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Appendix A

CONVERSION FACTORS

To Convert from	To	Multiply by
Btus	Calorie-grams	251.996
	Ergs	1.054×10^{10}
	Foot-pounds	777.649
	Hp-hours	0.000393
	Joules	1054.35
	Kilowatthours	0.000293
	Wattseconds	1054.35
Centimeters	Angstrom units	1×10^{8}
	Feet	0.0328
	Inches	0.3937
	Meters	0.01
	Miles (statute)	6.214×10^{-6}
	Millimeters	10
Circular mils	Square centimeters	5.067×10^{-6}
	Square inches	7.854×10^{-7}
Cubic inches	Cubic centimeters	16.387
	Gallons (U.S. liquid)	0.00433
Cubic meters	Cubic feet	35.315
Days	Hours	24
	Minutes	1440
	Seconds	86,400
Dynes	Gallons (U.S. liquid)	264.172
	Newtons	0.00001
	Pounds	2.248×10^{-6}
Electronvolts	Ergs	1.60209×10^{-12}
Ergs	Dyne-centimeters	1.0
	Electronvolts	6.242×10^{11}
	Foot-pounds	7.376×10^{-8}
	Joules	1×10^{-7}
	Kilowatthours	2.777×10^{-14}
Feet	Centimeters	30.48
	Meters	0.3048
Foot-candles	Lumens/square foot	1.0
	Lumens/square meter	10.764
Foot-pounds	Dyne-centimeters	1.3558×10^{7}
	Ergs	1.3558×10^{7}
	Horsepower-hours	5.050×10^{-7}
	Joules	1.3558
	Newton-meters	1.3558
Gallons (U.S. liquid)	Cubic inches	231
	Liters	3.785
	Ounces	128
	Pints	8

To Convert from	To	Multiply by
Gauss	Maxwells/square centimeter	1.0
	Lines/square centimeter	1.0
	Lines/square inch	6.4516
Gilberts	Ampere-turns	0.7958
Grams	Dynes	980.665
	Ounces	0.0353
	Pounds	0.0022
Horsepower	Btus/hour	2547.16
	Ergs/second	7.46×10^9
	Foot-pounds/second	550.221
	Joules/second	746
	Watts	746
Hours	Seconds	3600
Inches	Angstrom units	2.54×10^8
	Centimeters	2.54
	Feet	0.0833
	Meters	0.0254
Joules	Btus	0.000948
	Ergs	1×10^7
	Foot-pounds	0.7376
	Horsepower-hours	3.725×10^{-7}
	Kilowatthours	2.777×10^{-7}
	Wattseconds	1.0
Kilograms	Dynes	980,665
	Ounces	35.2
	Pounds	2.2
Lines	Maxwells	1.0
Lines/square centimeter	Gauss	1.0
Lines/square inch	Gauss	0.1550
	Webers/square inch	1×10^{-8}
Liters	Cubic centimeters	1000.028
	Cubic inches	61.025
	Gallons (U.S. liquid)	0.2642
	Ounces (U.S. liquid)	33.815
	Quarts (U.S. liquid)	1.0567
Lumens	Candle power (spher.)	0.0796
Lumens/square centimeter	Lamberts	1.0
Lumens/square foot	Foot-candles	1.0
Maxwells	Lines	1.0
	Webers	1×10^{-8}
Meters	Angstrom units	1×10^{10}
	Centimeters	100
	Feet	3.2808
	Inches	39.370
	Miles (statute)	0.000621

To Convert from	To	Multiply by
Miles (statute)	Feet	5280
	Kilometers	1.609
	Meters	1609.344
Miles/hour	Kilometers/hour	1.609344
Newton–meters	Dyne–centimeters	1×10^7
	Kilogram-meters	0.10197
Oersteds	Ampere-turns/inch	2.0212
	Ampere-turns/meter	79.577
	Gilberts/centimeter	1.0
Quarts (U.S. liquid)	Cubic centimeters	946.353
	Cubic inches	57.75
	Gallons (U.S. liquid)	0.25
	Liters	0.9463
	Pints (U.S. liquid)	2
	Ounces (U.S. liquid)	32
Radians	Degrees	57.2958
Slugs	Kilograms	14.5939
	Pounds	32.1740
Watts	Btus/hour	3.4144
	Ergs/second	1×10^7
	Horsepower	0.00134
	Joules/second	1.0
Webers	Lines	1×10^8
	Maxwells	1×10^8
Years	Days	365
	Hours	8760
	Minutes	525,600
	Seconds	3.1536×10^7

Appendix B

PSPICE AND MULTISIM

PSPICE 16.2

The PSpice software package used throughout this text is derived from programs developed at the University of California at Berkeley during the early 1970s. SPICE is an acronym for Simulation Program with Integrated Circuit Emphasis. Although a number of companies have customized SPICE for their particular use, Cadence Design Systems offers both a commercial and a demo version of OrCAD. The commercial or professional versions that engineering companies use can be quite expensive, so Cadence offers a free distribution of the enclosed demo version to provide an introduction to the power of this simulation package. This text uses the OrCAD 16.2 Demo version. Additional information can be found for the Cadence OrCAD 16.2 Release under the **OrCAD Inc.** heading of the web site at www.orcad.com. Additional hard copies can be obtained under **Cadence OrCAD Downloads,** where a request can be submitted online at the bottom of the section title **OrCAD Demo DVD.**

System requirements include:

Windows XP, Windows Vista, and Window Server 2003
Pentium 4 (32-bit) equivalent of faster
Minimum 512 MB memory (1 G or more recommended for XP and Vista)
200 MB swap space (or more)
65,000 color Windows display, with minimum 1024 × 768 (1280 × 1024) recommended

MULTISIM 10.1

Multisim is a product of Electronics Workbench, a subsidiary of National Instruments. Its web site is www.electronicsworkbench.com, and its phone number in the U.S. and Canada is 1 800-263-5552. In Europe, the web site is www.ewbeurope.com, and the phone number is 31-35-694-4444.

System requirements include:

Windows 2000/XP/NT (NT 4.0 service pack or later)
Pentium 4 or equivalent processor (600 MHz minimum)
128 MB of RAM (256 MB recommended)
100 MB of free disk space (500 MB recommended)

Appendix C

DETERMINANTS

Determinants are used to find the mathematical solutions for the variables in two or more simultaneous equations. Once the procedure is properly understood, solutions can be obtained with a minimum of time and effort and usually with fewer errors than when using other methods.

Consider the following equations, where x and y are the unknown variables and a_1, a_2, b_1, b_2, c_1, and c_2 are constants:

Col. 1		Col. 2		Col. 3	
a_1x	$+$	b_1y	$=$	c_1	(C.1a)
a_2x	$+$	b_2y	$=$	c_2	(C.1b)

It is certainly possible to solve for one variable in Eq. (C.1a) and substitute into Eq. (C.1b). That is, solving for x in Eq. (C.1a) gives

$$x = \frac{c_1 - b_1y}{a_1}$$

and substituting the result in Eq. (C.1b) gives

$$a_2\left(\frac{c_1 - b_1y}{a_1}\right) + b_2y = c_2$$

It is now possible to solve for y since it is the only variable remaining, and then substitute into either equation for x. This is acceptable for two equations, but it becomes a very tedious and lengthy process for three or more simultaneous equations.

Using determinants to solve for x and y requires that the following formats be established for each variable:

$$\begin{array}{cc} \text{Col. 1} & \text{Col. 2} \\ \end{array} \qquad \begin{array}{cc} \text{Col. 1} & \text{Col. 2} \\ \end{array}$$

$$x = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} \qquad y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} \qquad \text{(C.2)}$$

First note that only constants appear within the vertical brackets, and that the denominator of each is the same. In fact, the denominator is simply the coefficients of x and y in the same arrangement as in Eqs. (C.1a) and (C.1b). When solving for x, replace the coefficients of x in the numerator by the constants to the right of the equal sign in Eqs. (C.1a) and (C.1b), and repeat the coefficients of the y variable. When solving for y, replace the y coefficients in the numerator by the constants to the right of the equal sign, and repeat the coefficients of x.

Each configuration in the numerator and denominator of Eq. (C.2) is referred to as a *determinant (D)*, which can be evaluated numerically in the following manner:

$$\text{Determinant} = D = \begin{array}{c} \text{Col.} \; \text{Col.} \\ \underline{1} \quad \underline{2} \\ \begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix} \end{array} = a_1b_2 - a_2b_1 \tag{C.3}$$

The expanded value is obtained by first multiplying the top left element by the bottom right and then subtracting the product of the lower left and upper right elements. This particular determinant is referred to as a *second-order* determinant since it contains two rows and two columns.

It is important to remember when using determinants that the columns of the equations, as indicated in Eqs. (C.1a) and (C.1b), must be placed in the same order within the determinant configuration. That is, since a_1 and a_2 are in column 1 of Eqs. (C.1a) and (C.1b), they must be in column 1 of the determinant. (The same is true for b_1 and b_2.)

Expanding the entire expression for x and y, we have the following:

$$x = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{c_1b_2 - c_2b_1}{a_1b_2 - a_2b_1} \tag{C.4a}$$

$$y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{a_1c_2 - a_2c_1}{a_1b_2 - a_2b_1} \tag{C.4b}$$

EXAMPLE C.1 Evaluate the following determinants:

a. $\begin{vmatrix} 2 & 2 \\ 3 & 4 \end{vmatrix} = (2)(4) - (3)(2) = 8 - 6 = \mathbf{2}$

b. $\begin{vmatrix} 4 & -1 \\ 6 & 2 \end{vmatrix} = (4)(2) - (6)(-1) = 8 + 6 = \mathbf{14}$

c. $\begin{vmatrix} 0 & -2 \\ -2 & 4 \end{vmatrix} = (0)(4) - (-2)(-2) = 0 - 4 = \mathbf{-4}$

d. $\begin{vmatrix} 0 & 0 \\ 3 & 10 \end{vmatrix} = (0)(10) - (3)(0) = \mathbf{0}$

EXAMPLE C.2 Solve for x and y:

$$2x + y = 3$$
$$\underline{3x + 4y = 2}$$

Solution:

$$x = \frac{\begin{vmatrix} 3 & 1 \\ 2 & 4 \end{vmatrix}}{\begin{vmatrix} 2 & 1 \\ 3 & 4 \end{vmatrix}} = \frac{(3)(4) - (2)(1)}{(2)(4) - (3)(1)} = \frac{12 - 2}{8 - 3} = \frac{10}{5} = 2$$

$$y = \frac{\begin{vmatrix} 2 & 3 \\ 3 & 2 \end{vmatrix}}{5} = \frac{(2)(2) - (3)(3)}{5} = \frac{4 - 9}{5} = \frac{-5}{5} = \mathbf{-1}$$

Check:

$$\begin{aligned} 2x + y &= (2)(2) + (-1) \\ &= 4 - 1 = 3 \qquad \text{(checks)} \\ 3x + 4y &= (3)(2) + (4)(-1) \\ &= 6 - 4 = 2 \qquad \text{(checks)} \end{aligned}$$

EXAMPLE C.3 Solve for x and y:

$$\begin{aligned} -x + 2y &= 3 \\ 3x - 2y &= -2 \end{aligned}$$

Solution: In this example, note the effect of the minus sign and the use of parentheses to ensure that the proper sign is obtained for each product:

$$x = \frac{\begin{vmatrix} 3 & 2 \\ -2 & -2 \end{vmatrix}}{\begin{vmatrix} -1 & 2 \\ 3 & -2 \end{vmatrix}} = \frac{(3)(-2) - (-2)(2)}{(-1)(-2) - (3)(2)}$$

$$= \frac{-6 + 4}{2 - 6} = \frac{-2}{-4} = \mathbf{\frac{1}{2}}$$

$$y = \frac{\begin{vmatrix} -1 & 3 \\ 3 & -2 \end{vmatrix}}{-4} = \frac{(-1)(-2) - (3)(3)}{-4}$$

$$= \frac{2 - 9}{-4} = \frac{-7}{-4} = \mathbf{\frac{7}{4}}$$

EXAMPLE C.4 Solve for x and y:

$$\begin{aligned} x &= 3 - 4y \\ 20y &= -1 + 3x \end{aligned}$$

Solution: In this case, the equations must first be placed in the format of Eqs. (C.1a) and (C.1b):

$$\begin{aligned} x + 4y &= 3 \\ -3x + 20y &= -1 \end{aligned}$$

$$x = \frac{\begin{vmatrix} 3 & 4 \\ -1 & 20 \end{vmatrix}}{\begin{vmatrix} 1 & 4 \\ -3 & 20 \end{vmatrix}} = \frac{(3)(20) - (-1)(4)}{(1)(20) - (-3)(4)}$$

$$= \frac{60 + 4}{20 + 12} = \frac{64}{32} = \mathbf{2}$$

$$y = \frac{\begin{vmatrix} 1 & 3 \\ -3 & -1 \end{vmatrix}}{32} = \frac{(1)(-1) - (-3)(3)}{32}$$

$$= \frac{-1 + 9}{32} = \frac{8}{32} = \mathbf{\frac{1}{4}}$$

The use of determinants is not limited to the solution of two simultaneous equations; determinants can be applied to any number of simultaneous linear equations. First we examine a shorthand method that is applicable to third-order determinants only since most of the problems in the text are limited to this level of difficulty. We then investigate the general procedure for solving any number of simultaneous equations.

Consider the three following simultaneous equations

$$\begin{array}{ccccccc} \underline{\text{Col. 1}} & & \underline{\text{Col. 2}} & & \underline{\text{Col. 3}} & & \underline{\text{Col. 4}} \\ a_1x & + & b_1y & + & c_1z & = & d_1 \\ a_2x & + & b_2y & + & c_2z & = & d_2 \\ a_3x & + & b_3y & + & c_3z & = & d_3 \end{array}$$

in which x, y, and z are the variables, and $a_{1,2,3}$, $b_{1,2,3}$, $c_{1,2,3}$, and $d_{1,2,3}$ are constants.

The determinant configuration for x, y, and z can be found in a manner similar to that for two simultaneous equations. That is, to solve for x, find the determinant in the numerator by replacing column 1 with the elements to the right of the equal sign. The denominator is the determinant of the coefficients of the variables (the same applies to y and z). Again, the denominator is the same for each variable. We have

$$x = \frac{\begin{vmatrix} d_1 & b_1 & c_1 \\ d_2 & b_2 & c_2 \\ d_3 & b_3 & c_3 \end{vmatrix}}{D}, \quad y = \frac{\begin{vmatrix} a_1 & d_1 & c_1 \\ a_2 & d_2 & c_2 \\ a_3 & d_3 & c_3 \end{vmatrix}}{D}, \quad z = \frac{\begin{vmatrix} a_1 & b_1 & d_1 \\ a_2 & b_2 & d_2 \\ a_3 & b_3 & d_3 \end{vmatrix}}{D}$$

where

$$D = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}$$

A shorthand method for evaluating the third-order determinant consists of repeating the first two columns of the determinant to the right of the determinant and then summing the products along specific diagonals as follows:

$$D = \begin{array}{cccccc} & & & 4(-) & 5(-) & 6(-) \\ \left|\begin{matrix} a_1 \\ a_2 \\ a_3 \end{matrix}\right. & \begin{matrix} b_1 \\ b_2 \\ b_3 \end{matrix} & \left.\begin{matrix} c_1 \\ c_2 \\ c_3 \end{matrix}\right| & \begin{matrix} a_1 \\ a_2 \\ a_3 \end{matrix} & \begin{matrix} b_1 \\ b_2 \\ b_3 \end{matrix} & \\ & & & 1(+) & 2(+) & 3(+) \end{array}$$

The products of the diagonals 1, 2, and 3 are positive and have the following magnitudes:

$$+a_1b_2c_3 + b_1c_2a_3 + c_1a_2b_3$$

The products of the diagonals 4, 5, and 6 are negative and have the following magnitudes:

$$-a_3b_2c_1 - b_3c_2a_1 - c_3a_2b_1$$

The total solution is the sum of the diagonals 1, 2, and 3 minus the sum of the diagonals 4, 5, and 6:

$$\boxed{+(a_1b_2c_3 + b_1c_2a_3 + c_1a_2b_3) - (a_3b_2c_1 + b_3c_2c_1 + c_3a_2b_1)} \quad \text{(C.5)}$$

Warning: This method of expansion is good only for third-order determinants! It cannot be applied to fourth- and higher-order systems.

EXAMPLE C.5 Evaluate the following determinant:

$$\begin{vmatrix} 1 & 2 & 3 \\ -2 & 1 & 0 \\ 0 & 4 & 2 \end{vmatrix} \longrightarrow \begin{array}{ccccc} & & (-) & (-) & (-) \\ \left|\begin{matrix} 1 \\ -2 \\ 0 \end{matrix}\right. & \begin{matrix} 2 \\ 1 \\ 4 \end{matrix} & \left.\begin{matrix} 3 \\ 0 \\ 2 \end{matrix}\right| & \begin{matrix} 1 \\ -2 \\ 0 \end{matrix} & \begin{matrix} 2 \\ 1 \\ 4 \end{matrix} \\ & & (+) & (+) & (+) \end{array}$$

Solution:

$$\begin{aligned} &[(1)(1)(2) + (2)(0)(0) + (3)(-2)(4)] \\ &\qquad\qquad - [(0)(1)(3) + (4)(0)(1) + (2)(-2)(2)] \\ &\qquad = (2 + 0 - 24) - (0 + 0 - 8) = (-22) - (-8) \\ &\qquad = -22 + 8 = \mathbf{-14} \end{aligned}$$

EXAMPLE C.6 Solve for x, y, and z:

$$\begin{aligned} 1x + 0y - 2z &= -1 \\ 0x + 3y + 1z &= +2 \\ 1x + 2y + 3z &= 0 \end{aligned}$$

Solution:

$$x = \frac{\left|\begin{matrix} -1 & 0 & -2 \\ 2 & 3 & 1 \\ 0 & 2 & 3 \end{matrix}\right| \begin{matrix} -1 & 0 \\ 2 & 3 \\ 0 & 2 \end{matrix}}{\left|\begin{matrix} 1 & 0 & -2 \\ 0 & 3 & 1 \\ 1 & 2 & 3 \end{matrix}\right| \begin{matrix} 1 & 0 \\ 0 & 3 \\ 1 & 2 \end{matrix}}$$

$$= \frac{[(-1)(3)(3) + (0)(1)(0) + (-2)(2)(2)] - [(0)(3)(-2) + (2)(1)(-1) + (3)(2)(0)]}{[(1)(3)(3) + (0)(1)(1) + (-2)(0)(2)] - [(1)(3)(-2) + (2)(1)(1) + (3)(0)(0)]}$$

$$= \frac{(-9 + 0 - 8) - (0 - 2 + 0)}{(9 + 0 + 0) - (-6 + 2 + 0)}$$

$$= \frac{-17 + 2}{9 + 4} = -\frac{\mathbf{15}}{\mathbf{13}}$$

$$y = \frac{\left|\begin{matrix} 1 & -1 & -2 \\ 0 & 2 & 1 \\ 1 & 0 & 3 \end{matrix}\right| \begin{matrix} 1 & -1 \\ 0 & 2 \\ 1 & 0 \end{matrix}}{13}$$

$$= \frac{[(1)(2)(3) + (-1)(1)(1) + (-2)(0)(0)] - [(1)(2)(-2) + (0)(1)(1) + (3)(0)(-1)]}{13}$$

$$= \frac{(6 - 1 + 0) - (-4 + 0 + 0)}{13}$$

$$= \frac{5 + 4}{13} = \frac{\mathbf{9}}{\mathbf{13}}$$

$$z = \frac{\begin{vmatrix} 1 & 0 & -1 \\ 0 & 3 & 2 \\ 1 & 2 & 0 \end{vmatrix} \begin{matrix} 1 & 0 \\ 0 & 3 \\ 1 & 2 \end{matrix}}{13}$$

$$= \frac{[(1)(3)(0) + (0)(2)(1) + (-1)(0)(2)] - [(1)(3)(-1) + (2)(2)(1) + (0)(0)(0)]}{13}$$

$$= \frac{(0 + 0 + 0) - (-3 + 4 + 0)}{13}$$

$$= \frac{0 - 1}{13} = -\frac{1}{13}$$

or from $0x + 3y + 1z = +2$,

$$z = 2 - 3y = 2 - 3\left(\frac{9}{13}\right) = \frac{26}{13} - \frac{27}{13} = -\frac{1}{13}$$

Check:

$$\left.\begin{array}{r} 1x + 0y - 2z = -1 \\ 0x + 3y + 1z = +2 \\ 1x + 2y + 3z = 0 \end{array}\right\} \quad \left.\begin{array}{r} -\frac{15}{13} + 0 + \frac{2}{13} = -1 \\ 0 + \frac{27}{13} + \frac{-1}{13} = +2 \\ -\frac{15}{13} + \frac{18}{13} + \frac{-3}{13} = 0 \end{array}\right\} \quad \begin{array}{l} -\frac{13}{13} = -1\checkmark \\ \frac{26}{13} = +2\checkmark \\ -\frac{18}{13} + \frac{18}{13} = 0\checkmark \end{array}$$

The general approach to third-order or higher determinants requires that the determinant be expanded in the following form. There is more than one expansion that will generate the correct result, but this form is typically used when the material is first introduced.

$$D = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} = \underset{\substack{\uparrow \\ \text{Multiplying} \\ \text{factor}}}{a_1} \underbrace{\left(+\underbrace{\begin{vmatrix} b_2 & c_2 \\ b_3 & c_3 \end{vmatrix}}_{\text{Minor}}\right)}_{\text{Cofactor}} + \underset{\substack{\uparrow \\ \text{Multiplying} \\ \text{factor}}}{b_1} \underbrace{\left(-\underbrace{\begin{vmatrix} a_2 & c_2 \\ a_3 & c_3 \end{vmatrix}}_{\text{Minor}}\right)}_{\text{Cofactor}} + \underset{\substack{\uparrow \\ \text{Multiplying} \\ \text{factor}}}{c_1} \underbrace{\left(+\underbrace{\begin{vmatrix} a_2 & b_2 \\ a_3 & b_3 \end{vmatrix}}_{\text{Minor}}\right)}_{\text{Cofactor}}$$

This expansion was obtained by multiplying the elements of the first row of D by their corresponding cofactors. It is not a requirement that the first row be used as the multiplying factors. In fact, any *row* or *column* (not diagonals) may be used to expand a third-order determinant.

The sign of each cofactor is dictated by the position of the multiplying factors (a_1, b_1, and c_1 in this case) as in the following standard format:

$$\begin{vmatrix} + \rightarrow & - & + \\ \downarrow & & \\ - & + & - \\ & & \\ + & - & + \end{vmatrix}$$

Note that the proper sign for each element can be obtained by assigning the upper left element a positive sign and then changing signs as you move horizontally or vertically to the neighboring position.

For the determinant D, the elements would have the following signs:

$$\begin{vmatrix} a_1^{(+)} & b_1^{(-)} & c_1^{(+)} \\ a_2^{(-)} & b_2^{(+)} & c_2^{(-)} \\ a_3^{(+)} & b_3^{(-)} & c_3^{(+)} \end{vmatrix}$$

The minors associated with each multiplying factor are obtained by covering up the row and column in which the multiplying factor is located and writing a second-order determinant to include the remaining elements in the same relative positions that they have in the third-order determinant.

Consider the cofactors associated with a_1 and b_1 in the expansion of D. The sign is positive for a_1 and negative for b_1 as determined by the standard format. Following the procedure outlined above, we can find the minors of a_1 and b_1 as follows:

$$a_{1(\text{minor})} = \begin{vmatrix} \cancel{a_1} & \cancel{b_1} & \cancel{c_1} \\ \cancel{a_2} & b_2 & c_2 \\ \cancel{a_3} & b_3 & c_3 \end{vmatrix} = \begin{vmatrix} b_2 & c_2 \\ b_3 & c_3 \end{vmatrix}$$

$$b_{1(\text{minor})} = \begin{vmatrix} \cancel{a_1} & \cancel{b_1} & \cancel{c_1} \\ a_2 & \cancel{b_2} & c_2 \\ a_3 & \cancel{b_3} & c_3 \end{vmatrix} = \begin{vmatrix} a_2 & c_2 \\ a_3 & c_3 \end{vmatrix}$$

It was pointed out that any row or column may be used to expand the third-order determinant, and the same result will still be obtained. Using the first column of D, we obtain the expansion

$$D = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} = a_1\left(+\begin{vmatrix} b_2 & c_2 \\ b_3 & c_3 \end{vmatrix}\right) + a_2\left(-\begin{vmatrix} b_1 & c_1 \\ b_3 & c_3 \end{vmatrix}\right) + a_3\left(+\begin{vmatrix} b_1 & c_1 \\ b_2 & c_2 \end{vmatrix}\right)$$

The proper choice of row or column can often effectively reduce the amount of work required to expand the third-order determinant. For example, in the following determinants, the first column and third row, respectively, would reduce the number of cofactors in the expansion:

$$D = \begin{vmatrix} 2 & 3 & -2 \\ 0 & 4 & 5 \\ 0 & 6 & 7 \end{vmatrix} = 2\left(+\begin{vmatrix} 4 & 5 \\ 6 & 7 \end{vmatrix}\right) + 0 + 0 = 2(28 - 30)$$
$$= \mathbf{-4}$$

$$D = \begin{vmatrix} 1 & 4 & 7 \\ 2 & 6 & 8 \\ 2 & 0 & 3 \end{vmatrix} = 2\left(+\begin{vmatrix} 4 & 7 \\ 6 & 8 \end{vmatrix}\right) + 0 + 3\left(+\begin{vmatrix} 1 & 4 \\ 2 & 6 \end{vmatrix}\right)$$
$$= 2(32 - 42) + 3(6 - 8) = 2(-10) + 3(-2)$$
$$= \mathbf{-26}$$

EXAMPLE C.7 Expand the following third-order determinants:

a. $$D = \begin{vmatrix} 1 & 2 & 3 \\ 3 & 2 & 1 \\ 2 & 1 & 3 \end{vmatrix} = 1\left(+\begin{vmatrix} 2 & 1 \\ 1 & 3 \end{vmatrix}\right) + 3\left(-\begin{vmatrix} 2 & 3 \\ 1 & 3 \end{vmatrix}\right) + 2\left(+\begin{vmatrix} 2 & 3 \\ 2 & 1 \end{vmatrix}\right)$$

$$= 1[6 - 1] + 3[-(6 - 3)] + 2[2 - 6]$$
$$= 5 + 3(-3) + 2(-4)$$
$$= 5 - 9 - 8$$
$$= \mathbf{-12}$$

b. $$D = \begin{vmatrix} 0 & 4 & 6 \\ 2 & 0 & 5 \\ 8 & 4 & 0 \end{vmatrix} = 0 + 2\left(-\begin{vmatrix} 4 & 6 \\ 4 & 0 \end{vmatrix}\right) + 8\left(+\begin{vmatrix} 4 & 6 \\ 0 & 5 \end{vmatrix}\right)$$

$$= 0 + 2[-(0 - 24)] + 8[(20 - 0)]$$
$$= 0 + 2(24) + 8(20)$$
$$= 48 + 160$$
$$= \mathbf{208}$$

Appendix D

GREEK ALPHABET

Letter	Capital	Lowercase	Some Applications
Alpha	A	α	Area, angles, coefficients
Beta	B	β	Angles, coefficients, flux density
Gamma	Γ	γ	Specific gravity, conductivity
Delta	Δ	δ	Density, variation
Epsilon	E	ε	Base of natural logarithms
Zeta	Z	ζ	Coefficients, coordinates, impedance
Eta	H	η	Efficiency, hysteresis coefficient
Theta	Θ	θ	Phase angle, temperature
Iota	I	ι	
Kappa	K	κ	Dielectric constant, susceptibility
Lambda	Λ	λ	Wavelength
Mu	M	μ	Amplification factor, micro, permeability
Nu	N	ν	Reluctivity
Xi	Ξ	ξ	
Omicron	O	o	
Pi	Π	π	3.1416
Rho	P	ρ	Resistivity
Sigma	Σ	σ	Summation
Tau	T	τ	Time constant
Upsilon	Y	υ	
Phi	Φ	ϕ	Angles, magnetic flux
Chi	X	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference
Omega	Ω	ω	Ohms, angular velocity

Appendix E

MAGNETIC PARAMETER CONVERSIONS

	SI (MKS)	CGS	English
Φ	webers (Wb) 1 Wb	maxwells $= 10^8$ maxwells	lines $= 10^8$ lines
B	T $1\text{T} = 1\ \text{Wb/m}^2$	gauss (maxwells/cm^2) $= 10^4$ gauss	lines/in.^{2} $= 6.452 \times 10^4$ lines/in.^{2}
A	$1\ \text{m}^2$	$= 10^4\ \text{cm}^2$	$= 1550$ in.^{2}
μ_o	$4\pi \times 10^{-7}$ Wb/Am	$= 1$ gauss/oersted	$= 3.20$ lines/Am
$\mathcal{F}$	NI (ampere-turns, At) 1 At	$0.4\pi NI$ (gilberts) $= 1.257$ gilberts	NI (At) 1 gilbert − 0.7958 At
H	NI/l (At/m) 1At/m	$0.4\pi NI/l$ (oersteds) $= 1.26 \times 10^{-2}$ oersted	NI/l(At/in.) $= 2.54 \times 10^{-2}$ At/in.
H_g	$7.97 \times 10^5 B_g$ (At/m)	B_g (oersteds)	$0.313B_g$ (At/in.)

Appendix F

MAXIMUM POWER TRANSFER CONDITIONS

This appendix derives the maximum power transfer conditions for the situation where the resistive component of the load is adjustable but the load reactance is set in magnitude.*

For the circuit in Fig. F.1, the power delivered to the load is determined by

$$P = \frac{V_{R_L}^2}{R_L}$$

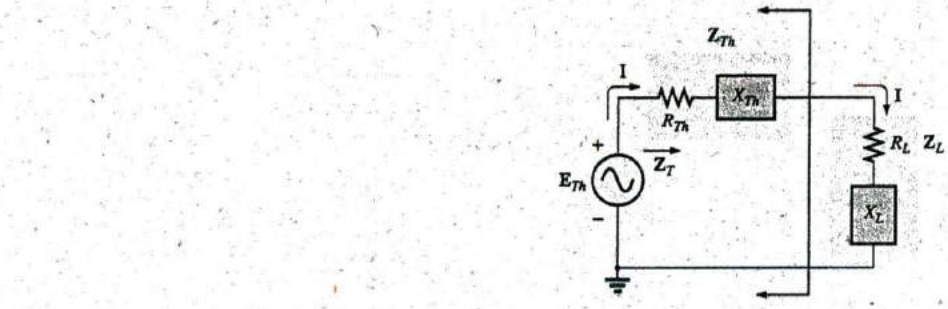

FIG. F.1

Applying the voltage divider rule gives

$$\mathbf{V}_{R_L} = \frac{R_L \mathbf{E}_{Th}}{R_L + R_{Th} + X_{Th} \angle 90° + X_L \angle 90°}$$

The magnitude of $\mathbf{V}_{R_L}$ is determined by

$$V_{R_L} = \frac{R_L E_{Th}}{\sqrt{(R_L + R_{Th})^2 + (X_{Th} + X_L)^2}}$$

and $$V_{R_L}^2 = \frac{R_L^2 E_{Th}^2}{(R_L + R_{Th})^2 + (X_{Th} + X_L)^2}$$

with $$P = \frac{V_{R_L}^2}{R_L} = \frac{R_L E_{Th}^2}{(R_L + R_{Th})^2 + (X_{Th} + X_L)^2}$$

Using differentiation (calculus), we find that maximum power will be transferred when $dP/dR_L = 0$. The result of the preceding operation is that

$$R_L = \sqrt{R_{Th}^2 + (X_{Th} + X_L)^2} \qquad \text{[Eq. (18.21)]}$$

The magnitude of the total impedance of the circuit is

$$Z_T = \sqrt{(R_{Th} + R_L)^2 + (X_{Th} + X_L)^2}$$

*With sincerest thanks for the input of Professor Harry J. Franz of the Beaver Campus of Pennsylvania State University.

Substituting this equation for R_L and applying a few algebraic maneuvers results in

$$Z_T = 2R_L(R_L + R_{Th})$$

and the power to the load R_L as

$$P = I^2R_L = \frac{E_{Th}^2}{Z_T^2}R_L = \frac{E_{Th}^2R_L}{2R_L(R_L + R_{Th})}$$

$$= \frac{E_{Th}^2}{4\left(\frac{R_L + R_{Th}}{2}\right)}$$

$$= \frac{E_{Th}^2}{4R_{av}}$$

with

$$R_{av} = \frac{R_L + R_{Th}}{2}$$

Appendix G

ANSWERS TO SELECTED ODD-NUMBERED PROBLEMS

Chapter 1

5. 29.05 mph
7. **(a)** 139.33 ft/s **(b)** 0.431 s
(c) 40.91 mph
11. MKS, CGS = 20°C;
SI, K = 293.15
13. 45.72 cm
15. **(a)** 14.6 **(b)** 56.0 **(c)** 1046.1
(d) 0.1 **(e)** 3.1
17. **(a)** 14.603 **(b)** 56.042
(c) 1046.060 **(d)** 0.063
(e) 3.142
19. **(a)** 15×10^3 **(b)** 5×10^{-3}
(c) 2.4×10^6 **(d)** 60×10^3
(e) 4.02×10^{-4} **(f)** 2×10^{-10}
21. **(a)** 100×10^3 **(b)** 10
(c) 1×10^9 **(d)** 1×10^{-3}
(e) 10 **(f)** 1×10^{24}
23. **(a)** 10×10^{-3} **(b)** 10×10^{-6}
(c) 10×10^6 **(d)** 1×10^{-9}
(e) 1×10^{42} **(f)** 1×10^3
25. **(a)** 1×10^6 **(b)** 10×10^{-3}
(c) 100×10^{30} **(d)** 1×10^{-63}
27. **(a)** 1×10^{-6} **(b)** 1×10^{-5}
(c) 1×10^{-8} **(d)** 1×10^{11}
29. Scientific: **(a)** 2.05×10^1
(b) 5.04×10^4 **(c)** 6.74×10^{-4}
(d) 4.60×10^{-2}
Engineering: **(a)** 20.46×10^0
(b) 50.42×10^3
(c) 674.00×10^{-6}
(d) 46.00×10^{-3}
31. **(a)** 0.06×10^6
(b) 400×10^{-6}
(c) 0.005×10^9
(d) 1200×10^{-9}
33. **(a)** 90 s **(b)** 72 s
(c) $50 \times 10^3\ \mu s$ **(d)** 160 mm
(e) 120 ns **(f)** 4629.63 days
35. **(a)** 2.54 m **(b)** 1.22 m
(c) 26.7 N **(d)** 0.13 lb
(e) 4921.26 ft **(f)** 3.22 m
37. 26.82 m/s
39. 3600 quarters
41. 345.6 m
43. 44.82 min/mile
45. **(a)** 4.74×10^{-3} Btu
(b) $7.1 \times 10^{-4}\ m^3$
(c) 1.21×10^5 s
(d) 2113.38 pints
47. 14.4
49. 0.93
51. 3.24
53. 1.20×10^{12}

Chapter 2

3. **(a)** 1.11 μN **(b)** 0.31 N
(c) 1138.34 kN
5. $F_2 = r_1^2 F_1 / r_2^2$
7. **(a)** 72 mN **(b)** $Q_1 = 20\ \mu C$,
$Q_2 = 40\ \mu C$
9. 0.48 J
11. 8 C
13. 4.29 mA
15. 192 C
17. 3 s
19. 2.25×10^{18} electrons
21. 22.43 mA
23. 6.67 V
25. 3.34 A
27. 60.0 Ah
29. W(60 Ah) : W(40 Ah) = 1.5 : 1;
I(60 Ah) : I(40 Ah) = 3600 A :
2400 A = 1.5 : 1
31. 13.89%
33. 129.6 kJ
37. **(a)** 38.1 kV **(b)** 342.9 kV

Chapter 3

1. **(a)** 500 mils **(b)** 20 mils
(c) 250 mils **(d)** 393.7 mils
(e) 120 mils **(f)** 39.37 mils
3. **(a)** 0.04 in. **(b)** 0.029 in.
(c) 0.2 in. **(d)** 0.025 in.
(e) 0.0025 in. **(f)** 0.55 in.
5. **(a)** 544 CM **(b)** 0.023 in.
7. **(a)** 942.73 CM **(b)** larger
(c) smaller
9. **(a)** 293.82 ft **(b)** 1.47 lb
(c) $-40°F \rightarrow +221°F$
11. **(a)** 21.71 $\mu\Omega$ **(b)** 35.59 $\mu\Omega$
13. 942.28 mΩ
15. **(a)** yes
(b) A(#0) : A(#12) = 16.16 : 1,
I(#0) : I(#12) = 7.5 : 1
17. **(a)** #2 **(b)** #0
19. 2.57 Ω
21. 3.69 Ω
23. **(a)** 27.85°C **(b)** −210.65°C
25. **(a)** 0.00393 **(b)** 83.61°C
27. 1.75°
29. 100.30 Ω
31. 6.5 kΩ
35. **(a)** blue, gray, black, silver
(b) orange, orange, silver, silver
(c) red, red, orange, silver
(d) green, blue, green, silver
37. yes, 423 Ω to 517 Ω
39. **(a)** 0.62 kΩ **(b)** 33 kΩ
(c) 390 Ω **(d)** 1.2 MΩ
41. **(a)** 629.72 mS
(b) 384.11 mS
43. 500 S
49. **(a)** 21.71 $\mu\Omega$ **(b)** 35.59 $\mu\Omega$
51. 0.15 in.
59. **(a)** 10 fc = 3 kΩ, 100 fc = 0.4 kΩ
(b) negative **(c)** no
(d) −321.43 Ω/fc

Chapter 4

1. 1.23 V
3. 16 kΩ
5. 72 mV
7. 54.55 Ω
9. 28.57 Ω
11. 1.2 kΩ
13. **(a)** 12.63 Ω
(b) 8.21×10^6 J
21. 16 s
23. 2.86 s
25. 207.36 mW
27. 129.10 mA, 15.49 V
29. 120 V
31. 9.61 V
33. 32 Ω, 120 V
35. 70.71 mA, 1.42 kV
37. **(a)** 864 J
(b) energy doubles, power the same
39. 59.80 kWh
41. **(a)** 120 kW **(b)** 576.92 A
(c) 216 kWh
43. **(a)** \$2.39/day **(b)** 16 ¢/hour
(c) 1.45 kWh **(d)** ≅ 24 **(e)** no
45. \$30.79
47. **(a)** 12 kW
(b) 10,130 W < 12 kW (yes)
(c) 20.26 kWh
49. \$1.13
51. 84.77%
53. **(a)** 238 W **(b)** 17.36%
55. **(a)** 1657.78 W **(b)** 15.07 A
(c) 19.38 A
57. 88%
59. 80%
61. $\eta_1 = 40\%$, $\eta_2 = 80\%$

Chapter 5

1. (a) E and R_1
 (b) R_1 and R_2
 (c) E_1, E_2 and R_1
 (d) E_1 and R_1; E_2, R_3, and R_4
 (e) R_3, R_4, and R_5; E and R_1
 (f) R_2 and R_3
3. (a) 7.7 kΩ (b) 17.5 kΩ
5. (a) 99 Ω (b) 7.52 kΩ
7. (a) 1.2 kΩ (b) 0 Ω (c) ∞ Ω
9. (a) the most: R_3; the least: R_1
 (b) R_3, $R_T = 90$ kΩ, $I_s = 0.5$ mA
 (c) $V_1 = 0.6$ V, $V_2 = 3.4$ V, $V_3 = 41$ V
11. (a) 4 A (b) 36 V (c) 3 Ω
 (d) $V_{4.7\,\Omega} = 18.8$ V, $V_{1.3\,\Omega} = 5.2$ V, $V_{3\,\Omega} = 12$ V
13. (a) $R_T = 6$ kΩ, $I = 9.94\ \mu$A, $V_{R_1} = 60$ V, $V_{R_2} = 20$ V, $V_{R_3} = 40$ V
 (b) $P_{R_1} = 1.2$ W, $P_{R_2} = 0.4$ W, $P_{R_3} = 0.8$ W (c) 2.4 W
 (d) 2.4 W (e) equal (f) R_1
 (g) dissipated (h) R_1 : 2 W; $R_2 : \frac{1}{2}$ W; R_3 = 1 W
15. $E = 90.5$ V, $R_1 = 2$ Ω, $R_2 = 29$ Ω
17. 6 Ω
19. (a) I(cw) = 1.17 A
 (b) I(ccw) = 173.91 mA
21. (a) $V = 2$ V (b) $V = 42$ V
 (c) $V_1 = 8$ V, $V_2 = -4$ V
23. (a) $V_1 = 4$ V, $V_2 = 10$ V
 (b) $V_1 = 14$ V, $V_2 = 18$ V
25. $R_2 = 100$ Ω, $R_3 = 200$ Ω
27. (a) 20 V (b) 20 V (c) 0.36 V
29. $V_2 = 4$ V, $V_4 = 6$ V, $I = 2$ mA, $E = 24$ V
31. (a) 80 Ω in series with bulb
 (b) $\frac{1}{4}$ W resistor
33. $V_{R_1} = 12$ V, $V_{R_2} = 42$ V, $V_{R_3} = 6$ V
35. (a) $V_a = 17$ V, $V_b = 21$ V, $V_{ab} = -4$ V (b) $V_a = 14$ V, $V_b = 30$ V, $V_{ab} = -16$ V
 (c) $V_a = 13$ V, $V_b = -8$ V, $V_{ab} = 21$ V
37. (a) $V_a = 20$ V, $V_b = 26$ V, $V_c = 35$ V, $V_d = -12$ V, $V_e = 0$ V (b) $V_{ab} = -6$ V, $V_{dc} = -47$ V, $V_{cb} = 9$ V
 (c) $V_{ac} = -15$ V, $V_{db} = -38$ V
39. $R_1 = 2$ kΩ, $R_2 = 2.25$ kΩ, $R_3 = 0.75$ kΩ, $R_4 = 1.25$ kΩ
41. $V_0 = 0$ V, $V_4 = 10$ V, $V_7 = 4$ V, $V_{10} = 20$ V, $V_{23} = 6$ V, $V_{30} = -8$ V, $V_{67} = 0$ V, $V_{56} = -6$ V, $I = 1.5$ A↑
43. (a) 2 Ω (b) 7.14%
45. (a) 1.2 mA (b) 1.17 mA
 (c) no

Chapter 6

1. (a) R_2 and R_3 (b) E and R_3
 (c) R_2 and R_3 (d) R_2 and R_3
 (e) E, R_1, R_2, R_3, and R_4 (f) E, R_1, R_2, R_3 (g) E_2, R_2, and R_3
3. (a) 12 Ω (b) 0.652 kΩ
 (c) 10.81 Ω (d) 3 kΩ
 (e) 2.62 Ω (f) 0.99 Ω
5. (a) 8 Ω (b) 18 kΩ
 (c) 6.8 kΩ (d) 2.4 kΩ
7. (a) 1.18 Ω (b) ∞ Ω (c) 2 Ω
9. (a) 6 Ω (b) 36 V
 (c) $I_s = 6$ A, $I_1 = 4.5$ A, $I_2 = 1.5$ A
11. (a) $I_1 = 2.4$ mA, $I_2 = 20$ mA, $I_3 = 3.53$ mA (b) 925.93 Ω
 (c) 25.92 mA (d) 25.93 mA
13. (a) 9 Ω (b) 27 V
15. $E = 36$ V, $R_1 = 24$ Ω, $I_3 = 9$ A
17. (a) 4 Ω (b) 12 Ω (c) 10 A
19. (a) 761.79 Ω, $I_1 = 60$ mA, $I_2 = 12.77$ mA, $I_3 = 6$ mA
 (b) $P_1 = 3.6$ W, $P_2 = 0.766$ W, $P_3 = 0.36$ W (c) 4.73 W
 (d) 4.73 W (e) R_1—smallest
21. 1.44 kW
23. (a) 14.67 A (b) 256 W
 (c) 14.67 A
25. (a) $I = 8$ A (b) $I_1 = 6$ mA, $I_2 = 15$ mA, $I_3 = 5$ mA
27. $R_1 = 3$ kΩ, $R_3 = 6$ kΩ, $R_T = 1.33$ kΩ, $E = 12$ V
29. (a) $I_1 = 64$ mA, $I_2 = 20$ mA, $I_3 = 16$ mA, $R = 3.2$ kΩ
 (b) $E = 30$ V, $I_1 = 1$ A, $I_3 = 0.5$ A, $R_2 = R_3 = 60$ Ω, $P_{R_2} = 15$ W
31. (a) $I_1 = 3$ A, $I_2 = 4$ A
 (b) $I_T = 8.5$ A, $I_1 = 6$ A
33. (a) 9 A (b) 0.9 A (c) 9 mA
 (d) 90 μA (e) very little
 (f) 9.1 A (g) 0.91 A
 (h) 9.1 mA (i) 91 μA
35. (a) 6 kΩ (b) $I_1 = 24$ mA, $I_2 = 8$ mA
37. (a) $I_1 = I_2 = 3$ A, $I_L = 6$ A
 (b) 36 W (c) 72 W (d) 6 A
39. $I = 3$ A, $R = 2$ Ω
41. (a) 6.13 V (b) 9 V (c) 9 V
43. (a) 16.48 V (b) 16.47 V
 (c) 16.32 V (d): (a) 13.33 V, (b) 13.25 V, (c) 11.43 V
45. 6 kΩ not connected

Chapter 7

1. (a) R_1, R_2, and E in series; R_3, R_4, and R_5 in parallel
 (b) E and R_1 in series; R_2, R_3, and R_4 in parallel
 (c) E and R_1 in series; R_2, R_3, and R_4 in parallel
 (d) E_1 and R_1 in series; E_2 and R_4 in parallel
 (e) E and R_1 in series; R_2 and R_3 in parallel
 (f) E, R_1, R_4, and R_6 in parallel; R_2 and R_5 in parallel
3. 3.6 kΩ
5. 12 kΩ
7. (a) 4 Ω (b) $I_s = 9$ A, $I_1 = 6$ A, $I_2 = 3$ A (c) 6 V
9. (a) $V_a = 36$ V, $V_b = 60$ V, $V_c = 20$ V (b) $I_1 = 24$ mA, $I_2 = 35.5$ mA
11. 22.5 Ω
13. (a) $I = 14$ A, $I_1 = 6$ A, $I_2 = 8$ A, $I_3 = 0.8$ A
15. (a) $I_s = 5$ A, $I_1 = 1$ A, $I_3 = 4$ A, $I_4 = 0.5$ A (b) $V_a = 17$ V, $V_{bc} = 10$ V
17. (a) $I_E = 2$ mA, $I_C = 2$ mA
 (b) $I_B = 24\ \mu$A
 (c) $V_B = 2.7$ V, $V_C = 3.6$ V
 (d) $V_{CE} = 1.6$ V, $V_{BC} = -0.9$ V
19. (a) 1.88 Ω (b) $V_1 = V_4 = 32$ V
 (c) 8 A (d) $I_s = 17$ A, $R_T = 1.88$ Ω
21. (a) 14 V (b) 9 A
 (c) $V_a = -6$ V, $V_b = -20$ V
23. 30 Ω
25. (a) no (b) 6 kΩ open
27. (a) 5.53 Ω (b) 7.23 A
 (c) 0.281 W
29. (a) 12 A (b) 0.5 A
 (c) 0.5 A (d) 6 A
31. $R_1 = 0.5$ kΩ, $R_2 = 2$ kΩ, $R_3 = 4$ kΩ, $R_4 = 1$ kΩ, $R_5 = 0.6$ kΩ, $P_{R_1} = 1$ W, $P_{R_2} = 2$ W, $P_{R_3} = \frac{1}{2}$ W, $P_{R_4} = 2$ W, $P_{R_5} = 1$ W
33. (a) yes (b) $R_1 = 750$ Ω, $R_2 = 250$ Ω (c) $R_1 = 745$ Ω, $R_2 = 255$ Ω
35. (a) 1 mA (b) $R_{shunt} = 5$ mΩ
37. (a) $R_s = 300$ kΩ,
 (b) 20,000 Ω/V
39. 0.05 μA

Chapter 8

1. (a) $I_1 = 4.8$ A, $I_2 = 1.2$ A
 (b) 9.6 V
3. 31.6 V
5. $V_3 = 1.6$ V, $I_2 = 0.1$ A
7. (a) $I_s = 4.68$ A, $R_p = 4.7$ Ω
 (b) $I_s = 4.09$ mA, $R_p = 2.2$ kΩ
9. (a) 18.18 A (b) yes, 18.18 A
11. (a) $I_T = 4.2$ A (b) 16.8 V
13. (a) $V_{ab} = -7$ V (b) 1.17 A↑

C-75A

15. (a) $I_1(\text{cw}) = -\frac{1}{7}$ A, $I_2(\text{ccw}) = \frac{5}{7}$ A, $I_3(\text{down}) = \frac{4}{7}$ A (b) 4.57 V
17. $I_1(\text{cw}) = 1.45$ mA, $I_2(\text{ccw}) = 8.51$ mA, $I_3(\text{down}) = 9.96$ mA
19. (d) 63.69 mA
21. (a) $I_{E_1}(\text{ccw}) = 3.06$ A, $I_{E_2}(\text{up}) = 3.25$ A (b) $P_{E_2} = 39$ W, $P_{R_3} = 0.43$ W
23. (a) $I_1(\text{cw}) = 2.03$ mA, $I_2(\text{left}) = 1.23$ mA, $I_3 = I_4(\text{cw}) = 1.23$ mA (b) 5.12 V
25. (b) $I_1(\text{cw}) = 1.21$ mA, $I_2(\text{cw}) = -0.48$ mA, $I_3(\text{cw}) = -0.62$ mA (c) $I_{E_1}(\text{down}) = 1.69$ mA, $I_{E_2}(\text{up}) = 0.62$ mA
27. (b) $I_1(\text{cw}) = 0.03$ mA, $I_2(\text{cw}) = -0.88$ mA, $I_3(\text{cw}) = -0.97$ mA, $I_4(\text{cw}) = -0.64$ mA (c) 5.46 mW
29. (a) $I_B = 63.02\ \mu$A, $I_C = 4.42$ mA, $I_E = 4.48$ mA (b) $V_B = 2.98$ V, $V_E = 2.28$ V, $V_C = 10.28$ V (c) 70.14
31. $I_{4\Omega} = 5.53$ A, $I_{6\Omega} = 2.47$ A, $I_{8\Omega} = 0.53$ A, $I_{1\Omega} = 8.53$ A
33. (b) 3.25 A
35. (b) $I_1(\text{cw}) = 3.31$ A, $I_2(\text{cw}) = -63.69$ mA, $I_3(\text{cw}) = 0.789$ A (c) 3.37 A
37. (b) −6.44 V
39. (b) $I_1(\text{cw}) = 2.37$ A, $I_2(\text{cw}) = -0.20$ A, $I_3(\text{cw}) = 1.25$ A (c) $V_a = 4.48$ V, $V_b = 10$ V (d) −5.52 V
41. (b) $V_1 = -49.94$ V, $V_2 = -69.37$ V (c) 3.46 A
43. (b) $V_1 = -2.56$ V, $V_2 = 4.03$ V (c) $V_{R_1} \mp = 2.56$ V, $V_{R_2} = V_{R_5} \pm = 4.03$ V, $V_{R_4} = V_{R_3}(-+) = 6.59$ V
45. (b) $V_1 = 7.24$ V, $V_2 = -2.45$ V, $V_3 = 1.41$ V (c) $V_{5\Omega}(-+) = 3.86$ V
47. (b) $V_1 = -5.31$ V, $V_2 = 0.62$ V, $V_3 = 3.75$ V (c) 69 mA
49. $V_1 = 10.08$ V, $V_2 = 6.94$ V, $V_3 = -17.06$ V
51. (a) $V_1 = -10.29$ V, $V_2 = -11.43$ V (b) $V_{5A} \mp = 10.29$ V; $V_{3A} \mp = 11.43$ V
53. (a) $V_1 = -6.64$ V, $V_2 = 1.29$ V, $V_3 = 10.66$ V (b) 1.34 A
55. (a) $V_1 = -6.92$ V, $V_2 = 12$ V, $V_3 = 2.3$ V (b) 3.46 A
57. (b) 20 mA (c) no (d) no
59. (b) 0 A (c) yes (d) yes
61. 3.33 mA
63. 1.76 mA
65. 133.33 mA
67. 0.83 mA
69. 4.2 Ω

Chapter 9

1. (a) 0.1 A↑ (b) same (c) same
3. 1.25 A↓
5. 52.12 V
7. 10.66 V
9. (a) $R_{Th} = 4.1\ \text{k}\Omega$, $E_{Th} = 96$ V (b) 2 kΩ : 0.495 W, 100 kΩ : 85 mW
11. $R_{Th} = 2.18\ \Omega$, $E_{Th} = 9.81$ V
13. $R_{Th} = 2\ \Omega$, $E_{Th} = 60$ V
15. (a) $R_{Th} = 10\ \Omega$, $E_{Th} = 2$ V (b) 20 Ω : 66.67 mA, 50 Ω : 33.33 mA, 100 Ω : 18.18 mA
17. $R_{Th} = 4.04\ \text{k}\Omega$, $E_{Th} = 9.74$ V
19. (a) $R_{Th} = 12.5\ \text{k}\Omega$, $E_{Th} = 20$ V (b) $R_{Th} = 2.72\ \text{k}\Omega$, $E_{Th} = 60$ mV (c) $R_{Th} = 2.2\ \text{k}\Omega$, $E_{Th} = 16$ V
21. (a) $R_N = 6\ \Omega$, $I_N = 1$ A (b) $E_{Th} = 6$ V, $R_{Th} = 6\ \Omega$
23. $R_N = 2.18\ \Omega$, $I_N = 4.5$ A
25. $R_N = 2\ \Omega$, $I_N = 30$ A
27. $R_N = 4.04\ \text{k}\Omega$, $I_N = 2.41$ mA
29. (a) $R_N = 3\ \Omega$, $I_N = 5$ A (b) $V_{100\,\Omega} \mp 55.34$ V
31. (a) 2.18 Ω (b) 11.06 W
33. (a) 4.04 kΩ (b) 5.87 mW
35. 0 Ω
37. 500 Ω, $P_{max} = 1.44$ W
39. $I_L = 39.3\ \mu$A, $V_L = 220$ mV
41. $I_L = 2.25$ A, $V_L = 6.08$ V
47. (a) 0.36 mA (b) 0.36 mA (c) yes

Chapter 10

1. (a) 36×10^3 N/C (b) 36×10^9 N/C
3. 50 μF
5. (a) 16.69 V/m (b) 1.97 kV/m (c) 100 : 1
7. 348.43 pF
9. 2.66 mm
11. (a) 24.78 nF (b) 10^6 V/m (c) 4.96 μC
13. 25.6 kV
15. 0.35 μF
17. 470 μF, 465.3 μF–474.7 μF
19. (a) 0.56 s (b) $v_C = 20\text{ V}(1 - e^{-t/0.56\text{ s}})$ (c) $1\tau = 12.64$ V, $3\tau = 19$ V, $5\tau = 19.87$ V (d) $i_C = 0.2\text{ mA}\, e^{-t/0.56\text{ s}}$, $v_R = 20\text{ V}e^{-t/0.56\text{ s}}$
21. (a) 5.5 ms (b) $v_C = 100\text{ V}(1 - e^{-t/5.5\text{ ms}})$ (c) $1\tau = 63.21$ V, $3\tau = 95.02$ V, $5\tau = 99.33$ V (d) $i_C = 18.18\text{ mA}\, e^{-t/5.5\text{ ms}}$, $v_{R_2} = 60\text{ V}\, e^{-t/5.5\text{ ms}}$
23. (a) 100 μs (b) 4.72 V (c) 11.99 V
25. (a) 263.2 ms (b) $v_C = 22\text{ V}(1 - e^{-t/263.2\text{ ms}})$, $i_C = 4.68\text{ mA}\, e^{-t/263.2\text{ ms}}$ (c) 21.51 V, 0.105 mA (d) $v_C = 21.51\text{ V}\, e^{-t/263.2\text{ ms}}$, $i_C = 4.58\text{ mA}\, e^{-t/263.2\text{ ms}}$
27. (a) $v_C = 60\text{ V}(1 - e^{-t/4.84\,\mu\text{s}})$, $i_C = 272.73\ \mu\text{A}\, e^{-t/4.84\,\mu\text{s}}$ (b) $v_C = 59.6\text{ V}\, e^{-t/15.18\,\mu\text{s}}$, $i_C = -86.96\ \mu\text{A}\, e^{-t/15.18\,\mu\text{s}}$
29. (a) $v_C = 40\text{ V} - 34\text{ V}\, e^{-t/22.1\text{ ms}}$ (b) $i_C = 7.23\text{ mA}\, e^{-t/22.1\text{ ms}}$
31. $v_C = -20\text{ V} + 10\text{ V}\, e^{-t/2.71\,\mu\text{s}}$, $i_C = -12.2\text{ mA}\, e^{-t/2.71\,\mu\text{s}}$
33. (a) 55.99 mV (b) 139.99 mV (c) 2.5 ms (d) 8.54 ms
35. $R = 54.60\ \text{k}\Omega$
37. (a) 22.07 V (b) 0.81 μA (c) 3.58 s
39. (a) $v_C = -27.2\text{ V} + 37.2\text{ V}\, e^{-t/18.26\text{ ms}}$, $i_C = -4.48\text{ mA}\, e^{-t/18.26\text{ ms}}$
41. (a) $v_C = 3.27\text{ V}(1 - e^{-t/53.80\text{ ms}})$, $i_C = 1.22\text{ mA}\, e^{-t/53.80\text{ ms}}$
43. (a) 19.63 V (b) 2.32 s (c) 1.15 s
45. 10 μs–20 μs: −1.18 A; 20 μs–30 μs: +7.05 A; 30 μs–40 μs: −7.05 A; 40 μs–50 μs: 0 A; 50 μs–55 μs: −4.7 A; 55 μs–60 μs: +4.7 A; 60 μs–70 μs: 0 A; 70 μs–80 μs: +4.7A; 80 μs–100 μs: −1.175 A
47. 6.67 μF
49. $V_1 = 10$ V, $Q_1 = 60\ \mu$C; $V_2 = 6.67$ V, $Q_2 = 40\ \mu$C; $V_3 = 3.33$ V, $Q_3 = 40\ \mu$C
51. $V_1 = 13.45$ V, $Q_1 = 2.96$ mC; $V_2 = 6.55$ V, $Q_2 = 2.16$ mC; $V_3 = 6.55$ V, $Q_3 = 0.786$ mC
53. 8640 pJ
55. $W_{200\,\mu F} = 9.70$ mJ, $W_{100\,\mu F} = 1.75$ mJ

Chapter 11

1. (a) 0.04 Wb/m² (b) 0.04 T (c) 88 At (d) 0.4×10^3 gauss
3. (a) 20.06 mH (b) increase ratio = μ_r
5. (a) 42.3 mH (b) 1.57 mH (c) 75.2 mH (d) 1.76 H

7. 6.0 V
9. 14 turns
11. (a) 15 μs
(b) $i_L = 1\ mA\ (1 - e^{-t/15\ \mu s})$
(c) $v_L = 20\ V\ e^{-t/15\ \mu s}$
$v_R = 20\ V\ (1 - e^{-t/15\ \mu s})$
(d) $i_L : 1\tau = 0.632$ mA,
$3\tau = 0.951$ mA,
$5\tau = 0.993$ mA; $v_L : 1\tau = 7.36$ V,
$3\tau = 0.98$ V, $5\tau = 140$ mV
13. $R = 1.2\ k\Omega$, $L = 3.6$ mH
15. (a) $i_L = 9.23\ mA -$
$17.23\ mA\ e^{-t/30.77\ \mu s}$,
$v_L = 67.2\ V\ e^{-t/30.77\ \mu s}$
17. (a) $i_L = 2\ mA + 4\ mA\ e^{-t/19.23\ \mu s}$,
$v_L = 41.6\ V\ e^{-t/19.23\ \mu s}$
19. (a) $i_L = 6\ mA\ (1 - e^{-t/0.5\ \mu s})$,
$v_L = 12\ V\ e^{-t/0.5\ \mu s}$
(b) $i_L = 5.19\ mA\ e^{-t/83.3\ \mu s}$,
$v_L = -62.28\ V\ e^{-t/83.3\ \mu s}$
21. (a) $i_L = 1.3\ mA\ (1 - e^{-t/7.56\ \mu s})$,
$v_L = 8.09\ V\ e^{-t/7.56\ \mu s}$
(b) 0.822 mA, 2.98 V
23. (a) $i_L = -4.54\ mA\ (1 - e^{-t/6.67\ \mu s})$,
$v_L = -6.81\ V\ e^{-t/6.67\ \mu s}$
(b) $i_L = -3.53$ mA, $v_L = -1.52$ V
(c) $i_L = -3.53\ mA\ e^{-t/2.13\ \mu s}$,
$v_L = +16.59\ V\ e^{-t/2.13\ \mu s}$
25. (a) $i_L = 0.68\ mA +$
$1.32\ mA\ e^{-t/0.49\ ms}$,
$v_L = -5.43\ V\ e^{-t/0.49\ ms}$
27. (a) 0.92 μs (b) 16.2 V
(c) 0.81 V
29. (a) 4.88 mA (b) 99.33 mA
(c) 13.86 ms
31. (a) 13.33 V (b) 7.98 μA
(c) 4.12 μs (d) 0.244 V
33. 0 ms–2 ms: 37.5 mV; 2 ms–6 ms: −37.5 mV; 6 ms–9 ms: +25 mV; 9 ms–13 ms: 0 V; 13 ms–14 ms: +25 mV; 14 ms–17 ms: 0 V; 17 ms–19 ms: −12.5 mV
35. 10.75 mH
37. 6.8 mH, 5.7 kΩ,
9.1 kΩ ∥ 2.45 mH
39. 25 mH, 2.2 kΩ, 18 μF
41. (a) $i_L = 3.56\ mA\ (1 - e^{-t/8.31\ \mu s})$,
$v_L = 4.29\ V\ e^{-t/8.31\ \mu s}$
43. $I_1 = 7$ A, $I_2 = 2$ A
45. $V_1 = 12$ V, $I_1 = 3$ A, $V_2 = -8$ V,
$I_2 = 0$ A

Chapter 12

1. Φ : CGS : 5×10^4 maxwells;
English : 5×10^4 lines
B: CGS: 8 gauss; English :
51.62 lines/in.^{2}
3. (a) 0.04 T
5. 952.4×10^3 At/Wb
7. 2624.67 At/m
9. 2.13 A
11. (a) 60 t (b) 13.34×10^{-4} Wb/Am
13. 2.70 A
15. 1.35 N
17. (a) 2.02 A (b) 2 N
19. 6.12 mWb
21. (a) $B = 1.5\ T\ (1 - e^{-H/700\ At/m})$
(b) 900 At/m: graph = 1.1 T,
Eq. = 1.09 T; 1800 At/m: graph = 1.38 T, Eq. = 1.39 T; 2700 At/m: graph = 1.47 T, Eq. = 1.47 T
Excellent results
(c) $H = -700 \log_e(1 - \frac{B}{1.5\ T})$
(d) 1 T: graph = 750 At/m, Eq. = 769.03 At/m; 1.4 T: graph = 1920 At/m, Eq. = 1895.64 At/m
(e) 40.1 mA vs. 44 mA in Example 12.1

Chapter 13

1. (a) 10 V (b) 15 ms: −10 V,
20 ms: 0 V (c) 20 V
(d) $T = 20$ ms (e) 2
3. (a) 40 mV (b) 1.5 ms: −40 mV;
5.1 ms: −40 mV (c) 80 mV
(d) 2 ms (e) 3.5
5. (a) 1 Hz (b) 16 Hz
(c) 25 Hz (d) 40 kHz
7. 0.3 ms
9. (a) 125 mV (b) 32 μs
(c) 31.25 kHz
11. (a) 60° (b) 216° (c) 18°
(d) 108°
13. (a) 628.32 rad/s
(b) 1.57×10^3 rad/s
(c) 12.56×10^3 rad/s
(d) 25.13×10^3 rad/s
15. 2.78 ms
17. (a) 20, 60 Hz (b) 12, 120 Hz
(c) 10^6, 1591.55 Hz (d) 8, 1.6 kHz
21. 0.48 A
23. 11.54°, 168.46°
27. (a) $v = 6 \times 10^{-3} \sin(2\pi\ 2000t + 30°)$ (b)
$i = 20 \times 10^{-3} \sin(2\pi\ 60t - 60°)$
29. $v = 12 \times 10^{-3} \sin(2\pi\ 2000t + 135°)$
31. v leads i by 90°
33. in phase
35. 13.95 μs
37. $\frac{1}{12}$ ms
39. 1 V
41. 2.33 V
43. (a) 0 V (b) 0 V (c) same
45. (a) 0.4 ms (b) 2.5 kHz
(c) −25 mV
47. (a) 84.85 V (b) 4.24 mA
(c) 5.66 μA
49. 1.43 V
51. $G = 0$ V, $V_{rms} = 8$ V
53. (a) $y = 2x \Rightarrow y^2 = 4x^2$
(b) 360 (c) 5.48 (d) 3.67
(e) rms ≅ 1.5 average

Chapter 14

1. —
3. (a) $3770 \cos 377t$
(b) $120 \cos(200t + 20°)$
(c) $4440.63 \cos(157t - 20°)$
(d) $200 \cos t$
5. (a) $v = 700 \sin 1000t$
(b) $v = 14.8 \sin(400t - 120°)$
7. (a) 22 mH (b) 1.2 H
9. (a) $v = 100 \sin(\omega t + 90°)$
(b) $v = 0.8 \sin(\omega t + 150°)$
(c) $v = 120 \sin(\omega t - 120°)$
11. (a) $i = 24 \sin(\omega t - 90°)$
(b) $i = 0.6 \sin(\omega t - 70°)$
13. (a) ∞ Ω (b) 530.79 Ω
(c) 15.92 Ω (d) 62.83 Ω
15. (a) 4.08 kHz (b) 34 Hz
(c) 408.09 kHz (d) 20.40 Hz
17. (a) $i = 6 \times 10^{-3} \sin(200t + 90°)$
(b) $i = 22.64 \times 10^{-6} \sin(377t + 90°)$
19. (a) $v = 1190.48 \sin(300t - 90°)$
(b) $v = 37.81 \sin(377t - 120°)$
21. (a) $X_C = 400\ \Omega$
(b) $X_L = 40\ \Omega$, $L = 254.78$ mH
(c) $R = 5\ \Omega$
23. —
25. 318.47 mH
27. 5070 pF
29. 192 W in each case
31. $i = 40 \sin(\omega t - 50°)$
33. (a) $i = 4.27 \sin(1000t - 30°)$
(b) 30 mH (c) 0 W
35. (a) $i_1 = 2.4 \sin(10^4 t + 150°)$, $i_2 = 12 \sin(10^4 t + 150°)$
(b) $i_s = 14.40 \sin(10^4 t + 150°)$
37. (a) 5.0 ∠36.87° (b) 2.83 ∠45°
(c) 12.65 ∠7.57°
(d) 1001.25 ∠2.86°
(e) 4123.11 ∠104.04°
(f) 0.894 ∠116.57°
39. (a) $4.6 + j\,3.86$
(b) $-6.0 + j\,10.39$ (c) $-j\,2000$
(d) $-0.006 - j\,0.0022$
(e) $47.97 + j\,1.68$
(f) $4.7 \times 10^{-4} - j\,1.71 \times 10^{-4}$
41. (a) $11.8 + j\,7.0$
(b) $151.90 + j\,49.90$
(c) $4.72 \times 10^{-6} + j\,71$
43. (a) $7.03 + j\,9.93$
(b) $95.7 + j\,22.77$
(c) 28.07 ∠−115.91°
45. (a) 8.00 ∠20°
(b) 49.68 ∠−64.0°
(c) 40×10^{-3} ∠40°

47. (a) $4 \angle 0°$ (b) $5.93 \angle -134.47°$
(c) $9.30 \angle -43.99°$

49. (a) $5.06 \angle 88.44°$
(b) $426 \angle 109.81°$

51. (a) $x = 3, y = 6$ or $x = 6, y = 3$
(b) $\theta = 30°$

53. (a) $14.14 \angle -180°$
(b) $4.24 \times 10^{-6} \angle 90°$
(c) $2.55 \times 10^{-6} \angle 70°$

55. $v_a = 63.25 \sin(377t + 63.43°)$

57. $v_a = 108.92 \sin(377t - 0.33°)$

Chapter 15

1. (a) $6.8\ \Omega \angle 0° = 6.8\ \Omega$
(b) $452.4\ \Omega \angle 90° = +j\,452.4\ \Omega$
(c) $1.48\ \Omega \angle 90° = +j\,1.48\ \Omega$
(d) $1\ k\Omega \angle -90° = -j\,1\ k\Omega$
(e) $33.86\ \Omega \angle -90° = -j\,33.86\ \Omega$ (f) $220\ \Omega \angle 0° = 220\ \Omega$

3. (a) $v = 88 \times 10^{-3} \sin 1000t$
(b) $v = 22.62 \sin(2\pi\, 200t + 150°)$
(c) $v = 270.96 \sin(157t - 50°)$

5. (a) $3\ \Omega - j\,1\ \Omega = 3.16\ \Omega \angle -18.43°$
(b) $1\ k\Omega + j\,4\ k\Omega = 4.12\ k\Omega \angle 75.96°$
(c) $470\ \Omega - j\,40\ \Omega = 471.7\ \Omega \angle -4.86°$

7. (a) $10\ \Omega \angle 36.87°$ (b) —
(c) $\mathbf{I} = 10\ A \angle -36.87°$, $\mathbf{V}_R = 80\ V \angle -36.87°$, $\mathbf{V}_L = 60\ V \angle 53.13°$ (d) —
(e) — (f) 800 W
(g) 0.8 lagging
(h) $v_R = 113.12 \sin(\omega t - 36.87°)$, $v_L = 84.84 \sin(\omega t + 53.13°)$, $i = 14.14 \sin(\omega t - 36.87°)$

9. (a) $5.66\ \Omega \angle -45°$ (b) —
(c) $L = 16$ mH, $C = 265\ \mu F$
(d) $\mathbf{I} = 8.83\ A \angle 45°$, $\mathbf{V}_R = 35.32\ V \angle 45°$, $\mathbf{V}_L = 52.98\ V \angle 135°$, $\mathbf{V}_C = 88.30\ V \angle -45°$ (e) —
(f) — (g) 311.8 W
(h) 0.707 leading
(i) $i = 12.49 \sin(377t + 4.5°)$, $e = 70.7 \sin 377t$, $v_R = 49.94 \sin(377t + 45°)$, $v_L = 74.91 \sin(377t + 135°)$, $v_C = 124.86 \sin(377t - 45°)$

11. $6.8\ \Omega$

13. (a) $292.4\ \mu A$ (b) 100 pF

15. (a) $\mathbf{V}_1 = 14.14\ V \angle -155°$, $\mathbf{V}_2 = 28.29\ V \angle 25°$
(b) $\mathbf{V}_1 = 112.92$ V, $\mathbf{V}_2 = 58.66\ V \angle -139.94°$

17. $3.2\ \Omega + j\,2.4\ \Omega$

19. —

21. —

23. (a) $\mathbf{Y}_T = 0.147\ S \angle 0° = 0.147$ S
(b) $\mathbf{Y}_T = 5\ mS \angle -90° = -j\,5$ mS
(c) $\mathbf{Y}_T = 0.5\ mS \angle 90° = +j\,0.5$ mS

25. (a) $54.7\ mS - j\,93.12$ mS
(b) $6.88\ mS + j\,9.08$ mS
(c) $4\ mS + j\,2$ mS

27. (a) $111.8\ mS \angle -26.57°$ (b) —
(c) $\mathbf{E} = 17.89\ V \angle 26.57°$, $\mathbf{I}_R = 1.79\ A \angle 26.57°$, $\mathbf{I}_L = 0.89\ A \angle -63.43°$ (d) —
(e) — (f) 32.04 W
(g) 0.894 lagging
(h) $e = 25.30 \sin(377t + 26.57°)$, $i_R = 2.58 + \sin(377t + 26.57°)$, $i_L = 1.26 \sin(377t - 63.43°)$, $i_s = 2.83 \sin 377t$

29. (a) $\mathbf{Y}_T = 0.89\ S \angle -19.81°$, $\mathbf{Z}_T = 1.12\ \Omega \angle 19.81°$ (b) —
(c) $C = 531\ \mu F$, $L = 5.31$ mH
(d) $\mathbf{E} = 2.40\ V \angle 79.81°$, $\mathbf{I}_R = 2.00\ A \angle 79.81°$, $\mathbf{I}_L = 1.20\ A \angle -10.19°$, $\mathbf{I}_C = 0.48\ A \angle 169.81°$ (f) —
(g) 4.8 W (h) 0.941 lagging
(i) $e = 3.39 \sin(377t + 79.81°)$, $i_R = 2.83 \sin(377t + 79.81°)$, $i_L = 1.70 \sin(377t - 10.19°)$, $i_C = 0.68 \sin(377t + 169.81°)$

31. (a) $\mathbf{I}_1 = 18.78\ A \angle 60.14°$, $\mathbf{I}_2 = 6.88\ A \angle -29.86°$
(b) $\mathbf{I}_1 = 6.62\ A \angle 12.89°$, $\mathbf{I}_2 = 1.97\ A \angle 129.46°$
(c) $\mathbf{I}_1 = 2.4\ A \angle 0°$, $\mathbf{I}_2 = 1.6\ A \angle 0°$

33. — 35. —

37. (a) $R_p = 100\ \Omega$, $X_p = 50\ \Omega$ (C)
(b) $R_p = 34\ k\Omega$, $X_p = 8.5\ k\Omega$ (L)

39. (a) $\mathbf{E} = 176.68\ V \angle 36.44°$, $\mathbf{I}_R = 0.803\ A \angle 36.44°$, $\mathbf{I}_L = 2.813\ A \angle -53.56°$
(b) 0.804 lagging
(c) 141.86 W
(d) — (e) —
(f) $1.11\ A \angle 126.43°$
(g) $142.15\ \Omega + j\,104.96\ \Omega$

Chapter 16

1. (a) $4\ \Omega \angle -22.65°$
(b) $3.5\ A \angle 22.65°$
(c) $3.5\ A \angle 22.65°$
(d) $1.94\ A \angle -33.66°$
(e) $14\ V \angle 112.65°$

3. (a) $19.86\ \Omega \angle 37.17°$
(b) $3.02\ A \angle -37.17°$
(c) $3.98\ A \angle 52.83°$
(d) $47.81\ V \angle -37.17°$
(e) 144.42 W

5. (a) $0.25\ A \angle 36.86°$
(b) $89.44\ V \angle -26.57°$ (c) 20 W

7. (a) $1.42\ A \angle 18.26°$
(b) $26.57\ V \angle 4.76°$ (c) 54.07 W

9. (a) $537.51\ \Omega \angle 56.07°$
(b) $93\ mA \angle -56.07°$
(c) $\mathbf{I}_1 = 106.48\ mA \angle -56.07°$, $\mathbf{I}_2 = 13.48\ mA \angle 123.93°$
(d) $\mathbf{V}_1 = 16.93\ V \angle 213.93°$, $\mathbf{V}_{ab} = 41.49\ V \angle 33.92°$
(e) 2.595 W (f) 0.558 lagging

11. (a) $1.52\ \Omega \angle -38.89°$
(b) $42.43\ V \angle 45°$
(c) $14.14\ A \angle 45°$
(d) $39.47\ A \angle 38.89°$

13. 139.71 mW

Chapter 17

1. —

3. $\mathbf{Z} = 5.15\ \Omega \angle 59.04°$, $\mathbf{E} = 10.30\ V \angle 179.04°$

5. $5.15\ A \angle -24.5°$

7. $2.55\ A \angle 132.72°$

9. $48.33\ A \angle -77.57°$

11. $0.68\ A \angle -162.9°$

13. $42.91\ \mathbf{I} \angle 149.31°$

15. $2.69\ mA \angle -174.8°$

17. $\mathbf{V}_1 = 14.68\ V \angle 68.89°$, $\mathbf{V}_2 = 12.97\ V \angle 155.88°$

19. $\mathbf{V}_1 = 19.86\ V \angle 43.8°$, $\mathbf{V}_2 = 8.94\ V \angle 106.9°$

21. $\mathbf{V}_1 = 220\ V \angle 0°$, $\mathbf{V}_2 = 96.30\ V \angle -12.32°$, $\mathbf{V}_3 = 100\ V \angle 90°$

23. $\mathbf{V}_1 = 5.74\ V \angle 122.76°$, $\mathbf{V}_2 = 4.04\ V \angle 145.03°$, $\mathbf{V}_3 = 25.94\ V \angle 78.07°$

25. $\mathbf{V}_1 = 4.37\ V \angle -128.66°$, $\mathbf{V}_2 = \mathbf{V}_{1\,k\Omega} = 2.25\ V \angle 17.63°$

27. $\mathbf{V}_1 = \mathbf{V}_{2\,k\Omega} = 10.67\ V \angle 180°$, $\mathbf{V}_2 = 6\ V \angle 180°$

29. $\mathbf{V}_L = -2451.92\mathbf{E}_i$

31. (a) not balanced
(b) $\mathbf{I}_{X_C} = 1.76\ mA \angle -71.54°$
(c) $\mathbf{V}_{X_C} = 7.03\ V \angle -18.46°$

33. balanced

35. $R_x = \dfrac{R_2 R_3}{R_1}$, $L_x = \dfrac{R_2 L_3}{R_1}$

37. $7.02\ A \angle 20.56°$

39. $36.9\ A \angle 23.87°$

Chapter 18

1. $6.09\ A \angle -32.12°$

3. $3.40\ A \angle 135.36°$

5. $v_C = 12\ V + 3.75 \sin(\omega t - 83.66°)$

7. $178.5\ mA \angle -26.57°$

9. $70.61\ mA \angle -11.31°$

11. $2.94\ mA \angle 0°$

13. $\mathbf{Z}_{Th} = 2.4\ \Omega \angle 36.87°$, $\mathbf{E}_{Th} = 80\ V \angle 36.87°$

15. $\mathbf{Z}_{Th} = 21.31\ \Omega\ \angle 32.2°$,
$\mathbf{E}_{Th} = 2.13\ V\ \angle 32.2°$

17. $\mathbf{Z}_{Th} = 5.00\ \Omega\ \angle -38.66°$,
$\mathbf{E}_{Th} = 77.14\ V\ \angle 50.41°$

19. **(a)** dc: $R_{Th} = 22\ \Omega$, $E_{Th} = -5\ V$;
ac: $\mathbf{Z}_{Th} = 66.04\ \Omega\ \angle 57.36°$,
$\mathbf{E}_{Th} = 6.21\ V\ \angle 207.36°$
(b) $i = -72.46\ mA + 62.36 \times 10^{-3} \sin(1000t + 173.42°)$

21. **(a)** $\mathbf{Z}_{Th} = 4.47\ k\Omega\ \angle -26.57°$,
$\mathbf{E}_{Th} = 31.31\ V\ \angle -26.57°$
(b) $6.26\ mA\ \angle 63.44°$

23. $\mathbf{Z}_{Th} = 4.44\ k\Omega\ \angle -0.03°$,
$\mathbf{E}_{Th} = -444.45 \times 10^3\ \mathbf{I}\ \angle 0.26°$

25. $\mathbf{Z}_{Th} = 5.10\ k\Omega\ \angle -11.31°$,
$\mathbf{E}_{Th} = -50\ V\ \angle 0°$

27. $\mathbf{Z}_{Th} = -39.22\ \Omega\ \angle 0°$,
$\mathbf{E}_{Th} = 20\ V\ \angle 53°$

29. $\mathbf{Z}_{Th} = 607.42\ \Omega\ \angle 0°$,
$\mathbf{E}_{Th} = 1.62\ V\ \angle 0°$

31. $\mathbf{Z}_N = 21.31\ \Omega\ \angle 32.2°$,
$\mathbf{I}_N = 0.1\ A\ \angle 0°$

33. $\mathbf{Z}_N = 9.66\ \Omega\ \angle 14.93°$,
$\mathbf{I}_N = 2.15\ A\ \angle -42.87°$

35. **(a)** dc: $R_N = 22\ \Omega$,
$I_N = -227.27\ mA$;
ac: $\mathbf{Z}_N = 66.04\ \Omega\ \angle 57.36°$,
$\mathbf{I}_N = 94\ mA\ \angle 150°$
(b) $\mathbf{I} = -72.46\ mA + 62.68 \times 10^{-3} \sin(1000t + 173.22°)$

37. **(a)** $\mathbf{Z}_N = 4.47\ k\Omega\ \angle -26.57°$,
$I_N = 7\ mA\ \angle 0°$
(b) $6.26\ mA\ \angle 63.44°$

39. $\mathbf{Z}_N = 4.44\ k\Omega\ \angle -0.03°$,
$\mathbf{I}_N = 100\mathbf{I}\ \angle 0.29°$

41. $\mathbf{Z}_N = 25\ k\Omega\ \angle 0°$,
$\mathbf{I}_N = 72\ mA\ \angle 0°$

43. $\mathbf{Z}_N = 6.65\ k\Omega\ \angle 0°$,
$\mathbf{I}_N = 0.79\ mA\ \angle 0°$

45. $\mathbf{Z}_L = 1.51\ \Omega - j\,0.39\ \Omega$,
$P_{max} = 1.61\ W$

47. $\mathbf{Z}_L = 2.48\ \Omega + j\,5.15\ \Omega$,
$P_{max} = 618.33\ W$

49. $\mathbf{Z}_L = 1.38\ k\Omega - j\,5.08\ k\Omega$,
$P_{max} = 50.04\ mW$

51. **(a)** $\mathbf{Z}_L = 4\ k\Omega + j\,2\ k\Omega$
(b) 61.27 mW

53. **(a)** 7.31 nF **(b)** 2940.27 Ω
(c) 1 mW

55. **(a)** $0.83\ mA\ \angle 0°$
(b) $0.83\ mA\ \angle 0°$
(c) the same

Chapter 19

1. **(a)** 130W **(b)** $Q_T = 0$ VAR,
$S_T = 130$ VA **(c)** 0.542 A
(d) $R_1 = 371.6\ \Omega$, $R_2 = 668.9\ \Omega$
(e) $I_1 = 0.348$ A, $I_2 = 0.193$ A

3. **(a)** $P_T = 400$ W, $Q_T = -400$ VAR (C), $S_T = 565.69$ VA,
$F_P = 0.707$ (leading) **(b)** —
(c) $5.66\ A\ \angle 135°$

5. **(a)** $P_T = 350$ W, $Q_T = -450$ VAR (C), $S_T = 570.09$ VA
(b) 0.614 (leading) **(c)** —
(d) $11.4\ A\ \angle 52.12°$

7. **(a)** $P_R = 200$ W, $P_{L,C} = 0$ W
(b) $Q_R = 0$ VAR, $Q_C = 800$ VAR (C), $Q_L = 100$ VAR (L)
(c) $S_R = 200$ VA,
$S_C = 80$ VA, $S_L = 100$ VA
(d) $P_T = 200$ W, $Q_T = 20$ VAR (L), $S_T = 200$ VA,
$F_P = 0.995$ lagging **(e)** —
(f) $10.05\ A\ \angle -5.73°$

9. **(a)** $P_L = 0$ W, $P_C = 0$ W,
$P_R = 38.99$ W
(b) $Q_L = 126.74$ VAR, $Q_C = 46.92$ VAR, $Q_R = 0$ VAR
(c) $S_L = 126.74$ VA,
$S_C = 46.92$ VA, $S_R = 38.99$ VA
(d) $P_T = 38.99$ W,
$Q_T = 79.82$ VAR (L), $S_T = 88.83$ VA, $F_P = 0.439$ (lagging)
(e) — **(f)** 0.31 J
(g) $W_L = 0.32$ J, $W_C = 0.12$ J

11. **(a)** $\mathbf{Z}_T = 2.30\ \Omega + j\,1.73\ \Omega$
(b) 4000 W

13. **(a)** $P_T = 900$ W, $Q_T = 0$ VAR,
$S_T = 900$ VA, $F_P = 1$
(b) $9\ A\ \angle 0°$ **(c)** —
(d) load 1: $X_C = 20\ \Omega$;
load 2: $R = 2.83\ \Omega$;
load 3: $R = 5.66\ \Omega$; $X_L = 4.72\ \Omega$

15. **(a)** $P_T = 1100$ W,
$Q_T = 2366.26$ VAR (C),
$S_T = 2609.44$ VA,
$F_P = 0.422$ (leading)
(b) $521.89\ V\ \angle -65.07°$
(c) load 1: $R = 1743.38\ \Omega$, $X_C = 1307.53\ \Omega$; load 2: $R = 43.59\ \Omega$,
$X_C = 99.88\ \Omega$

17. **(a)** 7.81 kVA **(b)** 0.640 (lagging)
(c) 65.08 A **(d)** 1105 μF
(e) 41.67 A

19. **(a)** 128.14 W
(b) *a-b*: 42.69 W, *b-c*: 64.03 W,
a-c: 106.72 W, *a-d*: 106.72 W,
c-d: 0 W, *d-e*: 0 W, *f-e*: 21.34 W

21. **(a)** $R = 5\ \Omega$, $L = 132.03$ mH
(b) $R = 10\ \Omega$
(c) $R = 15\ \Omega$, $L = 262.39$ mH

Chapter 20

1. **(a)** $\omega_s = 250$ rad/s,
$f = 39.79$ Hz
(b) $\omega_s = 3496.50$ rad/s,
$f_s = 556.49$ Hz

3. **(a)** 2 kΩ **(b)** 120 mA
(c) $V_R = 12$ V, $V_L = 240$ V,
$V_C = 240$ V **(d)** 20
(e) $L = 63.7$ mH, $C = 15{,}920$ pF
(f) 250 Hz
(g) $f_1 = 4.88$ kHz, $f_2 = 5.13$ kHz

5. **(a)** 400 Hz
(b) $f_1 = 5.8$ kHz, $f_2 = 6.2$ kHz
(c) $X_L = X_C = 45\ \Omega$
(d) 375 mW

7. **(a)** 10 **(b)** 20 Ω
(c) 1.5 mH, 3.98 μF
(d) $f_1 = 1.9$ kHz, $f_2 = 2.1$ kHz

9. **(a)** $R = 10\ \Omega$, $L = 13.26$ mH,
$C = 27.07\ \mu F$, $f_1 = 8.34$ kHz,
$f_2 = 8.46$ kHz

11. **(a)** 1 MHz **(b)** 160 kHz
(c) $R = 720\ \Omega$, $L = 0.716$ mH,
$C = 35.38$ pF **(d)** 56.23 Ω

13. **(a)** 159.16 kHz **(b)** 4 V
(c) 40 mA **(d)** 20

15. **(a)** 1.027 MHz **(b)** 114.1 V
(c) 13.69 W **(d)** 669 mW

17. $R = 91$ kΩ (closest to 93.33 kΩ),
$C = 240$ pF (closest to 250 pF)

19. **(a)** $f_s = 7.12$ kHz,
$f_p = 6.65$ kHz, $f_m = 7.01$ kHz
(b) $X_L = 20.88\ \Omega$, $X_C = 23.94\ \Omega$
(c) 55.56 Ω
(d) $Q_p = 2.32$, BW = 2.87 kHz
(e) $I_C = 92.73$ mA, $I_L = 99.28$ mA
(f) 2.22 V

21. **(a)** 3558.81 Hz
(b) 138.2 V
(c) 691 mW
(d) 575.86 Hz

23. **(a)** 98.54 Ω **(b)** 8.21
(c) 8.05 kHz **(d)** 4.83 V
(e) $f_1 = 7.55$ kHz, $f_2 = 8.55$ kHz

25. $R_s = 2.79$ kΩ, $C = 31{,}660$ pF

27. **(a)** 251.65 kHz **(b)** 4.44 kΩ
(c) 14.05 **(d)** 17.91 kHz
(e) $f_s = 251.65$ kHz,
$Z_{T_p} = 49.94\ \Omega$, $Q_p = 2.04$,
BW = 95.55 kHz
(f) $f_s = 251.65$ kHz,
$Z_{T_p} = 13.33$ kΩ,
$Q_p = 21.08$, BW = 11.94 kHz
(g) Network: $L/C = 100 \times 10^3$;
part (e): $L/C = 1 \times 10^3$;
part (f): $L/C = 400 \times 10^3$
(h) As the L/C ratio increased,
BW decreased and V_p increased.

Chapter 21

1. **(a)** left: 1.54 kHz, right: 5.62 kHz
(b) bottom: 0.22 V, top: 0.52 V

3. **(a)** 1000 **(b)** 10^{12} **(c)** 1.59
(d) 1.1 **(e)** 10^{10} **(f)** 1513.56
(g) 10.02 **(h)** 1,258,925.41

5. 1.68
7. −0.30
9. (a) 1.85
(b) 18.45 dB
11. 13.01
13. 38.49
15. 24.08 dB_s
17. —
19. (a) $f_c = 3617.16$ Hz;
$f = f_c: A_v = 0.707$;
$f = 0.1f_c: A_v = 0.995$;
$f = 0.5f_c: A_v = 0.894$;
$f = 2f_c: A_v = 0.447$;
$f = 10f_c: A_v = 0.0995$
(b) $f = f_c: \theta = -45°$;
$f = 0.1f_c: \theta = -5.71°$;
$f = 0.5f_c: \theta = -26.57°$;
$f = 2f_c: \theta = -63.43°$;
$f = 10f_c: \theta = -84.29°$
21. $C = 0.265\ \mu$F
23. (a) $f_c = 3.62$ kHz;
$f = f_c: A_v = 0.707$;
$f = 2f_c: A_v = 0.894$;
$f = 0.5f_c: A_v = 0.447$;
$f = 10f_c: A_v = 0.995$;
$f = \frac{1}{10}f_c: A_v = 0.0995$
(b) $f = f_c: \theta = 45°; f = 2f_c: \theta = 26.57°; f = 0.5f_c: \theta = 63.43°; f = 10f_c: \theta = 5.71°; f = \frac{1}{10}f_c: \theta = 84.29°$
25. $R = 795.77\ \Omega$, $R_{\text{standard}} = 750\ \Omega + 47\ \Omega = 797\ \Omega$
27. (a) low-pass section:
$f_{c_1} = 795.77$ Hz;
high-pass section:
$f_{c_2} = 1.94$ kHz;
$f = f_{c_1}: V_o = 0.654V_i$;
$f = f_{c_2}: V_o = 0.64V_i$;
At $f = f_{c_1} + \dfrac{BW}{2} = 1.37$ kHz;
$V_o = 0.706V_i$
(b) BW defined at $0.5V_i$;
$f = 500$ Hz: $V_o = 0.515V_i$;
$f = 4$ kHz: $V_o = 0.429V_i$; from plot BW ≅ 2.9 kHz with
$f_{\text{center}} = 1.93$ kHz
29. (a) $f_s = 98.1$ kHz
(b) $Q_s = 16.84$, BW = 5.83 kHz
(c) $f = f_s: A_v = 0.93$;
$f_1 = 95.19$ kHz, $f_2 = 101.02$ kHz;
$f = f_1: V_o = 0.64$ V;
$f = f_2: V_b = 0.66$ V
(d) $f = f_s: V_{o_{max}} = 0.93$ V;
$f_1 = 95.19$ kHz, $V_o = 0.66$ V;
$f_2 = 101.02$ kHz: $V_o = 0.66$ V
31. (a) $Q_s = 12.5$
(b) BW = 400 Hz, $f_1 = 4.8$ kHz, $f_2 = 5.2$ kHz
(c) $f = f_s$, $V_o = 25$ mV,
(d) $f = f_s$: $V_o = 25$ mV
33. (a) $f_p = 726.44$ kHz (band-stop);

35. (a), (b) $f_c = 7.20$ kHz
(c) $f = 0.5f_c: A_{v_{dB}} = -7$ dB;
$f = 2f_c: A_{v_{dB}} = -0.969$ dB;
$f = \frac{1}{10}f_c: A_{v_{dB}} = -20.04$ dB;
$f = 10f_c: A_{v_{dB}} = -0.043$ dB
(d) $f = 0.5f_c: A_v = 0.447; f = 2f_c: A_v = 0.894$;
(d) $f = 0.5f_c: \theta = 63.43°$;
$f = f_c: \theta = 45°; f = 2f_c: \theta = 26.57°$
37. (a), (b) $f_c = 13.26$ kHz
(c) $f = 0.5f_c: A_{v_{dB}} = -0.97$ dB;
$f = 2f_c: A_{v_{dB}} = -6.99$ dB;
$f = \frac{1}{10}f_c: A_{v_{dB}} = -0.04$ dB;
$f = 10f_c: A_{v_{dB}} = -20.04$ dB
(d) $f = 0.5f_c: A_v = 0.894$;
$f = 2f_c: A_v = 0.447$
(e) $f = 0.5f_c: \theta = -26.57°$,
$f = f_c: \theta = -45°$,
$f = 2f_c: \theta = -63.43°$
39. (a) $f_1 = 642.01$ Hz,
$f_c = 457.47$ Hz, vertical shift = −2.94 dB (b) $f = f_1: \theta = 45°$;
$f = f_c: \theta = 54.52°; f = f_1/2: \theta = 63.44°; f = \frac{1}{10}f_1: \theta = 84.29°$;
$f = 2f_1: \theta = 26.57°$;
$f = 10f_1: \theta = 5.71°$
41. (a) $f_1 = 19.41$ kHz, $f_c = 1.92$ kHz, vertical shift = −20 dB
(b) $f = f_c = f_1: \theta = -39.29°; f = 10$ kHz: $\theta = -51.88°$
43. (a) $f_1 = 945.66$ Hz, $f_c = 7.59$ kHz, vertical shift = −18.08 dB
(b) $f = f_1: \theta = 37.89°; f = f_c: \theta = 37.89°; f = 4$ kHz: $\theta = 48.96°$
45. (a) $f_1 = 180$ Hz, $f_2 = 18$ kHz, BW = 17,820 Hz, $f = 180$ Hz:
$A_{v_{dB}} = -2.99$ dB ≅ −3 dB,
$f = 18$ kHz: $A_{v_{dB}} = -3.105$ dB ≅ −3 dB
(b) $f = f_1: \theta = 90°; f = 1.8$ kHz: $\theta = 0.12° \cong 0°; f = 18$ kHz: $\theta = -90°$
47. $A_v = -120/[(1 - j\,50/f)(1 - j\,200/f)(1 + jf/36\text{ kHz})]$
49. $A_v = 1/(1 + jf/2000)$, $f_c = 2$ kHz
51. $A_{v_{dB}} = 20\log_{10}\sqrt{1 + (f_1/1000)^2} + 20\log_{10}\sqrt{1 + (f_2/2000)^2} + 40\log_{10}1/\sqrt{1 + (f_3/3000)^2}$;
$f = 1$ kHz: $A_{v_{dB}} = 3.06$ dB,
$f = 2$ kHz: $A_{v_{dB}} = 6.81$ dB,
$f = 3$ kHz: $A_{v_{dB}} = 9.1$ dB,
0 dB slope for asymptote at 13.06 dB for $f >> f_3$
53. (a) woofer, 400 Hz: $A_v = 0.673$;
tweeter, 5 kHz: $A_v = 0.678$
(b) woofer, 3 kHz: $A_v = 0.015$;
tweeter, 3 kHz: $A_v = 0.337$

Chapter 22

1. (a) 50 mH
(b) $e_p = 1.6$ V, $e_s = 5.12$ V
(c) $e_p = 15$ V, $e_s = 12$ V
3. (a) 355.56 mH
(b) $e_p = 24$ V, $e_s = 0.6$ V
(c) $e_p = 15$ V, $e_s = 12$ V
5. (a) 5 V (b) 625.59 μWb
7. 120 Hz
9. 30 Ω
11. 12,000 turns
13. (a) 3 (b) 2.78 W
15. (a) 364.55 Ω ∠86.86°
(b) 329.17 mA ∠−86.86°
(c) $\mathbf{V}_{R_e} = 6.58$ V ∠−86.86°,
$\mathbf{V}_{X_e} = 14.48$ V ∠3.14°,
$\mathbf{V}_{X_L} = 105.33$ V ∠3.14°
17. —
19. 3.2 H
21. $\mathbf{I}_1(\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}) + \mathbf{I}_2(\mathbf{Z}_m) = \mathbf{E}_1$;
$\mathbf{I}_1(\mathbf{Z}_m) + \mathbf{I}_2(\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}) = 0$
23. (a) 20 (b) 83.33 A
(c) 4.17 A
(d) $I_s = 4.17$ A, $I_p = 83.33$ A
25. (a) $\mathbf{V}_L = 25$ V ∠0°
(b) $\mathbf{I}_L = 5$ A ∠0°
(b) $\mathbf{Z}_L = 80\ \Omega$ ∠0°
(c) $\mathbf{Z}_{1/2} = 20\ \Omega$ ∠0°
27. (a) $\mathbf{E}_2 = 40$ V ∠0°,
$\mathbf{I}_2 = 3.33$ A ∠60°,
$\mathbf{E}_3 = 30$ V ∠60°, $\mathbf{I}_3 = 3$ A ∠60°
(b) $R_1 = 64.52\ \Omega$
29. $[\mathbf{Z}_1 + \mathbf{Z}_{L_1}]\mathbf{I}_1 - \mathbf{Z}_{M_{12}}\mathbf{I}_2 + \mathbf{Z}_{M_{13}} = \mathbf{E}_1$; $\mathbf{Z}_{M_{12}}\mathbf{I}_1 - [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}]$
$\mathbf{I}_2 + \mathbf{Z}_2\mathbf{I}_3 = 0$;
$\mathbf{Z}_{M_{13}}\mathbf{I}_1 + \mathbf{Z}_2\mathbf{I}_2 +$
$[\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}]\mathbf{I}_3 = 0$

Chapter 23

1. (a) 120.1 V (b) 120.1 V
(c) 12.01 A (d) 12.01 A
3. (a) 120.1 V (b) 120.1 V
(c) 16.98 A (d) 16.98 A
5. (a) $\theta_2 = -120°$, $\theta_3 = +120°$
(b) $\mathbf{V}_{an} = 120$ V ∠0°, $\mathbf{V}_{bn} = 120$ V ∠−120°, $\mathbf{V}_{cn} = 120$ V ∠120°
(c) $\mathbf{I}_{an} = 8$ A ∠−53.13°,
$\mathbf{I}_{bn} = 8$ A ∠−173.13°,
$\mathbf{I}_{cn} = 8$ A ∠66.87° (e) 8 A
(f) 207.85 V
7. $V_\phi = 127.0$ V, $I_\phi = 8.98$ A,
$I_L = 8.98$ A
9. (a) $\mathbf{E}_{AN} = 12.7$ kV ∠−30°,
$\mathbf{E}_{BN} = 12.7$ kV ∠−150°,
$\mathbf{E}_{CN} = 12.7$ kV ∠90°
(b–c) $\mathbf{I}_{an} = \mathbf{I}_{Aa} =$
11.29 A ∠−97.54°, $\mathbf{I}_{bn} = \mathbf{I}_{Bb} =$
11.29 A ∠−217.54°, $\mathbf{I}_{cn} =$
$\mathbf{I}_{Cc} = 11.29$ A ∠22.46°

(d) $\mathbf{V}_{an} = 12.16\text{ kV} \angle -29.34°$,
$\mathbf{V}_{bn} = 12.16\text{ kV} \angle -149.34°$,
$\mathbf{V}_{cn} = 12.16\text{ kV} \angle -90.66°$

11. (a) 120.1 V (b) 208 V
(c) 13.36 A (d) 23.15 A

13. (a) $\theta_2 = -120°, \theta_3 = +120°$
(b) $\mathbf{V}_{ab} = 208\text{ V} \angle 0°$,
$\mathbf{V}_{bc} = 208\text{ V} \angle -120°$,
$\mathbf{V}_{ca} = 208\text{ V} \angle 120°$
(d) $\mathbf{I}_{ab} = 9.46\text{ A} \angle 0°$,
$\mathbf{I}_{bc} = 9.46\text{ A} \angle -120°$,
$\mathbf{I}_{ca} = 9.46\text{ A} \angle 120°$
(e) 16.38 A (f) 120.1 V

15. (a) $\theta_2 = -120°, \theta_3 = +120°$
(b) $\mathbf{V}_{ab} = 208\text{ V} \angle 0°$,
$\mathbf{V}_{bc} = 208\text{ V} \angle -120°$,
$\mathbf{V}_{ca} = 208\text{ V} \angle 120°$
(d) $\mathbf{I}_{ab} = 86.67\text{ A} \angle -36.87°$,
$\mathbf{I}_{bc} = 16.67\text{ A} \angle -156.87°$
$\mathbf{I}_{ca} = 86.67\text{ A} \angle 83.13°$
(e) 150.11 A (f) 120.1 V

17. (a) $\mathbf{I}_{ab} = 15.33\text{ A} \angle -73.30°$,
$\mathbf{I}_{bc} = 15.33\text{ A} \angle -193.30°$,
$\mathbf{I}_{ca} = 15.33\text{ A} \angle 46.7°$
(b) $\mathbf{I}_{Aa} = 26.55\text{ A} \angle -103.30°$,
$\mathbf{I}_{Bb} = 26.55\text{ A} \angle 136.70°$,
$\mathbf{I}_{Cc} = 26.55\text{ A} \angle 16.70°$
(c) $\mathbf{E}_{AB} = 17.01\text{ kV} \angle -0.59°$,
$\mathbf{E}_{BC} = 17.01\text{ kV} \angle -120.59°$,
$\mathbf{E}_{CA} = 17.01\text{ kV} \angle 119.41°$

19. (a) 208 V (b) 120.09 V
(c) 7.08 A (d) 7.08 A

21. $V_\phi = 69.28\text{ V}, I_\phi = 2.89\text{ A}$,
$I_L = 2.89\text{ A}$

23. $V_\phi = 69.28\text{ V}, I_\phi = 5.77\text{ A}$,
$I_L = 5.77\text{ A}$

25. (a) 440 V (b) 440 V
(c) 29.33 A (d) 50.8 A

27. (a) $\theta_2 = -120°, \theta_3 = +120°$
(b) $\mathbf{V}_{ab} = 100\text{ V} \angle 0°$,
$\mathbf{V}_{bc} = 100\text{ V} \angle -120°$,
$\mathbf{V}_{ca} = 100\text{ V} \angle 120°$ (d) $\mathbf{I}_{ab} =$
$5\text{ A} \angle 0°, \mathbf{I}_{bc} = 5\text{ A} \angle -120°$,
$\mathbf{I}_{ca} = 5\text{ A} \angle 120°$ (e) 8.66 A

29. (a) $\theta_2 = -120°, \theta_3 = +120°$
(b) $\mathbf{V}_{ab} = 100\text{ V} \angle 0°$,
$\mathbf{V}_{bc} = 100\text{ V} \angle -120°$,
$\mathbf{V}_{ca} = 100\text{ V} \angle 120°$ (d) $\mathbf{I}_{ab} =$
$7.07\text{ A} \angle 45°, \mathbf{I}_{bc} = 7.07\text{ A} \angle -75°$,
$\mathbf{I}_{ca} = 7.07\text{ A} \angle 165°$ (e) 12.25 A

31. $P_T = 2160\text{ W}, Q_T = 0\text{ VAR}, S_T =$
$2160\text{ VA}, F_p = 1$

33. $P_T = 7210.67\text{ W}, Q_T =$
7210.67 VAR (C),
$S_T = 10{,}197.42\text{ VA}$,
$F_P = 0.707$ (leading)

35. $P_T = 7.26\text{ kW}, Q_T = 7.26\text{ kVAR}$
(L), $S_T = 10.27\text{ kVA}$,
$F_p = 0.707$ (lagging)

37. $P_T = 287.93\text{ W}, Q_T =$
575.86 VAR (L), $S_T = 643.83\text{ VA}$,
$F_p = 0.447$ (lagging)

39. $P_T = 900\text{ W}, Q_T = 1200\text{ VAR}$ (L),
$S_T = 1500\text{ VA}, F_p = 0.6$ (lagging)

41. $12.98\ \Omega - j\,7.31\ \Omega$

43. (a) 9,237.6 V (b) 80 A
(c) 1276.8 kW (d) 0.576 lagging
(e) $\mathbf{I}_{Aa} = 80\text{ A} \angle -54.83°$
(f) $\mathbf{V}_{an} = 7773.45\text{ V} \angle -4.87°$
(g) $62.52\ \Omega + j\,74.38\ \Omega$
(h) System: 0.576 lagging; Load:
0.643 lagging (i) 93.98%

45. (b) $P_T = 5899.64\text{ W}$,
$P_{\text{meter}} = 1966.55\text{ W}$

49. (a) 120.09 V (b) $\mathbf{I}_{an} = 8.49\text{ A}$,
$\mathbf{I}_{bn} = 7.08\text{ A}, \mathbf{I}_{cn} = 42.47\text{ A}$
(c) $P_T = 4.93\text{ kW}, Q_T =$
4.93 kVAR (L), $S_T = 6.97\text{ kVA}$,
$F_p = 0.707$ (lagging)
(d) $\mathbf{I}_{an} = 8.49\text{ A} \angle -75°$,
$\mathbf{I}_{bn} = 7.08\text{ A} \angle -195°$,
$\mathbf{I}_{cn} = 42.47\text{ A} \angle 45°$
(e) $35.09\text{ A} \angle -43.00°$

Chapter 24

1. (a) positive-going (b) 2 V
(c) 0.2 ms (d) 6 V (e) 6.5%
(f) 625 Hz (g) 12.5%

3. (a) positive-going (b) 10 mV
(c) 3.2 ms (d) 20 mV (e) 6.9%

5. $V_2 = 13.58\text{ mV}$

7. (a) 120 μs (b) 8.33 kHz
(c) maximum: 440 mV
minimum: 80 mV

9. prf = 125 kHz
Duty cycle = 62.5%

11. (a) 8 μs (b) 2 μs (c) 125 kHz
(d) 0 V (e) 3.46 mV

13. 18.88 mV

15. 117 mV

17. $v_C = 4\text{ V}(1 - e^{-t/20\text{ ms}})$

19. $i_C = -8\text{ mA}\, e^{-t}$

21. $i_C = 4\text{ mA}\, e^{-t/0.2\text{ ms}}$

23. $0 \to \frac{T}{2}$: $v_C = 20\text{ V}$,
$\frac{T}{2} \to T$: $v_C = 20\text{ V}e^{-t/0.2\text{ ms}}$,
$T \to \frac{3}{2}T$: $v_C = 20\text{ V}(1 - e^{-t/0.2\text{ ms}})$
$\frac{3}{2}T \to 2T$: $v_C = 20\text{ V}e^{-t/0.2\text{ ms}}$

25. $\mathbf{V}_{\text{scope}} = 10\text{ V}\angle 0°$,
$\theta_{Z_s} = \theta_{Z_p} = -59.5°$

Chapter 25

1. (I): (a) no (b) no (c) yes
(d) no (e) yes
(II): (a) yes (b) yes (c) yes
(d) yes (e) no
(III): (a) yes (b) yes (c) no
(d) yes (e) yes
(IV): (a) no (b) no (c) yes
(d) yes (e) yes

7. (a) 19.04 V (b) 4.53 A

9. 71.87 W

11. (a) $2 + 2.08\sin(400t - 33.69°) +$
$0.5\sin(800t - 53.13°)$
(b) 2.51 A (c) 24 +
$24.96\sin(400t - 33.69°) +$
$6\sin(800t - 53.13°)$ (d) 30.09 V
(e) $16.64\sin(400t + 56.31°) +$
$8\sin(800t + 36.87°)$ (f) 13.06 V
(g) 75.48 W

13. (a) $1.2\sin(400t + 53.13°)$
(b) 0.85 A (c) $18\sin(400t +$
$53.13°)$ (d) 12.73 V
(e) $18 + 23.98\sin(400t - 36.87°)$
(f) 24.73 V (g) 10.79 W

15. $2.26 \times 10^{-3}\sin(377t + 93.66°) +$
$1.92 \times 10^{-3}\sin(754t + 1.64°)$

17. $30 + 30.27\sin(20t + 7.59°) +$
$0.5\sin(40t - 30°)$

Chapter 26

1. $Z_i = 986.84\ \Omega$

3. (a) $I_{i_1} = 10\ \mu\text{A}$
(b) $Z_{i_2} = 4.5\text{ k}\Omega$
(c) $E_{i_3} = 6.9\text{ V}$

5. $Z_o = 44.59\text{ k}\Omega$

7. $Z_o = 10\text{ k}\Omega$

9. (a) $\mathbf{A}_v = -392.98$
(b) $\mathbf{A}_{v_T} = -320.21$

11. (a) $\mathbf{A}_{v_{NL}} = -2398.8$
(b) $\mathbf{E}_i = 50\text{ mV}$
(c) $\mathbf{Z}_i = 1\text{ k}\Omega$

13. (a) $\mathbf{A}_G = 6.067 \times 10^4$
(b) $\mathbf{A}_{G_T} = 4.94 \times 10^4$

15. (a) $\mathbf{A}_{v_T} = 1500$
(b) $\mathbf{A}_{i_T} = 187.5$
(c) $\mathbf{A}_{i_1} = 15, \mathbf{A}_{i_2} = 12.5$
(d) $\mathbf{A}_{i_T} = 187.5$

17. (a) $\mathbf{z}_{11} = (\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3)/$
$(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3)$,
$\mathbf{z}_{12} = \mathbf{Z}_1\mathbf{Z}_3/(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3)$,
$\mathbf{z}_{21} = \mathbf{z}_{12}$,
$\mathbf{z}_{22} = (\mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3)/$
$(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3)$

19. (a) $\mathbf{y}_{11} = (\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_1\mathbf{Y}_3)/$
$(\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3)$,
$\mathbf{y}_{12} = -\mathbf{Y}_1\mathbf{Y}_2/(\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3)$,
$\mathbf{y}_{21} = \mathbf{y}_{12}$,
$\mathbf{y}_{22} = (\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_2\mathbf{Y}_3)/$
$(\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3)$

21. $\mathbf{h}_{11} = \mathbf{Z}_1\mathbf{Z}_2/(\mathbf{Z}_1 + \mathbf{Z}_2)$,
$\mathbf{h}_{21} = -\mathbf{Z}_1/(\mathbf{Z}_1 + \mathbf{Z}_2)$,
$\mathbf{h}_{12} = \mathbf{Z}_1/(\mathbf{Z}_1 + \mathbf{Z}_2)$,
$\mathbf{h}_{22} = (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3)/$
$(\mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3)$

23. $\mathbf{h}_{11} = (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3)/$
$(\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_1\mathbf{Y}_3)$,
$\mathbf{h}_{21} = -\mathbf{Y}_2/(\mathbf{Y}_2 + \mathbf{Y}_3)$,
$\mathbf{h}_{12} = \mathbf{Y}_2/(\mathbf{Y}_2 + \mathbf{Y}_3)$
$\mathbf{h}_{22} = \mathbf{Y}_2\mathbf{Y}_3/(\mathbf{Y}_2 + \mathbf{Y}_3)$

25. (a) 47.62 (b) −99

27. $\mathbf{Z}_i = 9{,}219.5\ \Omega \angle -139.4°$,
$\mathbf{Z}_o = 29.07\text{ k}\Omega \angle -86.05°$

29. $\mathbf{h}_{11} = 2.5\text{ k}\Omega, \mathbf{h}_{12} = 0.5$,
$\mathbf{h}_{21} = -0.75, \mathbf{h}_{22} = 0.25\text{ mS}$

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