Fundamentals of ELECTRIC CIRCUITS

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PREFACE

Features

In spite of the numerous textbooks on circuit analysis available in the market, students often find the course difficult to learn. The main objective of this book is to present circuit analysis in a manner that is clearer, more interesting, and easier to understand than earlier texts. This objective is achieved in the following ways:

- A course in circuit analysis is perhaps the first exposure students have to electrical engineering. We have included several features to help students feel at home with the subject. Each chapter opens with either a historical profile of some electrical engineering pioneers to be mentioned in the chapter or a career discussion on a subdiscipline of electrical engineering. An introduction links the chapter with the previous chapters and states the chapter's objectives. The chapter ends with a summary of the key points and formulas.
- All principles are presented in a lucid, logical, step-by-step manner. We try to avoid wordiness and superfluous detail that could hide concepts and impede understanding the material.
- Important formulas are boxed as a means of helping students sort what is essential from what is not; and to ensure that students clearly get the gist of the matter, key terms are defined and highlighted.
- Marginal notes are used as a pedagogical aid. They serve multiple uses—hints, cross-references, more exposition, warnings, reminders, common mistakes, and problem-solving insights.
- Thoroughly worked examples are liberally given at the end of every section. The examples are regarded as part of the text and are explained clearly, without asking the reader to fill in missing steps. Thoroughly worked examples give students a good understanding of the solution and the confidence to solve problems themselves. Some of the problems are solved in two or three ways to facilitate an understanding and comparison of different approaches.
- To give students practice opportunity, each illustrative example is immediately followed by a practice problem with the answer. The students can follow the example step-by-step to solve the practice problem without flipping pages or searching the end of the book for answers. The practice problem is also intended to test students' understanding of the preceding example. It will reinforce their grasp of the material before moving to the next section.
- In recognition of ABET's requirement on integrating computer tools, the use of *PSpice* is encouraged in a student-friendly manner. Since the Windows version of *PSpice* is becoming popular, it is used instead of the MS-DOS version. *PSpice* is covered early so that students can use it throughout the text. Appendix D serves as a tutorial on *PSpice for Windows.*
- The operational amplifier (op amp) as a basic element is introduced early in the text.
- To ease the transition between the circuit course and signals/systems courses, Fourier and Laplace transforms are covered lucidly and thoroughly.
- The last section in each chapter is devoted to applications of the concepts covered in the chapter. Each chapter has at least one or two practical problems or devices. This helps students apply the concepts to real-life situations.
- Ten multiple-choice review questions are provided at the end of each chapter, with answers. These are intended to cover the little "tricks" that the examples and end-of-chapter problems may not cover. They serve as a self-test device and help students determine how well they have mastered the chapter.

Organization

This book was written for a two-semester or three-semester course in linear circuit analysis. The book may also be used for a one-semester course by a proper selection of chapters and sections. It is broadly divided into three parts.

- Part 1, consisting of Chapters 1 to 8, is devoted to dc circuits. It covers the fundamental laws and theorems, circuit techniques, passive and active elements.
- Part 2, consisting of Chapters 9 to 14, deals with ac circuits. It introduces phasors, sinusoidal steady-state analysis, ac power, rms values, three-phase systems, and frequency response.
- Part 3, consisting of Chapters 15 to 18, is devoted to advanced techniques for network analysis. It provides a solid introduction to the Laplace transform, Fourier series, the Fourier transform, and two-port network analysis.

The material in three parts is more than sufficient for a two-semester course, so that the instructor must select which chapters/sections to cover. Sections marked with the dagger sign (†) may be skipped, explained briefly, or assigned as homework. They can be omitted without loss of continuity. Each chapter has plenty of problems, grouped according to the sections of the related material, and so diverse that the instructor can choose some as examples and assign some as homework. More difficult problems are marked with a star (*). Comprehensive problems appear last; they are mostly applications problems that require multiple skills from that particular chapter.

The book is as self-contained as possible. At the end of the book are some appendixes that review solutions of linear equations, complex numbers, mathematical formulas, a tutorial on *PSpice for Windows*, and answers to odd-numbered problems. Answers to all the problems are in the solutions manual, which is available from the publisher.

Prerequisites

As with most introductory circuit courses, the main prerequisites are physics and calculus. Although familiarity with complex numbers is helpful in the later part of the book, it is not required.

Supplements

Solutions Manual—an Instructor's Solutions Manual is available to instructors who adopt the text. It contains complete solutions to all the end-of-chapter problems.

Transparency Masters—over 200 important figures are available as transparency masters for use as overheads.

Student CD-ROM—100 circuit files from the book are presented as *Electronics Workbench* (EWB) files; 15–20 of these files are accessible using the free demo of *Electronics Workbench*. The students are able to experiment with the files. For those who wish to fully unlock all 100 circuit files, EWB's full version may be purchased from Interactive Image Technologies for approximately $79.00. The CD-ROM also contains a selection of problem-solving, analysis and design tutorials, designed to further support important concepts in the text.

Problem-Solving Workbook—a paperback workbook is for sale to students who wish to practice their problem solving techniques. The workbook contains a discussion of problem solving strategies and 150 additional problems with complete solutions provided.

Online Learning Center (OLC)—the Web site for the book will serve as an online learning center for students as a useful resource for instructors. The OLC will provide access to:

- 300 test questions—for instructors only
- Downloadable figures for overhead presentations—for instructors only
- Solutions manual—for instructors only
- Web links to useful sites
- Sample pages from the Problem-Solving Workbook
- PageOut Lite—a service provided to adopters who want to create their own Web site. In just a few minutes, instructors can change the course syllabus into a Web site using PageOut Lite.

The URL for the web site is www.mhhe.com.alexander. Although the textbook is meant to be self-explanatory and act as a tutor for the student, the personal contact involved in teaching is not to be forgotten. The book and supplements are intended to supply the instructor with all the pedagogical tools necessary to effectively present the material.

ACKNOWLEDGMENTS

We wish to take the opportunity to thank the staff of McGraw-Hill for their commitment and hard work: Lynn Cox, Senior Editor; Scott Isenberg, Senior Sponsoring Editor; Kelley Butcher, Senior Developmental Editor; Betsy Jones, Executive Editor; Catherine Fields, Sponsoring Editor; Kimberly Hooker, Project Manager; and Michelle Flomenhoft, Editorial Assistant. They got numerous reviews, kept the book on track, and helped in many ways. We really appreciate their inputs. We are greatly in debt to Richard Mickey for taking the pain ofchecking and correcting the entire manuscript. We wish to record our thanks to Steven Durbin at Florida State University and Daniel Moore at Rose Hulman Institute of Technology for serving as accuracy checkers of examples, practice problems, and end-of-chapter problems. We also wish to thank the following reviewers for their constructive criticisms and helpful comments.

Promod Vohra, *Northern Illinois University*

Moe Wasserman, *Boston University*

Robert J. Krueger, *University of Wisconsin Milwaukee*

John O'Malley, *University of Florida*

Aniruddha Datta, *Texas A&M University*
John Bay, *Virginia Tech*
Wilhelm Eggimann, *Worcester Polytechnic Institute*
A. B. Bonds, *Vanderbilt University*
Tommy Williamson, *University of Dayton*
Cynthia Finelli, *Kettering University*
John A. Fleming, *Texas A&M University*
Roger Conant, *University of Illinois at Chicago*
Daniel J. Moore, *Rose-Hulman Institute of Technology*
Ralph A. Kinney, *Louisiana State University*
Cecilia Townsend, *North Carolina State University*
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Robin N. Strickland, *University of Arizona*
David N. Cowling, *Louisiana Tech University*
Jean-Pierre R. Bayard, *California State University*
Jack C. Lee, *University of Texas at Austin*
E. L. Gerber, *Drexel University*

The first author wishes to express his appreciation to his department chair, Dr. Dennis Irwin, for his outstanding support. In addition, he is extremely grateful to Suzanne Vazzano for her help with the solutions manual.

The second author is indebted to Dr. Cynthia Hirtzel, the former dean of the college of engineering at Temple University, and Drs.. Brian Butz, Richard Klafter, and John Helferty, his departmental chairpersons at different periods, for their encouragement while working on the manuscript. The secretarial support provided by Michelle Ayers and Carol Dahlberg is gratefully appreciated. Special thanks are due to Ann Sadiku, Mario Valenti, Raymond Garcia, Leke and Tolu Efuwape, and Ope Ola for helping in various ways. Finally, we owe the greatest debt to our wives, Paulette and Chris, without whose constant support and cooperation this project would have been impossible.

Please address comments and corrections to the publisher.

C. K. Alexander and M. N. O. Sadiku

Now we can solve for v_1.

$$8\left[\frac{v_1-5}{2}+\frac{v_1-0}{8}+\frac{v_1+3}{4}\right]=0$$

leads to $(4v_1-20)+(v_1)+(2v_1+6)=0$

$$7v_1=+14, \qquad v_1=+2\text{ V}, \qquad i_{8\Omega}=\frac{v_1}{8}=\frac{2}{8}=\underline{0.25\text{ A}}$$

5. ***Evaluate** the solution and check for accuracy.* We can now use Kirchoff's voltage law to check the results.

$$i_1=\frac{v_1-5}{2}=\frac{2-5}{2}=-\frac{3}{2}=-1.5\text{ A}$$

$$i_2=i_{8\Omega}=0.25\text{ A}$$

$$i_3=\frac{v_1+3}{4}=\frac{2+3}{4}=\frac{5}{4}=1.25\text{ A}$$

$$i_1+i_2+i_3=\underline{\mathbf{-1.5+0.25+1.25=0}} \qquad \text{(Checks.)}$$

Applying KVL to loop 1,

$$\begin{aligned}-5+v_1+v_2&=-5+(-i_1\times 2)+(i_2\times 8)\\&=-5+(-(-1.5)2)+(0.25\times 8)\\&=\underline{\mathbf{-5+3+2=0}} \qquad \text{(Checks.)}\end{aligned}$$

Applying KVL to loop 2,

$$\begin{aligned}-v_2+v_3-3&=-(i_2\times 8)+(i_3\times 4)-3\\&=-(0.25\times 8)+(1.25\times 4)-3\\&=\underline{\mathbf{-2+5-3=0}} \qquad \text{(Checks.)}\end{aligned}$$

So we now have a very high degree of confidence in the accuracy of our answer.

6. Has the problem been solved **Satisfactorily**? If so, present the solution; if not, then return to step 3 and continue through the process again. This problem has been solved satisfactorily.

The current through the 8-ohm resistor is 0.25 amp flowing down through the 8-ohm resistor.

1.9 SUMMARY

1. An electric circuit consists of electrical elements connected together.
2. The International System of Units (SI) is the international measurement language, which enables engineers to communicate their results. From the six principal units, the units of other physical quantities can be derived.
3. Current is the rate of charge flow.

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

4. Voltage is the energy required to move 1 C of charge through an element.

$$v = \frac{dw}{dq}$$

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

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

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

REVIEW QUESTIONS

1.1 One millivolt is one millionth of a volt.
(a) True (b) False

1.2 The prefix *micro* stands for:
(a) 10^6 (b) 10^3 (c) 10^{-3} (d) 10^{-6}

1.3 The voltage 2,000,000 V can be expressed in powers of 10 as:
(a) 2 mV (b) 2 kV (c) 2 MV (d) 2 GV

1.4 A charge of 2 C flowing past a given point each second is a current of 2 A.
(a) True (b) False

1.5 A 4-A current charging a dielectric material will accumulate a charge of 24 C after 6 s.
(a) True (b) False

1.6 The unit of current is:
(a) Coulomb (b) Ampere
(c) Volt (d) Joule

1.7 Voltage is measured in:
(a) Watts (b) Amperes
(c) Volts (d) Joules per second

1.8 The voltage across a 1.1 kW toaster that produces a current of 10 A is:
(a) 11 kV (b) 1100 V (c) 110 V (d) 11 V

1.9 Which of these is not an electrical quantity?
(a) charge (b) time (c) voltage
(d) current (e) power

1.10 The dependent source in Fig. 1.19 is:
(a) voltage-controlled current source
(b) voltage-controlled voltage source
(c) current-controlled voltage source
(d) current-controlled current source

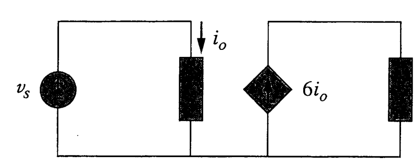


Figure 1.19 For Review Question 1.10.

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

PROBLEMS

Section 1.3 Charge and Current

1.1 How many coulombs are represented by these amounts of electrons:
(a) 6.482×10^{17} (b) 1.24×10^{18}
(c) 2.46×10^{19} (d) 1.628×10^{20}

1.2 Find the current flowing through an element if the charge flow is given by:
(a) $q(t) = (t + 2)$ mC
(b) $q(t) = (5t^2 + 4t - 3)$ C
(c) $q(t) = 10e^{-4t}$ pC
(d) $q(t) = 20 \cos 50\pi t$ nC
(e) $q(t) = 5e^{-2t} \sin 100t\ \mu$C

1.3 Find the charge $q(t)$ flowing through a device if the current is:
(a) $i(t) = 3$ A, $q(0) = 1$ C
(b) $i(t) = (2t + 5)$ mA, $q(0) = 0$
(c) $i(t) = 20 \cos(10t + \pi/6)\ \mu$A, $q(0) = 2\ \mu$C
(d) $i(t) = 10e^{-30t} \sin 40t$ A, $q(0) = 0$

1.4 The current flowing through a device is $i(t) = 5 \sin 6\pi t$ A. Calculate the total charge flow through the device from $t = 0$ to $t = 10$ ms.

1.5 Determine the total charge flowing into an element for $0 < t < 2$ s when the current entering its positive terminal is $i(t) = e^{-2t}$ mA.

1.6 The charge entering a certain element is shown in Fig. 1.20. Find the current at:
(a) $t = 1$ ms (b) $t = 6$ ms (c) $t = 10$ ms

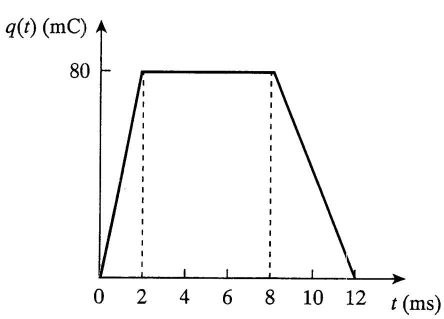


Figure 1.20 For Prob. 1.6.

1.7 The charge flowing in a wire is plotted in Fig. 1.21. Sketch the corresponding current.

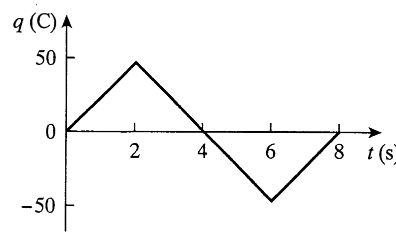


Figure 1.21 For Prob. 1.7.

1.8 The current flowing past a point in a device is shown in Fig. 1.22. Calculate the total charge through the point.

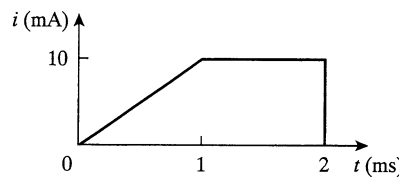


Figure 1.22 For Prob. 1.8.

1.9 The current through an element is shown in Fig. 1.23. Determine the total charge that passed through the element at:
(a) $t = 1$ s (b) $t = 3$ s (c) $t = 5$ s

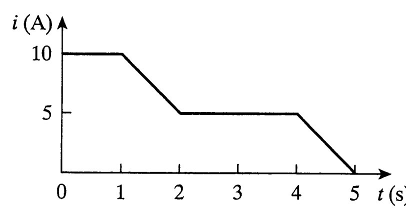


Figure 1.23 For Prob. 1.9.

Sections 1.4 and 1.5 Voltage, Power, and Energy

1.10 A certain electrical element draws the current $i(t) = 10 \cos 4t$ A at a voltage $v(t) = 120 \cos 4t$ V. Find the energy absorbed by the element in 2 s.

1.11 The voltage v across a device and the current i through it are

$$v(t) = 5 \cos 2t \text{ V}, \qquad i(t) = 10(1 - e^{-0.5t}) \text{ A}$$

Calculate:
(a) the total charge in the device at $t = 1$ s
(b) the power consumed by the device at $t = 1$ s.

1.12 The current entering the positive terminal of a device is $i(t) = 3e^{-2t}$ A and the voltage across the device is $v(t) = 5\,di/dt$ V.

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

(b) Calculate the power absorbed.

(c) Determine the energy absorbed in 3 s.

1.13 Figure 1.24 shows the current through and the voltage across a device. Find the total energy absorbed by the device for the period of $0 < t < 4$ s.

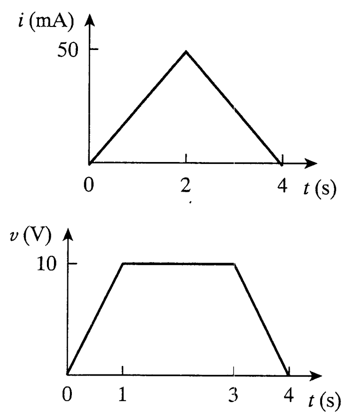


Figure 1.24 For Prob. 1.13.

Section 1.6 Circuit Elements

1.14 Figure 1.25 shows a circuit with five elements. If $p_1 = -205$ W, $p_2 = 60$ W, $p_4 = 45$ W, $p_5 = 30$ W, calculate the power p_3 received or delivered by element 3.

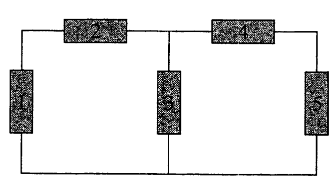


Figure 1.25 For Prob. 1.14.

1.15 Find the power absorbed by each of the elements in Fig. 1.26.

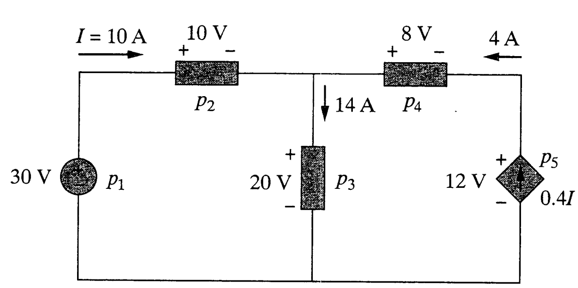


Figure 1.26 For Prob. 1.15.

1.16 Determine I_o in the circuit of Fig. 1.27.

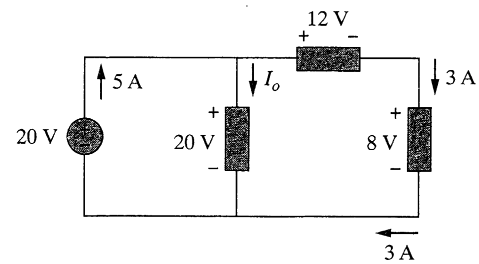


Figure 1.27 For Prob. 1.16.

1.17 Find V_o in the circuit of Fig. 1.28.

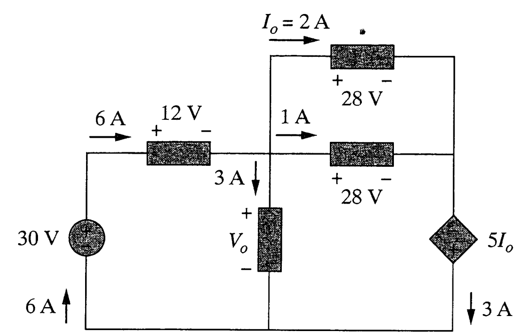


Figure 1.28 For Prob. 1.17.

Section 1.7 Applications

1.18 It takes eight photons to strike the surface of a photodetector in order to emit one electron. If 4×10^{11} photons/second strike the surface of the photodetector, calculate the amount of current flow.

1.19 Find the power rating of the following electrical appliances in your household:

(a) Lightbulb (b) Radio set
(c) TV set (d) Refrigerator
(e) Personal computer (f) PC printer
(g) Microwave oven (h) Blender

1.20 A 1.5-kW electric heater is connected to a 120-V source.

(a) How much current does the heater draw?

(b) If the heater is on for 45 minutes, how much energy is consumed in kilowatt-hours (kWh)?

(c) Calculate the cost of operating the heater for 45 minutes if energy costs 10 cents/kWh.

1.21 A 1.2-kW toaster takes roughly 4 minutes to heat four slices of bread. Find the cost of operating the toaster once per day for 1 month (30 days). Assume energy costs 9 cents/kWh.

1.22 A flashlight battery has a rating of 0.8 ampere-hours (Ah) and a lifetime of 10 hours.
(a) How much current can it deliver?
(b) How much power can it give if its terminal voltage is 6 V?
(c) How much energy is stored in the battery in kWh?

1.23 A constant current of 3 A for 4 hours is required to charge an automotive battery. If the terminal voltage is $10 + t/2$ V, where t is in hours,
(a) how much charge is transported as a result of the charging?
(b) how much energy is expended?
(c) how much does the charging cost? Assume electricity costs 9 cents/kWh.

1.24 A 30-W incandescent lamp is connected to a 120-V source and is left burning continuously in an otherwise dark staircase. Determine:
(a) the current through the lamp,
(b) the cost of operating the light for one non-leap year if electricity costs 12 cents per kWh.

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

Burner 1: 20 minutes Burner 2: 40 minutes
Burner 3: 15 minutes Burner 4: 45 minutes
Oven: 30 minutes

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

1.26 PECO (the electric power company in Philadelphia) charged a consumer $34.24 one month for using 215 kWh. If the basic service charge is $5.10, how much did PECO charge per kWh?

COMPREHENSIVE PROBLEMS

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

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

1.29 The power consumption for a certain household for a day is shown in Fig. 1.29. Determine:
(a) the total energy consumed in kWh
(b) the average power per hour.

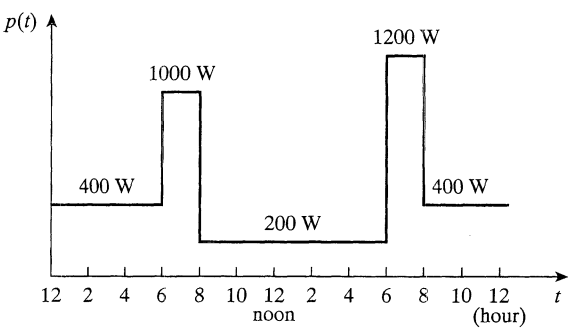


Figure 1.29 For Prob. 1.29.

1.30 The graph in Fig. 1.30 represents the power drawn by an industrial plant between 8:00 and 8:30 A.M. Calculate the total energy in MWh consumed by the plant.

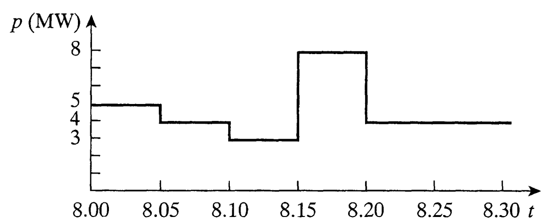


Figure 1.30 For Prob. 1.30.

1.31 A battery may be rated in ampere-hours (Ah). An lead-acid battery is rated at 160 Ah.
(a) What is the maximum current it can supply for 40 h?
(b) How many days will it last if it is discharged at 1 mA?

1.32 How much work is done by a 12-V automobile battery in moving 5×10^{20} electrons from the positive terminal to the negative terminal?

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

1.34 A 2-kW electric iron is connected to a 120-V line. Calculate the current drawn by the iron.

(b) For range 0–5 V,

$$R_2 = \frac{5}{100 \times 10^{-6}} - 2000 = 50{,}000 - 2000 = 48\ \text{k}\Omega$$

(c) For range 0–50 V,

$$R_3 = \frac{50}{100 \times 10^{-6}} - 2000 = 500{,}000 - 2000 = 498\ \text{k}\Omega$$

(d) For range 0–100 V,

$$R_4 = \frac{100\ \text{V}}{100 \times 10^{-6}} - 2000 = 1{,}000{,}000 - 2000 = 998\ \text{k}\Omega$$

Note that the ratio of the total resistance $(R_n + R_m)$ to the full-scale voltage V_{fs} is constant and equal to $1/I_{fs}$ for the four ranges. This ratio (given in ohms per volt, or Ω/V) is known as the *sensitivity* of the voltmeter. The larger the sensitivity, the better the voltmeter.

PRACTICE PROBLEM 2.17

Following the ammeter setup of Fig. 2.61, design an ammeter for the following multiple ranges:
(a) 0–1 A (b) 0–100 mA (c) 0–10 mA
Take the full-scale meter current as $I_m = 1$ mA and the internal resistance of the ammeter as $R_m = 50\ \Omega$.

Answer: Shunt resistors: 0.05 Ω, 0.505 Ω, 5.556 Ω.

2.9 SUMMARY

1. A resistor is a passive element in which the voltage v across it is directly proportional to the current i through it. That is, a resistor is a device that obeys Ohm's law,

$$v = iR$$

where R is the resistance of the resistor.

2. A short circuit is a resistor (a perfectly conducting wire) with zero resistance $(R = 0)$. An open circuit is a resistor with infinite resistance $(R = \infty)$.
3. The conductance G of a resistor is the reciprocal of its resistance:

$$G = \frac{1}{R}$$

4. A branch is a single two-terminal element in an electric circuit. A node is the point of connection between two or more branches. A loop is a closed path in a circuit. The number of branches b, the number of nodes n, and the number of independent loops l in a network are related as

$$b = l + n - 1$$

5. Kirchhoff's current law (KCL) states that the currents at any node algebraically sum to zero. In other words, the sum of the currents entering a node equals the sum of currents leaving the node.
6. Kirchhoff's voltage law (KVL) states that the voltages around a closed path algebraically sum to zero. In other words, the sum of voltage rises equals the sum of voltage drops.
7. Two elements are in series when they are connected sequentially, end to end. When elements are in series, the same current flows through them ($i_1 = i_2$). They are in parallel if they are connected to the same two nodes. Elements in parallel always have the same voltage across them ($v_1 = v_2$).
8. When two resistors R_1 ($= 1/G_1$) and R_2 ($= 1/G_2$) are in series, their equivalent resistance R_{eq} and equivalent conductance G_{eq} are
$$R_{eq} = R_1 + R_2, \qquad G_{eq} = \frac{G_1 G_2}{G_1 + G_2}$$
9. When two resistors R_1 ($= 1/G_1$) and R_2 ($= 1/G_2$) are in parallel, their equivalent resistance R_{eq} and equivalent conductance G_{eq} are
$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}, \qquad G_{eq} = G_1 + G_2$$
10. The voltage division principle for two resistors in series is
$$v_1 = \frac{R_1}{R_1 + R_2} v, \qquad v_2 = \frac{R_2}{R_1 + R_2} v$$
11. The current division principle for two resistors in parallel is
$$i_1 = \frac{R_2}{R_1 + R_2} i, \qquad i_2 = \frac{R_1}{R_1 + R_2} i$$
12. The formulas for a delta-to-wye transformation are
$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}, \qquad R_2 = \frac{R_c R_a}{R_a + R_b + R_c}$$
$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$
13. The formulas for a wye-to-delta transformation are
$$R_a = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}, \qquad R_b = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$$
$$R_c = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$
14. The basic laws covered in this chapter can be applied to the problems of electrical lighting and design of dc meters.

REVIEW QUESTIONS

2.1 The reciprocal of resistance is:
(a) voltage (b) current
(c) conductance (d) coulombs

2.2 An electric heater draws 10 A from a 120-V line. The resistance of the heater is:
(a) 1200 Ω (b) 120 Ω
(c) 12 Ω (d) 1.2 Ω

2.3 The voltage drop across a 1.5-kW toaster that draws 12 A of current is:
(a) 18 kV (b) 125 V
(c) 120 V (d) 10.42 V

2.4 The maximum current that a 2W, 80 kΩ resistor can safely conduct is:
(a) 160 kA (b) 40 kA
(c) 5 mA (d) 25 μA

2.5 A network has 12 branches and 8 independent loops. How many nodes are there in the network?
(a) 19 (b) 17 (c) 5 (d) 4

2.6 The current I in the circuit in Fig. 2.63 is:
(a) −0.8 A (b) −0.2 A
(c) 0.2 A (d) 0.8 A

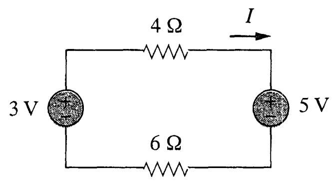


Figure 2.63 For Review Question 2.6.

2.7 The current I_o in Fig. 2.64 is:
(a) −4 A (b) −2 A (c) 4 A (d) 16 A

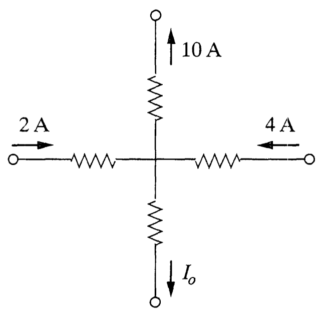


Figure 2.64 For Review Question 2.7.

2.8 In the circuit in Fig. 2.65, V is:
(a) 30 V (b) 14 V (c) 10 V (d) 6 V

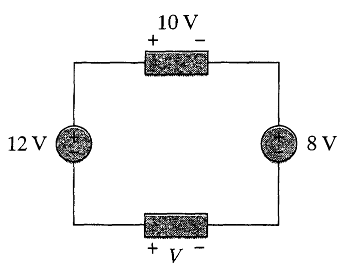


Figure 2.65 For Review Question 2.8.

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

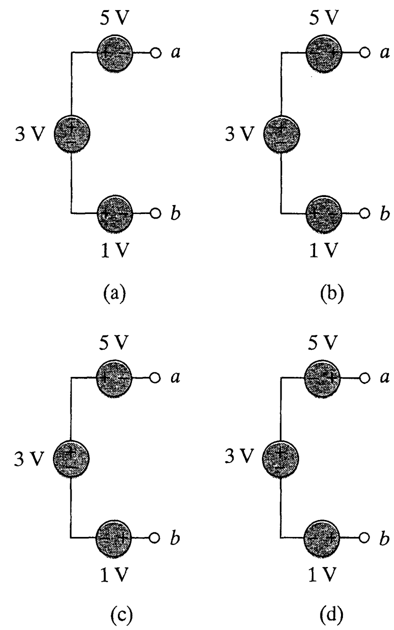


Figure 2.66 For Review Question 2.9.

2.10 The equivalent resistance of the circuit in Fig. 2.67 is:
(a) 4 kΩ (b) 5 kΩ (c) 8 kΩ (d) 14 kΩ

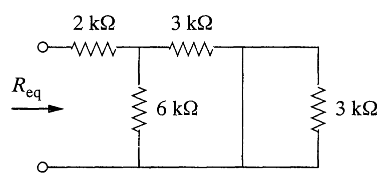


Figure 2.67 For Review Question 2.10.

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

PROBLEMS

Section 2.2 Ohm's Law

2.1 The voltage across a 5-kΩ resistor is 16 V. Find the current through the resistor.

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

2.3 When the voltage across a resistor is 120 V, the current through it is 2.5 mA. Calculate its conductance.

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

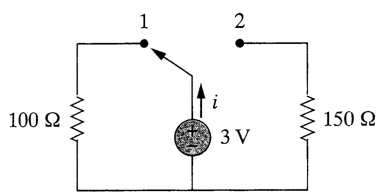


Figure 2.68 For Prob. 2.4.

Section 2.3 Nodes, Branches, and Loops

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

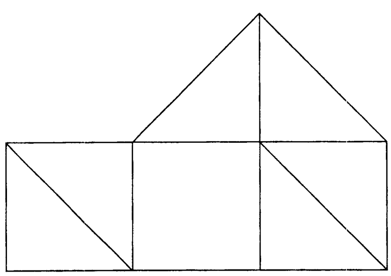


Figure 2.69 For Prob. 2.5.

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

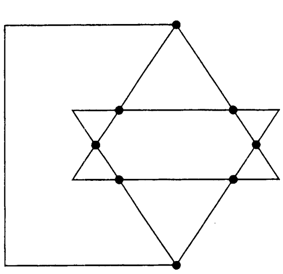


Figure 2.70 For Prob. 2.6.

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

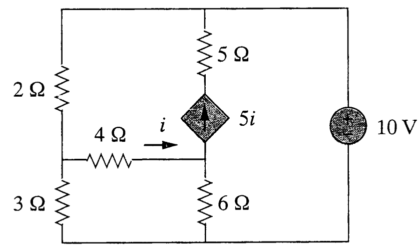


Figure 2.71 For Prob. 2.7.

Section 2.4 Kirchhoff's Laws

2.8 Use KCL to obtain currents i_1, i_2, and i_3 in the circuit shown in Fig. 2.72.

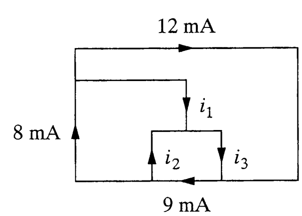


Figure 2.72 For Prob. 2.8.

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

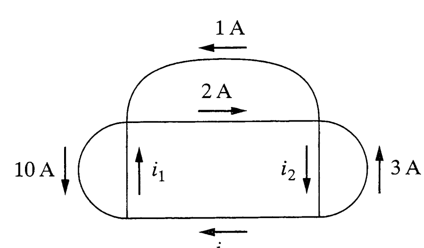


Figure 2.73 For Prob. 2.9.

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

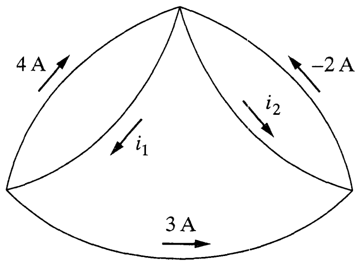


Figure 2.74 For Prob. 2.10.

2.11 Determine v_1 through v_4 in the circuit in Fig. 2.75.

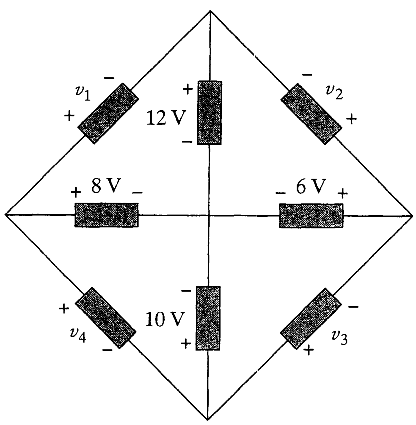


Figure 2.75 For Prob. 2.11.

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

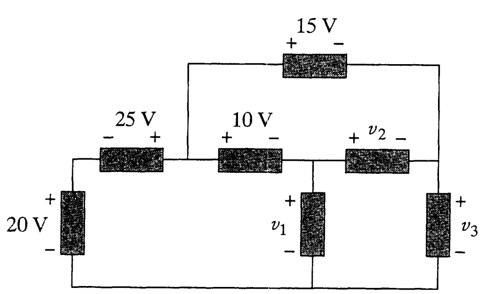


Figure 2.76 For Prob. 2.12.

2.13 Find v_1 and v_2 in the circuit in Fig. 2.77.

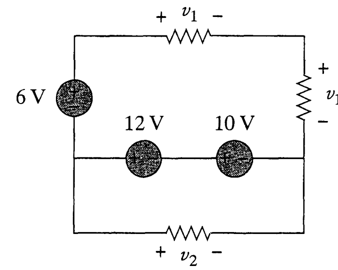


Figure 2.77 For Prob. 2.13.

2.14 Obtain v_1 through v_3 in the circuit of Fig. 2.78.

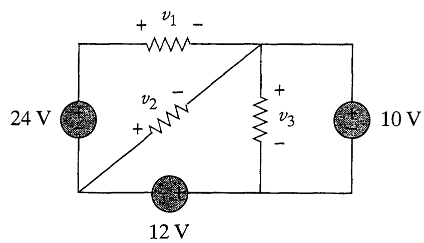


Figure 2.78 For Prob. 2.14.

2.15 Find I and V_{ab} in the circuit of Fig. 2.79.

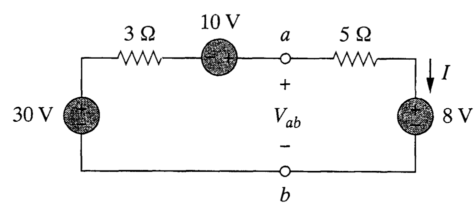


Figure 2.79 For Prob. 2.15.

2.16 From the circuit in Fig. 2.80, find I, the power dissipated by the resistor, and the power supplied by each source.

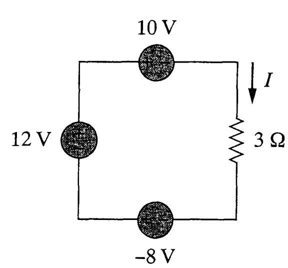


Figure 2.80 For Prob. 2.16.

2.17 Determine i_o in the circuit of Fig. 2.81.

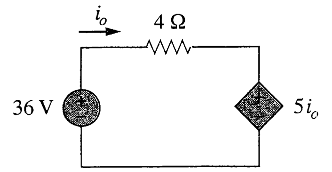


Figure 2.81 For Prob. 2.17.

2.18 Calculate the power dissipated in the 5-Ω resistor in the circuit of Fig. 2.82.

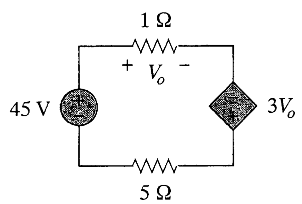


Figure 2.82 For Prob. 2.18.

2.19 Find V_o in the circuit in Fig. 2.83 and the power dissipated by the controlled source.

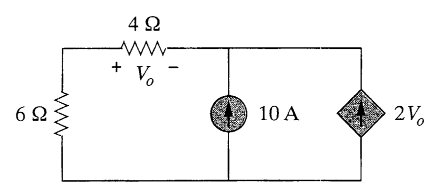


Figure 2.83 For Prob. 2.19.

2.20 For the circuit in Fig. 2.84, find V_o/V_s in terms of α, R_1, R_2, R_3, and R_4. If $R_1 = R_2 = R_3 = R_4$, what value of α will produce $|V_o/V_s| = 10$?

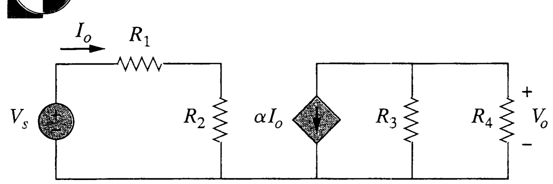


Figure 2.84 For Prob. 2.20.

2.21 For the network in Fig. 2.85, find the current, voltage, and power associated with the 20-kΩ resistor.

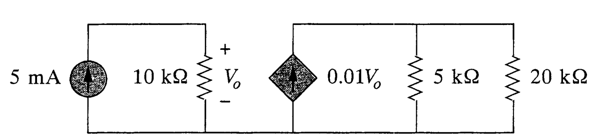


Figure 2.85 For Prob. 2.21.

Sections 2.5 and 2.6 Series and Parallel Resistors

2.22 For the circuit in Fig. 2.86, find i_1 and i_2.

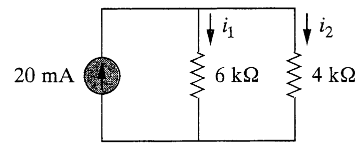


Figure 2.86 For Prob. 2.22.

2.23 Find v_1 and v_2 in the circuit in Fig. 2.87.

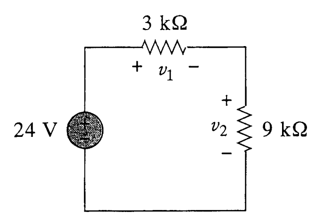


Figure 2.87 For Prob. 2.23.

2.24 Find v_1, v_2, and v_3 in the circuit in Fig. 2.88.

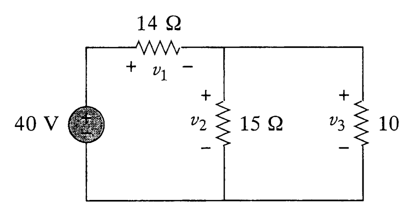


Figure 2.88 For Prob. 2.24.

2.25 Calculate v_1, i_1, v_2, and i_2 in the circuit of Fig. 2.89.

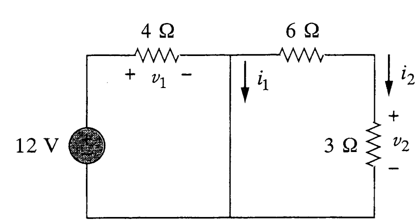


Figure 2.89 For Prob. 2.25.

2.26 Find i, v, and the power dissipated in the 6-Ω resistor in Fig. 2.90.

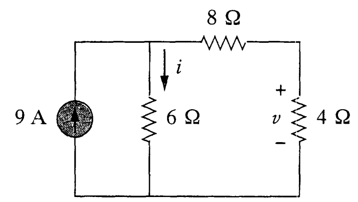


Figure 2.90 For Prob. 2.26.

2.27 In the circuit in Fig. 2.91, find v, i, and the power absorbed by the 4-Ω resistor.

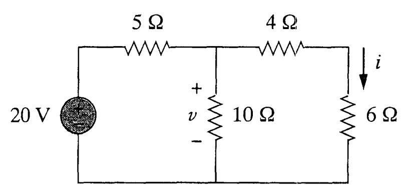


Figure 2.91 For Prob. 2.27.

2.28 Find i_1 through i_4 in the circuit in Fig. 2.92.

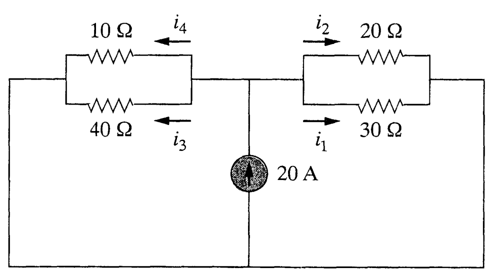


Figure 2.92 For Prob. 2.28.

2.29 Obtain v and i in the circuit in Fig. 2.93.

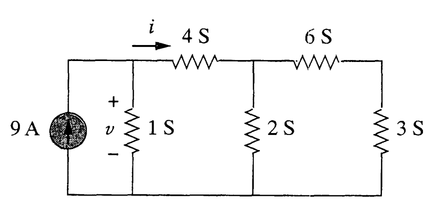


Figure 2.93 For Prob. 2.29.

2.30 Determine i_1, i_2, v_1, and v_2 in the ladder network in Fig. 2.94. Calculate the power dissipated in the 2-Ω resistor.

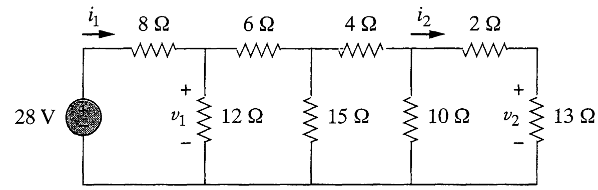


Figure 2.94 For Prob. 2.30.

2.31 Calculate V_o and I_o in the circuit of Fig. 2.95.

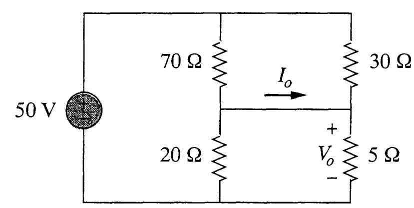


Figure 2.95 For Prob. 2.31.

2.32 Find V_o and I_o in the circuit of Fig. 2.96.

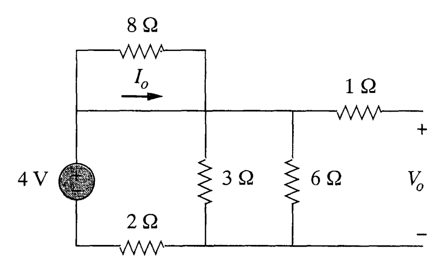


Figure 2.96 For Prob. 2.32.

2.33 In the circuit of Fig. 2.97, find R if $V_o = 4V$.

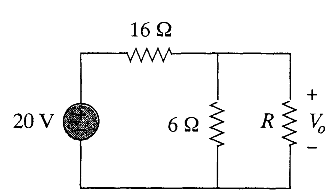


Figure 2.97 For Prob. 2.33.

2.34 Find I and V_s in the circuit of Fig. 2.98 if the current through the 3-Ω resistor is 2 A.

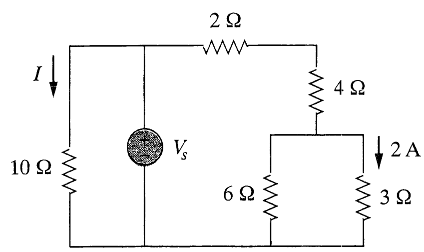


Figure 2.98 For Prob. 2.34.

2.35 Find the equivalent resistance at terminals a-b for each of the networks in Fig. 2.99.

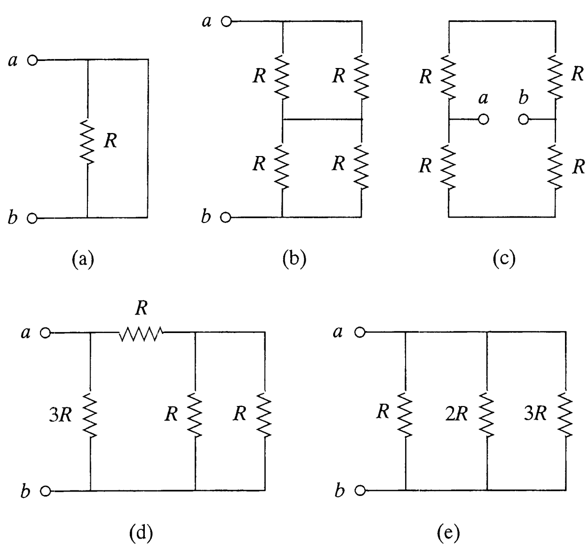


Figure 2.99 For Prob. 2.35.

2.36 For the ladder network in Fig. 2.100, find I and R_{eq}.

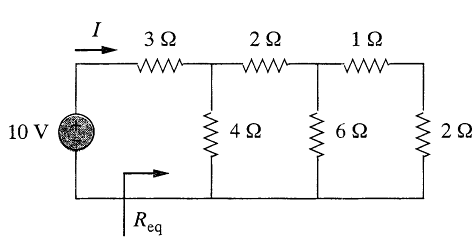


Figure 2.100 For Prob. 2.36.

2.37 If $R_{eq} = 50\ \Omega$ in the circuit in Fig. 2.101, find R.

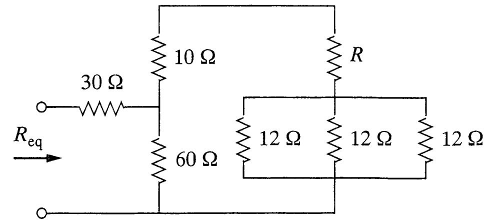


Figure 2.101 For Prob. 2.37.

2.38 Reduce each of the circuits in Fig. 2.102 to a single resistor at terminals a-b.

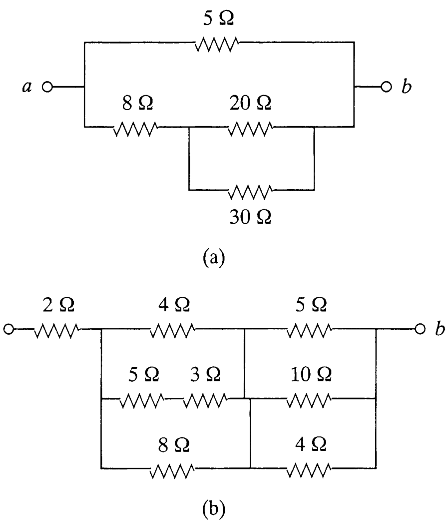


Figure 2.102 For Prob. 2.38.

2.39 Calculate the equivalent resistance R_{ab} at terminals a-b for each of the circuits in Fig. 2.103.

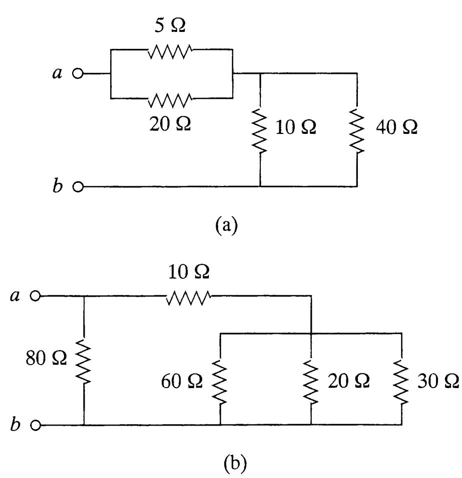


Figure 2.103 For Prob. 2.39.

2.40 Obtain the equivalent resistance at the terminals a-b for each of the circuits in Fig. 2.104.

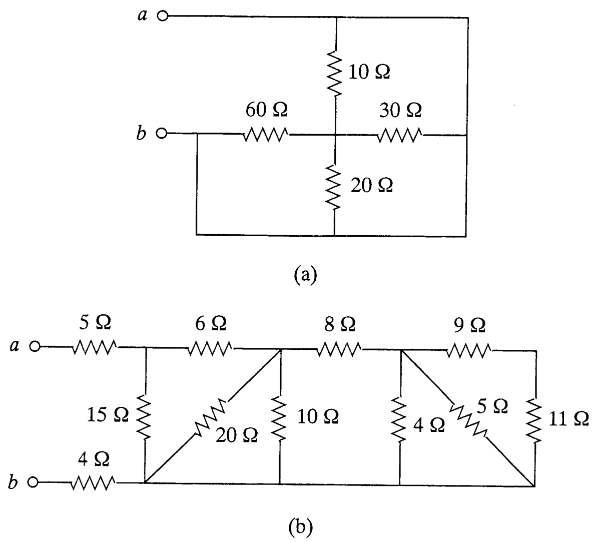


Figure 2.104 For Prob. 2.40.

2.41 Find R_{eq} at terminals a-b for each of the circuits in Fig. 2.105.

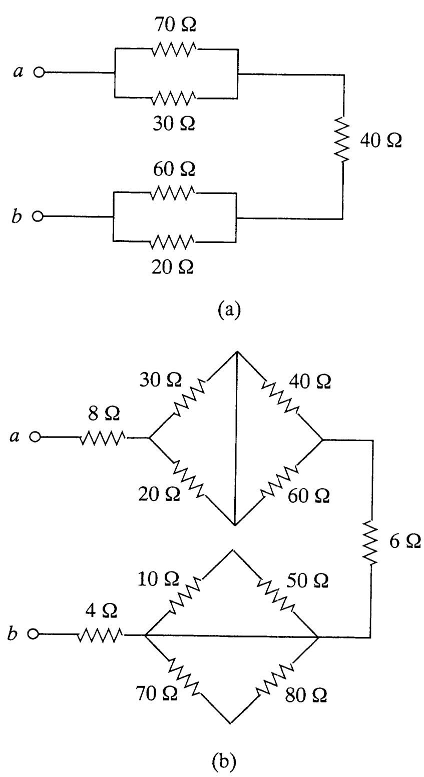


Figure 2.105 For Prob. 2.41.

2.42 Find the equivalent resistance R_{ab} in the circuit of Fig. 2.106.

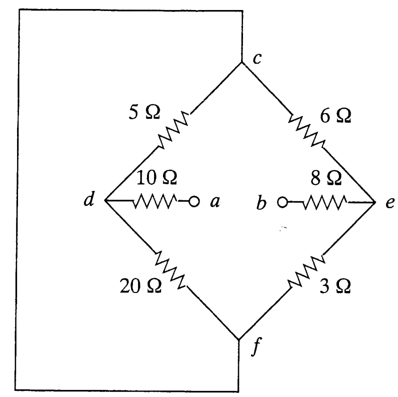


Figure 2.106 For Prob. 2.42.

Section 2.7 Wye-Delta Transformations

2.43 Convert the circuits in Fig. 2.107 from Y to Δ.

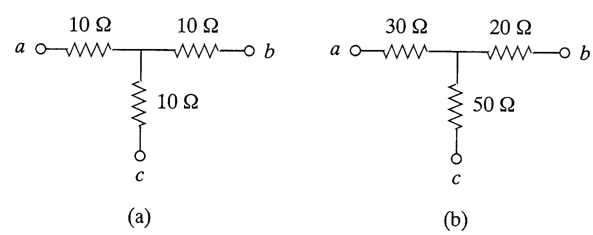


Figure 2.107 For Prob. 2.43.

2.44 Transform the circuits in Fig. 2.108 from Δ to Y.

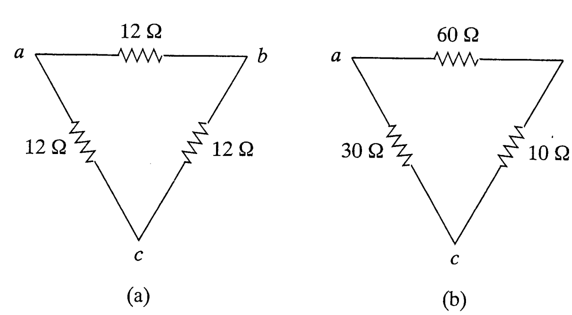


Figure 2.108 For Prob. 2.44.

2.45 What value of R in the circuit of Fig. 2.109 would cause the current source to deliver 800 mW to the resistors?

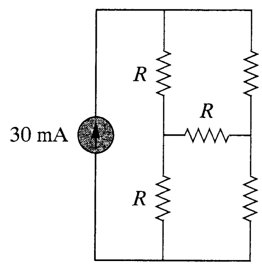


Figure 2.109 For Prob. 2.45.

2.46 Obtain the equivalent resistance at the terminals a-b for each of the circuits in Fig. 2.110.

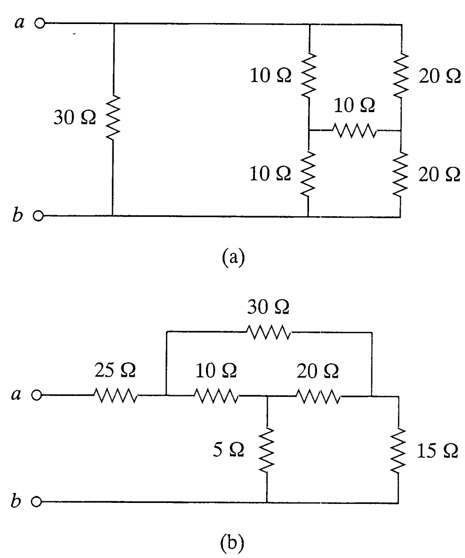
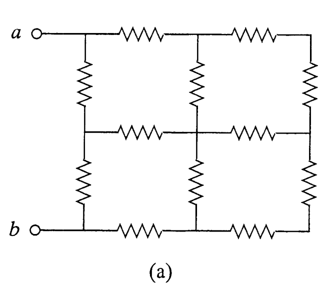


Figure 2.110 For Prob. 2.46.

***2.47** Find the equivalent resistance R_{ab} in each of the circuits of Fig. 2.111. Each resistor is 100 Ω.



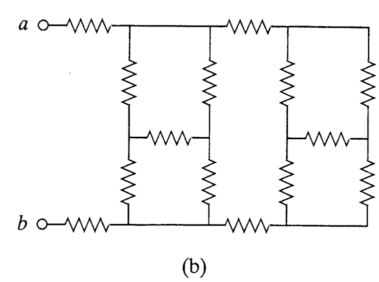


Figure 2.111 For Prob. 2.47.

***2.48** Obtain the equivalent resistance R_{ab} in each of the circuits of Fig. 2.112. In (b), all resistors have a value of 30 Ω.

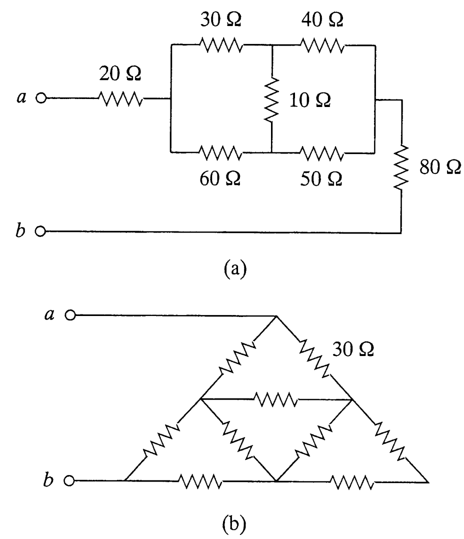


Figure 2.112 For Prob. 2.48.

2.49 Calculate I_o in the circuit of Fig. 2.113.

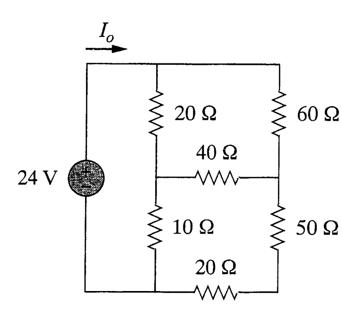


Figure 2.113 For Prob. 2.49.

*An asterisk indicates a challenging problem.

2.50 Determine V in the circuit of Fig. 2.114.

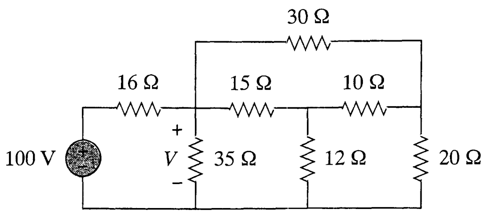


Figure 2.114 For Prob. 2.50.

***2.51** Find R_{eq} and I in the circuit of Fig. 2.115.

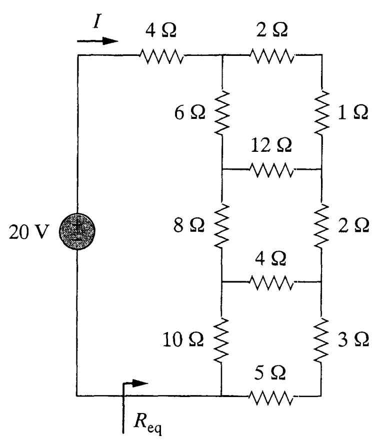


Figure 2.115 For Prob. 2.51.

Section 2.8 Applications

2.52 The lightbulb in Fig. 2.116 is rated 120 V, 0.75 A. Calculate V_s to make the lightbulb operate at the rated conditions.

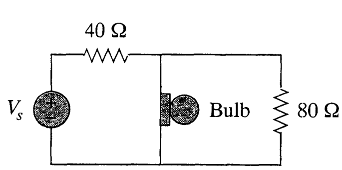


Figure 2.116 For Prob. 2.52.

2.53 Three lightbulbs are connected in series to a 100-V battery as shown in Fig. 2.117. Find the current I through the bulbs.

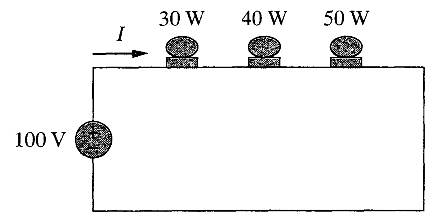


Figure 2.117 For Prob. 2.53.

2.54 If the three bulbs of Prob. 2.53 are connected in parallel to the 100-V battery, calculate the current through each bulb.

2.55 As a design engineer, you are asked to design a lighting system consisting of a 70-W power supply and two lightbulbs as shown in Fig. 2.118. You must select the two bulbs from the following three available bulbs.

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

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

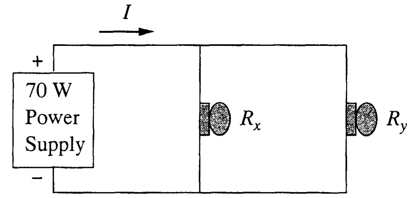


Figure 2.118 For Prob. 2.55.

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

2.57 The potentiometer (adjustable resistor) R_x in Fig. 2.119 is to be designed to adjust current i_x from 1 A to 10 A. Calculate the values of R and R_x to achieve this.

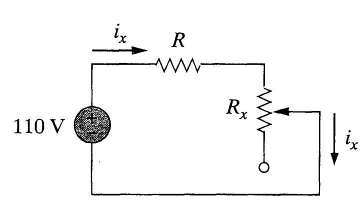


Figure 2.119 For Prob. 2.57.

2.58 A d'Arsonval meter with an internal resistance of 1 kΩ requires 10 mA to produce full-scale deflection. Calculate the value of a series resistance needed to measure 50 V of full scale.

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

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

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

2.60 (a) Obtain the voltage v_o in the circuit of Fig. 2.120(a).

(b) Determine the voltage v_o' measured when a voltmeter with 6-kΩ internal resistance is connected as shown in Fig. 2.120(b).

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

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

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

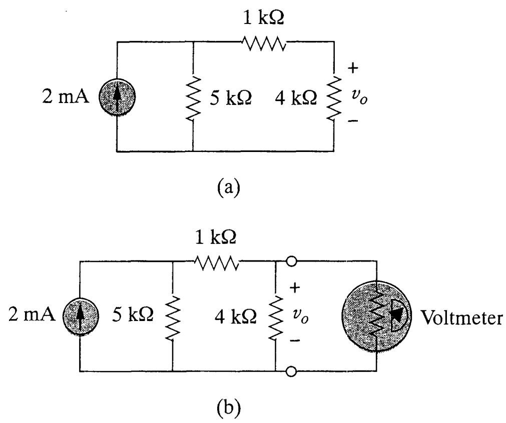


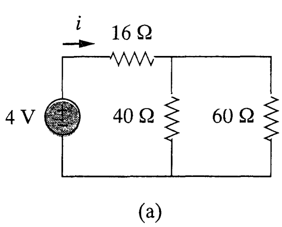
Figure 2.120 For Prob. 2.60.

2.61 (a) Find the current i in the circuit of Fig. 2.121(a).

(b) An ammeter with an internal resistance of 1 Ω is inserted in the network to measure i' as shown in Fig. 2.121(b). What is i'?

(c) Calculate the percent error introduced by the meter as

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



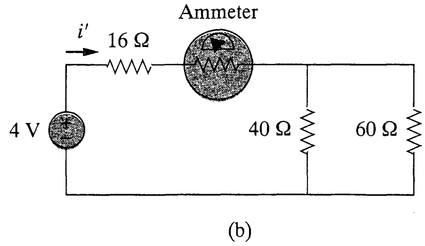


Figure 2.121 For Prob. 2.61.

2.62 A voltmeter is used to measure V_o in the circuit in Fig. 2.122. The voltmeter model consists of an ideal voltmeter in parallel with a 100-kΩ resistor. Let $V_s = 40$ V, $R_s = 10$ kΩ, and $R_1 = 20$ kΩ. Calculate V_o with and without the voltmeter when

(a) $R_2 = 1$ kΩ (b) $R_2 = 10$ kΩ

(c) $R_2 = 100$ kΩ

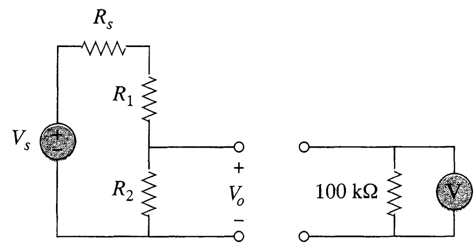


Figure 2.122 For Prob. 2.62.

2.63 An ammeter model consists of an ideal ammeter in series with a 20-Ω resistor. It is connected with a current source and an unknown resistor R_x as shown in Fig. 2.123. The ammeter reading is noted. When a potentiometer R is added and adjusted until the ammeter reading drops to one half its previous reading, then $R = 65$ Ω. What is the value of R_x?

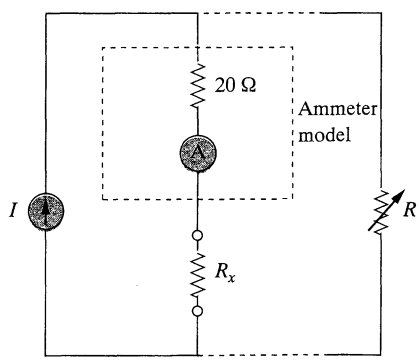


Figure 2.123 For Prob. 2.63.

2.64 The circuit in Fig. 2.124 is to control the speed of a motor such that the motor draws currents 5 A, 3 A, and 1 A when the switch is at high, medium, and low positions, respectively. The motor can be modeled as a load resistance of 20 mΩ. Determine the series dropping resistances R_1, R_2, and R_3.

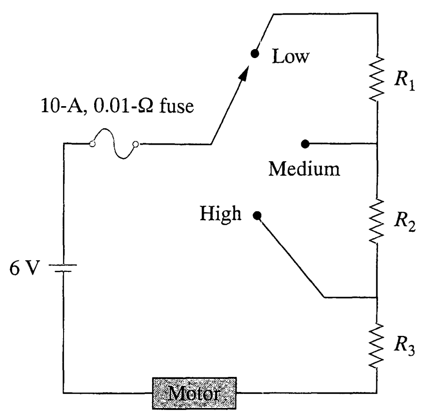


Figure 2.124 For Prob. 2.64.

2.65 An ohmmeter is constructed with a 2-V battery and 0.1-mA (full-scale) meter with 100-Ω internal resistance.

(a) Calculate the resistance of the (variable) resistor required to be in series with the meter and the battery.

(b) Determine the unknown resistance across the terminals of the ohmmeter that will cause the meter to deflect half scale.

COMPREHENSIVE PROBLEMS

2.66 An electric heater connected to a 120-V source consists of two identical 0.4-Ω elements made of Nichrome wire. The elements provide low heat when connected in series and high heat when connected in parallel. Find the power at low and high heat settings.

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

1.8 Ω 20 Ω 300 Ω 24 kΩ 56 kΩ

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

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

2.68 In the circuit in Fig. 2.125, the wiper divides the potentiometer resistance between αR and $(1-\alpha)R$, $0 \le \alpha \le 1$. Find v_o/v_s.

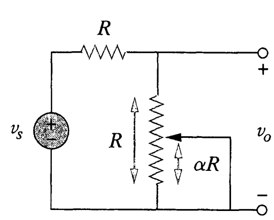


Figure 2.125 For Prob. 2.68.

2.69 An electric pencil sharpener rated 240 mW, 6 V is connected to a 9-V battery as shown in Fig. 2.126. Calculate the value of the series-dropping resistor R_x needed to power the sharpener.

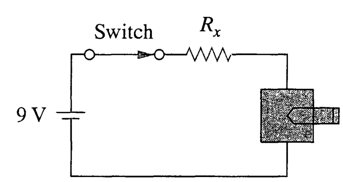


Figure 2.126 For Prob. 2.69.

2.70 A loudspeaker is connected to an amplifier as shown in Fig. 2.127. If a 10-Ω loudspeaker draws the maximum power of 12 W from the amplifier, determine the maximum power a 4-Ω loudspeaker will draw.

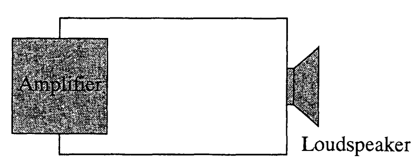


Figure 2.127 For Prob. 2.70.

2.71 In a certain application, the circuit in Fig. 2.128 must be designed to meet these two criteria:

(a) $V_o/V_s = 0.05$ (b) $R_{eq} = 40$ kΩ

If the load resistor 5 kΩ is fixed, find R_1 and R_2 to meet the criteria.

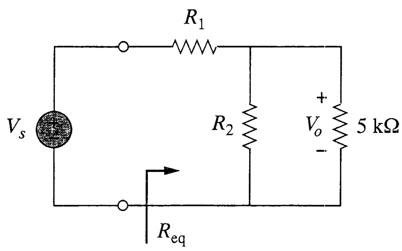


Figure 2.128 For Prob. 2.71.

2.72 The pin diagram of a resistance array is shown in Fig. 2.129. Find the equivalent resistance between the following:
(a) 1 and 2 (b) 1 and 3 (c) 1 and 4

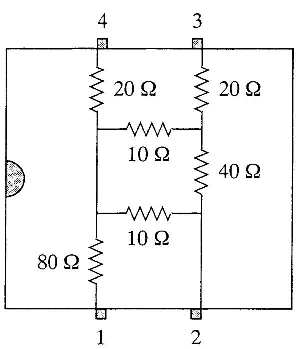


Figure 2.129 For Prob. 2.72.

2.73 Two delicate devices are rated as shown in Fig. 2.130. Find the values of the resistors R_1 and R_2 needed to power the devices using a 24-V battery.

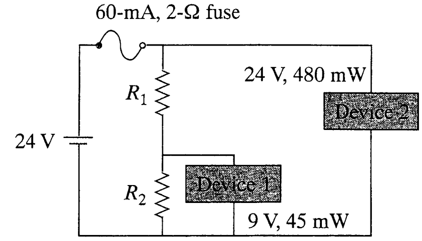


Figure 2.130 For Prob. 2.73.

PRACTICE PROBLEM 3.13

The transistor circuit in Fig. 3.45 has $\beta = 80$ and $V_{BE} = 0.7$ V. Find v_o and i_o.

Answer: -3 V, $-150\ \mu$A.

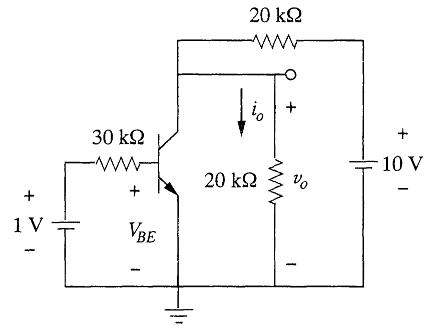


Figure 3.45 For Practice Prob. 3.13.

3.10 SUMMARY

1. Nodal analysis is the application of Kirchhoff's current law at the nonreference nodes. (It is applicable to both planar and nonplanar circuits.) We express the result in terms of the node voltages. Solving the simultaneous equations yields the node voltages.
2. A supernode consists of two nonreference nodes connected by a (dependent or independent) voltage source.
3. Mesh analysis is the application of Kirchhoff's voltage law around meshes in a planar circuit. We express the result in terms of mesh currents. Solving the simultaneous equations yields the mesh currents.
4. A supermesh consists of two meshes that have a (dependent or independent) current source in common.
5. Nodal analysis is normally used when a circuit has fewer node equations than mesh equations. Mesh analysis is normally used when a circuit has fewer mesh equations than node equations.
6. Circuit analysis can be carried out using *PSpice*.
7. DC transistor circuits can be analyzed using the techniques covered in this chapter.

REVIEW QUESTIONS

3.1 At node 1 in the circuit in Fig. 3.46, applying KCL gives:

(a) $2 + \dfrac{12 - v_1}{3} = \dfrac{v_1}{6} + \dfrac{v_1 - v_2}{4}$

(b) $2 + \dfrac{v_1 - 12}{3} = \dfrac{v_1}{6} + \dfrac{v_2 - v_1}{4}$

(c) $2 + \dfrac{12 - v_1}{3} = \dfrac{0 - v_1}{6} + \dfrac{v_1 - v_2}{4}$

(d) $2 + \dfrac{v_1 - 12}{3} = \dfrac{0 - v_1}{6} + \dfrac{v_2 - v_1}{4}$

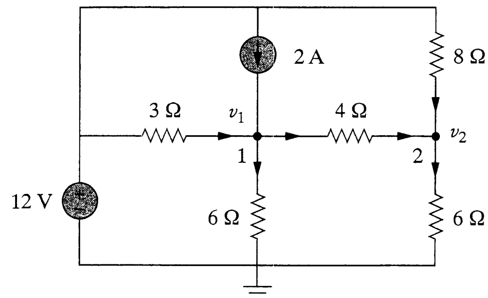


Figure 3.46 For Review Questions 3.1 and 3.2.

3.2 In the circuit in Fig. 3.46, applying KCL at node 2 gives:

(a) $\frac{v_2 - v_1}{4} + \frac{v_2}{8} = \frac{v_2}{6}$

(b) $\frac{v_1 - v_2}{4} + \frac{v_2}{8} = \frac{v_2}{6}$

(c) $\frac{v_1 - v_2}{4} + \frac{12 - v_2}{8} = \frac{v_2}{6}$

(d) $\frac{v_2 - v_1}{4} + \frac{v_2 - 12}{8} = \frac{v_2}{6}$

3.3 For the circuit in Fig. 3.47, v_1 and v_2 are related as:

(a) $v_1 = 6i + 8 + v_2$ (b) $v_1 = 6i - 8 + v_2$
(c) $v_1 = -6i + 8 + v_2$ (d) $v_1 = -6i - 8 + v_2$

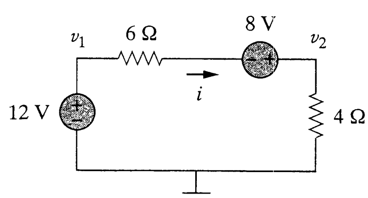


Figure 3.47 For Review Questions 3.3 and 3.4.

3.4 In the circuit in Fig. 3.47, the voltage v_2 is:

(a) −8 V (b) −1.6 V
(c) 1.6 V (d) 8 V

3.5 The current i in the circuit in Fig. 3.48 is:

(a) −2.667 A (b) −0.667 A
(c) 0.667 A (d) 2.667 A

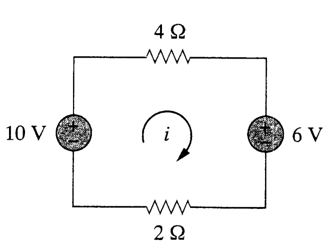


Figure 3.48 For Review Questions 3.5 and 3.6.

3.6 The loop equation for the circuit in Fig. 3.48 is:

(a) $-10 + 4i + 6 + 2i = 0$
(b) $10 + 4i + 6 + 2i = 0$
(c) $10 + 4i - 6 + 2i = 0$
(d) $-10 + 4i - 6 + 2i = 0$

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

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

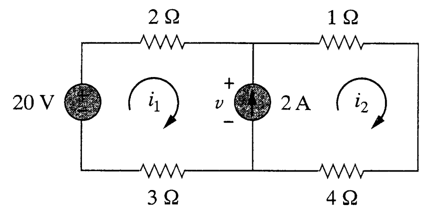


Figure 3.49 For Review Questions 3.7 and 3.8.

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

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

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

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

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

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

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

PROBLEMS

Sections 3.2 and 3.3 Nodal Analysis

3.1 Determine v_1, v_2, and the power dissipated in all the resistors in the circuit of Fig. 3.50.

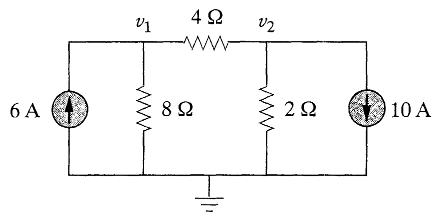


Figure 3.50 For Prob. 3.1.

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

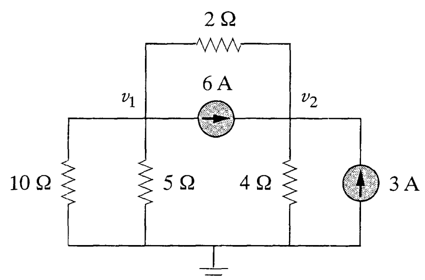


Figure 3.51 For Prob. 3.2.

3.3 Find the currents i_1 through i_4 and the voltage v_o in the circuit in Fig. 3.52.

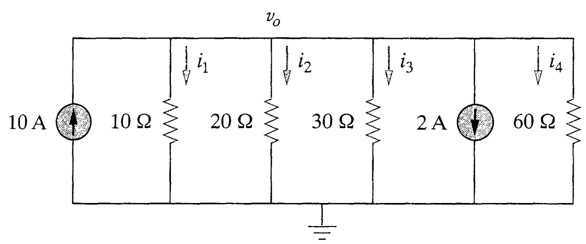


Figure 3.52 For Prob. 3.3.

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

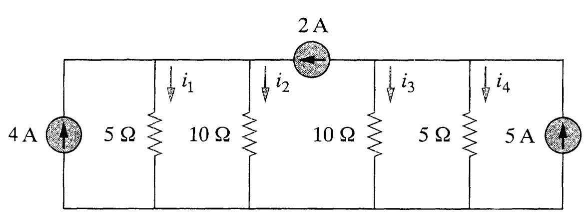


Figure 3.53 For Prob. 3.4.

3.5 Obtain v_o in the circuit of Fig. 3.54.

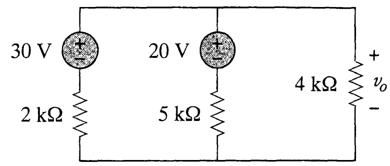


Figure 3.54 For Prob. 3.5.

3.6 Use nodal analysis to obtain v_o in the circuit in Fig. 3.55.

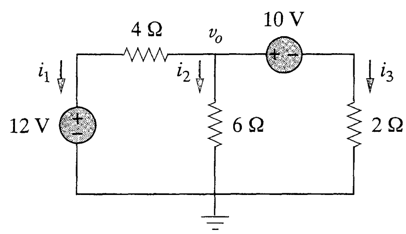


Figure 3.55 For Prob. 3.6.

3.7 Using nodal analysis, find v_o in the circuit of Fig. 3.56.

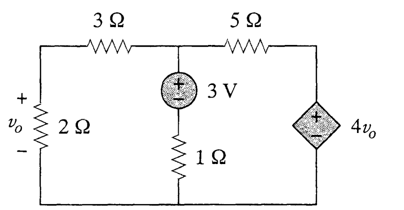


Figure 3.56 For Prob. 3.7.

3.8 Calculate v_o in the circuit in Fig. 3.57.

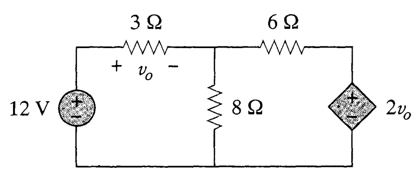


Figure 3.57 For Prob. 3.8.

3.9 Find i_o in the circuit in Fig. 3.58.

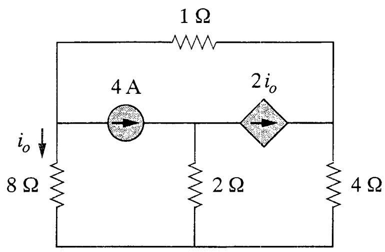


Figure 3.58 For Prob. 3.9.

3.10 Solve for i_1 and i_2 in the circuit in Fig. 3.22 (Section 3.5) using nodal analysis.

3.11 Use nodal analysis to find currents i_1 and i_2 in the circuit of Fig. 3.59.

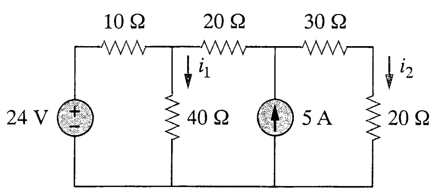


Figure 3.59 For Prob. 3.11.

3.12 Calculate v_1 and v_2 in the circuit in Fig. 3.60 using nodal analysis.

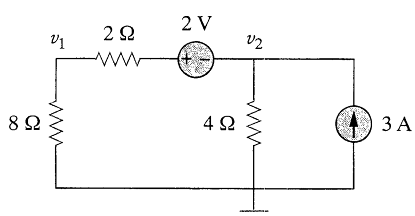


Figure 3.60 For Prob. 3.12.

3.13 Using nodal analysis, find v_o in the circuit of Fig. 3.61.

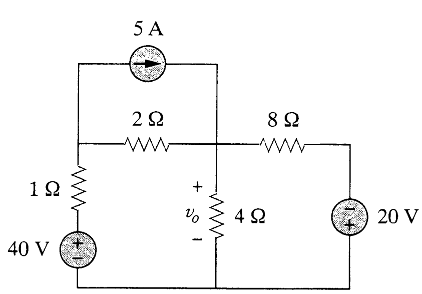


Figure 3.61 For Prob. 3.13.

3.14 Apply nodal analysis to find i_o and the power dissipated in each resistor in the circuit of Fig. 3.62.

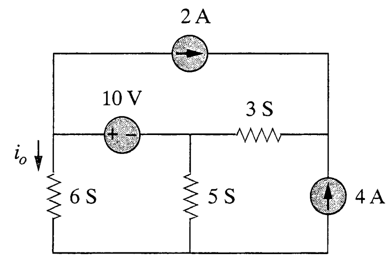


Figure 3.62 For Prob. 3.14.

3.15 Determine voltages v_1 through v_3 in the circuit of Fig. 3.63 using nodal analysis.

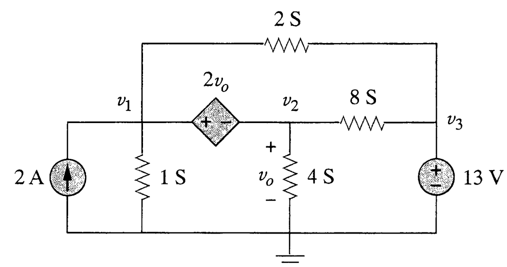


Figure 3.63 For Prob. 3.15.

3.16 Using nodal analysis, find current i_o in the circuit of Fig. 3.64.

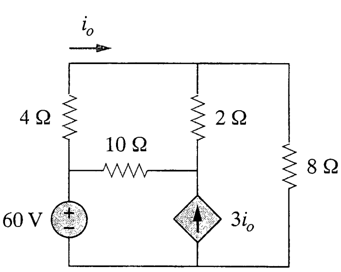


Figure 3.64 For Prob. 3.16.

3.17 Determine the node voltages in the circuit in Fig. 3.65 using nodal analysis.

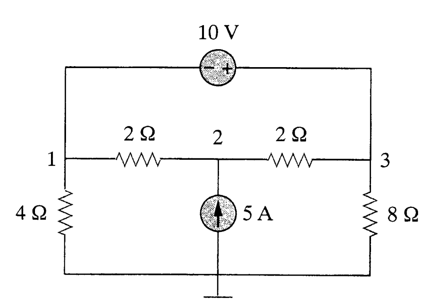


Figure 3.65 For Prob. 3.17.

3.18 For the circuit in Fig. 3.66, find v_1 and v_2 using nodal analysis.

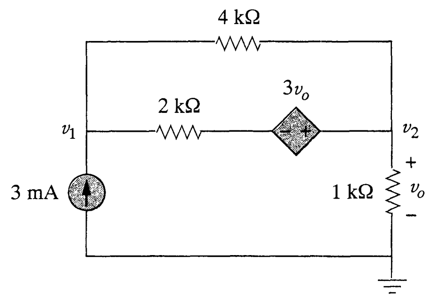


Figure 3.66 For Prob. 3.18.

3.19 Determine v_1 and v_2 in the circuit in Fig. 3.67.

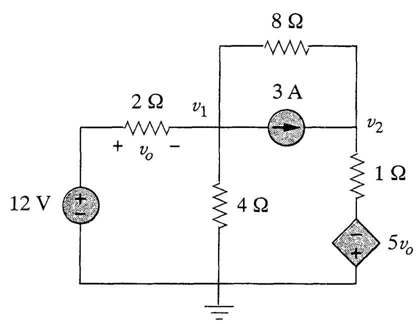


Figure 3.67 For Prob. 3.19.

3.20 Obtain v_1 and v_2 in the circuit of Fig. 3.68.

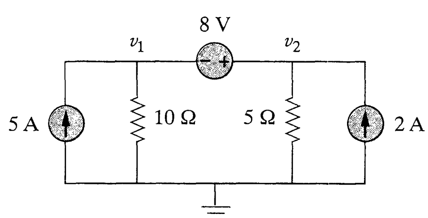


Figure 3.68 For Prob. 3.20.

3.21 Find v_o and i_o in the circuit in Fig. 3.69.

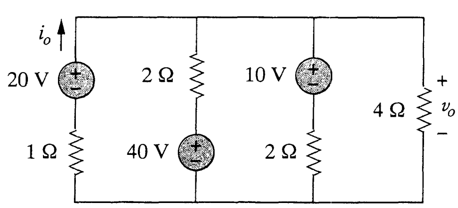


Figure 3.69 For Prob. 3.21.

***3.22** Use nodal analysis to determine voltages v_1, v_2, and v_3 in the circuit in Fig. 3.70.

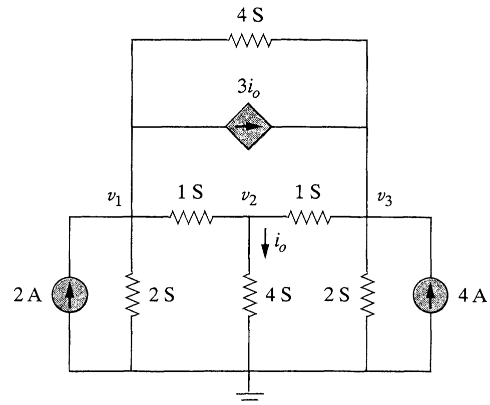


Figure 3.70 For Prob. 3.22.

3.23 Using nodal analysis, find v_o and i_o in the circuit of Fig. 3.71.

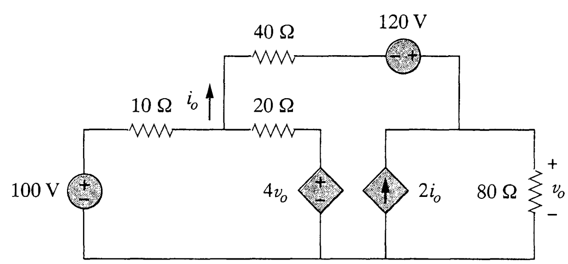


Figure 3.71 For Prob. 3.23.

3.24 Find the node voltages for the circuit in Fig. 3.72.

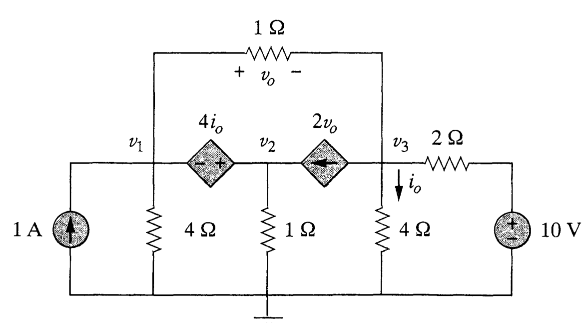


Figure 3.72 For Prob. 3.24.

*An asterisk indicates a challenging problem.

*3.25 Obtain the node voltages v_1, v_2, and v_3 in the circuit of Fig. 3.73.

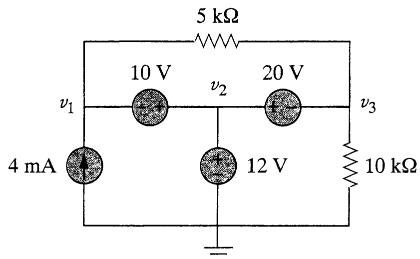


Figure 3.73 For Prob. 3.25.

Sections 3.4 and 3.5 Mesh Analysis

3.26 Which of the circuits in Fig. 3.74 is planar? For the planar circuit, redraw the circuits with no crossing branches.

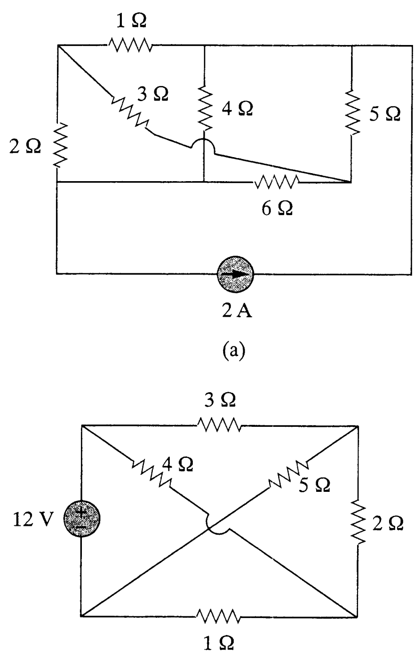


Figure 3.74 For Prob. 3.26.

3.27 Determine which of the circuits in Fig. 3.75 is planar and redraw it with no crossing branches.

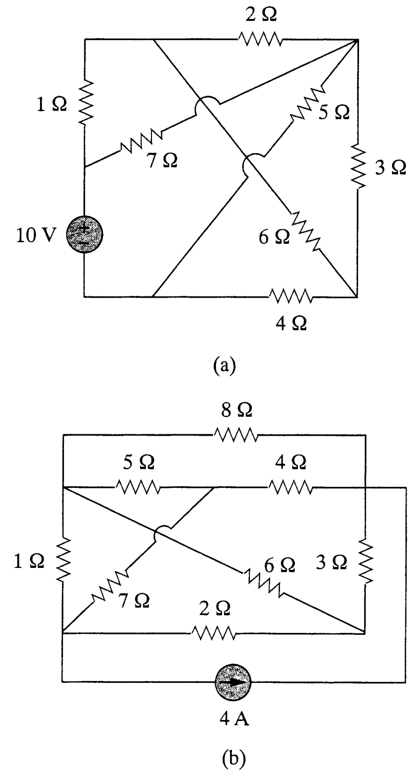


Figure 3.75 For Prob. 3.27.

3.28 Rework Prob. 3.5 using mesh analysis.

3.29 Rework Prob. 3.6 using mesh analysis.

3.30 Solve Prob. 3.7 using mesh analysis.

3.31 Solve Prob. 3.8 using mesh analysis.

3.32 For the bridge network in Fig. 3.76, find i_o using mesh analysis.

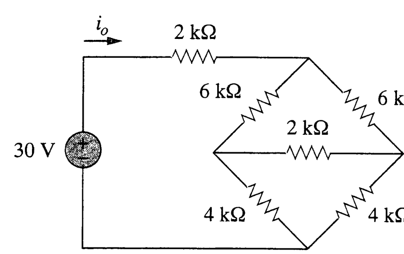


Figure 3.76 For Prob. 3.32.

3.33 Apply mesh analysis to find i in Fig. 3.77.

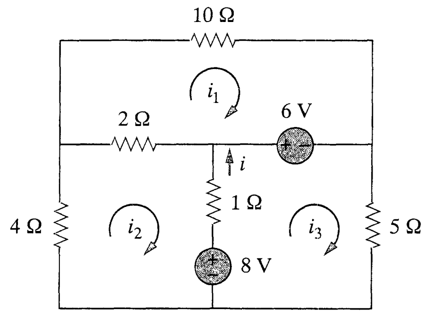


Figure 3.77 For Prob. 3.33.

3.34 Use mesh analysis to find v_{ab} and i_o in the circuit in Fig. 3.78.

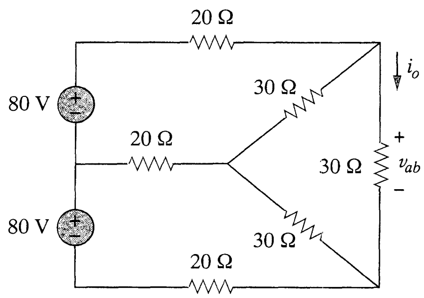


Figure 3.78 For Prob. 3.34.

3.35 Use mesh analysis to obtain i_o in the circuit of Fig. 3.79.

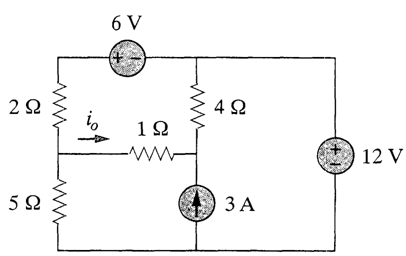


Figure 3.79 For Prob. 3.35.

3.36 Find current i in the circuit in Fig. 3.80.

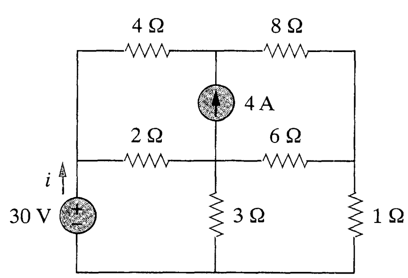


Figure 3.80 For Prob. 3.36.

3.37 Find v_o and i_o in the circuit of Fig. 3.81.

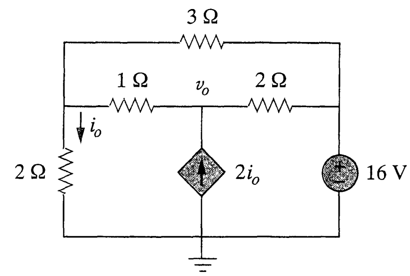


Figure 3.81 For Prob. 3.37.

3.38 Use mesh analysis to find the current i_o in the circuit in Fig. 3.82.

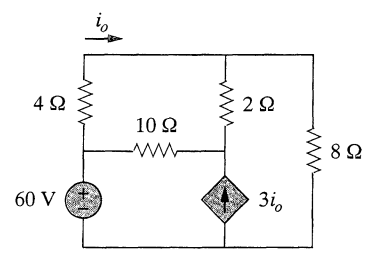


Figure 3.82 For Prob. 3.38.

3.39 Apply mesh analysis to find v_o in the circuit in Fig. 3.83.

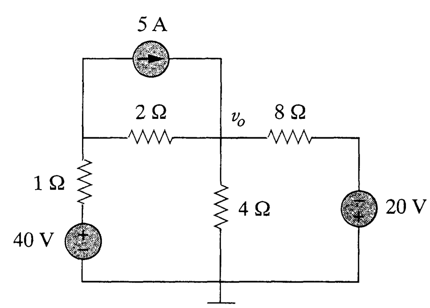


Figure 3.83 For Prob. 3.39.

3.40 Use mesh analysis to find i_1, i_2, and i_3 in the circuit of Fig. 3.84.

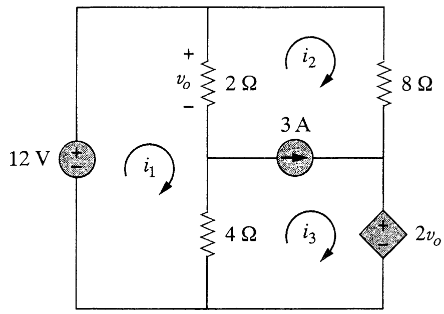


Figure 3.84 For Prob. 3.40.

3.41 Rework Prob. 3.11 using mesh analysis.

***3.42** In the circuit of Fig. 3.85, solve for i_1, i_2, and i_3.

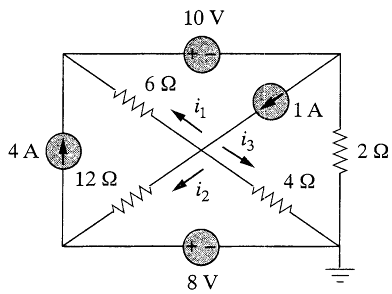


Figure 3.85 For Prob. 3.42.

3.43 Determine v_1 and v_2 in the circuit of Fig. 3.86.

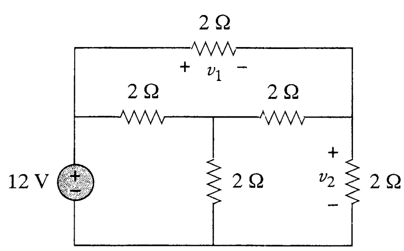


Figure 3.86 For Prob. 3.43.

3.44 Find i_1, i_2, and i_3 in the circuit in Fig. 3.87.

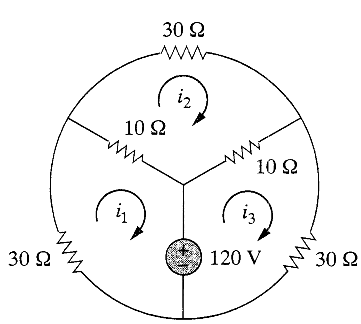


Figure 3.87 For Prob. 3.44.

3.45 Rework Prob. 3.23 using mesh analysis.

3.46 Calculate the power dissipated in each resistor in the circuit in Fig. 3.88.

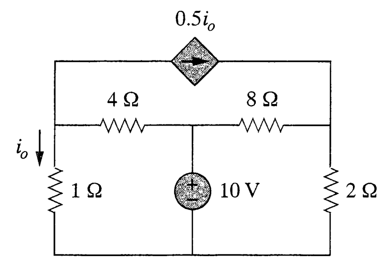


Figure 3.88 For Prob. 3.46.

3.47 Calculate the current gain i_o/i_s in the circuit of Fig. 3.89.

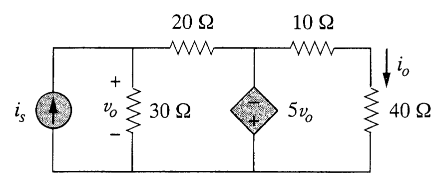


Figure 3.89 For Prob. 3.47.

3.48 Find the mesh currents i_1, i_2, and i_3 in the network of Fig. 3.90.

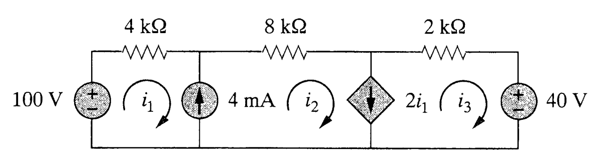


Figure 3.90 For Prob. 3.48.

3.49 Find v_x and i_x in the circuit shown in Fig. 3.91.

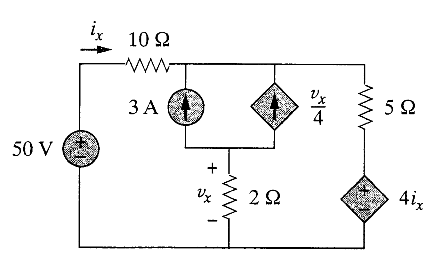


Figure 3.91 For Prob. 3.49.

3.50 Find v_o and i_o in the circuit of Fig. 3.92.

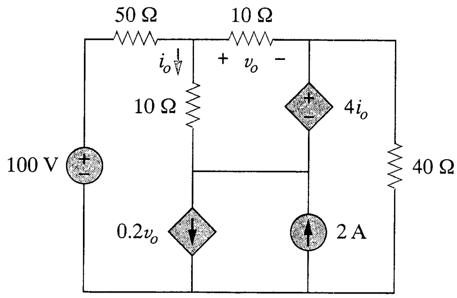


Figure 3.92 For Prob. 3.50.

Section 3.6 Nodal and Mesh Analyses by Inspection

3.51 Obtain the node-voltage equations for the circuit in Fig. 3.93 by inspection. Determine the node voltages v_1 and v_2.

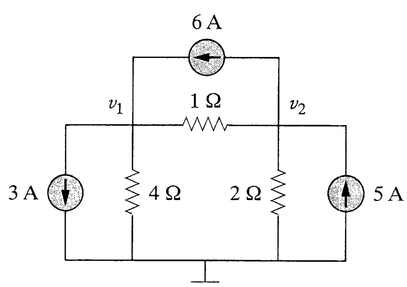


Figure 3.93 For Prob. 3.51.

3.52 By inspection, write the node-voltage equations for the circuit in Fig. 3.94 and obtain the node voltages.

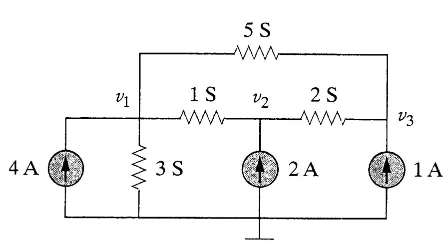


Figure 3.94 For Prob. 3.52.

3.53 For the circuit shown in Fig. 3.95, write the node-voltage equations by inspection.

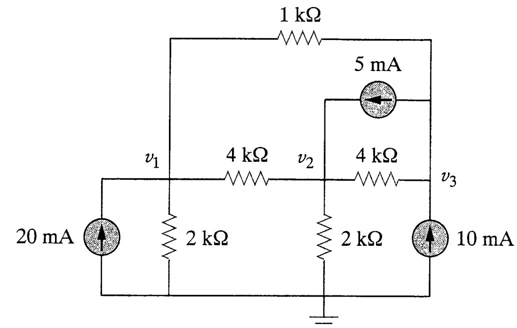


Figure 3.95 For Prob. 3.53.

3.54 Write the node-voltage equations of the circuit in Fig. 3.96 by inspection.

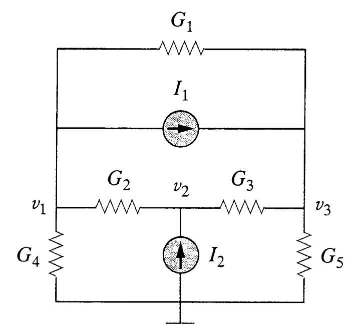


Figure 3.96 For Prob. 3.54.

3.55 Obtain the mesh-current equations for the circuit in Fig. 3.97 by inspection. Calculate the power absorbed by the 8-Ω resistor.

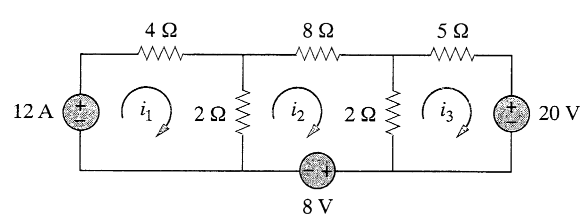


Figure 3.97 For Prob. 3.55.

3.56 By inspection, write the mesh-current equations for the circuit in Fig. 3.98.

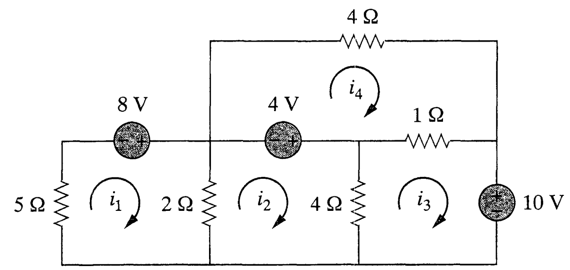


Figure 3.98 For Prob. 3.56.

3.57 Write the mesh-current equations for the circuit in Fig. 3.99.

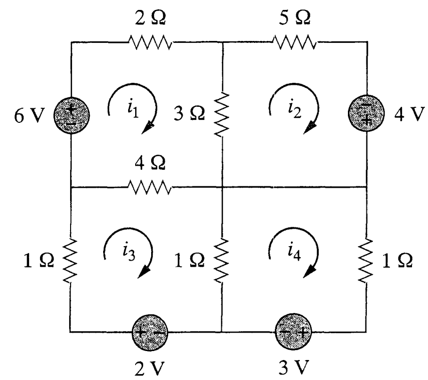


Figure 3.99 For Prob. 3.57.

3.58 By inspection, obtain the mesh-current equations for the circuit in Fig. 3.100.

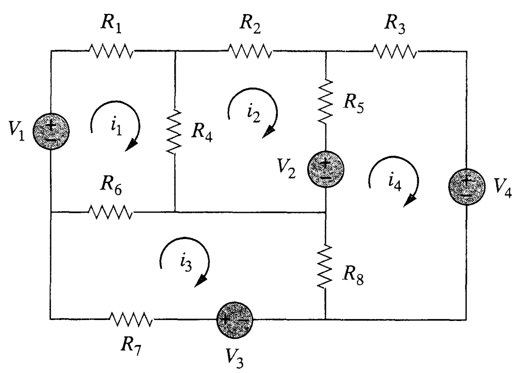


Figure 3.100 For Prob. 3.58.

Section 3.8 Circuit Analysis with *PSpice*

3.59 Use *PSpice* to solve Prob. 3.44.

3.60 Use *PSpice* to solve Prob. 3.22.

3.61 Rework Prob. 3.51 using *PSpice*.

3.62 Find the nodal voltages v_1 through v_4 in the circuit in Fig. 3.101 using *PSpice*.

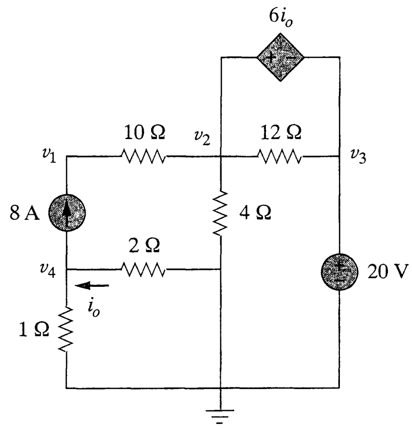


Figure 3.101 For Prob. 3.62.

3.63 Use *PSpice* to solve the problem in Example 3.4.

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

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

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

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

Section 3.9 Applications

3.66 Calculate v_o and i_o in the circuit of Fig. 3.102.

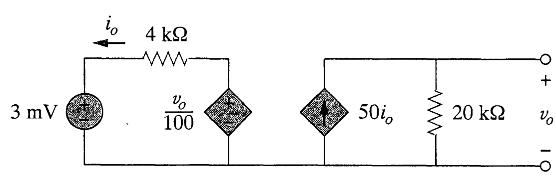


Figure 3.102 For Prob. 3.66.

3.67 For the simplified transistor circuit of Fig. 3.103, calculate the voltage v_o.

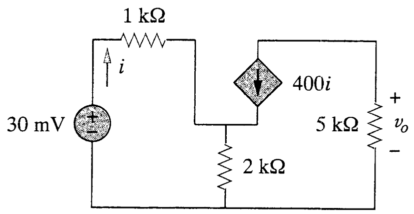


Figure 3.103 For Prob. 3.67.

3.68 For the circuit in Fig. 3.104, find the gain v_o/v_s.

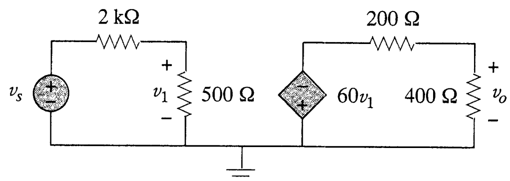


Figure 3.104 For Prob. 3.68.

***3.69** Determine the gain v_o/v_s of the transistor amplifier circuit in Fig. 3.105.

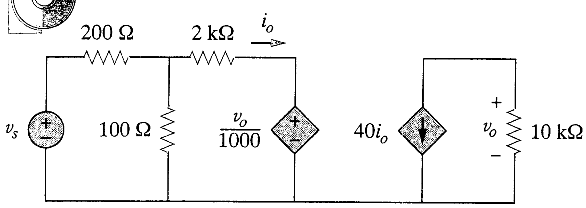


Figure 3.105 For Prob. 3.69.

3.70 For the simple transistor circuit of Fig. 3.106, let $\beta = 75$, $V_{BE} = 0.7$ V. What value of v_i is required to give a collector-emitter voltage of 2 V?

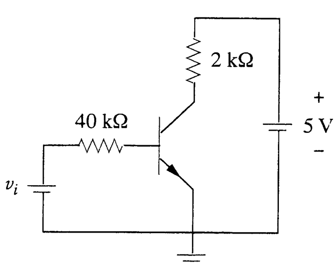


Figure 3.106 For Prob. 3.70.

3.71 Calculate v_s for the transistor in Fig. 3.107 given that $v_o = 4$ V, $\beta = 150$, $V_{BE} = 0.7$ V.

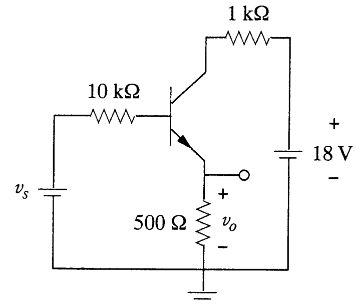


Figure 3.107 For Prob. 3.71.

3.72 For the transistor circuit of Fig. 3.108, find I_B, V_{CE}, and v_o. Take $\beta = 200$, $V_{BE} = 0.7$ V.

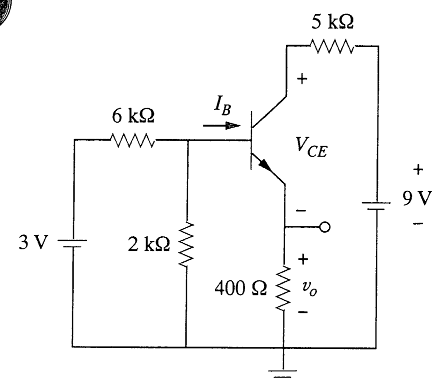


Figure 3.108 For Prob. 3.72.

3.73 Find I_B and V_C for the circuit in Fig. 3.109. Let $\beta = 100$, $V_{BE} = 0.7$ V.

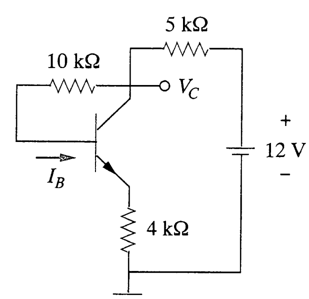


Figure 3.109 For Prob. 3.73.

COMPREHENSIVE PROBLEMS

***3.74** Rework Example 3.11 with hand calculation.

4.11 SUMMARY

1. A linear network consists of linear elements, linear dependent sources, and linear independent sources.
2. Network theorems are used to reduce a complex circuit to a simpler one, thereby making circuit analysis much simpler.
3. The superposition principle states that for a circuit having multiple independent sources, the voltage across (or current through) an element is equal to the algebraic sum of all the individual voltages (or currents) due to each independent source acting one at a time.
4. Source transformation is a procedure for transforming a voltage source in series with a resistor to a current source in parallel with a resistor, or vice versa.
5. Thevenin's and Norton's theorems allow us to isolate a portion of a network while the remaining portion of the network is replaced by an equivalent network. The Thevenin equivalent consists of a voltage source V_{Th} in series with a resistor R_{Th}, while the Norton equivalent consists of a current source I_N in parallel with a resistor R_N. The two theorems are related by source transformation.

$$R_N = R_{Th}, \qquad I_N = \frac{V_{Th}}{R_{Th}}$$

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

REVIEW QUESTIONS

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

(a) −2 (b) −0.2 (c) 0.2
(d) 2 (e) 20

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

(a) True (b) False

4.3 The superposition principle applies to power calculation.

(a) True (b) False

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

(a) 25 Ω (b) 20 Ω
(c) 5 Ω (d) 4 Ω

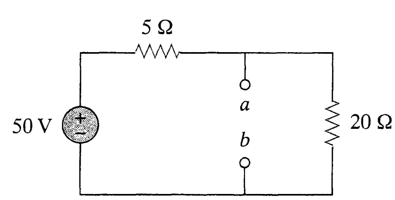


Figure 4.67 For Review Questions 4.4 to 4.6.

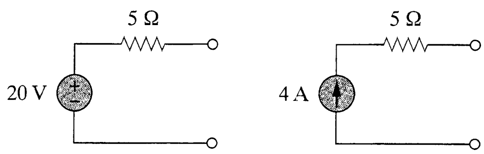
4.5 The Thevenin voltage across terminals a and b of the circuit in Fig. 4.67 is:

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

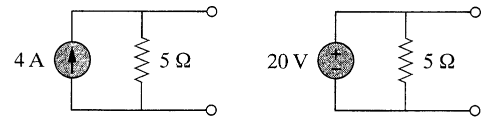
4.6 The Norton current at terminals a and b of the circuit in Fig. 4.67 is:
(a) 10 A (b) 2.5 A
(c) 2 A (d) 0 A

4.7 The Norton resistance R_N is exactly equal to the Thevenin resistance R_{Th}.
(a) True (b) False

4.8 Which pair of circuits in Fig. 4.68 are equivalent?
(a) a and b (b) b and d
(c) a and c (d) c and d



(a) (b)



(c) (d)

Figure 4.68 For Review Question 4.8.

4.9 A load is connected to a network. At the terminals to which the load is connected, $R_{Th} = 10\ \Omega$ and $V_{Th} = 40$ V. The maximum power supplied to the load is:
(a) 160 W (b) 80 W
(c) 40 W (d) 1 W

4.10 The source is supplying the maximum power to the load when the load resistance equals the source resistance.
(a) True (b) False

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

PROBLEMS

Section 4.2 Linearity Property

4.1 Calculate the current i_o in the current of Fig. 4.69. What does this current become when the input voltage is raised to 10 V?

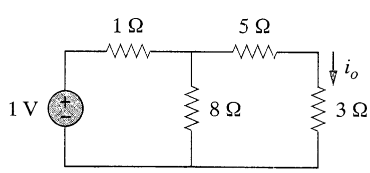


Figure 4.69 For Prob. 4.1.

4.2 Find v_o in the circuit of Fig. 4.70. If the source current is reduced to 1 μA, what is v_o?

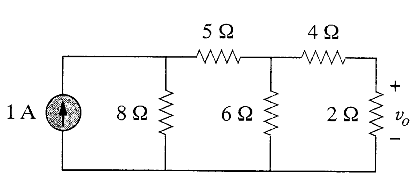


Figure 4.70 For Prob. 4.2.

4.3 (a) In the circuit in Fig. 4.71, calculate v_o and i_o when $v_s = 1$ V.
(b) Find v_o and i_o when $v_s = 10$ V.
(c) What are v_o and i_o when each of the 1-Ω resistors is replaced by a 10-Ω resistor and $v_s = 10$ V?

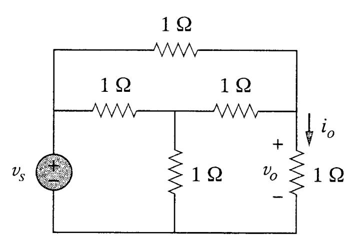


Figure 4.71 For Prob. 4.3.

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

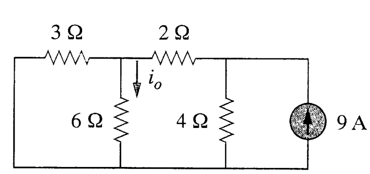


Figure 4.72 For Prob. 4.4.

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

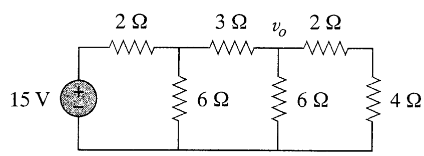


Figure 4.73 For Prob. 4.5.

Section 4.3 Superposition

4.6 Apply superposition to find i in the circuit of Fig. 4.74.

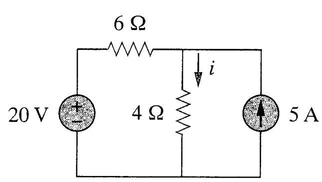


Figure 4.74 For Prob. 4.6.

4.7 Given the circuit in Fig. 4.75, calculate i_x and the power dissipated by the 10-Ω resistor using superposition.

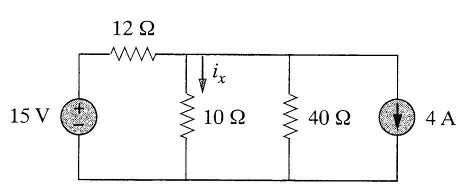


Figure 4.75 For Prob. 4.7.

4.8 For the circuit in Fig. 4.76, find the terminal voltage V_{ab} using superposition.

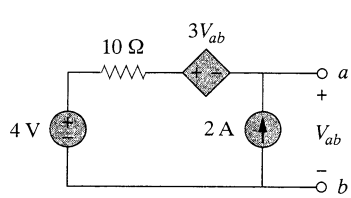


Figure 4.76 For Prob. 4.8.

4.9 Use superposition principle to find i in Fig. 4.77.

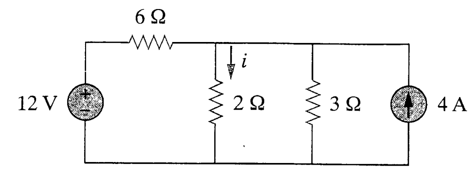


Figure 4.77 For Prob. 4.9.

4.10 Determine v_o in the circuit of Fig. 4.78 using the superposition principle.

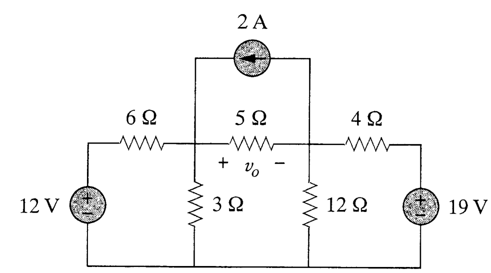


Figure 4.78 For Prob. 4.10.

4.11 Apply the superposition principle to find v_o in the circuit of Fig. 4.79.

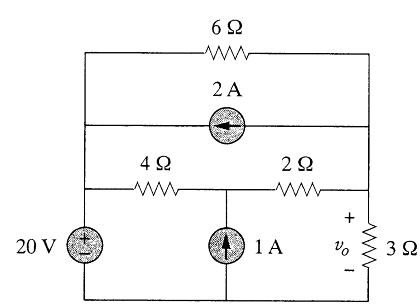


Figure 4.79 For Prob. 4.11.

4.12 For the circuit in Fig. 4.80, use superposition to find i. Calculate the power delivered to the 3-Ω resistor.

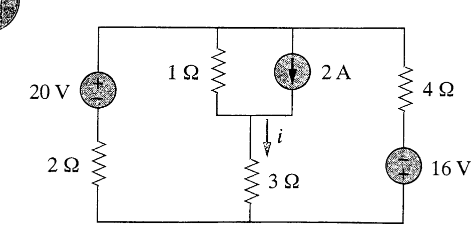


Figure 4.80 For Probs. 4.12 and 4.45.

4.13 Given the circuit in Fig. 4.81, use superposition to get i_o.

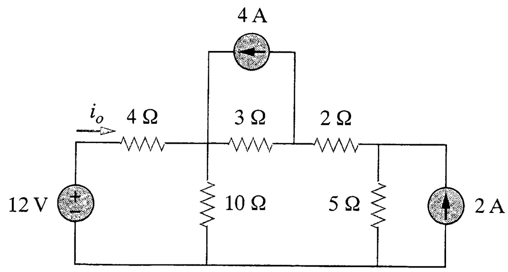


Figure 4.81 For Probs. 4.13 and 4.23.

4.14 Use superposition to obtain v_x in the circuit of Fig. 4.82. Check your result using *PSpice*.

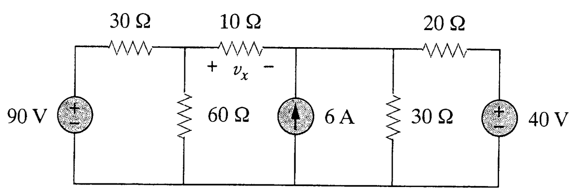


Figure 4.82 For Prob. 4.14.

4.15 Find v_x in Fig. 4.83 by superposition.

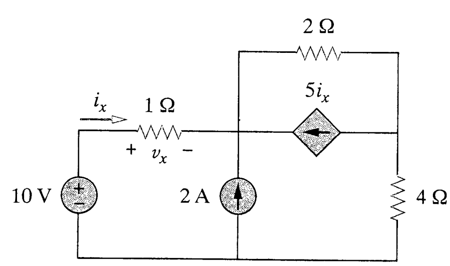


Figure 4.83 For Prob. 4.15.

4.16 Use superposition to solve for i_x in the circuit of Fig. 4.84.

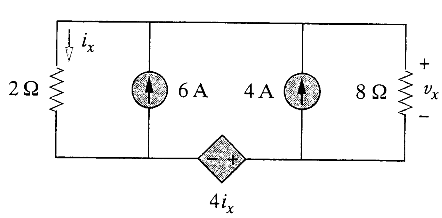


Figure 4.84 For Prob. 4.16.

Section 4.4 Source Transformation

4.17 Find i in Prob. 4.9 using source transformation.

4.18 Apply source transformation to determine v_o and i_o in the circuit in Fig. 4.85.

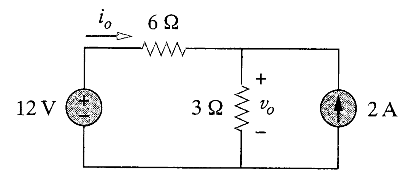


Figure 4.85 For Prob. 4.18.

4.19 For the circuit in Fig. 4.86, use source transformation to find i.

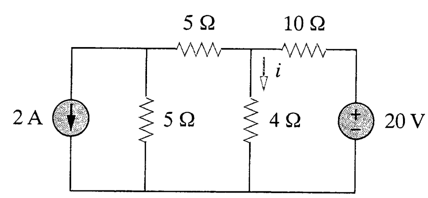


Figure 4.86 For Prob. 4.19.

4.20 Obtain v_o in the circuit of Fig. 4.87 using source transformation. Check your result using *PSpice*.

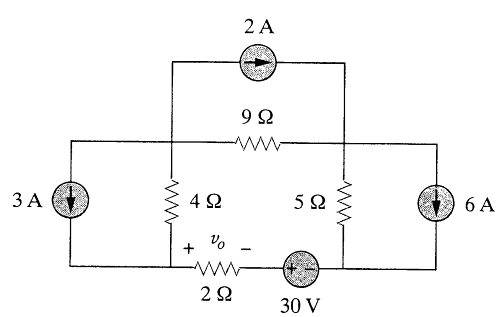


Figure 4.87 For Prob. 4.20.

4.21 Use source transformation to solve Prob. 4.14.

4.22 Apply source transformation to find v_x in the circuit of Fig. 4.88.

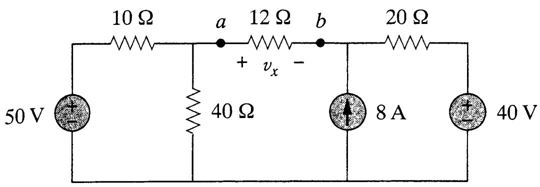


Figure 4.88 For Probs. 4.22 and 4.32.

4.23 Given the circuit in Fig. 4.81, use source transformation to find i_o.

4.24 Use source transformation to find v_o in the circuit of Fig. 4.89.

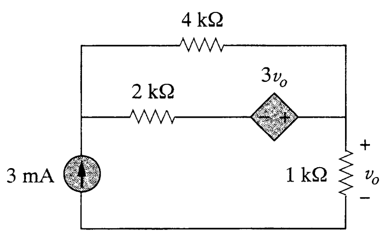


Figure 4.89 For Prob. 4.24.

4.25 Determine v_x in the circuit of Fig. 4.90 using source transformation.

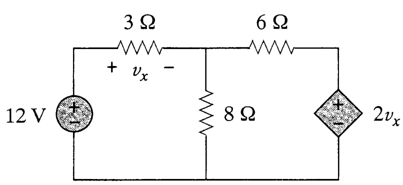


Figure 4.90 For Prob. 4.25.

4.26 Use source transformation to find i_x in the circuit of Fig. 4.91.

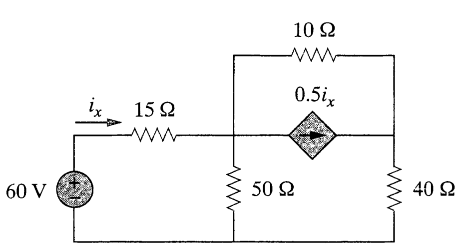


Figure 4.91 For Prob. 4.26.

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

4.27 Determine R_{Th} and V_{Th} at terminals 1-2 of each of the circuits in Fig. 4.92.

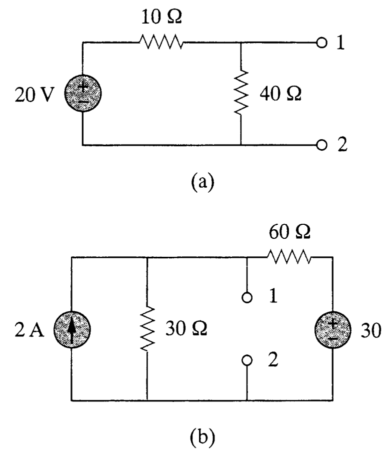


Figure 4.92 For Probs. 4.27 and 4.37.

4.28 Find the Thevenin equivalent at terminals *a*-*b* of the circuit in Fig. 4.93.

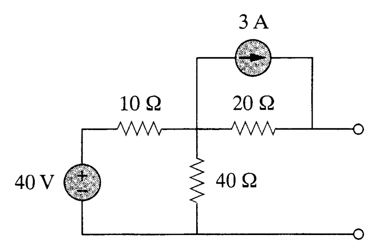


Figure 4.93 For Probs. 4.28 and 4.39.

4.29 Use Thevenin's theorem to find v_o in Prob. 4.10.

4.30 Solve for the current i in the circuit of Fig. 4.94 using Thevenin's theorem. (*Hint:* Find the Thevenin equivalent across the 12-Ω resistor.)

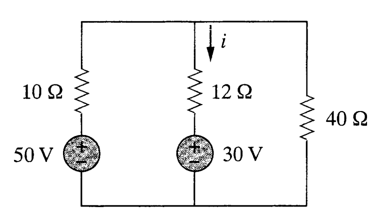


Figure 4.94 For Prob. 4.30.

4.31 For Prob. 4.8, obtain the Thevenin equivalent at terminals *a*-*b*.

4.32 Given the circuit in Fig. 4.88, obtain the Thevenin equivalent at terminals a-b and use the result to get v_x.

***4.33** For the circuit in Fig. 4.95, find the Thevenin equivalent between terminals a and b.

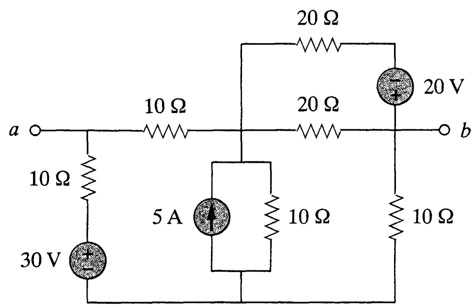


Figure 4.95 For Prob. 4.33.

4.34 Find the Thevenin equivalent looking into terminals a-b of the circuit in Fig. 4.96 and solve for i_x.

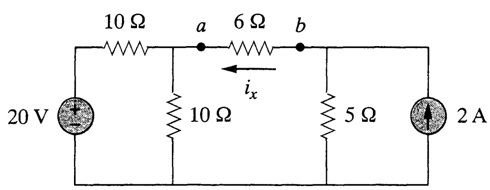


Figure 4.96 For Prob. 4.34.

4.35 For the circuit in Fig. 4.97, obtain the Thevenin equivalent as seen from terminals:
(a) a-b (b) b-c

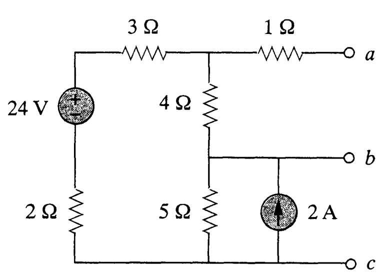


Figure 4.97 For Prob. 4.35.

4.36 Find the Norton equivalent of the circuit in Fig. 4.98.

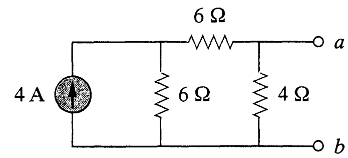


Figure 4.98 For Prob. 4.36.

4.37 Obtain R_N and I_N at terminals 1 and 2 of each of the circuits in Fig. 4.92.

4.38 Determine the Norton equivalent at terminals a-b for the circuit in Fig. 4.99.

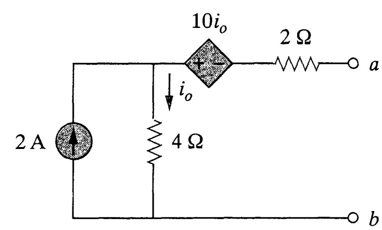


Figure 4.99 For Prob. 4.38.

4.39 Find the Norton equivalent looking into terminals a-b of the circuit in Fig. 4.93.

4.40 Obtain the Norton equivalent of the circuit in Fig. 4.100 to the left of terminals a-b. Use the result to find current i.

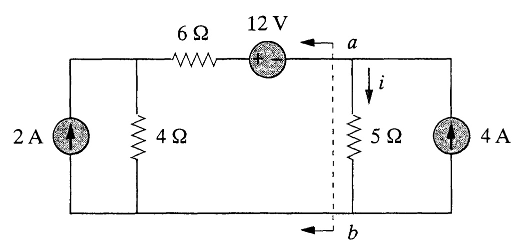


Figure 4.100 For Prob. 4.40.

4.41 Given the circuit in Fig. 4.101, obtain the Norton equivalent as viewed from terminals:
(a) a-b (b) c-d

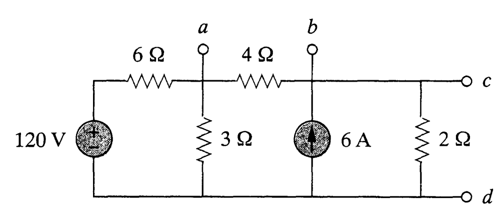


Figure 4.101 For Prob. 4.41.

*An asterisk indicates a challenging problem.

4.42 For the transistor model in Fig. 4.102, obtain the Thevenin equivalent at terminals a-b.

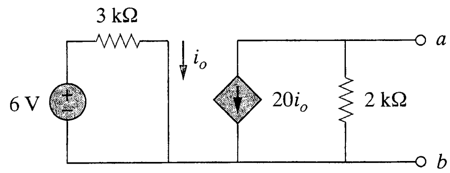


Figure 4.102 For Prob. 4.42.

4.43 Find the Norton equivalent at terminals a-b of the circuit in Fig. 4.103.

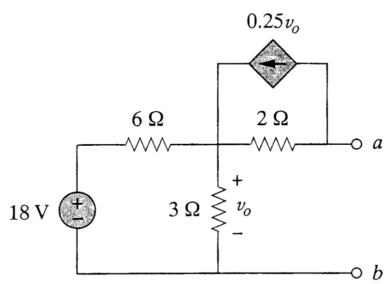


Figure 4.103 For Prob. 4.43.

***4.44** Obtain the Norton equivalent at terminals a-b of the circuit in Fig. 4.104.

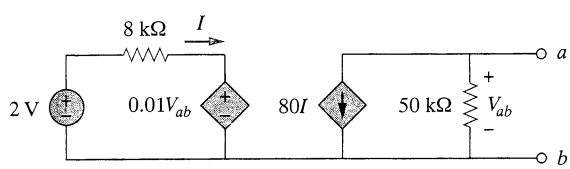


Figure 4.104 For Prob. 4.44.

4.45 Use Norton's theorem to find current i in the circuit of Fig. 4.80.

4.46 Obtain the Thevenin and Norton equivalent circuits at the terminals a-b for the circuit in Fig. 4.105.

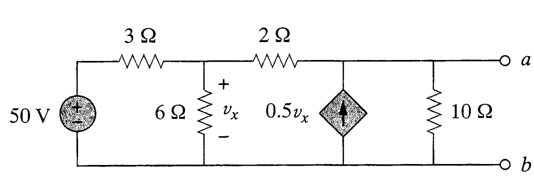


Figure 4.105 For Probs. 4.46 and 4.65.

4.47 The network in Fig. 4.106 models a bipolar transistor common-emitter amplifier connected to a load. Find the Thevenin resistance seen by the load.

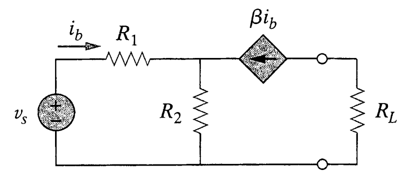


Figure 4.106 For Prob. 4.47.

4.48 Determine the Thevenin and Norton equivalents at terminals a-b of the circuit in Fig. 4.107.

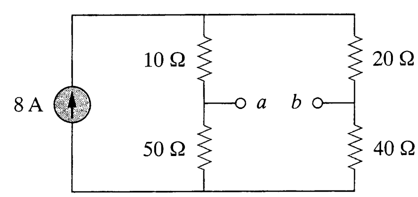


Figure 4.107 For Probs. 4.48 and 4.66.

***4.49** For the circuit in Fig. 4.108, find the Thevenin and Norton equivalent circuits at terminals a-b.

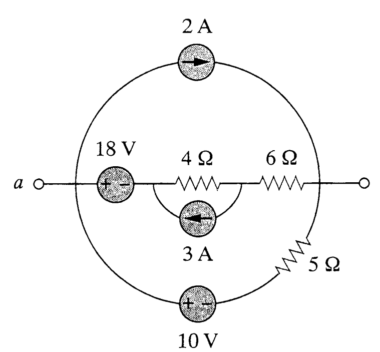


Figure 4.108 For Probs. 4.49 and 4.67.

***4.50** Obtain the Thevenin and Norton equivalent circuits at terminals a-b of the circuit in Fig. 4.109.

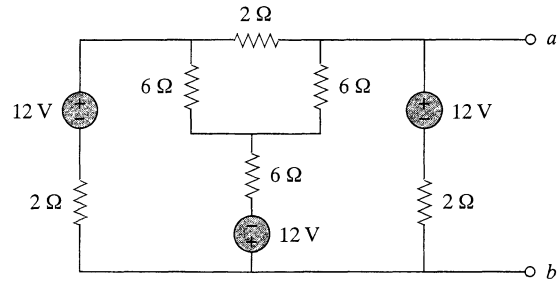


Figure 4.109 For Prob. 4.50.

***4.51** Find the Thevenin equivalent of the circuit in Fig. 4.110.

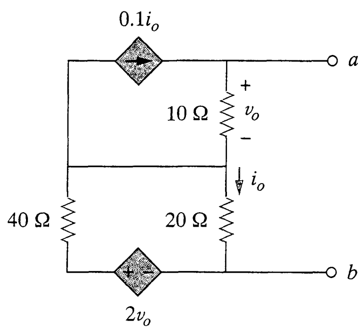


Figure 4.110 For Prob. 4.51.

4.52 Find the Norton equivalent for the circuit in Fig. 4.111.

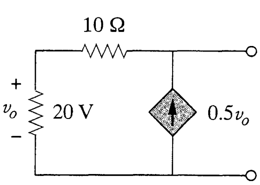


Figure 4.111 For Prob. 4.52.

4.53 Obtain the Thevenin equivalent seen at terminals *a-b* of the circuit in Fig. 4.112.

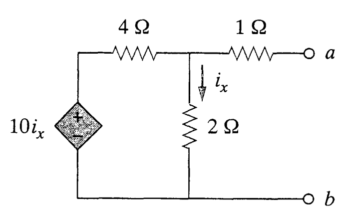


Figure 4.112 For Prob. 4.53.

Section 4.8 Maximum Power Transfer

4.54 Find the maximum power that can be delivered to the resistor *R* in the circuit in Fig. 4.113.

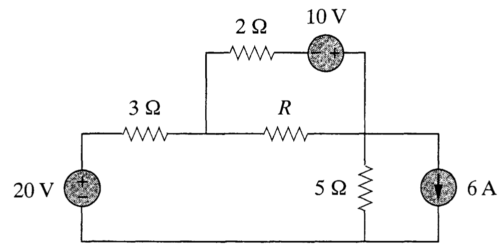


Figure 4.113 For Prob. 4.54.

4.55 Refer to Fig. 4.114. For what value of *R* is the power dissipated in *R* maximum? Calculate that power.

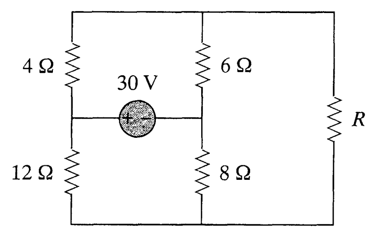


Figure 4.114 For Prob. 4.55.

***4.56** Compute the value of *R* that results in maximum power transfer to the 10-Ω resistor in Fig. 4.115. Find the maximum power.

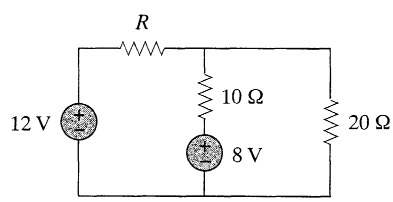


Figure 4.115 For Prob. 4.56.

4.57 Find the maximum power transferred to resistor *R* in the circuit of Fig. 4.116.

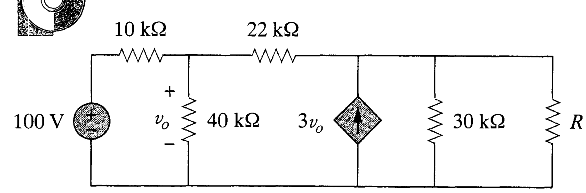


Figure 4.116 For Prob. 4.57.

4.58 For the circuit in Fig. 4.117, what resistor connected across terminals *a-b* will absorb maximum power from the circuit? What is that power?

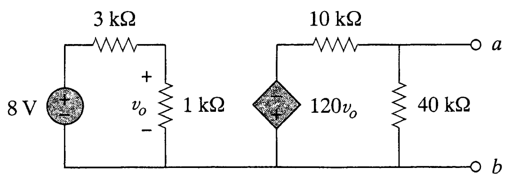


Figure 4.117 For Prob. 4.58.

4.59 (a) For the circuit in Fig. 4.118, obtain the Thevenin equivalent at terminals *a-b*.
(b) Calculate the current in $R_L = 8\ \Omega$.
(c) Find R_L for maximum power deliverable to R_L.
(d) Determine that maximum power.

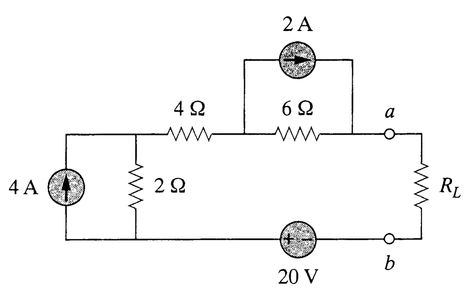


Figure 4.118 For Prob. 4.59.

4.60 For the bridge circuit shown in Fig. 4.119, find the load R_L for maximum power transfer and the maximum power absorbed by the load.

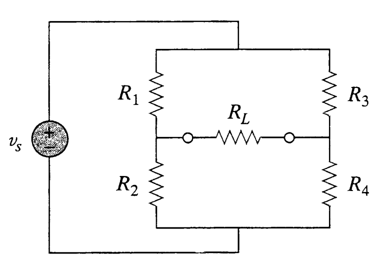


Figure 4.119 For Prob. 4.60.

4.61 For the circuit in Fig. 4.120, determine the value of *R* such that the maximum power delivered to the load is 3 mW.

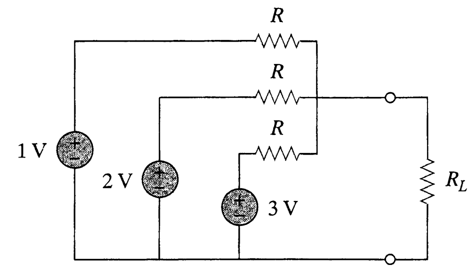


Figure 4.120 For Prob. 4.61.

Section 4.9 Verifying Circuit Theorems with *PSpice*

4.62 Solve Prob. 4.28 using *PSpice*.

4.63 Use *PSpice* to solve Prob. 4.35.

4.64 Use *PSpice* to solve Prob. 4.42.

4.65 Obtain the Thevenin equivalent of the circuit in Fig. 4.105 using *PSpice*.

4.66 Use *PSpice* to find the Thevenin equivalent circuit at terminals *a-b* of the circuit in Fig. 4.107.

4.67 For the circuit in Fig. 4.108, use *PSpice* to find the Thevenin equivalent at terminals *a-b*.

Section 4.10 Applications

4.68 A battery has a short-circuit current of 20 A and an open-circuit voltage of 12 V. If the battery is connected to an electric bulb of resistance 2 Ω, calculate the power dissipated by the bulb.

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

Terminal Voltage	12 V	0 V
Terminal Current	0 V	1.5 A

Find the Thevenin equivalent of the network.

4.70 A black box with a circuit in it is connected to a variable resistor. An ideal ammeter (with zero resistance) and an ideal voltmeter (with infinite resistance) are used to measure current and voltage as shown in Fig. 4.121. The results are shown in the table below.

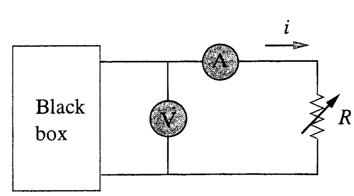


Figure 4.121 For Prob. 4.70.

(a) Find i when $R = 4\ \Omega$.

(b) Determine the maximum power from the box.

$R(\Omega)$	$V(\mathrm{V})$	$i(\mathrm{A})$
2	3	1.5
8	8	1.0
14	10.5	0.75

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

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

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

4.72 The Wheatstone bridge circuit shown in Fig. 4.122 is used to measure the resistance of a strain gauge. The adjustable resistor has a linear taper with a maximum value of 100 Ω. If the resistance of the strain gauge is found to be 42.6 Ω, what fraction of the full slider travel is the slider when the bridge is balanced?

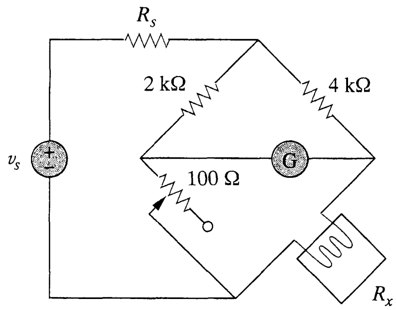


Figure 4.122 For Prob. 4.72.

4.73 (a) In the Wheatstone bridge circuit of Fig. 4.123, select the values of R_1 and R_3 such that the bridge can measure R_x in the range of 0–10 Ω.

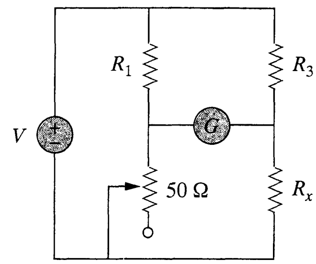


Figure 4.123 For Prob. 4.73.

(b) Repeat for the range of 0–100 Ω.

***4.74** Consider the bridge circuit of Fig. 4.124. Is the bridge balanced? If the 10-kΩ resistor is replaced by an 18-kΩ resistor, what resistor connected between terminals a-b absorbs the maximum power? What is this power?

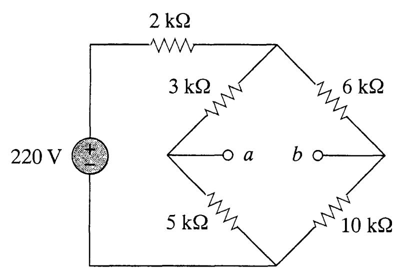


Figure 4.124 For Prob. 4.74.

COMPREHENSIVE PROBLEMS

4.75 The circuit in Fig. 4.125 models a common-emitter transistor amplifier. Find i_x using source transformation.

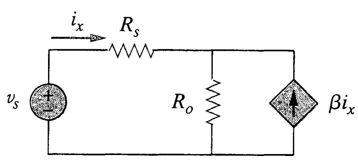


Figure 4.125 For Prob. 4.75.

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

(a) By specifying R_s and R_p of the interface circuit in Fig. 4.126, design an attenuator that will meet the following requirements:

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

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

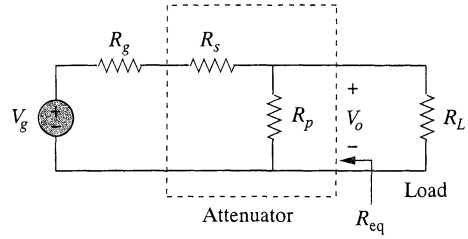


Figure 4.126 For Prob. 4.76.

*4.77 A dc voltmeter with a sensitivity of 20 kΩ/V is used to find the Thevenin equivalent of a linear network. Readings on two scales are as follows:

(a) 0–10 V scale: 4 V (b) 0–50 V scale: 5 V

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

*4.78 A resistance array is connected to a load resistor R and a 9-V battery as shown in Fig. 4.127.

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

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

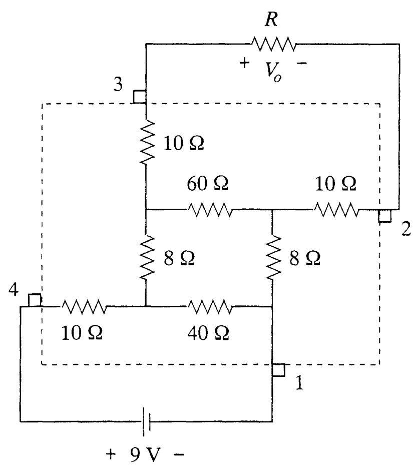


Figure 4.127 For Prob. 4.78.

4.79 A common-emitter amplifier circuit is shown in Fig. 4.128. Obtain the Thevenin equivalent to the left of points B and E.

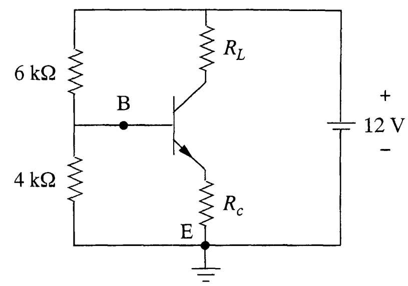
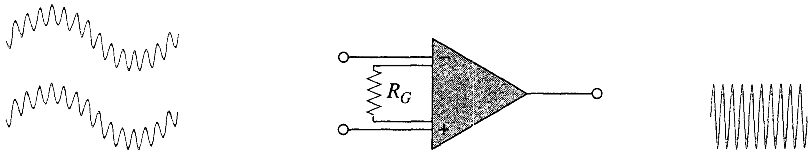


Figure 4.128 For Prob. 4.79.

*4.80 For Practice Prob. 4.17, determine the current through the 40-Ω resistor and the power dissipated by the resistor.



Small differential signals riding on larger common–mode signals

Instrumentation amplifier

Amplified differential signal, No common-mode signal

Figure 5.38 The IA rejects common voltages but amplifies small signal voltages.
(Source: T. L. Floyd, Electronic Devices, 2nd ed., Englewood Cliffs, NJ: Prentice Hall, 1996, p. 795.)

1. The voltage gain is adjusted by *one* external resistor R_G.
2. The input impedance of both inputs is very high and does not vary as the gain is adjusted.
3. The output v_o depends on the difference between the inputs v_1 and v_2, not on the voltage common to them (common-mode voltage).

Due to the widespread use of IAs, manufacturers have developed these amplifiers on single-package units. A typical example is the LH0036, developed by National Semiconductor. The gain can be varied from 1 to 1,000 by an external resistor whose value may vary from 100 Ω to 10 kΩ.

EXAMPLE 5.13

In Fig. 5.37, let $R = 10\ \text{k}\Omega$, $v_1 = 2.011$ V, and $v_2 = 2.017$ V. If R_G is adjusted to 500 Ω, determine: (a) the voltage gain, (b) the output voltage v_o.

Solution:

(a) The voltage gain is

$$A_v = 1 + \frac{2R}{R_G} = 1 + \frac{2 \times 10{,}000}{500} = 41$$

(b) The output voltage is

$$v_o = A_v(v_2 - v_1) = 41(2.017 - 2.011) = 41(6)\ \text{mV} = 246\ \text{mV}$$

PRACTICE PROBLEM 5.13

Determine the value of the external gain-setting resistor R_G required for the IA in Fig. 5.37 to produce a gain of 142 when $R = 25$ kΩ.

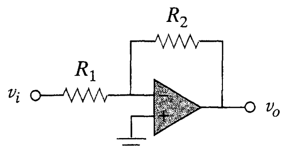
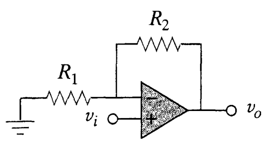
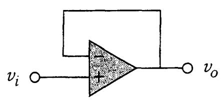
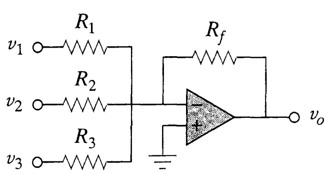
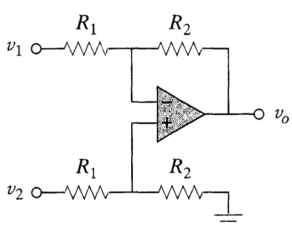
Answer: 354.6 Ω.

5.11 SUMMARY

1. The op amp is a high-gain amplifier that has high input resistance and low output resistance.

2. Table 5.3 summarizes the op amp circuits considered in this chapter. The expression for the gain of each amplifier circuit holds whether the inputs are dc, ac, or time-varying in general.

TABLE 5.3 Summary of basic op amp circuits.

Op amp circuit	Name/output-input relationship
	Inverting amplifier $v_o = -\frac{R_2}{R_1} v_i$
	Noninverting amplifier $v_o = \left(1 + \frac{R_2}{R_1}\right) v_i$
	Voltage follower $v_o = v_i$
	Summer $v_o = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3\right)$
	Difference amplifier $v_o = \frac{R_2}{R_1}(v_2 - v_1)$

3. An ideal op amp has an infinite input resistance, a zero output resistance, and an infinite gain.
4. For an ideal op amp, the current into each of its two input terminals is zero, and the voltage across its input terminals is negligibly small.
5. In an inverting amplifier, the output voltage is a negative multiple of the input.
6. In a noninverting amplifier, the output is a positive multiple of the input.
7. In a voltage follower, the output follows the input.
8. In a summing amplifier, the output is the weighted sum of the inputs.

9. In a difference amplifier, the output is proportional to the difference of the two inputs.
10. Op amp circuits may be cascaded without changing their input-output relationships.
11. *PSpice* can be used to analyze an op amp circuit.
12. Typical applications of the op amp considered in this chapter include the digital-to-analog converter and the instrumentation amplifier.

REVIEW QUESTIONS

5.1 The two input terminals of an op amp are labeled as:
(a) high and low.
(b) positive and negative.
(c) inverting and noninverting.
(d) differential and nondifferential.

5.2 For an ideal op amp, which of the following statements are not true?
(a) The differential voltage across the input terminals is zero.
(b) The current into the input terminals is zero.
(c) The current from the output terminal is zero.
(d) The input resistance is zero.
(e) The output resistance is zero.

5.3 For the circuit in Fig. 5.39, voltage v_o is:
(a) -6 V (b) -5 V
(c) -1.2 V (d) -0.2 V

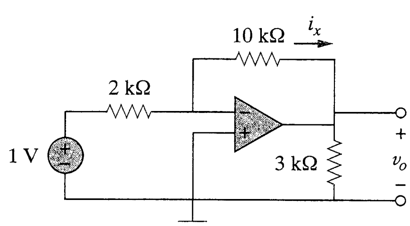


Figure 5.39 For Reivew Questions 5.3 and 5.4.

5.4 For the circuit in Fig. 5.39, current i_x is:
(a) 0.6 A (b) 0.5 A
(c) 0.2 A (d) 1/12 A

5.5 If $v_s = 0$ in the circuit of Fig. 5.40, current i_o is:
(a) -10 A (b) -2.5 A
(c) 10/12 A (d) 10/14 A

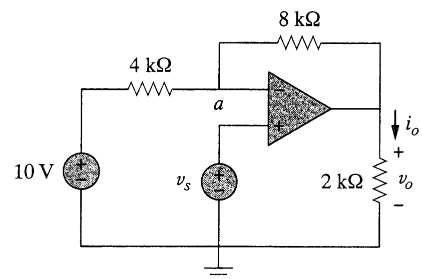


Figure 5.40 For Review Questions 5.5 to 5.7.

5.6 If $v_s = 8$ V in the circuit of Fig. 5.40, the output voltage is:
(a) -44 V (b) -8 V
(c) 4 V (d) 7 V

5.7 Refer to Fig. 5.40. If $v_s = 8$ V, voltage v_a is:
(a) -8 V (b) 0 V
(c) 10/3 V (d) 8 V

5.8 The power absorbed by the 4-kΩ resistor in Fig. 5.41 is:
(a) 9 mW (b) 4 mW
(c) 2 mW (d) 1 mW

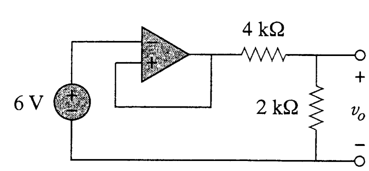


Figure 5.41 For Review Question 5.8.

5.9 Which of these amplifiers is used in a digital-to-analog converter?
(a) noninverter (b) voltage follower
(c) summer (d) difference amplifier

5.10 Difference amplifiers are used in:
(a) instrumentation amplifiers
(b) voltage followers
(c) voltage regulators
(d) buffers
(e) summing amplifiers
(f) subtracting amplifiers

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

PROBLEMS

Section 5.2 Operational Amplifiers

5.1 The equivalent model of a certain op amp is shown in Fig. 5.42. Determine:
(a) the input resistance
(b) the output resistance
(c) the voltage gain in dB.

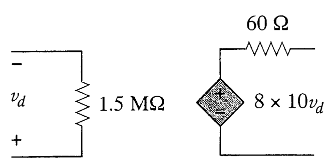


Figure 5.42 For Prob. 5.1.

5.2 The open-loop gain of an op amp is 100,000. Calculate the output voltage when there are inputs of $+10\ \mu$V on the inverting terminal and $+20\ \mu$V on the noninverting terminal.

5.3 Determine the output voltage when $-20\ \mu$V is applied to the inverting terminal of an op amp and $+30\ \mu$V to its noninverting terminal. Assume that the op amp has an open-loop gain of 200,000.

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

5.5 For the op amp circuit of Fig. 5.43, the op amp has an open-loop gain of 100,000, an input resistance of 10 kΩ, and an output resistance of 100 Ω. Find the voltage gain v_o/v_i using the nonideal model of the op amp.

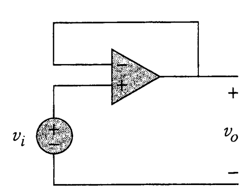


Figure 5.43 For Prob. 5.5.

5.6 Using the same parameters for the 741 op amp in Example 5.1, find v_o in the op amp circuit of Fig. 5.44.

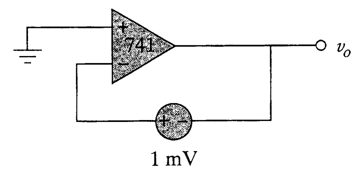


Figure 5.44 For Prob. 5.6.

5.7 The op amp in Fig. 5.45 has $R_i = 100$ kΩ, $R_o = 100\ \Omega$, $A = 100{,}000$. Find the differential voltage v_d and the output voltage v_o.

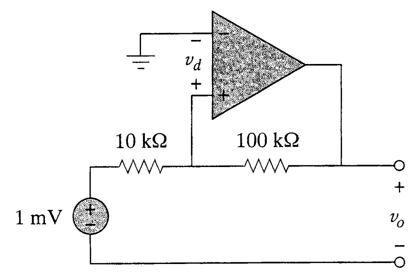


Figure 5.45 For Prob. 5.7.

Section 5.3 Ideal Op Amp

5.8 Obtain v_o for each of the op amp circuits in Fig. 5.46.

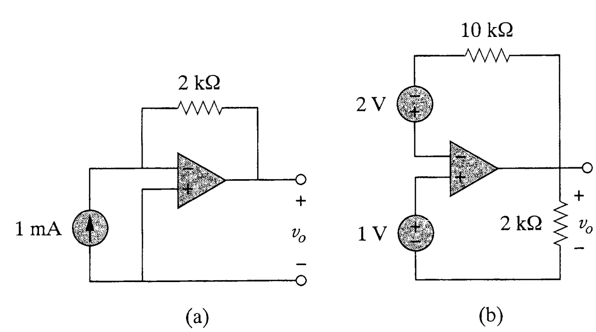


Figure 5.46 For Prob. 5.8.

5.9 Determine v_o for each of the op amp circuits in Fig. 5.47.

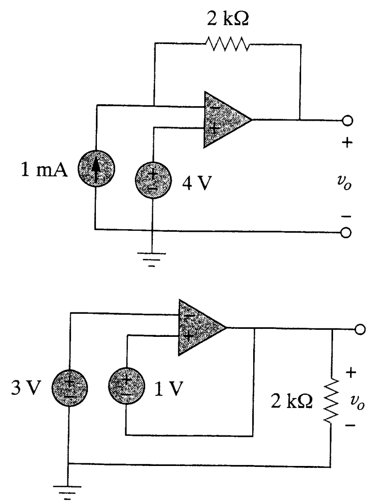


Figure 5.47 For Prob. 5.9.

5.10 Find the gain v_o/v_s of the circuit in Fig. 5.48.

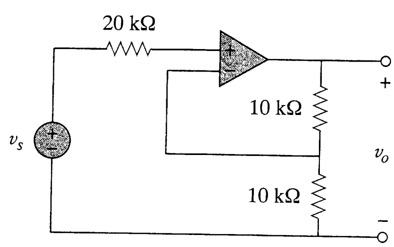


Figure 5.48 For Prob. 5.10.

5.11 Find v_o and i_o in the circuit in Fig. 5.49.

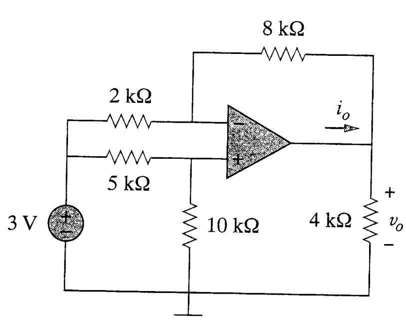


Figure 5.49 For Prob. 5.11.

5.12 Refer to the op amp circuit in Fig. 5.50. Determine the power supplied by the voltage source.

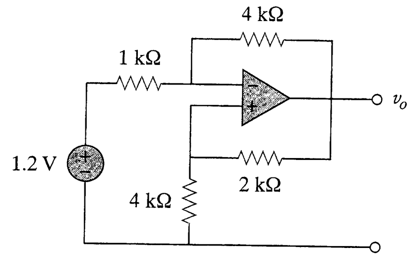


Figure 5.50 For Prob. 5.12.

5.13 Find v_o and i_o in the circuit of Fig. 5.51.

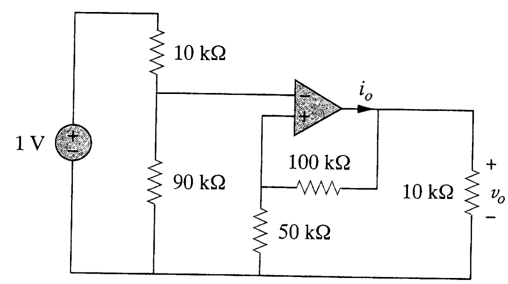


Figure 5.51 For Prob. 5.13.

5.14 Determine the output voltage v_o in the circuit of Fig. 5.52.

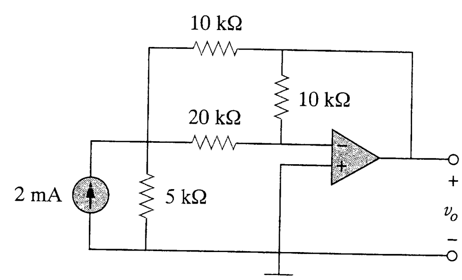


Figure 5.52 For Prob. 5.14.

Section 5.4 Inverting Amplifier

5.15 (a) For the circuit shown in Fig. 5.53, show that the gain is

$$\frac{v_o}{v_i} = -\frac{1}{R}\left(R_1 + R_2 + \frac{R_1 R_2}{R_3}\right)$$

(b) Evaluate the gain when $R = 10\text{ k}\Omega$, $R_1 = 100\text{ k}\Omega$, $R_2 = 50\text{ k}\Omega$, $R_3 = 25\text{ k}\Omega$.

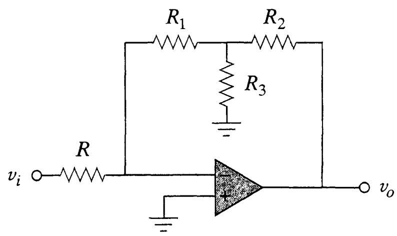


Figure 5.53 For Prob. 5.15.

5.16 Calculate the gain v_o/v_i when the switch in Fig. 5.54 is in:
(a) position 1 (b) position 2 (c) position 3

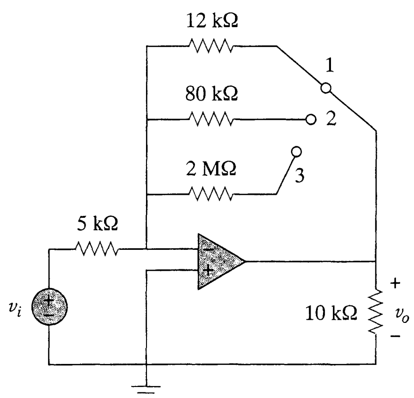


Figure 5.54 For Prob. 5.16.

5.17 Calculate the gain v_o/v_i of the op amp circuit in Fig. 5.55.

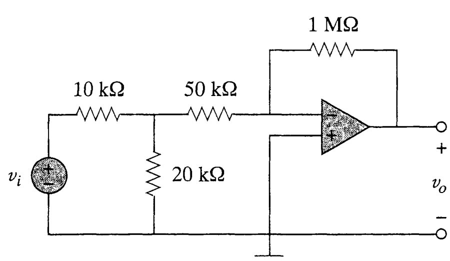


Figure 5.55 For Prob. 5.17.

5.18 Determine i_o in the circuit of Fig. 5.56.

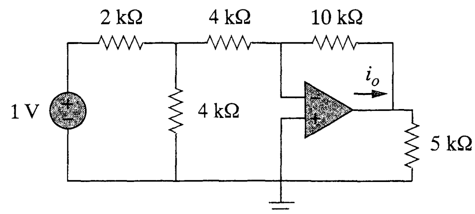


Figure 5.56 For Prob. 5.18.

5.19 In the circuit in Fig. 5.57, calculate v_o if $v_s = 0$.

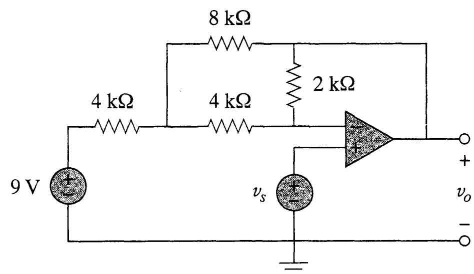


Figure 5.57 For Prob. 5.19.

5.20 Repeat the previous problem if $v_s = 3$ V.

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

Section 5.5 Noninverting Amplifier

5.22 Find v_a and v_o in the op amp circuit of Fig. 5.58.

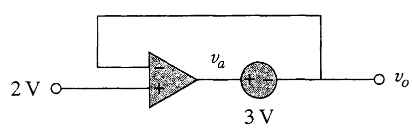


Figure 5.58 For Prob. 5.22.

5.23 Refer to Fig. 5.59.
(a) Determine the overall gain v_o/v_i of the circuit.
(b) What value of v_i will result in $v_o = 15\cos 120\pi t$?

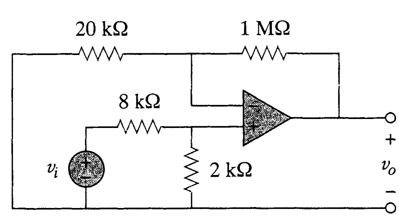


Figure 5.59 For Prob. 5.23.

5.24 Find i_o in the op amp circuit of Fig. 5.60.

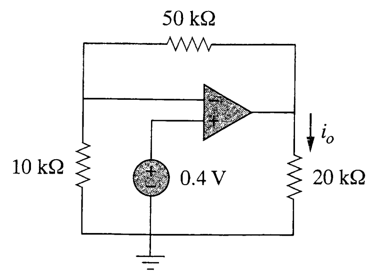


Figure 5.60 For Prob. 5.24.

5.25 In the circuit shown in Fig. 5.61, find i_x and the power absorbed by the 20-Ω resistor.

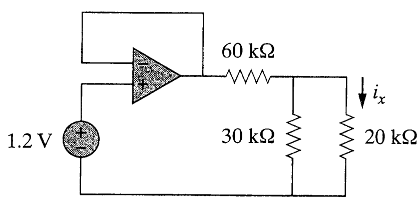


Figure 5.61 For Prob. 5.25.

5.26 For the circuit in Fig. 5.62, find i_x.

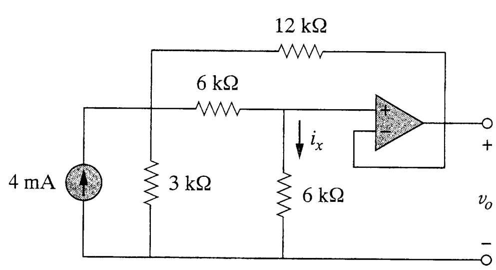


Figure 5.62 For Prob. 5.26.

5.27 Calculate i_x and v_o in the circuit of Fig. 5.63. Find the power dissipated by the 60-kΩ resistor.

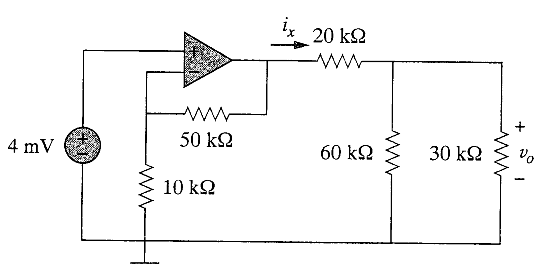


Figure 5.63 For Prob. 5.27.

5.28 Refer to the op amp circuit in Fig. 5.64. Calculate i_x and the power dissipated by the 3-kΩ resistor.

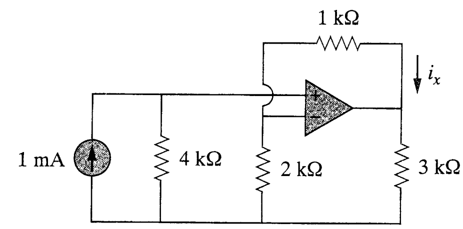


Figure 5.64 For Prob. 5.28.

5.29 Design a noninverting amplifier with a gain of 10.

Section 5.6 Summing Amplifier

5.30 Determine the output of the summing amplifier in Fig. 5.65.

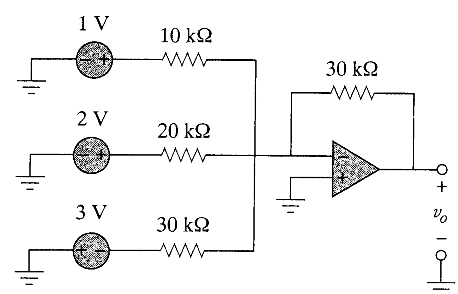


Figure 5.65 For Prob. 5.30.

5.31 Calculate the output voltage due to the summing amplifier shown in Fig. 5.66.

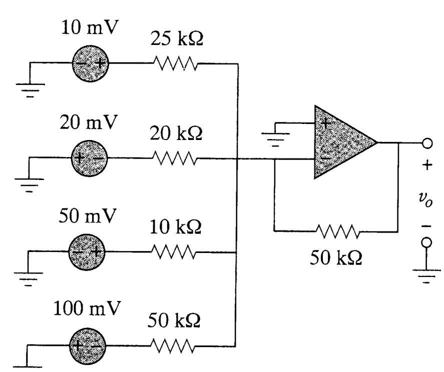


Figure 5.66 For Prob. 5.31.

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

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

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

5.33 A four-input summing amplifier has $R_1 = R_2 = R_3 = R_4 = 12$ kΩ. What value of feedback resistor is needed to make it an averaging amplifier?

5.34 Show that the output voltage v_o of the circuit in Fig. 5.67 is

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

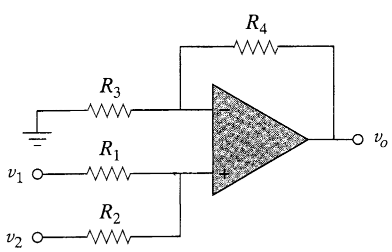


Figure 5.67 For Prob. 5.34.

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

$$v_o = 3v_1 - 2v_2$$

All resistances must be ≤ 100 kΩ.

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

$$-v_{out} = \frac{v_1 - v_2}{3} + \frac{v_3}{2}$$

Section 5.7 Difference Amplifier

5.37 Find v_o and i_o in the differential amplifier of Fig. 5.68.

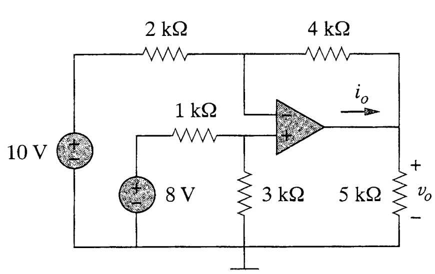


Figure 5.68 For Prob. 5.37.

5.38 The circuit in Fig. 5.69 is a differential amplifier driven by a bridge. Find v_o.

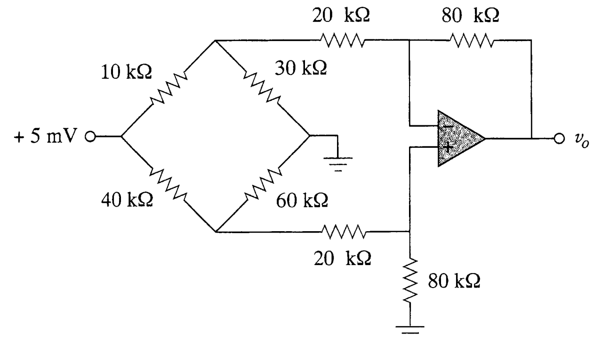


Figure 5.69 For Prob. 5.38.

5.39 Design a difference amplifier to have a gain of 2 and a common mode input resistance of 10 kΩ at each input.

5.40 Design a circuit to amplify the difference between two inputs by 2.

(a) Use only one op amp.

(b) Use two op amps.

5.41 Using two op amps, design a subtractor.

***5.42** The ordinary difference amplifier for fixed-gain operation is shown in Fig. 5.70(a). It is simple and reliable unless gain is made variable. One way of providing gain adjustment without losing simplicity and accuracy is to use the circuit in Fig. 5.70(b). Another way is to use the circuit in Fig. 5.70(c). Show that:

(a) for the circuit in Fig. 5.70(a),

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

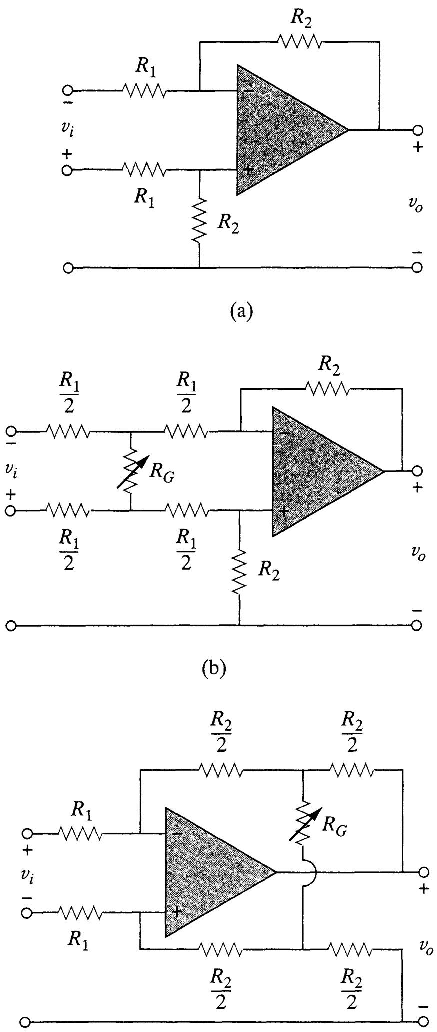
(b) for the circuit in Fig. 5.70(b),

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

(c) for the circuit in Fig. 5.70(c),

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

*An asterisk indicates a challenging problem.



(c)

Figure 5.70 For Prob. 5.42.

Section 5.8 Cascaded Op Amp Circuits

5.43 The individual gains of the stages in a multistage amplifier are shown in Fig. 5.71.

(a) Calculate the overall voltage gain v_o/v_i.

(b) Find the voltage gain that would be needed in a fourth stage which would make the overall gain to be 60 dB when added.

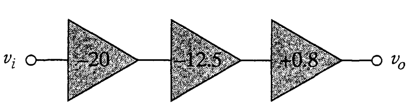


Figure 5.71 For Prob. 5.43.

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

5.45 Refer to the circuit in Fig. 5.72. Calculate i_o if:

(a) $v_s = 12$ mV (b) $v_s = 10\cos 377t$ mV.

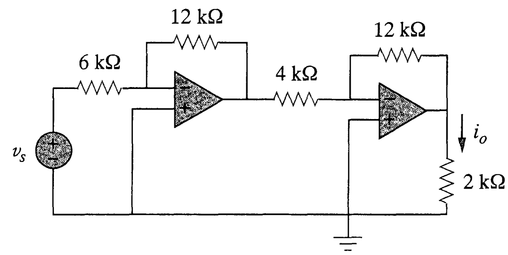


Figure 5.72 For Prob. 5.45.

5.46 Calculate i_o in the op amp circuit of Fig. 5.73.

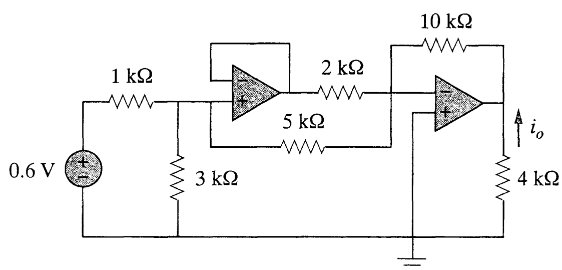


Figure 5.73 For Prob. 5.46.

5.47 Find the voltage gain v_o/v_s of the circuit in Fig. 5.74.

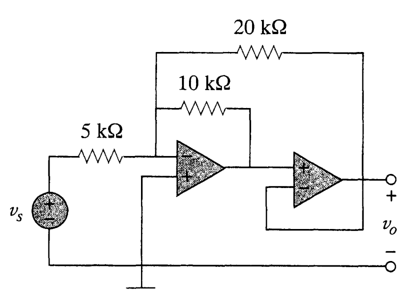


Figure 5.74 For Prob. 5.47.

5.48 Calculate the current gain i_o/i_s of the op amp circuit in Fig. 5.75.

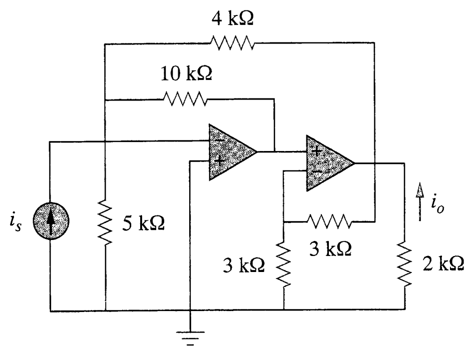


Figure 5.75 For Prob. 5.48.

5.49 Find v_o in terms of v_1 and v_2 in the circuit in Fig. 5.76.

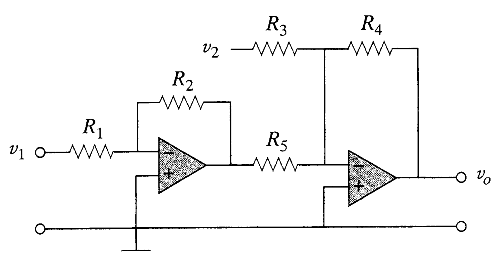


Figure 5.76 For Prob. 5.49.

5.50 Obtain the closed-loop voltage gain v_o/v_i of the circuit in Fig. 5.77.

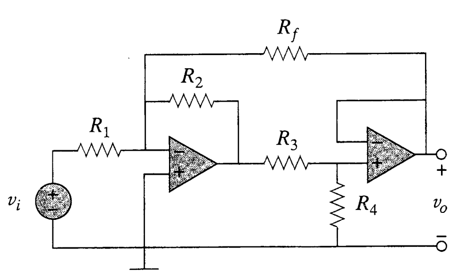


Figure 5.77 For Prob. 5.50.

5.51 Determine the gain v_o/v_i of the circuit in Fig. 5.78.

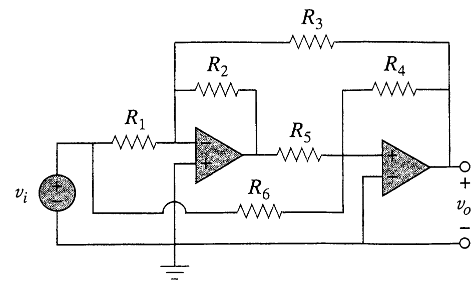


Figure 5.78 For Prob. 5.51.

5.52 For the circuit in Fig. 5.79, find v_o.

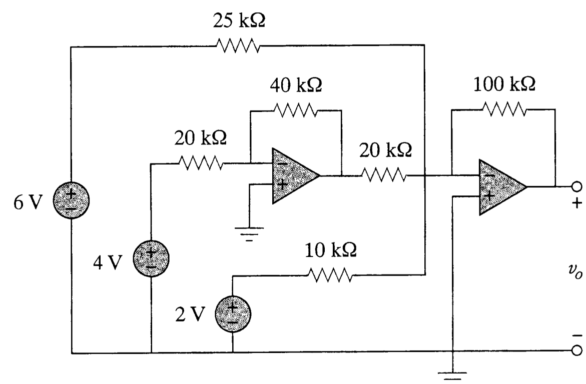


Figure 5.79 For Prob. 5.52.

5.53 Obtain the output v_o in the circuit of Fig. 5.80.

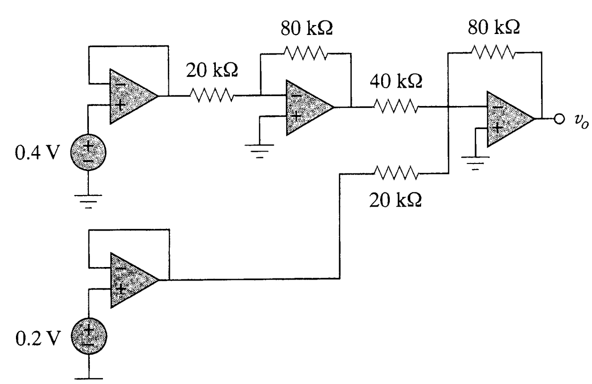


Figure 5.80 For Prob. 5.53.

5.54 Find v_o in the circuit in Fig. 5.81, assuming that $R_f = \infty$ (open circuit).

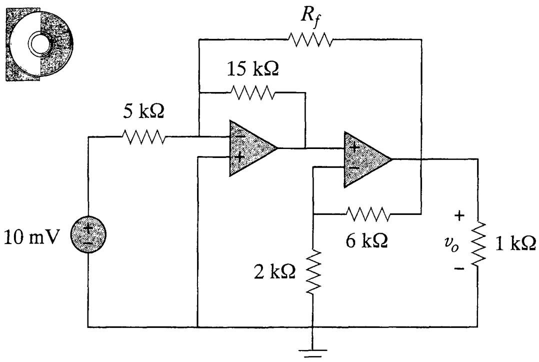


Figure 5.81 For Probs. 5.54 and 5.55.

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

5.56 Determine v_o in the op amp circuit of Fig. 5.82.

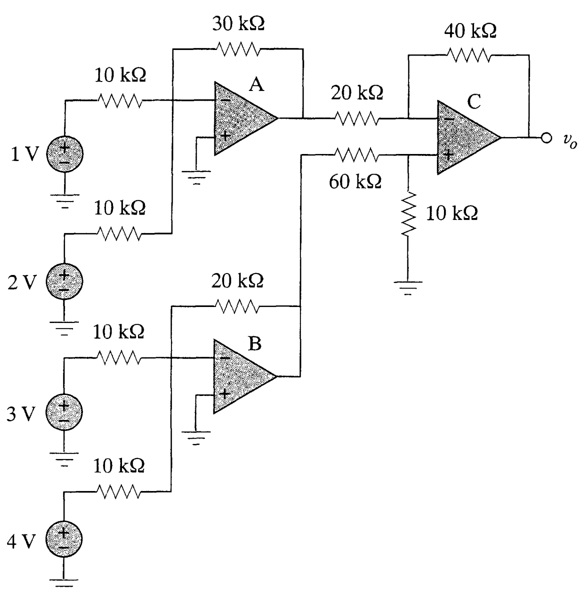


Figure 5.82 For Prob. 5.56.

5.57 Find the load voltage v_L in the circuit of Fig. 5.83.

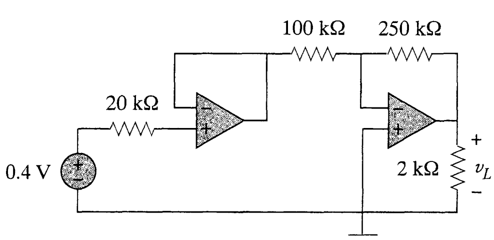


Figure 5.83 For Prob. 5.57.

5.58 Determine the load voltage v_L in the circuit of Fig. 5.84.

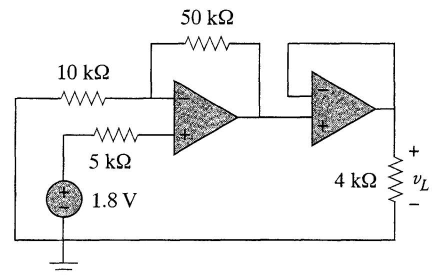


Figure 5.84 For Prob. 5.58.

5.59 Find i_o in the op amp circuit of Fig. 5.85.

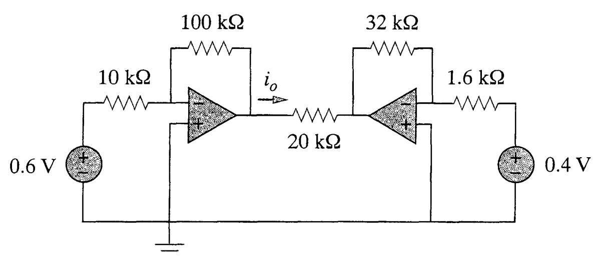


Figure 5.85 For Prob. 5.59.

Section 5.9 Op Amp Circuit Analysis with *PSpice*

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

5.61 Solve Prob. 5.18 using *PSpice* and op amp uA741.

5.62 Solve Prob. 5.38 using *PSpice* and op amp LM324.

5.63 Use *PSpice* to obtain v_o in the circuit of Fig. 5.86.

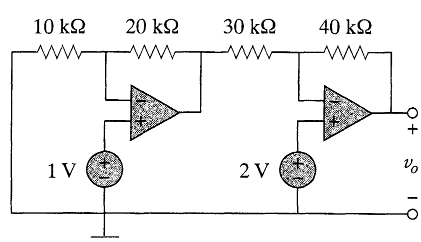


Figure 5.86 For Prob. 5.63.

5.64 Determine v_o in the op amp circuit of Fig. 5.87 using *PSpice*.

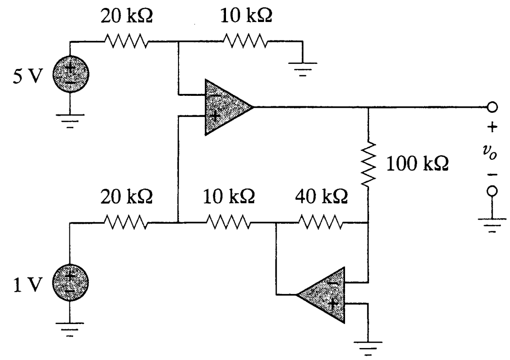


Figure 5.87 For Prob. 5.64.

5.65 Use *PSpice* to solve Prob. 5.56, assuming that the op amps are uA741.

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

Section 5.10 Applications

5.67 A five-bit DAC covers a voltage range of 0 to 7.75 V. Calculate how much voltage each bit is worth.

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

(a) If $|V_o| = 1.1875$ V is desired, what should $[V_1 V_2 V_3 V_4 V_5 V_6]$ be?

(b) Calculate $|V_o|$ if $[V_1 V_2 V_3 V_4 V_5 V_6] = [011011]$.

(c) What is the maximum value $|V_o|$ can assume?

***5.69** A four-bit *R-2R ladder* DAC is presented in Fig. 5.88.

(a) Show that the output voltage is given by

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

(b) If $R_f = 12$ kΩ and $R = 10$ kΩ, find $|V_o|$ for $[V_1 V_2 V_3 V_4] = [1011]$ and $[V_1 V_2 V_3 V_4] = [0101]$.

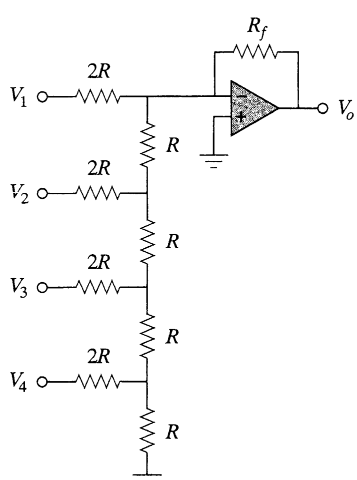


Figure 5.88 For Prob. 5.69.

5.70 If $R_G = 100\ \Omega$ and $R = 20$ kΩ, calculate the voltage gain of the IA in Fig. 5.37.

5.71 Assuming a gain of 200 for an IA, find its output voltage for:

(a) $v_1 = 0.402$ V and $v_2 = 0.386$ V

(b) $v_1 = 1.002$ V and $v_2 = 1.011$ V.

5.72 Figure 5.89 displays a two-op-amp instrumentation amplifier. Derive an expression for v_o in terms of v_1 and v_2. How can this amplifier be used as a subtractor?

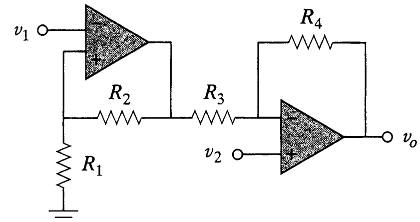


Figure 5.89 For Prob. 5.72.

***5.73** Figure 5.90 shows an instrumentation amplifier driven by a bridge. Obtain the gain v_o/v_i of the amplifier.

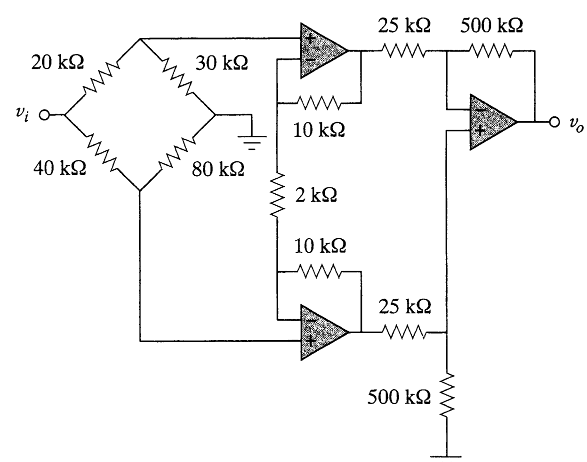


Figure 5.90 For Prob. 5.73.

COMPREHENSIVE PROBLEMS

5.74 A gain of 6 (+ or −, it does not matter) is required in an audio system. Design an op amp circuit to provide the gain with an input resistance of 2 kΩ.

5.75 The op amp circuit in Fig. 5.91 is a *current amplifier.* Find the current gain i_o/i_s of the amplifier.

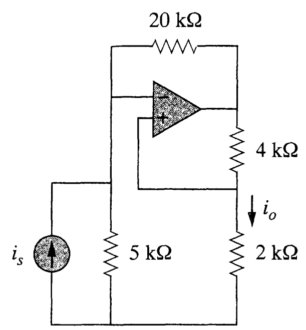


Figure 5.91 For Prob. 5.75.

5.76 A noninverting current amplifier is portrayed in Fig. 5.92. Calculate the gain i_o/i_s. Take $R_1 = 8$ kΩ and $R_2 = 1$ kΩ.

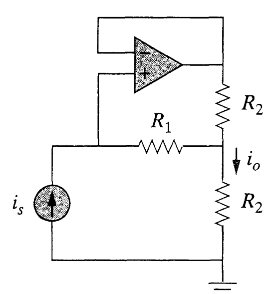


Figure 5.92 For Prob. 5.76.

5.77 Refer to the *bridge amplifier* shown in Fig. 5.93. Determine the voltage gain v_o/v_i.

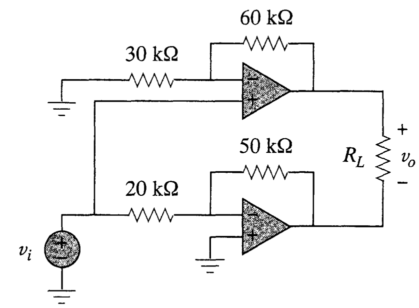


Figure 5.93 For Prob. 5.77.

***5.78** A voltage-to-current converter is shown in Fig. 5.94, which means that $i_L = Av_i$ if $R_1R_2 = R_3R_4$. Find the constant term A.

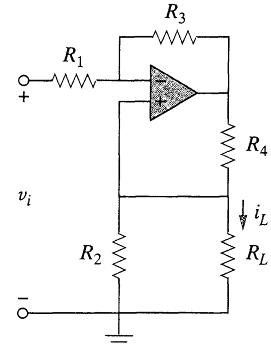


Figure 5.94 For Prob. 5.78.

PRACTICE PROBLEM 6.15

Design an analog computer circuit to solve the differential equation:

$$\frac{d^2v_o}{dt^2} + 3\frac{dv_o}{dt} + 2v_o = 4\cos 10t \qquad t > 0$$

subject to $v_o(0) = 2$, $v_o'(0) = 0$.

Answer: See Fig. 6.41, where $RC = 1$ s.

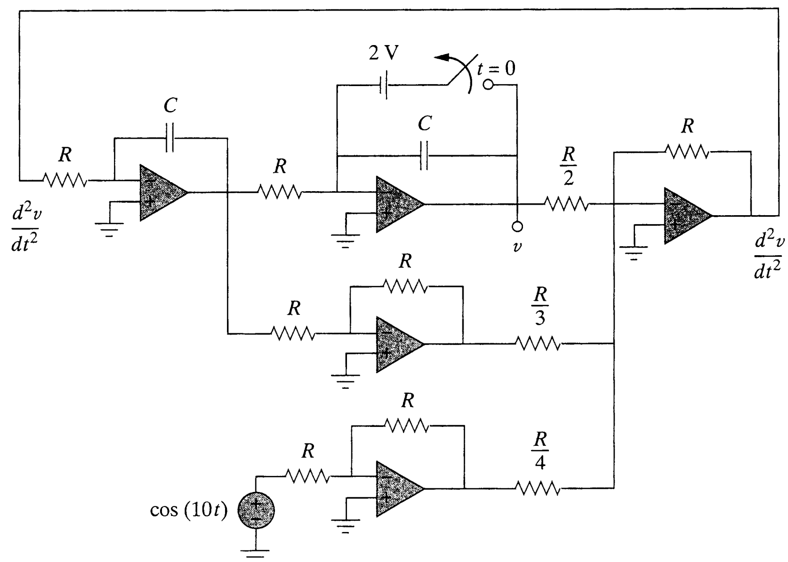


Figure 6.41 For Practice Prob. 6.15.

6.7 SUMMARY

1. The current through a capacitor is directly proportional to the time rate of change of the voltage across it.

$$i = C\frac{dv}{dt}$$

   The current through a capacitor is zero unless the voltage is changing. Thus, a capacitor acts like an open circuit to a dc source.

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

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

   The voltage across a capacitor cannot change instantly.

3. Capacitors in series and in parallel are combined in the same way as conductances.

4. The voltage across an inductor is directly proportional to the time rate of change of the current through it.

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

The voltage across the inductor is zero unless the current is changing. Thus an inductor acts like a short circuit to a dc source.

5. The current through an inductor is directly proportional to the time integral of the voltage across it.

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

The current through an inductor cannot change instantly.

6. Inductors in series and in parallel are combined in the same way resistors in series and in parallel are combined.
7. At any given time t, the energy stored in a capacitor is $\frac{1}{2}Cv^2$, while the energy stored in an inductor is $\frac{1}{2}Li^2$.
8. Three application circuits, the integrator, the differentiator, and the analog computer, can be realized using resistors, capacitors, and op amps.

REVIEW QUESTIONS

6.1 What charge is on a 5-F capacitor when it is connected across a 120-V source?
(a) 600 C (b) 300 C
(c) 24 C (d) 12 C

6.2 Capacitance is measured in:
(a) coulombs (b) joules
(c) henrys (d) farads

6.3 When the total charge in a capacitor is doubled, the energy stored:
(a) remains the same (b) is halved
(c) is doubled (d) is quadrupled

6.4 Can the voltage waveform in Fig. 6.42 be associated with a capacitor?
(a) Yes (b) No

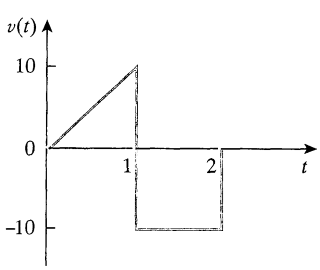


Figure 6.42 For Review Question 6.4.

6.5 The total capacitance of two 40-mF series-connected capacitors in parallel with a 4-mF capacitor is:
(a) 3.8 mF (b) 5 mF (c) 24 mF
(d) 44 mF (e) 84 mF

6.6 In Fig. 6.43, if $i = \cos 4t$ and $v = \sin 4t$, the element is:
(a) a resistor (b) a capacitor (c) an inductor

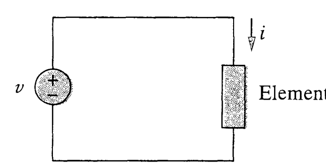


Figure 6.43 For Review Question 6.6.

6.7 A 5-H inductor changes its current by 3 A in 0.2 s. The voltage produced at the terminals of the inductor is:
(a) 75 V (b) 8.888 V
(c) 3 V (d) 1.2 V

6.8 If the current through a 10-mH inductor increases from zero to 2 A, how much energy is stored in the inductor?
(a) 40 mJ (b) 20 mJ
(c) 10 mJ (d) 5 mJ

6.9 Inductors in parallel can be combined just like resistors in parallel.
(a) True (b) False

6.10 For the circuit in Fig. 6.44, the voltage divider formula is:
(a) $v_1 = \frac{L_1 + L_2}{L_1} v_s$ (b) $v_1 = \frac{L_1 + L_2}{L_2} v_s$
(c) $v_1 = \frac{L_2}{L_1 + L_2} v_s$ (d) $v_1 = \frac{L_1}{L_1 + L_2} v_s$

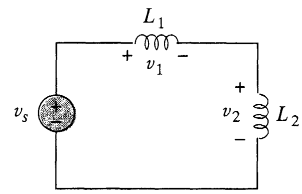


Figure 6.44 For Review Question 6.10.

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

PROBLEMS

Section 6.2 Capacitors

6.1 If the voltage across a 5-F capacitor is $2te^{-3t}$ V, find the current and the power.

6.2 A 40-μF capacitor is charged to 120 V and is then allowed to discharge to 80 V. How much energy is lost?

6.3 In 5 s, the voltage across a 40-mF capacitor changes from 160 V to 220 V. Calculate the average current through the capacitor.

6.4 A current of $6 \sin 4t$ A flows through a 2-F capacitor. Find the voltage $v(t)$ across the capacitor given that $v(0) = 1$ V.

6.5 If the current waveform in Fig. 6.45 is applied to a 20-μF capacitor, find the voltage $v(t)$ across the capacitor. Assume that $v(0) = 0$.

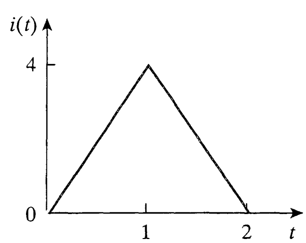


Figure 6.45 For Prob. 6.5.

6.6 The voltage waveform in Fig. 6.46 is applied across a 30-μF capacitor. Draw the current waveform through it.

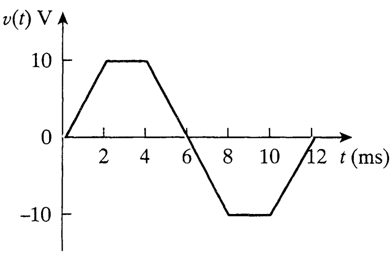


Figure 6.46 For Prob. 6.6.

6.7 At $t = 0$, the voltage across a 50-mF capacitor is 10 V. Calculate the voltage across the capacitor for $t > 0$ when current $4t$ mA flows through it.

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

6.9 If the voltage across a 2-F capacitor is as shown in Fig. 6.47, find the current through the capacitor.

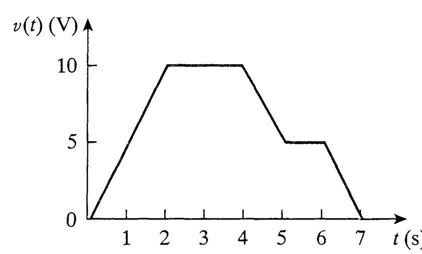


Figure 6.47 For Prob. 6.9.

6.10 The current through an initially uncharged 4-μF capacitor is shown in Fig. 6.48. Find the voltage across the capacitor for $0 < t < 3$.

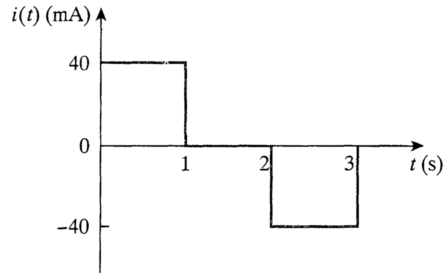


Figure 6.48 For Prob. 6.10.

6.11 A voltage of $60 \cos 4\pi t$ V appears across the terminals of a 3-mF capacitor. Calculate the current through the capacitor and the energy stored in it from $t = 0$ to $t = 0.125$ s.

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

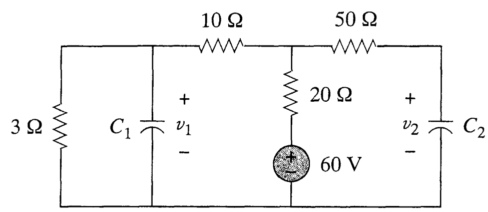


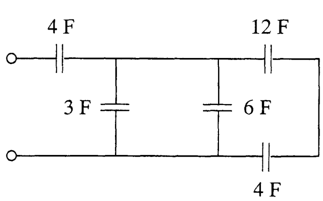
Figure 6.49 For Prob. 6.12.

Section 6.3 Series and Parallel Capacitors

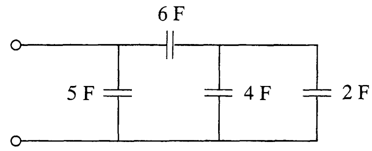
6.13 What is the total capacitance of four 30-mF capacitors connected in:
(a) parallel (b) series

6.14 Two capacitors (20 μF and 30 μF) are connected to a 100-V source. Find the energy stored in each capacitor if they are connected in:
(a) parallel (b) series

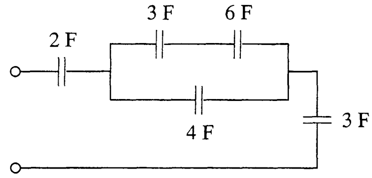
6.15 Determine the equivalent capacitance for each of the circuits in Fig. 6.50.



(a)



(b)



(c)

Figure 6.50 For Prob. 6.15.

6.16 Find C_{eq} for the circuit in Fig. 6.51.

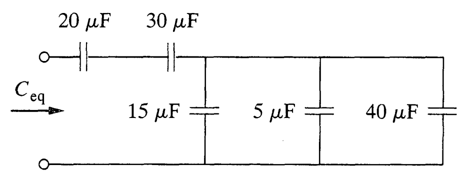


Figure 6.51 For Prob. 6.16.

6.17 Calculate the equivalent capacitance for the circuit in Fig. 6.52. All capacitances are in mF.

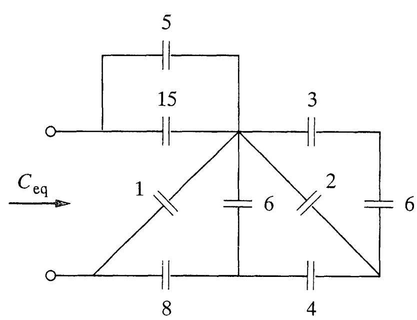


Figure 6.52 For Prob. 6.17.

6.18 Determine the equivalent capacitance at terminals a-b of the circuit in Fig. 6.53.

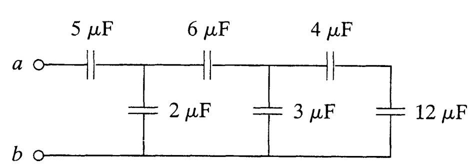


Figure 6.53 For Prob. 6.18.

6.19 Obtain the equivalent capacitance of the circuit in Fig. 6.54.

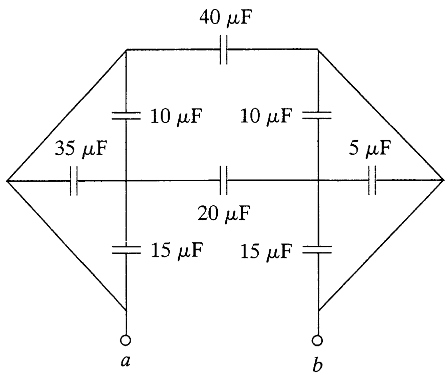


Figure 6.54 For Prob. 6.19.

6.20 For the circuit in Fig. 6.55, determine:
(a) the voltage across each capacitor,
(b) the energy stored in each capacitor.

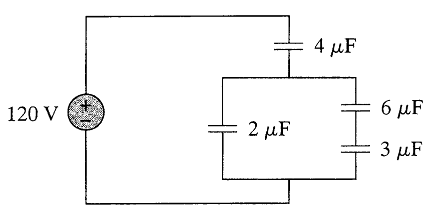


Figure 6.55 For Prob. 6.20.

6.21 Repeat Prob. 6.20 for the circuit in Fig. 6.56.

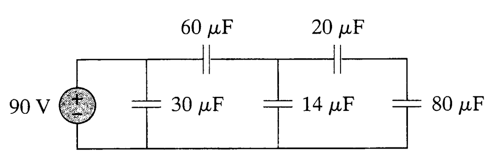


Figure 6.56 For Prob. 6.21.

6.22 (a) Show that the voltage-division rule for two capacitors in series as in Fig. 6.57(a) is

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

assuming that the initial conditions are zero.

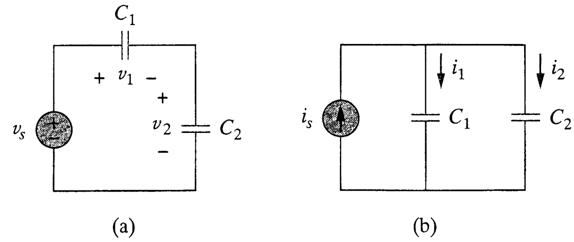


Figure 6.57 For Prob. 6.22.

(b) For two capacitors in parallel as in Fig. 6.57(b), show that the current-division rule is

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

assuming that the initial conditions are zero.

6.23 Three capacitors, $C_1 = 5\ \mu$F, $C_2 = 10\ \mu$F, and $C_3 = 20\ \mu$F, are connected in parallel across a 150-V source. Determine:
(a) the total capacitance,
(b) the charge on each capacitor,
(c) the total energy stored in the parallel combination.

6.24 The three capacitors in the previous problem are placed in series with a 200-V source. Compute:
(a) the total capacitance,
(b) the charge on each capacitor,
(c) the total energy stored in the series combination.

***6.25** Obtain the equivalent capacitance of the network shown in Fig. 6.58.

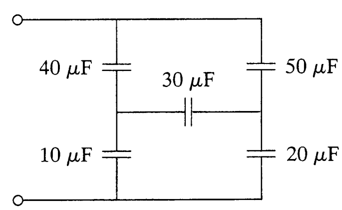


Figure 6.58 For Prob. 6.25.

6.26 Determine C_{eq} for each circuit in Fig. 6.59.

*An asterisk indicates a challenging problem.

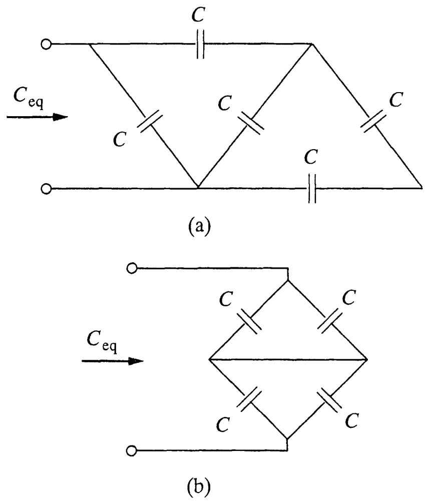


Figure 6.59 For Prob. 6.26.

6.27 Assuming that the capacitors are initially uncharged, find $v_o(t)$ in the circuit in Fig. 6.60.

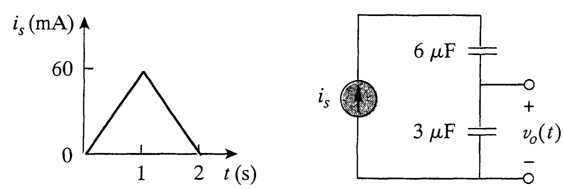


Figure 6.60 For Prob. 6.27.

6.28 If $v(0) = 0$, find $v(t)$, $i_1(t)$, and $i_2(t)$ in the circuit in Fig. 6.61.

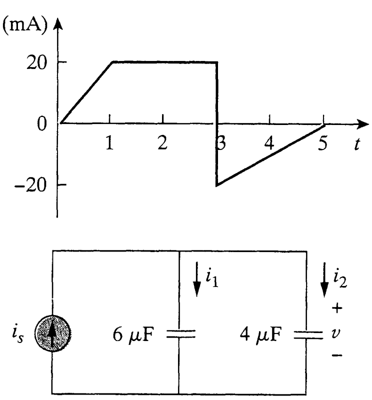


Figure 6.61 For Prob. 6.28.

6.29 For the circuit in Fig. 6.62, let $v = 10e^{-3t}$ V and $v_1(0) = 2$ V. Find:

(a) $v_2(0)$ (b) $v_1(t)$ and $v_2(t)$
(c) $i(t)$, $i_1(t)$, and $i_2(t)$

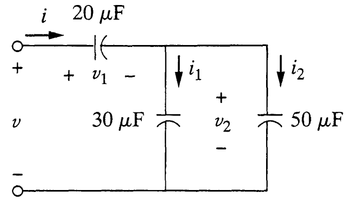


Figure 6.62 For Prob. 6.29.

Section 6.4 Inductors

6.30 The current through a 10-mH inductor is $6e^{-t/2}$ A. Find the voltage and the power at $t = 3$ s.

6.31 The current in a coil increases uniformly from 0.4 to 1 A in 2 s so that the voltage across the coil is 60 mV. Calculate the inductance of the coil.

6.32 The current through a 0.25-mH inductor is $12\cos 2t$ A. Determine the terminal voltage and the power.

6.33 The current through a 12-mH inductor is $4\sin 100t$ A. Find the voltage, and also the energy stored in the inductor for $0 < t < \pi/200$ s.

6.34 The current through a 40-mH inductor is

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

Find the voltage $v(t)$.

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

6.36 If the voltage waveform in Fig. 6.63 is applied across the terminals of a 5-H inductor, calculate the current through the inductor. Assume $i(0) = -1$ A.

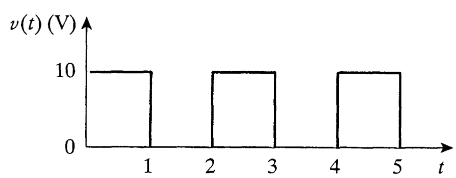


Figure 6.63 For Prob. 6.36.

6.37 The current in an 80-mH inductor increases from 0 to 60 mA. How much energy is stored in the inductor?

6.38 A voltage of $(4 + 10\cos 2t)$ V is applied to a 5-H inductor. Find the current $i(t)$ through the inductor if $i(0) = -1$ A.

6.39 If the voltage waveform in Fig. 6.64 is applied to a 10-mH inductor, find the inductor current $i(t)$. Assume $i(0) = 0$.

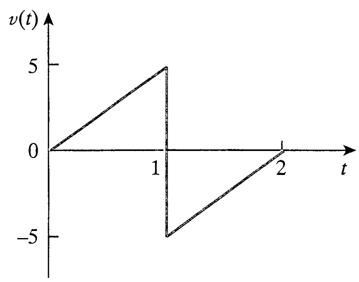


Figure 6.64 For Prob. 6.39.

6.40 Find v_C, i_L, and the energy stored in the capacitor and inductor in the circuit of Fig. 6.65 under dc conditions.

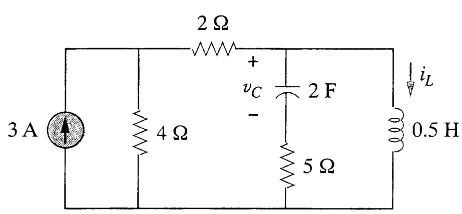


Figure 6.65 For Prob. 6.40.

6.41 For the circuit in Fig. 6.66, calculate the value of R that will make the energy stored in the capacitor the same as that stored in the inductor under dc conditions.

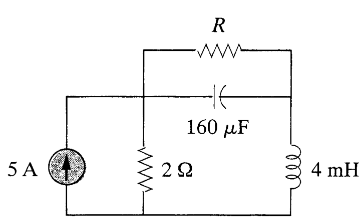


Figure 6.66 For Prob. 6.41.

6.42 Under dc conditions, find the voltage across the capacitors and the current through the inductors in the circuit of Fig. 6.67.

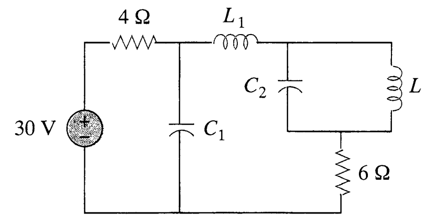


Figure 6.67 For Prob. 6.42.

Section 6.5 Series and Parallel Inductors

6.43 Find the equivalent inductance for each circuit in Fig. 6.68.

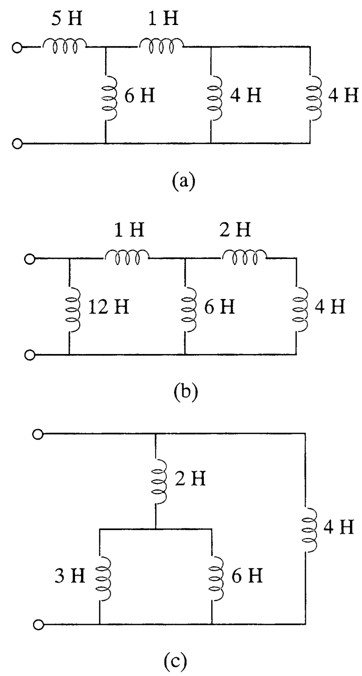


Figure 6.68 For Prob. 6.43.

6.44 Obtain L_{eq} for the inductive circuit of Fig. 6.69. All inductances are in mH.

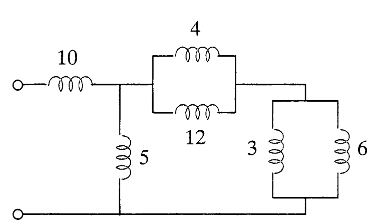


Figure 6.69 For Prob. 6.44.

6.45 Determine L_{eq} at terminals a-b of the circuit in Fig. 6.70.

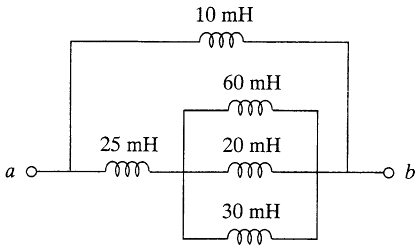


Figure 6.70 For Prob. 6.45.

6.46 Find L_{eq} at the terminals of the circuit in Fig. 6.71.

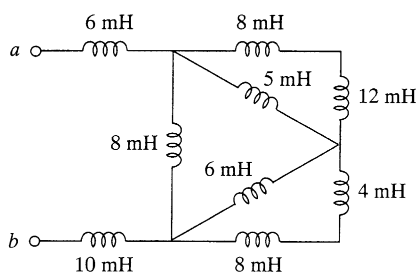


Figure 6.71 For Prob. 6.46.

6.47 Find the equivalent inductance looking into the terminals of the circuit in Fig. 6.72.

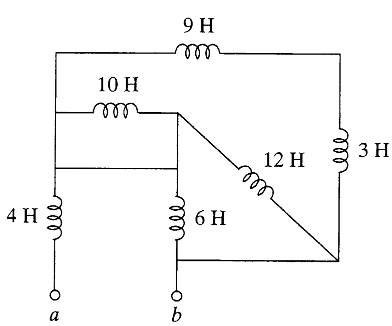


Figure 6.72 For Prob. 6.47.

6.48 Determine L_{eq} in the circuit in Fig. 6.73.

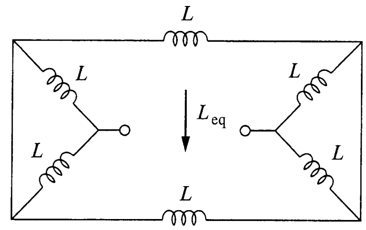


Figure 6.73 For Prob. 6.48.

6.49 Find L_{eq} in the circuit in Fig. 6.74.

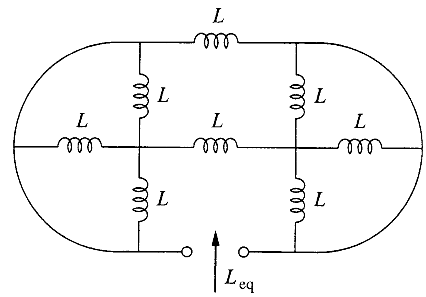


Figure 6.74 For Prob. 6.49.

***6.50** Determine L_{eq} that may be used to represent the inductive network of Fig. 6.75 at the terminals.

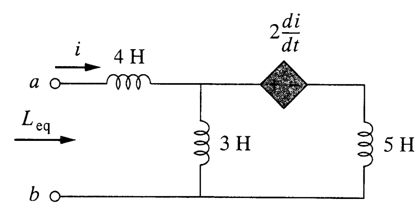


Figure 6.75 For Prob. 6.50.

6.51 The current waveform in Fig. 6.76 flows through a 3-H inductor. Sketch the voltage across the inductor over the interval $0 < t < 6$ s.

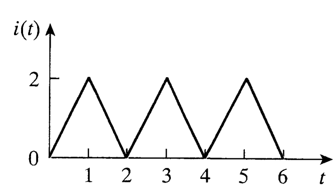


Figure 6.76 For Prob. 6.51.

6.52 (a) For two inductors in series as in Fig. 6.77(b), show that the current-division principle is

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

assuming that the initial conditions are zero.

(b) For two inductors in parallel as in Fig. 6.77(b), show that the current-division principle is

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

assuming that the initial conditions are zero.

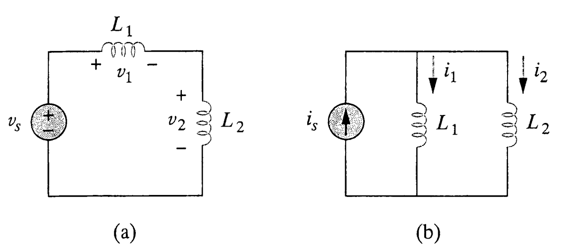


Figure 6.77 For Prob. 6.52.

6.53 In the circuit of Fig. 6.78, let $i_s(t) = 6e^{-2t}$ mA, $t \geq 0$ and $i_1(0) = 4$ mA. Find:

(a) $i_2(0)$,

(b) $i_1(t)$ and $i_2(t)$, $t > 0$,

(c) $v_1(t)$ and $v_2(t)$, $t > 0$,

(d) the energy in each inductor at $t = 0.5$ s.

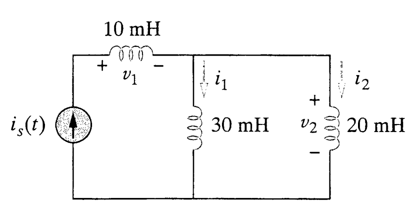


Figure 6.78 For Prob. 6.53.

6.54 The inductors in Fig. 6.79 are initially charged and are connected to the black box at $t = 0$. If $i_1(0) = 4$ A, $i_2(0) = -2$ A, and $v(t) = 50e^{-200t}$ mV, $t \geq 0$, find:

(a) the energy initially stored in each inductor,

(b) the total energy delivered to the black box from $t = 0$ to $t = \infty$,

(c) $i_1(t)$ and $i_2(t)$, $t \geq 0$,

(d) $i(t)$, $t \geq 0$.

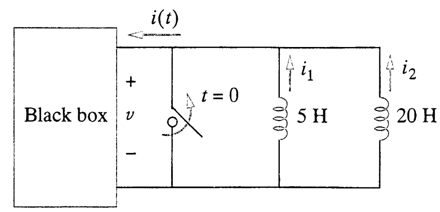


Figure 6.79 For Prob. 6.54.

6.55 Find i and v in the circuit of Fig. 6.80 assuming that $i(0) = 0 = v(0)$.

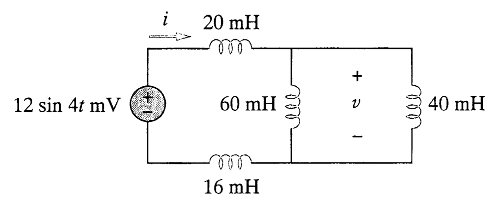


Figure 6.80 For Prob. 6.55.

Section 6.6 Applications

6.56 An op amp integrator has $R = 50$ kΩ and $C = 0.04$ μF. If the input voltage is $v_i = 10 \sin 50t$ mV, obtain the output voltage.

6.57 A 10-V dc voltage is applied to an integrator with $R = 50$ kΩ, $C = 100$ μF at $t = 0$. How long will it take for the op amp to saturate if the saturation voltages are +12 V and −12 V? Assume that the initial capacitor voltage was zero.

6.58 An op amp integrator with $R = 4$ MΩ and $C = 1$ μF has the input waveform shown in Fig. 6.81. Plot the output waveform.

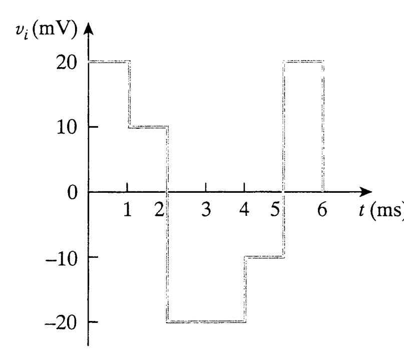


Figure 6.81 For Prob. 6.58.

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

$$v_o = -50 \int_0^t v_i(t)\, dt$$

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

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

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

If the integrating capacitor is $C = 2\ \mu$F, obtain other component values.

6.61 At $t = 1.5$ ms, calculate v_o due to the cascaded integrators in Fig. 6.82. Assume that the integrators are reset to 0 V at $t = 0$.

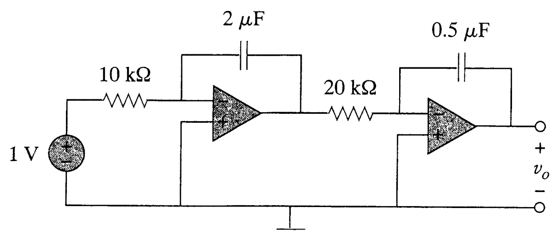


Figure 6.82 For Prob. 6.61.

6.62 Show that the circuit in Fig. 6.83 is a noninverting integrator.

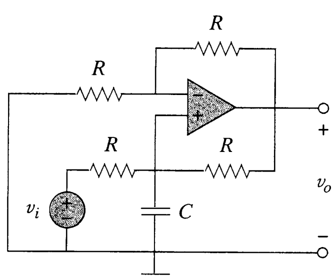
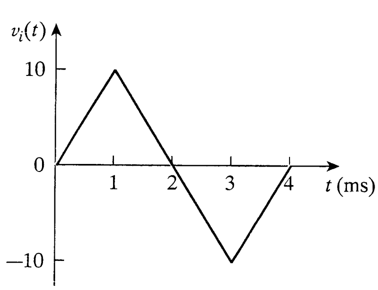
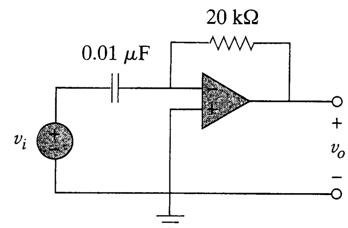


Figure 6.83 For Prob. 6.62.

6.63 The triangular waveform in Fig. 6.84(a) is applied to the input of the op amp differentiator in Fig. 6.84(b). Plot the output.



(a)



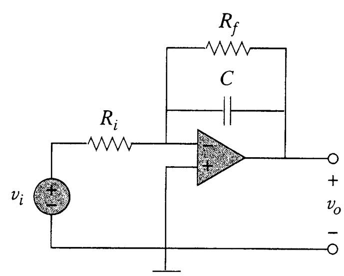
(b)

Figure 6.84 For Prob. 6.63.

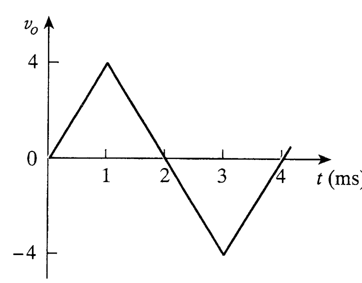
6.64 An op amp differentiator has $R = 250\ k\Omega$ and $C = 10\ \mu$F. The input voltage is a ramp $r(t) = 12t$ mV. Find the output voltage.

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

***6.66** The output v_o of the op amp circuit of Fig. 6.85(a) is shown in Fig. 6.85(b). Let $R_i = R_f = 1\ \text{M}\Omega$ and $C = 1\ \mu$F. Determine the input voltage waveform and sketch it.



(a)



(b)

Figure 6.85 For Prob. 6.66.

6.67 Design an analog computer to simulate

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

where $v_0(0) = 2$ and $v_0'(0) = 0$.

6.68 Design an analog computer to solve the differential equation

$$\frac{di(t)}{dt} + 3i(t) = 2 \qquad t > 0$$

and assume that $i(0) = 1$ mA.

6.69 Figure 6.86 presents an analog computer designed to solve a differential equation. Assuming $f(t)$ is known, set up the equation for $f(t)$.

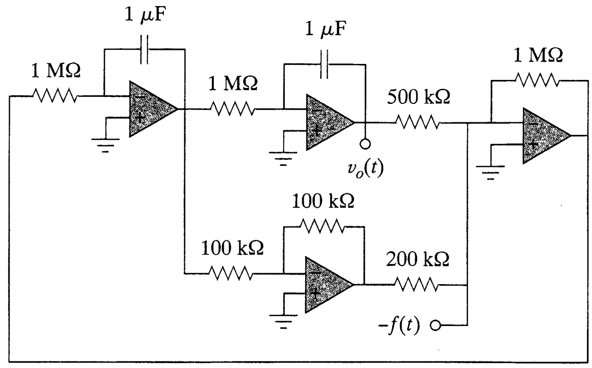


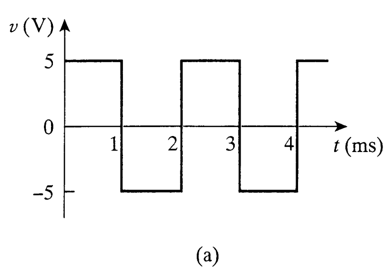
Figure 6.86 For Prob. 6.69.

COMPREHENSIVE PROBLEMS

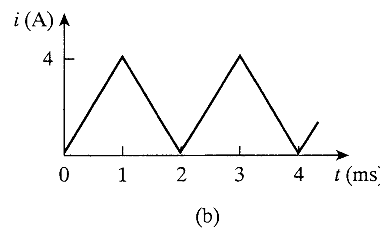
6.70 Your laboratory has available a large number of 10-μF capacitors rated at 300 V. To design a capacitor bank of 40-μF rated at 600 V, how many 10-μF capacitors are needed and how would you connect them?

6.71 When a capacitor is connected to a dc source, its voltage rises from 20 V to 36 V in 4 μs with an average charging current of 0.6 A. Determine the value of the capacitance.

6.72 A square-wave generator produces the voltage waveform shown in Fig. 6.87(a). What kind of a circuit component is needed to convert the voltage waveform to the triangular current waveform shown in Fig. 6.87(b)? Calculate the value of the component, assuming that it is initially uncharged.



(a)



(b)

Figure 6.87 For Prob. 6.72.

6.73 In an electric power plant substation, a capacitor bank is made of 10 capacitor strings connected in parallel. Each string consists of eight 1000-μF capacitors connected in series, with each capacitor charged to 100 V.

(a) Calculate the total capacitance of the bank.

(b) Determine the total energy stored in the bank.

is closed, the energy stored in the coil, and the voltage across the air gap, assuming that the switch takes 1 μs to open.

Solution:

The final current through the coil is

$$I = \frac{V_s}{R} = \frac{12}{4} = 3\text{ A}$$

The energy stored in the coil is

$$W = \frac{1}{2}LI^2 = \frac{1}{2} \times 6 \times 10^{-3} \times 3^2 = 27\text{ mJ}$$

The voltage across the gap is

$$V = L\frac{\Delta I}{\Delta t} = 6 \times 10^{-3} \times \frac{3}{1 \times 10^{-6}} = 18\text{ kV}$$

PRACTICE PROBLEM 7.22

The spark coil of an automobile ignition system has a 20-mH inductance and a 5-Ω resistance. With a supply voltage of 12 V, calculate: the time needed for the coil to fully charge, the energy stored in the coil, and the voltage developed at the spark gap if the switch opens in 2 μs.

Answer: 20 ms, 57.6 mJ, and 24 kV.

7.10 SUMMARY

1. The analysis in this chapter is applicable to any circuit that can be reduced to an equivalent circuit comprising a resistor and a single energy-storage element (inductor or capacitor). Such a circuit is first-order because its behavior is described by a first-order differential equation. When analyzing RC and RL circuits, one must always keep in mind that the capacitor is an open circuit to steady-state dc conditions while the inductor is a short circuit to steady-state dc conditions.
2. The natural response is obtained when no independent source is present. It has the general form

   $$x(t) = x(0)e^{-t/\tau}$$

   where x represents current through (or voltage across) a resistor, a capacitor, or an inductor, and $x(0)$ is the initial value of x. The natural response is also called the *transient response* because it is the temporary response that vanishes with time.
3. The time constant τ is the time required for a response to decay to $1/e$ of its initial value. For RC circuits, $\tau = RC$ and for RL circuits, $\tau = L/R$.
4. The singularity functions include the unit step, the unit ramp function, and the unit impulse functions. The unit step function $u(t)$ is

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

The unit impulse function is

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

The unit ramp function is

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

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

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

A more general form of this equation is

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

Or we may write it as

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

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

REVIEW QUESTIONS

7.1 An RC circuit has $R = 2\ \Omega$ and $C = 4$ F. The time constant is:
(a) 0.5 s (b) 2 s (c) 4 s
(d) 8 s (e) 15 s

7.2 The time constant for an RL circuit with $R = 2\ \Omega$ and $L = 4$ H is:
(a) 0.5 s (b) 2 s (c) 4 s
(d) 8 s (e) 15 s

7.3 A capacitor in an RC circuit with $R = 2\ \Omega$ and $C = 4$ F is being charged. The time required for the capacitor voltage to reach 63.2 percent of its steady-state value is:
(a) 2 s (b) 4 s (c) 8 s
(d) 16 s (e) none of the above

7.4 An RL circuit has $R = 2\ \Omega$ and $L = 4$ H. The time needed for the inductor current to reach 40 percent of its steady-state value is:
(a) 0.5 s (b) 1 s (c) 2 s
(d) 4 s (e) none of the above

7.5 In the circuit of Fig. 7.79, the capacitor voltage just before $t = 0$ is:
(a) 10 V (b) 7 V (c) 6 V
(d) 4 V (e) 0 V

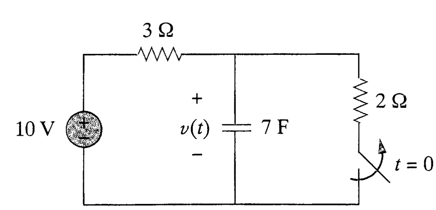


Figure 7.79 For Review Questions 7.5 and 7.6.

7.6 In the circuit of Fig. 7.79, $v(\infty)$ is:
(a) 10 V (b) 7 V (c) 6 V
(d) 4 V (e) 0 V

7.7 For the circuit of Fig. 7.80, the inductor current just before $t = 0$ is:
(a) 8 A (b) 6 A (c) 4 A
(d) 2 A (e) 0 A

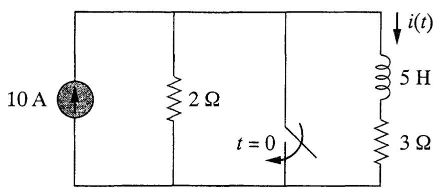


Figure 7.80 For Review Questions 7.7 and 7.8.

7.8 In the circuit of Fig. 7.80, $i(\infty)$ is:
(a) 8 A (b) 6 A (c) 4 A
(d) 2 A (e) 0 A

7.9 If v_s changes from 2 V to 4 V at $t = 0$, we may express v_s as:
(a) $\delta(t)$ V (b) $2u(t)$ V
(c) $2u(-t) + 4u(t)$ V (d) $2 + 2u(t)$ V
(e) $4u(t) - 2$ V

7.10 The pulse in Fig. 7.110(a) can be expressed in terms of singularity functions as:
(a) $2u(t) + 2u(t - 1)$ V (b) $2u(t) - 2u(t - 1)$ V
(c) $2u(t) - 4u(t - 1)$ V (d) $2u(t) + 4u(t - 1)$ V

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

PROBLEMS

Section 7.2 The Source-Free *RC* Circuit

7.1 Show that Eq. (7.9) can be obtained by working with the current i in the RC circuit rather than working with the voltage v.

7.2 Find the time constant for the RC circuit in Fig. 7.81.

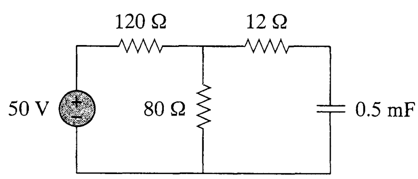


Figure 7.81 For Prob. 7.2.

7.3 Determine the time constant of the circuit in Fig. 7.82.

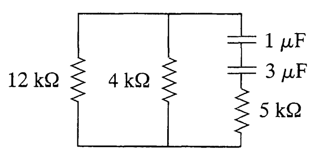


Figure 7.82 For Prob. 7.3.

7.4 Obtain the time constant of the circuit in Fig. 7.83.

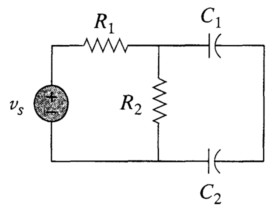


Figure 7.83 For Prob. 7.4.

7.5 The switch in Fig. 7.84 has been in position a for a long time, until $t = 4$ s when it is moved to position b and left there. Determine $v(t)$ at $t = 10$ s.

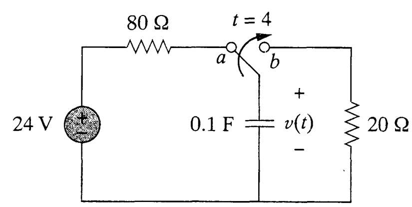


Figure 7.84 For Prob. 7.5.

7.6 If $v(0) = 20$ V in the circuit in Fig. 7.85, obtain $v(t)$ for $t > 0$.

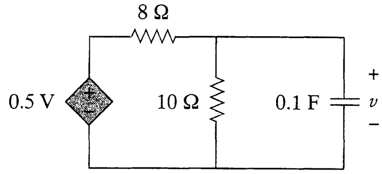


Figure 7.85 For Prob. 7.6.

7.7 For the circuit in Fig. 7.86, if

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

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

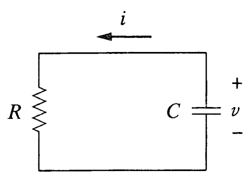


Figure 7.86 For Prob. 7.7.

7.8 In the circuit of Fig. 7.87, $v(0) = 20$ V. Find $v(t)$ for $t > 0$.

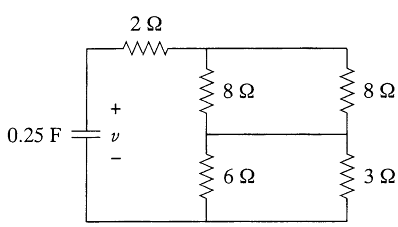


Figure 7.87 For Prob. 7.8.

7.9 Given that $i(0) = 3$ A, find $i(t)$ for $t > 0$ in the circuit in Fig. 7.88.

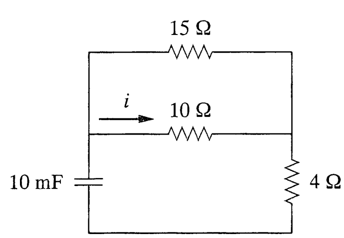


Figure 7.88 For Prob. 7.9.

Section 7.3 The Source-Free *RL* Circuit

7.10 Derive Eq. (7.20) by working with voltage v across the inductor of the RL circuit instead of working with the current i.

7.11 The switch in the circuit in Fig. 7.89 has been closed for a long time. At $t = 0$, the switch is opened. Calculate $i(t)$ for $t > 0$.

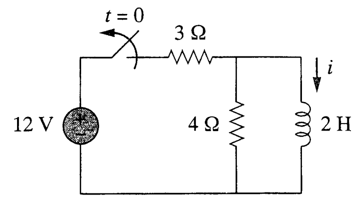


Figure 7.89 For Prob. 7.11.

7.12 For the circuit shown in Fig. 7.90, calculate the time constant.

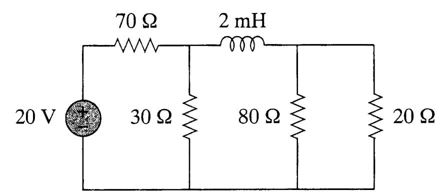


Figure 7.90 For Prob. 7.12.

7.13 What is the time constant of the circuit in Fig. 7.91?

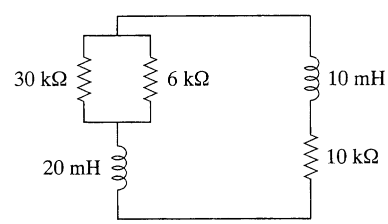


Figure 7.91 For Prob. 7.13.

7.14 Determine the time constant for each of the circuits in Fig. 7.92.

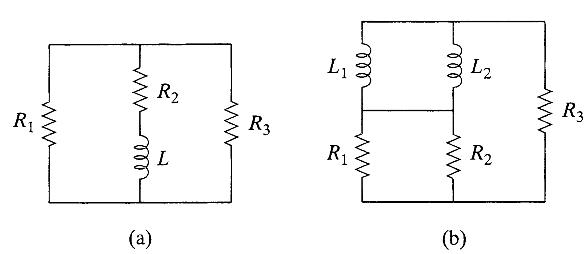


Figure 7.92 For Prob. 7.14.

7.15 Consider the circuit of Fig. 7.93. Find $v_o(t)$ if $i(0) = 2$ A and $v(t) = 0$.

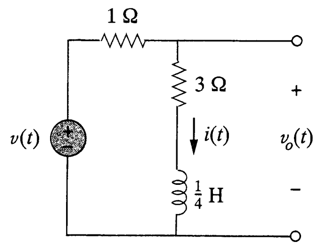


Figure 7.93 For Prob. 7.15.

7.16 For the circuit in Fig. 7.94, determine $v_o(t)$ when $i(0) = 1$ A and $v(t) = 0$.

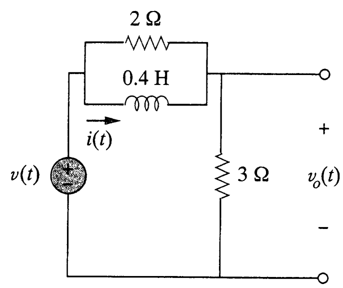


Figure 7.94 For Prob. 7.16.

7.17 In the circuit of Fig. 7.95, find $i(t)$ for $t > 0$ if $i(0) = 2$ A.

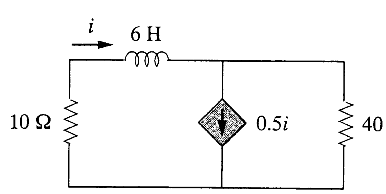


Figure 7.95 For Prob. 7.17.

7.18 For the circuit in Fig. 7.96,

$$v = 120e^{-50t} \text{ V}$$

and

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

(a) Find L and R.

(b) Determine the time constant.

(c) Calculate the initial energy in the inductor.

(d) What fraction of the initial energy is dissipated in 10 ms?

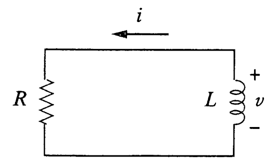


Figure 7.96 For Prob. 7.18.

7.19 In the circuit in Fig. 7.97, find the value of R for which energy stored in the inductor will be 1 J.

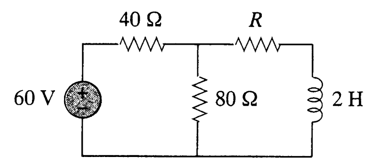


Figure 7.97 For Prob. 7.19.

7.20 Find $i(t)$ and $v(t)$ for $t > 0$ in the circuit of Fig. 7.98 if $i(0) = 10$ A.

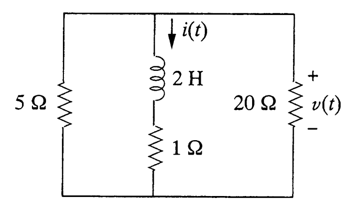


Figure 7.98 For Prob. 7.20.

7.21 Consider the circuit in Fig. 7.99. Given that $v_o(0) = 2$ V, find v_o and v_x for $t > 0$.

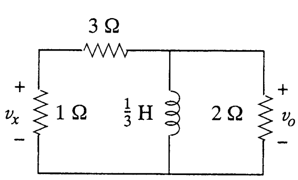


Figure 7.99 For Prob. 7.21.

Section 7.4 Singularity Functions

7.22 Express the following signals in terms of singularity functions.

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

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

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

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

7.23 Express the signals in Fig. 7.100 in terms of singularity functions.

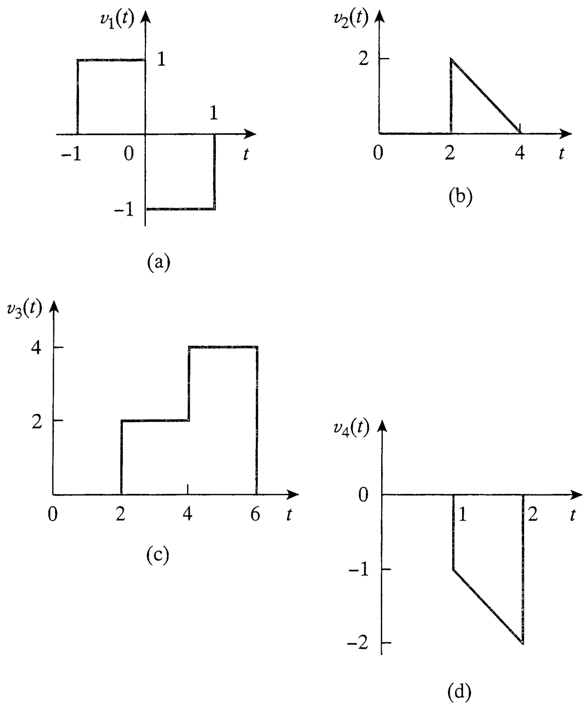


Figure 7.100 For Prob. 7.23.

7.24 Sketch the waveform that is represented by

$$v(t) = u(t) + u(t-1) - 3u(t-2) + 2u(t-3)$$

7.25 Sketch the waveform represented by

$$i(t) = r(t) + r(t-1) - u(t-2) - r(t-2) + r(t-3) + u(t-4)$$

7.26 Evaluate the following integrals involving the impulse functions:

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

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

7.27 Evaluate the following integrals:

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

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

7.28 The voltage across a 10-mH inductor is $20\delta(t-2)$ mV. Find the inductor current, assuming that the inductor is initially uncharged.

7.29 Find the solution of the following first-order differential equations subject to the specified initial conditions.

(a) $5\,dv/dt + 3v = 0, \quad v(0) = -2$

(b) $4\,dv/dt - 6v = 0, \quad v(0) = 5$

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

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

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

Section 7.5 Step Response of an *RC* Circuit

7.31 Calculate the capacitor voltage for $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.101.

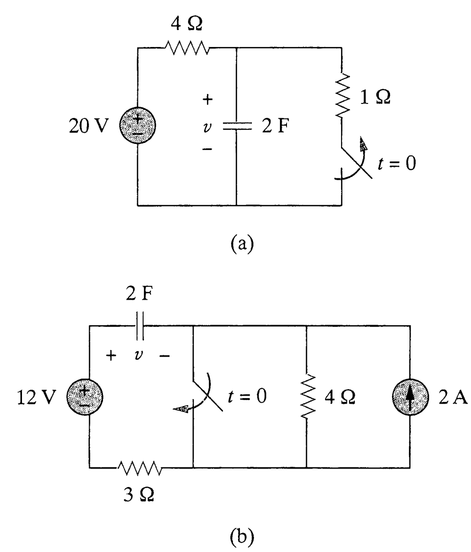


Figure 7.101 For Prob. 7.31.

7.32 Find the capacitor voltage for $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.102.

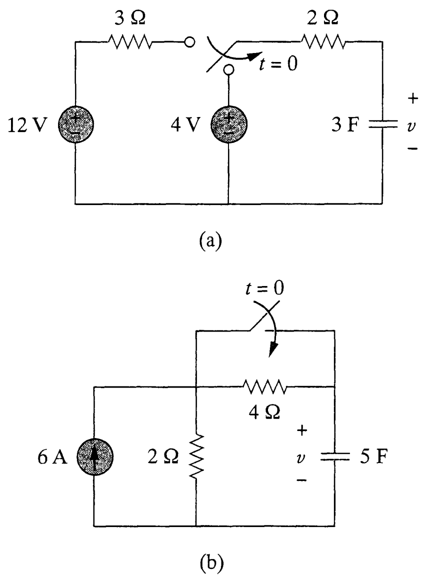


Figure 7.102 For Prob. 7.32.

7.33 For the circuit in Fig. 7.103, find $v(t)$ for $t > 0$.

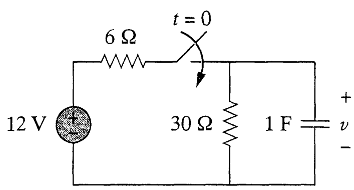


Figure 7.103 For Prob. 7.33.

7.34 (a) If the switch in Fig. 7.104 has been open for a long time and is closed at $t = 0$, find $v_o(t)$.
(b) Suppose that the switch has been closed for a long time and is opened at $t = 0$. Find $v_o(t)$.

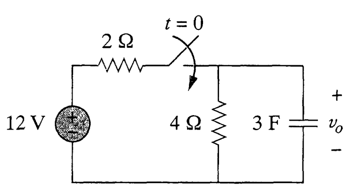


Figure 7.104 For Prob. 7.34.

7.35 Consider the circuit in Fig. 7.105. Find $i(t)$ for $t < 0$ and $t > 0$.

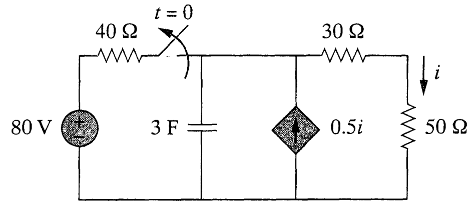


Figure 7.105 For Prob. 7.35.

7.36 The switch in Fig. 7.106 has been in position a for a long time. At $t = 0$, it moves to position b. Calculate $i(t)$ for all $t > 0$.

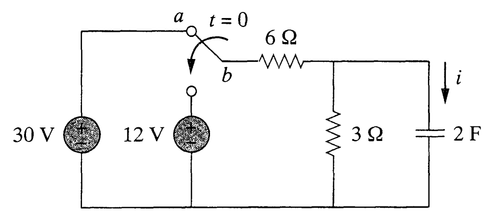


Figure 7.106 For Prob. 7.36.

7.37 Find the step responses $v(t)$ and $i(t)$ to $v_s = 5u(t)$ V in the circuit of Fig. 7.107.

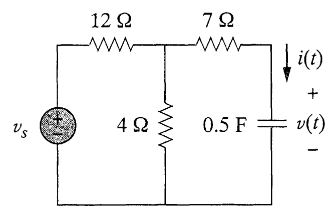


Figure 7.107 For Prob. 7.37.

7.38 Determine $v(t)$ for $t > 0$ in the circuit in Fig. 7.108 if $v(0) = 0$.

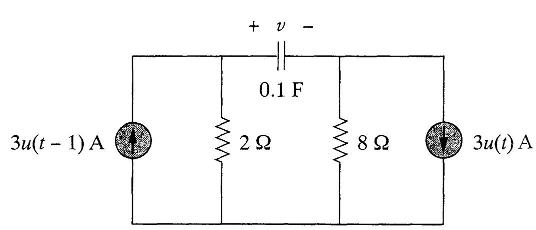


Figure 7.108 For Prob. 7.38.

7.39 Find $v(t)$ and $i(t)$ in the circuit of Fig. 7.109.

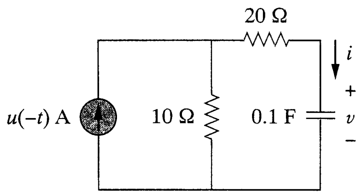


Figure 7.109 For Prob. 7.39.

7.40 If the waveform in Fig. 7.110(a) is applied to the circuit of Fig. 7.110(b), find $v(t)$. Assume $v(0) = 0$.

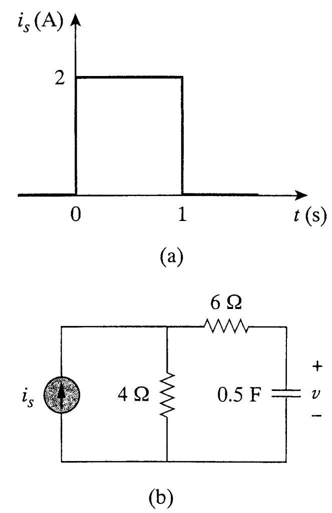


Figure 7.110 For Prob. 7.40 and Review Question 7.10.

***7.41** In the circuit in Fig. 7.111, find i_x for $t > 0$. Let $R_1 = R_2 = 1$ kΩ, $R_3 = 2$ kΩ, and $C = 0.25$ mF.

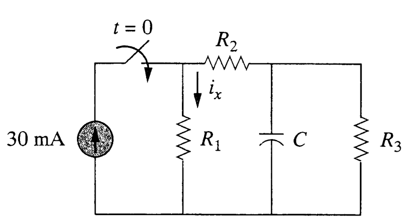


Figure 7.111 For Prob. 7.41.

Section 7.6 Step Response of an *RL* Circuit

7.42 Rather than applying the short-cut technique used in Section 7.6, use KVL to obtain Eq. (7.60).

7.43 For the circuit in Fig. 7.112, find $i(t)$ for $t > 0$.

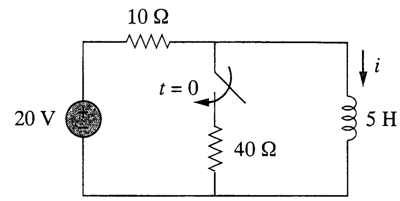


Figure 7.112 For Prob. 7.43.

7.44 Determine the inductor current $i(t)$ for both $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.113.

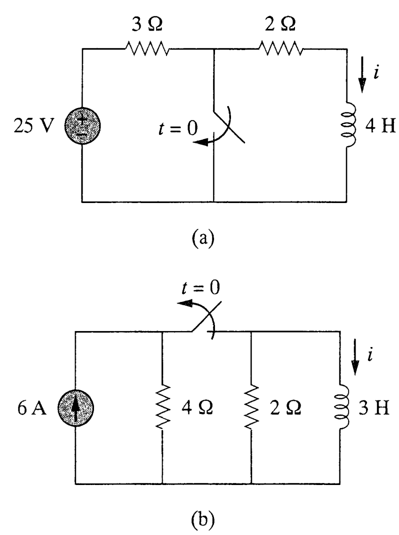
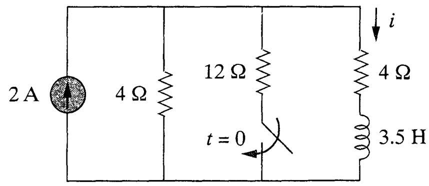


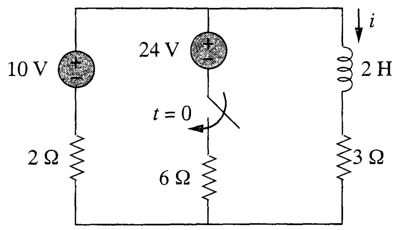
Figure 7.113 For Prob. 7.44.

7.45 Obtain the inductor current for both $t < 0$ and $t > 0$ in each of the circuits in Fig. 7.114.

*An asterisk indicates a challenging problem.



(a)



(b)

Figure 7.114 For Prob. 7.45.

7.46 Find $v(t)$ for $t < 0$ and $t > 0$ in the circuit in Fig. 7.115.

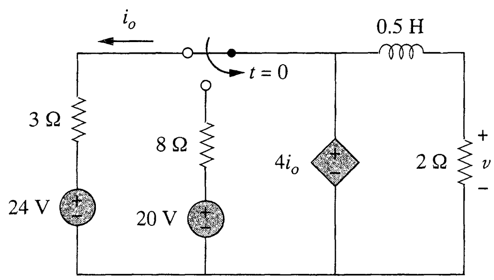


Figure 7.115 For Prob. 7.46.

7.47 For the network shown in Fig. 7.116, find $v(t)$ for $t > 0$.

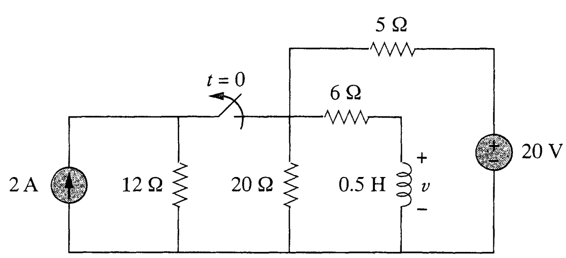


Figure 7.116 For Prob. 7.47.

***7.48** Find $i_1(t)$ and $i_2(t)$ for $t > 0$ in the circuit of Fig. 7.117.

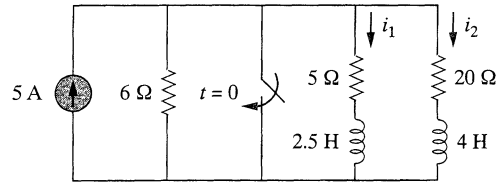


Figure 7.117 For Prob. 7.48.

7.49 Rework Prob. 7.15 if $i(0) = 10$ A and $v(t) = 20u(t)$ V.

7.50 Determine the step response $v_o(t)$ to $v_s = 18u(t)$ in the circuit of Fig. 7.118.

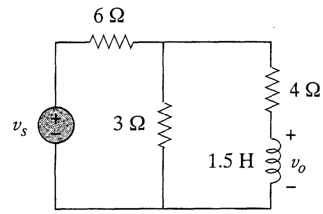


Figure 7.118 For Prob. 7.50.

7.51 Find $v(t)$ for $t > 0$ in the circuit of Fig. 7.119 if the initial current in the inductor is zero.

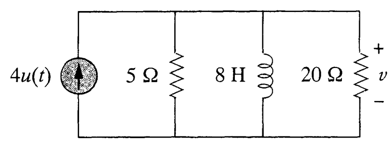


Figure 7.119 For Prob. 7.51.

7.52 In the circuit in Fig. 7.120, i_s changes from 5 A to 10 A at $t = 0$; that is, $i_s = 5u(-t) + 10u(t)$. Find v and i.

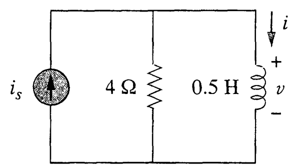


Figure 7.120 For Prob. 7.52.

7.53 For the circuit in Fig. 7.121, calculate $i(t)$ if $i(0) = 0$.

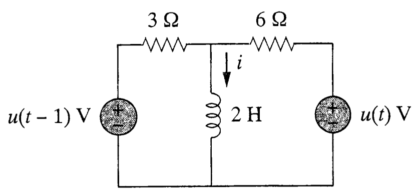


Figure 7.121 For Prob. 7.53.

7.54 Obtain $v(t)$ and $i(t)$ in the circuit of Fig. 7.122.

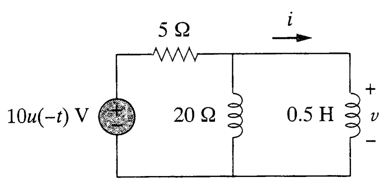


Figure 7.122 For Prob. 7.54.

7.55 Find $v_o(t)$ for $t > 0$ in the circuit of Fig. 7.123.

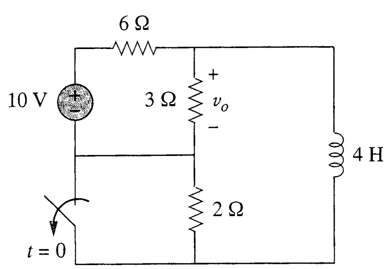
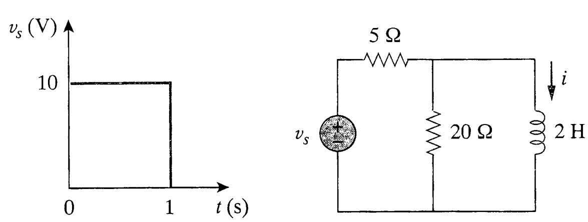


Figure 7.123 For Prob. 7.55.

7.56 If the input pulse in Fig. 7.124(a) is applied to the circuit in Fig. 7.124(b), determine the response $i(t)$.



(a) (b)

Figure 7.124 For Prob. 7.56.

Section 7.7 First-order Op Amp Circuits

7.57 Find the output current i_o for $t > 0$ in the op amp circuit of Fig. 7.125. Let $v(0) = -4$ V.

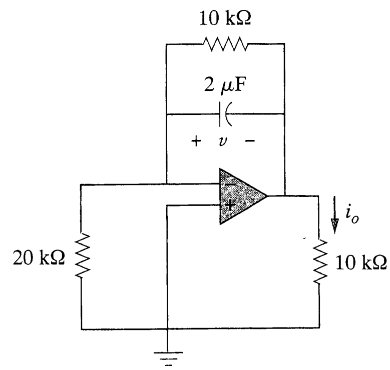


Figure 7.125 For Prob. 7.57.

7.58 If $v(0) = 5$ V, find $v_o(t)$ for $t > 0$ in the op amp circuit in Fig. 7.126. Let $R = 10$ kΩ and $C = 1$ μF.

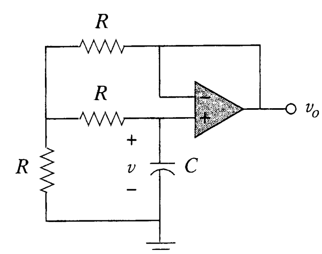


Figure 7.126 For Prob. 7.58.

7.59 Obtain v_o for $t > 0$ in the circuit of Fig. 7.127.

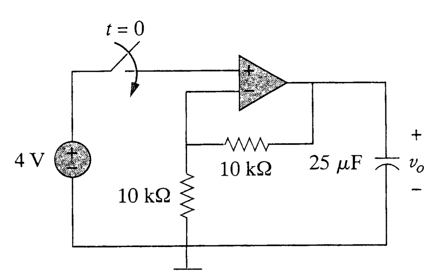


Figure 7.127 For Prob. 7.59.

7.60 For the op amp circuit in Fig. 7.128, find $v_o(t)$ for $t > 0$.

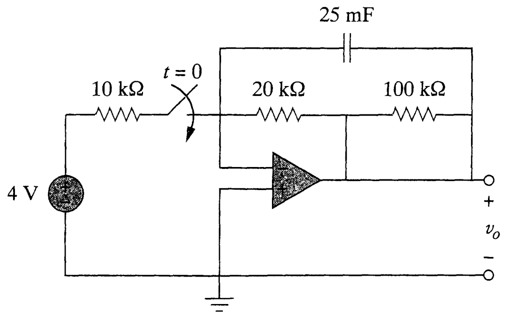


Figure 7.128 For Prob. 7.60.

7.61 Determine v_o for $t > 0$ when $v_s = 20$ mV in the op amp circuit of Fig. 7.129.

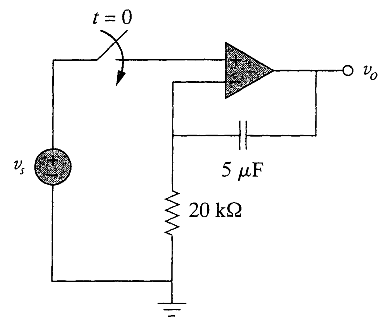


Figure 7.129 For Prob. 7.61.

7.62 For the op amp circuit in Fig. 7.130, find i_o for $t > 2$.

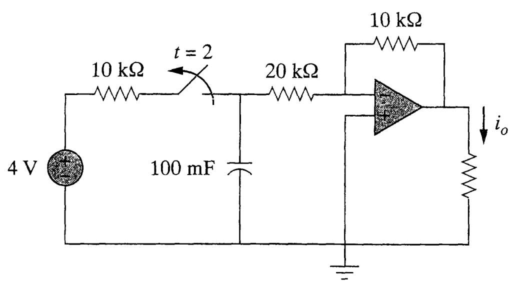


Figure 7.130 For Prob. 7.62.

7.63 Find i_o in the op amp circuit in Fig. 7.131. Assume that $v(0) = -2$ V, $R = 10$ kΩ, and $C = 10\ \mu$F.

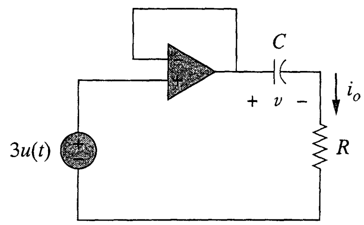


Figure 7.131 For Prob. 7.63.

7.64 For the op amp circuit of Fig. 7.132, let $R_1 = 10$ kΩ, $R_f = 20$ kΩ, $C = 20\ \mu$F, and $v(0) = 1$ V. Find v_o.

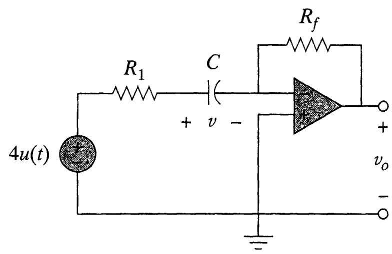


Figure 7.132 For Prob. 7.64.

7.65 Determine $v_o(t)$ for $t > 0$ in the circuit of Fig. 7.133. Let $i_s = 10u(t)\ \mu$A and assume that the capacitor is initially uncharged.

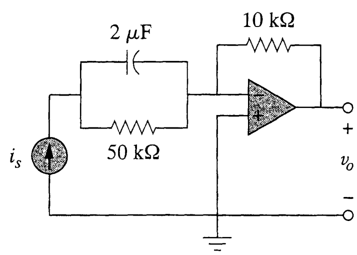


Figure 7.133 For Prob. 7.65.

7.66 In the circuit of Fig. 7.134, find v_o and i_o, given that $v_s = 4u(t)$ V and $v(0) = 1$ V.

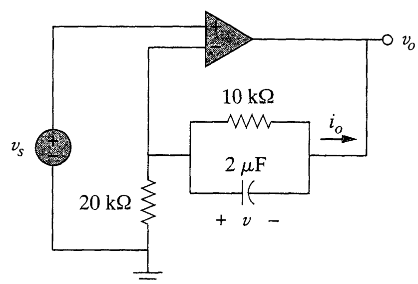


Figure 7.134 For Prob. 7.66.

Section 7.8 Transient Analysis with *PSpice*

7.67 Repeat Prob. 7.40 using *PSpice*.

7.68 The switch in Fig. 7.135 opens at $t = 0$. Use *PSpice* to determine $v(t)$ for $t > 0$.

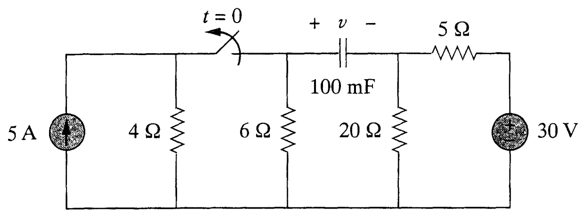


Figure 7.135 For Prob. 7.68.

7.69 The switch in Fig. 7.136 moves from position a to b at $t = 0$. Use *PSpice* to find $i(t)$ for $t > 0$.

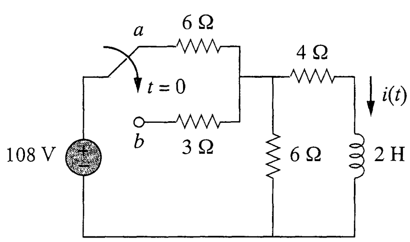


Figure 7.136 For Prob. 7.69.

7.70 Repeat Prob. 7.56 using *PSpice*.

Section 7.9 Applications

7.71 In designing a signal-switching circuit, it was found that a 100-μF capacitor was needed for a time constant of 3 ms. What value resistor is necessary for the circuit?

7.72 A simple relaxation oscillator circuit is shown in Fig. 7.137. The neon lamp fires when its voltage reaches 75 V and turns off when its voltage drops to 30 V. Its resistance is 120 Ω when on and infinitely high when off.

(a) For how long is the lamp on each time the capacitor discharges?

(b) What is the time interval between light flashes?

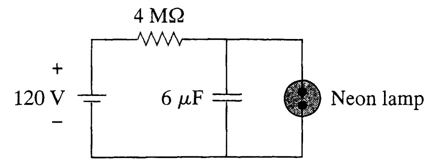


Figure 7.137 For Prob. 7.72.

7.73 Figure 7.138 shows a circuit for setting the length of time voltage is applied to the electrodes of a welding machine. The time is taken as how long it takes the capacitor to charge from 0 to 8 V. What is the time range covered by the variable resistor?

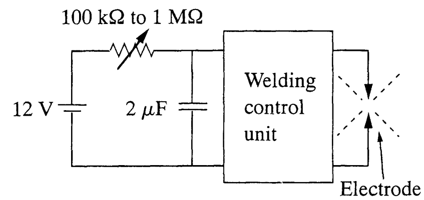


Figure 7.138 For Prob. 7.73.

7.74 A 120-V dc generator energizes a motor whose coil has an inductance of 50 H and a resistance of 100 Ω. A field discharge resistor of 400 Ω is connected in parallel with the motor to avoid damage to the motor, as shown in Fig. 7.139. The system is at steady state. Find the current through the discharge resistor 100 ms after the breaker is tripped.

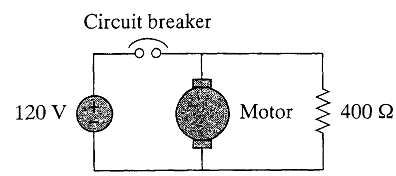


Figure 7.139 For Prob. 7.74.

COMPREHENSIVE PROBLEMS

7.75 The circuit in Fig. 7.140(a) can be designed as an approximate differentiator or an integrator, depending on whether the output is taken across the resistor or the capacitor, and also on the time constant $\tau = RC$ of the circuit and the width T of the input pulse in Fig. 7.140(b). The circuit is a differentiator if $\tau \ll T$, say $\tau < 0.1T$, or an integrator if $\tau \gg T$, say $\tau > 10T$.

(a) What is the minimum pulse width that will allow a differentiator output to appear across the capacitor?

(b) If the output is to be an integrated form of the input, what is the maximum value the pulse width can assume?

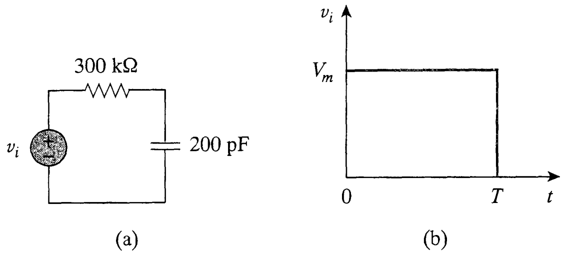


Figure 7.140 For Prob. 7.75.

7.76 An RL circuit may be used as a differentiator if the output is taken across the inductor and $\tau \ll T$ (say $\tau < 0.1T$), where T is the width of the input pulse. If R is fixed at 200 kΩ, determine the maximum value of L required to differentiate a pulse with $T = 10\ \mu s$.

7.77 An attenuator probe employed with oscilloscopes was designed to reduce the magnitude of the input voltage v_i by a factor of 10. As shown in Fig. 7.141, the oscilloscope has internal resistance R_s and capacitance C_s, while the probe has an internal resistance R_p. If R_p is fixed at 6 MΩ, find R_s and C_s for the circuit to have a time constant of 15 μs.

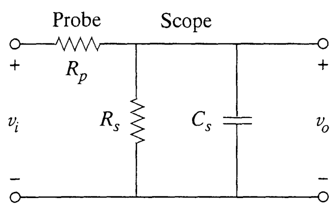


Figure 7.141 For Prob. 7.77.

7.78 The circuit in Fig. 7.142 is used by a biology student to study "frog kick." She noticed that the frog kicked a little when the switch was closed but kicked violently for 5 s when the switch was opened. Model the frog as a resistor and calculate its resistance. Assume that it takes 10 mA for the frog to kick violently.

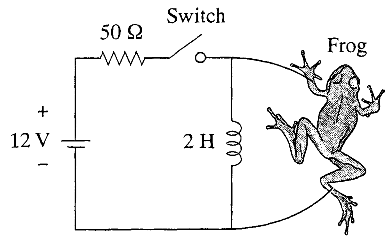


Figure 7.142 For Prob. 7.78.

7.79 To move a spot of a cathode-ray tube across the screen requires a linear increase in the voltage across the deflection plates, as shown in Fig. 7.143. Given that the capacitance of the plates is 4 nF, sketch the current flowing through the plates.

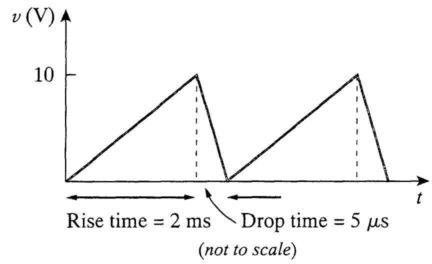


Figure 7.143 For Prob. 7.79.

Due to the inherent delay caused by the op amp, Wien-bridge oscillators are limited to operating in the frequency range of 1 MHz or less.

EXAMPLE 10.16

Design a Wien-bridge circuit to oscillate at 100 kHz.

Solution:

Using Eq. (10.14), we obtain the time constant of the circuit as

$$RC = \frac{1}{2\pi f_o} = \frac{1}{2\pi \times 100 \times 10^3} = 1.59 \times 10^{-6} \qquad (10.16.1)$$

If we select $R = 10\ \text{k}\Omega$, then we can select $C = 159$ pF to satisfy Eq. (10.16.1). Since the gain must be 3, $R_f/R_g = 2$. We could select $R_f = 20\ \text{k}\Omega$ while $R_g = 10\ \text{k}\Omega$.

PRACTICE PROBLEM 10.16

In the Wien-bridge oscillator circuit in Fig. 10.42, let $R_1 = R_2 = 2.5\ \text{k}\Omega$, $C_1 = C_2 = 1$ nF. Determine the frequency f_o of the oscillator.

Answer: 63.66 kHz.

10.10 SUMMARY

1. We apply nodal and mesh analysis to ac circuits by applying KCL and KVL to the phasor form of the circuits.
2. In solving for the steady-state response of a circuit that has independent sources with different frequencies, each independent source *must* be considered separately. The most natural approach to analyzing such circuits is to apply the superposition theorem. A separate phasor circuit for each frequency *must* be solved independently, and the corresponding response should be obtained in the time domain. The overall response is the sum of the time-domain responses of all the individual phasor circuits.
3. The concept of source transformation is also applicable in the frequency domain.
4. The Thevenin equivalent of an ac circuit consists of a voltage source $\mathbf{V}_{\text{Th}}$ in series with the Thevenin impedance $\mathbf{Z}_{\text{Th}}$.
5. The Norton equivalent of an ac circuit consists of a current source $\mathbf{I}_N$ in parallel with the Norton impedance $\mathbf{Z}_N$ $(= \mathbf{Z}_{\text{Th}})$.
6. *PSpice* is a simple and powerful tool for solving ac circuit problems. It relieves us of the tedious task of working with the complex numbers involved in steady-state analysis.
7. The capacitance multiplier and the ac oscillator provide two typical applications for the concepts presented in this chapter. A capacitance multiplier is an op amp circuit used in producing a multiple of a physical capacitance. An oscillator is a device that uses a dc input to generate an ac output.

REVIEW QUESTIONS

10.1 The voltage $\mathbf{V}_o$ across the capacitor in Fig. 10.43 is:
(a) $5\angle 0^\circ$ V (b) $7.071\angle 45^\circ$ V
(c) $7.071\angle -45^\circ$ V (d) $5\angle -45^\circ$ V

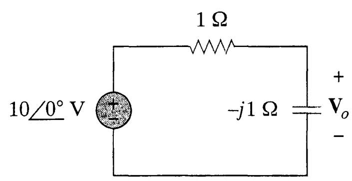


Figure 10.43 For Review Question 10.1.

10.2 The value of the current $\mathbf{I}_o$ in the circuit in Fig. 10.44 is:
(a) $4\angle 0^\circ$ A (b) $2.4\angle -90^\circ$ A
(c) $0.6\angle 0^\circ$ A (d) -1 A

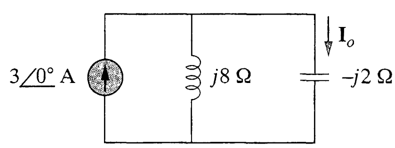


Figure 10.44 For Review Question 10.2.

10.3 Using nodal analysis, the value of $\mathbf{V}_o$ in the circuit of Fig. 10.45 is:
(a) -24 V (b) -8 V
(c) 8 V (d) 24 V

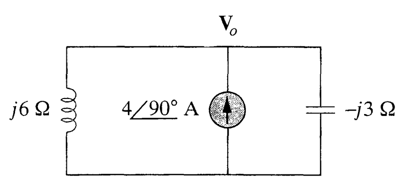


Figure 10.45 For Review Question 10.3.

10.4 In the circuit of Fig. 10.46, current $i(t)$ is:
(a) $10\cos t$ A (b) $10\sin t$ A (c) $5\cos t$ A
(d) $5\sin t$ A (e) $4.472\cos(t - 63.43^\circ)$ A

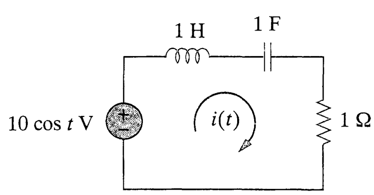


Figure 10.46 For Review Question 10.4.

10.5 Refer to the circuit in Fig. 10.47 and observe that the two sources do not have the same frequency. The current $i_x(t)$ can be obtained by:
(a) source transformation
(b) the superposition theorem
(c) *PSpice*

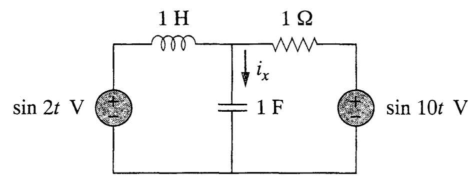


Figure 10.47 For Review Question 10.5.

10.6 For the circuit in Fig. 10.48, the Thevenin impedance at terminals a-b is:
(a) 1 Ω (b) $0.5 - j0.5$ Ω
(c) $0.5 + j0.5$ Ω (d) $1 + j2$ Ω
(e) $1 - j2$ Ω

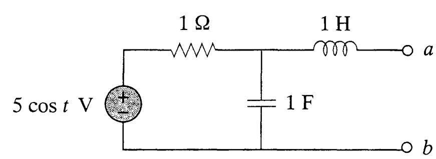


Figure 10.48 For Review Questions 10.6 and 10.7.

10.7 In the circuit of Fig. 10.48, the Thevenin voltage at terminals a-b is:
(a) $3.535\angle -45^\circ$ V (b) $3.535\angle 45^\circ$ V
(c) $7.071\angle -45^\circ$ V (d) $7.071\angle 45^\circ$ V

10.8 Refer to the circuit in Fig. 10.49. The Norton equivalent impedance at terminals a-b is:
(a) $-j4$ Ω (b) $-j2$ Ω
(c) $j2$ Ω (d) $j4$ Ω

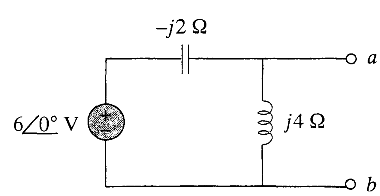


Figure 10.49 For Review Questions 10.8 and 10.9.

10.9 The Norton current at terminals a-b in the circuit of Fig. 10.49 is:

(a) $1\angle 0^\circ$ A (b) $1.5\angle -90^\circ$ A

(c) $1.5\angle 90^\circ$ A (d) $3\angle 90^\circ$ A

10.10 *PSpice* can handle a circuit with two independent sources of different frequencies.

(a) True (b) False

Answers: 10.1c, 10.2a, 10.3d, 10.4a, 10.5b, 10.6c, 10.7a, 10.8a, 10.9d, 10.10b.

PROBLEMS

Section 10.2 Nodal Analysis

10.1 Find v_o in the circuit in Fig. 10.50.

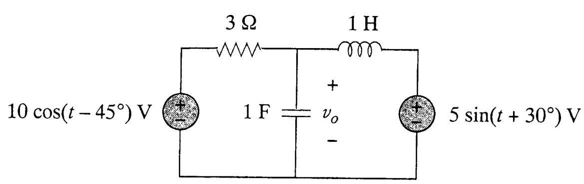


Figure 10.50 For Prob. 10.1.

10.2 For the circuit depicted in Fig. 10.51 below, determine i_o.

10.3 Determine v_o in the circuit of Fig. 10.52.

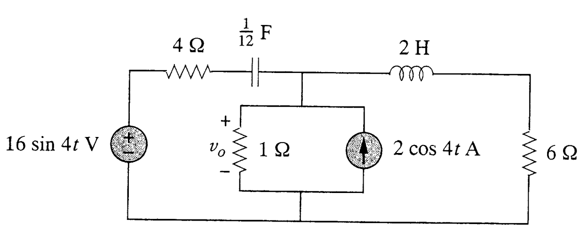


Figure 10.52 For Prob. 10.3.

10.4 Compute $v_o(t)$ in the circuit of Fig. 10.53.

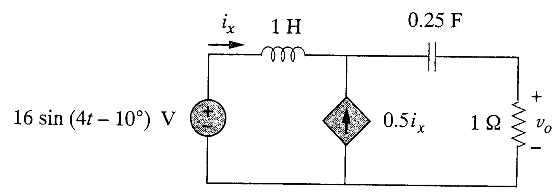


Figure 10.53 For Prob. 10.4.

10.5 Use nodal analysis to find v_o in the circuit of Fig. 10.54.

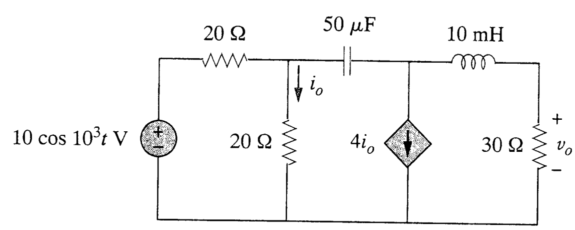


Figure 10.54 For Prob. 10.5.

10.6 Using nodal analysis, find $i_o(t)$ in the circuit in Fig. 10.55.

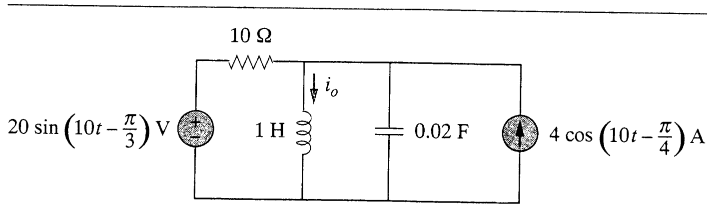


Figure 10.51 For Prob. 10.2.

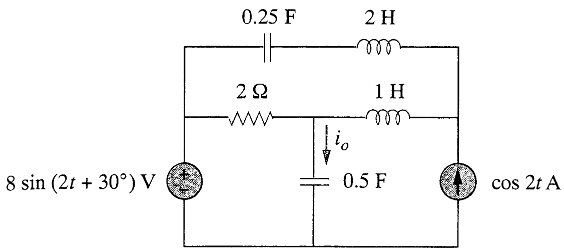


Figure 10.55 For Prob. 10.6.

10.7 By nodal analysis, find i_o in the circuit in Fig. 10.56.

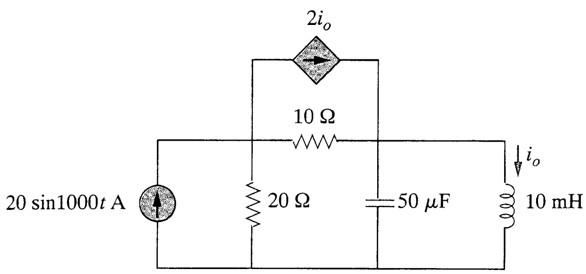


Figure 10.56 For Prob. 10.7.

10.8 Calculate the voltage at nodes 1 and 2 in the circuit of Fig. 10.57 using nodal analysis.

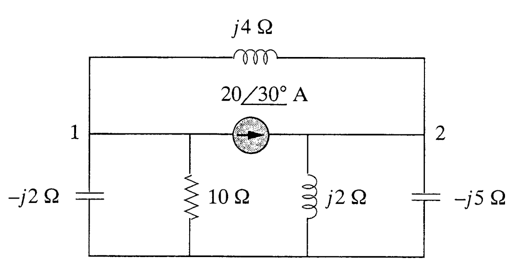


Figure 10.57 For Prob. 10.8.

10.9 Solve for the current **I** in the circuit of Fig. 10.58 using nodal analysis.

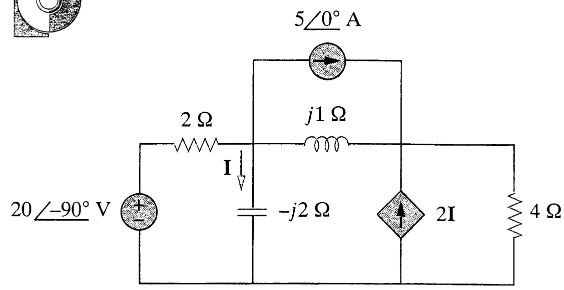


Figure 10.58 For Prob. 10.9.

10.10 Using nodal analysis, find $\mathbf{V}_1$ and $\mathbf{V}_2$ in the circuit of Fig. 10.59.

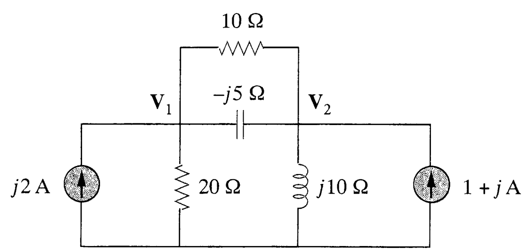


Figure 10.59 For Prob. 10.10.

10.11 By nodal analysis, obtain current $\mathbf{I}_o$ in the circuit in Fig. 10.60.

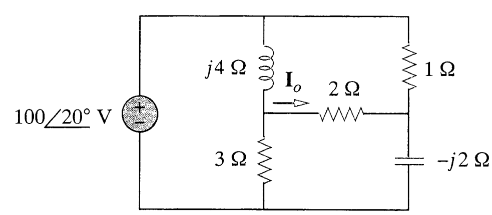


Figure 10.60 For Prob. 10.11.

10.12 Use nodal analysis to obtain $\mathbf{V}_o$ in the circuit of Fig. 10.61 below.

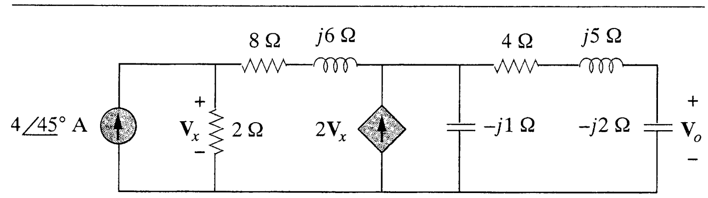


Figure 10.61 For Prob. 10.12.

10.13 Obtain $\mathbf{V}_o$ in Fig. 10.62 using nodal analysis.

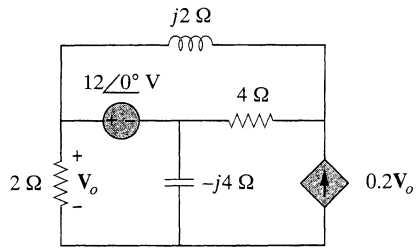


Figure 10.62 For Prob. 10.13.

10.14 Refer to Fig. 10.63. If $v_s(t) = V_m \sin \omega t$ and $v_o(t) = A \sin(\omega t + \phi)$, derive the expressions for A and ϕ.

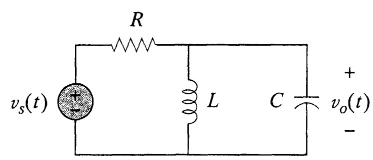


Figure 10.63 For Prob. 10.14.

10.15 For each of the circuits in Fig. 10.64, find $\mathbf{V}_o/\mathbf{V}_i$ for $\omega = 0$, $\omega \to \infty$, and $\omega^2 = 1/LC$.

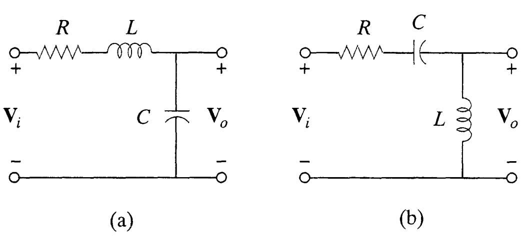


Figure 10.64 For Prob. 10.15.

10.16 For the circuit in Fig. 10.65, determine $\mathbf{V}_o/\mathbf{V}_s$.

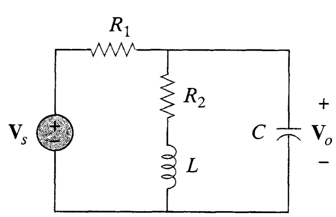


Figure 10.65 For Prob. 10.16.

Section 10.3 Mesh Analysis

10.17 Obtain the mesh currents $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 10.66.

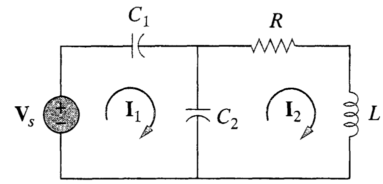


Figure 10.66 For Prob. 10.17.

10.18 Solve for i_o in Fig. 10.67 using mesh analysis.

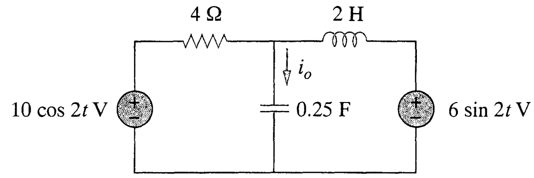


Figure 10.67 For Prob. 10.18.

10.19 Rework Prob. 10.5 using mesh analysis.

10.20 Using mesh analysis, find $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit of Fig. 10.68.

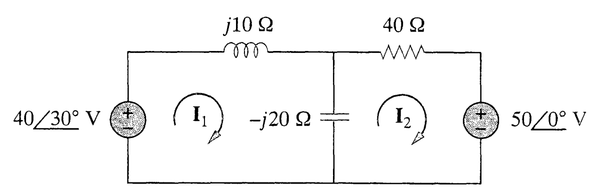


Figure 10.68 For Prob. 10.20.

10.21 By using mesh analysis, find $\mathbf{I}_1$ and $\mathbf{I}_2$ in the circuit depicted in Fig. 10.69.

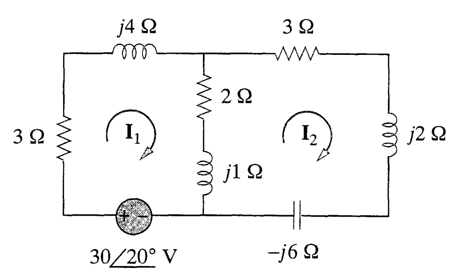


Figure 10.69 For Prob. 10.21.

10.22 Repeat Prob. 10.11 using mesh analysis.

10.23 Use mesh analysis to determine current $\mathbf{I}_o$ in the circuit of Fig. 10.70 below.

10.24 Determine $\mathbf{V}_o$ and $\mathbf{I}_o$ in the circuit of Fig. 10.71 using mesh analysis.

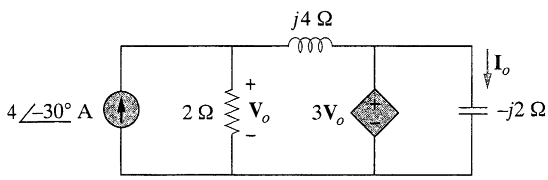


Figure 10.71 For Prob. 10.24.

10.25 Compute **I** in Prob. 10.9 using mesh analysis.

10.26 Use mesh analysis to find $\mathbf{I}_o$ in Fig. 10.28 (for Example 10.10).

10.27 Calculate $\mathbf{I}_o$ in Fig. 10.30 (for Practice Prob. 10.10) using mesh analysis.

10.28 Compute $\mathbf{V}_o$ in the circuit of Fig. 10.72 using mesh analysis.

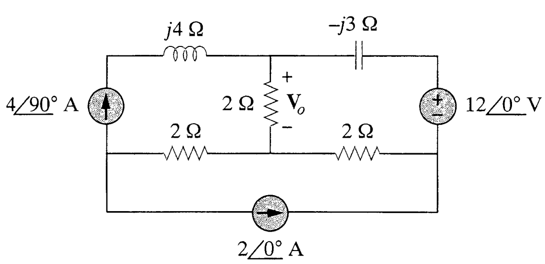


Figure 10.72 For Prob. 10.28.

10.29 Using mesh analysis, obtain $\mathbf{I}_o$ in the circuit shown in Fig. 10.73.

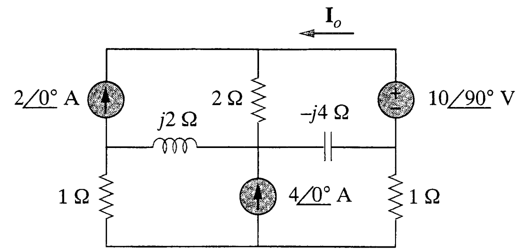


Figure 10.73 For Prob. 10.29.

Section 10.4 Superposition Theorem

10.30 Find i_o in the circuit shown in Fig. 10.74 using superposition.

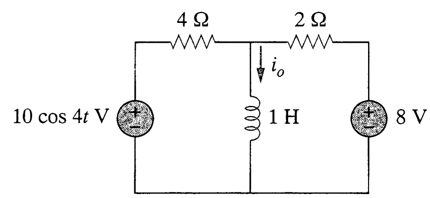


Figure 10.74 For Prob. 10.30.

10.31 Using the superposition principle, find i_x in the circuit of Fig. 10.75.

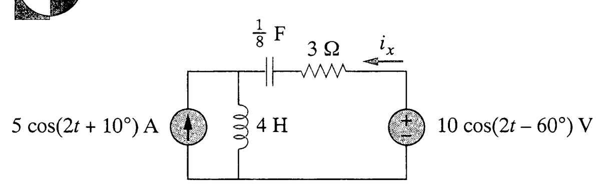


Figure 10.75 For Prob. 10.31.

10.32 Rework Prob. 10.2 using the superposition theorem.

10.33 Solve for $v_o(t)$ in the circuit of Fig. 10.76 using the superposition principle.

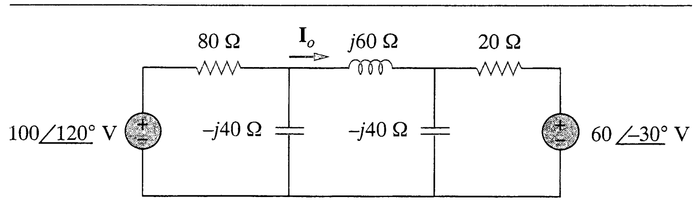


Figure 10.70 For Prob. 10.23.

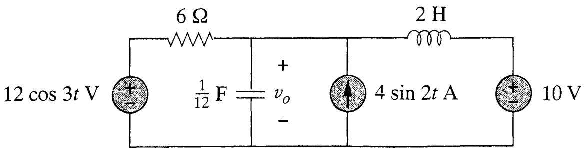


Figure 10.76 For Prob. 10.33.

10.34 Determine i_o in the circuit of Fig. 10.77.

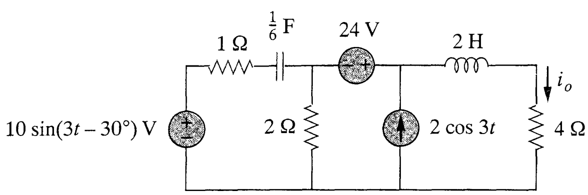


Figure 10.77 For Prob. 10.34.

10.35 Find i_o in the circuit in Fig. 10.78 using superposition.

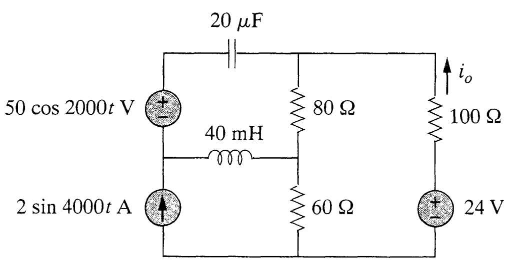


Figure 10.78 For Prob. 10.35.

Section 10.5 Source Transformation

10.36 Using source transformation, find i in the circuit of Fig. 10.79.

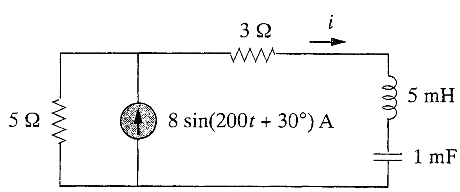


Figure 10.79 For Prob. 10.36.

10.37 Use source transformation to find v_o in the circuit in Fig. 10.80.

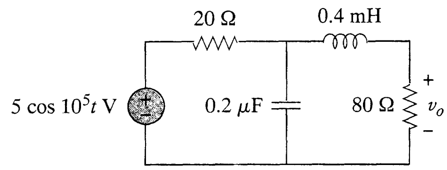


Figure 10.80 For Prob. 10.37.

10.38 Solve Prob. 10.20 using source transformation.

10.39 Use the method of source transformation to find $\mathbf{I}_x$ in the circuit of Fig. 10.81.

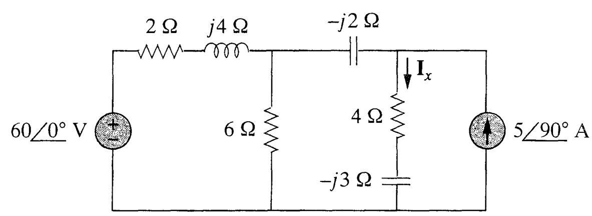


Figure 10.81 For Prob. 10.39.

10.40 Use the concept of source transformation to find $\mathbf{V}_o$ in the circuit of Fig. 10.82.

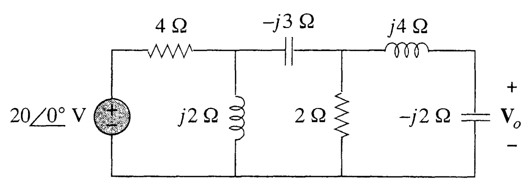


Figure 10.82 For Prob. 10.40.

Section 10.6 Thevenin and Norton Equivalent Circuits

10.41 Find the Thevenin and Norton equivalent circuits at terminals *a-b* for each of the circuits in Fig. 10.83.

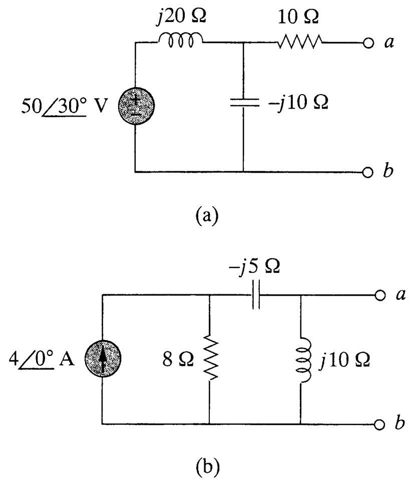


Figure 10.83 For Prob. 10.41.

10.42 For each of the circuits in Fig. 10.84, obtain Thevenin and Norton equivalent circuits at terminals a-b.

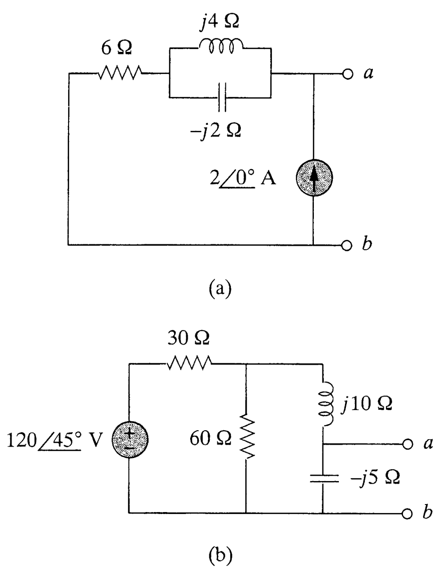


Figure 10.84 For Prob. 10.42.

10.43 Find the Thevenin and Norton equivalent circuits for the circuit shown in Fig. 10.85.

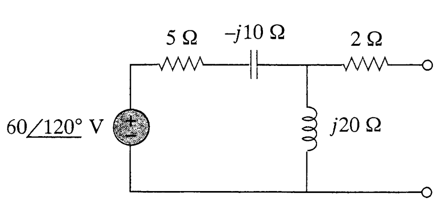


Figure 10.85 For Prob. 10.43.

10.44 For the circuit depicted in Fig. 10.86, find the Thevenin equivalent circuit at terminals a-b.

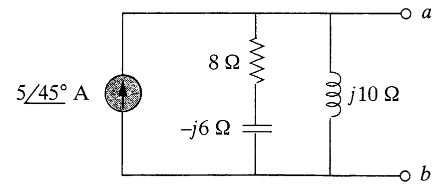


Figure 10.86 For Prob. 10.44.

10.45 Repeat Prob. 10.1 using Thevenin's theorem.

10.46 Find the Thevenin equivalent of the circuit in Fig. 10.87 as seen from:

(a) terminals a-b (b) terminals c-d

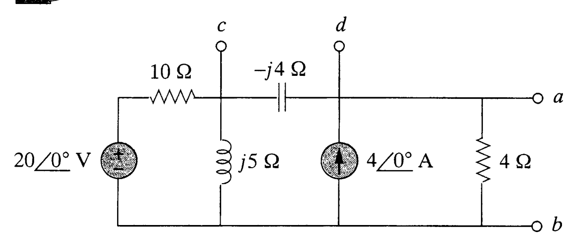


Figure 10.87 For Prob. 10.46.

10.47 Solve Prob. 10.3 using Thevenin's theorem.

10.48 Using Thevenin's theorem, find v_o in the circuit in Fig. 10.88.

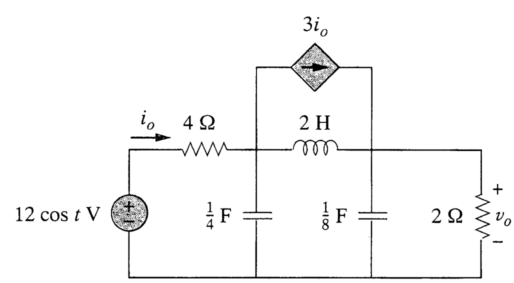


Figure 10.88 For Prob. 10.48.

10.49 Obtain the Norton equivalent of the circuit depicted in Fig. 10.89 at terminals a-b.

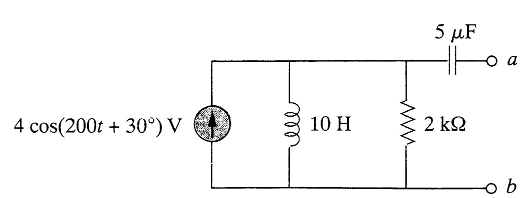


Figure 10.89 For Prob. 10.49.

10.50 For the circuit shown in Fig. 10.90, find the Norton equivalent circuit at terminals a-b.

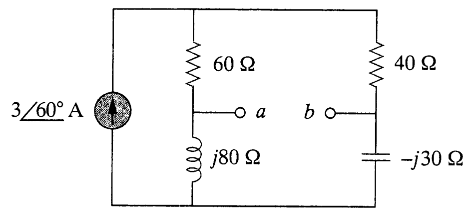


Figure 10.90 For Prob. 10.50.

10.51 Compute i_o in Fig. 10.91 using Norton's theorem.

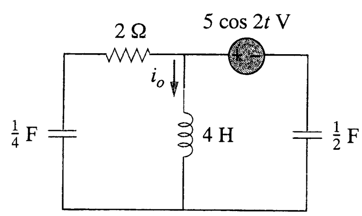


Figure 10.91 For Prob. 10.51.

10.52 At terminals a-b, obtain Thevenin and Norton equivalent circuits for the network depicted in Fig. 10.92. Take $\omega = 10$ rad/s.

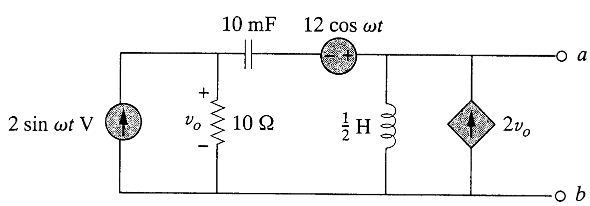


Figure 10.92 For Prob. 10.52.

Section 10.7 Op Amp AC Circuits

10.53 For the differentiator shown in Fig. 10.93, obtain $\mathbf{V}_o/\mathbf{V}_s$. Find $v_o(t)$ when $v_s(t) = V_m \sin \omega t$ and $\omega = 1/RC$.

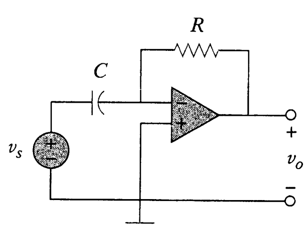


Figure 10.93 For Prob. 10.53.

10.54 The circuit in Fig. 10.94 is an integrator with a feedback resistor. Calculate $v_o(t)$ if $v_s = 2 \cos 4 \times 10^4 t$ V.

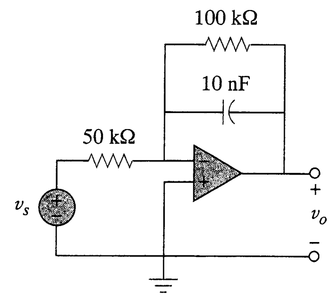


Figure 10.94 For Prob. 10.54.

10.55 Compute $i_o(t)$ in the op amp circuit in Fig. 10.95 if $v_s = 4 \cos 10^4 t$ V.

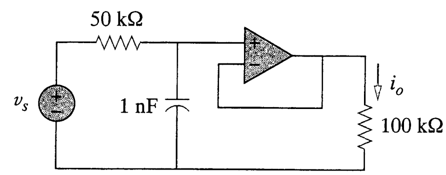


Figure 10.95 For Prob. 10.55.

10.56 If the input impedance is defined as $\mathbf{Z}_{in} = \mathbf{V}_s/\mathbf{I}_s$, find the input impedance of the op amp circuit in Fig. 10.96 when $R_1 = 10$ kΩ, $R_2 = 20$ kΩ, $C_1 = 10$ nF, $C_2 = 20$ nF, and $\omega = 5000$ rad/s.

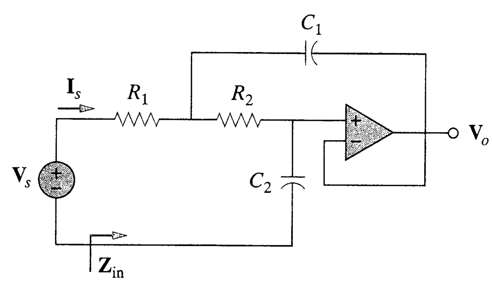


Figure 10.96 For Prob. 10.56.

10.57 Evaluate the voltage gain $\mathbf{A}_v = \mathbf{V}_o/\mathbf{V}_s$ in the op amp circuit of Fig. 10.97. Find $\mathbf{A}_v$ at $\omega = 0$, $\omega \to \infty$, $\omega = 1/R_1C_1$, and $\omega = 1/R_2C_2$.

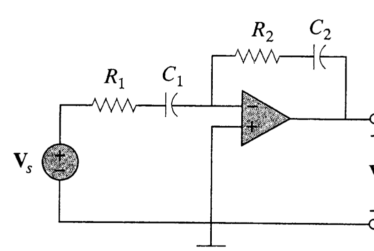


Figure 10.97 For Prob. 10.57.

10.58 In the op amp circuit of Fig. 10.98, find the closed-loop gain and phase shift if $C_1 = C_2 = 1$ nF, $R_1 = R_2 = 100$ kΩ, $R_3 = 20$ kΩ, $R_4 = 40$ kΩ, and $\omega = 2000$ rad/s.

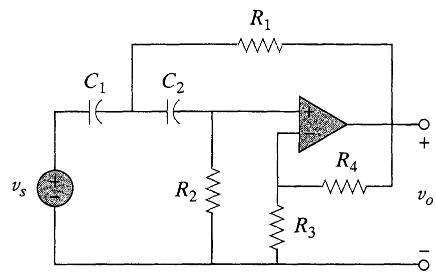


Figure 10.98 For Prob. 10.58.

10.59 Compute the closed-loop gain $\mathbf{V}_o/\mathbf{V}_s$ for the op amp circuit of Fig. 10.99.

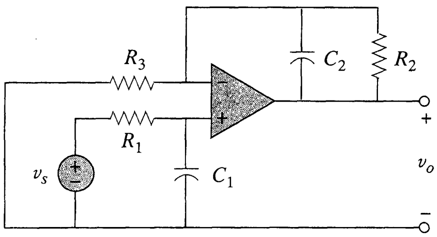


Figure 10.99 For Prob. 10.59.

10.60 Determine $v_o(t)$ in the op amp circuit in Fig. 10.100 below.

10.61 For the op amp circuit in Fig. 10.101, obtain $v_o(t)$.

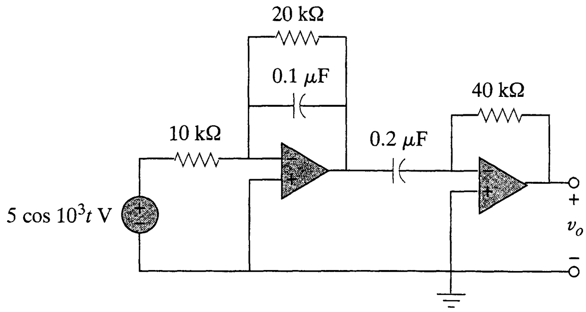


Figure 10.101 For Prob. 10.61.

10.62 Obtain $v_o(t)$ for the op amp circuit in Fig. 10.102 if $v_s = 4\cos(1000t - 60°)$ V.

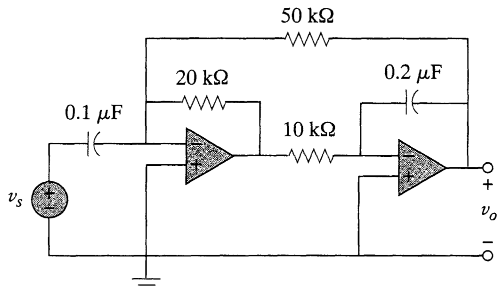


Figure 10.102 For Prob. 10.62.

Section 10.8 AC Analysis Using *PSpice*

10.63 Use *PSpice* to solve Example 10.10.

10.64 Solve Prob. 10.13 using *PSpice*.

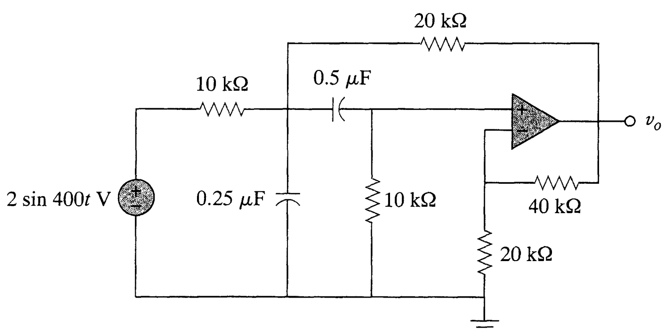


Figure 10.100 For Prob. 10.60.

10.65 Obtain $\mathbf{V}_o$ in the circuit of Fig. 10.103 using *PSpice*.

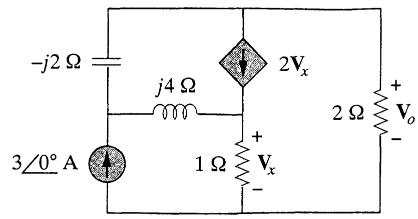


Figure 10.103 For Prob. 10.65.

10.66 Use *PSpice* to find $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_3$ in the network of Fig. 10.104.

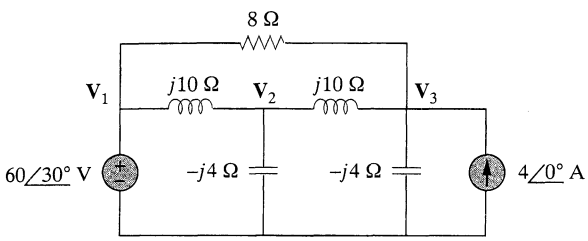


Figure 10.104 For Prob. 10.66.

10.67 Determine $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_3$ in the circuit of Fig. 10.105 using *PSpice*.

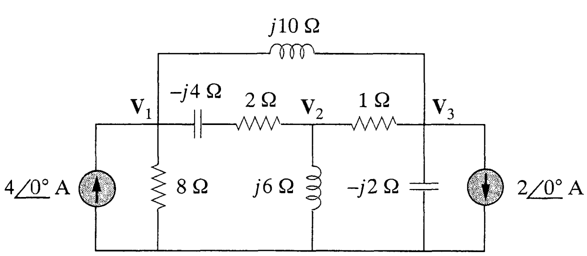


Figure 10.105 For Prob. 10.67.

10.68 Use *PSpice* to find v_o and i_o in the circuit of Fig. 10.106 below.

Section 10.9 Applications

10.69 The op amp circuit in Fig. 10.107 is called an *inductance simulator*. Show that the input impedance is given by

$$\mathbf{Z}_{\text{in}} = \frac{\mathbf{V}_{\text{in}}}{\mathbf{I}_{\text{in}}} = j\omega L_{\text{eq}}$$

where

$$L_{\text{eq}} = \frac{R_1 R_3 R_4}{R_2} C$$

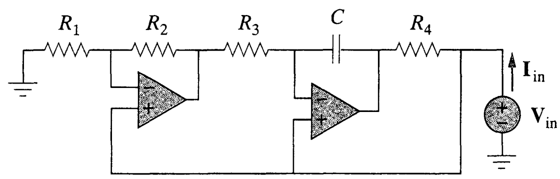


Figure 10.107 For Prob. 10.69.

10.70 Figure 10.108 shows a Wien-bridge network. Show that the frequency at which the phase shift between the input and output signals is zero is $f = \frac{1}{2}\pi RC$, and that the necessary gain is $\mathbf{A}_v = \mathbf{V}_o/\mathbf{V}_i = 3$ at that frequency.

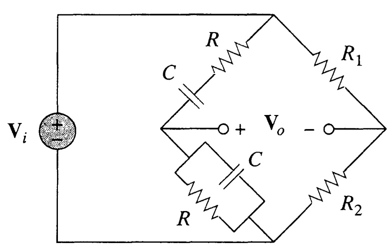


Figure 10.108 For Prob. 10.70.

10.71 Consider the oscillator in Fig. 10.109.

(a) Determine the oscillation frequency.

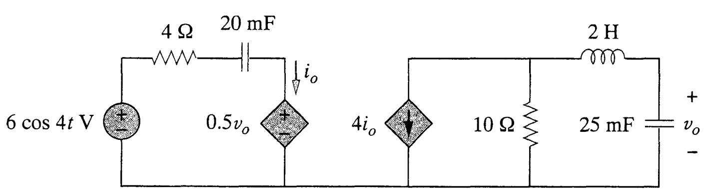


Figure 10.106 For Prob. 10.68.

(b) Obtain the minimum value of R for which oscillation takes place.

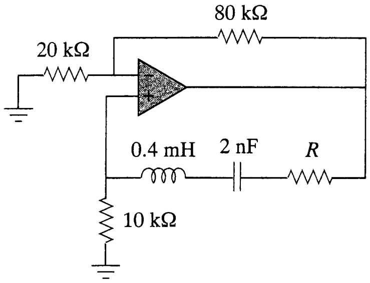


Figure 10.109 For Prob. 10.71.

10.72 The oscillator circuit in Fig. 10.110 uses an ideal op amp.
(a) Calculate the minimum value of R_o that will cause oscillation to occur.
(b) Find the frequency of oscillation.

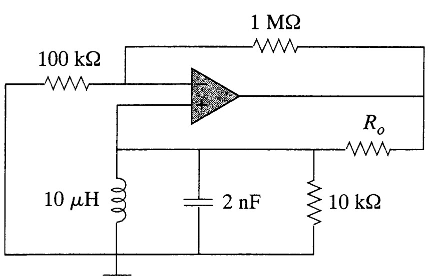


Figure 10.110 For Prob. 10.72.

10.73 Figure 10.111 shows a *Colpitts oscillator*. Show that the oscillation frequency is

$$f_o = \frac{1}{2\pi\sqrt{LC_T}}$$

where $C_T = C_1C_2/(C_1 + C_2)$. Assume $R_i \gg X_{C_2}$.

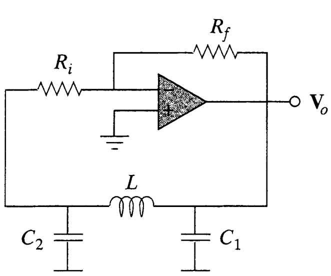


Figure 10.111 A Colpitts oscillator; for Prob. 10.73.

(*Hint:* Set the imaginary part of the impedance in the feedback circuit equal to zero.)

10.74 Design a Colpitts oscillator that will operate at 50 kHz.

10.75 Figure 10.112 shows a *Hartley oscillator*. Show that the frequency of oscillation is

$$f_o = \frac{1}{2\pi\sqrt{C(L_1 + L_2)}}$$

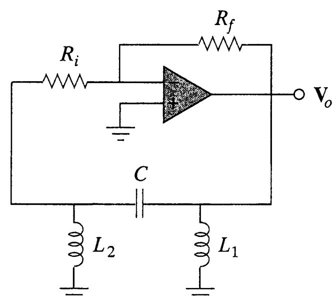


Figure 10.112 A Hartley oscillator; for Prob. 10.75.

10.76 Refer to the oscillator in Fig. 10.113.
(a) Show that

$$\frac{\mathbf{V}_2}{\mathbf{V}_o} = \frac{1}{3 + j(\omega L/R - R/\omega L)}$$

(b) Determine the oscillation frequency f_o.
(c) Obtain the relationship between R_1 and R_2 in order for oscillation to occur.

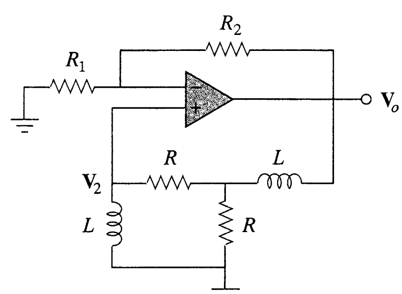


Figure 10.113 For Prob. 10.76.

CHAPTER 11

AC POWER ANALYSIS

An engineer is an unordinary person who can do for one dollar what any ordinary person can do for two dollars.

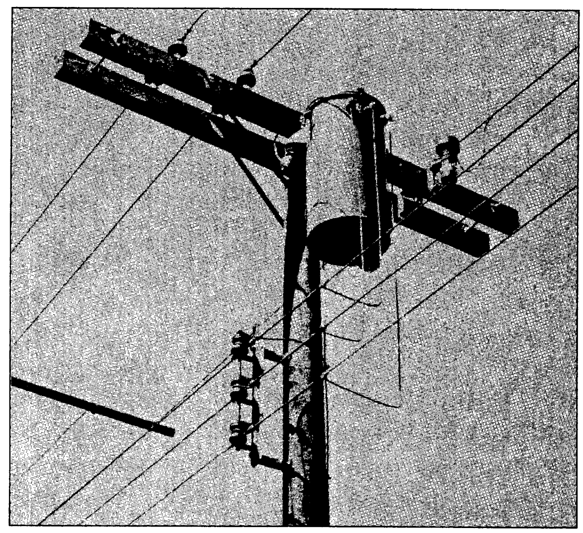
—Anonymous

Enhancing Your Career

Career in Power Systems The discovery of the principle of an ac generator by Michael Faraday in 1831 was a major breakthrough in engineering; it provided a convenient way of generating the electric power that is needed in every electronic, electrical, or electromechanical device we use now.

Electric power is obtained by converting energy from sources such as fossil fuels (gas, oil, and coal), nuclear fuel (uranium), hydro energy (water falling through a head), geothermal energy (hot water, steam), wind energy, tidal energy, and biomass energy (wastes). These various ways of generating electric power are studied in detail in the field of power engineering, which has become an indispensable subdiscipline of electrical engineering. An electrical engineer should be familiar with the analysis, generation, transmission, distribution, and cost of electric power.

The electric power industry is a very large employer of electrical engineers. The industry includes thousands of electric utility systems ranging from large, interconnected systems serving large regional areas to small power companies serving individual communities or factories. Due to the complexity of the power industry, there are numerous electrical engineering jobs in different areas of the industry: power plant (generation), transmission and distribution, maintenance, research, data acquisition and flow control, and management. Since electric power is used everywhere, electric utility companies are everywhere, offering exciting training and steady employment for men and women in thousands of communities throughout the world.



A pole-type transformer with a low-voltage, three-wire distribution system. Source: W. N. Alerich, Electricity, 3rd ed. Albany, NY: Delmar Publishers, 1981, p. 152. (Courtesy of General Electric.)

The values of R_1, R_2, L, and C may be selected such that the two filters have the same cutoff frequency, known as the *crossover frequency*, as shown in Fig. 14.64.

The principle behind the crossover network is also used in the resonant circuit for a TV receiver, where it is necessary to separate the video and audio bands of RF carrier frequencies. The lower-frequency band (picture information in the range from about 30 Hz to about 4 MHz) is channeled into the receiver's video amplifier, while the high-frequency band (sound information around 4.5 MHz) is channeled to the receiver's sound amplifier.

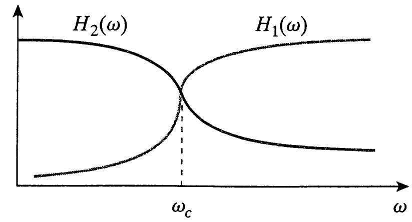


Figure 14.64 Frequency responses of the crossover network in Fig. 14.63.

EXAMPLE 14.19

In the crossover network of Fig. 14.63, suppose each speaker acts as a 6-Ω resistance. Find C and L if the crossover frequency is 2.5 kHz.

Solution:

For the highpass filter,

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

or

$$C = \frac{1}{2\pi f_c R_1} = \frac{1}{2\pi \times 2.5 \times 10^3 \times 6} = 10.61\ \mu\text{F}$$

For the lowpass filter,

$$\omega_c = 2\pi f_c = \frac{R_2}{L}$$

or

$$L = \frac{R_2}{2\pi f_c} = \frac{6}{2\pi \times 2.5 \times 10^3} = 382\ \mu\text{H}$$

PRACTICE PROBLEM 14.19

If each speaker in Fig. 14.63 has an 8-Ω resistance and $C = 10\ \mu$F, find L and the crossover frequency.

Answer: 0.64 mH, 1.989 kHz.

14.12 SUMMARY

1. The transfer function $\mathbf{H}(\omega)$ is the ratio of the output response $\mathbf{Y}(\omega)$ to the input excitation $\mathbf{X}(\omega)$; that is, $\mathbf{H}(\omega) = \mathbf{Y}(\omega)/\mathbf{X}(\omega)$.
2. The frequency response is the variation of the transfer function with frequency.
3. Zeros of a transfer function $\mathbf{H}(s)$ are the values of $s = j\omega$ that make $H(s) = 0$, while poles are the values of s that make $H(s) \rightarrow \infty$.
4. The decibel is the unit of logarithmic gain. For a gain G, its decibel equivalent is $G_{\text{dB}} = 20 \log_{10} G$.

5. Bode plots are semilog plots of the magnitude and phase of the transfer function as it varies with frequency. The straight-line approximations of H (in dB) and ϕ (in degrees) are constructed using the corner frequencies defined by the poles and zeros of $\mathbf{H}(\omega)$.
6. The resonant frequency is that frequency at which the imaginary part of a transfer function vanishes. For series and parallel RLC circuits,

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

7. The half-power frequencies (ω_1, ω_2) are those frequencies at which the power dissipated is one-half of that dissipated at the resonant frequency. The geometric mean between the half-power frequencies is the resonant frequency, or

$$\omega_0 = \sqrt{\omega_1 \omega_2}$$

8. The bandwidth is the frequency band between half-power frequencies:

$$B = \omega_2 - \omega_1$$

9. The quality factor is a measure of the sharpness of the resonance peak. It is the ratio of the resonant (angular) frequency to the bandwidth,

$$Q = \frac{\omega_0}{B}$$

10. A filter is a circuit designed to pass a band of frequencies and reject others. Passive filters are constructed with resistors, capacitors, and inductors. Active filters are constructed with resistors, capacitors, and an active device, usually an op amp.
11. Four common types of filters are lowpass, highpass, bandpass, and bandstop. A lowpass filter passes only signals whose frequencies are below the cutoff frequency ω_c. A highpass filter passes only signals whose frequencies are above the cutoff frequency ω_c. A bandpass filter passes only signals whose frequencies are within a prescribed range ($\omega_1 < \omega < \omega_2$). A bandstop filter passes only signals whose frequencies are outside a prescribed range ($\omega_1 > \omega > \omega_2$).
12. Scaling is the process whereby unrealistic element values are magnitude-scaled by a factor K_m and/or frequency-scaled by a factor K_f to produce realistic values.

$$R' = K_m R, \qquad L' = \frac{K_m}{K_f} L, \qquad C' = \frac{1}{K_m K_f} C$$

13. *PSpice* can be used to obtain the frequency response of a circuit if a frequency range for the response and the desired number of points within the range are specified in the AC Sweep.
14. The radio receiver—one practical application of resonant circuits—employs a bandpass resonant circuit to tune in one frequency among all the broadcast signals picked up by the antenna.

15. The Touch-Tone telephone and the crossover network are two typical applications of filters. The Touch-Tone telephone system employs filters to separate tones of different frequencies to activate electronic switches. The crossover network separates signals in different frequency ranges so that they can be delivered to different devices such as tweeters and woofers in a loudspeaker system.

REVIEW QUESTIONS

14.1 A zero of the transfer function

$$H(s) = \frac{10(s+1)}{(s+2)(s+3)}$$

is at

(a) 10 (b) -1 (c) -2 (d) -3

14.2 On the Bode magnitude plot, the slope of the pole $1/(5+j\omega)^2$ is

(a) 20 dB/decade (b) 40 dB/decade
(c) -40 dB/decade (d) -20 dB/decade

14.3 On the Bode phase plot, the slope of $[1 + j10\omega - \omega^2/25]^2$ is

(a) 45°/decade (b) 90°/decade
(c) 135°/decade (d) 180°/decade

14.4 How much inductance is needed to resonate at 5 kHz with a capacitance of 12 nF?

(a) 2652 H (b) 11.844 H
(c) 3.333 H (d) 84.43 mH

14.5 The difference between the half-power frequencies is called the:

(a) quality factor (b) resonant frequency
(c) bandwidth (d) cutoff frequency

14.6 In a series RLC circuit, which of these quality factors has the steepest curve at resonance?

(a) $Q = 20$ (b) $Q = 12$
(c) $Q = 8$ (d) $Q = 4$

14.7 In a parallel RLC circuit, the bandwidth B is directly proportional to R.

(a) True (b) False

14.8 When the elements of an RLC circuit are both magnitude-scaled and frequency-scaled, which quality is unaffected?

(a) resistor (b) resonant frequency
(c) bandwidth (d) quality factor

14.9 What kind of filter can be used to select a signal of one particular radio station?

(a) lowpass (b) highpass
(c) bandpass (d) bandstop

14.10 A voltage source supplies a signal of constant amplitude, from 0 to 40 kHz, to an RC lowpass filter. The load resistor experiences the maximum voltage at:

(a) dc (b) 10 kHz
(c) 20 kHz (d) 40 kHz

Answers: 14.1b, 14.2c, 14.3d, 14.4d, 14.5c, 14.6a, 14.7b, 14.8d, 14.9c, 14.10a.

PROBLEMS

Section 14.2 Transfer Function

14.1 Find the transfer function $\mathbf{V}_o/\mathbf{V}_i$ of the RC circuit in Fig. 14.65.

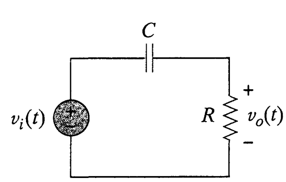


Figure 14.65 For Prob. 14.1.

14.2 Obtain the transfer function $\mathbf{V}_o/\mathbf{V}_i$ of the RL circuit of Fig. 14.66.

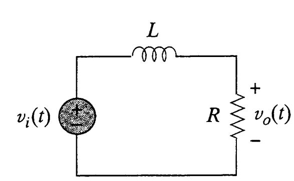


Figure 14.66 For Probs. 14.2 and 14.36.

14.3 (a) Given the circuit in Fig. 14.67, determine the transfer function $H(s) = V_o(s)/V_i(s)$.
(b) If $R = 40\ \text{k}\Omega$ and $C = 2\ \mu\text{F}$, specify the locations of the poles and zeros of $H(s)$.

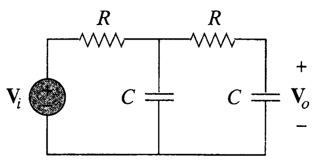


Figure 14.67 For Prob. 14.3.

14.4 Find the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o/\mathbf{V}_i$ of the circuits shown in Fig. 14.68.

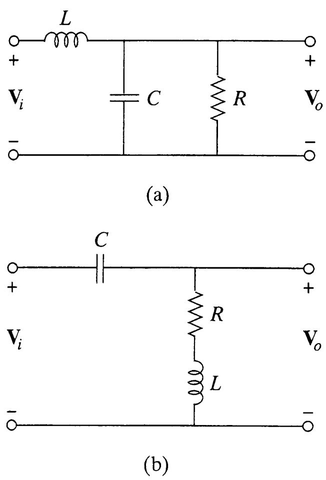


Figure 14.68 For Prob. 14.4.

14.5 Repeat Prob. 14.4 for the circuits in Fig. 14.69.

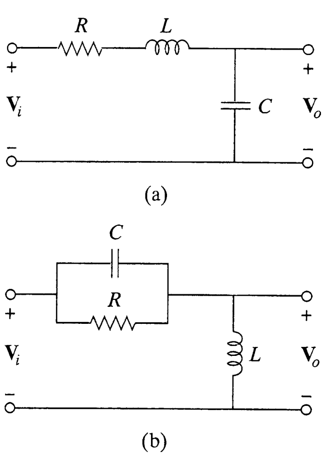


Figure 14.69 For Prob. 14.5.

14.6 Obtain the transfer function $\mathbf{H}(\omega) = \mathbf{I}_o/\mathbf{I}_s$ of the circuits shown in Fig. 14.70.

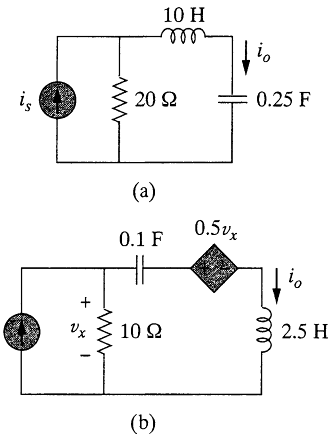


Figure 14.70 For Prob. 14.6.

Section 14.3 The Decibel Scale

14.7 Calculate $|\mathbf{H}(\omega)|$ if H_{dB} equals
(a) 0.05 dB (b) −6.2 dB (c) 104.7 dB

14.8 Determine the magnitude (in dB) and the phase (in degrees) of $\mathbf{H}(\omega)$ at $\omega = 1$ if $\mathbf{H}(\omega)$ equals
(a) 0.05 (b) 125
(c) $\dfrac{10j\omega}{2+j\omega}$ (d) $\dfrac{3}{1+j\omega} + \dfrac{6}{2+j\omega}$

Section 14.4 Bode Plots

14.9 A ladder network has a voltage gain of

$$\mathbf{H}(\omega) = \frac{10}{(1+j\omega)(10+j\omega)}$$

Sketch the Bode plots for the gain.

14.10 Sketch the Bode plots for

$$\mathbf{H}(\omega) = \frac{10+j\omega}{j\omega(2+j\omega)}$$

14.11 Construct the Bode plots for

$$G(s) = \frac{s+1}{s^2(s+10)}, \qquad s = j\omega$$

14.12 Draw the Bode plots for

$$\mathbf{H}(\omega) = \frac{50(j\omega+1)}{j\omega(-\omega^2+10j\omega+25)}$$

14.13 Construct the Bode magnitude and phase plots for

$$H(s) = \frac{40(s+1)}{(s+2)(s+10)}, \qquad s = j\omega$$

14.14 Sketch the Bode plots for

$$G(s) = \frac{s}{(s+2)^2(s+1)}, \qquad s = j\omega$$

14.15 Draw Bode plots for

$$G(s) = \frac{(s+2)^2}{s(s+5)(s+10)}, \qquad s = j\omega$$

14.16 A filter has

$$H(s) = \frac{s}{s^2 + 10s + 100}$$

Sketch the filter's Bode magnitude and phase plots.

14.17 Sketch Bode magnitude and phase plots for

$$N(s) = \frac{100(s^2 + s + 1)}{(s+1)(s+10)}, \qquad s = j\omega$$

Construct the straight-line approximate plots and the exact plots.

14.18 Construct Bode plots for

$$\mathbf{T}(\omega) = \frac{10j\omega(1 + j\omega)}{(10 + j\omega)(100 + 10j\omega - \omega^2)}$$

14.19 Find the transfer function $\mathbf{H}(\omega)$ with the Bode magnitude plot shown in Fig. 14.71.

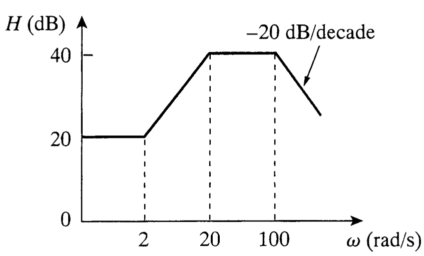


Figure 14.71 For Prob. 14.19.

14.20 The Bode magnitude plot of $\mathbf{H}(\omega)$ is shown in Fig. 14.72. Find $\mathbf{H}(\omega)$.

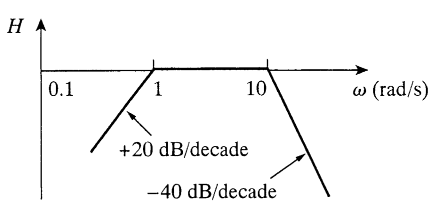


Figure 14.72 For Prob. 14.20.

14.21 The Bode phase plot of $\mathbf{G}(\omega)$ of a network is depicted in Fig. 14.73. Find $\mathbf{G}(\omega)$.

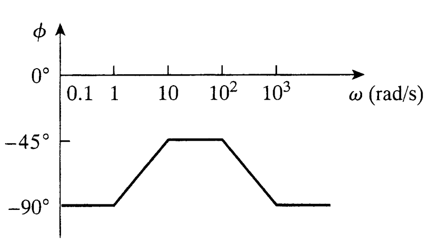


Figure 14.73 For Prob. 14.21.

Section 14.5 Series Resonance

14.22 A series RLC network has $R = 2\ \text{k}\Omega$, $L = 40$ mH, and $C = 1\ \mu$F. Calculate the impedance at resonance and at one-fourth, one-half, twice, and four times the resonant frequency.

14.23 Design a series RLC circuit that will have an impedance of 10 Ω at the resonant frequency of $\omega_0 = 50$ rad/s and a quality factor of 80. Find the bandwidth.

14.24 Design a series RLC circuit with $B = 20$ rad/s and $\omega_0 = 1000$ rad/s. Find the circuit's Q.

14.25 For the circuit in Fig. 14.74, find the frequency ω for which $v(t)$ and $i(t)$ are in phase.

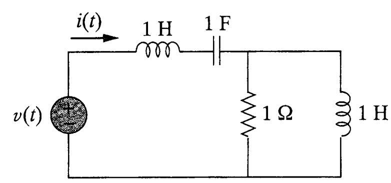


Figure 14.74 For Prob. 14.25.

Section 14.6 Parallel Resonance

14.26 Design a parallel resonant RLC circuit with $\omega_0 = 10$ rad/s and $Q = 20$. Calculate the bandwidth of the circuit.

14.27 A parallel resonant circuit with quality factor 120 has a resonant frequency of 6×10^6 rad/s. Calculate the bandwidth and half-power frequencies.

14.28 It is expected that a parallel RLC resonant circuit has a midband admittance of 25×10^3 S, quality factor of 80, and a resonant frequency of 200 krad/s. Calculate the values of R, L, and C. Find the bandwidth and the half-power frequencies.

14.29 Rework Prob. 14.22 if the elements are connected in parallel.

14.30 For the "tank" circuit in Fig. 14.75, find the resonant frequency.

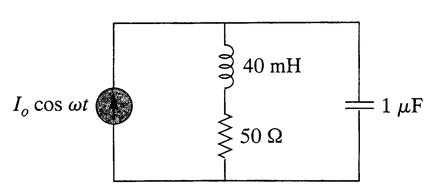


Figure 14.75 For Probs. 14.30 and 14.71.

14.31 For the circuits in Fig. 14.76, find the resonant frequency ω_0, the quality factor Q, and the bandwidth B.

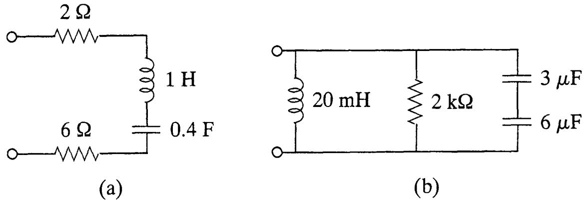


Figure 14.76 For Prob. 14.31.

14.32 Calculate the resonant frequency of each of the circuits in Fig. 14.77.

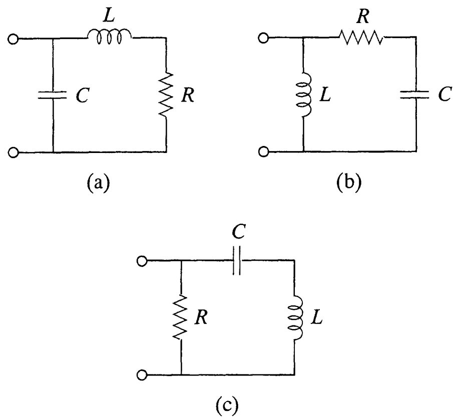


Figure 14.77 For Prob. 14.32.

***14.33** For the circuit in Fig. 14.78, find:
(a) the resonant frequency ω_0
(b) $\mathbf{Z}_{in}(\omega)$

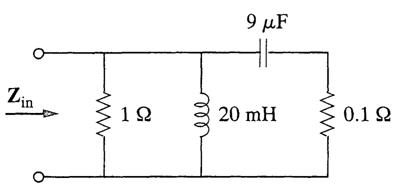


Figure 14.78 For Prob. 14.33.

14.34 In the circuit of Fig. 14.79, $i(t) = 10 \sin t$. Calculate the value of C such that $v(t) = V_o \sin t$ V. Find V_o.

*An asterisk indicates a challenging problem.

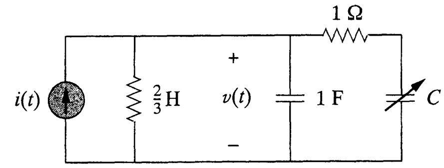


Figure 14.79 For Prob. 14.34.

14.35 For the network illustrated in Fig. 14.80, find
(a) the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o(\omega)/\mathbf{I}(\omega)$,
(b) the magnitude of $\mathbf{H}$ at $\omega_0 = 1$ rad/s.

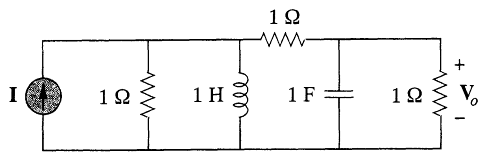


Figure 14.80 For Probs. 14.35, 14.61, and 14.72.

Section 14.7 Passive Filters

14.36 Show that the circuit in Fig. 14.66 is a lowpass filter. Calculate the corner frequency f_c if $L = 2$ mH and $R = 10$ kΩ.

14.37 Find the transfer function $\mathbf{V}_o/\mathbf{V}_s$ of the circuit in Fig. 14.81. Show that the circuit is a lowpass filter.

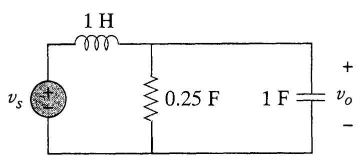


Figure 14.81 For Prob. 14.37.

14.38 Determine the cutoff frequency of the lowpass filter described by

$$\mathbf{H}(\omega) = \frac{4}{2 + j\omega 10}$$

Find the gain in dB and phase of $\mathbf{H}(\omega)$ at $\omega = 2$ rad/s.

14.39 Determine what type of filter is in Fig. 14.82. Calculate the corner frequency f_c.

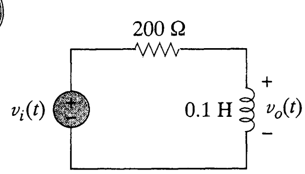


Figure 14.82 For Prob. 14.39.

14.40 Obtain the transfer function of a highpass filter with a passband gain of 10 and a cutoff frequency of 50 rad/s.

14.41 In a highpass RL filter with a cutoff frequency of 100 kHz, $L = 40$ mH. Find R.

14.42 Design a series RLC type bandpass filter with cutoff frequencies of 10 kHz and 11 kHz. Assuming $C = 80$ pF, find R, L, and Q.

14.43 Determine the range of frequencies that will be passed by a series RLC bandpass filter with $R = 10\ \Omega$, $L = 25$ mH, and $C = 0.4\ \mu$F. Find the quality factor.

14.44 (a) Show that for a bandpass filter,

$$\mathbf{H}(s) = \frac{sB}{s^2 + sB + \omega_0^2}$$

where B = bandwidth of the filter and ω_0 is the center frequency.

(b) Similarly, show that for a bandstop filter,

$$\mathbf{H}(s) = \frac{s^2 + \omega_0^2}{s^2 + sB + \omega_0^2}$$

14.45 Determine the center frequency and bandwidth of the bandpass filters in Fig. 14.83.

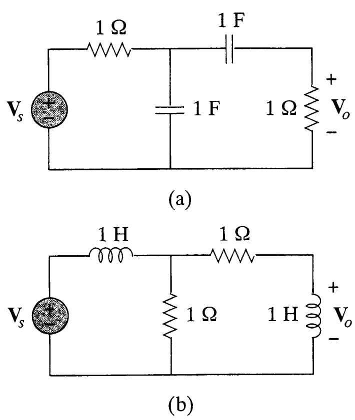


Figure 14.83 For Prob. 14.45.

14.46 The circuit parameters for a series RLC bandstop filter are $R = 2$ kΩ, $L = 0.1$ H, $C = 40$ pF. Calculate:

(a) the center frequency
(b) the half-power frequencies
(c) the quality factor

14.47 Find the bandwidth and center frequency of the bandstop filter of Fig. 14.84.

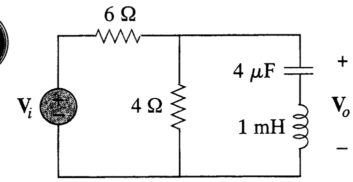


Figure 14.84 For Prob. 14.47.

Section 14.8 Active Filters

14.48 Find the transfer function for each of the active filters in Fig. 14.85.

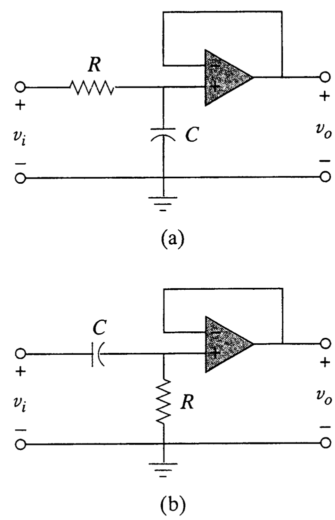


Figure 14.85 For Probs. 14.48 and 14.49.

14.49 The filter in Fig. 14.85(b) has a 3-dB cutoff frequency at 1 kHz. If its input is connected to a 120-mV variable frequency signal, find the output voltage at:

(a) 200 Hz (b) 2 kHz (c) 10 kHz

14.50 Obtain the transfer function of the active filter in Fig. 14.86. What kind of filter is it?

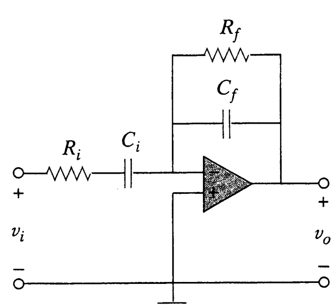


Figure 14.86 For Prob. 14.50.

14.51 A highpass filter is shown in Fig. 14.87. Show that the transfer function is

$$\mathbf{H}(\omega) = \left(1 + \frac{R_f}{R_i}\right)\frac{j\omega RC}{1 + j\omega RC}$$

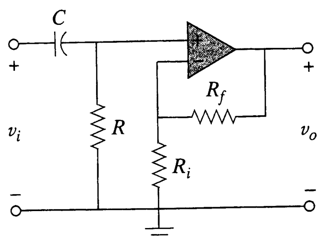


Figure 14.87 For Prob. 14.51.

14.52 A "general" first-order filter is shown in Fig. 14.88.

(a) Show that the transfer function is

$$\mathbf{H}(s) = \frac{R_4}{R_3 + R_4} \times \frac{s + (1/R_1C)[R_1/R_2 - R_3/R_4]}{s + 1/R_2C},$$

$s = j\omega$

(b) What condition must be satisfied for the circuit to operate as a highpass filter?

(c) What condition must be satisfied for the circuit to operate as a lowpass filter?

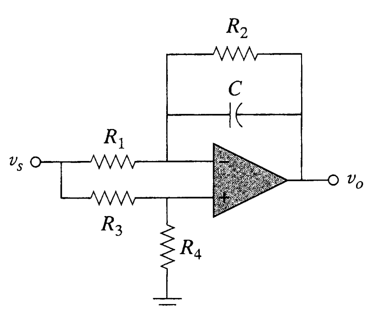


Figure 14.88 For Prob. 14.52.

14.53 Design an active lowpass filter with dc gain of 0.25 and a corner frequency of 500 Hz.

14.54 Design an active highpass filter with a high-frequency gain of 5 and a corner frequency of 200 Hz.

14.55 Design the filter in Fig. 14.89 to meet the following requirements:

(a) It must attenuate a signal at 2 kHz by 3 dB compared with its value at 10 MHz.

(b) It must provide a steady-state output of $v_o(t) = 10\sin(2\pi \times 10^8 t + 180°)$ V for an input $v_s(t) = 4\sin(2\pi \times 10^8 t)$ V.

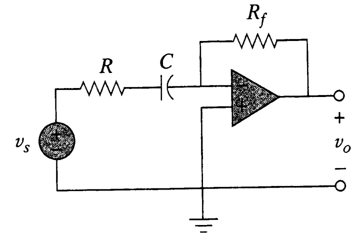


Figure 14.89 For Prob. 14.55.

***14.56** A second-order active filter known as a Butterworth filter is shown in Fig. 14.90.

(a) Find the transfer function $\mathbf{V}_o/\mathbf{V}_i$.

(b) Show that it is a lowpass filter.

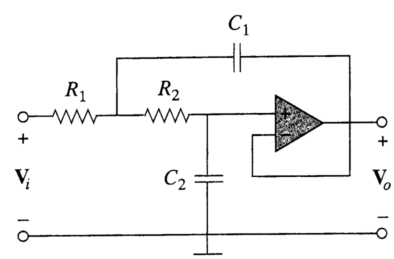


Figure 14.90 For Prob. 14.56.

Section 14.9 Scaling

14.57 Use magnitude and frequency scaling on the circuit of Fig. 14.75 to obtain an equivalent circuit in which the inductor and capacitor have magnitude 1 H and 1 C respectively.

14.58 What values of K_m and K_f will scale a 4-mH inductor and a 20-μF capacitor to 1 H and 2 F respectively?

14.59 Calculate the values of R, L, and C that will result in $R = 12$ kΩ, $L = 40$ μH, and $C = 300$ nF respectively when magnitude-scaled by 800 and frequency-scaled by 1000.

14.60 A series RLC circuit has $R = 10$ Ω, $\omega_0 = 40$ rad/s, and $B = 5$ rad/s. Find L and C when the circuit is scaled:

(a) in magnitude by a factor of 600,

(b) in frequency by a factor of 1000,

(c) in magnitude by a factor of 400 and in frequency by a factor of 10^5.

14.61 Redesign the circuit in Fig. 14.80 so that all resistive elements are scaled by a factor of 1000 and all frequency-sensitive elements are frequency-scaled by a factor of 10^4.

*14.62 Refer to the network in Fig. 14.91.
(a) Find $\mathbf{Z}_{\text{in}}(s)$.
(b) Scale the elements by $K_m = 10$ and $K_f = 100$. Find $\mathbf{Z}_{\text{in}}(s)$ and ω_0.

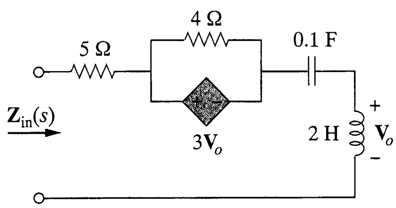


Figure 14.91 For Prob. 14.62.

14.63 (a) For the circuit in Fig. 14.92, draw the new circuit after it has been scaled by $K_m = 200$ and $K_f = 10^4$.
(b) Obtain the Thevenin equivalent impedance at terminals *a*-*b* of the scaled circuit at $\omega = 10^4$ rad/s.

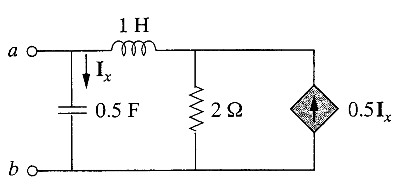


Figure 14.92 For Prob. 14.63.

14.64 Scale the lowpass active filter in Fig. 14.93 so that its corner frequency increases from 1 rad/s to 200 rad/s. Use a 1-μF capacitor.

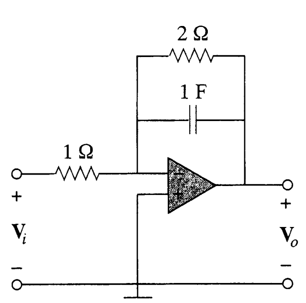


Figure 14.93 For Prob. 14.64.

Section 14.10 Frequency Response Using *PSpice*

14.65 Obtain the frequency response of the circuit in Fig. 14.94 using *PSpice*.

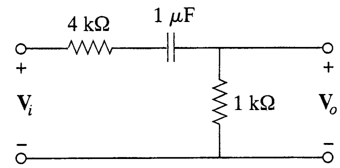


Figure 14.94 For Prob. 14.65.

14.66 Use *PSpice* to provide the frequency response (magnitude and phase of i) of the circuit in Fig. 14.95. Use linear frequency sweep from 1 to 10,000 Hz.

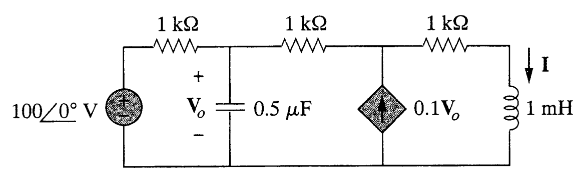


Figure 14.95 For Prob. 14.66.

14.67 In the interval $0.1 < f < 100$ Hz, plot the response of the network in Fig. 14.96. Classify this filter and obtain ω_0.

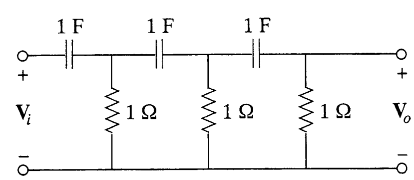


Figure 14.96 For Prob. 14.67.

14.68 Use *PSpice* to generate the magnitude and phase Bode plots of $\mathbf{V}_o$ in the circuit of Fig. 14.97.

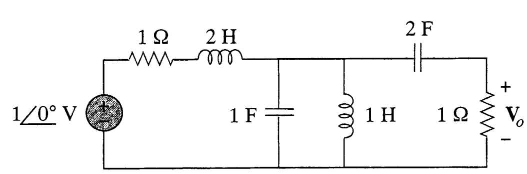


Figure 14.97 For Prob. 14.68.

14.69 Obtain the magnitude plot of the response $\mathbf{V}_o$ in the network of Fig. 14.98 for the frequency interval $100 < f < 1000$ Hz.

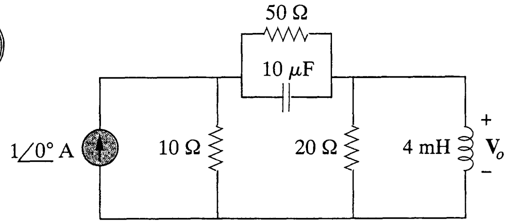


Figure 14.98 For Prob. 14.69.

14.70 Obtain the frequency response of the circuit in Fig. 14.40 (see Practice Problem 14.10). Take $R_1 = R_2 = 100\ \Omega$, $L = 2$ mH. Use $1 < f < 100{,}000$ Hz.

14.71 For the "tank" circuit of Fig. 14.75, obtain the frequency response (voltage across the capacitor) using *PSpice*. Determine the resonant frequency of the circuit.

14.72 Using *PSpice*, plot the magnitude of the frequency response of the circuit in Fig. 14.80.

Section 14.11 Applications

14.73 The resonant circuit for a radio broadcast consists of a 120-pF capacitor in parallel with a 240-μH inductor. If the inductor has an internal resistance of 400 Ω, what is the resonant frequency of the circuit? What would be the resonant frequency if the inductor resistance were reduced to 40 Ω?

14.74 A series-tuned antenna circuit consists of a variable capacitor (40 pF to 360 pF) and a 240-μH antenna coil which has a dc resistance of 12 Ω.

(a) Find the frequency range of radio signals to which the radio is tunable.

(b) Determine the value of Q at each end of the frequency range.

14.75 The crossover circuit in Fig. 14.99 is a lowpass filter that is connected to a woofer. Find the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o(\omega)/\mathbf{V}_i(\omega)$.

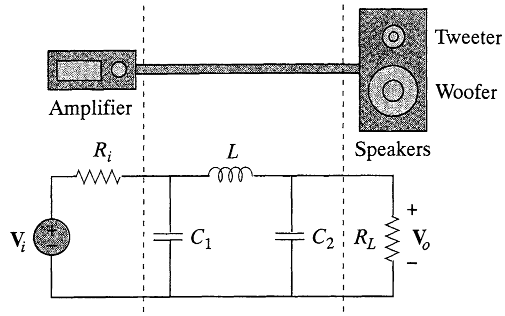


Figure 14.99 For Prob. 14.75.

14.76 The crossover circuit in Fig. 14.100 is a highpass filter that is connected to a tweeter. Determine the transfer function $\mathbf{H}(\omega) = \mathbf{V}_o(\omega)/\mathbf{V}_i(\omega)$.

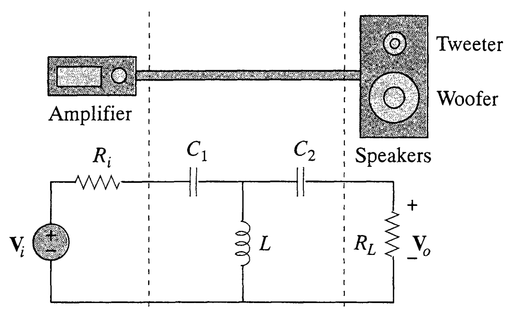


Figure 14.100 For Prob. 14.76.

COMPREHENSIVE PROBLEMS

14.77 A certain electronic test circuit produced a resonant curve with half-power points at 432 Hz and 454 Hz. If $Q = 20$, what is the resonant frequency of the circuit?

14.78 In an electronic device, a series circuit is employed that has a resistance of 100 Ω, a capacitive reactance of 5 kΩ, and an inductive reactance of 300 Ω when used at 2 MHz. Find the resonant frequency and bandwidth of the circuit.

14.79 In a certain application, a simple RC lowpass filter is designed to reduce high frequency noise. If the desired corner frequency is 20 kHz and $C = 0.5\ \mu$F, find the value of R.

14.80 In an amplifier circuit, a simple RC highpass filter is needed to block the dc component while passing the time-varying component. If the desired rolloff frequency is 15 Hz and $C = 10\ \mu$F, find the value of R.

14.81 Practical
RC filter design should allow for source and load resistances as shown in Fig. 14.101. Let $R = 4$ kΩ and $C =$ 40-nF. Obtain the cutoff frequency when:

(a) $R_s = 0$, $R_L = \infty$,

(b) $R_s = 1$ kΩ, $R_L = 5$ kΩ.

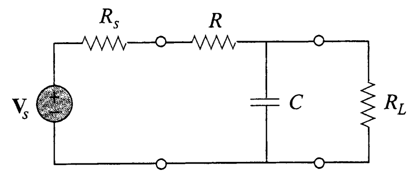


Figure 14.101 For Prob. 14.81.

14.82 The RC circuit in Fig. 14.102 is used for a lead compensator in a system design. Obtain the transfer function of the circuit.

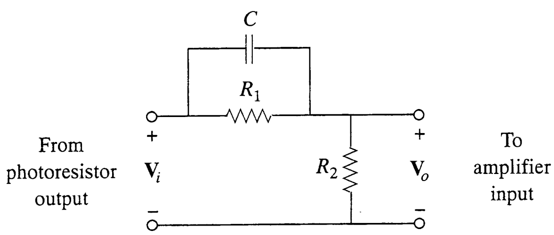


Figure 14.102 For Prob. 14.82.

14.83 A low-quality factor, double-tuned bandpass filter is shown in Fig. 14.103. Use *PSpice* to generate the magnitude plot of $\mathbf{V}_o(\omega)$.

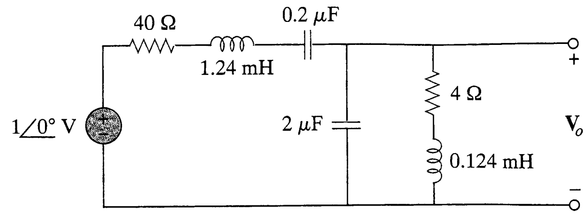


Figure 14.103 For Prob. 14.83.