R_b}, \quad \text{or} \quad R_c = \frac{R_2}{R_3}R_b,$$

and

$$\frac{R_1}{R_2} = \frac{R_b}{R_a}, \quad \text{or} \quad R_a = \frac{R_2}{R_1}R_b.$$

Now use these ratios in Eq. 3.43 to eliminate R_a and R_c. Use similar manipulations to find R_a and R_c as functions of R_1, R_2, and R_3.

3.63 Show that the expressions for Δ conductances as functions of the three Y conductances are

$$G_a = \frac{G_2G_3}{G_1 + G_2 + G_3},$$

$$G_b = \frac{G_1G_3}{G_1 + G_2 + G_3},$$

$$G_c = \frac{G_1G_2}{G_1 + G_2 + G_3},$$

where

$$G_a = \frac{1}{R_a}, \quad G_1 = \frac{1}{R_1}, \quad \text{etc.}$$

Sections 3.1–3.7

3.64 DESIGN PROBLEM Resistor networks are sometimes used as volume-control circuits. In this application, they are referred to as *resistance attenuators* or *pads*. A typical fixed-attenuator pad is shown in Fig. P3.64. In designing an attenuation pad, the circuit designer will select the values of R_1 and R_2 so that the ratio of v_o/v_i and the resistance seen by the input voltage source R_{ab} both have a specified value.

a) Show that if $R_{ab} = R_L$, then

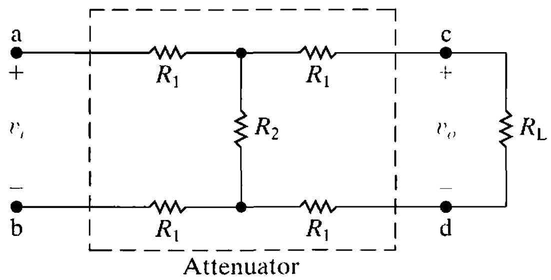
$$R_L^2 = 4R_1(R_1 + R_2),$$

$$\frac{v_o}{v_i} = \frac{R_2}{2R_1 + R_2 + R_L}.$$

b) Select the values of R_1 and R_2 so that $R_{ab} = R_L = 600\ \Omega$ and $v_o/v_i = 0.6$.

c) Choose values from Appendix H that are closest to R_1 and R_2 from part (b). Calculate the percent error in the resulting values for R_{ab} and v_0/v_1 if these new resistor values are used.

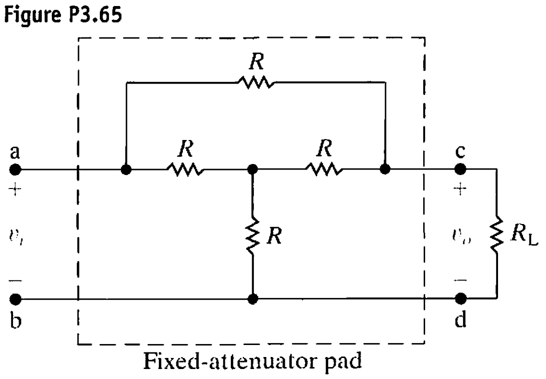
Figure P3.64



3.65 DESIGN PROBLEM a) The fixed-attenuator pad shown in Fig. P3.65 is called a *bridged tee*. Use a Y-to-Δ transformation to show that $R_{ab} = R_L$ if $R = R_L$.

b) Show that when $R = R_L$, the voltage ratio v_o/v_i equals 0.50.

Figure P3.65



3.66 DESIGN PROBLEM The design equations for the bridged-tee attenuator circuit in Fig. P3.66 are

$$R_2 = \frac{2RR_L^2}{3R^2 - R_L^2},$$

$$\frac{v_o}{v_i} = \frac{3R - R_L}{3R + R_L},$$

when R_2 has the value just given.

a) Design a fixed attenuator so that $v_i = 3.5v_o$ when $R_L = 300\ \Omega$.

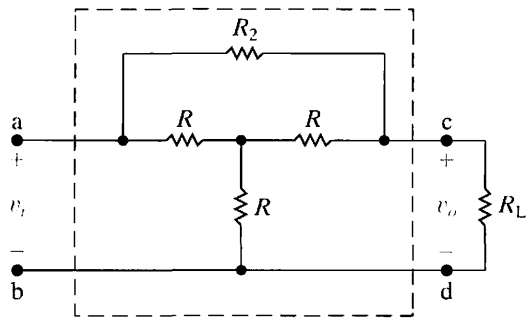
b) Assume the voltage applied to the input of the pad designed in (a) is 42 V. Which resistor in the pad dissipates the most power?

c) How much power is dissipated in the resistor in part (b)?

d) Which resistor in the pad dissipates the least power?

e) How much power is dissipated in the resistor in part (d)?

Figure P3.66



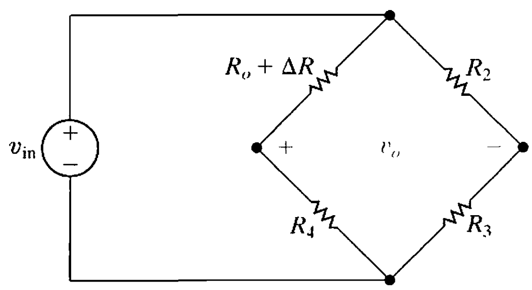
3.67 PSPICE MULTISIM a) For the circuit shown in Fig. P3.67 the bridge is balanced when $\Delta R = 0$. Show that if $\Delta R \ll R_o$ the bridge output voltage is approximately

$$v_o \approx \frac{-\Delta R R_4}{(R_o + R_4)^2} v_{in}$$

b) Given $R_2 = 1\ \text{k}\Omega$, $R_3 = 500\ \Omega$, $R_4 = 5\ \text{k}\Omega$, and $v_{in} = 6$ V, what is the approximate bridge output voltage if ΔR is 3% of R_o?

c) Find the actual value of v_o in part (b).

Figure P3.67



3.68 a) If percent error is defined as

$$\% \text{ error} = \left[\frac{\text{approximate value}}{\text{true value}} - 1\right] \times 100$$

show that the percent error in the approximation of v_o in Problem 3.67 is

$$\% \text{ error} = \frac{-(\Delta R)R_3}{(R_2 + R_3)R_4} \times 100.$$

b) Calculate the percent error in v_o, using the values in Problem 3.67(b).

3.69 DESIGN PROBLEM Assume the error in v_o in the bridge circuit in Fig. P3.67 is not to exceed 0.5%. What is the largest percent change in R_o that can be tolerated?

3.70 PRACTICAL PERSPECTIVE a) Derive Eq. 3.65.
b) Derive Eq. 3.68.

3.71 PRACTICAL PERSPECTIVE Derive Eq. 3.70.

3.72 Suppose the grid structure in Fig. 3.36 is 1 m wide and the vertical displacement of the five horizontal grid lines is 0.025 m. Specify the numerical values of $R_1 - R_5$ and $R_a - R_d$ to achieve a uniform power dissipation of 120 W/m, using a 12 V power supply. (*Hint:* Calculate σ first, then R_3, R_1, R_a, R_b, and R_2 in that order.)

3.73 PRACTICAL PERSPECTIVE PSPICE MULTISIM Check the solution to Problem 3.72 by showing that the total power dissipated equals the power developed by the 12 V source.

3.74 PRACTICAL PERSPECTIVE DESIGN PROBLEM PSPICE MULTISIM a) Design a defroster grid in Fig. 3.36 having five horizontal conductors to meet the following specifications: The grid is to be 1.5 m wide, the vertical separation between conductors is to be 0.03 m, and the power dissipation is to be 200 W/m when the supply voltage is 12 V.
b) Check your solution and make sure it meets the design specifications.