

Instructor's Resource Manual
to accompany

Introductory Circuit Analysis

Eleventh Edition

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Chapter 1

1. —

2. —

3. —

4. $v = \frac{d}{t} = \frac{20,000 \text{ ft}}{10 \text{ s}} \left[\frac{1 \text{ mi}}{5,280 \text{ ft}} \right] \left[\frac{60 \text{ s}}{1 \text{ min}} \right] \left[\frac{60 \text{ min}}{1 \text{ h}} \right] = 1363.64 \text{ mph}$

5. $4 \text{ min} \left[\frac{1 \text{ h}}{60 \text{ min}} \right] = 0.067 \text{ h}$

$$v = \frac{d}{t} = \frac{31 \text{ mi}}{1.067 \text{ h}} = 29.05 \text{ mph}$$

6. a. $\frac{95 \text{ mi}}{\cancel{h}} \left[\frac{5,280 \text{ ft}}{\cancel{mi}} \right] \left[\frac{1 \cancel{h}}{60 \cancel{min}} \right] \left[\frac{1 \cancel{min}}{60 \text{ s}} \right] = 139.33 \text{ ft/s}$

b. $t = \frac{d}{v} = \frac{60 \text{ ft}}{139.33 \text{ ft/s}} = 0.431 \text{ s}$

c. $v = \frac{d}{t} = \frac{60 \cancel{s}}{1 \cancel{s}} \left[\frac{60 \cancel{s}}{1 \text{ min}} \right] \left[\frac{60 \text{ min}}{1 \text{ h}} \right] \left[\frac{1 \text{ mi}}{5,280 \cancel{ft}} \right] = 40.91 \text{ mph}$

7. —

8. —

9. —

10. MKS, CGS, °C = $\frac{5}{9}(\text{°F} - 32) = \frac{5}{9}(68 - 32) = \frac{5}{9}(36) = 20^\circ$

SI: K = 273.15 + °C = 273.15 + 20 = 293.15

11. $1000 \cancel{J} \left[\frac{0.7378 \text{ ft-lb}}{1 \cancel{J}} \right] = 737.8 \text{ ft-lbs}$

12. $0.5 \text{ yd} \left[\frac{3 \cancel{ft}}{1 \cancel{yd}} \right] \left[\frac{12 \cancel{in.}}{1 \cancel{ft}} \right] \left[\frac{2.54 \text{ cm}}{1 \cancel{in.}} \right] = 45.72 \text{ cm}$

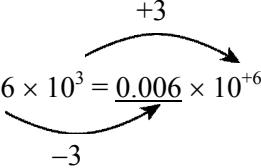
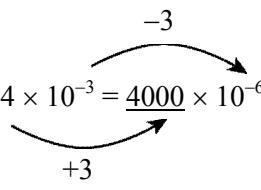
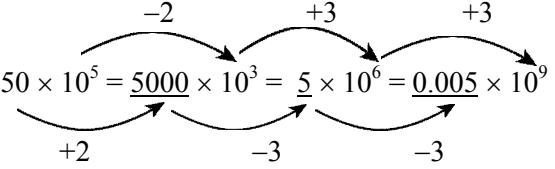
13. a. 10^4 b. 10^6 c. 10^3 d. 10^{-3} e. 10^0 f. 10^{-1}

14. a. 15×10^3 b. 30×10^{-3} c. 2.4×10^6 d. 150×10^3

e. 4.02×10^{-4} f. 2×10^{-10}

15. a. $4.2 \times 10^3 + 48.0 \times 10^3 = 52.2 \times 10^3 = \mathbf{5.22 \times 10^4}$
 b. $90 \times 10^3 + 360 \times 10^3 = 450 \times 10^3 = \mathbf{4.50 \times 10^5}$
 c. $50 \times 10^{-5} - 6 \times 10^{-5} = 44 \times 10^{-5} = \mathbf{4.4 \times 10^{-4}}$
 d. $1.2 \times 10^3 + 0.05 \times 10^3 - 0.6 \times 10^3 = 0.65 \times 10^3 = \mathbf{6.5 \times 10^2}$
16. a. $(10^2)(10^3) = 10^5 = \mathbf{100 \times 10^3}$
 b. $(10^{-2})(10^3) = 10^1 = \mathbf{10}$
 c. $(10^3)(10^6) = \mathbf{1 \times 10^9}$
 d. $(10^2)(10^{-5}) = \mathbf{1 \times 10^{-3}}$
 e. $(10^{-6})(10 \times 10^6) = \mathbf{10}$
 f. $(10^4)(10^{-8})(10^{28}) = \mathbf{1 \times 10^{24}}$
17. a. $(50 \times 10^3)(3 \times 10^{-4}) = 150 \times 10^{-1} = \mathbf{1.5 \times 10^1}$
 b. $(2.2 \times 10^3)(2 \times 10^{-3}) = 4.4 \times 10^0 = \mathbf{4.4}$
 c. $(82 \times 10^6)(2.8 \times 10^{-6}) = 229.6 = \mathbf{2.296 \times 10^2}$
 d. $(30 \times 10^{-4})(4 \times 10^{-3})(7 \times 10^8) = 840 \times 10^1 = \mathbf{8.40 \times 10^3}$
18. a. $10^2/10^4 = 10^{-2} = \mathbf{10 \times 10^{-3}}$
 b. $10^{-2}/10^3 = 10^{-5} = \mathbf{10 \times 10^{-6}}$
 c. $10^4/10^{-3} = 10^7 = \mathbf{10 \times 10^6}$
 d. $10^{-7}/10^2 = \mathbf{1.0 \times 10^{-9}}$
 e. $10^{38}/10^{-4} = \mathbf{1.0 \times 10^{42}}$
 f. $\sqrt{100}/10^{-2} = 10^1/10^{-2} = \mathbf{1 \times 10^3}$
19. a. $(2 \times 10^3)/(8 \times 10^{-5}) = 0.25 \times 10^8 = \mathbf{2.50 \times 10^7}$
 b. $(4 \times 10^{-3})/(60 \times 10^4) = 4/60 \times 10^{-7} = 0.667 \times 10^{-7} = \mathbf{6.67 \times 10^{-8}}$
 c. $(22 \times 10^{-5})/(5 \times 10^{-5}) = 22/5 \times 10^0 = \mathbf{4.4}$
 d. $(78 \times 10^{18})/(4 \times 10^{-6}) = \mathbf{1.95 \times 10^{25}}$
20. a. $(10^2)^3 = \mathbf{1.0 \times 10^6}$ b. $(10^{-4})^{1/2} = \mathbf{10.0 \times 10^{-3}}$
 c. $(10^4)^8 = \mathbf{100.0 \times 10^{30}}$ d. $(10^{-7})^9 = \mathbf{1.0 \times 10^{-63}}$
21. a. $(4 \times 10^2)^2 = 16 \times 10^4 = \mathbf{1.6 \times 10^5}$
 b. $(6 \times 10^{-3})^3 = 216 \times 10^{-9} = \mathbf{2.16 \times 10^{-7}}$
 c. $(4 \times 10^{-3})(6 \times 10^2)^2 = (4 \times 10^{-3})(36 \times 10^4) = 144 \times 10^1 = \mathbf{1.44 \times 10^3}$
 d. $((2 \times 10^{-3})(0.8 \times 10^4)(0.003 \times 10^5))^3 = (4.8 \times 10^3)^3 = (4.8)^3 \times (10^3)^3 = 110.6 \times 10^9 = \mathbf{1.11 \times 10^{11}}$
22. a. $(-10^{-3})^2 = \mathbf{1.0 \times 10^{-6}}$
 b. $\frac{(10^2)(10^{-4})}{10^3} = 10^{-2}/10^3 = \mathbf{1.0 \times 10^{-5}}$
 c. $\frac{(10^{-3})^2(10^2)}{10^4} = \frac{(10^{-6})(10^2)}{10^4} = \frac{10^{-4}}{10^4} = \mathbf{1.0 \times 10^{-8}}$
 d. $\frac{(10^3)(10^4)}{10^{-4}} = 10^7/10^{-4} = \mathbf{1.0 \times 10^{11}}$

- e. $(1 \times 10^{-4})^3(10^2)/10^6 = (10^{-12})(10^2)/10^6 = 10^{-10}/10^6 = \mathbf{1.0 \times 10^{-16}}$
- f. $\frac{[(10^2)(10^{-2})]^{-3}}{[(10^2)^2][10^{-3}]} = \frac{1}{(10^4)(10^{-3})} = \frac{1}{10} = \mathbf{1.0 \times 10^{-1}}$
23. a. $\frac{(3 \times 10^2)^2(10^2)}{3 \times 10^4} = (9 \times 10^4)(10^2)/(3 \times 10^4) = (9 \times 10^6)/(3 \times 10^4) = 3 \times 10^2 = \mathbf{300}$
- b. $\frac{(4 \times 10^4)^2}{(20)^3} = \frac{16 \times 10^8}{8 \times 10^3} = 2 \times 10^5 = \mathbf{200.0 \times 10^3}$
- c. $\frac{(6 \times 10^4)^2}{(2 \times 10^{-2})^2} = \frac{36 \times 10^8}{4 \times 10^{-4}} = \mathbf{9.0 \times 10^{12}}$
- d. $\frac{(27 \times 10^{-6})^{1/3}}{2 \times 10^5} = \frac{3 \times 10^{-2}}{2 \times 10^5} = 1.5 \times 10^{-7} = \mathbf{150.0 \times 10^{-9}}$
- e. $\frac{(4 \times 10^3)^2(3 \times 10^2)}{2 \times 10^{-4}} = \frac{(16 \times 10^6)(3 \times 10^2)}{2 \times 10^{-4}} = \frac{48 \times 10^8}{2 \times 10^{-4}} = \mathbf{24.0 \times 10^{12}}$
- f. $(16 \times 10^{-6})^{1/2}(10^5)^5(2 \times 10^{-2}) = (4 \times 10^{-3})(10^{25})(2 \times 10^{-2}) = 8 \times 10^{20}$
 $= \mathbf{800.0 \times 10^{18}}$
- g.
$$\begin{aligned} & \frac{[(3 \times 10^{-3})^3][1.60 \times 10^2]^2[(2 \times 10^2)(8 \times 10^{-4})]^{1/2}}{(7 \times 10^{-5})^2} \\ &= \frac{(27 \times 10^{-9})(2.56 \times 10^4)(16 \times 10^{-2})^{1/2}}{49 \times 10^{-10}} \\ &= \frac{(69.12 \times 10^{-5})(4 \times 10^{-1})}{49 \times 10^{-10}} = \frac{276.48 \times 10^{-6}}{49 \times 10^{-10}} \\ &= 5.64 \times 10^4 = \mathbf{56.4 \times 10^3} \end{aligned}$$

24. a. $6 \times 10^3 = \underline{0.006} \times 10^{+6}$

- b. $4 \times 10^{-3} = \underline{4000} \times 10^{-6}$

- c. $50 \times 10^5 = \underline{5000} \times 10^3 = \underline{5} \times 10^6 = \underline{0.005} \times 10^9$


d. $30 \times 10^{-8} = \underline{0.0003} \times 10^{-3} = \underline{0.3} \times 10^{-6} = \underline{300} \times 10^{-9}$

25. a. $0.05 \times 10^0 \text{ s} = \underline{50} \times 10^{-3} \text{ s} = 50 \text{ ms}$

b. $2000 \times 10^{-6} \text{ s} = \underline{2} \times 10^{-3} \text{ s} = 2 \text{ ms}$

c. $0.04 \times 10^{-3} \text{ s} = \underline{40} \times 10^{-6} \text{ s} = 40 \mu\text{s}$

d. $8400 \times 10^{-12} \text{ s} \Rightarrow \underline{0.0084} \times 10^{-6} \text{ s} = 0.0084 \mu\text{s}$

e. $4 \times 10^{-3} \times 10^3 \text{ m} = 4 \times 10^0 \text{ m} = \underline{4000} \times 10^{-3} \text{ m} = 4000 \text{ mm}$

f. $260 \times 10^3 \times 10^{-3} \text{ m} = \underline{0.26} \times 10^3 \text{ m} = 0.26 \text{ km}$

- 26.
- ~~$1.5 \text{ min} \left[\frac{60 \text{ s}}{1 \text{ min}} \right] = 90 \text{ s}$~~
 - $0.04 \cancel{\text{h}} \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \text{ min}} \right] = 144 \text{ s}$
 - $0.05 \cancel{\text{s}} \left[\frac{1 \mu\text{s}}{10^{-6} \cancel{\text{s}}} \right] = 0.05 \times 10^6 \mu\text{s} = 50 \times 10^3 \mu\text{s}$
 - $0.16 \cancel{\text{m}} \left[\frac{1 \text{ mm}}{10^{-3} \cancel{\text{m}}} \right] = 0.16 \times 10^3 \text{ mm} = 160 \text{ mm}$

e. $1.2 \times 10^{-7} \cancel{s} \left[\frac{1 \text{ ns}}{10^{-9} \cancel{s}} \right] = 1.2 \times 10^2 \text{ ns} = \mathbf{120 \text{ ns}}$

f. $3.62 \times 10^6 \cancel{s} \left[\frac{1 \cancel{\text{min}}}{60 \cancel{s}} \right] \left[\frac{1 \cancel{\text{h}}}{60 \cancel{\text{min}}} \right] \left[\frac{1 \text{ day}}{24 \cancel{\text{h}}} \right] = \mathbf{41.90 \text{ days}}$

27. a. $0.1 \mu\text{F} \left[\frac{10^{-6} \cancel{\text{F}}}{1 \mu\text{F}} \right] \left[\frac{1 \text{ pF}}{10^{-12} \cancel{\text{F}}} \right] = 0.1 \times 10^{-6} \times 10^{12} \text{ pF} = \mathbf{10^5 \text{ pF}}$

b. $80 \times 10^{-3} \cancel{\mu\text{m}} \left[\frac{100 \text{ cm}}{1 \cancel{\mu\text{m}}} \right] = 8000 \times 10^{-3} \text{ cm} = \mathbf{8 \text{ cm}}$

c. $60 \cancel{\text{cm}} \left[\frac{1 \cancel{\mu\text{m}}}{100 \cancel{\text{cm}}} \right] \left[\frac{1 \text{ km}}{1000 \cancel{\mu\text{m}}} \right] = \mathbf{60 \times 10^{-5} \text{ km}}$

d. $3.2 \cancel{\text{h}} \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \cancel{s}}{1 \cancel{\text{min}}} \right] \left[\frac{1 \text{ ms}}{10^{-3} \cancel{s}} \right] = \mathbf{11.52 \times 10^6 \text{ ms}}$

e. $0.016 \cancel{\mu\text{m}} \left[\frac{10^{-3} \cancel{\mu\text{m}}}{1 \cancel{\mu\text{m}}} \right] \left[\frac{1 \mu\text{m}}{10^{-6} \cancel{\mu\text{m}}} \right] = 0.016 \times 10^3 \text{ } \mu\text{m} = \mathbf{16 \mu\text{m}}$

f. $60 \cancel{\text{cm}^2} \left[\frac{1 \text{ m}}{100 \cancel{\text{cm}}} \right] \left[\frac{1 \text{ m}}{100 \cancel{\text{cm}}} \right] = \mathbf{60 \times 10^{-4} \text{ m}^2}$

28. a. $100 \cancel{\mu\text{m}} \left[\frac{1 \text{ m}}{39.37 \cancel{\mu\text{m}}} \right] = \mathbf{2.54 \text{ m}}$

b. $4 \cancel{\text{ft}} \left[\frac{12 \cancel{\mu\text{m}}}{1 \cancel{\text{ft}}} \right] \left[\frac{1 \text{ m}}{39.37 \cancel{\mu\text{m}}} \right] = \mathbf{1.22 \text{ m}}$

c. $6 \cancel{\text{lb}} \left[\frac{4.45 \text{ N}}{1 \cancel{\text{lb}}} \right] = \mathbf{26.7 \text{ N}}$

d. $60 \times 10^3 \cancel{\text{dynes}} \left[\frac{1 \cancel{\text{N}}}{10^5 \cancel{\text{dynes}}} \right] \left[\frac{1 \text{ lb}}{4.45 \cancel{\text{N}}} \right] = \mathbf{0.13 \text{ lb}}$

e. $150,000 \cancel{\text{cm}} \left[\frac{1 \cancel{\mu\text{m}}}{2.54 \cancel{\text{cm}}} \right] \left[\frac{1 \text{ ft}}{12 \cancel{\mu\text{m}}} \right] = \mathbf{4921.26 \text{ ft}}$

f. $0.002 \cancel{\mu\text{m}} \left[\frac{5280 \cancel{\text{ft}}}{1 \cancel{\mu\text{m}}} \right] \left[\frac{12 \cancel{\mu\text{m}}}{1 \cancel{\text{ft}}} \right] \left[\frac{1 \text{ m}}{39.37 \cancel{\mu\text{m}}} \right] = \mathbf{3.22 \text{ m}}$

29. $5280 \text{ ft}, \quad 5280 \cancel{\text{ft}} \left[\frac{1 \text{ yd}}{3 \cancel{\text{ft}}} \right] = 1760 \text{ yds}$

$$5280 \cancel{\text{ft}} \left[\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}} \right] \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] = 1609.35 \text{ m, } 1.61 \text{ km}$$

30. $299,792,458 \cancel{\text{s}} \left[\frac{39.37 \cancel{\text{in.}}}{1 \cancel{\text{m}}} \right] \left[\frac{1 \cancel{\text{ft}}}{12 \cancel{\text{in.}}} \right] \left[\frac{1 \text{ mi}}{5280 \cancel{\text{ft}}} \right] \left[\frac{60 \cancel{\text{s}}}{1 \cancel{\text{min}}} \right] \left[\frac{60 \cancel{\text{min}}}{1 \text{ h}} \right]$
 $= 670,615,288.1 \text{ mph} \approx 670.62 \times 10^6 \text{ mph}$

31. $100 \text{ yds} \left[\frac{3 \cancel{\text{ft}}}{1 \text{ yd}} \right] \left[\frac{1 \text{ mi}}{5,280 \cancel{\text{ft}}} \right] = 0.0568 \text{ mi}$

$$\frac{60 \text{ mi}}{\cancel{\text{h}}} \left[\frac{1 \cancel{\text{h}}}{60 \cancel{\text{min}}} \right] \left[\frac{1 \cancel{\text{min}}}{60 \text{ s}} \right] = 0.0167 \text{ mi/s}$$

$$t = \frac{d}{v} = \frac{0.0568 \text{ mi}}{0.0167 \text{ mi/s}} = 3.40 \text{ s}$$

32. $\frac{30 \cancel{\text{mi}}}{\cancel{\text{h}}} \left[\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}} \right] \left[\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}} \right] \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] \left[\frac{1 \cancel{\text{h}}}{60 \cancel{\text{min}}} \right] \left[\frac{1 \cancel{\text{min}}}{60 \text{ s}} \right] = 13.41 \text{ m/s}$

33. $\frac{50 \text{ yd}}{\cancel{\text{min}}} \left[\frac{60 \cancel{\text{min}}}{1 \text{ h}} \right] \left[\frac{3 \cancel{\text{ft}}}{1 \text{ yd}} \right] \left[\frac{1 \text{ mi}}{5,280 \cancel{\text{ft}}} \right] = 1.705 \text{ mi/h}$

$$t = \frac{d}{v} = \frac{3000 \text{ mi}}{1.705 \text{ mi/h}} = 1760 \cancel{\text{h}} \left[\frac{1 \text{ day}}{24 \cancel{\text{h}}} \right] = 73.33 \text{ days}$$

34. $10 \cancel{\text{km}} \left[\frac{1000 \cancel{\text{m}}}{1 \cancel{\text{km}}} \right] \left[\frac{39.37 \cancel{\text{in.}}}{1 \cancel{\text{m}}} \right] \left[\frac{1 \cancel{\text{ft}}}{12 \cancel{\text{in.}}} \right] \left[\frac{1 \text{ mi}}{5280 \cancel{\text{ft}}} \right] = 6.214 \text{ mi}$

$$v = \frac{1 \text{ mi}}{6.5 \text{ min}}, t = \frac{d}{v} = \frac{6.214 \cancel{\text{mi}}}{\frac{1 \cancel{\text{mi}}}{6.5 \text{ min}}} = 40.39 \text{ min}$$

35. $100 \text{ yds} \left[\frac{3 \cancel{\text{ft}}}{1 \text{ yd}} \right] \left[\frac{12 \text{ in.}}{1 \cancel{\text{ft}}} \right] = 3600 \text{ in} \Rightarrow 3600 \text{ quarters}$

36. 60 mph: $t = \frac{d}{v} = \frac{100 \text{ mi}}{60 \text{ mi/h}} = 1.67 \text{ h} = 1 \text{ h:40.2 min}$

75 mph: $t = \frac{d}{v} = \frac{100 \text{ mi}}{75 \text{ mi/h}} = 1.33 \text{ h} = 1 \text{ h:19.98 min}$

difference = 20.22 minutes

37. $d = vt = \left[600 \frac{\cancel{m}}{\cancel{s}} \right] \left[0.016 \cancel{h} \right] \left[\frac{60 \cancel{min}}{1 \cancel{h}} \right] \left[\frac{60 \cancel{s}}{1 \cancel{min}} \right] \left[\frac{1 \cancel{m}}{100 \cancel{cm}} \right] = 345.6 \text{ m}$

38. $d = 86 \cancel{\text{stories}} \left[\frac{14 \cancel{ft}}{\cancel{\text{story}}} \right] \left[\frac{1 \text{ step}}{\frac{9}{12} \cancel{ft}} \right] = 1605 \text{ steps}$

$$v = \frac{d}{t} \Rightarrow t = \frac{d}{v} = \frac{1605 \text{ steps}}{\frac{2 \text{ steps}}{\text{second}}} = 802.5 \cancel{\text{seconds}} \left[\frac{1 \text{ minute}}{60 \cancel{\text{seconds}}} \right] = 13.38 \text{ minutes}$$

39. $d = (86 \cancel{\text{stories}}) \left[\frac{14 \text{ ft}}{\cancel{\text{story}}} \right] = 1204 \cancel{ft} \left[\frac{1 \text{ mile}}{5,280 \cancel{ft}} \right] = 0.228 \text{ miles}$

$$\frac{\text{min}}{\text{mile}} = \frac{10.7833 \text{ min}}{0.228 \text{ miles}} = 47.30 \text{ min/mile}$$

40. $\frac{5 \text{ min}}{\text{mile}} \Rightarrow \frac{1 \cancel{\text{mile}}}{5 \text{ min}} \left[\frac{5,280 \text{ ft}}{1 \cancel{\text{mile}}} \right] = \frac{1056 \text{ ft}}{\text{minute}}, \quad \text{distance} = 86 \cancel{\text{stories}} \left[\frac{14 \text{ ft}}{\cancel{\text{story}}} \right] = 1204 \text{ ft}$

$$v = \frac{d}{t} \Rightarrow t = \frac{d}{v} = \frac{1204 \text{ ft}}{1056 \frac{\text{ft}}{\text{min}}} = 1.14 \text{ minutes}$$

41. a. $5 \cancel{J} \left[\frac{1 \text{ Btu}}{1054.35 \cancel{J}} \right] = 4.74 \times 10^{-3} \text{ Btu}$

b. $24 \cancel{\text{ounces}} \left[\frac{1 \cancel{\text{gallon}}}{128 \cancel{\text{ounces}}} \right] \left[\frac{1 \text{ m}^3}{264.172 \cancel{\text{gallons}}} \right] = 7.1 \times 10^{-4} \text{ m}^3$

c. $1.4 \cancel{\text{days}} \left[\frac{86,400 \text{ s}}{1 \cancel{\text{day}}} \right] = 1.21 \times 10^5 \text{ s}$

d. $1 \cancel{\text{m}^3} \left[\frac{264.172 \cancel{\text{gallons}}}{1 \cancel{\text{m}^3}} \right] \left[\frac{8 \text{ pints}}{1 \cancel{\text{gallon}}} \right] = 2113.38 \text{ pints}$

42. $6(4 + 8) = 72$

43. $(20 + 32)/4 = 13$

44. $\sqrt{(8^2 + 12^2)} = 14.42$

45. MODE = DEGREES: $\cos 50^\circ = 0.64$

46. MODE = DEGREES: $\tan^{-1}(3/4) = 36.87^\circ$

47. $\sqrt{400/(6^2 + 10)} = \mathbf{2.95}$

48. $\mathbf{205 \times 10^{-6}}$

49. $\mathbf{1.20 \times 10^{12}}$

50. $6.667 \times 10^6 + 0.5 \times 10^6 = \mathbf{7.17 \times 10^6}$

Chapter 2

1. —

2. a. $F = k \frac{Q_1 Q_2}{r^2} = \frac{(9 \times 10^9)(1 \text{ C})(2 \text{ C})}{(1 \text{ m})^2} = 18 \times 10^9 \text{ N}$

b. $F = k \frac{Q_1 Q_2}{r^2} = \frac{(9 \times 10^9)(1 \text{ C})(2 \text{ C})}{(3 \text{ m})^2} = 2 \times 10^9 \text{ N}$

c. $F = k \frac{Q_1 Q_2}{r^2} = \frac{(9 \times 10^9)(1 \text{ C})(2 \text{ C})}{(10 \text{ m})^2} = 0.18 \times 10^9 \text{ N}$

d. Exponentially, $\frac{r_3}{r_1} = \frac{10 \text{ m}}{1 \text{ m}} = 10$ while $\frac{F_1}{F_2} = \frac{18 \times 10^9 \text{ N}}{0.18 \times 10^9 \text{ N}} = 100$

3. a. $r = 1 \text{ mi}:$

$$1 \text{ mi} \left[\frac{5280 \text{ ft}}{1 \text{ mi}} \right] \left[\frac{12 \text{ in.}}{1 \text{ ft}} \right] \left[\frac{1 \text{ m}}{39.37 \text{ in.}} \right] = 1609.35 \text{ m}$$

$$F = \frac{k Q_1 Q_2}{r^2} = \frac{(9 \times 10^9)(8 \times 10^{-6} \text{ C})(40 \times 10^{-6} \text{ C})}{(1609.35 \text{ m})^2} = \frac{2880 \times 10^{-3}}{2.59 \times 10^6} \\ = 1.11 \mu\text{N}$$

b. $r = 10 \text{ ft}:$

$$10 \text{ ft} \left[\frac{12 \text{ in.}}{1 \text{ ft}} \right] \left[\frac{1 \text{ m}}{39.37 \text{ in.}} \right] = 3.05 \text{ m}$$

$$F = \frac{k Q_1 Q_2}{r^2} = \frac{2880 \times 10^{-3}}{(3.05 \text{ m})^2} = \frac{2880 \times 10^{-3}}{9.30} = 0.31 \text{ N}$$

c. $\frac{1 \text{ in.}}{16} \left[\frac{1 \text{ m}}{39.37 \text{ in.}} \right] = 1.59 \text{ mm}$

$$F = \frac{k Q_1 Q_2}{r^2} = \frac{2880 \times 10^{-3}}{(1.59 \times 10^{-3} \text{ m})^2} = \frac{2880 \times 10^{-3}}{2.53 \times 10^{-6}} = 1138.34 \times 10^3 \text{ N} \\ = 1138.34 \text{ kN}$$

4. —

5. $F = \frac{k Q_1 Q_2}{r^2} \Rightarrow r = \sqrt{\frac{k Q_1 Q_2}{F}} = \sqrt{\frac{(9 \times 10^9)(20 \times 10^{-6})^2}{3.6 \times 10^4}} = 10 \text{ mm}$

6. $F = \frac{kQ_1Q_2}{r^2} \Rightarrow 1.8 = \frac{kQ_1Q_2}{(2\text{ m})^2} \Rightarrow kQ_1Q_2 = 4(1.8) = 7.2$

a. $F = \frac{kQ_1Q_2}{r^2} = \frac{7.2}{(10)^2} = 72 \text{ mN}$

b. $Q_1/Q_2 = 1/2 \Rightarrow Q_2 = 2Q_1$
 $7.2 = kQ_1Q_2 = (9 \times 10^9)(Q_1)(2Q_1) = 9 \times 10^9 (2Q_1^2)$
 $\frac{7.2}{18 \times 10^9} = Q_1^2 \Rightarrow Q_1 = \sqrt{\frac{7.2}{18 \times 10^9}} = 20 \mu\text{C}$
 $Q_2 = 2Q_1 = 2(2 \times 10^{-5} \text{ C}) = 40 \mu\text{C}$

7. $V = \frac{W}{Q} = \frac{1.2 \text{ J}}{0.4 \text{ mC}} = 3 \text{ kV}$

8. $W = VQ = (60 \text{ V})(8 \text{ mC}) = 0.48 \text{ J}$

9. $Q = \frac{W}{V} = \frac{96 \text{ J}}{16 \text{ V}} = 6 \text{ C}$

10. $Q = \frac{W}{V} = \frac{72 \text{ J}}{9 \text{ V}} = 8 \text{ C}$

11. $I = \frac{Q}{t} = \frac{12 \text{ mC}}{2.8 \text{ s}} = 4.29 \text{ mA}$

12. $I = \frac{Q}{t} = \frac{312 \text{ C}}{(2)(60 \text{ s})} = 2.60 \text{ A}$

13. $Q = It = (40 \text{ mA})(0.8)(60 \text{ s}) = 1.92 \text{ C}$

14. $Q = It = (250 \text{ mA})(1.2)(60 \text{ s}) = 18.0 \text{ C}$

15. $t = \frac{Q}{I} = \frac{6 \text{ mC}}{2 \text{ mA}} = 3 \text{ s}$

16. $21.847 \times 10^{18} \cancel{\text{electrons}} \left[\frac{1 \text{ C}}{6.242 \times 10^{18} \cancel{\text{electrons}}} \right] = 3.5 \text{ C}$
 $I = \frac{Q}{t} = \frac{3.5 \text{ C}}{12 \text{ s}} = 0.29 \text{ A}$

17. $Q = It = (4 \text{ mA})(90 \text{ s}) = 360 \text{ mC}$
 $360 \text{ mC} \left[\frac{6.242 \times 10^{18} \text{ electrons}}{1 \text{ C}} \right] = 2.25 \times 10^{18} \text{ electrons}$

18. $I = \frac{Q}{t} = \frac{86 \text{ C}}{(1.2)(60 \text{ s})} = 1.194 \text{ A} > 1 \text{ A (yes)}$

19. $0.84 \times 10^{16} \cancel{\text{electrons}} \left[\frac{1 \text{ C}}{6.242 \times 10^{18} \cancel{\text{electrons}}} \right] = 1.346 \text{ mC}$

$$I = \frac{Q}{t} = \frac{1.346 \text{ mC}}{60 \text{ ms}} = 22.43 \text{ mA}$$

20. a. $Q = It = (2 \text{ mA})(0.01 \mu\text{s}) = 2 \times 10^{-11} \text{ C}$
 $2 \times 10^{-11} \cancel{C} \left[\frac{6.242 \times 10^{18} \cancel{\text{electrons}}}{1 \cancel{C}} \right] \left[\frac{1 \text{ ¢}}{\cancel{\text{electron}}} \right]$
 $= 1.25 \times 10^8 \text{ ¢} = \$1.25 \times 10^6 = \mathbf{1.25 \text{ million}}$

b. $Q = It = (100 \mu\text{A})(1.5 \text{ ns}) = 1.5 \times 10^{-13} \text{ C}$
 $1.5 \times 10^{-13} \cancel{C} \left[\frac{6.242 \times 10^{18} \cancel{\text{electrons}}}{1 \cancel{C}} \right] \left[\frac{\$1}{\cancel{\text{electron}}} \right] = \mathbf{0.94 \text{ million}}$

(a) > (b)

21. $Q = It = (200 \times 10^{-3} \text{ A})(30 \text{ s}) = 6 \text{ C}$
 $V = \frac{W}{Q} = \frac{40 \text{ J}}{6 \text{ C}} = \mathbf{6.67 \text{ V}}$

22. $Q = It = \left[\frac{420 \text{ C}}{\cancel{\text{min}}} \right] (0.5 \cancel{\text{min}}) = 210 \text{ C}$
 $V = \frac{W}{Q} = \frac{742 \text{ J}}{210 \text{ C}} = \mathbf{3.53 \text{ V}}$

23. $Q = \frac{W}{V} = \frac{0.4 \text{ J}}{24 \text{ V}} = 0.0167 \text{ C}$
 $I = \frac{Q}{t} = \frac{0.0167 \text{ C}}{5 \times 10^{-3} \text{ s}} = \mathbf{3.34 \text{ A}}$

24. $I = \frac{\text{Ah rating}}{t(\text{hours})} = \frac{200 \text{ Ah}}{40 \text{ h}} = \mathbf{5 \text{ A}}$

25. $\text{Ah} = (0.8 \text{ A})(75 \text{ h}) = \mathbf{60.0 \text{ Ah}}$

26. $t(\text{hours}) = \frac{\text{Ah rating}}{I} = \frac{32 \text{ Ah}}{1.28 \text{ A}} = \mathbf{25 \text{ h}}$

27. 40 Ah(for 1 h): $W_1 = VQ = V \cdot I \cdot t = (12 \text{ V})(40 \text{ A})(1 \cancel{\text{h}}) \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 1.728 \times 10^6 \text{ J}$

60 Ah(for 1 h): $W_2 = (12 \text{ V})(60 \text{ A})(1 \cancel{\text{h}}) \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 2.592 \times 10^6 \text{ J}$

Ratio $W_2/W_1 = 1.5$ or 50% more energy available with 60 Ah rating.

For 60 s discharge: $40 \text{ Ah} = It = I[60 \cancel{s}] \left[\frac{1 \cancel{\text{min}}}{60 \cancel{s}} \right] \left[\frac{1 \text{ h}}{60 \cancel{\text{min}}} \right] = I(16.67 \times 10^{-3} \text{ h})$

$$\text{and } I = \frac{40 \text{ Ah}}{16.67 \times 10^{-3} \text{ h}} = 2400 \text{ A}$$

$$60 \text{ Ah} = It = I[60 \cancel{s}] \left[\frac{1 \cancel{\text{min}}}{60 \cancel{s}} \right] \left[\frac{1 \text{ h}}{60 \cancel{\text{min}}} \right] = I(16.67 \times 10^{-3} \text{ h})$$

$$\text{and } I = \frac{60 \text{ Ah}}{16.67 \times 10^{-3} \text{ h}} = 3600 \text{ A}$$

$I_2/I_1 = 1.5$ or 50 % more starting current available at 60 Ah

28. $I = \frac{3 \text{ Ah}}{6.0 \text{ h}} = 500 \text{ mA}$

$$Q = It = (500 \text{ mA})(6 \cancel{\text{h}}) \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 10.80 \text{ kC}$$

$$W = QV = (10.8 \text{ kC})(12 \text{ V}) \cong 129.6 \text{ kJ}$$

29. –

30. –

31. –

32. –

33. –

34. –

35. $4 \cancel{\text{min}} \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 240 \text{ s}$

$$Q = It = (2.5 \text{ A})(240 \text{ s}) = 600 \text{ C}$$

36. $Q = It = (10 \times 10^{-3} \text{ A})(20 \text{ s}) = 200 \text{ mC}$
 $W = VQ = (12.5 \text{ V})(200 \times 10^{-3} \text{ C}) = 2.5 \text{ J}$

Chapter 3

1. a. 0.5 in. = **500 mils**
- b. $0.02 \text{ in.} \left[\frac{1000 \text{ mils}}{1 \text{ in.}} \right] = 20 \text{ mils}$
- c. $\frac{1}{4} \text{ in.} = 0.25 \text{ in.} \left[\frac{1000 \text{ mils}}{1 \text{ in.}} \right] = 250 \text{ mils}$
- d. 1 in. = **1000 mils**
- e. $0.02 \text{ ft} \left[\frac{12 \text{ in.}}{1 \text{ ft}} \right] \left[\frac{10^3 \text{ mils}}{1 \text{ in.}} \right] = 240 \text{ mils}$
- f. $0.1 \text{ m} \left[\frac{1 \text{ in.}}{2.54 \text{ m}} \right] \left[\frac{1000 \text{ mils}}{1 \text{ in.}} \right] = 39.37 \text{ mils}$
2. a. $A_{\text{CM}} = (30 \text{ mils})^2 = 900 \text{ CM}$
- b. 0.016 in. = 16 mils, $A_{\text{CM}} = (16 \text{ mils})^2 = 256 \text{ CM}$
- c. $\frac{1}{8}'' = 0.125'' = 125 \text{ mils}, A_{\text{CM}} = (125 \text{ mils})^2 = 15.63 \times 10^3 \text{ CM}$
- d. $1 \text{ m} \left[\frac{1 \text{ in.}}{2.54 \text{ m}} \right] \left[\frac{1000 \text{ mils}}{1 \text{ in.}} \right] = 393.7 \text{ mils}, A_{\text{CM}} = (393.7 \text{ mils})^2 = 155 \times 10^3 \text{ CM}$
- e. $0.02 \text{ ft} \left[\frac{12 \text{ in.}}{1 \text{ ft}} \right] \left[\frac{1000 \text{ mils}}{1 \text{ in.}} \right] = 240 \text{ mils}, A_{\text{CM}} = (240 \text{ mils})^2 = 57.60 \times 10^3 \text{ CM}$
- f. $0.0042 \text{ m} \left[\frac{39.37 \text{ in.}}{1 \text{ m}} \right] = 0.1654 \text{ in.} = 165.4 \text{ mils}, A_{\text{CM}} = (165.4 \text{ mils})^2 = 27.36 \times 10^3 \text{ CM}$
3. $A_{\text{CM}} = (d_{\text{mils}})^2 \rightarrow d_{\text{mils}} = \sqrt{A_{\text{CM}}}$
- a. $d = \sqrt{1600 \text{ CM}} = 40 \text{ mils} = 0.04 \text{ in.}$
- b. $d = \sqrt{820 \text{ CM}} = 28.64 \text{ mils} = 0.029 \text{ in.}$
- c. $d = \sqrt{40,000 \text{ CM}} = 200 \text{ mils} = 0.2 \text{ in.}$

d. $d = \sqrt{625 \text{ CM}} = 25 \text{ mils} = \mathbf{0.025 \text{ in.}}$

e. $d = \sqrt{6.25 \text{ CM}} = 2.5 \text{ mils} = \mathbf{0.0025 \text{ in.}}$

f. $d = \sqrt{100 \text{ CM}} = 10 \text{ mils} = \mathbf{0.01 \text{ in.}}$

4. $0.01 \text{ in.} = 10 \text{ mils}, A_{\text{CM}} = (10 \text{ mils})^2 = 100 \text{ CM}$

$$R = \rho \frac{l}{A} = (10.37) \frac{(200')}{100 \text{ CM}} = \mathbf{20.74 \Omega}$$

5. $A_{\text{CM}} = (4 \text{ mils})^2 = 16 \text{ CM}, R = \rho \frac{l}{A} = (9.9) \frac{(150 \text{ ft})}{16 \text{ CM}} = \mathbf{92.81 \Omega}$

6. a. $A = \rho \frac{l}{R} = 17 \left(\frac{80'}{2.5 \Omega} \right) = \mathbf{544 \text{ CM}}$

b. $d = \sqrt{A_{\text{CM}}} = \sqrt{544 \text{ CM}} = 23.32 \text{ mils} = \mathbf{23.3 \times 10^{-3} \text{ in.}}$

7. $\frac{1}{32}'' = 0.03125'' = 31.25 \text{ mils}, A_{\text{CM}} = (31.25 \text{ mils})^2 = 976.56 \text{ CM}$

$$R = \rho \frac{l}{R} \Rightarrow l = \frac{RA}{\rho} = \frac{(2.2 \Omega)(976.56 \text{ CM})}{600} = \mathbf{3.58 \text{ ft}}$$

8. a. $A_{\text{CM}} = \rho \frac{l}{A} = \frac{(10.37)(300')}{3.3 \Omega} = \mathbf{942.73 \text{ CM}}$

$$d = \sqrt{942.73 \text{ CM}} = 30.70 \text{ mils} = \mathbf{30.7 \times 10^{-3} \text{ in.}}$$

b. larger

c. smaller

9. a. $R_{\text{silver}} > R_{\text{copper}} > R_{\text{aluminum}}$

b. Silver: $R = \rho \frac{l}{A} = \frac{(9.9)(10 \text{ ft})}{1 \text{ CM}} = \mathbf{99 \Omega} \quad \{ A_{\text{CM}} = (1 \text{ mil})^2 = 1 \text{ CM}$

Copper: $R = \rho \frac{l}{A} = \frac{(10.37)(50 \text{ ft})}{100 \text{ CM}} = \mathbf{5.19 \Omega} \quad \{ A_{\text{CM}} = (10 \text{ mils})^2 = 100 \text{ CM}$

Aluminum: $R = \rho \frac{l}{A} = \frac{(17)(200 \text{ ft})}{2500 \text{ CM}} = \mathbf{1.36 \Omega} \quad \{ A_{\text{CM}} = (50 \text{ mils})^2 = 2500 \text{ CM}$

10. $\rho = \frac{RA}{l} = \frac{(500 \Omega)(94 \text{ CM})}{1000'} = 47 \Rightarrow \mathbf{\text{nickel}}$

11. a. $3'' = 3000 \text{ mils}, 1/2'' = 0.5 \text{ in.} = 500 \text{ mils}$
 $\text{Area} = (3 \times 10^3 \text{ mils})(5 \times 10^2 \text{ mils}) = 15 \times 10^5 \text{ sq. mils}$
 $15 \times 10^5 \text{ sq mils} \left[\frac{4/\pi \text{ CM}}{1 \text{ sq mil}} \right] = 19.108 \times 10^5 \text{ CM}$

$$R = \rho \frac{l}{A} = \frac{(10.37)(4')}{19.108 \times 10^5 \text{ CM}} = 21.71 \mu\Omega$$

b. $R = \rho \frac{l}{A} = \frac{(17)(4')}{19.108 \times 10^5 \text{ CM}} = 35.59 \mu\Omega$
 Aluminum bus-bar has almost 64% higher resistance.

- c. increases
 d. decreases

12. $I_2 = 2I_1, A_2 = A_1/4, \rho_2 = \rho_1$

$$\frac{R_2}{R_1} = \frac{\frac{\rho_2 l_2}{A_2}}{\frac{\rho_1 l_1}{A_1}} = \frac{\rho_2 l_2 A_1}{\rho_1 l_1 A_2} = \frac{2l_1 A_1}{l_1 A_1 / 4} = 8$$

and $R_2 = 8R_1 = 8(0.2 \Omega) = 1.6 \Omega$

$\Delta R = 1.6 \Omega - 0.2 \Omega = 1.4 \Omega$

13. $A = \frac{\pi d^2}{4} \Rightarrow d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(0.04 \text{ in.}^2)}{\pi}} = 0.2257 \text{ in.}$

$d_{\text{mils}} = 225.7 \text{ mils}$

$A_{\text{CM}} = (225.7 \text{ mils})^2 = 50,940.49 \text{ CM}$

$$\frac{R_1}{R_2} = \frac{\frac{\rho_1 l_1}{A_1}}{\frac{\rho_2 l_2}{A_2}} = \frac{\rho_1 l_1 A_2}{\rho_2 l_2 A_1} = \frac{l_1 A_2}{l_2 A_1} \quad (\rho_1 = \rho_2)$$

and $R_2 = \frac{R_1 l_2 A_1}{l_1 A_2} = \frac{(800 \text{ m}\Omega)(300 \text{ ft})(40,000 \text{ CM})}{(200 \text{ ft})(50,940.49 \text{ CM})} = 942.28 \text{ m}\Omega$

14. a. #11: $450 \text{ ft} \left[\frac{1.260 \Omega}{1000 \text{ ft}} \right] = 0.567 \Omega$

$$\#14: 450 \text{ ft} \left[\frac{2.525 \Omega}{1000 \text{ ft}} \right] = 1.136 \Omega$$

b. Resistance: $\#14/\#11 = 1.136 \Omega / 0.567 \Omega \cong 2:1$

c. Area: $\#14/\#11 = 4106.8 \text{ CM} / 8234.0 \text{ CM} \cong 1:2$

15. a. #8: $R = 1800 \cancel{\text{ft}} \left[\frac{0.6282 \Omega}{1000 \cancel{\text{ft}}} \right] = 1.13 \Omega$

#18: $R = 1800 \cancel{\text{ft}} \left[\frac{6.385 \Omega}{1000 \cancel{\text{ft}}} \right] = 11.49 \Omega$

b. #18:#8 = $11.49 \Omega : 1.13 \Omega = 10.17 : 1 \approx 10:1$

c. #18:#8 = $1624.3 \text{ CM} : 16,509 \text{ CM} = 1 : 10.16 \approx 1:10$

16. a. $A = \rho \frac{l}{R} = \frac{(10.37)(30')}{6 \text{ m}\Omega} = \frac{311.1 \text{ CM}}{6 \times 10^{-3}} = 51,850 \text{ CM} \Rightarrow \#3$
but 110 A $\Rightarrow \#2$

b. $A = \rho \frac{l}{R} = \frac{(10.37)(30')}{3 \text{ m}\Omega} = \frac{311.1 \text{ CM}}{3 \times 10^{-3}} = 103,700 \text{ CM} \Rightarrow \#0$

17. a. $A/\text{CM} = 230 \text{ A} / 211,600 \text{ CM} = 1.09 \text{ mA/CM}$

b. $\frac{1.09 \text{ mA}}{\cancel{\text{CM}}} \left[\frac{1 \cancel{\text{CM}}}{\frac{\pi}{4} \text{ sq mils}} \right] \left[\frac{1000 \cancel{\text{mils}}}{1 \text{ in.}} \right] \left[\frac{1000 \cancel{\text{mils}}}{1 \text{ in.}} \right] = 1.39 \text{ kA/in.}^2$

c. $5 \cancel{\text{kA}} \left[\frac{1 \text{ in.}^2}{1.39 \cancel{\text{kA}}} \right] = 3.6 \text{ in.}^2$

18. $\frac{1}{12} \text{ in.} = 0.083 \cancel{\text{in.}} \left(\frac{2.54 \text{ cm}}{1 \cancel{\text{in.}}} \right) = 0.21 \text{ cm}$

$$A = \frac{\pi d^2}{4} = \frac{(3.14)(0.21 \text{ cm})^2}{4} = 0.035 \text{ cm}^2$$

$$l = \frac{RA}{\rho} = \frac{(2 \Omega)(0.035 \text{ cm}^2)}{1.724 \times 10^{-6}} = 40,603 \text{ cm} = 406.03 \text{ m}$$

19. a. $\frac{1}{2}'' \left[\frac{2.54 \text{ cm}}{1''} \right] = 1.27 \text{ cm}, 3 \cancel{\mu\text{m}} \left[\frac{2.54 \text{ cm}}{1 \cancel{\mu\text{m}}} \right] = 7.62 \text{ cm}$

$$4 \cancel{\text{ft}} \left[\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}} \right] \left[\frac{2.54 \text{ cm}}{1 \cancel{\text{in.}}} \right] = 121.92 \text{ cm}$$

$$R = \rho \frac{l}{A} = \frac{(1.724 \times 10^{-6})(121.92 \text{ cm})}{(1.27 \text{ cm})(7.62 \text{ cm})} = 21.71 \mu\Omega$$

b. $R = \rho \frac{\ell}{A} = \frac{(2.825 \times 10^{-6})(121.92 \text{ cm})}{(1.27 \text{ cm})(7.62 \text{ cm})} = 35.59 \mu\Omega$

- c. increases
- d. decreases
20. $R_s = \frac{\rho}{d} = 100 \Rightarrow d = \frac{\rho}{100} = \frac{250 \times 10^{-6}}{100} = 2.5 \mu\text{m}$
21. $R = R_s \frac{l}{w} \Rightarrow w = \frac{R_s l}{R} = \frac{(150 \Omega)(1/2 \text{ in.})}{500 \Omega} = 0.15 \text{ in.}$
22. a. $d = 1 \text{ in.} = 1000 \text{ mils}$
 $A_{CM} = (10^3 \text{ mils})^2 = 10^6 \text{ CM}$
 $\rho_1 = \frac{RA}{l} = \frac{(1 \text{ m}\Omega)(10^6 \text{ CM})}{10^3 \text{ ft}} = 1 \text{ CM}\cdot\Omega/\text{ft}$
- b. $1 \text{ in.} = 2.54 \text{ cm}$
 $A = \frac{\pi d^2}{4} = \frac{\pi (2.54 \text{ cm})^2}{4} = 5.067 \text{ cm}^2$
 $l = 1000 \text{ ft} \left[\frac{12 \text{ in.}}{1 \text{ ft}} \right] \left[\frac{2.54 \text{ cm}}{1 \text{ in.}} \right] = 30,480 \text{ cm}$
 $\rho_2 = \frac{RA}{l} = \frac{(1 \text{ m}\Omega)(5.067 \text{ cm}^2)}{30,480 \text{ cm}} = 1.66 \times 10^{-7} \Omega\text{-cm}$
- c. $k = \frac{\rho_2}{\rho_1} = \frac{1.66 \times 10^{-7} \Omega\text{-cm}}{1 \text{ CM}\cdot\Omega/\text{ft}} = 1.66 \times 10^{-7}$
23. $\frac{234.5 + 10}{2 \Omega} = \frac{234.5 + 80}{R_2}, \quad R_2 = \frac{(314.5)(2 \Omega)}{244.5} = 2.57 \Omega$
24. $\frac{236 + 0}{0.02 \Omega} = \frac{236 + 100}{R_2}$
 $R_2 = \frac{(0.02 \Omega)(336)}{236} = 0.028 \Omega$
25. $C = \frac{5}{9}(\text{°F} - 32) = \frac{5}{9}(32 - 32) = 0^\circ (=32^\circ\text{F})$
 $C = \frac{5}{9}(70 - 32) = 21.11^\circ (=70^\circ\text{F})$
 $\frac{234.5^\circ + 21.11^\circ}{4 \Omega} = \frac{234.5^\circ + 0^\circ}{R_2}$
 $R_2 = \frac{(234.5)(4 \Omega)}{255.61} = 3.67 \Omega$

26.
$$\frac{234.5 + 30}{0.76 \Omega} = \frac{234.5 - 40}{R_2}$$

$$R_2 = \frac{(194.5)(0.76 \Omega)}{264.5} = \mathbf{0.56 \Omega}$$

27.
$$\frac{243 + (-30)}{0.04 \Omega} = \frac{243 + 0}{R_2}$$

$$R_2 = \frac{(243)(40 \text{ m}\Omega)}{213} = \mathbf{46 \text{ m}\Omega}$$

28. a. $68^\circ\text{F} = 20^\circ\text{C}, 32^\circ\text{F} = 0^\circ\text{C}$

$$\frac{234.5 + 20}{0.002} = \frac{234.5 + 0}{R_2}$$

$$R_2 = \frac{(234.5)(2 \text{ m}\Omega)}{254.5} = \mathbf{1.84 \text{ m}\Omega}$$

$$212^\circ\text{F} = 100^\circ\text{C}$$

$$\frac{234.5 + 20}{2 \text{ m}\Omega} = \frac{234.5 + 100}{R_2}$$

$$R_2 = \frac{(334.5)(2 \text{ m}\Omega)}{254.5} = \mathbf{2.63 \text{ m}\Omega}$$

b. $\frac{\Delta R}{\Delta T} = \frac{2.63 \text{ m}\Omega - 2 \text{ m}\Omega}{100^\circ\text{C} - 20^\circ\text{C}} = \frac{0.63 \text{ m}\Omega}{80^\circ\text{C}} = 7.88 \mu\Omega/\text{C}$ or $\mathbf{7.88 \times 10^{-5} \Omega/10^\circ\text{C}}$

29. a. $\frac{234.5 + 4}{1 \Omega} = \frac{234.5 + t_2}{1.1 \Omega}, \quad t_2 = \mathbf{27.85^\circ\text{C}}$

b. $\frac{234.5 + 4}{1 \Omega} = \frac{234.5 + t_2}{0.1 \Omega}, \quad t_2 = \mathbf{-210.65^\circ\text{C}}$

30. a. $K = 273.15 + {}^\circ\text{C}$

$$50 = 273.15 + {}^\circ\text{C}$$

$${}^\circ\text{C} = -223.15^\circ$$

$$\frac{234.5 + 20}{10 \Omega} = \frac{234.5 - 223.15}{R_2}$$

$$R_2 = \frac{11.35}{254.5}(10 \Omega) = \mathbf{0.446 \Omega}$$

b. $K = 273.15 + {}^\circ\text{C}$

$$38.65 = 273.15 + {}^\circ\text{C}$$

$${}^\circ\text{C} = -234.5^\circ$$

$$\frac{234.5 + 20}{10 \Omega} = \frac{234.5 - 234.5}{R_2}$$

$$R_2 = \frac{(0)10 \Omega}{254.5} = \mathbf{0 \Omega}$$

Recall: $-234.5^\circ =$

Inferred absolute zero

$$R = \mathbf{0 \Omega}$$

c. $F = \frac{9}{5} {}^\circ\text{C} + 32 = \frac{9}{5}(-273.15^\circ) + 32 = \mathbf{-459.67^\circ}$

$$31. \quad a. \quad \alpha_{20} = \frac{1}{|T_i| + 20^\circ\text{C}} = \frac{1}{234.5 + 20} = \frac{1}{254.5} = 0.003929 \cong \mathbf{0.00393}$$

$$\begin{aligned}
 b. \quad R &= R_{20}[1 + \alpha_{20}(t - 20^\circ\text{C})] \\
 1 \Omega &= 0.8 \Omega[1 + 0.00393(t - 20^\circ)] \\
 1.25 &= 1 + 0.00393t - 0.0786 \\
 1.25 - 0.9214 &= 0.00393t \\
 0.3286 &= 0.00393t \\
 t &= \frac{0.3286}{0.00393} = \mathbf{83.61^\circ\text{C}}
 \end{aligned}$$

$$32. \quad R = R_{20}[1 + \alpha_{20}(t - 20^\circ\text{C})] \\ = 0.4 \Omega[1 + 0.00393(16 - 20)] = 0.4 \Omega[1 - 0.01572] = \mathbf{0.39 \Omega}$$

33. Table: 1000' of #12 copper wire = 1.588Ω @ 20°C

$$C^\circ = \frac{5}{9}(F^\circ - 32) = \frac{5}{9}(115 - 32) = 46.11^\circ C$$

$$R = R_{20}[1 + \alpha_{20}(t - 20^\circ\text{C})]$$

$$= 1.588 \Omega[1 + 0.00393(46.11 - 20)]$$

$$= \mathbf{1.75 \Omega}$$

$$34. \quad \Delta R = \frac{R_{\text{nominal}}}{10^6} (\text{PPM})(\Delta T) = \frac{22 \Omega}{10^6} (200)(65^\circ - 20^\circ) = 0.198 \Omega$$

$$R = R_{\text{nominal}} + \Delta R = \mathbf{22.198 \Omega}$$

$$35. \quad \Delta R = \frac{R_{\text{nominal}}}{10^6} (\text{PPM})(\Delta T) = \frac{100 \Omega}{10^6} (100)(50^\circ - 20^\circ) = 0.30 \Omega$$

$$R = R_{\text{nominal}} + \Delta R = 100 \Omega + 0.30 \Omega = \mathbf{100.30 \Omega}$$

36. —

37. —

38. #12: Area = 6529 CM²

$$d = \sqrt{6529 \text{ CM}} = 80.8 \text{ mils} = 0.0808 \text{ } \mu\text{m} \cdot \left[\frac{2.54 \text{ cm}}{1 \mu\text{m}} \right] = 0.205 \text{ cm}$$

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.205 \text{ cm})^2}{4} = 0.033 \text{ cm}^2$$

$$I = \frac{1 \text{ MA}}{\cancel{\text{cm}^2}} [0.033 \cancel{\text{cm}^2}] = 33 \text{ kA} \gg 20 \text{ A}$$

39. —

40. a. 2 times larger

b. 4 times larger

$$41. \quad 10 \text{ k}\Omega - 3.5 \text{ k}\Omega = \mathbf{6.5 \text{ k}\Omega}$$

42. **6.25 kΩ and 18.75 kΩ**
43. —
44. a. $560 \text{ k}\Omega \pm 5\% = 560 \text{ k}\Omega \pm 28 \text{ k}\Omega$, **532 kΩ ↔ 588 kΩ**
 b. $220 \Omega \pm 10\% = 220 \Omega \pm 22 \Omega$, **198 Ω ↔ 242 Ω**
 c. $100 \Omega \pm 20\% = 100 \Omega \pm 20 \Omega$, **80 Ω ↔ 120 Ω**
45. a. 120Ω = Brown, Red, Brown, Silver
 b. 8.2Ω = Gray, Red, Gold, Silver
 c. $6.8 \text{ k}\Omega$ = Blue, Gray, Red, Silver
 d. $3.3 \text{ M}\Omega$ = Orange, Orange, Green, Silver
46. $10 \Omega \pm 20\% \Rightarrow 8 \Omega - 12 \Omega$
 $15 \Omega \pm 20\% \Rightarrow 12 \Omega - 18 \Omega$ } no overlap, continuance
47. $10 \Omega \pm 10\% \Rightarrow 10 \Omega \pm 1 \Omega = 9 \Omega - 11 \Omega$
 $15 \Omega \pm 10\% \Rightarrow 15 \Omega \pm 1.5 \Omega = 13.5 \Omega - 16.5 \Omega$ } No overlap
48. a. $621 = 62 \times 10^1 \Omega = 620 \Omega = \mathbf{0.62 \text{ k}\Omega}$
 b. $333 = 33 \times 10^3 \Omega = \mathbf{33 \text{ k}\Omega}$
 c. $Q2 = 3.9 \times 10^2 \Omega = \mathbf{390 \Omega}$
 d. $C6 = 1.2 \times 10^6 \Omega = \mathbf{1.2 \text{ M}\Omega}$
49. a. $G = \frac{1}{R} = \frac{1}{120 \Omega} = \mathbf{8.33 \text{ mS}}$
 b. $G = \frac{1}{4 \text{ k}\Omega} = \mathbf{0.25 \text{ mS}}$
 c. $G = \frac{1}{2.2 \text{ M}\Omega} = \mathbf{0.46 \mu\text{S}}$
 $G_a > G_b > G_c$ vs. $R_c > R_b > R_a$
50. a. Table 3.2, $\Omega/1000' = 1.588 \Omega$
 $G = \frac{1}{R} = \frac{1}{1.588 \Omega} = \mathbf{629.72 \text{ mS}}$
 or $G = \frac{A}{\rho l} = \frac{6529.9 \text{ CM (Table 3.2)}}{(10.37)(1000')} = \mathbf{629.69 \text{ mS (Cu)}}$
- b. $G = \frac{6529.9 \text{ CM}}{(17)(1000')} = \mathbf{384.11 \text{ mS (Al)}}$
 c. $G = \frac{6529.9 \text{ CM}}{(74)(1000')} = \mathbf{88.24 \text{ mS (Fe)}}$

51. $A_2 = 1 \frac{2}{3} A_1 = \frac{5}{3} A_1, l_2 = \left(1 - \frac{2}{3}\right)l_1 = \frac{l_1}{3}, \rho_2 = \rho_1$

$$\frac{G_1}{G_2} = \frac{\rho_1 \frac{A_1}{l_1}}{\rho_2 \frac{A_2}{l_2}} = \frac{\rho_1 l_1 A_1}{\rho_2 l_2 A_2} = \frac{\left(\frac{l_1}{3}\right) A_1}{l_1 \left(\frac{5}{3} A_1\right)} = \frac{1}{5}$$

$$G_2 = 5G_1 = 5(100 \text{ S}) = \mathbf{500 \text{ S}}$$

52. —

53. —

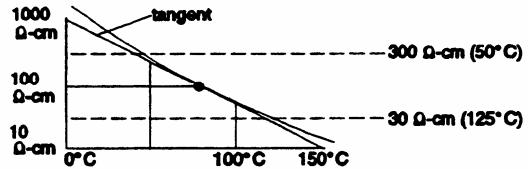
54. —

55. a. -50°C specific resistance $\cong 10^5 \Omega\text{-cm}$
 50°C specific resistance $\cong 500 \Omega\text{-cm}$
 200°C specific resistance $\cong 7 \Omega\text{-cm}$

b. negative

c. No

d. $\rho = \frac{\Delta\Omega\text{-cm}}{\Delta T} = \frac{300 - 30}{125 - 50} = \frac{270 \Omega\text{-cm}}{75^\circ\text{C}} \cong 3.6 \Omega\text{-cm}/^\circ\text{C}$



56. a. Log scale: $10 \text{ fc} \Rightarrow 3 \text{ k}\Omega$
 $100 \text{ fc} \Rightarrow 0.4 \text{ k}\Omega$

c. no—log scales imply linearity

b. negative

d. $1 \text{ k}\Omega \Rightarrow \cong 30 \text{ fc}$
 $10 \text{ k}\Omega \Rightarrow \cong 2 \text{ fc}$

$$\left| \frac{\Delta R}{\Delta f_c} \right| = \frac{10 \text{ k}\Omega - 1 \text{ k}\Omega}{30 \text{ fc} - 2 \text{ fc}} = 321.43 \Omega/\text{fc}$$

$$\text{and } \frac{\Delta R}{\Delta f_c} = \mathbf{-321.43 \Omega/\text{fc}}$$

57. a. @ 0.5 mA, $V \cong \mathbf{195 \text{ V}}$
@ 1 mA, $V \cong \mathbf{200 \text{ V}}$
@ 5 mA, $V \cong \mathbf{215 \text{ V}}$

b. $\Delta V_{\text{total}} = 215 \text{ V} - 195 \text{ V} = \mathbf{20 \text{ V}}$

c. $5 \text{ mA}:0.5 \text{ mA} = \mathbf{10:1}$
compared to
 $215 \text{ V}:200 \text{ V} = \mathbf{1.08:1}$

Chapter 4

1. $V = IR = (2.5 \text{ A})(47 \Omega) = \mathbf{117.5 \text{ V}}$

2. $I = \frac{V}{R} = \frac{12 \text{ V}}{6.8 \Omega} = \mathbf{1.76 \text{ A}}$

3. $R = \frac{V}{I} = \frac{6 \text{ V}}{1.5 \text{ mA}} = \mathbf{4 \text{ k}\Omega}$

4. $I = \frac{V}{R} = \frac{12 \text{ V}}{40 \times 10^{-3} \Omega} = \mathbf{300 \text{ A}}$

5. $V = IR = (3.6 \mu\text{A})(0.02 \text{ M}\Omega) = 0.072 \text{ V} = \mathbf{72 \text{ mV}}$

6. $I = \frac{V}{R} = \frac{62 \text{ V}}{15 \text{ k}\Omega} = \mathbf{4.13 \text{ mA}}$

7. $R = \frac{V}{I} = \frac{120 \text{ V}}{2.2 \text{ A}} = \mathbf{54.55 \Omega}$

8. $I = \frac{V}{R} = \frac{120 \text{ V}}{7.5 \text{ k}\Omega} = \mathbf{16 \text{ mA}}$

9. $R = \frac{V}{I} = \frac{120 \text{ V}}{4.2 \text{ A}} = \mathbf{28.57 \Omega}$

10. $R = \frac{V}{I} = \frac{4.5 \text{ V}}{125 \text{ mA}} = \mathbf{36 \Omega}$

11. $R = \frac{V}{I} = \frac{24 \text{ mV}}{20 \mu\text{A}} = \mathbf{1.2 \text{ k}\Omega}$

12. $V = IR = (15 \text{ A})(0.5 \Omega) = \mathbf{7.5 \text{ V}}$

13. a. $R = \frac{V}{I} = \frac{120 \text{ V}}{9.5 \text{ A}} = \mathbf{12.63 \Omega}$

b. $t = 1 \cancel{\text{h}} \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 3600 \text{ s}$

$$\begin{aligned} W &= Pt = VIt \\ &= (120 \text{ V})(9.5 \text{ A})(3600 \text{ s}) \\ &= \mathbf{4.1 \times 10^6 \text{ J}} \end{aligned}$$

14. $V = IR = (2.4 \mu\text{A})(3.3 \text{ M}\Omega) = \mathbf{7.92 \text{ V}}$

15. —

16. b. $(0.13 \text{ mA})(500 \text{ h}) = \mathbf{65 \text{ mAh}}$

17. —

18. —

19. —

20. $P = \frac{W}{t} = \frac{420 \text{ J}}{4 \cancel{\text{min}} \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right]} = \frac{420 \text{ J}}{240 \text{ s}} = \mathbf{1.75 \text{ W}}$

21. $t = \frac{W}{P} = \frac{640 \text{ J}}{40 \text{ J/s}} = \mathbf{16 \text{ s}}$

22. a. $8 \cancel{\text{h}} \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 28,800 \text{ s}$
 $W = Pt = (2 \text{ W})(28,000 \text{ s}) = \mathbf{57.6 \text{ kJ}}$

b. $\text{kWh} = \frac{(2 \text{ W})(8 \text{ h})}{1000} = \mathbf{16 \times 10^{-3} \text{ kWh}}$

23. $I = \frac{Q}{t} = \frac{300 \text{ C}}{1 \cancel{\text{min}} \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right]} = 5 \text{ C/s} = 5 \text{ A}$
 $P = I^2R = (5 \text{ A})^2 10 \Omega = \mathbf{250 \text{ W}}$

24. $P = VI = (3 \text{ V})(1.4 \text{ A}) = 4.20 \text{ W}$

$$t = \frac{W}{P} = \frac{12 \text{ J}}{4.2 \text{ W}} = \mathbf{2.86 \text{ s}}$$

25. $I = \frac{48 \text{ C}}{\cancel{\text{min}} \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right]} = 0.8 \text{ A}$
 $P = EI = (6 \text{ V})(0.8 \text{ A}) = \mathbf{4.8 \text{ W}}$

26. $P = I^2R = (7.2 \text{ mA})^2 4 \text{ k}\Omega = \mathbf{207.36 \text{ mW}}$

27. $P = I^2R \Rightarrow I = \sqrt{\frac{P}{R}} = \sqrt{\frac{240 \text{ mW}}{2.2 \text{ k}\Omega}} = \mathbf{10.44 \text{ mA}}$

28. $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{2 \text{ W}}{120 \Omega}} = \mathbf{129.10 \text{ mA}}$

$$V = IR = (129.10 \text{ mA})(120 \Omega) = \mathbf{15.49 \text{ V}}$$

29. $I = \frac{E}{R} = \frac{12 \text{ V}}{5.6 \text{ k}\Omega} = 2.14 \text{ mA}$

$$P = I^2 R = (2.14 \text{ mA})^2 5.6 \text{ k}\Omega = 25.65 \text{ mW}$$

$$W = P \cdot t = (25.65 \text{ mW}) \left(1 \cancel{\text{h}} \left[\frac{60 \text{ min}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] \right) = 92.34 \text{ J}$$

30. $E = \frac{P}{I} = \frac{324 \text{ W}}{2.7 \text{ A}} = 120 \text{ V}$

31. $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{1 \text{ W}}{4.7 \text{ M}\Omega}} = 461.27 \mu\text{A}$

no

32. $V = \sqrt{PR} = \sqrt{(42 \text{ mW})(2.2 \text{ k}\Omega)} = \sqrt{92.40} = 9.61 \text{ V}$

33. $P = EI = (9 \text{ V})(45 \text{ mA}) = 405 \text{ mW}$

34. $P = VI, I = \frac{P}{V} = \frac{100 \text{ W}}{120 \text{ V}} = 0.833 \text{ A}$

$$R = \frac{V}{I} = \frac{120 \text{ V}}{0.833 \text{ A}} = 144.06 \Omega$$

35. $V = \frac{P}{I} = \frac{450 \text{ W}}{3.75 \text{ A}} = 120 \text{ V}$

$$R = \frac{V}{I} = \frac{120 \text{ V}}{3.75 \text{ A}} = 32 \Omega$$

36. a. $P = EI$ and $I = \frac{P}{E} = \frac{0.4 \times 10^{-3} \text{ W}}{3 \text{ V}} = 0.13 \text{ mA}$

b. Ah rating = $(0.13 \text{ mA})(500 \text{ h}) = 66.5 \text{ mAh}$

37. $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{100 \text{ W}}{20 \text{ k}\Omega}} = \sqrt{5 \times 10^{-3}} = 70.71 \text{ mA}$

$$V = \sqrt{PR} = \sqrt{(100 \text{ W})(20 \text{ k}\Omega)} = 1.42 \text{ kV}$$

38. a. $W = Pt = \left(\frac{V^2}{R} \right) t = \left(\frac{12 \text{ V}}{10 \Omega} \right)^2 60 \text{ s} = 864 \text{ J}$

b. Energy doubles, power the same

39. $\frac{12 \text{ h}}{\cancel{\text{week}}} \left[\frac{4 \frac{1}{3} \cancel{\text{weeks}}}{\cancel{3}} \right] [5 \text{ months}] = 260 \text{ h}$

$$\text{kWh} = \frac{(230 \text{ W})(260 \text{ h})}{1000} = \mathbf{59.80 \text{ kWh}}$$

40. $\text{kWh} = \frac{Pt}{1000} \Rightarrow t = \frac{(1000)(\text{kWh})}{P} = \frac{(1000)(12 \text{ kWh})}{1500 \text{ W}} = \mathbf{8 \text{ h}}$

41. $\text{kWh} = \frac{(24 \text{ W})(3 \text{ h})}{1000} = 72 \times 10^{-3} \text{ kWh}$
 $(72 \times 10^{-3} \text{ kWh})(9\text{¢}/\text{kWh}) = \mathbf{0.65\text{¢}}$

42. a. $\text{kWh} = \frac{Pt}{1000} \Rightarrow P = \frac{(1000)(\text{kWh})}{t} = \frac{(1000)(1200 \text{ kWh})}{10 \text{ h}} = \mathbf{120 \text{ kW}}$

b. $I = \frac{P}{E} = \frac{120 \times 10^3 \text{ W}}{208 \text{ V}} = \mathbf{576.92 \text{ A}}$

c. $P_{\text{lost}} = P_i - P_o = P_i - \eta P_i = P_i(1 - \eta) = 120 \text{ kW}(1 - 0.82) = 21.6 \text{ kW}$
 $\text{kWh}_{\text{lost}} = \frac{Pt}{1000} = \frac{(21.6 \text{ kW})(10 \text{ h})}{1000} = \mathbf{216 \text{ kWh}}$

43. $\#\text{kWh} = \frac{\$1.00}{9\text{¢}} = 11.11$

$$\text{kWh} = \frac{Pt}{1000} \Rightarrow t = \frac{(\text{kWh})(1000)}{P} = \frac{(11.11)(1000)}{.250} = \mathbf{44.44 \text{ h}}$$

$$t = \frac{(\text{kWh})(1000)}{P} = \frac{(11.11)(1000)}{4800} = \mathbf{2.32 \text{ h}}$$

44. a. $W = Pt = (60 \text{ W})(1 \text{ h}) = \mathbf{60 \text{ Wh}}$

b. $W = Pt = (60 \text{ W}) \left(1 \cancel{\text{h}} \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] \right) = \mathbf{216 \text{ kW s}}$

c. $1 \text{ kJ} = 1 \text{ Ws}, \therefore \mathbf{216 \text{ kJ}}$

d. $W = \frac{Pt}{1000} = \frac{(60 \text{ W})(1 \text{ h})}{1000} = \mathbf{60 \times 10^{-3} \text{ kWh}}$

45. a. $P = EI = (9 \text{ V})(0.455 \text{ A}) = \mathbf{4.1 \text{ W}}$

b. $R = \frac{E}{I} = \frac{9 \text{ V}}{0.455 \text{ A}} = \mathbf{19.78 \Omega}$

c. $W = Pt = (4.1 \text{ W})(21,600 \text{ s}) = \mathbf{88.56 \text{ kJ}}$

$$6 \cancel{\text{h}} \left[\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}} \right] \left[\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right] = 21,600 \text{ s}$$

46. a. $P = EI = (120 \text{ V})(100 \text{ A}) = \mathbf{12 \text{ kW}}$

b. $P_T = 5 \cancel{\text{hp}} \left[\frac{746 \text{ W}}{\cancel{\text{hp}}} \right] + 3000 \text{ W} + 2400 \text{ W} + 1000 \text{ W}$

$$= 10,130 < 12,000 \text{ W } (\text{Yes})$$

c. $W = Pt = (10.13 \text{ kW})(2 \text{ h}) = \mathbf{20.26 \text{ kWh}}$

47. $\text{kWh} = \frac{(860 \text{ W})(6 \text{ h}) + (4800 \text{ W})(1/2 \text{ h}) + (900 \text{ W}) \left(20 \cancel{\text{min}} \left(\frac{1 \text{ h}}{60 \cancel{\text{min}}} \right) \right) + (110 \text{ W})(3.5 \text{ h})}{1000}$
 $= \frac{5160 \text{ Wh} + 2400 \text{ Wh} + 300 \text{ Wh} + 385 \text{ Wh}}{1000} = 8.245 \text{ kWh}$
 $(8.245 \text{ kWh})(9\text{¢}/\text{kWh}) = \mathbf{74.21\text{¢}}$

48. $\text{kWh} = \frac{(200 \text{ W})(4 \text{ h}) + (1200 \text{ W}) \left(20 \cancel{\text{min}} \left(\frac{1 \text{ h}}{60 \cancel{\text{min}}} \right) \right) + (70 \text{ W})(1.5 \text{ h}) + (150 \text{ W}) \left(130 \cancel{\text{min}} \left(\frac{1 \text{ h}}{60 \cancel{\text{min}}} \right) \right)}{1000}$
 $= \frac{800 \text{ Wh} + 400 \text{ Wh} + 105 \text{ Wh} + 325 \text{ Wh}}{1000} = \mathbf{1.63 \text{ kWh}}$
 $(1.63 \text{ kWh})(9\text{¢}/\text{kWh}) = \mathbf{14.67\text{¢}}$

49. $\eta = \frac{P_o}{P_i} \times 100\% = \frac{(0.5 \cancel{\text{hp}}) \left[\frac{746 \text{ W}}{\cancel{\text{hp}}} \right]}{395 \text{ W}} \times 100\% = \frac{373}{395} \times 100\% = 94.43\%$

50. $\eta = \frac{P_o}{P_i}, P_i = \frac{P_o}{\eta} = \frac{(1.8 \cancel{\text{hp}})(746 \text{ W}/\cancel{\text{hp}})}{0.685} = 1960.29 \text{ W}$

$$P_i = EI, I = \frac{P_i}{E} = \frac{1960.29 \text{ W}}{120 \text{ V}} = \mathbf{16.34 \text{ A}}$$

51. $\eta = \frac{P_o}{P_i} \times 100\% = \frac{746 \text{ W}}{(4 \text{ A})(220 \text{ V})} \times 100\% = \frac{746}{880} \times 100\% = \mathbf{84.77\%}$

52. a. $P_i = EI = (120 \text{ V})(2.4 \text{ A}) = 288 \text{ W}$
 $P_i = P_o + P_{\text{lost}}, P_{\text{lost}} = P_i - P_o = 288 \text{ W} - 50 \text{ W} = \mathbf{238 \text{ W}}$

b. $\eta\% = \frac{P_o}{P_i} \times 100\% = \frac{50 \text{ W}}{288 \text{ W}} \times 100\% = \mathbf{17.36\%}$

53. $P_i = EI = \frac{P_o}{\eta} \Rightarrow I = \frac{P_o}{\eta E} = \frac{(3.6 \cancel{\text{hp}})(746 \text{ W}/\cancel{\text{hp}})}{(0.76)(220 \text{ V})} = \mathbf{16.06 \text{ A}}$

54. a. $P_i = \frac{P_o}{\eta} = \frac{(2 \cancel{\text{hp}})(746 \text{ W}/\cancel{\text{hp}})}{0.9} = \mathbf{1657.78 \text{ W}}$

b. $P_i = EI = 1657.78 \text{ W}$
 $(110 \text{ V})I = 1657.78 \text{ W}$
 $I = \frac{1657.78 \text{ W}}{110 \text{ V}} = \mathbf{15.07 \text{ A}}$

c. $P_i = \frac{P_o}{\eta} = \frac{(2 \cancel{\text{hp}})(746 \text{ W}/\cancel{\text{hp}})}{0.7} = 2131.43 \text{ W}$

$P_i = EI = 2131.43 \text{ W}$
 $(110 \text{ V})I = 2131.43 \text{ W}$

$$I = \frac{2131.43 \text{ W}}{110 \text{ V}} = \mathbf{19.38 \text{ A}}$$

55. $P_i = \frac{P_o}{\eta} = \frac{(15 \cancel{\text{hp}})(746 \text{ W}/\cancel{\text{hp}})}{0.9} = 12,433.33 \text{ W}$

$$I = \frac{P_i}{E} = \frac{12,433.33 \text{ W}}{220 \text{ V}} = \mathbf{56.52 \text{ A}}$$

56. $\eta_T = \eta_1 \cdot \eta_2$
 $0.75 = 0.85 \times \eta_2$
 $\eta_2 = \mathbf{0.88}$

57. $\eta_T = \eta_1 \cdot \eta_2 = (0.87)(0.75) = 0.6525 \Rightarrow \mathbf{65.25\%}$

58. $\eta_1 = \eta_2 = .08$
 $\eta_T = (\eta_1)(\eta_2) = (0.8)(0.8) = 0.64$
 $\eta_T = \frac{W_o}{W_i} \Rightarrow W_o = \eta_T W_i = (0.64)(60 \text{ J}) = \mathbf{38.4 \text{ J}}$

59. $\eta_T = \eta_1 \cdot \eta_2 = 0.72 = 0.9 \eta_2$
 $\eta_2 = \frac{0.72}{0.9} = 0.8 \Rightarrow \mathbf{80\%}$

60. a. $\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 = (0.98)(0.87)(0.21) = 0.1790 \Rightarrow \mathbf{17.9\%}$

b. $\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 = (0.98)(0.87)(0.90) = 0.7673 \Rightarrow \mathbf{76.73\%}$
$$\frac{76.73\% - 17.9\%}{17.9\%} \times 100\% = \mathbf{328.66\%}$$

61. $\eta_T = \frac{P_o}{P_i} = \eta_1 \cdot \eta_2 = \eta_1 \cdot 2\eta_1 = 2\eta_1^2$
$$\eta_1^2 = \frac{P_o}{2P_i} \Rightarrow \eta_1 = \sqrt{\frac{P_o}{2P_i}} = \sqrt{\frac{128 \text{ W}}{2(400 \text{ W})}} = 0.4$$

$$\eta_2 = 2\eta_1 = 2(0.4) = 0.8$$

$$\therefore \eta_2 = \mathbf{40\%, \eta_2 = 80\%}$$

Chapter 5

1. a. E and R_1
b. R_1 and R_2
c. E and R_1
d. E and R_1, R_3 and R_4

2. a. $R_T = 0.1 \text{ k}\Omega + 0.39 \text{ k}\Omega + 1.2 \text{ k}\Omega = \mathbf{1.69 \text{ k}\Omega}$
b. $R_T = 1.2 \Omega + 2.7 \Omega + 8.2 \Omega = \mathbf{12.1 \Omega}$
c. $R_T = 8.2 \text{ k}\Omega + 10 \text{ k}\Omega + 9.1 \text{ k}\Omega + 1.8 \text{ k}\Omega + 2.7 \text{ k}\Omega = \mathbf{31.8 \text{ k}\Omega}$
d. $R_T = 47 \Omega + 820 \Omega + 91 \Omega + 1.2 \text{ k}\Omega = \mathbf{2158.0 \Omega}$

3. a. $R_T = 1.2 \text{ k}\Omega + 1 \text{ k}\Omega + 2.2 \text{ k}\Omega + 3.3 \text{ k}\Omega = \mathbf{7.7 \text{ k}\Omega}$
b. $R_T = 1 \text{ k}\Omega + 2 \text{ k}\Omega + 3 \text{ k}\Omega + 4.7 \text{ k}\Omega + 6.8 \text{ k}\Omega = \mathbf{17.5 \text{ k}\Omega}$

4. a. **1 MΩ**
b. **100 Ω, 1 kΩ**
c. $R_T = 100 \Omega + 1 \text{ k}\Omega + 1 \text{ M}\Omega + 200 \text{ k}\Omega = \mathbf{1.2011 \text{ M}\Omega}$ vs. **1.2 MΩ** for part b.

5. a. $R_T = 105 \Omega = 10 \Omega + 33 \Omega + R, \quad R = \mathbf{62 \Omega}$
b. $R_T = 10 \text{ k}\Omega = 2.2 \text{ k}\Omega + R + 2.7 \text{ k}\Omega + 3.3 \text{ k}\Omega, \quad R = \mathbf{1.8 \text{ k}\Omega}$
c. $R_T = 138 \text{ k}\Omega = R + 56 \text{ k}\Omega + 22 \text{ k}\Omega + 33 \text{ k}\Omega, \quad R = \mathbf{27 \text{ k}\Omega}$
d. $R_T = 91 \text{ k}\Omega = 24 \text{ k}\Omega + R_1 + 43 \text{ k}\Omega + 2R_1 = 67 \text{ k}\Omega + 3R_1, \quad R_1 = \mathbf{8 \text{ k}\Omega}$
 $R_2 = \mathbf{16 \text{ k}\Omega}$

6. a. **1.2 kΩ**
b. $3.3 \text{ k}\Omega + 4.3 \text{ k}\Omega = \mathbf{7.6 \text{ k}\Omega}$
c. **0 Ω**
d. **∞ Ω**

7. a. $R_T = 10 \Omega + 12 \Omega + 18 \Omega = \mathbf{40 \Omega}$
b. $I_s = \frac{E}{R_T} = \frac{120 \text{ V}}{40 \Omega} = \mathbf{3 \text{ A}}$
c. $V_1 = I_1 R_1 = (3 \text{ A})(10 \Omega) = \mathbf{30 \text{ V}}, \quad V_2 = I_2 R_2 = (3 \text{ A})(12 \Omega) = \mathbf{36 \text{ V}},$
 $V_3 = I_3 R_3 = (3 \text{ A})(18 \Omega) = \mathbf{54 \text{ V}}$

8. a. the most: R_3 , the least: R_1
b. $R_3, R_T = 1.2 \text{ k}\Omega + 6.8 \text{ k}\Omega + 82 \text{ k}\Omega = \mathbf{90 \text{ k}\Omega}$
 $I_s = \frac{E}{R_T} = \frac{45 \text{ V}}{90 \text{ k}\Omega} = \mathbf{0.5 \text{ mA}}$
c. $V_1 = I_1 R_1 = (0.5 \text{ mA})(1.2 \text{ k}\Omega) = \mathbf{0.6 \text{ V}}, \quad V_2 = I_2 R_2 = (0.5 \text{ mA})(6.8 \text{ k}\Omega) = \mathbf{3.4 \text{ V}},$
 $V_3 = I_3 R_3 = (0.5 \text{ mA})(82 \text{ k}\Omega) = \mathbf{41 \text{ V}}$, results agree with part (a)

9. a. $R_T = 12 \text{ k}\Omega + 4 \text{ k}\Omega + 6 \text{ k}\Omega = 22 \text{ k}\Omega$
 $E = IR_T = (4 \text{ mA})(22 \text{ k}\Omega) = \mathbf{88 \text{ V}}$
b. $R_T = 18 \Omega + 14 \Omega + 8 \Omega + 40 \Omega = 80 \Omega$
 $E = IR_T = (250 \text{ mA})(80 \Omega) = \mathbf{20 \text{ V}}$

10. a. $I = \frac{V}{R} = \frac{5.2 \text{ V}}{1.3 \Omega} = 4 \text{ A}$
 b. $E = IR_T = (4 \text{ A})(9 \Omega) = 36 \text{ V}$
 c. $R_T = 9 \Omega = 4.7 \Omega + 1.3 \Omega + R, R = 3 \Omega$
 d. $V_{4.7 \Omega} = (4 \text{ A})(4.7 \Omega) = 18.8 \text{ V}$
 $V_{1.3 \Omega} = (4 \text{ A})(1.3 \Omega) = 5.2 \text{ V}$
 $V_3 \Omega = (4 \text{ A})(3 \Omega) = 12 \text{ V}$

- b. a. $I = \frac{V}{R} = \frac{6.6 \text{ V}}{2.2 \text{ k}\Omega} = 3 \text{ mA}$
 b. $V_{3.3 \text{ k}\Omega} = (3 \text{ mA})(3.3 \text{ k}\Omega) = 9.9 \text{ V}$
 $E = 6.6 \text{ V} + 9 \text{ V} + 9.9 \text{ V} = 25.5 \text{ V}$
 c. $R = \frac{V}{I} = \frac{9 \text{ V}}{3 \text{ mA}} = 3 \text{ k}\Omega$
 d. $V_{2.2 \text{ k}\Omega} = 6.6 \text{ V}, V_{3 \text{ k}\Omega} = 9 \text{ V}, V_{3.3 \text{ k}\Omega} = 9.9 \text{ V}$

11. a. $I = \frac{E}{R_T} = \frac{36 \text{ V}}{4.4 \text{ k}\Omega} = 8.18 \text{ mA}, V = \frac{1}{2}E = \frac{1}{2}(36 \text{ V}) = 18 \text{ V}$

- b. $R_T = 1 \text{ k}\Omega + 2.4 \text{ k}\Omega + 5.6 \text{ k}\Omega = 9 \text{ k}\Omega$
 $I = \frac{E}{R_T} = \frac{22.5 \text{ V}}{9 \text{ k}\Omega} = 2.5 \text{ mA}, V = 2.5 \text{ mA}(2.4 \text{ k}\Omega + 5.6 \text{ k}\Omega) = 20 \text{ V}$
 c. $R_T = 10 \text{ k}\Omega + 22 \text{ k}\Omega + 33 \text{ k}\Omega + 10 \text{ M}\Omega = 10.065 \text{ M}\Omega$
 $I = \frac{E}{R_T} = \frac{100 \text{ V}}{10.065 \text{ M}\Omega} = 9.94 \mu\text{A}$
 $V = (9.935 \mu\text{A})(10 \text{ M}\Omega) = 99.35 \text{ V}$

12. a. $R_T = 3 \text{ k}\Omega + 1 \text{ k}\Omega + 2 \text{ k}\Omega = 6 \text{ k}\Omega$
 $I_s = \frac{E}{R_T} = \frac{120 \text{ V}}{6 \text{ k}\Omega} = 20 \text{ mA}$
 $V_{R_1} = (20 \text{ mA})(3 \text{ k}\Omega) = 60 \text{ V}$
 $V_{R_2} = (20 \text{ mA})(1 \text{ k}\Omega) = 20 \text{ V}$
 $V_{R_3} = (20 \text{ mA})(2 \text{ k}\Omega) = 40 \text{ V}$

- b. $P_{R_1} = I_1^2 R_1 = (20 \text{ mA})^2 \cdot 3 \text{ k}\Omega = 1.2 \text{ W}$
 $P_{R_2} = I_2^2 R_2 = (20 \text{ mA})^2 \cdot 1 \text{ k}\Omega = 0.4 \text{ W}$
 $P_{R_3} = I_3^2 R_3 = (20 \text{ mA})^2 \cdot 2 \text{ k}\Omega = 0.8 \text{ W}$
 c. $P_T = P_{R_1} + P_{R_2} + P_{R_3} = 1.2 \text{ W} + 0.4 \text{ W} + 0.8 \text{ W} = 2.4 \text{ W}$
 d. $P_T = EI_s = (120 \text{ V})(20 \text{ mA}) = 2.4 \text{ W}$

- e. the same
- f. R_1 – the largest
- g. dissipated
- h. $R_1: 2 \text{ W}, R_2: 1/2 \text{ W}, R_3: 1 \text{ W}$
13. a. $R_T = 22 \Omega + 10 \Omega + 47 \Omega + 3 \Omega = \mathbf{82.0 \Omega}$
 $I_s = \frac{E}{R_T} = \frac{20.5 \text{ V}}{82.0 \Omega} = \mathbf{250 \text{ mA}}$
- $$V_{R_1} = I_1 R_1 = (250 \text{ mA})(22 \Omega) = \mathbf{5.50 \text{ V}}$$
- $$V_{R_2} = I_2 R_2 = (250 \text{ mA})(10 \Omega) = \mathbf{2.50 \text{ V}}$$
- $$V_{R_3} = I_3 R_3 = (250 \text{ mA})(47 \Omega) = \mathbf{11.75 \text{ V}}$$
- $$V_{R_4} = I_4 R_4 = (250 \text{ mA})(3 \Omega) = \mathbf{0.75 \text{ V}}$$
- b. $P_{R_1} = I_1^2 R_1 = (250 \text{ mA})^2 \cdot 22 \Omega = \mathbf{1.38 \text{ W}}$
 $P_{R_2} = I_2^2 R_2 = (250 \text{ mA})^2 \cdot 10 \Omega = \mathbf{625.00 \text{ mW}}$
 $P_{R_3} = I_3^2 R_3 = (250 \text{ mA})^2 \cdot 47 \Omega = \mathbf{2.94 \text{ W}}$
 $P_{R_4} = I_4^2 R_4 = (250 \text{ mA})^2 \cdot 3 \Omega = \mathbf{187.50 \text{ mW}}$
- c. $P_T = P_{R_1} + P_{R_2} + P_{R_3} + P_{R_4} = 1.38 \text{ W} + 625.00 \text{ mW} + 2.94 \text{ W} + 187.50 \text{ mW} = \mathbf{5.13 \text{ W}}$
- d. $P = EI_s = (20.5 \text{ V})(250 \text{ mA}) = \mathbf{5.13 \text{ W}}$
- e. the same
- f. 47Ω – the largest
- g. dissipated
- h. $R_1: 2 \text{ W}; R_2: 1/2 \text{ W}, R_3: 5 \text{ W}, R_4: 1/2 \text{ W}$
14. a. $P = 21 \text{ W} = (1 \text{ A})^2 \cdot R, \quad R = \mathbf{21 \Omega}$
 $V_1 = I_1 R_1 = (1 \text{ A})(2 \Omega) = \mathbf{2 \text{ V}}, \quad V_2 = I_2 R_2 = (1 \text{ A})(1 \Omega) = \mathbf{1 \text{ V}}$
 $V_3 = I_3 R_3 = (1 \text{ A})(21 \Omega) = \mathbf{21 \text{ V}}$
 $E = V_1 + V_2 + V_3 = 2 \text{ V} + 1 \text{ V} + 21 \text{ V} = \mathbf{24 \text{ V}}$
- b. $P = 4 \text{ W} = I^2 \cdot R, \quad I = \sqrt{4} = \mathbf{2 \text{ A}}$
 $P = 8 \text{ W} = I^2 R_1 = (2 \text{ A})^2 R_1, \quad R_1 = \mathbf{2 \Omega}$
 $R_T = 16 \Omega = 2 \Omega + R_2 + 1 \Omega = 3 \Omega + R_2, \quad R_2 = \mathbf{13 \Omega}$
 $E = IR_T = (2 \text{ A})(16 \Omega) = \mathbf{32 \text{ V}}$

15. a. $R_T = NR_1 = 8 \left(28 \frac{1}{8} \Omega \right) = 225 \Omega$

$$I = \frac{E}{R_T} = \frac{120 \text{ V}}{225 \Omega} = 0.53 \text{ A}$$

b. $P = I^2 R = \left(\frac{8}{15} \text{ A} \right)^2 \left(28 \frac{1}{8} \Omega \right) = \left(\frac{64}{225} \right) \left(\frac{225}{8} \right) = 8 \text{ W}$

c. $V = IR = \left(\frac{8}{15} \text{ A} \right) \left(\frac{225}{8} \Omega \right) = 15 \text{ V}$

d. All go out!

16. $P_s = P_{R_1} + P_{R_2} + P_{R_3}$

$$E \cdot I = I^2 R_1 + I^2 R_2 + 24$$

$$(R_1 + R_2)I^2 - E \cdot I + 24 = 0$$

$$6I^2 - 24I + 24 = 0$$

$$I^2 - 4I + 4 = 0$$

$$I = \frac{-(-4) \pm \sqrt{(-4)^2 - 4(1)(4)}}{2(1)} = \frac{4 \pm \sqrt{16 - 16}}{2} = \frac{4}{2} = 2 \text{ A}$$

$$P = 24 \text{ W} = (2 \text{ A})^2 R, \quad R = \frac{24 \Omega}{4} = 6 \Omega$$

17. a. $V_{ab} = -4 \text{ V} - 8 \text{ V} + 12 \text{ V} = 0 \text{ V}$

b. $V_{ab} = -4 \text{ V} - 8 \text{ V} + 6 \text{ V} = -6 \text{ V}$

c. $V_{ab} = -10 \text{ V} + 18 \text{ V} - 6 \text{ V} + 12 \text{ V} = 14 \text{ V}$

18. a. $E_T = 16 \text{ V} - 4 \text{ V} - 8 \text{ V} = 4 \text{ V}, I = \frac{4 \text{ V}}{10.3 \Omega} = 388.35 \text{ mA (CCW)}$

b. $E_T = 18 \text{ V} - 12 \text{ V} - 4 \text{ V} = 2 \text{ V}, I = \frac{2 \text{ V}}{11.5 \Omega} = 173.91 \text{ mA (CW)}$

19. a. $P = 8 \text{ mW} = I^2 R, \quad R = \frac{8 \text{ mW}}{I^2} = \frac{8 \text{ mW}}{(2 \text{ mA})^2} = 2 \text{ k}\Omega$

$$I = \frac{E}{R_T} = \frac{20 \text{ V} - E}{3 \text{ k}\Omega + 2 \text{ k}\Omega} = 2 \text{ mA (CW)}, \quad E = 10 \text{ V}$$

b. $I = \frac{16 \text{ V}}{2 \text{ k}\Omega} = 8 \text{ mA}, R = \frac{V}{I} = \frac{12 \text{ V}}{8 \text{ mA}} = 1.5 \text{ k}\Omega$

$$I = \frac{E}{R_T} = \frac{E - 4 \text{ V} - 10 \text{ V}}{2 \text{ k}\Omega + 1.5 \text{ k}\Omega} = \frac{E - 14 \text{ V}}{3.5 \text{ k}\Omega} = 8 \text{ mA (CCW)}$$

$$E = 42 \text{ V}$$

20. a. $+10\text{ V} + 4\text{ V} - 3\text{ V} - V = 0$
 $V = 14\text{ V} - 3\text{ V} = \mathbf{11\text{ V}}$
- b. $+30\text{ V} + 20\text{ V} - 8\text{ V} - V = 0$
 $V = 50\text{ V} - 8\text{ V} = \mathbf{42\text{ V}}$
- c. $+16\text{ V} - 10\text{ V} - 4\text{ V} - V + 60\text{ V} = 0$
 $V = 76\text{ V} - 14\text{ V} = \mathbf{62\text{ V}}$
21. a. $+60\text{ V} - 12\text{ V} - V - 20\text{ V} = 0$
 $V = 60\text{ V} - 32\text{ V} = \mathbf{28\text{ V}}$
- b. $+E - 14\text{ V} - 6\text{ V} - 2\text{ V} + 18\text{ V} = 0$
 $E = 22\text{ V} - 18\text{ V} = \mathbf{4\text{ V}}$
22. a. $+10\text{ V} - V_2 = 0$
 $V_2 = \mathbf{10\text{ V}}$
 $+10\text{ V} - 6\text{ V} - V_1 = 0$
 $V_1 = \mathbf{4\text{ V}}$
- b. $+24\text{ V} - 10\text{ V} - V_1 = 0$
 $V_1 = \mathbf{14\text{ V}}$
 $+10\text{ V} - V_2 + 8\text{ V} = 0$
 $V_2 = \mathbf{18\text{ V}}$
23. a. $+20\text{ V} - V_1 - 10\text{ V} - 1\text{ V} = 0, V_1 = \mathbf{9\text{ V}}$
 $+10\text{ V} - 2\text{ V} - V_2 = 0, V_2 = \mathbf{8\text{ V}}$
- b. $+10\text{ V} - V_1 + 6\text{ V} - 2\text{ V} - 3\text{ V} = 0, V_1 = \mathbf{11\text{ V}}$
 $+10\text{ V} - V_2 - 3\text{ V} = 0, V_2 = \mathbf{7\text{ V}}$
24. $\frac{1\text{ V}}{2\Omega} = \frac{50\text{ V}}{R_2}, R_2 = \frac{(50\text{ V})(2\Omega)}{1\text{ V}} = \mathbf{100\Omega}$
 $\frac{1\text{ V}}{2\Omega} = \frac{100\text{ V}}{R_3}, R_3 = \frac{(100\text{ V})(2\Omega)}{1\text{ V}} = \mathbf{200\Omega}$
25. a. **8.2 kΩ**
b. $V_3: V_2 = 8.2\text{ k}\Omega : 1\text{ k}\Omega = \mathbf{8.2:1}$
 $V_3: V_1 = 8.2\text{ k}\Omega : 100\Omega = \mathbf{82:1}$
c. $V_3 = \frac{R_3 E}{R_T} = \frac{(8.2\text{ k}\Omega)(60\text{ V})}{0.1\text{ k}\Omega + 1\text{ k}\Omega + 8.2\text{ k}\Omega} = \mathbf{52.90\text{ V}}$
d. $V' = \frac{(R_2 + R_3)E}{R_T} = \frac{(1\text{ k}\Omega + 8.2\text{ k}\Omega)(60\text{ V})}{9.3\text{ k}\Omega} = \mathbf{59.35\text{ V}}$

26. a. $V = \frac{40 \Omega(30 \text{ V})}{40 \Omega + 20 \Omega} = 20 \text{ V}$

b. $V = \frac{(2 \text{ k}\Omega + 3 \text{ k}\Omega)(40 \text{ V})}{4 \text{ k}\Omega + 1 \text{ k}\Omega + 2 \text{ k}\Omega + 3 \text{ k}\Omega} = \frac{(5 \text{ k}\Omega)(40 \text{ V})}{10 \text{ k}\Omega} = 20 \text{ V}$

c. $\frac{(1.5 \Omega + 0.6 \Omega + 0.9 \Omega)(0.72 \text{ V})}{(2.5 \Omega + 1.5 \Omega + 0.6 \Omega + 0.9 \Omega + 0.5 \Omega)} = \frac{(3 \Omega)(0.72 \text{ V})}{6 \text{ k}\Omega} = 0.36 \text{ V}$

27. a. $\frac{V_1}{6 \Omega} = \frac{20 \text{ V}}{2 \Omega}, V_1 = \frac{(6 \Omega)(20 \text{ V})}{2 \Omega} = 60 \text{ V}$

$\frac{V_2}{4 \Omega} = \frac{20 \text{ V}}{2 \Omega}, V_2 = \frac{(4 \Omega)(20 \text{ V})}{2 \Omega} = 40 \text{ V}$

$$E = V_1 + 20 \text{ V} + V_2 = 60 \text{ V} + 20 \text{ V} + 40 \text{ V} = 120 \text{ V}$$

b. $120 \text{ V} - V_1 - 80 \text{ V} = 0, V_1 = 40 \text{ V}$
 $80 \text{ V} - 10 \text{ V} - V_3 = 0, V_3 = 70 \text{ V}$

c. $\frac{1000 \text{ V}}{100 \Omega} = \frac{V_2}{2 \Omega}, V_2 = \frac{2 \Omega(1000 \text{ V})}{100 \Omega} = 20 \text{ V}$

$\frac{1000 \text{ V}}{100 \Omega} = \frac{V_1}{1 \Omega}, V_1 = \frac{1 \Omega(1000 \text{ V})}{100 \Omega} = 10 \text{ V}$

$$E = V_1 + V_2 + 1000 \text{ V} = 10 \text{ V} + 20 \text{ V} + 1000 \text{ V} = 1030 \text{ V}$$

d. $16 \text{ V} - V_1 - 6 \text{ V} = 0, V_1 = 10 \text{ V}$

$$V_2 = \frac{6 \text{ V}}{2} = 3 \text{ V}$$

28. $\frac{2 \text{ V}}{1 \text{ k}\Omega} = \frac{V_2}{2 \text{ k}\Omega}, V_2 = \frac{2 \text{ k}\Omega(2 \text{ V})}{1 \text{ k}\Omega} = 4 \text{ V}$

$$\frac{2 \text{ V}}{1 \text{ k}\Omega} = \frac{V_4}{3 \text{ k}\Omega}, V_4 = \frac{3 \text{ k}\Omega(2 \text{ V})}{1 \text{ k}\Omega} = 6 \text{ V}$$

$$I = \frac{2 \text{ V}}{1 \text{ k}\Omega} = 2 \text{ mA}$$

$$E = 2 \text{ V} + 4 \text{ V} + 12 \text{ V} + 6 \text{ V} = 24 \text{ V}$$

29. a. $4 \text{ V} = \frac{R(20 \text{ V})}{2 \text{ k}\Omega + 6 \text{ k}\Omega}, \quad R = 1.6 \text{ k}\Omega$

b. $100 \text{ V} = \frac{(6 \text{ }\Omega + R)140 \text{ V}}{3 \text{ }\Omega + 6 \text{ }\Omega + R}$
 $300 \text{ }\Omega + 600 \text{ }\Omega + 100R = 840 \text{ }\Omega + 140 \text{ R}$
 $140R - 100R = -840 \text{ }\Omega + 900 \text{ }\Omega$
 $40R = 60 \text{ }\Omega$
 $R = \frac{60 \text{ }\Omega}{40} = 1.5 \text{ }\Omega$

30. a. $\frac{4 \text{ V}}{10 \text{ }\Omega} = \frac{V_2}{20 \text{ }\Omega} \Rightarrow V_2 = \frac{20 \text{ }\Omega(4 \text{ V})}{10 \text{ }\Omega} = 8 \text{ V}$

b. $V_3 = E - V_1 - V_2 = 40 \text{ V} - 4 \text{ V} - 8 \text{ V} = 28 \text{ V}$

c. $\frac{4 \text{ V}}{10 \text{ }\Omega} = \frac{28 \text{ V}}{R_3} \Rightarrow R_3 = \frac{(28 \text{ V})(10 \text{ }\Omega)}{4 \text{ V}} = 70 \text{ }\Omega$

31. a. $R_{\text{bulb}} = \frac{8 \text{ V}}{50 \text{ mA}} = 160 \text{ }\Omega$
 $V_{\text{bulb}} = 8 \text{ V} = \frac{R_{\text{bulb}}(12 \text{ V})}{R_{\text{bulb}} + R_x} = \frac{160 \text{ }\Omega(12 \text{ V})}{160 \text{ }\Omega + R_x}, R_x = 80 \text{ }\Omega \text{ in series with the bulb}$

b. $V_R = 12 \text{ V} - 8 \text{ V} = 4 \text{ V}, P = \frac{V^2}{R} = \frac{(4 \text{ V})^2}{80 \text{ }\Omega} = 0.2 \text{ W}, \therefore 1/4 \text{ W okay}$

32. $V_{R_1} + V_{R_2} = 72 \text{ V}$
 $\frac{1}{5}V_{R_2} + V_{R_2} = 72 \text{ V}$
 $V_{R_2} \left[1 + \frac{1}{5} \right] = 72 \text{ V}, V_{R_2} = \frac{72 \text{ V}}{1.2} = 60 \text{ V}$
 $R_2 = \frac{V_{R_2}}{I_{R_2}} = \frac{60 \text{ V}}{4 \text{ mA}} = 15 \text{ k}\Omega, R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{72 \text{ V} - 60 \text{ V}}{4 \text{ mA}} = \frac{12 \text{ V}}{4 \text{ mA}} = 3 \text{ k}\Omega$

33. $R_T = R_1 + R_2 + R_3 = 2R_3 + 7R_3 + R_3 = 10R_3$
 $V_{R_3} = \frac{R_3(60 \text{ V})}{10R_3} = 6 \text{ V}, V_{R_1} = 2V_{R_3} = 2(6 \text{ V}) = 12 \text{ V}, V_{R_2} = 7V_{R_3} = 7(6 \text{ V}) = 42 \text{ V}$

34. a. $V_{R_3} = 4V_{R_2} = 4(3V_{R_1}) = 12V_{R_1}$
 $E = V_{R_1} + 3V_{R_1} + 12V_{R_1} \therefore R_T = R_1 + 3R_1 + 12R_1 = 16R_1 = \frac{64 \text{ V}}{10 \text{ mA}} = 6.4 \text{ k}\Omega$
 $R_1 = \frac{6.4 \text{ k}\Omega}{16} = 400 \text{ }\Omega, R_2 = 3R_1 = 1.2 \text{ k}\Omega, R_3 = 12R_1 = 4.8 \text{ k}\Omega$

b. $R_T = \frac{64 \text{ V}}{10 \mu\text{A}} = 6.4 \text{ M}\Omega$, $R_1 = \frac{6.4 \text{ M}\Omega}{16} = 400 \text{ k}\Omega$, $R_2 = 1.2 \text{ M}\Omega$, $R_3 = 4.8 \text{ M}\Omega$

$$\frac{I_1}{I'} = \frac{10 \text{ mA}}{10 \mu\text{A}} = 10^3 \text{ and } \frac{R'_1}{R_1} = \frac{400 \text{ k}\Omega}{400 \Omega} = 10^3 \text{ also}$$

35. a. $V_a = +12 \text{ V} - 8 \text{ V} = 4 \text{ V}$
 $V_b = -8 \text{ V}$
 $V_{ab} = V_a - V_b = 4 \text{ V} - (-8 \text{ V}) = 12 \text{ V}$

b. $V_a = 20 \text{ V} - 6 \text{ V} = 14 \text{ V}$
 $V_b = +4 \text{ V}$
 $V_{ab} = V_a - V_b = 14 \text{ V} - 4 \text{ V} = 10 \text{ V}$

c. $V_a = +10 \text{ V} + 3 \text{ V} = 13 \text{ V}$
 $V_b = +6 \text{ V}$
 $V_{ab} = V_a - V_b = 13 \text{ V} - 6 \text{ V} = 7 \text{ V}$

36. a. $I(\text{CW}) = \frac{80 \text{ V} - 26 \text{ V}}{6 \Omega + 3 \Omega} = \frac{54 \text{ V}}{9 \Omega} = 6 \text{ A}$
 $V = IR = (6 \text{ A})(3 \Omega) = 18 \text{ V}$

b. $I(\text{CW}) = \frac{70 \text{ V} - 10 \text{ V}}{10 \Omega + 20 \Omega + 30 \Omega} = \frac{60 \text{ V}}{60 \Omega} = 1 \text{ A}$
 $V = IR = (1 \text{ A})(10 \Omega) = 10 \text{ V}$

37. a. $I = \frac{16 \text{ V} - 4 \text{ V}}{10 \Omega + 20 \Omega} = \frac{12 \text{ V}}{30 \Omega} = 0.4 \text{ A (CW)}$
 $V_a = 16 \text{ V} - I(10 \Omega) = 16 \text{ V} - (0.4 \text{ A})(10 \Omega) = 16 \text{ V} - 4 \text{ V} = 12 \text{ V}$
 $V_1 = IR = (0.4 \text{ A})(20 \Omega) = 8 \text{ V}$

b. $I = \frac{12 \text{ V} + 10 \text{ V} + 8 \text{ V}}{2.2 \text{ k}\Omega + 3.3 \text{ k}\Omega} = \frac{30 \text{ V}}{5.5 \text{ k}\Omega} = 5.455 \text{ mA}$
 $V_a = 12 \text{ V} - I(2.2 \text{ k}\Omega) + 10 \text{ V}$
 $= 12 \text{ V} - (5.455 \text{ mA})(2.2 \text{ k}\Omega) + 10 \text{ V}$
 $= 12 \text{ V} - 12 \text{ V} + 10 \text{ V} = 10 \text{ V}$
 $V_1 = I(2.2 \text{ k}\Omega) = (5.455 \text{ mA})(2.2 \text{ k}\Omega) = 12 \text{ V}$

38. $I = \frac{47 \text{ V} - 20 \text{ V}}{2 \text{ k}\Omega + 3 \text{ k}\Omega + 4 \text{ k}\Omega} = \frac{27 \text{ V}}{9 \text{ k}\Omega} = 3 \text{ mA (CCW)}$
 $V_{2\text{k}\Omega} = 6 \text{ V}, V_{3\text{k}\Omega} = 9 \text{ V}, V_{4\text{k}\Omega} = 12 \text{ V}$

a. $V_a = 20 \text{ V}, V_b = 20 \text{ V} + 6 \text{ V} = 26 \text{ V}, V_c = 20 \text{ V} + 6 \text{ V} + 9 \text{ V} = 35 \text{ V}$
 $V_d = -12 \text{ V}, V_e = 0 \text{ V}$

b. $V_{ab} = -6 \text{ V}, V_{dc} = -47 \text{ V}, V_{cb} = 9 \text{ V}$

c. $V_{ac} = -15 \text{ V}, V_{db} = -47 \text{ V} + 9 \text{ V} = -38 \text{ V}$

39. $I_{R_2} = \frac{4 \text{ V} + 4 \text{ V}}{8 \Omega} = \frac{8 \text{ V}}{8 \Omega} = 1 \text{ A}$, $R_1 = \frac{V_{R_1}}{I} = \frac{12 \text{ V} - 4 \text{ V}}{1 \text{ A}} = \frac{8 \text{ V}}{1 \text{ A}} = 8 \Omega$,

 $R_3 = \frac{V_{R_3}}{I} = \frac{8 \text{ V} - 4 \text{ V}}{1 \text{ A}} = \frac{4 \text{ V}}{1 \text{ A}} = 4 \Omega$

40. $V_{R_2} = 48 \text{ V} - 12 \text{ V} = 36 \text{ V}$
 $R_2 = \frac{V_{R_2}}{I} = \frac{36 \text{ V}}{16 \text{ mA}} = 2.25 \text{ k}\Omega$
 $V_{R_3} = 12 \text{ V} - 0 \text{ V} = 12 \text{ V}$
 $R_3 = \frac{V_{R_3}}{I} = \frac{12 \text{ V}}{16 \text{ mA}} = 0.75 \text{ k}\Omega$
 $V_{R_4} = 20 \text{ V}$
 $R_4 = \frac{V_{R_4}}{I} = \frac{20 \text{ V}}{16 \text{ mA}} = 1.25 \text{ k}\Omega$
 $V_{R_1} = E - V_{R_2} - V_{R_3} - V_{R_4}$
 $= 100 \text{ V} - 36 \text{ V} - 12 \text{ V} - 20 \text{ V} = 32 \text{ V}$
 $R_1 = \frac{V_{R_1}}{I} = \frac{32 \text{ V}}{16 \text{ mA}} = 2 \text{ k}\Omega$

41. $I = \frac{44 \text{ V} - 20 \text{ V}}{2 \text{ k}\Omega + 4 \text{ k}\Omega + 6 \text{ k}\Omega} = \frac{24 \text{ V}}{12 \text{ k}\Omega} = 2 \text{ mA (CW)}$
 $V_{2\text{k}\Omega} = IR = (2 \text{ mA})(2 \text{ k}\Omega) = 4 \text{ V}$
 $V_{4\text{k}\Omega} = IR = (2 \text{ mA})(4 \text{ k}\Omega) = 8 \text{ V}$
 $V_{6\text{k}\Omega} = IR = (2 \text{ mA})(6 \text{ k}\Omega) = 12 \text{ V}$

- a. $V_a = 44 \text{ V}$, $V_b = 44 \text{ V} - 4 \text{ V} = 40 \text{ V}$, $V_c = 44 \text{ V} - 4 \text{ V} - 8 \text{ V} = 32 \text{ V}$
 $V_d = 20 \text{ V}$
- b. $V_{ab} = V_{2\text{k}\Omega} = 4 \text{ V}$, $V_{cb} = -V_{4\text{k}\Omega} = -8 \text{ V}$
 $V_{cd} = V_{6\text{k}\Omega} = 12 \text{ V}$
- c. $V_{ad} = V_a - V_d = 44 \text{ V} - 20 \text{ V} = 24 \text{ V}$
 $V_{ca} = V_c - V_a = 32 \text{ V} - 44 \text{ V} = -12 \text{ V}$

42. $V_0 = 0 \text{ V}$
 $V_4 = -12 \text{ V} + 2 \text{ V} = 0$, $V_4 = +10 \text{ V}$
 $V_7 = 4 \text{ V}$
 $V_{10} = 20 \text{ V}$
 $V_{23} = +6 \text{ V}$
 $V_{30} = -8 \text{ V}$
 $V_{67} = 0 \text{ V}$
 $V_{56} = -6 \text{ V}$
 $I = \frac{V_4}{4 \Omega} = \frac{V_{23}}{4 \Omega} = \frac{6 \text{ V}}{4 \Omega} = 1.5 \text{ A} \uparrow$

43. $V_0 = \mathbf{0} \text{ V}$, $V_{03} = V_0 - V_3 = \mathbf{0} \text{ V}$, $V_2 = (2 \text{ mA})(3 \text{ k}\Omega + 1 \text{ k}\Omega) = (2 \text{ mA})(4 \text{ k}\Omega) = \mathbf{8 \text{ V}}$
 $V_{23} = V_2 - V_3 = 8 \text{ V} - 0 \text{ V} = \mathbf{8 \text{ V}}$, $V_{12} = 20 \text{ V} - 8 \text{ V} = \mathbf{12 \text{ V}}$,
 $\Sigma I_i = \Sigma I_o \Rightarrow I_i = 2 \text{ mA} + 5 \text{ mA} + 10 \text{ mA} = \mathbf{17 \text{ mA}}$

44. a. $V_L = I_L R_L = (2 \text{ A})(28 \text{ }\Omega) = 56 \text{ V}$
 $V_{\text{int}} = 60 \text{ V} - 56 \text{ V} = 4 \text{ V}$
 $R_{\text{int}} = \frac{V_{\text{int}}}{I} = \frac{4 \text{ V}}{2 \text{ A}} = \mathbf{2 \Omega}$

b. $VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{60 \text{ V} - 56 \text{ V}}{56 \text{ V}} \times 100\% = \mathbf{7.14\%}$

45. a. $V_L = \frac{3.3 \Omega(12 \text{ V})}{3.3 \Omega + 0.05 \Omega} = \mathbf{11.82 \text{ V}}$

b. $VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{12 \text{ V} - 11.82 \text{ V}}{11.82 \text{ V}} \times 100\% = \mathbf{1.52\%}$

c. $I_s = I_L = \frac{11.82 \text{ V}}{3.3 \Omega} = 3.58 \text{ A}$
 $P_s = EI_s = (12 \text{ V})(3.58 \text{ A}) = \mathbf{42.96 \text{ W}}$
 $P_{\text{int}} = I^2 R_{\text{int}} = (3.58 \text{ A})^2 0.05 \Omega = \mathbf{0.64 \text{ W}}$

46. a. $I = \frac{E}{R_T} = \frac{12 \text{ V}}{2 \text{ k}\Omega + 8 \text{ k}\Omega} = \frac{12 \text{ V}}{10 \text{ k}\Omega} = \mathbf{1.2 \text{ mA}}$

b. $I = \frac{E}{R_T} = \frac{12 \text{ V}}{10 \text{ k}\Omega + 0.25 \text{ k}\Omega} = \frac{12 \text{ V}}{10.25 \text{ k}\Omega} = \mathbf{1.17 \text{ mA}}$

c. not for most applications.

Chapter 6

1. a. R_2 and R_3
b. E and R_3
c. E and R_1
d. R_2 , R_3 and R_4
e. E , R_1 , R_2 , R_3 , and R_4
f. E , R_1 , R_2 , and R_3
g. R_2 and R_3
2. a. R_3 and R_4 , R_5 and R_6
b. E and R_1
3. a. $R_T = \frac{(9.1\Omega)(18\Omega)}{9.1\Omega + 18\Omega} = \mathbf{6.04\Omega}$
- b.
$$R_T = \frac{1}{\frac{1}{1k\Omega} + \frac{1}{2k\Omega} + \frac{1}{3k\Omega}} = \frac{1}{1 \times 10^{-3}S + 0.5 \times 10^{-3}S + 0.333 \times 10^{-3}S}$$
$$= \frac{1}{1.833 \times 10^{-3}S} = \mathbf{545.55\Omega}$$
- c.
$$R_T = \frac{1}{\frac{1}{100\Omega} + \frac{1}{1k\Omega} + \frac{1}{10k\Omega}} = \frac{1}{10 \times 10^{-3}S + 1 \times 10^{-3}S + 0.1 \times 10^{-3}S} = \frac{1}{11.1 \times 10^{-3}S}$$
$$= \mathbf{90.09\Omega}$$
- d. $R'_T = \frac{18k\Omega}{3} = 6k\Omega$
 $R_T = \frac{(6k\Omega)(6M\Omega)}{6k\Omega + 6M\Omega} = \mathbf{5.99\ k\Omega}$
- e. $R'_T = \frac{22\Omega}{4} = 5.5\ \Omega$, $R_{T''} = \frac{10\Omega}{2} = 5\ \Omega$
 $R_T = \frac{(5.5\Omega)(5\Omega)}{5.5\Omega + 5\Omega} = \mathbf{2.62\Omega}$
- f.
$$R_T = \frac{1}{\frac{1}{1\Omega} + \frac{1}{1k\Omega} + \frac{1}{1M\Omega}} = \frac{1}{1000 \times 10^{-3}S + 1 \times 10^{-3}S + 0.001 \times 10^{-3}S}$$
$$= \frac{1}{1001.001 \times 10^{-3}S} = \mathbf{0.99\Omega}$$
4. a. $R_T = \frac{1}{\frac{1}{1k\Omega} + \frac{1}{1.2k\Omega} + \frac{1}{0.3k\Omega}} = \frac{1}{1 \times 10^{-3}S + 0.833 \times 10^{-3}S + 3.333 \times 10^{-3}S}$
$$= \frac{1}{5.166 \times 10^{-3}S} = \mathbf{193.57\Omega}$$

b. $R_T = \frac{1}{\frac{1}{1\text{ k}\Omega} + \frac{1}{1.2\text{ k}\Omega} + \frac{1}{2.2\text{ k}\Omega} + \frac{1}{1\text{ k}\Omega}} = \frac{1}{1 \times 10^{-3}\text{ S} + 0.833 \times 10^{-3}\text{ S} + 0.455 \times 10^{-3}\text{ S} + 1 \times 10^{-3}\text{ S}}$
 $= \frac{1}{3.288 \times 10^{-3}\text{ S}} = \mathbf{304.14\text{ }\Omega}$

5. a. $R'_T = 3\text{ }\Omega \parallel 6\text{ }\Omega = 2\text{ }\Omega$

$$R_T = 1.6\text{ }\Omega = \frac{(2\text{ }\Omega)(R)}{2\text{ }\Omega + R}, \quad R = \mathbf{8\text{ }\Omega}$$

b. $R'_T = \frac{6\text{ k}\Omega}{3} = 2\text{ k}\Omega$

$$R_T = 1.8\text{ k}\Omega = \frac{(2\text{ k}\Omega)(R)}{2\text{ k}\Omega + R}, \quad R = \mathbf{18\text{ k}\Omega}$$

c. $R_T = 10\text{ k}\Omega = \frac{(20\text{ k}\Omega)(R)}{20\text{ k}\Omega + R}, \quad R = \mathbf{20\text{ k}\Omega}$

d. $R_T = 628.93\text{ }\Omega = \frac{1}{\frac{1}{1.2\text{ k}\Omega} + \frac{1}{R} + \frac{1}{2.2\text{ k}\Omega}} = \frac{1}{833.33 \times 10^{-3}\text{ S} + \frac{1}{R} + 454.55 \times 10^{-3}\text{ S}}$
 $811.32 \times 10^{-3} + \frac{628.93\text{ }\Omega}{R} = 1$

$$R = \frac{628.93\text{ }\Omega}{1 - 811.32 \times 10^{-3}} = \mathbf{3.3\text{ k}\Omega}$$

e. $R' = R_1 \parallel R_2 = \frac{R_1}{2}, R_3 = \frac{R_1}{2}$

$$R_T = 1.6\text{ k}\Omega = \frac{R'R_3}{R' + R_3} = \frac{\left(\frac{R_1}{2}\right)\left(\frac{R_1}{2}\right)}{\frac{R_1}{2} + \frac{R_1}{2}} = \frac{R_1}{4} \quad R_1 = 4(1.6\text{ k}\Omega) = \mathbf{6.4\text{ k}\Omega = R_2}$$

$$R_3 = \frac{6.4\text{ k}\Omega}{2} = \mathbf{3.2\text{ k}\Omega}$$

6. a. $1.2\text{ k}\Omega$

b. about $1\text{ k}\Omega$

c. $R_T = \frac{1}{\frac{1}{1.2\text{ k}\Omega} + \frac{1}{22\text{ k}\Omega} + \frac{1}{220\text{ k}\Omega} + \frac{1}{2.2\text{ M}\Omega}}$
 $= \frac{1}{833.333 \times 10^{-6}\text{ S} + 45.455 \times 10^{-6}\text{ S} + 4.545 \times 10^{-6}\text{ S} + 0.455 \times 10^{-6}\text{ S}}$
 $= \frac{1}{883.788 \times 10^{-6}\text{ S}} = \mathbf{1.131\text{ k}\Omega}$

d. $220\text{ k}\Omega, 2.2\text{ M}\Omega: R_T = \frac{(1.2\text{ k}\Omega)(22\text{ k}\Omega)}{1.2\text{ k}\Omega + 22\text{ k}\Omega} = \mathbf{1.138\text{ k}\Omega}$

e. R_T reduced.

7. a. $R_T = \frac{(2\Omega)(8\Omega)}{2\Omega + 8\Omega} = 1.6\Omega$

b. $\infty\Omega$

c. $\infty\Omega$

d. $R_T = \frac{1}{\frac{1}{4\Omega} + \frac{1}{2\Omega} + \frac{1}{10\Omega}} = \frac{1}{0.25S + 0.50S + 0.10S} = \frac{1}{0.85S} = 1.18\Omega$

8. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$$\frac{1}{20\Omega} = \frac{1}{R_1} + \frac{1}{5R_1} + \frac{1}{R_1} = \frac{1}{2}\left[\frac{1}{R_1}\right] + \frac{1}{5}\left[\frac{1}{R_1}\right] + 2\left[\frac{1}{R_1}\right] = 3.2\left[\frac{1}{R_1}\right]$$

and $R_1 = 3.2(20\Omega) = 64\Omega$

$R_2 = 5R_1 = 5(64\Omega) = 320\Omega$

$R_3 = \frac{1}{2}R_1 = \frac{64\Omega}{2} = 32\Omega$

9. $24\Omega \parallel 24\Omega = 12\Omega$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{12\Omega} + \frac{1}{120\Omega}$$

$$0.1S = \frac{1}{R_1} + 0.08333S + 0.00833S$$

$$0.1S = \frac{1}{R_1} + 0.09167S$$

$$\frac{1}{R_1} = 0.1S - 0.09167S = 0.00833S$$

$$R_1 = \frac{1}{0.00833S} = 120\Omega$$

10. a. $R_T = \frac{(8\Omega)(24\Omega)}{8\Omega + 24\Omega} = 6\Omega$

b. $V_{R_1} = V_{R_2} = 36V$

c. $I_s = \frac{E}{R_T} = \frac{36V}{6\Omega} = 6A$

$$I_1 = \frac{V_{R_1}}{R_1} = \frac{36V}{8\Omega} = 4.5A$$

$$I_2 = \frac{V_{R_2}}{R_2} = \frac{36V}{24\Omega} = 1.5A$$

d. $I_s = I_1 + I_2$
 $6A = 4.5A + 1.5A = 6A$ (checks)

11. a. $R_T = \frac{1}{\frac{1}{3\Omega} + \frac{1}{9\Omega} + \frac{1}{36\Omega}} = \frac{1}{0.333S + 0.111S + 0.028S}$
 $= \frac{1}{472 \times 10^{-3}S} = 2.12 \Omega$
- b. $V_{R_1} = V_{R_2} = V_{R_3} = 18 V$
- c. $I_s = \frac{E}{R_T} = \frac{18 V}{2.12 \Omega} = 8.5 A$
 $I_1 = \frac{V_{R_1}}{R_1} = \frac{18 V}{3 \Omega} = 6 A, I_2 = \frac{V_{R_2}}{R_2} = \frac{18 V}{9 \Omega} = 2 A, I_3 = \frac{V_{R_3}}{R_3} = \frac{18 V}{36 \Omega} = 0.5 A$
- d. $I_s = 8.5 A = 6 A + 2 A + 0.5 A = 8.5 A$ (checks)
12. a. $R_T = \frac{1}{\frac{1}{10k\Omega} + \frac{1}{1.2k\Omega} + \frac{1}{6.8k\Omega}} = \frac{1}{100 \times 10^{-6}S + 833.333 \times 10^{-6}S + 147.059 \times 10^{-6}S}$
 $= \frac{1}{1.080 \times 10^{-3}S} = 925.93 \Omega$
- b. $V_{R_1} = V_{R_2} = V_{R_3} = 24 V$
- c. $I_s = \frac{E}{R_T} = \frac{24 V}{925.93 \Omega} = 25.92 mA$
 $I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{24 V}{10 k\Omega} = 2.4 mA, I_{R_2} = \frac{V_{R_2}}{R_2} = \frac{24 V}{1.2 k\Omega} = 20 mA,$
 $I_{R_3} = \frac{V_{R_3}}{R_3} = \frac{24 V}{6.8 k\Omega} = 3.53 mA$
- d. $I_T = 25.92 mA = 2.4 mA + 20 mA + 3.53 mA = 25.93 mA$ (checks)
13. a. $R_T \approx 1 k\Omega$
- b. $R_T = \frac{1}{\frac{1}{10k\Omega} + \frac{1}{22k\Omega} + \frac{1}{1.2k\Omega} + \frac{1}{56k\Omega}}$
 $= \frac{1}{100 \times 10^{-6}S + 45.46 \times 10^{-6}S + 833.333 \times 10^{-6}S + 17.86 \times 10^{-6}S}$
 $= \frac{1}{996.65 \times 10^{-6}S} = 1.003 k\Omega, \text{ very close}$
- c. I_3 the most, I_4 the least
- d. $I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{44 V}{10 k\Omega} = 4.4 mA, I_{R_2} = \frac{V_{R_2}}{R_2} = \frac{44 V}{22 k\Omega} = 2 mA$
 $I_{R_3} = \frac{V_{R_3}}{R_3} = \frac{44 V}{1.2 k\Omega} = 36.67 mA, I_{R_4} = \frac{V_{R_4}}{R_4} = \frac{44 V}{56 k\Omega} = 0.79 mA$

e. $I_s = \frac{E}{R_T} = \frac{44 \text{ V}}{1.003 \text{ k}\Omega} = 43.87 \text{ mA}$

f. $I_s = 43.87 \text{ mA} = 4.4 \text{ mA} + 2 \text{ mA} + 36.67 \text{ mA} + 0.79 \text{ mA} = 43.86 \text{ mA}$ (checks)

14. —

15. $R'_T = 3 \Omega \parallel 6 \Omega = 2 \Omega, R_T = R'_T \parallel R_3 = 2 \Omega \parallel 2 \Omega = 1 \Omega$

$$I_s = I' = \frac{E}{R_T} = \frac{12 \text{ V}}{1 \Omega} = 12 \text{ A}$$

$$I_{R_1} = \frac{E}{R_1} = \frac{12 \text{ V}}{3 \Omega} = 4 \text{ A}$$

$$I'' = I' - I_{R_1} = 12 \text{ A} - 4 \text{ A} = 8 \text{ A}$$

$$V = E = 12 \text{ V}$$

16. $I_3 = \frac{(20 \Omega)(10.8 \text{ A})}{20 \Omega + 4 \Omega} = 9 \text{ A}$

$$E = V_{R_3} = I_3 R_3 = (9 \text{ A})(4 \Omega) = 36 \text{ V}$$

$$I_{R_1} = 12.3 \text{ A} - 10.8 \text{ A} = 1.5 \text{ A}$$

$$R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{36 \text{ V}}{1.5 \text{ A}} = 24 \Omega$$

17. a. $R_T = 20 \Omega \parallel 5 \Omega = 4 \Omega$

$$I_s = \frac{E}{R_T} = \frac{30 \text{ V}}{4 \Omega} = 7.5 \text{ A}$$

CDR: $I_1 = \frac{5 \Omega I_s}{5 \Omega + 20 \Omega} = \frac{1}{5}(7.5 \text{ A}) = 1.5 \text{ A}$

b. $10 \text{ k}\Omega \parallel 10 \text{ k}\Omega = 5 \text{ k}\Omega$

$$R_T = 1 \text{ k}\Omega \parallel 5 \text{ k}\Omega = 0.833 \text{ k}\Omega$$

$$I_s = \frac{E}{R_T} = \frac{8 \text{ V}}{0.833 \text{ k}\Omega} = 9.6 \text{ mA}$$

$$R'_T = 10 \text{ k}\Omega \parallel 1 \text{ k}\Omega = 0.9091 \text{ k}\Omega$$

$$I_1 = \frac{R'_T I_s}{R'_T + 10 \text{ k}\Omega} = \frac{(0.9091 \text{ k}\Omega)(9.6 \text{ mA})}{0.9091 \text{ k}\Omega + 10 \text{ k}\Omega} = \frac{8.727 \text{ mA}}{10.9091} = 0.8 \text{ mA}$$

18. a. $I = \frac{24 \text{ V} - 8 \text{ V}}{4 \text{ k}\Omega} = \frac{16 \text{ V}}{4 \text{ k}\Omega} = 4 \text{ mA}$

b. $V = 24 \text{ V}$

c. $I_s = \frac{24 \text{ V}}{10 \text{ k}\Omega} + 4 \text{ mA} + \frac{24 \text{ V}}{2 \text{ k}\Omega} = 2.4 \text{ mA} + 4 \text{ mA} + 12 \text{ mA} = 18.4 \text{ mA}$

19. a. $R_T = \frac{1}{\frac{1}{1\text{k}\Omega} + \frac{1}{33\text{k}\Omega} + \frac{1}{8.2\text{k}\Omega}} = \frac{1}{1000 \times 10^{-6}\text{S} + 30.303 \times 10^{-6}\text{S} + 121.951 \times 10^{-6}\text{S}}$
 $= \frac{1}{1.152 \times 10^{-3}\text{S}} = \mathbf{867.86\ \Omega}$
 $I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{100\text{ V}}{1\text{k}\Omega} = \mathbf{100\ mA}, I_{R_2} = \frac{V_{R_2}}{R_2} = \frac{100\text{ V}}{33\text{k}\Omega} = \mathbf{3.03\ mA}$
 $I_{R_3} = \frac{V_{R_3}}{R_3} = \frac{100\text{ V}}{8.2\text{k}\Omega} = \mathbf{12.2\ mA}$
- b. $P_{R_1} = V_{R_1} \cdot I_{R_1} = (100\text{ V})(100\text{ mA}) = \mathbf{10\ W}$
 $P_{R_2} = V_{R_2} \cdot I_{R_2} = (100\text{ V})(3.03\text{ mA}) = \mathbf{0.30\ W}$
 $P_{R_3} = V_{R_3} \cdot I_{R_3} = (100\text{ V})(12.2\text{ mA}) = \mathbf{1.22\ W}$
- c. $I_s = \frac{E}{R_T} = \frac{100\text{ V}}{867.86\ \Omega} = 115.23\text{ mA}$
 $P_s = E_s I_s = (100\text{ V})(115.23\text{ mA}) = \mathbf{11.52\ W}$
- d. $P_s = \mathbf{11.52\ W} = 10\text{ W} + 0.30\text{ W} + 1.22\text{ W} = \mathbf{11.52\ W}$ (checks)
- e. R_1 = the smallest parallel resistor

20. a. $I_{\text{bulb}} = \frac{E}{R_{\text{bulb}}} = \frac{120\text{ V}}{1.8\text{k}\Omega} = \mathbf{66.667\ mA}$
- b. $R_T = \frac{R}{N} = \frac{1.8\text{k}\Omega}{8} = \mathbf{225\ \Omega}$
- c. $I_s = \frac{E}{R_T} = \frac{120\text{ V}}{225\ \Omega} = \mathbf{0.533\ A}$
- d. $P = \frac{V^2}{R} = \frac{(120\text{ V})^2}{1.8\text{k}\Omega} = \mathbf{8\ W}$
- e. $P_s = 8(8\text{ W}) = \mathbf{64\ W}$
- f. none, I_s drops by 66.667 mA

21. $R_T = \frac{1}{\frac{1}{5\ \Omega} + \frac{1}{10\ \Omega} + \frac{1}{20\ \Omega}} = \frac{1}{200 \times 10^{-3}\text{S} + 100 \times 10^{-3}\text{S} + 50 \times 10^{-3}\text{S}}$
 $= \frac{1}{350 \times 10^{-3}\text{S}} = 2.86\ \Omega$
 $I_s = \frac{E}{R_T} = \frac{60\text{ V}}{2.86\ \Omega} = 20.98\text{ A}$
 $P = E \cdot I_s = (60\text{ V})(20.98\text{ A}) = \mathbf{1.26\ kW}$

22. a. $P_1 = 10(60 \text{ W}) = 600 \text{ W} = E \cdot I_1 = 120 \text{ V} \cdot I_1, I_1 = \frac{600 \text{ W}}{120 \text{ V}} = 5 \text{ A}$
 $P_2 = 400 \text{ W} = 120 \text{ V} \cdot I_2, I_2 = \frac{400 \text{ W}}{120 \text{ V}} = 3.33 \text{ A}$
 $P_3 = 200 \text{ W} = 120 \text{ V} \cdot I_3, I_3 = \frac{200 \text{ W}}{120 \text{ V}} = 1.67 \text{ A}$
 $P_4 = 110 \text{ W} = 120 \text{ V} \cdot I_4, I_4 = \frac{110 \text{ W}}{120 \text{ V}} = 0.92 \text{ A}$
- b. $I_s = 5 \text{ A} + 3.33 \text{ A} + 1.67 \text{ A} + 0.92 \text{ A} = 10.92 \text{ A}$ (no)
c. $R_T = \frac{E}{I_s} = \frac{120 \text{ V}}{10.92 \text{ A}} = 10.99 \Omega$
d. $P_s = E \cdot I_s = (120 \text{ V})(10.92 \text{ A}) = 1.31 \text{ kW}$
 $P_s = 1.31 \text{ kW} = 600 \text{ W} + 400 \text{ W} + 200 \text{ W} + 110 \text{ W} = 1.31 \text{ kW}$ (the same)
23. a. $8 \Omega \parallel 12 \Omega = 4.8 \Omega, 4.8 \Omega \parallel 4 \Omega = 2.182 \Omega$
 $I_1 = \frac{24 \text{ V} + 8 \text{ V}}{2.182 \Omega} = 14.67 \text{ A}$
- b. $P_4 = \frac{V^2}{R} = \frac{(24 \text{ V} + 8 \text{ V})^2}{4 \Omega} = 256 \text{ W}$
- c. $I_2 = I_1 = 14.67 \text{ A}$
24. $I_1 = 12.6 \text{ mA} - 8.5 \text{ mA} = 4.1 \text{ mA}$
 $I_2 = 8.5 \text{ mA} - 4 \text{ mA} = 4.5 \text{ mA}$
25. a. $9 \text{ A} + 2 \text{ A} + I_1 = 12 \text{ A}, I_1 = 12 \text{ A} - 11 \text{ A} = 1 \text{ A}$
 $I_2 + 1 \text{ A} = 1 \text{ A} + 3 \text{ A}, I_2 = 4 \text{ A} - 1 \text{ A} = 3 \text{ A}$
- b. $6 \text{ A} = 2 \text{ A} + I_1, I_1 = 6 \text{ A} - 2 \text{ A} = 4 \text{ A}$
 $4 \text{ A} + 5 \text{ A} = I_2, I_2 = 9 \text{ A}$
 $9 \text{ A} = I_3 + 3 \text{ A}, I_3 = 9 \text{ A} - 3 \text{ A} = 6 \text{ A}$
 $3 \text{ A} + 10 \text{ A} = I_4, I_4 = 13 \text{ A}$
26. a. $I_1 + 5 \text{ mA} = 8 \text{ mA}, I_1 = 3 \text{ mA}$
 $5 \text{ mA} = I_2 + 3.5 \text{ mA}, I_2 = 1.5 \text{ mA}$
 $I_1 = 3 \text{ mA} = I_3 + 1 \text{ mA}, I_3 = 2 \text{ mA}$
 $I_4 = 5 \text{ mA}$
- b. $I_3 = 1.5 \mu\text{A} + 0.5 \mu\text{A} = 2.0 \mu\text{A}$
 $6 \mu\text{A} = I_2 + I_3 = I_2 + 2 \mu\text{A}, I_2 = 4 \mu\text{A}$
 $I_2 + 1.5 \mu\text{A} = I_4, I_4 = 4 \mu\text{A} + 1.5 \mu\text{A} = 5.5 \mu\text{A}$
 $I_1 = 6 \mu\text{A}$

$$27. \quad I_{R_2} = 5 \text{ mA} - 2 \text{ mA} = 3 \text{ mA}$$

$$E = V_{R_2} = (3 \text{ mA})(4 \text{ k}\Omega) = 12 \text{ V}$$

$$R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{12 \text{ V}}{(9 \text{ mA} - 5 \text{ mA})} = \frac{12 \text{ V}}{4 \text{ mA}} = 3 \text{ k}\Omega$$

$$R_3 = \frac{V_{R_3}}{I_{R_3}} = \frac{12 \text{ V}}{2 \text{ mA}} = 6 \text{ k}\Omega$$

$$R_T = \frac{E}{I_T} = \frac{12 \text{ V}}{9 \text{ mA}} = 1.33 \text{ k}\Omega$$

$$28. \quad \text{a.} \quad R_1 = \frac{E}{I_1} = \frac{10 \text{ V}}{2 \text{ A}} = 5 \Omega$$

$$I_2 = I - I_1 = 3 \text{ A} - 2 \text{ A} = 1 \text{ A}$$

$$R = \frac{E}{I_2} = \frac{10 \text{ V}}{1 \text{ A}} = 10 \Omega$$

$$\text{b.} \quad E = I_1 R_1 = (2 \text{ A})(6 \Omega) = 12 \text{ V}$$

$$I_2 = \frac{E}{R_2} = \frac{12 \text{ V}}{9 \Omega} = 1.33 \text{ A}$$

$$I_3 = \frac{P}{V} = \frac{12 \text{ W}}{12 \text{ V}} = 1 \text{ A}$$

$$R_3 = \frac{E}{I_3} = \frac{12 \text{ V}}{1 \text{ A}} = 12 \Omega$$

$$I = I_1 + I_2 + I_3 = 2 \text{ A} + 1.33 \text{ A} + 1 \text{ A} = 4.33 \text{ A}$$

$$\text{c.} \quad I_1 = \frac{64 \text{ V}}{1 \text{ k}\Omega} = 64 \text{ mA}$$

$$I_3 = \frac{64 \text{ V}}{4 \text{ k}\Omega} = 16 \text{ mA}$$

$$I_s = I_1 + I_2 + I_3$$

$$I_2 = I_s - I_1 - I_3 = 100 \text{ mA} - 64 \text{ mA} - 16 \text{ mA} = 20 \text{ mA}$$

$$R = \frac{E}{I_2} = \frac{64 \text{ V}}{20 \text{ mA}} = 3.2 \text{ k}\Omega$$

$$I = I_2 + I_3 = 20 \text{ mA} + 16 \text{ mA} = 36 \text{ mA}$$

d. $P = \frac{V_1^2}{R_1} \Rightarrow V_1 = \sqrt{PR_1} = \sqrt{(30 \text{ W})(30 \Omega)} = 30 \text{ V}$

$$E = V_1 = 30 \text{ V}$$

$$I_1 = \frac{E}{R_1} = \frac{30 \text{ V}}{30 \Omega} = 1 \text{ A}$$

Because $R_3 = R_2$, $I_3 = I_2$, and $I_s = I_1 + I_2 + I_3 = I_1 + 2I_2$
 $2 \text{ A} = 1 \text{ A} + 2I_2$

$$I_2 = \frac{1}{2}(1 \text{ A}) = 0.5 \text{ A}$$

$$I_3 = 0.5 \text{ A}$$

$$R_2 = R_3 = \frac{E}{I_2} = \frac{30 \text{ V}}{0.5 \text{ A}} = 60 \Omega$$

$$P_{R_2} = I_2^2 R_2 = (0.5 \text{ A})^2 \cdot 60 \Omega = 15 \text{ W}$$

29. $I_2 = \frac{4 \Omega}{12 \Omega} I_1 = \frac{1}{3} I_1 = 2 \text{ A}$

$$I_3 = \frac{4 \Omega}{2 \Omega} I_1 = 2I_1 = 12 \text{ A}$$

$$I_4 = \frac{4 \Omega}{40 \Omega} I_1 = \frac{1}{10} I_1 = 0.6 \text{ A}$$

$$I_T = I_1 + I_2 + I_3 + I_4 = 6 \text{ A} + 2 \text{ A} + 12 \text{ A} + 0.6 \text{ A} = 20.6 \text{ A}$$

30. a. $I_1 = \frac{8 \text{ k}\Omega(20 \text{ mA})}{2 \text{ k}\Omega + 8 \text{ k}\Omega} = 16 \text{ mA}$

$$I_2 = 20 \text{ mA} - 16 \text{ mA} = 4 \text{ mA}$$

b. $R_T = \frac{1}{\frac{1}{2.2 \text{ k}\Omega} + \frac{1}{1.2 \text{ k}\Omega} + \frac{1}{0.2 \text{ k}\Omega}} = \frac{1}{454.55 \times 10^{-6} \text{ S} + 833.33 \times 10^{-6} \text{ S} + 5000 \times 10^{-6} \text{ S}}$
 $= \frac{1}{6,288 \times 10^{-6} \text{ S}} = 159.03 \Omega$

$$I_x = \frac{R_T}{R_x} I, \quad I_1 = \frac{159.03 \Omega}{2.2 \text{ k}\Omega} (18 \text{ mA}) = 1.30 \text{ mA}$$

$$I_2 = \frac{159.03 \Omega}{1.2 \text{ k}\Omega} (18 \text{ mA}) = 2.39 \text{ mA}$$

$$I_3 = \frac{159.03 \Omega}{0.2 \text{ k}\Omega} (18 \text{ mA}) = 14.31 \text{ mA}$$

$$I_4 = 18 \text{ mA}$$

c. $R_T = \frac{1}{\frac{1}{4\Omega} + \frac{1}{8\Omega} + \frac{1}{12\Omega}} = \frac{1}{250 \times 10^{-3}S + 125 \times 10^{-3}S + 83.333 \times 10^{-3}S}$

$$= \frac{1}{458.333 \times 10^{-3}} = 2.18 \Omega$$

$$I_x = \frac{R_T}{R_x} I, \quad I_1 = \frac{2.18 \Omega}{4 \Omega} (6 A) = 3.27 A$$

$$I_2 = \frac{2.18 \Omega}{8 \Omega} (6 A) = 1.64 A$$

$$I_3 = \frac{2.18 \Omega}{12 \Omega} (6 A) = 1.09 A$$

$$I_4 = 6 A$$

d. $I_1 = I_2 = \frac{20 \Omega (9 A)}{20 \Omega + 10 \Omega} = 6 A$

$$I_3 = 9 A - I_1 = 9 A - 6 A = 3 A$$

$$I_4 = 9 A$$

31. a. $I_1 \cong \frac{9}{10} (10 A) = 9 A$

b. $I_1/I_2 = 10 \Omega / 1 \Omega = 10, \quad I_2 = \frac{I_1}{10} = \frac{9 A}{10} \cong 0.9 A$

c. $I_1/I_3 = 1 k\Omega / 1 \Omega = 1000, I_3 = I_1/1000 = 9 A/1000 \cong 9 mA$

d. $I_1/I_4 = 100 k\Omega / 1 \Omega = 100,000, \quad I_4 = I_1/100,000 = 9 A/100,000 \cong 90 \mu A$

e. very little effect, 1/100,000

f. $R_T = \frac{1}{\frac{1}{1\Omega} + \frac{1}{10\Omega} + \frac{1}{1k\Omega} + \frac{1}{100k\Omega}}$

$$= \frac{1}{1 S + 0.1 S + 1 \times 10^{-3} S + 10 \times 10^{-6} S}$$

$$= \frac{1}{1.10 S} = 0.91 \Omega$$

$$I_x = \frac{R_T}{R_x} I, \quad I_1 = \frac{0.91 \Omega}{1 \Omega} (10 A) = 9.1 A \text{ excellent (9 A)}$$

g. $I_2 = \frac{0.91 \Omega}{10 \Omega} (10 A) = 0.91 A \text{ excellent (0.9 A)}$

h. $I_3 = \frac{0.91 \Omega}{1 k\Omega} (10 A) = 9.1 mA \text{ excellent (9 mA)}$

i. $I_4 = \frac{0.91 \Omega}{100 k\Omega} (10 A) = 91 \mu A \text{ excellent (90 \mu A)}$

32. a. CDR: $I_{6\Omega} = \frac{2\Omega I}{2\Omega + 6\Omega} = 1\text{ A}$

$$I = \frac{1\text{ A}(8\Omega)}{2\Omega} = 4\text{ A} = I_2$$

$$I_1 = I - 1\text{ A} = 3\text{ A}$$

b. $I_3 = I = 7\text{ }\mu\text{A}$

By inspection: $I_2 = 2\text{ }\mu\text{A}$

$$I_1 = I - 2(2\text{ }\mu\text{A}) = 7\text{ }\mu\text{A} - 4\text{ }\mu\text{A} = 3\text{ }\mu\text{A}$$

$$V_R = (2\text{ }\mu\text{A})(9\Omega) = 18\text{ }\mu\text{V}$$

$$R = \frac{V_R}{I_R} = \frac{18\text{ }\mu\text{V}}{3\text{ }\mu\text{A}} = 6\text{ }\Omega$$

33. a. $R = 3(2\text{ k}\Omega) = 6\text{ k}\Omega$

b. $I_1 = \frac{6\text{ k}\Omega(32\text{ mA})}{6\text{ k}\Omega + 2\text{ k}\Omega} = 24\text{ mA}$

$$I_2 = \frac{I_1}{3} = \frac{24\text{ mA}}{3} = 8\text{ mA}$$

34. $84\text{ mA} = I_1 + I_2 + I_3 = I_1 + 2I_1 + 2I_2 = I_1 + 2I_1 + 2(2I_1)$

$$84\text{ mA} = I_1 + 2I_1 + 4I_1 = 7I_1$$

$$\text{and } I_1 = \frac{84\text{ mA}}{7} = 12\text{ mA}$$

$$I_2 = 2I_1 = 2(12\text{ mA}) = 24\text{ mA}$$

$$I_3 = 2I_2 = 2(24\text{ mA}) = 48\text{ mA}$$

$$R_1 = \frac{V_{R_1}}{I_1} = \frac{24\text{ V}}{12\text{ mA}} = 2\text{ k}\Omega$$

$$R_2 = \frac{V_{R_2}}{I_2} = \frac{24\text{ V}}{24\text{ mA}} = 1\text{ k}\Omega$$

$$R_3 = \frac{V_{R_3}}{I_3} = \frac{24\text{ V}}{48\text{ mA}} = 0.5\text{ k}\Omega$$

35. a. $P_L = V_L I_L$

$$72\text{ W} = 12\text{ V} \cdot I_L$$

$$I_L = \frac{72\text{ W}}{12\text{ V}} = 6\text{ A}$$

$$I_1 = I_2 = \frac{I_L}{2} = \frac{6\text{ A}}{2} = 3\text{ A}$$

b. $P_{\text{source}} = EI = (12\text{ V})(3\text{ A}) = 36\text{ W}$

c. $P_{s_1} + P_{s_2} = 36\text{ W} + 36\text{ W} = 72\text{ W}$ (the same)

d. $I_{\text{drain}} = 6\text{ A}$ (twice as much)

36. $R_T = 8 \Omega \parallel 56 \Omega = 7 \Omega$

$$I_2 = I_3 = \frac{E}{R_T} = \frac{12 \text{ V}}{7 \Omega} = 1.71 \text{ A}$$

$$I_1 = \frac{1}{2} I_2 = \frac{1}{2}(1.71 \text{ A}) = 0.86 \text{ A}$$

37. $I_{8\Omega} = \frac{16 \text{ V}}{8 \Omega} = 2 \text{ A}, \quad I = 5 \text{ A} - 2 \text{ A} = 3 \text{ A}$

$$I_R = 5 \text{ A} + 3 \text{ A} = 8 \text{ A}, \quad R = \frac{V_R}{I_R} = \frac{16 \text{ V}}{8 \text{ A}} = 2 \Omega$$

38. a. $I_s = \frac{E}{R_T} = \frac{12 \text{ V}}{0.1 \text{ k}\Omega + 10 \text{ k}\Omega} = \frac{12 \text{ V}}{10.1 \text{ k}\Omega} = 1.188 \text{ mA}$

$$V_L = I_s R_L = (1.19 \text{ mA})(10 \text{ k}\Omega) = 11.90 \text{ V}$$

b. $I_s = \frac{12 \text{ V}}{100 \Omega} = 120 \text{ mA}$

c. $V_L = E = 12 \text{ V}$

39. a. $V_L = \frac{4.7 \text{ k}\Omega(9 \text{ V})}{4.7 \text{ k}\Omega + 2.2 \text{ k}\Omega} = \frac{42.3 \text{ V}}{6.9} = 6.13 \text{ V}$

b. $V_L = E = 9 \text{ V}$

c. $V_L = E = 9 \text{ V}$

40. a. $I_1 = \frac{20 \text{ V}}{4 \Omega} = 5 \text{ A}, \quad I_2 = 0 \text{ A}$

b. $V_1 = 0 \text{ V}, \quad V_2 = 20 \text{ V}$

c. $I_s = I_1 = 5 \text{ A}$

41. a. $V_2 = \frac{22 \text{ k}\Omega(20 \text{ V})}{22 \text{ k}\Omega + 4.7 \text{ k}\Omega} = 16.48 \text{ V}$

b. $R'_T = 11 \text{ M}\Omega \parallel 22 \text{ k}\Omega = 21.956 \text{ k}\Omega$

$$V_2 = \frac{21.956 \text{ k}\Omega(20 \text{ V})}{21.956 \text{ k}\Omega + 4.7 \text{ k}\Omega} = 16.47 \text{ V} \text{ (very close to ideal)}$$

c. $R_m = 20 \text{ V}[20,000 \Omega/\text{V}] = 400 \text{ k}\Omega$

$$R'_T = 400 \text{ k}\Omega \parallel 22 \text{ k}\Omega = 20.853 \text{ k}\Omega$$

$$V_2 = \frac{20.853 \text{ k}\Omega(20 \text{ V})}{20.853 \text{ k}\Omega + 4.7 \text{ k}\Omega} = 16.32 \text{ V} \text{ (still very close to ideal)}$$

d: a. $V_2 = \frac{200 \text{ k}\Omega(20 \text{ V})}{200 \text{ k}\Omega + 100 \text{ k}\Omega} = 13.33 \text{ V}$

b. $R'_T = 200 \text{ k}\Omega \parallel 11 \text{ M}\Omega = 196.429 \text{ k}\Omega$

$$V_2 = \frac{(196.429 \text{ k}\Omega)(20 \text{ V})}{196.429 \text{ k}\Omega + 100 \text{ k}\Omega} = 13.25 \text{ V} \text{ (very close to ideal)}$$

c. $R_m = 400 \text{ k}\Omega$
 $R'_T = 400 \text{ k}\Omega \parallel 200 \text{ k}\Omega = 133.333 \text{ k}\Omega$
 $V_2 = \frac{(133.333 \text{ k}\Omega)(20 \text{ V})}{133.333 \text{ k}\Omega + 100 \text{ k}\Omega} = 11.43 \text{ V}$ (a 1.824 V drop from $R_{\text{int}} = 11 \text{ M}\Omega$ level)

- e. DMM level of 11 MΩ not a problem for most situations
VOM level of 400 kΩ can be a problem for some situations.

42. a. $V_{ab} = 20 \text{ V}$

b. $V_{ab} = \frac{11 \text{ M}\Omega(20 \text{ V})}{11 \text{ M}\Omega + 1 \text{ M}\Omega} = 18.33 \text{ V}$

c. $R_m = 200 \text{ V}[20,000 \text{ }\Omega/\text{V}] = 4 \text{ M}\Omega$

$V_{ab} = \frac{4 \text{ M}\Omega(20 \text{ V})}{4 \text{ M}\Omega + 1 \text{ M}\Omega} = 16.0 \text{ V}$ (significant drop from ideal)

$R_m = 20 \text{ V}[20,000 \text{ }\Omega/\text{V}] = 400 \text{ k}\Omega$

$V_{ab} = \frac{400 \text{ k}\Omega(20 \text{ V})}{400 \text{ k}\Omega + 1 \text{ M}\Omega} = 5.71 \text{ V}$ (significant error)

43. not operating properly, 6 kΩ not connected at both ends

$R_T = \frac{6 \text{ V}}{3.5 \text{ mA}} = 1.71 \text{ k}\Omega$

$R_T = 3 \text{ k}\Omega \parallel 4 \text{ k}\Omega = 1.71 \text{ k}\Omega$

44. $V_{ab} = E + I_{4 \text{ k}\Omega} \cdot R_{4 \text{ k}\Omega}$

$I_{4 \text{ k}\Omega} = \frac{12 \text{ V} - 4 \text{ V}}{1 \text{ k}\Omega + 4 \text{ k}\Omega} = \frac{8 \text{ V}}{5 \text{ k}\Omega} = 1.6 \text{ mA}$

$V_{ab} = 4 \text{ V} + (1.6 \text{ mA})(4 \text{ k}\Omega) = 4 \text{ V} + 6.4 \text{ V} = 10.4 \text{ V}$

4 V supply connected in reverse so that

$I = \frac{12 \text{ V} + 4 \text{ V}}{1 \text{ k}\Omega + 4 \text{ k}\Omega} = \frac{16 \text{ V}}{5 \text{ k}\Omega} = 3.2 \text{ mA}$

and $V_{ab} = 12 \text{ V} - (3.2 \text{ mA})(1 \text{ k}\Omega) = 12 \text{ V} - 3.2 \text{ V} = 8.8 \text{ V}$ obtained

Chapter 7

1.
 - a. E and R_1 in series; R_2 , R_3 and R_4 in parallel
 - b. E and R_1 in series; R_2 , R_3 and R_4 in parallel
 - c. R_1 and R_2 in series; E , R_3 and R_4 in parallel
 - d. E and R_1 in series, R_4 and R_5 in series; R_2 and R_3 in parallel
 - e. E and R_1 in series, R_2 and R_3 in parallel
 - f. E , R_1 and R_4 in parallel; R_6 and R_7 in series; R_2 and R_5 in parallel

2.
 - a. $R_T = 4 \Omega + 10 \Omega + 4 \Omega = 18 \Omega$
 - b. $R_T = 10 \Omega + \frac{10 \Omega}{2} = 10 \Omega + 5 \Omega = 15 \Omega$
 - c. $R_T = 4 \Omega \parallel (4 \Omega + 4 \Omega) + 10 \Omega = 4 \Omega \parallel 8 \Omega + 10 \Omega = 2.67 \Omega + 10 \Omega = 12.67 \Omega$
 - d. $R_T = 10 \Omega$

3.
 - a. yes
 - b. $I_2 = I_s - I_1 = 10 \text{ A} - 4 \text{ A} = 6 \text{ A}$
 - c. yes
 - d. $V_3 = E - V_2 = 14 \text{ V} - 8 \text{ V} = 6 \text{ V}$
 - e. $R'_T = 4 \Omega \parallel 2 \Omega = 1.33 \Omega$, $R''_T = 4 \Omega \parallel 6 \Omega = 2.4 \Omega$
 $R_T = R'_T + R''_T = 1.33 \Omega + 2.4 \Omega = 3.73 \Omega$
 - f. $R'_T = R''_T = \frac{20 \Omega}{2} = 10 \Omega$, $R_T = R'_T + R''_T = 10 \Omega + 10 \Omega = 20 \Omega$
 $I_s = \frac{E}{R_T} = \frac{20 \text{ V}}{20 \Omega} = 1 \text{ A}$
 - g. $P_s = EI_s = P_{\text{absorbed}} = (20 \text{ V})(1 \text{ A}) = 20 \text{ W}$

4.
 - a. $R'_T = R_3 \parallel R_4 = \frac{12 \Omega}{2} = 6 \Omega$, $R''_T = R_2 \parallel R'_T = \frac{6 \Omega}{2} = 3 \Omega$
 $R_T = R_1 + R''_T = 4 \Omega + 3 \Omega = 7 \Omega$
 - b. $I_s = \frac{E}{R_T} = \frac{14 \text{ V}}{7 \Omega} = 2 \text{ A}$, $I_2 = \frac{1}{2}I_s = \frac{2 \text{ A}}{2} = 1 \text{ A}$
 $I_3 = \frac{1 \text{ A}}{2} = 0.5 \text{ A}$
 - c. $I_5 = 1 \text{ A}$
 - d. $V_2 = I_2 R_2 = (1 \text{ A})(6 \Omega) = 6 \text{ V}$
 $V_4 = V_2 = 6 \text{ V}$

5.
 - a. $R'_T = R_1 \parallel R_2 = 10 \Omega \parallel 15 \Omega = 6 \Omega$
 $R_T = R'_T \parallel (R_3 + R_4) = 6 \Omega \parallel (10 \Omega + 2 \Omega) = 6 \Omega \parallel 12 \Omega = 4 \Omega$
 - b. $I_s = \frac{E}{R_T} = \frac{36 \text{ V}}{4 \Omega} = 9 \text{ A}$, $I_1 = \frac{E}{R'_T} = \frac{36 \text{ V}}{6 \Omega} = 6 \text{ A}$
 $I_2 = \frac{E}{R_3 + R_4} = \frac{36 \text{ V}}{10 \Omega + 2 \Omega} = \frac{36 \text{ V}}{12 \Omega} = 3 \text{ A}$
 - c. $V_4 = I_4 R_4 = I_2 R_4 = (3 \text{ A})(2 \Omega) = 6 \text{ V}$

6. a. $R'_T = 1.2 \text{ k}\Omega + 6.8 \text{ k}\Omega = 8 \text{ k}\Omega, R''_T = 2 \text{ k}\Omega \parallel R'_T = 2 \text{ k}\Omega \parallel 8 \text{ k}\Omega = 1.6 \text{ k}\Omega$

$$R'''_T = R''_T + 2.4 \text{ k}\Omega = 1.6 \text{ k}\Omega + 2.4 \text{ k}\Omega = 4 \text{ k}\Omega$$

$$R_T = 1 \text{ k}\Omega \parallel R'''_T = 1 \text{ k}\Omega \parallel 4 \text{ k}\Omega = \mathbf{0.8 \text{ k}\Omega}$$

b. $I_s = \frac{E}{R_T} = \frac{48 \text{ V}}{0.8 \text{ k}\Omega} = \mathbf{60 \text{ mA}}$

c. $V = \frac{R''_T E}{R''_T + 2.4 \text{ k}\Omega} = \frac{(1.6 \text{ k}\Omega)(48 \text{ V})}{1.6 \text{ k}\Omega + 2.4 \text{ k}\Omega} = \mathbf{19.2 \text{ V}}$

7. a. $R_T = (R_1 \parallel R_2 \parallel R_3) \parallel (R_6 + R_4 \parallel R_5)$

$$= (12 \text{ k}\Omega \parallel 12 \text{ k}\Omega \parallel 3 \text{ k}\Omega) \parallel (10.4 \text{ k}\Omega + 9 \text{ k}\Omega \parallel 6 \text{ k}\Omega)$$

$$= (6 \text{ k}\Omega \parallel 3 \text{ k}\Omega) \parallel (10.4 \text{ k}\Omega + 3.6 \text{ k}\Omega)$$

$$= 2 \text{ k}\Omega \parallel 14 \text{ k}\Omega = 1.75 \text{ k}\Omega$$

$$I_s = \frac{E}{R_T} = \frac{28 \text{ V}}{1.75 \text{ k}\Omega} = \mathbf{16 \text{ mA}}, \quad I_2 = \frac{E}{R_2} = \frac{28 \text{ V}}{12 \text{ k}\Omega} = \mathbf{2.33 \text{ mA}}$$

$$R' = R_1 \parallel R_2 \parallel R_3 = 2 \text{ k}\Omega$$

$$R'' = R_6 + R_4 \parallel R_5 = 14 \text{ k}\Omega$$

$$I_6 = \frac{R'(I_s)}{R' + R''} = \frac{2 \text{ k}\Omega(16 \text{ mA})}{2 \text{ k}\Omega + 14 \text{ k}\Omega} = \mathbf{2 \text{ mA}}$$

b. $V_1 = E = \mathbf{28 \text{ V}}$

$$R' = R_4 \parallel R_5 = 6 \text{ k}\Omega \parallel 9 \text{ k}\Omega = 3.6 \text{ k}\Omega$$

$$V_5 = I_6 R' = (2 \text{ mA})(3.6 \text{ k}\Omega) = \mathbf{7.2 \text{ V}}$$

c. $P = \frac{V_{R_3}^2}{R_3} = \frac{(28 \text{ V})^2}{3 \text{ k}\Omega} = \mathbf{261.33 \text{ mW}}$

8. a. $R' = R_4 \parallel R_5 \parallel (R_7 + R_8) = 4 \Omega \parallel 8 \Omega \parallel (6 \Omega + 2 \Omega) = 4 \Omega \parallel 8 \Omega \parallel 8 \Omega$
 $= 4 \Omega \parallel 4 \Omega = 2 \Omega$

$$R'' = (R_3 + R') \parallel (R_6 + R_9) = (8 \Omega + 2 \Omega) \parallel (6 \Omega + 4 \Omega)
= 10 \Omega \parallel 10 \Omega = 5 \Omega$$

$$R_T = R_1 \parallel (R_2 + R'') = 10 \Omega \parallel (5 \Omega + 5 \Omega) = 10 \Omega \parallel 10 \Omega = \mathbf{5 \Omega}$$

$$I = \frac{E}{R_T} = \frac{80 \text{ V}}{5 \Omega} = \mathbf{16 \text{ A}}$$

b. $I_{R_2} = \frac{I}{2} = \frac{16 \text{ A}}{2} = \mathbf{8 \text{ A}}$

$$I_3 = I_9 = \frac{8 \text{ A}}{2} = \mathbf{4 \text{ A}}$$

c. $I_8 = \frac{(R_4 \parallel R_5)(I_3)}{(R_4 \parallel R_5) + (R_7 + R_8)}$
 $= \frac{(4 \Omega \parallel 8 \Omega)(4 \text{ A})}{(4 \Omega \parallel 8 \Omega) + (6 \Omega + 2 \Omega)}$
 $= \frac{(2.67)(4 \text{ A})}{2.67 \Omega + 8 \Omega} = \mathbf{1 \text{ A}}$

d. $-I_8R_8 - V_x + I_9R_9 = 0$
 $V_x = I_9R_9 - I_8R_8 = (4 \text{ A})(4 \Omega) - (1 \text{ A})(2 \Omega) = 16 \text{ V} - 2 \text{ V} = \mathbf{14 \text{ V}}$

9. $I_1 = \frac{20 \text{ V}}{5 \Omega} = \mathbf{4 \text{ A}}$
 $R_T = 16 \Omega \parallel 25 \Omega = 9.756 \Omega$
 $I_2 = \frac{7 \text{ V}}{9.756 \Omega} = \mathbf{0.72 \text{ A}}$

10. a, b. $I_1 = \frac{24 \text{ V}}{4 \Omega} = \mathbf{6 \text{ A} \downarrow}, I_3 = \frac{8 \text{ V}}{10 \Omega} = \mathbf{0.8 \text{ A} \uparrow}$
 $I_2 = \frac{24 \text{ V} + 8 \text{ V}}{2 \Omega} = \frac{32 \text{ V}}{2 \Omega} = \mathbf{16 \text{ A}}$
 $I = I_1 + I_2 = 6 \text{ A} + 16 \text{ A} = \mathbf{22 \text{ A} \downarrow}$

11. a. $R' = R_4 + R_5 = 14 \Omega + 6 \Omega = 20 \Omega$
 $R'' = R_2 \parallel R' = 20 \Omega \parallel 20 \Omega = 10 \Omega$
 $R''' = R'' + R_1 = 10 \Omega + 10 \Omega = 20 \Omega$
 $R_T = R_3 \parallel R''' = 5 \Omega \parallel 20 \Omega = \mathbf{4 \Omega}$
 $I_s = \frac{E}{R_T} = \frac{20 \text{ V}}{4 \Omega} = \mathbf{5 \text{ A}}$
 $I_1 = \frac{20 \text{ V}}{R_1 + R''} = \frac{20 \text{ V}}{10 \Omega + 10 \Omega} = \frac{20 \text{ V}}{20 \Omega} = \mathbf{1 \text{ A}}$
 $I_3 = \frac{20 \text{ V}}{5 \Omega} = \mathbf{4 \text{ A}}$
 $I_4 = \frac{I_1}{2} = (\text{since } R' = R_2) = \frac{1 \text{ A}}{2} = \mathbf{0.5 \text{ A}}$

b. $V_a = I_3R_3 - I_4R_5 = (4 \text{ A})(5 \Omega) - (0.5 \text{ A})(6 \Omega) = 20 \text{ V} - 3 \text{ V} = \mathbf{17 \text{ V}}$
 $V_{bc} = \left(\frac{I_1}{2}\right)R_2 = (0.5 \text{ A})(20 \Omega) = \mathbf{10 \text{ V}}$

12. a. $I_1 = \frac{E}{R_1 + R_4 \parallel (R_2 + R_3 \parallel R_5)} = \frac{20 \text{ V}}{3 \Omega + 3 \Omega \parallel (3 \Omega + 6 \Omega \parallel 6 \Omega)}$
 $= \frac{20 \text{ V}}{3 \Omega + 3 \Omega \parallel (3 \Omega + 3 \Omega)} = \frac{20 \text{ V}}{3 \Omega + 3 \Omega \parallel 6 \Omega} = \frac{20 \text{ V}}{3 \Omega + 2 \Omega}$
 $= \mathbf{4 \text{ A}}$

b. CDR: $I_2 = \frac{R_4(I_1)}{R_4 + R_2 + R_3 \parallel R_5} = \frac{3 \Omega(4 \text{ A})}{3 \Omega + 3 \Omega + 6 \Omega \parallel 6 \Omega}$

$$= \frac{12 \text{ A}}{6+3} = \mathbf{1.33 \text{ A}}$$

$$I_3 = \frac{I_2}{2} = \mathbf{0.67 \text{ A}}$$

c. $I_4 = I_1 - I_2 = 4 \text{ A} - 1.33 \text{ A} = 2.67 \text{ A}$
 $V_a = I_4 R_4 = (2.67 \text{ A})(3 \Omega) = \mathbf{8 \text{ V}}$
 $V_b = I_3 R_3 = (0.67 \text{ A})(6 \Omega) = \mathbf{4 \text{ V}}$

13. a. $I_E = \frac{V_E}{R_E} = \frac{2 \text{ V}}{1 \text{ k}\Omega} = \mathbf{2 \text{ mA}}$
 $I_C = I_E = \mathbf{2 \text{ mA}}$

b. $I_B = \frac{V_{R_B}}{R_B} = \frac{V_{CC} - (V_{BE} + V_E)}{R_B} = \frac{8 \text{ V} - (0.7 \text{ V} + 2 \text{ V})}{220 \text{ k}\Omega}$
 $= \frac{8 \text{ V} - 2.7 \text{ V}}{220 \text{ k}\Omega} = \frac{5.3 \text{ V}}{220 \text{ k}\Omega} = \mathbf{24 \mu\text{A}}$

c. $V_B = V_{BE} + V_E = \mathbf{2.7 \text{ V}}$
 $V_C = V_{CC} - I_C R_C = 8 \text{ V} - (2 \text{ mA})(2.2 \text{ k}\Omega) = 8 \text{ V} - 4.4 \text{ V} = \mathbf{3.6 \text{ V}}$

d. $V_{CE} = V_C - V_E = 3.6 \text{ V} - 2 \text{ V} = \mathbf{1.6 \text{ V}}$
 $V_{BC} = V_B - V_C = 2.7 \text{ V} - 3.6 \text{ V} = \mathbf{-0.9 \text{ V}}$

14. a. $I_G = 0 \therefore V_G = \frac{270 \text{ k}\Omega(16 \text{ V})}{270 \text{ k}\Omega + 2000 \text{ k}\Omega} = \mathbf{1.9 \text{ V}}$
 $V_G - V_{GS} - V_S = 0$
 $V_S = V_G - V_{GS} = 1.9 \text{ V} - (-1.75 \text{ V}) = \mathbf{3.65 \text{ V}}$

b. $I_1 = I_2 = \frac{16 \text{ V}}{270 \text{ k}\Omega + 2000 \text{ k}\Omega} = \mathbf{7.05 \mu\text{A}}$
 $I_D = I_S = \frac{V_S}{R_S} = \frac{3.65 \text{ V}}{1.5 \text{ k}\Omega} = \mathbf{2.43 \text{ mA}}$

c. $V_{DS} = V_{DD} - I_D R_D - I_S R_S = V_{DD} - I_D(R_D + R_S)$ since $I_D = I_S$
 $= 16 \text{ V} - (2.43 \text{ mA})(4 \text{ k}\Omega) = 16 \text{ V} - 9.72 \text{ V} = \mathbf{6.28 \text{ V}}$

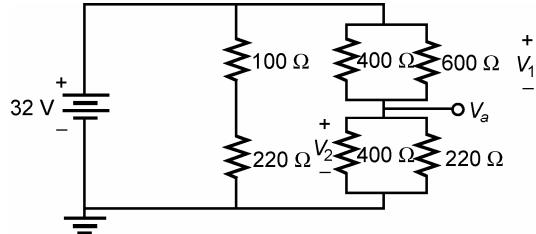
d. $V_{DD} - I_D R_D - V_{DG} - V_G = 0$
 $V_{DG} = V_{DD} - I_D R_D - V_G$
 $= 16 \text{ V} - (2.43 \text{ mA})(2.5 \text{ k}\Omega) - 1.9 \text{ V} = 16 \text{ V} - 6.08 \text{ V} - 1.9 \text{ V} = \mathbf{8.02 \text{ V}}$

15.

a.

Network redrawn:

$$\begin{aligned}100\ \Omega + 220\ \Omega &= 320\ \Omega \\400\ \Omega \parallel 600\ \Omega &= 240\ \Omega \\400\ \Omega \parallel 220\ \Omega &= 141.94\ \Omega \\240\ \Omega + 141.94\ \Omega &= 381.94\ \Omega\end{aligned}$$



$$R_T = 320\ \Omega \parallel 381.94\ \Omega = \mathbf{174.12\ \Omega}$$

b. $V_a = \frac{141.94\ \Omega(32\text{ V})}{141.94\ \Omega + 240\ \Omega} = \mathbf{11.89\ V}$

c. $V_1 = 32\text{ V} - V_a = 32\text{ V} - 11.89\text{ V} = \mathbf{20.11\ V}$

d. $V_2 = V_a = \mathbf{11.89\ V}$

e. $I_{600\Omega} = \frac{20.11\text{ V}}{600\ \Omega} = 33.52\text{ mA}$

$$I_{220\Omega} = \frac{11.89\text{ V}}{220\ \Omega} = 54.05\text{ mA}$$

$$I + I_{600\Omega} = I_{220\Omega}$$

$$\begin{aligned}I &= I_{220\Omega} - I_{600\Omega} \\&= 54.05\text{ mA} - 33.52\text{ mA} \\&= \mathbf{20.53\ mA} \rightarrow\end{aligned}$$

16.

a. $I = \frac{E_1}{R_2 + R_3} = \frac{9\text{ V}}{7\ \Omega + 8\ \Omega} = \mathbf{0.6\ A}$

b. $E_1 - V_1 + E_2 = 0$
 $V_1 = E_1 + E_2 = 9\text{ V} + 19\text{ V} = \mathbf{28\ V}$

17.

a. R_8 "shorted out"

$$\begin{aligned}R' &= R_3 + R_4 \parallel R_5 + R_6 \parallel R_7 \\&= 10\ \Omega + 6\ \Omega \parallel 6\ \Omega + 6\ \Omega \parallel 3\ \Omega \\&= 10\ \Omega + 3\ \Omega + 2\ \Omega \\&= 15\ \Omega\end{aligned}$$

$$\begin{aligned}R_T &= R_1 + R_2 \parallel R' \\&= 10\ \Omega + 30\ \Omega \parallel 15\ \Omega = 10\ \Omega + 10\ \Omega \\&= 20\ \Omega\end{aligned}$$

$$I = \frac{E}{R_T} = \frac{100\text{ V}}{20\ \Omega} = 5\text{ A}$$

$$I_2 = \frac{R'(I)}{R' + R_2} = \frac{(15\ \Omega)(5\text{ A})}{15\ \Omega + 30\ \Omega} = \mathbf{1.67\ A}$$

$$I_3 = I - I_2 = 5 \text{ A} - 1\frac{2}{3} \text{ A} = 3\frac{1}{3} \text{ A}$$

$$I_6 = \frac{R_7 I_3}{R_7 + R_6} = \frac{3\Omega \left(\frac{10}{3} \text{ A} \right)}{3\Omega + 6\Omega} = 1.11 \text{ A}$$

$$I_8 = 0 \text{ A}$$

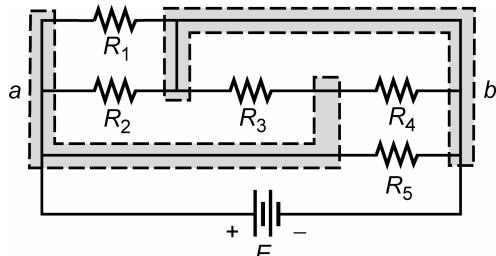
b. $V_4 = I_3(R_4 \parallel R_5) = \left(\frac{10}{3} \text{ A} \right)(3 \Omega) = 10 \text{ V}$
 $V_8 = 0 \text{ V}$

18. $8 \Omega \parallel 8 \Omega = 4 \Omega$

$$I = \frac{30 \text{ V}}{4\Omega + 6\Omega} = \frac{30 \text{ V}}{10\Omega} = 3 \text{ A}$$

$$V = I(8 \Omega \parallel 8 \Omega) = (3 \text{ A})(4 \Omega) = 12 \text{ V}$$

19. a. All resistors in parallel (between terminals a & b)



$$R_T = \underbrace{16 \Omega \parallel 16 \Omega}_{8 \Omega \parallel 8 \Omega} \parallel 8 \Omega \parallel 4 \Omega \parallel 32 \Omega$$

$$\underbrace{8 \Omega \parallel 8 \Omega}_{4 \Omega \parallel 4 \Omega} \parallel 4 \Omega \parallel 32 \Omega$$

$$\underbrace{4 \Omega \parallel 4 \Omega}_{2 \Omega} \parallel 32 \Omega$$

$$2 \Omega \parallel 32 \Omega = 1.88 \Omega$$

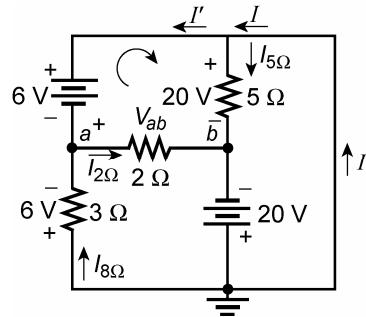
b. All in parallel. Therefore, $V_1 = V_4 = E = 32 \text{ V}$

c. $I_3 = V_3/R_3 = 32 \text{ V}/4 \Omega = 8 \text{ A} \leftarrow$

d. $I_s = I_1 + I_2 + I_3 + I_4 + I_5$
 $= \frac{32 \text{ V}}{16 \Omega} + \frac{32 \text{ V}}{8 \Omega} + \frac{32 \text{ V}}{4 \Omega} + \frac{32 \text{ V}}{32 \Omega} + \frac{32 \text{ V}}{16 \Omega}$
 $= 2 \text{ A} + 4 \text{ A} + 8 \text{ A} + 1 \text{ A} + 2 \text{ A}$
 $= 17 \text{ A}$

$$R_T = \frac{E}{I_s} = \frac{32 \text{ V}}{17 \text{ A}} = 1.88 \Omega \text{ as above}$$

20. a.



$$\text{KVL: } +6\text{ V} - 20\text{ V} + V_{ab} = 0$$

$$V_{ab} = +20\text{ V} - 6\text{ V} = \mathbf{14\text{ V}}$$

b. $I_{5\Omega} = \frac{20\text{ V}}{5\Omega} = 4\text{ A}$

$$I_{2\Omega} = \frac{V_{ab}}{2\Omega} = \frac{14\text{ V}}{2\Omega} = 7\text{ A}$$

$$I_{3\Omega} = \frac{6\text{ V}}{3\Omega} = 2\text{ A}$$

$$I' + I_{3\Omega} = I_{2\Omega}$$

$$\text{and } I' = I_{2\Omega} - I_{3\Omega} = 7\text{ A} - 2\text{ A} = 5\text{ A}$$

$$I = I' + I_{5\Omega} = 5\text{ A} + 4\text{ A} = \mathbf{9\text{ A}}$$

21. a. Applying Kirchoff's voltage law in the CCW direction in the upper "window":

$$+18\text{ V} + 20\text{ V} - V_{8\Omega} = 0$$

$$V_{8\Omega} = 38\text{ V}$$

$$I_{8\Omega} = \frac{38\text{ V}}{8\Omega} = 4.75\text{ A}$$

$$I_{3\Omega} = \frac{18\text{ V}}{3\Omega + 6\Omega} = \frac{18\text{ V}}{9\Omega} = 2\text{ A}$$

$$\text{KCL: } I_{18\text{V}} = 4.75\text{ A} + 2\text{ A} = \mathbf{6.75\text{ A}}$$

b. $V = (I_{3\Omega})(6\Omega) + 20\text{ V} = (2\text{ A})(6\Omega) + 20\text{ V} = 12\text{ V} + 20\text{ V} = \mathbf{32\text{ V}}$

22. $I_2R_2 = I_3R_3$ and $I_2 = \frac{I_3R_3}{R_2} = \frac{2R_3}{20} = \frac{R_3}{10}$ (since the voltage across parallel elements is the same)

$$I_1 = I_2 + I_3 = \frac{R_3}{10} + 2$$

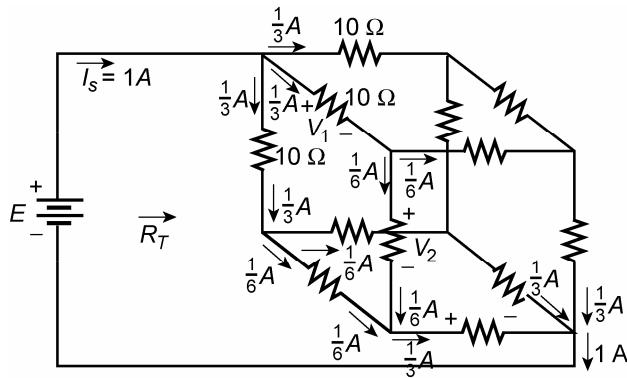
$$\text{KVL: } 120 = I_1 12 + I_3 R_3 = \left(\frac{R_3}{10} + 2 \right) 12 + 2R_3$$

$$\text{and } 120 = 1.2R_3 + 24 + 2R_3$$

$$3.2R_3 = 96\text{ }\Omega$$

$$R_3 = \frac{96\text{ }\Omega}{3.2} = \mathbf{30\text{ }\Omega}$$

23. Assuming $I_s = 1$ A, the current I_s will divide as determined by the load appearing in each branch. Since balanced I_s will split equally between all three branches.



$$V_1 = \left(\frac{1}{3} A \right) (10 \Omega) = \frac{10}{3} V$$

$$V_2 = \left(\frac{1}{6} A \right) (10 \Omega) = \frac{10}{6} V$$

$$V_3 = \left(\frac{1}{3} A\right)(10 \Omega) = \frac{10}{3} V$$

$$E = V_1 + V_2 + V_3 = \frac{10}{3} \text{ V} + \frac{10}{6} \text{ V} + \frac{10}{3} \text{ V} = 8.33 \text{ V}$$

$$R_T = \frac{E}{I} = \frac{8.33 \text{ V}}{1 \text{ A}} = 8.33 \Omega$$

- $$24. \quad 36 \text{ k}\Omega \parallel 6 \text{ k}\Omega \parallel 12 \text{ k}\Omega = 3.6 \text{ k}\Omega$$

$$V = \frac{3.6 \text{ k}\Omega(45 \text{ V})}{3.6 \text{ k}\Omega + 6 \text{ k}\Omega} = 16.88 \text{ V} \neq 27 \text{ V}. \text{ Therefore, not operating properly!}$$

6 k Ω resistor "open"

$$R' = 12 \text{ k}\Omega \parallel 36 \text{ k}\Omega = 9 \text{ k}\Omega, V = \frac{R'(45 \text{ V})}{R' + 6 \text{ k}\Omega} = \frac{9 \text{ k}\Omega(45 \text{ V})}{9 \text{ k}\Omega + 6 \text{ k}\Omega} = 27 \text{ V}$$

- $$\begin{aligned}
 25. \quad a. \quad & R'_T = R_5 \parallel (R_6 + R_7) = 6 \Omega \parallel 3 \Omega = 2 \Omega \\
 & R''_T = R_3 \parallel (R_4 + R'_T) = 4 \Omega \parallel (2 \Omega + 2 \Omega) = 2 \Omega \\
 & R_T = R_1 + R_2 + R''_T = 3 \Omega + 5 \Omega + 2 \Omega = 10 \Omega \\
 & I = \frac{240 \text{ V}}{10 \Omega} = 24 \text{ A}
 \end{aligned}$$

$$b. \quad I_4 = \frac{4\Omega(I)}{4\Omega + 4\Omega} = \frac{4\Omega(24\text{ A})}{8\Omega} = 12\text{ A}$$

$$I_7 = \frac{6\Omega(12\text{ A})}{6\Omega + 3\Omega} = \frac{72\text{ A}}{9} = 8\text{ A}$$

c. $V_3 = I_3 R_3 = (I - I_4)R_3 = (24 \text{ A} - 12 \text{ A})4 \Omega = 48 \text{ V}$
 $V_5 = I_5 R_5 = (I_4 - I_7)R_5 = (4 \text{ A})6 \Omega = 24 \text{ V}$
 $V_7 = I_7 R_7 = (8 \text{ A})2 \Omega = 16 \text{ V}$

d. $P = I_7^2 R_7 = (8 \text{ A})^2 2 \Omega = 128 \text{ W}$
 $P = EI = (240 \text{ V})(24 \text{ A}) = 5760 \text{ W}$

26. a. $R'_T = R_4 \parallel (R_6 + R_7 + R_8) = 2 \Omega \parallel 7 \Omega = 1.56 \Omega$
 $R''_T = R_2 \parallel (R_3 + R_5 + R'_T) = 2 \Omega \parallel (4 \Omega + 1 \Omega + 1.56 \Omega) = 1.53 \Omega$
 $R_T = R_1 + R''_T = 4 \Omega + 1.53 \Omega = 5.53 \Omega$

b. $I = 2 \text{ V}/5.53 \Omega = 361.66 \text{ mA}$

c. $I_3 = \frac{2 \Omega(I)}{2 \Omega + 6.56 \Omega} = \frac{2 \Omega(361.66 \text{ mA})}{2 \Omega + 6.56 \Omega} = 84.50 \text{ mA}$
 $I_8 = \frac{2 \Omega(84.5 \text{ mA})}{2 \Omega + 7 \Omega} = 18.78 \text{ mA}$

27. The 12 Ω resistors are in parallel.

Network redrawn:

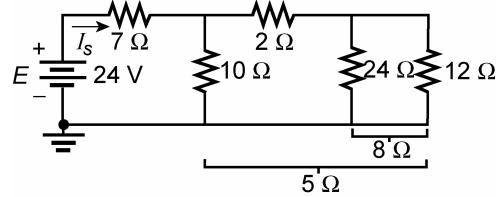
$$R_T = 12 \Omega$$

$$I_s = \frac{E}{R_T} = \frac{24 \text{ V}}{12 \Omega} = 2 \text{ A}$$

$$I_{2\Omega} = \frac{I_s}{2} = \frac{2 \text{ A}}{2} = 1 \text{ A}$$

$$I_{12\Omega} = \frac{24 \Omega(I_{2\Omega})}{24 \Omega + 12 \Omega} = \frac{2}{3} \text{ A}$$

$$P_{10\Omega} = (I_{10\Omega})^2 10 \Omega = \left(\frac{2}{3} \text{ A}\right)^2 \cdot 10 \Omega = 4.44 \text{ W}$$



28. a. $R_{10} + R_{11} \parallel R_{12} = 1 \Omega + 2 \Omega \parallel 2 \Omega = 2 \Omega$
 $R_4 \parallel (R_5 + R_6) = 10 \Omega \parallel 10 \Omega = 5 \Omega$
 $R_1 + R_2 \parallel (R_3 + 5 \Omega) = 3 \Omega + 6 \Omega \parallel 6 \Omega = 6 \Omega$
 $R_T = 2 \Omega \parallel 3 \Omega \parallel 6 \Omega = 2 \Omega \parallel 2 \Omega = 1 \Omega$
 $I = 12 \text{ V}/1 \Omega = 12 \text{ A}$

b. $I_1 = 12 \text{ V}/6 \Omega = 2 \text{ A}$
 $I_3 = \frac{6 \Omega(2 \text{ A})}{6 \Omega + 6 \Omega} = 1 \text{ A}$
 $I_4 = \frac{1 \text{ A}}{2} = 0.5 \text{ A}$

c. $I_6 = I_4 = 0.5 \text{ A}$

d. $I_{10} = \frac{12 \text{ A}}{2} = 6 \text{ A}$

29. a. $E = (40 \text{ mA})(1.6 \text{ k}\Omega) = \mathbf{64 \text{ V}}$

b. $R_{L_2} = \frac{48 \text{ V}}{12 \text{ mA}} = \mathbf{4 \text{ k}\Omega}$

$$R_{L_3} = \frac{24 \text{ V}}{8 \text{ mA}} = \mathbf{3 \text{ k}\Omega}$$

c. $I_{R_1} = 72 \text{ mA} - 40 \text{ mA} = 32 \text{ mA}$

$$I_{R_2} = 32 \text{ mA} - 12 \text{ mA} = 20 \text{ mA}$$

$$I_{R_3} = 20 \text{ mA} - 8 \text{ mA} = 12 \text{ mA}$$

$$R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{64 \text{ V} - 48 \text{ V}}{32 \text{ mA}} = \frac{16 \text{ V}}{32 \text{ mA}} = \mathbf{0.5 \text{ k}\Omega}$$

$$R_2 = \frac{V_{R_2}}{I_{R_2}} = \frac{48 \text{ V} - 24 \text{ V}}{20 \text{ mA}} = \frac{24 \text{ V}}{20 \text{ mA}} = \mathbf{1.2 \text{ k}\Omega}$$

$$R_3 = \frac{V_{R_3}}{I_{R_3}} = \frac{24 \text{ V}}{12 \text{ mA}} = \mathbf{2 \text{ k}\Omega}$$

30. $I_{R_1} = 40 \text{ mA}$

$$I_{R_2} = 40 \text{ mA} - 10 \text{ mA} = 30 \text{ mA}$$

$$I_{R_3} = 30 \text{ mA} - 20 \text{ mA} = 10 \text{ mA}$$

$$I_{R_5} = 40 \text{ mA}$$

$$I_{R_4} = 40 \text{ mA} - 4 \text{ mA} = 36 \text{ mA}$$

$$R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{120 \text{ V} - 100 \text{ V}}{40 \text{ mA}} = \frac{20 \text{ V}}{40 \text{ mA}} = \mathbf{0.5 \text{ k}\Omega}$$

$$R_2 = \frac{V_{R_2}}{I_{R_2}} = \frac{100 \text{ V} - 40 \text{ V}}{30 \text{ mA}} = \frac{60 \text{ V}}{30 \text{ mA}} = \mathbf{2 \text{ k}\Omega}$$

$$R_3 = \frac{V_{R_3}}{I_{R_3}} = \frac{40 \text{ V}}{10 \text{ mA}} = \mathbf{4 \text{ k}\Omega}$$

$$R_4 = \frac{V_{R_4}}{I_{R_4}} = \frac{36 \text{ V}}{36 \text{ mA}} = \mathbf{1 \text{ k}\Omega}$$

$$R_5 = \frac{V_{R_5}}{I_{R_5}} = \frac{60 \text{ V} - 36 \text{ V}}{40 \text{ mA}} = \frac{24 \text{ V}}{40 \text{ mA}} = \mathbf{0.6 \text{ k}\Omega}$$

$$P_1 = I_1^2 R_1 = (40 \text{ mA})^2 0.5 \text{ k}\Omega = \mathbf{0.8 \text{ W}} \text{ (1 watt resistor)}$$

$$P_2 = I_2^2 R_2 = (30 \text{ mA})^2 2 \text{ k}\Omega = \mathbf{1.8 \text{ W}} \text{ (2 watt resistor)}$$

$$P_3 = I_3^2 R_3 = (10 \text{ mA})^2 4 \text{ k}\Omega = \mathbf{0.4 \text{ W}} \text{ (1/2 watt or 1 watt resistor)}$$

$$P_4 = I_4^2 R_4 = (36 \text{ mA})^2 1 \text{ k}\Omega = \mathbf{1.3 \text{ W}} \text{ (2 watt resistor)}$$

$$P_5 = I_5^2 R_5 = (40 \text{ mA})^2 0.6 \text{ k}\Omega = \mathbf{0.96 \text{ W}} \text{ (1 watt resistor)}$$

All power levels less than **2 W**. Four less than **1 W**.

31. a. **yes, $R_L \gg R_{\max}$** (potentiometer)

$$\text{b. VDR: } V_{R_2} = 3 \text{ V} = \frac{R_2(12 \text{ V})}{R_1 + R_2} = \frac{R_2(12 \text{ V})}{1 \text{ k}\Omega}$$

$$R_2 = \frac{3 \text{ V}(1 \text{ k}\Omega)}{12 \text{ V}} = 0.25 \text{ k}\Omega = \mathbf{250 \Omega}$$

$$R_1 = 1 \text{ k}\Omega - 0.25 \text{ k}\Omega = 0.75 \text{ k}\Omega = \mathbf{750 \Omega}$$

$$\text{c. } V_{R_1} = E - V_L = 12 \text{ V} - 3 \text{ V} = 9 \text{ V} \quad (\text{Chose } V_{R_1} \text{ rather than } V_{R_2 \parallel R_L} \text{ since numerator of VDR})$$

$$V_{R_1} = 9 \text{ V} = \frac{R_1(12 \text{ V})}{R_1 + (R_2 \parallel R_L)} \quad \text{equation "cleaner")}$$

$$9R_1 + 9(R_2 \parallel R_L) = 12R_1$$

$$\left. \begin{array}{l} R_1 = 3(R_2 \parallel R_L) \\ R_1 + R_2 = 1 \text{ k}\Omega \end{array} \right\} 2 \text{ eq. 2 unk}(R_L = 10 \text{ k}\Omega)$$

$$R_1 = \frac{3R_2 R_L}{R_2 + R_L} \Rightarrow \frac{3R_2}{R_2 + 10 \text{ k}\Omega} 10 \text{ k}\Omega$$

$$\text{and } R_1(R_2 + 10 \text{ k}\Omega) = 30 \text{ k}\Omega R_2$$

$$R_1 R_2 + 10 \text{ k}\Omega R_1 = 30 \text{ k}\Omega R_2$$

$$R_1 + R_2 = 1 \text{ k}\Omega: (1 \text{ k}\Omega - R_2)R_2 + 10 \text{ k}\Omega (1 \text{ k}\Omega - R_2) = 30 \text{ k}\Omega R_2$$

$$R_2^2 + 39 \text{ k}\Omega R_2 - 10 \text{ k}\Omega^2 = 0$$

$$R_2 = 0.255 \text{ k}\Omega, -39.255 \text{ k}\Omega$$

$$R_2 = \mathbf{255 \Omega}$$

$$R_1 = 1 \text{ k}\Omega - R_2 = \mathbf{745 \Omega}$$

32. a. $V_{ab} = \frac{80 \text{ }\Omega(40 \text{ V})}{100 \text{ }\Omega} = \mathbf{32 \text{ V}}$

$$V_{bc} = 40 \text{ V} - 32 \text{ V} = \mathbf{8 \text{ V}}$$

$$\text{b. } 80 \text{ }\Omega \parallel 1 \text{ k}\Omega = 74.07 \text{ }\Omega$$

$$20 \text{ }\Omega \parallel 10 \text{ k}\Omega = 19.96 \text{ }\Omega$$

$$V_{ab} = \frac{74.07 \text{ }\Omega(40 \text{ V})}{74.07 \text{ }\Omega + 19.96 \text{ }\Omega} = \mathbf{31.51 \text{ V}}$$

$$V_{bc} = 40 \text{ V} - 31.51 \text{ V} = \mathbf{8.49 \text{ V}}$$

c. $P = \frac{(31.51\text{ V})^2}{80\Omega} + \frac{(8.49\text{ V})^2}{20\Omega} = 12.411\text{ W} + 3.604\text{ W} = \mathbf{16.02\text{ W}}$

d. $P = \frac{(32\text{ V})^2}{80\Omega} + \frac{(8\text{ V})^2}{20\Omega} = 12.8\text{ W} + 3.2\text{ W} = \mathbf{16\text{ W}}$

The applied loads dissipate less than 20 mW of power.

33. a. $I_{CS} = \mathbf{1\text{ mA}}$

b. $R_{\text{shunt}} = \frac{R_m I_{CS}}{I_{\max} - I_{CS}} = \frac{(100\Omega)(1\text{ mA})}{20\text{ A} - 1\text{ mA}} \cong \frac{0.1}{20} \Omega = \mathbf{5\text{ m}\Omega}$

34. 25 mA: $R_{\text{shunt}} = \frac{(1\text{ k}\Omega)(50\text{ }\mu\text{A})}{25\text{ mA} - 0.05\text{ mA}} \cong \mathbf{2\text{ }\Omega}$

50 mA: $R_{\text{shunt}} = \frac{(1\text{ k}\Omega)(50\text{ }\mu\text{A})}{50\text{ mA} - 0.05\text{ mA}} = \mathbf{1\text{ }\Omega}$

100 mA: $R_{\text{shunt}} \cong \mathbf{0.5\text{ }\Omega}$

35. a. $R_s = \frac{V_{\max} - V_{VS}}{I_{CS}} = \frac{15\text{ V} - (50\text{ }\mu\text{A})(1\text{ k}\Omega)}{50\text{ }\mu\text{A}} = \mathbf{300\text{ k}\Omega}$

b. $\Omega/\text{V} = 1/I_{CS} = 1/50\text{ }\mu\text{A} = \mathbf{20,000}$

36. 5 V: $R_s = \frac{5\text{ V} - (1\text{ mA})(100\Omega)}{1\text{ mA}} = \mathbf{4.9\text{ k}\Omega}$

50 V: $R_s = \frac{50\text{ V} - 0.1\text{ V}}{1\text{ mA}} = \mathbf{49.9\text{ k}\Omega}$

500 V: $R_s = \frac{500\text{ V} - 0.1\text{ V}}{1\text{ mA}} = \mathbf{499.9\text{ k}\Omega}$

37. $10\text{ M}\Omega = (0.5\text{ V})(\Omega/\text{V}) \Rightarrow \Omega/\text{V} = 20 \times 10^6$

$$I_{CS} = 1/(\Omega/\text{V}) = \frac{1}{20 \times 10^6} = \mathbf{0.05\text{ }\mu\text{A}}$$

38. a. $R_s = \frac{E}{I_m} - R_m - \frac{\text{zero adjust}}{2} = \frac{3\text{ V}}{100\text{ }\mu\text{A}} - 1\text{ k}\Omega - \frac{2\text{ k}\Omega}{2} = \mathbf{28\text{ k}\Omega}$

$$\begin{aligned}
 b. \quad xI_m &= \frac{E}{R_{\text{series}}} + R_m + \frac{\text{zero adjust}}{2} + R_{\text{unk}} \\
 R_{\text{unk}} &= \frac{E}{xI_m} - \left(R_{\text{series}} + R_m + \frac{\text{zero adjust}}{2} \right) \\
 &= \frac{3 \text{ V}}{x100 \mu\text{A}} - 30 \text{ k}\Omega \Rightarrow \frac{30 \times 10^3}{x} - 30 \times 10^3 \\
 x &= \frac{3}{4}, R_{\text{unk}} = 10 \text{ k}\Omega; x = \frac{1}{2}, R_{\text{unk}} = 30 \text{ k}\Omega; x = \frac{1}{4}, R_{\text{unk}} = 90 \text{ k}\Omega
 \end{aligned}$$

39. —

40. a. Carefully redrawing the network will reveal that all three resistors are in parallel and $R_T = \frac{R}{N} = \frac{12 \Omega}{3} = 4 \Omega$
- b. Again, all three resistors are in parallel and $R_T = \frac{R}{N} = \frac{18 \Omega}{3} = 6 \Omega$

Chapter 8

1. a. $I_2 = I_3 = 10 \text{ mA}$
 b. $V_1 = I_1 R_1 = (10 \text{ mA})(1 \text{ k}\Omega) = 10 \text{ V}$
 c. $R_T = 1 \text{ k}\Omega + 2.2 \text{ k}\Omega + 0.56 \text{ k}\Omega = 3.76 \text{ k}\Omega$
 $V_s = IR_T = (10 \text{ mA})(3.76 \text{ k}\Omega) = 37.6 \text{ V}$
2. a. $I_2 = \frac{R_s(I)}{R_s + R_1 + R_2} = \frac{10 \text{ k}\Omega(4 \text{ A})}{10 \text{ k}\Omega + 10 \Omega} = 3.996 \text{ A}, I_2 \approx I$
 b. $V_2 = I_2 R_2 = (3.996 \text{ A})(6 \Omega) = 23.98 \text{ V}$
 c. $V_s = I_2(R_1 + R_2) = (3.996 \text{ A})(10 \Omega) = 39.96 \text{ V}$
3. $V_{R_1} = IR_1 = (6 \text{ A})(3 \Omega) = 18 \text{ V}$
 $E + V_{R_1} - V_s = 0, V_s = E + V_{R_1} = 10 \text{ V} + 18 \text{ V} = 28 \text{ V}$
4. a. $V_s = E = 24 \text{ V}$
 b. $I_2 = \frac{E}{R_1 + R_2} = \frac{24 \text{ V}}{1 \Omega + 3 \Omega} = \frac{24 \text{ V}}{4 \Omega} = 6 \text{ A}$
 c. $I + I_s = I_2, I_s = I_2 - I = 6 \text{ A} - 2 \text{ A} = 4 \text{ A}$
5. $V_I = V_2 = V_s = IR_T = 0.6 \text{ A}[6 \Omega \parallel 24 \Omega \parallel 24 \Omega] = 0.6 \text{ A}[6 \Omega \parallel 12 \Omega] = 2.4 \text{ V}$
 $I_2 = \frac{V_2}{R_2} = \frac{2.4 \text{ V}}{24 \Omega} = 0.1 \text{ A}$
 $V_3 = \frac{R_3 V_s}{R_3 + R_4} = \frac{16 \Omega(2.4 \text{ V})}{24 \Omega} = 1.6 \text{ V}$
6. a. $I_1 = \frac{E}{R_1} = \frac{24 \text{ V}}{2 \Omega} = 12 \text{ A}, I_{R_2} = \frac{E}{R_2 + R_3} = \frac{24 \text{ V}}{6 \Omega + 2 \Omega} = \frac{24 \Omega}{8 \Omega} = 3 \text{ A}$
 KCL: $I + I_s - I_1 - I_{R_2} = 0$
 $I_s = I_1 + I_{R_2} - I = 12 \text{ A} + 3 \text{ A} - 4 \text{ A} = 11 \text{ A}$

 b. $V_s = E = 24 \text{ V}$
 VDR: $V_3 = \frac{R_3 E}{R_2 + R_3} = \frac{2 \Omega(24 \text{ V})}{6 \Omega + 2 \Omega} = \frac{48 \text{ V}}{8 \Omega} = 6 \text{ V}$
7. a. $I = \frac{E}{R_s} = \frac{18 \text{ V}}{6 \Omega} = 3 \text{ A}, R_p = R_s = 6 \Omega$
 b. $I = \frac{E}{R_s} = \frac{9 \text{ V}}{2.2 \text{ k}\Omega} = 4.09 \text{ mA}, R_p = R_s = 2.2 \text{ k}\Omega$

8. a. $E = IR_s = (1.5 \text{ A})(3 \Omega) = \mathbf{4.5 \text{ V}}, R_s = \mathbf{3 \Omega}$

b. $E = IR_s = (6 \text{ mA})(4.7 \text{ k}\Omega) = \mathbf{28.2 \text{ V}}, R_s = \mathbf{4.7 \text{ k}\Omega}$

9. a. CDR: $I_L = \frac{R_s(I)}{R_s + R_L} = \frac{100 \Omega(12 \text{ A})}{100 \Omega + 2 \Omega} = \mathbf{11.76 \text{ A}}, I_L \cong I$

b. $E_s = IR = (12 \text{ A})(100 \Omega) = \mathbf{1.2 \text{ kV}}$
 $R_s = 100 \Omega$

$$I = \frac{E_s}{R_s + R_L} = \frac{1.2 \text{ kV}}{100 \Omega + 2 \Omega} = \mathbf{11.76 \text{ A}}$$

10. a. $E = IR_2 = (2 \text{ A})(6.8 \Omega) = \mathbf{13.6 \text{ V}}, R = \mathbf{6.8 \Omega}$

b. $I_1(\text{CW}) = (12 \text{ V} + 13.6 \text{ V})/(10 \Omega + 6.8 \Omega + 39 \Omega) = \frac{25.6 \text{ V}}{55.8 \Omega} = \mathbf{458.78 \text{ mA}}$

c. $V_{ab} = I_1 R_3 = (458.78 \text{ mA})(39 \Omega) = \mathbf{17.89 \text{ V}}$

11. a. $I_T = 6.8 \text{ A} - 1.2 \text{ A} - 3.6 \text{ A} = \mathbf{2 \text{ A}}$

b. $V_s = I_T \cdot R = (2 \text{ A})(4 \Omega) = \mathbf{8 \text{ V}}$

12. $I_T \uparrow = 7 \text{ A} - 3 \text{ A} = \mathbf{4 \text{ A}}$

CDR: $I_1 = \frac{R_2(I_T)}{R_1 + R_2} = \frac{6 \Omega(4 \text{ A})}{4 \Omega + 6 \Omega} = \mathbf{2.4 \text{ A}}$

$V_2 = I_1 R_1 = (2.4 \text{ A})(4 \Omega) = \mathbf{9.6 \text{ V}}$

13. a. Conversions: $I_1 = E_1/R_1 = 9 \text{ V}/3 \Omega = \mathbf{3 \text{ A}}, R_1 = \mathbf{3 \Omega}$

$$I_2 = E_2/R_2 = 20 \text{ V}/2 \Omega = \mathbf{10 \text{ A}}, R_2 = \mathbf{2 \Omega}$$

b. $I_T \downarrow = 10 \text{ A} - 3 \text{ A} = 7 \text{ A}, R_T = 3 \Omega \parallel 6 \Omega \parallel 2 \Omega \parallel 12 \Omega$

$$= 2 \Omega \parallel 2 \Omega \parallel 12 \Omega$$

$$= 1 \Omega \parallel 12 \Omega$$

$$= 0.92 \Omega$$

$$V_{ab} = -I_T R_T = -(7 \text{ A})(0.92 \Omega) = \mathbf{-6.44 \text{ V}}$$

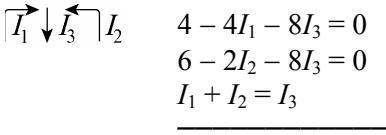
c. $I_3 \uparrow = \frac{6.44 \text{ V}}{6 \Omega} = \mathbf{1.07 \text{ A}}$

14. a. $I = \frac{E}{R_2} = \frac{12 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{5.45 \text{ mA}}, R_p = \mathbf{2.2 \text{ k}\Omega}$

b. $I_T \uparrow = 8 \text{ mA} + 5.45 \text{ mA} - 3 \text{ mA} = 10.45 \text{ mA}$
 $R' = 6.8 \text{ k}\Omega \parallel 2.2 \text{ k}\Omega = 1.66 \text{ k}\Omega$
 $V_1 = I_T R' = (10.45 \text{ mA})(1.66 \text{ k}\Omega) = \mathbf{17.35 \text{ V}}$

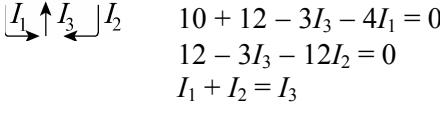
c. $V_1 = V_2 + 12 \text{ V} \Rightarrow V_2 = V_1 - 12 \text{ V} = 17.35 \text{ V} - 12 \text{ V}$
 $= \mathbf{5.35 \text{ V}}$

d. $I_2 = \frac{V_2}{R_2} = \frac{5.35 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{2.43 \text{ mA}}$

15. a. 
 $4 - 4I_1 - 8I_3 = 0$
 $6 - 2I_2 - 8I_3 = 0$
 $I_1 + I_2 = I_3$

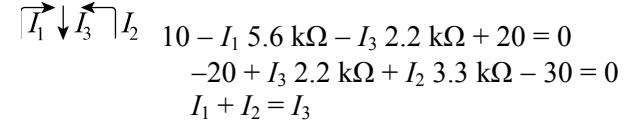
$$I_1 = -\frac{1}{7} \text{ A}, I_2 = \frac{5}{7} \text{ A}, I_3 = \frac{4}{7} \text{ A}$$

$$I_{R_1} = I_1 = -\frac{1}{7} \text{ A}, I_{R_2} = I_2 = \frac{5}{7} \text{ A}, I_{R_3} = I_3 = \frac{4}{7} \text{ A}$$

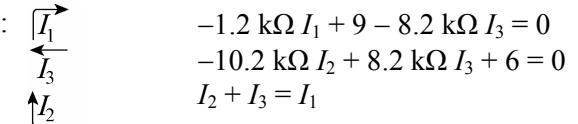
b. 
 $10 + 12 - 3I_3 - 4I_1 = 0$
 $12 - 3I_3 - 12I_2 = 0$
 $I_1 + I_2 = I_3$

$$I_{R_1} = I_1 = \mathbf{3.06 \text{ A}}, I_{R_2} = I_2 = \mathbf{0.19 \text{ A}}$$

$$I_{R_3} = I_3 = \mathbf{3.25 \text{ A}}$$

16. (I): 
 $10 - I_1 5.6 \text{ k}\Omega - I_3 2.2 \text{ k}\Omega + 20 = 0$
 $-20 + I_3 2.2 \text{ k}\Omega + I_2 3.3 \text{ k}\Omega - 30 = 0$
 $I_1 + I_2 = I_3$

$$I_1 = I_{R_1} = \mathbf{1.45 \text{ mA}}, I_2 = I_{R_2} = \mathbf{8.51 \text{ mA}}, I_3 = I_{R_3} = \mathbf{9.96 \text{ mA}}$$

(II): 
 $-1.2 \text{ k}\Omega I_1 + 9 - 8.2 \text{ k}\Omega I_3 = 0$
 $-10.2 \text{ k}\Omega I_2 + 8.2 \text{ k}\Omega I_3 + 6 = 0$
 $I_2 + I_3 = I_1$

$$I_1 = \mathbf{2.03 \text{ mA}}, I_2 = \mathbf{1.23 \text{ mA}}, I_3 = \mathbf{0.8 \text{ mA}}$$

$$I_{R_1} = I_1 = \mathbf{2.03 \text{ mA}}$$

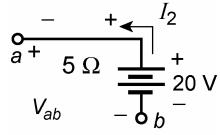
$$I_{R_2} = I_3 = \mathbf{0.8 \text{ mA}}$$

$$I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23 \text{ mA}}$$

17. (I):

$$\begin{array}{l} -25 - 2I_1 - 3I_3 + 60 = 0 \\ -60 + 3I_3 + 6 - 5I_2 - 20 = 0 \\ I_1 = I_2 + I_3 \end{array}$$

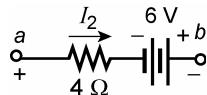
$$I_2 = \mathbf{-8.55 \text{ A}}$$



$$V_{ab} = 20 \text{ V} - I_2 5 \Omega = 20 \text{ V} - (8.55 \text{ A})(5 \Omega) = \mathbf{-22.75 \text{ V}}$$

(II): Source conversion: $E = IR_1 = (3 \text{ A})(3 \Omega) = 9 \text{ V}$, $R_1 = 3 \Omega$

$I_2 = 1.27 \text{ A}$



$$V_{ab} = I_2 4 \Omega - 6 \text{ V} = (1.27 \text{ A})4 \Omega - 6 \text{ V} = \mathbf{-0.92 \text{ V}}$$

18. $I_1 = I_{R_1}$ (CW), $I_2 = I_{R_2}$ (down), $I_3 = I_{R_3}$ (right), $I_4 = I_{R_4}$ (down)
 $I_5 = I_{R_5}$ (CW)

a. $E_1 - I_1 R_1 - I_2 R_2 = 0$
 $I_2 R_2 - I_3 R_3 - I_4 R_4 = 0$
 $I_4 R_4 - I_5 R_5 - E_2 = 0$
 $I_1 = I_2 + I_3$
 $I_3 = I_4 + I_5$

b. $E_1 - I_2(R_1 + R_2) - I_3 R_1 = 0$
 $I_2 R_2 - I_3(R_3 + R_4) + I_5 R_4 = 0$
 $I_3 R_4 - I_5(R_4 + R_5) - E_2 = 0$

c. $I_2(R_1 + R_2) + I_3 R_1 + 0 = E_1$
 $I_2(R_2) - I_3(R_3 + R_4) + I_5 R_4 = 0$
 $0 + I_3 R_4 - I_5(R_4 + R_5) = E_2$

$$\begin{array}{rcl} 3I_2 + 2I_3 + 0 & = 10 \\ 1I_2 - 9I_3 + 5I_5 & = 0 \\ 0 + 5I_3 - 8I_5 & = 6 \end{array}$$

d. $I_3 = I_{R_3} = \mathbf{-63.69 \text{ mA}}$

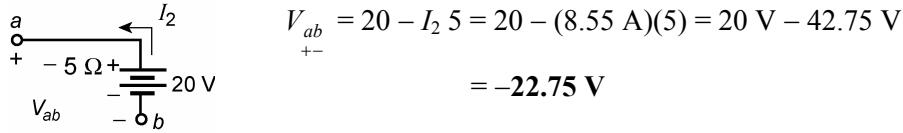
19. a. $20 \text{ V} - I_B(270 \text{ k}\Omega) - 0.7 \text{ V} - I_E(0.51 \text{ k}\Omega) = 0$
 $I_E(0.51 \text{ k}\Omega) + 8 \text{ V} + I_C(2.2 \text{ k}\Omega) - 20 \text{ V} = 0$
 $I_E = I_B + I_C$
-
- $I_B = 63.02 \mu\text{A}, I_C = 4.42 \text{ mA}, I_E = 4.48 \text{ mA}$
- b. $V_B = 20 \text{ V} - I_B(270 \text{ k}\Omega) = 20 \text{ V} - (63.02 \mu\text{A})(270 \text{ k}\Omega) = 20 \text{ V} - 17.02 \text{ V} = 2.98 \text{ V}$
 $V_E = I_E R_E = (4.48 \text{ mA})(510 \Omega) = 2.28 \text{ V}$
 $V_C = 20 \text{ V} - I_C(2.2 \text{ k}\Omega) = 20 \text{ V} - (4.42 \text{ mA})(2.2 \text{ k}\Omega) = 20 \text{ V} - 9.72 \text{ V} = 10.28 \text{ V}$
- c. $\beta \cong I_C/I_B = 4.42 \text{ mA}/63.02 \mu\text{A} = 70.14$
20. a. $\overbrace{I_1}^{\uparrow} \overbrace{I_2}^{\downarrow}$ $4 - 4I_1 - 8(I_1 - I_2) = 0$
 $-8(I_2 - I_1) - 2I_2 - 6 = 0$
-
- $I_1 = -\frac{1}{7} \text{ A}, I_2 = -\frac{5}{7} \text{ A}$
 $I_{R_1} = I_1 = -\frac{1}{7} \text{ A}$
 $I_{R_2} = I_2 = -\frac{5}{7} \text{ A}$
 $I_{R_3} = I_1 - I_2 = \left(-\frac{1}{7} \text{ A}\right) - \left(-\frac{5}{7} \text{ A}\right) = \frac{4}{7} \text{ A} \text{ (dir. of } I_1)$
- b. $\overbrace{I_1}^{\uparrow} \overbrace{I_2}^{\downarrow}$ $-10 - 4I_1 - 3(I_1 - I_2) - 12 = 0$
 $12 - 3(I_2 - I_1) - 12I_2 = 0$
-
- $I_1 = -3.06 \text{ A}, I_2 = 0.19 \text{ A}$
- $I_{R_1} = I_1 = -3.06 \text{ A}$
 $I_{R_3} = I_2 = 0.19 \text{ A}$
 $I_{R_2} = I_1 - I_2 = (-3.06 \text{ A}) - (0.19 \text{ A}) = -3.25 \text{ A}$
21. (I): $\overbrace{I_1}^{\uparrow} \overbrace{I_2}^{\downarrow}$ $10 - I_1(5.6 \text{ k}\Omega) - 2.2 \text{ k}\Omega(I_1 - I_2) + 20 = 0$
 $-20 - 2.2 \text{ k}\Omega(I_2 - I_1) - I_2 3.3 \text{ k}\Omega - 30 = 0$
-
- $I_1 = 1.45 \text{ mA}, I_2 = 8.51 \text{ mA}$
 $I_{R_1} = I_1 = 1.45 \text{ mA}, I_{R_2} = I_2 = 8.51 \text{ mA}$
 $I_{R_3} = I_2 - I_1 = 7.06 \text{ mA} \text{ (direction of } I_2)$

$$(II): \quad \begin{array}{l} \overrightarrow{I_1} \\ \overrightarrow{I_2} \end{array} \quad \begin{aligned} -I_1(1.2 \text{ k}\Omega) + 9 - 8.2 \text{ k}\Omega(I_1 - I_2) &= 0 \\ -I_2(1.1 \text{ k}\Omega) + 6 - I_2(9.1 \text{ k}\Omega) - 8.2 \text{ k}\Omega(I_2 - I_1) &= 0 \end{aligned}$$

$$\begin{aligned} I_1 &= \mathbf{2.03 \text{ mA}}, I_2 = \mathbf{1.23 \text{ mA}} \\ I_{R_1} &= I_1 = \mathbf{2.03 \text{ mA}}, I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23 \text{ mA}} \\ I_{R_2} &= I_1 - I_2 = 2.03 \text{ mA} - 1.23 \text{ mA} = \mathbf{0.80 \text{ mA}} \text{ (direction of } I_1) \end{aligned}$$

$$22. \quad (I): \quad \begin{array}{l} \overrightarrow{I_1} \\ \overrightarrow{I_2} \end{array} \quad \begin{aligned} -25 - 2I_1 - 3(I_1 - I_2) + 60 &= 0 \\ -60 - 3(I_2 - I_1) + 6 - 5I_2 - 20 &= 0 \end{aligned}$$

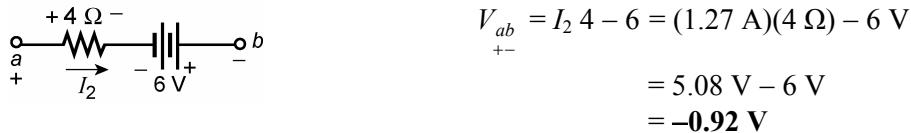
$$I_1 = \mathbf{1.87 \text{ A}}, I_2 = \mathbf{-8.55 \text{ A}}$$



(II): Source conversion: $E = 9 \text{ V}, R = 3 \Omega$

$$\begin{array}{l} \overrightarrow{I_2} \\ \overrightarrow{I_3} \end{array} \quad \begin{aligned} 9 - 3I_2 - 4I_2 + 6 - 6(I_2 - I_3) &= 0 \\ -6(I_3 - I_2) - 8I_3 - 4 &= 0 \end{aligned}$$

$$I_2 = \mathbf{1.27 \text{ A}}, I_3 = \mathbf{0.26 \text{ A}}$$



$$23. \quad (a): \quad \begin{array}{l} \overrightarrow{I_1} \\ \overrightarrow{I_2} \\ \overrightarrow{I_3} \end{array} \quad \begin{aligned} 10 - I_1 2 - 1(I_1 - I_2) &= 0 \\ -1(I_2 - I_1) - I_2 4 - 5(I_2 - I_3) &= 0 \\ -5(I_3 - I_2) - I_3 3 - 6 &= 0 \end{aligned}$$

$$\begin{array}{r} 3I_1 - 1I_2 + 0 = 10 \\ -1I_1 + 10I_2 - 5I_3 = 0 \\ 0 - 5I_2 + 8I_3 = -6 \end{array}$$

$$I_2 = I_{R_3} = \mathbf{-63.69 \text{ mA}}$$

$$24. \quad \text{a.} \quad \begin{array}{l} \overrightarrow{I_1} \\ \overrightarrow{I_2} \end{array} \quad \begin{aligned} -1I_1 - 4 - 5I_1 + 6 - 1(I_1 - I_2) &= 0 \\ -1(I_2 - I_1) - 6 - 3I_2 - 15 - 10I_2 &= 0 \end{aligned}$$

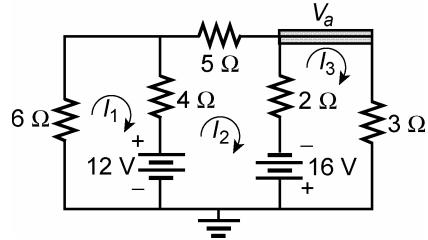
$$I_1 = I_{5\Omega} = \mathbf{72.16 \text{ mA}}$$

$$\begin{aligned} V_a &= -4 - (72.16 \text{ mA})(6 \Omega) \\ &= -4 - 0.433 \text{ V} \\ &= \mathbf{-4.43 \text{ V}} \end{aligned}$$

b. Network redrawn:

$$\begin{aligned}
 -6I_1 - 4(I_1 - I_2) - 12 &= 0 \\
 12 - 4(I_2 - I_1) - 5I_2 - 2(I_2 - I_3) + 16 &= 0 \\
 -16 - 2(I_3 - I_2) - 3I_3 &= 0
 \end{aligned}$$

$$I_2 = I_{5\Omega} = \mathbf{1.95 \text{ A}}$$



$$\begin{aligned}
 V_a &= (I_3)(3 \Omega) \\
 &= (-2.42 \text{ mA})(3 \Omega) \\
 &= \mathbf{-7.26 \text{ V}}
 \end{aligned}$$

25. (I): $I_1(2.2 \text{ k}\Omega + 9.1 \text{ k}\Omega) - 9.1 \text{ k}\Omega I_2 = 18$
 $I_2(9.1 \text{ k}\Omega + 7.5 \text{ k}\Omega + 6.8 \text{ k}\Omega) - 9.1 \text{ k}\Omega I_1 - 6.8 \text{ k}\Omega I_3 = -18$
 $I_3(6.8 \text{ k}\Omega + 3.3 \text{ k}\Omega) - I_2 6.8 \text{ k}\Omega = -3$

$$I_1 = \mathbf{1.21 \text{ mA}}, I_2 = \mathbf{-0.48 \text{ mA}}, I_3 = \mathbf{-0.62 \text{ mA}}$$

(II): $16 - 4I_1 - 3(I_1 - I_2) - 12 - 4(I_1 - I_3) = 0$
 $12 - 3(I_2 - I_1) - 10 I_2 - 15 - 4(I_2 - I_3) = 0$
 $-16 - 4(I_3 - I_1) - 4(I_3 - I_2) - 7I_3 = 0$

$$I_1 = \mathbf{-0.24 \text{ A}}, I_2 = \mathbf{-0.52 \text{ A}}, I_3 = \mathbf{-1.28 \text{ A}}$$

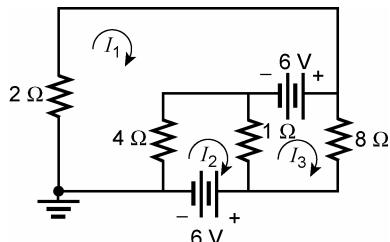
26. a. $-6.8 \text{ k}\Omega I_1 - 4.7 \text{ k}\Omega(I_1 - I_2) + 6 - 2.2 \text{ k}\Omega(I_1 - I_4) = 0$
 $-6 - 4.7 \text{ k}\Omega(I_2 - I_1) - 2.7 \text{ k}\Omega I_2 - 8.2 \text{ k}\Omega(I_2 - I_3) = 0$
 $-1.1 \text{ k}\Omega I_3 - 22 \text{ k}\Omega(I_3 - I_4) - 8.2 \text{ k}\Omega(I_3 - I_2) - 9 = 0$
 $5 - 1.2 \text{ k}\Omega I_4 - 2.2 \text{ k}\Omega(I_4 - I_1) - 22 \text{ k}\Omega(I_4 - I_3) = 0$

$$I_1 = \mathbf{0.03 \text{ mA}}, I_2 = \mathbf{-0.88 \text{ mA}}, I_3 = \mathbf{-0.97 \text{ mA}}, I_4 = \mathbf{-0.64 \text{ mA}}$$

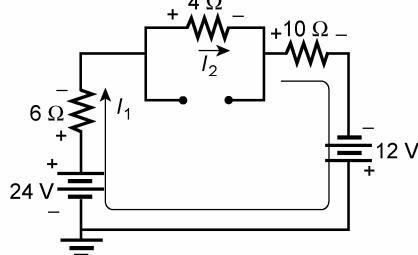
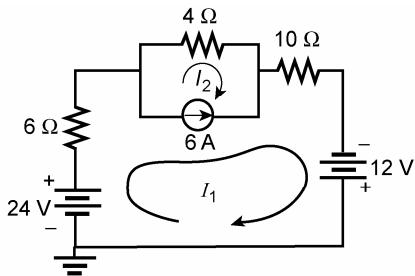
b. Network redrawn:

$$\begin{aligned}
 -2I_1 - 6 - 4I_1 + 4I_2 &= 0 \\
 -4I_2 + 4I_1 - 1I_2 + 1I_3 - 6 &= 0 \\
 -1I_3 + 1I_2 + 6 - 8I_3 &= 0
 \end{aligned}$$

$$I_1 = \mathbf{-3.8 \text{ A}}, I_2 = \mathbf{-4.20 \text{ A}}, I_3 = \mathbf{0.20 \text{ A}}$$



27. a.



$$24 \text{ V} - 6I_1 - 4I_2 - 10I_1 + 12 \text{ V} = 0$$

$$\text{and } 16I_1 + 4I_2 = 36$$

$$I_1 - I_2 = 6 \text{ A}$$

$$I_1 = I_2 + 6 \text{ A}$$

$$16[I_2 + 6 \text{ A}] + 4I_2 = 36$$

$$16I_2 + 96 + 4I_2 = 36$$

$$20I_2 = -60$$

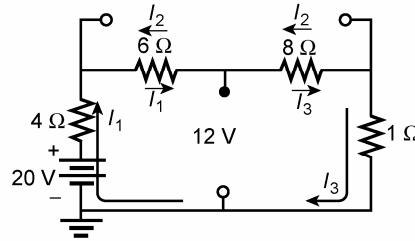
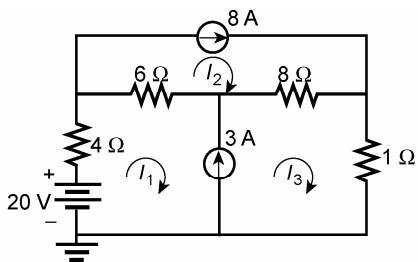
$$I_2 = -3 \text{ A}$$

$$I_1 = I_2 + 6 \text{ A} = -3 \text{ A} + 6 \text{ A} = 3 \text{ A}$$

$$I_{24\text{V}} = I_{6\Omega} = I_{10\Omega} = I_{12\text{V}} = 3 \text{ A (CW)}$$

$$I_{4\Omega} = 3 \text{ A (CCW)}$$

b.



$$20 \text{ V} - 4I_1 - 6(I_1 - I_2) - 8(I_3 - I_2) - 1I_3 = 0$$

$$10I_1 - 14I_2 + 9I_3 = 20$$

$$I_3 - I_1 = 3 \text{ A}$$

$$I_2 = 8 \text{ A}$$

$$10I_1 - 14(8 \text{ A}) + 9[I_1 + 3 \text{ A}] = 20$$

$$19I_1 = 105$$

$$I_1 = 5.526 \text{ A}$$

$$I_3 = I_1 + 3 \text{ A} = 5.526 \text{ A} + 3 \text{ A} = 8.526 \text{ A}$$

$$I_2 = 8 \text{ A}$$

$$I_{20\text{V}} = I_{4\Omega} = 5.53 \text{ A (dir. of } I_1)$$

$$I_{6\Omega} = I_2 - I_1 = 2.47 \text{ A (dir. of } I_2)$$

$$I_{8\Omega} = I_3 - I_2 = 0.53 \text{ A (dir. of } I_3)$$

$$I_{1\Omega} = 8.53 \text{ A (dir. of } I_3)$$

28. a. 

$$\begin{array}{rcl} (4+8)I_1 - 8I_2 = 4 \\ (8+2)I_2 - 8I_1 = -6 \\ \hline \end{array}$$

b. 

$$I_1 = -\frac{1}{7}\text{ A}, I_2 = -\frac{5}{7}\text{ A}$$

$$\begin{array}{rcl} (4+3)I_1 - 3I_2 = -10 - 12 \\ (3+12)I_2 - 3I_1 = 12 \\ \hline \\ I_1 = -3.06 \text{ A}, I_2 = 0.19 \text{ A} \end{array}$$

29. (I): 

a. $I_1(5.6 \text{ k}\Omega + 2.2 \text{ k}\Omega) - 2.2 \text{ k}\Omega (I_2) = 10 + 20$
 $I_2(2.2 \text{ k}\Omega + 3.3 \text{ k}\Omega) - 2.2 \text{ k}\Omega (I_1) = -20 - 30$

b. $I_1 = 1.45 \text{ mA}, I_2 = -8.51 \text{ mA}$

c. $I_{R_1} = I_1 = 1.45 \text{ mA}, I_{R_2} = I_2 = -8.51 \text{ mA}$
 $I_{R_3} = I_1 + I_2 = 8.51 \text{ mA} + 1.44 \text{ mA} = 9.96 \text{ mA}$ (direction of I_1)

(II): 

a. $I_1(1.2 \text{ k}\Omega + 8.2 \text{ k}\Omega) - 8.2 \text{ k}\Omega I_2 = 9$
 $I_2(8.2 \text{ k}\Omega + 1.1 \text{ k}\Omega + 9.1 \text{ k}\Omega) - 8.2 \text{ k}\Omega I_1 = 6$

b. $I_1 = 2.03 \text{ mA}, I_2 = 1.23 \text{ mA}$

c. $I_{R_1} = I_1 = 2.03 \text{ mA}, I_{R_3} = I_{R_4} = I_2 = 1.23 \text{ mA}$
 $I_{R_2} = I_1 - I_2 = 2.03 \text{ mA} - 1.23 \text{ mA} = 0.80 \text{ mA}$ (direction of I_1)

30. (I): 

$$\begin{array}{rcl} (2+3)I_1 - 3I_2 = -25 + 60 \\ (3+5)I_2 - 3I_1 = -60 + 6 - 20 \\ \hline \end{array}$$

b. $I_1 = 1.87 \text{ A}, I_2 = -8.55 \text{ A}$

c. $I_{R_1} = I_1 = 1.87 \text{ A}, I_{R_2} = I_2 = -8.55 \text{ A}$
 $I_{R_3} = I_1 - I_2 = 1.87 \text{ A} - (-8.55 \text{ A}) = 10.42 \text{ A}$ (direction of I_1)

(II): a. 

$$\begin{array}{rcl} (3+4+6)I_2 - 6I_3 = 9 + 6 \\ (6+8)I_3 - 6I_2 = -4 \\ \hline \end{array}$$

b. $I_2 = 1.27 \text{ A}, I_3 = 0.26 \text{ A}$

c. $I_{R_2} = I_2 = 1.27 \text{ A}, I_{R_3} = I_3 = 0.26 \text{ A}$
 $I_{R_4} = I_2 - I_3 = 1.27 \text{ A} - 0.26 \text{ A} = 1.01 \text{ A}$
 $I_{R_1} = 3 \text{ A} - I_2 = 3 \text{ A} - 1.27 \text{ A} = 1.73 \text{ A}$

31. $\begin{array}{c} I_1 \downarrow \\ I_2 \downarrow \\ I_3 \downarrow \end{array}$

$$I_1(2+1) - 1I_2 = 10$$

$$I_2(1+4+5) - 1I_1 - 5I_3 = 0$$

$$I_3(5+3) - 5I_2 = -6$$

$$I_2 = I_{R_3} = -63.69 \text{ mA} \text{ (exact match with problem 18)}$$

32. From Sol. 24(b)

$\begin{array}{c} I_1 \downarrow \\ I_2 \downarrow \\ I_3 \downarrow \end{array}$

$$I_1(6+4) - 4I_2 = -12$$

$$I_2(4+5+2) - 4I_1 - 2I_3 = 12 + 16$$

$$I_3(2+3) - 2I_2 = -16$$

$$I_{5\Omega} = I_2 = 1.95 \text{ A}$$

$$I_3 = -2.42 \text{ A}, \therefore V_a = (I_3)(3 \Omega) = (-2.42 \text{ A})(3 \Omega) = -7.26 \text{ V}$$

33. (I): $\begin{array}{c} I_1 \downarrow \\ I_2 \downarrow \\ I_3 \downarrow \end{array}$

$$(2.2 \text{ k}\Omega + 9.1 \text{ k}\Omega)I_1 - 9.1 \text{ k}\Omega I_2 = 18$$

$$(9.1 \text{ k}\Omega + 7.5 \text{ k}\Omega + 6.8 \text{ k}\Omega)I_2 - 9.1 \text{ k}\Omega I_1 - 6.8 \text{ k}\Omega I_3 = -18$$

$$(6.8 \text{ k}\Omega + 3.3 \text{ k}\Omega)I_3 - 6.8 \text{ k}\Omega I_2 = -3$$

$$I_1 = 1.21 \text{ mA}, I_2 = -0.48 \text{ mA}, I_3 = -0.62 \text{ mA}$$

(II):

$\begin{array}{c} I_1 \downarrow \\ I_3 \downarrow \\ I_2 \downarrow \end{array}$

$$(4 \Omega + 4 \Omega + 3 \Omega)I_1 - 3 \Omega I_2 - 4 \Omega I_3 = 16 - 12$$

$$(4 \Omega + 3 \Omega + 10 \Omega)I_2 - 3I_1 - 4 \Omega I_3 = 12 - 15$$

$$(4 \Omega + 4 \Omega + 7 \Omega)I_3 - 4I_1 - 4I_2 = -16$$

$$I_1 = -0.24 \text{ A}, I_2 = -0.52 \text{ A}, I_3 = -1.28 \text{ A}$$

34. a. $\begin{array}{c} I_1 \downarrow \\ I_4 \downarrow \\ I_2 \downarrow \\ I_3 \downarrow \end{array}$

$$I_1(6.8 \text{ k}\Omega + 4.7 \text{ k}\Omega + 2.2 \text{ k}\Omega) - 4.7 \text{ k}\Omega I_2 - 2.2 \text{ k}\Omega I_4 = 6$$

$$I_2(2.7 \text{ k}\Omega + 8.2 \text{ k}\Omega + 4.7 \text{ k}\Omega) - 4.7 \text{ k}\Omega I_1 - 8.2 \text{ k}\Omega I_3 = -6$$

$$I_3(8.2 \text{ k}\Omega + 1.1 \text{ k}\Omega + 22 \text{ k}\Omega) - 22 \text{ k}\Omega I_4 - 8.2 \text{ k}\Omega I_2 = -9$$

$$I_4(2.2 \text{ k}\Omega + 22 \text{ k}\Omega + 1.2 \text{ k}\Omega) - 2.2 \text{ k}\Omega I_1 - 22 \text{ k}\Omega I_3 = 5$$

$$I_1 = 0.03 \text{ mA}, I_2 = -0.88 \text{ mA}, I_3 = -0.97 \text{ mA}, I_4 = -0.64 \text{ mA}$$

b. From Sol. 26(b):

$$I_1(2+4) - 4I_2 = -6$$

$$I_2(4+1) - 4I_1 - 1I_3 = -6$$

$$I_3(1+8) - 1I_2 = 6$$

$$I_1 = 3.8 \text{ A}, I_2 = -4.20 \text{ A}, I_3 = 0.20 \text{ A}$$

35. a. $\begin{array}{c} V_1 \\ \circ \\ V_2 \\ \circ \end{array}$

$$V_1 \left[\frac{1}{2} + \frac{1}{5} + \frac{1}{2} \right] - \frac{1}{2} V_2 = 5 \quad V_1 = \mathbf{8.08 \text{ V}}$$

$$V_2 \left[\frac{1}{2} + \frac{1}{4} \right] - \frac{1}{2} V_1 = 3 \quad V_2 = \mathbf{9.39 \text{ V}}$$

$$V_2 \left[\frac{1}{2} + \frac{1}{4} \right] - \frac{1}{2} V_1 = 3$$

Symmetry is present

b. $\begin{array}{c} V_1 \\ \circ \\ V_2 \\ \circ \end{array}$

$$V_1 \left[\frac{1}{2} + \frac{1}{4} \right] - \frac{1}{4} V_2 = 4 - 2 \quad V_1 = \mathbf{4.80 \text{ V}}$$

$$V_2 \left[\frac{1}{4} + \frac{1}{20} + \frac{1}{5} \right] - \frac{1}{4} V_1 = 2 \quad V_2 = \mathbf{6.40 \text{ V}}$$

$$V_2 \left[\frac{1}{4} + \frac{1}{20} + \frac{1}{5} \right] - \frac{1}{4} V_1 = 2$$

Symmetry is present

36. (I): $\begin{array}{c} V_1 \\ \circ \\ V_2 \\ \circ \end{array}$

$$V_1 \left[\frac{1}{3} + \frac{1}{6} + \frac{1}{4} \right] - \frac{1}{4} V_2 = -5 - 3$$

$$V_2 \left[\frac{1}{8} + \frac{1}{4} \right] - \frac{1}{4} V_1 = 3 - 4$$

$$V_1 = \mathbf{-14.86 \text{ V}}, \quad V_2 = \mathbf{-12.57 \text{ V}}$$

$$V_{R_1} = V_{R_4} = \mathbf{-14.86 \text{ V}}$$

$$V_{R_2} = \mathbf{-12.57 \text{ V}}$$

$${}^+ V_{R_3} = 12 \text{ V} + 12.57 \text{ V} - 14.86 \text{ V} = \mathbf{9.71 \text{ V}}$$

(II): $\begin{array}{c} V_1 \\ \circ \\ V_2 \\ \circ \end{array}$

$$V_1 \left[\frac{1}{5} + \frac{1}{3} + \frac{1}{2} \right] - \frac{1}{3} V_2 - \frac{1}{2} V_2 = -6$$

$$V_2 \left[\frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{8} \right] - \frac{1}{3} V_1 - \frac{1}{2} V_1 = 7$$

$$V_1 = \mathbf{-2.56 \text{ V}}, \quad V_2 = \mathbf{4.03 \text{ V}}$$

$$V_{R_1} = \mathbf{-2.56 \text{ V}}$$

$$V_{R_2} = V_{R_5} = \mathbf{4.03 \text{ V}}$$

$$V_{R_4} = V_{R_3} = 4.03 \text{ V} + 2.56 \text{ V} = \mathbf{6.59 \text{ V}}$$

37. (I): a.

$$\begin{aligned} V_1 \left[\frac{1}{2.2 \text{ k}\Omega} + \frac{1}{9.1 \text{ k}\Omega} + \frac{1}{7.5 \text{ k}\Omega} \right] - \frac{1}{7.5 \text{ k}\Omega} V_2 &= -1.98 \text{ mA} \\ V_2 \left[\frac{1}{7.5 \text{ k}\Omega} + \frac{1}{6.8 \text{ k}\Omega} + \frac{1}{3.3 \text{ k}\Omega} \right] - \frac{1}{7.5 \text{ k}\Omega} V_1 &= 0.91 \text{ mA} \end{aligned}$$

b. $V_1 = -2.65 \text{ V}, V_2 = 0.95 \text{ V}$

c. $V_{R_3} = V_1 = -2.65 \text{ V}, V_{R_5} = V_2 = 0.95 \text{ V}, V_{R_4} = V_2 - V_1 = 3.60 \text{ V}$

$$R_1 \quad \begin{array}{c} + \\ \swarrow \searrow \\ V_{R_1} \\ - \end{array} = 18 \text{ V} - 2.65 \text{ V} = 15.35 \text{ V}$$

$$R_2 \quad \begin{array}{c} - \\ \swarrow \searrow \\ V_{R_2} \\ + \end{array} = 3 \text{ V} - 0.95 \text{ V} = 2.05 \text{ V}$$

(II): a.

$$\begin{array}{ccc} \circ V_1 & \circ V_2 & V_1 \left[\frac{1}{4} + \frac{1}{4} + \frac{1}{7} \right] - \frac{1}{4} V_2 - \frac{1}{4} V_3 = 4 \\ \circ V_3 & & \end{array}$$

$$\begin{array}{ccc} \stackrel{\oplus}{=} & & V_2 \left[\frac{1}{4} + \frac{1}{3} + \frac{1}{10} \right] - \frac{1}{4} V_1 - \frac{1}{3} V_3 = 4 + 1.5 \end{array}$$

$$V_3 \left[\frac{1}{4} + \frac{1}{3} + \frac{1}{4} \right] - \frac{1}{4} V_1 - \frac{1}{3} V_3 = -4 - 4$$

b. $V_1 = 8.88 \text{ V}, V_2 = 9.83 \text{ V}, V_3 = -3.01 \text{ V}$

c. $V_{R_6} = V_1 = 8.88 \text{ V}, V_{R_4} = V_3 = -3.01 \text{ V}, V_{R_5} = V_2 - V_1 = \frac{(+)}{V_2} - \frac{(-)}{V_1} = 0.95 \text{ V}$

$$\begin{array}{ccc} \cancel{-V_{R_1}}^+ & & V_{R_1} = 16 \text{ V} - V_1 + V_3 = 4.12 \text{ V} \\ R_1 & & \end{array}$$

$$\begin{array}{ccc} \cancel{-V_{R_2}}^+ & & V_{R_2} = V_2 - V_3 - 12 \text{ V} = 0.84 \text{ V} \\ R_2 & & \end{array}$$

$$R_3 \quad \begin{array}{c} - \\ \swarrow \searrow \\ V_{R_3} \\ + \end{array} = 15 \text{ V} - V_2 = 5.17 \text{ V}$$

38. (I): $\begin{array}{ccc} \circ V_1 & & \\ \circ V_2 & & \circ V_3 \end{array}$

$$V_1 \left[\frac{1}{3} + \frac{1}{6} + \frac{1}{6} \right] - \frac{1}{6} V_2 - \frac{1}{6} V_3 = 5$$

$$\underline{\underline{\frac{1}{6} + \frac{1}{4} + \frac{1}{5}}} - \frac{1}{6} V_1 - \frac{1}{5} V_3 = -3$$

$$V_3 \left[\frac{1}{6} + \frac{1}{5} + \frac{1}{7} \right] - \frac{1}{5} V_2 - \frac{1}{6} V_1 = 0$$

$$V_1 = 7.24 \text{ V}, V_2 = -2.45 \text{ V}, V_3 = 1.41 \text{ V}$$

(II): Source conversion: $I = 4 \text{ A}$, $R = 4 \Omega$

$$\begin{array}{ccc} \circ V_1 & \circ V_2 & \circ V_3 \end{array} V_1 \left[\frac{1}{9} + \frac{1}{20} + \frac{1}{20} \right] - \frac{1}{20} V_2 - \frac{1}{20} V_3 = -2$$

$$V_2 \left[\frac{1}{20} + \frac{1}{20} + \frac{1}{18} \right] - \frac{1}{20} V_1 - \frac{1}{20} V_3 = 0$$

$$V_3 \left[\frac{1}{20} + \frac{1}{20} + \frac{1}{4} \right] - \frac{1}{20} V_2 - \frac{1}{20} V_1 = 4$$

$$V_1 = -6.64 \text{ V}, V_2 = 1.29 \text{ V}, V_3 = 10.66 \text{ V}$$

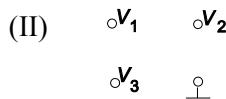
39. (I) $\begin{array}{ccc} \circ V_1 & \circ V_2 & \circ V_3 \end{array}$

$$\left[\frac{1}{2} + \frac{1}{2} \right] V_1 - \frac{1}{2} V_2 + 0 = -5$$

$$\left[\frac{1}{2} + \frac{1}{9} + \frac{1}{7} + \frac{1}{2} \right] V_2 - \frac{1}{2} V_1 - \frac{1}{2} V_3 = 0$$

$$\left[\frac{1}{2} + \frac{1}{2} + \frac{1}{4} \right] V_3 - \frac{1}{2} V_2 = 5$$

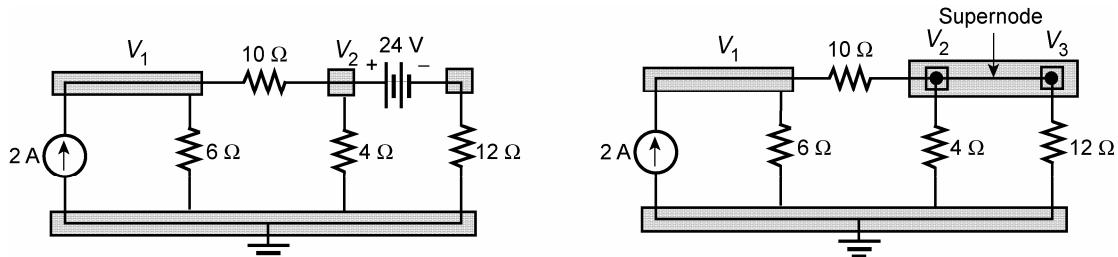
$$V_1 = -5.31 \text{ V}, V_2 = -0.62 \text{ V}, V_3 = 3.75 \text{ V}$$

(II) 

$$\begin{aligned} V_1 \left[\frac{1}{2} + \frac{1}{6} \right] - \frac{1}{6} V_3 &= -5 \\ V_2 \left[\frac{1}{4} \right] &= 5 - 2 \\ V_3 \left[\frac{1}{6} + \frac{1}{5} \right] - \frac{1}{6} V_1 &= 2 \end{aligned}$$

$$V_1 = -6.92 \text{ V}, V_2 = 12 \text{ V}, V_3 = 2.3 \text{ V}$$

40. a.



$$\sum I_i = \sum I_o$$

Node V_1 :

$$2 \text{ A} = \frac{V_1}{6\Omega} + \frac{V_1 - V_2}{10\Omega}$$

Supernode V_2, V_3 :

$$0 = \frac{V_2 - V_1}{10\Omega} + \frac{V_2}{4\Omega} + \frac{V_3}{12\Omega}$$

Independent source:

$$V_2 - V_3 = 24 \text{ V} \text{ or } V_3 = V_2 - 24 \text{ V}$$

2 eq. 2 unknowns:

$$\frac{V_1}{6\Omega} + \frac{V_1 - V_2}{10\Omega} = 2 \text{ A}$$

$$\frac{V_2 - V_1}{10\Omega} + \frac{V_2}{4\Omega} + \frac{V_2 - 24 \text{ V}}{12\Omega} = 0$$

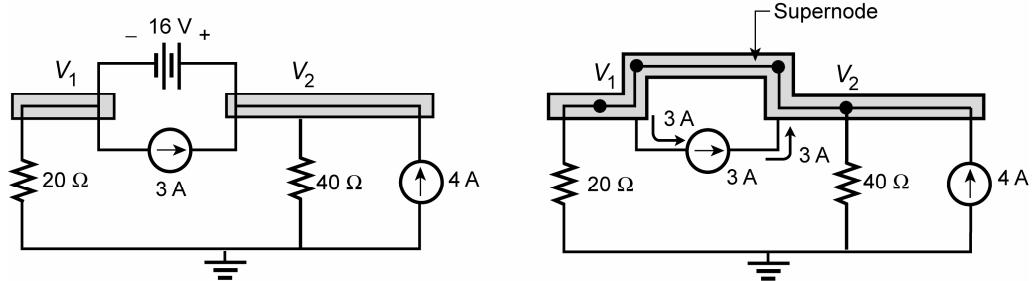
$$0.267V_1 - 0.1V_2 = 2$$

$$+0.1V_1 - 0.433V_2 = -2$$

$$V_1 = 10.08 \text{ V}, V_2 = 6.94 \text{ V}$$

$$V_3 = V_2 - 24 \text{ V} = -17.06 \text{ V}$$

b.



$$\Sigma I_i = \Sigma I_o$$

Supernode:

$$3 \text{ A} + 4 \text{ A} = 3 \text{ A} + \frac{V_1}{20 \Omega} + \frac{V_2}{40 \Omega}$$

$$\begin{aligned} 2 \text{ eq. } 2 \text{ unk. } & \left\{ \begin{array}{l} 4 \text{ A} = \frac{V_1}{20 \Omega} + \frac{V_2}{40 \Omega} \\ V_2 - V_1 = 16 \text{ V} \end{array} \right. \end{aligned}$$

$$\text{Subt. } V_2 = 16 \text{ V} + V_1$$

$$4 \text{ A} = \frac{V_1}{20 \Omega} + \frac{(16 \text{ V} + V_1)}{40 \Omega}$$

$$\text{and } V_1 = 48 \text{ V}$$

$$V_2 = 16 \text{ V} + V_1 = 64 \text{ V}$$

41. a.

$\overset{\text{V}_1}{\circ}$ $\overset{\text{V}_2}{\circ}$

$$V_1 \left[\frac{1}{2} + \frac{1}{5} + \frac{1}{2} \right] - \frac{1}{2} V_2 = 5$$

$$V_2 \left[\frac{1}{2} + \frac{1}{4} \right] - \frac{1}{2} V_1 = 3$$

$$V_1 = 8.08 \text{ V}, V_2 = 9.39 \text{ V}$$

Symmetry present

b.

$\overset{\text{V}_1}{\circ}$ $\overset{\text{V}_2}{\circ}$

$$V_1 \left[\frac{1}{2} + \frac{1}{4} \right] - \frac{1}{4} V_2 = 4 - 2$$

$$V_2 \left[\frac{1}{4} + \frac{1}{20} + \frac{1}{5} \right] - \frac{1}{4} V_1 = 2$$

$$V_1 = 4.8 \text{ V}, V_2 = 6.4 \text{ V}$$

Symmetry present

42. (I): a. Note the solution to problem 36(I).
- b. $V_1 = -14.86 \text{ V}, V_2 = -12.57 \text{ V}$
- c. $V_{R_1} = V_{R_4} = V_1 = -14.86 \text{ V}, V_{R_2} = V_2 = -12.57 \text{ V}$
- $$\begin{array}{rcl} +V_{R_3} - \\ \hline R_3 & & V_{R_3} = V_1 - V_2 + 12 \text{ V} = (-14.86 \text{ V}) - (-12.57 \text{ V}) + 12 \text{ V} = 9.71 \text{ V} \end{array}$$

- (II): a. Note the solution to problem 36(II).
- b. $V_1 = -2.56 \text{ V}, V_2 = 4.03 \text{ V}$
- c. $V_{R_1} = V_1 = -2.56 \text{ V}, V_{R_2} = V_{R_5} = V_2 = 4.03 \text{ V}$
- $$\begin{array}{rcl} (+) \quad (-) \\ V_{R_3} = V_{R_4} = V_2 - V_1 = 6.59 \text{ V} \end{array}$$

43. (I): a. Source conversion: $I = 5 \text{ A}, R = 3 \Omega$

$$\begin{array}{ccc} \circ V_1 & & V_1 \left[\frac{1}{3} + \frac{1}{6} + \frac{1}{6} \right] - \frac{1}{6} V_2 - \frac{1}{6} V_3 = 5 \\ \circ V_2 & \oplus & V_2 \left[\frac{1}{6} + \frac{1}{4} + \frac{1}{5} \right] - \frac{1}{6} V_1 - \frac{1}{5} V_3 = -3 \\ \circ V_3 & & V_3 \left[\frac{1}{6} + \frac{1}{5} + \frac{1}{7} \right] - \frac{1}{5} V_2 - \frac{1}{6} V_1 = 0 \end{array}$$

- b. $V_1 = 7.24 \text{ V}, V_2 = -2.45 \text{ V}, V_3 = 1.41 \text{ V}$
- c. $R_1 \left\{ \begin{array}{c} - \\ + \end{array} \right\} V_{R_1} = 15 \text{ V} - 7.24 \text{ V} = 7.76 \text{ V}$
- $V_{R_2} = V_2 = -2.45 \text{ V}, V_{R_3} = V_3 = 1.41 \text{ V}$
- $$\begin{array}{rcl} (+) \quad (-) \\ V_{R_4} = V_3 - V_2 = 1.41 \text{ V} - (-2.45 \text{ V}) = 3.86 \text{ V} \\ V_{R_5} = V_1 - V_2 = 7.24 \text{ V} - (-2.45 \text{ V}) = 9.69 \text{ V} \\ V_{R_6} = V_1 - V_3 = 7.24 \text{ V} - 1.41 \text{ V} = 5.83 \text{ V} \end{array}$$

(II): a. Source conversion: $I = 4 \text{ A}$, $R = 4 \Omega$

$$\begin{array}{l}
 V_1 \left[\frac{1}{9} + \frac{1}{20} + \frac{1}{20} \right] - \frac{1}{20}V_2 - \frac{1}{20}V_3 = -2 \\
 V_2 \left[\frac{1}{20} + \frac{1}{20} + \frac{1}{18} \right] - \frac{1}{20}V_1 - \frac{1}{20}V_3 = 0 \\
 V_3 \left[\frac{1}{20} + \frac{1}{20} + \frac{1}{4} \right] - \frac{1}{20}V_2 - \frac{1}{20}V_1 = 4
 \end{array}$$

b. $V_1 = -6.64 \text{ V}$, $V_2 = 1.29 \text{ V}$, $V_3 = 10.66 \text{ V}$

c. $V_{R_1} = V_1 = -6.64 \text{ V}$, $R_2 \xrightarrow[-]{\substack{\downarrow \\ \uparrow}} V_{R_2} = 16 \text{ V} - 10.66 \text{ V} = 5.34 \text{ V}$

$$V_{R_3} = V_2 = 1.29 \text{ V}, V_{R_4} = V_2 - V_1 = 1.29 \text{ V} - (-6.64 \text{ V}) = 7.93 \text{ V}$$

$$V_{R_5} = V_3 - V_2 = 10.66 \text{ V} - 1.29 \text{ V} = 9.37 \text{ V}$$

$$V_{R_6} = V_3 - V_1 = 10.66 \text{ V} - (-6.64 \text{ V}) = 17.30 \text{ V}$$

44. a. Note the solution to problem 39(I).

$$V_1 = -5.31 \text{ V}, V_2 = -0.62 \text{ V}, V_3 = 3.75 \text{ V}$$

$$V_{5A} = V_1 = -5.31 \text{ V}$$

b. Note the solution to problem 39(II).

$$V_1 = -6.92 \text{ V}, V_2 = 12 \text{ V}, V_3 = 2.3 \text{ V}$$

$$V_{2A} = V_2 - V_3 = 9.7 \text{ V}, V_{5A} = V_2 - V_1 = 18.92 \text{ V}$$

45. a.

$I_1 \swarrow$	$I_2 \downarrow$	$I_1(6 + 5 + 10) - 5I_2 - 10I_3 = 6$
$I_1 \downarrow$	$I_3 \downarrow$	$I_2(5 + 5 + 5) - 5I_1 - 5I_3 = 0$
		$I_3(5 + 10 + 20) - 10I_1 - 5I_2 = 0$

$$I_1 = 0.39 \text{ A}, I_2 = 0.18 \text{ A}, I_3 = 0.14 \text{ A}$$

b. $I_5 = I_2 - I_3 = 40 \text{ mA}$ (direction of I_2)

c, d. no

46. Source conversion: $I = 1 \text{ A}$, $R = 6 \Omega$

$$\begin{array}{ll}
 \textcircled{V}_1 & \left[\frac{1}{6} + \frac{1}{5} + \frac{1}{5} \right] V_1 - \frac{1}{5} V_2 - \frac{1}{5} V_3 = 1 \\
 \textcircled{V}_3 & \textcircled{V}_2 \\
 \hline
 \textcircled{\textcircled{V}} & \left[\frac{1}{5} + \frac{1}{5} + \frac{1}{20} \right] V_2 - \frac{1}{5} V_1 - \frac{1}{5} V_3 = 0 \\
 & \left[\frac{1}{5} + \frac{1}{5} + \frac{1}{10} \right] V_3 - \frac{1}{5} V_1 - \frac{1}{5} V_2 = 0 \\
 \hline
 V_{R_s} & = 196.70 \text{ mV, no}
 \end{array}$$

47. a.  $I_1(2 \text{ k}\Omega + 33 \text{ k}\Omega + 3.3 \text{ k}\Omega) - 33 \text{ k}\Omega I_2 - 3.3 \text{ k}\Omega I_3 = 24$

$$\begin{aligned}
 I_2(33 \text{ k}\Omega + 56 \text{ k}\Omega + 36 \text{ k}\Omega) - 33 \text{ k}\Omega I_1 - 36 \text{ k}\Omega I_3 &= 0 \\
 I_3(3.3 \text{ k}\Omega + 36 \text{ k}\Omega + 5.6 \text{ k}\Omega) - 36 \text{ k}\Omega I_2 - 3.3 \text{ k}\Omega I_1 &= 0
 \end{aligned}$$

$$I_1 = 0.97 \text{ mA}, I_2 = I_3 = 0.36 \text{ mA}$$

$$\text{b. } I_5 = I_2 - I_3 = 0.36 \text{ mA} - 0.36 \text{ mA} = 0$$

c, d. yes

48. Source conversion: $I = 12 \text{ A}$, $R = 2 \text{ k}\Omega$

$$\begin{array}{ll}
 \textcircled{V}_1 & \left[\frac{1}{2 \text{ k}\Omega} + \frac{1}{33 \text{ k}\Omega} + \frac{1}{56 \text{ k}\Omega} \right] V_1 - \frac{1}{56 \text{ k}\Omega} V_2 - \frac{1}{33 \text{ k}\Omega} V_3 = 12 \\
 \textcircled{V}_3 & \textcircled{V}_2 \\
 \hline
 \textcircled{\textcircled{V}} & \left[\frac{1}{56 \text{ k}\Omega} + \frac{1}{36 \text{ k}\Omega} + \frac{1}{5.6 \text{ k}\Omega} \right] V_2 - \frac{1}{56 \text{ k}\Omega} V_1 - \frac{1}{36 \text{ k}\Omega} V_3 = 0 \\
 & \left[\frac{1}{33 \text{ k}\Omega} + \frac{1}{3.3 \text{ k}\Omega} + \frac{1}{36 \text{ k}\Omega} \right] V_3 - \frac{1}{33 \text{ k}\Omega} V_1 - \frac{1}{36 \text{ k}\Omega} V_2 = 0 \\
 \hline
 I_{R_s} & = 0 \text{ A, yes}
 \end{array}$$

49. Source conversion: $I = 9 \text{ mA}$, $R = 1 \text{ k}\Omega$

$$\begin{array}{ll}
 \textcircled{V}_1 & V_1 \left[\frac{1}{1 \text{ k}\Omega} + \frac{1}{100 \text{ k}\Omega} + \frac{1}{200 \text{ k}\Omega} \right] - \frac{1}{100 \text{ k}\Omega} V_2 - \frac{1}{200 \text{ k}\Omega} V_3 = 4 \text{ mA} \\
 \textcircled{V}_2 & V_2 \left[\frac{1}{100 \text{ k}\Omega} + \frac{1}{200 \text{ k}\Omega} + \frac{1}{1 \text{ k}\Omega} \right] - \frac{1}{100 \text{ k}\Omega} V_1 - \frac{1}{1 \text{ k}\Omega} V_3 = -9 \text{ mA} \\
 & V_3 \left[\frac{1}{200 \text{ k}\Omega} + \frac{1}{100 \text{ k}\Omega} + \frac{1}{1 \text{ k}\Omega} \right] - \frac{1}{200 \text{ k}\Omega} V_1 - \frac{1}{1 \text{ k}\Omega} V_2 = 9 \text{ mA}
 \end{array}$$

50. a.

$$I_1 = I_{10V} = 3.33 \text{ mA}$$

Source conversion: $I = 10 \text{ V}/1 \text{ kΩ} = 10 \text{ mA}$, $R = 1 \text{ kΩ}$

$$\begin{aligned} \textcircled{V}_1 & V_1 \left[\frac{1}{1 \text{ kΩ}} + \frac{1}{2 \text{ kΩ}} + \frac{1}{2 \text{ kΩ}} \right] - \frac{1}{2 \text{ kΩ}} V_2 - \frac{1}{2 \text{ kΩ}} V_3 = 10 \text{ mA} \\ \textcircled{V}_3 & V_3 \left[\frac{1}{2 \text{ kΩ}} + \frac{1}{2 \text{ kΩ}} + \frac{1}{2 \text{ kΩ}} \right] - \frac{1}{2 \text{ kΩ}} V_1 - \frac{1}{2 \text{ kΩ}} V_2 = 0 \\ \textcircled{V}_2 & V_2 \left[\frac{1}{2 \text{ kΩ}} + \frac{1}{2 \text{ kΩ}} + \frac{1}{2 \text{ kΩ}} \right] - \frac{1}{2 \text{ kΩ}} V_3 - \frac{1}{2 \text{ kΩ}} V_1 = 0 \end{aligned}$$

$$V_1 = 6.67 \text{ V} = E - IR_s = 10 \text{ V} - I(1 \text{ kΩ})$$

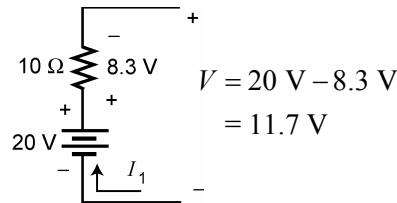
$$I = \frac{10 - 6.67 \text{ V}}{1 \text{ kΩ}} = 3.33 \text{ mA}$$

b.

Source conversion: $E = 20 \text{ V}$, $R = 10 \Omega$

$$\begin{aligned} (10 + 10 + 20)I_1 - 10I_2 - 20I_3 &= 20 \\ (10 + 20 + 20)I_2 - 10I_1 - 20I_3 &= 0 \\ (20 + 20 + 10)I_3 - 20I_1 - 20I_2 &= 0 \end{aligned}$$

$$I_1 = I_{20V} = 0.83 \text{ A}$$



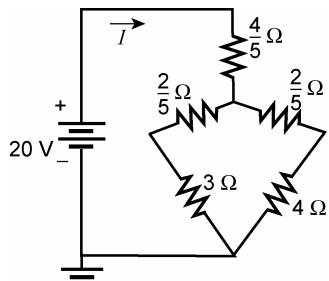
$$I_s = \frac{V}{R_s} = \frac{11.70 \text{ V}}{10 \Omega} = 1.17 \text{ A}$$

$$\begin{aligned} \textcircled{V}_1 & V_1 \left[\frac{1}{10} + \frac{1}{10} + \frac{1}{20} \right] - \left[\frac{1}{20} \right] V_2 - \left[\frac{1}{10} \right] V_3 = 2 \\ \textcircled{V}_3 & V_3 \left[\frac{1}{10} + \frac{1}{20} + \frac{1}{20} \right] - \left[\frac{1}{20} \right] V_1 - \left[\frac{1}{10} \right] V_2 = 0 \\ \textcircled{V}_2 & V_2 \left[\frac{1}{10} + \frac{1}{20} + \frac{1}{20} \right] - \left[\frac{1}{10} \right] V_3 - \left[\frac{1}{20} \right] V_1 = 0 \end{aligned}$$

$$I_{R_s} = \frac{V_1}{R_s} = 1.17 \text{ A}$$

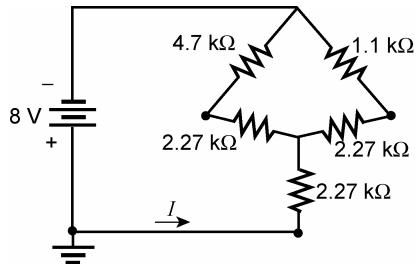
51.

a.



$$\begin{aligned}
 I &= \frac{20 \text{ V}}{\frac{4}{5} \Omega + \left[\frac{2}{5} \Omega + 3 \Omega \right] \parallel \left[\frac{2}{5} \Omega + 4 \Omega \right]} \\
 &= \frac{20 \text{ V}}{\frac{4}{5} \Omega + (3.14 \Omega) \parallel (4.4 \Omega)} \\
 &= 7.36 \text{ A}
 \end{aligned}$$

b.

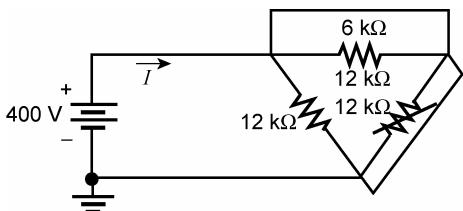


$$\begin{aligned}
 R_T &= 2.27 \text{ k}\Omega + [4.7 \text{ k}\Omega + 2.27 \text{ k}\Omega] \parallel [1.1 \text{ k}\Omega + 2.27 \text{ k}\Omega] \\
 &= 2.27 \text{ k}\Omega + [6.97 \text{ k}\Omega] \parallel [3.37 \text{ k}\Omega] \\
 &= 2.27 \text{ k}\Omega + 2.27 \text{ k}\Omega \\
 &= 4.54 \text{ k}\Omega
 \end{aligned}$$

$$I = \frac{8 \text{ V}}{4.54 \text{ k}\Omega} = 1.76 \text{ mA}$$

52.

a.



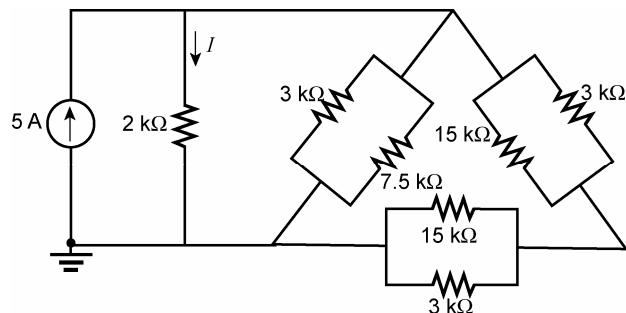
(Y-Δ conversion)

$$\begin{aligned}
 I &= \frac{400 \text{ V}}{12 \text{ k}\Omega \parallel 12 \text{ k}\Omega \parallel 6 \text{ k}\Omega} = \frac{400 \text{ V}}{3 \text{ k}\Omega} \\
 &= 133.33 \text{ mA}
 \end{aligned}$$

b.

$$\begin{aligned}
 I &= \frac{42 \text{ V}}{(18 \Omega \parallel 18 \Omega) \parallel [(18 \Omega \parallel 18 \Omega) + (18 \Omega \parallel 18 \Omega)]} = \frac{42 \text{ V}}{9 \Omega \parallel [9 \Omega + 9 \Omega]} \\
 &= 7 \text{ A} \text{ (Y-Δ conversion)}
 \end{aligned}$$

53.



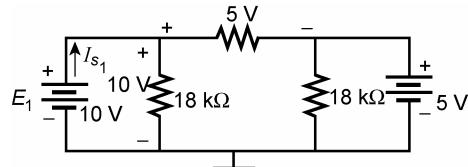
$$3 \text{ k}\Omega \parallel 7.5 \text{ k}\Omega = 2.14 \text{ k}\Omega$$

$$3 \text{ k}\Omega \parallel 15 \text{ k}\Omega = 2.5 \text{ k}\Omega$$

$$R'_T = 2.14 \text{ k}\Omega \parallel (2.5 \text{ k}\Omega + 2.5 \text{ k}\Omega) = 1.5 \text{ k}\Omega$$

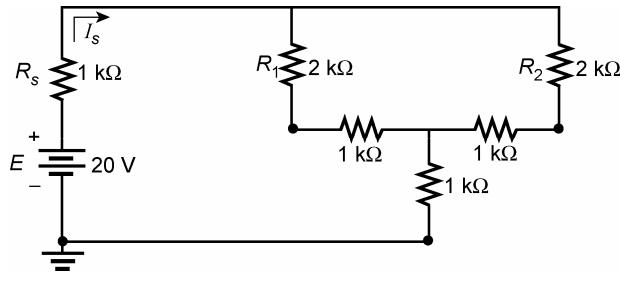
$$\text{CDR: } I = \frac{(1.5 \text{ k}\Omega)(5 \text{ A})}{1.5 \text{ k}\Omega + 2 \text{ k}\Omega} = \mathbf{2.14 \text{ A}}$$

54.



$$I_{s_1} = \frac{10 \text{ V}}{18 \text{ k}\Omega} + \frac{5 \text{ V}}{18 \text{ k}\Omega} = \frac{15 \text{ V}}{18 \text{ k}\Omega} = \mathbf{0.83 \text{ mA}}$$

55.



$$R' = R_1 + 1 \text{ k}\Omega = 3 \text{ k}\Omega$$

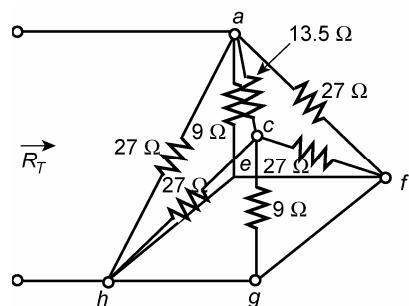
$$R'' = R_2 + 1 \text{ k}\Omega = 3 \text{ k}\Omega$$

$$R'_T = \frac{3 \text{ k}\Omega}{2} = 1.5 \text{ k}\Omega$$

$$R_T = 1 \text{ k}\Omega + 1.5 \text{ k}\Omega + 1 \text{ k}\Omega = 3.5 \text{ k}\Omega$$

$$I_s = \frac{E}{R_T} = \frac{20 \text{ V}}{3.5 \text{ k}\Omega} = \mathbf{5.71 \text{ mA}}$$

56.



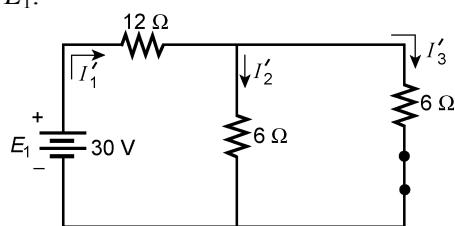
$$c - g: 27 \text{ }\Omega \parallel 9 \text{ }\Omega \parallel 27 \text{ }\Omega = 5.4 \text{ }\Omega$$

$$a - h: 27 \text{ }\Omega \parallel 9 \text{ }\Omega \parallel 27 \text{ }\Omega = 5.4 \text{ }\Omega$$

$$\begin{aligned} R_T &= 5.4 \text{ }\Omega \parallel (13.5 \text{ }\Omega + 5.4 \text{ }\Omega) \\ &= 5.4 \text{ }\Omega \parallel 18.9\Omega \\ &= \mathbf{4.2 \Omega} \end{aligned}$$

Chapter 9

1. a. E_1 :



$$I'_1 = \frac{30 \text{ V}}{12 \Omega + 6 \Omega \parallel 6 \Omega} = \frac{30 \text{ V}}{12 \Omega + 3 \Omega} = 2 \text{ A}$$

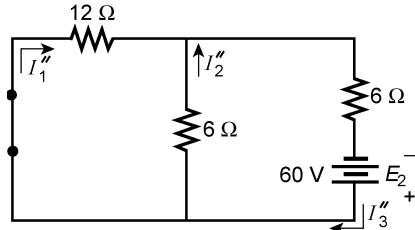
$$I'_2 = I'_3 = \frac{I'_1}{2} = 1 \text{ A}$$

$$I''_3 = \frac{60 \text{ V}}{6 \Omega + 6 \Omega \parallel 12 \Omega} = \frac{60 \text{ V}}{6 \Omega + 4 \Omega} = 6 \text{ A}$$

$$I''_1 = \frac{6 \Omega (I''_3)}{6 \Omega + 12 \Omega} = 2 \text{ A}$$

$$I''_2 = \frac{12 \Omega (I''_3)}{12 \Omega + 6 \Omega} = 4 \text{ A}$$

E_2 :



$$I_1 = I'_1 + I''_1 = 2 \text{ A} + 2 \text{ A} = 4 \text{ A} \text{ (dir. of } I'_1)$$

$$I_2 = I''_2 - I'_2 = 4 \text{ A} - 1 \text{ A} = 3 \text{ A} \text{ (dir. of } I''_2)$$

$$I_3 = I'_3 + I''_3 = 1 \text{ A} + 6 \text{ A} = 7 \text{ A} \text{ (dir. of } I'_3)$$

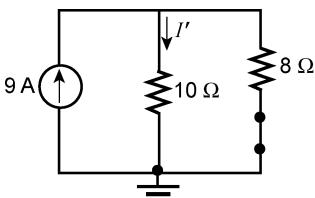
b. E_1 : $P'_1 = I_1'^2 R_l = (2 \text{ A})^2 12 \Omega = 48 \text{ W}$

E_2 : $P''_1 = I_1''^2 R_l I'' R_1 = (2 \text{ A})^2 12 \Omega = 48 \text{ W}$

c. $P_1 = I_1^2 R_l = (4 \text{ A})^2 12 \Omega = 192 \text{ W}$

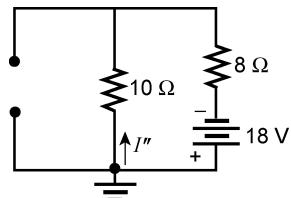
d. $P'_1 + P''_1 = 48 \text{ W} + 48 \text{ W} = 96 \text{ W} \neq 192 \text{ W} = P_1$

2. I:



$$I' = \frac{8 \Omega (9 \text{ A})}{8 \Omega + 10 \Omega} = 4 \text{ A}$$

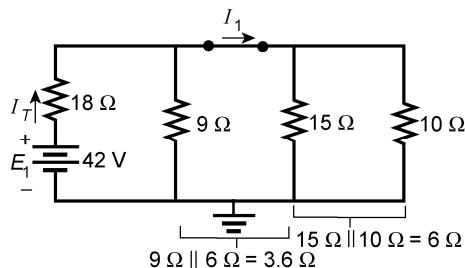
E:



$$I'' = \frac{18 \text{ V}}{10 \Omega + 8 \Omega} = 1 \text{ A}$$

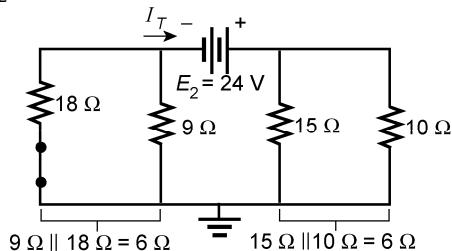
$$I = I' - I'' = 4 \text{ A} - 1 \text{ A} = 3 \text{ A} \text{ (dir of } I')$$

3.

 E_1 :

$$I_T = \frac{42 \text{ V}}{18 \Omega + 3.6 \Omega} = 1.944 \text{ A}$$

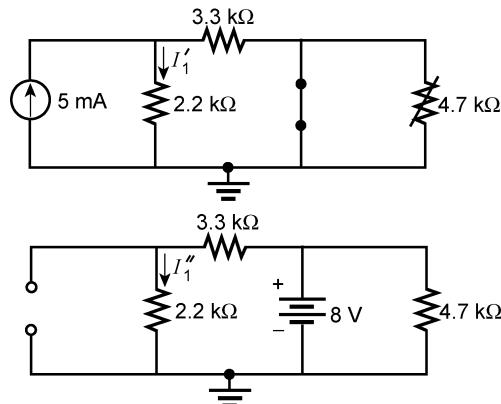
$$I_1 = \frac{9 \Omega (I_T)}{9 \Omega + 6 \Omega} = \frac{9 \Omega (1.944 \text{ A})}{15 \Omega} = 1.17 \text{ A}$$

 E_2 :

$$I_T = \frac{E_2}{R_T} = \frac{24 \text{ V}}{12 \Omega} = 2 \text{ A}$$

$$I_{24\text{V}} = I_T + I_1 = 2 \text{ A} + 1.17 \text{ A} = \mathbf{3.17 \text{ A (dir. of } I_1)}$$

4.

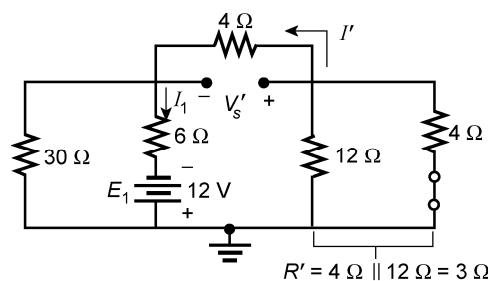


$$I'_1 = \frac{3.3 \text{ k}\Omega (5 \text{ mA})}{2.2 \text{ k}\Omega + 3.3 \text{ k}\Omega} = \frac{16.5 \text{ mA}}{5.5} = 3 \text{ mA}$$

$$I''_1 = \frac{8 \text{ V}}{3.3 \text{ k}\Omega + 2.2 \text{ k}\Omega} = \frac{8 \text{ V}}{5.5 \text{ k}\Omega} = 1.45 \text{ mA}$$

$$I_1 = I'_1 + I''_1 = 3 \text{ mA} + 1.45 \text{ mA} = \mathbf{4.45 \text{ mA}}$$

5.

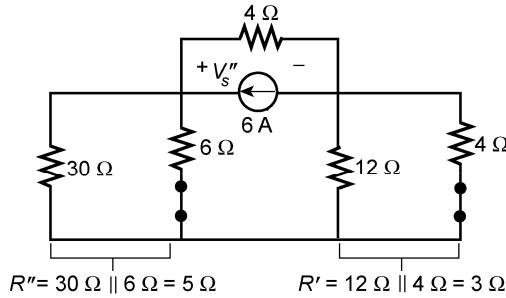
 E_1 :

$$I_1 = \frac{E_1}{R_T} = \frac{12 \text{ V}}{6 \Omega + 5.88 \Omega} = 1.03 \text{ A}$$

$$I' = \frac{30 \Omega(I_1)}{30 \Omega + 7 \Omega} = \frac{30 \Omega(1.03 \text{ A})}{37 \Omega} = 835.14 \text{ mA}$$

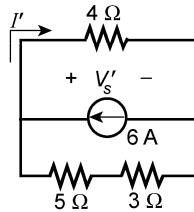
$$V'_s = I'(4 \Omega) = (835.14 \text{ mA})(4 \Omega) = 3.34 \text{ V}$$

I:

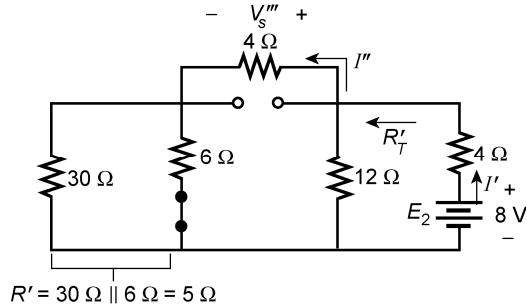


$$I' = \frac{8 \Omega(6 \text{ A})}{8 \Omega + 4 \Omega} = 4 \text{ A}$$

$$V''_s = I'(4 \Omega) = 4 \text{ A}(4 \Omega) = 16 \text{ V}$$



E₂:



$$R'_T = 12 \Omega \parallel (4 \Omega + 5 \Omega) = 12 \Omega \parallel 9 \Omega = 5.14 \Omega$$

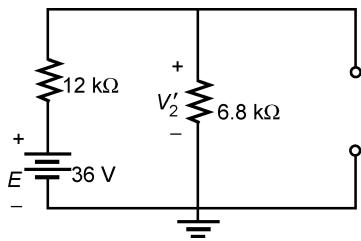
$$I' = \frac{E_2}{R_T} = \frac{8 \text{ V}}{4 \Omega + 5.14 \Omega} = 0.875 \text{ A}$$

$$I'' = \frac{12 \Omega(I')}{12 \Omega + 9 \Omega} = \frac{12 \Omega(0.875 \text{ A})}{21 \Omega} = 0.5 \text{ A}$$

$$V'''_s = I''(4 \Omega) = 0.5 \text{ A}(4 \Omega) = 2 \text{ V}$$

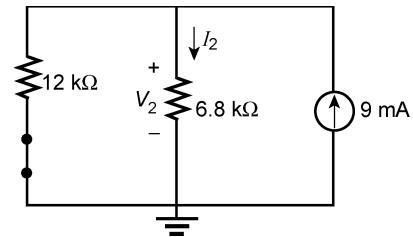
$$V_s = V''_s - V'_s - V'''_s = 16 \text{ V} - 3.34 \text{ V} - 2 \text{ V} = \mathbf{10.66 \text{ V}}$$

6. E:



$$V_2' = \frac{6.8 \text{ k}\Omega (36 \text{ V})}{6.8 \text{ k}\Omega + 12 \text{ k}\Omega} = 13.02 \text{ V}$$

I:



$$I_2 = \frac{12 \text{ k}\Omega (9 \text{ mA})}{12 \text{ k}\Omega + 6.8 \text{ k}\Omega} = 5.75 \text{ mA}$$

$$V_2'' = I_2 R_2 = (5.75 \text{ mA})(6.8 \text{ k}\Omega) = 39.10 \text{ V}$$

$$V_2 = V_2' + V_2'' = 13.02 \text{ V} + 39.10 \text{ V} = \mathbf{52.12 \text{ V}}$$

7. a. $R_{Th} = R_3 + R_1 \parallel R_2 = 4 \Omega + 6 \Omega \parallel 3 \Omega = 4 \Omega + 2 \Omega = \mathbf{6 \Omega}$

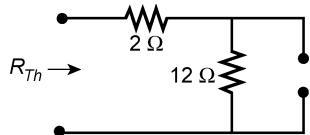
$$E_{Th} = \frac{R_2 E}{R_2 + R_1} = \frac{3 \Omega (18 \text{ V})}{3 \Omega + 6 \Omega} = 6 \text{ V}$$

b. $I_1 = \frac{E_{Th}}{R_{Th} + R} = \frac{6 \text{ V}}{6 \Omega + 2 \Omega} = \mathbf{0.75 \text{ A}}$

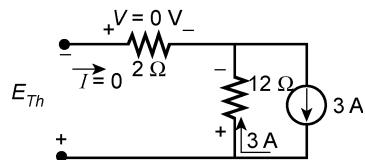
$$I_2 = \frac{6 \text{ V}}{6 \Omega + 30 \Omega} = \mathbf{166.67 \text{ mA}}$$

$$I_3 = \frac{6 \text{ V}}{6 \Omega + 100 \Omega} = \mathbf{56.60 \text{ mA}}$$

8. a.



$$R_{Th} = 2 \Omega + 12 \Omega = \mathbf{14 \Omega}$$

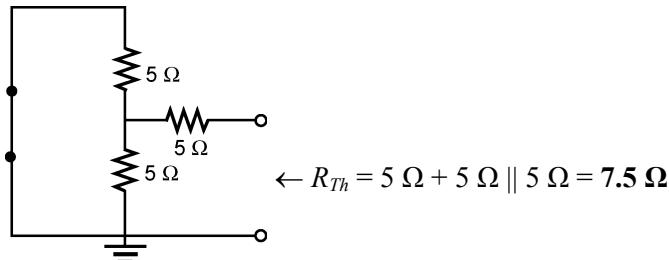


$$E_{Th} = IR = (3 \text{ A})(12 \Omega) = \mathbf{36 \text{ V}}$$

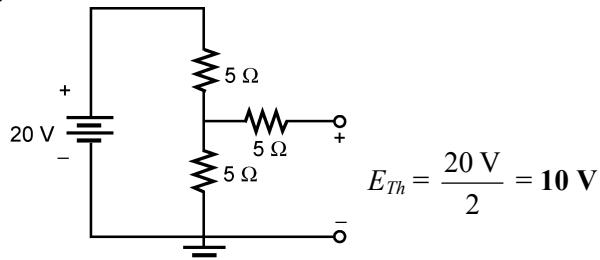
b. $R = 2 \Omega$: $P = \left(\frac{E_{Th}}{R_{Th} + R} \right)^2 R = \left(\frac{36 \text{ V}}{14 \Omega + 2 \Omega} \right)^2 2 \Omega = 10.13 \text{ W}$

$$R = 100 \Omega: P = \left(\frac{36 \text{ V}}{14 \Omega + 100 \Omega} \right)^2 100 \Omega = 9.97 \text{ W}$$

9. a. R_{Th} :



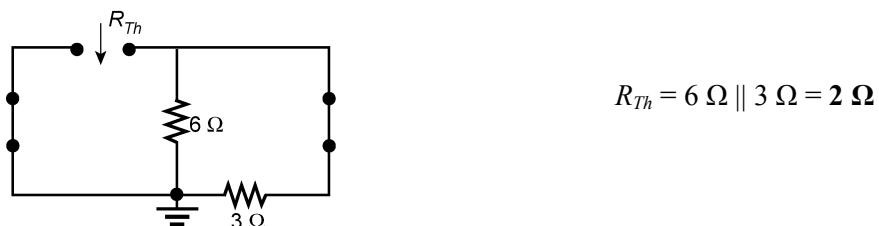
E_{Th} :



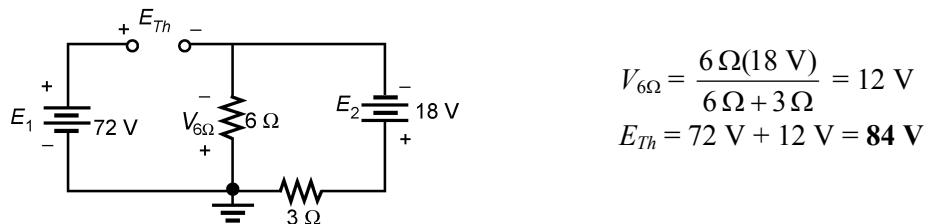
b. $R = 2 \Omega$: $P = \left(\frac{E_{Th}}{R_{Th} + R} \right)^2 R = \left(\frac{10 \text{ V}}{7.5 \Omega + 2 \Omega} \right)^2 2 \Omega = 2.22 \text{ W}$

$$R = 100 \Omega: P = \left(\frac{10 \text{ V}}{7.5 \Omega + 100 \Omega} \right)^2 100 \Omega = 0.87 \text{ W}$$

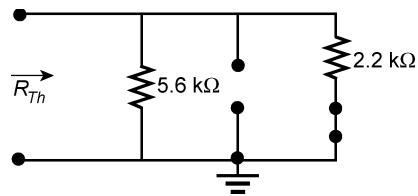
10. R_{Th} :



E_{Th} :



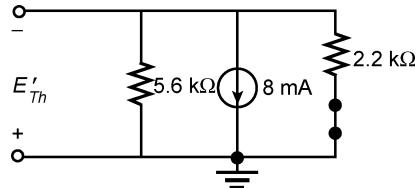
11. R_{Th} :



$$R_{Th} = 5.6 \text{ k}\Omega \parallel 2.2 \text{ k}\Omega = 1.58 \text{ k}\Omega$$

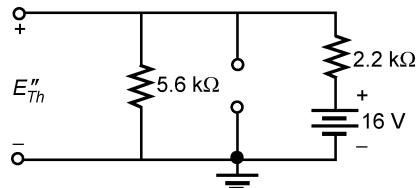
E_{Th} : Superposition:

I:



$$\begin{aligned} E'_{Th} &= IR_T \\ &= 8 \text{ mA}(5.6 \text{ k}\Omega \parallel 2.2 \text{ k}\Omega) \\ &= 8 \text{ mA}(1.579 \text{ k}\Omega) \\ &= 12.64 \text{ V} \end{aligned}$$

E:

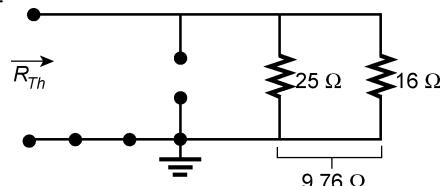


$$E''_{Th} = \frac{5.6 \text{ k}\Omega(16 \text{ V})}{5.6 \text{ k}\Omega + 2.2 \text{ k}\Omega} = 11.49 \text{ V}$$

$$E_{Th} = 11.49 \text{ V} - 12.64 \text{ V} = -1.15 \text{ V}$$

-

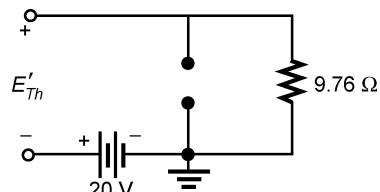
12. a. R_{Th} :



$$R_{Th} = 25 \Omega \parallel 16 \Omega = 9.76 \Omega$$

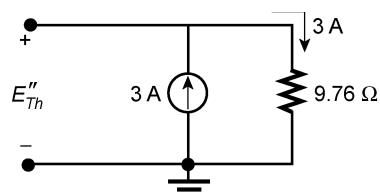
E_{Th} : Superposition:

E:



$$E'_{Th} = -20 \text{ V}$$

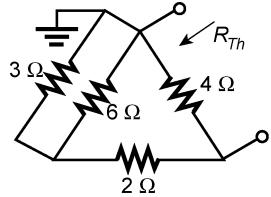
I:



$$E''_{Th} = (3 \text{ A})(9.76 \Omega) = 29.28 \text{ V}$$

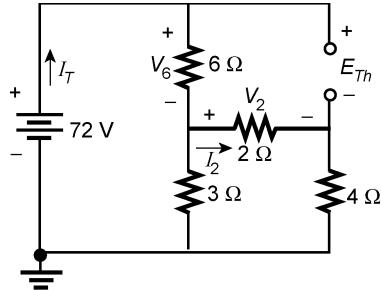
$$E_{Th} = E''_{Th} - E'_{Th} = 29.28 \text{ V} - 20 \text{ V} = 9.28 \text{ V}$$

b. R_{Th} :



$$R_{Th} = 4 \Omega \parallel (2 \Omega + 6 \Omega \parallel 3 \Omega) = 2 \Omega$$

E_{Th} :

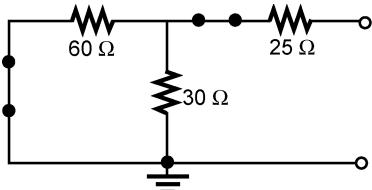


$$I_T = \frac{72 \text{ V}}{6 \Omega + 3 \Omega \parallel (2 \Omega + 4 \Omega)} = 9 \text{ A}$$

$$I_2 = \frac{3 \Omega (I_T)}{3 \Omega + 6 \Omega} = \frac{3 \Omega (9 \text{ A})}{9 \Omega} = 3 \text{ A}$$

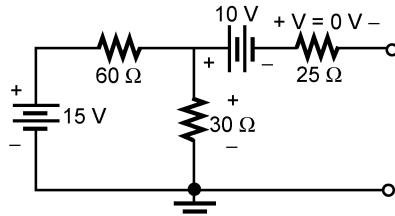
$$E_{Th} = V_6 + V_2 = (I_T)(6 \Omega) + I_2(2 \Omega) = (9 \text{ A})(6 \Omega) + (3 \text{ A})(2 \Omega) = 60 \text{ V}$$

13. (I): R_{Th} :



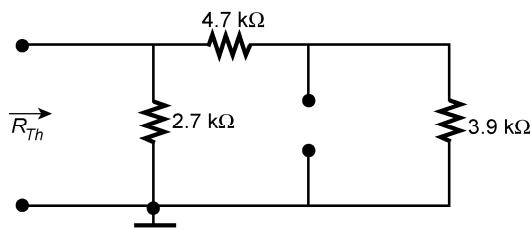
$$\leftarrow R_{Th} = 25 \Omega + 60 \Omega \parallel 30 \Omega = 45 \Omega$$

E_{Th} :



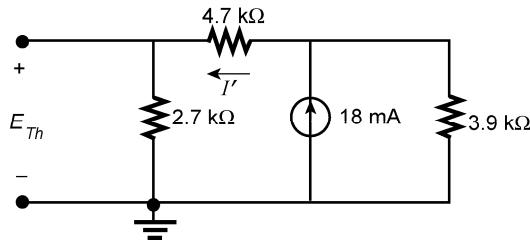
$$\begin{aligned} E_{Th} &= V_{30\Omega} - 10 \text{ V} - 0 \\ &= \frac{30 \Omega (15 \text{ V})}{30 \Omega + 60 \Omega} - 10 \text{ V} \\ &= 5 \text{ V} - 10 \text{ V} = -5 \text{ V} \end{aligned}$$

(II): R_{Th} :



$$R_{Th} = 2.7 \text{ k}\Omega \parallel (4.7 \text{ k}\Omega + 3.9 \text{ k}\Omega) = 2.7 \text{ k}\Omega \parallel 8.6 \text{ k}\Omega = 2.06 \text{ k}\Omega$$

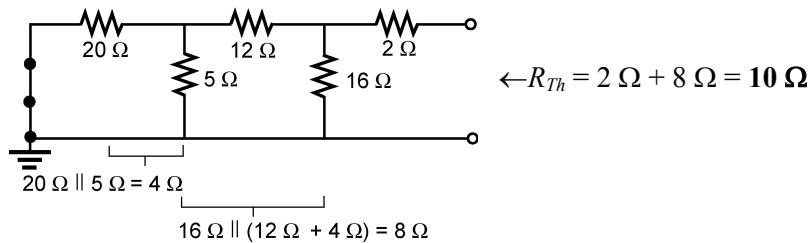
E_{Th}:



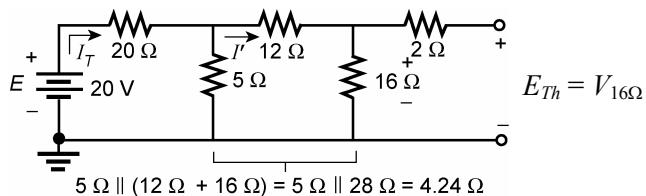
$$I' = \frac{3.9 \text{ k}\Omega(18 \text{ mA})}{3.9 \text{ k}\Omega + 7.4 \text{ k}\Omega} = 6.21 \text{ mA}$$

$$E_{Th} = I'(2.7 \text{ k}\Omega) = (6.21 \text{ mA})(2.7 \text{ k}\Omega) = \mathbf{16.77 \text{ V}}$$

14. (I): R_{Th} :



$$E_{Th}:$$

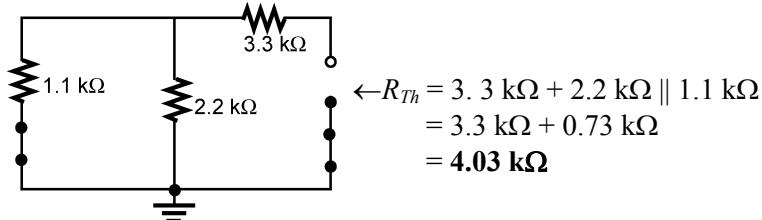


$$I_T = \frac{20 \text{ V}}{20 \Omega + 4.24 \Omega} = 825.08 \text{ mA}$$

$$I = \frac{5\Omega(I_T)}{5\Omega + 28\Omega} = \frac{5\Omega(825.08 \text{ mA})}{33\Omega} = 125.01 \text{ mA}$$

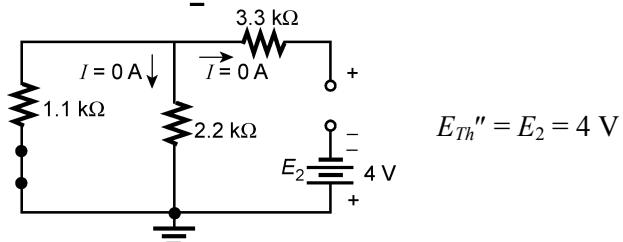
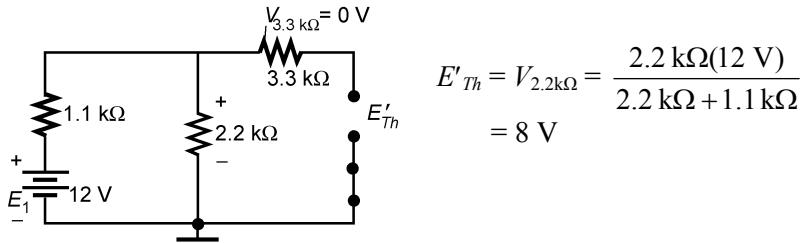
$$E_{Th} = V_{16\Omega} = (I')(16 \Omega) = (125.01 \text{ mA})(16 \Omega) = 2 \text{ V}$$

(II): R_{Th} :



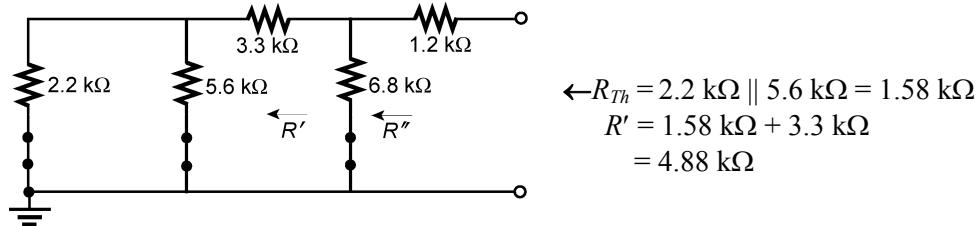
E_{Th} : Superposition:

E_1 :



$$E_{Th} = E'_Th + E''_Th = 8 \text{ V} + 4 \text{ V} = 12 \text{ V}$$

15. R_{Th} :



$$R'' = 4.88 \text{ k}\Omega \parallel 6.8 \text{ k}\Omega = 2.84 \text{ k}\Omega$$

$$R_{Th} = 1.2 \text{ k}\Omega + R'' = 1.2 \text{ k}\Omega + 2.84 \text{ k}\Omega = 4.04 \text{ k}\Omega$$

E_{Th} : Source conversions:

$$I_1 = \frac{22 \text{ V}}{2.2 \text{ k}\Omega} = 10 \text{ mA}, R_s = 2.2 \text{ k}\Omega$$

$$I_2 = \frac{12 \text{ V}}{5.6 \text{ k}\Omega} = 2.14 \text{ mA}, R_s = 5.6 \text{ k}\Omega$$

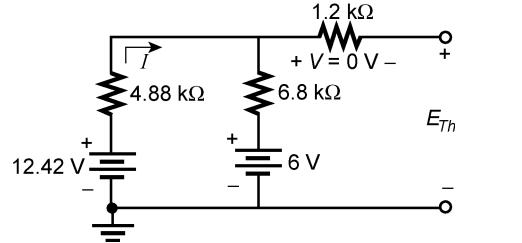
Combining parallel current sources: $I'_T = I_1 - I_2 = 10 \text{ mA} - 2.14 \text{ mA} = 7.86 \text{ mA}$

$$2.2 \text{ k}\Omega \parallel 5.6 \text{ k}\Omega = 1.58 \text{ k}\Omega$$

Source conversion:

$$E = (7.86 \text{ mA})(1.58 \text{ k}\Omega) = 12.42 \text{ V}$$

$$R' = R_s + 3.3 \text{ k}\Omega = 1.58 \text{ k}\Omega + 3.3 \text{ k}\Omega = 4.88 \text{ k}\Omega$$

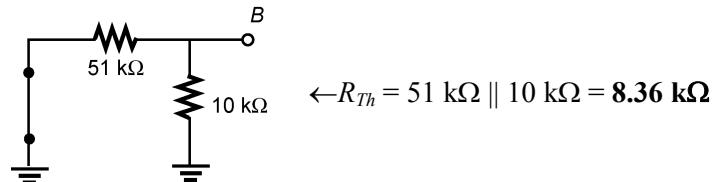


$$I = \frac{12.42 \text{ V} - 6 \text{ V}}{4.88 \text{ k}\Omega + 6.8 \text{ k}\Omega} = \frac{6.42 \text{ V}}{11.68 \text{ k}\Omega} = 549.66 \mu\text{A}$$

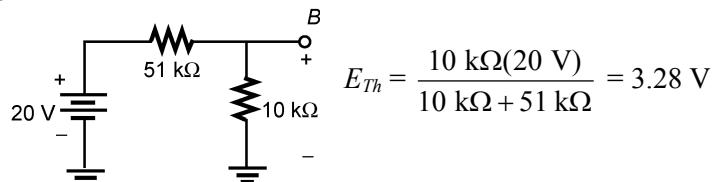
$$V_{6.8\text{k}\Omega} = I(6.8 \text{ k}\Omega) = (549.66 \mu\text{A})(6.8 \text{ k}\Omega) = 3.74 \text{ V}$$

$$E_{Th} = 6 \text{ V} + V_{6.8\text{k}\Omega} = 6 \text{ V} + 3.74 \text{ V} = \mathbf{9.74 \text{ V}}$$

16. a. R_{Th} :



E_{Th} :



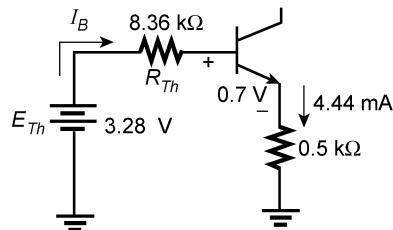
$$\text{b. } I_E R_E + V_{CE} + I_C R_C = 20 \text{ V}$$

but $I_C = I_E$

$$\text{and } I_E(R_C + R_E) + V_{CE} = 20 \text{ V}$$

$$\text{or } I_E = \frac{20 \text{ V} - V_{CE}}{R_C + R_E} = \frac{20 \text{ V} - 8 \text{ V}}{2.2 \text{ k}\Omega + 0.5 \text{ k}\Omega} = \frac{12 \text{ V}}{2.7 \text{ k}\Omega} = \mathbf{4.44 \text{ mA}}$$

c.



$$E_{Th} - I_B R_{Th} - V_{BE} - V_E = 0$$

$$\text{and } I_B = \frac{E_{Th} - V_{BE} - V_E}{R_{Th}} = \frac{3.28 \text{ V} - 0.7 \text{ V} - (4.44 \text{ mA})(0.5 \text{ k}\Omega)}{8.36 \text{ k}\Omega}$$

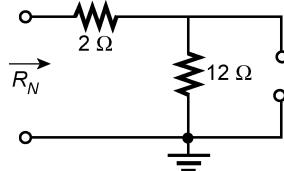
$$= \frac{2.58 \text{ V} - 2.22 \text{ V}}{8.36 \text{ k}\Omega} = \frac{0.36 \text{ V}}{8.36 \text{ k}\Omega} = 43.06 \mu\text{A}$$

d. $V_C = 20 \text{ V} - I_C R_C = 20 \text{ V} - (4.44 \text{ mA})(2.2 \text{ k}\Omega)$
 $= 20 \text{ V} - 9.77 \text{ V}$
 $= 10.23 \text{ V}$

17. a. $E_{Th} = 20 \text{ V}$
 $I = 1.6 \text{ mA} = \frac{E_{Th}}{R_{Th}} = \frac{20 \text{ V}}{R_{Th}}, R_{Th} = \frac{20 \text{ V}}{1.6 \text{ mA}} = 12.5 \text{ k}\Omega$

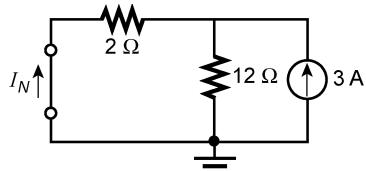
b. $E_{Th} = 60 \text{ mV}, R_{Th} = 2.72 \text{ k}\Omega$
c. $E_{Th} = 16 \text{ V}, R_{Th} = 2.2 \text{ k}\Omega$

18. R_N :



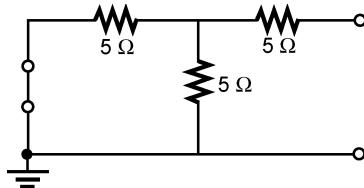
$$R_N = 2 \Omega + 12 \Omega = 14 \Omega$$

I_N :



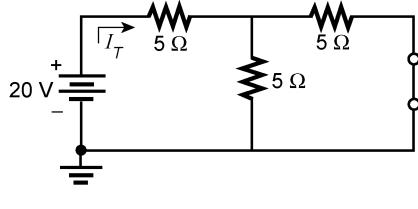
$$I_N = \frac{12 \Omega(3 \text{ A})}{12 \Omega + 2 \Omega} = 2.57 \text{ A}$$

19. a. R_N :



$$\leftarrow R_N = 5 \Omega + \frac{5 \Omega}{2} = 7.5 \Omega$$

I_N :

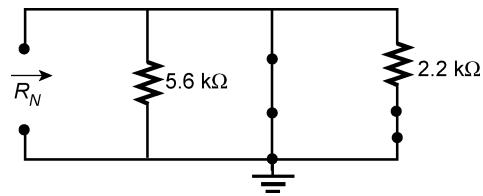


$$I_T = \frac{20 \text{ V}}{5 \Omega + \frac{5 \Omega}{2}} = 2.67 \text{ A}$$

$$I_N = \frac{I_T}{2} = 1.34 \text{ A}$$

b. $E_{Th} = I_N R_N = (1.34 \text{ A})(7.5 \Omega) = 10.05 \text{ V} \cong 10 \text{ V}, R_{Th} = R_N = 7.5 \Omega$

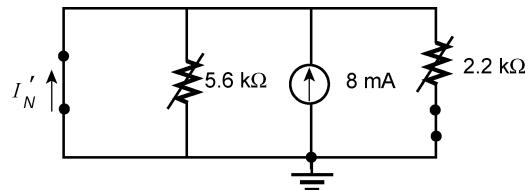
20. R_N :



$$R_N = 5.6 \text{ k}\Omega \parallel 2.2 \text{ k}\Omega = 1.58 \text{ k}\Omega$$

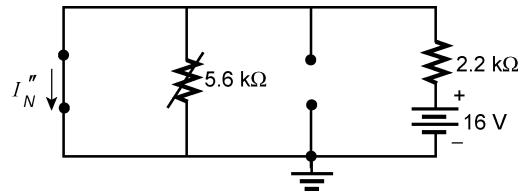
I_N :

I :



$$I'_N = 8 \text{ mA}$$

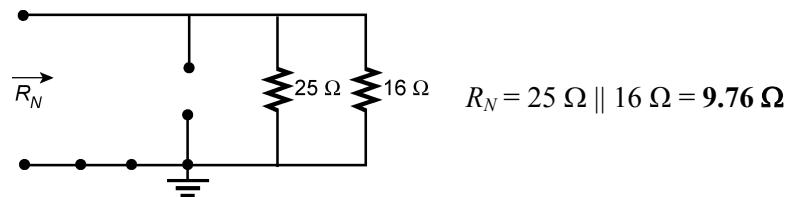
E :



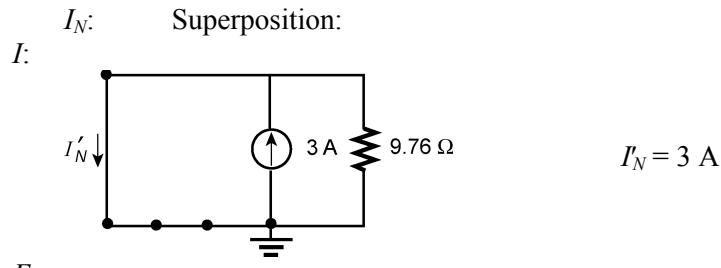
$$I''_N = \frac{16 \text{ V}}{2.2 \text{ k}\Omega} = 7.27 \text{ mA}$$

$$I_N \uparrow = 8 \text{ mA} - 7.27 \text{ mA} = 0.73 \text{ mA}$$

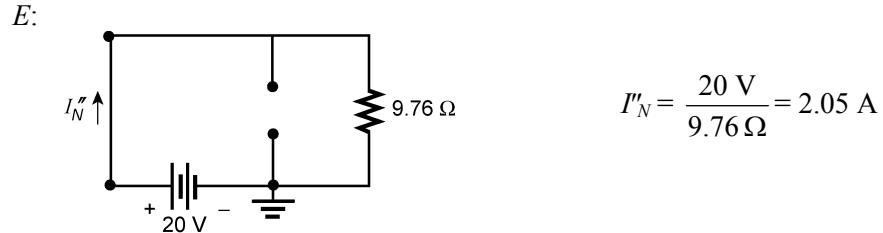
21. (I): (a)



$$R_N = 25 \Omega \parallel 16 \Omega = 9.76 \Omega$$



$$I_N = 3 \text{ A}$$

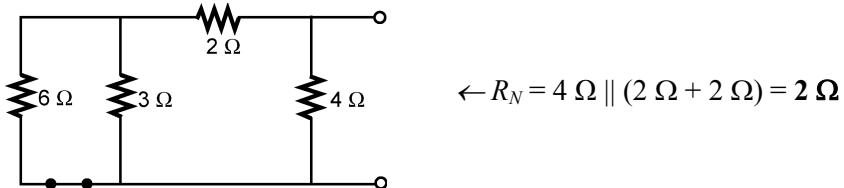


$$I_N' = \frac{20 \text{ V}}{9.76 \Omega} = 2.05 \text{ A}$$

$$I_N = I_N - I_N' = 3 \text{ A} - 2.05 \text{ A} = 0.95 \text{ A} \quad (\text{direction of } I_N)$$

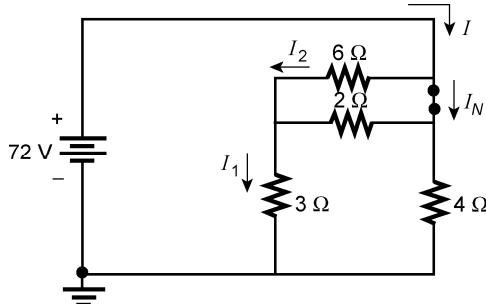
b. $E_{Th} = I_N R_N = (0.95 \text{ A})(9.76 \Omega) = 9.27 \text{ V} \approx 9.28 \text{ V}, R_{Th} = R_N = 9.76 \Omega$

(II): a. R_N :



$$\leftarrow R_N = 4 \Omega \parallel (2 \Omega + 2 \Omega) = 2 \Omega$$

I_N :



$$I = \frac{72 \text{ V}}{4 \Omega \parallel (3 \Omega + 6 \Omega \parallel 2 \Omega)}$$

$$= \frac{72 \text{ V}}{2.118 \Omega} \approx 34 \text{ A}$$

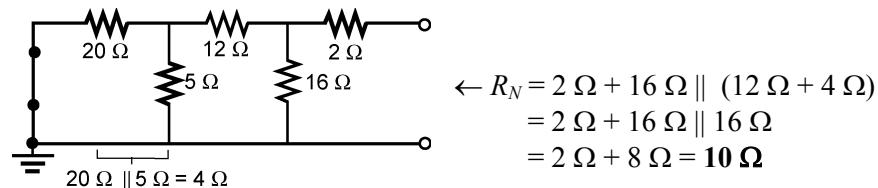
$$I_1 = \frac{4 \Omega(I)}{4 \Omega + 4.5 \Omega} = 16 \text{ A}$$

$$I_2 = \frac{2 \Omega(I_1)}{2 \Omega + 6 \Omega} = 4 \text{ A}$$

$$I_N = I - I_2 = 34 \text{ A} - 4 \text{ A} = 30 \text{ A}$$

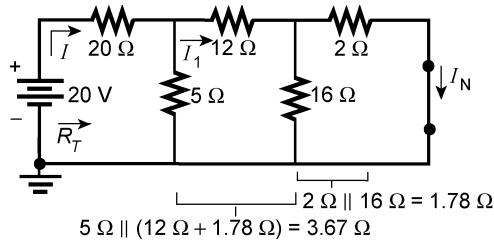
b. $E_{Th} = I_N R_N = (30 \text{ A})(2 \Omega) = 60 \text{ V}, R_{Th} = R_N = 2 \Omega$

22. (I) R_N :



$$\begin{aligned} \leftarrow R_N &= 2 \Omega + 16 \Omega \parallel (12 \Omega + 4 \Omega) \\ &= 2 \Omega + 16 \Omega \parallel 16 \Omega \\ &= 2 \Omega + 8 \Omega = 10 \Omega \end{aligned}$$

I_N :

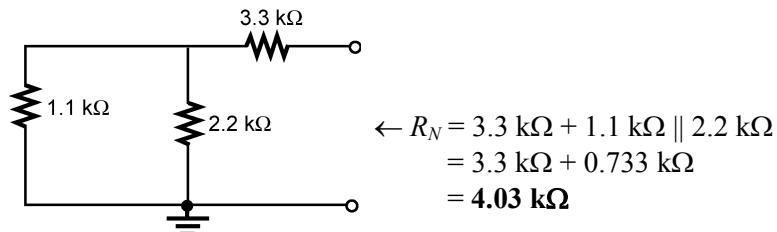


$$I = \frac{E}{R_T} = \frac{20\text{ V}}{20\Omega + 3.67\Omega} = 0.845\text{ A}$$

$$I_1 = \frac{5\Omega(0.845\text{ A})}{5\Omega + 13.78\Omega} = 0.225\text{ A}$$

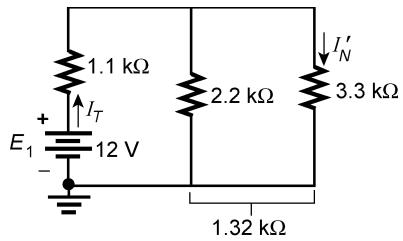
$$I_N = \frac{16\Omega(0.225\text{ A})}{16\Omega + 2\Omega} = \mathbf{0.2\text{ A}}$$

(II): R_N :



I_N : Superposition:

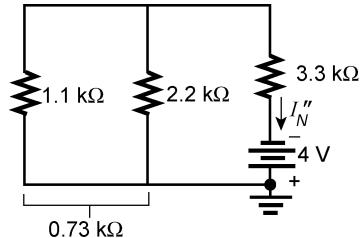
E_1 :



$$I_T = \frac{12\text{ V}}{1.1\text{ k}\Omega + 1.32\text{ k}\Omega} = 4.96\text{ mA}$$

$$I'_N = \frac{2.2\text{ k}\Omega(4.96\text{ mA})}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega} = 1.98\text{ mA}$$

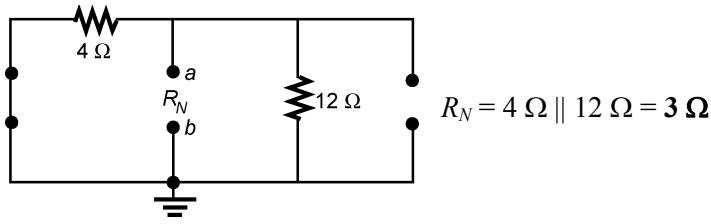
E_2 :



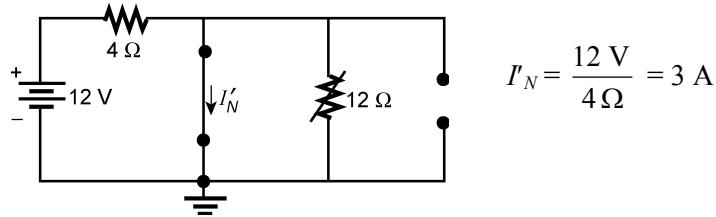
$$I''_N = \frac{4\text{ V}}{3.3\text{ k}\Omega + 0.73\text{ k}\Omega} = 0.99\text{ mA}$$

$$I_N = I'_N + I''_N = 1.98\text{ mA} + 0.99\text{ mA} = \mathbf{2.97\text{ mA}}$$

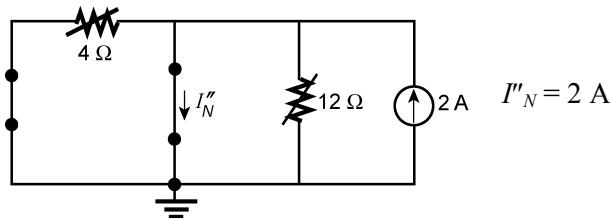
23. a. R_N :



$E = 12 \text{ V}$:

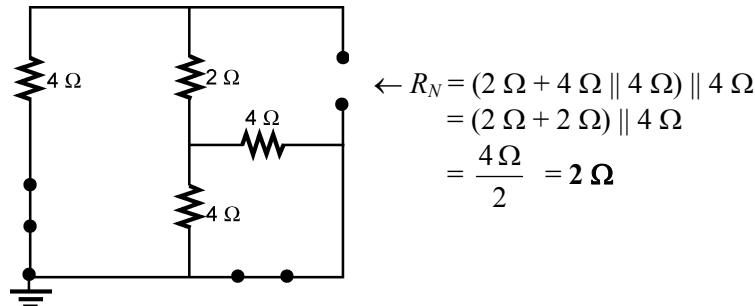


$I = 2 \text{ A}$:

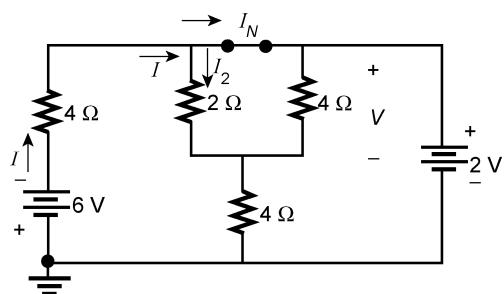


$$I_N = I'_N + I''_N = 3 \text{ A} + 2 \text{ A} = 5 \text{ A}$$

b. R_N :



I_N :



$$I = \frac{V_{4\Omega}}{4\Omega} = \frac{6 \text{ V} - 2 \text{ V}}{4 \Omega} = \frac{4 \text{ V}}{4 \Omega} = 1 \text{ A}$$

$$V = \frac{(4 \Omega \parallel 2 \Omega)(2 \text{ V})}{(4 \Omega \parallel 2 \Omega) + 4 \Omega} = 0.5 \text{ V}$$

$$I_2 = \frac{V}{R} = \frac{0.5 \text{ V}}{2 \Omega} = 0.25 \text{ A}$$

$$I_N = I - I_2 = 1 \text{ A} - 0.25 \text{ A} = \mathbf{0.75 \text{ A}}$$

24. (I): (a) $R = R_{Th} = \mathbf{9.76 \Omega}$ (from problem 12)

(II): (a) $R = R_{Th} = \mathbf{2 \Omega}$ (from problem 12)

(I): (b) $P_{max} = E_{Th}^2 / 4R_{Th} = (9.28 \text{ V})^2 / 4(9.76 \Omega) = \mathbf{2.21 \text{ W}}$

(II): (b) $P_{max} = E_{Th}^2 / 4R_{Th} = (60 \text{ V})^2 / 4(2 \Omega) = \mathbf{450 \text{ W}}$

25. (I): (a) $R = R_{Th} = \mathbf{10 \Omega}$ (from problem 14)

(II): (a) $R = R_{Th} = \mathbf{4.03 \text{ k}\Omega}$ (from problem 14)

(I): (b) $P_{max} = E_{Th}^2 / 4R_{Th} = (2 \text{ V})^2 / 4(10 \Omega) = \mathbf{100 \text{ mW}}$

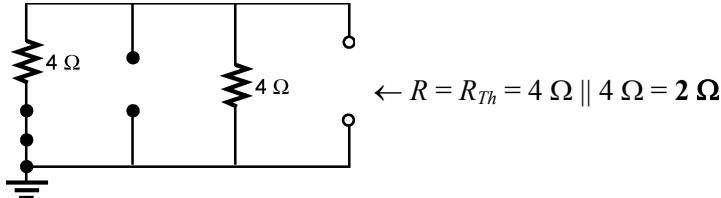
(II): (b) $P_{max} = E_{Th}^2 / 4R_{Th} = (12 \text{ V})^2 / 4(4.03 \text{ k}\Omega) = \mathbf{8.93 \text{ mW}}$

26. $R_L = R_{Th} = \mathbf{4.04 \text{ k}\Omega}$ (from problem 15)

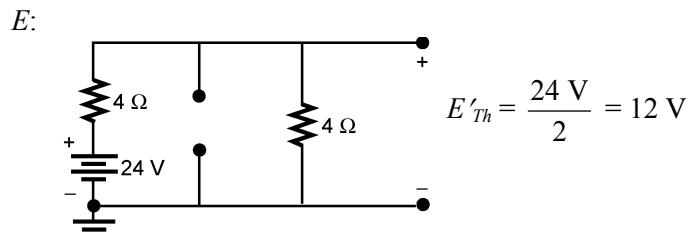
$E_{Th} = \mathbf{9.74 \text{ V}}$ (from problem 15)

$P_{max} = E_{Th}^2 / 4R_{Th} = (9.74 \text{ V})^2 / 4(4.04 \text{ k}\Omega) = \mathbf{5.87 \text{ mW}}$

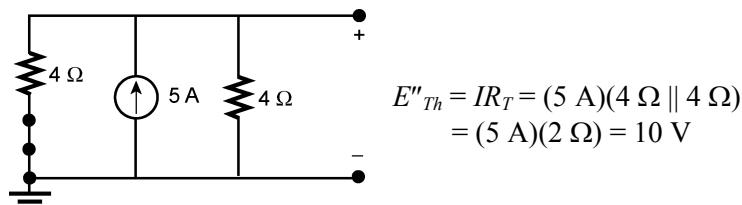
27. a.



b. E_{Th} :



I:



$$E_{Th} = E'_Th + E''_Th = 12 \text{ V} + 10 \text{ V} = \mathbf{22 \text{ V}}$$

$$P_{max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(22 \text{ V})^2}{4(2 \Omega)} = \mathbf{60.5 \text{ W}}$$

c.

$$P = I^2 R = \left(\frac{E_{Th}}{R_{Th} + R} \right)^2 R$$

$$R = \frac{1}{4}(2\Omega) = 0.5\Omega, P = 38.72\text{ W}$$

$$R = \frac{1}{2}(2\Omega) = 1\Omega, P = 53.78\text{ W}$$

$$R = \frac{3}{4}(2\Omega) = 1.5\Omega, P = 59.27\text{ W}$$

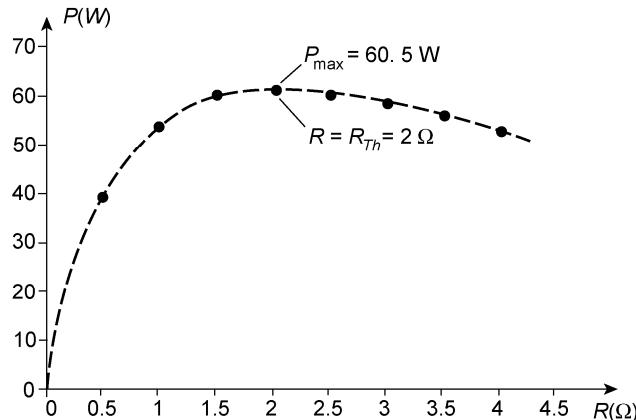
$$R = 2\Omega, P = 60.5\text{ W}$$

$$R = \frac{5}{4}(2\Omega) = 2.5\Omega, P = 59.75\text{ W}$$

$$R = \frac{3}{2}(2\Omega) = 3\Omega, P = 58\text{ W}$$

$$R = \frac{7}{4}(2\Omega) = 3.5\Omega, P = 56\text{ W}$$

$$R = 2(2\Omega) = 4\Omega, P = 53.78\text{ W}$$



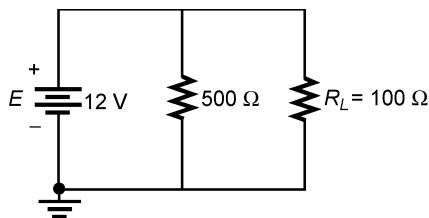
28. $P_{\max} = \left(\frac{E_{Th}}{R_{Th} + R_4} \right)^2 R_4$
with $R_1 = 0\Omega$ E_{Th} is a maximum and R_{Th} a minimum
 $\therefore P_{\max}$ a **maximum**

29. a.

V , and therefore V_4 , will be its largest value when R_2 is as large as possible. Therefore choose $R_2 = \text{open-circuit } (\infty\Omega)$. Then $P_4 = \frac{V_4^2}{R_4}$ will be a maximum.

b. No, examine each individually.

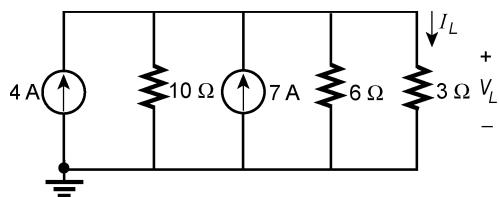
30.



Since R_L fixed, maximum power to R_L when V_{R_L} a maximum as defined by $P_L = \frac{V_{R_L}^2}{R_L}$

$$\therefore R = 500 \Omega \text{ and } P_{\max} = \frac{(12 \text{ V})^2}{100 \Omega} = 1.44 \text{ W}$$

31.



$$I_T \uparrow = 4 \text{ A} + 7 \text{ A} = 11 \text{ A}$$

$$R_T = 10 \Omega \parallel 6 \Omega \parallel 3 \Omega = 1.67 \Omega$$

$$V_L = I_T R_T = (11 \text{ A})(1.67 \Omega) = 18.37 \text{ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{18.37 \text{ V}}{3 \Omega} = 6.12 \text{ A}$$

32. $E_{\text{eq}} = \frac{-5 \text{ V}/2.2 \text{ k}\Omega + 20 \text{ V}/8.2 \text{ k}\Omega}{1/2.2 \text{ k}\Omega + 1/8.2 \text{ k}\Omega} = 0.2879 \text{ V}$

$$R_{\text{eq}} = \frac{1}{1/2.2 \text{ k}\Omega + 1/8.2 \text{ k}\Omega} = 1.7346 \text{ k}\Omega$$

$$I_L = \frac{E_{\text{eq}}}{R_{\text{eq}} + R_L} = \frac{0.2879 \text{ V}}{1.7346 \text{ k}\Omega + 5.6 \text{ k}\Omega} = 39.3 \mu\text{A}$$

$$V_L = I_L R_L = (39.3 \mu\text{A})(5.6 \text{ k}\Omega) = 220 \text{ mV}$$

33. $I_T \downarrow = 5 \text{ A} - 0.4 \text{ A} - 0.2 \text{ A} = 4.40 \text{ A}$

$$R_T = 200 \Omega \parallel 80 \Omega \parallel 50 \Omega \parallel 50 \Omega = 17.39 \Omega$$

$$V_L = I_T R_T = (4.40 \text{ A})(17.39 \Omega) = 75.52 \text{ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{76.52 \text{ V}}{200 \Omega} = 0.38 \text{ A}$$

34. $I_{\text{eq}} = \frac{(4 \text{ A})(4.7 \Omega) + (1.6 \text{ A})(3.3 \Omega)}{4.7 \Omega + 3.3 \Omega} = \frac{18.8 \text{ V} + 5.28 \text{ V}}{8 \Omega} = 3.01 \text{ A}$

$$R_{\text{eq}} = 4.7 \Omega + 3.3 \Omega = 8 \Omega$$

$$I_L = \frac{R_{\text{eq}}(I_{\text{eq}})}{R_{\text{eq}} + R_L} = \frac{8 \Omega(3.01 \text{ A})}{8 \Omega + 2.7 \Omega} = 2.25 \text{ A}$$

$$V_L = I_L R_L = (2.25 \text{ A})(2.7 \Omega) = 6.08 \text{ V}$$

35. $I_{eq} = \frac{(4 \text{ mA})(8.2 \text{ k}\Omega) + (8 \text{ mA})(4.7 \text{ k}\Omega) - (10 \text{ mA})(2 \text{ k}\Omega)}{8.2 \text{ k}\Omega + 4.7 \text{ k}\Omega + 2 \text{ k}\Omega}$
 $= \frac{32.8 \text{ V} + 37.6 \text{ V} - 20 \text{ V}}{14.9 \text{ k}\Omega} = 3.38 \text{ mA}$

$R_{eq} = 8.2 \text{ k}\Omega + 4.7 \text{ k}\Omega + 2 \text{ k}\Omega = 14.9 \text{ k}\Omega$

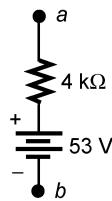
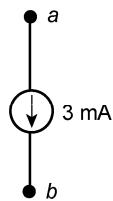
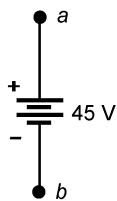
$I_L = \frac{R_{eq} I_{eq}}{R_{eq} + R_L} = \frac{(14.9 \text{ k}\Omega)(3.38 \text{ mA})}{14.9 \text{ k}\Omega + 6.8 \text{ k}\Omega} = 2.32 \text{ mA}$

$V_L = I_L R_L = (2.32 \text{ mA})(6.8 \text{ k}\Omega) = 15.78 \text{ V}$

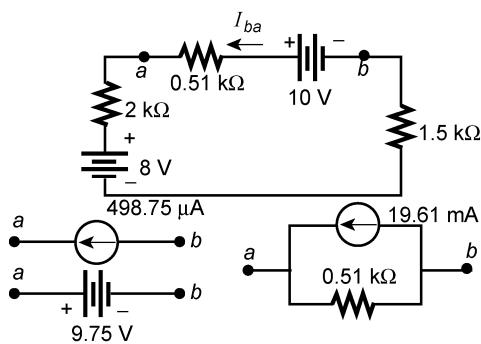
36. $15 \text{ k}\Omega \parallel (8 \text{ k}\Omega + 7 \text{ k}\Omega) = 15 \text{ k}\Omega \parallel 15 \text{ k}\Omega = 7.5 \text{ k}\Omega$

$V_{ab} = \frac{7.5 \text{ k}\Omega(60 \text{ V})}{7.5 \text{ k}\Omega + 2.5 \text{ k}\Omega} = 45 \text{ V}$

$I_{ab} = \frac{45 \text{ V}}{15 \text{ k}\Omega} = 3 \text{ mA}$



37.

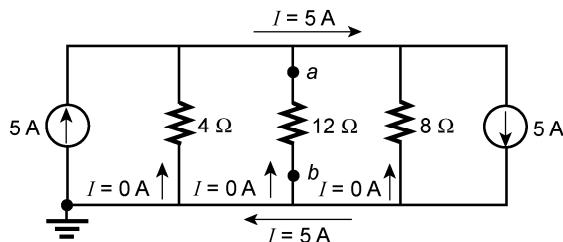


$I_{ba} = \frac{10 \text{ V} - 8 \text{ V}}{2 \text{ k}\Omega + 0.51 \text{ k}\Omega + 1.5 \text{ k}\Omega} = 498.75 \mu\text{A}$

$V_{0.51\text{k}\Omega} = (498.75 \mu\text{A})(0.51 \text{ k}\Omega) = 0.25 \text{ V}$

$V_{ab} = 10 \text{ V} - 0.25 \text{ V} = 9.75 \text{ V}$

38.



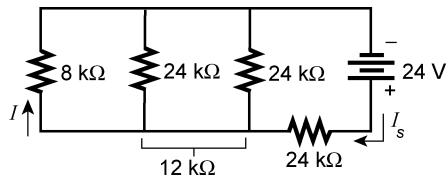
$\therefore R_2 = \text{short-circuit, open-circuit, any value}$

$V_{ab} = 0 \text{ V} (\text{short})$
 $I_{ab} = 0 \text{ A} (\text{open})$

R_2 any resistive value

39. a. $I_s = \frac{24 \text{ V}}{8 \text{ k}\Omega + \frac{24 \text{ k}\Omega}{3}} = 1.5 \text{ mA}$, $I = \frac{I_s}{3} = \mathbf{0.5 \text{ mA}}$

b.

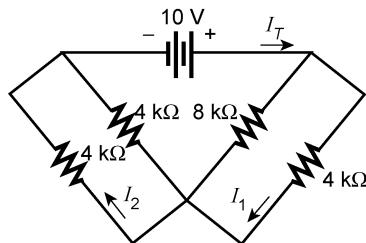


$$I_s = \frac{24 \text{ V}}{24 \text{ k}\Omega + 8 \text{ k}\Omega \parallel 12 \text{ k}\Omega} = 0.83 \text{ mA}$$

$$I = \frac{12 \text{ k}\Omega(I_s)}{12 \text{ k}\Omega + 8 \text{ k}\Omega} = \mathbf{0.5 \text{ mA}}$$

c. yes

40. (a)



$$I_T = \frac{10 \text{ V}}{4 \text{ k}\Omega \parallel 8 \text{ k}\Omega + 4 \text{ k}\Omega \parallel 4 \text{ k}\Omega}$$

$$= \frac{10 \text{ V}}{2.67 \text{ k}\Omega + 2 \text{ k}\Omega}$$

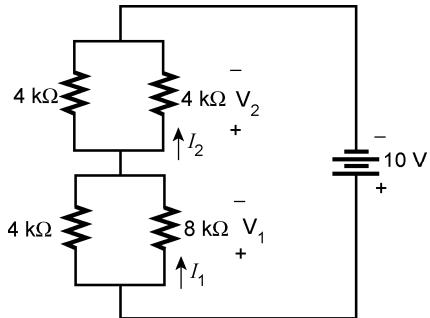
$$= \frac{10 \text{ V}}{4.67 \text{ k}\Omega} = 2.14 \text{ mA}$$

$$I_1 = \frac{8 \Omega(I_T)}{8 \Omega + 4 \Omega} = 1.43 \text{ mA}$$

$$I_2 = I_T/2 = 1.07 \text{ mA}$$

$$I = I_1 - I_2 = 1.43 \text{ mA} - 1.07 \text{ mA} = \mathbf{0.36 \text{ mA}}$$

(b)



$$V_1 = \frac{(8 \text{ k}\Omega \parallel 4 \text{ k}\Omega)(10 \text{ V})}{8 \text{ k}\Omega \parallel 4 \text{ k}\Omega + 4 \text{ k}\Omega \parallel 4 \text{ k}\Omega} = 5.72 \text{ V}$$

$$I_1 = \frac{V_1}{8 \text{ k}\Omega} = 0.71 \text{ mA}$$

$$V_2 = E - V_1 = 10 \text{ V} - 5.72 \text{ V} = 4.28 \text{ V}$$

$$I_2 = \frac{V_2}{4 \text{ k}\Omega} = 1.07 \text{ mA}$$

$$I = I_2 - I_1 = 1.07 \text{ mA} - 0.71 \text{ mA} = \mathbf{0.36 \text{ mA}}$$

41. a. $I_{R_2} = \frac{R_1(I)}{R_1 + R_2 + R_3} = \frac{3 \Omega(6 \text{ A})}{3 \Omega + 2 \Omega + 4 \Omega} = 2 \text{ A}$

$$V = I_{R_2} R_2 = (2 \text{ A})(2 \Omega) = \mathbf{4 \text{ V}}$$

b. $I_{R_1} = \frac{R_2(I)}{R_1 + R_2 + R_3} = \frac{2 \Omega(6 \text{ A})}{3 \Omega + 2 \Omega + 4 \Omega} = 1.33 \text{ A}$

$$V = I_{R_1} R_1 = (1.33 \text{ A})(3 \Omega) = \mathbf{4 \text{ V}}$$

Chapter 10

1. (a) $\mathcal{E} = k \frac{Q_1}{r^2} = \frac{(9 \times 10^9)(4 \mu\text{C})}{(2 \text{ m})^2} = 9 \times 10^3 \text{ N/C}$

(b) $\mathcal{E} = k \frac{Q_1}{r^2} = \frac{(9 \times 10^9)(4 \mu\text{C})}{(1 \text{ mm})^2} = 36 \times 10^9 \text{ N/C}$

$\mathcal{E}(1 \text{ mm}) : \mathcal{E}(2 \text{ m}) = 4 \times 10^6 : 1$

2. $\mathcal{E} = \frac{kQ}{r^2} \Rightarrow r = \sqrt{\frac{kQ}{\mathcal{E}}} = \sqrt{\frac{(9 \times 10^9)(2 \mu\text{C})}{72 \text{ N/C}}} = 15.81 \text{ m}$

3. $C = \frac{Q}{V} = \frac{1200 \mu\text{C}}{10 \text{ V}} = 120 \mu\text{F}$

4. $Q = CV = (0.15 \mu\text{F})(45 \text{ V}) = 6.75 \mu\text{C}$

5. $\mathcal{E} = \frac{V}{d} = \frac{100 \text{ mV}}{2 \text{ mm}} = 50 \text{ V/m}$

6. $d = 10 \text{ mils} \left[\frac{10^{-3} \text{ in.}}{1 \text{ mil}} \right] \left[\frac{1 \text{ m}}{39.37 \text{ in.}} \right] = 0.254 \text{ mm}$

$$\mathcal{E} = \frac{V}{d} = \frac{100 \text{ mV}}{0.254 \text{ mm}} = 393.70 \text{ V/m}$$

7. $V = \frac{Q}{C} = \frac{160 \mu\text{C}}{4 \mu\text{F}} = 40 \text{ V}$

$$\mathcal{E} = \frac{V}{d} = \frac{40 \text{ V}}{5 \text{ mm}} = 8 \times 10^3 \text{ V/m}$$

8. $C = 8.85 \times 10^{-12} \epsilon_r \frac{A}{d} = 8.85 \times 10^{-12} (1) \frac{(0.1 \text{ m}^2)}{2 \text{ mm}} = 442.50 \text{ pF}$

9. $C = 8.85 \times 10^{-12} \epsilon_r \frac{A}{d} = 8.85 \times 10^{-12} (2.5) \frac{(0.1 \text{ m}^2)}{2 \text{ mm}} = 1.11 \text{ nF}$

10. $C = 8.85 \times 10^{-12} \epsilon_r \frac{A}{d} \Rightarrow d = \frac{8.85 \times 10^{-12} (4)(0.15 \text{ m}^2)}{2 \mu\text{F}} = 2.66 \mu\text{m}$

11. $C = \epsilon_r C_o \Rightarrow \epsilon_r = \frac{C}{C_o} = \frac{6 \text{ nF}}{1200 \text{ pF}} = 5 \text{ (mica)}$

12. a. $C = 8.85 \times 10^{-12} (1) \frac{(0.08 \text{ m}^2)}{0.2 \text{ mm}} = 3.54 \text{ nF}$

b. $\mathcal{E} = \frac{V}{d} = \frac{200 \text{ V}}{0.2 \text{ mm}} = 10^6 \text{ V/m}$

c. $Q = CV = (3.54 \text{ nF})(200 \text{ V}) = 0.71 \mu\text{C}$

13. a. $\mathcal{E} = \frac{V}{d} = \frac{200 \text{ V}}{0.2 \text{ mm}} = 10^6 \text{ V/m}$

b. $Q = \epsilon \mathcal{E} A = \epsilon_r \epsilon_0 \mathcal{E} A = (7)(8.85 \times 10^{-12})(10^6 \text{ V/m})(0.08 \text{ m}^2) = 4.96 \mu\text{C}$

c. $C = \frac{Q}{V} = \frac{4.96 \mu\text{C}}{200 \text{ V}} = 24.80 \text{ nF}$

14. a. $C = \frac{1}{2}(5 \mu\text{F}) = 2.5 \mu\text{F}$

b. $C = 2(5 \mu\text{F}) = 10 \mu\text{F}$

c. $C = 20(5 \mu\text{F}) = 100 \mu\text{F}$

d. $C = \frac{(4)\left(\frac{1}{3}\right)}{\left(\frac{1}{4}\right)}(5 \mu\text{F}) = 26.67 \mu\text{F}$

15. $d = \frac{8.85 \times 10^{-12} \epsilon_r A}{C} = \frac{(8.85 \times 10^{-12})(5)(0.02 \text{ m}^2)}{0.006 \mu\text{F}} = 0.1475 \text{ mm} = 147.5 \mu\text{m}$

$$d = 0.1475 \cancel{\text{mm}} \left[\frac{10^{-3} \cancel{\mu\text{m}}}{1 \cancel{\text{mm}}} \right] \left[\frac{39.37 \cancel{\text{in.}}}{1 \cancel{\mu\text{m}}} \right] \left[\frac{1000 \text{ mils}}{1 \cancel{\text{in.}}} \right] = 5.807 \text{ mils}$$

$$5.807 \cancel{\text{mils}} \left[\frac{5000 \text{ V}}{1 \cancel{\text{mil}}} \right] = 29.04 \text{ kV}$$

16. mica: $\frac{1200 \text{ V}}{5000 \text{ V}} = 1200 \text{ V} \left[\frac{1 \cancel{\text{mil}}}{5000 \text{ V}} \right] = 0.24 \text{ mils}$

$$0.24 \text{ mils} \left[\frac{1 \cancel{\text{m}}}{1000 \text{ mils}} \right] \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] = 6.10 \mu\text{m}$$

17. $\frac{200}{1 \times 10^6} (22 \mu\text{F})/\text{°C} = 4400 \text{ pF/°C}$

$$\frac{4400 \text{ pF}}{\text{°C}} [\Delta T] = \frac{4400 \text{ pF}}{\text{°C}} [80^\circ\text{C}] = 0.35 \mu\text{F}$$

18. $J = \pm 5\%$, Size $\Rightarrow 40 \text{ pF} \pm 2 \text{ pF}$, **38 pF \rightarrow 42 pF**

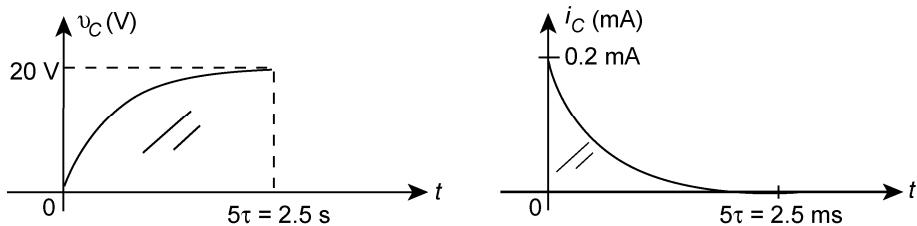
19. $M = \pm 20\%$, Size $\Rightarrow 220 \mu F \pm 44 \mu F$, **176 $\mu F \rightarrow 264 \mu F$**
20. $K = \pm 10\%$, Size $\Rightarrow 33,000 \text{ pF} \pm 3300 \text{ pF}$, **29,700 $\text{pF} \rightarrow 36,300 \text{ pF}$**
21. a. $\tau = RC = (10^5 \Omega)(5.1 \mu F) = \mathbf{0.51 \text{ s}}$

$$\text{b. } v_C = E(1 - e^{-t/\tau}) = \mathbf{20 \text{ V}(1 - e^{-t/0.51 \text{ s}})}$$

$$\text{c. } 1\tau = 0.632(20 \text{ V}) = \mathbf{12.64 \text{ V}}, 3\tau = 0.95(20 \text{ V}) = \mathbf{19 \text{ V}} \\ 5\tau = 0.993(20 \text{ V}) = \mathbf{19.87 \text{ V}}$$

$$\text{d. } i_C = \frac{20 \text{ V}}{100 \text{ k}\Omega} e^{-t/\tau} = \mathbf{0.2 \text{ mA} e^{-t/0.51 \text{ s}}} \\ v_R = E e^{-t/\tau} = \mathbf{20 \text{ V} e^{-t/0.51 \text{ s}}}$$

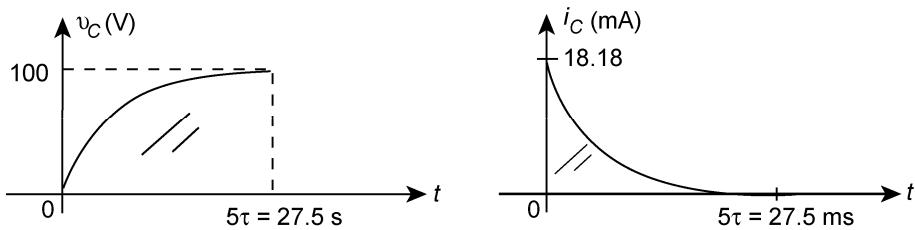
e.



22. a. $\tau = RC = (10^6 \Omega)(5.1 \mu F) = \mathbf{5.1 \text{ s}}$ b. $v_C = E(1 - e^{-t/\tau}) = \mathbf{20 \text{ V}(1 - e^{-t/5.1 \text{ s}})}$
- c. $1\tau = \mathbf{12.64 \text{ V}}, 3\tau = \mathbf{19 \text{ V}}, 5\tau = \mathbf{19.87 \text{ V}}$ d. $i_C = \frac{20 \text{ V}}{1 \text{ M}\Omega} e^{-t/\tau} = \mathbf{20 \mu A e^{-t/5.1 \text{ s}}} \\ v_R = E e^{-t/\tau} = \mathbf{20 \text{ V} e^{-t/5.1 \text{ s}}}$
- e. Same as problem 21 with $5\tau = 25 \text{ s}$ and $I_m = 20 \mu \text{A}$

23. a. $\tau = RC = (2.2 \text{ k}\Omega + 3.3 \text{ k}\Omega)1 \mu F = (5.5 \text{ k}\Omega)(1 \mu F) = \mathbf{5.5 \text{ ms}}$
- b. $v_C = E(1 - e^{-t/\tau}) = \mathbf{100 \text{ V}(1 - e^{-t/5.5 \text{ ms}})}$
- c. $1\tau = \mathbf{63.21 \text{ V}}, 3\tau = \mathbf{95.02 \text{ V}}, 5\tau = \mathbf{99.33 \text{ V}}$
- d. $i_C = \frac{E}{R_T} e^{-t/\tau} = \frac{100 \text{ V}}{5.5 \text{ k}\Omega} e^{-t/\tau} = \mathbf{18.18 \text{ mA} e^{-t/5.5 \text{ ms}}} \\ V_{R_2} = \frac{3.3 \text{ k}\Omega(100 \text{ V})}{3.3 \text{ k}\Omega + 2.2 \text{ k}\Omega} = 60 \text{ V} \\ v_R = v_{R_2} = \mathbf{60 \text{ V} e^{-t/5.5 \text{ ms}}}$

e.

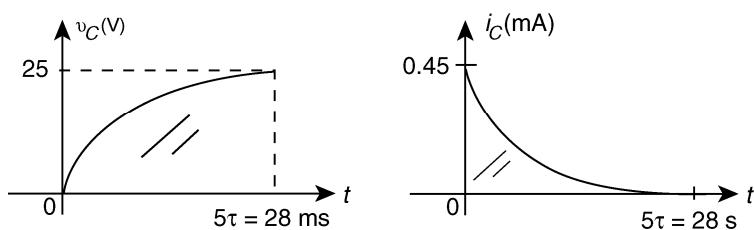


24. a. $\tau = RC = (56 \text{ k}\Omega)(0.1 \mu\text{F}) = 5.6 \text{ ms}$

b. $v_C = E(1 - e^{-t/\tau}) = 25 \text{ V}(1 - e^{-t/5.6\text{ms}})$

c. $i_C = \frac{E}{R} e^{-t/\tau} = \frac{25 \text{ V}}{56 \text{ k}\Omega} e^{-t/\tau} = 0.45 \text{ mA} e^{-t/5.6\text{ms}}$

d.



25. a. **5 ms**

b. $v_C = 60 \text{ mV}(1 - e^{-2\text{ms}/5\text{ms}}) = 60 \text{ mV}(1 - e^{-0.4}) = 60 \text{ mV}(1 - 0.670) = 60 \text{ mV}(0.330) = \mathbf{19.8 \text{ mV}}$

c. $v_C = 60 \text{ mV}(1 - e^{-100\text{ms}/5\text{ms}}) = 60 \text{ mV}(1 - e^{-20}) = 60 \text{ mV}(1 - 2.06 \times 10^{-9}) \cong 60 \text{ mV}(1) = \mathbf{60 \text{ mV}}$

26. a. $\tau = 40 \text{ ms}, 5\tau = 5(40 \text{ ms}) = \mathbf{200 \text{ ms}}$

b. $\tau = RC, R = \frac{\tau}{C} = \frac{40 \text{ ms}}{10 \mu\text{F}} = \mathbf{4 \text{ k}\Omega}$

c. $v_C(20 \text{ ms}) = 12 \text{ V}(1 - e^{-20 \text{ ms}/40 \text{ ms}}) = 12 \text{ V}(1 - e^{-0.5}) = 12 \text{ V}(1 - 0.607) = 12 \text{ V}(0.393) = \mathbf{4.72 \text{ V}}$

d. $v_C = 12 \text{ V}(1 - e^{-10}) = 12 \text{ V}(1 - 45 \times 10^{-6}) \cong \mathbf{12.0 \text{ V}}$

e. $Q = CV = (10 \mu\text{F})(12 \text{ V}) = \mathbf{120 \mu\text{C}}$

f. $\tau = RC = (1000 \times 10^6 \Omega)(10 \mu\text{F}) = 10 \times 10^3 \text{ s}$

$$5\tau = 50 \times 10^3 \text{ s} \left[\frac{1 \text{ min}}{60 \text{ s}} \right] \left[\frac{1 \text{ h}}{60 \text{ min}} \right] = \mathbf{13.89 \text{ h}}$$

27. a. $\tau = RC = (2 \text{ k}\Omega)(100 \mu\text{F}) = \mathbf{200 \text{ ms}}$

b. $v_C = E(1 - e^{-t/\tau}) = 8 \text{ V}(1 - e^{-t/200\text{ms}})$

$$i_C = \frac{E}{R} e^{-t/\tau} = \frac{8 \text{ V}}{2 \text{ k}\Omega} e^{-t/200\text{ms}} = \mathbf{4 \text{ mA} e^{-t/200\text{ms}}}$$

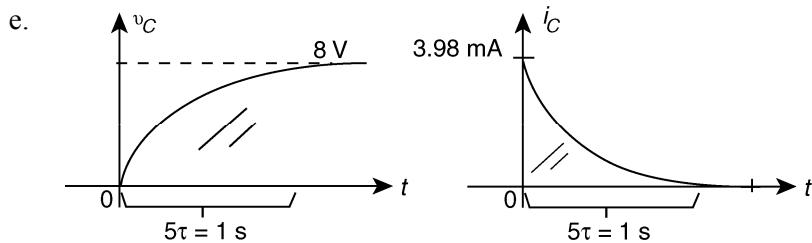
c. $v_C(1 \text{ s}) = 8 \text{ V}(1 - e^{-1\text{s}/200\text{ms}}) = 8 \text{ V}(1 - e^{-5})$

$$= 8 \text{ V}(1 - 6.738 \times 10^{-3}) = 8 \text{ V}(0.9933) = \mathbf{7.95 \text{ V}}$$

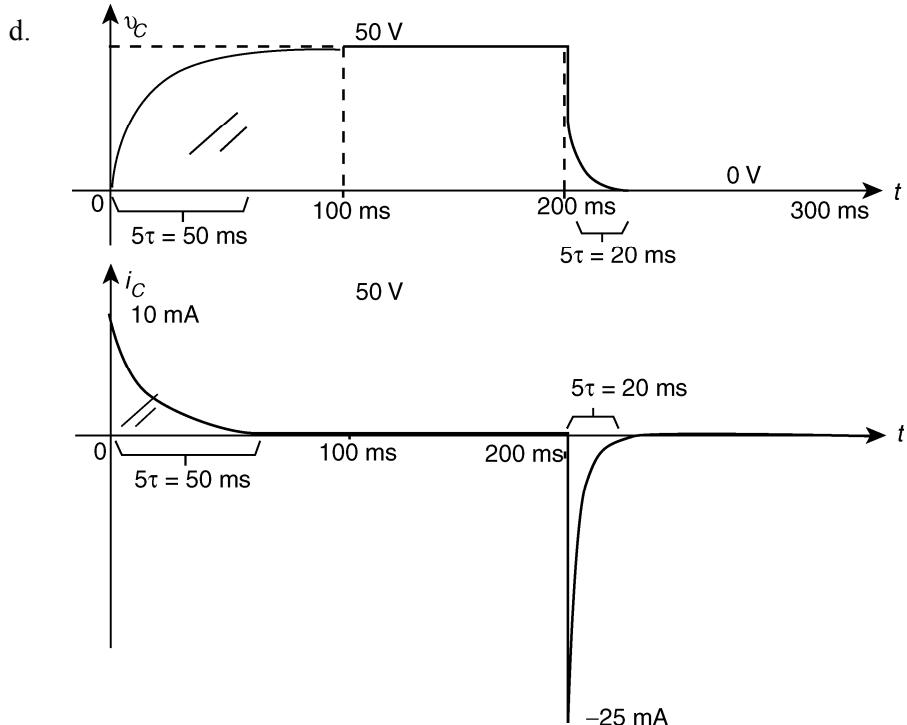
$$i_C(1 \text{ s}) = 4 \text{ mA} e^{-5} = 4 \text{ mA}(6.738 \times 10^{-3}) = \mathbf{26.95 \mu\text{A}}$$

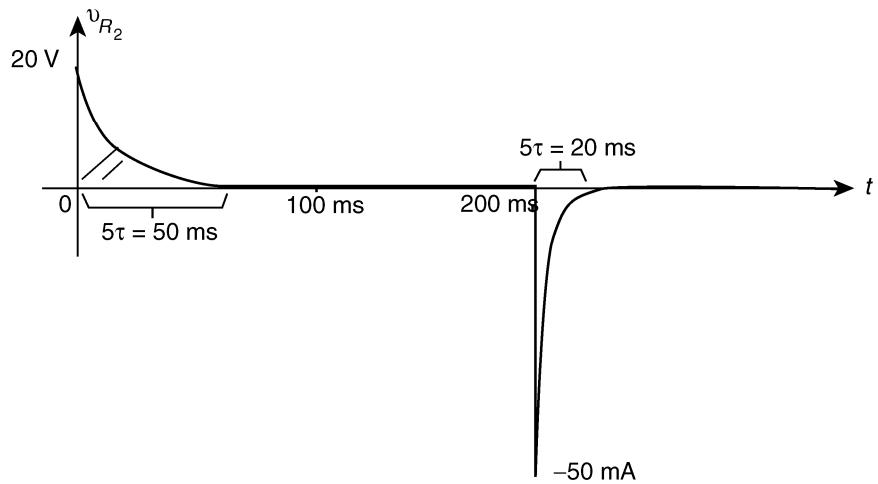
d. $v_C = 7.95 \text{ V} e^{-t/200\text{ms}}$

$$i_C = \frac{7.95 \text{ V}}{2 \text{ k}\Omega} e^{-t/200\text{ms}} = 3.98 \text{ mA} e^{-t/200\text{ms}}$$

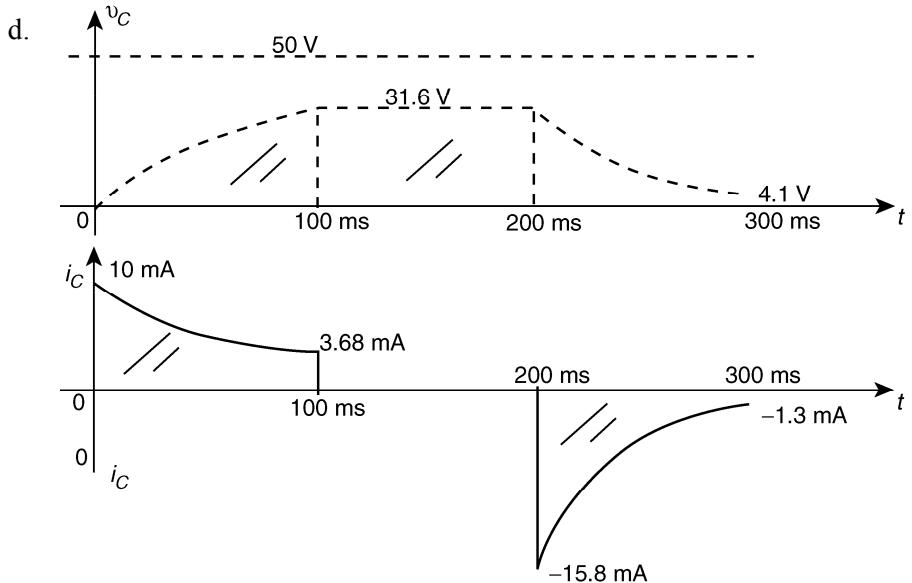


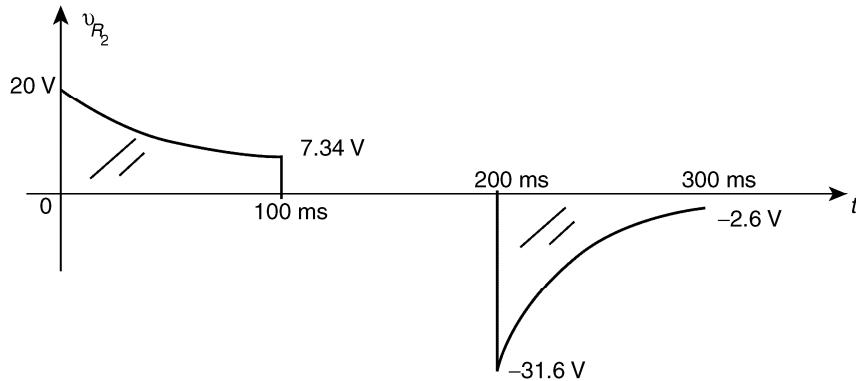
28. a. $\tau = RC = (3 \text{ k}\Omega + 2 \text{ k}\Omega)(2 \mu\text{F}) = 10 \text{ ms}$
 $v_C = 50 \text{ V}(1 - e^{-t/10\text{ms}})$
 $i_C = \frac{50 \text{ V}}{5 \text{ k}\Omega} e^{-t/10\text{ms}} = 10 \text{ mA} e^{-t/10\text{ms}}$
 $v_{R_1} = i_C \cdot R_1 = (10 \text{ mA})(3 \text{ k}\Omega) e^{-t/10\text{ms}} = 30 \text{ V} e^{-t/10\text{ms}}$
- b. 100ms: $e^{-10} = 45.4 \times 10^{-6}$
 $v_C = 50 \text{ V}(1 - 45.4 \times 10^{-6}) = 50 \text{ V}$
 $i_C = 10 \text{ mA}(45.4 \times 10^{-6}) = 0.45 \mu\text{A}$
 $v_{R_1} = 30 \text{ V}(45.4 \times 10^{-6}) = 1.36 \text{ mV}$
- c. 200 ms: $\tau' = R_2 C = (2 \text{ k}\Omega)(2 \mu\text{F}) = 4 \text{ ms}$
 $v_C = 50 \text{ V} e^{-t/4\text{ms}}$
 $i_C = -\frac{50 \text{ V}}{2 \text{ k}\Omega} e^{-t/4\text{ms}} = -25 \text{ mA} e^{-t/4\text{ms}}$
 $v_{R_2} = v_C = -50 \text{ V} e^{-t/4\text{ms}}$





29. a. $\tau = RC = (5 \text{ k}\Omega)(20 \mu\text{F}) = 100 \text{ ms}$
 $v_C = 50 \text{ V}(1 - e^{-t/100\text{ms}})$
 $i_C = \frac{50 \text{ V}}{5 \text{ k}\Omega} e^{-t/100\text{ms}} = 10 \text{ mA} e^{-t/100\text{ms}}$
 $v_{R_1} = i_C \cdot R_1 = (10 \text{ mA})(3 \text{ k}\Omega) e^{-t/100\text{ms}} = 30 \text{ V} e^{-t/100\text{ms}}$
- b. 100 ms: $e^{-1} = 0.368$
 $v_C = 50 \text{ V}(1 - 0.368) = 50 \text{ V}(0.632) = 31.6 \text{ V}$
 $i_C = 10 \text{ mA}(0.368) = 3.68 \text{ mA}$
 $v_{R_1} = 30 \text{ V}(0.368) = 11.04 \text{ V}$
- c. 200 ms: $\tau' = R_2 C = (2 \text{ k}\Omega)(20 \mu\text{F}) = 40 \text{ ms}$
 $v_C = 31.6 \text{ V} e^{-t/40\text{ms}}$
 $i_C = -\frac{31.6 \text{ V}}{2 \text{ k}\Omega} e^{-t/40\text{ms}} = -15.8 \text{ mA} e^{-t/40\text{ms}}$
 $v_{R_2} = -v_C = -31.6 \text{ V} e^{-t/40\text{ms}}$





30. a. $\tau = R_1 C = (10^5 \Omega)(10 \text{ pF}) = 1 \mu\text{s}$

$$v_C = 80 \text{ V} \left(1 - e^{-t/1\mu\text{s}}\right)$$

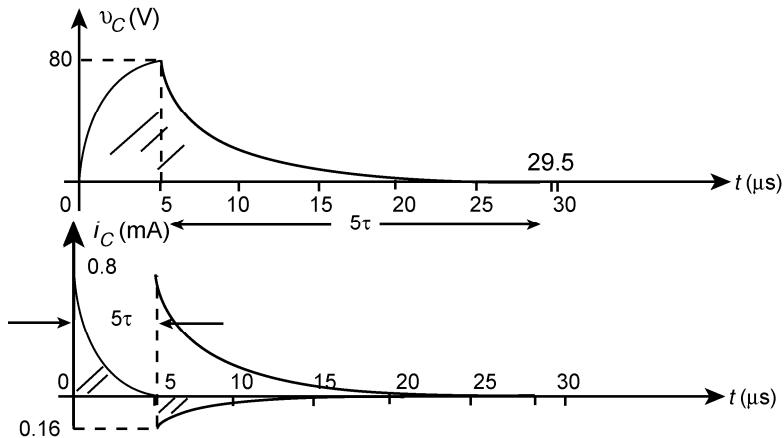
$$i_C = \frac{80 \text{ V}}{100 \text{ k}\Omega} e^{-t/\tau} = 0.8 \text{ mA} e^{-t/1\mu\text{s}}$$

b. $\tau' = R' C = (490 \text{ k}\Omega)(10 \text{ pF}) = 4.9 \mu\text{s}$

$$v_C = 80 \text{ V} e^{-t/\tau'} = 80 \text{ V} e^{-t/4.9 \times 10^{-6}}$$

$$i_C = \frac{80 \text{ V}}{490 \text{ k}\Omega} e^{-t/\tau'} = 0.16 \text{ mA} e^{-t/4.9 \times 10^{-6}}$$

c.



31. a. $\tau = RC = (2 \text{ m}\Omega)(1000 \mu\text{F}) = 2 \mu\text{s}$

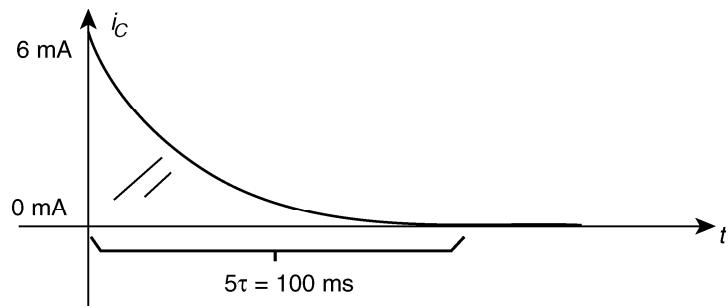
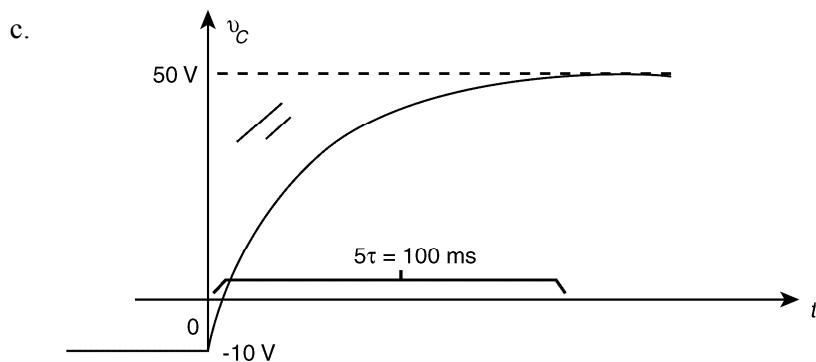
$$5\tau = 10 \mu\text{s}$$

b. $I_m = \frac{V}{R} = \frac{6 \text{ V}}{2 \text{ m}\Omega} = 3 \text{ kA}$

c. yes

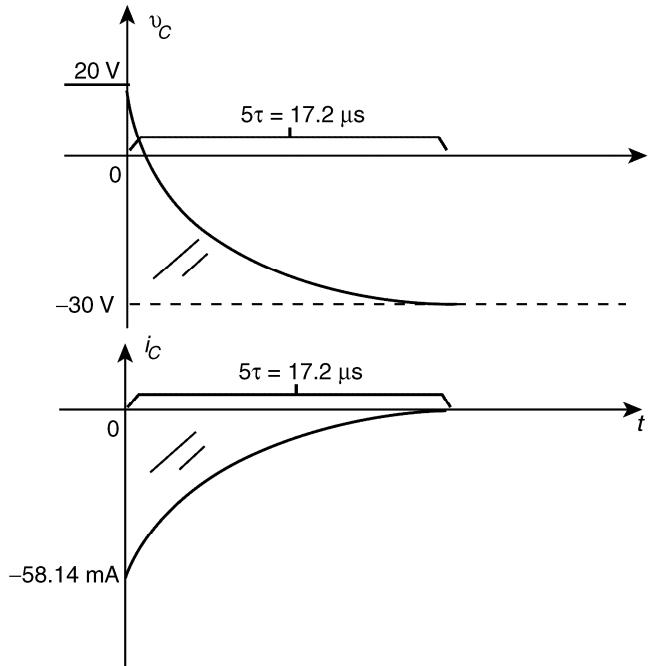
32. a. $v_C = V_f + (V_i - V_f)e^{-t/\tau}$
 $\tau = RC = (10 \text{ k}\Omega)(2 \mu\text{F}) = 20 \text{ ms}, V_f = 50 \text{ V}, V_i = -10 \text{ V}$
 $v_C = 50 \text{ V} + (-10 \text{ V} - (+50 \text{ V}))e^{-t/20\text{ms}}$
 $v_C = \mathbf{50 \text{ V} - 60 \text{ V} e^{-t/20\text{ms}}}$

b. Initially $V_R = E + v_C = 50 \text{ V} + 10 \text{ V} = 60 \text{ V}$
 $i_C = \frac{V_R}{R} e^{-t/\tau} = \frac{60 \text{ V}}{10 \text{ k}\Omega} e^{-t/20\text{ms}} = \mathbf{6 \text{ mA } e^{-t/20\text{ms}}}$

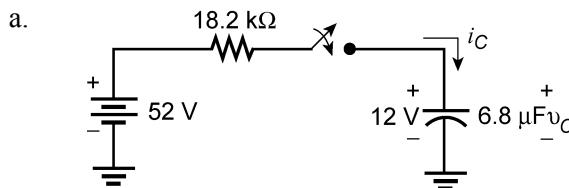


33. $\tau = RC = (2.2 \text{ k}\Omega)(2000 \mu\text{F}) = 4.4 \text{ s}$
 $v_C = V_C e^{-t/\tau} = \mathbf{40 \text{ V} e^{-t/4.4 \text{ s}}}$
 $I_C = \frac{V_C}{R} e^{-t/\tau} = \frac{40 \text{ V}}{2.2 \text{ k}\Omega} e^{-t/4.4 \text{ s}} = \mathbf{18.18 \text{ mA} e^{-t/4.4 \text{ s}}}$
 $v_R = v_C = \mathbf{40 \text{ V} e^{-t/4.4 \text{ s}}}$

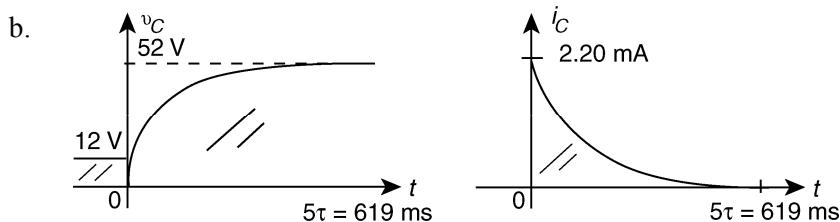
34. $v_C = V_f + (V_i - V_f)e^{-t/\tau}$
 $\tau = RC = (860 \Omega)(4000 \text{ pF}) = 3.44 \mu\text{s}, V_f = -30 \text{ V}, V_i = 20 \text{ V}$
 $v_C = -30 \text{ V} + (20 \text{ V} - (-30 \text{ V}))e^{-t/3.44\mu\text{s}}$
 $v_C = \mathbf{-30 \text{ V} + 50 \text{ V} e^{-t/3.44\mu\text{s}}}$
 $I_m = \frac{20 \text{ V} + 30 \text{ V}}{860 \Omega} = 58.14 \text{ mA}$
 $i_C = \mathbf{-58.14 \text{ mA} e^{-t/3.44\mu\text{s}}}$



35.



$$\begin{aligned}\tau &= RC = (18.2 \text{ k}\Omega)(6.8 \mu \text{F}) = 123.8 \text{ ms} \\ v_C &= V_f + (V_i - V_f) e^{-t/\tau} \\ &= 52 \text{ V} + (12 \text{ V} - 52 \text{ V}) e^{-t/123.8 \text{ ms}} \\ v_C &= \mathbf{52 \text{ V} - 40 \text{ V} e^{-t/123.8 \text{ ms}}} \\ v_R(0+) &= 52 \text{ V} - 12 \text{ V} = 40 \text{ V} \\ i_C &= \frac{40 \text{ V}}{18.2 \text{ k}\Omega} e^{-t/123.8 \text{ ms}} \\ &= \mathbf{2.20 \text{ mA} e^{-t/123.8 \text{ ms}}}\end{aligned}$$



36.

a. $v_C = 12 \text{ V}(1 - e^{-10\mu s/20\mu s}) = 12 \text{ V}(1 - e^{-0.5}) = 12 \text{ V}(1 - 0.607) = 12 \text{ V}(0.393) = \mathbf{4.72 \text{ V}}$

b. $v_C = 12 \text{ V}(1 - e^{-10\pi/\tau}) = 12 \text{ V}(1 - e^{-10}) = 12 \text{ V}(1 - 45.4 \times 10^{-6}) \cong \mathbf{12 \text{ V}}$

c. $6 \text{ V} = 12 \text{ V}(1 - e^{-t/20\mu s})$

$$0.5 = 1 - e^{-t/20\mu s}$$

$$-0.5 = -e^{-t/20\mu s}$$

$$0.5 = e^{-t/20\mu s}$$

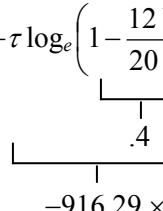
$$\log_e 0.5 = \log_e e^{-t/20\mu s}$$

$$-0.693 = -t/20\mu s$$

$$t = 0.693 (20 \mu s) = \mathbf{13.86 \mu s}$$

d. $v_C = 11.98 \text{ V} = 12 \text{ V}(1 - e^{-t/20 \mu\text{s}})$
 $0.998 = 1 - e^{-t/20 \mu\text{s}}$
 $-0.002 = -e^{-t/20 \mu\text{s}}$
 $0.002 = -e^{-t/20 \mu\text{s}}$
 $\log_e 0.002 = -t/20 \mu\text{s}$
 $-6.215 = -t/20 \mu\text{s}$
 $t = (6.215)(20 \mu\text{s}) = \mathbf{124.3 \mu\text{s}}$

37. $\tau = RC = (33 \text{ k}\Omega)(20 \mu\text{F}) = 0.66 \text{ s}$
 $v_C = 12 \text{ V}(1 - e^{-t/0.66 \text{ s}})$
 $8 \text{ V} = 12 \text{ V}(1 - e^{-t/0.66 \text{ s}})$
 $8 \text{ V} = 12 \text{ V} - 12 \text{ V}e^{-t/0.66 \text{ s}}$
 $-4 \text{ V} = -12 \text{ V}e^{-t/0.66 \text{ s}}$
 $0.333 = e^{-t/0.66 \text{ s}}$
 $\log_e 0.333 = -t/0.66 \text{ s}$
 $-1.0996 = -t/0.66 \text{ s}$
 $t = 1.0996(0.66 \text{ s}) = \mathbf{0.73 \text{ s}}$

38. $t = -\tau \log_e \left(1 - \frac{v_C}{E}\right)$
 $10 \text{ s} = -\tau \log_e \left(1 - \frac{12 \text{ V}}{20 \text{ V}}\right)$


$$\tau = \frac{10 \text{ s}}{0.916} = 10.92 \text{ s}$$

$$\tau = RC \Rightarrow R = \frac{\tau}{C} = \frac{10.92 \text{ s}}{200 \mu\text{F}} = \mathbf{54.60 \text{ k}\Omega}$$

39. a. $\tau = (R_1 + R_2)C = (20 \text{ k}\Omega)(6 \mu\text{F}) = 0.12 \text{ s}$
 $v_C = E(1 - e^{-t/\tau})$
 $60 \text{ V} = 80 \text{ V}(1 - e^{-t/0.12 \text{ s}})$
 $0.75 = 1 - e^{-t/0.12 \text{ s}}$
 $0.25 = e^{-t/0.12 \text{ s}}$
 $t = -(0.12 \text{ s})(-1.39)$
 $= \mathbf{166.80 \text{ ms}}$

b. $i_C = \frac{E}{R} e^{-t/\tau}$
 $i_C = \frac{80 \text{ V}}{20 \text{ k}\Omega} e^{-\frac{166.80 \text{ ms}}{0.12 \text{ s}}} = 4 \text{ mA} e^{-1.39}$
 $= (4 \text{ mA})(249.08 \times 10^{-3})$
 $\approx \mathbf{1 \text{ mA}}$

c. $i_s = i_C = 4 \text{ mA} e^{-t/\tau} = 4 \text{ mA} e^{-2\tau/\tau} = 4 \text{ mA} e^{-2}$
 $= 4 \text{ mA}(135.34 \times 10^{-3})$
 $= 0.54 \text{ mA}$

$$P_s = EI_s = (80 \text{ V})(0.54 \text{ mA})$$

$$= \mathbf{43.20 \text{ mW}}$$

40. a. $\tau = RC = (1 \text{ M}\Omega)(0.2 \mu\text{F}) = 0.2 \text{ s}$

$$v_C = 60 \text{ V}(1 - e^{-t/0.2s})$$

$$i_C = \frac{E}{R} e^{-t/\tau} = \frac{60 \text{ V}}{1 \text{ M}\Omega} e^{-t/0.2s} = 60 \mu\text{A} e^{-t/0.2s}$$

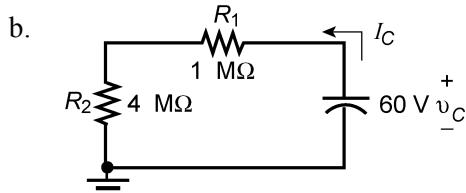
$$v_{R_1} = E e^{-t/\tau} = 60 \text{ V} e^{-t/0.2s}$$

$v_C: 0.5 \text{ s} = \mathbf{55.07 \text{ V}}$

$1 \text{ s} = \mathbf{59.58 \text{ V}}$

$i_C: 0.5 \text{ s} = \mathbf{4.93 \text{ V}}$

$1 \text{ s} = \mathbf{0.40 \text{ V}}$



$$\tau' = RC = (1 \text{ M}\Omega + 4 \text{ M}\Omega)(0.2 \mu\text{F})$$

$$= (5 \text{ M}\Omega)(0.2 \mu\text{F})$$

$$= 1 \text{ s}$$

$$i_C = \frac{60 \text{ V}}{5 \text{ M}\Omega} e^{-t} = 12 \mu\text{A} e^{-t}$$

$$8 \mu\text{A} = 12 \mu\text{A} e^{-t}$$

$$0.667 = e^{-t}$$

$$\log_e 0.667 = -t$$

$$-0.41 = -t$$

$$t = \mathbf{0.41 \text{ s}}$$

$$v_C = 60 \text{ V} e^{-t\tau'}$$

$$10 \text{ V} = 60 \text{ V} e^{-t}$$

$$0.167 = e^{-t}$$

$$\log_e 0.167 = -t$$

$$-1.79 = -t$$

$$t = 1.79 \text{ s}$$

Longer = $1.79 \text{ s} - 0.41 \text{ s} = \mathbf{1.38 \text{ s}}$

41. a. $v_m = v_R = E e^{-t/\tau} = 60 \text{ V} e^{-1\tau/\tau} = 60 \text{ V} e^{-1}$
 $= 60 \text{ V}(0.3679)$
 $= \mathbf{22.07 \text{ V}}$

b. $i_C = \frac{E}{R} e^{-t/\tau} = \frac{60 \text{ V}}{10 \text{ M}\Omega} e^{-2\tau/\tau} = 6 \mu\text{A} e^{-2}$
 $= 6 \mu\text{A}(0.1353)$
 $= \mathbf{0.81 \mu\text{A}}$

c.

$$v_C = E(1 - e^{-t/\tau})$$

$$50 \text{ V} = 60 \text{ V}(1 - e^{-t/2 \text{ s}})$$

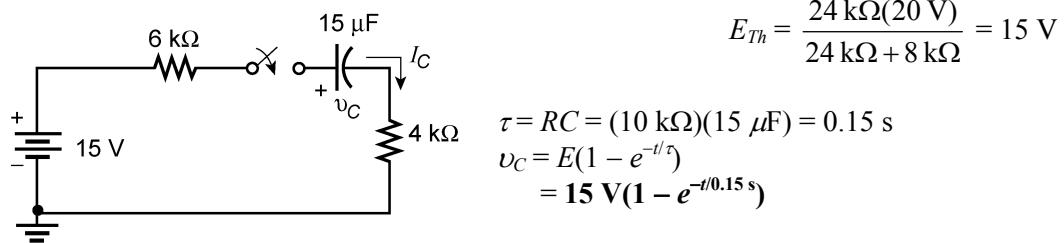
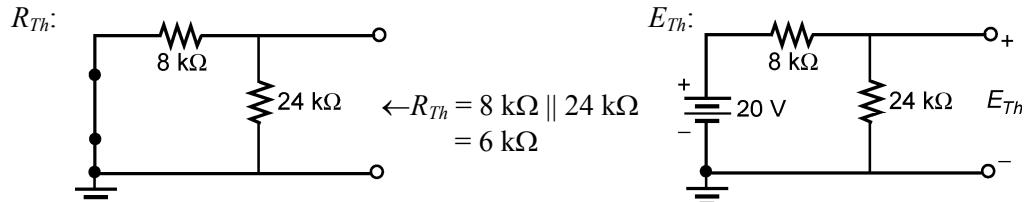
$$0.8333 = 1 - e^{-t/2 \text{ s}}$$

$$\log_e 0.1667 = -t/2 \text{ s}$$

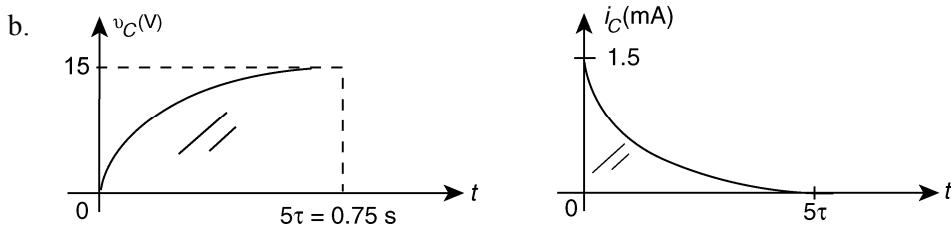
$$t = -(2 \text{ s})(-1.792)$$

$$= \mathbf{3.58 \text{ s}}$$

42. a. Thevenin's theorem:



$$i_C = \frac{E}{R} e^{-t/\tau} = \frac{15 \text{ V}}{10 \text{k}\Omega} e^{-t/0.15} = \mathbf{1.5 \text{ mA} e^{-t/0.15 \text{ s}}}$$



43. a. Source conversion and combining series resistors:

$$\tau = RC = (8.3 \text{ k}\Omega)(2.2 \mu\text{F}) = 18.26 \text{ ms}$$

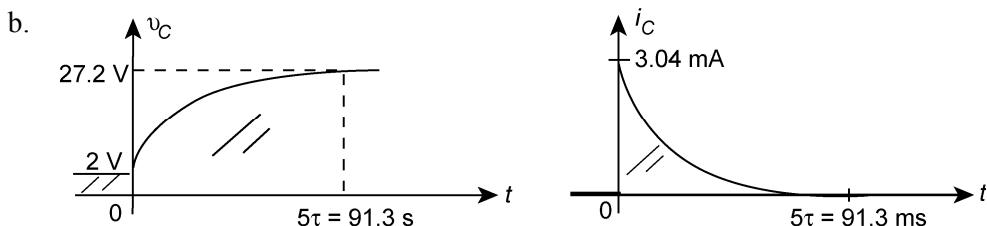
$$v_C = V_f + (V_i - V_f)e^{-t/\tau} = 27.2 \text{ V} + (2 \text{ V} - 27.2 \text{ V})e^{-t/18.26 \text{ ms}}$$

$$v_C = \mathbf{27.2 \text{ V} - 25.2 \text{ V} e^{-t/18.26 \text{ ms}}}$$

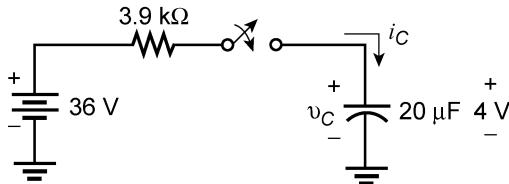
$$v_R(0+) = 27.2 \text{ V} - 2 \text{ V} = 25.2 \text{ V}$$

$$i_C = \frac{25.2 \text{ V}}{8.3 \text{ k}\Omega} e^{-t/18.26 \text{ ms}}$$

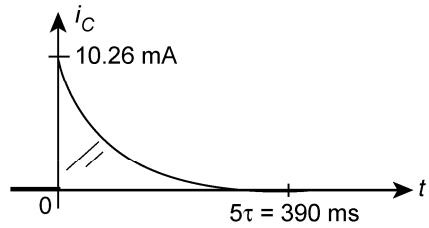
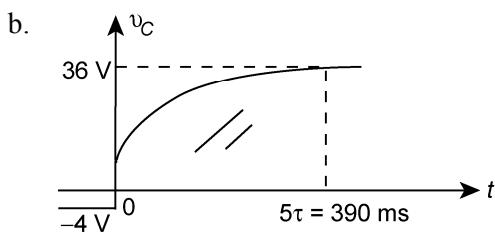
$$i_C = \mathbf{3.04 \text{ mA} e^{-t/18.26 \text{ ms}}}$$



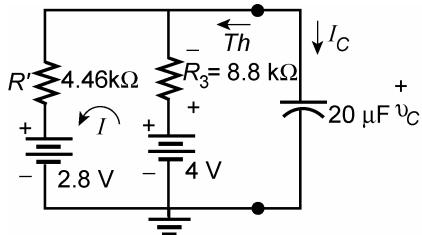
44. a. $R_{Th} = 3.9 \text{ k}\Omega + 0 \Omega \parallel 1.8 \text{ k}\Omega = 3.9 \text{ k}\Omega$
 $E_{Th} = 36 \text{ V}$



$$\begin{aligned}\tau &= RC = (3.9 \text{ k}\Omega)(20 \mu\text{F}) = 78 \text{ ms} \\ v_C &= V_f + (V_i - V_f)e^{-t/\tau} \\ &= 36 \text{ V} + (-4 \text{ V} - 36 \text{ V})e^{-t/78 \text{ ms}} \\ v_C &= 36 \text{ V} - 40 \text{ V}e^{-t/78 \text{ ms}} \\ v_R(0+) &= 36 \text{ V} + 4 \text{ V} = 40 \text{ V} \\ i_C &= \frac{40 \text{ V}}{3.9 \text{ k}\Omega} e^{-t/78 \text{ ms}} \\ i_C &= 10.26 \text{ mA} e^{-t/78 \text{ ms}}\end{aligned}$$

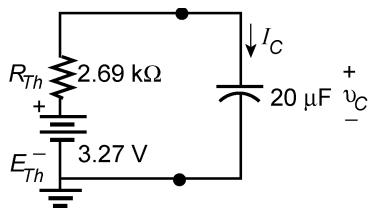


45. Source conversion:
 $E = IR_1 = (5 \text{ mA})(0.56 \text{ k}\Omega) = 2.8 \text{ V}$
 $R' = R_1 + R_2 = 0.56 \text{ k}\Omega + 3.9 \text{ k}\Omega = 4.46 \text{ k}\Omega$



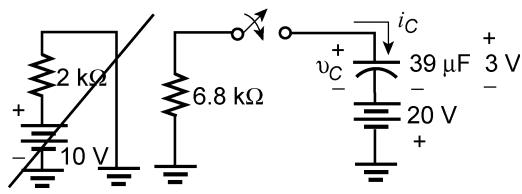
$$\begin{aligned}R_{Th} &= 4.46 \text{ k}\Omega \parallel 6.8 \text{ k}\Omega = 2.69 \text{ k}\Omega \\ I &= \frac{4 \text{ V} - 2.8 \text{ V}}{6.8 \text{ k}\Omega + 4.46 \text{ k}\Omega} = \frac{1.2 \text{ V}}{11.26 \text{ k}\Omega} = 0.107 \text{ mA}\end{aligned}$$

$$\begin{aligned}E_{Th} &= 4 \text{ V} - (0.107 \text{ mA})(6.8 \text{ k}\Omega) \\ &= 4 \text{ V} - 0.727 \text{ V} \\ &= 3.27 \text{ V}\end{aligned}$$



$$\begin{aligned}v_C &= 3.27 \text{ V}(1 - e^{-t/\tau}) \\ \tau &= RC = (2.69 \text{ k}\Omega)(20 \mu\text{F}) \\ &= 53.80 \text{ ms} \\ v_C &= 3.27 \text{ V}(1 - e^{-t/53.80 \text{ ms}}) \\ i_C &= \frac{3.27 \text{ V}}{2.69 \text{ k}\Omega} e^{-t/\tau} \\ &= 1.22 \text{ mA } e^{-t/53.80 \text{ ms}}\end{aligned}$$

46. a.



$$\tau = RC = (6.8 \text{ k}\Omega)(39 \mu\text{F}) = 265.2 \text{ ms}$$

$$v_C = V_f + (V_i - V_f)e^{-t/\tau}$$

$$= 20 \text{ V} + (3 \text{ V} - 20 \text{ V})e^{-t/265.2 \text{ ms}}$$

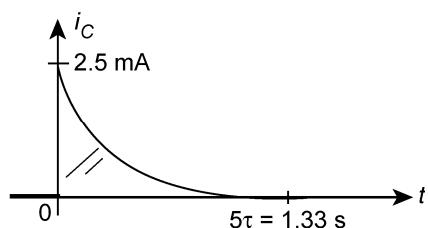
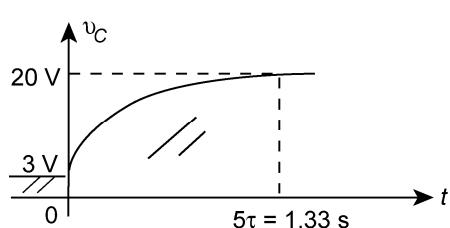
$$v_C = 20 \text{ V} - 17 \text{ V}e^{-t/265.2 \text{ ms}}$$

$$v_R(0+) = 20 \text{ V} - 3 \text{ V} = 17 \text{ V}$$

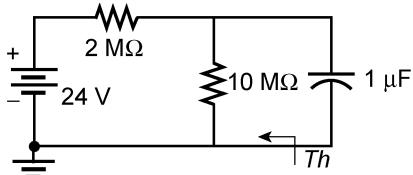
$$i_C = \frac{17 \text{ V}}{6.8 \text{ k}\Omega} e^{-t/265.2 \text{ ms}}$$

$$i_C = 2.5 \text{ mA} e^{-t/265.2 \text{ ms}}$$

b.



47. a.



$$R_{Th} = 2 \text{ M}\Omega \parallel 10 \text{ M}\Omega = 1.67 \text{ M}\Omega$$

$$E_{Th} = \frac{10 \text{ M}\Omega(24 \text{ V})}{10 \text{ M}\Omega + 2 \text{ M}\Omega} = 20 \text{ V}$$

$$v_C = E_{Th}(1 - e^{-t/\tau})$$

$$= 20 \text{ V}(1 - e^{-4\tau/\tau})$$

$$= 20 \text{ V}(1 - e^{-4})$$

$$= 20 \text{ V}(1 - 0.0183)$$

$$= 19.63 \text{ V}$$

$$\tau = R_{Th}C = (1.67 \text{ M}\Omega)(1 \mu\text{F}) = 1.67 \text{ s}$$

$$i_C = \frac{E}{R} e^{-t/\tau}$$

$$3 \mu\text{A} = \frac{20 \text{ V}}{1.67 \text{ M}\Omega} e^{-t/1.67 \text{ s}}$$

$$0.25 = e^{-t/1.67 \text{ s}}$$

$$\log_e 0.25 = -t/1.67 \text{ s}$$

$$t = -(1.67 \text{ s})(-0.69) \\ = 2.32 \text{ s}$$

c.

$$v_{\text{meter}} = v_C$$

$$v_C = E_{Th}(1 - e^{-t/\tau})$$

$$10 \text{ V} = 20 \text{ V}(1 - e^{-t/1.67 \text{ s}})$$

$$0.5 = 1 - e^{-t/1.67 \text{ s}}$$

$$-0.5 = -e^{-t/1.67 \text{ s}}$$

$$\log_e 0.5 = -t/1.67 \text{ s}$$

$$t = -(1.67 \text{ s})(-0.69) \\ = 1.15 \text{ s}$$

$$48. \quad i_{C_{ao}} = C \frac{\Delta v_C}{\Delta t}$$

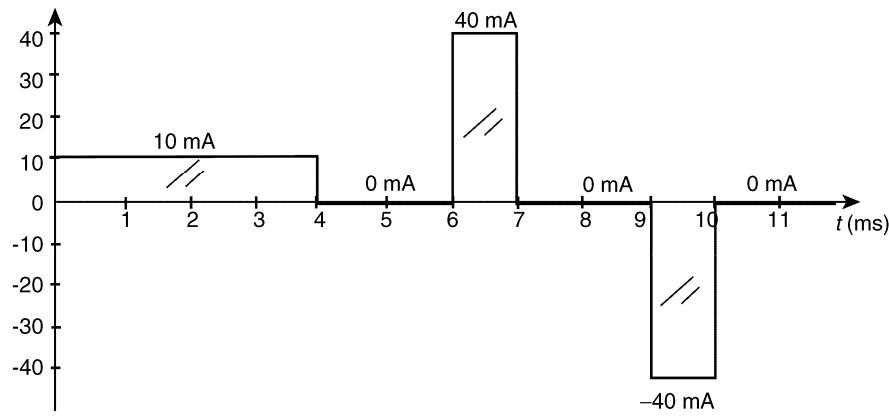
$$0 \rightarrow 4 \text{ ms}: i_C = 2 \times 10^{-6} \frac{(20 \text{ V})}{4 \text{ ms}} = \mathbf{10 \text{ mA}}$$

$$4 \rightarrow 6 \text{ ms}: i_C = 2 \times 10^{-6} \frac{(0 \text{ V})}{2 \text{ ms}} = \mathbf{0 \text{ mA}}$$

$$6 \rightarrow 7 \text{ ms}: i_C = 2 \times 10^{-6} \frac{(20 \text{ V})}{1 \text{ ms}} = \mathbf{40 \text{ mA}}$$

$$7 \rightarrow 9 \text{ ms}: i_C = 2 \times 10^{-6} \frac{(0 \text{ V})}{2 \text{ ms}} = \mathbf{0 \text{ mA}}$$

$$9 \rightarrow 11 \text{ ms}: i_C = -2 \times 10^{-6} \frac{(40 \text{ V})}{2 \text{ ms}} = \mathbf{-40 \text{ mA}}$$



$$49. \quad i_{C_{ao}} = C \frac{\Delta v_C}{\Delta t}$$

$$0 \rightarrow 20 \mu\text{s}: i_C = 4.7 \mu\text{F} \frac{(-5 \text{ V})}{20 \mu\text{s}} = \mathbf{-1.18 \text{ A}}$$

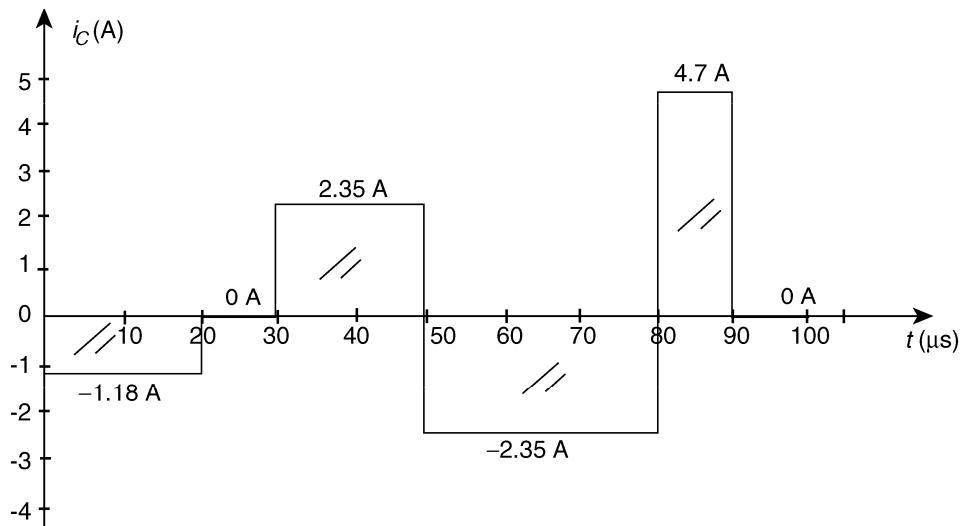
$$20 \rightarrow 30 \mu\text{s}: i_C = 4.7 \mu\text{F} \frac{(0 \text{ V})}{10 \mu\text{s}} = \mathbf{0 \text{ A}}$$

$$30 \rightarrow 50 \mu\text{s}: i_C = 4.7 \mu\text{F} \frac{(+10 \text{ V})}{20 \mu\text{s}} = \mathbf{+2.35 \text{ A}}$$

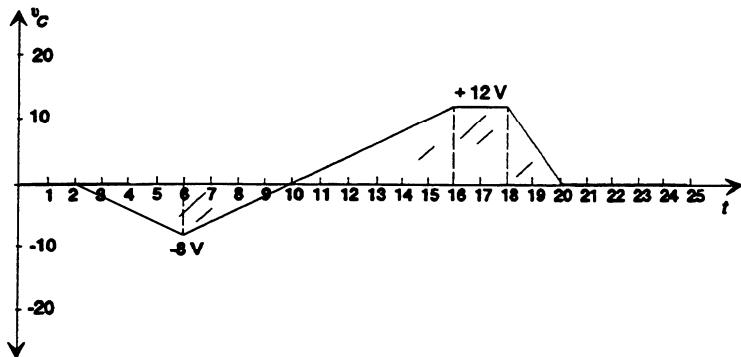
$$50 \rightarrow 80 \mu\text{s}: i_C = 4.7 \mu\text{F} \frac{(-15 \text{ V})}{30 \mu\text{s}} = \mathbf{-2.35 \text{ A}}$$

$$80 \rightarrow 90 \mu\text{s}: i_C = 4.7 \mu\text{F} \frac{(+10 \text{ V})}{10 \mu\text{s}} = \mathbf{+4.7 \text{ A}}$$

$$90 \mu\text{s} \rightarrow 100 \mu\text{s}: i_C = 4.7 \mu\text{F} \frac{(0 \text{ V})}{10 \mu\text{s}} = \mathbf{0 \text{ A}}$$



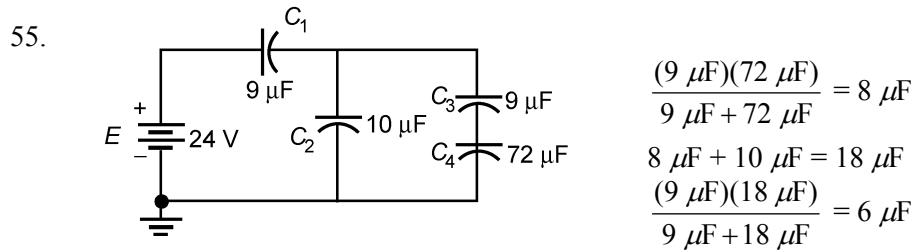
50. $i_C = C \frac{\Delta v_C}{\Delta t} \Rightarrow \Delta v_C = \frac{\Delta t}{C} (i_C)$
 $0 \rightarrow 2 \text{ ms}: i_C = 0 \text{ mA } \Delta v_C = \mathbf{0 \text{ V}}$
 $2 \rightarrow 6 \text{ ms}: i_C = -80 \text{ mA } \Delta v_C = \frac{(2 \text{ ms})}{20 \mu\text{F}} (-80 \text{ mA}) = \mathbf{-8 \text{ V}}$
 $6 \rightarrow 16 \text{ ms}: i_C = +40 \text{ mA } \Delta v_C = \frac{(10 \text{ ms})}{20 \mu\text{F}} (40 \text{ mA}) = \mathbf{+20 \text{ V}}$
 $16 \rightarrow 18 \text{ ms}: i_C = 0 \text{ mA } \Delta v_C = \mathbf{0 \text{ V}}$
 $18 \rightarrow 20 \text{ ms}: i_C = -120 \text{ mA } \Delta v_C = \frac{(2 \text{ ms})}{20 \mu\text{F}} (-120 \text{ mA}) = \mathbf{-12 \text{ V}}$
 $20 \rightarrow 25 \text{ ms}: i_C = 0 \text{ mA } \Delta v_C = \mathbf{0 \text{ V}}$



51. $C_T = 6 \mu\text{F} + 4 \mu\text{F} + 3 \mu\text{F} \parallel 6 \mu\text{F} = 10 \mu\text{F} + 2 \mu\text{F} = \mathbf{12 \mu\text{F}}$
52. $C'_T = 6 \mu\text{F} \parallel 12 \mu\text{F} = 4 \mu\text{F}$
 $C''_T = C'_T + 12 \mu\text{F} = 4 \mu\text{F} + 12 \mu\text{F} = 16 \mu\text{F}$
 $C_T = 6 \mu\text{F} \parallel C''_T = \frac{6 \mu\text{F} \cdot C''_T}{6 \mu\text{F} + C''_T} = \frac{(6 \mu\text{F})(16 \mu\text{F})}{6 \mu\text{F} + 16 \mu\text{F}} = \mathbf{4.36 \mu\text{F}}$

53. $V_1 = 10 \text{ V}$, $Q_1 = V_1 C_1 = (10 \text{ V})(6 \mu\text{F}) = 60 \mu\text{C}$
 $C_T = 6 \mu\text{F} \parallel 12 \mu\text{F} = 4 \mu\text{F}$, $Q_T = C_T E = (4 \mu\text{F})(10 \text{ V}) = 40 \mu\text{C}$
 $Q_2 = Q_3 = 40 \mu\text{C}$
 $V_2 = \frac{Q_2}{C_2} = \frac{40 \mu\text{C}}{6 \mu\text{F}} = 6.67 \text{ V}$
 $V_3 = \frac{Q_3}{C_3} = \frac{40 \mu\text{C}}{12 \mu\text{F}} = 3.33 \text{ V}$

54. $C_T = 1200 \text{ pF} \parallel (200 \text{ pF} + 400 \text{ pF}) \parallel 600 \text{ pF}$
 $= 1200 \text{ pF} \parallel 600 \text{ pF} \parallel 600 \text{ pF} = 1200 \text{ pF} \parallel 300 \text{ pF}$
 $= 240 \text{ pF}$
 $Q_T = C_T E = (240 \text{ pF})(40 \text{ V}) = 9.60 \text{ nC}$
 $Q_1 = Q_4 = Q_T = 9.60 \text{ nC}$
 $V_1 = \frac{Q_1}{C_1} = \frac{9.60 \text{ nC}}{1200 \text{ pF}} = 8.00 \text{ V}$, $V_4 = \frac{Q_4}{C_4} = \frac{9.60 \text{ nC}}{600 \text{ pF}} = 16.00 \text{ V}$
 $V_2 = V_3 = E - V_1 - V_4 = 40 \text{ V} - 8 \text{ V} - 16 \text{ V} = 16 \text{ V}$
 $Q_2 = C_2 V_2 = (200 \text{ pF})(16 \text{ V}) = 3.20 \text{ nC}$, $Q_3 = C_3 V_3 = (400 \text{ pF})(16 \text{ V}) = 6.40 \text{ nC}$



$$C_T = \frac{Q}{V} = \frac{Q}{E} \Rightarrow Q = C_T E = (6 \mu\text{F})(24 \text{ V}) = 144 \mu\text{C}$$

$$Q_1 = 144 \mu\text{C}$$

$$V_1 = \frac{Q_1}{C_1} = \frac{144 \mu\text{C}}{9 \mu\text{F}} = 16 \text{ V}$$

$$V_2 = E - V_1 = 24 \text{ V} - 16 \text{ V} = 8 \text{ V}$$

$$Q_2 = C_2 V_2 = 10 \mu\text{F}(8 \text{ V}) = 80 \mu\text{C}$$

$$Q_{3-4} = C' V = (8 \mu\text{F})(8 \text{ V}) = 64 \mu\text{C}$$

$$Q_3 = Q_4 = 64 \mu\text{C}$$

$$V_3 = \frac{Q_3}{C_3} = \frac{64 \mu\text{C}}{9 \mu\text{F}} = 7.11 \text{ V}$$

$$V_4 = \frac{Q_4}{C_4} = \frac{64 \mu\text{C}}{72 \mu\text{F}} = 0.89 \text{ V}$$

56. $V_{4\text{k}\Omega} = \frac{4 \text{k}\Omega(48 \text{ V})}{4 \text{k}\Omega + 2 \text{k}\Omega} = 32 \text{ V} = V_{0.08\mu\text{F}}$
 $Q_{0.08\mu\text{F}} = (0.08 \mu\text{F})(32 \text{ V}) = 2.56 \mu\text{C}$
 $V_{0.04\mu\text{F}} = 48 \text{ V}$
 $Q_{0.04\mu\text{F}} = (0.04 \mu\text{F})(48 \text{ V}) = 1.92 \mu\text{C}$

57. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(120 \text{ pF})(12 \text{ V})^2 = \mathbf{8,640 \text{ pJ}}$

58. $W = \frac{Q^2}{2C} \Rightarrow Q = \sqrt{2CW} = \sqrt{2(6 \mu\text{F})(1200 \text{ J})} = \mathbf{0.12 \text{ C}}$

59. a. $V_{6\mu\text{F}} = V_{12\mu\text{F}} = \frac{3 \text{ k}\Omega(24 \text{ V})}{3 \text{ k}\Omega + 6 \text{ k}\Omega} = 8 \text{ V}$
 $W_{6\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(6 \mu\text{F})(8 \text{ V})^2 = \mathbf{0.19 \text{ mJ}}$
 $W_{12\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(12 \mu\text{F})(8 \text{ V})^2 = \mathbf{0.38 \text{ mJ}}$

b. $C_T = \frac{(6 \mu\text{F})(12 \mu\text{F})}{6 \mu\text{F} + 12 \mu\text{F}} = 4 \mu\text{F}$
 $Q_T = C_TV = (4 \mu\text{F})(8 \text{ V}) = 32 \mu\text{C}$
 $Q_{6\mu\text{F}} = Q_{12\mu\text{F}} = 32 \mu\text{C}$
 $V_{6\mu\text{F}} = \frac{Q}{C} = \frac{32 \mu\text{C}}{6 \mu\text{F}} = 5.33 \text{ V}$
 $V_{12\mu\text{F}} = \frac{Q}{C} = \frac{32 \mu\text{C}}{12 \mu\text{F}} = 2.67 \text{ V}$
 $W_{6\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(6 \mu\text{F})(5.33 \text{ V})^2 = \mathbf{85.23 \muJ}$
 $W_{12\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(12 \mu\text{F})(2.67 \text{ V})^2 = \mathbf{42.77 \muJ}$

60. a. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(1000 \mu\text{F})(100 \text{ V})^2 = \mathbf{5 \text{ pJ}}$
b. $Q = CV = (1000 \mu\text{F})(100 \text{ V}) = \mathbf{0.1 \text{ C}}$
c. $I = Q/t = 0.1 \text{ C}/(1/2000) = \mathbf{200 \text{ A}}$
d. $P = V_{av}I_{av} = W/t = 5 \text{ J}/(1/2000 \text{ s}) = \mathbf{10,000 \text{ W}}$
e. $t = Q/I = 0.1 \text{ C}/10 \text{ mA} = \mathbf{10 \text{ s}}$

Chapter 11

1. a. $B = \frac{\Phi}{A} = \frac{4 \times 10^{-4} \text{ Wb}}{0.01 \text{ m}^2} = 4 \times 10^{-2} \text{ Wb/m}^2 = \mathbf{0.04 \text{ Wb/m}^2}$

b. **0.04 T**

c. $F = NI = (40 \text{ t})(2.2 \text{ A}) = \mathbf{88 \text{ At}}$

d. $0.04 \mathcal{N} \left[\frac{10^4 \text{ gauss}}{\mathcal{N}} \right] = \mathbf{0.4 \times 10^3 \text{ gauss}}$

2. $A = \frac{\pi d^2}{4} = \frac{\pi (5 \text{ mm})^2}{4} = 19.63 \times 10^{-6} \text{ m}^2$

$$L = \frac{N^2 \mu A}{\ell} = \frac{(200 \text{ t})^2 (4\pi \times 10^{-7}) (19.63 \times 10^{-6} \text{ m}^2)}{100 \text{ mm}} = \mathbf{9.87 \mu H}$$

3. $d = 0.2 \text{ mH} \left[\frac{1 \text{ m}}{39.37 \text{ mH}} \right] = 5.08 \text{ mm}$

$$A = \frac{\pi d^2}{4} = \frac{(\pi)(5.08 \text{ mm})^2}{4} = 20.27 \times 10^{-6} \text{ m}^2$$

$$\ell = 1.6 \text{ mH} \left(\frac{1 \text{ m}}{39.37 \text{ mH}} \right) = 40.64 \text{ mm}$$

$$L = \frac{N^2 \mu_r \mu_o A}{\ell} = \frac{(200 \text{ t})^2 (500) (4\pi \times 10^{-7}) (20.27 \times 10^{-6} \text{ m}^2)}{40.64 \text{ mm}} = \mathbf{12.54 \text{ mH}}$$

4. $L = N^2 \frac{\mu_r \mu_o}{\ell} = \frac{(200 \text{ t})^2 (1000) (4\pi \times 10^{-7}) (1.5 \times 10^{-4} \text{ m}^2)}{0.15 \text{ m}} = \mathbf{50.27 \text{ mH}}$

5. $L = \frac{N^2 \mu_r \mu_o A}{\ell}$

a. $L' = (3)^2 L_o = 9 L_o = 9(5 \text{ mH}) = \mathbf{45 \text{ mH}}$

b. $L' = \frac{1}{3} L_o = \frac{1}{3} (5 \text{ mH}) = \mathbf{1.67 \text{ mH}}$

c. $L' = \frac{(2)(2)^2}{\frac{1}{2}} L_o = 16 (5 \text{ mH}) = \mathbf{80 \text{ mH}}$

d. $L' = \frac{\left(\frac{1}{2}\right)^2 \frac{1}{2} (1500) L_o}{\frac{1}{2}} = 375 (5 \text{ mH}) = \mathbf{1875 \text{ mH}}$

6. a. $12 \times 10^3 \mu \text{H} \pm 5\% \Rightarrow 12,000 \mu \text{H} \pm 600 \mu \text{H} \Rightarrow \mathbf{11,400 \mu \text{H} \rightarrow 12,600 \mu \text{H}}$

b. $47 \mu \text{H} \pm 10\% \Rightarrow 47 \mu \text{H} \pm 4.7 \mu \text{H} \Rightarrow \mathbf{42.3 \mu F \rightarrow 51.7 \mu F}$

7. $e = N \frac{d\phi}{dt} = (50 \text{ t})(120 \text{ mWb/s}) = \mathbf{6.0 \text{ V}}$

8. $e = N \frac{d\phi}{dt} \Rightarrow \frac{d\phi}{dt} = \frac{e}{N} = \frac{20 \text{ V}}{200 \text{ t}} = \mathbf{100 \text{ mWb/s}}$

9. $e = N \frac{d\phi}{dt} \Rightarrow N = e \left(\frac{1}{\frac{d\phi}{dt}} \right) = 42 \text{ mV} \left(\frac{1}{3 \text{ m Wb/s}} \right) = \mathbf{14 \text{ turns}}$

10. a. $e = L \frac{di_L}{dt} = (5 \text{ H})(1 \text{ A/s}) = \mathbf{5 \text{ V}}$

b. $e = L \frac{di_L}{dt} = (5 \text{ H})(60 \text{ mA/s}) = \mathbf{0.3 \text{ V}}$

$$e = L \frac{di_L}{dt} = (5 \text{ H}) \left[\frac{0.5 \text{ A}}{\mu\text{s}} \right] \left[\frac{1000 \mu\text{s}}{1 \text{ s}} \right] = \mathbf{2.5 \text{ kV}}$$

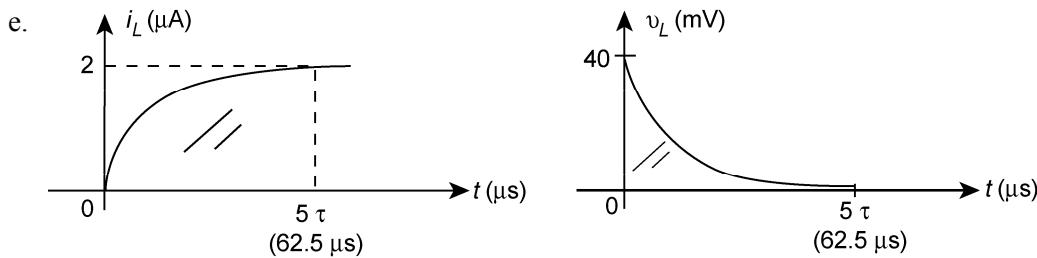
11. $e = L \frac{di_L}{dt} = (50 \text{ mH}) \left(\frac{0.1 \text{ mA}}{\mu\text{s}} \right) = \mathbf{5 \text{ V}}$

12. a. $\tau = \frac{L}{R} = \frac{250 \text{ mH}}{20 \text{ k}\Omega} = \mathbf{12.5 \mu\text{s}}$

b. $i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{40 \text{ mV}}{20 \text{ k}\Omega} (1 - e^{-t/\tau})$
 $= 2 \mu\text{A} (1 - e^{-t/12.5 \mu\text{s}})$

c. $v_L = E e^{-t/\tau} = \mathbf{40 \text{ mV} e^{-t/12.5 \mu\text{s}}}$
 $v_R = i_L R = i_L R = E(1 - e^{-t/\tau}) = \mathbf{40 \text{ mV} (1 - e^{-t/12.5 \mu\text{s}})}$

d. $i_L: 1\tau = \mathbf{1.26 \mu\text{A}}, 3\tau = \mathbf{1.9 \mu\text{A}}, 5\tau = \mathbf{1.99 \mu\text{A}}$
 $v_L: 1\tau = \mathbf{14.72 \text{ V}}, 3\tau = \mathbf{1.99 \text{ V}}, 5\tau = \mathbf{0.27 \text{ V}}$

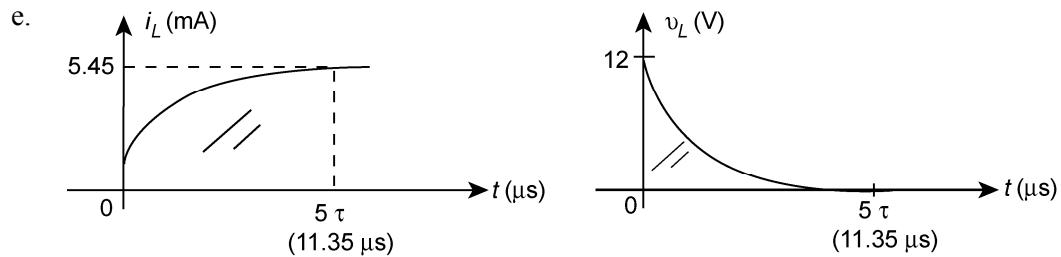


13. a. $\tau = \frac{L}{R} = \frac{5 \text{ mH}}{2.2 \text{ k}\Omega} = 2.27 \mu\text{s}$

b. $i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{12 \text{ V}}{2.2 \text{ k}\Omega}(1 - e^{-t/2.27 \mu\text{s}}) = 5.45 \text{ mA}(1 - e^{-t/2.27 \mu\text{s}})$

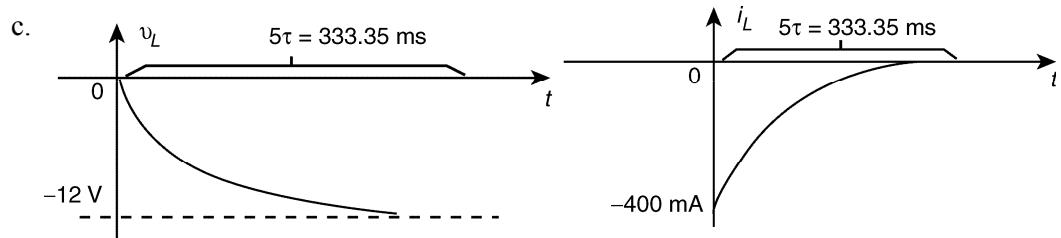
c. $v_L = Ee^{-t/\tau} = 12 \text{ V}e^{-t/2.27 \mu\text{s}}$
 $v_R = i_L R = i_L R = E(1 - e^{-t/\tau}) = 12 \text{ V}(1 - e^{-t/2.27 \mu\text{s}})$

d. $i_L: 1\tau = 3.45 \text{ mA}, 3\tau = 5.18 \text{ mA}, 5\tau = 5.41 \text{ mA}$
 $v_L: 1\tau = 4.42 \text{ V}, 3\tau = 0.60 \text{ V}, 5\tau = 0.08 \text{ V}$

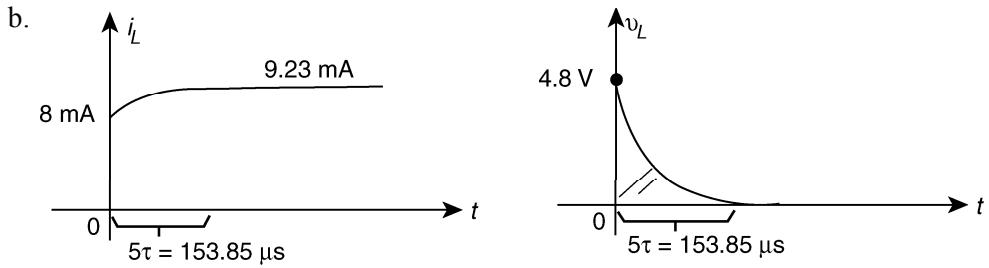


14. a. $\tau = \frac{L}{R} = \frac{2 \text{ H}}{(20 \Omega + 10 \Omega)} = \frac{2 \text{ H}}{30 \Omega} = 66.67 \text{ ms}$

b. $v_L = -E(1 - e^{-t/\tau}) = -12 \text{ V}(1 - e^{-t/66.67 \text{ ms}})$
 $i_L = -\frac{E}{R}e^{-t/\tau} = -\frac{12 \text{ V}}{30 \Omega}e^{-t/66.67 \text{ ms}} = -400 \text{ mA}e^{-t/66.67 \text{ ms}}$



15. a. $i_L = I_f + (I_i - I_f)e^{-t/\tau}$
 $I_i = 8 \text{ mA}, I_f = \frac{E}{R} = \frac{36 \text{ V}}{3.9 \text{ k}\Omega} = 9.23 \text{ mA}, \tau = \frac{L}{R} = \frac{120 \text{ mH}}{3.9 \text{ k}\Omega} = 30.77 \mu\text{s}$
 $i_L = 9.23 \text{ mA} + (8 \text{ mA} - 9.23 \text{ mA})e^{-t/30.77 \mu\text{s}}$
 $i_L = 9.23 \text{ mA} - 1.23 \text{ mA}e^{-t/30.77 \mu\text{s}}$
 $+E - v_L - v_R = 0 \text{ and } v_L = E - v_R$
 $v_R = i_L R = i_L R = (8 \text{ mA})(3.9 \text{ k}\Omega) = 31.2 \text{ V}$
 $v_L = E - v_R = 36 \text{ V} - 31.2 \text{ V} = 4.8 \text{ V}$
 $v_L = 4.8 \text{ V}e^{-t/30.77 \mu\text{s}}$



16. a. $I_i = -8 \text{ mA}$, $I_f = 9.23 \text{ mA}$, $\tau = \frac{L}{R} = \frac{120 \text{ mH}}{3.9 \text{ k}\Omega} = 30.77 \mu\text{s}$

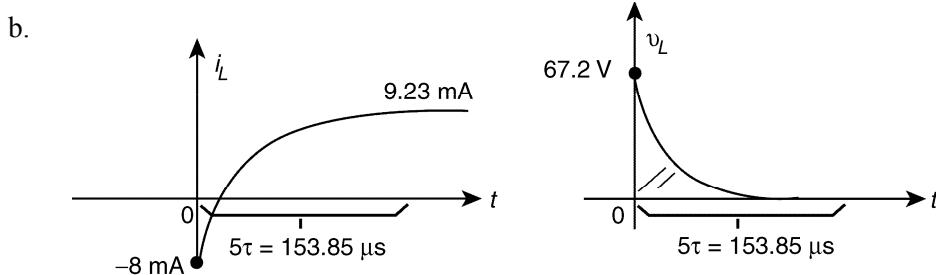
$$\begin{aligned} i_L &= I_f + (I_i - I_f)e^{-t/\tau} \\ &= 9.23 \text{ mA} + (-8 \text{ mA} - 9.23 \text{ mA})e^{-t/30.77 \mu\text{s}} \\ i_L &= \mathbf{9.23 \text{ mA} - 17.23 \text{ mA } e^{-t/30.77 \mu\text{s}}} \end{aligned}$$

$$+E - v_L - v_R = 0 \text{ (at } t = 0^-)$$

$$\text{but, } v_R = i_R R = -i_L R = (-8 \text{ mA})(3.9 \text{ k}\Omega) = -31.2 \text{ V}$$

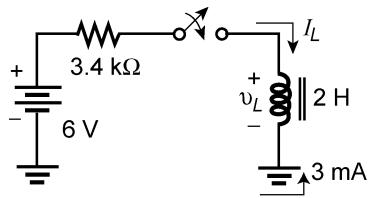
$$v_L = E - v_R = 36 \text{ V} - (-31.2 \text{ V}) = 67.2 \text{ V}$$

$$v_L = \mathbf{67.2 \text{ V } e^{-t/30.77 \mu\text{s}}}$$



c. Final levels are the same. Transition period defined by 5τ is also the same.

17. a. Source conversion:



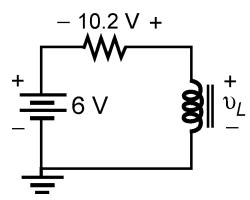
$$\tau = \frac{L}{R} = \frac{2 \text{ H}}{3.4 \text{ k}\Omega} = 588.2 \mu\text{s}$$

$$i_L = I_f + (I_i - I_f)e^{-t/\tau}$$

$$I_f = \frac{6 \text{ V}}{3.4 \text{ k}\Omega} = 1.76 \text{ mA}$$

$$i_L = 1.76 \text{ mA} + (-3 \text{ mA} - 1.76 \text{ mA})e^{-t/588.2 \mu\text{s}}$$

$$i_L = \mathbf{1.76 \text{ mA} - 4.76 \text{ mA } e^{-t/588.2 \mu\text{s}}}$$

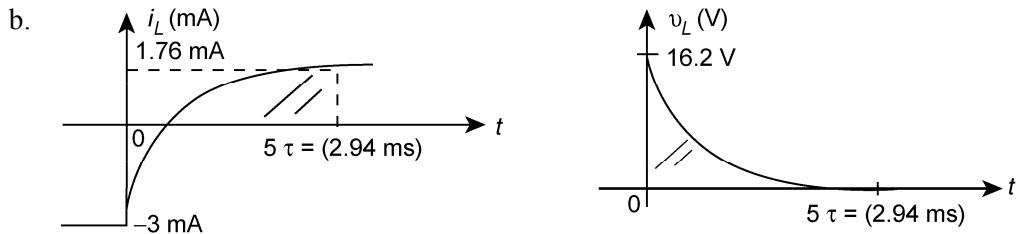


$$v_R(0+) = 3 \text{ mA}(3.4 \text{ k}\Omega) = 10.2 \text{ V}$$

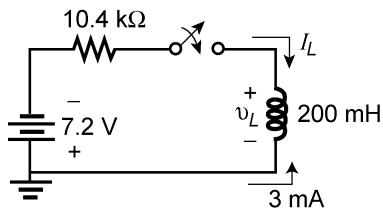
$$\text{KVL: } +6 \text{ V} + 10.2 \text{ V} - v_L(0+) = 0$$

$$v_L(0+) = 16.2 \text{ V}$$

$$v_L = \mathbf{16.2 \text{ V } e^{-t/588.2 \mu\text{s}}}$$



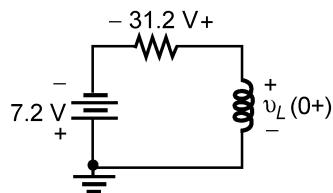
18. a.



$$I_f = -\frac{7.2 \text{ V}}{10.4 \text{ k}\Omega} = -0.69 \text{ mA}$$

$$\tau = \frac{L}{R} = \frac{200 \text{ mH}}{10.4 \text{ k}\Omega} = 19.23 \mu\text{s}$$

$$i_L = I_f + (I_i - I_f)e^{-t/\tau} \\ = -0.69 \text{ mA} + (-3 \text{ mA} - (-0.69 \text{ mA}))e^{-t/19.23 \mu\text{s}} \\ i_L = -0.69 \text{ mA} - 2.31 \text{ mA} e^{-t/19.23 \mu\text{s}}$$

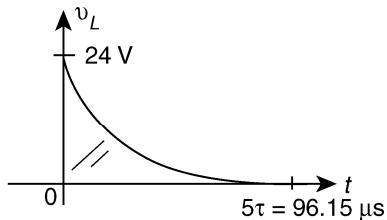
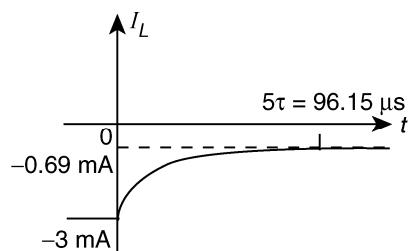


$$\text{KVL: } -7.2 \text{ V} + 31.2 \text{ V} - v_L(0+) = 0$$

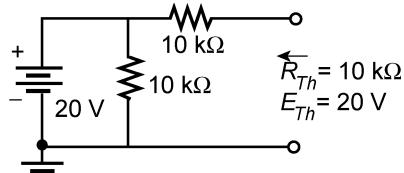
$$v_L(0+) = 24 \text{ V}$$

$$v_L = 24 \text{ V} e^{-t/19.23 \mu\text{s}}$$

b.



19. a.



$$\tau = \frac{L}{R} = \frac{10 \text{ mH}}{10 \text{ k}\Omega} = 1 \mu\text{s}$$

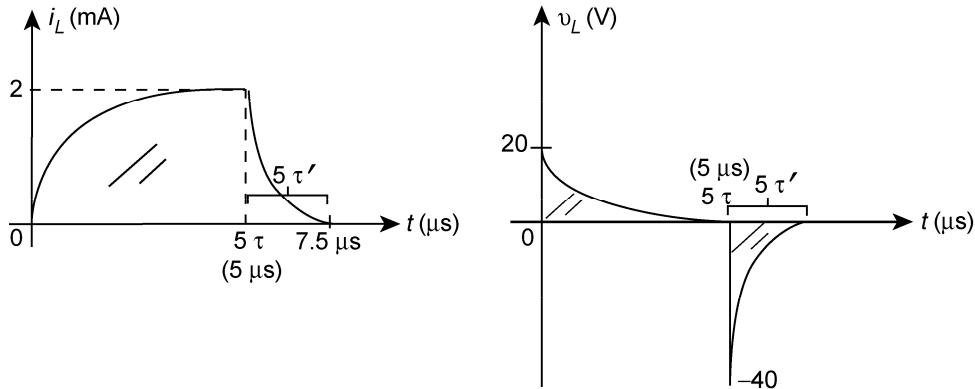
$$v_L = 20 \text{ V} e^{-t/1 \mu\text{s}}, i_L = \frac{E}{R} (1 - e^{-t/\tau}) = 2 \text{ mA} (1 - e^{-t/1 \mu\text{s}})$$

b. $5\tau \Rightarrow$ steady state

$$\tau' = \frac{L}{R} = \frac{10 \text{ mH}}{10 \text{ k}\Omega} = 1 \mu\text{s}$$

$$i_L = I_m e^{-t/\tau'} = 2 \text{ mA} e^{-t/1\mu\text{s}}$$

$$v_L = -(2 \text{ mA})(20 \text{ k}\Omega) e^{-t/\tau} = -40 \text{ V} e^{-t/1\mu\text{s}}$$



20. a. $\tau = \frac{L}{R} = \frac{1 \text{ mH}}{2 \text{ k}\Omega} = 0.5 \mu\text{s}$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{12 \text{ V}}{2 \text{ k}\Omega}(1 - e^{-t/0.5\mu\text{s}}) = 6 \text{ mA}(1 - e^{-t/0.5\mu\text{s}})$$

$$v_L = E e^{-t/\tau} = 12 \text{ V} e^{-t/0.5\mu\text{s}}$$

b. $i_L = 6 \text{ mA}(1 - e^{-t/0.5\mu\text{s}}) = 6 \text{ mA}(1 - e^{-1\mu\text{s}/0.5\mu\text{s}})$
 $= 6 \text{ mA}(1 - e^{-2}) = 5.19 \text{ mA}$

$$i_L = I_m e^{-t/\tau'} \quad \tau' = \frac{L}{R} = \frac{1 \text{ mH}}{12 \text{ k}\Omega} = 83.3 \text{ ns}$$

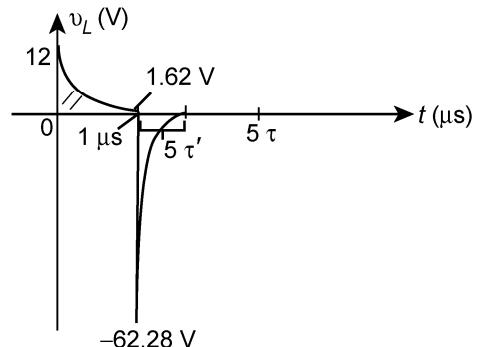
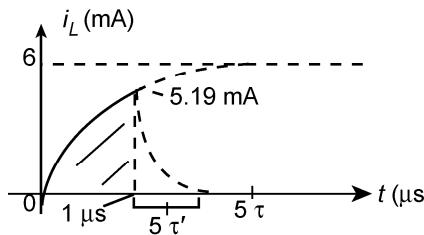
$$i_L = 5.19 \text{ mA} e^{-t/83.3\text{ns}}$$

$$t = 1 \mu\text{s}: v_L = 12 \text{ V} e^{-t/0.5\mu\text{s}} = 12 \text{ V} e^{-2} = 12 \text{ V}(0.1353) = 1.62 \text{ V}$$

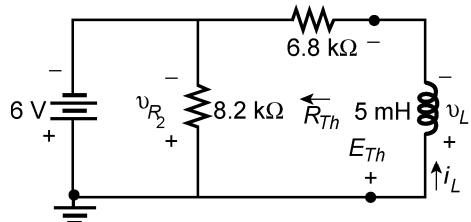
$$V'_L = (5.19 \text{ mA})(12 \text{ k}\Omega) = 62.28 \text{ V}$$

$$v_L = -62.28 \text{ V} e^{-t/83.3\text{ns}}$$

c.

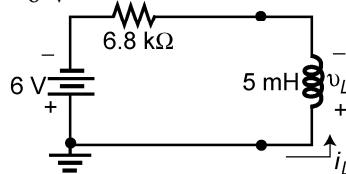


21. a.



$$R_{Th} = 6.8 \text{ k}\Omega$$

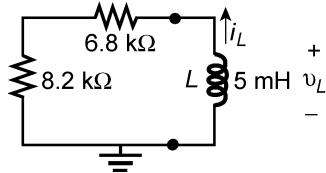
$$E_{Th} = 6 \text{ V}$$



$$\tau = \frac{L}{R} = \frac{5 \text{ mH}}{6.8 \text{ k}\Omega} = 0.74 \mu\text{s}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{6 \text{ V}}{6.8 \text{ k}\Omega}(1 - e^{-t/0.74\mu\text{s}}) = 0.88 \text{ mA}(1 - e^{-t/0.74\mu\text{s}})$$

$$v_L = E e^{-t/\tau} = 6 \text{ V} e^{-t/0.74\mu\text{s}}$$

b. Assume steady state and $I_L = 0.88 \text{ mA}$ 

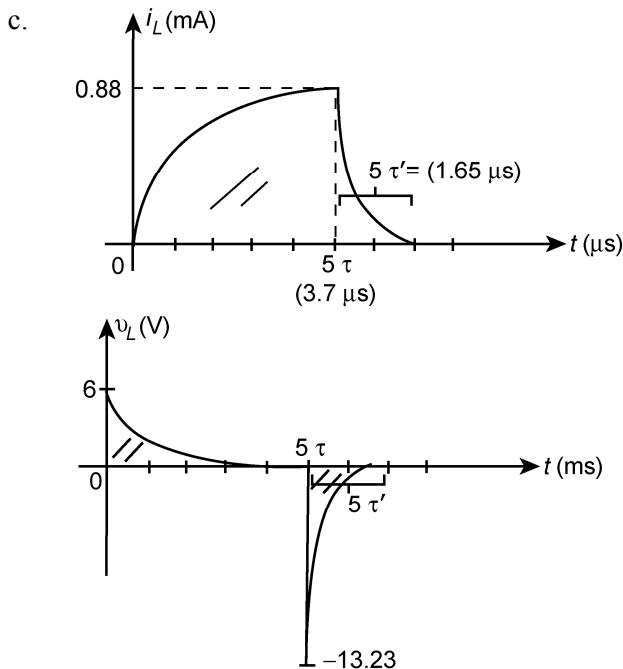
$$\tau' = \frac{L}{R} = \frac{5 \text{ mH}}{15 \text{ k}\Omega} = 0.33 \mu\text{s}$$

$$i_L = I_m e^{-t/\tau'} = 0.88 \text{ mA } e^{-t/0.33\mu\text{s}}$$

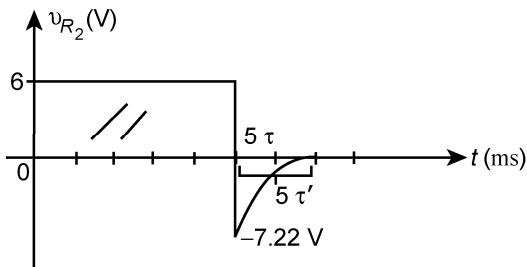
$$v_L = -V_m e^{-t/\tau'}$$

$$V_m = I_m R = (0.88 \text{ mA})(15 \text{ k}\Omega) = 13.23 \text{ V}$$

$$v_L = -13.23 \text{ V } e^{-t/0.33\mu\text{s}}$$



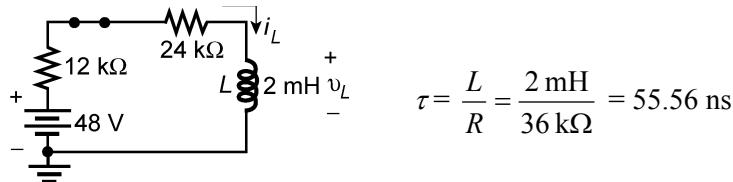
d. $V_{R_{2\max}} = I_m R_2 = (0.88 \text{ mA})(8.2 \text{ kΩ}) = 7.22 \text{ V}$



22. a. $R_{Th} = 2 \text{ kΩ} + 3 \text{ kΩ} \parallel 6 \text{ kΩ} = 2 \text{ kΩ} + 2 \text{ kΩ} = 4 \text{ kΩ}$
 $E_{Th} = \frac{6 \text{ kΩ}(12 \text{ V})}{6 \text{ kΩ} + 3 \text{ kΩ}} = 8 \text{ V}, \tau = \frac{L}{R} = \frac{100 \text{ mH}}{4 \text{ kΩ}} = 25 \text{ μs}$
 $I_f = \frac{E_{Th}}{R_{Th}} = \frac{8 \text{ V}}{4 \text{ kΩ}} = 2 \text{ mA}$
 $i_L = 2 \text{ mA}(1 - e^{-t/25\mu s})$
 $v_L = 8 \text{ V}e^{-t/25\mu s}$

b. $i_L = 2 \text{ mA}(1 - e^{-1}) = 1.26 \text{ mA}$
 $v_L = 8 \text{ V}e^{-1} = 2.94 \text{ V}$

23. a. Source conversion: $E = IR = (4 \text{ mA})(12 \text{ k}\Omega) = 48 \text{ V}$



$$\tau = \frac{L}{R} = \frac{2 \text{ mH}}{36 \text{ k}\Omega} = 55.56 \text{ ns}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{48 \text{ V}}{36 \text{ k}\Omega}(1 - e^{-t/55.56\text{ns}}) = 1.33 \text{ mA}(1 - e^{-t/55.56\text{ns}})$$

$$v_L = E e^{-t/\tau} = 48 \text{ V} e^{-t/55.56\text{ns}}$$

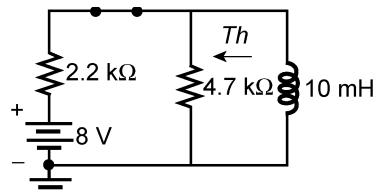
- b. $t = 100 \text{ ns}$:

$$i_L = 1.33 \text{ mA}(1 - e^{-100\text{ns}/55.56\text{ns}}) = 1.33 \text{ mA}(1 - \underbrace{e^{-1.8}}_{0.165}) = 1.11 \text{ mA}$$

$$v_L = 48 \text{ V} e^{-1.8} = 7.93 \text{ V}$$

24.

a.



$$R_{Th} = 2.2 \text{ k}\Omega \parallel 4.7 \text{ k}\Omega = 1.50 \text{ k}\Omega$$

$$E_{Th} = \frac{4.7 \text{ k}\Omega(8 \text{ V})}{4.7 \text{ k}\Omega + 2.2 \text{ k}\Omega} = 5.45 \text{ V}$$

$$\tau = \frac{L}{R} = \frac{10 \text{ mH}}{1.50 \text{ k}\Omega} = 6.67 \mu\text{s}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{5.45 \text{ V}}{1.5 \text{ k}\Omega}(1 - e^{-t/6.67\mu\text{s}}) = 3.63 \text{ mA}(1 - e^{-t/6.67\mu\text{s}})$$

$$v_L = E e^{-t/\tau} = 5.45 \text{ V} e^{-t/6.67\mu\text{s}}$$

- b. $t = 10 \mu\text{s}$:

$$i_L = 3.63 \text{ mA}(1 - e^{-10\mu\text{s}/6.67\mu\text{s}}) = 3.63 \text{ mA}(1 - \underbrace{e^{-1.4}}_{0.246})$$

$$= 2.74 \text{ mA}$$

$$v_L = 5.45 \text{ V}(0.246) = 1.34 \text{ V}$$

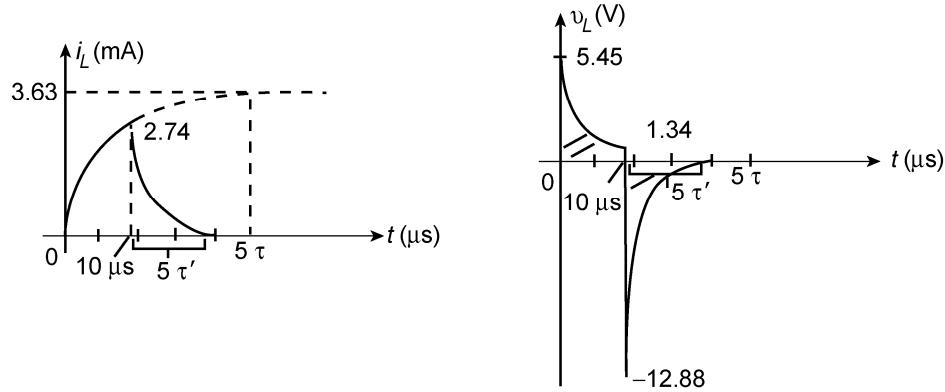
$$\text{c. } \tau' = \frac{L}{R} = \frac{10 \text{ mH}}{4.7 \text{ k}\Omega} = 2.13 \mu\text{s}$$

$$i_L = 2.74 \text{ mA} e^{-t/2.13\mu\text{s}}$$

At $t = 10 \mu\text{s}$

$$V_L = (2.74 \text{ mA})(4.7 \text{ k}\Omega) = 12.88 \text{ V}$$

$$v_L = -12.88 \text{ V} e^{-t/2.13\mu\text{s}}$$



25. a. $v_L = E e^{-t/\tau}$ $\tau = \frac{L}{R_1 + R_3} = \frac{0.6 \text{ H}}{100 \Omega + 20 \Omega} = \frac{0.6 \text{ H}}{120 \Omega} = 5 \text{ ms}$

$$v_L = 36 \text{ V} e^{-t/5 \text{ ms}}$$

$$v_L = 36 \text{ V} e^{-25 \text{ ms}/5 \text{ ms}} = 36 \text{ V} e^{-5} = 36 \text{ V}(0.00674) = \mathbf{0.24 \text{ V}}$$

b. $v_L = 36 \text{ V} e^{-1 \text{ ms}/5 \text{ ms}} = 36 \text{ V} e^{-0.2} = 36 \text{ V}(0.819) = \mathbf{29.47 \text{ V}}$

c. $v_{R_1} = i_{R_1} R_1 = i_L R_1 = \left(\frac{E}{R_1 + R_3} (1 - e^{-t/\tau}) \right) R_1$
 $= \left(\frac{36 \text{ V}}{120 \Omega} (1 - e^{-t/5 \text{ ms}}) \right) 100 \Omega$
 $= (300 \text{ mA} (1 - e^{-t/5 \text{ ms}})) 100 \Omega$
 $= 30 \text{ V} (1 - e^{-5 \text{ ms}/5 \text{ ms}}) = 30 \text{ V} (1 - e^{-1})$
 $= 30 \text{ V} (1 - 0.368) = \mathbf{18.96 \text{ V}}$

d. $i_L = 300 \text{ mA} (1 - e^{-t/5 \text{ ms}})$

$$100 \text{ mA} = 300 \text{ mA} (1 - e^{-t/5 \text{ ms}})$$

$$0.333 = 1 - e^{-t/5 \text{ ms}}$$

$$0.667 = e^{-t/5 \text{ ms}}$$

$$\log_e 0.667 = -t/5 \text{ ms}$$

$$0.405 = t/5 \text{ ms}$$

$$t = 0.405(5 \text{ ms}) = \mathbf{2.03 \text{ ms}}$$

26. a. $I_i = \frac{16 \text{ V}}{4.7 \text{ k}\Omega + 3.3 \text{ k}\Omega} = 2 \text{ mA}$

$t = 0 \text{ s}$: Thevenin:

$$R_{Th} = 3.3 \text{ k}\Omega + 1 \text{ k}\Omega \parallel 4.7 \text{ k}\Omega = 3.3 \text{ k}\Omega + 0.82 \text{ k}\Omega = 4.12 \text{ k}\Omega$$

$$E_{Th} = \frac{1 \text{ k}\Omega(16 \text{ V})}{1 \text{ k}\Omega + 4.7 \text{ k}\Omega} = 2.81 \text{ V}$$

$$i_L = I_f + (I_i - I_f) e^{-t/\tau}$$

$$I_f = \frac{2.81 \text{ V}}{4.12 \text{ k}\Omega} = 0.68 \text{ mA}, \tau = \frac{L}{R} = \frac{2 \text{ H}}{4.12 \text{ k}\Omega} = 0.49 \text{ ms}$$

$$i_L = 0.68 \text{ mA} + (2 \text{ mA} - 0.68 \text{ mA})e^{-t/0.49 \text{ ms}}$$

$$i_L = \mathbf{0.68 \text{ mA} + 1.32 \text{ mA} e^{-t/0.49 \text{ ms}}}$$

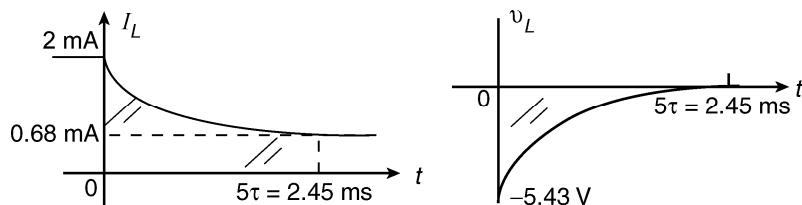
$$v_R(0+) = 2 \text{ mA}(4.12 \text{ k}\Omega) = 8.24 \text{ V}$$

$$\text{KVL}(0+): 2.81 \text{ V} - 8.24 \text{ V} - v_L = 0$$

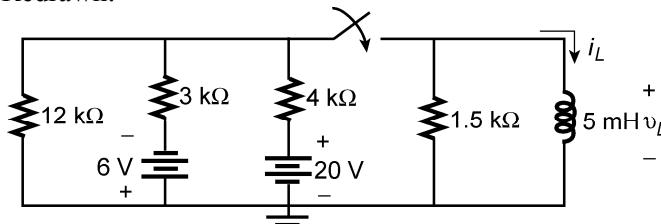
$$v_L = -5.43 \text{ V}$$

$$v_L = \mathbf{-5.43 \text{ V} e^{-t/0.49 \text{ ms}}}$$

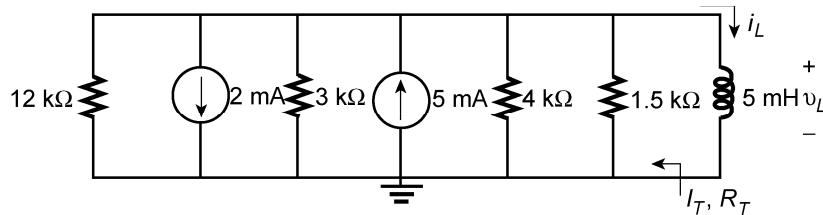
b.



27. a. Redrawn:



Source conversions:



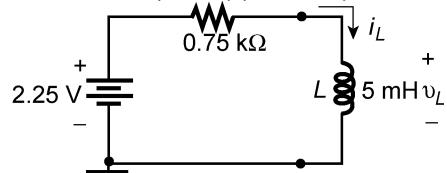
$$I_T = 5 \text{ mA} - 2 \text{ mA} = 3 \text{ mA} \uparrow$$

$$\frac{1}{R_T} = \frac{1}{12 \text{ k}\Omega} + \frac{1}{3 \text{ k}\Omega} + \frac{1}{4 \text{ k}\Omega} + \frac{1}{1.5 \text{ k}\Omega}$$

$$\text{and } R_T = 0.75 \text{ k}\Omega$$

Source conversion:

$$E_T = I_T R_T = (3 \text{ mA})(0.75 \text{ k}\Omega) = 2.25 \text{ V}$$



$$\tau = \frac{L}{R} = \frac{5 \text{ mH}}{0.75 \text{ k}\Omega} = 6.67 \mu\text{s}$$

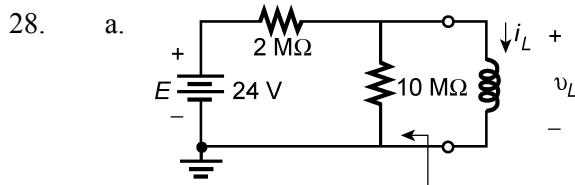
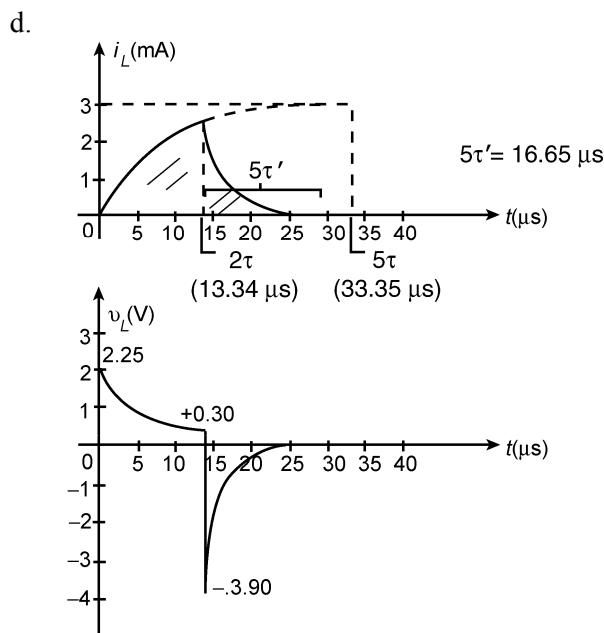
$$i_L = \frac{2.25 \text{ V}}{0.75 \text{ k}\Omega} (1 - e^{-t/\tau}) = 3 \text{ mA} (1 - e^{-t/6.67 \mu\text{s}})$$

$$v_L = \mathbf{2.25 \text{ V} e^{-t/6.67 \mu\text{s}}}$$

- b. 2τ : $0.865 I_m$, $0.135 V_m$
 i_L : $0.865(3 \text{ mA}) = \mathbf{2.60 \text{ mA}}$
 v_L : $0.135(2.25 \text{ V}) = \mathbf{0.30 \text{ V}}$

c.

$\tau' = \frac{L}{R} = \frac{5 \text{ mH}}{1.5 \text{ k}\Omega} = 3.33 \mu\text{s}$
 $i_L = \mathbf{2.60 \text{ mA}} e^{-t/3.33 \mu\text{s}}$
 $i_L(0+) = 2.60 \text{ mA}$
 $v_R(0+) = (2.60 \text{ mA})(1.5 \text{ k}\Omega) = 3.90 \text{ V}$
 $v_L = -3.90 \text{ V} e^{-t/3.33 \mu\text{s}}$



$$R_{Th} = 2 \text{ M}\Omega \parallel 10 \text{ M}\Omega = 1.67 \text{ M}\Omega$$

$$E_{Th} = \frac{10 \text{ M}\Omega(24 \text{ V})}{10 \text{ M}\Omega + 2 \text{ M}\Omega} = 20 \text{ V}$$

$$I_L(0^-) = \frac{E_{Th}}{R_{Th}} = \frac{20 \text{ V}}{1.67 \text{ M}\Omega} = \mathbf{12 \mu\text{A}}$$

$$\tau' = \frac{L}{R_{meter}} = \frac{5 \text{ H}}{10 \text{ M}\Omega} = 5 \mu\text{s}$$

$$i_L = 12 \mu\text{A} e^{-t/5 \mu\text{s}}$$

$$10 \mu\text{A} = 12 \mu\text{A} e^{-t/5 \mu\text{s}}$$

$$0.833 = e^{-t/5 \mu\text{s}}$$

$$\log_e 0.833 = -t/5 \mu\text{s}$$

$$0.183 = t/5 \mu s$$

$$t = 0.183(5 \mu s) = \mathbf{0.92 \mu s}$$

b. $v_L(0^+) = i_L(0^+)R_m = (12 \mu A)(10 M\Omega) = 120 V$
 $v_L = 120 V e^{-t/5\mu s} = 120 V e^{-10\mu s/5\mu s} = 120 V e^{-2} = 120 V(0.135) = \mathbf{16.2 V}$

c. $v_L = 120 V e^{-5\tau/\tau} = 120 V e^{-5} = 120 V(6.74 \times 10^{-3}) = \mathbf{0.81 V}$

29. a. $I_i = -\frac{24 V}{2.2 k\Omega} = -10.91 \text{ mA}$

Switch open: $I_f = -\frac{24 V}{2.2 k\Omega + 4.7 k\Omega} = -\frac{24 V}{6.9 k\Omega} = -3.48 \text{ mA}$

$$i_L = I_f + (I_i - I_f)e^{-t/\tau}$$

$$\tau = \frac{L}{R} = \frac{1.2 H}{6.9 k\Omega} = 173.9 \mu s$$

$$i_L = -3.48 \text{ mA} + (-10.91 \text{ mA} - (-3.48 \text{ mA}))e^{-t/173.9 \mu s}$$

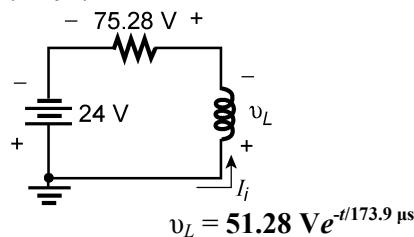
$$i_L = \mathbf{-3.48 \text{ mA} - 7.43 \text{ mA} e^{-t/173.9 \mu s}}$$

$$t = 0+:$$

$$v_R(0+) = (10.91 \text{ mA})(6.9 k\Omega) = 75.28 \text{ V}$$

$$\text{KVL: } -24 \text{ V} + 75.28 \text{ V} - v_L = 0$$

$$v_L = 51.28 \text{ V}$$



$$v_L = \mathbf{51.28 V e^{-t/173.9 \mu s}}$$

30. a. $i_L = 100 \text{ mA}(1 - e^{-1 \text{ ms}/20 \text{ ms}}) = 100 \text{ mA}(1 - e^{-1/20})$
 $= 100 \text{ mA}(1 - e^{-0.05}) = 100 \text{ mA}(1 - 951.23 \times 10^{-3}) = 100 \text{ mA}(48.77 \times 10^{-3})$
 $= \mathbf{4.88 \text{ mA}}$

b. $i_L = 100 \text{ mA}(1 - e^{-100 \text{ ms}/20 \text{ ms}}) = 100 \text{ mA}(1 - e^{-5})$
 $= \mathbf{99.33 \text{ mA}}$

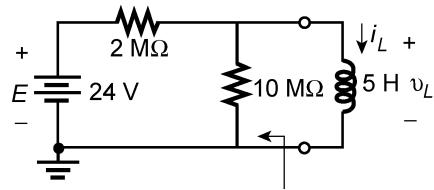
c. $50 \text{ mA} = 100 \text{ mA}(1 - e^{-t/\tau})$
 $0.5 = 1 - e^{-t/\tau}$
 $-0.5 = -e^{-t/\tau}$
 $0.5 = e^{-t/\tau}$
 $\log_e 0.5 = -t/\tau$
 $t = -(\tau)(\log_e 0.5) = -(20 \text{ ms})(\log_e 0.5) = -(20 \text{ ms})(-693.15 \times 10^{-3})$
 $= \mathbf{13.86 \text{ ms}}$

d. $99 \text{ mA} = 100 \text{ mA}(1 - e^{-t/20 \text{ ms}})$
 $0.99 = 1 - e^{-t/20 \text{ ms}}$
 $-0.01 = -e^{-t/20 \text{ ms}}$
 $0.01 = e^{-t/20 \text{ ms}}$
 $\log_e 0.01 = -t/20 \text{ ms}$
 $t = -(20 \text{ ms})(\log_e 0.01) = -(20 \text{ ms})(-4.605) = \mathbf{92.1 \text{ ms}}$

31. a. $L \Rightarrow$ open circuit equivalent

$$V_L = \frac{10 \text{ M}\Omega(24 \text{ V})}{10 \text{ M}\Omega + 2 \text{ M}\Omega} = 20 \text{ V}$$

b.



$$R_{Th} = 2 \text{ M}\Omega \parallel 10 \text{ M}\Omega = 1.67 \text{ M}\Omega$$

$$E_{Th} = \frac{10 \text{ M}\Omega(24 \text{ V})}{10 \text{ M}\Omega + 2 \text{ M}\Omega} = 20 \text{ V}$$

$$I_{L\text{final}} = \frac{E_{Th}}{R_{Th}} = \frac{20 \text{ V}}{1.67 \text{ M}\Omega} = 12 \mu\text{A}$$

c.

$$i_L = 12 \mu\text{A}(1 - e^{-t/3 \mu\text{s}}) \quad \tau = \frac{L}{R} = \frac{5 \text{ H}}{1.67 \text{ M}\Omega} = 3 \mu\text{s}$$

$$10 \mu\text{A} = 12 \mu\text{A}(1 - e^{-t/3 \mu\text{s}})$$

$$0.8333 = 1 - e^{-t/3 \mu\text{s}}$$

$$0.1667 = e^{-t/3 \mu\text{s}}$$

$$\log_e(0.1667) = -t/3 \mu\text{s}$$

$$1.792 = t/3 \mu\text{s}$$

$$t = 1.792(3 \mu\text{s}) = \mathbf{5.38 \mu\text{s}}$$

d. $v_L = 20 \text{ V } e^{-t/3 \mu\text{s}} = 20 \text{ V } e^{-12 \mu\text{s}/3 \mu\text{s}} = 20 \text{ V } e^{-4}$
 $= 20 \text{ V}(0.0183) = \mathbf{0.37 \text{ V}}$

32. $e_L = L \frac{\Delta i}{\Delta t} : \quad 0 - 3 \text{ ms}, e_L = \mathbf{0 \text{ V}}$

$$3 - 8 \text{ ms}, e_L = (200 \text{ mH}) \left(\frac{40 \times 10^{-3} \text{ A}}{5 \times 10^{-3} \text{ s}} \right) = \mathbf{1.6 \text{ V}}$$

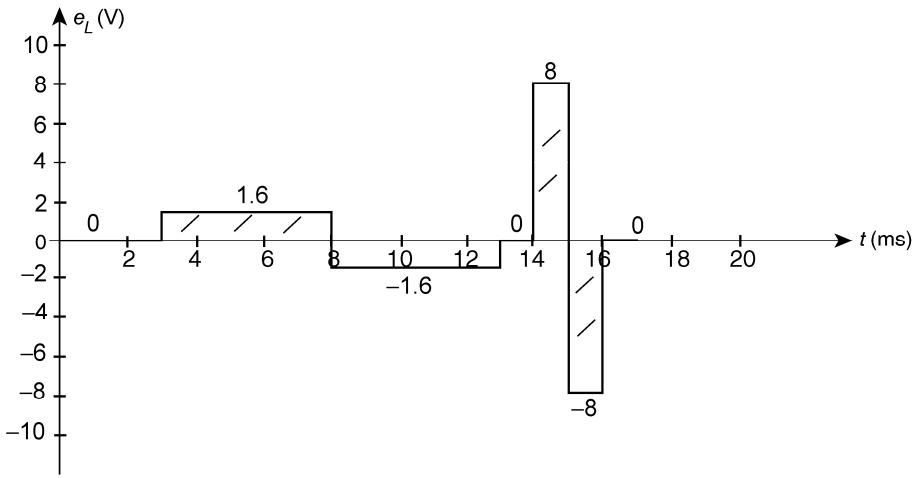
$$8 - 13 \text{ ms}, e_L = -(200 \text{ mH}) \left(\frac{40 \times 10^{-3} \text{ A}}{5 \times 10^{-3} \text{ s}} \right) = \mathbf{-1.6 \text{ V}}$$

$$13 - 14 \text{ ms}, e_L = \mathbf{0 \text{ V}}$$

$$14 - 15 \text{ ms}, e_L = (200 \text{ mH}) \left(\frac{40 \times 10^{-3} \text{ A}}{5 \times 10^{-3} \text{ s}} \right) = \mathbf{8 \text{ V}}$$

$15 - 16 \text{ ms}, e_L = -8 \text{ V}$

$16 - 17 \text{ ms}, e_L = 0 \text{ V}$



$$33. \quad v_L = L \frac{\Delta i_L}{\Delta t}$$

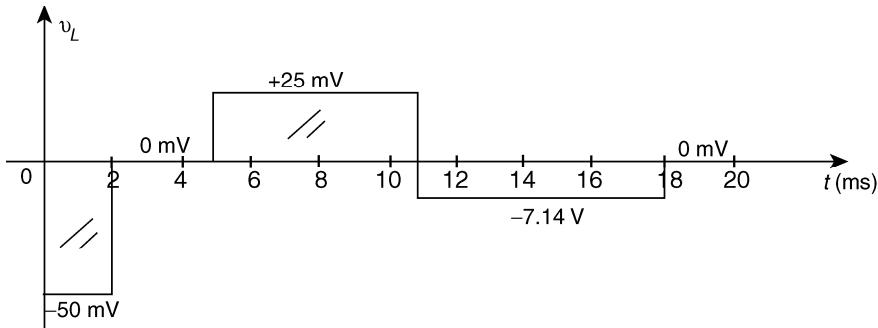
$$0 \rightarrow 2 \text{ ms}: v_L = (5 \text{ mH}) \left(-\frac{20 \text{ mA}}{2 \text{ ms}} \right) = -50 \text{ mV}$$

$$2 \rightarrow 5 \text{ ms}: \Delta i_L = 0 \text{ mA}, v_L = 0 \text{ V}$$

$$5 \rightarrow 11 \text{ ms}: v_L = (5 \text{ mH}) \left(\frac{+30 \text{ mA}}{6 \text{ ms}} \right) = +25 \text{ mV}$$

$$11 \rightarrow 18 \text{ ms}: v_L = (5 \text{ mH}) \left(\frac{-10 \text{ mA}}{7 \text{ ms}} \right) = -7.14 \text{ V}$$

$$18 \rightarrow : \Delta i_L = 0 \text{ mA}, v_L = 0 \text{ V}$$



$$34. \quad L = 10 \text{ mH}, 4 \text{ mA at } t = 0 \text{ s}$$

$$v_L = L \frac{\Delta i}{\Delta t} \Rightarrow \Delta i = \frac{\Delta t}{L} v_L$$

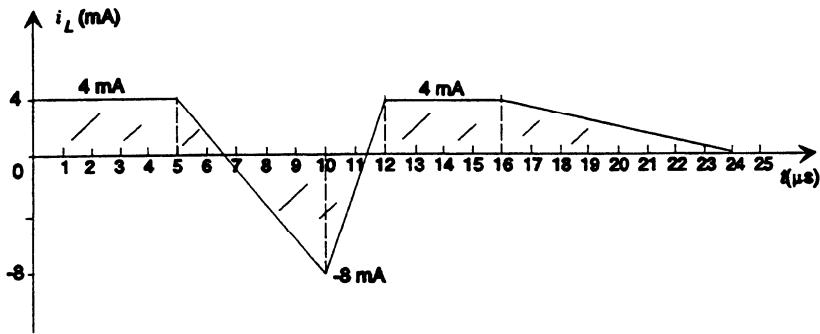
$$0 - 5 \mu\text{s}: v_L = 0 \text{ V}, \Delta i_L = 0 \text{ mA and } i_L = 4 \text{ mA}$$

$$5 - 10 \mu\text{s}: \Delta i_L = \frac{5 \mu\text{s}}{10 \text{ mH}} (-24 \text{ V}) = -12 \text{ mA}$$

$$10 - 12 \mu\text{s}: \Delta i_L = \frac{2 \mu\text{s}}{10 \text{ mH}} (+60 \text{ V}) = +12 \text{ mA}$$

12 - 16 μs : $v_L = 0 \text{ V}$, $\Delta i_L = 0 \text{ mA}$ and $i_L = 4 \text{ mA}$

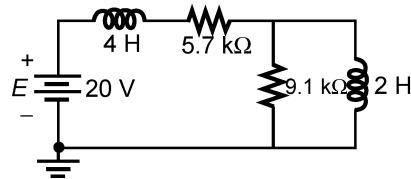
$$16 - 24 \mu\text{s}: \Delta i_L = \frac{8 \mu\text{s}}{10 \text{ mH}} (-5 \text{ V}) = -4 \text{ mA}$$



35. a. $L_T = L_1 + L_2 \parallel (L_3 + L_4) = 6 \text{ H} + 6 \text{ H} \parallel (6 \text{ H} + 6 \text{ H})$
 $= 6 \text{ H} + 6 \text{ H} \parallel 12 \text{ H} = 6 \text{ H} + 4 \text{ H} = \mathbf{10 \text{ H}}$

b. $L_T = (L_1 + L_2 \parallel L_3) \parallel L_4 = (4 \text{ H} + 4 \text{ H} \parallel 4 \text{ H}) \parallel 4 \text{ H}$
 $= (4 \text{ H} + 2 \text{ H}) \parallel 4 \text{ H} = 6 \text{ H} \parallel 4 \text{ H} = \mathbf{2.4 \text{ H}}$

36. $L'_T = 6 \text{ H} \parallel (1 \text{ H} + 2 \text{ H}) = 6 \text{ H} \parallel 3 \text{ H} = 2 \text{ H}$



37. $L'_T = 6 \text{ mH} + 14 \text{ mH} \parallel 35 \text{ mH} = 6 \text{ mH} + 10 \text{ mH} = \mathbf{16 \text{ mH}}$

$$C'_T = 9 \mu\text{F} + 10 \mu\text{F} \parallel 90 \mu\text{F} = 9 \mu\text{F} + 9 \mu\text{F} = \mathbf{18 \mu\text{F}}$$

16 mH in series with 18 μF

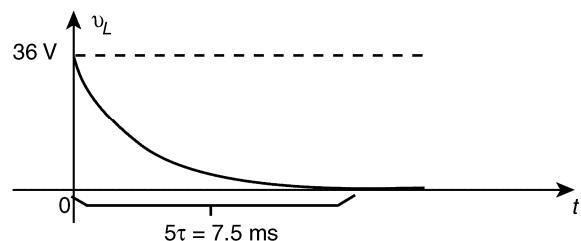
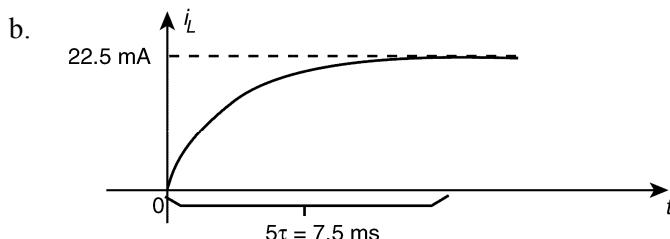
38. a. $R'_T = 2 \text{ k}\Omega \parallel 8 \text{ k}\Omega = 1.6 \text{ k}\Omega, \quad L'_T = 4 \text{ H} \parallel 6 \text{ H} = 2.4 \text{ H}$

$$\tau = \frac{L'_T}{R'_T} = \frac{2.4 \text{ H}}{1.6 \text{ k}\Omega} = 1.5 \text{ ms}$$

$$i_L = \frac{E}{R'_T} (1 - e^{-t/\tau})$$

$$= \frac{36 \text{ V}}{1.6 \text{ k}\Omega} (1 - e^{-t/1.5 \text{ ms}}) = \mathbf{22.5 \text{ mA} (1 - e^{-t/1.5 \text{ ms}})}$$

$$v_L = E e^{-t/\tau} = \mathbf{36 \text{ V} e^{-t/1.5 \text{ ms}}}$$



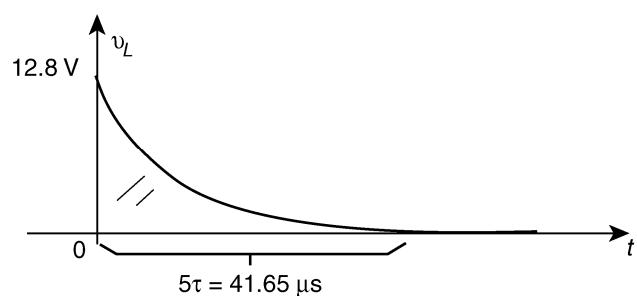
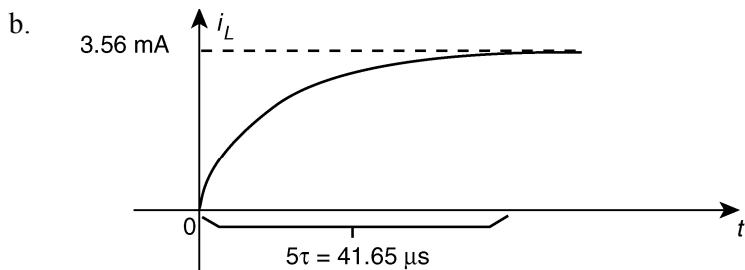
39. a. Source conversion: $E = 16 \text{ V}$, $R_s = 2 \text{ k}\Omega$
 $R_{Th} = 2 \text{ k}\Omega + 2 \text{ k}\Omega \parallel 8 \text{ k}\Omega = 2 \text{ k}\Omega + 16 \text{ k}\Omega = 3.6 \text{ k}\Omega$

$$E_{Th} = \frac{8 \text{ k}\Omega(16 \text{ V})}{8 \text{ k}\Omega + 2 \text{ k}\Omega} = 12.8 \text{ V}$$

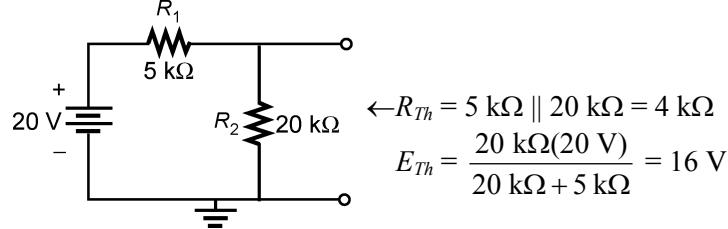
$$I_m = \frac{E_{Th}}{R_{Th}} = \frac{12.8 \text{ V}}{3.6 \text{ k}\Omega} = 3.56 \text{ mA}, \quad \tau = \frac{L}{R} = \frac{30 \text{ mH}}{3.6 \text{ k}\Omega} = 8.33 \mu\text{s}$$

$$i_L = 3.56 \text{ mA}(1 - e^{-t/8.33\mu\text{s}})$$

$$v_L = E_{Th}e^{-t/\tau} = 12.8 \text{ V}e^{-t/8.33\mu\text{s}}$$



40. a.



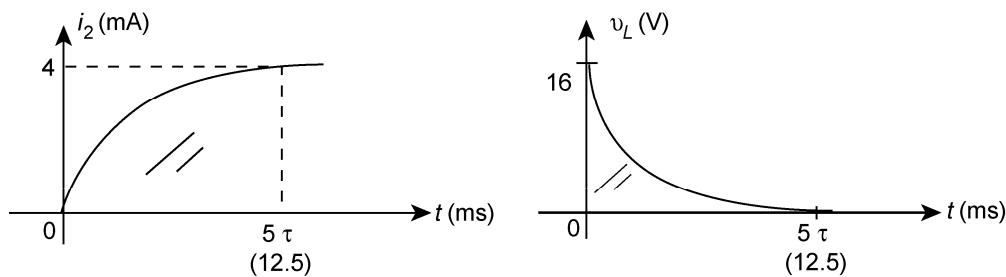
$$L_T = 5 \text{ H} + 6 \text{ H} \parallel 30 \text{ H} = 5 \text{ H} + 5 \text{ H} = \mathbf{10 \text{ H}}$$

$$\tau = \frac{L_T}{R} = \frac{10 \text{ H}}{4 \text{ k}\Omega} = 2.5 \text{ ms}$$

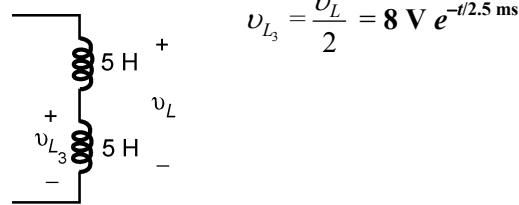
$$v_L = 16 \text{ V} e^{-t/2.5 \text{ ms}}$$

$$i_L = \frac{16 \text{ V}}{4 \text{ k}\Omega} (1 - e^{-t/\tau}) = 4 \text{ mA} (1 - e^{-t/2.5 \text{ ms}})$$

b.



c.



$$v_{L_3} = \frac{v_L}{2} = 8 \text{ V} e^{-t/2.5 \text{ ms}}$$

$$41. I_{R_1} = \frac{E}{R_1} = \frac{20 \text{ V}}{4 \Omega} = 5 \text{ A}$$

$$I_2 = I_{R_2} = \frac{E}{R_2 + R_3} = \frac{20 \text{ V}}{6 \Omega + 4 \Omega} = \frac{20 \text{ V}}{10 \Omega} = 2 \text{ A}$$

$$I_1 = I_{R_1} + I_2 = 5 \text{ A} + 2 \text{ A} = 7 \text{ A}$$

$$42. I_1 = I_2 = \mathbf{0 \text{ A}}$$

$$V_1 = V_2 = E = \mathbf{60 \text{ V}}$$

$$43. I_1 = \frac{12 \text{ V}}{4 \Omega} = \mathbf{3 \text{ A}}, \quad I_2 = \mathbf{0 \text{ A}}$$

$$V_1 = \mathbf{12 \text{ V}}, \quad V_2 = \mathbf{0 \text{ V}}$$

$$44. \quad V_1 = \frac{(3\Omega + 3\Omega \parallel 6\Omega)(50V)}{(3\Omega + 3\Omega \parallel 6\Omega) + 20\Omega} = \frac{(3\Omega + 2\Omega)(50V)}{(3\Omega + 2\Omega) + 20\Omega} = 10V$$

$$R_T = 20\Omega + 3\Omega + 3\Omega \parallel 6\Omega = 23\Omega + 2\Omega = 25\Omega$$

$$I_s = I_1 = \frac{50V}{25\Omega} = 2A$$

$$I_{5\Omega} = 0A, \therefore I_2 = \frac{6\Omega(I_s)}{6\Omega + 3\Omega} = \frac{6\Omega(2A)}{6\Omega + 3\Omega} = 1.33A$$

$$V_2 = \frac{(3\Omega \parallel 6\Omega)(50V)}{(3\Omega \parallel 6\Omega) + 20\Omega + 3\Omega} = \frac{2\Omega(50V)}{2\Omega + 23\Omega}$$
$$= 4V$$

Chapter 12

1. Φ : CGS: **5×10^4 Maxwells**, English: **5×10^4 lines**
 B : CGS: **8 Gauss**, English: **51.62 lines/in.²**

2. Φ : SI **6×10^{-4} Wb**, English **60,000 lines**
 B : SI **0.465 T**, CGS **4.65×10^3 Gauss**, English **30,000 lines/in.²**

3. a. $B = \frac{\Phi}{A} = \frac{4 \times 10^{-4} \text{ Wb}}{0.01 \text{ m}^2} = \mathbf{0.04 \text{ T}}$

4. a. $\mathcal{R} = \frac{l}{\mu A} = \frac{0.06 \text{ m}}{\mu 2 \times 10^{-4} \text{ m}^2} = \frac{300}{\mu \text{m}}$

b. $\mathcal{R} = \frac{l}{\mu A} = \frac{0.0762 \text{ m}}{\mu 5 \times 10^{-4} \text{ m}^2} = \frac{152.4}{\mu \text{m}}$

c. $\mathcal{R} = \frac{l}{\mu A} = \frac{0.1 \text{ m}}{\mu 1 \times 10^{-4} \text{ m}^2} = \frac{1000}{\mu \text{m}}$

from the above $\mathcal{R}_{(c)} > \mathcal{R}_{(a)} > \mathcal{R}_{(b)}$

5. $\mathcal{R} = \frac{\mathcal{F}}{\Phi} = \frac{400 \text{ At}}{4.2 \times 10^{-4} \text{ Wb}} = \mathbf{952.4 \times 10^3 \text{ At/Wb}}$

6. $\mathcal{R} = \frac{\mathcal{F}}{\Phi} = \frac{120 \text{ gilberts}}{72,000 \text{ maxwells}} = \mathbf{1.67 \times 10^{-3} \text{ rems (CGS)}}$

7. ~~6 in.~~ $\left[\frac{1 \text{ m}}{39.37 \text{ in.}} \right] = 0.1524 \text{ m}$

$$H = \frac{\mathcal{F}}{l} = \frac{400 \text{ At}}{0.1524 \text{ m}} = \mathbf{2624.67 \text{ At/m}}$$

8. $\mu = \frac{2B}{H} = \frac{2(1200 \times 10^{-4} \text{ T})}{600 \text{ At/m}} = \mathbf{4 \times 10^{-4} \text{ Wb/Am}}$

9. $B = \frac{\Phi}{A} = \frac{10 \times 10^{-4} \text{ Wb}}{3 \times 10^{-3} \text{ m}^2} = 0.33 \text{ T}$

Fig. 12.7: $H \cong 800 \text{ At/m}$

$$NI = Hl \Rightarrow I = Hl/N = (800 \text{ At/m})(0.2 \text{ m})/75 \text{ t} = \mathbf{2.13 \text{ A}}$$

10. $B = \frac{\Phi}{A} = \frac{3 \times 10^{-4} \text{ Wb}}{5 \times 10^{-4} \text{ m}^2} = 0.6 \text{ T}$

Fig. 12.7, $H_{\text{iron}} = 2500 \text{ At/m}$

Fig. 12.8, $H_{\text{steel}} = 70 \text{ At/m}$

$$NI = Hl_{(\text{iron})} + Hl_{(\text{steel})}$$

$$(100 \text{ t})I = (H_{\text{iron}} + H_{\text{steel}})l$$

$$(100 \text{ t})I = (2500 \text{ At/m} + 70 \text{ At/m})0.3 \text{ m}$$

$$I = \frac{771 \text{ A}}{100} = \mathbf{7.71 \text{ A}}$$

11. a. $N_1 I_1 + N_2 I_2 = Hl$

$$B = \frac{\Phi}{A} = \frac{12 \times 10^{-4} \text{ Wb}}{12 \times 10^{-4} \text{ m}^2} = 1 \text{ T}$$

Fig. 12.7: $H \cong 750 \text{ At/m}$

$$N_1(2 \text{ A}) + 30 \text{ At} = (750 \text{ At/m})(0.2 \text{ m})$$

$$N_1 = \mathbf{60 \text{ t}}$$

b. $\mu = \frac{B}{H} = \frac{1 \text{ T}}{750 \text{ At/m}} = \mathbf{13.34 \times 10^{-4} \text{ Wb/Am}}$

12. a. $80,000 \cancel{\text{lines}} \left[\frac{1 \text{ Wb}}{10^8 \cancel{\text{lines}}} \right] = 8 \times 10^4 \times 10^{-8} \text{ Wb} = 8 \times 10^{-4} \text{ Wb}$

$$l_{(\text{cast steel})} = 5.5 \cancel{\text{in.}} \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] = 0.14 \text{ m}$$

$$l_{(\text{sheet steel})} = 0.5 \cancel{\text{in.}} \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] = 0.013 \text{ m}$$

$$\text{Area} = 1 \cancel{\text{in.}^2} \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] \left[\frac{1 \text{ m}}{39.37 \cancel{\text{in.}}} \right] = 6.45 \times 10^{-4} \text{ m}^2$$

$$B = \frac{\Phi}{A} = \frac{8 \times 10^{-4} \text{ Wb}}{6.45 \times 10^{-4} \text{ m}^2} = 1.24 \text{ T}$$

Fig 12.8: $H_{\text{sheet steel}} \cong 460 \text{ At/m}$, Fig. 12.7: $H_{\text{cast steel}} \cong 1275 \text{ At/m}$

$$\begin{aligned} NI &= Hl_{(\text{sheet steel})} + Hl_{(\text{cast iron})} \\ &= (460 \text{ At/m})(0.013 \text{ m}) + (1275 \text{ At/m})(0.14 \text{ m}) \\ &= 5.98 \text{ At} + 178.50 \text{ At} \end{aligned}$$

$$NI = \mathbf{184.48 \text{ At}}$$

b. Cast steel: $\mu = \frac{B}{H} = \frac{1.24 \text{ T}}{1275 \text{ At/m}} = \mathbf{9.73 \times 10^{-4} \text{ Wb/Am}}$

$$\text{Sheet steel: } \mu = \frac{B}{H} = \frac{1.24 \text{ T}}{460 \text{ At/m}} = \mathbf{26.96 \times 10^{-4} \text{ Wb/Am}}$$

$$13. \quad N_1I + N_2 = \frac{Hl}{\text{cast steel}} + \frac{Hl}{\text{cast iron}}$$

$$(20 \text{ t})I + (30 \text{ t})I = "$$

$$(50 \text{ t})I = "$$

$$B = \frac{\Phi}{A} \text{ with } 0.25 \text{ m}^2 \left[\frac{1 \text{ m}}{39.37 \text{ m}} \right] \left[\frac{1 \text{ m}}{39.37 \text{ m}} \right] = 1.6 \times 10^{-4} \text{ m}^2$$

$$B = \frac{0.8 \times 10^{-4} \text{ Wb}}{1.6 \times 10^{-4} \text{ m}^2} = 0.5 \text{ T}$$

Fig. 12.8: $H_{\text{cast steel}} \cong 280 \text{ At/m}$

Fig. 12.7: $H_{\text{cast iron}} \cong 1500 \text{ At/m}$

$$l_{\text{cast steel}} = 5.5 \text{ m} \left[\frac{1 \text{ m}}{39.37 \text{ m}} \right] = 0.14 \text{ m}$$

$$l_{\text{cast iron}} = 2.5 \text{ m} \left[\frac{1 \text{ m}}{39.37 \text{ m}} \right] = 0.064 \text{ m}$$

$$(50 \text{ t})I = (280 \text{ At/m})(0.14 \text{ m}) + (1500 \text{ At/m})(0.064 \text{ m})$$

$$50I = 39.20 + 96.00 = 135.20$$

$$I = \mathbf{2.70 \text{ A}}$$

$$14. \quad \text{a. } l_{ab} = l_{ef} = 0.05 \text{ m}, l_{af} = 0.02 \text{ m}, l_{bc} = l_{de} = 0.0085 \text{ m}$$

$$NI = 2H_{ab}l_{ab} + 2H_{bc}l_{bc} + H_{fa}l_{fa} + H_g l_g$$

$$B = \frac{\Phi}{A} = \frac{2.4 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{ m}^2} = 1.2 \text{ T} \Rightarrow H \cong 360 \text{ At/m (Fig. 12.8)}$$

$$100I = 2(360 \text{ At/m})(0.05 \text{ m}) + 2(360 \text{ At/m})(0.0085 \text{ m}) \\ + (360 \text{ At/m})(0.02 \text{ m}) + 7.97 \times 10^5 (1.2 \text{ T})(0.003 \text{ m}) \\ = 36 \text{ At} + 6.12 \text{ At} + 7.2 \text{ At} + 2869 \text{ At}$$

$$100I = 2918.32 \text{ At}$$

$$I \cong \mathbf{29.18 \text{ A}}$$

b. air gap: metal = 2869 At:49.72 At = **58.17:1**

$$\mu_{\text{sheet steel}} = \frac{B}{H} = \frac{1.2 \text{ T}}{360 \text{ At/m}} = \mathbf{3.33 \times 10^{-3} \text{ Wb/Am}}$$

$$\mu_{\text{air}} = 4\pi \times 10^{-7} \text{ Wb/Am}$$

$$\mu_{\text{sheet steel}} : \mu_{\text{air}} = 3.33 \times 10^{-3} \text{ Wb/Am} : 4\pi \times 10^{-7} \cong \mathbf{2627:1}$$

$$15. \quad 4 \text{ cm} \left[\frac{1 \text{ m}}{100 \text{ cm}} \right] = 0.04 \text{ m}$$

$$f = \frac{1}{2} NI \frac{d\phi}{dx} = \frac{1}{2} (80 \text{ t})(0.9 \text{ A}) \frac{(8 \times 10^{-4} \text{ Wb} - 0.5 \times 10^{-4} \text{ Wb})}{\frac{1}{2}(0.04 \text{ m})} = \frac{36(7.5 \times 10^{-4})}{0.02}$$

$$= \mathbf{1.35 \text{ N}}$$

16. $C = 2\pi r = (6.28)(0.3 \text{ m}) = 1.88 \text{ m}$

$$B = \frac{\Phi}{A} = \frac{2 \times 10^{-4} \text{ Wb}}{1.3 \times 10^{-4} \text{ m}^2} = 1.54 \text{ T}$$

Fig. 12.7: $H_{\text{sheet steel}} \approx 2100 \text{ At/m}$

$$H_g = 7.97 \times 10^5 B_g = (7.97 \times 10^5)(1.54 \text{ T}) = 1.23 \times 10^6 \text{ At/m}$$

$$N_1 I_1 + N_2 I_2 = H_g l_g + H l_{(\text{sheet steel})}$$

$$(200 \text{ t})I_1 + (40 \text{ t})(0.3 \text{ A}) = (1.23 \times 10^6 \text{ At/m})(2 \text{ mm}) + (2100 \text{ At/m})(1.88 \text{ m})$$

$$I_1 = 31.98 \text{ A}$$

17. a. $0.2 \text{ cm} \left[\frac{1 \text{ m}}{100 \text{ cm}} \right] = 2 \times 10^{-3} \text{ m}$

$$A = \frac{\pi d^2}{4} = \frac{(3.14)(0.01 \text{ m})^2}{4} = 0.79 \times 10^{-4} \text{ m}^2$$

$$NI = H_g l_g, H_g = 7.96 \times 10^5 B_g$$

$$(200 \text{ t})I = \left[(7.96 \times 10^5) \left(\frac{0.2 \times 10^{-4} \text{ Wb}}{0.79 \times 10^{-4} \text{ m}^2} \right) \right] 2 \times 10^{-3} \text{ m}$$

$$I = 2.02 \text{ A}$$

b. $B_g = \frac{\Phi}{A} = \frac{2 \times 10^{-4} \text{ Wb}}{0.79 \times 10^{-4} \text{ m}^2} = 0.25 \text{ T}$

$$F \approx \frac{1}{2} \frac{B_g^2 A}{\mu_o} = \frac{1}{2} \frac{(0.25 \text{ T})^2 (0.79 \times 10^{-4} \text{ m}^2)}{4\pi \times 10^{-7}} \\ \approx 2 \text{ N}$$

18.

Table:

Section	$\Phi(\text{Wb})$	$A(\text{m}^2)$	$B(\text{T})$	H	$l(\text{m})$	Hl
a-b, g-h		5×10^{-4}			0.2	
b-c, f-g	2×10^{-4}	5×10^{-4}			0.1	
c-d, e-f	2×10^{-4}	5×10^{-4}			0.099	
a-h		5×10^{-4}			0.2	
b-g		2×10^{-4}			0.2	
d-e	2×10^{-4}	5×10^{-4}			0.002	

$$B_{bc} = B_{cd} = B_g = B_{ef} = B_{fg} = \frac{\Phi}{A} = \frac{2 \times 10^{-4} \text{ Wb}}{5 \times 10^{-4} \text{ m}^2} = 0.4 \text{ T}$$

Air gap: $H_g = 7.97 \times 10^5 (0.4 \text{ T}) = 3.19 \times 10^5 \text{ At/m}$

$$H_{g\ell_g} = (3.19 \times 10^5 \text{ At/m})(2 \text{ mm}) = 638 \text{ At}$$

Fig 12.8: $H_{bc} = H_{cd} = H_{ef} = H_{fg} = 55 \text{ At/m}$

$$H_{bc\ell_{bc}} = H_{fg\ell_{fg}} = (55 \text{ At/m})(0.1 \text{ m}) = 5.5 \text{ At}$$

$$H_{cd\ell_{cd}} = H_{ef\ell_{ef}} = (55 \text{ At/m})(0.099 \text{ m}) = 5.45 \text{ At}$$

For loop 2: $\sum \mathcal{F} = 0$

$$H_{bc\ell_{bc}} + H_{cd\ell_{cd}} + H_{g\ell_g} + H_{e\ell_{ef}} + H_{f\ell_{fg}} - H_{gb\ell_{gb}} = 0$$

$$5.5 \text{ At} + 5.45 \text{ At} + 638 \text{ At} + 5.45 \text{ At} + 5.50 \text{ At} - H_{gb\ell_{gb}} = 0$$

$$H_{gb\ell_{gb}} = 659.90 \text{ At}$$

$$\text{and } H_{gb} = \frac{659.90 \text{ At}}{0.2 \text{ m}} = 3300 \text{ At/m}$$

Fig 12.7: $B_{gb} \cong 1.55 \text{ T}$

$$\text{with } \Phi_2 = B_{gb}A = (1.55 \text{ T})(2 \times 10^{-4} \text{ m}^2) = 3.1 \times 10^{-4} \text{ Wb}$$

$$\Phi_T = \Phi_1 + \Phi_2$$

$$= 2 \times 10^{-4} \text{ Wb} + 3.1 \times 10^{-4} \text{ Wb}$$

$$= 5.1 \times 10^{-4} \text{ Wb} = \Phi_{ab} = \Phi_{ha} = \Phi_{gh}$$

$$B_{ab} = B_{ha} = B_{gh} = \frac{\Phi_T}{A} = \frac{5.1 \times 10^{-4} \text{ Wb}}{5 \times 10^{-4} \text{ m}^2} = 1.02 \text{ T}$$

B-H curve: (Fig 12.8):

$$H_{ab} = H_{ha} = H_{gh} \cong 180 \text{ At/m}$$

$$H_{ab\ell_{ab}} = (180 \text{ At/m})(0.2 \text{ m}) = 36 \text{ At}$$

$$H_{hal_{ha}} = (180 \text{ At/m})(0.2 \text{ m}) = 36 \text{ At}$$

$$H_{gh\ell_{gh}} = (180 \text{ At/m})(0.2 \text{ m}) = 36 \text{ At}$$

which **completes** the table!

Loop #1: $\sum \mathcal{F} = 0$

$$NI = H_{ab\ell_{ab}} + H_{bg\ell_{bg}} + H_{gh\ell_{gh}} + H_{ah\ell_{ah}}$$

$$(200 \text{ t})I = 36 \text{ At} + 659.49 \text{ At} + 36 \text{ At} + 36 \text{ At}$$

$$(200 \text{ t})I = 767.49 \text{ At}$$

$$I \cong \mathbf{3.84 \text{ A}}$$

19. $NI = HI$

$$l = 2\pi r = (6.28)(0.08 \text{ m}) = 0.50 \text{ m}$$

$$(100 \text{ t})(2 \text{ A}) = H(0.50 \text{ m})$$

$$H = 400 \text{ At/m}$$

Fig. 12.8: $B \cong 0.68 \text{ T}$

$$\Phi = BA = (0.68 \text{ T})(0.009 \text{ m}^2)$$

$$\Phi = \mathbf{6.12 \text{ mWb}}$$

20. $NI = H_{ab}(l_{ab} + l_{bc} + l_{de} + l_{ef} + l_{fa}) + H_g l_g$
 $300 \text{ At} = H_{ab}(0.8 \text{ m}) + 7.97 \times 10^5 B_g(0.8 \text{ mm})$
 $300 \text{ At} = H_{ab}(0.8 \text{ m}) + 637.6 B_g$
Assuming $637.6 B_g \gg H_{ab}(0.8 \text{ m})$
then $300 \text{ At} = 637.6 B_g$
and $B_g = 0.47 \text{ T}$
 $\Phi = BA = (0.47 \text{ T})(2 \times 10^{-4} \text{ m}^2) = 0.94 \times 10^{-4} \text{ Wb}$
 $B_{ab} = B_g = 0.47 \text{ T} \Rightarrow H \cong 270 \text{ At/m (Fig. 12.8)}$
 $300 \text{ At} = (270 \text{ At/m})(0.8 \text{ m}) + 637.6(0.47 \text{ T})$
 $300 \text{ At} \neq 515.67 \text{ At}$
∴ Poor approximation!
 $\frac{300 \text{ At}}{515.67 \text{ At}} \times 100\% \cong 58\%$
Reduce Φ to 58%
 $0.58(0.94 \times 10^{-4} \text{ Wb}) = 0.55 \times 10^{-4} \text{ Wb}$
 $B = \frac{\Phi}{A} = \frac{0.55 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{ m}^2} = 0.28 \text{ T} \Rightarrow H \cong 190 \text{ At/m (Fig. 12.8)}$
 $300 \text{ At} = (190 \text{ At/m})(0.8 \text{ m}) + 637.6(0.28 \text{ T})$
 $300 \text{ At} \neq 330.53 \text{ At}$
Reduce Φ another 10% = $0.55 \times 10^{-4} \text{ Wb} - 0.1(0.55 \times 10^{-4} \text{ Wb})$
= $0.495 \times 10^{-4} \text{ Wb}$
 $B = \frac{\Phi}{A} = \frac{0.495 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{ m}^2} = 0.25 \text{ T} \Rightarrow H \cong 175 \text{ At/m (Fig. 12.7)}$
 $300 \text{ At} = (175 \text{ At/m})(0.8) + 637.6(0.25 \text{ T})$
 $300 \text{ At} \neq 318.53 \text{ At but within } 5\% \therefore \text{OK}$
 $\Phi \cong \mathbf{0.55 \times 10^{-4} \text{ Wb}}$
21. a. $1\tau = 0.632 T_{\max}$
 $T_{\max} \cong 1.5 \text{ T for cast steel}$
 $0.632(1.5 \text{ T}) = 0.945 \text{ T}$
At 0.945 T, $H \cong 700 \text{ At/m (Fig. 12.7)}$
 $\therefore B = 1.5 \text{ T} (1 - e^{-H/700 \text{ At/m}})$
- b. $H = 900 \text{ At/m:}$
 $B = 1.5 \text{ T} \left(1 - e^{-\frac{900 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.09 \text{ T}}$
Graph: $\cong \mathbf{1.1 \text{ T}}$
 $H = 1800 \text{ At/m:}$
 $B = 1.5 \text{ T} \left(1 - e^{-\frac{1800 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.39 \text{ T}}$
Graph: $\cong \mathbf{1.38 \text{ T}}$
 $H = 2700 \text{ At/m:}$
 $B = 1.5 \left(1 - e^{-\frac{2700 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.47 \text{ T}}$
Graph: $\cong \mathbf{1.47 \text{ T}}$
Excellent comparison!

$$\begin{aligned}
 \text{c. } B &= 1.5 \text{ T} (1 - e^{-H/700 \text{ At/m}}) = 1.5 \text{ T} - 1.5 \text{ T} e^{-H/700 \text{ At/m}} \\
 B - 1.5 \text{ T} &= -1.5 \text{ T} e^{-H/700 \text{ At/m}} \\
 1.5 - B &= 1.5 \text{ T} e^{-H/700 \text{ At/m}} \\
 \frac{1.5 \text{ T} - B}{1.5 \text{ T}} &= e^{-H/700 \text{ At/m}} \\
 \log_e \left(1 - \frac{B}{1.5 \text{ T}} \right) &= \frac{-H}{700 \text{ At/m}} \\
 \text{and } H &= -700 \log_e \left(1 - \frac{B}{1.5 \text{ T}} \right)
 \end{aligned}$$

d. $B = 1 \text{ T}$:

$$H = -700 \log_e \left(1 - \frac{1 \text{ T}}{1.5 \text{ T}} \right) = \mathbf{769.03 \text{ At/m}}$$

Graph: $\cong \mathbf{750 \text{ At/m}}$

$B = 1.4 \text{ T}$:

$$H = -700 \log_e \left(1 - \frac{1.4 \text{ T}}{1.5 \text{ T}} \right) = \mathbf{1895.64 \text{ At/m}}$$

Graph: $\cong \mathbf{1920 \text{ At/m}}$

$$\begin{aligned}
 \text{e. } H &= -700 \log_e \left(1 - \frac{B}{1.5 \text{ T}} \right) \\
 &= -700 \log_e \left(1 - \frac{0.2 \text{ T}}{1.5 \text{ T}} \right) \\
 &= 100.2 \text{ At/m} \\
 I &= \frac{Hl}{N} = \frac{(100.2 \text{ At/m})(0.16 \text{ m})}{400 \text{ t}} = \mathbf{40.1 \text{ mA}}
 \end{aligned}$$

vs 44 mA for Ex. 12.1

Chapter 13

1. a. **20 mA**
b. 15 ms: **-20 mA**, 20 ms: **0 mA**
c. **40 mA**
d. **20 ms**
e. **2.5 cycles**
2. a. **40 V**
b. 5 μ s: **40 V**, 11 μ s: **-40 V**
c. **80 V**
d. **4 μ s**
e. **3 cycles**
3. a. **8 mV**
b. 3 μ s: **-8 mV**, 9 μ s: **0 mV**
c. **16 mV**
d. **4.5 μ s**
e. $\frac{10 \mu\text{S}}{4.5 \mu\text{S}/\text{cycle}} = \mathbf{2.22 \text{ cycles}}$
4. a. $T = \frac{1}{f} = \frac{1}{25 \text{ Hz}} = \mathbf{40 \text{ ms}}$
b. $T = \frac{1}{f} = \frac{1}{40 \text{ mHz}} = \mathbf{25 \text{ ns}}$
c. $T = \frac{1}{f} = \frac{1}{25 \text{ kHz}} = \mathbf{40 \mu\text{s}}$
d. $T = \frac{1}{f} = \frac{1}{1 \text{ Hz}} = \mathbf{1 \text{ s}}$
5. a. $f = \frac{1}{T} = \frac{0}{\frac{1}{60} \text{ s}} = \mathbf{60 \text{ Hz}}$
b. $f = \frac{1}{T} = \frac{1}{0.01 \text{ s}} = \mathbf{100 \text{ Hz}}$
c. $f = \frac{1}{T} = \frac{1}{40 \text{ ms}} = \mathbf{25 \text{ Hz}}$
d. $f = \frac{1}{T} = \frac{1}{25 \mu\text{s}} = \mathbf{40 \text{ kHz}}$
6. $T = \frac{1}{20 \text{ Hz}} = 0.05 \text{ s}, 5(0.05 \text{ s}) = \mathbf{0.25 \text{ s}}$

7. $T = \frac{24 \text{ ms}}{80 \text{ cycles}} = \mathbf{0.3 \text{ ms}}$

8. $f = \frac{42 \text{ cycles}}{6 \text{ s}} = \mathbf{7 \text{ Hz}}$

9. a. $V_{\text{peak}} = (3 \text{ div.})(50 \text{ mV/div}) = \mathbf{150 \text{ mV}}$

b. $T = (4 \text{ div.})(10 \mu\text{s/div.}) = \mathbf{40 \mu\text{s}}$

c. $f = \frac{1}{T} = \frac{1}{40 \mu\text{s}} = \mathbf{25 \text{ kHz}}$

10. a. Radians = $\left(\frac{\pi}{180^\circ}\right)45^\circ = \frac{\pi}{4} \text{ rad}$

b. Radians = $\left(\frac{\pi}{180^\circ}\right)60^\circ = \frac{\pi}{3} \text{ rad}$

c. Radians = $\left(\frac{\pi}{180^\circ}\right)270^\circ = \mathbf{1.5\pi \text{ rad}}$

d. Radians = $\left(\frac{\pi}{180^\circ}\right)170^\circ = \mathbf{0.94\pi \text{ rad}}$

11. a. Degrees = $\left(\frac{180^\circ}{\pi}\right)\frac{\pi}{4} = \mathbf{45^\circ}$

b. Degrees = $\left(\frac{180^\circ}{\pi}\right)\frac{\pi}{6} = \mathbf{30^\circ}$

c. Degrees = $\left(\frac{180^\circ}{\pi}\right)\frac{1}{10}\pi = \mathbf{18^\circ}$

d. Degrees = $\left(\frac{180^\circ}{\pi}\right)0.6\pi = \mathbf{108^\circ}$

12. a. $\omega = \frac{2\pi}{T} = \frac{2\pi}{2 \text{ s}} = \mathbf{3.14 \text{ rad/s}}$

b. $\omega = \frac{2\pi}{0.3 \times 10^{-3} \text{ s}} = \mathbf{20.94 \times 10^3 \text{ rad/s}}$

c. $\omega = \frac{2\pi}{4 \times 10^{-6} \text{ s}} = \mathbf{1.57 \times 10^6 \text{ rad/s}}$

d. $\omega = \frac{2\pi}{1/25 \text{ s}} = \mathbf{157.1 \text{ rad/s}}$

13. a. $\omega = 2\pi f = 2\pi(50 \text{ Hz}) = \mathbf{314.16 \text{ rad/s}}$

b. $\omega = 2\pi f = 2\pi(600 \text{ Hz}) = \mathbf{3769.91 \text{ rad/s}}$

c. $\omega = 2\pi f = 2\pi(2 \text{ kHz}) = \mathbf{12.56 \times 10^3 \text{ rad/s}}$

d. $\omega = 2\pi f = 2\pi(0.004 \text{ MHz}) = \mathbf{25.13 \times 10^3 \text{ rad/s}}$

14. a. $\omega = 2\pi f = \frac{2\pi}{T} \Rightarrow f = \frac{\omega}{2\pi}$
 $T = \frac{2\pi}{\omega} = \frac{1}{f}$
 $f = \frac{\omega}{2\pi} = \frac{754 \text{ rad/s}}{2\pi} = \mathbf{120 \text{ Hz}, T = 8.33 \text{ ms}}$
- b. $f = \frac{\omega}{2\pi} = \frac{8.4 \text{ rad/s}}{2\pi} = \mathbf{1.34 \text{ Hz}, T = 746.27 \text{ ms}}$
- c. $f = \frac{\omega}{2\pi} = \frac{6000 \text{ rad/s}}{2\pi} = \mathbf{954.93 \text{ Hz}, T = 1.05 \text{ ms}}$
- d. $f = \frac{\omega}{2\pi} = \frac{1/16 \text{ rad/s}}{2\pi} = \mathbf{9.95 \times 10^{-3} \text{ Hz}, T = 100.5 \text{ ms}}$
15. $(45^\circ) \left(\frac{\pi}{180^\circ} \right) = \frac{\pi}{4} \text{ radians}$
 $t = \frac{\theta}{\omega} = \frac{\pi/4 \text{ rad}}{2\pi f} = \frac{\pi/4 \text{ rad}}{2\pi(60 \text{ Hz})} = \frac{1}{(8)(60)} = \frac{1}{480} = \mathbf{2.08 \text{ ms}}$
16. $(30^\circ) \left(\frac{\pi}{180^\circ} \right) = \frac{\pi}{6}, \alpha = \omega t \Rightarrow \omega = \frac{\alpha}{t} = \frac{\pi/6}{5 \times 10^{-3} \text{ s}} = \mathbf{104.7 \text{ rad/s}}$
17. a. Amplitude = 20, $f = \frac{\omega}{2\pi} = \frac{377 \text{ rad/s}}{2\pi} = \mathbf{60 \text{ Hz}}$
b. Amplitude = 5, $f = \frac{\omega}{2\pi} = \frac{754 \text{ rad/s}}{2\pi} = \mathbf{120 \text{ Hz}}$
c. Amplitude = 10^6 , $f = \frac{\omega}{2\pi} = \frac{10,000 \text{ rad/s}}{2\pi} = \mathbf{1591.55 \text{ Hz}}$
d. Amplitude = -6.4, $f = \frac{\omega}{2\pi} = \frac{942 \text{ rad/s}}{2\pi} = \mathbf{149.92 \text{ Hz}}$
18. -
19. -
20. $T = \frac{2\pi}{\omega} = \frac{2\pi}{157} = 40 \text{ ms}, \frac{1}{2} \text{ cycle} = \mathbf{20 \text{ ms}}$
21. $i = 0.5 \sin 72^\circ = 0.5(0.9511) = \mathbf{0.48 \text{ A}}$

22. $1.2\pi \left(\frac{180^\circ}{\pi} \right) = 216^\circ$
 $v = 20 \sin 216^\circ = 20(-0.588) = -11.76 \text{ V}$

23. $6 \times 10^{-3} = 30 \times 10^{-3} \sin \alpha$
 $0.2 = \sin \alpha$
 $\alpha = \sin^{-1} 0.2 = 11.54^\circ \text{ and } 180^\circ - 11.54^\circ = 168.46^\circ$

24. $v = V_m \sin \alpha$ $\frac{30^\circ}{360^\circ} = \frac{1 \text{ ms}}{T}$
 $40 = V_m \sin 30^\circ = V_m (0.5)$ $T = 1 \text{ ms} \left(\frac{360}{30} \right) = 12 \text{ ms}$
 $\therefore V_m = \frac{40}{0.5} = 80 \text{ V}$ $f = \frac{1}{T} = \frac{1}{12 \times 10^{-3} \text{ s}} = 83.33 \text{ Hz}$
 $\omega = 2\pi f = (2\pi)(83.33 \text{ Hz}) = 523.58 \text{ rad/s}$

and $v = 80 \sin 523.58t$

25. —

26. —

27. a. $\omega = 2\pi f = 377 \text{ rad/s}$
 $v = 25 \sin(\omega t + 30^\circ)$

b. $\pi - \frac{2}{3}\pi = \frac{\pi}{3} = 60^\circ, \omega = 2\pi f = 6.28 \times 10^3 \text{ rad/s}$
 $i = 3 \times 10^{-3} \sin(6.28 \times 10^3 t - 60^\circ)$

28. a. $\omega = 2\pi f = 2\pi(40 \text{ Hz}) = 251.33 \text{ rad/s}$
 $v = 0.01 \sin(251.33t - 110^\circ)$

b. $\omega = 2\pi f = 2\pi(10 \text{ kHz}) = 62.83 \times 10^3 \text{ rad/s}, \frac{3}{4}\pi \left(\frac{180^\circ}{\pi} \right) = 135^\circ$
 $i = 2 \times 10^{-3} \sin(62.83 \times 10^3 t + 135^\circ)$

29. v leads i by 10°

30. i leads v by 70°

31. i leads v by 80°

32. $v = 2 \sin(\omega t - \underbrace{30^\circ + 90^\circ}_{+60^\circ})$ in phase
 $i = 5 \sin(\omega t + 60^\circ)$

33. $v = 4 \sin(\omega t + 90^\circ + 90^\circ + 180^\circ = 4 \sin \omega t)$ i leads v by 190°
 $i = \sin(\omega t + 10^\circ + 180^\circ) = \sin(\omega t + 190^\circ)$

34. $T = \frac{1}{f} = \frac{1}{1000 \text{ Hz}} = 1 \text{ ms}$
 $t_1 = \frac{120^\circ}{180^\circ} \left(\frac{T}{2} \right) = \frac{2}{3} \left(\frac{1 \text{ ms}}{2} \right) = \frac{1}{3} \text{ ms}$

35. $\omega = 2\pi f = 50,000 \text{ rad/s}$
 $f = \frac{50,000}{2\pi} = 7957.75 \text{ Hz}$
 $T = \frac{1}{f} = 125.66 \mu\text{s}$
 $t_1 = \frac{40^\circ}{180^\circ} \left(\frac{T}{2} \right) = 0.222(62.83 \mu\text{s}) = \mathbf{13.95 \mu\text{s}}$

36. a. $T = (8 \text{ div.})(1 \text{ ms/div.}) = \mathbf{8 \text{ ms}}$ (both waveforms)

b. $f = \frac{1}{T} = \frac{1}{8 \text{ ms}} = \mathbf{125 \text{ Hz (both)}}$

c. Peak = $(2.5 \text{ div})(0.5 \text{ V/div.}) = 1.25 \text{ V}$
 $V_{\text{rms}} = 0.707(1.25 \text{ V}) = \mathbf{0.884 \text{ V}}$

d. Phase shift = 4.6 div., $T = 8 \text{ div.}$

$$\theta = \frac{4.6 \text{ div.}}{8 \text{ div.}} \times 360^\circ = \mathbf{207^\circ \text{ } i \text{ leads } e}$$

or $e \text{ leads } i \text{ by } 153^\circ$

37. $G = \frac{(6 \text{ V})(1 \text{ s}) + (3 \text{ V})(1 \text{ s}) - (3 \text{ V})(1 \text{ s})}{3 \text{ s}} = \frac{6 \text{ V}}{3} = \mathbf{2 \text{ V}}$

38. $G = \frac{\left[\frac{1}{2}(4 \text{ ms})(20 \text{ mA}) \right] - (2 \text{ ms})(5 \text{ mA})}{8 \text{ ms}} = \frac{40 \text{ mA} - 10 \text{ mA}}{8} = \frac{30 \text{ mA}}{8} = \mathbf{3.87 \text{ mA}}$

39. $G = \frac{2A_m - (5 \text{ mA})(\pi)}{2\pi} = \frac{2(20 \text{ mA}) - (5 \text{ mA})(\pi)}{2\pi} = \frac{40 \text{ mA} - 15.708 \text{ mA}}{2\pi} = \mathbf{3.87 \text{ mA}}$

40. a. $T = (2 \text{ div.})(50 \mu\text{s}) = \mathbf{100 \mu\text{s}}$
b. $f = \frac{1}{T} = \frac{1}{100 \mu\text{s}} = \mathbf{10 \text{ kHz}}$
c. Average = $(-1.5 \text{ div.})(0.2 \text{ V/div.}) = \mathbf{-0.3 \text{ V}}$

41. a. $T = (4 \text{ div.})(10 \mu\text{s/div.}) = \mathbf{40 \mu\text{s}}$

b. $f = \frac{1}{T} = \frac{1}{40 \mu\text{s}} = \mathbf{25 \text{ kHz}}$

c.
$$G = \frac{(2.5 \text{ div.})(1.5 \cancel{\text{div.}}) + (1 \text{ div.})(0.5 \cancel{\text{div.}}) + (1 \text{ div.})(0.6 \cancel{\text{div.}}) + (2.5 \text{ div.})(0.4 \cancel{\text{div.}}) + (1 \text{ div.})(1 \cancel{\text{div.}})}{4 \cancel{\text{div.}}}$$

$$= \frac{3.75 \text{ div.} + 0.5 \text{ div.} + 0.6 \text{ div.} + 1 \text{ div.} + 1 \text{ div.}}{4}$$

$$= \frac{6.85 \text{ div.}}{4} = 1.713 \text{ div.}$$

$$1.713 \cancel{\text{div.}}(10 \text{ mV}/\cancel{\text{div.}}) = \mathbf{17.13 \text{ mV}}$$

42. a. $V_{\text{rms}} = 0.7071(140 \text{ V}) = \mathbf{98.99 \text{ V}}$
 b. $I_{\text{rms}} = 0.7071(6 \text{ mA}) = \mathbf{4.24 \text{ mA}}$
 c. $V_{\text{rms}} = 0.7071(40 \mu\text{V}) = \mathbf{28.28 \mu\text{V}}$

43. a. $v = 14.14 \sin 377t$
 b. $i = 70.7 \times 10^{-3} \sin 377t$
 c. $v = 2.83 \times 10^3 \sin 377t$

44.
$$V_{\text{rms}} = \sqrt{\frac{(2 \text{ V})^2(4 \text{ s}) + (-2 \text{ V})^2(1 \text{ s}) + (3 \text{ V})^2\left(\frac{1}{2} \text{ s}\right)}{12 \text{ s}}} = \mathbf{1.43 \text{ V}}$$

45.
$$V_{\text{rms}} = \sqrt{\frac{(3 \text{ V})^2(2 \text{ s}) + (2 \text{ V})^2(2 \text{ s}) + (1 \text{ V})^2(2 \text{ s}) + (-1 \text{ V})^2(2 \text{ s}) + (-3 \text{ V})^2(2 \text{ s}) + (-2 \text{ V})^2(2 \text{ s})}{12 \text{ s}}} = \mathbf{+2.16 \text{ V}}$$

46.
$$G = \frac{(10 \text{ V})(4 \text{ ms}) - (10 \text{ V})(4 \text{ ms})}{8 \text{ ms}} = \frac{0}{8 \text{ ms}} = \mathbf{0 \text{ V}}$$

$$V_{\text{rms}} = \sqrt{\frac{(10 \text{ V})^2(4 \text{ ms}) + (-10 \text{ V})^2(4 \text{ ms})}{8 \text{ ms}}} = \mathbf{10 \text{ V}}$$

47. a. $T = (4 \text{ div.})(10 \mu\text{s}/\text{div.}) = \mathbf{40 \mu\text{s}}$
 $f = \frac{1}{T} = \frac{1}{40 \mu\text{s}} = \mathbf{25 \text{ kHz}}$
 $\text{Av.} = (1 \text{ div.})(20 \text{ mV}/\text{div.}) = \mathbf{20 \text{ mV}}$
 $\text{Peak} = (2 \text{ div.})(20 \text{ mV}/\text{div.}) = \mathbf{40 \text{ mV}}$

$$\text{rms} = \sqrt{V_0^2 + \frac{V_{\text{max}}^2}{2}} = \sqrt{(20 \text{ mV})^2 + \frac{(40 \text{ mV})^2}{2}} = \mathbf{34.64 \text{ mV}}$$

b. $T = (2 \text{ div.})(50 \mu\text{s}) = 100 \mu\text{s}$

$$f = \frac{1}{T} = \frac{1}{100 \mu\text{s}} = 10 \text{ kHz}$$

$$\text{Av.} = (-1.5 \text{ div.})(0.2 \text{ V/div.}) = -0.3 \text{ V}$$

$$\text{Peak} = (1.5 \text{ div.})(0.2 \text{ V/div.}) = 0.3 \text{ mV}$$

$$\text{rms} = \sqrt{V_0^2 + \frac{V_{\text{max}}^2}{2}} = \sqrt{(0.3 \text{ V})^2 + \frac{(0.3 \text{ V})^2}{2}} = 367.42 \text{ mV}$$

48. a. $V_{dc} = IR = (4 \text{ mA})(2 \text{ k}\Omega) = 8 \text{ V}$

$$\text{Meter indication} = 2.22(8 \text{ V}) = 17.76 \text{ V}$$

b. $V_{\text{rms}} = 0.707(16 \text{ V}) = 11.31 \text{ V}$

Chapter 14

1. —
2. —
3. a. $(377)(10) \cos 377t = \mathbf{3770 \cos 377t}$
b. $(754)(0.6) \cos(754t + 20^\circ) = \mathbf{452.4 \cos(754t + 20^\circ)}$
c. $(\sqrt{2} 20)(157) \cos(157t - 20^\circ) = \mathbf{4440.63 \cos(157t - 20^\circ)}$
d. $(-200)(1) \cos(t + 180^\circ) = -200 \cos(t + 180^\circ) = \mathbf{200 \cos t}$
4. a. $I_m = V_m/R = 150 \text{ V}/5 \Omega = 30 \text{ A}, i = \mathbf{30 \sin 200t}$
b. $I_m = V_m/R = 30 \text{ V}/5 \Omega = 6 \text{ A}, i = \mathbf{6 \sin(377t + 20^\circ)}$
c. $I_m = V_m/R = 40 \text{ V}/5 \Omega = 8 \text{ A}, i = \mathbf{8 \sin(\omega t + 100^\circ)}$
d. $I_m = V_m/R = 80 \text{ V}/5 \Omega = 16 \text{ A}, i = \mathbf{16 \sin(\omega t + 220^\circ)}$
5. a. $V_m = I_m R = (0.1 \text{ A})(7 \times 10^3 \Omega) = 700 \text{ V}$
 $v = \mathbf{700 \sin 1000t}$
b. $V_m = I_m R = (2 \times 10^{-3} \text{ A})(7 \times 10^3 \Omega) = 14.8 \text{ V}$
 $v = \mathbf{14.8 \sin(400t - 120^\circ)}$
c. $i = 6 \times 10^{-6} \sin(\omega t - 2^\circ + 90^\circ) = 6 \times 10^{-6} \sin(\omega t + 88^\circ)$
 $V_m = I_m R = (6 \times 10^{-6} \text{ A})(7 \times 10^3 \Omega) = 42 \times 10^{-3} \text{ V}$
 $v = \mathbf{42 \times 10^{-3} \sin(\omega t + 88^\circ)}$
d. $i = 0.004 \sin(\omega t + 90^\circ + 90^\circ + 180^\circ) = 0.004 \sin(\omega t + 360^\circ) = 0.0004 \sin \omega t$
 $V_m = I_m R = (4 \times 10^{-3} \text{ A})(7 \times 10^3 \Omega) = 28 \text{ V}$
 $v = \mathbf{28 \sin \omega t}$
6. a. $\mathbf{0 \Omega}$
b. $X_L = 2\pi f L = 2\pi L f = (6.28)(2 \text{ H})f = 12.56f = 12.56(10 \text{ Hz}) = \mathbf{125.6 \Omega}$
c. $X_L = 12.56f = 12.56(60 \text{ Hz}) = \mathbf{753.6 \Omega}$
d. $X_L = 12.56f = 12.56(2000 \text{ Hz}) = \mathbf{25.13 \text{ k}\Omega}$
e. $X_L = 12.56f = 12.56(10^5 \text{ Hz}) = \mathbf{1.256 \text{ M}\Omega}$

7. a. $L = \frac{X_L}{2\pi f} = \frac{20 \Omega}{2\pi(2 \text{ Hz})} = \mathbf{1.59 \text{ H}}$

b. $L = \frac{X_L}{2\pi f} = \frac{1000 \Omega}{2\pi(60 \text{ Hz})} = \mathbf{2.65 \text{ H}}$

c. $L = \frac{X_L}{2\pi f} = \frac{5280 \Omega}{2\pi(500 \text{ Hz})} = \mathbf{1.68 \text{ H}}$

8. a. $X_L = 2\pi fL \Rightarrow f = \frac{X_L}{2\pi L} = \frac{X_L}{(6.28)(10 \text{ H})} = \frac{X_L}{62.8}$
 $f = \frac{100 \Omega}{62.8} = \mathbf{1.59 \text{ Hz}}$

b. $f = \frac{X_L}{62.8} = \frac{3770 \Omega}{62.8} = \mathbf{60.03 \text{ Hz}}$

c. $f = \frac{X_L}{62.8} = \frac{15,700 \Omega}{62.8} = \mathbf{250 \text{ Hz}}$

d. $f = \frac{X_L}{62.8} = \frac{243 \Omega}{62.8} = \mathbf{3.87 \text{ Hz}}$

9. a. $V_m = I_m X_L = (5 \text{ A})(20 \Omega) = 100 \text{ V}$
 $v = \mathbf{100 \sin(\omega t + 90^\circ)}$

b. $V_m = I_m X_L = (40 \times 10^{-3} \text{ A})(20 \Omega) = 0.8 \text{ V}$
 $v = \mathbf{0.8 \sin(\omega t + 150^\circ)}$

c. $i = 6 \sin(\omega t + 150^\circ)$, $V_m = I_m X_L = (6 \text{ A})(20 \Omega) = 120 \text{ V}$
 $v = 120 \sin(\omega t + 240^\circ) = \mathbf{120 \sin(\omega t - 120^\circ)}$

d. $i = 3 \sin(\omega t + 100^\circ)$, $V_m = I_m X_L = (3 \text{ A})(20 \Omega) = 60 \text{ V}$
 $v = \mathbf{60 \sin(\omega t + 190^\circ)}$

10. a. $X_L = \omega L = (100 \text{ rad/s})(0.1 \text{ H}) = 10 \Omega$
 $V_m = I_m X_L = (10 \text{ A})(10 \Omega) = 100 \text{ V}$
 $v = \mathbf{100 \sin(100t + 90^\circ)}$

b. $X_L = \omega L = (377 \text{ rad/s})(0.1 \text{ H}) = 37.7 \Omega$
 $V_m = I_m X_L = (6 \times 10^{-3} \text{ A})(37.7 \Omega) = 226.2 \text{ mV}$
 $v = \mathbf{226.2 \times 10^{-3} \sin(377t + 90^\circ)}$

c. $X_L = \omega L = (400 \text{ rad/s})(0.1 \text{ H}) = 40 \Omega$
 $V_m = I_m X_L = (5 \times 10^{-6} \text{ A})(40 \Omega) = 200 \mu\text{V}$
 $v = \mathbf{200 \times 10^{-6} \sin(400t + 110^\circ)}$

- d. $i = 4 \sin(20t + 200^\circ)$
 $X_L = \omega L = (20 \text{ rad/s})(0.1 \text{ H}) = 2 \Omega$
 $V_m = I_m X_L = (4 \text{ A})(2 \Omega) = 8 \text{ V}$
 $v = 8 \sin(20t + 290^\circ) = \mathbf{8 \sin(20t - 70^\circ)}$
11. a. $I_m = \frac{V_m}{X_L} = \frac{120 \text{ V}}{50 \Omega} = 2.4 \text{ A}, i = \mathbf{2.4 \sin(\omega t - 90^\circ)}$
- b. $I_m = \frac{V_m}{X_L} = \frac{30 \text{ V}}{50 \Omega} = 0.6 \text{ A}, i = \mathbf{0.6 \sin(\omega t - 70^\circ)}$
- c. $v = 40 \sin(\omega t + 100^\circ)$
 $I_m = \frac{V_m}{X_L} = \frac{40 \text{ V}}{50 \Omega} = 0.8 \text{ A}, i = \mathbf{0.8 \sin(\omega t + 10^\circ)}$
- d. $v = 80 \sin(377t + 220^\circ)$
 $I_m = \frac{V_m}{X_L} = \frac{80 \text{ V}}{50 \Omega} = 1.6 \text{ A}, i = \mathbf{1.6 \sin(377t + 130^\circ)}$
12. a. $X_L = \omega L = (60 \text{ rad/s})(0.2 \text{ H}) = 12 \Omega$
 $I_m = V_m/X_L = 1.5 \text{ V}/12 \Omega = 0.125 \text{ A}$
 $i = \mathbf{0.125 \sin(60t - 90^\circ)}$
- b. $X_L = \omega L = (10 \text{ rad/s})(0.2 \text{ H}) = 2 \Omega$
 $I_m = V_m/X_L = 16 \text{ mV}/2 \Omega = 8 \text{ mA}$
 $i = 8 \times 10^{-3} \sin(t + 2^\circ - 90^\circ) = \mathbf{8 \times 10^{-3} \sin(t - 88^\circ)}$
- c. $v = 4.8 \sin(0.05t + 230^\circ)$
 $X_L = \omega L = (0.05 \text{ rad/s})(0.2 \text{ H}) = 0.01 \Omega$
 $I_m = V_m/X_L = 4.8 \text{ V}/0.01 \Omega = 480 \text{ A}$
 $i = 480 \sin(0.05t + 230^\circ - 90^\circ) = \mathbf{480 \sin(0.05t + 140^\circ)}$
- d. $v = 9 \times 10^{-3} \sin(377t + 90^\circ)$
 $X_L = \omega L = (377 \text{ rad/s})(0.2 \text{ H}) = 75.4 \Omega$
 $I_m = V_m/X_L = 9 \text{ mV}/75.4 \Omega = 0.119 \text{ mA}$
 $i = \mathbf{0.119 \times 10^{-3} \sin 377t}$
13. a. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(0 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \infty \Omega$
- b. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(60 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{530.79 \Omega}$
- c. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(120 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{265.39 \Omega}$

d. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(2 \text{ kHz})(5 \times 10^{-6} \text{ F})} = \mathbf{15.92 \Omega}$

e. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(2 \times 10^6 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{62.83 \Omega}$

14. a. $C = \frac{1}{2\pi fX_C} = \frac{1}{6.28(60 \text{ Hz})(250 \Omega)} = \mathbf{10.62 \mu F}$

b. $C = \frac{1}{2\pi fX_C} = \frac{1}{6.28(312 \text{ Hz})(55 \Omega)} = \mathbf{9.28 \mu F}$

c. $C = \frac{1}{2\pi fX_C} = \frac{1}{6.28(25 \text{ Hz})(10 \Omega)} = \mathbf{636.94 \mu F}$

15. a. $f = \frac{1}{2\pi CX_C} = \frac{1}{2\pi(50 \times 10^{-6} \text{ F})(100 \Omega)} = \mathbf{31.83 \text{ Hz}}$

b. $f = \frac{1}{2\pi CX_C} = \frac{1}{2\pi(50 \times 10^{-6} \text{ F})(684 \Omega)} = \mathbf{4.66 \text{ Hz}}$

c. $f = \frac{1}{2\pi CX_C} = \frac{1}{2\pi(50 \times 10^{-6} \text{ F})(342 \Omega)} = \mathbf{9.31 \text{ Hz}}$

d. $f = \frac{1}{2\pi CX_C} = \frac{1}{2\pi(50 \times 10^{-6} \text{ F})(2000 \Omega)} = \mathbf{1.59 \text{ Hz}}$

16. a. $I_m = V_m/X_C = 120 \text{ V}/2.5 \Omega = 48 \text{ A}$
 $i = \mathbf{48 \sin(\omega t + 90^\circ)}$

b. $I_m = V_m/X_C = 0.4 \text{ V}/2.5 \Omega = 0.16 \text{ A}$
 $i = \mathbf{0.16 \sin(\omega t + 110^\circ)}$

c. $v = 8 \sin(\omega t + 100^\circ)$
 $I_m = V_m/X_C = 8 \text{ V}/2.5 \Omega = 3.2 \text{ A}$
 $i = \mathbf{3.2 \sin(\omega t + 190^\circ)}$

d. $v = -70 \sin(\omega t + 40^\circ) = 70 \sin(\omega t + 220^\circ)$
 $I_m = V_m/X_C = 70 \text{ V}/2.5 \Omega = 28 \text{ A}$
 $i = 28 \sin(\omega t + 310^\circ) = \mathbf{28 \sin(\omega t - 50^\circ)}$

17. a. $v = 30 \sin 200t, X_C = \frac{1}{\omega C} = \frac{1}{(200)(1 \times 10^{-6})} = 5 \text{ k}\Omega$
 $I_m = \frac{V_m}{X_C} = \frac{30 \text{ V}}{5 \text{ k}\Omega} = 6 \text{ mA}, i = 6 \times 10^{-3} \sin(200t + 90^\circ)$
- b. $v = 60 \times 10^{-3} \sin 377t, X_C = \frac{1}{\omega C} = \frac{1}{(377)(1 \times 10^{-6})} = 2.65 \text{ k}\Omega$
 $I_m = \frac{V_m}{X_C} = \frac{60 \times 10^{-3} \text{ V}}{2,650 \Omega} = 22.64 \mu\text{A}, i = 22.64 \times 10^{-6} \sin(377t + 90^\circ)$
- c. $v = 120 \sin(374t + 210^\circ), X_C = \frac{1}{\omega C} = \frac{1}{(374)(1 \times 10^{-6})} = 2.67 \text{ k}\Omega$
 $I_m = \frac{V_m}{X_C} = \frac{120 \text{ V}}{2,670 \Omega} = 44.94 \text{ mA}, i = 44.94 \times 10^{-3} \sin(374t + 300^\circ)$
- d. $v = 70 \sin(800t + 70^\circ), X_C = \frac{1}{\omega C} = \frac{1}{(800)(1 \times 10^{-6})} = 1.25 \text{ k}\Omega$
 $I_m = \frac{V_m}{X_C} = \frac{70 \text{ V}}{1250 \Omega} = 56 \text{ mA}, i = 56 \times 10^{-3} \sin(\omega t + 160^\circ)$
18. a. $V_m = I_m X_C = (50 \times 10^{-3} \text{ A})(10 \Omega) = 0.5 \text{ V}$
 $v = 0.5 \sin(\omega t - 90^\circ)$
- b. $V_m = I_m X_C = (2 \times 10^{-6})(10 \Omega) = 20 \mu\text{V}$
 $v = 20 \times 10^{-6} \sin(\omega t - 30^\circ)$
- c. $i = -6 \sin(\omega t - 30^\circ) = 6 \sin(\omega t + 150^\circ)$
 $V_m = I_m X_C = (6 \text{ A})(10 \Omega) = 60 \text{ V}$
 $v = 60 \sin(\omega t + 60^\circ)$
- d. $i = 3 \sin(\omega t + 100^\circ)$
 $V_m = I_m X_C = (3 \text{ A})(10 \Omega) = 30 \text{ V}$
 $v = 30 \sin(\omega t + 10^\circ)$
19. a. $i = 0.2 \sin 300t, X_C = \frac{1}{\omega C} = \frac{1}{(300)(0.5 \times 10^{-6})} = 6.67 \text{ k}\Omega$
 $V_m = I_m X_C = (0.2 \text{ A})(6,670 \Omega) = 1334 \text{ V}, v = 1334 \sin(300t - 90^\circ)$
- b. $i = 8 \times 10^{-3} \sin 377t, X_C = \frac{1}{\omega C} = \frac{1}{(377)(0.5 \times 10^{-6})} = 5.31 \text{ k}\Omega$
 $V_m = I_m X_C = (8 \times 10^{-3} \text{ A})(5.31 \times 10^3 \Omega) = 42.48 \text{ V}$
 $v = 42.48 \sin(377t - 90^\circ)$

c. $i = 60 \times 10^{-3} \sin(754t + 90^\circ)$, $X_C = \frac{1}{\omega C} = \frac{1}{(754)(0.5 \times 10^{-6})} = 2.65 \text{ k}\Omega$

$$V_m = I_m X_C = (60 \times 10^{-3} \text{ A})(2.65 \times 10^3 \Omega) = 159 \text{ V}$$

$$v = 159 \sin 754t$$

d. $i = 80 \times 10^{-3} \sin(1600t - 80^\circ)$, $X_C = \frac{1}{\omega C} = \frac{1}{(1600)(0.5 \times 10^{-6})} = 1.25 \text{ k}\Omega$

$$V_m = I_m X_C = (80 \times 10^{-3} \text{ A})(1.25 \times 10^3 \Omega) = 100 \text{ V}$$

$$v = 100 \sin(1600t - 170^\circ)$$

20. a. v leads i by $90^\circ \Rightarrow L, X_L = V_m/I_m = 550 \text{ V}/11 \text{ A} = 50 \Omega$

$$L = \frac{X_L}{\omega} = \frac{50 \Omega}{377 \text{ rad/s}} = 132.63 \text{ mH}$$

b. v leads i by $90^\circ \Rightarrow L, X_L = V_m/I_m = 36 \text{ V}/4 \text{ A} = 9 \Omega$

$$L = \frac{1}{\omega X_L} = \frac{1}{(754 \text{ rad/s})(9 \Omega)} = 147.36 \mu\text{H}$$

c. v and i are in phase $\Rightarrow R$

$$R = \frac{V_m}{I_m} = \frac{10.5 \text{ V}}{1.5 \text{ A}} = 7 \Omega$$

21. a. $i = 5 \sin(\omega t + 90^\circ)$
 $v = 2000 \sin \omega t$ } i leads v by $90^\circ \Rightarrow C$

$$X_C = \frac{V_m}{I_m} = \frac{2000 \text{ V}}{5 \text{ A}} = 400 \Omega$$

b. $i = 2 \sin(157t + 60^\circ)$
 $v = 80 \sin(157t + 150^\circ)$ } v leads i by $90^\circ \Rightarrow L$

$$X_L = \frac{V_m}{I_m} = \frac{80 \text{ V}}{2 \text{ A}} = 40 \Omega, L = \frac{X_L}{\omega} = \frac{40 \Omega}{157 \text{ rad/s}} = 254.78 \text{ mH}$$

c. $v = 35 \sin(\omega t - 20^\circ)$
 $i = 7 \sin(\omega t - 20^\circ)$ } in phase $\Rightarrow R$

$$R = \frac{V_m}{I_m} = \frac{35 \text{ V}}{7 \text{ A}} = 5 \Omega$$

22. —

23. —

24. $X_C = \frac{1}{2\pi fC} = R \Rightarrow f = \frac{1}{2\pi RC} = \frac{1}{2\pi(2 \times 10^3 \Omega)(1 \times 10^{-6} F)} = \frac{1}{12.56 \times 10^{-3}}$
 $\approx \mathbf{79.62 \text{ Hz}}$

25. $X_L = 2\pi fL = R$
 $L = \frac{R}{2\pi f} = \frac{10,000 \Omega}{2\pi(5 \times 10^3 \text{ Hz})} = \mathbf{318.47 \text{ mH}}$

26. $X_C = X_L$
 $\frac{1}{2\pi fC} = 2\pi fL$
 $f^2 = \frac{1}{4\pi^2 LC}$
and $f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(10 \times 10^{-3} \text{ H})(1 \times 10^{-6} \text{ F})}} = \mathbf{1.59 \text{ kHz}}$

27. $X_C = X_L$
 $\frac{1}{2\pi fC} = 2\pi fL \Rightarrow C = \frac{1}{4\pi^2 f^2 L} = \frac{1}{4(9.86)(2500 \times 10^6)(2 \times 10^{-3})} = \mathbf{5.07 \text{ nF}}$

28. a. $P = \frac{V_m I_m}{2} \cos \theta = \frac{(550 \text{ V})(11 \text{ A})}{2} \cos 90^\circ = ()(0) = \mathbf{0 \text{ W}}$
b. $P = \frac{V_m I_m}{2} \cos \theta = \frac{(36 \text{ V})(4 \text{ A})}{2} \cos 90^\circ = ()(0) = \mathbf{0 \text{ W}}$

c. $P = \frac{V_m I_m}{2} \cos \theta = \frac{(10.5 \text{ V})(1.5 \text{ A})}{2} \cos 0^\circ = \mathbf{7.88 \text{ W}}$

29. a. $P = \frac{V_m I_m}{2} \cos \theta = \frac{(5 \text{ A})(2000 \text{ V})}{2} \cos 90^\circ = \mathbf{0 \text{ W}}$

b. $\cos \theta = 0 \Rightarrow \mathbf{0 \text{ W}}$
c. $P = \frac{(35 \text{ V})(7 \text{ A})}{2} \cos 0^\circ = \mathbf{122.5 \text{ W}}$

30. a. $P = \frac{(60 \text{ V})(15 \text{ A})}{2} \cos 30^\circ = \mathbf{389.7 \text{ W}}, F_p = \mathbf{0.866}$
b. $P = \frac{(50 \text{ V})(2 \text{ A})}{2} \cos 0^\circ = \mathbf{50 \text{ W}}, F_p = \mathbf{1.0}$

c. $P = \frac{(50 \text{ V})(3 \text{ A})}{2} \cos 10^\circ = \mathbf{73.86 \text{ W}}, F_p = \mathbf{0.985}$

d. $P = \frac{(75 \text{ V})(0.08 \text{ A})}{2} \cos 40^\circ = \mathbf{2.30 \text{ W}}, F_p = \mathbf{0.766}$

31. $R = \frac{V_m}{I_m} = \frac{48 \text{ V}}{8 \text{ A}} = 6 \Omega, P = I^2 R = \left(\frac{8 \text{ A}}{\sqrt{2}}\right)^2 6 \Omega = \mathbf{192 \text{ W}}$

$$P = \frac{V_m I_m}{2} \cos \theta = \frac{(48 \text{ V})(8 \text{ A})}{2} \cos 0^\circ = \mathbf{192 \text{ W}}$$

$$P = VI \cos \theta = \left(\frac{48 \text{ V}}{\sqrt{2}}\right) \left(\frac{8 \text{ A}}{\sqrt{2}}\right) \cos 0^\circ = \mathbf{192 \text{ W}}$$

All the same!

32. $P = 100 \text{ W}: F_p = \cos \theta = P/VI = 100 \text{ W}/(150 \text{ V})(2 \text{ A}) = \mathbf{0.333}$

$P = 0 \text{ W}: F_p = \cos \theta = \mathbf{0}$

$P = 300 \text{ W}: F_p = \frac{300}{300} = \mathbf{1}$

33. $P = \frac{V_m I_m}{2} \cos \theta$

$$500 \text{ W} = \frac{(50 \text{ V})I_m}{2} (0.5) \Rightarrow I_m = 40 \text{ A}$$

$$i = \mathbf{40 \sin(\omega t - 50^\circ)}$$

34. a. $I_m = E_m/R = 30 \text{ V}/6.8 \Omega = 4.41 \text{ A}, i = \mathbf{4.41 \sin(377t + 20^\circ)}$

b. $P = I^2 R = \left(\frac{4.41 \text{ A}}{\sqrt{2}}\right)^2 3 \Omega = \mathbf{29.18 \text{ W}}$

c. $T = \frac{2\pi}{\omega} = \frac{6.28}{377 \text{ rad/s}} = \mathbf{16.67 \text{ ms}}$

$$6(16.67 \text{ ms}) = 100.02 \text{ ms} \cong \mathbf{0.1 \text{ s}}$$

35. a. $I_m = \frac{V_m}{X_L} = \frac{100 \text{ V}}{25 \Omega} = 4 \text{ A}, i = \mathbf{4 \sin(314t - 30^\circ)}$

b. $L = \frac{X_L}{\omega} = \frac{25 \Omega}{314 \text{ rad/s}} = \mathbf{79.62 \text{ mH}}$

c. $L \Rightarrow \mathbf{0 \text{ W}}$

36. a. $E_m = I_m X_C = (30 \times 10^{-3} \text{ A})(2.4 \text{ k}\Omega) = 72 \text{ V}$
 $e = 72 \sin(377t - 20^\circ - 90^\circ) = 72 \sin(377t - 110^\circ)$

b. $C = \frac{1}{\omega X_C} = \frac{1}{(377 \text{ rad/s})(2.4 \text{ k}\Omega)} = 1.11 \mu\text{F}$

c. $P = 0 \text{ W}$

37. a. $X_{C_1} = \frac{1}{2\pi f C_1} = \frac{1}{\omega C_1} = \frac{1}{(10^4 \text{ rad/s})(2 \mu\text{F})} = 50 \Omega$

$$X_{C_2} = \frac{1}{\omega C_2} = \frac{1}{(10^4)(10 \mu\text{F})} = 10 \Omega$$

$$\mathbf{E} = 100 \text{ V} \angle 60^\circ \quad \mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_{C_1}} = \frac{120 \text{ V} \angle 60^\circ}{50 \Omega \angle -90^\circ} = 2.4 \text{ A} \angle 150^\circ$$

$$\mathbf{I}_2 = \frac{\mathbf{E}}{\mathbf{Z}_{C_2}} = \frac{120 \text{ V} \angle 60^\circ}{10 \Omega \angle -90^\circ} = 12 \text{ A} \angle 150^\circ$$

$$i_1 = \sqrt{2} 2.4 \sin(10^4 t + 150^\circ) = 3.39 \sin(10^4 t + 150^\circ)$$

$$i_2 = \sqrt{2} 12 \sin(10^4 t + 150^\circ) = 16.97 \sin(10^4 t + 150^\circ)$$

b. $\mathbf{I}_s = \mathbf{I}_1 + \mathbf{I}_2 = 2.4 \text{ A} \angle 150^\circ + 12 \text{ A} \angle 150^\circ = 14.4 \text{ A} \angle 150^\circ$
 $i_s = \sqrt{2} 14.4 \sin(10^4 t + 150^\circ) = 20.36 \sin(10^4 t + 150^\circ)$

38. a. $L_1 \parallel L_2 = 60 \text{ mH} \parallel 120 \text{ mH} = 40 \text{ mH}$

$$X_{L_T} = 2\pi f L_T = 2\pi(10^3 \text{ Hz})(40 \text{ mH}) = 251.33 \Omega$$

$$V_m = I_m X_{L_T} = (\sqrt{2} 24 \text{ A})(251.33 \Omega) = \sqrt{2} 6.03 \text{ kV}$$

$$\text{and } v_s = \sqrt{2} 6.03 \text{ kV} \sin(10^3 t + 30^\circ + 90^\circ)$$

$$\text{or } v_s = 8.53 \times 10^3 \sin(10^3 t + 120^\circ)$$

b. $I_{m1} = \frac{V_m}{X_{L_1}}, \quad X_{L_1} = 2\pi f L_1 = 2\pi(10^3 \text{ Hz})(60 \text{ mH}) = 376.99 \Omega$

$$I_{m1} = \frac{8.53 \times 10^3}{376.99 \Omega} = 22.63 \text{ A}$$

$$\text{and } i_1 = 22.63 \sin(10^3 t + 30^\circ)$$

$$X_{L_2} = 2\pi f L_2 = 2\pi(10^3 \text{ Hz})(120 \text{ mH}) = 753.98 \Omega$$

$$I_{m2} = \frac{8.53 \times 10^3}{753.98 \Omega} = 11.31 \text{ A}$$

$$\text{and } i_2 = 11.31 \sin(10^3 t + 30^\circ)$$

39. a. $5.0 \angle 36.87^\circ$ b. $2.83 \angle 45^\circ$
 c. $17.09 \angle 69.44^\circ$ d. $1.0 \times 10^3 \angle 84.29^\circ$
 e. $1077.03 \angle 21.80^\circ$ f. $6.58 \times 10^{-3} \angle 81.25^\circ$
 g. $11.78 \angle -49.82^\circ$ h. $8.94 \angle -153.43^\circ$
 i. $61.85 \angle -104.04^\circ$ j. $101.73 \angle -39.94^\circ$
 k. $4,326.66 \angle 123.69^\circ$ l. $25.5 \times 10^{-3} \angle -78.69^\circ$
40. a. $5.196 + j3.0$ b. $6.946 + j39.39$
 c. $2530.95 + j6953.73$ d. $3.96 \times 10^{-4} + j5.57 \times 10^{-5}$
 e. $j0.04$ f. $6.91 \times 10^{-3} + j6.22 \times 10^{-3}$
 g. $-56.29 + j32.50$ h. $-0.85 + j0.85$
 i. $-469.85 - j171.01$ j. $5177.04 - j3625.0$
 k. $-4.31 - j6.16$ l. $-6.93 \times 10^{-3} - j4.00 \times 10^{-3}$
41. a. $15.03 \angle 86.19$ b. $60.21 \angle 4.76^\circ$
 c. $0.30 \angle 88.09^\circ$ d. $223.61 \angle -63.43^\circ$
 e. $86.18 \angle 93.73^\circ$ f. $38.69 \angle -94.0^\circ$
42. a. $12.95 + j1.13$ b. $8.37 + j159.78$
 c. $7.00 \times 10^{-6} + j2.44 \times 10^{-7}$ d. $-8.69 + j0.46$
 e. $75.82 - j5.30$ f. $-34.51 - j394.49$
43. a. $11.8 + j7.0$ b. $151.90 + j49.90$
 c. $4.72 \times 10^{-6} + j71$ d. $5.20 + j1.60$
 e. $209.30 + j311.0$ f. $-21.20 + j12.0$
 g. $6 \angle 20^\circ + 8 \angle 80^\circ = (5.64 + j2.05) + (1.39 + j7.88) = 7.03 + j9.93$
 h. $(29.698 + j29.698) + (31.0 + j53.69) - (-35 + j60.62) = 95.7 + j22.77$
44. a. $-12.0 + j34.0$ b. $86.80 + j312.40$
 c. $56. \times 10^{-3} - j8 \times 10^{-3}$ d. $698.00 \angle -114^\circ$
 e. $8.00 \angle 20^\circ$ f. $49.68 \angle -64.0^\circ$
 g. $40 \times 10^{-3} \angle 40^\circ$ h. $-16,740 \angle 160^\circ$

45. a. $6.0 \angle -50^\circ$
 b. $200 \times 10^{-6} \angle 60^\circ$
 c. $109 \angle -170.0^\circ$
 d. $76.47 \angle -80^\circ$
 e. $4 \angle 0^\circ$
 f. $5.93 \angle -134.47^\circ$
 g. $(0.05 + j0.25)/(8 - j60) = 0.255 \angle 78.69^\circ / 60.53 \angle -82.41^\circ = 4.21 \times 10^{-3} \angle 161.10^\circ$
 h. $9.30 \angle -43.99^\circ$

46. a. $\frac{10 - j5}{1 + j0} = 10.0 - j5.0$
 b. $\frac{8 \angle 60^\circ}{102 + j400} = \frac{8 \angle 60^\circ}{412.80 \angle 75.69^\circ} = 19.38 \times 10^{-3} \angle -15.69^\circ$
 c. $\frac{(6 \angle 20^\circ)(120 \angle -40^\circ)(8.54 \angle 69.44^\circ)}{2 \angle -30^\circ} = \frac{6.15 \times 10^3 \angle 49.44^\circ}{2 \angle -30^\circ} = 3.07 \times 10^3 \angle 79.44^\circ$
 d. $\frac{(0.16 \angle 120^\circ)(300 \angle 40^\circ)}{9.487 \angle 71.565^\circ} = \frac{48 \angle 160^\circ}{9.487 \angle 71.565^\circ} = 5.06 \angle 88.44^\circ$

e.
$$\left(\frac{1}{4 \times 10^{-4} \angle 20^\circ} \right) \left(\frac{8}{j(j^2)} \right) \left(\frac{1}{36 - j30} \right)$$

$$(2500 \angle -20^\circ) \left(\frac{8}{-j} \right) \left(\frac{1}{46.861 \angle -39.81^\circ} \right)$$

$$(2500 \angle -20^\circ)(8j)(0.0213 \angle 39.81^\circ) = 426 \angle 109.81^\circ$$

47. a. $x + j4 + 3x + jy - j7 = 16$
 $(x + 3x) + j(4 + y - 7) = 16 + j0$
 $x + 3x = 16 \quad 4 + y - 7 = 0$
 $4x = 16 \quad y = +7 - 4$
 $x = 4 \quad y = 3$

b. $(10 \angle 20^\circ)(x \angle -60^\circ) = 30.64 - j25.72$
 $10x \angle -40^\circ = 40 \angle -40^\circ$
 $10x = 40$
 $x = 4$

$$\begin{array}{r}
 \text{c. } \frac{5x + j10}{2 - jy} \\
 \hline
 10x + j20 - j5xy - j^2 10y = 90 - j70 \\
 (10x + 10y) + j(20 - 5xy) = 90 - j70 \\
 10x + 10y = 90 \\
 x + y = 9 \\
 x = 9 - y \Rightarrow
 \end{array}
 \quad
 \begin{array}{l}
 20 - 5xy = -70 \\
 20 - 5(9 - y)y = -70 \\
 5y(9 - y) = 90 \\
 y^2 - 9y + 18 = 0 \\
 y = \frac{-(-9) \pm \sqrt{(-9)^2 - 4(1)(18)}}{2} \\
 y = \frac{9 \pm 3}{2} = 6, 3
 \end{array}$$

For $y = 6, x = 3$

$y = 3, x = 6$

($x = 3, y = 6$) or ($x = 6, y = 3$)

$$\begin{array}{l}
 \text{d. } \frac{80 \angle 0^\circ}{40 \angle \theta} = 4 \angle -\theta = 3.464 - j2 = 4 \angle -30^\circ \\
 \theta = 30^\circ
 \end{array}$$

- | | | |
|-----|--|--|
| 48. | a. 160.0 $\angle 30^\circ$ | b. 25×10^{-3} $\angle -40^\circ$ |
| | c. 70.71 $\angle -90^\circ$ | d. 14.14 $\angle 0^\circ$ |
| | e. 4.24×10^{-6} $\angle 90^\circ$ | f. 2.55×10^{-6} $\angle 70^\circ$ |
| 49. | a. 56.57 sin(377t + 20°) | b. 169.68 sin (377t + 10°) |
| | c. 11.31×10^{-3} $\sin(377t + 120^\circ)$ | d. 7.07 sin(377t + 90°) |
| | e. 1696.8 sin(377t - 50°) | f. 6000 sin(377t - 180°) |

50. (Using peak values)

$$\begin{aligned}
 e_{in} = v_a + v_b &\Rightarrow v_a = e_{in} - v_b \\
 &= 60 \text{ V} \angle 20^\circ - 20 \text{ V} \angle -20^\circ \\
 &= 46.49 \text{ V} \angle 36.05^\circ
 \end{aligned}$$

and $e_{in} = 46.49 \sin (377t + 36.05^\circ)$

51. $i_s = i_1 + i_2 \Rightarrow i_1 = i_s - i_2$
 (Using peak values) $= (20 \times 10^{-6} \text{ A} \angle 60^\circ) - (6 \times 10^{-6} \text{ A} \angle -30^\circ) = 20.88 \times 10^{-6} \text{ A} \angle 76.70^\circ$
 $i_1 = \mathbf{20.88 \times 10^{-6}}$ sin ($\omega t + 76.70^\circ$)

52. $e = v_a + v_b + v_c$
 $= 60 \text{ V} \angle 30^\circ + 30 \text{ V} \angle 60^\circ + 40 \text{ V} \angle 120^\circ$
 $= 102.07 \text{ V} \angle 62.61^\circ$
 and $e = \mathbf{102.07}$ sin ($\omega t + 62.61^\circ$)

53. (Using effective values)

$$\begin{aligned}\mathbf{I}_s &= \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3 = 4.24 \text{ mA} \angle 180^\circ + 5.66 \text{ mA} \angle -180^\circ + 11.31 \text{ mA} \angle -180^\circ \\ &= -4.24 \text{ mA} - 5.66 \text{ mA} - 11.31 \text{ mA} \\ &= 21.21 \times 10^{-3} \sin(377t + 180^\circ) \\ i_s &= \mathbf{-21.21 \times 10^{-3} \sin 377t}$$

Chapter 15

1. a. $R \angle 0^\circ = 6.8 \Omega \angle 0^\circ = 6.8 \Omega$

b. $X_L = \omega L = (377 \text{ rads/s})(1.2 \text{ H}) = 452.4 \Omega$
 $X_L \angle 90^\circ = 452.4 \Omega \angle 90^\circ = +j452.4 \Omega$

c. $X_L = 2\pi fL = (6.28)(50 \text{ Hz})(0.05 \text{ H}) = 15.7 \Omega$
 $X_L \angle 90^\circ = 15.7 \Omega \angle 90^\circ = +j15.7 \Omega$

d. $X_C = \frac{1}{\omega C} = \frac{1}{(100 \text{ rad/s})(10 \times 10^{-6} \text{ F})} = 1 \text{ k}\Omega$
 $X_C \angle -90^\circ = 1 \text{ k}\Omega \angle -90^\circ = -j1 \text{ k}\Omega$

e. $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10 \times 10^3 \text{ Hz})(0.05 \times 10^{-6} \text{ F})} = 318.47 \Omega$
 $X_C \angle -90^\circ = 318.47 \Omega \angle -90^\circ = -j318.47 \Omega$

f. $R \angle 0^\circ = 220 \Omega \angle 0^\circ = 220 \Omega$

2. a. $\mathbf{V} = 10.61 \text{ V} \angle 10^\circ, \mathbf{I} = \frac{V \angle \theta}{R \angle 0^\circ} = \frac{10.61 \text{ V} \angle 10^\circ}{3 \Omega \angle 0^\circ} = 3.54 \text{ A} \angle 10^\circ$
 $i = 5 \sin(\omega t + 10^\circ)$

b. $\mathbf{V} = 39.60 \text{ V} \angle 10^\circ, \mathbf{I} = \frac{V \angle \theta}{X_L \angle 90^\circ} = \frac{39.60 \text{ V} \angle 10^\circ}{7 \Omega \angle 90^\circ} = 5.66 \text{ A} \angle -80^\circ$
 $i = 8 \sin(\omega t - 80^\circ)$

c. $\mathbf{V} = 17.68 \text{ V} \angle -20^\circ, \mathbf{I} = \frac{V \angle \theta}{X_C \angle -90^\circ} = \frac{17.68 \text{ V} \angle -20^\circ}{100 \Omega \angle -90^\circ} = 0.1768 \text{ A} \angle 70^\circ$
 $i = 0.25 \sin(\omega t + 70^\circ)$

d. $\mathbf{V} = 2.828 \text{ mV} \angle -120^\circ, \mathbf{I} = \frac{V \angle \theta}{R \angle 0^\circ} = \frac{2.828 \text{ mV} \angle -120^\circ}{5.1 \text{ k}\Omega \angle 0^\circ} = 0.555 \mu\text{A} \angle -120^\circ$
 $i = 0.785 \times 10^{-6} \sin(\omega t - 120^\circ)$

e. $\mathbf{V} = 11.312 \text{ V} \angle 60^\circ, \mathbf{I} = \frac{V \angle \theta}{X_L \angle 90^\circ} = \frac{11.312 \text{ V} \angle 60^\circ}{(377 \text{ rad/s})(0.2 \text{ H} \angle 90^\circ)} = 150.03 \text{ mA} \angle -30^\circ$
 $i = 106.09 \times 10^{-3} \sin(377t - 30^\circ)$

f. $\mathbf{V} = 84.84 \text{ V} \angle 0^\circ, X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(5 \text{ kHz})(2 \mu\text{F})} = 15.924 \Omega$
 $\mathbf{I} = \frac{V \angle \theta}{X_C \angle -90^\circ} = \frac{84.84 \text{ V} \angle 0^\circ}{15.924 \Omega \angle -90^\circ} = 5.328 \text{ A} \angle 90^\circ$
 $i = 7.534 \sin(\omega t + 90^\circ)$

3. a. $\mathbf{I} = (0.707)(4 \text{ mA} \angle 0^\circ) = 2.828 \text{ mA} \angle 0^\circ$
 $\mathbf{V} = (I \angle 0^\circ)(R \angle 0^\circ) = 2.828 \text{ mA} \angle 0^\circ(22 \Omega \angle 0^\circ) = 62.216 \text{ mV} \angle 0^\circ$
 $v = 88 \times 10^{-3} \sin \omega t$
- b. $\mathbf{I} = (0.707)(1.5 \text{ A} \angle 60^\circ) = 1.061 \text{ A} \angle 60^\circ$
 $X_L = \omega L = (1000 \text{ rad/s})(0.016 \text{ H}) = 16 \Omega$
 $\mathbf{V} = (I \angle \theta)(X_L \angle 90^\circ) = (1.061 \text{ A} \angle 60^\circ)(16 \Omega \angle 90^\circ) = 16.98 \text{ V} \angle 150^\circ$
 $v = 16.98 \sin(1000t + 150^\circ)$
- c. $\mathbf{I} = (0.707)(2 \text{ mA} \angle 40^\circ) = 1.414 \text{ mA} \angle 40^\circ$
 $X_C = \frac{1}{\omega C} = \frac{1}{(157 \text{ rad/s})(0.05 \times 10^{-6} \text{ F})} = 127.39 \text{ k}\Omega$
 $\mathbf{V} = (I \angle \theta)(X_C \angle -90^\circ) = 1.414 \text{ mA} \angle 40^\circ(127.39 \text{ k}\Omega \angle -90^\circ) = 180.13 \text{ V} \angle -50^\circ$
 $V_p = \sqrt{2}(180.13 \text{ V}) = 254.7 \text{ V}$
and $v = 254.7 \sin(157t - 50^\circ)$
4. a. $\mathbf{Z}_T = 6.8 \Omega + j8.2 \Omega = 10.65 \Omega \angle 50.33^\circ$
- b. $\mathbf{Z}_T = 2 \Omega - j6 \Omega + 10 \Omega = 12 \Omega - j6 \Omega = 13.42 \Omega \angle -26.57^\circ$
- c. $\mathbf{Z}_T = 1 \text{ k}\Omega + j3 \text{ k}\Omega + 4 \text{ k}\Omega + j7 \text{ k}\Omega = 5 \text{ k}\Omega + j10 \text{ k}\Omega = 11.18 \text{ k}\Omega \angle 63.44^\circ$
5. a. $\mathbf{Z}_T = 3 \Omega + j4 \Omega - j5 \Omega = 3 \Omega - j1 \Omega = 3.16 \Omega \angle -18.43^\circ$
- b. $\mathbf{Z}_T = 1 \text{ k}\Omega + j8 \text{ k}\Omega - j4 \text{ k}\Omega = 1 \text{ k}\Omega + j4 \text{ k}\Omega = 4.12 \text{ k}\Omega \angle 75.96^\circ$
- c. $L_T = 240 \text{ mH}$
 $X_L = \omega L = 2\pi fL = 2\pi(10^3 \text{ Hz})(240 \times 10^{-3} \text{ H}) = 1.51 \text{ k}\Omega$
 $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10^3 \text{ Hz})(0.1 \times 10^{-6} \text{ F})} = 1.59 \text{ k}\Omega$
 $= 470 \Omega + j1.51 \text{ k}\Omega - j1.59 \text{ k}\Omega$
 $= 470 \Omega - j80 \Omega = 476.76 \Omega \angle -9.66^\circ$
6. a. $\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120 \text{ V} \angle 0^\circ}{60 \text{ A} \angle 70^\circ} = 2 \Omega \angle -70^\circ = 0.684 \Omega - j1.879 \Omega = R - jX_C$
- b. $\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{80 \text{ V} \angle 320^\circ}{20 \text{ mA} \angle 40^\circ} = 4 \text{ k}\Omega \angle 280^\circ = 4 \text{ k}\Omega \angle -80^\circ = 0.695 \text{ k}\Omega - j3.939 \Omega$
 $= R - jX_C$
- c. $\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{8 \text{ kV} \angle 0^\circ}{0.2 \text{ A} \angle -60^\circ} = 40 \text{ k}\Omega \angle 60^\circ = 20 \text{ k}\Omega + j34.64 \text{ k}\Omega = R + jX_L$

7. a. $\mathbf{Z}_T = 8 \Omega + j6 \Omega = \mathbf{10} \Omega \angle 36.87^\circ$
- c. $\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 100 \text{ V} \angle 0^\circ / 10 \Omega \angle 36.87^\circ = \mathbf{10} \text{ A} \angle -36.87^\circ$
 $\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (10 \text{ A} \angle -36.87^\circ)(8 \Omega \angle 0^\circ) = \mathbf{80} \text{ V} \angle -36.87^\circ$
 $\mathbf{V}_L = (I \angle \theta)(X_L \angle 90^\circ) = (10 \text{ A} \angle -36.87^\circ)(6 \Omega \angle 90^\circ) = \mathbf{60} \text{ V} \angle 53.13^\circ$
- f. $P = I^2 R = (10 \text{ A})^2 8 \Omega = \mathbf{800} \text{ W}$
- g. $F_p = \cos \theta_T = R/Z_T = 8 \Omega / 10 \Omega = \mathbf{0.8 \text{ lagging}}$
- h. $v_R = 113.12 \sin(\omega t - 36.87^\circ)$
 $v_L = 84.84 \sin(\omega t + 53.13^\circ)$
 $i = 14.14 \sin(\omega t - 36.87^\circ)$
8. a. $\mathbf{Z}_T = 6 \Omega - j30 \Omega = \mathbf{30.59} \Omega \angle -78.69^\circ$
- c. $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{120 \text{ V} \angle 20^\circ}{30.59 \Omega \angle -78.69^\circ} = \mathbf{3.92} \text{ A} \angle 98.69^\circ$
- $\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (3.92 \text{ A} \angle 98.69^\circ)(6 \Omega \angle 0^\circ) = \mathbf{23.52} \text{ V} \angle 98.69^\circ$
 $\mathbf{V}_C = (I \angle \theta)(X_C \angle -90^\circ) = (3.92 \text{ A} \angle 98.69^\circ)(30 \Omega \angle -90^\circ) = \mathbf{117.60} \text{ V} \angle 8.69^\circ$
- f. $P = I^2 R = (3.92 \text{ A})^2 6 \Omega = \mathbf{92.2} \text{ W}$
- g. $F_p = R/Z_T = 6 \Omega / 30.59 \Omega = \mathbf{0.196 \text{ leading}}$
- h. $i = 5.54 \sin(377t + 98.69^\circ)$
 $v_R = 33.26 \sin(377t + 98.69^\circ)$
 $v_C = 166.29 \sin(377t + 8.69^\circ)$
9. a. $X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(10^3 \text{ Hz})(0.2 \times 10^{-6} \text{ F})} = 795.77 \Omega$
- $\mathbf{Z}_T = 2.2 \text{ k}\Omega - j795.77 \Omega = \mathbf{2.34 \text{ k}\Omega} \angle -19.89^\circ$
- b. $\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 14.14 \text{ V} \angle 0^\circ / 2.34 \text{ k}\Omega \angle -19.89^\circ = \mathbf{6.04 \text{ mA}} \angle 19.89^\circ$
- c. $\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (6.04 \text{ mA} \angle 19.89^\circ)(2.2 \times 10^3 \Omega \angle 0^\circ) = \mathbf{13.29 \text{ V}} \angle 19.89^\circ$
 $\mathbf{V}_C = (I \angle \theta)(X_C \angle -90^\circ) = (6.04 \text{ mA} \angle 19.89^\circ)(795.77 \Omega \angle -90^\circ) = \mathbf{4.81 \text{ V}} \angle -70.11^\circ$
- d. $P = I^2 R = (6.04 \text{ mA})^2 2.2 \text{ k}\Omega = \mathbf{80.26 \text{ mW}}$
 $F_p = \cos \theta_T = \cos 19.89^\circ = \mathbf{0.94 \text{ leading}}$

10. a. $\mathbf{Z}_T = 4 \Omega + j6 \Omega - j10 \Omega = 4 \Omega - j4 \Omega = \mathbf{5.66 \Omega \angle -45^\circ}$

c. $X_L = \omega L \Rightarrow L = \frac{X_L}{\omega} = \frac{6 \Omega}{377 \text{ rad/s}} = \mathbf{16 \text{ mH}}$

$$X_C = \frac{1}{\omega C} \Rightarrow C = \frac{1}{\omega X_C} = \frac{1}{(377 \text{ rad/s})(10 \Omega)} = \mathbf{265 \mu F}$$

d. $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50 \text{ V} \angle 0^\circ}{5.66 \Omega \angle -45^\circ} = \mathbf{8.83 \text{ A} \angle 45^\circ}$

$$\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (8.83 \text{ A} \angle 45^\circ)(4 \Omega \angle 0^\circ) = \mathbf{35.32 \text{ V} \angle 45^\circ}$$

$$\mathbf{V}_L = (I \angle \theta)(X_L \angle 90^\circ) = (8.83 \text{ A} \angle 45^\circ)(6 \Omega \angle 90^\circ) = \mathbf{52.98 \text{ V} \angle 135^\circ}$$

$$\mathbf{V}_C = (I \angle \theta)(X_C \angle -90^\circ) = (8.83 \text{ A} \angle 45^\circ)(10 \Omega \angle -90^\circ) = \mathbf{88.30 \text{ V} \angle -45^\circ}$$

f. $\mathbf{E} = \mathbf{V}_R + \mathbf{V}_L + \mathbf{V}_C$

$$50 \text{ V} \angle 0^\circ = 35.32 \text{ V} \angle 45^\circ + 52.98 \text{ V} \angle 135^\circ + 88.30 \text{ V} \angle -45^\circ$$

$$50 \text{ V} \angle 0^\circ = 49.95 \text{ V} \angle 0^\circ \cong 50 \text{ V} \angle 0^\circ$$

g. $P = I^2 R = (8.83 \text{ A})^2 4 \Omega = \mathbf{311.88 \text{ W}}$

h. $F_p = \cos \theta_T = \frac{R}{Z_T} = 4 \Omega / 5.66 \Omega = \mathbf{0.707 \text{ leading}}$

i. $i = 12.49 \sin(377t + 45^\circ)$

$$e = 70.7 \sin 377t$$

$$v_R = 49.94 \sin(377t + 45^\circ)$$

$$v_L = 74.91 \sin(377t + 135^\circ)$$

$$v_C = 124.86 \sin(377t - 45^\circ)$$

11. a. $\mathbf{Z}_T = 1.8 \text{ k}\Omega + j2 \text{ k}\Omega - j0.6 \text{ k}\Omega = \mathbf{1.8 \text{ k}\Omega + j1.2 \text{ k}\Omega = 2.16 \text{ k}\Omega \angle 33.69^\circ}$

c. $X_C = \frac{1}{\omega C} \Rightarrow C = \frac{1}{\omega X_C} = \frac{1}{(314 \text{ rad/s})(0.6 \text{ k}\Omega)} = \mathbf{5.31 \mu F}$

$$X_L = \omega L \Rightarrow L = \frac{X_L}{\omega} = \frac{2 \times 10^3 \Omega}{314 \text{ rad/s}} = \mathbf{6.37 \text{ H}}$$

d. $\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 4.242 \text{ V} \angle 60^\circ / 2.16 \text{ k}\Omega \angle 33.69^\circ = \mathbf{1.96 \text{ mA} \angle 26.31^\circ}$

$$\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (1.96 \text{ mA} \angle 26.31^\circ)(1.8 \text{ k}\Omega \angle 0^\circ) = \mathbf{3.53 \text{ V} \angle 26.31^\circ}$$

$$\mathbf{V}_L = (I \angle \theta)(X_L \angle 90^\circ) = (1.96 \text{ mA} \angle 26.31^\circ)(2 \text{ k}\Omega \angle 90^\circ) = \mathbf{2.68 \text{ V} \angle 116.31^\circ}$$

$$\mathbf{V}_C = (I \angle \theta)(X_C \angle -90^\circ) = (1.96 \text{ mA} \angle 26.31^\circ)(0.6 \text{ k}\Omega \angle -90^\circ) = \mathbf{1.18 \text{ V} \angle -63.69^\circ}$$

g. $P = I^2 R = (1.96 \text{ mA})^2 1.8 \text{ k}\Omega = \mathbf{6.91 \text{ mW}}$

h. $F_p = \cos \theta_T = \cos 33.69^\circ = \mathbf{0.832 \text{ lagging}}$

i. $i = 2.77 \times 10^{-3} \sin(\omega t + 26.31^\circ)$

$$v_R = 4.99 \sin(\omega t + 26.31^\circ)$$

$$v_L = 3.79 \sin(\omega t + 116.31^\circ)$$

$$v_C = 1.67 \sin(\omega t - 63.69^\circ)$$

12. $V_{80\Omega}(\text{rms}) = 0.7071 \left(\frac{45.27 \text{ V}}{2} \right) = 16 \text{ V}$

$$V_{\text{scope}} = \frac{80\Omega (20 \text{ V})}{80\Omega + R} = 16 \text{ V}$$

$$1600 = 1280 + 16 R$$

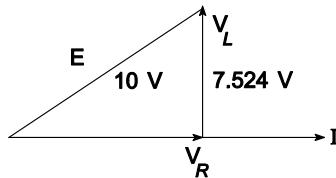
$$R = \frac{320}{16} = 20 \Omega$$

13. a. $V_L(\text{rms}) = 0.7071 \left(\frac{21.28 \text{ V}}{2} \right) = 7.524 \text{ V}$

$$X_L = \frac{V_L}{I_L} = \frac{7.524 \text{ V}}{29.94 \text{ mA}} = 251.303 \Omega$$

$$X_L = 2\pi f L \Rightarrow L = \frac{X_L}{2\pi f} = \frac{251.303 \Omega}{2\pi(1 \text{ kHz})} = 39.996 \text{ mH} \cong 40 \text{ mH}$$

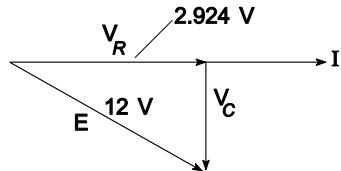
b.



$$\begin{aligned} E^2 &= V_R^2 + V_L^2 \\ V_R &= \sqrt{E^2 - V_L^2} \\ &= \sqrt{(100 \text{ V}) - (56.611)} = \sqrt{43.389} = 6.587 \text{ V} \end{aligned}$$

$$R = \frac{V_R}{I_R} = \frac{6.587 \text{ V}}{29.94 \text{ mA}} = 220 \Omega$$

14. $V_R(\text{rms}) = 0.7071 \left(\frac{8.27 \text{ V}}{2} \right) = 2.924 \text{ V}$



$$\begin{aligned} V_C &= \sqrt{E^2 - V_R^2} \\ &= \sqrt{144 - 8.55} = \sqrt{135.45} = 11.638 \text{ V} \end{aligned}$$

$$I_C = I_R = \frac{2.924 \text{ V}}{10 \text{ k}\Omega} = 292.4 \mu\text{A}$$

$$X_C = \frac{V_C}{I_C} = \frac{11.638 \text{ V}}{292.4 \mu\text{A}} = 39.802 \text{ k}\Omega$$

$$X_C = \frac{1}{2\pi f C} \Rightarrow C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(40 \text{ kHz})(39.802 \text{ k}\Omega)} = 99.967 \text{ pF} \cong 100 \text{ pF}$$

15. a. $\mathbf{V}_1 = \frac{(2 \text{ k}\Omega \angle 0^\circ)(120 \text{ V} \angle 60^\circ)}{2 \text{ k}\Omega + j8 \text{ k}\Omega} = \frac{240 \text{ V} \angle 60^\circ}{8.25 \angle 75.96^\circ} = \mathbf{29.09 \text{ V} \angle -15.96^\circ}$

$$\mathbf{V}_2 = \frac{(8 \text{ k}\Omega \angle 90^\circ)(120 \text{ V} \angle 60^\circ)}{8.25 \text{ k}\Omega \angle 75.96^\circ} = \mathbf{116.36 \text{ V} \angle 74.04^\circ}$$

b. $\mathbf{V}_1 = \frac{(40 \Omega \angle 90^\circ)(60 \text{ V} \angle 5^\circ)}{6.8 \Omega + j40 \Omega + 22 \Omega} = \frac{2400 \text{ V} \angle 95^\circ}{28.8 + j40} = \mathbf{48.69 \text{ V} \angle 40.75^\circ}$

$$\mathbf{V}_2 = \frac{(22 \Omega \angle 0^\circ)(60 \text{ V} \angle 5^\circ)}{49.29 \Omega \angle 54.25^\circ} = \frac{1.32 \text{ kV} \angle 5^\circ}{49.29 \Omega \angle 54.25^\circ} = \mathbf{26.78 \text{ V} \angle -49.25^\circ}$$

16. a. $\mathbf{V}_1 = \frac{(20 \Omega \angle 90^\circ)(20 \text{ V} \angle 70^\circ)}{20 \Omega + j20 \Omega - j40 \Omega} = \mathbf{14.14 \text{ V} \angle -155^\circ}$

$$\mathbf{V}_2 = \frac{(40 \Omega \angle -90^\circ)(20 \text{ V} \angle 70^\circ)}{28.28 \Omega \angle -45^\circ} = \mathbf{28.29 \text{ V} \angle 25^\circ}$$

b. $\mathbf{Z}_T = 4.7 \text{ k}\Omega + j30 \text{ k}\Omega + 3.3 \text{ k}\Omega - j10 \text{ k}\Omega = 8 \text{ k}\Omega + j20 \text{ k}\Omega = 21.541 \text{ k}\Omega \angle 68.199^\circ$

$$\mathbf{Z}'_T = 3.3 \text{ k}\Omega + j30 \text{ k}\Omega - j10 \text{ k}\Omega = 3.3 \text{ k}\Omega + j20 \text{ k}\Omega = 20.27 \text{ k}\Omega \angle 80.631^\circ$$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'_T \mathbf{E}}{\mathbf{Z}_T} = \frac{(20.27 \text{ k}\Omega \angle 80.631^\circ)(120 \text{ V} \angle 0^\circ)}{21.541 \text{ k}\Omega \angle 68.199^\circ} = \mathbf{112.92 \text{ V} \angle 12.432^\circ}$$

$$\mathbf{V}_2 = \frac{\mathbf{Z}''_T \mathbf{E}}{\mathbf{Z}_T} \quad \mathbf{Z}''_T = 3.3 \text{ k}\Omega - j10 \text{ k}\Omega = 10.53 \text{ k}\Omega \angle -71.737^\circ$$

$$= \frac{(10.53 \text{ k}\Omega \angle -71.737^\circ)(120 \text{ V} \angle 0^\circ)}{21.541 \text{ k}\Omega \angle 68.199^\circ} = \mathbf{58.66 \text{ V} \angle -139.94^\circ}$$

17. a. $X_L = \omega L = (377 \text{ rad/s})(0.4 \text{ H}) = 150.8 \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(4 \mu\text{F})} = 663 \Omega$$

$$\mathbf{Z}_T = 30 \Omega + j150.8 \Omega - j663 \Omega = 30 \Omega - j512.2 \Omega = \mathbf{513.08 \Omega \angle -86.65^\circ}$$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{20 \text{ V} \angle 40^\circ}{513.08 \Omega \angle -86.65^\circ} = \mathbf{39 \text{ mA} \angle 126.65^\circ}$$

$$\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (39 \text{ mA} \angle 126.65^\circ)(30 \Omega \angle 0^\circ) = \mathbf{1.17 \text{ V} \angle 126.65^\circ}$$

$$\mathbf{V}_C = (39 \text{ mA} \angle 126.65^\circ)(0.663 \text{ k}\Omega \angle -90^\circ) = \mathbf{25.86 \text{ V} \angle 36.65^\circ}$$

b. $\cos \theta_T = \frac{R}{Z_T} = \frac{30 \Omega}{513.08 \Omega} = \mathbf{0.058 \text{ leading}}$

c. $P = I^2 R = (39 \text{ mA})^2 30 \Omega = \mathbf{45.63 \text{ mW}}$

f. $\mathbf{V}_R = \frac{(30 \Omega \angle 0^\circ)(20 \text{ V} \angle 40^\circ)}{\mathbf{Z}_T} = \frac{600 \text{ V} \angle 40^\circ}{513.08 \Omega \angle -86.65^\circ} = \mathbf{1.17 \text{ V} \angle 126.65^\circ}$

$$\mathbf{V}_C = \frac{(0.663 \text{ k}\Omega \angle -90^\circ)(20 \text{ V} \angle 40^\circ)}{513.08 \Omega \angle -86.65^\circ} = \mathbf{25.84 \text{ V} \angle 36.65^\circ}$$

g. $\mathbf{Z}_T = 30 \Omega - j512.2 \Omega = R - jX_C$

18. a. $X_L = \omega L = (377 \text{ rad/s})(0.4 \text{ H}) = 150.8 \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(220 \times 10^{-6} \text{ F})} = 12.06 \Omega$$

$$\begin{aligned}\mathbf{Z}_T &= 30 \Omega + j150.8 \Omega - j12.06 \Omega \\ &= 30 \Omega + j138.74 \Omega = 141.95 \Omega \angle 77.80^\circ\end{aligned}$$

$$\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 20 \text{ V} \angle 40^\circ / 141.95 \Omega \angle 77.80^\circ = 140.89 \text{ mA} \angle -37.80^\circ$$

$$\mathbf{V}_R = (I \angle \theta)(R \angle 0^\circ) = (140.89 \text{ mA} \angle -37.80^\circ)(30 \Omega \angle 0^\circ) = 4.23 \text{ V} \angle -37.80^\circ$$

$$\begin{aligned}\mathbf{V}_C &= (I \angle \theta)(X_C \angle -90^\circ) = (140.89 \text{ mA} \angle -37.80^\circ)(12.06 \Omega \angle -90^\circ) \\ &= 1.70 \text{ V} \angle -127.80^\circ\end{aligned}$$

b. $F_p = \cos \theta_T = R/Z_T = 30 \Omega / 141.95 \Omega = 0.211 \text{ lagging}$

c. $P = I^2 R = (140.89 \text{ mA})^2 30 \Omega = 595.50 \text{ mW}$

f. $\mathbf{V}_R = \frac{(30 \Omega \angle 0^\circ)(20 \text{ V} \angle 40^\circ)}{141.95 \Omega \angle 77.80^\circ} = 4.23 \text{ V} \angle -37.80^\circ$

$$\mathbf{V}_C = \frac{(12.06 \Omega \angle -90^\circ)(20 \text{ V} \angle 40^\circ)}{141.95 \Omega \angle 77.80^\circ} = 1.70 \text{ V} \angle -127.80^\circ$$

g. $\mathbf{Z}_T = 30 \Omega + j138.74 \Omega = R + jX_L$

19. $P = VI \cos \theta \Rightarrow 8000 \text{ W} = (200 \text{ V})(I)(0.8)$

$$I = \frac{8000 \text{ A}}{160} = 50 \text{ A}$$

$$0.8 = \cos \theta$$

$$\theta = 36.87^\circ$$

$$\mathbf{V} = 200 \text{ V} \angle 0^\circ, \mathbf{I} = 50 \text{ A} \angle -36.87^\circ$$

$$\mathbf{Z}_T = \frac{\mathbf{V}}{\mathbf{I}} = \frac{200 \text{ V} \angle 0^\circ}{50 \text{ A} \angle -36.87^\circ} = 4 \Omega \angle 36.87^\circ = 3.2 \Omega + j2.4 \Omega$$

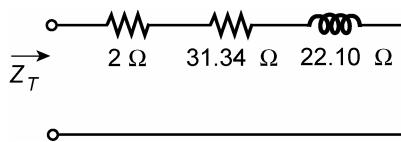
20. $P = VI \cos \theta \Rightarrow 300 \text{ W} = (120 \text{ V})(3 \text{ A}) \cos \theta$

$$\cos \theta = 0.833 \Rightarrow \theta = 33.59^\circ$$

$$\mathbf{V} = 120 \text{ V} \angle 0^\circ, \mathbf{I} = 3 \text{ A} \angle -33.59^\circ$$

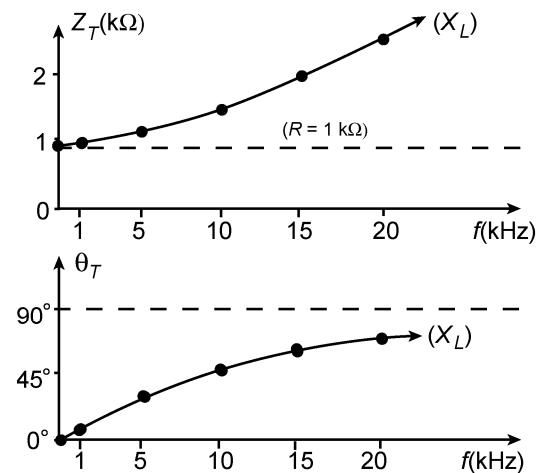
$$\mathbf{Z}_T = \frac{\mathbf{V}}{\mathbf{I}} = \frac{120 \text{ V} \angle 0^\circ}{3 \text{ A} \angle -33.59^\circ} = 40 \Omega \angle 33.59^\circ = 33.34 \Omega + j22.10 \Omega$$

$$R_T = 33.34 \Omega = 2 \Omega + R \Rightarrow R = 31.34 \Omega$$



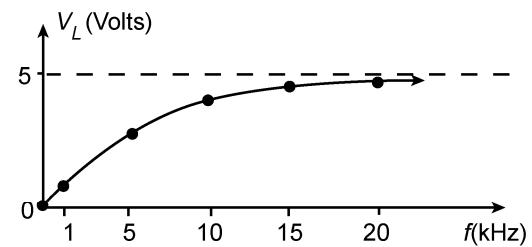
21. a. $Z_T = \sqrt{R^2 + X_L^2} \angle \tan^{-1} X_L/R$

f	Z_T	θ_T
0 Hz	1.0 k Ω	0.0°
1 kHz	1.008 k Ω	7.16°
5 kHz	1.181 k Ω	32.14°
10 kHz	1.606 k Ω	51.49°
15 kHz	2.134 k Ω	62.05°
20 kHz	2.705 k Ω	68.3°



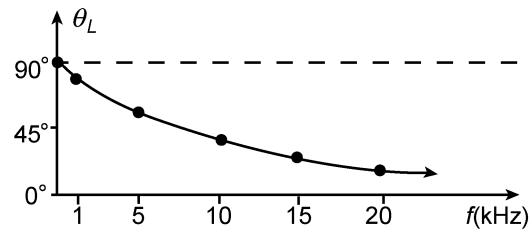
b. $V_L = \frac{X_L E}{Z_T}$

f	V_L
0 Hz	0.0 V
1 kHz	0.623 V
5 kHz	2.66 V
10 kHz	3.888 V
15 kHz	4.416 V
20 kHz	4.646 V



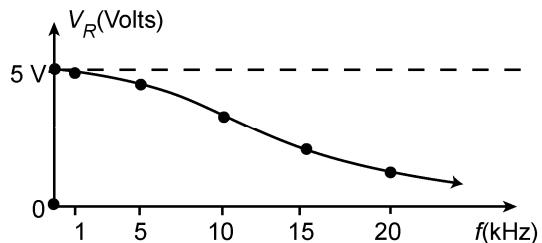
c.

f	$\theta_L = 90^\circ - \tan^{-1} X_L/R$
0 Hz	90.0°
1 kHz	82.84°
5 kHz	57.85°
10 kHz	38.5°
15 kHz	27.96°
20 kHz	21.7°



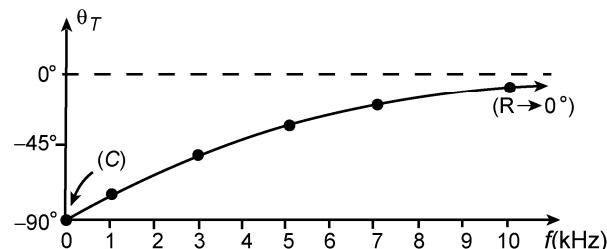
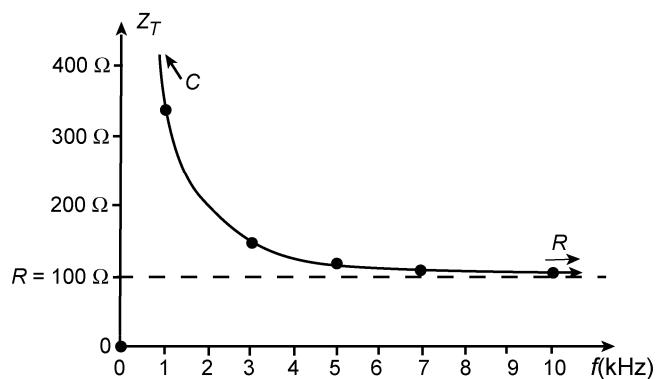
d.

f	$V_R = RE/Z_T$
0 Hz	5.0 V
1 kHz	4.96 V
5 kHz	4.23 V
10 kHz	3.11 V
15 kHz	2.34 V
20 kHz	1.848 V



22. a. $Z_T = \sqrt{R^2 + X_C^2} \angle -\tan^{-1} X_C/R$
 $|Z_T| = \sqrt{R^2 + X_C^2}, \theta_T = -\tan^{-1} X_C/R$

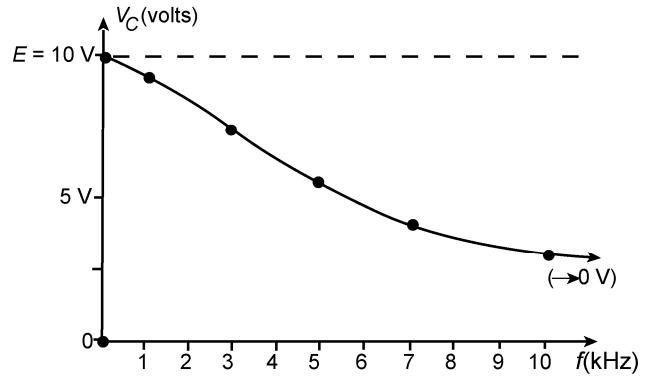
f	$ Z_T $	θ_T
0 kHz	$\infty \Omega$	-90.0°
1 kHz	333.64 Ω	-72.56°
3 kHz	145.8 Ω	-46.7°
5 kHz	118.54 Ω	-32.48°
7 kHz	109.85 Ω	-24.45°
10 kHz	104.94 Ω	-17.66°



b. $\mathbf{V}_C = \frac{(X_C \angle -90^\circ)(E \angle 0^\circ)}{R - jX_C} = \frac{X_C E}{\sqrt{R^2 + X_C^2}} \angle -90^\circ + \tan^{-1} X_C / R$

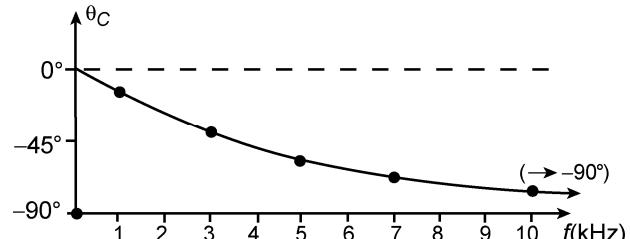
$$|V_C| = \frac{X_C E}{\sqrt{R^2 + X_C^2}}$$

f	$ V_C $
0 Hz	10.0 V
1 kHz	9.54 V
3 kHz	7.28 V
5 kHz	5.37 V
7 kHz	4.14 V
10 kHz	3.03 V



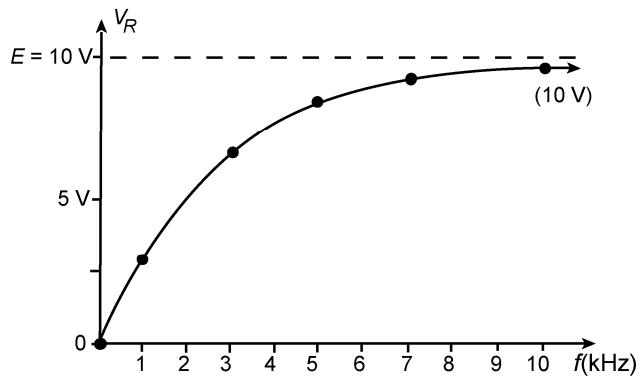
c. $\theta_C = -90^\circ + \tan^{-1} X_C / R$

f	θ_C
0 Hz	0.0°
1 kHz	-17.44°
3 kHz	-43.3°
5 kHz	-57.52°
7 kHz	-65.55°
10 kHz	-72.34°



d. $|V_R| = \frac{RE}{\sqrt{R^2 + X_C^2}}$

f	$ V_R $
0 Hz	0.0 V
1 kHz	3.0 V
3 kHz	6.86 V
5 kHz	8.44 V
7 kHz	9.10 V
10 kHz	9.53 V



23. a. $Z_T = \sqrt{R^2 + (X_L - X_C)^2} \angle \tan^{-1}(X_L - X_C) / R$

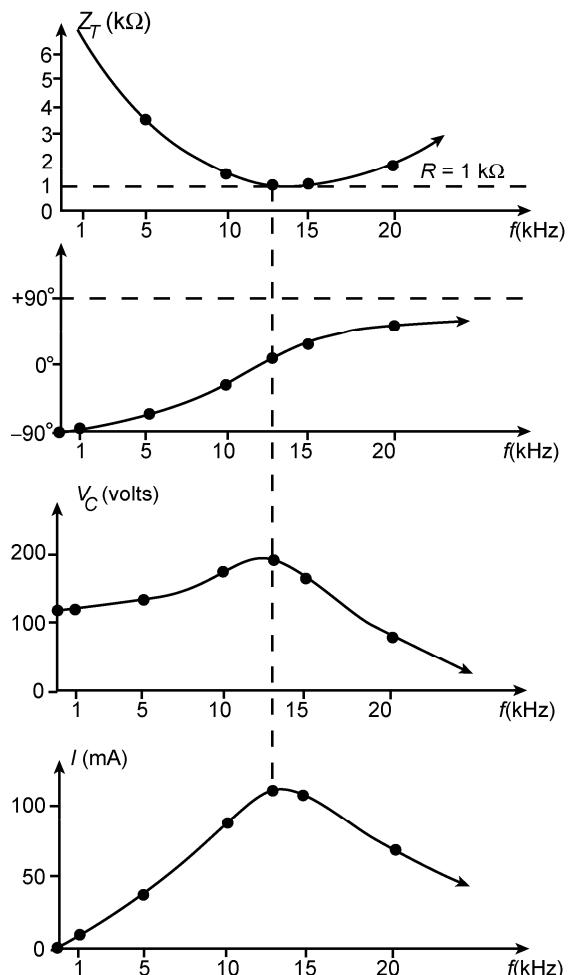
f	Z_T	θ_T
0 Hz	$\infty \Omega$	-90.0°
1 kHz	19,793.97 Ω	-87.1°
5 kHz	3,496.6 Ω	-73.38°
10 kHz	1,239.76 Ω	-36.23°
15 kHz	1,145.47 Ω	$+29.19^\circ$
20 kHz	1,818.24 Ω	$+56.63^\circ$

b. $|V_C| = \frac{X_C E}{Z_T}$

f	$ V_C $
0 Hz	120.0 V
1 kHz	120.61 V
5 kHz	136.55 V
10 kHz	192.57 V
15 kHz	138.94 V
20 kHz	65.65 V

c. $|I| = \frac{E}{Z_T}$

f	I
0 Hz	0.0 mA
1 kHz	6.062 mA
5 kHz	34.32 mA
10 kHz	96.79 mA
15 kHz	104.76 mA
20 kHz	66.0 mA



24. a. $X_C = \frac{1}{2\pi fC} = R \Rightarrow f = \frac{1}{2\pi RC} = \frac{1}{2\pi(220 \Omega)(0.47 \mu F)} = 1.54 \text{ kHz}$

b. Low frequency: X_C very large resulting in large Z_T
 High frequency: X_C approaches zero ohms and Z_T approaches R

c. $f = 100 \text{ Hz}: X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(100 \text{ Hz})(0.47 \mu F)} = 3.39 \text{ k}\Omega$
 $Z_T \approx X_C$

$f = 10 \text{ kHz}: X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10 \text{ kHz})(0.47 \mu F)} = 33.86 \Omega$
 $Z_T \approx R$

d. —

e. $f = 40 \text{ kHz}: X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(40 \text{ kHz})(0.47 \mu F)} = 8.47 \text{ k}\Omega$
 $\theta = -\tan^{-1} \frac{X_C}{R} = -\tan^{-1} \frac{8.47 \Omega}{220 \Omega} = -2.2^\circ$

25. a. $\mathbf{Z}_T = 91 \Omega \angle 0^\circ = R \angle 0^\circ, \mathbf{Y}_T = 10.99 \text{ mS} \angle 0^\circ = G \angle 0^\circ$

b. $\mathbf{Z}_T = 200 \Omega \angle 90^\circ = X_L \angle 90^\circ, \mathbf{Y}_T = 5 \text{ mS} \angle -90^\circ = B_L \angle -90^\circ$

c. $\mathbf{Z}_T = 0.2 \text{ k}\Omega \angle -90^\circ = X_C \angle -90^\circ, \mathbf{Y}_T = 5.00 \text{ mS} \angle 90^\circ = B_C \angle 90^\circ$

d. $\mathbf{Z}_T = \frac{(10 \Omega \angle 0^\circ)(60 \Omega \angle 90^\circ)}{10 \Omega + j60 \Omega} = 9.86 \Omega \angle 9.46^\circ = 9.73 \Omega + j1.62 \Omega = R + jX_L$
 $\mathbf{Y}_T = 0.10 \text{ S} \angle -9.46^\circ = 0.1 \text{ S} - j0.02 \text{ S} = G - jB_L$

e. $22 \Omega \parallel 2.2 \Omega = 2 \Omega$
 $\mathbf{Z}_T = \frac{(2 \Omega \angle 0^\circ)(6 \Omega \angle -90^\circ)}{2 \Omega - j6 \Omega} = \frac{12 \Omega \angle -90^\circ}{6.32 \Omega \angle -71.57^\circ} = 1.90 \Omega \angle -18.43^\circ$
 $= 1.80 \Omega - j0.6 \Omega = R - jX_C$
 $\mathbf{Y}_T = 0.53 \text{ S} \angle 18.43^\circ = 0.5 \text{ S} + j0.17 \text{ S} = G + jB_C$

f. $\mathbf{Y}_T = \frac{1}{3 \text{ k}\Omega \angle 0^\circ} + \frac{1}{6 \text{ k}\Omega \angle 90^\circ} + \frac{1}{9 \text{ k}\Omega \angle -90^\circ}$
 $= 0.333 \times 10^{-3} \angle 0^\circ + 0.167 \times 10^{-3} \angle -90^\circ + 0.111 \times 10^{-3} \angle 90^\circ$
 $= 0.333 \times 10^{-3} \text{ S} - j0.056 \times 10^{-3} \text{ S} = 0.34 \text{ mS} \angle -9.55^\circ$
 $= G - jB_L$
 $\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = 2.94 \text{ k}\Omega \angle 9.55^\circ = 2.90 \text{ k}\Omega + j0.49 \text{ k}\Omega$

26. a. $\mathbf{Z}_T = 4.7 \Omega + j8 \Omega = \mathbf{9.28 \Omega \angle 59.57^\circ}$, $\mathbf{Y}_T = \mathbf{0.108 S \angle -59.57^\circ}$

$$\mathbf{Y}_T = \mathbf{54.7 mS} - j\mathbf{93.12 mS} = G - jB_L$$

b. $\mathbf{Z}_T = 33 \Omega + 20 \Omega - j70 \Omega = \mathbf{53 \Omega - j70 \Omega = 87.80 \Omega \angle -52.87^\circ}$

$$\mathbf{Y}_T = \mathbf{11.39 mS \angle 52.87^\circ} = \mathbf{6.88 mS + j9.08 mS} = G + jB_C$$

c. $\mathbf{Z}_T = 200 \Omega + j500 \Omega - j600 \Omega = \mathbf{200 \Omega - j100 \Omega = 223.61 \Omega \angle -26.57^\circ}$

$$\mathbf{Y}_T = \mathbf{4.47 mS \angle 26.57^\circ} = \mathbf{4 mS + j2 mS} = G + jB_C$$

27. a. $\mathbf{Y}_T = \frac{\mathbf{I}}{\mathbf{E}} = \frac{60 \text{ A} \angle 70^\circ}{120 \text{ V} \angle 0^\circ} = 0.5 \text{ S} \angle 70^\circ = 0.171 \text{ S} + j0.470 \text{ S} = G + jB_C$

$$R = \frac{1}{G} = \mathbf{5.85 \Omega}, X_C = \frac{1}{B_C} = \mathbf{2.13 \Omega}$$

b. $\mathbf{Y}_T = \frac{\mathbf{I}}{\mathbf{E}} = \frac{20 \text{ mA} \angle 40^\circ}{80 \text{ V} \angle 320^\circ} = 0.25 \text{ mS} \angle -280^\circ = 0.25 \text{ mS} \angle 80^\circ$

$$= 0.043 \text{ mS} + j0.246 \text{ mS} = G + jB_C$$

$$R = \frac{1}{G} = \mathbf{23.26 \text{ k}\Omega}, X_C = \frac{1}{B_C} = \mathbf{4.07 \text{ k}\Omega}$$

c. $\mathbf{Y}_T = \frac{\mathbf{I}}{\mathbf{E}} = \frac{0.2 \text{ A} \angle -60^\circ}{8 \text{ kV} \angle 0^\circ} = 0.25 \text{ mS} \angle -60^\circ = 0.0125 \text{ mS} - j0.02165 \text{ mS} = G - jB_L$

$$R = \frac{1}{G} = \mathbf{80 \text{ k}\Omega}, X_L = \frac{1}{B_L} = \mathbf{46.19 \text{ k}\Omega}$$

28. a. $\mathbf{Y}_T = \frac{1}{10 \Omega \angle 0^\circ} + \frac{1}{20 \Omega \angle 90^\circ} = 0.1 \text{ S} - j0.05 \text{ S} = \mathbf{111.8 mS \angle -26.57^\circ}$

c. $\mathbf{E} = \mathbf{I}_s / \mathbf{Y}_T = 2 \text{ A} \angle 0^\circ / 111.8 \text{ mS} \angle -26.57^\circ = \mathbf{17.89 V \angle 26.57^\circ}$

$$\mathbf{I}_R = \frac{E \angle \theta}{R \angle 0^\circ} = 17.89 \text{ V} \angle 26.57^\circ / 10 \Omega \angle 0^\circ = \mathbf{1.79 A \angle 26.57^\circ}$$

$$\mathbf{I}_L = \frac{E \angle \theta}{X_L \angle 90^\circ} = 17.89 \text{ V} \angle 26.57^\circ / 20 \Omega \angle 90^\circ = \mathbf{0.89 A \angle -63.43^\circ}$$

f. $P = I^2 R = (1.79 \text{ A})^2 10 \Omega = \mathbf{32.04 \text{ W}}$

g. $F_p = \frac{G}{Y_T} = \frac{0.1 \text{ S}}{111.8 \text{ mS}} = \mathbf{0.894 \text{ lagging}}$

h. $e = \mathbf{25.30 \sin(377t + 26.57^\circ)}$

$$i_R = \mathbf{2.53 \sin(377t + 26.57^\circ)}$$

$$i_L = \mathbf{1.26 \sin(377t - 63.43^\circ)}$$

$$i_s = \mathbf{2.83 \sin 377t}$$

29. a. $\mathbf{Y}_T = \frac{1}{10 \text{ k}\Omega \angle 0^\circ} + \frac{1}{20 \text{ k}\Omega \angle -90^\circ} = 0.1 \text{ mS} \angle 0^\circ + 0.05 \text{ mS} \angle -90^\circ$
 $= \mathbf{0.112 \text{ mS} \angle 26.57^\circ}$

c. $\mathbf{E} = \frac{\mathbf{I}_s}{\mathbf{Y}_T} = \frac{2 \text{ mA} \angle 20^\circ}{0.1118 \text{ mS} \angle 26.565^\circ} = \mathbf{17.89 \text{ V} \angle -6.57^\circ}$
 $\mathbf{I}_R = \frac{\mathbf{E}}{\mathbf{Z}_R} = \frac{17.89 \text{ V} \angle -6.57^\circ}{10 \text{ k}\Omega \angle 0^\circ} = \mathbf{1.79 \text{ mA} \angle -6.57^\circ}$
 $\mathbf{I}_C = \frac{\mathbf{E}}{\mathbf{Z}_C} = \frac{17.89 \text{ V} \angle -6.57^\circ}{20 \text{ k}\Omega \angle -90^\circ} = \mathbf{0.90 \text{ mA} \angle 83.44^\circ}$

e. $\mathbf{I}_s = \mathbf{I}_R + \mathbf{I}_C$
 $2 \text{ mA} \angle 20^\circ = 1.79 \text{ mA} \angle -6.57^\circ + 0.90 \text{ mA} \angle 83.44^\circ$
 $= 1.88 \text{ mA} + j0.69 \text{ mA}$
 $2 \text{ mA} \angle 20^\circ \checkmark 2 \text{ mA} \angle 20.15^\circ$

f. $P = I^2 R = (1.79 \text{ mA})^2 10 \text{ k}\Omega = \mathbf{32.04 \text{ mW}}$

g. $F_p = \frac{G}{Y_T} = \frac{0.1 \text{ mS}}{0.1118 \text{ mS}} = \mathbf{0.894 \text{ leading}}$

h. $\omega = 2\pi f = 377 \text{ rad/s}$
 $i_s = 2.83 \times 10^{-3} \sin(\omega t + 20^\circ)$
 $i_R = 2.53 \times 10^{-3} \sin(\omega t - 6.57^\circ)$
 $i_C = 1.27 \times 10^{-3} \sin(\omega t + 83.44^\circ)$
 $e = 25.3 \sin(\omega t - 6.57^\circ)$

30. a. $\mathbf{Y}_T = \frac{1}{12 \Omega \angle 0^\circ} + \frac{1}{10 \Omega \angle 90^\circ} = 0.083 \text{ S} - j0.1 \text{ S} = \mathbf{129.96 \text{ mS} \angle -50.31^\circ}$

c. $\mathbf{I}_s = \mathbf{E} \mathbf{Y}_T = (60 \text{ V} \angle 0^\circ)(0.13 \text{ S} \angle -50.31^\circ) = \mathbf{7.8 \text{ A} \angle -50.31^\circ}$
 $\mathbf{I}_R = \frac{\mathbf{E} \angle \theta}{R \angle 0^\circ} = 60 \text{ V} \angle 0^\circ / 12 \Omega \angle 0^\circ = \mathbf{5 \text{ A} \angle 0^\circ}$
 $\mathbf{I}_L = \frac{\mathbf{E} \angle \theta}{X_L \angle 90^\circ} = 60 \text{ V} \angle 0^\circ / 10 \Omega \angle 90^\circ = \mathbf{6 \text{ A} \angle -90^\circ}$

f. $P = I^2 R = (5 \text{ A})^2 12 \Omega = \mathbf{300 \text{ W}}$

g. $F_p = G/Y_T = 0.083 \text{ S} / 0.13 \text{ S} = \mathbf{0.638 \text{ lagging}}$

h. $e = 84.84 \sin 377t$
 $i_R = 7.07 \sin 377t$
 $i_L = 8.484 \sin(377t - 90^\circ)$
 $i_s = 11.03 \sin(377t - 50.31^\circ)$

31. a.
$$\begin{aligned}\mathbf{Y}_T &= \frac{1}{1.2\Omega \angle 0^\circ} + \frac{1}{2\Omega \angle 90^\circ} + \frac{1}{5\Omega \angle -90^\circ} \\ &= 0.833 \text{ S} \angle 0^\circ + 0.5 \text{ S} \angle -90^\circ + 0.2 \text{ S} \angle 90^\circ \\ &= 0.833 \text{ S} - j0.3 \text{ S} = \mathbf{0.89 \text{ S} \angle -19.81^\circ} \\ \mathbf{Z}_T &= 1.12 \Omega \angle 19.81^\circ\end{aligned}$$

c.
$$\begin{aligned}X_C &= \frac{1}{\omega C} \Rightarrow C = \frac{1}{\omega X_C} = \frac{1}{(377 \text{ rad/s})(5 \Omega)} = \mathbf{531 \mu F} \\ X_L &= \omega L \Rightarrow L = \frac{X_L}{\omega} = \frac{2\Omega}{377 \text{ rad/s}} = \mathbf{5.31 \text{ mH}}\end{aligned}$$

d.
$$\begin{aligned}\mathbf{E} &= \frac{\mathbf{I}_s}{\mathbf{Y}_T} = \frac{(0.707)(3 \text{ A}) \angle 60^\circ}{0.885 \text{ S} \angle -19.81^\circ} = \frac{2.121 \text{ A} \angle 60^\circ}{0.885 \text{ S} \angle -19.81^\circ} = \mathbf{2.40 \text{ V} \angle 79.81^\circ} \\ \mathbf{I}_R &= \frac{E \angle \theta}{R \angle 0^\circ} = \frac{2.397 \text{ V} \angle 79.81^\circ}{1.2\Omega \angle 0^\circ} = \mathbf{2.00 \text{ A} \angle 79.81^\circ} \\ \mathbf{I}_L &= \frac{E \angle \theta}{X_L \angle 90^\circ} = \frac{2.397 \text{ V} \angle 79.81^\circ}{2\Omega \angle 90^\circ} = \mathbf{1.20 \text{ A} \angle -10.19^\circ} \\ \mathbf{I}_C &= \frac{E \angle \theta}{X_C \angle -90^\circ} = \frac{2.397 \text{ V} \angle 79.81^\circ}{5\Omega \angle -90^\circ} = \mathbf{0.48 \text{ A} \angle 169.81^\circ}\end{aligned}$$

f.
$$\begin{aligned}\mathbf{I}_s &= \mathbf{I}_R + \mathbf{I}_L + \mathbf{I}_C \\ 2.121 \text{ A} \angle 60^\circ &= 2.00 \text{ A} \angle 79.81^\circ + 1.20 \text{ A} \angle -10.19^\circ + 0.48 \text{ A} \angle 169.81^\circ \\ 2.121 \text{ A} \angle 60^\circ &\stackrel{\checkmark}{=} 2.13 \text{ A} \angle 60.01^\circ\end{aligned}$$

g.
$$P = I^2 R = (2.00 \text{ A})^2 1.2 \Omega = \mathbf{4.8 \text{ W}}$$

h.
$$F_p = \frac{G}{Y_T} = \frac{0.833 \text{ S}}{0.885 \text{ S}} = \mathbf{0.941 \text{ lagging}}$$

i.
$$\begin{aligned}e &= 3.39 \sin(377t + 79.81^\circ) \\ i_R &= 2.83 \sin(377t + 79.81^\circ) \\ i_L &= 1.70 \sin(377t - 10.19^\circ) \\ i_C &= 0.68 \sin(377t + 169.81^\circ)\end{aligned}$$

32. a.
$$\begin{aligned}\mathbf{Y}_T &= \frac{1}{3k\Omega \angle 0^\circ} + \frac{1}{4k\Omega \angle 90^\circ} + \frac{1}{8k\Omega \angle -90^\circ} \\ &= 0.333 \text{ mS} \angle 0^\circ + 0.25 \text{ mS} \angle -90^\circ + 0.125 \text{ mS} \angle 90^\circ \\ &= \mathbf{0.333 \text{ mS} + j0.125 \text{ mS} = 0.356 \text{ mS} \angle 20.57^\circ}\end{aligned}$$

c.
$$\begin{aligned}X_L &= \omega L \Rightarrow L = X_L/\omega = 4000 \Omega / 377 \text{ rad/s} = \mathbf{10.61 \text{ H}} \\ X_C &= \frac{1}{\omega C} \Rightarrow C = \frac{1}{\omega X_C} = \frac{1}{(377 \text{ rad/s})(8 k\Omega)} = \mathbf{0.332 \mu F}\end{aligned}$$

d. $\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 3.535 \text{ mA} \angle -20^\circ / 0.356 \text{ mS} \angle 20.57^\circ = \mathbf{9.93 \text{ V} \angle -40.57^\circ}$

$$\mathbf{I}_R = \frac{E \angle \theta}{R \angle 0^\circ} = 9.93 \text{ V} \angle -40.57^\circ / 3 \text{ k}\Omega \angle 0^\circ = \mathbf{3.31 \text{ mA} \angle -40.57^\circ}$$

$$\mathbf{I}_L = \frac{E \angle \theta}{X_L \angle 90^\circ} = 9.93 \text{ V} \angle -40.57^\circ / 4 \text{ k}\Omega \angle 90^\circ = \mathbf{2.48 \text{ mA} \angle -130.57^\circ}$$

$$\mathbf{I}_C = \frac{E \angle \theta}{X_C \angle -90^\circ} = 9.93 \text{ V} \angle -40.57^\circ / 8 \text{ k}\Omega \angle -90^\circ = \mathbf{1.24 \text{ mA} \angle 49.43^\circ}$$

g. $P = I^2 R = (3.31 \text{ mA})^2 3 \text{ k}\Omega = \mathbf{32.87 \text{ mW}}$

h. $F_p = G/Y_T = 0.333 \text{ mS} / 0.356 \text{ mS} = \mathbf{0.935 \text{ leading}}$

i. $e = \mathbf{14.04 \sin(377t - 40.57^\circ)}$
 $i_R \cong \mathbf{4.68 \times 10^{-3} \sin(377t - 40.57^\circ)}$
 $i_L \cong \mathbf{3.51 \times 10^{-3} \sin(377t - 130.57^\circ)}$
 $i_C = \mathbf{1.75 \times 10^{-3} \sin(377t + 49.43^\circ)}$

33. a. $\mathbf{Y}_T = \frac{1}{5 \Omega \angle -90^\circ} + \frac{1}{22 \Omega \angle 0^\circ} + \frac{1}{10 \Omega \angle 90^\circ}$
 $= 0.2 \text{ S} \angle 90^\circ + 0.045 \text{ S} \angle 0^\circ + 0.1 \text{ S} \angle -90^\circ$
 $= 0.045 \text{ S} + j0.1 \text{ S} = \mathbf{0.110 \text{ S} \angle 65.77^\circ}$
 $\mathbf{Z}_T = \mathbf{9.09 \Omega \angle -65.77^\circ}$

c. $C = \frac{1}{\omega X_C} = \frac{1}{(377 \text{ rad/s})(5 \Omega)} = \mathbf{636.9 \mu F}$
 $L = \frac{X_L}{\omega} = \frac{10 \Omega}{314 \text{ rad/s}} = \mathbf{31.8 \text{ mH}}$

d. $\mathbf{E} = (0.707)(35.4 \text{ V}) \angle 60^\circ = \mathbf{25.03 \text{ V} \angle 60^\circ}$
 $\mathbf{I}_s = \mathbf{EY}_T = (25.03 \text{ V} \angle 60^\circ)(0.11 \text{ S} \angle 65.77^\circ) = \mathbf{2.75 \text{ A} \angle 125.77^\circ}$
 $\mathbf{I}_C = \frac{E \angle \theta}{X_C \angle -90^\circ} = \frac{25.03 \text{ V} \angle 60^\circ}{5 \angle -90^\circ} = \mathbf{5 \text{ A} \angle 150^\circ}$
 $\mathbf{I}_R = \frac{E \angle \theta}{R \angle 0^\circ} = \frac{25.03 \text{ V} \angle 60^\circ}{22 \Omega \angle 0^\circ} = \mathbf{1.14 \text{ A} \angle 60^\circ}$
 $\mathbf{I}_L = \frac{E \angle \theta}{X_L \angle 90^\circ} = \frac{25.03 \text{ V} \angle 60^\circ}{10 \Omega \angle 90^\circ} = \mathbf{2.50 \text{ A} \angle -30^\circ}$

f. $\mathbf{I}_s = \mathbf{I}_C + \mathbf{I}_R + \mathbf{I}_L$
 $2.75 \text{ A} \angle 125.77^\circ = 5 \text{ A} \angle 150^\circ + 1.14 \text{ A} \angle 60^\circ + 2.50 \text{ A} \angle -30^\circ$
 $= (-4.33 + j2.5) + (0.57 + j0.9) + (2.17 - j1.25)$
 $= -1.59 + j2.24$
 $\checkmark = 2.75 \angle 125.4^\circ$

g. $P = I^2 R = (1.14 \text{ A})^2 22 \Omega = \mathbf{28.59 \text{ W}}$

h. $F_p = \frac{G}{Y_T} = \frac{0.045 \text{ S}}{0.110 \text{ S}} = \mathbf{0.409 \text{ leading}}$

i. $e = 35.4 \sin(314t + 60^\circ)$
 $i_s = 3.89 \sin(314t + 125.77^\circ)$
 $i_C = 7.07 \sin(314t + 150^\circ)$
 $i_R = 1.61 \sin(314t + 60^\circ)$
 $i_L = 3.54 \sin(314t - 30^\circ)$

34. a. $\mathbf{I}_1 = \frac{(80 \Omega \angle 90^\circ)(20 \text{ A} \angle 40^\circ)}{22 \Omega + j80 \Omega} = \frac{1600 \text{ A} \angle 130^\circ}{82.97 \angle 74.62^\circ} = \mathbf{19.28 \text{ A} \angle 55.38^\circ}$

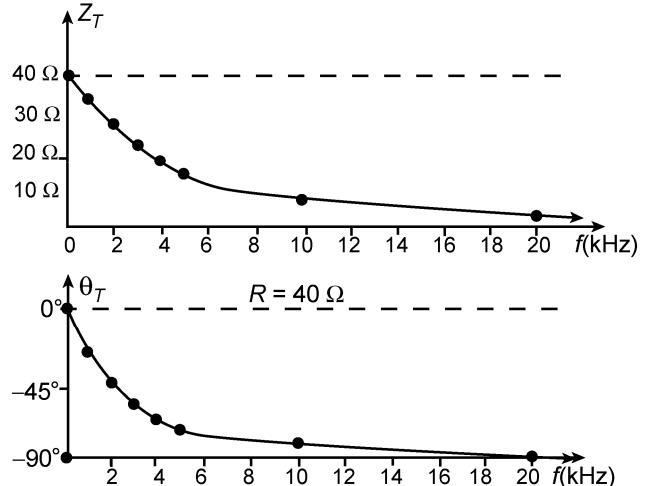
$$\mathbf{I}_2 = \frac{(22 \Omega \angle 0^\circ)(20 \text{ A} \angle 40^\circ)}{82.97 \Omega \angle 74.62^\circ} = \frac{440 \text{ A} \angle 40^\circ}{82.97 \angle 74.62^\circ} = \mathbf{5.30 \text{ A} \angle -34.62^\circ}$$

b. $\mathbf{I}_1 = \frac{(12 \Omega - j6 \Omega)(6 \text{ A} \angle 30^\circ)}{12 \Omega - j6 \Omega + j4 \Omega} = \frac{(13.42 \angle -26.57^\circ)(6 \text{ A} \angle 30^\circ)}{12 - j2}$
 $= \frac{80.52 \text{ A} \angle 3.43^\circ}{12.17 \angle -9.46^\circ} = \mathbf{6.62 \text{ A} \angle 12.89^\circ}$
 $\mathbf{I}_2 = \frac{(4 \Omega \angle 90^\circ)(6 \text{ A} \angle 30^\circ)}{12.17 \Omega \angle -9.46^\circ} = \frac{24 \text{ A} \angle 120^\circ}{12.17 \angle -9.46^\circ} = \mathbf{1.97 \text{ A} \angle 129.46^\circ}$

35. a. $\mathbf{Z}_T = \frac{(R \angle 0^\circ)(X_C \angle -90^\circ)}{R - jX_C} = \frac{RX_C}{\sqrt{R^2 + X_C^2}} \angle -90^\circ + \tan^{-1} X_C/R$

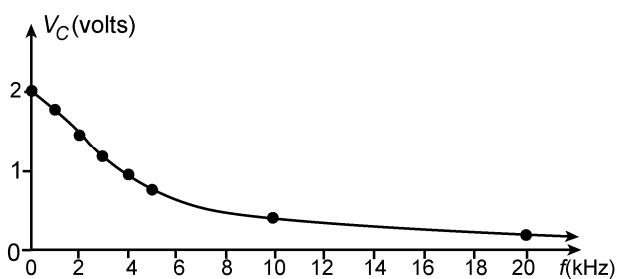
$$|Z_T| = \frac{RX_C}{\sqrt{R^2 + X_C^2}} \quad \theta_T = -90^\circ + \tan^{-1} X_C/R$$

f	$ Z_T $	θ_T
0 Hz	40.0Ω	0.0°
1 kHz	35.74Ω	-26.67°
2 kHz	28.22Ω	-45.14°
3 kHz	22.11Ω	-56.44°
4 kHz	17.82Ω	-63.55°
5 kHz	14.79Ω	-68.30°
10 kHz	7.81Ω	-78.75°
20 kHz	3.959Ω	-89.86°



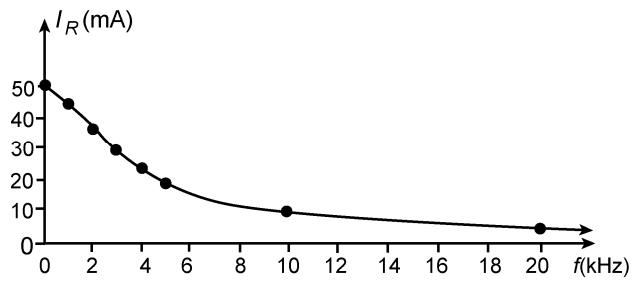
b. $|V_C| = \frac{IRX_C}{\sqrt{R^2 + X_C^2}} = I[Z_T(f)]$

f	$ V_C $
0 kHz	2.0 V
1 kHz	1.787 V
2 kHz	1.411 V
3 kHz	1.105 V
4 kHz	0.891 V
5 kHz	0.740 V
10 kHz	0.391 V
20 kHz	0.198 V



c. $|I_R| = \left| \frac{V_C}{R} \right|$

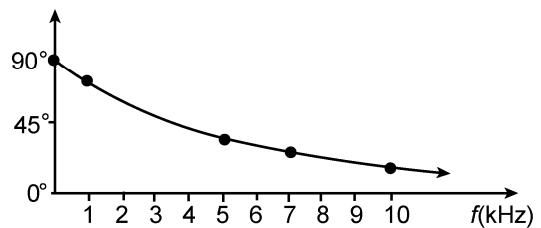
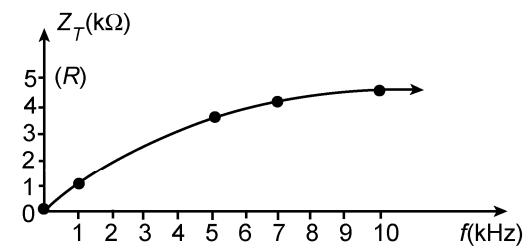
f	$ I_R $
0 kHz	50.0 mA
1 kHz	44.7 mA
2 kHz	35.3 mA
3 kHz	27.64 mA
4 kHz	22.28 mA
5 kHz	18.50 mA
10 kHz	9.78 mA
20 kHz	4.95 mA



36. a. $\mathbf{Z}_T = \frac{\mathbf{Z}_R \mathbf{Z}_L}{\mathbf{Z}_R + \mathbf{Z}_L} = \frac{(R \angle 0^\circ)(X_L \angle 90^\circ)}{R + jX_L} = \frac{RX_L}{\sqrt{R^2 + X_L^2}} \angle 90^\circ - \tan^{-1} X_L/R$

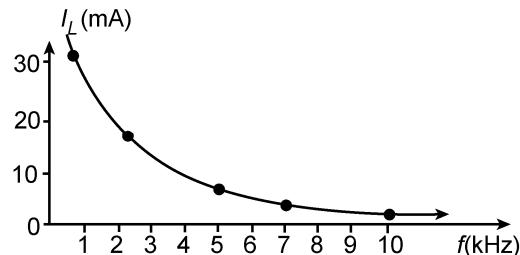
$$|\mathbf{Z}_T| = \frac{RX_L}{\sqrt{R^2 + X_L^2}} \theta_T = 90^\circ - \tan^{-1} X_L/R$$

f	$ Z_T $	θ_T
0 Hz	0.0 kΩ	90.0°
1 kHz	1.22 kΩ	75.86°
5 kHz	3.91 kΩ	38.53°
7 kHz	4.35 kΩ	29.6°
10 kHz	4.65 kΩ	21.69°

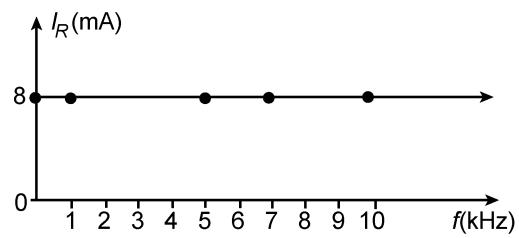


b. $|I_L| = \frac{E}{X_L}$

f	$ I_L $
0 Hz	∞
1 kHz	31.75 mA
5 kHz	6.37 mA
7 kHz	4.55 mA
10 kHz	3.18 mA

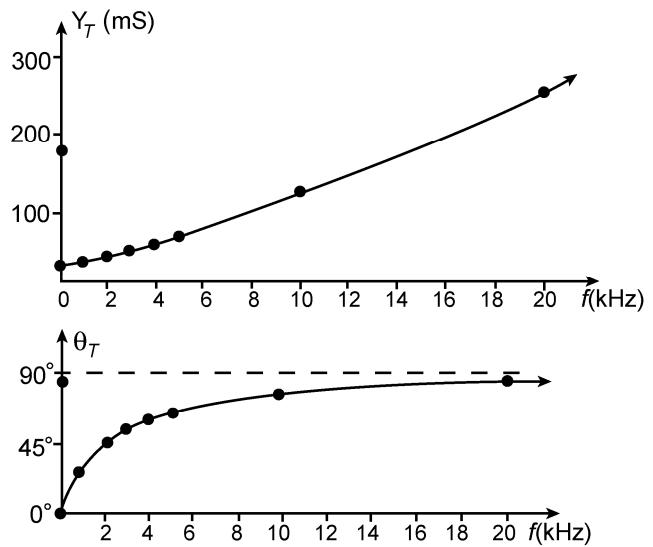


c. $I_R = \frac{E}{R} = \frac{40 \text{ V}}{5 \text{ k}\Omega} = 8 \text{ mA (constant)}$



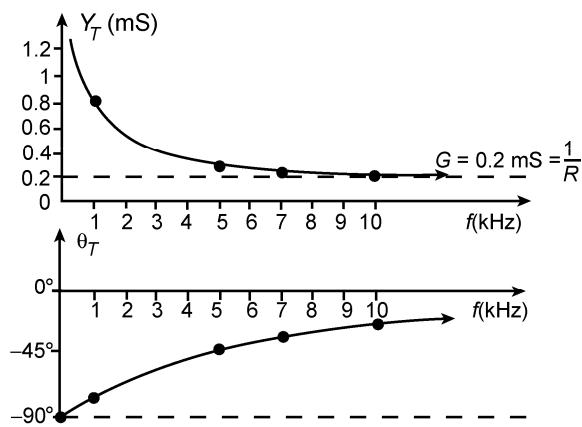
37. $\mathbf{Y}_T = \frac{\sqrt{R^2 + X_C^2}}{RX_C} \angle 90^\circ - \tan^{-1} X_C/R$

f	$ Y_T $	θ_T
0 Hz	25.0 mS	0.0°
1 kHz	27.98 mS	26.67°
2 kHz	35.44 mS	45.14°
3 kHz	45.23 mS	56.44°
4 kHz	56.12 mS	63.55°
5 kHz	67.61 mS	68.30°
10 kHz	128.04 mS	78.75°
20 kHz	252.59 mS	89.86°



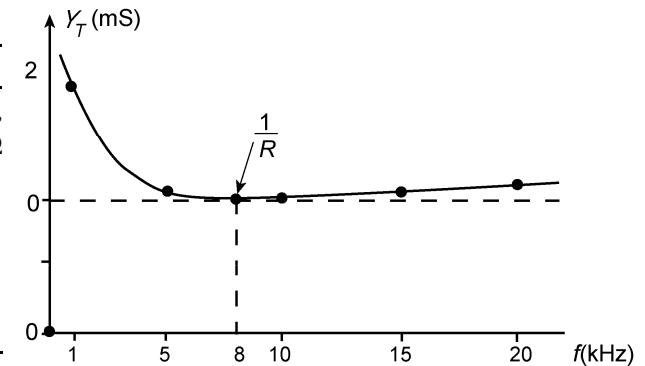
38. $Y_T = \frac{1}{Z_T}$ (use data of Prob. 36), $\theta_{T_y} = -\theta_{T_z}$

f	Y_T	θ_T
0 Hz	∞	-90.0°
1 kHz	0.82 mS	-75.86°
5 kHz	0.256 mS	-38.53°
7 kHz	0.23 mS	-29.6°
10 kHz	0.215 mS	-21.69°

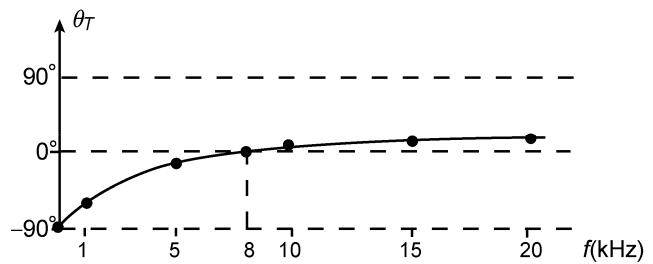


39. a. $\mathbf{Y}_T = G \angle 0^\circ + B_L \angle -90^\circ + B_C \angle 90^\circ$
 $= \sqrt{G^2 + (B_C - B_L)^2} \angle \tan^{-1} \frac{B_C - B_L}{G}$

f	$ Y_T $
0 Hz	$X_L \Rightarrow 0 \Omega, Z_T = 0 \Omega, Y_T = \infty \Omega$
1 kHz	1.857 mS
5 kHz	1.018 mS
10 kHz	1.004 mS
15 kHz	1.036 mS
20 kHz	1.086 mS

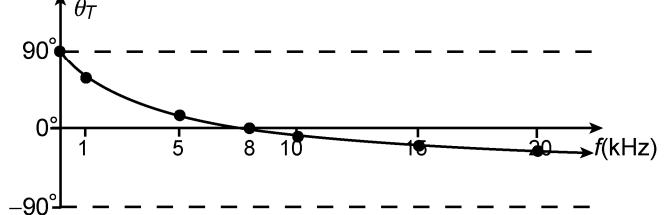
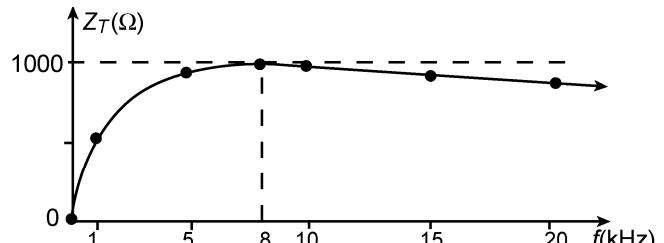


f	$ \theta_T $
0 Hz	-90.0°
1 kHz	-57.42°
5 kHz	-10.87°
10 kHz	+5.26°
15 kHz	+15.16°
20 kHz	+22.95°



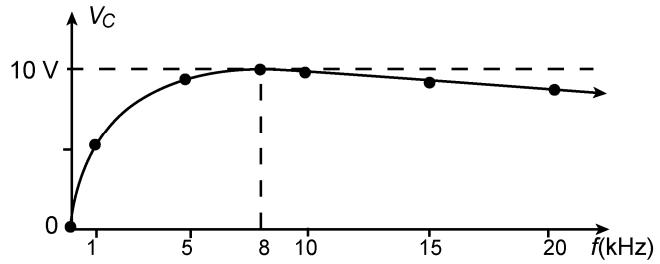
b. $Z_T = \frac{1}{Y_T}, \theta_{Tz} = -\theta_{Ty}$

f	Z_T	θ_T
0 kHz	0.0 Ω	90.0°
1 kHz	538.5 Ω	57.42°
5 kHz	982.32 Ω	10.87°
10 kHz	996.02 Ω	-5.26°
15 kHz	965.25 Ω	-15.16°
20 kHz	921.66 Ω	-22.95°



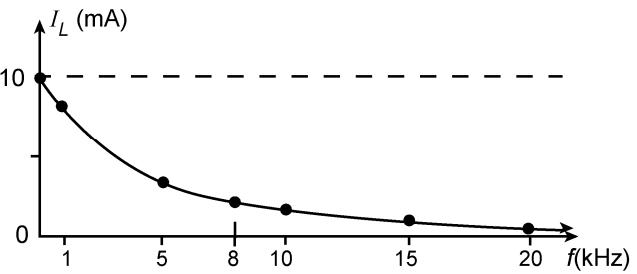
c. $V_C(f) = I[Z_T(f)]$

f	$ V_C $
0 kHz	0.0 V
1 kHz	5.39 V
5 kHz	9.82 V
10 kHz	9.96 V
15 kHz	9.65 V
20 kHz	9.22 V



d. $I_L = \frac{V_C(f)}{X_L}$

f	I_L
0 kHz	10.0 mA
1 kHz	8.57 mA
5 kHz	3.13 mA
10 kHz	1.59 mA
15 kHz	1.02 mA
20 kHz	0.733 mA



40. a. $R_p = \frac{R_s^2 + X_s^2}{R_s} = \frac{(20\Omega)^2 + (40\Omega)^2}{20\Omega} = 100\Omega(R)$

$$X_p = \frac{R_s^2 + X_s^2}{X_s} = \frac{2000\Omega}{40} = 50\Omega(C)$$

b. $R_p = \frac{R_s^2 + X_s^2}{R_s} = \frac{(2\text{k}\Omega)^2 + (3\text{k}\Omega)^2}{2\text{k}\Omega} = 6.5\text{k}\Omega(R)$

$$X_p = \frac{R_s^2 + X_s^2}{X_s} = \frac{(2\text{k}\Omega)^2 + (3\text{k}\Omega)^2}{3\text{k}\Omega} = 4.33\text{k}\Omega(C)$$

41. a. $R_s = \frac{R_p X_p^2}{X_p^2 + R_p^2} = \frac{(8.2\text{k}\Omega)(20\text{k}\Omega)^2}{(20\text{k}\Omega)^2 + (8.2\text{k}\Omega)^2} = 7.02\text{k}\Omega$

$$X_s = \frac{R_p^2 X_p}{X_p^2 + R_p^2} = \frac{(8.2\text{k}\Omega)^2(20\text{k}\Omega)}{467.24\text{k}\Omega} = 2.88\text{k}\Omega$$

$$\mathbf{Z}_T = 7.02\text{k}\Omega - j2.88\text{k}\Omega$$

b. $R_s = \frac{R_p X_p^2}{X_p^2 + R_p^2} = \frac{(68\Omega)(40\Omega)^2}{(40\Omega)^2 + (68\Omega)^2} = 17.48\Omega$

$$X_s = \frac{R_p^2 X_p}{X_p^2 + R_p^2} = \frac{(68\Omega)^2(40\Omega)}{6224\Omega^2} = 29.72\Omega$$

$$\mathbf{Z}_T = 17.48\Omega + j29.72\Omega$$

42. a. $C_T = 2 \mu\text{F}$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3 \text{ Hz})(2 \mu\text{F})} = 79.62 \Omega$$

$$X_L = \omega L = 2\pi(10^3 \text{ Hz})(10 \text{ mH}) = 62.80 \Omega$$

$$\mathbf{Y}_T = \frac{1}{220 \Omega \angle 0^\circ} + \frac{1}{79.62 \Omega \angle -90^\circ} + \frac{1}{62.8 \Omega \angle 90^\circ}$$

$$\begin{aligned} &= 4.55 \text{ mS} \angle 0^\circ + 12.56 \text{ mS} \angle 90^\circ + 15.92 \text{ mS} \angle -90^\circ \\ &= \mathbf{4.55 \text{ mS} - j3.36 \text{ mS} = 5.66 \text{ mS} \angle -36.44^\circ} \end{aligned}$$

$$\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 1 \text{ A} \angle 0^\circ / 5.66 \text{ mS} \angle -36.44^\circ = \mathbf{176.68 \text{ V} \angle 36.44^\circ}$$

$$\mathbf{I}_R = \frac{\mathbf{E} \angle \theta}{R \angle 0^\circ} = 176.68 \text{ V} \angle 36.44^\circ / 220 \Omega \angle 0^\circ = \mathbf{0.803 \text{ A} \angle 36.44^\circ}$$

$$\mathbf{I}_L = \frac{\mathbf{E} \angle \theta}{X_L \angle 90^\circ} = 176.68 \text{ V} \angle 36.44^\circ / 62.80 \angle 90^\circ = \mathbf{2.813 \text{ A} \angle -53.56^\circ}$$

b. $F_p = G/Y_T = 4.55 \text{ mS} / 5.66 \text{ mS} = \mathbf{0.804 \text{ lagging}}$

e. $P = I^2 R = (0.803 \text{ A})^2 220 \Omega = \mathbf{141.86 \text{ W}}$

f. $\mathbf{I}_s = \mathbf{I}_R + 2\mathbf{I}_C + \mathbf{I}_L$

$$\begin{aligned} \text{and } \mathbf{I}_C &= \frac{\mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L}{2} \\ &= \frac{1 \text{ A} \angle 0^\circ - 0.803 \text{ A} \angle 36.44^\circ - 2.813 \text{ A} \angle -53.56^\circ}{2} \\ &= \frac{1 - (0.646 + j0.477) - (1.671 - j2.263)}{2} = \frac{-1.317 + j1.786}{2} \\ \mathbf{I}_C &= -0.657 + j0.893 = \mathbf{1.11 \text{ A} \angle 126.43^\circ} \end{aligned}$$

g. $\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{5.66 \text{ mS} \angle -36.44^\circ} = 176.7 \Omega \angle 36.44^\circ$
 $= \mathbf{142.15 \Omega + j104.96 \Omega} = R + jX_L$

43. a. $(R = 220 \Omega) \parallel (L = 1 \text{ H}) \parallel (C = 2 \mu\text{F})$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3 \text{ Hz})(2 \mu\text{F})} = 79.62 \Omega$$

$$X_L = \omega L = 2\pi(10^3 \text{ Hz})(1 \text{ H}) = 6.28 \text{ k}\Omega$$

$$\begin{aligned} \mathbf{Y}_T &= \frac{1}{220 \Omega \angle 0^\circ} + \frac{1}{6.28 \times 10^3 \Omega \angle 90^\circ} + \frac{1}{79.62 \Omega \angle -90^\circ} \\ &= 0.0045 - j0.1592 \times 10^{-3} + j0.0126 \\ &= 4.5 \times 10^{-3} - j0.1592 \times 10^{-3} + j12.6 \times 10^{-3} \\ &= \mathbf{4.5 \text{ mS} + j12.44 \text{ mS} = 13.23 \text{ mS} \angle 70.11^\circ} \end{aligned}$$

$$\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 1 \text{ A } \angle 0^\circ / 13.23 \text{ mS } \angle 70.11^\circ = \mathbf{75.6 \text{ V } \angle -70.11^\circ}$$

$$\mathbf{I}_R = \frac{E \angle \theta}{R \angle 0^\circ} = 75.6 \text{ V } \angle -70.11^\circ / 220 \Omega \angle 0^\circ = \mathbf{0.34 \text{ A } \angle -70.11^\circ}$$

$$\mathbf{I}_L = \frac{E \angle \theta}{X_L \angle 90^\circ} = 75.6 \text{ V } \angle -70.11^\circ / 6.28 \text{ k}\Omega \angle 90^\circ = \mathbf{12.04 \text{ mA } \angle -160.11^\circ}$$

b. $F_p = \frac{G}{Y_T} = \frac{4.5 \text{ mS}}{13.23 \text{ mS}} = \mathbf{0.340 \text{ leading}}$

c. $P = I^2 R = (0.34 \text{ A})^2 220 \Omega = \mathbf{25.43 \text{ W}}$

f. $2\mathbf{I}_C = \mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L$

$$\begin{aligned} \mathbf{I}_C &= \frac{\mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L}{2} = \frac{1 \text{ A } \angle 0^\circ - 0.34 \text{ A } \angle -70.11^\circ - 12.04 \text{ mA } \angle -160.11^\circ}{2} \\ &= \frac{1 - (0.12 - j0.32) - (-11.32 \times 10^{-3} - j4.1 \times 10^{-3})}{2} \end{aligned}$$

$$= \frac{0.89 + j0.32}{2}$$

$$\mathbf{I}_C = 0.45 + j0.16 = \mathbf{0.47 \text{ A } \angle 19.63^\circ}$$

g. $\mathbf{Z}_T = \frac{1}{Y_T} = \frac{1}{13.23 \text{ mS } \angle 70.11^\circ} = 75.59 \Omega \angle -70.11^\circ = \mathbf{25.72 \Omega - j71.08 \Omega}$

$$R = \mathbf{25.72 \Omega}, X_C = \mathbf{71.08 \Omega}$$

44. $P = VI \cos \theta = 3000 \text{ W}$

$$\cos \theta = \frac{3000 \text{ W}}{VI} = \frac{3000 \text{ W}}{(100 \text{ V})(40 \text{ A})} = \frac{3000}{4000} = 0.75 \text{ (lagging)}$$

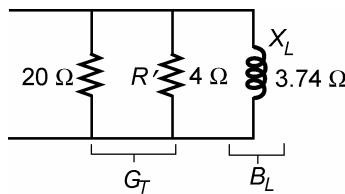
$$\theta = \cos^{-1} 0.75 = 41.41^\circ$$

$$\mathbf{Y}_T = \frac{\mathbf{I}}{\mathbf{E}} = \frac{40 \text{ A } \angle -41.41^\circ}{100 \text{ V } \angle 0^\circ} = 0.4 \text{ S } \angle -41.41^\circ = 0.3 \text{ S} - j0.265 \text{ S} = G_T - jB_L$$

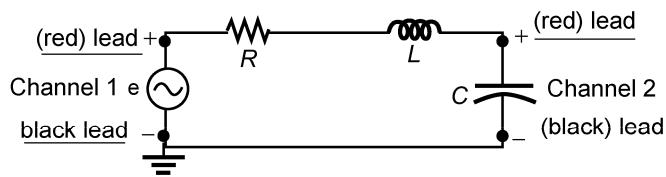
$$G_T = 0.3 \text{ S} = \frac{1}{20 \Omega} + \frac{1}{R'} = 0.05 \text{ S} + \frac{I}{R'}$$

$$\text{and } R' = \frac{1}{0.25 \text{ S}} = 4 \Omega$$

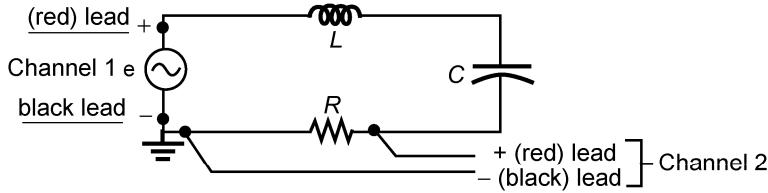
$$X_L = \frac{1}{B_L} = \frac{1}{0.265 \text{ S}} = \mathbf{3.74 \Omega}$$



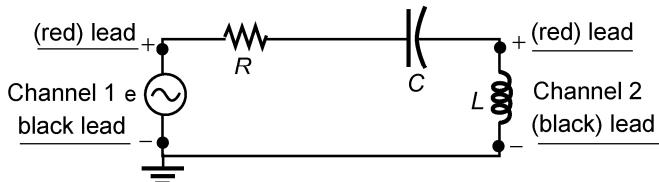
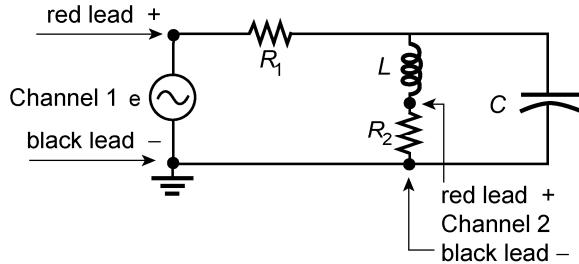
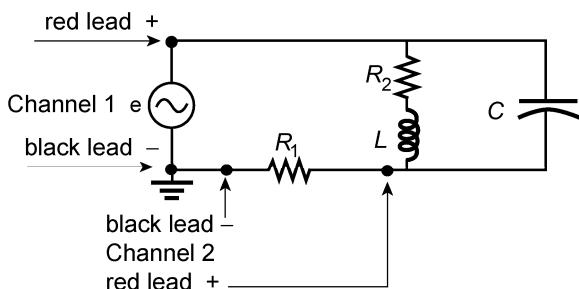
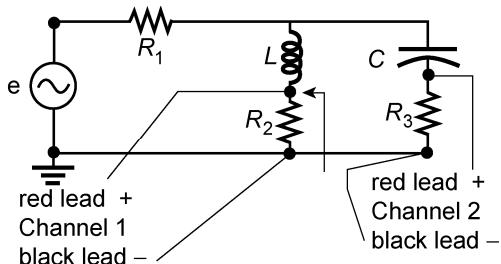
45. a.



b.



c.

46. a. e and v_{R_2} b. e and i_s c. i_L and i_C 

47. (I): (a) $\theta_{\text{div.}} = 0.8 \text{ div.}, \theta_T = 4 \text{ div.}$

$$\theta = \frac{0.8 \text{ div.}}{4 \text{ div.}} \times 360^\circ = 72^\circ$$

v_1 leads v_2 by 72°

(b) v_1 : peak-to-peak = (5 div.)(0.5 V/div.) = **2.5 V**

$$V_1(\text{rms}) = 0.7071 \left(\frac{2.5 \text{ V}}{2} \right) = \mathbf{0.88 \text{ V}}$$

v_2 : peak-to-peak = (2.4 div.)(0.5 V/div.) = **1.2 V**

$$V_2(\text{rms}) = 0.7071 \left(\frac{1.2 \text{ V}}{2} \right) = \mathbf{0.42 \text{ V}}$$

(c) $T = (4 \text{ div.})(0.2 \text{ ms/div.}) = 0.8 \text{ ms}$

$$f = \frac{1}{T} = \frac{1}{0.8 \text{ ms}} = \mathbf{1.25 \text{ kHz}} \text{ (both)}$$

(II): (a) $\theta_{\text{div.}} = 2.2 \text{ div.}, \theta_T = 6 \text{ div.}$

$$\theta = \frac{2.2 \text{ div.}}{6 \text{ div.}} \times 360^\circ = 132^\circ$$

v_1 leads v_2 by 132°

(b) v_1 : peak-to-peak = (2.8 div.)(2 V/div.) = **5.6 V**

$$V_1(\text{rms}) = 0.7071 \left(\frac{5.6 \text{ V}}{2} \right) = \mathbf{1.98 \text{ V}}$$

v_2 : peak-to-peak = (4 div.)(2 V/div.) = **8 V**

$$V_2(\text{rms}) = 0.7071 \left(\frac{8 \text{ V}}{2} \right) = \mathbf{2.83 \text{ V}}$$

(c) $T = (6 \text{ div.})(10 \mu\text{s/div.}) = 60 \mu\text{s}$

$$f = \frac{1}{T} = \frac{1}{60 \mu\text{s}} = \mathbf{16.67 \text{ kHz}}$$

Chapter 16

1. a. $\mathbf{Z}_T = 2 \Omega + j6 \Omega + 8 \Omega \angle -90^\circ \parallel 12 \Omega \angle -90^\circ$
 $= 2 \Omega + j6 \Omega + \frac{(8 \Omega \angle -90^\circ)(12 \Omega \angle -90^\circ)}{-j8\Omega - j12\Omega} = 2 \Omega + j6 \Omega + \frac{96 \Omega \angle -180^\circ}{20 \angle -90^\circ}$
 $= 2 \Omega + j6 \Omega + 4.8 \Omega \angle -90^\circ = 2 \Omega + j6 \Omega - j4.8 \Omega = 2 \Omega + j1.2 \Omega$
 $\mathbf{Z}_T = \mathbf{2.33 \Omega \angle 30.96^\circ}$
- b. $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{12 \text{ V} \angle 0^\circ}{2.33 \Omega \angle 30.96^\circ} = \mathbf{5.15 \text{ A} \angle -30.96^\circ}$
- c. $\mathbf{I}_1 = \mathbf{I} = \mathbf{5.15 \text{ A} \angle -30.96^\circ}$
- d. $(\text{CDR})\mathbf{I}_2 = \frac{(12 \Omega \angle -90^\circ)(5.15 \text{ A} \angle -30.96^\circ)}{-j12\Omega - j8\Omega} = \frac{61.80 \text{ A} \angle -120.96^\circ}{20 \angle -90^\circ} = \mathbf{3.09 \text{ A} \angle -30.96^\circ}$
 $\mathbf{I}_3 = \frac{(8 \Omega \angle -90^\circ)(5.15 \text{ A} \angle -30.96^\circ)}{20 \Omega \angle -90^\circ} = \frac{41.2 \text{ A} \angle -120.96^\circ}{20 \angle -90^\circ} = \mathbf{2.06 \text{ A} \angle -30.96^\circ}$
- e. $\mathbf{V}_L = (I \angle \theta)(X_L \angle 90^\circ) = (5.15 \text{ A} \angle -30.96^\circ)(6 \Omega \angle 90^\circ) = \mathbf{30.9 \text{ V} \angle 59.04^\circ}$
2. a. $\mathbf{Z}_T = 3 \Omega + j6 \Omega + 2 \Omega \angle 0^\circ \parallel 8 \Omega \angle -90^\circ$
 $= 3 \Omega + j6 \Omega + 1.94 \Omega \angle -14.04^\circ$
 $= 3 \Omega + j6 \Omega + 1.88 \Omega - j0.47 \Omega$
 $= 4.88 \Omega + j5.53 \Omega = \mathbf{7.38 \Omega \angle 48.57^\circ}$
- b. $\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{30 \text{ V} \angle 0^\circ}{7.38 \Omega \angle 48.57^\circ} = \mathbf{4.07 \text{ A} \angle -48.57^\circ}$
- c. $\mathbf{I}_C = \frac{\mathbf{Z}_{R_2} \mathbf{I}_s}{\mathbf{Z}_{R_2} + \mathbf{Z}_C} = \frac{(2 \Omega \angle 0^\circ)(4.07 \text{ A} \angle -48.57^\circ)}{2 \Omega - j8 \Omega}$
 $= \frac{8.14 \text{ A} \angle -48.57^\circ}{8.25 \angle -75.96^\circ} = \mathbf{0.987 \text{ A} \angle 27.39^\circ}$
- d. $\mathbf{V}_L = \frac{\mathbf{Z}_L \mathbf{E}}{\mathbf{Z}_T} = \frac{(6 \Omega \angle 90^\circ)(30 \text{ V} \angle 0^\circ)}{7.38 \Omega \angle 48.57^\circ} = \frac{180 \text{ V} \angle 90^\circ}{7.38 \Omega \angle 48.57^\circ}$
 $= \mathbf{24.39 \text{ V} \angle 41.43^\circ}$
3. a. $\mathbf{Z}_T = 12 \Omega \angle 90^\circ \parallel (9.1 \Omega - j12 \Omega) = 12 \Omega \angle 90^\circ \parallel 15.06 \Omega \angle -52.826^\circ$
 $= \frac{180.72 \Omega \angle 37.17^\circ}{9.10 \angle 0^\circ}$
 $= \mathbf{19.86 \Omega \angle 37.17^\circ}$
 $\mathbf{Y}_T = \frac{1}{\mathbf{Z}_T} = \frac{1}{19.86 \Omega \angle 37.17^\circ} = \mathbf{50.35 \text{ mS} \angle -37.17^\circ}$

b. $\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60 \text{ V} \angle 30^\circ}{19.86 \Omega \angle 37.17^\circ} = \mathbf{3.02 \text{ A} \angle -7.17^\circ}$

c. (CDR) $\mathbf{I}_2 = \frac{(12 \Omega \angle 90^\circ)(3.02 \text{ A} \angle -7.17^\circ)}{j12\Omega + 9.1\Omega - j12\Omega} = \frac{36.24 \text{ A} \angle 82.83^\circ}{9.1 \angle 0^\circ}$
 $= \mathbf{3.98 \text{ A} \angle 82.83^\circ}$

d. (VDR) $\mathbf{V}_C = \frac{(12 \Omega \angle -90^\circ)(60 \text{ V} \angle 30^\circ)}{9.1\Omega - j12\Omega} = \frac{720 \text{ V} \angle -60^\circ}{15.06 \angle -52.826^\circ}$
 $= \mathbf{47.81 \text{ V} \angle -7.17^\circ}$

e. $P = EI \cos \theta = (60 \text{ V})(3.02 \text{ A}) \cos(30^\circ - 7.17^\circ)$
 $= 181.20(0.922) = \mathbf{167.07 \text{ W}}$

4. a. $\mathbf{Z}_T = 2 \Omega + \frac{(4 \Omega \angle -90^\circ)(6\Omega \angle 90^\circ)}{-j4\Omega + j6\Omega} + \frac{(4 \Omega \angle 0^\circ)(3 \Omega \angle 90^\circ)}{4\Omega + j3\Omega}$
 $= 2 \Omega + \frac{24 \Omega \angle 0^\circ}{2 \angle 90^\circ} + \frac{12 \Omega \angle 90^\circ}{5 \angle 36.87^\circ}$
 $= 2 \Omega + 12 \Omega \angle -90^\circ + 2.4 \angle 53.13^\circ$
 $= 2 \Omega - j12 \Omega + 1.44 \Omega + j1.92 \Omega$
 $= \mathbf{3.44 \Omega - j10.08 \Omega = 10.65 \Omega \angle -71.16^\circ}$

b. $\mathbf{V}_2 = \mathbf{I}(2.4 \Omega \angle 53.13^\circ) = (5 \text{ A} \angle 0^\circ)(2.4 \Omega \angle 53.13^\circ) = \mathbf{12 \text{ V} \angle 53.13^\circ}$
 $\mathbf{I}_L = \frac{(4 \Omega \angle 0^\circ)(\mathbf{I})}{4\Omega + j3\Omega} = \frac{(4 \Omega \angle 0^\circ)(5 \text{ A} \angle 0^\circ)}{5 \Omega \angle 36.87^\circ} = \frac{20 \text{ A} \angle 0^\circ}{5 \angle 36.87^\circ} = \mathbf{4 \text{ A} \angle -36.87^\circ}$

c. $F_p = \frac{R}{\mathbf{Z}_T} = \frac{3.44 \Omega}{10.65 \Omega} = \mathbf{0.323 \text{ (leading)}}$

5. a. $400 \Omega \angle -90^\circ \parallel 400 \Omega \angle -90^\circ = \frac{400 \Omega \angle -90^\circ}{2} = 200 \Omega \angle -90^\circ$
 $\mathbf{Z}' = 200 \Omega - j200 \Omega = 282.843 \Omega \angle -45^\circ$
 $\mathbf{Z}'' = -j200 \Omega + j560 \Omega = +j360 \Omega = 360 \Omega \angle 90^\circ$
 $\mathbf{Z}_T = \mathbf{Z}' \parallel \mathbf{Z}'' = \frac{(282.843 \Omega \angle -45^\circ)(360 \Omega \angle 90^\circ)}{(200 \Omega - j200 \Omega) + j360 \Omega} = \frac{101.83 \text{ k}\Omega \angle 45^\circ}{256.12 \angle 38.66^\circ}$
 $= 397.59 \Omega \angle 6.34^\circ$
 $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100 \text{ V} \angle 0^\circ}{397.59 \Omega \angle 6.34^\circ} = \mathbf{0.25 \text{ A} \angle -6.34^\circ}$

b. $\mathbf{V}_C = \frac{(200 \Omega \angle -90^\circ)(100 \text{ V} \angle 0^\circ)}{200 \Omega - j200 \Omega} = \frac{20,000 \text{ V} \angle -90^\circ}{282.843 \angle -45^\circ} = \mathbf{70.71 \text{ V} \angle -45^\circ}$

c. $P = EI \cos \theta = (100 \text{ V})(0.25 \text{ A}) \cos 6.34^\circ$
 $= (25)(0.994) = \mathbf{24.85 \text{ W}}$

6. a. $\mathbf{Z}_1 = 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ$
 $\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{120 \text{ V} \angle 60^\circ}{5 \Omega \angle 53.13^\circ} = 24 \text{ A} \angle 6.87^\circ$

b. $\mathbf{V}_C = \frac{(13 \Omega \angle -90^\circ)(120 \text{ V} \angle 60^\circ)}{-j13 \Omega + j7 \Omega} = \frac{1560 \text{ V} \angle -30^\circ}{6 \angle -90^\circ} = 260 \text{ V} \angle 60^\circ$
c. $V_{R_1} = (I_1 \angle \theta)R \angle 0^\circ = (24 \text{ A} \angle 6.87^\circ)(3 \Omega \angle 0^\circ) = 72 \text{ V} \angle 6.87^\circ$
 $\mathbf{V}_{ab} + V_{R_1} - \mathbf{V}_C = 0$
 $\mathbf{V}_{ab} = \mathbf{V}_C - V_{R_1} = 260 \text{ V} \angle 60^\circ - 72 \text{ V} \angle 6.87^\circ$
 $= (130 \text{ V} + j225.167 \text{ V}) - (71.483 \text{ V} + j8.612 \text{ V})$
 $= 58.52 \text{ V} + j216.56 \text{ V} = 224.33 \text{ V} \angle 74.88^\circ$

7. a.

$\mathbf{Z}_1 = 10 \Omega \angle 0^\circ$
 $\mathbf{Z}_2 = 80 \Omega \angle 90^\circ \parallel 20 \Omega \angle 0^\circ$
 $= \frac{1600 \Omega \angle 90^\circ}{20 + j80} = \frac{1600 \Omega \angle 90^\circ}{82.462 \angle 75.964^\circ}$
 $= 19.403 \Omega \angle 14.036^\circ$
 $\mathbf{Z}_3 = 60 \Omega \angle -90^\circ$

$$\begin{aligned}\mathbf{Z}_T &= (\mathbf{Z}_1 + \mathbf{Z}_2) \parallel \mathbf{Z}_3 \\ &= (10 \Omega + 18.824 \Omega + j4.706 \Omega) \parallel 60 \Omega \angle -90^\circ \\ &= 29.206 \Omega \angle 9.273^\circ \parallel 6 \Omega \angle -90^\circ = \frac{1752.36 \Omega \angle -80.727^\circ}{28.824 + j4.706 - j60} \\ &= \frac{1752.36 \Omega \angle -80.727^\circ}{62.356 \angle -62.468^\circ} = 28.103 \Omega \angle -18.259^\circ \\ \mathbf{I}_1 &= \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{40 \text{ V} \angle 0^\circ}{28.103 \Omega \angle -18.259^\circ} = 1.42 \text{ A} \angle 18.26^\circ\end{aligned}$$

b. $\mathbf{V}_1 = \frac{\mathbf{Z}_2 \mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(19.403 \Omega \angle 14.036^\circ)(40 \text{ V} \angle 0^\circ)}{29.206 \Omega \angle 9.273^\circ} = \frac{776.12 \text{ V} \angle 14.036^\circ}{29.206 \angle 9.273^\circ}$
 $= 26.57 \text{ V} \angle 4.76^\circ$

c. $P = EI \cos \theta = (40 \text{ V})(1.423 \text{ A}) \cos 18.259^\circ$
 $= 54.07 \text{ W}$

8. a. $\mathbf{Z}_1 = 2 \Omega + j1 \Omega = 2.236 \Omega \angle 26.565^\circ$, $\mathbf{Z}_2 = 3 \Omega \angle 0^\circ$

$$\mathbf{Z}_3 = 16 \Omega + j15 \Omega - j7 \Omega = 16 \Omega + j8 \Omega = 17.889 \Omega \angle 26.565^\circ$$

$$\begin{aligned}\mathbf{Y}_T &= \frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} = \frac{1}{2.236 \Omega \angle 26.565^\circ} + \frac{1}{3 \Omega \angle 0^\circ} + \frac{1}{17.889 \Omega \angle 26.565^\circ} \\ &= 0.447 \text{ S} \angle -26.565^\circ + 0.333 \text{ S} \angle 0^\circ + 0.056 \text{ S} \angle -26.565^\circ \\ &= (0.4 \text{ S} - j0.2 \text{ S}) + (0.333 \text{ S}) + (0.05 \text{ S} - j0.025 \text{ S}) \\ &= 0.783 \text{ S} - j0.225 \text{ S} = \mathbf{0.82 \text{ S} \angle -16.03^\circ}\end{aligned}$$

$$\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{0.82 \text{ S} \angle -16.03^\circ} = \mathbf{1.23 \Omega \angle 16.03^\circ}$$

b. $\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{60 \text{ V} \angle 0^\circ}{2.236 \Omega \angle 26.565^\circ} = \mathbf{26.83 \text{ A} \angle -26.57^\circ}$

$$\mathbf{I}_2 = \frac{\mathbf{E}}{\mathbf{Z}_2} = \frac{60 \text{ V} \angle 0^\circ}{3 \Omega \angle 0^\circ} = \mathbf{20 \text{ A} \angle 0^\circ}$$

$$\mathbf{I}_3 = \frac{\mathbf{E}}{\mathbf{Z}_3} = \frac{60 \text{ V} \angle 0^\circ}{17.889 \Omega \angle 26.565^\circ} = \mathbf{3.35 \text{ A} \angle -26.57^\circ}$$

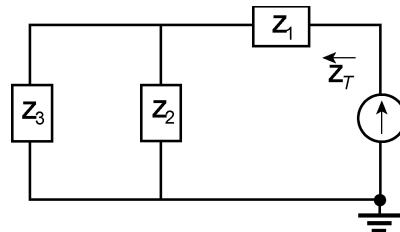
c. $\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60 \text{ V} \angle 0^\circ}{1.227 \Omega \angle 16.032^\circ} = \mathbf{48.9 \text{ A} \angle -16.03^\circ}$

$$\mathbf{I}_s = \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3$$

$$\begin{aligned}48.9 \text{ A} \angle -16.03^\circ &\stackrel{?}{=} 26.83 \text{ A} \angle -26.57^\circ + 20 \text{ A} \angle 0^\circ + 3.35 \text{ A} \angle -26.57^\circ \\ &= (24 \text{ A} - j12 \text{ A}) + (20 \text{ A}) + (3 \text{ A} - j1.5 \text{ A}) \\ &\stackrel{\checkmark}{=} 47 \text{ A} + j13.5 \text{ A} = \mathbf{48.9 \text{ A} \angle -16.03^\circ} \text{ (checks)}$$

d. $F_p = \frac{G}{Y_T} = \frac{0.783 \text{ S}}{0.820 \text{ S}} = \mathbf{0.955 \text{ (lagging)}}$

9. a.



$$\mathbf{Z}' = 3 \Omega \angle 0^\circ \parallel 4 \Omega \angle -90^\circ = \frac{12 \Omega \angle -90^\circ}{3 - j4}$$

$$= \frac{12 \Omega \angle -90^\circ}{5 \angle -53.13^\circ} = 2.4 \Omega \angle -36.87^\circ$$

$$\begin{aligned}\mathbf{Z}_3 &= 2 \mathbf{Z}' + j7 \Omega \\ &= 4.8 \Omega \angle -36.87^\circ + j7 \Omega \\ &= 3.84 \Omega - j2.88 \Omega + j7 \Omega \\ &= 3.84 \Omega + j4.12 \Omega \\ &= 5.63 \Omega \angle 47.02^\circ\end{aligned}$$

$$\begin{aligned}
\mathbf{Z}_T &= \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3 = 8.8 \Omega + 8.2 \Omega \angle 0^\circ \parallel 5.63 \Omega \angle 47.02^\circ \\
&= 8.8 \Omega + \frac{46.18 \Omega \angle 47.02^\circ}{8.2 + 3.84 + j4.12} = 8.8 \Omega + \frac{46.18 \Omega \angle 47.02^\circ}{12.73 \angle 18.89^\circ} \\
&= 8.8 \Omega + 3.63 \Omega \angle 28.13^\circ = 8.8 \Omega + 3.20 \Omega + j1.71 \Omega \\
&= 12 \Omega + j1.71 \Omega = \mathbf{12.12 \Omega \angle 8.11^\circ} \\
\mathbf{Y}_T &= \frac{1}{\mathbf{Z}_T} = \mathbf{82.51 \text{ mS} \angle -8.11^\circ}
\end{aligned}$$

b. $\mathbf{V}_1 = \mathbf{I}\mathbf{Z}_1 = (3 \text{ A} \angle 30^\circ)(6.8 \Omega \angle 0^\circ) = \mathbf{20.4 \text{ V} \angle 30^\circ}$
 $\mathbf{V}_2 = \mathbf{I}(\mathbf{Z}_2 \parallel \mathbf{Z}_3) = (3 \text{ A} \angle 30^\circ)(3.63 \Omega \angle 28.13^\circ) = \mathbf{10.89 \text{ V} \angle 58.13^\circ}$

c. $\mathbf{I}_3 = \frac{\mathbf{V}_2}{\mathbf{Z}_3} = \frac{10.89 \text{ V} \angle 58.13^\circ}{5.63 \Omega \angle 47.02^\circ} = \mathbf{1.93 \text{ A} \angle 11.11^\circ}$

10. a. $X_{L_1} = \omega L_1 = 2\pi(10^3 \text{ Hz})(0.1 \text{ H}) = 628 \Omega$
 $X_{L_2} = \omega L_2 = 2\pi(10^3 \text{ Hz})(0.2 \text{ H}) = 1.256 \text{ k}\Omega$
 $X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3 \text{ Hz})(1 \mu\text{F})} = 0.159 \text{ k}\Omega$
 $\mathbf{Z}_T = R \angle 0^\circ + X_{L_1} \angle 90^\circ + X_C \angle -90^\circ \parallel X_{L_2} \angle 90^\circ$
 $= 300 \Omega + j628 \Omega + 0.159 \text{ k}\Omega \angle -90^\circ \parallel 1.256 \text{ k}\Omega \angle 90^\circ$
 $= 300 \Omega + j628 \Omega - j182 \Omega$
 $= \mathbf{300 \Omega + j446 \Omega = 537.51 \Omega \angle 56.07^\circ}$
 $\mathbf{Y}_T = \frac{1}{\mathbf{Z}_T} = \frac{1}{537.51 \Omega \angle 56.07^\circ} = \mathbf{1.86 \text{ mS} \angle -56.07^\circ}$

b. $\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50 \text{ V} \angle 0^\circ}{537.51 \Omega \angle 56.07^\circ} = \mathbf{93 \text{ mA} \angle -56.07^\circ}$

c. (CDR): $\mathbf{I}_1 = \frac{\mathbf{Z}_{L_2} \mathbf{I}_s}{\mathbf{Z}_{L_2} + \mathbf{Z}_C} = \frac{(1.256 \text{ k}\Omega \angle 90^\circ)(93 \text{ mA} \angle -56.07^\circ)}{+j1.256 \text{ k}\Omega - j0.159 \text{ k}\Omega}$
 $= \frac{116.81 \text{ mA} \angle 33.93^\circ}{1.097 \angle 90^\circ} = \mathbf{106.48 \text{ mA} \angle -56.07^\circ}$
 $\mathbf{I}_2 = \frac{\mathbf{Z}_C \mathbf{I}_s}{\mathbf{Z}_{L_2} + \mathbf{Z}_C} = \frac{(0.159 \text{ k}\Omega \angle -90^\circ)(93 \text{ mA} \angle -56.07^\circ)}{1.097 \text{ k}\Omega \angle 90^\circ}$
 $= \frac{14.79 \text{ mA} \angle -146.07^\circ}{1.097 \angle 90^\circ} = 13.48 \text{ mA} \angle -236.07^\circ$
 $= \mathbf{13.48 \text{ mA} \angle 123.93^\circ}$

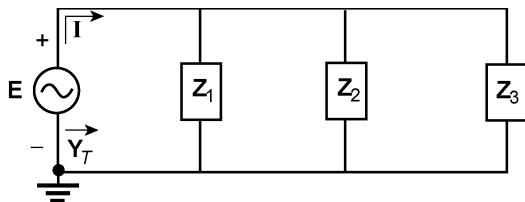
d. $\mathbf{V}_1 = (I_2 \angle \theta)(X_{L_2} \angle 90^\circ) = (13.48 \text{ mA} \angle 123.92^\circ)(1.256 \text{ k}\Omega \angle 90^\circ)$
 $= 16.93 \text{ V} \angle 213.93^\circ$

$$\begin{aligned}\mathbf{V}_{ab} &= \mathbf{E} - (I_s \angle \theta)(R \angle 0^\circ) = 50 \text{ V} \angle 0^\circ - (93 \text{ mA} \angle -56.07^\circ)(300 \Omega \angle 0^\circ) \\ &= 50 \text{ V} - 27.9 \text{ V} \angle -56.07^\circ \\ &= 50 \text{ V} - (15.573 \text{ V} - j23.149 \text{ V}) \\ &= 34.43 \text{ V} + j23.149 \text{ V} = 41.49 \text{ V} \angle 33.92^\circ\end{aligned}$$

e. $P = I_s^2 R = (93 \text{ mA})^2 300 \Omega = 2.595 \text{ W}$

f. $F_p = \frac{R}{Z_T} = \frac{300 \Omega}{537.51 \Omega} = 0.558 \text{ (lagging)}$

11.



$$\begin{aligned}\mathbf{Z}_1 &= 2 \Omega - j2 \Omega = 2.828 \Omega \angle -45^\circ \\ \mathbf{Z}_2 &= 3 \Omega - j9 \Omega + j6 \Omega \\ &= 3 \Omega - j3 \Omega = 4.243 \Omega \angle -45^\circ \\ \mathbf{Z}_3 &= 10 \Omega \angle 0^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{Y}_T &= \frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} = \frac{1}{2.828 \Omega \angle -45^\circ} + \frac{1}{4.243 \Omega \angle -45^\circ} + \frac{1}{10 \Omega \angle 0^\circ} \\ &= 0.354 \text{ S} \angle 45^\circ + 0.236 \text{ S} \angle 45^\circ + 0.1 \text{ S} \angle 0^\circ = 0.59 \text{ S} \angle 45^\circ + 0.1 \text{ S} \angle 0^\circ \\ &= 0.417 \text{ S} + j0.417 \text{ S} + 0.1 \text{ S}\end{aligned}$$

$$\mathbf{Y}_T = 0.517 \text{ S} + j0.417 \text{ S} = 0.66 \text{ S} \angle 38.89^\circ$$

$$\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{0.66 \text{ S} \angle 38.89^\circ} = 1.52 \Omega \angle -38.89^\circ$$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50 \text{ V} \angle 0^\circ}{1.52 \Omega \angle -38.89^\circ} = 32.89 \text{ A} \angle 38.89^\circ$$

12. $\mathbf{Z}' = 12 \Omega - j20 \Omega = 23.32 \Omega \angle -59.04^\circ$

$$X_L \angle 90^\circ \parallel \mathbf{Z}' = 20 \Omega \angle 90^\circ \parallel 23.32 \Omega \angle -59.04^\circ = 33.34 \Omega \angle 19.99^\circ$$

$$\begin{aligned}\mathbf{Z}'' &= R_3 \angle 0^\circ + X_L \angle 90^\circ \parallel \mathbf{Z}' = 12 \Omega + 33.34 \Omega \angle 19.99^\circ \\ &= 12 \Omega + (31.33 \Omega - j11.40 \Omega) \\ &= 43.33 \Omega - j11.40 \Omega = 44.80 \Omega \angle 14.74^\circ\end{aligned}$$

$$R_2 \angle 0^\circ \parallel \mathbf{Z}'' = 20 \Omega \angle 0^\circ \parallel 44.80 \Omega \angle 14.74^\circ = 13.93 \Omega \angle 4.54^\circ$$

$$\begin{aligned}\mathbf{Z}_T &= R_1 \angle 0^\circ + R_2 \angle 0^\circ \parallel \mathbf{Z}'' = 12 \Omega + 13.93 \angle 4.54^\circ \\ &= 12 \Omega + (13.89 \Omega + j1.10 \Omega) \\ &= 25.89 \Omega + j1.10 \Omega = 25.91 \Omega \angle 2.43^\circ\end{aligned}$$

$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100 \text{ V} \angle 0^\circ}{25.91 \Omega \angle 2.43^\circ} = 3.86 \text{ A} \angle -2.43^\circ$$

$$\mathbf{I}_{R_1} = \mathbf{I}$$

$$\begin{aligned}\mathbf{I}_{R_3} &= \frac{R_2 \angle 0^\circ \mathbf{I}_s}{R_2 \angle 0^\circ + \mathbf{Z}''} = \frac{(20 \Omega \angle 0^\circ)(3.86 \text{ A} \angle -2.43^\circ)}{\underbrace{20 \Omega + 43.33 \Omega}_{63.33 \Omega} + j11.40 \Omega} = \frac{77.20 \text{ A} \angle -2.43^\circ}{64.35 \angle 10.20^\circ} \\ &= 1.20 \text{ A} \angle -12.63^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{I}_4 &= \frac{X_L \angle 90^\circ \mathbf{I}_{R_3}}{X_L \angle 90^\circ + \mathbf{Z}'} = \frac{(20 \Omega \angle 90^\circ)(1.20 \text{ A} \angle -12.63^\circ)}{j20 \Omega + 12 \Omega - j20 \Omega} = \frac{24.00 \text{ A} \angle 77.37^\circ}{12 \angle 0^\circ} \\ &= \mathbf{2.00 \text{ A} \angle 77.37^\circ}\end{aligned}$$

13. $R_3 + R_4 = 2.7 \text{ k}\Omega + 4.3 \text{ k}\Omega = 7 \text{ k}\Omega$
 $R' = 3 \text{ k}\Omega \parallel 7 \text{ k}\Omega = 2.1 \text{ k}\Omega$
 $\mathbf{Z}' = 2.1 \text{ k}\Omega - j10 \Omega$

$$\begin{aligned}(\text{CDR}) \quad \mathbf{I}' \text{ (of } 10 \Omega \text{ cap.)} &= \frac{(40 \text{ k}\Omega \angle 0^\circ)(20 \text{ mA} \angle 0^\circ)}{40 \text{ k}\Omega + 2.1 \text{ k}\Omega - j10 \Omega} \\ &= 19 \text{ mA} \angle +0.014^\circ \text{ as expected since } R_1 \gg \mathbf{Z}'\end{aligned}$$

$$\begin{aligned}(\text{CDR}) \quad \mathbf{I}_4 &= \frac{(3 \text{ k}\Omega \angle 0^\circ)(19 \text{ mA} \angle 0.014^\circ)}{3 \text{ k}\Omega + 7 \text{ k}\Omega} = \frac{57 \text{ mA} \angle 0.014^\circ}{10} \\ &= 5.7 \text{ mA} \angle 0.014^\circ \\ P &= I^2 R = (5.7 \text{ mA})^2 4.3 \text{ k}\Omega = \mathbf{139.71 \text{ mW}}\end{aligned}$$

14. $\mathbf{Z}' = X_{C_2} \angle -90^\circ \parallel R_1 \angle 0^\circ = 2 \Omega \angle -90^\circ \parallel 1 \Omega \angle 0^\circ$
 $= \frac{2 \Omega \angle -90^\circ}{1 - j2} = \frac{2 \Omega \angle -90^\circ}{2.236 \angle -63.435^\circ}$
 $= 0.894 \Omega \angle -26.565^\circ$
 $\mathbf{Z}'' = X_{L_2} \angle 90^\circ + \mathbf{Z}' = +j8 \Omega + 0.894 \Omega \angle -26.565^\circ$
 $= +j8 \Omega + (0.8 \Omega - j4 \Omega)$
 $= 0.8 \Omega + j4 = 4.079 \Omega \angle 78.69^\circ$

$$\begin{aligned}\mathbf{I}_{X_{L_2}} &= \frac{X_{C_1} \angle -90^\circ \mathbf{I}}{X_{C_1} \angle -90^\circ + \mathbf{Z}''} = \frac{(2 \Omega \angle -90^\circ)(0.5 \text{ A} \angle 0^\circ)}{-j2 \Omega + (0.8 \Omega + j4 \Omega)} = \frac{1 \text{ A} \angle -90^\circ}{0.8 + j2} \\ &= \frac{1 \text{ A} \angle -90^\circ}{2.154 \angle 68.199^\circ} = 0.464 \text{ A} \angle -158.99^\circ \\ \mathbf{I}_1 &= \frac{X_{C_2} \angle -90^\circ \mathbf{I}_{X_{C_2}}}{X_{C_2} \angle -90^\circ + R_1} = \frac{(2 \Omega \angle -90^\circ)(0.464 \text{ A} \angle -158.99^\circ)}{-j2 \Omega + 1 \Omega} = \frac{0.928 \text{ A} \angle -248.99^\circ}{2.236 \angle -63.435^\circ} \\ &= \mathbf{0.42 \text{ A} \angle 174.45^\circ}\end{aligned}$$

Chapter 17

1. —

2. a. $\mathbf{Z} = 2.2 \Omega + 5.6 \Omega + j8.2 \Omega = 7.8 \Omega + j8.2 \Omega = 11.32 \Omega \angle 46.43^\circ$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{20 \text{ V} \angle 20^\circ}{11.32 \Omega \angle 46.43^\circ} = 1.77 \text{ A} \angle -26.43^\circ$$

b. $\mathbf{Z} = -j5 \Omega + 2 \Omega \angle 0^\circ \parallel 5 \Omega \angle 90^\circ = -j5 \Omega + 1.72 \Omega + j0.69 \Omega = 4.64 \Omega \angle -68.24^\circ$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{60 \text{ V} \angle 30^\circ}{4.64 \Omega \angle -68.24^\circ} = 12.93 \text{ A} \angle 98.24^\circ$$

3. a. $\mathbf{Z} = 15 \Omega - j16 \Omega = 21.93 \Omega \angle -46.85^\circ$

$$\mathbf{E} = \mathbf{IZ} = (0.5 \text{ A} \angle 60^\circ)(21.93 \Omega \angle -46.85^\circ) = 10.97 \text{ V} \angle 13.15^\circ$$

b. $\mathbf{Z} = 10 \Omega \angle 0^\circ \parallel 6 \Omega \angle 90^\circ = 5.15 \Omega \angle 59.04^\circ$

$$\mathbf{E} = \mathbf{IZ} = (2 \text{ A} \angle 120^\circ)(5.15 \Omega \angle 59.04^\circ) = 10.30 \text{ V} \angle 179.04^\circ$$

4. a. $\mathbf{I} = \frac{\mu \mathbf{V}}{R} = \frac{16 \text{ V}}{4 \times 10^3} = 4 \times 10^{-3} \text{ A}$

$$\mathbf{Z} = 4 \text{ k}\Omega \angle 0^\circ$$

b. $\mathbf{V} = (h\mathbf{I})(R) = (50 \text{ I})(50 \text{ k}\Omega) = 2.5 \times 10^6 \text{ I}$

$$\mathbf{Z} = 50 \text{ k}\Omega \angle 0^\circ$$

5. a. Clockwise mesh currents:

$$\begin{aligned} \mathbf{E} - \mathbf{I}_1 \mathbf{Z}_1 - \mathbf{I}_1 \mathbf{Z}_2 + \mathbf{I}_2 \mathbf{Z}_2 &= 0 \\ -\mathbf{I}_2 \mathbf{Z}_2 + \mathbf{I}_1 \mathbf{Z}_2 - \mathbf{I}_2 \mathbf{Z}_3 - \mathbf{E}_2 &= 0 \\ \hline [\mathbf{Z}_1 + \mathbf{Z}_2] \mathbf{I}_1 - \mathbf{Z}_2 \mathbf{I}_2 &= \mathbf{E}_1 \\ -\mathbf{Z}_2 \mathbf{I}_1 + [\mathbf{Z}_2 + \mathbf{Z}_3] \mathbf{I}_2 &= -\mathbf{E}_2 \end{aligned}$$

$$\mathbf{Z}_1 = R_1 \angle 0^\circ = 4 \Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = X_L \angle 90^\circ = 6 \Omega \angle 90^\circ$$

$$\mathbf{Z}_3 = X_C \angle -90^\circ = 8 \Omega \angle -90^\circ$$

$$\mathbf{E}_1 = 10 \text{ V} \angle 0^\circ, \mathbf{E}_2 = 40 \text{ V} \angle 60^\circ$$

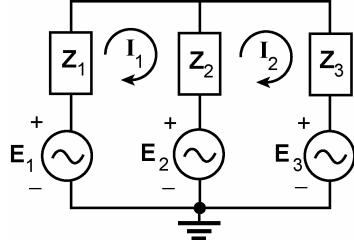
$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\begin{vmatrix} \mathbf{E}_1 & -\mathbf{Z}_2 \\ -\mathbf{E}_2 & [\mathbf{Z}_2 + \mathbf{Z}_3] \end{vmatrix}}{\begin{vmatrix} [\mathbf{Z}_1 + \mathbf{Z}_2] & -\mathbf{Z}_2 \\ -\mathbf{Z}_2 & [\mathbf{Z}_2 + \mathbf{Z}_3] \end{vmatrix}} = \frac{[\mathbf{Z}_2 + \mathbf{Z}_3] \mathbf{E}_1 - \mathbf{Z}_2 \mathbf{E}_2}{\mathbf{Z}_1 \mathbf{Z}_2 + \mathbf{Z}_1 \mathbf{Z}_3 + \mathbf{Z}_2 \mathbf{Z}_3} = 5.15 \text{ A} \angle -24.5^\circ$$

- b. By interchanging the right two branches, the general configuration of part (a) will result and

$$\begin{aligned}\mathbf{I}_{50\Omega} &= \mathbf{I}_1 = \frac{[\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{E}_1 - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} \\ &= 0.44 \text{ A } \angle 143.48^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{Z}_1 &= R_1 = 50 \Omega \angle 0^\circ \\ \mathbf{Z}_2 &= X_C \angle -90^\circ = 60 \Omega \angle -90^\circ \\ \mathbf{Z}_3 &= X_L \angle 90^\circ = 20 \Omega \angle 90^\circ \\ \mathbf{E}_1 &= 5 \text{ V } \angle 30^\circ, \mathbf{E}_2 = 20 \text{ V } \angle 0^\circ\end{aligned}$$

6. a.



$$\begin{aligned}\mathbf{Z}_1 &= 12 \Omega + j12 \Omega = 16.971 \Omega \angle 45^\circ \\ \mathbf{Z}_2 &= 3 \Omega \angle 0^\circ \\ \mathbf{Z}_3 &= -j1 \Omega \\ \mathbf{E}_1 &= 20 \text{ V } \angle 50^\circ \\ \mathbf{E}_2 &= 60 \text{ V } \angle 70^\circ \\ \mathbf{E}_3 &= 40 \text{ V } \angle 0^\circ\end{aligned}$$

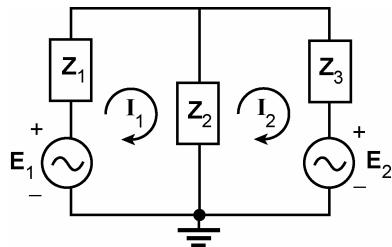
$$\begin{aligned}\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_2] - \mathbf{Z}_2\mathbf{I}_2 &= \mathbf{E}_1 - \mathbf{E}_2 \\ \mathbf{I}_2[\mathbf{Z}_2 + \mathbf{Z}_3] - \mathbf{Z}_2\mathbf{I}_1 &= \mathbf{E}_2 - \mathbf{E}_3\end{aligned}$$

$$\begin{aligned}(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 &= \mathbf{E}_1 - \mathbf{E}_2 \\ -\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 &= \mathbf{E}_2 - \mathbf{E}_3\end{aligned}$$

Using determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{(\mathbf{E}_1 - \mathbf{E}_2)(\mathbf{Z}_2 + \mathbf{Z}_3) + \mathbf{Z}_2(\mathbf{E}_2 - \mathbf{E}_3)}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = 2.55 \text{ A } \angle 132.72^\circ$$

b.



Source conversion:

$$\begin{aligned}\mathbf{E}_1 &= \mathbf{I}\mathbf{Z} = (6 \text{ A } \angle 0^\circ)(2 \Omega \angle 0^\circ) \\ &= 12 \text{ V } \angle 0^\circ \\ \mathbf{Z}_1 &= 2 \Omega + 20 \Omega + j20 \Omega = 22 \Omega + j20 \Omega \\ &= 29.732 \Omega \angle 42.274^\circ \\ \mathbf{Z}_2 &= -j10 \Omega = 10 \Omega \angle -90^\circ \\ \mathbf{Z}_3 &= 10 \Omega \angle 0^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_2] - \mathbf{Z}_2\mathbf{I}_2 &= \mathbf{E}_1 \\ \mathbf{I}_2[\mathbf{Z}_2 + \mathbf{Z}_3] - \mathbf{Z}_2\mathbf{I}_1 &= -\mathbf{E}_2\end{aligned}$$

$$\begin{aligned}(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 &= \mathbf{E}_1 \\ -\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 &= -\mathbf{E}_2\end{aligned}$$

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\mathbf{E}_1(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = 0.495 \text{ A } \angle 72.26^\circ$$

7. a. Clockwise mesh currents:

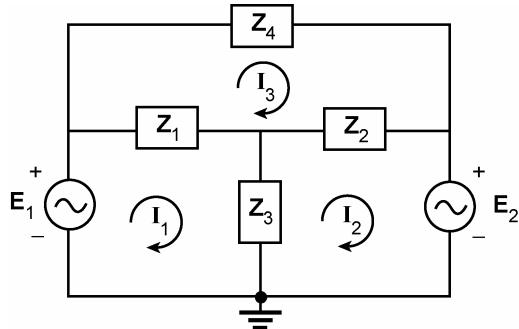
$$\begin{aligned} \mathbf{E}_1 - \mathbf{I}_1 \mathbf{Z}_1 - \mathbf{I}_1 \mathbf{Z}_2 + \mathbf{I}_2 \mathbf{Z}_2 &= 0 \\ -\mathbf{I}_2 \mathbf{Z}_2 + \mathbf{I}_1 \mathbf{Z}_2 - \mathbf{I}_2 \mathbf{Z}_3 - \mathbf{I}_2 \mathbf{Z}_4 + \mathbf{I}_3 \mathbf{Z}_4 &= 0 \\ -\mathbf{I}_3 \mathbf{Z}_4 + \mathbf{I}_2 \mathbf{Z}_4 - \mathbf{I}_3 \mathbf{Z}_5 - \mathbf{E}_2 &= 0 \end{aligned}$$

$$\begin{aligned} \mathbf{Z}_1 &= 4 \Omega + j3 \Omega, \mathbf{Z}_2 = -j1 \Omega \\ \mathbf{Z}_3 &= +j6 \Omega, \mathbf{Z}_4 = !j2 \Omega \\ \mathbf{Z}_5 &= 8 \Omega \\ \mathbf{E}_1 &= 60 \text{ V} \angle 0^\circ, \mathbf{E}_2 = 120 \text{ V} \angle 120^\circ \end{aligned}$$

$$\begin{array}{l} [\mathbf{Z}_1 + \mathbf{Z}_2] \mathbf{I}_1 - \mathbf{Z}_2 \mathbf{I}_2 + 0 = \mathbf{E}_1 \\ -\mathbf{Z}_2 \mathbf{I}_1 + [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4] \mathbf{I}_2 - \mathbf{Z}_4 \mathbf{I}_3 = 0 \\ 0 - \mathbf{Z}_4 \mathbf{I}_2 + [\mathbf{Z}_4 + \mathbf{Z}_5] \mathbf{I}_3 = -\mathbf{E}_2 \end{array}$$

$$\begin{aligned} \mathbf{I}_{R_1} = \mathbf{I}_3 &= \frac{[\mathbf{Z}_2 \mathbf{Z}_4] \mathbf{E}_1 + [\mathbf{Z}_2^2 - [\mathbf{Z}_1 + \mathbf{Z}_2] [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4]] \mathbf{E}_2}{[\mathbf{Z}_1 + \mathbf{Z}_2][\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4][\mathbf{Z}_4 + \mathbf{Z}_5] - [\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{Z}_4^2 - [\mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{Z}_2^2} \\ &= 13.07 \text{ A} \angle -33.71^\circ \end{aligned}$$

b.



$$\begin{aligned} \mathbf{Z}_1 &= 15 \Omega \angle 0^\circ, \mathbf{Z}_2 = 15 \Omega \angle 0^\circ \\ \mathbf{Z}_3 &= -j10 \Omega = 10 \Omega \angle -90^\circ \\ \mathbf{Z}_4 &= 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ \\ \mathbf{E}_1 &= 220 \text{ V} \angle 0^\circ \\ \mathbf{E}_2 &= 100 \text{ V} \angle 90^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_3) - \mathbf{I}_2 \mathbf{Z}_3 - \mathbf{I}_3 \mathbf{Z}_1 &= \mathbf{E}_1 \\ \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{I}_1 \mathbf{Z}_3 - \mathbf{I}_3 \mathbf{Z}_2 &= -\mathbf{E}_2 \\ \mathbf{I}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_1 \mathbf{Z}_1 - \mathbf{I}_2 \mathbf{Z}_2 &= 0 \end{aligned}$$

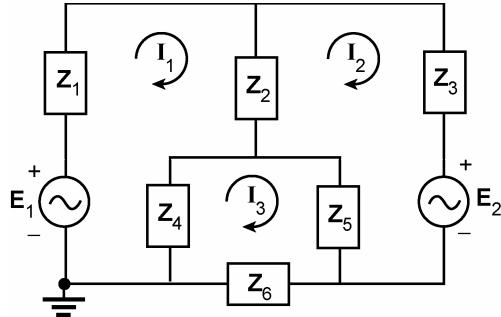
$$\begin{array}{lll} \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_3) - \mathbf{I}_2 \mathbf{Z}_3 - \mathbf{I}_3 \mathbf{Z}_1 & - \mathbf{I}_3 \mathbf{Z}_1 & = \mathbf{E}_1 \\ -\mathbf{I}_1 \mathbf{Z}_3 & + \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{I}_3 \mathbf{Z}_2 & = -\mathbf{E}_2 \\ -\mathbf{I}_1 \mathbf{Z}_1 & - \mathbf{I}_2 \mathbf{Z}_2 & + \mathbf{I}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) = 0 \end{array}$$

Applying determinants:

$$\begin{aligned} \mathbf{I}_3 &= \frac{-(\mathbf{Z}_1 + \mathbf{Z}_3)(\mathbf{Z}_2)\mathbf{E}_2 - \mathbf{Z}_1 \mathbf{Z}_3 \mathbf{E}_2 + \mathbf{E}_1 [\mathbf{Z}_2 \mathbf{Z}_3 + \mathbf{Z}_1 (\mathbf{Z}_2 + \mathbf{Z}_3)]}{(\mathbf{Z}_1 + \mathbf{Z}_3)[(\mathbf{Z}_2 + \mathbf{Z}_3)(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{Z}_2^2] + \mathbf{Z}_3 [\mathbf{Z}_3 (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{Z}_1 \mathbf{Z}_2] - \mathbf{Z}_1 [-\mathbf{Z}_2 \mathbf{Z}_3 - \mathbf{Z}_1 (\mathbf{Z}_2 + \mathbf{Z}_3)]} \\ &= 48.33 \text{ A} \angle -77.57^\circ \end{aligned}$$

or $\mathbf{I}_3 = \frac{\mathbf{E}_1 - \mathbf{E}_2}{\mathbf{Z}_4}$ if one carefully examines the network!

8. a.



$$\begin{aligned} \mathbf{Z}_1 &= 5 \Omega \angle 0^\circ, \mathbf{Z}_2 = 5 \Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 4 \Omega \angle 0^\circ, \mathbf{Z}_4 = 6 \Omega \angle -90^\circ \\ \mathbf{Z}_5 &= 4 \Omega \angle 0^\circ, \mathbf{Z}_6 = 6 \Omega + j8 \Omega \\ \mathbf{E}_1 &= 20 \text{ V} \angle 0^\circ, \mathbf{E}_2 = 40 \text{ V} \angle 60^\circ \end{aligned}$$

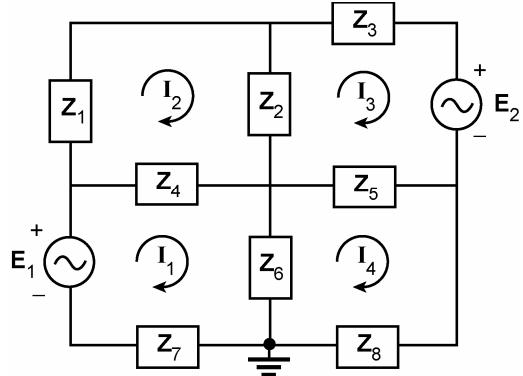
$$\begin{aligned} \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_3\mathbf{Z}_4 &= \mathbf{E}_1 \\ \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5) - \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_3\mathbf{Z}_5 &= -\mathbf{E}_2 \\ \mathbf{I}_3(\mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6) - \mathbf{I}_1\mathbf{Z}_4 - \mathbf{I}_2\mathbf{Z}_5 &= 0 \end{aligned}$$

$$\begin{array}{l} (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 - \mathbf{Z}_4\mathbf{I}_3 = \mathbf{E}_1 \\ -\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5)\mathbf{I}_2 - \mathbf{Z}_5\mathbf{I}_3 = -\mathbf{E}_2 \\ -\mathbf{Z}_4\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_2 + (\mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6)\mathbf{I}_3 = 0 \end{array}$$

Using $\mathbf{Z}' = \mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4$, $\mathbf{Z}'' = \mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5$, $\mathbf{Z}''' = \mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6$ and determinants:

$$\begin{aligned} \mathbf{I}_{R_1} = \mathbf{I}_1 &= \frac{\mathbf{E}_1(\mathbf{Z}''\mathbf{Z}''' - \mathbf{Z}_5^2) - \mathbf{E}_2(\mathbf{Z}_2\mathbf{Z}''' + \mathbf{Z}_4\mathbf{Z}_5)}{\mathbf{Z}'(\mathbf{Z}''\mathbf{Z}''' - \mathbf{Z}_5^2) - \mathbf{Z}_2(\mathbf{Z}_2\mathbf{Z}''' + \mathbf{Z}_4\mathbf{Z}_5) - \mathbf{Z}_4(\mathbf{Z}_2\mathbf{Z}_5 + \mathbf{Z}_4\mathbf{Z}')} \\ &= 3.04 \text{ A} \angle 169.12^\circ \end{aligned}$$

b.



$$\begin{aligned} \mathbf{Z}_1 &= 10 \Omega + j20 \Omega & \mathbf{Z}_2 &= -j20 \Omega \\ \mathbf{Z}_3 &= 80 \Omega \angle 0^\circ & \mathbf{Z}_4 &= 6 \Omega \angle 0^\circ \\ \mathbf{Z}_5 &= 15 \Omega \angle 90^\circ & \mathbf{Z}_6 &= 10 \Omega \angle 0^\circ \\ \mathbf{Z}_7 &= 5 \Omega \angle 0^\circ & \mathbf{Z}_8 &= 5 \Omega - j20 \Omega \\ \mathbf{E}_1 &= 25 \text{ V} \angle 0^\circ & \mathbf{E}_2 &= 75 \text{ V} \angle 20^\circ \end{aligned}$$

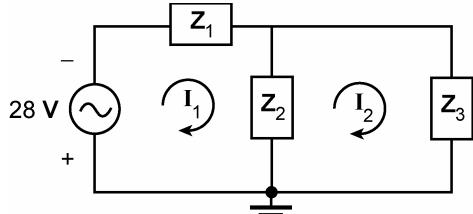
$$\begin{aligned} \mathbf{I}_1(\mathbf{Z}_4 + \mathbf{Z}_6 + \mathbf{Z}_7) - \mathbf{I}_2\mathbf{Z}_4 - \mathbf{I}_4\mathbf{Z}_6 &= \mathbf{E}_1 \\ \mathbf{I}_2(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_1\mathbf{Z}_4 - \mathbf{I}_3\mathbf{Z}_2 &= 0 \\ \mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5) - \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_4\mathbf{Z}_5 &= -\mathbf{E}_2 \\ \mathbf{I}_4(\mathbf{Z}_5 + \mathbf{Z}_6 + \mathbf{Z}_8) - \mathbf{I}_1\mathbf{Z}_6 - \mathbf{I}_3\mathbf{Z}_5 &= 0 \end{aligned}$$

$$\begin{array}{l} (\mathbf{Z}_4 + \mathbf{Z}_6 + \mathbf{Z}_7)\mathbf{I}_1 - \mathbf{Z}_4\mathbf{I}_2 + 0 - \mathbf{Z}_6\mathbf{I}_4 = \mathbf{E}_1 \\ -\mathbf{Z}_4\mathbf{I}_1 + (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4)\mathbf{I}_2 - \mathbf{Z}_2\mathbf{I}_3 + 0 = 0 \\ 0 - \mathbf{Z}_2\mathbf{I}_2 + (\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5)\mathbf{I}_3 - \mathbf{Z}_5\mathbf{I}_4 = -\mathbf{E}_2 \\ -\mathbf{Z}_6\mathbf{I}_1 + 0 - \mathbf{Z}_5\mathbf{I}_3 + (\mathbf{Z}_5 + \mathbf{Z}_6 + \mathbf{Z}_8)\mathbf{I}_4 = 0 \end{array}$$

Applying determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_{80\Omega} = 0.68 \text{ A} \angle -162.9^\circ$$

9.



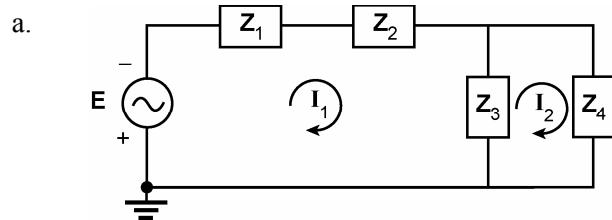
$$\begin{aligned}Z_1 &= 5 \text{ k}\Omega \angle 0^\circ \\Z_2 &= 10 \text{ k}\Omega \angle 0^\circ \\Z_3 &= 1 \text{ k}\Omega + j4 \text{ k}\Omega = 4.123 \text{ k}\Omega \angle 75.96^\circ\end{aligned}$$

$$\begin{aligned}I_1(Z_1 + Z_2) - Z_2 I_2 &= -28 \text{ V} \\I_2(Z_2 + Z_3) - Z_2 I_1 &= 0\end{aligned}$$

$$\begin{aligned}(Z_1 + Z_2)I_1 - Z_2 I_2 &= -28 \text{ V} \\-Z_2 I_1 + (Z_2 + Z_3)I_2 &= 0\end{aligned}$$

$$I_L = I_2 = \frac{-Z_2 28 \text{ V}}{Z_1 Z_2 + Z_1 Z_3 + Z_2 Z_3} = -3.17 \times 10^{-3} \text{ V} \angle 137.29^\circ$$

10.



Source Conversion:

$$\begin{aligned}\mathbf{E} &= (I \angle 0^\circ)(R_p \angle 0^\circ) \\&= (50 \text{ I})(40 \text{ k}\Omega \angle 0^\circ) \\&= 2 \times 10^6 \text{ I} \angle 0^\circ \\Z_1 &= R_s = R_p = 40 \text{ k}\Omega \angle 0^\circ \\Z_2 &= -j0.2 \text{ k}\Omega \\Z_3 &= 8 \text{ k}\Omega \angle 0^\circ \\Z_4 &= 4 \text{ k}\Omega \angle 90^\circ\end{aligned}$$

$$\begin{aligned}I_1(Z_1 + Z_2 + Z_3) - Z_3 I_2 &= -\mathbf{E} \\I_2(Z_3 + Z_4) - Z_3 I_1 &= 0\end{aligned}$$

$$\begin{aligned}(Z_1 + Z_2 + Z_3)I_1 - Z_3 I_2 &= -\mathbf{E} \\-Z_3 I_1 + (Z_3 + Z_4)I_2 &= 0\end{aligned}$$

$$I_L = I_2 = \frac{-Z_3 \mathbf{E}}{(Z_1 + Z_2 + Z_3)(Z_3 + Z_4) - Z_3^2} = 42.91 \text{ I} \angle 149.31^\circ$$

11.

$$\begin{aligned}6V_x - I_1 1 \text{ k}\Omega - 10 \text{ V} \angle 0^\circ &= 0 \\10 \text{ V} \angle 0^\circ - I_2 4 \text{ k}\Omega - I_2 2 \text{ k}\Omega &= 0\end{aligned}$$

$$V_x = I_2 2 \text{ k}\Omega$$

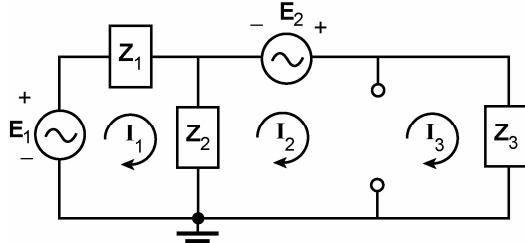
$$\begin{aligned}-I_1 1 \text{ k}\Omega + I_2 12 \text{ k}\Omega &= 10 \text{ V} \angle 0^\circ \\-I_2 6 \text{ k}\Omega &= -10 \text{ V} \angle 0^\circ\end{aligned}$$

$$I_2 = I_{2k\Omega} = \frac{10 \text{ V} \angle 0^\circ}{6 \text{ k}\Omega} = 1.67 \text{ mA} \angle 0^\circ = I_{2k\Omega}$$

$$\begin{aligned}-I_1 1 \text{ k}\Omega + (1.667 \text{ mA} \angle 0^\circ)(12 \text{ k}\Omega) &= 10 \text{ V} \angle 0^\circ \\-I_1 1 \text{ k}\Omega + 20 \text{ V} \angle 0^\circ &= 10 \text{ V} \angle 0^\circ \\-I_1 1 \text{ k}\Omega &= -10 \text{ V} \angle 0^\circ\end{aligned}$$

$$\mathbf{I}_1 = \mathbf{I}_{1k\Omega} = \frac{10 \text{ V} \angle 0^\circ}{1 \text{ k}\Omega} = 10 \text{ mA} \angle 0^\circ$$

12.



$$\begin{aligned} \mathbf{E}_1 - \mathbf{I}_1 \mathbf{Z}_1 - \mathbf{Z}_2(\mathbf{I}_1 - \mathbf{I}_2) &= 0 \\ -\mathbf{Z}_2(\mathbf{I}_2 - \mathbf{I}_1) + \mathbf{E}_2 - \mathbf{I}_3 \mathbf{Z}_3 &= 0 \end{aligned}$$

$$\mathbf{I}_3 - \mathbf{I}_2 = \mathbf{I}$$

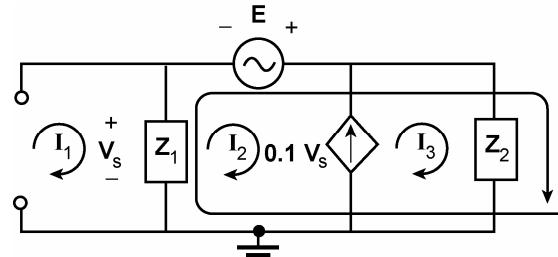
Substituting, we obtain:

$$\begin{aligned} \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2) - \mathbf{I}_2 \mathbf{Z}_2 &= \mathbf{E}_1 \\ \mathbf{I}_1 \mathbf{Z}_2 - \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) &= \mathbf{I} \mathbf{Z}_3 - \mathbf{E}_2 \end{aligned}$$

Determinants:

$$\begin{aligned} \mathbf{I}_1 &= 1.39 \text{ mA} \angle -126.48^\circ, \mathbf{I}_2 = 1.341 \text{ mA} \angle -10.56^\circ, \mathbf{I}_3 = 2.693 \text{ mA} \angle -174.8^\circ \\ \mathbf{I}_{10k\Omega} &= \mathbf{I}_3 = \mathbf{2.693 \text{ mA} \angle -174.8^\circ} \end{aligned}$$

13.



$$\begin{aligned} -\mathbf{Z}_1(\mathbf{I}_2 - \mathbf{I}_1) + \mathbf{E} - \mathbf{I}_3 \mathbf{Z}_3 &= 0 \\ \mathbf{I}_1 &= 6 \text{ mA} \angle 0^\circ, 0.1 \mathbf{V}_s = \mathbf{I}_3 - \mathbf{I}_2, \mathbf{V}_s = (\mathbf{I}_1 - \mathbf{I}_2) \mathbf{Z}_1 \end{aligned}$$

Substituting:

$$\begin{aligned} (1 \text{ k}\Omega) \mathbf{I}_2 + (4 \text{ k}\Omega + j6 \text{ k}\Omega) \mathbf{I}_3 &= 16 \text{ V} \angle 0^\circ \\ (99 \Omega) \mathbf{I}_2 + \mathbf{I}_3 &= 0.6 \text{ V} \angle 0^\circ \end{aligned}$$

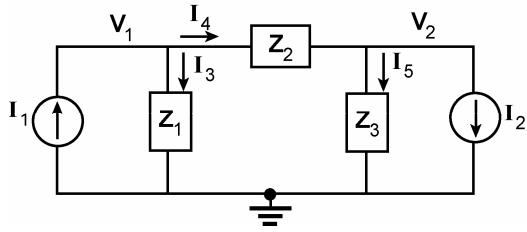
$$\begin{aligned} \mathbf{E}_1 &= 5 \text{ V} \angle 0^\circ \\ \mathbf{E}_2 &= 20 \text{ V} \angle 0^\circ \\ \mathbf{Z}_1 &= 2.2 \text{ k}\Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 5 \text{ k}\Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 10 \text{ k}\Omega \angle 0^\circ \\ \mathbf{I} &= 4 \text{ mA} \angle 0^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Z}_1 &= 1 \text{ k}\Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 4 \text{ k}\Omega + j6 \text{ k}\Omega \\ \mathbf{E} &= 10 \text{ V} \angle 0^\circ \end{aligned}$$

Determinants:

$$\mathbf{I}_3 = \mathbf{I}_{6 \text{ k}\Omega} = \mathbf{1.38 \text{ mA} \angle -56.31^\circ}$$

14. a.



$$\begin{aligned}\mathbf{Z}_1 &= 4 \Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 5 \Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 2 \Omega \angle -90^\circ \\ \mathbf{I}_1 &= 3 \text{ A} \angle 0^\circ \\ \mathbf{I}_2 &= 5 \text{ A} \angle 30^\circ\end{aligned}$$

$$\mathbf{I}_1 = \mathbf{I}_3 + \mathbf{I}_4$$

$$\mathbf{I}_1 = \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} \Rightarrow \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} \right] - \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_2} \right] = \mathbf{I}_1$$

$$\text{or } \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{V}_2[\mathbf{Y}_2] = \mathbf{I}_1$$

$$\mathbf{I}_4 = \mathbf{I}_5 + \mathbf{I}_2$$

$$\frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} = \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \mathbf{I}_2 \Rightarrow \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} \right] - \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_2} \right] = -\mathbf{I}_2$$

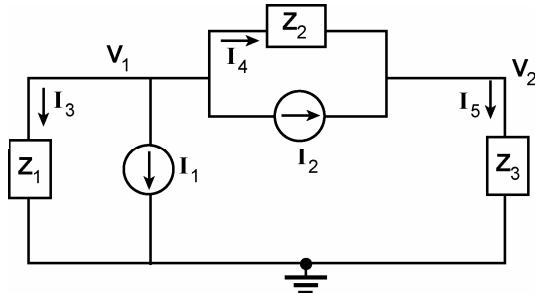
$$\text{or } \mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{V}_1[\mathbf{Y}_2] = -\mathbf{I}_2$$

$$\begin{array}{rcl} [\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 & - \mathbf{Y}_2\mathbf{V}_2 = \mathbf{I}_1 \\ -\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{V}_2 = -\mathbf{I}_2 \end{array}$$

$$\mathbf{V}_1 = \frac{[\mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{I}_1 - \mathbf{Y}_2\mathbf{I}_2}{\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_1\mathbf{Y}_3 + \mathbf{Y}_2\mathbf{Y}_3} = 14.68 \text{ V} \angle 68.89^\circ$$

$$\mathbf{V}_2 = \frac{-[\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{I}_2 + \mathbf{Y}_2\mathbf{I}_1}{\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_1\mathbf{Y}_3 + \mathbf{Y}_2\mathbf{Y}_3} = 12.97 \text{ V} \angle 155.88^\circ$$

b.



$$\mathbf{Z}_1 = 3 \Omega + j4 \Omega = 5 \angle 53.13^\circ$$

$$\mathbf{Z}_2 = 2 \Omega \angle 0^\circ$$

$$\begin{aligned}\mathbf{Z}_3 &= 6 \Omega \angle 0^\circ \parallel 8 \Omega \angle -90^\circ \\ &= 4.8 \Omega \angle -36.87^\circ\end{aligned}$$

$$\mathbf{I}_1 = 0.6 \text{ A} \angle 20^\circ$$

$$\mathbf{I}_2 = 4 \text{ A} \angle 80^\circ$$

$$0 = \mathbf{I}_1 + \mathbf{I}_3 + \mathbf{I}_4 + \mathbf{I}_2$$

$$0 = \mathbf{I}_1 + \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} + \mathbf{I}_2$$

$$\mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} \right] - \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_2} \right] = -\mathbf{I}_1 - \mathbf{I}_2$$

$$\text{or } \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{V}_2[\mathbf{Y}_2] = -\mathbf{I}_1 - \mathbf{I}_2$$

$$\mathbf{I}_2 + \mathbf{I}_4 = \mathbf{I}_5$$

$$\mathbf{I}_2 + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} = \frac{\mathbf{V}_2}{\mathbf{Z}_3}$$

$$\mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} \right] - \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_2} \right] = +\mathbf{I}_2$$

or $\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{V}_1[\mathbf{Y}_2] = \mathbf{I}_2$

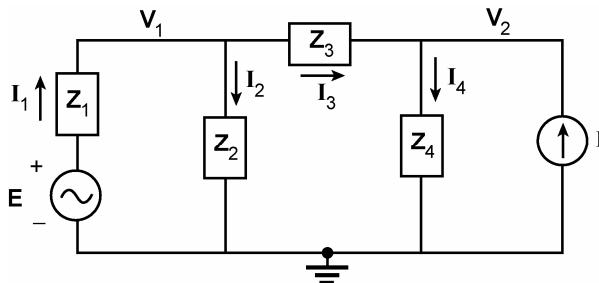
and $\underline{\mathbf{[Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 - \mathbf{Y}_2\mathbf{V}_2 = -\mathbf{I}_1 - \mathbf{I}_2}$
 $\underline{-\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{V}_2 = \mathbf{I}_2}$

Applying determinants:

$$\mathbf{V}_1 = \frac{-[\mathbf{Y}_2 + \mathbf{Y}_3][\mathbf{I}_1 + \mathbf{I}_2] + \mathbf{Y}_2\mathbf{I}_2}{\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_1\mathbf{Y}_3 + \mathbf{Y}_2\mathbf{Y}_3} = 5.12 \text{ V} \angle -79.36^\circ$$

$$\mathbf{V}_2 = \frac{\mathbf{Y}_1\mathbf{I}_2 - \mathbf{I}_1\mathbf{Y}_2}{\mathbf{Y}_1\mathbf{Y}_2 + \mathbf{Y}_1\mathbf{Y}_3 + \mathbf{Y}_2\mathbf{Y}_3} = 2.71 \text{ V} \angle 39.96^\circ$$

15. a.



$$\begin{aligned} \mathbf{Z}_1 &= 5 \Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 6 \Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 4 \Omega \angle -90^\circ \\ \mathbf{Z}_4 &= 2 \Omega \angle 0^\circ \\ \mathbf{E} &= 30 \text{ V} \angle 50^\circ \\ \mathbf{I} &= 0.04 \text{ A} \angle 90^\circ \end{aligned}$$

$$\mathbf{I}_1 = \mathbf{I}_2 + \mathbf{I}_3$$

$$\frac{\mathbf{E}_1 - \mathbf{V}_1}{\mathbf{Z}_1} = \frac{\mathbf{V}_1}{\mathbf{Z}_2} + \frac{(\mathbf{V}_1 - \mathbf{V}_2)}{\mathbf{Z}_3} \Rightarrow \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} \right] - \frac{\mathbf{V}_2}{\mathbf{Z}_3} = \frac{\mathbf{E}_1}{\mathbf{Z}_1}$$

or $\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{Y}_3\mathbf{V}_2 = \mathbf{E}_1\mathbf{Y}_1$

$$\mathbf{I}_3 + \mathbf{I} = \mathbf{I}_4$$

$$\frac{\mathbf{V}_1 - \mathbf{V}_2 + \mathbf{I}}{\mathbf{Z}_3} = \frac{\mathbf{V}_2}{\mathbf{Z}_4} \Rightarrow \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_4} \right] - \frac{\mathbf{V}_1}{\mathbf{Z}_3} = \mathbf{I}$$

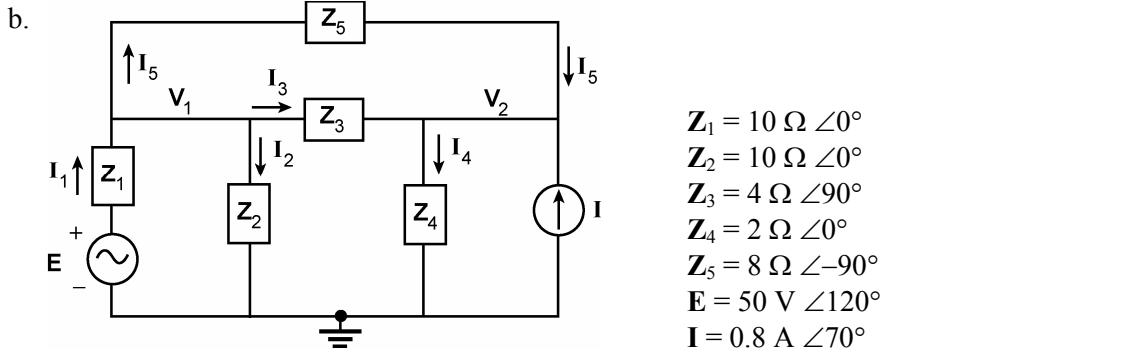
or $\mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_4] - \mathbf{V}_1\mathbf{Y}_3 = \mathbf{I}$

resulting in

$$\begin{aligned} \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{V}_2\mathbf{Y}_3 &= \mathbf{E}_1\mathbf{Y}_1 \\ -\mathbf{V}_1[\mathbf{Y}_3] + \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_4] &= +\mathbf{I} \end{aligned}$$

Using determinants:

$$\mathbf{V}_1 = 19.86 \text{ V} \angle 43.8^\circ \text{ and } \mathbf{V}_2 = 8.94 \text{ V} \angle 106.9^\circ$$



$$\mathbf{Z}_1 = 10 \Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 10 \Omega \angle 0^\circ$$

$$\mathbf{Z}_3 = 4 \Omega \angle 90^\circ$$

$$\mathbf{Z}_4 = 2 \Omega \angle 0^\circ$$

$$\mathbf{Z}_5 = 8 \Omega \angle -90^\circ$$

$$\mathbf{E} = 50 \text{ V} \angle 120^\circ$$

$$\mathbf{I} = 0.8 \text{ A} \angle 70^\circ$$

$$\mathbf{I}_1 = \mathbf{I}_2 + \mathbf{I}_5$$

$$\frac{\mathbf{E} - \mathbf{V}_1}{\mathbf{Z}_1} = \frac{\mathbf{V}_1}{\mathbf{Z}_2} + \frac{(\mathbf{V}_1 - \mathbf{V}_2)}{\mathbf{Z}_5} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_3} \Rightarrow \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_5} \right] - \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_5} \right] = \frac{\mathbf{E}}{\mathbf{Z}_1}$$

$$\text{or } \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_5] - \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_5] = \mathbf{E}_1 \mathbf{Y}_1$$

$$\mathbf{I}_3 + \mathbf{I}_5 = \mathbf{I}_4 + \mathbf{I}$$

$$\frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_3} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_5} = \frac{\mathbf{V}_2}{\mathbf{Z}_4} + \mathbf{I} \Rightarrow \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_4} + \frac{1}{\mathbf{Z}_5} \right] - \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_5} \right] = -\mathbf{I}$$

$$\text{or } \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{V}_1[\mathbf{Y}_3 + \mathbf{Y}_5] = -\mathbf{I}$$

resulting in

$$\begin{aligned} \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_5] - \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_5] &= \mathbf{E}_1 \mathbf{Y}_1 \\ -\mathbf{V}_1[\mathbf{Y}_3 + \mathbf{Y}_5] + \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_5] &= -\mathbf{I} \end{aligned}$$

Applying determinants:

$$\mathbf{V}_1 = 19.78 \text{ V} \angle 132.48^\circ \text{ and } \mathbf{V}_2 = 13.37 \text{ V} \angle 98.78^\circ$$

$$\begin{aligned} 16. \quad \mathbf{I} &= \frac{\mathbf{V}_1 + \mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_1 - \mathbf{Z}_2} \\ 0 &= \frac{\mathbf{V}_2 - \mathbf{V}_1}{\mathbf{Z}_2} + \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \frac{\mathbf{V}_2 - \mathbf{E}}{\mathbf{Z}_4} \end{aligned}$$

$$\begin{aligned} \mathbf{Z}_1 &= 2 \Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 20 \Omega + j 20 \Omega \\ \mathbf{Z}_3 &= 10 \Omega \angle -90^\circ \\ \mathbf{Z}_4 &= 10 \Omega \angle 0^\circ \\ \mathbf{I} &= 6 \text{ A} \angle 0^\circ \\ \mathbf{E} &= 30 \text{ V} \angle 0^\circ \end{aligned}$$

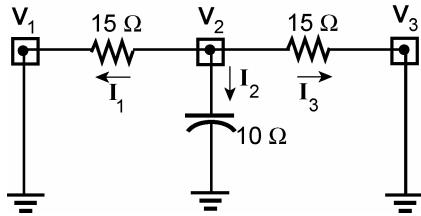
Rearranging:

$$\begin{aligned} \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} \right] - \frac{1}{\mathbf{Z}_2} \mathbf{V}_2 &= \mathbf{I} \\ \frac{-\mathbf{V}_1}{\mathbf{Z}_2} + \mathbf{V}_2 \left[\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_4} \right] &= \frac{\mathbf{E}}{\mathbf{Z}_4} \end{aligned}$$

Determinants and substituting:

$$\mathbf{V}_1 = 11.74 \text{ V} \angle -4.61^\circ, \mathbf{V}_2 = 22.53 \text{ V} \angle -36.48^\circ$$

17.



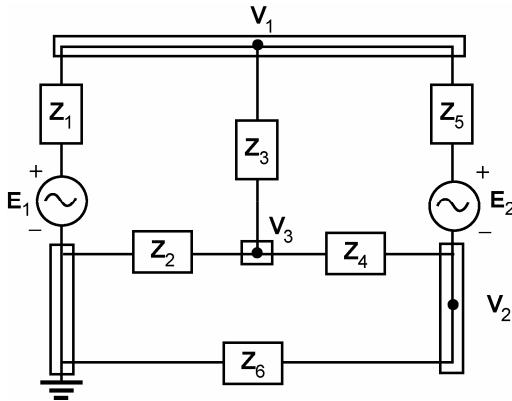
(Note that $3 + j4$ branch has no effect on nodal voltages)

$$\begin{aligned}\sum \mathbf{I}_i &= \sum \mathbf{I}_o \\ 0 &= \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3 \\ &= \frac{\mathbf{V}_2 - \mathbf{V}_1}{15\Omega} + \frac{\mathbf{V}_2}{10\Omega \angle -90^\circ} + \frac{\mathbf{V}_2 - \mathbf{V}_3}{15\Omega}\end{aligned}$$

Through manipulation:

$$\begin{aligned}\mathbf{V}_2[2 + j1.5] - \mathbf{V}_1 - \mathbf{V}_3 &= 0 \\ \text{but } \mathbf{V}_1 &= 220 \text{ V} \angle 0^\circ \text{ and } \mathbf{V}_3 = 100 \text{ V} \angle 90^\circ \\ \text{and } \mathbf{V}_2 &= \frac{220 + j100}{2 + j1.5} = 96.66 \text{ V} \angle -12.43^\circ \\ \text{with } \mathbf{V}_3 &= 0 \text{ V} \angle 0^\circ\end{aligned}$$

18.



$$\begin{aligned}\mathbf{Z}_1 &= 5 \Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 6 \Omega \angle -90^\circ \\ \mathbf{Z}_3 &= 5 \Omega \angle 90^\circ \\ \mathbf{Z}_4 &= 4 \Omega \angle 0^\circ \\ \mathbf{Z}_5 &= 4 \Omega \angle 0^\circ \\ \mathbf{Z}_6 &= 6 \Omega + j8 \Omega \\ \mathbf{E}_1 &= 20 \text{ V} \angle 0^\circ \\ \mathbf{E}_2 &= 40 \text{ V} \angle 60^\circ\end{aligned}$$

$$\text{node } \mathbf{V}_1: \frac{\mathbf{V}_1 - \mathbf{E}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_3}{\mathbf{Z}_3} + \frac{\mathbf{V}_1 - \mathbf{E}_2 - \mathbf{V}_2}{\mathbf{Z}_5} = 0$$

$$\text{node } \mathbf{V}_2: \frac{\mathbf{V}_2 + \mathbf{E}_2 - \mathbf{V}_1}{\mathbf{Z}_5} + \frac{\mathbf{V}_2 - \mathbf{V}_3}{\mathbf{Z}_4} + \frac{\mathbf{V}_2}{\mathbf{Z}_6} = 0$$

$$\text{node } \mathbf{V}_3: \frac{\mathbf{V}_3}{\mathbf{Z}_2} + \frac{\mathbf{V}_3 - \mathbf{V}_1}{\mathbf{Z}_3} + \frac{\mathbf{V}_3 - \mathbf{V}_2}{\mathbf{Z}_4} = 0$$

Rearranging:

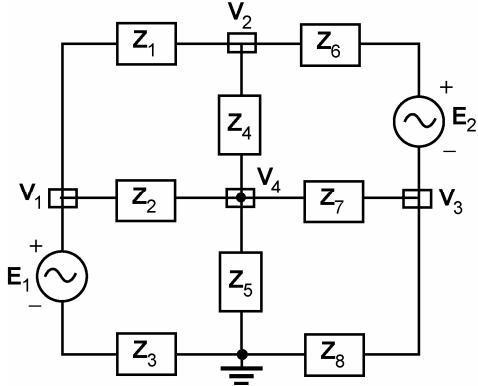
$$\mathbf{V}_1 \left(\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_5} \right) - \frac{\mathbf{V}_2 - \mathbf{V}_3}{\mathbf{Z}_5} = \frac{\mathbf{E}_1 + \mathbf{E}_2}{\mathbf{Z}_1 + \mathbf{Z}_5}$$

$$\mathbf{V}_2 \left(\frac{1}{\mathbf{Z}_5} + \frac{1}{\mathbf{Z}_4} + \frac{1}{\mathbf{Z}_6} \right) - \frac{\mathbf{V}_1 - \mathbf{V}_3}{\mathbf{Z}_5} = -\frac{\mathbf{E}_2}{\mathbf{Z}_5}$$

$$\mathbf{V}_3 \left(\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_4} \right) - \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_3 + \mathbf{Z}_4} = 0$$

Determinants: $\mathbf{V}_1 = 5.84 \text{ V} \angle 29.4^\circ$, $\mathbf{V}_2 = 28.06 \text{ V} \angle -89.15^\circ$, $\mathbf{V}_3 = 31.96 \text{ V} \angle -77.6^\circ$

19.



$$\begin{aligned}
 \mathbf{Z}_1 &= 10 \Omega + j20 \Omega \\
 \mathbf{Z}_2 &= 6 \Omega \angle 0^\circ \\
 \mathbf{Z}_3 &= 5 \Omega \angle 0^\circ \\
 \mathbf{Z}_4 &= 20 \Omega \angle -90^\circ \\
 \mathbf{Z}_5 &= 10 \Omega \angle 0^\circ \\
 \mathbf{Z}_6 &= 80 \Omega \angle 0^\circ \\
 \mathbf{Z}_7 &= 15 \Omega \angle 90^\circ \\
 \mathbf{Z}_8 &= 5 \Omega - j20 \Omega
 \end{aligned}$$

$$\begin{aligned}
 \mathbf{E}_1 &= 25 \text{ V} \angle 0^\circ \\
 \mathbf{E}_2 &= 75 \text{ V} \angle 20^\circ
 \end{aligned}$$

$$\mathbf{V}_1: \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_4}{\mathbf{Z}_2} + \frac{\mathbf{V}_1 - \mathbf{E}_1}{\mathbf{Z}_3} = 0$$

$$\mathbf{V}_2: \frac{\mathbf{V}_2 - \mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2 - \mathbf{V}_4}{\mathbf{Z}_4} + \frac{\mathbf{V}_2 - \mathbf{E}_2 - \mathbf{V}_3}{\mathbf{Z}_6} = 0$$

$$\mathbf{V}_3: \frac{\mathbf{V}_3 + \mathbf{E}_2 - \mathbf{V}_2}{\mathbf{Z}_6} + \frac{\mathbf{V}_3 - \mathbf{V}_4}{\mathbf{Z}_7} + \frac{\mathbf{V}_3}{\mathbf{Z}_8} = 0$$

$$\mathbf{V}_4: \frac{\mathbf{V}_4 - \mathbf{V}_1}{\mathbf{Z}_2} + \frac{\mathbf{V}_4 - \mathbf{V}_2}{\mathbf{Z}_4} + \frac{\mathbf{V}_4 - \mathbf{V}_3}{\mathbf{Z}_7} + \frac{\mathbf{V}_4}{\mathbf{Z}_5} = 0$$

Rearranging:

$$\mathbf{V}_1 \left(\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} \right) - \frac{\mathbf{V}_2}{\mathbf{Z}_1} - \frac{\mathbf{V}_4}{\mathbf{Z}_2} = \frac{\mathbf{E}_1}{\mathbf{Z}_3}$$

$$\mathbf{V}_2 \left(\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_4} + \frac{1}{\mathbf{Z}_6} \right) - \frac{\mathbf{V}_1}{\mathbf{Z}_1} - \frac{\mathbf{V}_4}{\mathbf{Z}_4} - \frac{\mathbf{V}_3}{\mathbf{Z}_6} = \frac{\mathbf{E}_2}{\mathbf{Z}_6}$$

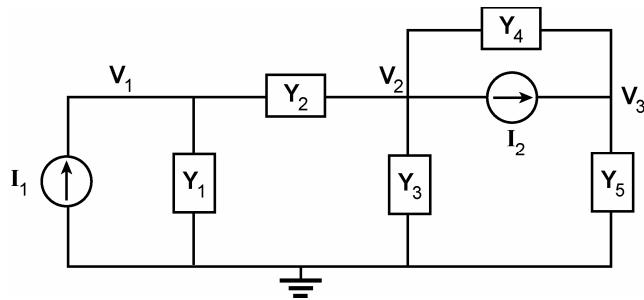
$$\mathbf{V}_3 \left(\frac{1}{\mathbf{Z}_6} + \frac{1}{\mathbf{Z}_7} + \frac{1}{\mathbf{Z}_8} \right) - \frac{\mathbf{V}_2}{\mathbf{Z}_6} - \frac{\mathbf{V}_4}{\mathbf{Z}_7} = -\frac{\mathbf{E}_2}{\mathbf{Z}_6}$$

$$\mathbf{V}_4 \left(\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_4} + \frac{1}{\mathbf{Z}_7} + \frac{1}{\mathbf{Z}_5} \right) - \frac{\mathbf{V}_1}{\mathbf{Z}_2} - \frac{\mathbf{V}_2}{\mathbf{Z}_4} - \frac{\mathbf{V}_3}{\mathbf{Z}_7} = 0$$

Setting up and then using determinants:

$$\begin{aligned}
 \mathbf{V}_1 &= 14.62 \text{ V} \angle -5.86^\circ, \mathbf{V}_2 = 35.03 \text{ V} \angle -37.69^\circ \\
 \mathbf{V}_3 &= 32.4 \text{ V} \angle -73.34^\circ, \mathbf{V}_4 = 5.67 \text{ V} \angle 23.53^\circ
 \end{aligned}$$

20. a.



$$\begin{aligned}
 \mathbf{Y}_1 &= \frac{1}{4\Omega \angle 0^\circ} = 0.25 \text{ S} \angle 0^\circ \\
 \mathbf{Y}_2 &= \frac{1}{1\Omega \angle 90^\circ} = 1 \text{ S} \angle -90^\circ \\
 \mathbf{Y}_3 &= \frac{1}{5\Omega \angle 0^\circ} = 0.2 \text{ S} \angle 0^\circ \\
 \mathbf{Y}_4 &= \frac{1}{4\Omega \angle -90^\circ} = 0.25 \text{ S} \angle 90^\circ \\
 \mathbf{Y}_5 &= \frac{1}{8\Omega \angle 90^\circ} = 0.125 \text{ S} \angle -90^\circ \\
 \mathbf{I}_1 &= 2 \text{ A} \angle 30^\circ \\
 \mathbf{I}_2 &= 3 \text{ A} \angle 150^\circ
 \end{aligned}$$

$$\begin{aligned}
 \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{Y}_2\mathbf{V}_2 &= \mathbf{I}_1 \\
 \mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_3 &= -\mathbf{I}_2 \\
 \mathbf{V}_3[\mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_4\mathbf{V}_2 &= \mathbf{I}_2
 \end{aligned}$$

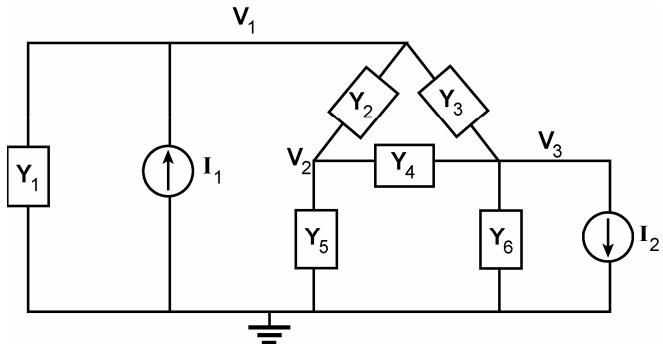
$$\begin{array}{ccc}
 [\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 & -\mathbf{Y}_2\mathbf{V}_2 & +0=\mathbf{I}_1 \\
 -\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4]\mathbf{V}_2 & -\mathbf{Y}_4\mathbf{V}_3 & =-\mathbf{I}_2 \\
 0 & -\mathbf{Y}_4\mathbf{V}_2 + [\mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_3 & =\mathbf{I}_2
 \end{array}$$

$$\begin{aligned}
 \mathbf{V}_1 &= \frac{\mathbf{I}_1 \left[(\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4)(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_4^2 \right] - \mathbf{I}_2 \left[\mathbf{Y}_2 \mathbf{Y}_5 \right]}{[\mathbf{Y}_1 + \mathbf{Y}_2] \left[(\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4)(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_4^2 \right] - \mathbf{Y}_2^2 (\mathbf{Y}_4 + \mathbf{Y}_5)} = \mathbf{Y}_\Delta \\
 &= 5.74 \text{ V} \angle 122.76^\circ
 \end{aligned}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}_1 \mathbf{Y}_2 (\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{I}_2 \mathbf{Y}_5 (\mathbf{Y}_1 + \mathbf{Y}_2)}{\mathbf{Y}_\Delta} = 4.04 \text{ V} \angle 145.03^\circ$$

$$\mathbf{V}_3 = \frac{\mathbf{I}_2 \left[(\mathbf{Y}_1 + \mathbf{Y}_2)(\mathbf{Y}_3 + \mathbf{Y}_4) - \mathbf{Y}_2^2 \right] - \mathbf{Y}_2 \mathbf{Y}_4 \mathbf{I}_1}{\mathbf{Y}_\Delta} = 25.94 \text{ V} \angle 78.07^\circ$$

b.



$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{Y}_2\mathbf{V}_2 - \mathbf{Y}_3\mathbf{V}_3 = \mathbf{I}_1$$

$$\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_3 = 0$$

$$\mathbf{V}_3[\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6] - \mathbf{Y}_3\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_2 = -\mathbf{I}_2$$

$$\begin{array}{l} [\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{V}_1 - \mathbf{Y}_2\mathbf{V}_2 - \mathbf{Y}_3\mathbf{V}_3 = \mathbf{I}_1 \\ -\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_2 - \mathbf{Y}_4\mathbf{V}_3 = 0 \\ -\mathbf{Y}_3\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_2 + [\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6]\mathbf{V}_3 = -\mathbf{I}_2 \end{array}$$

$$\begin{aligned} \mathbf{Y}_1 &= \frac{1}{4\Omega \angle 0^\circ} \\ &= 0.25 \text{ S} \angle 0^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Y}_2 &= \frac{1}{6\Omega \angle 0^\circ} \\ &= 0.167 \text{ S} \angle 0^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Y}_3 &= \frac{1}{8\Omega \angle 0^\circ} \\ &= 0.125 \text{ S} \angle 0^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Y}_4 &= \frac{1}{2\Omega \angle -90^\circ} \\ &= 0.5 \text{ S} \angle 90^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Y}_5 &= \frac{1}{5\Omega \angle 90^\circ} \\ &= 0.2 \text{ S} \angle -90^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Y}_6 &= \frac{1}{4\Omega \angle 90^\circ} \\ &= 0.25 \text{ S} \angle -90^\circ \end{aligned}$$

$$\mathbf{I}_1 = 4 \text{ A} \angle 0^\circ$$

$$\mathbf{I}_2 = 6 \text{ A} \angle 90^\circ$$

$$\begin{aligned} \mathbf{V}_1 &= \frac{\mathbf{I}_1[(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5)(\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6) - \mathbf{Y}_4^2] - \mathbf{I}_2[\mathbf{Y}_2\mathbf{Y}_4 + \mathbf{Y}_3(\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_5)]}{\mathbf{Y}_\Delta = (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3)[(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5)(\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6) - \mathbf{Y}_4^2] - \mathbf{Y}_2[\mathbf{Y}_2(\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6) + \mathbf{Y}_3\mathbf{Y}_4] - \mathbf{Y}_3[\mathbf{Y}_2\mathbf{Y}_4 + \mathbf{Y}_3(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5)]} \\ &= 15.13 \text{ V} \angle 1.29^\circ \end{aligned}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}_1[(\mathbf{Y}_2)(\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6) + \mathbf{Y}_3\mathbf{Y}_4] + \mathbf{I}_2[\mathbf{Y}_4(\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3) - \mathbf{Y}_2\mathbf{Y}_3]}{\mathbf{Y}_\Delta} = 17.24 \text{ V} \angle 3.73^\circ$$

$$\begin{aligned} \mathbf{V}_3 &= \frac{\mathbf{I}_1[(\mathbf{Y}_3)(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_4] + \mathbf{I}_2[\mathbf{Y}_2^2 - (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3)(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5)]}{\mathbf{Y}_\Delta} \\ &= 10.59 \text{ V} \angle -0.11^\circ \end{aligned}$$

21. Left node: \mathbf{V}_1
 $\sum \mathbf{I}_i = \sum \mathbf{I}_o$

$$4\mathbf{I}_x = \mathbf{I}_x + 5 \text{ mA} \angle 0^\circ + \frac{\mathbf{V}_1 - \mathbf{V}_2}{2 \text{ k}\Omega}$$

Right node: \mathbf{V}_2
 $\sum \mathbf{I}_i = \sum \mathbf{I}_o$

$$8 \text{ mA} \angle 0^\circ = \frac{\mathbf{V}_2}{1 \text{ k}\Omega} + \frac{\mathbf{V}_2 - \mathbf{V}_1}{2 \text{ k}\Omega} + 4\mathbf{I}_x$$

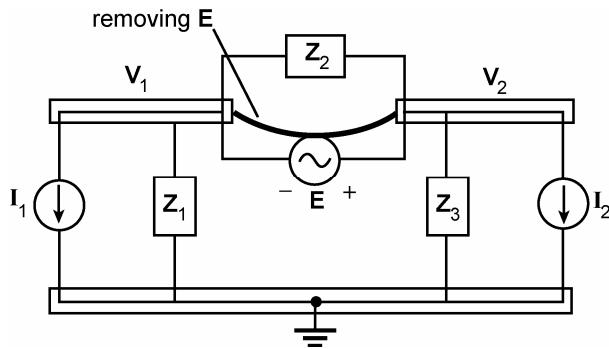
$$\text{Insert } \mathbf{I}_x = \frac{\mathbf{V}_1}{4 \text{ k}\Omega} \angle -90^\circ$$

Rearrange, reduce and 2 equations with 2 unknowns result:

$$\begin{array}{l} \mathbf{V}_1[1.803 \angle 123.69^\circ] + \mathbf{V}_2 = 10 \\ \mathbf{V}_1[2.236 \angle 116.57^\circ] + 3\mathbf{V}_2 = 16 \end{array}$$

Determinants: $\mathbf{V}_1 = 4.37 \text{ V} \angle -128.66^\circ$
 $\mathbf{V}_2 = \mathbf{V}_{1k\Omega} = 2.25 \text{ V} \angle 17.63^\circ$

22.



$$\begin{aligned}\mathbf{Z}_1 &= 1 \text{ k}\Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 2 \text{ k}\Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 3 \text{ k}\Omega \angle -90^\circ \\ \mathbf{I}_1 &= 12 \text{ mA} \angle 0^\circ \\ \mathbf{I}_2 &= 4 \text{ mA} \angle 0^\circ \\ \mathbf{E} &= 10 \text{ V} \angle 0^\circ\end{aligned}$$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$0 = \mathbf{I}_1 + \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \mathbf{I}_2$$

$$\text{and } \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2}{\mathbf{Z}_3} = -\mathbf{I}_1 - \mathbf{I}_2$$

with $\mathbf{V}_2 - \mathbf{V}_1 = \mathbf{E}$

Substituting and rearranging:

$$\mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_3} \right] = -\mathbf{I}_1 - \mathbf{I}_2 - \frac{\mathbf{E}}{\mathbf{Z}_3}$$

and solving for \mathbf{V}_1 :

$$\begin{aligned}\mathbf{V}_1 &= 15.4 \text{ V} \angle 178.2^\circ \\ \text{with } \mathbf{V}_2 &= \mathbf{V}_C = 5.41 \text{ V} \angle 174.87^\circ\end{aligned}$$

23. Left node: \mathbf{V}_1

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$2 \text{ mA} \angle 0^\circ = 12 \text{ mA} \angle 0^\circ + \frac{\mathbf{V}_1}{2 \text{ k}\Omega} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{1 \text{ k}\Omega}$$

$$\text{and } 1.5 \mathbf{V}_1 - \mathbf{V}_2 = -10$$

Right node: \mathbf{V}_2

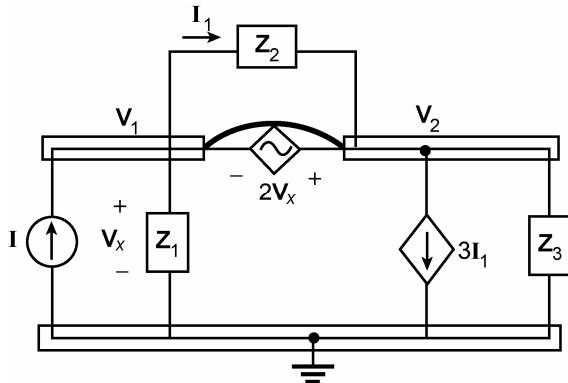
$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$0 = 2 \text{ mA} \angle 0^\circ + \frac{\mathbf{V}_2 - \mathbf{V}_1}{1 \text{ k}\Omega} - \frac{\mathbf{V}_2 - 6 \mathbf{V}_x}{3.3 \text{ k}\Omega}$$

$$\text{and } 2.7 \mathbf{V}_1 - 3.7 \mathbf{V}_2 = -6.6$$

Using determinants: $\mathbf{V}_1 = \mathbf{V}_{2k\Omega} = -10.67 \text{ V} \angle 0^\circ = 10.67 \text{ V} \angle 180^\circ$
 $\mathbf{V}_2 = -6 \text{ V} \angle 0^\circ = 6 \text{ V} \angle 180^\circ$

24.



$$\mathbf{Z}_1 = 2 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 1 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_3 = 1 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{I} = 5 \text{ mA } \angle 0^\circ$$

$$\mathbf{V}_1: \mathbf{I} = \frac{\mathbf{V}_1}{\mathbf{Z}_1} + 3\mathbf{I}_1 + \frac{\mathbf{V}_2}{\mathbf{Z}_3}$$

$$\text{with } \mathbf{I}_1 = \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2}$$

$$\text{and } \mathbf{V}_2 - \mathbf{V}_1 = 2\mathbf{V}_x = 2\mathbf{V}_1 \text{ or } \mathbf{V}_2 = 3\mathbf{V}_1$$

Substituting will result in:

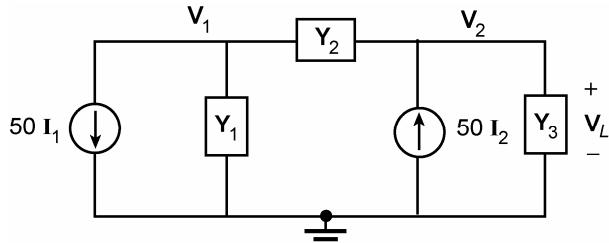
$$\mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} + \frac{3}{\mathbf{Z}_2} \right] + 3\mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_3} - \frac{3}{\mathbf{Z}_2} \right] = \mathbf{I}$$

$$\text{or } \mathbf{V}_1 \left[\frac{1}{\mathbf{Z}_1} - \frac{6}{\mathbf{Z}_2} + \frac{3}{\mathbf{Z}_3} \right] = \mathbf{I}$$

$$\text{and } \mathbf{V}_1 = \mathbf{V}_x = -2 \text{ V } \angle 0^\circ$$

$$\text{with } \mathbf{V}_2 = -6 \text{ V } \angle 0^\circ$$

25.



$$\mathbf{I}_1 = \frac{\mathbf{E}_i \angle \theta}{R_1 \angle 0^\circ} = 1 \times 10^{-3} \mathbf{E}_i$$

$$\mathbf{Y}_1 = \frac{1}{50 \text{ k}\Omega} = 0.02 \text{ mS } \angle 0^\circ$$

$$\mathbf{Y}_2 = \frac{1}{1 \text{ k}\Omega} = 1 \text{ mS } \angle 0^\circ$$

$$\mathbf{Y}_3 = 0.02 \text{ mS } \angle 0^\circ$$

$$\mathbf{I}_2 = (\mathbf{V}_1 - \mathbf{V}_2)\mathbf{Y}_2$$

$$\mathbf{V}_1(\mathbf{Y}_1 + \mathbf{Y}_2) - \mathbf{Y}_2\mathbf{V}_2 = -50\mathbf{I}_1$$

$$\mathbf{V}_2(\mathbf{Y}_2 + \mathbf{Y}_3) - \mathbf{Y}_2\mathbf{V}_1 = 50\mathbf{I}_2 = 50(\mathbf{V}_1 - \mathbf{V}_2)\mathbf{Y}_2 = 50\mathbf{Y}_2\mathbf{V}_1 - 50\mathbf{Y}_2\mathbf{V}_2$$

$$\begin{aligned} & (\mathbf{Y}_1 + \mathbf{Y}_2)\mathbf{V}_1 - \mathbf{Y}_2\mathbf{V}_2 = -50\mathbf{I}_1 \\ & -51\mathbf{Y}_2\mathbf{V}_1 + (51\mathbf{Y}_2 + \mathbf{Y}_3)\mathbf{V}_2 = 0 \end{aligned}$$

$$\mathbf{V}_L = \mathbf{V}_2 = \frac{-(50)(51)\mathbf{Y}_2\mathbf{I}_1}{(\mathbf{Y}_1 + \mathbf{Y}_2)(51\mathbf{Y}_2 + \mathbf{Y}_3) - 51\mathbf{Y}_2^2} = -2451.92 \mathbf{E}_i$$

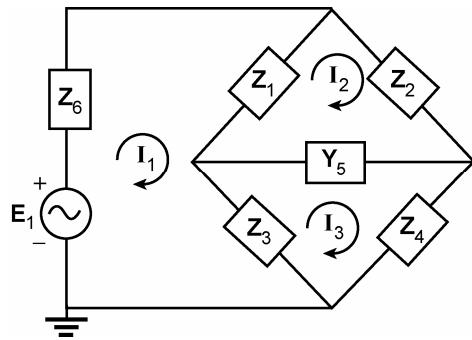
26. a. yes

$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$

$$\frac{5 \times 10^3 \angle 0^\circ}{2.5 \times 10^3 \angle 90^\circ} = \frac{8 \times 10^3 \angle 0^\circ}{4 \times 10^3 \angle 90^\circ}$$

$$2 \angle -90^\circ = 2 \angle -90^\circ \text{ (balanced)} \checkmark$$

- b. $\mathbf{Z}_1 = 5 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_2 = 8 \text{ k}\Omega \angle 0^\circ$
 $\mathbf{Z}_3 = 2.5 \text{ k}\Omega \angle 90^\circ, \mathbf{Z}_4 = 4 \text{ k}\Omega \angle 90^\circ$
 $\mathbf{Z}_5 = 5 \text{ k}\Omega \angle -90^\circ, \mathbf{Z}_6 = 1 \text{ k}\Omega \angle 0^\circ$

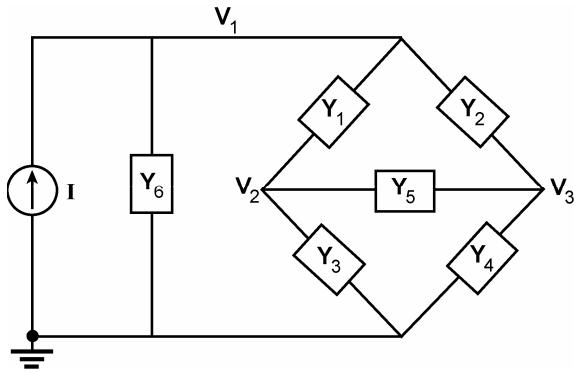


$$\begin{aligned} \mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6] - \mathbf{Z}_1\mathbf{I}_2 - \mathbf{Z}_3\mathbf{I}_3 &= \mathbf{E} \\ \mathbf{I}_2[\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5] - \mathbf{Z}_1\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_3 &= 0 \\ \mathbf{I}_3[\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5] - \mathbf{Z}_3\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_2 &= 0 \end{aligned}$$

$$\begin{aligned} [\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6]\mathbf{I}_1 & - \mathbf{Z}_1\mathbf{I}_2 & - \mathbf{Z}_3\mathbf{I}_3 &= \mathbf{E} \\ -\mathbf{Z}_1\mathbf{I}_1 + [\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5]\mathbf{I}_2 & & - \mathbf{Z}_5\mathbf{I}_3 &= 0 \\ -\mathbf{Z}_3\mathbf{I}_1 & - \mathbf{Z}_5\mathbf{I}_2 + [\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{I}_3 & &= 0 \end{aligned}$$

$$\begin{aligned} \mathbf{I}_2 &= \frac{\mathbf{E}[\mathbf{Z}_1(\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5) + \mathbf{Z}_3\mathbf{Z}_5]}{\mathbf{Z}_\Delta} \\ \mathbf{I}_3 &= \frac{\mathbf{E}[\mathbf{Z}_1\mathbf{Z}_5 + \mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)]}{\mathbf{Z}_\Delta} \\ \mathbf{I}_{Z_5} &= \mathbf{I}_2 - \mathbf{I}_3 = \frac{\mathbf{E}[\mathbf{Z}_1\mathbf{Z}_4 - \mathbf{Z}_3\mathbf{Z}_2]}{\mathbf{Z}_\Delta} = \frac{\mathbf{E}[20 \times 10^6 \angle 90^\circ - 20 \times 10^6 \angle 90^\circ]}{\mathbf{Z}_\Delta} = \mathbf{0} \text{ A} \end{aligned}$$

c.



$$V_1[Y_1 + Y_2 + Y_6] - Y_1 V_2 - Y_2 V_3 = I$$

$$V_2[Y_1 + Y_3 + Y_5] - Y_1 V_1 - Y_5 V_3 = 0$$

$$V_3[Y_2 + Y_4 + Y_5] - Y_2 V_1 - Y_5 V_2 = 0$$

$$\begin{array}{l} [Y_1 + Y_2 + Y_6]V_1 \quad -Y_1 V_2 \quad -Y_2 V_3 = I \\ \quad -Y_1 V_1 + [Y_1 + Y_3 + Y_5]V_2 \quad \quad \quad -Y_5 V_3 = 0 \\ \quad -Y_2 V_1 \quad \quad \quad -Y_5 V_2 + [Y_2 + Y_4 + Y_5]V_3 = 0 \end{array}$$

$$\mathbf{I} = \frac{\mathbf{E}_s}{\mathbf{R}_s} = \frac{10 \text{ V} \angle 0^\circ}{1 \text{ k}\Omega \angle 0^\circ} = 10 \text{ mA} \angle 0^\circ$$

$$\mathbf{Y}_1 = \frac{1}{5 \text{ k}\Omega \angle 0^\circ} = 0.2 \text{ mS} \angle 0^\circ$$

$$\mathbf{Y}_2 = \frac{1}{8 \text{ k}\Omega \angle 0^\circ} = 0.125 \text{ mS} \angle 0^\circ$$

$$\mathbf{Y}_3 = \frac{1}{2.5 \text{ k}\Omega \angle 90^\circ} = 0.4 \text{ mS} \angle -90^\circ$$

$$\mathbf{Y}_4 = \frac{1}{4 \text{ k}\Omega \angle 90^\circ} = 0.25 \text{ mS} \angle -90^\circ$$

$$\mathbf{Y}_5 = \frac{1}{5 \text{ k}\Omega \angle -90^\circ} = 0.2 \text{ mS} \angle 90^\circ$$

$$\mathbf{Y}_6 = \frac{1}{1 \text{ k}\Omega \angle 0^\circ}$$

$$\mathbf{V}_2 = 1 \text{ mS} \angle 0^\circ$$

$$\mathbf{V}_2 = \frac{\mathbf{I}[Y_1(Y_2 + Y_4 + Y_5) + Y_2 Y_5]}{Y_\Delta = (Y_1 + Y_2 + Y_6)[(Y_1 + Y_3 + Y_5)(Y_2 + Y_4 + Y_5) - Y_5^2] - Y_1[Y_1(Y_2 + Y_4 + Y_5) + Y_2 Y_5] - Y_2[Y_1 Y_5 + Y_2(Y_1 + Y_3 + Y_5)]}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}[Y_1 Y_5 + Y_2(Y_1 + Y_3 + Y_5)]}{Y_\Delta}$$

$$\mathbf{V}_{Z_5} = \mathbf{V}_2 - \mathbf{V}_3 = \frac{\mathbf{I}[Y_1 Y_4 - Y_4 Y_3]}{Y_\Delta} = \frac{\mathbf{I}[0.05 \times 10^{-3} \angle -90^\circ - 0.05 \times 10^{-3} \angle -90^\circ]}{Y_\Delta}$$

$$= \mathbf{0} \text{ V}$$

27. a. $\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$

$$\frac{4 \times 10^3 \angle 0^\circ}{4 \times 10^3 \angle 90^\circ} \stackrel{?}{=} \frac{4 \times 10^3 \angle 0^\circ}{4 \times 10^3 \angle -90^\circ}$$

$1 \angle -90^\circ \neq 1 \angle 90^\circ$ (**not balanced**)

b. The solution to 26(b) resulted in

$$\mathbf{I}_3 = \mathbf{I}_{X_C} = \frac{\mathbf{E}(\mathbf{Z}_1 \mathbf{Z}_5 + \mathbf{Z}_3 (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5))}{\mathbf{Z}_\Delta}$$

where $\mathbf{Z}_\Delta = (\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6)[(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)(\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5) - \mathbf{Z}_5^2]$

$$- \mathbf{Z}_1[\mathbf{Z}_1(\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5) - \mathbf{Z}_3 \mathbf{Z}_5] - \mathbf{Z}_3[\mathbf{Z}_1 \mathbf{Z}_5 + \mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)]$$

and $\mathbf{Z}_1 = 5 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_2 = 8 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_3 = 2.5 \text{ k}\Omega \angle 90^\circ$

$$\mathbf{Z}_4 = 4 \text{ k}\Omega \angle 90^\circ, \mathbf{Z}_5 = 5 \text{ k}\Omega \angle -90^\circ, \mathbf{Z}_6 = 1 \text{ k}\Omega \angle 0^\circ$$

and $\mathbf{I}_{X_C} = 1.76 \text{ mA} \angle -71.54^\circ$

c. The solution to 26(c) resulted in

$$\mathbf{V}_3 = \mathbf{V}_{X_C} = \frac{\mathbf{I}[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)]}{\mathbf{Y}_\Delta}$$

where $\mathbf{Y}_\Delta = (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6)[(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_5^2]$
 $- \mathbf{Y}_1[\mathbf{Y}_1(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_5]$
 $- \mathbf{Y}_2[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)]$

with $\mathbf{Y}_1 = 0.2 \text{ mS} \angle 0^\circ, \mathbf{Y}_2 = 0.125 \text{ mS} \angle 0^\circ, \mathbf{Y}_3 = 0.4 \text{ mS} \angle -90^\circ$
 $\mathbf{Y}_4 = 0.25 \text{ mS} \angle -90^\circ, \mathbf{Y}_5 = 0.2 \text{ mS} \angle 90^\circ$

Source conversion: $\mathbf{Y}_6 = 1 \text{ mS} \angle 0^\circ, \mathbf{I} = 10 \text{ mA} \angle 0^\circ$
and $\mathbf{V}_3 = 7.03 \text{ V} \angle -18.46^\circ$

28. $\mathbf{Z}_1\mathbf{Z}_4 = \mathbf{Z}_3\mathbf{Z}_2$

$$(R_1 - jX_C)(R_x + jX_{L_x}) = R_3R_2 \quad X_C = \frac{1}{\omega C} = \frac{1}{(10^3 \text{ rad/s})(1 \mu\text{F})} = 1 \text{ k}\Omega$$

$$(1 \text{ k}\Omega - j1 \text{ k}\Omega)(R_x + jX_{L_x}) = (0.1 \text{ k}\Omega)(0.1 \text{ k}\Omega) = 10 \text{ k}\Omega$$

$$\text{and } R_x + jX_{L_x} = \frac{10 \times 10^3 \Omega}{1 \times 10^3 - j1 \times 10^3} = \frac{10 \times 10^3}{1.414 \times 10^3} \angle -45^\circ = 5 \Omega + j5 \Omega$$

$$\therefore R_x = 5 \Omega, L_x = \frac{X_{L_x}}{\omega} = \frac{5 \Omega}{10^3 \text{ rad/s}} = 5 \text{ mH}$$

29. $X_{C_1} = \frac{1}{\omega C} = \frac{1}{(1000 \text{ rad/s})(3 \mu\text{F})} = \frac{1}{3} \text{ k}\Omega$

$$\mathbf{Z}_1 = R_1 \parallel X_{C_1} \angle -90^\circ = (2 \text{ k}\Omega \angle 0^\circ) \parallel 2 \frac{1}{3} \text{ k}\Omega \angle -90^\circ = 328.8 \Omega \angle -80.54^\circ$$

$$\mathbf{Z}_2 = R_2 \angle 0^\circ = 0.5 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_3 = R_3 \angle 0^\circ = 4 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_4 = R_x + jX_{L_x} = 1 \text{ k}\Omega + j6 \text{ k}\Omega$$

$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$

$$\frac{328.8 \Omega \angle -80.54^\circ}{4 \text{ k}\Omega \angle 0^\circ} \stackrel{?}{=} \frac{0.5 \text{ k}\Omega \angle 0^\circ}{6.083 \Omega \angle 80.54^\circ}$$

$$82.2 \angle -80.54^\circ \leq 82.2 \angle -80.54^\circ \text{ (balanced)}$$

30. Apply Eq. 17.6.

31. For balance:

$$R_1(R_x + jX_{L_x}) = R_2(R_3 + jX_{L_3})$$

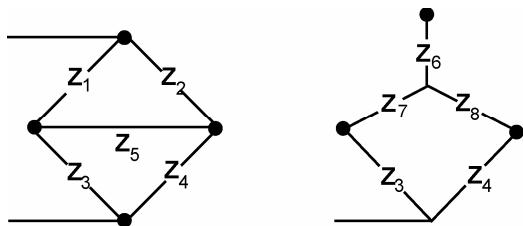
$$R_1R_x + jR_1 X_{L_x} = R_2R_3 + jR_2 X_{L_3}$$

$$\therefore R_1R_x = R_2R_3 \text{ and } R_x = \frac{R_2R_3}{R_1}$$

$$R_1 X_{L_x} = R_2 X_{L_3} \text{ and } R_1\omega L_x = R_2\omega L_3$$

$$\text{so that } L_x = \frac{R_2 L_3}{R_1}$$

32. a.



$$\mathbf{Z}_1 = 8 \Omega \angle -90^\circ = -j8 \Omega$$

$$\mathbf{Z}_2 = 4 \Omega \angle 90^\circ = +j4 \Omega$$

$$\mathbf{Z}_3 = 8 \Omega \angle 90^\circ = +j8 \Omega$$

$$\mathbf{Z}_4 = 6 \Omega \angle -90^\circ = -j6 \Omega$$

$$\mathbf{Z}_5 = 5 \Omega \angle 0^\circ$$

$$\mathbf{Z}_6 = \frac{\mathbf{Z}_1 \mathbf{Z}_2}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 5 \Omega \angle 38.66^\circ$$

$$\mathbf{Z}_7 = \frac{\mathbf{Z}_1 \mathbf{Z}_5}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 6.25 \Omega \angle -51.34^\circ$$

$$\mathbf{Z}_8 = \frac{\mathbf{Z}_2 \mathbf{Z}_5}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 3.125 \Omega \angle 128.66^\circ$$

$$\mathbf{Z}' = \mathbf{Z}_7 + \mathbf{Z}_3 = 3.9 \Omega + j3.12 \Omega = 4.99 \Omega \angle 38.66^\circ$$

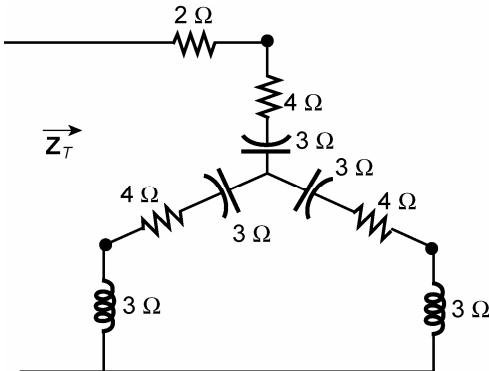
$$\mathbf{Z}'' = \mathbf{Z}_8 + \mathbf{Z}_4 = -1.95 \Omega - j3.56 \Omega = 4.06 \Omega \angle -118.71^\circ$$

$$\mathbf{Z}' \parallel \mathbf{Z}'' = 10.13 \Omega \angle -67.33^\circ = 3.90 \Omega - j9.35 \Omega$$

$$\mathbf{Z}_T = \mathbf{Z}_6 + \mathbf{Z}' \parallel \mathbf{Z}'' = 7.80 \Omega - j6.23 \Omega = 9.98 \Omega \angle -38.61^\circ$$

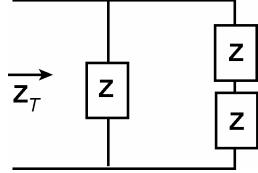
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{120 \text{ V} \angle 0^\circ}{9.98 \Omega \angle -38.61^\circ} = \mathbf{12.02 A} \angle 38.61^\circ$$

b. $\mathbf{Z}_Y = \frac{\mathbf{Z}_\Delta}{3} = \frac{12 \Omega - j9 \Omega}{3} = 4 \Omega - j3 \Omega$



$$\begin{aligned}
\mathbf{Z}_T &= 2 \Omega + 4 \Omega + j3 \Omega + [4 \Omega - j3 \Omega + j3 \Omega] \parallel [4 \Omega - j3 \Omega + j3 \Omega] \\
&= 6 \Omega - j3 \Omega + 2 \Omega \\
&= 8 \Omega - j3 \Omega = 8.544 \Omega \angle -20.56^\circ \\
\mathbf{I} &= \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60 \text{ V} \angle 0^\circ}{8.544 \Omega \angle -20.56^\circ} = 7.02 \text{ A} \angle 20.56^\circ
\end{aligned}$$

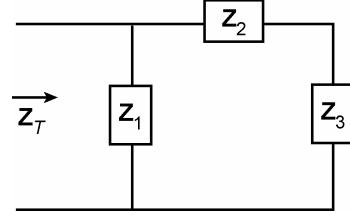
33. a.



$$\begin{aligned}
\mathbf{Z}_\Delta &= 3\mathbf{Z}_Y = 3(3 \Omega \angle 90^\circ) = 9 \Omega \angle 90^\circ \\
\mathbf{Z} &= 9 \Omega \angle 90^\circ \parallel (12 \Omega - j16 \Omega) \\
&= 9 \Omega \angle 90^\circ \parallel 20 \Omega \angle 53.13^\circ \\
&= 12.96 \Omega \angle 67.13^\circ
\end{aligned}$$

$$\begin{aligned}
\mathbf{Z}_T &= \mathbf{Z} \parallel 2\mathbf{Z} = \frac{2\mathbf{Z}^2}{\mathbf{Z} + 2\mathbf{Z}} = \frac{2}{3}\mathbf{Z} = \frac{2}{3} [12.96 \Omega \angle 67.13^\circ] = 8.64 \Omega \angle 67.13^\circ \\
\mathbf{I} &= \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100 \text{ V} \angle 0^\circ}{8.64 \Omega \angle 67.13^\circ} = 11.57 \text{ A} \angle -67.13^\circ
\end{aligned}$$

b. $\mathbf{Z}_\Delta = 3\mathbf{Z}_Y = 3(5 \Omega) = 15 \Omega$

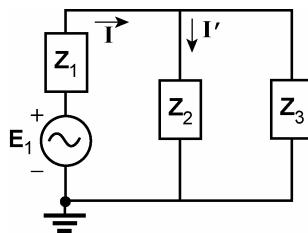


$$\begin{aligned}
\mathbf{Z}_1 &= 15 \Omega \angle 0^\circ \parallel 5 \Omega \angle -90^\circ \\
&= 4.74 \Omega \angle -71.57^\circ \\
\mathbf{Z}_2 &= 15 \Omega \angle 0^\circ \parallel 6 \Omega \angle 90^\circ \\
&= 5.57 \Omega \angle 68.2^\circ = 2.07 \Omega + j5.17 \Omega \\
\mathbf{Z}_3 &= \mathbf{Z}_1 = 4.74 \Omega \angle -71.57^\circ \\
&= 1.5 \Omega - j4.5 \Omega
\end{aligned}$$

$$\begin{aligned}
\mathbf{Z}_T &= \mathbf{Z}_1 \parallel (\mathbf{Z}_2 + \mathbf{Z}_3) = (4.74 \Omega \angle -71.57^\circ) \parallel (2.07 \Omega + j5.17 \Omega + 1.5 \Omega - j4.5 \Omega) \\
&= (4.74 \Omega \angle -7.57^\circ) \parallel (3.63 \Omega \angle 10.63^\circ) \\
&= 2.71 \Omega \angle -23.87^\circ \\
\mathbf{I} &= \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100 \text{ V} \angle 0^\circ}{2.71 \Omega \angle -23.87^\circ} = 36.9 \text{ A} \angle 23.87^\circ
\end{aligned}$$

Chapter 18

1. a.

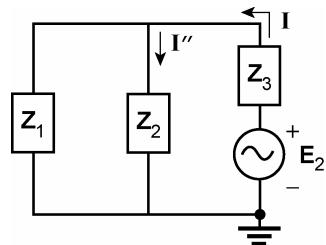


$$\mathbf{Z}_1 = 3 \Omega \angle 0^\circ, \mathbf{Z}_2 = 8 \Omega \angle 90^\circ, \mathbf{Z}_3 = 6 \Omega \angle -90^\circ$$

$$\mathbf{Z}_2 \parallel \mathbf{Z}_3 = 8 \Omega \angle 90^\circ \parallel 6 \Omega \angle -90^\circ = 24 \Omega \angle -90^\circ$$

$$\mathbf{I} = \frac{\mathbf{E}_1}{\mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3} = \frac{30 \text{ V} \angle 30^\circ}{3 \Omega - j24 \Omega} = 1.24 \text{ A} \angle 112.875^\circ$$

$$\mathbf{I}' = \frac{\mathbf{Z}_3 \mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(6 \Omega \angle -90^\circ)(1.24 \text{ A} \angle 112.875^\circ)}{2 \Omega \angle 90^\circ} = 3.72 \text{ A} \angle -67.125^\circ$$



$$\mathbf{Z}_1 \parallel \mathbf{Z}_2 = 3 \Omega \angle 0^\circ \parallel 8 \Omega \angle 90^\circ = 2.809 \Omega \angle 20.556^\circ$$

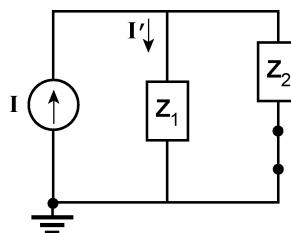
$$\mathbf{I} = \frac{\mathbf{E}_2}{\mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2} = \frac{60 \text{ V} \angle 10^\circ}{-j6 \Omega + 2.630 \Omega + j0.986 \Omega}$$

$$= 10.597 \text{ A} \angle 72.322^\circ$$

$$\mathbf{I}'' = \frac{\mathbf{Z}_1 \mathbf{I}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(3 \Omega \angle 0^\circ)(10.597 \text{ A} \angle 72.322^\circ)}{3 \Omega + j8 \Omega} = 3.721 \text{ A} \angle 2.878^\circ$$

$$\begin{aligned} \mathbf{I}_{L_1} &= \mathbf{I}' + \mathbf{I}'' = 3.72 \text{ A} \angle -67.125^\circ + 3.721 \text{ A} \angle 2.878^\circ \\ &= 1.446 \text{ A} - j3.427 \text{ A} + 3.716 \text{ A} + j0.187 \text{ A} \\ &= 5.162 \text{ A} - j3.24 \text{ A} \\ &= \mathbf{6.09 \text{ A} \angle -32.12^\circ} \end{aligned}$$

b.



$$\mathbf{Z}_1 = 8 \Omega \angle 90^\circ, \mathbf{Z}_2 = 5 \Omega \angle -90^\circ$$

$$\mathbf{I} = 0.3 \text{ A} \angle 60^\circ, \mathbf{E} = 10 \text{ V} \angle 0^\circ$$

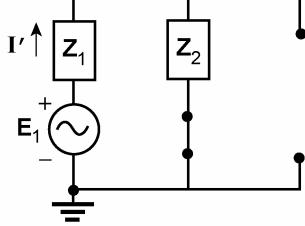
$$\mathbf{I}' = \frac{\mathbf{Z}_2 \mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(5 \Omega \angle -90^\circ)(0.3 \text{ A} \angle 60^\circ)}{+j8 \Omega - j5 \Omega}$$

$$= 0.5 \text{ A} \angle -120^\circ$$

$$\mathbf{I}'' = \frac{\mathbf{E}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{10 \text{ V} \angle 0^\circ}{3 \Omega \angle 90^\circ} = 3.33 \text{ A} \angle -90^\circ$$

$$\begin{aligned} \mathbf{I}_{Z_1} &= \mathbf{I}_{L_1} = \mathbf{I}' + \mathbf{I}'' \\ &= 0.5 \text{ A} \angle -120^\circ + 3.33 \text{ A} \angle -90^\circ \\ &= -0.25 \text{ A} - j0.433 \text{ A} - j3.33 \text{ A} \\ &= -0.25 \text{ A} - j3.763 \text{ A} \\ &= \mathbf{3.77 \text{ A} \angle -93.8^\circ} \end{aligned}$$

2. a. \mathbf{E}_1 :

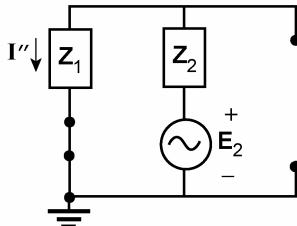


$$\mathbf{E}_1 = 20 \text{ V} \angle 0^\circ, \quad \mathbf{Z}_1 = 4 \Omega + j3 \Omega = 5 \Omega \angle 36.87^\circ$$

$$\mathbf{Z}_2 = 1 \Omega \angle 0^\circ$$

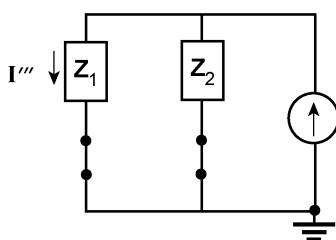
$$\begin{aligned}\mathbf{I}' &= \frac{\mathbf{E}_1}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{20 \text{ V} \angle 0^\circ}{4 \Omega + j3 \Omega + 1 \Omega} \\ &= 3.43 \text{ A} \angle -30.96^\circ\end{aligned}$$

\mathbf{E}_2 :



$$\begin{aligned}\mathbf{I}'' &= \frac{\mathbf{E}_2}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{120 \text{ V} \angle 0^\circ}{5.83 \Omega \angle 30.96^\circ} \\ &= 20.58 \text{ A} \angle -30.96^\circ\end{aligned}$$

\mathbf{I} :

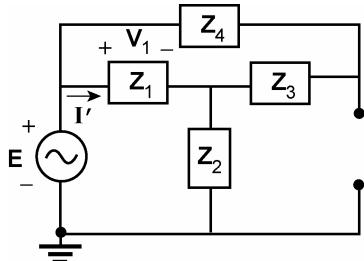


$$\begin{aligned}\mathbf{I}''' &= \frac{\mathbf{Z}_2 \mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(1 \Omega \angle 0^\circ)(0.5 \text{ A} \angle 60^\circ)}{5.83 \Omega \angle 30.96^\circ} \\ &= 0.0858 \text{ A} \angle 29.04^\circ\end{aligned}$$

$$\uparrow \mathbf{I}_L = \mathbf{I}' - \mathbf{I}'' - \mathbf{I}'''$$

$$\begin{aligned}&= (3.43 \text{ A} \angle -30.96^\circ) - (20.58 \text{ A} \angle -30.96^\circ) - (0.0858 \text{ A} \angle 29.04^\circ) \\ &= 17.20 \text{ A} \angle 149.30^\circ \text{ or } 17.20 \text{ A} \angle -30.70^\circ \downarrow\end{aligned}$$

b. \mathbf{E} :



$$\mathbf{Z}_1 = 3 \Omega \angle 90^\circ, \mathbf{Z}_2 = 7 \Omega \angle -90^\circ$$

$$\mathbf{E} = 10 \text{ V} \angle 90^\circ$$

$$\mathbf{Z}_3 = 6 \Omega \angle -90^\circ, \mathbf{Z}_4 = 4 \Omega \angle 0^\circ$$

$$\mathbf{Z}' = \mathbf{Z}_1 \parallel (\mathbf{Z}_3 + \mathbf{Z}_4)$$

$$= 3 \Omega \angle 90^\circ \parallel (4 \Omega - j6 \Omega)$$

$$\begin{aligned}&= 3 \Omega \angle 90^\circ \parallel 7.21 \Omega \angle -56.31^\circ \\ &= 4.33 \Omega \angle 70.56^\circ\end{aligned}$$

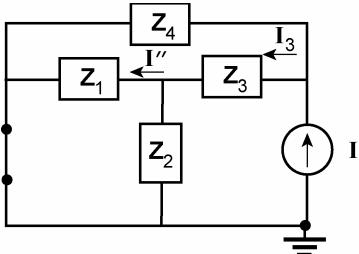
$$\mathbf{V}_1 = \frac{\mathbf{Z}' \mathbf{E}}{\mathbf{Z}' + \mathbf{Z}_2}$$

$$= \frac{(4.33 \Omega \angle 70.56^\circ)(10 \text{ V} \angle 90^\circ)}{(1.44 \Omega + j4.08 \Omega) - j7 \Omega}$$

$$= \frac{43.3 \text{ V} \angle 160.56^\circ}{3.26 \angle -63.75^\circ} = 13.28 \text{ V} \angle 224.31^\circ$$

$$\begin{aligned}\mathbf{I}' &= \frac{\mathbf{V}_1}{\mathbf{Z}_1} = \frac{13.28 \text{ V} \angle 224.31^\circ}{3 \Omega \angle 90^\circ} \\ &= 4.43 \text{ A} \angle 134.31^\circ\end{aligned}$$

I:



$$\begin{aligned}\mathbf{Z}'' &= \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 \\ &= -j6 \Omega + 3 \Omega \angle 90^\circ \parallel 7 \Omega \angle -90^\circ \\ &= -j6 \Omega + 5.25 \Omega \angle 90^\circ \\ &= -j6 \Omega + j5.25 \Omega \\ &= -j0.75 \Omega = 0.75 \Omega \angle -90^\circ\end{aligned}$$

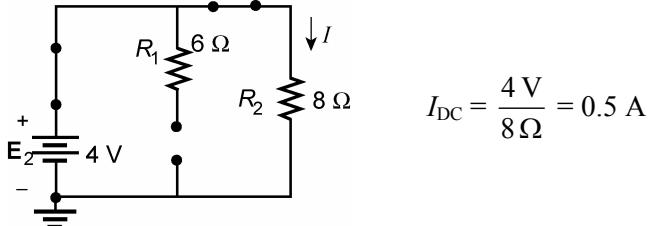
CDR:

$$\begin{aligned}\mathbf{I}_3 &= \frac{\mathbf{Z}_4 \mathbf{I}}{\mathbf{Z}_4 + \mathbf{Z}''} = \frac{(4 \Omega \angle 0^\circ)(0.6 \text{ A} \angle 120^\circ)}{4 \Omega - j0.75 \Omega} = \frac{2.4 \text{ A} \angle 120^\circ}{4.07 \angle -10.62^\circ} \\ &= 0.59 \text{ A} \angle 130.62^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{I}'' &= \frac{\mathbf{Z}_2 \mathbf{I}_3}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(7 \Omega \angle -90^\circ)(0.59 \text{ A} \angle 130.62^\circ)}{-j7 \Omega + j3 \Omega} = \frac{4.13 \text{ A} \angle 40.62^\circ}{4 \angle -90^\circ} \\ &= 1.03 \text{ A} \angle 130.62^\circ\end{aligned}$$

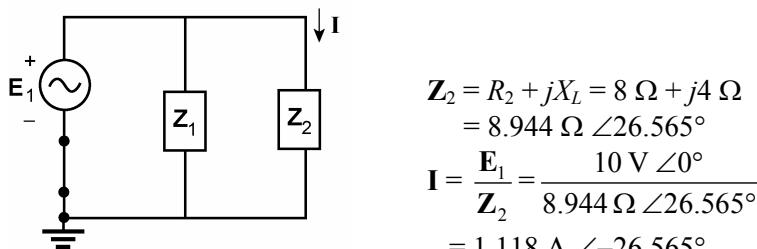
$$\begin{aligned}\mathbf{I}_L &= \mathbf{I}' - \mathbf{I}'' \text{ (direction of } \mathbf{I}'\text{)} \\ &= 4.43 \text{ A} \angle 134.31^\circ - 1.03 \text{ A} \angle 130.62^\circ \\ &= (-3.09 \text{ A} + j3.17 \text{ A}) - (-0.67 \text{ A} + j0.78 \text{ A}) = -2.42 \text{ A} + j2.39 \text{ A} \\ &= \mathbf{3.40 \text{ A} \angle 135.36^\circ}\end{aligned}$$

3. DC:



$$I_{DC} = \frac{4 \text{ V}}{8 \Omega} = 0.5 \text{ A}$$

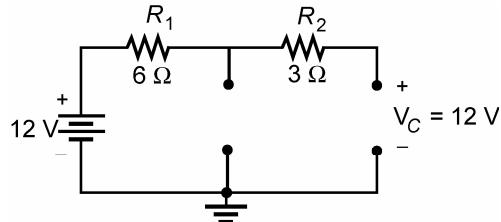
AC:



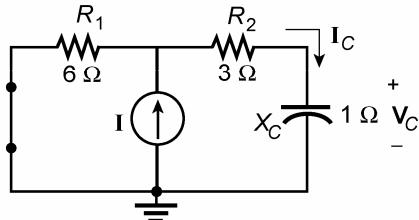
$$\begin{aligned}\mathbf{Z}_2 &= R_2 + jX_L = 8 \Omega + j4 \Omega \\ &= 8.944 \Omega \angle 26.565^\circ \\ \mathbf{I} &= \frac{\mathbf{E}_1}{\mathbf{Z}_2} = \frac{10 \text{ V} \angle 0^\circ}{8.944 \Omega \angle 26.565^\circ} \\ &= 1.118 \text{ A} \angle -26.565^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{I} &= 0.5 \text{ A} + 1.118 \text{ A} \angle -26.57^\circ \\ i &= 0.5 \text{ A} + 1.58 \sin(\omega t - 26.57^\circ)\end{aligned}$$

4. DC:



AC:

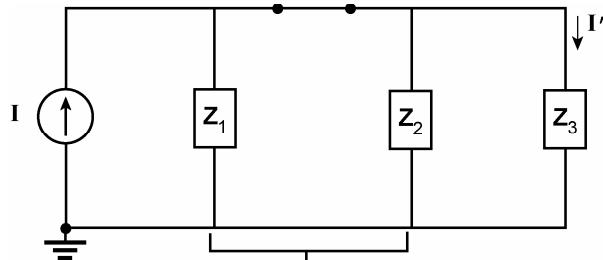


$$\begin{aligned} \mathbf{I}_C &= \frac{(6 \Omega \angle 0^\circ)(\mathbf{I})}{6 \Omega + 3 \Omega - j1 \Omega} \\ &= \frac{(6 \Omega \angle 0^\circ)(4 \text{ A } \angle 0^\circ)}{9 \Omega - j1 \Omega} \\ &= \frac{24 \text{ A } \angle 0^\circ}{9.055 \angle -6.34^\circ} \\ &= 2.65 \text{ A } \angle 6.34^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{V}_C &= \mathbf{I}_C \mathbf{X}_C = (2.65 \text{ A } \angle 6.34^\circ)(1 \Omega \angle -90^\circ) = 2.65 \text{ V } \angle -83.66^\circ \\ &= 12 \text{ V } + 2.65 \text{ V } \angle -83.66^\circ \end{aligned}$$

$$v_C = 12 \text{ V} + 3.75 \sin(\omega t - 83.66^\circ)$$

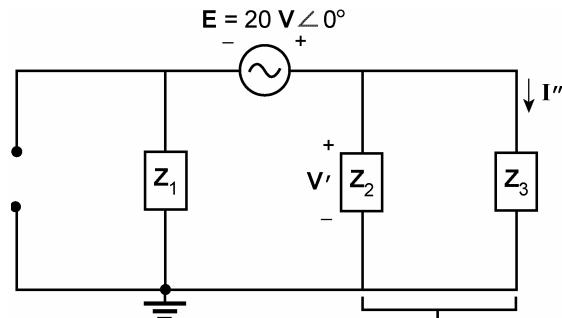
5.



$$\begin{aligned} \mathbf{E} &= 20 \text{ V } \angle 0^\circ \\ \mathbf{Z}_1 &= 10 \text{ k}\Omega \angle 0^\circ \\ \mathbf{Z}_2 &= 5 \text{ k}\Omega - j5 \text{ k}\Omega \\ &= 7.071 \text{ k}\Omega \angle -45^\circ \\ \mathbf{Z}_3 &= 5 \text{ k}\Omega \angle 90^\circ \\ \mathbf{I} &= 5 \text{ mA } \angle 0^\circ \end{aligned}$$

$$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 10 \text{ k}\Omega \angle 0^\circ \parallel 7.071 \text{ k}\Omega \angle -45^\circ = 4.472 \text{ k}\Omega \angle -26.57^\circ$$

$$\begin{aligned} (\text{CDR}) \quad \mathbf{I}' &= \frac{\mathbf{Z}' \mathbf{I}}{\mathbf{Z}' + \mathbf{Z}_3} = \frac{(4.472 \text{ k}\Omega \angle -26.57^\circ)(5 \text{ mA } \angle 0^\circ)}{4 \text{ k}\Omega - j2 \text{ k}\Omega + j5 \text{ k}\Omega} = \frac{22.36 \text{ mA } \angle -26.57^\circ}{5 \angle 36.87^\circ} \\ &= 4.472 \text{ mA } \angle -63.44^\circ \end{aligned}$$



$$\begin{aligned} \mathbf{Z}'' &= \mathbf{Z}_2 \parallel \mathbf{Z}_3 \\ &= 7.071 \text{ k}\Omega \angle -45^\circ \parallel 5 \text{ k}\Omega \angle 90^\circ \\ &= 7.071 \text{ k}\Omega \angle 45^\circ \end{aligned}$$

(VDR)

$$\mathbf{V}' = \frac{\mathbf{Z}''\mathbf{E}}{\mathbf{Z}'' + \mathbf{Z}_1} = \frac{(7.071 \text{ k}\Omega \angle 45^\circ)(20 \text{ V} \angle 0^\circ)}{(5 \text{ k}\Omega + j5 \text{ k}\Omega) + (10 \text{ k}\Omega)} = \frac{141.42 \text{ V} \angle 45^\circ}{15.81 \angle 18.435^\circ}$$

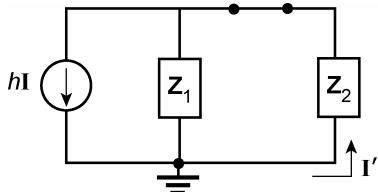
$$= 8.945 \text{ V} \angle 26.565^\circ$$

$$\mathbf{I}'' = \frac{\mathbf{V}'}{\mathbf{Z}_3} = \frac{8.945 \text{ V} \angle 26.565^\circ}{5 \text{ k}\Omega \angle 90^\circ} = 1.789 \text{ mA} \angle -63.435^\circ = 0.8 \text{ mA} - j1.6 \text{ mA}$$

$$\mathbf{I} = \mathbf{I}' + \mathbf{I}'' = (2 \text{ mA} - j4 \text{ mA}) + (0.8 \text{ mA} - j1.6 \text{ mA}) = 2.8 \text{ mA} - j5.6 \text{ mA}$$

$$= \mathbf{6.26 \text{ mA} \angle -63.43^\circ}$$

6.



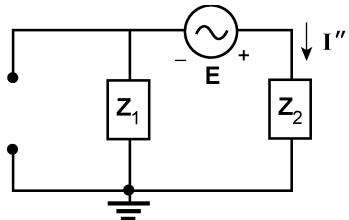
$$\mathbf{Z}_1 = 20 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 10 \text{ k}\Omega \angle 90^\circ$$

$$\mathbf{I} = 2 \text{ mA} \angle 0^\circ$$

$$\mathbf{E} = 10 \text{ V} \angle 0^\circ$$

$$\mathbf{I}' = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20 \text{ k}\Omega \angle 0^\circ)(100)(2 \text{ mA} \angle 0^\circ)}{20 \text{ k}\Omega + j10 \text{ k}\Omega} = 0.179 \text{ A} \angle -26.57^\circ$$



$$\mathbf{I}'' = \frac{\mathbf{E}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{10 \text{ V} \angle 0^\circ}{22.36 \text{ k}\Omega \angle 26.57^\circ}$$

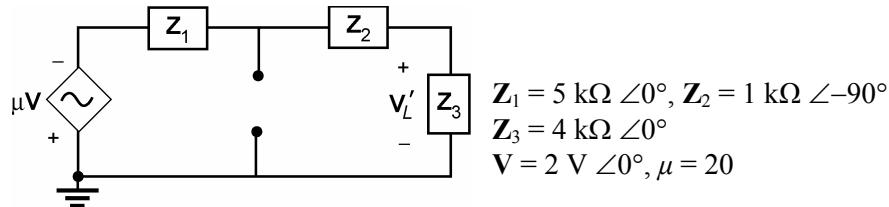
$$= 0.447 \text{ mA} \angle -26.57^\circ$$

$$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}'' \text{ (direction of } \mathbf{I}'\text{)}$$

$$= 179 \text{ mA} \angle -26.57^\circ - 0.447 \text{ mA} \angle -26.57^\circ$$

$$= \mathbf{178.55 \text{ mA} \angle -26.57^\circ}$$

7. $\mu\mathbf{V}$:



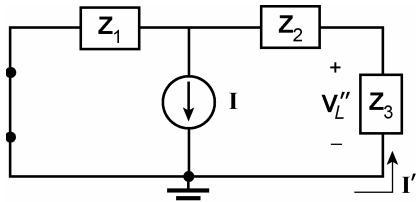
$$\mathbf{Z}_1 = 5 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_2 = 1 \text{ k}\Omega \angle -90^\circ$$

$$\mathbf{Z}_3 = 4 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{V} = 2 \text{ V} \angle 0^\circ, \mu = 20$$

$$\mathbf{V}'_L = \frac{-\mathbf{Z}_3(\mu\mathbf{V})}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3} = \frac{-(4 \text{ k}\Omega \angle 0^\circ)(20)(2 \text{ V} \angle 0^\circ)}{5 \text{ k}\Omega - j1 \text{ k}\Omega + 4 \text{ k}\Omega} = -17.67 \text{ V} \angle 6.34^\circ$$

\mathbf{I} :



CDR: $\mathbf{I}' = \frac{\mathbf{Z}_1 \mathbf{I}}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3}$

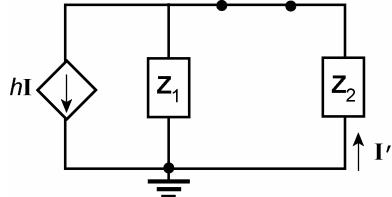
$$= \frac{(5 \text{ k}\Omega \angle 0^\circ)(2 \text{ mA} \angle 0^\circ)}{9.056 \text{ k}\Omega \angle -6.34^\circ}$$

$$= 1.104 \text{ mA} \angle 6.34^\circ$$

$$\mathbf{V}''_L = -\mathbf{I}' \mathbf{Z}_3 = -(1.104 \text{ mA} \angle 6.34^\circ)(4 \text{ k}\Omega \angle 0^\circ) = -4.416 \text{ V} \angle 6.34^\circ$$

$$\mathbf{V}_L = \mathbf{V}'_L + \mathbf{V}''_L = -17.67 \text{ V} \angle 6.34^\circ - 4.416 \text{ V} \angle 6.34^\circ = \mathbf{-22.09 \text{ V} \angle 6.34^\circ}$$

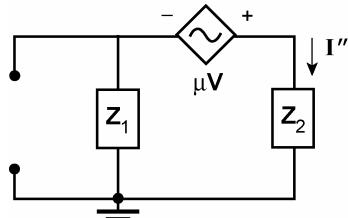
8.



$$\mathbf{Z}_1 = 20 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 5 \text{ k}\Omega + j5 \text{ k}\Omega$$

$$\mathbf{I}' = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20 \text{ k}\Omega \angle 0^\circ)(100)(1 \text{ mA} \angle 0^\circ)}{20 \text{ k}\Omega + 5 \text{ k}\Omega + j5 \text{ k}\Omega} = 78.45 \text{ mA} \angle -11.31^\circ$$



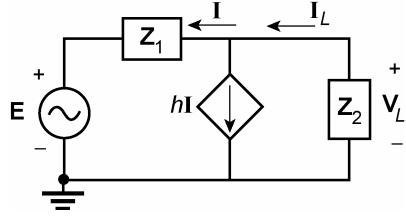
$$\mathbf{I}'' = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(10 \text{ V} \angle 0^\circ)}{25.495 \text{ k}\Omega \angle 11.31^\circ} = 7.845 \text{ mA} \angle -11.31^\circ$$

$$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}'' \quad (\text{direction of } \mathbf{I}')$$

$$= 78.45 \text{ mA} \angle -11.31^\circ - 7.845 \text{ mA} \angle -11.31^\circ$$

$$= 70.61 \text{ mA} \angle -11.31^\circ$$

9.



$$\mathbf{Z}_1 = 2 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_2 = 2 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{V}_L = -\mathbf{I}_L \mathbf{Z}_2$$

$$\mathbf{I}_L = h\mathbf{I} + \mathbf{I} = (h+1)\mathbf{I}$$

$$\mathbf{V}_L = -(h+1)\mathbf{I}\mathbf{Z}_2$$

and by KVL: $\mathbf{V}_L = \mathbf{I}\mathbf{Z}_1 + \mathbf{E}$

$$\text{so that } \mathbf{I} = \frac{\mathbf{V}_L - \mathbf{E}}{\mathbf{Z}_1}$$

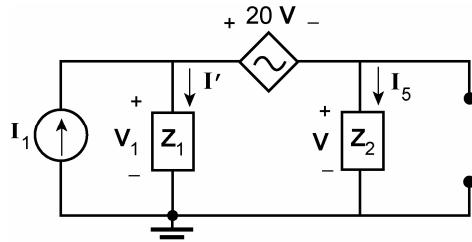
$$\mathbf{V}_L = -(h+1)\mathbf{I}\mathbf{Z}_2 = -(h+1) \left[\frac{\mathbf{V}_L - \mathbf{E}}{\mathbf{Z}_1} \right] \mathbf{Z}_2$$

Subt. for $\mathbf{Z}_1, \mathbf{Z}_2$

$$\mathbf{V}_L = -(h+1)(\mathbf{V}_L - \mathbf{E})$$

$$\mathbf{V}_L(2+h) = \mathbf{E}(h+1)$$

$$\mathbf{V}_L = \frac{(h+1)}{(h+2)} \mathbf{E} = \frac{51}{52} (20 \text{ V} \angle 53^\circ) = 19.62 \text{ V} \angle 53^\circ$$

10. \mathbf{I}_1 :

$$\mathbf{I}_1 = 1 \text{ mA} \angle 0^\circ$$

$$\mathbf{Z}_1 = 2 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 5 \text{ k}\Omega \angle 0^\circ$$

$$\text{KVL: } \mathbf{V}_1 - 20 \text{ V} - \mathbf{V} = 0$$

$$\mathbf{I}' = \frac{\mathbf{V}_1}{\mathbf{Z}_1} \therefore \mathbf{I}' = \frac{21 \text{ V}}{\mathbf{Z}_1} \text{ or } \mathbf{V} = \frac{\mathbf{Z}_1}{21} \mathbf{I}'$$

$$\mathbf{V}_1 = 21 \text{ V}$$

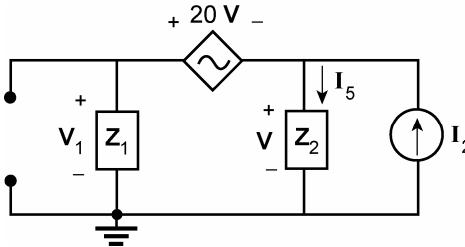
$$\mathbf{V} = \mathbf{I}_5 \mathbf{Z}_2 = [\mathbf{I}_1 - \mathbf{I}'] \mathbf{Z}_2$$

$$\frac{\mathbf{Z}_1}{21} \mathbf{I}' = \mathbf{I}_1 \mathbf{Z}_2 - \mathbf{I}' \mathbf{Z}_2$$

$$\mathbf{I}' \left[\frac{\mathbf{Z}_1}{21} + \mathbf{Z}_2 \right] = \mathbf{I}_1 \mathbf{Z}_2$$

$$\text{and } \mathbf{I}' = \frac{\mathbf{Z}_2}{\frac{\mathbf{Z}_1}{21} + \mathbf{Z}_2} \quad [\mathbf{I}_1] = \frac{(5 \text{ k}\Omega \angle 0^\circ)(1 \text{ mA} \angle 0^\circ)}{\left(\frac{2 \text{ k}\Omega \angle 0^\circ}{21} \right) + 5 \text{ k}\Omega \angle 0^\circ} = 0.981 \text{ mA} \angle 0^\circ$$

\mathbf{I}_2 :



$$V_1 = 20 \text{ V} + V = 21 \text{ V}$$

$$I'' = \frac{V_1}{Z_1} = \frac{21 \text{ V}}{Z_1} \Rightarrow V = \frac{Z_1}{21} I''$$

$$I_5 = \frac{V}{Z_2} = \frac{Z_1}{21 Z_2} I''$$

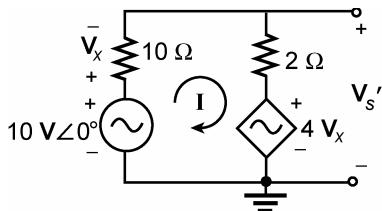
$$I'' = I_2 - I_5 = I_2 - \frac{Z_1}{21 Z_2} I''$$

$$I'' \left[1 + \frac{Z_1}{21 Z_2} \right] = I_2$$

$$I'' = \frac{I_2}{1 + \frac{Z_1}{21 Z_2}} = \frac{2 \text{ mA} \angle 0^\circ}{1 + \frac{2 \text{ k}\Omega}{21(5 \text{ k}\Omega)}} = 1.963 \text{ mA} \angle 0^\circ$$

$$\begin{aligned} \mathbf{I} &= \mathbf{I}' + \mathbf{I}'' = 0.981 \text{ mA} \angle 0^\circ + 1.963 \text{ mA} \angle 0^\circ \\ &= \mathbf{2.94 \text{ mA} \angle 0^\circ} \end{aligned}$$

11. \mathbf{E}_1 :



$$10 \text{ V} \angle 0^\circ - \mathbf{I} 10 \Omega - \mathbf{I} 2 \Omega - 4 V_x = 0$$

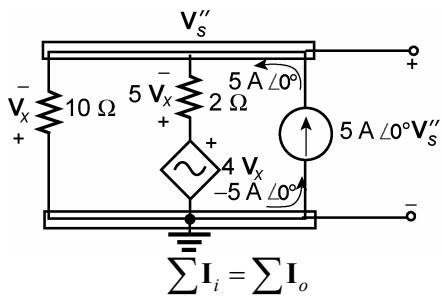
$$\text{with } V_x = \mathbf{I} 10 \Omega$$

Solving for \mathbf{I} :

$$\mathbf{I} = \frac{10 \text{ V} \angle 0^\circ}{52 \Omega} = 192.31 \text{ mA} \angle 0^\circ$$

$$V_s' = 10 \text{ V} \angle 0^\circ - \mathbf{I}(10 \Omega) = 10 \text{ V} - (192.31 \text{ mA} \angle 0^\circ)(10 \Omega \angle 0^\circ) = 8.08 \text{ V} \angle 0^\circ$$

I:



$$5 A \angle 0^\circ + \frac{V_x}{10 \Omega} + \frac{5 V_x}{2 \Omega} = 0$$

$$5 A + 0.1 V_x + 2.5 V_x = 0$$

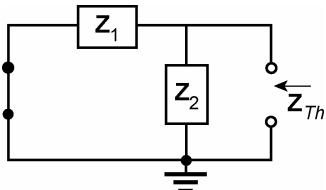
$$2.6 V_x = -5 A$$

$$V_x = -\frac{5}{2.6} V = -1.923 V$$

$$V_s'' = -V_x = -(-1.923 V) = 1.923 V \angle 0^\circ$$

$$V_s = V_s' + V_s'' = 8.08 V \angle 0^\circ + 1.923 V \angle 0^\circ = 10 V \angle 0^\circ$$

12. a. Z_{Th} :



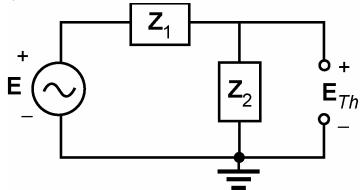
$$Z_1 = 3 \Omega \angle 0^\circ, Z_2 = 4 \Omega \angle 90^\circ$$

$$E = 100 V \angle 0^\circ$$

$$Z_{Th} = Z_1 \parallel Z_2 = (3 \Omega \angle 0^\circ \parallel 4 \Omega \angle 90^\circ)$$

$$= 2.4 \Omega \angle 36.87^\circ = 1.92 \Omega + j1.44 \Omega$$

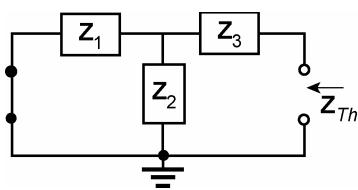
E_{Th} :



$$E_{Th} = \frac{Z_2 E}{Z_2 + Z_1} = \frac{(4 \Omega \angle 90^\circ)(100 V \angle 0^\circ)}{5 \Omega \angle 53.13^\circ}$$

$$= 80 V \angle 36.87^\circ$$

b. Z_{Th} :



$$Z_{Th} = Z_3 + Z_1 \parallel Z_2$$

$$= +j6 k\Omega + (2 k\Omega \angle 0^\circ \parallel 3 k\Omega \angle -90^\circ)$$

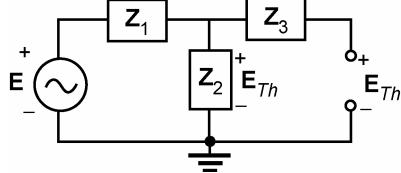
$$= +j6 k\Omega + 1.664 k\Omega \angle -33.69^\circ$$

$$= +j6 k\Omega + 1.385 k\Omega - j0.923 k\Omega$$

$$= 1.385 k\Omega + j5.077 k\Omega$$

$$= 5.26 k\Omega \angle 74.74^\circ$$

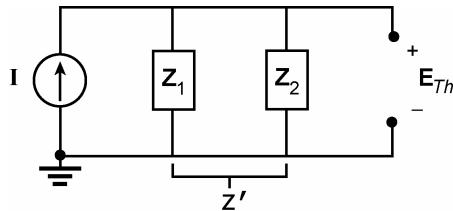
E_{Th} :



$$E_{Th} = \frac{Z_2 E}{Z_2 + Z_1} = \frac{(3 k\Omega \angle -90^\circ)(20 V \angle 0^\circ)}{2 k\Omega - j3 k\Omega}$$

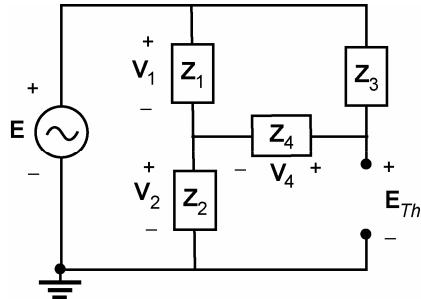
$$= \frac{60 V \angle -90^\circ}{3.606 \angle -56.31^\circ} = 16.64 V \angle -33.69^\circ$$

13. a. From #27. $\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
 $\mathbf{Z}_{Th} = \mathbf{Z}_N = 21.31 \Omega \angle 32.2^\circ$



$$\begin{aligned}\mathbf{E}_{Th} &= \mathbf{I}\mathbf{Z}' = \mathbf{I}\mathbf{Z}_{Th} \\ &= (0.1 \text{ A} \angle 0^\circ)(21.31 \Omega \angle 32.12^\circ) \\ &= 2.13 \text{ V} \angle 32.2^\circ\end{aligned}$$

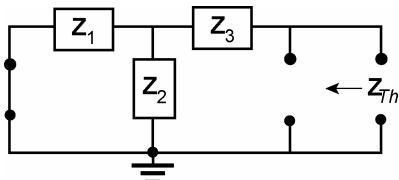
- b. From #27. $\mathbf{Z}_{Th} = \mathbf{Z}_N = 6.81 \Omega \angle -54.23^\circ = 3.98 \Omega - j5.53 \Omega$



$$\begin{aligned}\mathbf{Z}_1 &= 2 \Omega \angle 0^\circ, \mathbf{Z}_3 = 8 \Omega \angle -90^\circ \\ \mathbf{Z}_2 &= 4 \Omega \angle 90^\circ, \mathbf{Z}_4 = 10 \Omega \angle 0^\circ \\ \mathbf{E} &= 50 \text{ V} \angle 0^\circ \\ \mathbf{E}_{Th} &= \mathbf{V}_2 + \mathbf{V}_4 \\ \mathbf{V}_2 &= \frac{\mathbf{Z}_2 \mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1 \parallel (\mathbf{Z}_3 + \mathbf{Z}_4)} \\ &= \frac{(4 \Omega \angle 90^\circ)(50 \text{ V} \angle 0^\circ)}{+j4 \Omega + 2 \Omega \angle 0^\circ \parallel (10 \Omega - j8 \Omega)} \\ &= 47.248 \text{ V} \angle 24.7^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{V}_1 &= \mathbf{E} - \mathbf{V}_2 = 50 \text{ V} \angle 0^\circ - 47.248 \text{ V} \angle 24.7^\circ = 20.972 \text{ V} \angle -70.285^\circ \\ \mathbf{V}_4 &= \frac{\mathbf{Z}_4 \mathbf{V}_1}{\mathbf{Z}_4 + \mathbf{Z}_3} = \frac{(10 \Omega \angle 0^\circ)(20.972 \text{ V} \angle -70.285^\circ)}{10 \Omega - j8 \Omega} = 16.377 \text{ V} \angle -31.625^\circ \\ \mathbf{E}_{Th} &= \mathbf{V}_2 + \mathbf{V}_4 = 47.248 \text{ V} \angle 24.7^\circ + 16.377 \text{ V} \angle -31.625^\circ \\ &= (42.925 \text{ V} + j19.743 \text{ V}) + (13.945 \text{ V} - j8.587 \text{ V}) \\ &= 56.870 \text{ V} + j11.156 \text{ V} = 57.95 \text{ V} \angle 11.10^\circ\end{aligned}$$

14. a. \mathbf{Z}_{Th} :

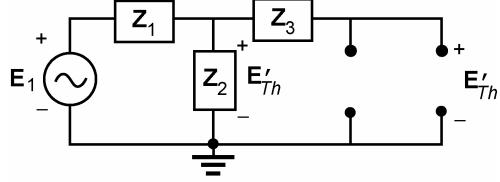


$$\begin{aligned}\mathbf{Z}_1 &= 10 \Omega \angle 0^\circ, \mathbf{Z}_2 = 8 \Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 8 \Omega \angle -90^\circ\end{aligned}$$

$$\begin{aligned}\mathbf{Z}_{Th} &= \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 \\ &= -j8 \Omega + 10 \Omega \angle 0^\circ \parallel 8 \Omega \angle 90^\circ \\ &= -j8 \Omega + 6.247 \Omega \angle 51.34^\circ \\ &= -j8 \Omega + 3.902 \Omega + j4.878 \Omega \\ &= 3.902 \Omega - j3.122 \Omega \\ &= 5.00 \Omega \angle -38.66^\circ\end{aligned}$$

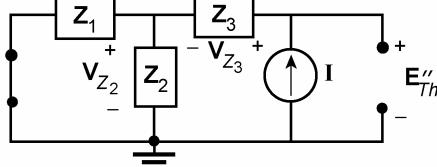
\mathbf{E}_{Th} : Superposition:

(E₁)



$$\begin{aligned}\mathbf{E}'_{Th} &= \frac{(8\Omega \angle 90^\circ)(120V \angle 0^\circ)}{10\Omega + j8\Omega} \\ &= \frac{960V \angle 90^\circ}{12.806 \angle 38.66^\circ} \\ &= 74.965V \angle 51.34^\circ\end{aligned}$$

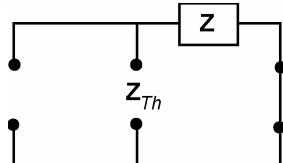
(I)



$$\begin{aligned}\mathbf{E}''_{Th} &= \mathbf{V}_{Z_2} + \mathbf{V}_{Z_3} \\ &= \mathbf{I}\mathbf{Z}_3 + \mathbf{I}(\mathbf{Z}_1 \parallel \mathbf{Z}_2) \\ &= \mathbf{I}(\mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2) \\ &= (0.5A \angle 60^\circ)(-j8\Omega + 10\Omega \angle 0^\circ \parallel 8\Omega \angle 90^\circ) \\ &= (0.5A \angle 60^\circ)(-j8\Omega + 3.902\Omega + j4.878\Omega) \\ &= (0.5A \angle 60^\circ)(3.902\Omega - j3.122\Omega) \\ &= (0.5A \angle 60^\circ)(4.997\Omega \angle -38.663^\circ) \\ &= 2.499V \angle 21.337^\circ\end{aligned}$$

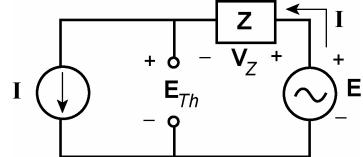
$$\begin{aligned}\mathbf{E}_{Th} &= \mathbf{E}'_{Th} + \mathbf{E}''_{Th} \\ &= 74.965V \angle 51.34^\circ + 2.449V \angle 21.337^\circ \\ &= (46.83V + j58.538V) + (2.328V + j0.909V) \\ &= 49.158V + j59.447V = 77.14V \angle 50.41^\circ\end{aligned}$$

b. \mathbf{Z}_{Th} :



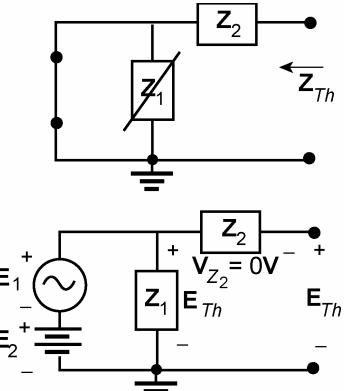
$$\mathbf{Z}_{Th} = \mathbf{Z} = 10\Omega - j10\Omega = 14.14\Omega \angle -45^\circ$$

\mathbf{E}_{Th} :



$$\begin{aligned}\mathbf{E}_{Th} &= \mathbf{E} - \mathbf{V}_Z \\ &= 20V \angle 40^\circ - \mathbf{I}\mathbf{Z} \\ &= 20V \angle 40^\circ - (0.6A \angle 90^\circ)(14.14\Omega \angle -45^\circ) \\ &= 20V \angle 40^\circ - 8.484V \angle 45^\circ \\ &= (15.321V + j12.856V) - (6V + j6V) \\ &= 9.321V + j6.856V \\ &= 11.57V \angle 36.34^\circ\end{aligned}$$

15. a.



$$\mathbf{Z}_1 = 6 \Omega - j2 \Omega = 6.325 \Omega \angle -18.435^\circ$$

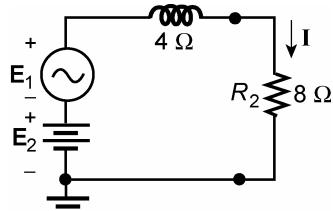
$$\mathbf{Z}_2 = 4 \Omega \angle 90^\circ$$

$$\mathbf{Z}_{Th} = \mathbf{Z}_2 = 4 \Omega \angle 90^\circ$$

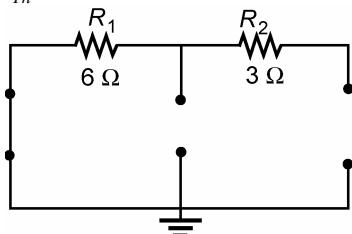
By inspection:

$$\begin{aligned}\mathbf{E}_{Th} &= \mathbf{E}_2 + \mathbf{E}_1 \\ &= 4 \text{ V} + 10 \text{ V} \angle 0^\circ \\ \text{DC} &\quad \text{AC}\end{aligned}$$

b.

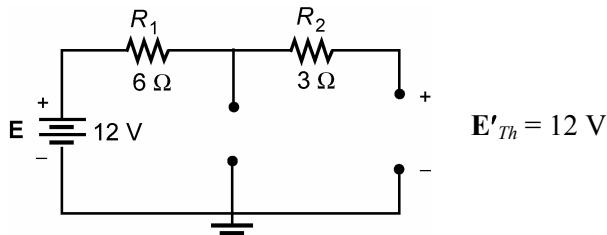


$$\begin{aligned}\mathbf{I} &= \frac{\mathbf{E}_2}{R_2} + \frac{\mathbf{E}_1}{R_2 + jX_L} \\ &= \frac{4 \text{ V}}{8 \Omega} + \frac{10 \text{ V} \angle 0^\circ}{8 \Omega + j4 \Omega} \\ &= 0.5 \text{ A} + \frac{10 \text{ V} \angle 0^\circ}{8.944 \Omega \angle 26.565^\circ} \\ &= 0.5 \text{ A} + 1.118 \text{ A} \angle -26.565^\circ \\ (\text{dc}) &\quad (\text{ac}) \\ i &= 0.5 + 1.58 \sin(\omega t - 26.57^\circ)\end{aligned}$$

16. a. \mathbf{Z}_{Th} :

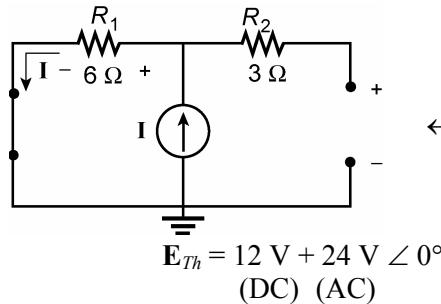
$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_{R_1} + \mathbf{Z}_{R_2} = 6 \Omega + 3 \Omega = 9 \Omega$$

DC:



$$\mathbf{E}'_{Th} = 12 \text{ V}$$

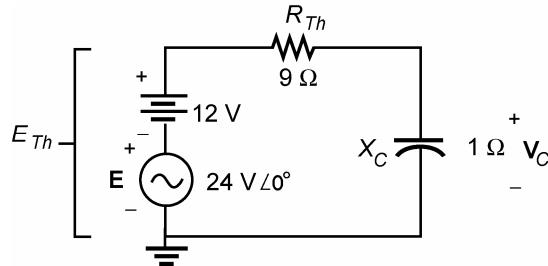
AC:



$$\leftarrow \mathbf{E}''_{Th} = \mathbf{I} \mathbf{Z}_{R_1} = (4 \text{ A} \angle 0^\circ)(6 \Omega \angle 0^\circ) = 24 \text{ V} \angle 0^\circ$$

$$\begin{aligned}\mathbf{E}_{Th} &= 12 \text{ V} + 24 \text{ V} \angle 0^\circ \\ (\text{DC}) &\quad (\text{AC})\end{aligned}$$

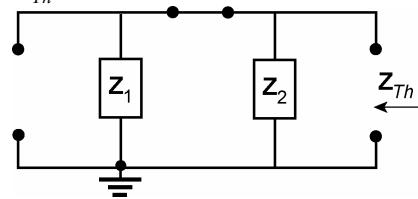
b.



$$\begin{aligned} \text{DC: } V_C &= 12 \text{ V} \\ \text{AC: } V_C &= \frac{\mathbf{Z}_C \mathbf{E}}{\mathbf{Z}_C + \mathbf{Z}_{R_{Th}}} \\ &= \frac{(1 \Omega \angle -90^\circ)(24 \text{ V} \angle 0^\circ)}{-j1\Omega + 9\Omega} \\ &= \frac{24 \text{ V} \angle -90^\circ}{9.055 \angle -6.34^\circ} \\ V_C &= 2.65 \text{ V} \angle -83.66^\circ \end{aligned}$$

$$\begin{aligned} v_C &= 12 \text{ V} + 2.65 \text{ V} \angle -83.66^\circ \\ &= 12 \text{ V} + 3.75 \sin(\omega t - 83.66^\circ) \end{aligned}$$

17. a.

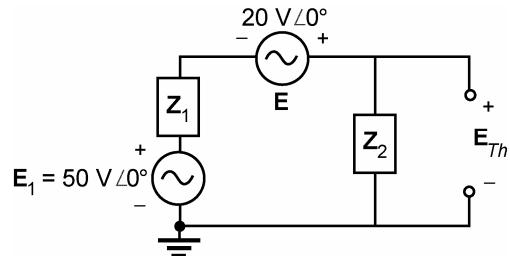
 \mathbf{Z}_{Th} :

$$\begin{aligned} Z_1 &= 10 \text{ k}\Omega \angle 0^\circ \\ Z_2 &= 5 \text{ k}\Omega - j5 \text{ k}\Omega \\ &= 7.071 \text{ k}\Omega \angle -45^\circ \end{aligned}$$

$$\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (10 \text{ k}\Omega \angle 0^\circ) \parallel (7.071 \text{ k}\Omega \angle -45^\circ) = 4.47 \text{ k}\Omega \angle -26.57^\circ$$

Source conversion:

$$\mathbf{E}_1 = (I \angle 0^\circ)(R_1 \angle 0^\circ) = (5 \text{ mA} \angle 0^\circ)(10 \text{ k}\Omega \angle 0^\circ) = 50 \text{ V} \angle 0^\circ$$

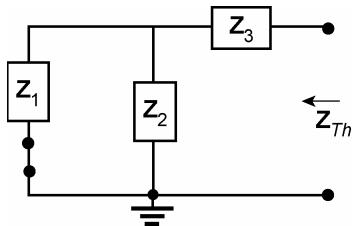


$$\begin{aligned} \mathbf{E}_{Th} &= \frac{\mathbf{Z}_2(\mathbf{E} + \mathbf{E}_1)}{\mathbf{Z}_2 + \mathbf{Z}_1} \\ &= \frac{(7.071 \text{ k}\Omega \angle -45^\circ)(20 \text{ V} \angle 0^\circ + 50 \text{ V} \angle 0^\circ)}{(5 \text{ k}\Omega - j5 \text{ k}\Omega) + (10 \text{ k}\Omega)} \\ &= \frac{(7.071 \text{ k}\Omega \angle -45^\circ)(70 \text{ V} \angle 0^\circ)}{(15 \text{ k}\Omega - j5 \text{ k}\Omega)} \\ &= \frac{494.97 \text{ V} \angle -45^\circ}{15.811 \angle -18.435^\circ} \\ &= 31.31 \text{ V} \angle -26.57^\circ \end{aligned}$$

b.

$$\begin{aligned} \mathbf{I} &= \frac{\mathbf{E}_{Th}}{\mathbf{Z}_{Th} + \mathbf{Z}_L} = \frac{31.31 \text{ V} \angle -26.565^\circ}{4.472 \text{ k}\Omega \angle -26.565^\circ + 5 \text{ k}\Omega \angle 90^\circ} \\ &= \frac{31.31 \text{ V} \angle -26.565^\circ}{4 \text{ k}\Omega - j2 \text{ k}\Omega + j5 \text{ k}\Omega} = \frac{31.31 \text{ V} \angle -26.565^\circ}{4 \text{ k}\Omega + j3 \text{ k}\Omega} \\ &= \frac{31.31 \text{ V} \angle -26.565^\circ}{5 \text{ k}\Omega \angle 36.87^\circ} = 6.26 \text{ mA} \angle 63.44^\circ \end{aligned}$$

18.

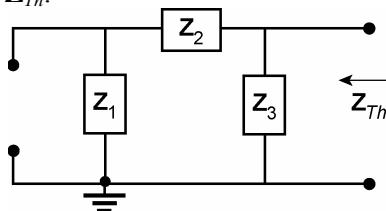


$$\begin{aligned}Z_1 &= 10 \text{ k}\Omega \angle 0^\circ \\Z_2 &= 10 \text{ k}\Omega \angle 0^\circ \\Z_3 &= 1 \text{ k}\Omega \angle -90^\circ\end{aligned}$$

$$Z_{Th} = Z_3 + Z_1 \parallel Z_2 = 5 \text{ k}\Omega - j1 \text{ k}\Omega \cong 5.1 \text{ k}\Omega \angle -11.31^\circ$$

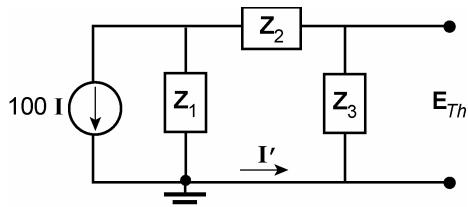
 E_{Th} : (VDR)

$$E_{Th} = \frac{Z_2(20 \text{ V})}{Z_2 + Z_1} = \frac{(10 \text{ k}\Omega \angle 0^\circ)(20 \text{ V})}{10 \text{ k}\Omega + 10 \text{ k}\Omega} = 10 \text{ V}$$

19. Z_{Th} :

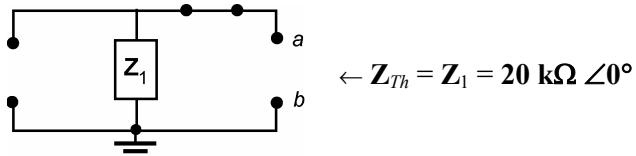
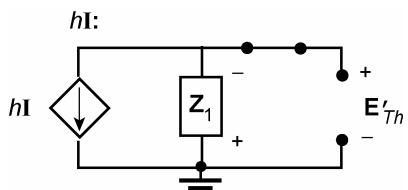
$$\begin{aligned}Z_1 &= 40 \text{ k}\Omega \angle 0^\circ \\Z_2 &= 0.2 \text{ k}\Omega \angle -90^\circ \\Z_3 &= 5 \text{ k}\Omega \angle 0^\circ\end{aligned}$$

$$Z_{Th} = Z_3 \parallel (Z_1 + Z_2) = 5 \text{ k}\Omega \angle 0^\circ \parallel (40 \text{ k}\Omega - j0.2 \text{ k}\Omega) = 4.44 \text{ k}\Omega \angle -0.03^\circ$$



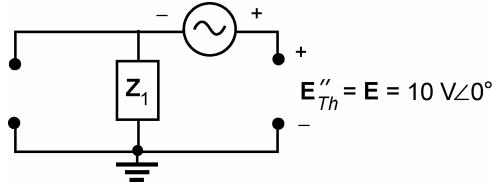
$$\begin{aligned}I' &= \frac{Z_1(100 \text{ I})}{Z_1 + Z_2 + Z_3} \\&= \frac{(40 \text{ k}\Omega \angle 0^\circ)(100 \text{ I})}{45 \text{ k}\Omega \angle -0.255^\circ} \\&= 88.89 \text{ I} \angle 0.255^\circ\end{aligned}$$

$$E_{Th} = -I'Z_3 = -(88.89 \text{ I} \angle 0.255^\circ)(5 \text{ k}\Omega \angle 0^\circ) = -444.45 \times 10^3 \text{ I} \angle 0.26^\circ$$

20. Z_{Th} : E_{Th} :

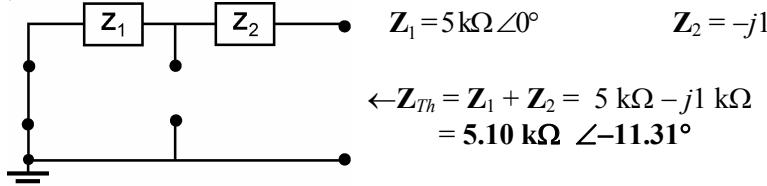
$$\begin{aligned}E'_{Th} &= -(hI)(Z_1) \\&= -(100)(2 \text{ mA} \angle 0^\circ)(20 \text{ k}\Omega \angle 0^\circ) \\&= -4 \text{ kV} \angle 0^\circ\end{aligned}$$

E:



$$\begin{aligned}\mathbf{E}_{Th} &= \mathbf{E}'_{Th} + \mathbf{E}''_{Th} \\ &= -4 \text{ kV} \angle 0^\circ + 10 \text{ V} \angle 0^\circ \\ &= \mathbf{-3990 \text{ V} \angle 0^\circ}\end{aligned}$$

21. \mathbf{Z}_{Th} :



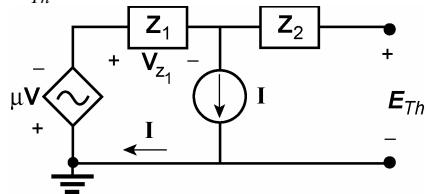
$$\mathbf{Z}_1 = 5 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = -j1$$

$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 + \mathbf{Z}_2 = 5 \text{ k}\Omega - j1 \text{ k}\Omega$$

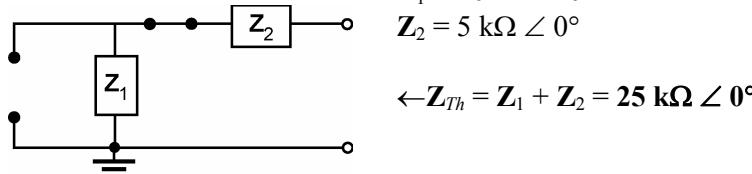
$$= 5.10 \text{ k}\Omega \angle -11.31^\circ$$

\mathbf{E}_{Th} :



$$\begin{aligned}\mathbf{E}_{Th} &= -[\mu\mathbf{V} + \mathbf{V}_{z_1}] \\ &= -\mu\mathbf{V} - \mathbf{I}\mathbf{Z}_1 \\ &= -(20)(2 \text{ V} \angle 0^\circ) - (2 \text{ mA} \angle 0^\circ)(5 \text{ k}\Omega \angle 0^\circ) \\ &= \mathbf{-50 \text{ V} \angle 0^\circ}\end{aligned}$$

22. \mathbf{Z}_{Th} :

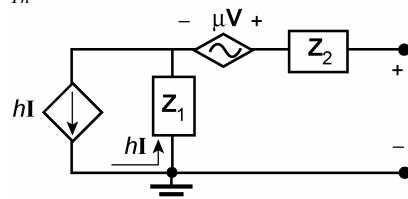


$$\mathbf{Z}_1 = 20 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 5 \text{ k}\Omega \angle 0^\circ$$

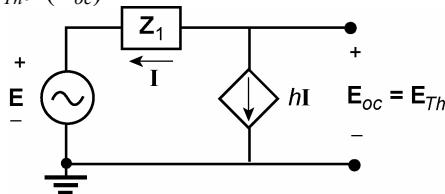
$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 + \mathbf{Z}_2 = 25 \text{ k}\Omega \angle 0^\circ$$

\mathbf{E}_{Th} :



$$\begin{aligned}\mathbf{E}_{Th} &= \mu\mathbf{V} - (h\mathbf{I})(\mathbf{Z}_1) \\ &= (20)(10 \text{ V} \angle 0^\circ) - (100)(1 \text{ mA} \angle 0^\circ)(20 \text{ k}\Omega \angle 0^\circ) \\ &= \mathbf{-1800 \text{ V} \angle 0^\circ}\end{aligned}$$

23. \mathbf{E}_{Th} : (\mathbf{E}_{oc})

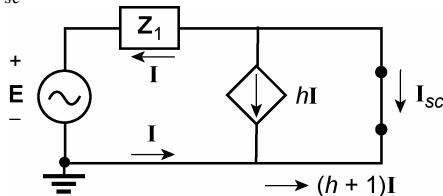


$$h\mathbf{I} = -\mathbf{I} \quad Z_1 = 2 \text{ k}\Omega \angle 0^\circ$$

$$\therefore \mathbf{I} = 0$$

and $h\mathbf{I} = 0$
with $\mathbf{E}_{oc} = \mathbf{E}_{Th} = \mathbf{E} = 20 \text{ V} \angle 53^\circ$

\mathbf{I}_{sc} :



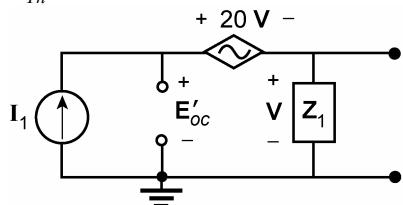
$$\mathbf{I}_{sc} = -(h + 1)\mathbf{I}$$

$$= -(h + 1)(10 \text{ mA} \angle 53^\circ)$$

$$= -510 \text{ mA} \angle 53^\circ$$

$$Z_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{20 \text{ V} \angle 53^\circ}{-510 \text{ mA} \angle 53^\circ} = -39.22 \Omega \angle 0^\circ$$

24. \mathbf{E}_{Th} :



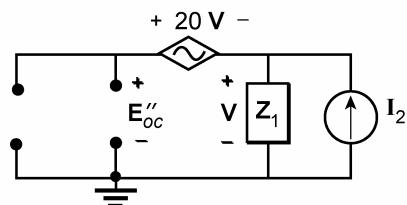
$$\mathbf{E}'_{oc} = 21 \text{ V} \quad Z_1 = 5 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{V} = \mathbf{I}_1 Z_1 = (1 \text{ mA} \angle 0^\circ)(5 \text{ k}\Omega \angle 0^\circ)$$

$$= 5 \text{ V} \angle 0^\circ$$

$$\mathbf{E}'_{oc} = \mathbf{E}'_{Th} = 21(5 \text{ V} \angle 0^\circ)$$

$$= 105 \text{ V} \angle 0^\circ$$



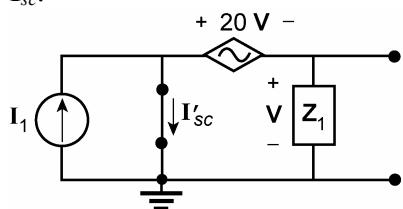
$$\mathbf{V} = \mathbf{I}_2 Z_1$$

$$= (2 \text{ mA} \angle 0^\circ)(5 \text{ k}\Omega \angle 0^\circ)$$

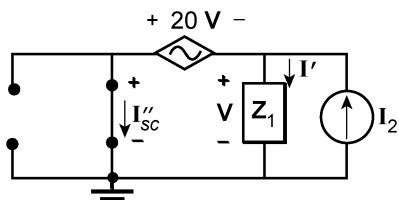
$$= 10 \text{ V} \angle 0^\circ$$

$$\mathbf{E}''_{oc} = \mathbf{E}''_{Th} = \mathbf{V} + 20 \text{ V} = 21 \text{ V} = 210 \text{ V} \angle 0^\circ$$

\mathbf{I}_{sc} :



$$\mathbf{I}'_{sc} = \mathbf{I}_1$$



$$20 \text{ V} = \mathbf{V} \therefore \mathbf{V} = 0 \text{ V}$$

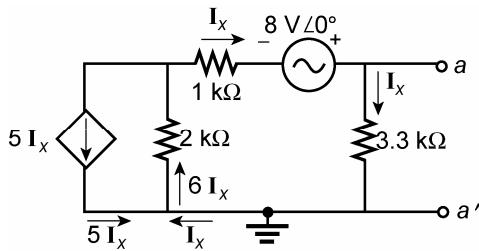
and $\mathbf{I}' = 0 \text{ A}$
 $\therefore \mathbf{I}''_{sc} = \mathbf{I}_2$

$$\mathbf{I}_{sc} = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 3 \text{ mA} \angle 0^\circ$$

$$\mathbf{E}_{oc} = \mathbf{E}'_{oc} + \mathbf{E}''_{oc} = 315 \text{ V} \angle 0^\circ = \mathbf{E}_{Th}$$

$$Z_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{315 \text{ V} \angle 0^\circ}{3 \text{ mA} \angle 0^\circ} = 105 \text{ k}\Omega \angle 0^\circ$$

25. \mathbf{E}_{oc} :
 (\mathbf{E}_{Th})

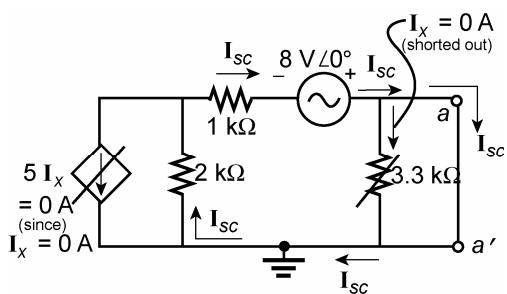


$$\text{KVL: } -6 \mathbf{I}_x(2 \text{ k}\Omega) - \mathbf{I}_x(1 \text{ k}\Omega) + 8 \text{ V} \angle 0^\circ - \mathbf{I}_x(3.3 \text{ k}\Omega) = 0$$

$$\mathbf{I}_x = \frac{8 \text{ V} \angle 0^\circ}{16.3 \text{ k}\Omega} = 0.491 \text{ mA} \angle 0^\circ$$

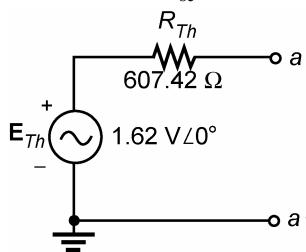
$$\mathbf{E}_{oc} = \mathbf{E}_{Th} = \mathbf{I}_x(3.3 \text{ k}\Omega) = 1.62 \text{ V} \angle 0^\circ$$

\mathbf{I}_{sc} :



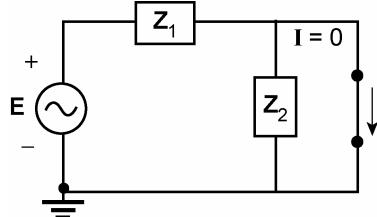
$$\mathbf{I}_{sc} = \frac{8 \text{ V}}{3 \text{ k}\Omega} = 2.667 \text{ mA} \angle 0^\circ$$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{1.62 \text{ V} \angle 0^\circ}{2.667 \text{ mA} \angle 0^\circ} = 607.42 \Omega \angle 0^\circ$$



26. a. From Problem 12(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 1.92 \Omega + j1.44 \Omega = 2.4 \Omega \angle 36.87^\circ$

\mathbf{I}_N :

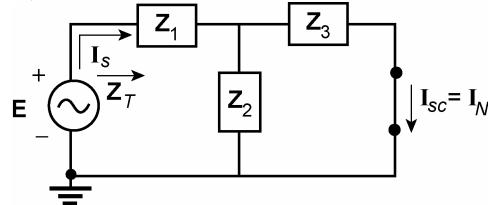


$$\mathbf{Z}_1 = 3 \Omega \angle 0^\circ, \mathbf{Z}_2 = 4 \Omega \angle 90^\circ$$

$$\begin{aligned} \mathbf{I}_{sc} &= \mathbf{I}_N = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{100 \text{ V} \angle 0^\circ}{3 \Omega \angle 0^\circ} \\ &= 33.33 \text{ A} \angle 0^\circ \end{aligned}$$

b. From Problem 12(b): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 5.263 \text{ k}\Omega \angle 74.74^\circ = 1.39 \text{ k}\Omega + j5.08 \text{ k}\Omega$

$\mathbf{I}_N:$



$$\mathbf{Z}_1 = 2 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_2 = 3 \text{ k}\Omega \angle -90^\circ$$

$$\mathbf{Z}_3 = 6 \text{ k}\Omega \angle 90^\circ$$

$$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3$$

$$= 2 \text{ k}\Omega + 3 \text{ k}\Omega \angle -90^\circ \parallel 6 \text{ k}\Omega \angle 90^\circ$$

$$= 2 \text{ k}\Omega + 6 \text{ k}\Omega \angle -90^\circ$$

$$= 2 \text{ k}\Omega - j6 \text{ k}\Omega$$

$$= 6.325 \text{ k}\Omega \angle -71.565^\circ$$

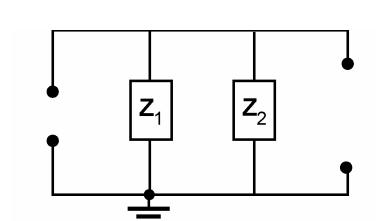
$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{20 \text{ V} \angle 0^\circ}{6.325 \text{ k}\Omega \angle -71.565^\circ}$$

$$= 3.162 \text{ mA} \angle 71.565^\circ$$

$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{Z}_2 \mathbf{I}_s}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(3 \text{ k}\Omega \angle -90^\circ)(3.162 \text{ mA} \angle 71.565^\circ)}{-j3 \text{ k}\Omega + j6 \text{ k}\Omega}$$

$$= \frac{9.486 \text{ mA} \angle -18.435^\circ}{3 \angle 90^\circ} = 3.16 \text{ mA} \angle -108.44^\circ$$

27. a.



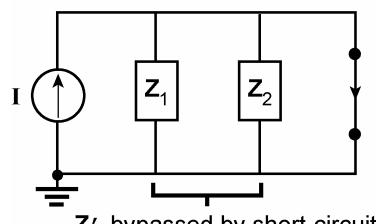
$$\mathbf{Z}_1 = 20 \Omega + j20 \Omega = 28.284 \Omega \angle 45^\circ$$

$$\mathbf{Z}_2 = 68 \Omega \angle 0^\circ$$

$$\leftarrow \mathbf{Z}_N = \mathbf{Z}_1 \parallel \mathbf{Z}_2$$

$$= (28.284 \Omega \angle 45^\circ) \parallel (68 \Omega \angle 0^\circ)$$

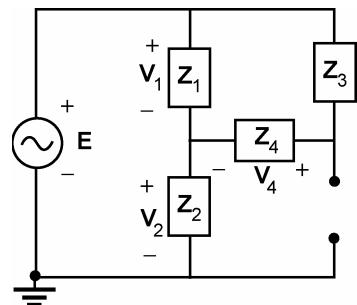
$$= 21.31 \Omega \angle 32.2^\circ$$



$$\leftarrow \mathbf{I}_{sc} = \mathbf{I} = \mathbf{I}_N = 0.1 \text{ A} \angle 0^\circ$$

Z' bypassed by short-circuit

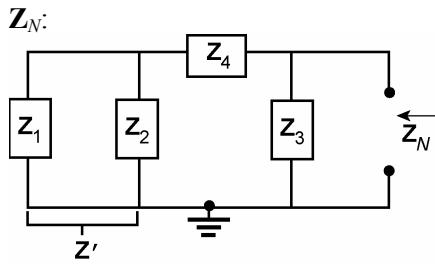
b.



$$\mathbf{Z}_1 = 2 \Omega \angle 0^\circ, \mathbf{Z}_2 = 4 \Omega \angle 90^\circ$$

$$\mathbf{Z}_3 = 8 \Omega \angle -90^\circ, \mathbf{Z}_4 = 10 \Omega \angle 0^\circ$$

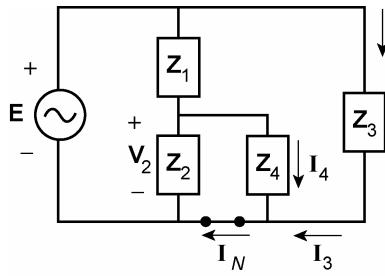
$$\mathbf{E} = 50 \text{ V} \angle 0^\circ$$



$$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 2 \Omega \angle 0^\circ \parallel 4 \Omega \angle 90^\circ \\ = 1.789 \Omega \angle 26.565^\circ = 1.6 \Omega + j0.8 \Omega$$

$$\mathbf{Z}' + \mathbf{Z}_4 = 1.6 \Omega + j0.8 \Omega + 10 \Omega = 11.6 \Omega + j0.8 \Omega = 11.628 \Omega \angle 3.945^\circ$$

$$\mathbf{Z}_N = \mathbf{Z}_3 \parallel (\mathbf{Z}' + \mathbf{Z}_4) = (8 \Omega \angle -90^\circ) \parallel (11.628 \Omega \angle 3.945^\circ) = 6.81 \Omega \angle -54.23^\circ \\ = 3.98 \Omega - j5.53 \Omega$$



$$\mathbf{I}_3 = \frac{\mathbf{E}}{\mathbf{Z}_3} = \frac{50 \text{ V} \angle 0^\circ}{8 \Omega \angle -90^\circ} = 6.250 \text{ A} \angle 90^\circ$$

$$\mathbf{Z}' = \mathbf{Z}_2 \parallel \mathbf{Z}_4 = 4 \Omega \angle 90^\circ \parallel 10 \Omega \angle 0^\circ \\ = 3.714 \Omega \angle 68.2^\circ$$

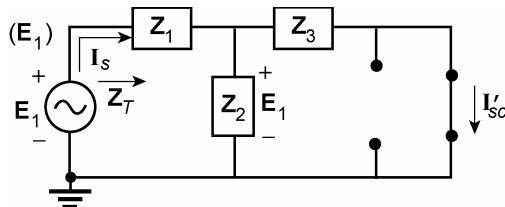
$$\mathbf{V}_2 = \frac{\mathbf{Z}' \mathbf{E}}{\mathbf{Z}' + \mathbf{Z}_1} = \frac{(3.714 \Omega \angle 68.2^\circ)(50 \text{ V} \angle 0^\circ)}{1.378 \Omega + j3.448 \Omega + 2 \Omega} \\ = \frac{185.7 \text{ V} \angle 68.2^\circ}{4.827 \angle 45.588^\circ} = 38.471 \text{ V} \angle 22.612^\circ$$

$$\mathbf{I}_4 = \frac{\mathbf{V}_2}{\mathbf{Z}_4} = \frac{38.471 \text{ V} \angle 22.612^\circ}{10 \Omega \angle 0^\circ} = 3.847 \text{ A} \angle 22.612^\circ$$

$$\mathbf{I}_N = \mathbf{I}_3 + \mathbf{I}_4 = 6.250 \text{ A} \angle 90^\circ + 3.847 \text{ A} \angle 22.612^\circ \\ = +j6.25 \text{ A} + 3.551 \text{ A} + j1.479 \text{ A} = 3.551 \text{ A} + j7.729 \text{ A} \\ = 8.51 \text{ A} \angle 65.32^\circ$$

28. a. From Problem 14(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 5.00 \Omega \angle -38.66^\circ$

\mathbf{I}_N : Superposition:



$$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3 \\ = 10 \Omega + 8 \Omega \angle 90^\circ \parallel 8 \Omega \angle -90^\circ \\ = 10 \Omega + \frac{64 \Omega \angle 0^\circ}{0} \\ = \text{very large impedance}$$

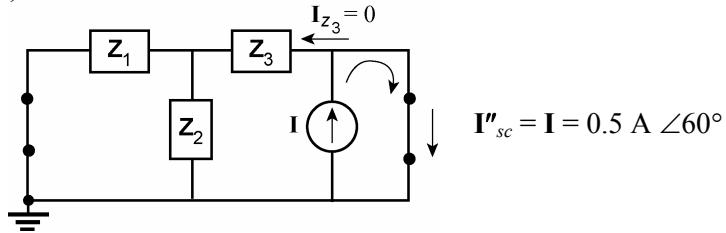
$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = 0 \text{ A}$$

$$\text{and } \mathbf{V}_{Z_1} = 0 \text{ V}$$

$$\text{with } \mathbf{V}_{Z_2} = \mathbf{V}_{Z_3} = \mathbf{E}_1 = 120 \text{ V} \angle 0^\circ$$

$$\text{so that } \mathbf{I}'_{sc} = \frac{\mathbf{E}_1}{\mathbf{Z}_3} = \frac{120 \text{ V} \angle 0^\circ}{8 \Omega \angle -90^\circ} \\ = 15 \text{ A} \angle 90^\circ$$

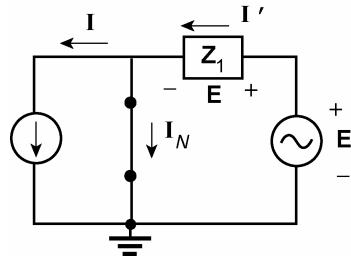
(I)



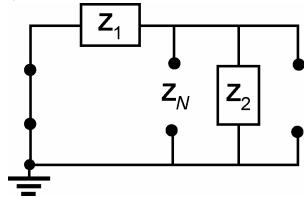
$$\mathbf{I}''_{sc} = \mathbf{I} = 0.5 \text{ A} \angle 60^\circ$$

$$\begin{aligned}\mathbf{I}_N &= \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = +j15 \text{ A} + 0.5 \text{ A} \angle 60^\circ = +j15 \text{ A} + 0.25 \text{ A} + j0.433 \text{ A} \\ &= 0.25 \text{ A} + j15.433 \text{ A} = \mathbf{15.44 A} \angle 89.07^\circ\end{aligned}$$

b. From Problem 14(b): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 10 \Omega - j10 \Omega = \mathbf{14.14 \Omega} \angle -45^\circ$

 $\mathbf{I}_{N'}$: $\mathbf{I}_N = \mathbf{I}' - \mathbf{I}$

$$\begin{aligned}&= \frac{\mathbf{E}}{\mathbf{Z}} - \mathbf{I} \\ &= \frac{20 \text{ V} \angle 40^\circ}{14.142 \Omega \angle -45^\circ} - 0.6 \text{ A} \angle 90^\circ \\ &= 1.414 \text{ A} \angle 85^\circ - j0.6 \text{ A} \\ &= 0.123 \text{ A} + j1.409 \text{ A} - j0.6 \text{ A} \\ &= 0.123 \text{ A} + j0.809 \text{ A} \\ &= \mathbf{0.82 A} \angle 81.35^\circ\end{aligned}$$

29. a. $\mathbf{Z}_{N'}$:

$$\mathbf{E} = 20 \text{ V} \angle 0^\circ, \mathbf{I}_2 = 0.4 \text{ A} \angle 20^\circ$$

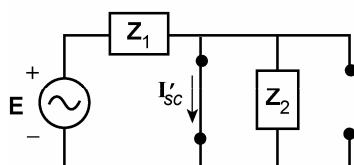
$$\mathbf{Z}_1 = 6 \Omega + j8 \Omega = 10 \Omega \angle 53.13^\circ$$

$$\mathbf{Z}_2 = \Omega - j12 \Omega = 15 \Omega \angle -53.13^\circ$$

$$\begin{aligned}\mathbf{Z}_N &= \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (10 \Omega \angle 53.13^\circ) \parallel (15 \Omega \angle -53.13^\circ) \\ &= \mathbf{9.66 \Omega} \angle 14.93^\circ\end{aligned}$$

 $\mathbf{I}_{N'}$:

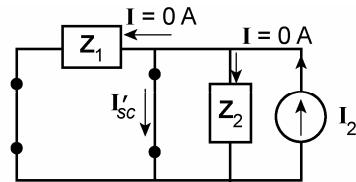
(E)



$$\mathbf{I}'_{sc} = \mathbf{E}/\mathbf{Z}_1 = 20 \text{ V} \angle 0^\circ / 10 \Omega \angle 53.13^\circ$$

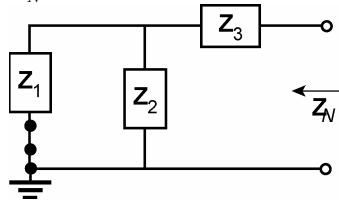
$$= 2 \text{ A} \angle -53.13^\circ$$

$$\begin{aligned}\mathbf{I}_N &= \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 2 \text{ A} \angle -53.13^\circ + 0.4 \text{ A} \angle 20^\circ \\ &= \mathbf{2.15 A} \angle -42.87^\circ\end{aligned}$$

(I₂)

$$\mathbf{I}''_{sc} = \mathbf{I}_2 = 0.4 \text{ A} \angle 20^\circ$$

b. \mathbf{Z}_N :

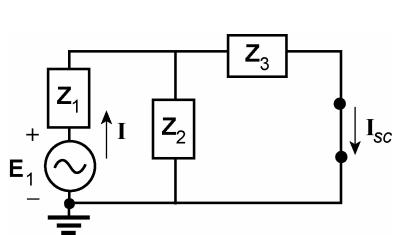


$$\mathbf{E}_1 = 120 \text{ V} \angle 30^\circ, \mathbf{Z}_1 = 3 \Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 8 \Omega - j8 \Omega, \mathbf{Z}_3 = 4 \Omega \angle 90^\circ$$

$$\begin{aligned}\mathbf{Z}_N &= \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 \\ &= 4 \Omega \angle 90^\circ + (3 \Omega \angle 0^\circ) \parallel (8 \Omega - j8 \Omega) \\ &= 4.37 \Omega \angle 55.67^\circ = 2.47 \Omega + j3.61 \Omega\end{aligned}$$

\mathbf{I}_N :



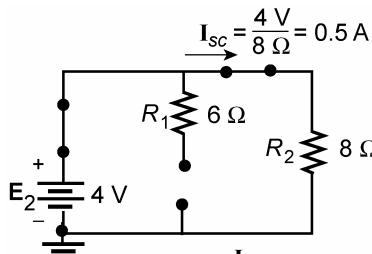
$$\begin{aligned}\mathbf{I} &= \frac{\mathbf{E}_1}{\mathbf{Z}_T} = \frac{120 \text{ V} \angle 30^\circ}{\mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3} \\ &= \frac{120 \text{ V} \angle 30^\circ}{3 \Omega + (8 \Omega - j8 \Omega) \parallel 4 \Omega \angle 90^\circ} \\ &= \frac{120 \text{ V} \angle 30^\circ}{6.65 \Omega \angle 46.22^\circ} \\ &= 18.05 \text{ A} \angle -16.22^\circ\end{aligned}$$

$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{Z}_2(\mathbf{I})}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(8 \Omega - j8 \Omega)(18.05 \text{ A} \angle -16.22^\circ)}{8 \Omega - j8 \Omega + j4 \Omega} = 22.83 \text{ A} \angle -34.65^\circ$$

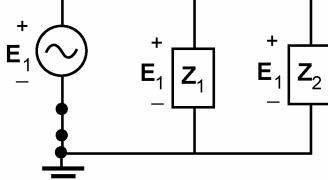
30. a. $\mathbf{Z}_N = 8 \Omega \angle 0^\circ$

\mathbf{I}_N :

DC



AC

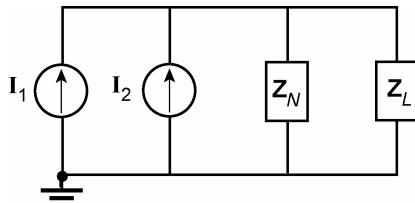


$$\begin{aligned}\mathbf{Z}_1 &= 6 \Omega - j2 \Omega \\ \mathbf{Z}_2 &= 8 \Omega \angle 0^\circ\end{aligned}$$

$$\mathbf{I}_{sc} = \frac{\mathbf{E}_1}{\mathbf{Z}_2} = \frac{10 \text{ V} \angle 0^\circ}{8 \Omega \angle 0^\circ} = 1.25 \text{ A} \angle 0^\circ$$

$$\mathbf{I}_N = 0.5 \text{ A} + 1.25 \text{ A} \angle 0^\circ$$

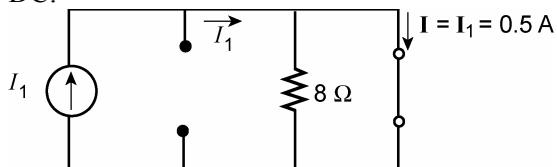
b.



$$\mathbf{Z}_N = 8 \Omega \angle 0^\circ$$

$$\mathbf{Z}_L = 4 \Omega \angle 90^\circ$$

DC:



AC:

$$\mathbf{I} = \frac{\mathbf{Z}_N(\mathbf{I}_2)}{\mathbf{Z}_N + \mathbf{Z}_L} = \frac{(8 \Omega \angle 0^\circ)(1.25 \text{ A} \angle 0^\circ)}{8 \Omega + j4 \Omega} = 1.118 \text{ A} \angle -26.57^\circ$$

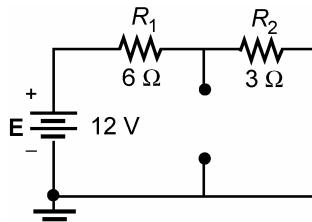
$$I_{8\Omega} = 0.5 \text{ A} + 1.118 \text{ A} \angle -26.57^\circ$$

(dc) (ac)

$$i = 0.5 + 1.58 \sin(\omega t - 26.57^\circ)$$

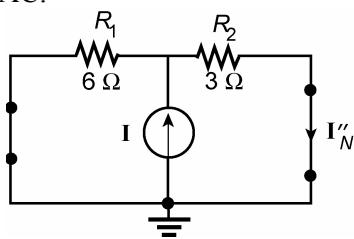
31. a. From #16 $\mathbf{Z}_N = \mathbf{Z}_{Th} = 9 \Omega \angle 0^\circ$

DC:



$$\mathbf{I}'_N = \frac{E}{R_T} = \frac{12 \text{ V}}{9 \Omega} = 1.33 \text{ A}$$

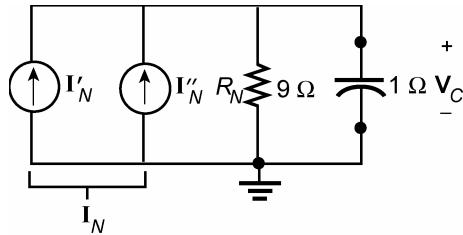
AC:



$$\begin{aligned} \mathbf{I}''_N &= \frac{R_1 \mathbf{I}}{R_1 + R_2} = \frac{(6 \Omega \angle 0^\circ)(4 \text{ A} \angle 0^\circ)}{9 \Omega \angle 0^\circ} \\ &= \frac{24 \text{ V} \angle 0^\circ}{9 \Omega \angle 0^\circ} = 2.67 \text{ A} \angle 0^\circ \end{aligned}$$

$$\mathbf{I}_N = 1.33 \text{ A} + 2.67 \text{ A} \angle 0^\circ$$

b.



$$\text{DC: } V_C = IR \\ = (1.33 \text{ A})(9 \Omega) \\ = 12 \text{ V}$$

$$\text{AC: } Z' = 9 \Omega \angle 0^\circ \parallel 1 \Omega \angle -90^\circ \\ = 0.994 \Omega \angle -83.66^\circ$$

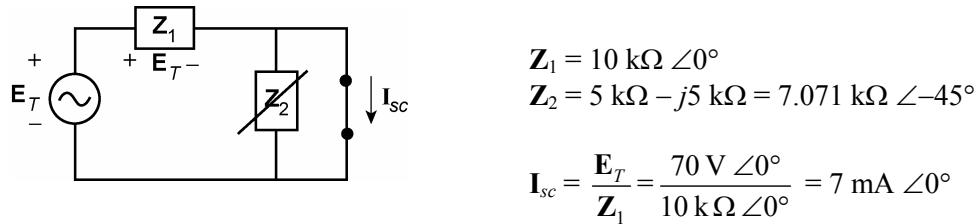
$$\mathbf{V}_C = \mathbf{I}Z' = (2.667 \text{ A} \angle 0^\circ)(0.994 \Omega \angle -83.66^\circ) \\ = 2.65 \text{ V} \angle -83.66^\circ$$

$$V_C = 12 \text{ V} + 2.65 \text{ V} \angle -83.66^\circ$$

32. a. Note Problem 17(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 4.47 \text{ k}\Omega \angle -26.57^\circ$

Using the same source conversion: $\mathbf{E}_1 = 50 \text{ V} \angle 0^\circ$

Defining $\mathbf{E}_T = \mathbf{E}_1 + \mathbf{E} = 50 \text{ V} \angle 0^\circ + 20 \text{ V} \angle 0^\circ = 70 \text{ V} \angle 0^\circ$



$$\mathbf{Z}_1 = 10 \text{ k}\Omega \angle 0^\circ$$

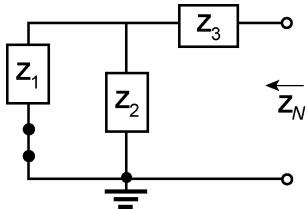
$$\mathbf{Z}_2 = 5 \text{ k}\Omega - j5 \text{ k}\Omega = 7.071 \text{ k}\Omega \angle -45^\circ$$

$$\mathbf{I}_{sc} = \frac{\mathbf{E}_T}{\mathbf{Z}_1} = \frac{70 \text{ V} \angle 0^\circ}{10 \text{ k}\Omega \angle 0^\circ} = 7 \text{ mA} \angle 0^\circ$$

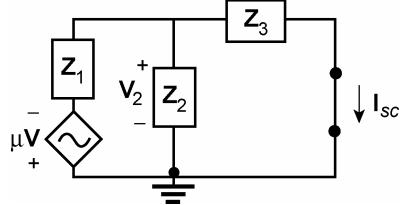
$$\mathbf{I}_N = \mathbf{I}_{sc} = 7 \text{ mA} \angle 0^\circ$$

$$\begin{aligned} \text{b. } \mathbf{I} &= \frac{\mathbf{Z}_N(\mathbf{I}_N)}{\mathbf{Z}_N + \mathbf{Z}_L} = \frac{(4.472 \text{ k}\Omega \angle -26.565^\circ)(7 \text{ mA} \angle 0^\circ)}{4.472 \text{ k}\Omega \angle -26.565^\circ + 5 \text{ k}\Omega \angle 90^\circ} \\ &= \frac{31.30 \text{ mA} \angle -26.565^\circ}{4 - j2 + j5} = \frac{31.30 \text{ mA} \angle -26.565^\circ}{4 + j3} \\ &= \frac{31.30 \text{ mA} \angle -26.565^\circ}{5 \angle 36.87^\circ} = 6.26 \text{ mA} \angle 63.44^\circ \text{ as obtained in Problem 17.} \end{aligned}$$

33.

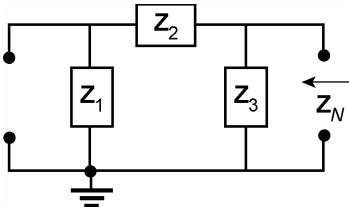
 Z_N :

$$\begin{aligned}Z_1 &= 10 \text{ k}\Omega \angle 0^\circ, Z_2 = 10 \text{ k}\Omega \angle 0^\circ \\Z_3 &= -j1 \text{ k}\Omega \\Z_N &= Z_3 + Z_1 \parallel Z_2 = 5 \text{ k}\Omega - j1 \text{ k}\Omega \\&= 5.1 \text{ k}\Omega \angle -11.31^\circ\end{aligned}$$

 I_N :

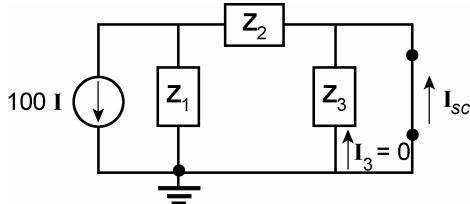
$$\begin{aligned}V_2 &= \frac{-(Z_2 \parallel Z_3)20 \text{ V}}{(Z_2 \parallel Z_3) + Z_1} \\&= \frac{-(0.995 \text{ k}\Omega \angle -84.29^\circ)(20 \text{ V})}{0.1 \text{ k}\Omega - j0.99 \text{ k}\Omega + 10 \text{ k}\Omega} \\V_2 &= -1.961 \text{ V} \angle -78.69^\circ\end{aligned}$$

$$I_N = I_{sc} = \frac{V_2}{Z_3} = \frac{-1.961 \text{ V} \angle -78.69^\circ}{1 \text{ k}\Omega \angle -90^\circ} = -1.96 \times 10^{-3} \text{ V} \angle 11.31^\circ$$

34. Z_N :

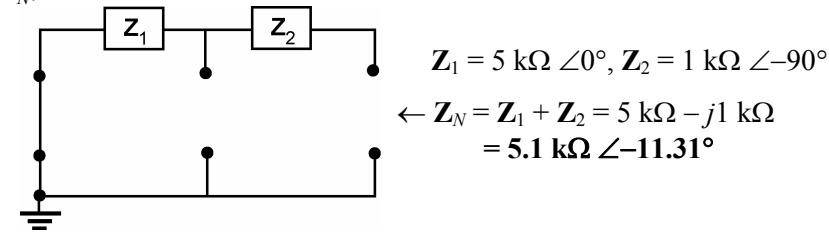
$$\begin{aligned}Z_1 &= 40 \text{ k}\Omega \angle 0^\circ, Z_2 = 0.2 \text{ k}\Omega \angle -90^\circ \\Z_3 &= 5 \text{ k}\Omega \angle 0^\circ\end{aligned}$$

$$\begin{aligned}Z_N &= Z_3 \parallel (Z_1 + Z_2) \\&= 5 \text{ k}\Omega \angle 0^\circ \parallel (40 \text{ k}\Omega - j0.2 \text{ k}\Omega) \\&= 4.44 \text{ k}\Omega \angle -0.03^\circ\end{aligned}$$

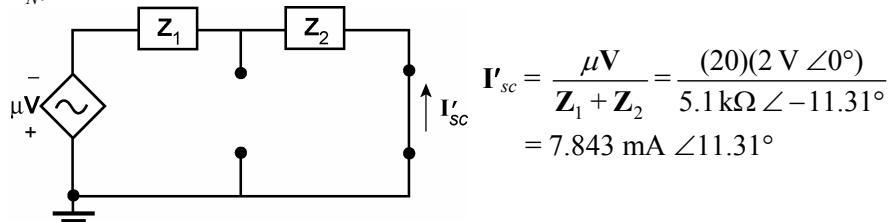
 I_N :

$$\begin{aligned}I_N = I_{sc} &= \frac{Z_1(100 I)}{Z_1 + Z_2} \\&= \frac{(40 \text{ k}\Omega \angle 0^\circ)(100 I)}{40 \text{ k}\Omega \angle -0.286^\circ} \\&= 100 I \angle 0.29^\circ\end{aligned}$$

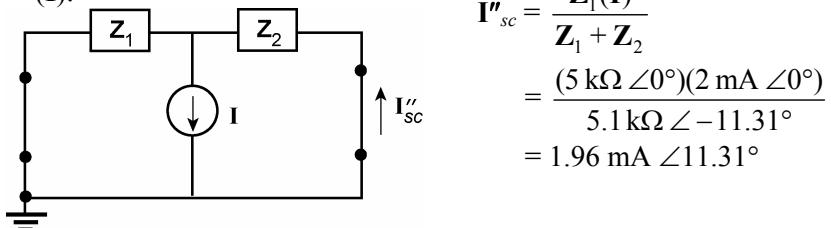
35. \mathbf{Z}_N :



\mathbf{I}_N :

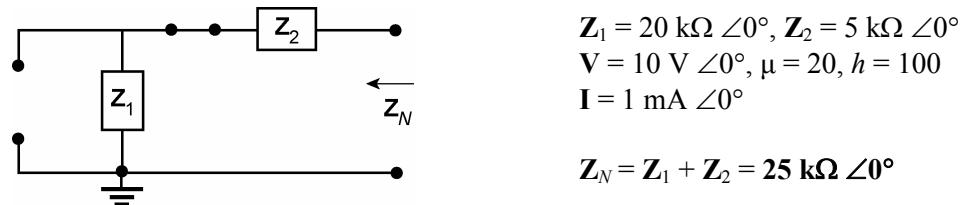


(I):

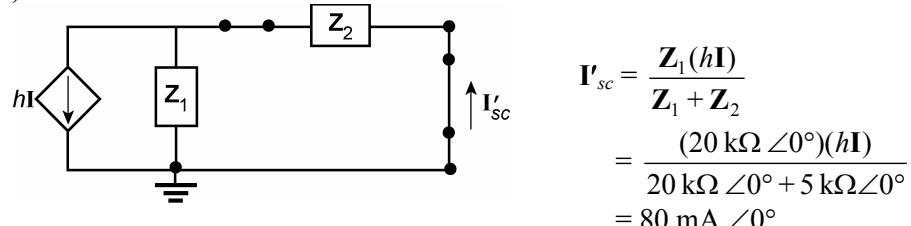


$$\begin{aligned} \mathbf{I}_N &= \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 7.843 \text{ mA} \angle 11.31^\circ + 1.96 \text{ mA} \angle 11.31^\circ \\ &= 9.81 \text{ mA} \angle 11.31^\circ \end{aligned}$$

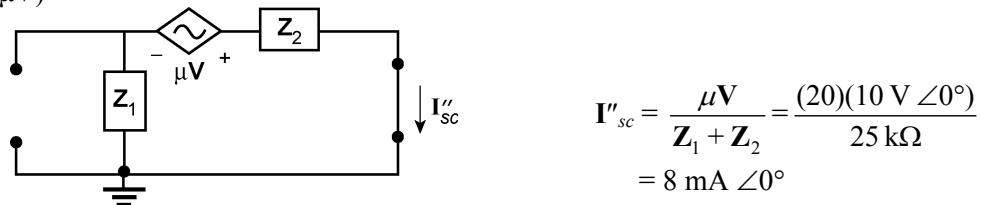
36. \mathbf{Z}_N :



$\mathbf{I}_N: (h\mathbf{I})$

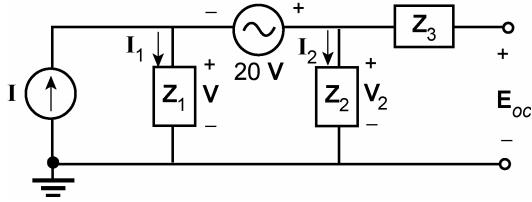


($\mu\mathbf{V}$)



$$\mathbf{I}_N (\text{direction of } \mathbf{I}'_{sc}) = \mathbf{I}'_{sc} - \mathbf{I}''_{sc} = 80 \text{ mA} \angle 0^\circ - 8 \text{ mA} \angle 0^\circ = 72 \text{ mA} \angle 0^\circ$$

37.



$$Z_1 = 1 \text{ k}\Omega \angle 0^\circ$$

$$Z_2 = 3 \text{ k}\Omega \angle 0^\circ$$

$$Z_3 = 4 \text{ k}\Omega \angle 0^\circ$$

$$V_2 = 21 \text{ V} = E_{oc} \Rightarrow V = \frac{E_{oc}}{21}$$

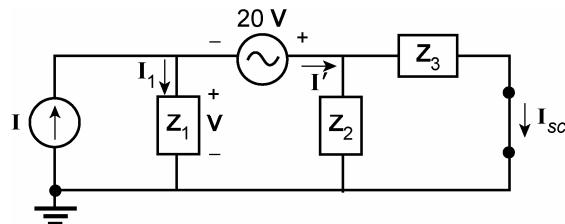
$$I = I_1 + I_2, I_1 = \frac{V}{Z_1} = \frac{E_{oc}}{21Z_1}$$

$$I_2 = \frac{E_{oc}}{Z_2}, I = I_1 + I_2 = \frac{E_{oc}}{21Z_1} + \frac{E_{oc}}{Z_2} = E_{oc} \left[\frac{1}{21Z_1} + \frac{1}{Z_2} \right]$$

$$I = E_{oc} \left[\frac{Z_2 + 21Z_1}{21Z_1 Z_2} \right]$$

$$\text{and } E_{oc} = \frac{21Z_1 Z_2 I}{Z_2 + 21Z_1} = \frac{(21)(1\text{ k}\Omega \angle 0^\circ)(3\text{ k}\Omega \angle 0^\circ)(2\text{ mA} \angle 0^\circ)}{3\text{ k}\Omega + 21(1\text{ k}\Omega \angle 0^\circ)}$$

$$E_{Th} = E_{oc} = 5.25 \text{ V} \angle 0^\circ$$



$$I_{sc} = \frac{V_3}{Z_3} = \frac{21V}{Z_3} \Rightarrow V = \frac{Z_3}{21} I_{sc}$$

$$V = I_1 Z_1$$

$$I = I_1 + I'$$

$$I_{sc} = \frac{Z_2 I'}{Z_2 + Z_3} \Rightarrow I' = \left(\frac{Z_2 + Z_3}{Z_2} \right) I_{sc}$$

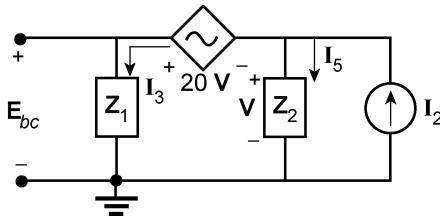
$$I = I_1 + I' = \frac{V}{Z_1} + \left(\frac{Z_2 + Z_3}{Z_2} \right) I_{sc} = \left[\frac{Z_3}{21Z_1} + \frac{Z_2 + Z_3}{Z_2} \right] I_{sc}$$

$$I_{sc} = \frac{I}{\frac{Z_3}{21Z_1} + \frac{Z_2 + Z_3}{Z_2}} = \frac{2\text{ mA} \angle 0^\circ}{\frac{4\text{ k}\Omega}{21\text{ k}\Omega} + \frac{7\text{ k}\Omega}{3\text{ k}\Omega}} = 0.79 \text{ mA} \angle 0^\circ$$

$$\therefore I_N = 0.79 \text{ mA} \angle 0^\circ$$

$$Z_N = \frac{E_{oc}}{I_{sc}} = \frac{5.25 \text{ V} \angle 0^\circ}{0.79 \text{ mA} \angle 0^\circ} = 6.65 \text{ k}\Omega \angle 0^\circ$$

38.



$$\mathbf{Z}_1 = 2 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 5 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{I}_2 = \mathbf{I}_3 + \mathbf{I}_5$$

$$\mathbf{V} = \mathbf{I}_5 \mathbf{Z}_2 = (\mathbf{I}_2 - \mathbf{I}_3) \mathbf{Z}_2$$

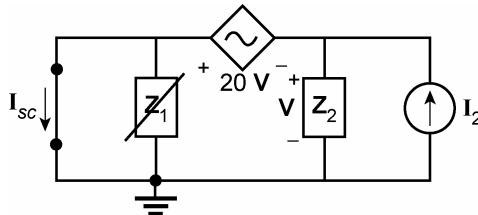
$$\mathbf{E}_{oc} = \mathbf{E}_{Th} = 21 \text{ V} = 21(\mathbf{I}_2 - \mathbf{I}_3) \mathbf{Z}_2$$

$$= 21 \left(\mathbf{I}_2 - \frac{\mathbf{E}_{oc}}{\mathbf{Z}_1} \right) \mathbf{Z}_2$$

$$\mathbf{E}_{oc} \left[1 + 21 \frac{\mathbf{Z}_2}{\mathbf{Z}_1} \right] = 21 \mathbf{Z}_2 \mathbf{I}_2$$

$$\mathbf{E}_{oc} = \frac{21 \mathbf{Z}_2 \mathbf{I}_2}{1 + 21 \frac{\mathbf{Z}_2}{\mathbf{Z}_1}} = \frac{21(5 \text{ k}\Omega \angle 0^\circ)(2 \text{ mA} \angle 0^\circ)}{1 + 21 \left(\frac{5 \text{ k}\Omega \angle 0^\circ}{2 \text{ k}\Omega \angle 0^\circ} \right)}$$

$$\mathbf{E}_{Th} = \mathbf{E}_{oc} = 3.925 \text{ V} \angle 0^\circ$$

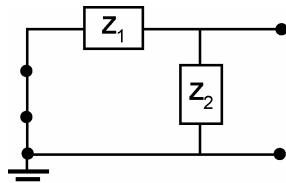


$$20 \text{ V} \neq -\mathbf{V} \therefore \mathbf{V} = 0$$

$$\text{and } \mathbf{I}_N = \mathbf{I}_{sc} = \mathbf{I}_2 = 2 \text{ mA} \angle 0^\circ$$

$$\mathbf{Z}_N = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{3.925 \text{ V} \angle 0^\circ}{2 \text{ mA} \angle 0^\circ} = 1.96 \text{ k}\Omega$$

39. a.



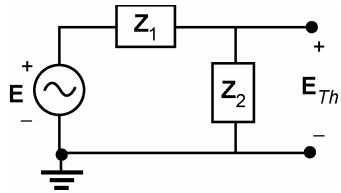
$$\mathbf{Z}_1 = 3 \Omega + j4 \Omega, \mathbf{Z}_2 = -j6 \Omega$$

$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$$

$$= 5 \Omega \angle 53.13^\circ \parallel 6 \Omega \angle -90^\circ$$

$$= 8.32 \Omega \angle -3.18^\circ$$

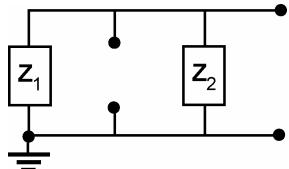
$$\mathbf{Z}_L = 8.32 \Omega \angle 3.18^\circ = 8.31 \Omega - j0.46 \Omega$$



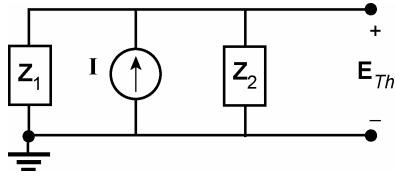
$$\begin{aligned} \mathbf{E}_{Th} &= \frac{\mathbf{Z}_2 \mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} \\ &= \frac{(6 \Omega \angle -90^\circ)(120 \text{ V} \angle 0^\circ)}{3.61 \Omega \angle -33.69^\circ} \\ &= \mathbf{199.45 \text{ V} \angle -56.31^\circ} \end{aligned}$$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(3.124 \text{ V})^2}{4(8.31 \Omega)} = \mathbf{1198.2 \text{ W}}$$

b.



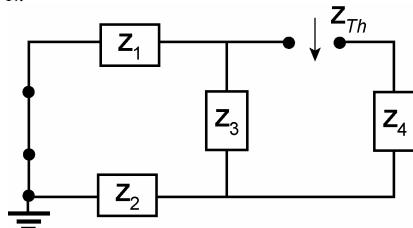
$$\begin{aligned} \mathbf{Z}_1 &= 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ \\ \mathbf{Z}_2 &= 2 \Omega \angle 0^\circ \\ \leftarrow \mathbf{Z}_N &= \mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 \\ &= 5 \Omega \angle 53.13^\circ \parallel 2 \Omega \angle 0^\circ \\ &= \frac{10 \Omega \angle 53.13^\circ}{2 + 3 + j4} \\ &= \frac{10 \Omega \angle 53.13^\circ}{5 + j4} \\ &= \frac{10 \Omega \angle 53.13^\circ}{6.403 \angle 38.66^\circ} \\ &= \mathbf{1.56 \Omega \angle 14.47^\circ} \\ \mathbf{Z}_{Th} &= 1.56 \Omega \angle 14.47^\circ \\ &= 1.51 \Omega + j0.39 \Omega \\ \mathbf{Z}_L &= 1.51 \Omega - j0.39 \Omega \end{aligned}$$



$$\begin{aligned} \mathbf{E}_{Th} &= \mathbf{I}(\mathbf{Z}_1 \parallel \mathbf{Z}_2) \\ &= (2 \text{ A} \angle 30^\circ)(1.562 \Omega \angle 14.47^\circ) \\ &= \mathbf{3.12 \text{ V} \angle 44.47^\circ} \end{aligned}$$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(3.12 \text{ V})^2}{4(1.51 \Omega)} = \mathbf{1.61 \text{ W}}$$

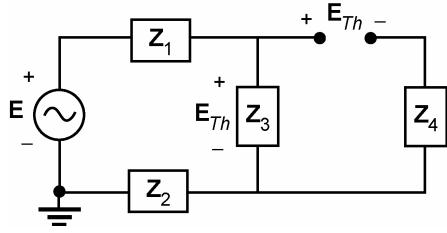
40. a. \mathbf{Z}_{Th} :



$$\begin{aligned} \mathbf{Z}_1 &= 4 \Omega \angle 90^\circ, \mathbf{Z}_2 = 10 \Omega \angle 0^\circ \\ \mathbf{Z}_3 &= 5 \Omega \angle -90^\circ, \mathbf{Z}_4 = 6 \Omega \angle -90^\circ \\ \mathbf{E} &= 60 \text{ V} \angle 60^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Z}_{Th} &= \mathbf{Z}_4 + \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2) = -j6 \Omega + (5 \Omega \angle -90^\circ) \parallel (10 \Omega + j4 \Omega) \\ &= 2.475 \Omega - j4.754 \Omega \\ &= 11.04 \Omega \angle -77.03^\circ \\ \mathbf{Z}_L &= \mathbf{11.04 \Omega \angle -77.03^\circ} \end{aligned}$$

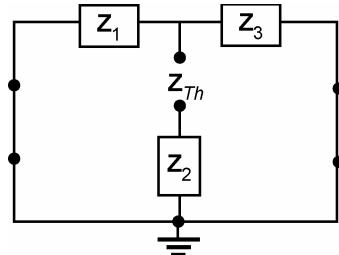
\mathbf{E}_{Th} :



$$\begin{aligned}\mathbf{E}_{Th} &= \frac{\mathbf{Z}_3(\mathbf{E})}{\mathbf{Z}_3 + \mathbf{Z}_1 + \mathbf{Z}_2} \\ &= \frac{(5 \Omega \angle -90^\circ)(60 \text{ V} \angle 60^\circ)}{-j5 \Omega + j4 \Omega + 10 \Omega} \\ &= 29.85 \text{ V} \angle -24.29^\circ\end{aligned}$$

$$P_{\max} = E_{Th}^2 / 4R_{Th} = (29.85 \text{ V})^2 / 4(2.475 \Omega) = 90 \text{ W}$$

b.

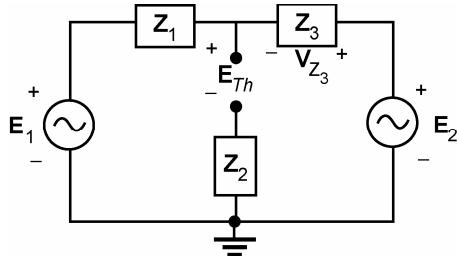


$$\begin{aligned}\mathbf{Z}_1 &= 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ \\ \mathbf{Z}_2 &= -j8 \Omega \\ \mathbf{Z}_3 &= 12 \Omega + j9 \Omega\end{aligned}$$

$$\mathbf{Z}_{Th} = \mathbf{Z}_2 + \mathbf{Z}_1 \parallel \mathbf{Z}_3 = -j8 \Omega + (5 \Omega \angle 53.13^\circ) \parallel (15 \Omega \angle 36.87^\circ)$$

$$= 5.71 \Omega \angle -64.30^\circ = 2.475 \Omega - j5.143 \Omega$$

$$\mathbf{Z}_L = 5.71 \Omega \angle 64.30^\circ = 2.48 \Omega + j5.15 \Omega$$



$$\begin{aligned}\mathbf{E}_{Th} + \mathbf{V}_{Z_3} - \mathbf{E}_2 &= 0 \\ \mathbf{E}_{Th} &= \mathbf{E}_2 - \mathbf{V}_{Z_3} \\ \mathbf{V}_{Z_3} &= \frac{\mathbf{Z}_3(\mathbf{E}_2 - \mathbf{E}_1)}{\mathbf{Z}_3 + \mathbf{Z}_1} \\ &= 168.97 \text{ V} \angle 112.53^\circ\end{aligned}$$

$$\mathbf{E}_{Th} = \mathbf{E}_2 - \mathbf{V}_{Z_3} = 200 \text{ V} \angle 90^\circ - 168.97 \text{ V} \angle 112.53^\circ = 78.24 \text{ V} \angle 34.16^\circ$$

$$P_{\max} = E_{Th}^2 / 4R_{Th} = (78.24 \text{ V})^2 / 4(2.475 \Omega) = 618.33 \text{ W}$$

41. $\mathbf{I} = \frac{\mathbf{E} \angle 0^\circ}{R_i \angle 0^\circ} = \frac{1 \text{ V} \angle 0^\circ}{1 \text{ k}\Omega \angle 0^\circ} = 1 \text{ mA} \angle 0^\circ$

$$\mathbf{Z}_{Th} = 40 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{E}_{Th} = (50 \mathbf{I})(40 \text{ k}\Omega \angle 0^\circ) = (50)(1 \text{ mA} \angle 0^\circ)(40 \text{ k}\Omega \angle 0^\circ) = 2000 \text{ V} \angle 0^\circ$$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(2 \text{ kV})^2}{4(40 \text{ k}\Omega)} = 25 \text{ W}$$

42. a. $\mathbf{Z}_{Th} = \mathbf{Z}_N = 8 \Omega \angle 0^\circ$ (Problem 30(b))
 $\mathbf{Z}_L = 8 \Omega \angle 0^\circ$
 $\mathbf{E}_{Th} = \mathbf{I}_N \cdot \mathbf{Z}_N : \quad \text{DC: } \mathbf{E}_{Th} = \mathbf{I}'_N \cdot \mathbf{Z}_N = (0.5 \text{ A})(8 \Omega) = 4 \text{ V}$
 $\text{AC: } \mathbf{E}_{Th} = \mathbf{I}'_N \cdot \mathbf{Z}_N = (1.25 \text{ A} \angle 0^\circ)(8 \Omega \angle 0^\circ) = 10 \text{ V}$
- b. $P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(4 \text{ V})^2}{4(8 \Omega)} + \frac{(10 \text{ V})^2}{4(8 \Omega)} = 0.5 \text{ W} + 3.13 \text{ W} = \mathbf{3.63 \text{ W}}$

43. From #16, $\mathbf{Z}_{Th} = 9 \Omega$, $\mathbf{E}_{Th} = 12 \text{ V} + 24 \text{ V} \angle 0^\circ$

- a. $\therefore \mathbf{Z}_L = 9 \Omega$
- b. $P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(12 \text{ V})^2}{4(9 \Omega)} + \frac{(24 \text{ V})^2}{4(9 \Omega)} = 4 \text{ W} + 16 \text{ W} = \mathbf{20 \text{ W}}$
or $E_{Th} = \sqrt{V_0^2 + V_{\text{eff}}^2} = 26.833 \text{ V}$
and $P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(26.833 \text{ V})^2}{4(9 \Omega)} = \mathbf{20 \text{ W}}$

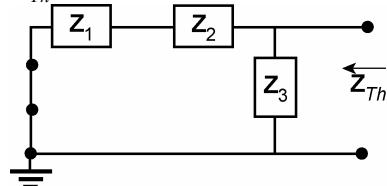
44. a. Problem 17(a):
 $\mathbf{Z}_{Th} = 4.47 \text{ k}\Omega \angle -26.57^\circ = 4 \text{ k}\Omega - j2 \text{ k}\Omega$
 $\mathbf{Z}_L = 4 \text{ k}\Omega + j2 \text{ k}\Omega$
 $\mathbf{E}_{Th} = \mathbf{31.31 \text{ V} \angle -26.57^\circ}$

- b. $P_{\max} = E_{Th}^2 / 4R_{Th} = (31.31 \text{ V})^2 / 4(4 \text{ k}\Omega) = \mathbf{61.27 \text{ mW}}$

45. a. $\mathbf{Z}_{Th} = 2 \text{ k}\Omega \angle 0^\circ \parallel 2 \text{ k}\Omega \angle -90^\circ = 1 \text{ k}\Omega - j1 \text{ k}\Omega$
 $R_L = \sqrt{R_{Th}^2 + (X_{Th} + X_{\text{Load}})^2}$
 $= \sqrt{(1 \text{ k}\Omega)^2 + (-1 \text{ k}\Omega + 2 \text{ k}\Omega)^2}$
 $= \sqrt{(1 \text{ k}\Omega)^2 + (1 \text{ k}\Omega)^2}$
 $= \mathbf{1.41 \text{ k}\Omega}$

- b. $R_{av} = (R_{Th} + R_{\text{Load}})/2 = (1 \text{ k}\Omega + 1.41 \text{ k}\Omega)/2 = 1.21 \text{ k}\Omega$
 $P_{\max} = \frac{E_{Th}^2}{4R_{av}} = \frac{(50 \text{ V})^2}{4(1.21 \text{ k}\Omega)} = \mathbf{516.53 \text{ mW}}$

46. a. \mathbf{Z}_{Th} :



$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(10 \text{ kHz})(4 \text{ nF})} \approx 3978.87 \Omega$$

$$X_L = 2\pi f L = 2\pi(10 \text{ kHz})(30 \text{ mH}) \approx 1884.96 \Omega$$

$$\begin{aligned} \mathbf{Z}_1 &= 1 \text{ k}\Omega \angle 0^\circ, \mathbf{Z}_2 = 1884.96 \Omega \angle 90^\circ \\ \mathbf{Z}_3 &= 3978.87 \Omega \angle -90^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Z}_{Th} &= (\mathbf{Z}_1 + \mathbf{Z}_2) \parallel \mathbf{Z}_3 = (1 \text{ k}\Omega + j1884.96 \Omega) \parallel 3978.87 \Omega \angle -90^\circ \\ &= 2133.79 \Omega \angle 62.05^\circ \parallel 3978.87 \Omega \angle -90^\circ \\ &= 3658.65 \Omega \angle 36.52^\circ \end{aligned}$$

$$\therefore \mathbf{Z}_L = 3658.65 \Omega \angle -36.52^\circ = 2940.27 \Omega - j2177.27 \Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(10 \text{ kHz})(2177.27 \Omega)} = 7.31 \text{ nF}$$

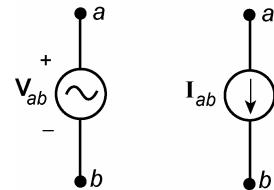
$$\text{b. } R_L = R_{Th} = 2940.27 \Omega$$

$$\text{c. } \mathbf{E}_{Th} = \frac{\mathbf{Z}_3(\mathbf{E})}{\mathbf{Z}_3 + \mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(3978.87 \Omega \angle -90^\circ)(2 \text{ V} \angle 0^\circ)}{1 \text{ k}\Omega + j1884.96 \Omega - j3978.87 \Omega} = 3.43 \text{ V} \angle -25.53^\circ$$

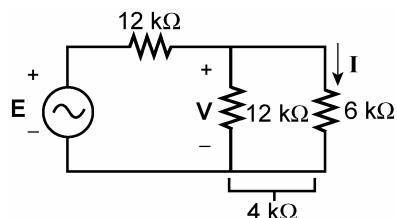
$$P_{\max} = E_{Th}^2 / 4R_{Th} = (3.43 \text{ V})^2 / 4(2940.27 \Omega) = 1 \text{ mW}$$

$$47. \quad \mathbf{I}_{ab} = \frac{(4 \text{ k}\Omega \angle 0^\circ)(4 \text{ mA} \angle 0^\circ)}{4 \text{ k}\Omega + 8 \text{ k}\Omega} = 1.33 \text{ mA} \angle 0^\circ$$

$$\mathbf{V}_{ab} = (\mathbf{I}_{ab})(8 \text{ k}\Omega \angle 0^\circ) = 10.67 \text{ V} \angle 0^\circ$$



48. a.

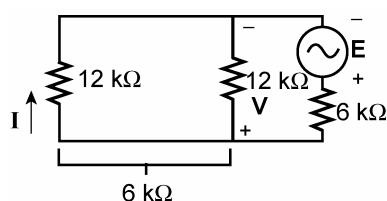


$$\mathbf{V} = \frac{4 \text{ k}\Omega(\mathbf{E})}{4 \text{ k}\Omega + 12 \text{ k}\Omega} = \frac{1}{4}(20 \text{ V} \angle 0^\circ)$$

$$= 5 \text{ V} \angle 0^\circ$$

$$\mathbf{I} = \frac{5 \text{ V} \angle 0^\circ}{6 \text{ k}\Omega} = 0.83 \text{ mA} \angle 0^\circ$$

b.

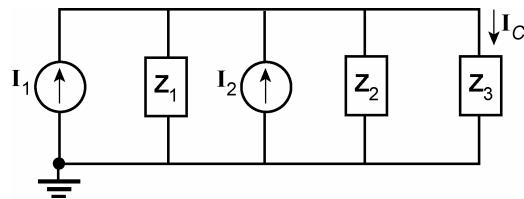


$$\mathbf{V} = \frac{6 \text{ k}\Omega(\mathbf{E})}{6 \text{ k}\Omega + 6 \text{ k}\Omega} = \frac{1}{2}(20 \text{ V} \angle 0^\circ)$$

$$= 10 \text{ V} \angle 0^\circ$$

$$\mathbf{I} = \frac{10 \text{ V} \angle 0^\circ}{12 \text{ k}\Omega} = 0.83 \text{ mA} \angle 0^\circ$$

49.



$$\mathbf{I}_1 = \frac{100 \text{ V} \angle 0^\circ}{2 \text{ k}\Omega \angle 0^\circ} = 50 \text{ mA} \angle 0^\circ$$

$$\mathbf{I}_2 = \frac{50 \text{ V} \angle 0^\circ}{4 \text{ k}\Omega \angle 90^\circ}$$

$$= 12.5 \text{ mA} \angle -90^\circ$$

$$\mathbf{Z}_1 = 2 \text{ k}\Omega \angle 0^\circ$$

$$\mathbf{Z}_2 = 4 \text{ k}\Omega \angle 90^\circ$$

$$\mathbf{Z}_3 = 4 \text{ k}\Omega \angle -90^\circ$$

$$\begin{aligned}\mathbf{I}_T &= \mathbf{I}_1 - \mathbf{I}_2 = (50 \text{ mA} \angle 0^\circ - 12.5 \text{ mA} \angle -90^\circ) = 50 \text{ mA} + j12.5 \text{ mA} \\ &= 51.54 \text{ mA} \angle 14.04^\circ\end{aligned}$$

$$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (2 \text{ k}\Omega \angle 0^\circ) \parallel (4 \text{ k}\Omega \angle 90^\circ) = 1.79 \text{ k}\Omega \angle 26.57^\circ$$

$$\begin{aligned}\mathbf{I}_C &= \frac{\mathbf{Z}' \mathbf{I}_T}{\mathbf{Z}' + \mathbf{Z}_3} = \frac{(1.79 \text{ k}\Omega \angle 26.57^\circ)(51.54 \text{ mA} \angle 14.04^\circ)}{1.6 \text{ k}\Omega + j0.8 \text{ k}\Omega - j4 \text{ k}\Omega} \\ &= 25.77 \text{ mA} \angle 104.04^\circ\end{aligned}$$

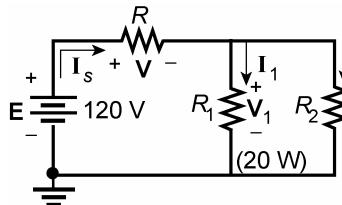
Chapter 19

1. a. $P_T = 60 \text{ W} + 20 \text{ W} + 40 \text{ W} = \mathbf{120 \text{ W}}$

b. $Q_T = \mathbf{0 \text{ VARs}}, S_T = P_T = \mathbf{120 \text{ VA}}$

c. $S_T = EI_s, I_s = \frac{S_T}{E} = \frac{120 \text{ VA}}{240 \text{ V}} = \mathbf{0.5 \text{ A}}$

d.



$$P = I_s^2 R, R = \frac{P}{I_s^2} = \frac{60 \text{ W}}{(0.5 \text{ A})^2} = 240 \Omega$$

$$V = I_s R = (0.5 \text{ A})(240 \Omega) = 120 \text{ V}$$

$$V_1 = V_2 = E - V = 240 \text{ V} - 120 \text{ V} = 120 \text{ V}$$

$$P_1 = \frac{V_1^2}{R_1}, R_1 = \frac{V_1^2}{P_1} = \frac{(120 \text{ V})^2}{20 \text{ W}} = \mathbf{720 \Omega}$$

$$P_2 = \frac{V_2^2}{R_2}, R_2 = \frac{V_2^2}{P_2} = \frac{(120 \text{ V})^2}{40 \text{ W}} = \mathbf{360 \Omega}$$

e. $I_1 = \frac{V_1}{R_1} = \frac{120 \text{ V}}{720 \Omega} = \mathbf{0.17 \text{ A}}, I_2 = \frac{V_2}{R_2} = \frac{120 \text{ V}}{360 \Omega} = \mathbf{0.33 \text{ A}}$

2. a. $\mathbf{Z}_T = 3 \Omega - j5 \Omega + j9 \Omega = 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50 \text{ V} \angle 0^\circ}{5 \Omega \angle 53.13^\circ} = 10 \text{ A} \angle -53.13^\circ$$

R: $P = I^2 R = (10 \text{ A})^2 3 \Omega = \mathbf{300 \text{ W}}$

L: $P = \mathbf{0 \text{ W}}$

C: $P = \mathbf{0 \text{ W}}$

b. R: $Q = \mathbf{0 \text{ VAR}}$

C: $Q_C = I^2 X_C = (10 \text{ A})^2 5 \Omega = \mathbf{500 \text{ VAR}}$

L: $Q_L = I^2 X_L = (10 \text{ A})^2 9 \Omega = \mathbf{900 \text{ VAR}}$

c. R: $S = \mathbf{300 \text{ VA}}$

C: $S = \mathbf{500 \text{ VA}}$

L: $S = \mathbf{900 \text{ VA}}$

d. $P_T = 300 \text{ W}$

$Q_T = Q_L - Q_C = \mathbf{400 \text{ VAR}(L)}$

$$S_T = \sqrt{P_T^2 + Q_T^2} = EI = (50 \text{ V})(10 \text{ A}) = \mathbf{500 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{300 \text{ W}}{500 \text{ VA}} = \mathbf{0.6 \text{ lagging}}$$

e. —

f. $W_R = \frac{VI}{f_1} : W_R = 2 \left[\frac{VI}{f_2} \right] = 2 \left[\frac{VI}{2f_1} \right] = \frac{VI}{f_1}$

$$V = IR = (10 \text{ A})(3 \Omega) = 30 \text{ V}$$

$$W_R = \frac{(30 \text{ V})(10 \text{ A})}{60 \text{ Hz}} = 5 \text{ J}$$

g. $V_C = IX_C = (10 \text{ A})(5 \Omega) = 50 \text{ V}$

$$W_C = \frac{VI}{\omega_l} = \frac{(50 \text{ V})(10 \text{ A})}{(2\pi)(60 \text{ Hz})} = 1.33 \text{ J}$$

$$V_L = IX_L = (10 \text{ A})(9 \Omega) = 90 \text{ V}$$

$$W_L = \frac{VI}{\omega_l} = \frac{(90 \text{ V})(10 \text{ A})}{376.8} = 2.39 \text{ J}$$

3. a. $P_T = 0 + 100 \text{ W} + 300 \text{ W} = 400 \text{ W}$

$$Q_T = 200 \text{ VAR}(L) - 600 \text{ VAR}(C) + 0 = -400 \text{ VAR}(C)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 565.69 \text{ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{400 \text{ W}}{565.69 \text{ VA}} = 0.707 \text{ (leading)}$$

b. —

c. $P_T = EI_s \cos \theta_T$

$$400 \text{ W} = (100 \text{ V})I_s(0.7071)$$

$$I_s = \frac{400 \text{ W}}{70.71 \text{ V}} = 5.66 \text{ A}$$

$$\mathbf{I}_s = 5.66 \text{ A} \angle 135^\circ$$

4. a. $P_T = 600 \text{ W} + 500 \text{ W} + 100 \text{ W} = 1200 \text{ W}$

$$Q_T = 1200 \text{ VAR}(L) + 600 \text{ VAR}(L) - 600 \text{ VAR}(C) = 1200 \text{ VAR}(L)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \sqrt{(1200 \text{ W})^2 + (1200 \text{ VAR})^2} = 1697 \text{ VA}$$

b. $F_p = \frac{P_T}{S_T} = \frac{1200 \text{ W}}{1697 \text{ VA}} = 0.7071 \text{ (lagging)}$

c. —

d. $I_s = \frac{S_T}{E} = \frac{1697 \text{ VA}}{200 \text{ V}} = 8.485 \text{ A}, 0.7071 \Rightarrow 45^\circ \text{ (lagging)}$

$$\mathbf{I}_s = 8.49 \text{ A} \angle -45^\circ$$

5. a. $P_T = 200 \text{ W} + 200 \text{ W} + 0 + 100 \text{ W} = 500 \text{ W}$

$$Q_T = 100 \text{ VAR}(L) + 100 \text{ VAR}(L) - 200 \text{ VAR}(C) - 200 \text{ VAR}(C) = -200 \text{ VAR}(C)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 538.52 \text{ VA}$$

b. $F_p = \frac{P_T}{S_T} = \frac{500 \text{ W}}{538.52 \text{ VA}} = 0.928 \text{ (leading)}$

c. —

d. $P_T = EI_s \cos \theta_T$
 $500 \text{ W} = (50 \text{ V})I_s(0.928)$
 $I_s = \frac{500 \text{ W}}{46.4 \text{ V}} = 10.776 \text{ A}$
 $\mathbf{I}_s = 10.78 \text{ A} \angle 21.88^\circ$

6. a. $\mathbf{I}_R = \frac{60 \text{ V} \angle 30^\circ}{20 \Omega \angle 0^\circ} = 3 \text{ A} \angle 30^\circ$
 $P = I^2 R = (3 \text{ A})^2 20 \Omega = 180 \text{ W}$
 $Q_R = 0 \text{ VAR}$
 $S = P = 180 \text{ VA}$

b. $\mathbf{I}_L = \frac{60 \text{ V} \angle 30^\circ}{10 \Omega \angle 90^\circ} = 6 \text{ A} \angle -60^\circ$
 $P_L = 0 \text{ W}$
 $Q_L = I^2 X_L = (6 \text{ A})^2 10 \Omega = 360 \text{ VAR}(L)$
 $S = Q = 360 \text{ VA}$

c. $P_T = 180 \text{ W} + 400 \text{ W} = 580 \text{ W}$
 $Q_T = 600 \text{ VAR}(L) + 360 \text{ VAR}(L) = 960 \text{ VAR}(L)$
 $S_T = \sqrt{(580 \text{ W})^2 + (960 \text{ VAR})^2} = 1121.61 \text{ VA}$
 $F_p = \frac{P_T}{S_T} = \frac{580 \text{ W}}{1121.61 \text{ VA}} = 0.517 \text{ (lagging)} \quad \theta = 58.87^\circ$

d. $S_T = EI_s$
 $I_s = \frac{S_T}{E} = \frac{1121.61 \text{ VA}}{60 \text{ V}} = 18.69 \text{ A}$
 $\theta_{I_s} = 30^\circ - 58.87^\circ = -28.87^\circ$
 $\mathbf{I}_s = 18.69 \text{ A} \angle -28.87^\circ$

7. a. $R: P = \frac{E^2}{R} = \frac{(20 \text{ V})^2}{2 \Omega} = 200 \text{ W}$
 $P_{L,C} = 0 \text{ W}$

b. $R: Q = 0 \text{ VAR}$
 $C: Q_C = \frac{E^2}{X_C} = \frac{(20 \text{ V})^2}{5 \Omega} = 80 \text{ VAR}(C)$
 $L: Q_L = \frac{E^2}{X_L} = \frac{(20 \text{ V})^2}{4 \Omega} = 100 \text{ VAR}(L)$

c. $R: S = \mathbf{200 \text{ VA}}$

$C: S = \mathbf{80 \text{ VA}}$

$L: S = \mathbf{100 \text{ VA}}$

d. $P_T = 200 \text{ W} + 0 + 0 = \mathbf{200 \text{ W}}$

$$Q_T = 0 + 80 \text{ VAR}(C) + 100 \text{ VAR}(L) = \mathbf{20 \text{ VAR}(L)}$$

$$S_T = \sqrt{(200 \text{ W})^2 + (20 \text{ VAR})^2} = \mathbf{200 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{200 \text{ W}}{200.998 \text{ VA}} = \mathbf{0.995 \text{ (lagging)}} \Rightarrow 5.73^\circ$$

e. —

f. $I_s = \frac{S_T}{E} = \frac{200.998 \text{ VA}}{20 \text{ V}} = 10.05 \text{ A}$

$$\mathbf{I}_s = 10.05 \text{ A} \angle -5.73^\circ$$

8. a. $R - L: \mathbf{I} = \frac{50 \text{ V} \angle 60^\circ}{5 \Omega \angle 53.13^\circ} = 10 \text{ A} \angle 6.87^\circ$

$$P_R = I^2 R = (10 \text{ A})^2 3 \Omega = \mathbf{300 \text{ W}}$$

$$P_L = \mathbf{0 \text{ W}}$$

$$P_C = \mathbf{0 \text{ W}}$$

b. $Q_R = \mathbf{0 \text{ VAR}}$

$$Q_L = I^2 X_L = (10 \text{ A})^2 4 \Omega = \mathbf{400 \text{ VAR}}$$

$$\mathbf{I}_C = \frac{50 \text{ V} \angle 60^\circ}{10 \Omega \angle -90^\circ} = 5 \text{ A} \angle 150^\circ$$

$$Q_C = I^2 X_C = (5 \text{ A})^2 10 \Omega = \mathbf{250 \text{ VAR}}$$

c. $S_R = P = \mathbf{300 \text{ VA}}$

$$S_L = Q_L = \mathbf{400 \text{ VA}}$$

$$S_C = Q_C = \mathbf{250 \text{ VA}}$$

d. $P_T = P_R = \mathbf{300 \text{ W}}$

$$Q_T = 400 \text{ VAR}(L) - 250 \text{ VAR}(C) = \mathbf{150 \text{ VAR}(L)}$$

$$S_T = \sqrt{(300 \text{ W})^2 + (150 \text{ VAR})^2} = \mathbf{335.41 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{300 \text{ W}}{335.41 \text{ VA}} = \mathbf{0.894 \text{ (lagging)}}$$

e. —

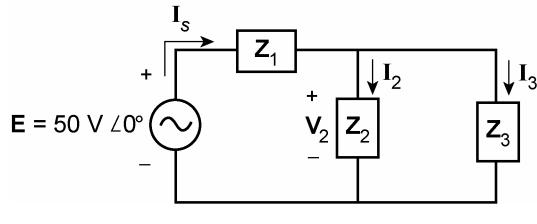
f. $I_s = \frac{S_T}{E} = \frac{335.41 \text{ VA}}{50 \text{ V}} = 6.71 \text{ A}$

$0.894 \Rightarrow 26.62^\circ \text{ lagging}$

$$\theta = 60^\circ - 26.62^\circ = 33.38^\circ$$

$$\mathbf{I}_s = 6.71 \text{ A} \angle 33.38^\circ$$

9. a-c.



$$X_L = \omega L = (400 \text{ rad/s})(0.1 \text{ H}) = 40 \Omega$$

$$X_C = \frac{1}{\omega C} = \frac{1}{(400 \text{ rad/s})(100 \mu\text{F})} = 25 \Omega$$

$$\begin{aligned} Z_1 &= 40 \Omega \angle 90^\circ, Z_2 = 25 \Omega \angle -90^\circ \\ Z_3 &= 30 \Omega \angle 0^\circ \end{aligned}$$

$$\begin{aligned} Z_T &= Z_1 + Z_2 \parallel Z_3 = +j40 \Omega + (25 \Omega \angle -90^\circ) \parallel (30 \Omega \angle 0^\circ) \\ &= +j40 \Omega + 19.21 \Omega \angle -50.19^\circ \\ &= +j40 \Omega + 12.3 \Omega - j14.76 \Omega \\ &= 12.3 \Omega + j25.24 \Omega \\ &= 28.08 \Omega \angle 64.02^\circ \end{aligned}$$

$$I_s = \frac{E}{Z_T} = \frac{50 \text{ V} \angle 0^\circ}{28.08 \Omega \angle 64.02^\circ} = 1.78 \text{ A} \angle -64.02^\circ$$

$$V_2 = I_s(Z_2 \parallel Z_3) = (1.78 \text{ A} \angle -64.02^\circ)(19.21 \Omega \angle -50.19^\circ) = 34.19 \text{ V} \angle -114.21^\circ$$

$$I_2 = \frac{V_2}{Z_2} = \frac{34.19 \text{ V} \angle -114.21^\circ}{25 \Omega \angle -90^\circ} = 1.37 \text{ A} \angle -24.21^\circ$$

$$I_3 = \frac{V_2}{Z_3} = \frac{34.19 \text{ V} \angle -114.21^\circ}{30 \Omega \angle 0^\circ} = 1.14 \text{ A} \angle -114.21^\circ$$

$$\mathbf{Z}_1: P = 0 \text{ W}, Q_L = I_s^2 X_L = (1.78 \text{ A})^2 40 \Omega = \mathbf{126.74 \text{ VAR}(L)}, S = \mathbf{126.74 \text{ VA}}$$

$$\mathbf{Z}_2: P = 0 \text{ W}, Q_C = I_2^2 X_C = (1.37 \text{ A})^2 25 \Omega = \mathbf{46.92 \text{ VAR}(C)}, S = \mathbf{46.92 \text{ VA}}$$

$$\mathbf{Z}_3: P = I_3^2 R = (1.14 \text{ A})^2 30 \Omega = \mathbf{38.99 \text{ W}}, Q_R = 0 \text{ VAR}, S = \mathbf{38.99 \text{ VA}}$$

d. $P_T = 0 + 0 + 38.99 \text{ W} = \mathbf{38.99 \text{ W}}$

$$Q_T = +126.74 \text{ VAR}(L) - 46.92 \text{ VAR}(C) + 0 = \mathbf{79.82 \text{ VAR}(L)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{88.83 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{38.99 \text{ W}}{88.83 \text{ VA}} = \mathbf{0.439 \text{ (lagging)}}$$

e. —

$$f. W_R = \frac{V_R I_R}{2f_1} = \frac{V_2 I_3}{2f_1} = \frac{(34.19 \text{ V})(1.14 \text{ A})}{2(63.69 \text{ Hz})} = \mathbf{0.31 \text{ J}}$$

$$f_1 = \frac{\omega_1}{2\pi} = \frac{400 \text{ rad/s}}{6.28} = 63.69 \text{ Hz}$$

$$g. W_L = \frac{V_L I_L}{\omega_1} = \frac{(I_s X_L) I_s}{\omega_1} = \frac{I_s^2 X_L}{\omega_1} = \frac{(1.78 \text{ A})^2 40 \Omega}{400 \text{ rad/s}} = \mathbf{0.32 \text{ J}}$$

$$W_C = \frac{V_C I_C}{\omega_1} = \frac{V_2 I_2}{\omega_1} = \frac{(34.19 \text{ V})(1.37 \text{ A})}{400 \text{ rad/s}} = \mathbf{0.12 \text{ J}}$$

10. a. $I_s = \frac{S_T}{E} = \frac{10,000 \text{ VA}}{200 \text{ V}} = 50 \text{ A}$
 $0.5 \Rightarrow 60^\circ \text{ leading}$
 $\therefore \mathbf{I}_s \text{ leads } \mathbf{E} \text{ by } 60^\circ$
 $\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}_s} = \frac{200 \text{ V} \angle 0^\circ}{50 \text{ A} \angle 60^\circ} = 4 \Omega \angle -60^\circ = 2 \Omega - j3.464 \Omega = R - jX_C$

b. $F_p = \frac{P_T}{S_T} \Rightarrow P_T = F_p S_T = (0.5)(10,000 \text{ VA}) = \mathbf{5000 \text{ W}}$

11. a. $I = \frac{S_T}{E} = \frac{5000 \text{ VA}}{120 \text{ V}} = 41.67 \text{ A}$
 $F_p = 0.8 \Rightarrow 36.87^\circ \text{ (lagging)}$
 $\mathbf{E} = 120 \text{ V} \angle 0^\circ, \mathbf{I} = 41.67 \text{ A} \angle -36.87^\circ$
 $\mathbf{Z} = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120 \text{ V} \angle 0^\circ}{41.67 \text{ A} \angle -36.87^\circ} = 2.88 \Omega \angle 36.87^\circ = \mathbf{2.30 \Omega + j1.73 \Omega} = R + jX_L$

b. $P = S \cos \theta = (5000 \text{ VA})(0.8) = \mathbf{4000 \text{ W}}$

12. a. $P_T = 0 + 300 \text{ W} = \mathbf{300 \text{ W}}$
 $Q_T = 600 \text{ VAR}(C) + 200(L) = \mathbf{400 \text{ VAR}(C)}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{500 \text{ VA}}$
 $F_p = \frac{P_T}{S_T} = \frac{300 \text{ W}}{500 \text{ VA}} = \mathbf{0.6 \text{ (leading)}}$

b. $I_s = \frac{S_T}{E} = \frac{500 \text{ VA}}{30 \text{ V}} = 16.67 \text{ A}$
 $F_p = 0.6 \Rightarrow 53.13^\circ$
 $\mathbf{I}_s = \mathbf{16.67 \text{ A} \angle 53.13^\circ}$

c. —

d. Load: 600 VAR(C), 0 W

$$R = 0, L = 0, Q_C = I^2 X_C \Rightarrow X_C = \frac{Q_C}{I^2} = \frac{600 \text{ VAR}}{(16.67 \text{ A})^2} = \mathbf{2.159 \Omega}$$

Load: 200 VAR(L), 300 W
 $C = 0, R = P/I^2 = 300 \text{ W}/(16.67 \text{ A})^2 = \mathbf{1.079 \Omega}$

$$X_L = \frac{Q_L}{I^2} = \frac{200 \text{ VAR}}{(16.67 \text{ A})^2} = \mathbf{0.7197 \Omega}$$

$$\mathbf{Z}_T = j2.159 \Omega + 1.0796 \Omega + j0.7197 \Omega \\ = \mathbf{1.08 \Omega - j1.44 \Omega}$$

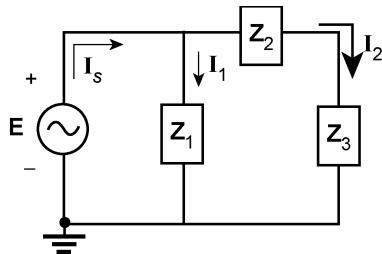
13. a. $P_T = 0 + 300 \text{ W} + 600 \text{ W} = \mathbf{900 \text{ W}}$
 $Q_T = 500 \text{ VAR}(C) + 0 + 500 \text{ VAR}(L) = \mathbf{0 \text{ VAR}}$
 $S_T = P_T = \mathbf{900 \text{ VA}}$

$$F_p = \frac{P_T}{S_T} = \mathbf{1}$$

b. $I_s = \frac{S_T}{E} = \frac{900 \text{ VA}}{100 \text{ V}} = 9 \text{ A}, \mathbf{I}_s = 9 \text{ A} \angle 0^\circ$

c. —

d.



$\mathbf{Z}_1:$ $Q_C = \frac{V^2}{X_C} \Rightarrow X_C = \frac{V^2}{Q_C} = \frac{10^4}{500} = \mathbf{20 \Omega}$

$$\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{100 \text{ V} \angle 0^\circ}{20 \Omega \angle -90^\circ} = 5 \text{ A} \angle 90^\circ$$

$$\mathbf{I}_2 = \mathbf{I}_s - \mathbf{I}_1 = 9 \text{ A} - j5 \text{ A} = 10.296 \text{ A} \angle -29.05^\circ$$

$\mathbf{Z}_2:$ $R = \frac{P}{I^2} = \frac{300 \text{ W}}{(10.296 \text{ A})^2} = \frac{300}{106} = \mathbf{2.83 \Omega}$

$$X_{L,C} = \mathbf{0 \Omega}$$

$\mathbf{Z}_3:$ $R = \frac{P}{I^2} = \frac{600 \text{ W}}{(10.296 \text{ A})^2} = \mathbf{5.66 \Omega}$

$$X_L = \frac{Q}{I^2} = \frac{500}{(10.296 \text{ A})^2} = \mathbf{4.72 \Omega}, X_C = \mathbf{0 \Omega}$$

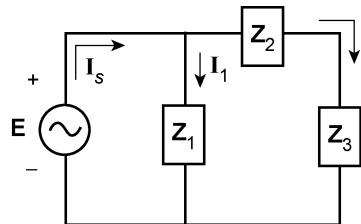
14. a. $P_T = 200 \text{ W} + 30 \text{ W} + 0 = \mathbf{230 \text{ W}}$
 $Q_T = 0 + 40 \text{ VAR}(L) + 100 \text{ VAR}(L) = \mathbf{140 \text{ VAR}(L)}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{269.26 \text{ VA}}$

$$F_p = \frac{P_T}{S_T} = \frac{230 \text{ W}}{269.26 \text{ VA}} = \mathbf{0.854 \text{ (lagging)}} \Rightarrow 31.35^\circ$$

b. $I_s = \frac{S_T}{E} = \frac{269.26 \text{ VA}}{100 \text{ V}} = 2.6926 \text{ A}$

$$\mathbf{I}_s = 2.69 \text{ A} \angle -31.35^\circ$$

c.

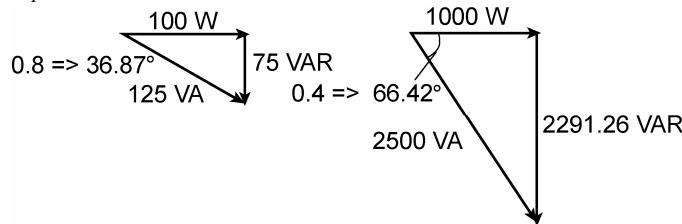


$$\begin{aligned} \mathbf{Z}_1: \quad R &= \frac{V^2}{P} = \frac{10^4}{200} = 50 \Omega \\ X_L, X_C &= 0 \Omega \\ \mathbf{I}_1 &= \frac{100 \text{ V} \angle 0^\circ}{50 \Omega \angle 0^\circ} = 2 \text{ A} \angle 0^\circ \\ \mathbf{I}_2 &= \mathbf{I}_s - \mathbf{I}_1 \\ &= 2.6926 \text{ A} \angle -31.35^\circ - 2 \text{ A} \angle 0^\circ \\ &= 2.299 \text{ A} - j1.40 \text{ A} - 2.0 \text{ A} \\ &= 0.299 \text{ A} - j1.40 \text{ A} \\ &= 1.432 \text{ A} \angle -77.94^\circ \end{aligned}$$

$$\begin{aligned} \mathbf{Z}_2: \quad R &= \frac{P}{I_2^2} = \frac{30 \text{ W}}{(1.432 \text{ A})^2} = 14.63 \Omega, X_L &= \frac{Q}{I_2^2} = \frac{40 \text{ VAR}}{(1.432 \text{ A})^2} = 19.50 \Omega \\ X_C &= 0 \Omega \end{aligned}$$

$$\mathbf{Z}_3: \quad X_L = \frac{Q}{I_2^2} = \frac{100 \text{ VAR}}{(1.432 \text{ A})^2} = 48.76 \Omega, R = 0 \Omega, X_C = 0 \Omega$$

15. a. $P_T = 100 \text{ W} + 1000 \text{ W} = 1100 \text{ W}$



$$Q_T = 75 \text{ VAR}(C) + 2291.26 \text{ VAR}(C) = 2366.26 \text{ VAR}(C)$$

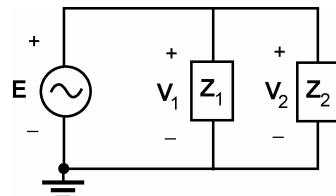
$$S_T = \sqrt{P_T^2 + Q_T^2} = 2609.44 \text{ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{1100 \text{ W}}{2609.44 \text{ VA}} = 0.422 \text{ (leading)} \Rightarrow 65.04^\circ$$

b. $S_T = EI \Rightarrow E = \frac{S_T}{I} = \frac{2609.44 \text{ VA}}{5 \text{ A}} = 521.89 \text{ V}$

$$\mathbf{E} = 521.89 \text{ V} \angle -65.07^\circ$$

c.



$$I_{Z_1} = \frac{S}{V_1} = \frac{S}{E} = \frac{125 \text{ VA}}{521.89 \text{ V}} = 0.2395 \text{ A}$$

$$I_{Z_2} = \frac{S}{V_2} = \frac{S}{E} = \frac{2500 \text{ VA}}{521.89 \text{ V}} = 4.79 \text{ A}$$

$$\mathbf{Z}_1: R = \frac{P}{I_{Z_1}^2} = \frac{100 \text{ W}}{(0.2395)^2} = \mathbf{1743.38 \Omega}$$

$$Q = I_{Z_1}^2 X_C \Rightarrow X_C = \frac{Q}{I_{Z_1}^2} = \frac{75 \text{ VAR}}{(0.2395)^2} = \mathbf{1307.53 \Omega}$$

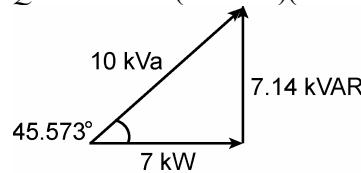
$$\mathbf{Z}_2: R = \frac{P}{I_{Z_1}^2 X_C} = \frac{1000 \text{ W}}{(4.790 \text{ A})^2} = \mathbf{43.59 \Omega}$$

$$X_C = \frac{Q}{I_{Z_1}^2 X_C} = \frac{2291.26 \text{ VAR}}{(4.790 \text{ A})^2} = \mathbf{99.88 \Omega}$$

16. a. $0.7 \Rightarrow 45.573^\circ$

$$P = S \cos \theta = (10 \text{ kVA})(0.7) = 7 \text{ kW}$$

$$Q = S \sin \theta = (10 \text{ kVA})(0.714) = 7.14 \text{ kVAR}(L)$$



b. $Q_C = 7.14 \text{ kVAR} = \frac{V^2}{X_C}$

$$X_C = \frac{V^2}{Q_C} = \frac{(208 \text{ V})^2}{7.14 \text{ kVAR}} = 6.059 \Omega$$

$$X_C = \frac{1}{2\pi f C} \Rightarrow C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60 \text{ Hz})(6.059 \Omega)} = \mathbf{438 \mu F}$$

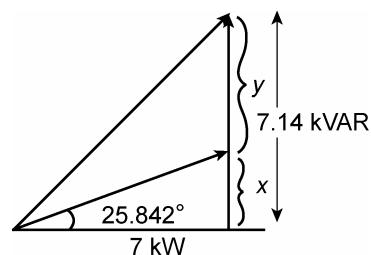
c. Uncompensated:

$$I_s = \frac{S_T}{E} = \frac{10,000 \text{ VA}}{208 \text{ V}} = \mathbf{48.08 \text{ A}}$$

Compensated:

$$I_s = \frac{S_T}{E} = \frac{P_T}{E} = \frac{7,000 \text{ W}}{208 \text{ V}} = \mathbf{33.65 \text{ A}}$$

d.



$$\cos \theta = 0.9$$

$$\theta = \cos^{-1} 0.9 = 25.842^\circ$$

$$\tan \theta = \frac{x}{7 \text{ kW}}$$

$$x = (7 \text{ kW})(\tan 25.842^\circ)$$

$$= (7 \text{ kW})(0.484)$$

$$= 3.39 \text{ kVAR}$$

$$y = (7.14 - 3.39) \text{ kVAR}$$

$$= 3.75 \text{ kVAR}$$

$$Q_C = 3.75 \text{ kVAR} = \frac{V^2}{X_C}$$

$$X_C = \frac{V^2}{Q_C} = \frac{(208 \text{ V})^2}{3.75 \text{ kVAR}} = 11.537 \Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60 \text{ Hz})(11.537 \Omega)} = 230 \mu\text{F}$$

Uncompensated:

$$I_s = 48.08 \text{ A}$$

Compensated:

$$S_T = \sqrt{(7 \text{ kW})^2 + (3.39 \text{ kVAR})^2} = 7.778 \text{ kVA}$$

$$I_s = \frac{S_T}{E} = \frac{7.778 \text{ kVA}}{208 \text{ V}} = 37.39 \text{ A}$$

17. a. $P_T = 5 \text{ kW}, Q_T = 6 \text{ kVAR}(L)$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 7.81 \text{ kVA}$$

b. $F_p = \frac{P_T}{S_T} = \frac{5 \text{ kW}}{7.81 \text{ kVA}} = 0.640 \text{ (lagging)}$

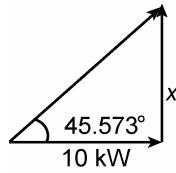
c. $I_s = \frac{S_T}{E} = \frac{7,810 \text{ VA}}{120 \text{ V}} = 65.08 \text{ A}$

d. $X_C = \frac{1}{2\pi f C}, Q_C = I^2 X_C = \frac{E^2}{X_C} = \frac{(120 \text{ V})^2}{X_C}$
 and $X_C = \frac{(120 \text{ V})^2}{Q_C} = \frac{14,400}{6000} = 2.4 \Omega$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60 \text{ Hz})(2.4 \Omega)} = 1105 \mu\text{F}$

e. $S_T = EI_s = P_T$

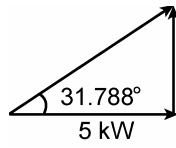
$$\therefore I_s = \frac{P_T}{E} = \frac{5000 \text{ W}}{120 \text{ V}} = 41.67 \text{ A}$$

18. a. Load 1: $P = 20,000 \text{ W}$, $Q = 0 \text{ VAR}$
 Load 2: $\theta = \cos^{-1} 0.7 = 45.573^\circ$



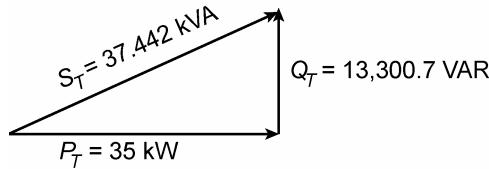
$$\tan \theta = \frac{x}{10 \text{ kW}} \\ x = (10 \text{ kW}) \tan 45.573^\circ \\ = (10 \text{ kW})(1.02) \\ = 10,202 \text{ VAR}(L)$$

- Load 3: $\theta = \cos^{-1} 0.85 = 31.788^\circ$



$$\tan \theta = \frac{x}{5 \text{ kW}} \\ x = (5 \text{ kW}) \tan 31.788^\circ \\ = (5 \text{ kW})(0.62) \\ = 3098.7 \text{ VAR}(L)$$

$$P_T = 20,000 \text{ W} + 10,000 \text{ W} + 5,000 \text{ W} = 35 \text{ kW} \\ Q_T = 0 + 10,202 \text{ VAR} + 3098.7 \text{ VAR} = 13,300.7 \text{ VAR}(L) \\ S_T = \sqrt{P_T^2 + Q_T^2} = 37,442 \text{ VA} = 37.442 \text{ kVA}$$



- b. $Q_C = Q_L = 13,300.7 \text{ VAR}$

$$X_C = \frac{E^2}{Q_C} = \frac{(10^3 \text{ V})^2}{13,300.7 \text{ VAR}} = 75.184 \Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60 \text{ Hz})(75.184 \Omega)} = 35.28 \mu\text{F}$$

- c. Uncompensated:

$$I_s = \frac{S_T}{E} = \frac{37.442 \text{ kVA}}{1 \text{ kV}} = 37.44 \text{ A}$$

Compensated:

$$S_T = P_T = 35 \text{ kW}$$

$$I_s = \frac{S_T}{E} = \frac{35 \text{ kW}}{1 \text{ kV}} = 35 \text{ A}$$

19. a. $\mathbf{Z}_T = R_1 + R_2 + R_3 + jX_L - jX_C$
 $= 2 \Omega + 3 \Omega + 1 \Omega + j3 \Omega - j12 \Omega = 6 \Omega - j9 \Omega = 10.82 \Omega \angle -56.31^\circ$
 $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50 \text{ V} \angle 0^\circ}{10.82 \Omega \angle -56.31^\circ} = 4.62 \text{ A} \angle 56.31^\circ$
 $P = VI \cos \theta = (50 \text{ V})(4.62 \text{ A}) \cos 56.31^\circ = 128.14 \text{ W}$

- b. a-b: $P = I^2R = (4.62 \text{ A})^2 2 \Omega = \mathbf{42.69 \text{ W}}$
 b-c: $P = I^2R = (4.62 \text{ A})^2 3 \Omega = \mathbf{64.03 \text{ W}}$
 a-c: $42.69 \text{ W} + 64.03 \text{ W} = \mathbf{106.72 \text{ W}}$
 a-d: $\mathbf{106.72 \text{ W}}$
 c-d: $\mathbf{0 \text{ W}}$
 d-e: $\mathbf{0 \text{ W}}$
 f-e: $P = I^2R = (4.62 \text{ A})^2 1 \Omega = \mathbf{21.34 \text{ W}}$

20. a. $S_T = 660 \text{ VA} = EI_s$
 $I_s = \frac{660 \text{ VA}}{120 \text{ V}} = 5.5 \text{ A}$
 $\theta = \cos^{-1} 0.6 = 53.13^\circ$
 $\therefore \mathbf{E = 120 \text{ V} \angle 0^\circ, I_s = 5.5 \text{ A} \angle -53.13^\circ}$
 $P = EI \cos \theta = (120 \text{ V})(5.5 \text{ A})(0.6) = \mathbf{396 \text{ W}}$
 Wattmeter = **396 W**, Ammeter = **5.5 A**, Voltmeter = **120 V**

b. $Z_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120 \text{ V} \angle 0^\circ}{5.5 \text{ A} \angle -53.13^\circ} = \mathbf{21.82 \Omega \angle 53.13^\circ = 13.09 \Omega + j17.46 \Omega = R + jX_L}$

21. a. $R = \frac{P}{I^2} = \frac{80 \text{ W}}{(4 \text{ A})^2} = \mathbf{5 \Omega}, Z_T = \frac{E}{I} = \frac{200 \text{ V}}{4 \text{ A}} = 50 \Omega$
 $X_L = \sqrt{Z_T^2 - R^2} = \sqrt{(50 \Omega)^2 - (5 \Omega)^2} = 49.75 \Omega$
 $L = \frac{X_L}{2\pi f} = \frac{49.75 \Omega}{(2\pi)(60 \text{ Hz})} = \mathbf{132.03 \text{ mH}}$

b. $R = \frac{P}{I^2} = \frac{90 \text{ W}}{(3 \text{ A})^2} = \mathbf{10 \Omega}$

c. $R = \frac{P}{I^2} = \frac{60 \text{ W}}{(2 \text{ A})^2} = \mathbf{15 \Omega}, Z_T = \frac{E}{I} = \frac{200 \text{ V}}{2 \text{ A}} = 100 \Omega$
 $X_L = \sqrt{Z_T^2 - R^2} = \sqrt{(100 \Omega)^2 - (15 \Omega)^2} = 98.87 \Omega$
 $L = \frac{X_L}{2\pi f} = \frac{98.87 \Omega}{376.8} = \mathbf{262.39 \text{ mH}}$

22. a. $X_L = 2\pi fL = (6.28)(50 \text{ Hz})(0.08 \text{ H}) = 25.12 \Omega$
 $Z_T = \sqrt{R^2 + X_L^2} = \sqrt{(4 \Omega)^2 + (25.12 \Omega)^2} = 25.44 \Omega$
 $I = \frac{E}{Z_T} = \frac{60 \text{ V}}{25.44 \Omega} = 2.358 \text{ A}$
 $P = I^2R = (2.358 \text{ A})^2 4 \Omega = \mathbf{22.24 \text{ W}}$

b.

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{30 \text{ W}}{7 \Omega}} = 2.07 \text{ A}$$
$$Z_T = \frac{E}{I} = \frac{60 \text{ V}}{2.07 \text{ A}} = 28.99 \Omega$$
$$X_L = \sqrt{(28.99 \Omega)^2 - (7 \Omega)^2} = 28.13 \Omega$$
$$L = \frac{X_L}{2\pi f} = \frac{28.13 \Omega}{(2\pi)(50 \text{ Hz})} = 89.54 \text{ mH}$$

c.

$$P = I^2 R = (1.7 \text{ A})^2 10 \Omega = 28.9 \text{ W}$$
$$Z_T = \frac{E}{I} = \frac{60 \text{ V}}{1.7 \text{ A}} = 35.29 \Omega$$
$$X_L = \sqrt{(35.29 \Omega)^2 - (10 \Omega)^2} = 33.84 \Omega$$
$$L = \frac{X_L}{2\pi f} = \frac{33.84 \Omega}{314} = 107.77 \text{ mH}$$

Chapter 20

1. a. $\omega_s = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{1 \text{ H}}(16 \mu\text{F})} = 250 \text{ rad/s}$

$$f_s = \frac{\omega_s}{2\pi} = \frac{250 \text{ rad/s}}{2\pi} = 39.79 \text{ Hz}$$

b. $\omega_s = \frac{1}{\sqrt{(0.5 \text{ H})(0.16 \mu\text{F})}} = 3535.53 \text{ rad/s}$

$$f_s = \frac{\omega_s}{2\pi} = \frac{3535.53 \text{ rad/s}}{2\pi} = 562.7 \text{ Hz}$$

c. $\omega_s = \frac{1}{\sqrt{(0.28 \text{ mH})(7.46 \mu\text{F})}} = 21,880 \text{ rad/s}$

$$f_s = \frac{\omega_s}{2\pi} = \frac{21,880 \text{ rad/s}}{2\pi} = 3482.31 \text{ Hz}$$

2. a. $X_C = 30 \Omega$ b. $Z_{T_s} = 10 \Omega$ c. $I = \frac{E}{Z_{T_s}} = \frac{50 \text{ mV}}{10 \Omega} = 5 \text{ mA}$

d. $V_R = IR = (5 \text{ mA})(10 \Omega) = 50 \text{ mV} = E$

$$V_L = IX_L = (5 \text{ mA})(30 \Omega) = 150 \text{ mV}$$

$$V_C = IX_C = (5 \text{ mA})(30 \Omega) = 150 \text{ mV}$$

$$V_L = V_C$$

e. $Q_s = \frac{X_L}{R} = \frac{30 \Omega}{10 \Omega} = 3 \text{ (low Q)}$ f. $P = I^2 R = (5 \text{ mA})^2 10 \Omega = 0.25 \text{ mW}$

3. a. $X_L = 40 \Omega$

b. $I = \frac{E}{Z_{T_s}} = \frac{20 \text{ mV}}{2 \Omega} = 10 \text{ mA}$

c. $V_R = IR = (10 \text{ mA})(2 \Omega) = 20 \text{ mV} = E$

$$V_L = IX_L = (10 \text{ mA})(40 \Omega) = 400 \text{ mV}$$

$$V_C = IX_C = (10 \text{ mA})(40 \Omega) = 400 \text{ mV}$$

$$V_L = V_C = 20 V_R$$

d. $Q_s = \frac{X_L}{R} = \frac{40 \Omega}{2 \Omega} = 20 \text{ (high Q)}$

e. $X_L = 2\pi fL, L = \frac{X_L}{2\pi f} = \frac{40 \Omega}{2\pi(5 \text{ kHz})} = 1.27 \text{ mH}$

$$X_C = \frac{1}{2\pi fC}, C = \frac{1}{2\pi fX_C} = \frac{1}{2\pi(5 \text{ kHz})(40 \Omega)} = 795.77 \text{ nF}$$

f. $BW = \frac{f_s}{Q_s} = \frac{5 \text{ kHz}}{20} = \mathbf{250 \text{ Hz}}$

g. $f_2 = f_s + \frac{BW}{2} = 5 \text{ kHz} + \frac{0.25 \text{ kHz}}{2} = \mathbf{5.13 \text{ kHz}}$

$$f_1 = f_s - \frac{BW}{2} = 5 \text{ kHz} - \frac{0.25 \text{ kHz}}{2} = \mathbf{4.88 \text{ kHz}}$$

4. a. $f_s = \frac{1}{2\pi\sqrt{LC}} \Rightarrow L = \frac{1}{(2\pi f_s)^2 C} = \frac{1}{(2\pi 1.8 \text{ kHz})^2 2 \mu\text{F}} = \mathbf{3.91 \text{ mH}}$

b. $X_L = 2\pi fL = 2\pi(1.8 \text{ kHz})(3.91 \text{ mH}) = \mathbf{44.2 \Omega}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.8 \text{ kHz})(2 \mu\text{F})} = \mathbf{44.2 \Omega}$$

$$X_L = X_C$$

c. $E_{\text{rms}} = (0.707)(20 \text{ mV}) = 14.14 \text{ mV}$

$$I_{\text{rms}} = \frac{E_{\text{rms}}}{R} = \frac{14.14 \text{ mV}}{4.7 \Omega} = \mathbf{3.01 \text{ mA}}$$

d. $P = I^2 R = (3.01 \text{ mA})^2 4.7 \Omega = \mathbf{42.58 \mu\text{W}}$

e. $S_T = P_T = \mathbf{42.58 \mu\text{VA}}$

f. $F_p = \mathbf{1}$

g. $Q_s = \frac{X_L}{R} = \frac{44.2 \Omega}{4.7 \Omega} = \mathbf{9.4}$

$$BW = \frac{f_s}{Q_s} = \frac{1.8 \text{ kHz}}{9.4} = \mathbf{191.49 \text{ Hz}}$$

h.
$$\begin{aligned} f_2 &= \frac{1}{2\pi} \left[\frac{R}{2L} + \frac{1}{2} \sqrt{\left(\frac{R}{L}\right)^2 + \frac{4}{LC}} \right] \\ &= \frac{1}{2\pi} \left[\frac{4.7 \Omega}{2(3.91 \text{ mH})} + \frac{1}{2} \sqrt{\left(\frac{4.7 \Omega}{3.91 \text{ mH}}\right)^2 + \frac{4}{(3.91 \text{ mH})(2 \mu\text{F})}} \right] \\ &= \frac{1}{2\pi} \left[601.02 + 11.324 \times 10^3 \right] \\ &= \mathbf{1897.93 \text{ Hz}} \end{aligned}$$

$$\begin{aligned} f_1 &= \frac{1}{2\pi} \left[-\frac{R}{2L} + \frac{1}{2} \sqrt{\left(\frac{R}{L}\right)^2 + \frac{4}{LC}} \right] \\ &= \frac{1}{2\pi} \left[-601.02 + 11.324 \times 10^3 \right] \\ &= \mathbf{1.71 \text{ kHz}} \end{aligned}$$

$$P_{\text{HPF}} = \frac{1}{2} P_{\text{max}} = \frac{1}{2} (42.58 \mu\text{W}) = \mathbf{21.29 \mu\text{W}}$$

5. a. $BW = f_s/Q_s = 6000 \text{ Hz}/15 = \mathbf{400 \text{ Hz}}$
- b. $f_2 = f_s + \frac{BW}{2} = 6000 \text{ Hz} + 200 \text{ Hz} = \mathbf{6200 \text{ Hz}}$
 $f_1 = f_s - \frac{BW}{2} = 6000 \text{ Hz} - 200 \text{ Hz} = \mathbf{5800 \text{ Hz}}$
- c. $Q_s = \frac{X_L}{R} \Rightarrow X_L = Q_s R = (15)(3 \Omega) = \mathbf{45 \Omega} = X_C$
- d. $P_{\text{HPF}} = \frac{1}{2} P_{\text{max}} = \frac{1}{2} (I^2 R) = \frac{1}{2} (0.5 \text{ A})^2 3\Omega = \mathbf{375 \text{ mW}}$
6. a. $L = \frac{X_L}{2\pi f} = \frac{200 \Omega}{2\pi(10^4 \text{ Hz})} = 3.185 \text{ mH}$
 $BW = \frac{R}{2\pi L} = \frac{5 \Omega}{2\pi(3.185 \text{ mH})} \cong \mathbf{250 \text{ Hz}}$
 or $Q_s = \frac{X_L}{R} = \frac{X_C}{R} = \frac{200 \Omega}{5 \Omega} = 40$, $BW = \frac{f_s}{Q_s} = \frac{10,000 \text{ Hz}}{40} = \mathbf{250 \text{ Hz}}$
- b. $f_2 = f_s + BW/2 = 10,000 \text{ Hz} + 250 \text{ Hz}/2 = \mathbf{10,125 \text{ Hz}}$
 $f_1 = f_s - BW/2 = 10,000 \text{ Hz} - 125 \text{ Hz} = \mathbf{9,875 \text{ Hz}}$
- c. $Q_s = \frac{X_L}{R} = \frac{200 \Omega}{5 \Omega} = \mathbf{40}$
- d. $\mathbf{I} = \frac{E \angle 0^\circ}{R \angle 0^\circ} = \frac{30 \text{ V} \angle 0^\circ}{5 \Omega \angle 0^\circ} = 6 \text{ A} \angle 0^\circ$, $\mathbf{V}_L = (I \angle 0^\circ)(X_L \angle 90^\circ)$
 $= (6 \text{ A} \angle 0^\circ)(200 \Omega \angle 90^\circ)$
 $= \mathbf{1200 \text{ V} \angle 90^\circ}$
 $\mathbf{V}_C = (I \angle 0^\circ)(X_C \angle -90^\circ) = \mathbf{1200 \text{ V} \angle -90^\circ}$
- e. $P = I^2 R = (6 \text{ A})^2 5 \Omega = \mathbf{180 \text{ W}}$
7. a. $BW = \frac{f_s}{Q_s} \Rightarrow Q_s = f_s/BW = 2000 \text{ Hz}/200 \text{ Hz} = \mathbf{10}$
- b. $Q_s = \frac{X_L}{R} \Rightarrow X_L = Q_s R = (10)(2 \Omega) = \mathbf{20 \Omega}$
- c. $L = \frac{X_L}{2\pi f} = \frac{20 \Omega}{(6.28)(2 \text{ kHz})} = \mathbf{1.59 \text{ mH}}$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{(6.28)(2 \text{ kHz})(20 \Omega)} = \mathbf{3.98 \mu\text{F}}$

- d. $f_2 = f_s + BW/2 = 2000 \text{ Hz} + 100 \text{ Hz} = \mathbf{2100 \text{ Hz}}$
 $f_1 = f_s - BW/2 = 2000 \text{ Hz} - 100 \text{ Hz} = \mathbf{1900 \text{ Hz}}$
8. a. $BW = 6000 \text{ Hz} - 5400 \text{ Hz} = \mathbf{600 \text{ Hz}}$
- b. $BW = f_s/Q_s \Rightarrow f_s = Q_s BW = (9.5)(600 \text{ Hz}) = \mathbf{5700 \text{ Hz}}$
- c. $Q_s = \frac{X_L}{R} \Rightarrow X_L = X_C = Q_s R = (9.5)(2 \Omega) = \mathbf{19 \Omega}$
- d. $L = \frac{X_L}{2\pi f} = \frac{19 \Omega}{2\pi(5700 \text{ Hz})} = \mathbf{0.53 \text{ mH}}$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(5.7 \text{ kHz})(19 \Omega)} = \mathbf{1.47 \mu F}$
9. $I_M = \frac{E}{R} \Rightarrow R = \frac{E}{I_M} = \frac{5 \text{ V}}{500 \text{ mA}} = \mathbf{10 \Omega}$
 $BW = f_s/Q_s \Rightarrow Q_s = f_s/BW = 8400 \text{ Hz}/120 \text{ Hz} = 70$
 $Q_s = \frac{X_L}{R} \Rightarrow X_L = Q_s R = (70)(10 \Omega) = \mathbf{700 \Omega}$
 $X_C = X_L = \mathbf{700 \Omega}$
 $L = \frac{X_L}{2\pi f} = \frac{700 \Omega}{(2\pi)(8.4 \text{ kHz})} = \mathbf{13.26 \text{ mH}}$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(8.4 \text{ kHz})(0.7 \text{ k}\Omega)} = \mathbf{27.07 \text{ nF}}$
 $f_2 = f_s + BW/2 = 8400 \text{ Hz} + 120 \text{ Hz}/2 = \mathbf{8460 \text{ Hz}}$
 $f_1 = f_s - BW/2 = 8400 \text{ Hz} - 60 \text{ Hz} = \mathbf{8340 \text{ Hz}}$
10. $Q_s = \frac{X_L}{R} \Rightarrow X_L = Q_s R = 20(2 \Omega) = \mathbf{40 \Omega} = X_C$
 $BW = \frac{f_s}{Q_s} \Rightarrow f_s = Q_s BW = (20)(400 \text{ Hz}) = \mathbf{8 \text{ kHz}}$
 $L = \frac{X_L}{2\pi f} = \frac{40 \Omega}{2\pi(8 \text{ kHz})} = \mathbf{795.77 \mu H}$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(8 \text{ kHz})(40 \Omega)} = \mathbf{497.36 \text{ nF}}$
 $f_2 = f_s + BW/2 = 8000 \text{ Hz} + 400 \text{ Hz}/2 = \mathbf{8200 \text{ Hz}}$
 $f_1 = f_s - BW/2 = 8000 \text{ Hz} - 200 \text{ Hz} = \mathbf{7800 \text{ Hz}}$
11. a. $f_s = \frac{\omega_s}{2\pi} = \frac{2\pi \times 10^6 \text{ rad/s}}{2\pi} = \mathbf{1 \text{ MHz}}$
- b. $\frac{f_2 - f_1}{f_s} = 0.16 \Rightarrow BW = f_2 - f_1 = 0.16 f_s = 0.16(1 \text{ MHz}) = \mathbf{160 \text{ kHz}}$

c. $P = \frac{V_R^2}{R} \Rightarrow R = \frac{V_R^2}{P} = \frac{(120 \text{ V})^2}{20 \text{ W}} = 720 \Omega$

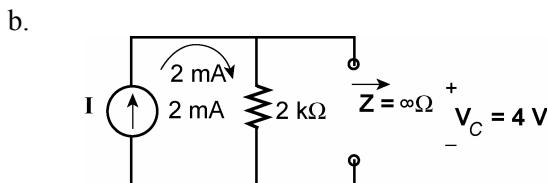
 $BW = \frac{R}{2\pi L} \Rightarrow L = \frac{R}{2\pi BW} = \frac{720 \Omega}{(6.28)(160 \text{ kHz})} = 0.716 \text{ mH}$
 $f_s = \frac{1}{2\pi\sqrt{LC}} \Rightarrow C = \frac{1}{4\pi^2 f_s^2 L} = \frac{1}{4\pi^2 (10^6 \text{ Hz})^2 (0.716 \text{ mH})} = 35.38 \text{ pF}$

d. $Q_\ell = \frac{X_L}{R_\ell} = 80 \Rightarrow R_P = \frac{X_L}{80} = \frac{2\pi f_s L}{80} = \frac{2\pi (10^6 \text{ Hz})(0.716 \text{ mH})}{80} = 56.23 \Omega$

12. a. $Q_\ell = \frac{X_L}{R_\ell}$
 $R_\ell = \frac{X_L}{Q_\ell} = \frac{2\pi f L}{Q_\ell} = \frac{2\pi (1 \text{ MHz})(100 \mu\text{H})}{12.5} = 50.27 \Omega$
 $\frac{f_2 - f_1}{f_s} = \frac{1}{Q_s} = 0.2$
 $Q_s = \frac{1}{0.2} = 5 = \frac{X_L}{R} = \frac{2\pi f L}{R} = \frac{2\pi (1 \text{ MHz})(100 \mu\text{H})}{R} = \frac{628.32 \Omega}{R}$
 $R = \frac{628.32 \Omega}{5} = 125.66$
 $R = R_d + R_\ell$
 $125.66 \Omega = R_d + 50.27 \Omega$
and $R_d = 125.66 \Omega - 50.27 \Omega = 75.39 \Omega$

c. $X_C = \frac{1}{2\pi f C} = X_L$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi (1 \text{ MHz})(628.32 \Omega)} = 253.3 \text{ pF}$

13. a. $f_p = \frac{1}{2\pi\sqrt{LC}} = \frac{2}{2\pi\sqrt{(0.1 \text{ mH})(10 \text{ nF})}} = 159.16 \text{ kHz}$



c. $I_L = \frac{V_L}{X_L} = \frac{4 \text{ V}}{2\pi f_p L} = \frac{4 \text{ V}}{100 \Omega} = 40 \text{ mA}$

$I_C = \frac{V_L}{X_C} = \frac{4 \text{ V}}{1/2\pi f_p C} = \frac{4 \text{ V}}{100 \Omega} = 40 \text{ mA}$

d. $Q_p = \frac{R_s}{X_{L_p}} = \frac{2 \text{ k}\Omega}{2\pi f_p L} = \frac{2 \text{ k}\Omega}{100 \Omega} = 20$

14. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.5 \text{ mH})(30 \text{ nF})}} = 41.09 \text{ kHz}$

b. $Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f L}{R_\ell} = \frac{2\pi(41.09 \text{ kHz})(0.5 \text{ mH})}{8 \Omega} = 16.14 \geq 10 \text{ (yes)}$

c. Since $Q_\ell \geq 10$, $f_p \approx f_s = 41.09 \text{ kHz}$

d. $X_L = 2\pi f_p L = 2\pi(41.09 \text{ kHz})(0.5 \text{ mH}) = 129.1 \Omega$

$$X_C = \frac{2}{2\pi f_p C} = \frac{2}{2\pi(41.09 \text{ kHz})(30 \text{ nF})} = 129.1 \Omega$$

$$X_L = X_C$$

e. $Z_{T_p} = Q_\ell^2 R_\ell = (16.14)^2 8 \Omega = 2.084 \text{ k}\Omega$

f. $V_C = IZ_{T_p} = (10 \text{ mA})(2.084 \text{ k}\Omega) = 20.84 \text{ V}$

g. $Q_\ell \geq 10$, $Q_p = Q_\ell = 16.14$

$$BW = \frac{f_p}{Q_p} = \frac{41.09 \text{ kHz}}{16.14} = 2545.85 \text{ Hz}$$

h. $I_L = I_C = Q_\ell I_T = (16.14)(10 \text{ mA}) = 161.4 \text{ mA}$

15. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.1 \text{ mH})(2 \mu\text{F})}} = 11,253.95 \text{ Hz}$

b. $Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_s L}{R_\ell} = \frac{2\pi(11,253.95 \text{ Hz})(0.1 \text{ mH})}{4 \Omega} = 1.77 \text{ (low } Q_\ell)$

c. $f_p = f_s \sqrt{1 - \frac{R_\ell^2 C}{L}} = 11,253.95 \text{ Hz} \sqrt{1 - \frac{(4 \Omega)^2 2 \mu\text{F}}{0.1 \text{ mH}}} = 11,253.95 \text{ Hz}(0.825) = 9,280.24 \text{ Hz}$

$$f_m = f_s \sqrt{1 - \frac{1}{4} \left[\frac{R_\ell^2 C}{L} \right]} = 11,253.95 \text{ Hz} \sqrt{1 - \frac{1}{4} \left[\frac{(4 \Omega)^2 2 \mu\text{F}}{0.1 \text{ mH}} \right]} = 11,253.95 \text{ Hz}(0.996) = 10,794.41 \text{ Hz}$$

d. $X_L = 2\pi f_p L = 2\pi(9,280.24 \text{ Hz})(0.1 \text{ mH}) = \mathbf{5.83 \Omega}$

$$X_C = \frac{1}{2\pi f_p C} = \frac{1}{2\pi(9,280.24 \text{ Hz})(2 \mu\text{F})} = \mathbf{8.57 \Omega}$$

$$X_L \neq X_C, X_C > X_L$$

e. $Z_{T_p} = R_s \parallel R_p = R_s \parallel \left(\frac{R_\ell^2 + X_L^2}{R_\ell} \right) = \frac{R_\ell^2 + X_L^2}{R_\ell} = \frac{(4 \Omega)^2 + (5.83 \Omega)^2}{4 \Omega} = \mathbf{12.5 \Omega}$

f. $V_C = IZ_{T_p} = (2 \text{ mA})(12.5 \Omega) = \mathbf{25 \text{ mV}}$

g. Since $R_s = \infty \Omega$ $Q_p = Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_p L}{R_\ell} = \frac{2\pi(9,280.24 \text{ Hz})(0.1 \text{ mH})}{4 \Omega} = \mathbf{1.46}$
 $BW = \frac{f_p}{Q_p} = \frac{9,280.24 \text{ Hz}}{1.46} = \mathbf{6.36 \text{ kHz}}$

h. $I_C = \frac{V_C}{X_C} = \frac{25 \text{ mV}}{8.57 \Omega} = \mathbf{2.92 \text{ mA}}$

$$I_L = \frac{V_L}{Z_{R-L}} = \frac{V_C}{R_\ell + jX_L} = \frac{25 \text{ mV}}{4 \Omega + j5.83 \Omega} = \frac{25 \text{ mV}}{7.07 \Omega} = \mathbf{3.54 \text{ mA}}$$

16. a. $Q_\ell = \frac{X_L}{R_L} = \frac{100 \Omega}{20 \Omega} = 5 \leq 10$
 $\therefore \frac{X_L}{R_\ell^2 + X_L^2} = \frac{1}{X_C} \Rightarrow X_C = \frac{R_\ell^2 + X_\ell^2}{X_L} = \frac{(20 \Omega)^2 + (100 \Omega)^2}{100 \Omega} = \mathbf{104 \Omega}$

b. $Z_T = R_s \parallel R_p = R_s \parallel \frac{R_\ell^2 + X_L^2}{R_\ell} = 1000 \Omega \parallel \frac{10,400 \Omega}{20} = \mathbf{342.11 \Omega}$

c. $\mathbf{E} = \mathbf{IZ}_{T_p} = (5 \text{ mA} \angle 0^\circ)(342.11 \Omega \angle 0^\circ) = 1.711 \text{ V} \angle 0^\circ$

$$\mathbf{I}_C = \frac{\mathbf{E}}{X_C \angle -90^\circ} = \frac{1.711 \text{ V} \angle 0^\circ}{104 \Omega \angle -90^\circ} = \mathbf{16.45 \text{ mA} \angle 90^\circ}$$

$$\mathbf{Z}_L = 20 \Omega + j100 \Omega = 101.98 \Omega \angle 78.69^\circ$$

$$\mathbf{I}_L = \frac{\mathbf{E}}{\mathbf{Z}_L} = \frac{1.711 \text{ V} \angle 0^\circ}{101.98 \Omega \angle 78.69^\circ} = \mathbf{16.78 \text{ mA} \angle -78.69^\circ}$$

d. $L = \frac{X_L}{2\pi f} = \frac{100 \Omega}{2\pi(20 \text{ kHz})} = \mathbf{795.77 \mu\text{H}}$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(20 \text{ kHz})(104 \Omega)} = \mathbf{76.52 \text{ nF}}$$

e. $Q_p = \frac{R}{X_C} = \frac{342.11\Omega}{104\Omega} = 3.29$
 $BW = f_p/Q_p = 20,000 \text{ Hz}/3.29 = 6079.03 \text{ Hz}$

17. a. $Q_\ell = \frac{X_L}{R_\ell} = \frac{30\Omega}{2\Omega} = 15$ (use approximate approach): $X_C = X_L = 30 \Omega$

b. $Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell = 450 \Omega \parallel (15)^2 2 \Omega = 450 \Omega \parallel 450 \Omega = 225 \Omega$

c. $\mathbf{E} = \mathbf{I} \mathbf{Z}_{T_p} = (80 \text{ mA} \angle 0^\circ)(225 \Omega \angle 0^\circ) = 18 \text{ V} \angle 0^\circ$

$$\mathbf{I}_C = \frac{\mathbf{E}}{X_C \angle -90^\circ} = \frac{18 \text{ V} \angle 0^\circ}{30 \Omega \angle -90^\circ} = 0.6 \text{ A} \angle 90^\circ$$

$$\mathbf{I}_L = \frac{\mathbf{E}}{\mathbf{Z}_{R-L}} = \frac{18 \text{ V} \angle 0^\circ}{2\Omega + j30\Omega} = \frac{18 \text{ V} \angle 0^\circ}{30.07 \Omega \angle 86.19^\circ} \equiv 0.6 \text{ A} \angle -86.19^\circ$$

d. $X_L = 2\pi f_p L, L = \frac{X_L}{2\pi f_p} = \frac{30\Omega}{2\pi(20 \times 10^3 \text{ Hz})} = 0.239 \text{ mH}$

$$X_C = \frac{1}{2\pi f_p C}, C = \frac{1}{2\pi f_p X_C} = \frac{1}{2\pi(20 \times 10^3 \text{ Hz})(30 \Omega)} = 265.26 \text{ nF}$$

e. $Q_p = \frac{Z_{T_p}}{X_L} = \frac{225 \Omega}{30 \Omega} = 7.5, BW = \frac{f_p}{Q_p} = \frac{20,000 \text{ Hz}}{7.5} = 2.67 \text{ kHz}$

18. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(80 \mu\text{H})(0.03 \mu\text{F})}} = 102.73 \text{ kHz}$
 $f_p = f_s \sqrt{1 - \frac{R_\ell^2 C}{L}} = 102.73 \text{ kHz} \sqrt{1 - \frac{(1.5 \Omega)^2 0.03 \mu\text{F}}{80 \mu\text{H}}} = 102.73 \text{ kHz}(.99958)$
 $= 102.69 \text{ kHz}$

$$f_m = f_s \sqrt{1 - \frac{1}{4} \left[\frac{R_\ell^2 C}{L} \right]} = 102.73 \text{ kHz}(0.99989) = 102.72 \text{ kHz}$$

Since $f_s \approx f_p \approx f_m \Rightarrow$ high Q_p

b. $X_L = 2\pi f_p L = 2\pi(102.69 \text{ kHz})(80 \mu\text{H}) = 51.62 \Omega$

$$X_C = \frac{1}{2\pi f_p C} = \frac{1}{2\pi(102.69 \text{ kHz})(0.03 \mu\text{F})} = 51.66 \Omega$$

$X_L \approx X_C$

c. $Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{51.62 \Omega}{1.5 \Omega} = 34.41$$

$$Z_{T_p} = 10 \text{ k}\Omega \parallel (34.41)^2 1.5 \Omega = 10 \text{ k}\Omega \parallel 1.776 \text{ k}\Omega = \mathbf{1.51 \text{ k}\Omega}$$

d. $Q_p = \frac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \frac{Z_{T_p}}{X_L} = \frac{1.51 \text{ k}\Omega}{51.62 \Omega} = \mathbf{29.25}$

$$BW = \frac{f_p}{Q_p} = \frac{102.69 \text{ kHz}}{29.25} = \mathbf{3.51 \text{ kHz}}$$

e. $I_T = \frac{R_s I_s}{R_s + Q_\ell^2 R_\ell} = \frac{10 \text{ k}\Omega (10 \text{ mA})}{10 \text{ k}\Omega + 1.78 \text{ k}\Omega} = 8.49 \text{ mA}$

$$I_C = I_L \equiv Q_\ell I_T = (34.41)(8.49 \text{ mA}) = \mathbf{292.14 \text{ mA}}$$

f. $V_C = IZ_{T_p} = (10 \text{ mA})(1.51 \text{ k}\Omega) = \mathbf{15.1 \text{ V}}$

19. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.5 \text{ mH})(1 \mu\text{F})}} = \mathbf{7.12 \text{ kHz}}$

$$f_p = f_s \sqrt{1 - \frac{R_\ell^2 C}{L}} = 7.12 \text{ kHz} \sqrt{1 - \frac{(8 \Omega)^2 (1 \mu\text{F})}{0.5 \text{ mH}}} = 7.12 \text{ kHz}(0.9338) = \mathbf{6.65 \text{ kHz}}$$

$$f_m = f_s \sqrt{1 - \frac{1}{4} \left[\frac{R_\ell^2 C}{L} \right]} = 7.12 \text{ kHz} \sqrt{1 - \frac{1}{4} \left[\frac{(8 \Omega)^2 (1 \mu\text{F})}{0.5 \text{ mH}} \right]} = 7.12 \text{ kHz} (0.9839) \\ = \mathbf{7.01 \text{ kHz}}$$

Low Q_p

b. $X_L = 2\pi f_p L = 2\pi(6.647 \text{ kHz})(0.5 \text{ mH}) = 20.88 \Omega$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(6.647 \text{ kHz})(1 \mu\text{F})} = 23.94 \Omega \\ X_C > X_L \text{ (low } Q\text{)}$$

c. $Z_{T_p} = R_s \parallel R_p = R_s \parallel \frac{R_\ell^2 + X_L^2}{R_\ell} = 500 \Omega \parallel \frac{(8 \Omega)^2 + (20.88 \Omega)^2}{8 \Omega} = 500 \Omega \parallel 62.5 \Omega \\ = \mathbf{55.56 \Omega}$

d. $Q_p = \frac{Z_{T_p}}{X_{L_p}} = \frac{55.56 \Omega}{23.94 \Omega} = \mathbf{2.32}$

$$BW = \frac{f_p}{Q_p} = \frac{6.647 \text{ kHz}}{2.32} = \mathbf{2.87 \text{ kHz}}$$

e. One method: $V_C = IZ_{T_p} = (40 \text{ mA})(55.56 \Omega) = 2.22 \text{ V}$

$$I_C = \frac{V_C}{X_C} = \frac{2.22 \text{ V}}{23.94 \Omega} = \mathbf{92.73 \text{ mA}}$$

$$I_L = \frac{|V_C|}{|R_\ell + jX_L|} = \frac{2.22 \text{ V}}{|8 + j20.88|} = \frac{2.22 \text{ V}}{22.36 \Omega} = \mathbf{99.28 \text{ mA}}$$

f. $V_C = \mathbf{2.22 \text{ V}}$

20. a. $Z_{T_p} = \frac{R_\ell^2 + X_L^2}{R_\ell} = 50 \text{ k}\Omega$
 $(50 \Omega)^2 + X_L^2 = (50 \text{ k}\Omega)(50 \Omega)$
 $X_L = \sqrt{250 \times 10^4 - 2.5 \times 10^3} = \mathbf{1580.3 \Omega}$

b. $Q = \frac{X_L}{R_\ell} = \frac{1580.3}{50} = 31.61 \geq 10$
 $\therefore X_C = X_L = \mathbf{1580.3 \Omega}$

c. $X_L = 2\pi f_p L \Rightarrow f_p = \frac{X_L}{2\pi L} = \frac{1580.3 \Omega}{2\pi(16 \text{ mH})} = \mathbf{15.72 \text{ kHz}}$

d. $X_C = \frac{1}{2\pi f_p C} \Rightarrow C = \frac{1}{2\pi f_s X_C} = \frac{1}{2\pi(15.72 \text{ kHz})(1580.3 \Omega)} = \mathbf{6.4 \text{ nF}}$

21. a. $Q_\ell = 20 > 10 \therefore f_p = f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(200 \text{ mH})(10 \text{ nF})}} = \mathbf{3558.81 \text{ Hz}}$

b. $Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f L}{R_\ell} \Rightarrow R_\ell = \frac{2\pi f L}{Q_\ell} = \frac{2\pi(3558.81 \text{ Hz})(0.2 \text{ H})}{20} = 223.61 \Omega$
 $Z_{T_p} = R_s \parallel R_p = R_s \parallel Q_\ell^2 R_\ell = 40 \text{ k}\Omega \parallel (20)^2 223.61 \Omega$
 $Z_{T_p} = 27.64 \text{ k}\Omega$
 $V_C = IZ_{T_p} = (5 \text{ mA})(27.64 \text{ k}\Omega) = \mathbf{138.2 \text{ V}}$

c. $P = I^2 R = (5 \text{ mA})^2 27.64 \text{ k}\Omega = \mathbf{691 \text{ mW}}$

d. $Q_p = \frac{R}{X_L} = \frac{R_s \parallel R_p}{X_L} = \frac{27.64 \text{ k}\Omega}{2\pi(3558.81 \text{ Hz})(0.2 \text{ H})} = \mathbf{6.18}$
 $BW = \frac{f_p}{Q_p} = \frac{3558.81 \text{ Hz}}{6.18} = \mathbf{575.86 \text{ Hz}}$

22. a. Ratio of X_C to R_ℓ suggests high Q system.

$$\therefore X_L = \mathbf{400 \Omega} = X_C$$

b. $Q_\ell = \frac{X_L}{R_\ell} = \frac{400 \Omega}{8 \Omega} = \mathbf{50}$

c. $Q_p = \frac{R}{X_L} = \frac{R_s \parallel R_p}{X_L} = \frac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \frac{20 \text{ k}\Omega \parallel (50)^2 8 \Omega}{400 \Omega} = \frac{10 \text{ k}\Omega}{400 \Omega} = \mathbf{25}$

$$BW = \frac{f_p}{Q_p} \Rightarrow f_p = Q_p BW = (25)(1000 \text{ Hz}) = \mathbf{25 \text{ kHz}}$$

d. $V_{C_{\max}} = IZ_{T_p} = (0.1 \text{ mA})(10 \text{ k}\Omega) = \mathbf{1 \text{ V}}$

e. $f_2 = f_p + BW/2 = 25 \text{ kHz} + \frac{1 \text{ kHz}}{2} = \mathbf{25.5 \text{ kHz}}$

$$f_1 = f_p - BW/2 = 25 \text{ kHz} - \frac{1 \text{ kHz}}{2} = \mathbf{24.5 \text{ kHz}}$$

23. a. $X_C = \frac{R_\ell^2 + X_L^2}{X_L} \Rightarrow X_L^2 - X_L X_C + R_\ell^2 = 0$

$$X_L^2 - 100 X_L + 144 = 0$$

$$X_L = \frac{-(-100) \pm \sqrt{(100)^2 - 4(1)(144)}}{2}$$

$$= 50 \Omega \pm \frac{\sqrt{10^4 - 576}}{2} = 50 \Omega \pm 48.54 \Omega$$

$$X_L = \mathbf{98.54 \Omega \text{ or } 1.46 \Omega}$$

b. $Q_\ell = \frac{X_L}{R_\ell} = \frac{98.54 \Omega}{12 \Omega} = \mathbf{8.21}$

c. $Q_p = \frac{R_s \parallel R_p}{X_{L_p}} = \frac{40 \text{ k}\Omega \parallel \frac{R_\ell^2 + X_L^2}{R_\ell}}{X_C} = \frac{40 \text{ k}\Omega \parallel \frac{(12 \Omega)^2 + (98.54 \Omega)^2}{12 \Omega}}{100 \Omega}$

$$= \frac{40 \text{ k}\Omega \parallel 821.18 \Omega}{100 \Omega} = \frac{804.66 \Omega}{100 \Omega} = \mathbf{8.05}$$

$$BW = f_p/Q_p \Rightarrow f_p = Q_p BW = (8.05)(1 \text{ kHz}) = \mathbf{8.05 \text{ kHz}}$$

d. $V_{C_{\max}} = IZ_{T_p} = (6 \text{ mA})(804.66 \Omega) = \mathbf{4.83 \text{ V}}$

e. $f_2 = f_p + BW/2 = 8.05 \text{ kHz} + \frac{1 \text{ kHz}}{2} = \mathbf{8.55 \text{ kHz}}$

$$f_1 = f_p - BW/2 = 8.05 \text{ kHz} - \frac{1 \text{ kHz}}{2} = \mathbf{7.55 \text{ kHz}}$$

24. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.5 \text{ mH})(30 \text{ nF})}} = \mathbf{41.09 \text{ kHz}}$

$$f_p = f_s \sqrt{1 - \frac{R_\ell^2 C}{L}} = 41.09 \text{ kHz} \sqrt{1 - \frac{(6 \Omega)^2 30 \text{ nF}}{0.5 \text{ mH}}} = 41.09 \text{ kHz}(0.9978) = \mathbf{41 \text{ kHz}}$$

$$f_m = f_s \sqrt{1 - \frac{1}{4} \left[\frac{R_\ell^2 C}{L} \right]} = 41.09 \text{ kHz} \sqrt{1 - \frac{1}{4} \left[\frac{(6 \Omega)^2 (30 \text{ nF})}{0.5 \text{ mH}} \right]} = 41.09 \text{ kHz}(0.0995) = \mathbf{41.07 \text{ kHz}}$$

High Q_p

b. $\mathbf{I} = \frac{80 \text{ V} \angle 0^\circ}{20 \text{ k}\Omega \angle 0^\circ} = 4 \text{ mA} \angle 0^\circ, R_s = 20 \text{ k}\Omega$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f L}{R_\ell} = \frac{2\pi(41 \text{ kHz})(0.5 \text{ mH})}{6 \Omega} = \mathbf{21.47 \text{ (high } Q \text{ coil)}}$$

$$Q_p = \frac{R_s \parallel R_p}{X_{L_p}} = \frac{R_s \parallel \frac{R_\ell^2 + X_L^2}{R_\ell}}{\frac{R_\ell^2 + X_L^2}{X_L}} = \frac{20 \text{ k}\Omega \parallel \frac{(6 \Omega)^2 + (128.81 \Omega)^2}{6 \Omega}}{\frac{(6 \Omega)^2 + (128.81 \Omega)^2}{128.81 \Omega}}$$

$$= \frac{20 \text{ k}\Omega \parallel 2.771 \text{ k}\Omega}{129.09 \Omega} = \frac{2.434 \text{ k}\Omega}{129.09 \Omega} = \mathbf{18.86 \text{ (high } Q_p)}$$

c. $Z_{T_p} = R_s \parallel R_p = 20 \text{ k}\Omega \parallel 2.771 \text{ k}\Omega = \mathbf{2.43 \text{ k}\Omega}$

d. $V_C = IZ_{T_p} = (4 \text{ mA})(2.43 \text{ k}\Omega) = \mathbf{9.74 \text{ V}}$

e. $BW = \frac{f_p}{Q_p} = \frac{41 \text{ kHz}}{18.86} = \mathbf{2.17 \text{ kHz}}$

f. $X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(41 \text{ kHz})(30 \text{ nF})} = \mathbf{129.39 \Omega}$

$$I_C = \frac{V_C}{X_C} = \frac{9.736 \text{ V}}{129.39 \Omega} = \mathbf{75.25 \text{ mA}}$$

$$I_L = \frac{V_C}{|R + jX_L|} = \frac{9.736 \text{ V}}{6 \Omega + j128.81 \Omega} = \frac{9.736 \text{ V}}{128.95 \Omega} = \mathbf{75.50 \text{ mA}}$$

25. $Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_p L}{R_\ell} \Rightarrow R_\ell = \frac{2\pi f_p L}{Q_\ell} = \frac{2\pi(20 \text{ kHz})(2 \text{ mH})}{80} = \mathbf{3.14 \Omega}$

$$BW = f_p/Q_p \Rightarrow Q_p = f_p/BW = 20 \text{ kHz}/1.8 \text{ kHz} = \mathbf{11.11}$$

$$\text{High } Q \therefore f_p \approx f_s = \frac{1}{2\pi\sqrt{LC}} \Rightarrow C = \frac{1}{4\pi^2 f_p^2 L} = \frac{1}{4\pi^2 (20 \text{ kHz})^2 2 \text{ mH}} = \mathbf{31.66 \text{ nF}}$$

$$Q_p = \frac{R}{X_C} \Rightarrow R = Q_p X_C = \frac{Q_p}{2\pi f_p C} = \frac{11.11}{2\pi(20 \text{ kHz})(31.66 \text{ nF})} = \mathbf{2.79 \text{ k}\Omega}$$

$$R_p = Q_\ell^2 R_\ell = (80)^2 \cdot 3.14 \Omega = 20.1 \text{ k}\Omega$$

$$R = R_s \parallel R_p = \frac{R_s R_p}{R_s + R_p} \Rightarrow R_s = \frac{R_p R}{R_p - R} = \frac{(20.1 \text{ k}\Omega)(2.793 \text{ k}\Omega)}{20.1 \text{ k}\Omega - 2.793 \text{ k}\Omega} = 3.24 \text{ k}\Omega$$

26. $V_{C_{\max}} = IZ_{T_p} \Rightarrow Z_{T_p} = \frac{V_{C_{\max}}}{I} = \frac{1.8 \text{ V}}{0.2 \text{ mA}} = 9 \text{ k}\Omega$

 $Q_p = \frac{R}{X_L} = \frac{R_s \parallel R_p}{X_L} = \frac{R_p}{X_L} \Rightarrow X_L = \frac{R_p}{Q_p} = \frac{9 \text{ k}\Omega}{30} = 300 \text{ }\Omega = X_C$
 $BW = \frac{f_p}{Q_p} \Rightarrow f_p = Q_p BW = (30)(500 \text{ Hz}) = 15 \text{ kHz}$
 $L = \frac{X_L}{2\pi f} = \frac{300 \text{ }\Omega}{2\pi(15 \text{ kHz})} = 3.18 \text{ mH}$
 $C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(15 \text{ kHz})(300 \text{ }\Omega)} = 35.37 \text{ nF}$
 $Q_p = Q_\ell (R_s = \infty \Omega) = \frac{X_L}{R_\ell} \Rightarrow R_\ell = \frac{X_L}{Q_p} = \frac{300 \text{ }\Omega}{30} = 10 \text{ }\Omega$

27. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(200 \mu\text{H})(2 \text{ nF})}} = 251.65 \text{ kHz}$

 $Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi(251.65 \text{ kHz})(200 \mu\text{H})}{20 \Omega} = 15.81 \geq 10$
 $\therefore f_p = f_s = 251.65 \text{ kHz}$

b. $Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell = 40 \text{ k}\Omega \parallel (15.81)^2 \cdot 20 \Omega = 4.44 \text{ k}\Omega$

c. $Q_p = \frac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \frac{4.444 \text{ k}\Omega}{316.23 \Omega} = 14.05$

d. $BW = \frac{f_p}{Q_p} = \frac{251.65 \text{ kHz}}{14.05} = 17.91 \text{ kHz}$

e. **20 μH, 20 nF**

f_s the same since product LC the same

$$f_s = 251.65 \text{ kHz}$$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi(251.65 \text{ kHz})(20 \mu\text{H})}{20 \Omega} = 1.581$$

Low Q_ℓ :

$$f_p = f_s \sqrt{1 - \frac{R_\ell^2 C}{L}} = (251.65 \text{ kHz}) \sqrt{1 - \frac{(20 \Omega)^2 (20 \text{ nF})}{20 \mu\text{H}}} \\ = (251.65 \text{ kHz})(0.775) = 194.93 \text{ kHz}$$

$$X_L = 2\pi f_p L = 2\pi(194.93 \text{ kHz})(20 \mu\text{H}) = 24.496 \Omega$$

$$R_p = \frac{R_\ell^2 + X_L^2}{R_\ell} = \frac{(20 \Omega)^2 + (24.496 \Omega)^2}{20 \Omega} = 50 \Omega$$

$$Z_{T_p} = R_s \parallel R_p = 40 \text{ k}\Omega \parallel 50 \Omega = \mathbf{49.94 \Omega}$$

$$Q_p = \frac{R}{X_L} = \frac{49.94 \Omega}{24.496 \Omega} = \mathbf{2.04}$$

$$BW = \frac{f_p}{Q_p} = \frac{194.93 \text{ kHz}}{2.04} = \mathbf{95.55 \text{ kHz}}$$

f. **0.4 mH, 1 nF**

$f_s = 251.65 \text{ kHz}$ since LC product the same

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi(251.65 \text{ kHz})(0.4 \text{ mH})}{20 \Omega} = 31.62 \geq 10$$

$$\therefore f_p = f_s = \mathbf{251.65 \text{ kHz}}$$

$$Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell = 40 \text{ k}\Omega \parallel (31.62)^2 20 \Omega = 40 \text{ k}\Omega \parallel (\cong 20 \text{ k}\Omega) \cong \mathbf{13.33 \text{ k}\Omega}$$

$$Q_p = \frac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \frac{13.33 \text{ k}\Omega}{632.47 \Omega} = \mathbf{21.08}$$

$$BW = \frac{f_p}{Q_p} = \frac{251.65 \text{ kHz}}{21.08} = \mathbf{11.94 \text{ kHz}}$$

g. Network $\frac{L}{C} = \frac{200 \mu\text{H}}{2 \text{ nF}} = \mathbf{100 \times 10^3}$

part (e) $\frac{L}{C} = \frac{20 \mu\text{H}}{20 \text{ nF}} = \mathbf{1 \times 10^3}$

part (f) $\frac{L}{C} = \frac{0.4 \text{ mH}}{1 \text{ nF}} = \mathbf{400 \times 10^3}$

h. Yes, as $\frac{L}{C}$ ratio increased BW decreased.

Also, $V_p = IZ_{T_p}$ and for a fixed I , Z_{T_p} and therefore V_p will increase with increase in the L/C ratio.

Chapter 21

1. a. left: $d_1 = \frac{3}{16}'' = 0.1875'', d_2 = 1''$

$$\begin{aligned}\text{Value} &= 10^3 \times 10^{0.1875''/1''} \\ &= 10^3 \times 1.54 \\ &= \mathbf{1.54 \text{ kHz}}\end{aligned}$$

right: $d_1 = \frac{3}{4}'' = 0.75'', d_2 = 1''$

$$\begin{aligned}\text{Value} &= 10^3 \times 10^{0.75''/1''} \\ &= 10^3 \times 5.623 \\ &= \mathbf{5.62 \text{ kHz}}\end{aligned}$$

b. bottom: $d_1 = \frac{5}{16}'' = 0.3125'', d_2 = \frac{15}{16}'' = 0.9375''$

$$\begin{aligned}\text{Value} &= 10^{-1} \times 10^{0.3125''/0.9375''} = 10^{-1} \times 10^{0.333} \\ &= 10^{-1} \times 2.153 \\ &= \mathbf{0.22 \text{ V}}\end{aligned}$$

top: $d_1 = \frac{11}{16}'' = 0.6875'', d_2 = 0.9375''$

$$\begin{aligned}\text{Value} &= 10^{-1} \times 10^{0.6875''/0.9375''} = 10^{-1} \times 10^{0.720} \\ &= 10^{-1} \times 5.248 \\ &= \mathbf{0.52 \text{ V}}\end{aligned}$$

2. a. **5** b. **-4** c. **8** d. **-6**

e. **1.30** f. **3.94** g. **4.75** h. **-0.498**

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**

4. a. **11.51** b. **-9.21** c. **2.996** d. **9.07**

5. $\log_{10} 48 = \mathbf{1.68}$

$$\log_{10} 8 + \log_{10} 6 = 0.903 + 0.778 = \mathbf{1.68}$$

6. $\log_{10} 0.2 = \mathbf{-0.699}$

$$\log_{10} 18 - \log_{10} 90 = 1.255 - 1.954 = \mathbf{-0.699}$$

7. $\log_{10} 0.5 = \mathbf{-0.30}$

$$-\log_{10} 2 = -(0.301) = \mathbf{-0.30}$$

8. $\log_{10} 27 = \mathbf{1.43}$

$$3 \log_{10} 3 = 3(0.4771) = \mathbf{1.43}$$

9. a. $\text{bels} = \log_{10} \frac{P_2}{P_1} = \log_{10} \frac{280 \text{ mW}}{4 \text{ mW}} = \log_{10} 70 = \mathbf{1.85}$

b. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = 10(\log_{10} 70) = 10(1.845) = \mathbf{18.45}$

10. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1}$

$$6 \text{ dB} = 10 \log_{10} \frac{100 \text{ W}}{P_1}$$

$$0.6 = \log_{10} x$$

$$x = 3.981 = \frac{100 \text{ W}}{P_1}$$

$$P_1 = \frac{100 \text{ W}}{3.981} = \mathbf{25.12 \text{ W}}$$

11. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{40 \text{ W}}{2 \text{ W}} = 10 \log_{10} 20 = \mathbf{13.01}$

12. $\text{dB}_m = 10 \log_{10} \frac{P}{1 \text{ mW}}$

$$\text{dB}_m = 10 \log_{10} \frac{120 \text{ mW}}{1 \text{ mW}} = 10 \log_{10} 120 = \mathbf{20.79}$$

13. $\text{dB}_v = 20 \log_{10} \frac{V_2}{V_1} = 20 \log_{10} \frac{8.4 \text{ V}}{0.1 \text{ V}} = 20 \log_{10} 84 = \mathbf{38.49}$

14. $\text{dB}_v = 20 \log_{10} \frac{V_2}{V_1}$

$$22 = 20 \log_{10} \frac{V_o}{20 \text{ mV}}$$

$$1.1 = \log_{10} x$$

$$x = 12.589 = \frac{V_o}{20 \text{ mV}}$$

$$V_o = \mathbf{251.79 \text{ mV}}$$

15. $\text{dB}_s = 20 \log_{10} \frac{P}{0.0002 \mu\text{bar}}$

$$\text{dB}_s = 20 \log_{10} \frac{0.001 \mu\text{bar}}{0.0002 \mu\text{bar}} = \mathbf{13.98}$$

$$\text{dB}_s = 20 \log_{10} \frac{0.016 \mu\text{bar}}{0.0002 \mu\text{bar}} = \mathbf{38.06}$$

Increase = **24.08 dB_s**

16. $60 \text{ dB}_s \Rightarrow 90 \text{ dB}_s$
 quiet loud

$$60 \text{ dB}_s = 20 \log_{10} \frac{P_1}{0.002 \text{ } \mu\text{bar}} = 20 \log_{10} x$$

$$\begin{aligned} 3 &= \log_{10} x \\ x &= \mathbf{1000} \end{aligned}$$

$$90 \text{ dB}_s = 20 \log_{10} \frac{P_2}{0.002 \text{ } \mu\text{bar}} = 20 \log_{10} y$$

$$\begin{aligned} 4.5 &= \log_{10} y \\ y &= \mathbf{31.623 \times 10^3} \end{aligned}$$

$$\begin{aligned} \frac{x}{y} &= \frac{\frac{P_1}{0.002 \text{ } \cancel{\mu\text{bar}}}}{\frac{P_2}{0.002 \text{ } \cancel{\mu\text{bar}}}} = \frac{P_1}{P_2} = \frac{10^3}{31.623 \times 10^3} \end{aligned}$$

and $P_2 = \mathbf{31.62 P_1}$

18. a. $8 \text{ dB} = 20 \log_{10} \frac{V_2}{0.775 \text{ V}}$

$$0.4 = \log_{10} \frac{V_2}{0.775 \text{ V}}$$

$$\frac{V_2}{0.775 \text{ V}} = 2.512$$

$$V_2 = (2.512)(0.775 \text{ V}) = 1.947 \text{ V}$$

$$P = \frac{V^2}{R} = \frac{(1.947 \text{ V})^2}{600 \Omega} = \mathbf{6.32 \text{ mW}}$$

b. $-5 \text{ dB} = 20 \log_{10} \frac{V_2}{0.775 \text{ V}}$

$$-0.25 = \log_{10} \frac{V_2}{0.775 \text{ V}}$$

$$\frac{V_2}{0.775 \text{ V}} = 0.562$$

$$V_2 = (0.562)(0.775 \text{ V}) = 0.436 \text{ V}$$

$$P = \frac{V^2}{R} = \frac{(0.436 \text{ V})^2}{600 \Omega} = \mathbf{0.32 \text{ mW}}$$

19. a. $A_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} \angle -90^\circ + \tan^{-1} X_C/R = \frac{1}{\sqrt{\left(\frac{R}{X_C}\right)^2 + 1}} \angle -\tan^{-1} R/X_C$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2 \text{ k}\Omega)(0.02 \text{ }\mu\text{F})} = \mathbf{3617.16 \text{ Hz}}$$

$$f = f_c: \quad A_v = \frac{V_o}{V_i} = \mathbf{0.707}$$

$$f = 0.1f_c: \quad \text{At } f_c, \quad X_C = R = 2.2 \text{ k}\Omega$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi 0.1 f_c C} = \frac{1}{0.1} \left[\frac{1}{2\pi f_c C} \right] = 10 [2.2 \text{ k}\Omega] = 22 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{R}{X_C}\right)^2 + 1}} = \frac{1}{\sqrt{\left(\frac{2.2 \text{ k}\Omega}{22 \text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(1)^2 + 1}} = \mathbf{0.995}$$

$$f = 0.5f_c = \frac{1}{2} f_c : \quad X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \left(\frac{f_c}{2}\right) C} = 2 \left[\frac{1}{2\pi f_c C} \right] = 2 [2.2 \text{ k}\Omega] = 4.4 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{2.2 \text{ k}\Omega}{4.4 \text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(0.5)^2 + 1}} = \mathbf{0.894}$$

$$f = 2f_c : \quad X_C = \frac{1}{2\pi(2f_c)C} = \frac{1}{2} \left[\frac{1}{2\pi f_c C} \right] = \frac{1}{2} [2.2 \text{ k}\Omega] = 1.1 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{2.2 \text{ k}\Omega}{1.1 \text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(2)^2 + 1}} = \mathbf{0.447}$$

$$f = 10f_c : \quad X_C = \frac{1}{2\pi(10f_c)C} = \frac{1}{10} \left[\frac{1}{2\pi f_c C} \right] = \frac{1}{10} [2.2 \text{ k}\Omega] = 0.22 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{2.2 \text{ k}\Omega}{0.22 \text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(10)^2 + 1}} = \mathbf{0.0995}$$

b. $\theta = -\tan^{-1} R/X_C$

$$f = f_c : \quad \theta = -\tan^{-1} = \mathbf{-45^\circ}$$

$$f = 0.1f_c : \quad \theta = -\tan^{-1} 2.2 \text{ k}\Omega/22 \text{ k}\Omega = -\tan^{-1} \frac{1}{10} = \mathbf{-5.71^\circ}$$

$$f = 0.5f_c : \quad \theta = -\tan^{-1} 2.2 \text{ k}\Omega/4.4 \text{ k}\Omega = -\tan^{-1} \frac{1}{2} = \mathbf{-26.57^\circ}$$

$$f = 2f_c : \quad \theta = -\tan^{-1} 2.2 \text{ k}\Omega/1.1 \text{ k}\Omega = -\tan^{-1} 2 = \mathbf{-63.43^\circ}$$

$$f = 10f_c : \quad \theta = -\tan^{-1} 2.2 \text{ k}\Omega/0.22 \text{ k}\Omega = -\tan^{-1} 10 = \mathbf{-84.29^\circ}$$

20. a. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(1 \text{ k}\Omega)(0.01 \mu\text{F})} = 15.915 \text{ kHz}$

$$f = 2f_c = 31.83 \text{ kHz}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(31.83 \text{ kHz})(0.01 \mu\text{F})} = 500 \Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{500 \Omega}{\sqrt{(1 \text{ k}\Omega)^2 + (0.5 \text{ k}\Omega)^2}} = 0.4472$$

$$V_o = 0.4472 V_i = 0.4472(10 \text{ mV}) = \mathbf{4.47 \text{ mV}}$$

b. $f = \frac{1}{10}f_c = \frac{1}{10}(15,915 \text{ kHz}) = 1.5915 \text{ kHz}$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(1.5915 \text{ kHz})(0.01 \mu\text{F})} = 10 \text{ k}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{10 \text{ k}\Omega}{\sqrt{(1 \text{ k}\Omega)^2 + (10 \text{ k}\Omega)^2}} = 0.995$$

$$V_o = 0.995 V_i = 0.995(10 \text{ mV}) = \mathbf{9.95 \text{ mV}}$$

c. Yes, at $f = f_c$, $V_o = 7.07 \text{ mV}$
at $f = \frac{1}{10}f_c$, $V_o = 9.95 \text{ mV}$ (much higher)
at $f = 2f_c$, $V_o = 4.47 \text{ mV}$ (much lower)

21. $f_c = 500 \text{ Hz} = \frac{1}{2\pi RC} = \frac{1}{2\pi(1.2 \text{ k}\Omega)C}$

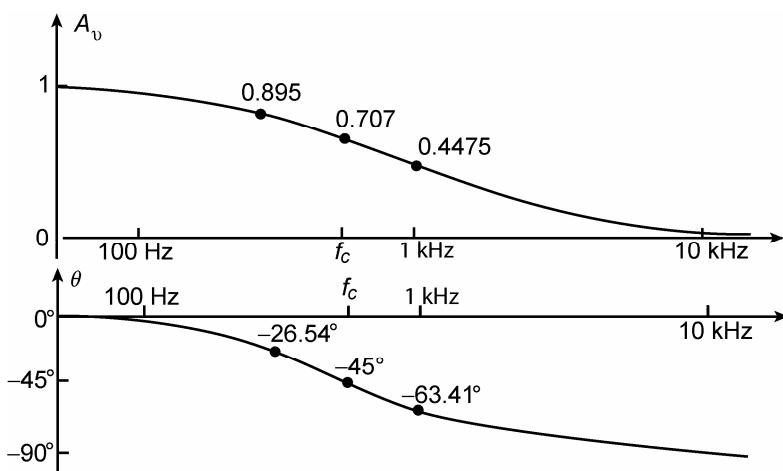
$$C = \frac{1}{2\pi R f_c} = \frac{1}{2\pi(1.2 \text{ k}\Omega)(500 \text{ Hz})} = \mathbf{0.265 \mu\text{F}}$$

$$A_v = \frac{V_o}{V_i} = \frac{1}{\sqrt{\left(\frac{R}{X_C}\right)^2 + 1}}$$

At $f = 250 \text{ Hz}$, $X_C = 2402.33 \Omega$ and $A_v = 0.895$
At $f = 1000 \text{ Hz}$, $X_C = 600.58 \Omega$ and $A_v = 0.4475$
 $\theta = -\tan^{-1} R/X_C$

At $f = 250 \text{ Hz} = \frac{1}{2}f_c$, $\theta = -26.54^\circ$

At $f = 1 \text{ kHz} = 2f_c$, $\theta = -63.41^\circ$



22. a. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(4.7 \text{ k}\Omega)(500 \text{ pF})} = \mathbf{67.73 \text{ kHz}}$

b. $f = 0.1 f_c = 0.1(67.726 \text{ kHz}) \cong 6.773 \text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6.773 \text{ kHz})(500 \text{ pF})} = 46.997 \text{ k}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{46.997 \text{ k}\Omega}{\sqrt{(4.7 \text{ k}\Omega)^2 + (46.997 \text{ k}\Omega)^2}} = \mathbf{0.995} \cong 1$$

c. $f = 10f_c = 677.26 \text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(677.26 \text{ kHz})(500 \text{ pF})} \cong 470 \text{ }\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{470 \text{ }\Omega}{\sqrt{(4.7 \text{ k}\Omega)^2 + (470 \text{ }\Omega)^2}} = \mathbf{0.0995} \cong 0.1$$

d. $A_v = \frac{V_o}{V_i} = 0.01 = \frac{X_C}{\sqrt{R^2 + X_C^2}}$

$$\sqrt{R^2 + X_C^2} = \frac{X_C}{0.01} = 100 X_C$$

$$R^2 + X_C^2 = 10^4 X_C^2$$

$$R^2 = 10^4 X_C^2 - X_C^2 = 9,999 X_C^2$$

$$X_C = \frac{R}{\sqrt{9,999}} = \frac{4.7 \text{ k}\Omega}{99.995} \cong 47 \text{ }\Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(47 \text{ }\Omega)(500 \text{ pF})} = \mathbf{6.77 \text{ MHz}}$$

23. a. $A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} \angle \tan^{-1} X_C/R = \frac{1}{\sqrt{1 + \left(\frac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2 \text{ k}\Omega)(20 \text{ nF})} = \mathbf{3.62 \text{ kHz}}$$

$$f = f_c: \quad A_v = \frac{V_o}{V_i} = \mathbf{0.707}$$

$$f = 2f_c: \quad \text{At } f_c, X_C = R = 2.2 \text{ k}\Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(2f_c)C} = \frac{1}{2} \left[\frac{1}{2\pi f_c C} \right] = \frac{1}{2} [2.2 \text{ k}\Omega] = 1.1 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left(\frac{1.1 \text{ k}\Omega}{2.2 \text{ k}\Omega}\right)^2}} = \mathbf{0.894}$$

$$f = \frac{1}{2}f_c; \quad X_C = \frac{1}{2\pi\left(\frac{f_c}{2}\right)C} = 2\left[\frac{1}{2\pi f_c C}\right] = 2[2.2 \text{ k}\Omega] = 4.4 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left(\frac{4.4 \text{ k}\Omega}{2.2 \text{ k}\Omega}\right)^2}} = \mathbf{0.447}$$

$$f = 10f_c; \quad X_C = \frac{1}{2\pi(10f_c)C} = \frac{1}{10}\left[\frac{1}{2\pi f_c C}\right] = \frac{2.2 \text{ k}\Omega}{10} = 0.22 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left(\frac{0.22 \text{ k}\Omega}{2.2 \text{ k}\Omega}\right)^2}} = \mathbf{0.995}$$

$$f = \frac{1}{10}f_c; \quad X_C = \frac{1}{2\pi\left(\frac{f_c}{10}\right)C} = 10\left[\frac{1}{2\pi f_c C}\right] = 10[2.2 \text{ k}\Omega] = 22 \text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left(\frac{22 \text{ k}\Omega}{2.2 \text{ k}\Omega}\right)^2}} = \mathbf{0.0995}$$

b. $f = f_c, \quad \theta = \mathbf{45^\circ}$

$$f = 2f_c, \quad \theta = \tan^{-1}(X_C/R) = \tan^{-1} 1.1 \text{ k}\Omega / 2.2 \text{ k}\Omega = \tan^{-1} \frac{1}{2} = \mathbf{26.57^\circ}$$

$$f = \frac{1}{2}f_c, \quad \theta = \tan^{-1} \frac{4.4 \text{ k}\Omega}{2.2 \text{ k}\Omega} = \tan^{-1} 2 = \mathbf{63.43^\circ}$$

$$f = 10f_c, \quad \theta = \tan^{-1} \frac{0.22 \text{ k}\Omega}{2.2 \text{ k}\Omega} = \mathbf{5.71^\circ}$$

$$f = \frac{1}{10}f_c, \quad \theta = \tan^{-1} \frac{22 \text{ k}\Omega}{2.2 \text{ k}\Omega} = \mathbf{84.29^\circ}$$

24. a. $f = f_c: A_v = \frac{V_o}{V_i} = \mathbf{0.707}$

b. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(10 \text{ k}\Omega)(1000 \text{ pF})} = 15.915 \text{ kHz}$

$$f = 4f_c = 4(15.915 \text{ kHz}) = 63.66 \text{ kHz}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(63.66 \text{ kHz})(1000 \text{ pF})} = 2.5 \text{ k}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10 \text{ k}\Omega}{\sqrt{(10 \text{ k}\Omega)^2 + (2.5 \text{ k}\Omega)^2}} = \mathbf{0.970} \text{ (significant rise)}$$

c. $f = 100f_c = 100(15.915 \text{ kHz}) = 1591.5 \text{ kHz} \approx 1.592 \text{ MHz}$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(1.592 \text{ MHz})(1000 \text{ pF})} = 99.972 \Omega$$

$$A_v = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10 \text{ k}\Omega}{\sqrt{(10 \text{ k}\Omega)^2 + (99.972 \Omega)^2}} = 0.99995 \approx 1$$

d. At $f = f_c$, $V_o = 0.707V_i = 0.707(10 \text{ mV}) = 7.07 \text{ mV}$

$$P_o = \frac{V_o^2}{R} = \frac{(7.07 \text{ mV})^2}{10 \text{ k}\Omega} \approx 5 \text{ nW}$$

25. $A_v = \frac{V_o}{V_i} = \frac{1}{\sqrt{1 + \left(\frac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$

$$f_c = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi(2 \text{ kHz})(0.1 \mu\text{F})} = 795.77 \Omega$$

$$R = 795.77 \Omega \Rightarrow \underbrace{750 \Omega + 47 \Omega}_{\text{nominal values}} = 797 \Omega$$

$$\therefore f_c = \frac{1}{2\pi(797 \Omega)(0.1 \mu\text{F})} = 1996.93 \text{ Hz} \text{ using nominal values}$$

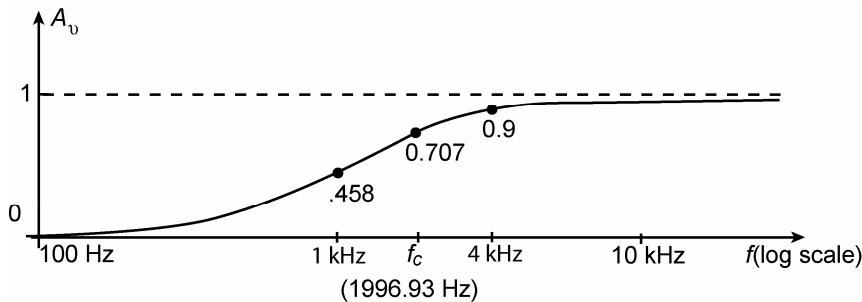
At $f = 1 \text{ kHz}, A_v = 0.458$

$$f = 4 \text{ kHz}, A_v \approx 0.9$$

$$\theta = \tan^{-1} \frac{X_C}{R}$$

$$f = 1 \text{ kHz}, \theta = 63.4^\circ$$

$$f = 4 \text{ kHz}, \theta = 26.53^\circ$$



26. a. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(100 \text{ k}\Omega)(20 \text{ pF})} = \mathbf{79.58 \text{ kHz}}$

b. $f = 0.01f_c = 0.01(79.577 \text{ kHz}) = 0.7958 \text{ kHz} \cong 796 \text{ Hz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(796 \text{ Hz})(20 \text{ pF})} = 9.997 \text{ M}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{100 \text{ k}\Omega}{\sqrt{(100 \text{ k}\Omega)^2 + (9.997 \text{ M}\Omega)^2}} = \mathbf{0.01} \cong 0$$

c. $f = 100f_c = 100(79.577 \text{ kHz}) \cong 7.96 \text{ MHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(7.96 \text{ MHz})(20 \text{ pF})} = 999.72 \text{ }\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{100 \text{ k}\Omega}{\sqrt{(100 \text{ k}\Omega)^2 + (999.72 \text{ }\Omega)^2}} = \mathbf{0.99995} \cong 1$$

d. $A_v = \frac{V_o}{V_i} = 0.5 = \frac{R}{\sqrt{R^2 + X_C^2}}$

$$\sqrt{R^2 + X_C^2} = 2R$$

$$R^2 + X_C^2 = 4R^2$$

$$X_C^2 = 4R^2 - R^2 = 3R^2$$

$$X_C = \sqrt{3R^2} = \sqrt{3}R = \sqrt{3} (100 \text{ k}\Omega) = 173.2 \text{ k}\Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(173.2 \text{ k}\Omega)(20 \text{ pF})}$$

$$f = \mathbf{45.95 \text{ kHz}}$$

27. a. low-pass section: $f_{c_1} = \frac{1}{2\pi RC} = \frac{1}{2\pi(0.1 \text{ k}\Omega)(2 \text{ }\mu\text{F})} = \mathbf{795.77 \text{ Hz}}$

high-pass section: $f_{c_2} = \frac{1}{2\pi RC} = \frac{1}{2\pi(10 \text{ k}\Omega)(8 \text{ nF})} = \mathbf{1989.44 \text{ Hz}}$

For the analysis to follow, it is assumed $(R_2 + jX_{C_2}) \parallel R_1 \cong R_1$ for all frequencies of interest.

At $f_{c_1} = 795.77 \text{ Hz}$:

$$V_{R_1} = 0.707 V_i$$

$$X_{C_2} = \frac{1}{2\pi fC_2} = 25 \text{ k}\Omega$$

$$|V_o| = \frac{25 \text{ k}\Omega(V_{R_1})}{\sqrt{(10 \text{ k}\Omega)^2 + (25 \text{ k}\Omega)^2}} = 0.9285 V_{R_1}$$

$$V_o = (0.9285)(0.707 V_i) = \mathbf{0.66 V_i}$$

At $f_{c_2} = 1989.44$ Hz:

$$V_o = 0.707 V_{R_l}$$

$$X_{C_1} = \frac{1}{2\pi f C_1} = 40 \Omega$$

$$|V_{R_l}| = \frac{R_l V_i}{\sqrt{R_l^2 + X_{C_1}^2}} = \frac{100 \Omega (V_i)}{\sqrt{(100 \Omega)^2 + (40 \Omega)^2}} = 0.928 V_i$$

$$|V_o| = (0.707)(0.928 V_i) = \mathbf{0.66} V_i$$

$$\text{At } f = 795.77 \text{ Hz} + \frac{(1989.44 \text{ Hz} - 795.77 \text{ Hz})}{2} = 1392.60 \text{ Hz}$$

$$X_{C_1} = 57.14 \Omega, X_{C_2} = 14.29 \text{ k}\Omega$$

$$|V_{R_l}| = \frac{100 \Omega (V_i)}{\sqrt{(100 \Omega)^2 + (57.14 \Omega)^2}} = 0.868 V_i$$

$$|V_o| = \frac{14.29 \text{ k}\Omega (V_{R_l})}{\sqrt{(10 \text{ k}\Omega)^2 + (14.29 \text{ k}\Omega)^2}} = 0.8193 V_{R_l}$$

$$V_o = 0.8193 (0.868 V_i) = \mathbf{0.71} V_i$$

$$\text{and } A_v = \frac{V_o}{V_i} = \mathbf{0.71} (\cong \text{maximum value})$$

After plotting the points it was determined that the gain should also be determined at $f = 500$ Hz and 4 kHz:

$$f = 500 \text{ Hz}: \quad X_{C_1} = 159.15 \Omega, X_{C_2} = 39.8 \text{ k}\Omega,$$

$$V_{R_l} = 0.532 V_i, V_o = 0.97 V_{R_l}$$

$$V_o = \mathbf{0.52} V_i$$

$$f = 4 \text{ kHz}: \quad X_{C_1} = 19.89 \Omega, X_{C_2} = 4.97 \text{ k}\Omega,$$

$$V_{R_l} = 0.981 V_i, V_o = 0.445 V_{R_l}$$

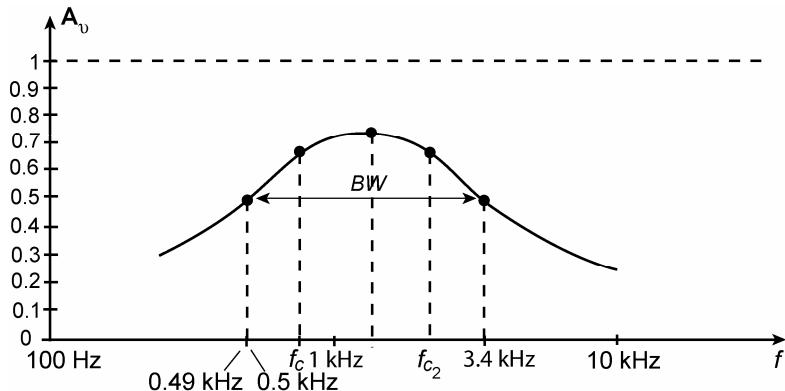
$$V_o = \mathbf{0.44} V_i$$

- b. Using $0.707(0.711) = 0.5026 \cong 0.5$ to define the bandwidth

$$BW = 3.4 \text{ kHz} - 0.49 \text{ kHz} = 2.91 \text{ kHz}$$

and $BW \cong \mathbf{2.9 \text{ kHz}}$

$$\text{with } f_{\text{center}} = 490 \text{ Hz} + \left(\frac{2.9 \text{ kHz}}{2} \right) = \mathbf{1940 \text{ Hz}}$$



$$28. \quad f_1 = \frac{1}{2\pi R_1 C_1} = 4 \text{ kHz}$$

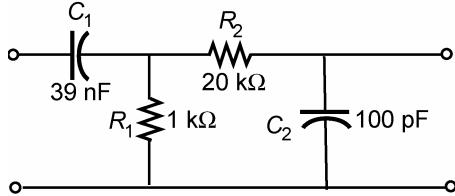
Choose $R_1 = 1 \text{ k}\Omega$

$$C_1 = \frac{1}{2\pi f_1 R_1} = \frac{1}{2\pi(4 \text{ kHz})(1 \text{ k}\Omega)} = 39.8 \text{ nF} \therefore \text{Use } 39 \text{ nF}$$

$$f_2 = \frac{1}{2\pi R_2 C_2} = 80 \text{ kHz}$$

Choose $R_2 = 20 \text{ k}\Omega$

$$C_2 = \frac{1}{2\pi f_2 R_2} = \frac{1}{2\pi(80 \text{ kHz})(20 \text{ k}\Omega)} = 99.47 \text{ pF} \therefore \text{Use } 100 \text{ pF}$$



$$\text{Center frequency} = 4 \text{ kHz} + \frac{80 \text{ kHz} - 4 \text{ kHz}}{2} = 42 \text{ kHz}$$

$$\text{At } f = 42 \text{ kHz}, X_{C_1} = 97.16 \Omega, X_{C_2} = 37.89 \text{ k}\Omega$$

Assuming $Z_2 \gg Z_1$

$$|V_{R_1}| = \frac{R_1(V_i)}{\sqrt{R_1^2 + X_{C_1}^2}} = 0.995 V_i$$

$$|V_o| = \frac{X_{C_2}(V_{R_1})}{\sqrt{R_2^2 + X_{C_1}^2}} = 0.884 V_i$$

$$V_o = 0.884 V_{R_1} = 0.884(0.995 V_i) = 0.88 V_i$$

$$\text{as } f = f_1: V_{R_1} = 0.707 V_i, X_{C_2} = 221.05 \text{ k}\Omega$$

$$\text{and } V_o = 0.996 V_{R_1}$$

$$\text{so that } V_o = 0.996 V_{R_1} = 0.996(0.707 V_i) = 0.704 V_i$$

Although $A_v = 0.88$ is less than the desired level of 1, f_1 and f_2 do define a band of frequencies for which $A_v \geq 0.7$ and the power to the load is significant.

29. a. $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(5 \text{ mH})(500 \text{ pF})}} = \mathbf{100.66 \text{ kHz}}$

b. $Q_s = \frac{X_L}{R + R_\ell} = \frac{2\pi(100.658 \text{ kHz})(5 \text{ mH})}{160 \Omega + 12 \Omega} = \mathbf{18.39}$

$$BW = \frac{f_s}{Q_s} = \frac{100.658 \text{ kHz}}{18.39} = \mathbf{5,473.52 \text{ Hz}}$$

c. At $f = f_s$: $V_{o_{\max}} = \frac{R}{R + R_\ell} V_i = \frac{160 \Omega(1 \text{ V})}{172 \Omega} = 0.93 \text{ V}$ and $A_v = \frac{V_o}{V_i} = \mathbf{0.93}$

Since $Q_s \geq 10$, $f_1 = f_s - \frac{BW}{2} = 100.658 \text{ kHz} - \frac{5,473.52 \text{ Hz}}{2} = 97,921.24 \text{ Hz}$

$$f_2 = f_s + \frac{BW}{2} = 103,394.76 \text{ Hz}$$

At $f = 95 \text{ kHz}$: $X_L = 2\pi f L = 2\pi(95 \times 10^3 \text{ Hz})(5 \text{ mH}) = 2.98 \text{ k}\Omega$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(95 \times 10^3 \text{ Hz})(500 \text{ pF})} = 3.35 \text{ k}\Omega$$

$$\begin{aligned} \mathbf{V}_o &= \frac{160 \Omega(1 \text{ V} \angle 0^\circ)}{172 + j2.98 \text{ k}\Omega - j3.35 \text{ k}\Omega} = \frac{160 \text{ V} \angle 0^\circ}{172 - j370} \\ &= \frac{160 \text{ V} \angle 0^\circ}{480 \angle -65.07^\circ} = \mathbf{0.39 \text{ V} \angle 65.07^\circ} \end{aligned}$$

At $f = 105 \text{ kHz}$: $X_L = 2\pi f L = 2\pi(105 \text{ kHz})(5 \text{ mH}) = 3.3 \text{ k}\Omega$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(105 \text{ kHz})(500 \text{ pF})} = 3.03 \text{ k}\Omega$$

$$\begin{aligned} \mathbf{V}_o &= \frac{160 (1 \text{ V} \angle 0^\circ)}{172 + j3.3 \text{ k}\Omega - j3.03 \text{ k}\Omega} = \frac{160 \text{ V} \angle 0^\circ}{172 + j270} \\ &= \frac{160 \text{ V} \angle 0^\circ}{320 \angle 57.50^\circ} = \mathbf{0.5 \angle -57.50^\circ} \end{aligned}$$

d. $f = f_s$: $V_{o_{\max}} = \mathbf{0.93 \text{ V}}$

$$f = f_1 = 97,921.24 \text{ Hz}, V_o = 0.707(0.93 \text{ V}) = \mathbf{0.66 \text{ V}}$$

$$f = f_2 = 103,394.76 \text{ Hz}, V_o = 0.707(0.93 \text{ V}) = \mathbf{0.66 \text{ V}}$$

30. a. $f_p = \frac{1}{2\pi\sqrt{LC}} \sqrt{1 - \frac{R_\ell^2 C}{L}} \cong \mathbf{159.15 \text{ kHz}}$

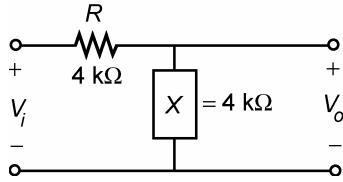
$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_p L}{R_\ell} = \frac{2\pi(159.15 \text{ kHz})(1 \text{ mH})}{16 \Omega} = 62.5 \gg 10$$

$$Z_{T_p} = Q_\ell^2 R_\ell = (62.5)^2 16 \Omega = 62.5 \text{ k}\Omega \gg 4 \text{ k}\Omega$$

and $V_o \cong V_i$ at resonance.

However, $R = 4 \text{ k}\Omega$ affects the shape of the resonance curve and $BW = f_p/Q_\ell$ cannot be applied.

For $A_v = \frac{V_o}{V_i} = 0.707$, $|X| = R$ for the following configuration



For frequencies near f_p , $X_L \gg R_\ell$ and $\mathbf{Z}_L = R_\ell + jX_L \approx X_L$ and $X = X_L \parallel X_C$.

For frequencies near f_p but less than f_p

$$X = \frac{X_C X_L}{X_C - X_L}$$

and for $A_v = 0.707$

$$\frac{X_C X_L}{X_C - X_L} = R$$

Substituting $X_C = \frac{1}{2\pi f_1 C}$ and $X_L = 2\pi f_1 L$

the following equation can be derived:

$$f_1^2 + \frac{1}{2\pi RC} f_1 - \frac{1}{4\pi^2 LC} = 0$$

For this situation:

$$\frac{1}{2\pi RC} = \frac{1}{2\pi(4 \text{ k}\Omega)(0.001 \mu\text{F})} = 39.79 \times 10^3$$

$$\frac{1}{4\pi^2 LC} = \frac{1}{4\pi^2(1 \text{ mH})(0.001 \mu\text{F})} = 2.53 \times 10^{10}$$

and solving the quadratic equation, $f_1 = 140.4 \text{ kHz}$

$$\text{and } \frac{BW}{2} = 159.15 \text{ kHz} - 140.4 \text{ kHz} = 18.75 \text{ kHz}$$

with $BW = 2(18.75 \text{ kHz}) = 37.5 \text{ kHz}$

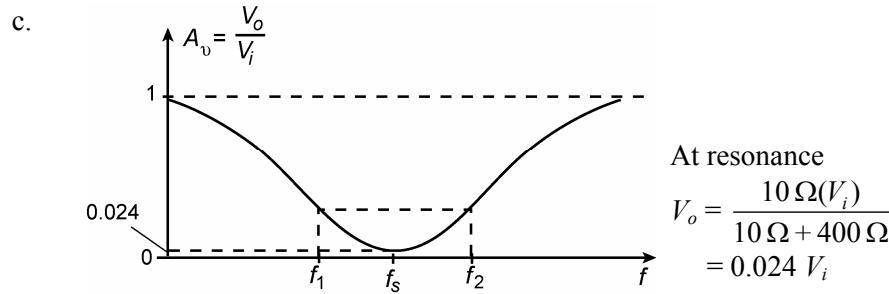
b. $Q_p = \frac{f_p}{BW} = \frac{159.15 \text{ kHz}}{37.5 \text{ kHz}} = 4.24$

31. a. $Q_s = \frac{X_L}{R + R_\ell} = \frac{5000 \Omega}{400 \Omega + 10 \Omega} = \frac{5000 \Omega}{410 \Omega} = 12.2$

b. $BW = \frac{f_s}{Q_s} = \frac{5000 \text{ Hz}}{12.2} = 409.84 \text{ Hz}$

$$f_1 = 5000 \text{ Hz} - \frac{409.84 \text{ Hz}}{2} = 4.80 \text{ kHz}$$

$$f_2 = 5000 \text{ Hz} + \frac{410 \text{ Hz}}{2} = 5.20 \text{ kHz}$$



d. At resonance, $10 \Omega \parallel 2 \text{ k}\Omega = 9.95 \Omega$

$$V_o = \frac{9.95 \Omega(V_i)}{9.95 \Omega + 400 \Omega} \cong 0.024 V_i \text{ as above!}$$

32. a. $Q_\ell = \frac{X_L}{R_\ell} = \frac{400 \Omega}{10 \Omega} = 40$

$$Z_{T_p} = Q_\ell^2 R_\ell = (40)^2 20 \Omega = 32 \text{ k}\Omega \gg 1 \text{ k}\Omega$$

At resonance, $V_o = \frac{32 \text{ k}\Omega V_i}{32 \text{ k}\Omega + 1 \text{ k}\Omega} = 0.97 V_i$

$$\text{and } A_v = \frac{V_o}{V_i} = 0.97$$

For the low cutoff frequency note solution to Problem 30:

$$f_1^2 + \frac{1}{2\pi RC} f_1 - \frac{1}{4\pi^2 LC} = 0$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(20 \text{ kHz})(400 \Omega)} = 19.9 \text{ nF}$$

$$L = \frac{X_L}{2\pi f} = \frac{400 \Omega}{2\pi(20 \text{ kHz})} = 3.18 \text{ mH}$$

Substituting into the above equation and solving

$$f_1 = 16.4 \text{ kHz}$$

with $\frac{BW}{2} = 20 \text{ kHz} - 16.4 \text{ kHz} = 3.6 \text{ kHz}$

and $BW = 2(3.6 \text{ kHz}) = 7.2 \text{ kHz}$

$$Q_p = \frac{f_p}{BW} = \frac{20 \text{ kHz}}{7.2 \text{ kHz}} = 2.78$$

b. —

c. At resonance

$$Z_{T_p} = 32 \text{ k}\Omega \parallel 100 \text{ k}\Omega = 24.24 \text{ k}\Omega$$

$$\text{with } V_o = \frac{24.24 \text{ k}\Omega V_i}{24.24 \text{ k}\Omega + 1 \text{ k}\Omega} = 0.96 V_i$$

$$\text{and } A_v = \frac{V_o}{V_i} = 0.96 \text{ vs } 0.97 \text{ above}$$

At frequencies to the right and left of f_p , the impedance Z_{T_p} will decrease and be affected less and less by the parallel 100 kΩ load. The characteristics, therefore, are only slightly affected by the 100 kΩ load.

d. At resonance

$$Z_{T_p} = 32 \text{ k}\Omega \parallel 20 \text{ k}\Omega = 12.31 \text{ k}\Omega$$

$$\text{with } V_o = \frac{12.31 \text{ k}\Omega V_i}{12.31 \text{ k}\Omega + 1 \text{ k}\Omega} = 0.925 V_i \text{ vs } 0.97 V_i \text{ above}$$

At frequencies to the right and left of f_p , the impedance of each frequency will actually be less due to the parallel 20 kΩ load. The effect will be to narrow the resonance curve and decrease the bandwidth with an increase in Q_p .

33. a. $f_p = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(400 \mu\text{H})(120 \text{ pF})}} = 726.44 \text{ kHz}$ (band-stop)

$$X_{L_s} \angle 90^\circ + (X_{L_p} \angle 90^\circ \parallel X_C \angle -90^\circ) = 0$$

$$jX_{L_s} + \frac{(X_{L_p} \angle 90^\circ)(X_C \angle -90^\circ)}{jX_{L_p} - jX_C} = 0$$

$$jX_{L_s} + \frac{X_{L_p} X_C}{j(X_{L_p} - X_C)} = 0$$

$$jX_{L_s} - j \frac{X_{L_p} X_C}{(X_{L_p} - X_C)} = 0$$

$$X_{L_s} - \frac{X_{L_p} X_C}{X_{L_p} - X_C} = 0$$

$$X_{L_s} X_C - X_{L_s} X_{L_p} + X_{L_p} X_C = 0$$

$$\frac{\omega L_s}{\omega C} - \omega L_s + \frac{\omega L_p}{\omega C} = 0$$

$$L_s L_p \omega^2 - \frac{1}{C} [L_s + L_p] = 0$$

$$\omega = \sqrt{\frac{L_s + L_p}{C L_s L_p}}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{L_s + L_p}{C L_s L_p}} = \frac{1}{2\pi} \sqrt{\frac{460 \times 10^{-6}}{28.8 \times 10^{-19}}} = \mathbf{2.01 \text{ MHz (pass-band)}}$$

34. a. $f_s = \frac{1}{2\pi\sqrt{LC}} \Rightarrow L_s = \frac{1}{4\pi^2 f_s^2 C} = \frac{1}{4\pi^2 (100 \text{ kHz})^2 (200 \text{ pF})} = 12.68 \text{ mH}$

$$X_L = 2\pi f L = 2\pi (30 \text{ kHz})(12.68 \text{ mH}) = 2388.91 \Omega$$

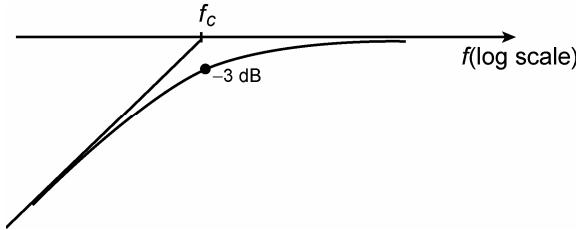
$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi (30 \text{ kHz})(200 \text{ pF})} = 26.54 \text{ k}\Omega$$

$$X_C - X_L = 26.54 \text{ k}\Omega - 2388.91 \Omega = 24.15 \text{ k}\Omega(C)$$

$$X_{L_p} = X_{C_{(\text{net})}} = 24.15 \text{ k}\Omega$$

$$L_p = \frac{X_L}{2\pi f} = \frac{24.15 \text{ k}\Omega}{2\pi (30 \text{ kHz})} = \mathbf{128.19 \text{ mH}}$$

35. a, b. $f_c = \frac{1}{2\pi R C} = \frac{1}{2\pi (0.47 \text{ k}\Omega)(0.05 \mu\text{F})} = \mathbf{772.55 \text{ Hz}}$



c. $f = \frac{1}{2} f_c: \quad A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (f_c/f)^2}} = 20 \log_{10} \frac{1}{\sqrt{1 + (2)^2}} = \mathbf{-7 \text{ dB}}$

$$f = 2f_c: \quad A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{-0.969 \text{ dB}}$$

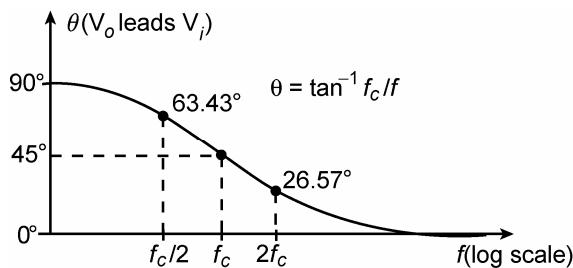
$$f = \frac{1}{10} f_c: \quad A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (10)^2}} = \mathbf{-20.04 \text{ dB}}$$

$$f = 10f_c: \quad A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (0.1)^2}} = \mathbf{-0.043 \text{ dB}}$$

d. $f = \frac{1}{2} f_c: \quad A_v = \frac{1}{\sqrt{1 + (f_c/f)^2}} = \frac{1}{\sqrt{1 + (2)^2}} = \mathbf{0.447}$

$$f = 2f_c: \quad A_v = \frac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{0.894}$$

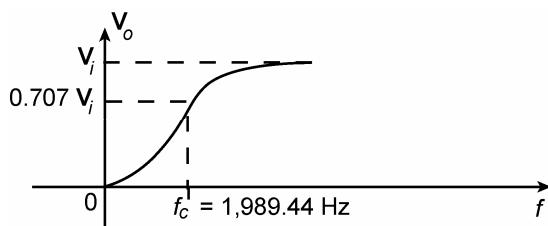
e.



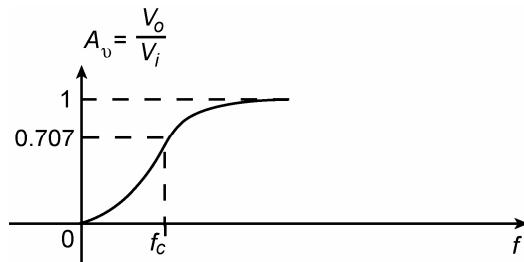
36. a. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(6\text{ k}\Omega \parallel 12\text{ k}\Omega)0.01\mu\text{F}} = \frac{1}{2\pi(4\text{ k}\Omega)(0.01\mu\text{F})} = 1989.44 \text{ Hz}$

$$\frac{V_o}{V_i} = \frac{1}{\sqrt{1 + (f_c/f)^2}}$$

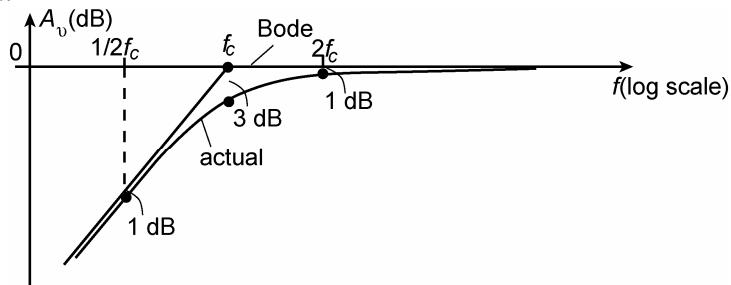
and $V_o = \left(\frac{1}{\sqrt{1 + (f_c/f)^2}} \right) V_i$



b.



c. & d.



e. Remember the log scale! $1.5f_c$ is not midway between f_c and $2f_c$

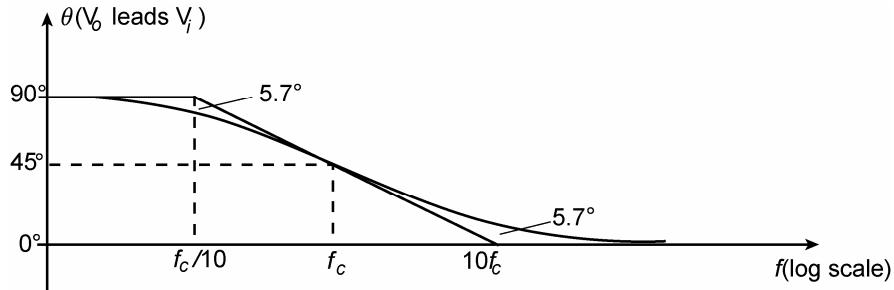
$$A_{v_{\text{dB}}} = 20 \log_{10} A_v$$

$$-1.5 = 20 \log_{10} A_v$$

$$-0.075 = \log_{10} A_v$$

$$A_v = \frac{V_o}{V_i} = \mathbf{0.84}$$

f. $\theta = \tan^{-1} f_c/f$



37. a, b. $A_v = \frac{V_o}{V_i} = A_v \angle \theta = \frac{1}{\sqrt{1 + (f/f_c)^2}} \angle -\tan^{-1} f/f_c$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(12 \text{ k}\Omega)(1 \text{ nF})} = \mathbf{13.26 \text{ kHz}}$$

c. $f = f_c/2 = 6.63 \text{ kHz}$

$$A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{-0.97 \text{ dB}}$$

$$f = 2f_c = 26.52 \text{ kHz}$$

$$A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (2)^2}} = \mathbf{-6.99 \text{ dB}}$$

$$f = f_c/10 = 1.326 \text{ kHz}$$

$$A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (0.1)^2}} = \mathbf{-0.04 \text{ dB}}$$

$$f = 10f_c = 132.6 \text{ kHz}$$

$$A_{v_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1 + (10)^2}} = \mathbf{-20.04 \text{ dB}}$$

d. $f = f_c/2: A_v = \frac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{0.894}$

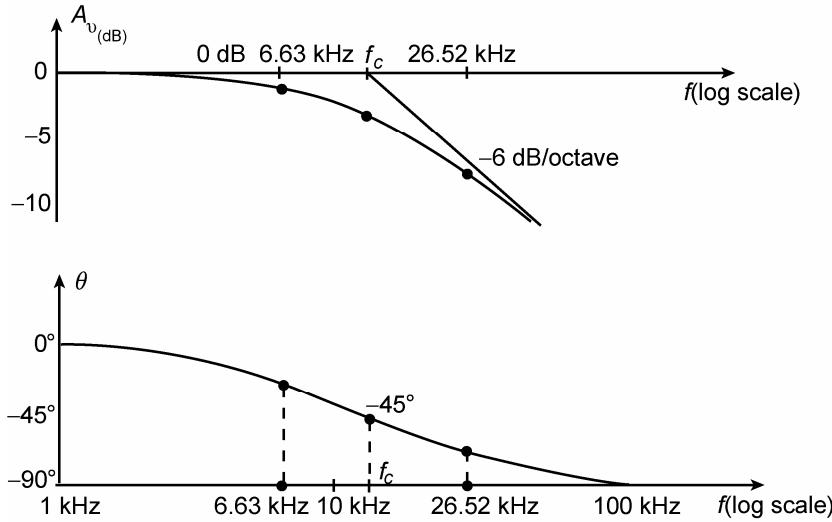
$$f = 2f_c: A_v = \frac{1}{\sqrt{1 + (2)^2}} = \mathbf{0.447}$$

e. $\theta = \tan^{-1} f/f_c$

$$f=f_c/2: \quad \theta = -\tan^{-1} 0.5 = -26.57^\circ$$

$$f=f_c: \quad \theta = -\tan^{-1} 1 = -45^\circ$$

$$f=2f_c: \quad \theta = -\tan^{-1} 2 = -63.43^\circ$$



38. a. $R_2 \parallel X_C = \frac{(R_2)(-jX_C)}{R_2 - jX_C} = -j \frac{R_2 X_C}{R_2 - jX_C}$

$$\mathbf{V}_o = \frac{\left(\frac{-jR_2 X_C}{R_2 - jX_C} \right) \mathbf{V}_i}{R_l - j \frac{R_2 X_C}{R_2 - jX_C}} = -j \frac{R_2 X_C \mathbf{V}_i}{R_l(R_2 - jX_C) - jR_2 X_C}$$

$$= \frac{-jR_2 X_C \mathbf{V}_i}{R_l R_2 - jR_l X_C - jR_2 X_C} = \frac{-jR_2 X_C \mathbf{V}_i}{R_l R_2 - j(R_l + R_2) X_C}$$

$$= \frac{R_2 X_C \mathbf{V}_i}{jR_l R_2 + (R_l + R_2) X_C} = \frac{R_2 \mathbf{V}_i}{j \frac{R_l R_2}{X_C} + (R_l + R_2)}$$

$$= \frac{R_2 \mathbf{V}_i}{R_l + R_2 + j \frac{R_l R_2}{X_C}} = \frac{\left(\frac{R_2}{R_l + R_2} \right) \mathbf{V}_i}{1 + j \left(\frac{R_l R_2}{R_l + R_2} \right) \frac{1}{X_C}}$$

$$\text{and } \mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{\frac{R_2}{R_l + R_2}}{1 + j \omega \left(\frac{R_l R_2}{R_l + R_2} \right) C}$$

$$\text{or } \mathbf{A}_v = \frac{R_2}{R_l + R_2} \left[\frac{1}{1 + j 2\pi f (R_l \parallel R_2) C} \right]$$

$$\text{defining } f_c = \frac{1}{2\pi(R_1 \parallel R_2)C}$$

$$A_v = \frac{R_2}{R_1 + R_2} \left[\frac{1}{1 + j f/f_c} \right]$$

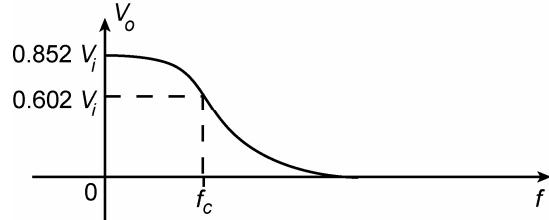
$$\text{and } A_v = \frac{R_2}{R_1 + R_2} \left[\frac{1}{\sqrt{1 + (f/f_c)^2}} \angle -\tan^{-1} f/f_c \right]$$

$$\text{with } |V_o| = \frac{R_2}{R_1 + R_2} \left[\frac{1}{\sqrt{1 + (f/f_c)^2}} \right] |V_i|$$

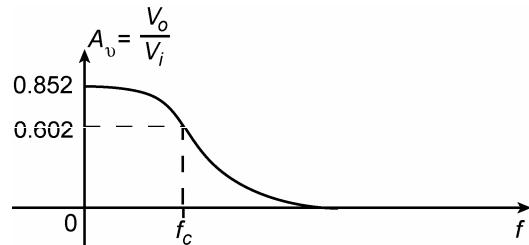
$$\text{for } f \ll f_c, V_o = \frac{R_2}{R_1 + R_2} V_i = \frac{27 \text{ k}\Omega}{4.7 \text{ k}\Omega + 27 \text{ k}\Omega} V_i = 0.852 V_i$$

$$\text{at } f = f_c: V_o = 0.852[0.707]V_i = 0.602V_i$$

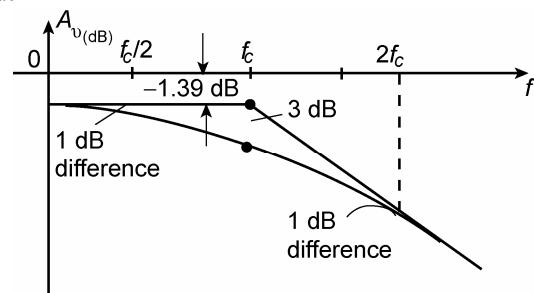
$$f_c = \frac{1}{2\pi(R_1 \parallel R_2)C} = 994.72 \text{ Hz}$$



b.



c. & d.



$$\begin{aligned} -20 \log_{10} \frac{R_1 + R_2}{R_2} &= -20 \log_{10} \frac{4.7 \text{ k}\Omega + 27 \text{ k}\Omega}{27 \text{ k}\Omega} \\ &= -20 \log_{10} 1.174 = -1.39 \text{ dB} \end{aligned}$$

e. $A_{v_{dB}} \approx -1.39 \text{ dB} - 0.5 \text{ dB} = -1.89 \text{ dB}$

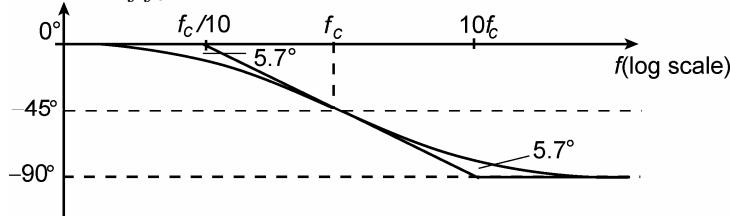
$$A_{v_{dB}} = 20 \log_{10} A_v$$

$$-1.89 = 20 \log_{10} A_v$$

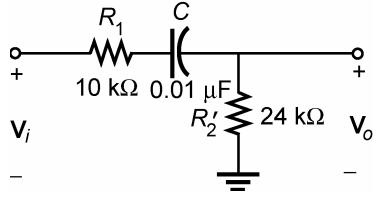
$$0.0945 = \log_{10} A_v$$

$$A_v = \frac{V_o}{V_i} = \mathbf{0.80}$$

f. $\theta = -\tan^{-1} f/f_c$



39.

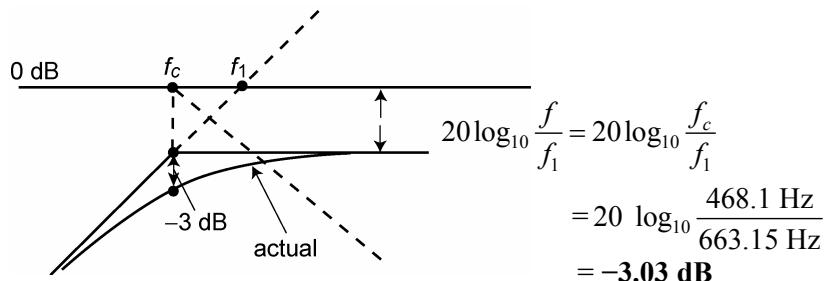


a. From Section 21.11,

$$A_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{j f/f_1}{1 + j f/f_c}$$

$$f_1 = \frac{1}{2\pi R'_2 C} = \frac{1}{2\pi(24 \text{ k}\Omega)(0.01 \mu\text{F})} = 663.15 \text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 + R'_2)C} = \frac{1}{2\pi(10 \text{ k}\Omega + 24 \text{ k}\Omega)(0.01 \mu\text{F})} = 468.1 \text{ Hz}$$



b. $\theta = 90^\circ - \tan^{-1} \frac{f}{f_1} = +\tan^{-1} \frac{f_1}{f}$

$$f = f_1: \quad \theta = 45^\circ$$

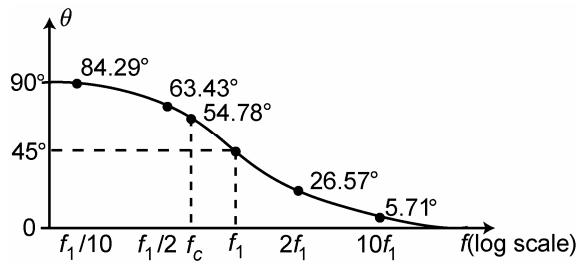
$$f = f_c: \quad \theta = 54.78^\circ$$

$$f = \frac{1}{2}f_1 = 331.58 \text{ Hz}, \theta = 63.43^\circ$$

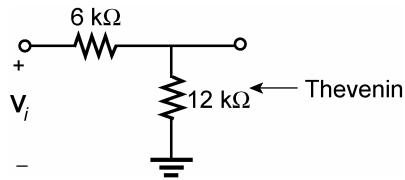
$$f = \frac{1}{10}f_1 = 66.31 \text{ Hz}, \theta = 84.29^\circ$$

$$f = 2f_1 = 1,326.3 \text{ Hz}, \theta = 26.57^\circ$$

$$f = 10f_1 = 6,631.5 \text{ Hz}, \theta = 5.71^\circ$$

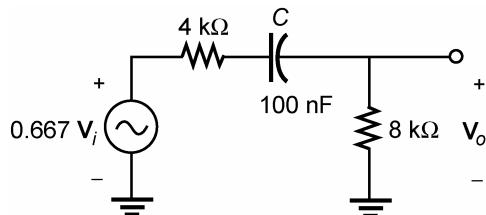


40. a.



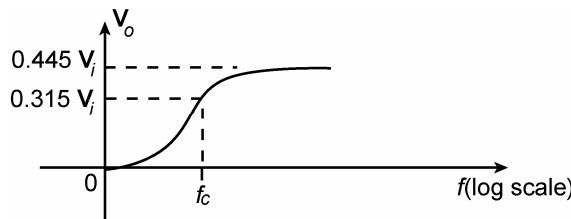
$$V_{Th} = \frac{12 \text{ k}\Omega V_i}{12 \text{ k}\Omega + 6 \text{ k}\Omega} = 0.667 V_i$$

$$R_{Th} = 6 \text{ k}\Omega \parallel 12 \text{ k}\Omega = 4 \text{ k}\Omega$$



$f = \infty \text{ Hz}: (C \Rightarrow \text{short circuit})$

$$V_o = \frac{8 \text{ k}\Omega (0.667 V_i)}{8 \text{ k}\Omega + 4 \text{ k}\Omega} = 0.445 V_i$$

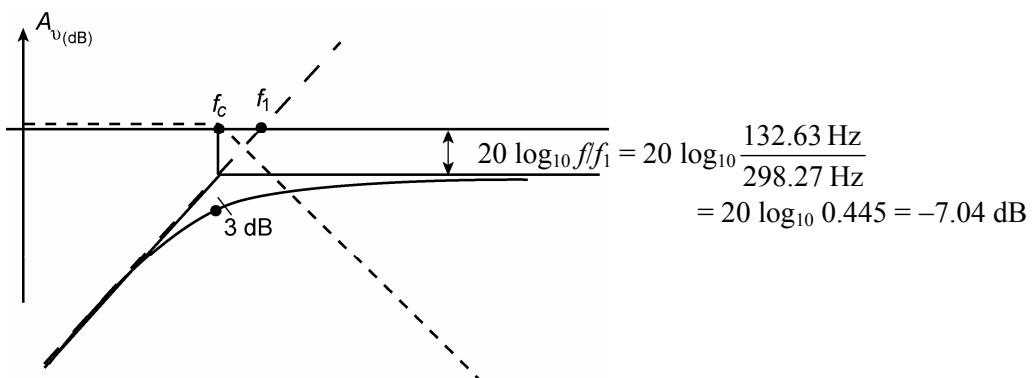


$$\text{voltage-divider rule: } \mathbf{V}_o = \frac{R_2(0.667 \mathbf{V}_i)}{R_1 + R_2 - jX_C} = \frac{0.667 R_2 \mathbf{V}_i}{R_1 + R_2 - jX_C}$$

$$\text{and } \mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{0.667 R_2}{R_1 + R_2 - jX_C} = \frac{j2\pi f(0.667 R_2)C}{1 + j2\pi f(R_1 + R_2)C}$$

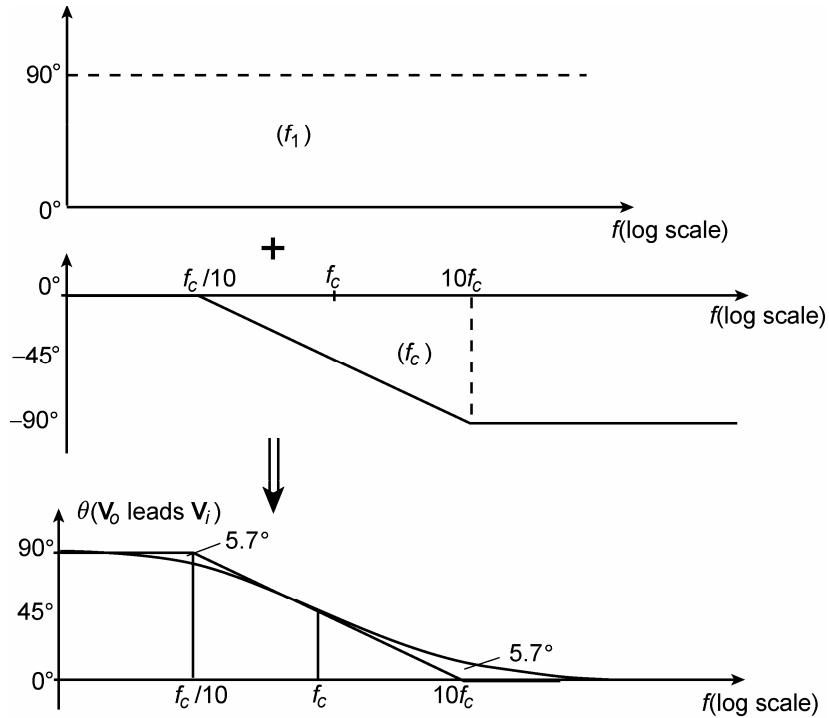
$$\text{so that } \mathbf{A}_v = \frac{j f/f_1}{1 + j f/f_c} \text{ with } f_1 = \frac{1}{2\pi 0.667 R_2 C} = \frac{1}{2\pi 0.667 (8 \text{ k}\Omega)(100 \text{ nF})} \\ = 298.27 \text{ Hz}$$

$$\text{and } f_c = \frac{1}{2\pi(R_1 + R_2)C} = \frac{1}{2\pi(4 \text{ k}\Omega + 8 \text{ k}\Omega)(100 \text{ nF})} \\ = 132.63 \text{ Hz}$$



b. $\theta = 90^\circ - \tan^{-1} f/f_c = +\tan^{-1} f_c/f = \tan^{-1} 132.6 \text{ Hz}/f$

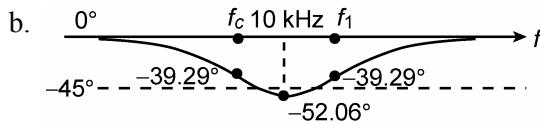
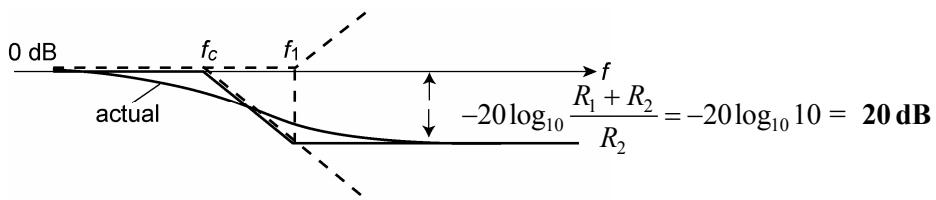
or



41. a. $\mathbf{A}_v = \frac{1 + j \frac{f}{f_1}}{1 + j \frac{f}{f_c}}$

$$f_1 = \frac{1}{2\pi R_2 C} = \frac{1}{2\pi(10 \text{ k}\Omega)(800 \text{ pF})} = 19,894.37 \text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 + R_2)C} = \frac{1}{2\pi(10 \text{ k}\Omega + 90 \text{ k}\Omega)(800 \text{ pF})} = 1,989.44 \text{ Hz}$$



$$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$$

$$f = 10 \text{ kHz}$$

$$\theta = \tan^{-1} \frac{10 \text{ kHz}}{19.89 \text{ kHz}} - \tan^{-1} \frac{10 \text{ kHz}}{1.989 \text{ kHz}} = 26.69^\circ - 78.75^\circ = -52.06^\circ$$

$$f = f_c: (f_1 = 10 f_c)$$

$$\theta = \tan^{-1} \frac{f_c}{10 f_c} - \tan^{-1} \frac{f_c}{f_c} = \tan^{-1} 0.1 \tan^{-1} 1 = 5.71^\circ - 45^\circ = -39.29^\circ$$

42. a. R_1 no effect!
Note Section 21.12.

$$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1 + j(f/f_1)}{1 + j(f/f_c)}$$

$$f_1 = \frac{1}{2\pi(6 \text{ k}\Omega)(0.01 \mu\text{F})} = 2652.58 \text{ Hz}$$

$$f_c = \frac{1}{2\pi(12 \text{ k}\Omega + 6 \text{ k}\Omega)(0.01 \mu\text{F})} = 884.19 \text{ Hz}$$

Note Fig. 21.65.

Asymptote at 0 dB from $0 \rightarrow f_c$
 -6 dB/octave from f_c to f_1
 -9.54 dB from f_1 on $\left(-20 \log \frac{12 \text{ k}\Omega + 6 \text{ k}\Omega}{6 \text{ k}\Omega} = -9.54 \text{ dB} \right)$

(b) Note Fig. 21.67.

From 0° to -26.50° at f_c and f_1

$$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$$

At $f = 1500$ Hz (between f_c and f_1)

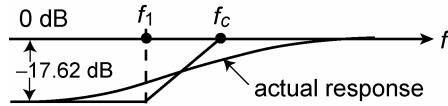
$$\theta = \tan^{-1} 1500 \text{ Hz}/2652.58 \text{ Hz} - \tan^{-1} 1500 \text{ Hz}/884.19 \text{ Hz} \\ = 29.49^\circ - 59.48^\circ = -30^\circ$$

43. a. $\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1 - jf_1/f}{1 - jf_c/f}$

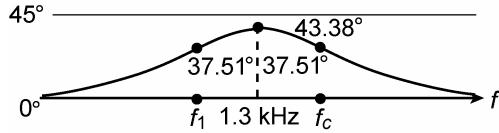
$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3 \text{ k}\Omega)(0.05 \mu\text{F})} = 964.58 \text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \parallel R_2)C} = \frac{1}{2\pi \underbrace{(3.3 \text{ k}\Omega \parallel 0.5 \text{ k}\Omega)}_{0.434 \text{ k}\Omega}(0.05 \mu\text{F})} = 7,334.33 \text{ Hz}$$

$$-20 \log_{10} \frac{R_1 + R_2}{R_2} = -20 \log_{10} \frac{3.3 \text{ k}\Omega + 0.5 \text{ k}\Omega}{0.5 \text{ k}\Omega} = -20 \log_{10} 7.6 = -17.62 \text{ dB}$$



b.



$$\theta = -\tan^{-1} \frac{f_1}{f} + \tan^{-1} \frac{f_c}{f}$$

$$f = 1.3 \text{ kHz}: \quad \theta = -\tan^{-1} \frac{964.58 \text{ kHz}}{1.3 \text{ kHz}} + \tan^{-1} \frac{7334.33 \text{ Hz}}{1.3 \text{ kHz}} \\ = -36.57^\circ + 79.95^\circ = 43.38^\circ$$

44. a. Note Section 21.13.

$$\mathbf{A}_v = \frac{1 - j(f_1/f)}{1 - j(f_c/f)}$$

$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3 \text{ k}\Omega)(0.05 \mu\text{F})} = 964.58 \text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \parallel R_2)C} = \frac{1}{2\pi \underbrace{(3.3 \text{ k}\Omega \parallel 0.5 \text{ k}\Omega)}_{0.434 \text{ k}\Omega} 0.05 \mu\text{F}} = 7334.33 \text{ Hz}$$

Note Fig. 21.72.

$$-20 \log_{10} \frac{R_1 + R_2}{R_2} = -20 \log_{10} \frac{3.3 \text{ k}\Omega + 0.5 \text{ k}\Omega}{0.5 \text{ k}\Omega} = -17.62 \text{ dB}$$

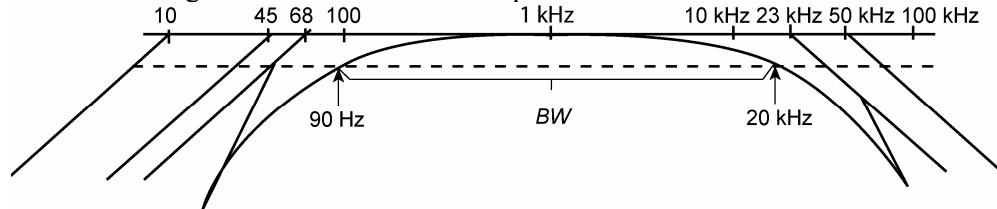
Asymptote at -17.62 dB from $0 \rightarrow f_1$
 $+6 \text{ dB/octave}$ from f_1 to f_c
 0 dB from f_c on

b. $\theta = -\tan^{-1} f_1/f + \tan^{-1} f_c/f$

Test at 3 kHz

$$\begin{aligned} \theta &= -\tan^{-1} 964.58 \text{ Hz}/3.0 \text{ kHz} + \tan^{-1} 7334.33 \text{ Hz}/3.0 \text{ kHz} \\ &= -17.82^\circ + 67.75^\circ = 49.93^\circ \approx 50^\circ \end{aligned}$$

Therefore rising above 45° at and near the peak



50 kHz vs 23 kHz \rightarrow drop about 1 dB at 23 kHz due to 50 kHz break.

Ignore effect of break frequency at 10 Hz.

Assume -2 dB drop at 68 Hz due to break frequency at 45 Hz.

Rough sketch suggests low cut-off frequency of 90 Hz.

Checking: Ignoring upper terms

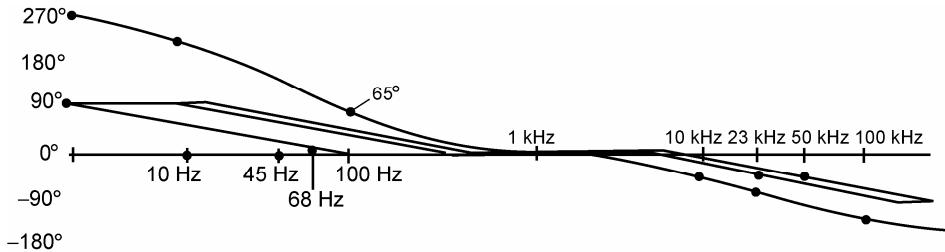
$$\begin{aligned} A'_{\text{vdB}} &= -20 \log_{10} \sqrt{1 + \left(\frac{10 \text{ Hz}}{f} \right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{45 \text{ Hz}}{f} \right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{68 \text{ Hz}}{f} \right)^2} \\ &= -0.0532 \text{ dB} - 0.969 \text{ dB} - 1.96 \text{ dB} \\ &= -2.98 \text{ dB} \quad (\text{excellent}) \end{aligned}$$

High frequency cutoff: Try 20 kHz

$$\begin{aligned} A'_{\text{vdB}} &= -20 \log_{10} \sqrt{1 + \left(\frac{f}{23 \text{ kHz}} \right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{f}{50 \text{ kHz}} \right)^2} \\ &= -2.445 \text{ dB} - 0.6445 \text{ dB} \\ &= -3.09 \text{ dB} \quad (\text{excellent}) \end{aligned}$$

$$\therefore BW = 20 \text{ kHz} - 90 \text{ Hz} = 19,910 \text{ Hz} \approx 20 \text{ kHz}$$

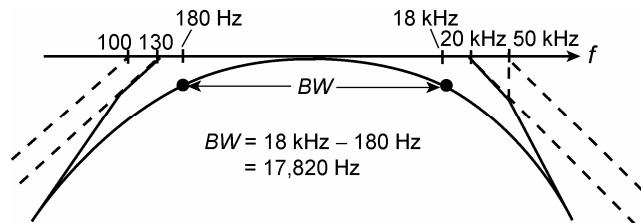
$$f_1 = 90 \text{ Hz}, f_2 = 20 \text{ kHz}$$



Testing: $f = 100 \text{ Hz}$

$$\begin{aligned}\theta &= \tan^{-1} \frac{10 \text{ Hz}}{f} + \tan^{-1} \frac{45 \text{ Hz}}{f} + \tan^{-1} \frac{68 \text{ Hz}}{f} - \tan^{-1} \frac{f}{23 \text{ kHz}} - \tan^{-1} \frac{f}{50 \text{ kHz}} \\ &= \tan^{-1} 0.1 + \tan^{-1} 0.45 + \tan^{-1} 0.68 - \tan^{-1} 0.00435 - \tan^{-1} 0.002 \\ &= 5.71^\circ + 24.23^\circ + 34.22^\circ - 0.249^\circ - 0.115^\circ \\ &= \mathbf{63.8^\circ} \text{ vs about } 65^\circ \text{ on the plot}\end{aligned}$$

45. a. $\frac{A_v}{A_{v_{\max}}} = \frac{1}{\left(1 - j \frac{100 \text{ Hz}}{f}\right) \left(1 - j \frac{130 \text{ Hz}}{f}\right) \left(1 + j \frac{f}{20 \text{ kHz}}\right) \left(1 + j \frac{f}{50 \text{ kHz}}\right)}$



Proximity of 100 Hz to 130 Hz will raise lower cutoff frequency above 130 Hz:

Testing: $f = 180 \text{ Hz}$: (with lower terms only)

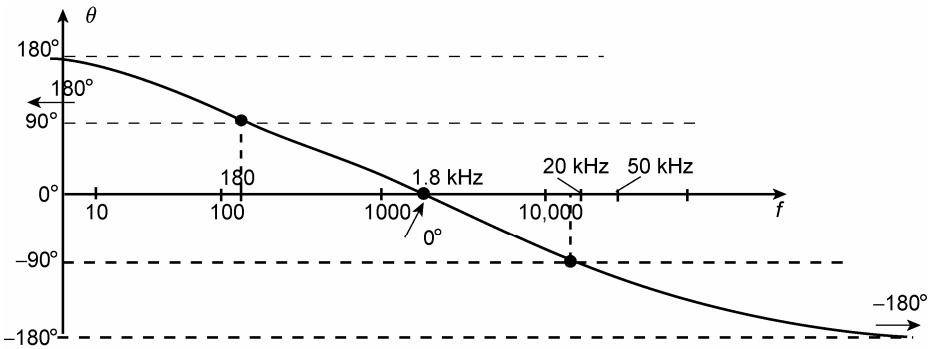
$$\begin{aligned}A_{v_{\text{dB}}} &= -20 \log_{10} \sqrt{1 + \left(\frac{100}{f}\right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{130}{f}\right)^2} \\ &= -20 \log_{10} \sqrt{1 + \left(\frac{100}{180}\right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{130}{180}\right)^2} \\ &= 1.17 \text{ dB} - 1.82 \text{ dB} = \mathbf{-2.99 \text{ dB}} \approx -3 \text{ dB}\end{aligned}$$

Proximity of 50 kHz to 20 kHz will lower high cutoff frequency below 20 kHz:

Testing: $f = 18 \text{ kHz}$: (with upper terms only)

$$\begin{aligned}A_{v_{\text{dB}}} &= -20 \log_{10} \sqrt{1 + \left(\frac{f}{20 \text{ kHz}}\right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{f}{50 \text{ kHz}}\right)^2} \\ &= -20 \log_{10} \sqrt{1 + \left(\frac{18 \text{ kHz}}{20 \text{ kHz}}\right)^2} - 20 \log_{10} \sqrt{1 + \left(\frac{13 \text{ kHz}}{20 \text{ kHz}}\right)^2} \\ &= -2.576 \text{ dB} - 0.529 \text{ dB} = \mathbf{-3.105 \text{ dB}}\end{aligned}$$

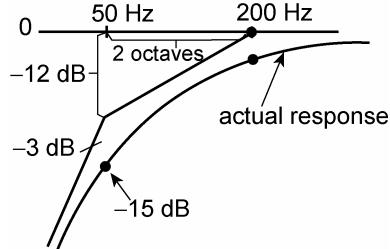
b.

Testing: $f = 1.8 \text{ kHz}$:

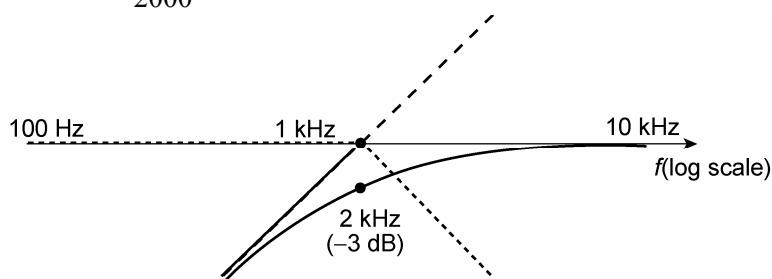
$$\begin{aligned}\theta &= \tan^{-1} \frac{100}{1.8 \text{ kHz}} + \tan^{-1} \frac{130}{1.8 \text{ kHz}} - \tan^{-1} \frac{1.8 \text{ kHz}}{20 \text{ kHz}} - \tan^{-1} \frac{1.8 \text{ kHz}}{50 \text{ kHz}} \\ &= 3.18^\circ + 4.14^\circ - 5.14^\circ - 2.06^\circ \\ &= \mathbf{0.12^\circ \cong 0^\circ}\end{aligned}$$

47. $f_{\text{low}} = f_{\text{high}} - BW = 36 \text{ kHz} - 35.8 \text{ kHz} = 0.2 \text{ kHz} = 200 \text{ Hz}$

$$A_v = \frac{-120}{\left(1 - j \frac{50}{f}\right) \left(1 - j \frac{200}{f}\right) \left(1 + j \frac{f}{36 \text{ kHz}}\right)}$$

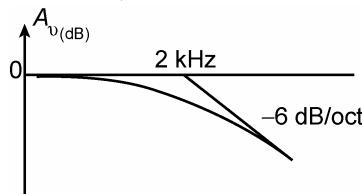


$$\begin{aligned}48. \quad A_v &= \frac{0.05}{0.05 - j \frac{100}{f}} = \frac{1}{1 - j \frac{100}{0.05 f}} = \frac{1}{1 - j \frac{2000}{f}} = \frac{+jf}{+jf + 2000} \\ &= \frac{+j \frac{f}{2000}}{1 + j \frac{f}{2000}} \text{ and } f_l = 2000 \text{ Hz}\end{aligned}$$

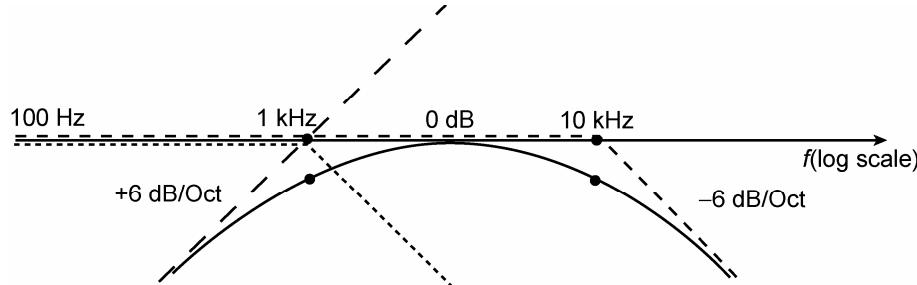


$$49. \quad A_v = \frac{200}{200 + j0.1f} = \frac{1}{1 + j\frac{0.1f}{200}} = \frac{1}{1 + j\frac{f}{2000}}$$

$$A_{v_{dB}} = 20 \log_{20} \frac{1}{\sqrt{1 + \left(\frac{f}{2000}\right)^2}}, \quad \frac{f}{2000} = 1 \text{ and } f = 2 \text{ kHz}$$

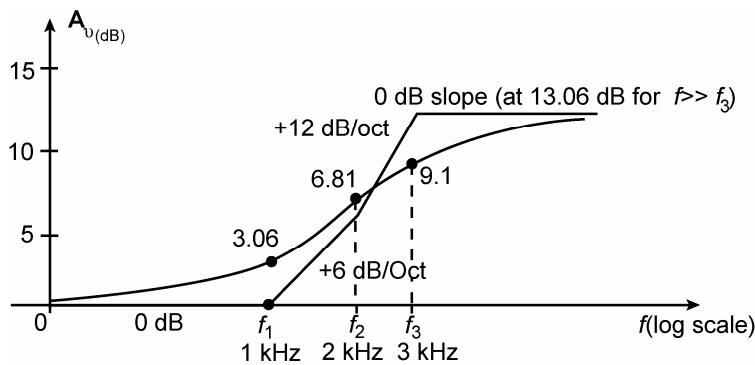


$$50. \quad A_v = \frac{jf/1000}{(1 + jf/1000)(1 + jf/10,000)}$$

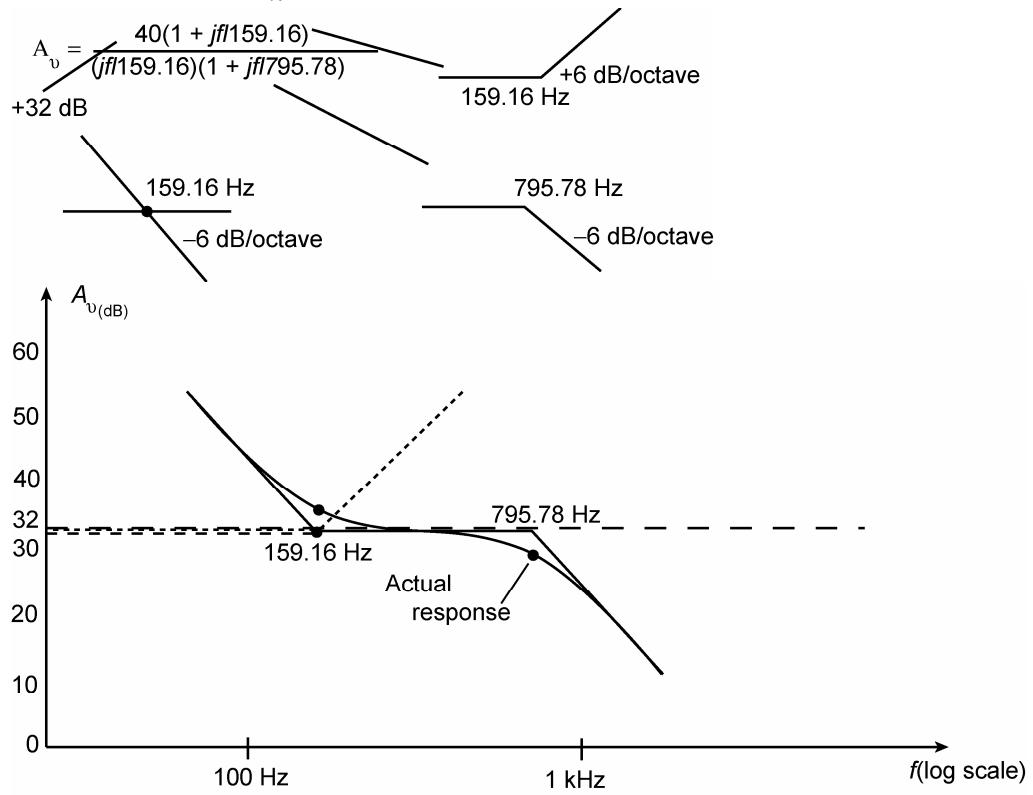


$$51. \quad A_v = \frac{\left(1 + j\frac{f}{1000}\right)\left(1 + j\frac{f}{2000}\right)}{\left(1 + j\frac{f}{3000}\right)^2}$$

$$A_{v_{dB}} = 20 \log_{10} \sqrt{1 + \left(\frac{f_1}{1000}\right)^2} + 20 \log_{10} \sqrt{1 + \left(\frac{f_2}{2000}\right)^2} + 40 \log_{10} \frac{1}{\sqrt{1 + \left(\frac{f_3}{3000}\right)^2}}$$



52. $\frac{j\omega}{1000} = j \frac{2\pi f}{1000} = j \frac{f}{\frac{1000}{2\pi}} = j \frac{f}{159.16 \text{ Hz}}$, $\frac{j\omega}{5000} = j \frac{f}{\frac{5000}{2\pi}} = j \frac{f}{795.78 \text{ Hz}}$



53. a. Woofer – 400 Hz:

$$X_L = 2\pi fL = 2\pi(400 \text{ Hz})(4.7 \text{ mH}) = 11.81 \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(400 \text{ Hz})(39 \mu\text{F})} = 10.20 \Omega$$

$$R \parallel X_C = 8 \Omega \angle 0^\circ \parallel 10.20 \angle -90^\circ = 6.3 \Omega \angle -38.11^\circ$$

$$\mathbf{V}_o = \frac{(R \parallel X_C)(\mathbf{V}_i)}{(R \parallel X_C) + jX_L} = \frac{(6.3 \Omega \angle -38.11^\circ)(\mathbf{V}_i)}{(6.3 \Omega \angle -38.11^\circ) + j11.81 \Omega}$$

$$\mathbf{V}_o = 0.673 \angle -96.11^\circ \mathbf{V}_i$$

$$\text{and } A_v = \frac{V_o}{V_i} = 0.673 \text{ vs desired } 0.707 \text{ (off by less than 5%)}$$

Tweeter – 5 kHz:

$$X_L = 2\pi fL = 2\pi(5 \text{ kHz})(0.39 \text{ mH}) = 12.25 \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(5 \text{ kHz})(2.7 \mu\text{F})} = 11.79 \Omega$$

$$R \parallel X_L = 8 \Omega \angle 0^\circ \parallel 12.25 \Omega \angle 90^\circ = 6.7 \Omega \angle 33.15^\circ$$

$$\mathbf{V}_o = \frac{(6.7 \Omega \angle 33.15^\circ)(\mathbf{V}_i)}{(6.7 \Omega \angle 33.15^\circ) - j11.79 \Omega}$$

$$\mathbf{V}_o = 0.678 \angle 88.54^\circ \mathbf{V}_i$$

and $A_v = \frac{V_o}{V_i} = \mathbf{0.678}$ vs 0.707 (off by less than 5%)

b. Woofer – 3 kHz:

$$X_L = 2\pi fL = 2\pi(3 \text{ kHz})(4.7 \text{ mH}) = 88.59 \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3 \text{ kHz})(39 \mu\text{F})} = 1.36 \Omega$$

$$R \parallel X_C = 8 \Omega \angle 0^\circ \parallel 1.36 \Omega \angle -90^\circ = 1.341 \Omega \angle -80.35^\circ$$

$$\mathbf{V}_o = \frac{(R \parallel X_C)(\mathbf{V}_i)}{(R \parallel X_C) + jX_L} = \frac{(1.341 \Omega \angle -80.35^\circ)(\mathbf{V}_i)}{(1.341 \Omega \angle -80.35^\circ) + j88.59 \Omega}$$

$$\mathbf{V}_o = 0.015 \angle -170.2^\circ \mathbf{V}_i$$

and $A_v = \frac{V_o}{V_i} = \mathbf{0.015}$ vs desired 0 (excellent)

Tweeter – 3 kHz:

$$X_L = 2\pi fL = 2\pi(3 \text{ kHz})(0.39 \text{ mH}) = 7.35 \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3 \text{ kHz})(2.7 \mu\text{F})} = 19.65 \Omega$$

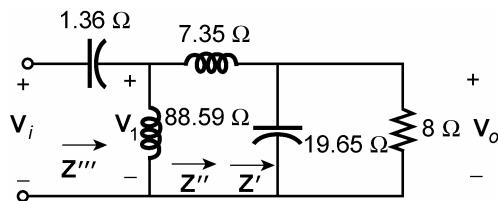
$$R \parallel X_L = 8 \Omega \angle 0^\circ \parallel 7.35 \Omega \angle 90^\circ = 5.42 \Omega \angle 47.42^\circ$$

$$\mathbf{V}_o = \frac{(R \parallel X_L)(\mathbf{V}_i)}{(R \parallel X_L) + jX_C} = \frac{(5.42 \Omega \angle 47.42^\circ)(\mathbf{V}_i)}{(5.42 \Omega \angle 47.42^\circ) - j19.65 \Omega}$$

$$\mathbf{V}_o = 0.337 \angle 124.24^\circ \mathbf{V}_i$$

and $A_v = \frac{V_o}{V_i} = \mathbf{0.337}$ (acceptable since relatively close to cut frequency for tweeter)

c. Mid-range speaker – 3 kHz:



$$\mathbf{Z}' = \overbrace{7.41 \Omega}^{\text{impedance}} \angle -22.15^\circ$$

$$\mathbf{Z}'' = \overbrace{8.24 \Omega}^{\text{impedance}} \angle 33.58^\circ$$

$$\mathbf{Z}''' = \overbrace{7.816 \Omega}^{\text{impedance}} \angle 37.79^\circ$$

$$\mathbf{V}_1 = \frac{\mathbf{Z}''' \mathbf{V}_i}{\mathbf{Z}''' - jX_C} = \frac{(7.816 \Omega \angle 37.79^\circ) \mathbf{V}_i}{7.816 \Omega \angle 37.79^\circ - j1.36 \Omega} = 1.11 \angle 8.83^\circ \mathbf{V}_i$$

$$\mathbf{V}_o = \frac{\mathbf{Z}' \mathbf{V}_1}{\mathbf{Z}' + jX_L} = \frac{(7.41 \Omega \angle -22.15^\circ) \mathbf{V}_i}{7.41 \Omega \angle -22.15^\circ + j7.35 \Omega} = 0.998 \angle -46.9^\circ \mathbf{V}_i$$

and $A_v = \frac{V_o}{V_i} = \mathbf{0.998}$ (excellent)

Chapter 22

1. a. $M = k\sqrt{L_p L_s} \Rightarrow L_s = \frac{M^2}{L_p k^2} = \frac{(80 \text{ mH})^2}{(50 \text{ mH})(0.8)^2} = 0.2 \text{ H}$

b. $e_p = N_p \frac{d\phi_p}{dt} = (20)(0.08 \text{ Wb/s}) = 1.6 \text{ V}$

$$e_s = kN_s \frac{d\phi_p}{dt} = (0.8)(80 \text{ t})(0.08 \text{ Wb/s}) = 5.12 \text{ V}$$

c. $e_p = L_p \frac{di_p}{dt} = (50 \text{ mH})(0.03 \times 10^3 \text{ A/s}) = 15 \text{ V}$

$$e_s = M \frac{di_p}{dt} = (80 \text{ mH})(0.03 \times 10^3 \text{ A/s}) = 24 \text{ V}$$

2. a. $k = 1$

(a) $L_s = \frac{M^2}{L_p k^2} = \frac{(80 \text{ mH})^2}{(50 \text{ mH})(1)^2} = 128 \text{ mH}$

(b) $e_p = 1.6 \text{ V}, e_s = kN_s \frac{d\phi_p}{dt} = (1)(80 \text{ t})(0.08 \text{ Wb/s}) = 6.4 \text{ V}$

(c) $e_p = 15 \text{ V}, e_s = 24 \text{ V}$

b. $k = 0.2$

(a) $L_s = \frac{M^2}{L_p k^2} = \frac{(80 \text{ mH})^2}{(50 \text{ mH})(0.2)^2} = 3.2 \text{ H}$

(b) $e_p = 1.6 \text{ V}, e_s = kN_s \frac{d\phi_p}{dt} = (0.2)(80 \text{ t})(0.08 \text{ Wb/s}) = 1.28 \text{ V}$

(c) $e_p = 15 \text{ V}, e_s = 24 \text{ V}$

3. a. $L_s = \frac{M^2}{L_p k^2} = \frac{(80 \text{ mH})^2}{(50 \text{ mH})(0.9)^2} = 158.02 \text{ mH}$

b. $e_p = N_p \frac{d\phi_p}{dt} = (300 \text{ t})(0.08 \text{ Wb/s}) = 24 \text{ V}$

$$e_s = kN_s \frac{d\phi_p}{dt} = (0.9)(25 \text{ t})(0.08 \text{ Wb/s}) = 1.8 \text{ V}$$

c. e_p and e_s the same as problem 1: $e_p = 15 \text{ V}, e_s = 24 \text{ V}$

4. a. $E_s = \frac{N_s}{N_p} E_p = \frac{64 \text{ t}}{8 \text{ t}} (25 \text{ V}) = \mathbf{200 \text{ V}}$

b. $\Phi_{\max} = \frac{E_p}{4.4fN_p} = \frac{25 \text{ V}}{4.4(60 \text{ Hz})(8 \text{ t})} = \mathbf{11.73 \text{ mWb}}$

5. a. $E_s = \frac{N_s}{N_p} E_p = \frac{30 \text{ t}}{240 \text{ t}} (25 \text{ V}) = \mathbf{3.13 \text{ V}}$

b. $\Phi_{m(\max)} = \frac{E_p}{4.44 f N_p} = \frac{25 \text{ V}}{(4.44)(60 \text{ Hz})(240 \text{ t})} = \mathbf{391.02 \mu\text{Wb}}$

6. $E_p = \frac{N_p}{N_s} E_s = \frac{60 \text{ t}}{720 \text{ t}} (240 \text{ V}) = \mathbf{20 \text{ V}}$

7. $f = \frac{E_p}{(4.44)N_p \Phi_{m(\max)}} = \frac{25 \text{ V}}{(4.44)(8 \text{ t})(12.5 \text{ mWb})} = \mathbf{56.31 \text{ Hz}}$

8. a. $I_L = a I_p = \left(\frac{1}{5}\right) (2 \text{ A}) = \mathbf{0.4 \text{ A}}$
 $V_L = I_L Z_L = \left(\frac{2}{5} \text{ A}\right) (2 \Omega) = \mathbf{0.8 \text{ V}}$

b. $Z_{\text{in}} = a^2 Z_L = \left(\frac{1}{5}\right)^2 2 \Omega = \mathbf{0.08 \Omega}$

9. $Z_p = \frac{V_g}{I_p} = \frac{1600 \text{ V}}{4 \text{ A}} = \mathbf{400 \Omega}$

10. $V_g = a V_L = \left(\frac{1}{4}\right) (1200 \text{ V}) = \mathbf{300 \text{ V}}$

$I_p = \frac{V_g}{Z_i} = \frac{300 \text{ V}}{4 \Omega} = \mathbf{75 \text{ A}}$

11. $I_L = I_s = \frac{V_L}{Z_L} = \frac{240 \text{ V}}{20 \Omega} = 12 \text{ A}$

$\frac{I_s}{I_p} = a = \frac{N_p}{N_s} \Rightarrow \frac{12 \text{ A}}{0.05 \text{ A}} = \frac{N_p}{50}$

$N_p = \frac{50(12)}{0.05} = \mathbf{12,000 \text{ turns}}$

12. a. $a = \frac{N_p}{N_s} = \frac{400 \text{ t}}{1200 \text{ t}} = \frac{1}{3}$

$$Z_i = a^2 Z_L = \left(\frac{1}{3}\right)^2 [9 \Omega + j12 \Omega] = 1 \Omega + j1.333 \Omega = 1.667 \Omega \angle 53.13^\circ$$

$$I_p = V_g/Z_i = 100 \text{ V}/1.667 \Omega = 60 \text{ A}$$

b. $I_L = aI_p = \frac{1}{3} (60 \text{ A}) = 20 \text{ A}, V_L = I_L Z_L = (20 \text{ A})(15 \Omega) = 300 \text{ V}$

13. a. $Z_p = a^2 Z_L \Rightarrow a = \sqrt{\frac{Z_p}{Z_L}}$

$$Z_p = \frac{V_p}{I_p} = \frac{10 \text{ V}}{20 \text{ V}/72 \Omega} = 36 \Omega$$

$$a = \sqrt{\frac{36 \Omega}{4 \Omega}} = 3$$

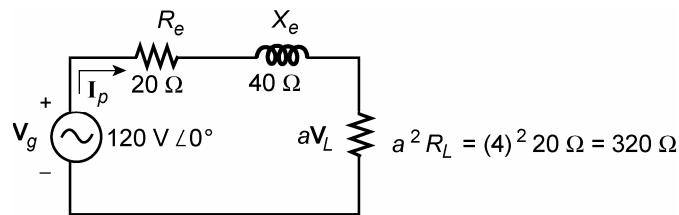
b. $\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{1}{3} \Rightarrow V_s = \frac{1}{3} V_p = \frac{1}{3} (10 \text{ V}) = 3 \frac{1}{3} \text{ V}$

$$P = \frac{V_s^2}{Z_s} = \frac{(3.33 \text{ V})^2}{4 \Omega} = 2.78 \text{ W}$$

14. a. $R_e = R_p + a^2 R_s = 4 \Omega + (4)^2 1 \Omega = 20 \Omega$

b. $X_e = X_p + a^2 X_s = 8 \Omega + (4)^2 2 \Omega = 40 \Omega$

c.



d. $\mathbf{I}_p = \frac{\mathbf{V}_g}{\mathbf{Z}_p} = \frac{120 \text{ V} \angle 0^\circ}{20 \Omega + 320 \Omega + j40 \Omega} = \frac{120 \text{ V} \angle 0^\circ}{340 \Omega + j40 \Omega} = 0.351 \text{ A} \angle -6.71^\circ$

e. $aV_L = \frac{a^2 R_L V_g}{(R_e + a^2 R_L) + jX_e} = \mathbf{I}_p a^2 R_L$
 or $\mathbf{V}_L = a\mathbf{I}_p R_L \angle 0^\circ = (4)(0.351 \text{ A} \angle -6.71^\circ)(20 \Omega \angle 0^\circ) = 28.1 \text{ V} \angle -6.71^\circ$

f. —

g. $V_L = \frac{N_s}{N_p} V_g = \frac{1}{4} (120 \text{ V}) = 30 \text{ V}$

15. a. $a = \frac{N_p}{N_s} = \frac{4 \text{ t}}{1 \text{ t}} = 4$
 $R_e = R_p + a^2 R_s = 4 \Omega + (4)^2 1 \Omega = 20 \Omega$
 $X_e = X_p + a^2 X_s = 8 \Omega + (4)^2 2 \Omega = 40 \Omega$
 $\mathbf{Z}_p = \mathbf{Z}_{R_e} + \mathbf{Z}_{X_e} + a^2 \mathbf{Z}_{X_L} = 20 \Omega + j40 \Omega + j(4)^2 20 \Omega$
 $= 20 \Omega + j40 \Omega + j320 \Omega = 20 \Omega + j360 \Omega = \mathbf{360.56 \Omega \angle 86.82^\circ}$

b. $\mathbf{I}_p = \frac{\mathbf{V}_g}{\mathbf{Z}_p} = \frac{120 \text{ V} \angle 0^\circ}{360.56 \Omega \angle 86.82^\circ} = 332.82 \text{ mA} \angle -86.82^\circ$

c. $\mathbf{V}_{R_e} = (I \angle 0^\circ)(R_e \angle 0^\circ) = (332.82 \text{ mA} \angle -86.82^\circ)(20 \Omega \angle 0^\circ)$
 $= \mathbf{6.66 \text{ V} \angle -86.82^\circ}$

$$\mathbf{V}_{X_e} = (I \angle 0^\circ)(X_e \angle 90^\circ) = (332.82 \text{ mA} \angle -86.82^\circ)(40 \Omega \angle 90^\circ)$$

$$= \mathbf{13.31 \text{ V} \angle 3.18^\circ}$$

$$\mathbf{V}_{X_L} = \mathbf{I}(a^2 Z_{X_L}) = (332.82 \text{ mA} \angle -86.82^\circ)(320 \Omega \angle 90^\circ)$$

$$= \mathbf{106.50 \text{ V} \angle 3.18^\circ}$$

16. a. $a = N_p/N_s = 4 \text{ t}/1 \text{ t} = 4, R_e = R_p + a^2 R_s = 4 \Omega + (4)^2 1 \Omega = 20 \Omega$
 $X_e = X_p + a^2 X_s = 8 \Omega + (4)^2 2 \Omega = 40 \Omega$
 $\mathbf{Z}_p = R_e + jX_e - ja^2 X_C = 20 \Omega + j40 \Omega - j(4)^2 20 \Omega$
 $= 20 \Omega - j280 \Omega = \mathbf{280.71 \Omega \angle -85.91^\circ}$

b. $\mathbf{I}_p = \frac{\mathbf{V}_g}{\mathbf{Z}_p} = \frac{120 \text{ V} \angle 0^\circ}{280.71 \Omega \angle -85.91^\circ} = \mathbf{0.43 \text{ A} \angle 85.91^\circ}$

c. $\mathbf{V}_{R_e} = (I_p \angle 0^\circ)(R_e \angle 0^\circ) = (0.427 \text{ A} \angle 85.91^\circ)(20 \Omega \angle 0^\circ) = \mathbf{8.54 \text{ V} \angle 85.91^\circ}$
 $\mathbf{V}_{X_e} = (I_p \angle 0^\circ)(X_e \angle 90^\circ) = (0.427 \text{ A} \angle 85.91^\circ)(40 \Omega \angle 90^\circ) = \mathbf{17.08 \text{ V} \angle 175.91^\circ}$
 $\mathbf{V}_{X_C} = (I_p \angle 0^\circ)(a^2 X_C \angle -90^\circ) = (0.427 \text{ A} \angle 85.91^\circ)(320 \Omega \angle -90^\circ) = \mathbf{136.64 \text{ V} \angle -4.09^\circ}$

17. —

18. Coil 1: $L_1 - M_{12}$
 Coil 2: $L_2 - M_{12}$
 $L_T = L_1 + L_2 - 2M_{12} = 4 \text{ H} + 7 \text{ H} - 2(1 \text{ H}) = \mathbf{9 \text{ H}}$

19. $L_{T_{(+)}} = L_1 + L_2 + 2M_{12}$
 $M_{12} = k\sqrt{L_1 L_2} = (0.8)\sqrt{(200 \text{ mH})(600 \text{ mH})} = \mathbf{277 \text{ mH}}$
 $L_{T_{(+)}} = 200 \text{ mH} + 600 \text{ mH} + 2(277 \text{ mH}) = \mathbf{1.35 \text{ H}}$

20. $M_{23} = k\sqrt{L_2 L_3} = 1\sqrt{(1 \text{ H})(4 \text{ H})} = 2 \text{ H}$
 Coil 1: $L_1 + M_{12} - M_{13} = 2 \text{ H} + 0.2 \text{ H} - 0.1 \text{ H} = 2.1 \text{ H}$
 Coil 2: $L_2 + M_{12} - M_{23} = 1 \text{ H} + 0.2 \text{ H} - 2 \text{ H} = -0.8 \text{ H}$
 Coil 3: $L_3 - M_{23} - M_{13} = 4 \text{ H} - 2 \text{ H} - 0.1 \text{ H} = 1.9 \text{ H}$
 $L_T = 2.1 \text{ H} - 0.8 \text{ H} + 1.9 \text{ H} = \mathbf{3.2 \text{ H}}$

21. $\mathbf{E}_1 - \mathbf{I}_1[\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}] - \mathbf{I}_2[\mathbf{Z}_m] = 0$
 $\mathbf{I}_2[\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}] + \mathbf{I}_1[\mathbf{Z}_m] = 0$

$$\mathbf{I}_1(\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}) + \mathbf{I}_2(\mathbf{Z}_m) = \mathbf{E}_1$$

$$\mathbf{I}_1(\mathbf{Z}_m) + \mathbf{I}_2(\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}) = 0 \quad X_m = -\omega M \angle 90^\circ$$

22. $\mathbf{Z}_i = \mathbf{Z}_p + \frac{(\omega M)^2}{\mathbf{Z}_s + \mathbf{Z}_L} = R_p + jX_{L_p} + \frac{(\omega M)^2}{R_s + jX_{L_s} + R_L}$
 $R_p = 2 \Omega, X_{L_p} = \omega L_p = (10^3 \text{ rad/s})(8 \text{ H}) = 8 \text{ k}\Omega$
 $R_s = 1 \Omega, X_{L_s} = \omega L_s = (10^3 \text{ rad/s})(2 \text{ H}) = 2 \text{ k}\Omega$
 $M = k\sqrt{L_p L_s} = 0.05\sqrt{(8 \text{ H})(2 \text{ H})} = 0.2 \text{ H}$

$$\mathbf{Z}_i = 2 \Omega + j8 \text{ k}\Omega + \frac{(10^3 \text{ rad/s} \cdot 0.2 \text{ H})^2}{1\Omega + j2 \text{ k}\Omega + 20 \Omega}$$

$$= 2 \Omega + j8 \text{ k}\Omega + \frac{4 \times 10^4 \Omega}{21 + j2 \times 10^3}$$

$$= 2 \Omega + j8 \text{ k}\Omega + 0.21 \Omega - j19.99 \Omega = 2.21 \Omega + j7980 \Omega$$

 $\mathbf{Z}_i = \mathbf{7980 \Omega \angle 89.98^\circ}$

23. a. $a = \frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{2400 \text{ V}}{120 \text{ V}} = \mathbf{20}$
 b. $10,000 \text{ VA} = V_s I_s \Rightarrow I_s = \frac{10,000 \text{ VA}}{V_s} = \frac{10,000 \text{ VA}}{120 \text{ V}} = \mathbf{83.33 \text{ A}}$
 c. $I_p = \frac{10,000 \text{ VA}}{V_p} = \frac{10,000 \text{ VA}}{2400 \text{ V}} = \mathbf{4.17 \text{ A}}$
 d. $a = \frac{V_p}{V_s} = \frac{120 \text{ V}}{2400 \text{ V}} = 0.05 = \frac{1}{20}$
 $I_s = \frac{10,000 \text{ VA}}{2400 \text{ V}} = \mathbf{4.17 \text{ A}}, I_p = \mathbf{83.33 \text{ A}}$

24. $I_s = I_1 = 2 \text{ A}$, $E_p = V_L = 40 \text{ V}$
 $E_s = V_s - V_L = 200 \text{ V} - 40 \text{ V} = 160 \text{ V}$
 $V_g I_1 = V_L I_L \Rightarrow I_L = V_g / V_L \cdot I_1 = \frac{200 \text{ V}}{40 \text{ V}} (2 \text{ A}) = 10 \text{ A}$
 $I_p + I_1 = I_L \Rightarrow I_p = I_L - I_1 = 10 \text{ A} - 2 \text{ A} = 8 \text{ A}$

25. a. $\mathbf{E}_s = \frac{N_s}{N_p} \mathbf{E}_p$
 $= \frac{25 \text{ t}}{100 \text{ t}} (100 \text{ V} \angle 0^\circ) = 25 \text{ V} \angle 0^\circ = \mathbf{V}_L$
 $\mathbf{I}_s = \frac{\mathbf{E}_s}{\mathbf{Z}_L} = \frac{25 \text{ V} \angle 0^\circ}{5 \Omega \angle 0^\circ} = 5 \text{ A} \angle 0^\circ = \mathbf{I}_L$

b. $\mathbf{Z}_i = a^2 \mathbf{Z}_L = \left(\frac{N_p}{N_s} \right)^2 \mathbf{Z}_L = \left(\frac{100 \text{ t}}{25 \text{ t}} \right)^2 5 \Omega \angle 0^\circ = (4)^2 5 \Omega \angle 0^\circ = 80 \Omega \angle 0^\circ$

c. $\mathbf{Z}_{l/2} = \frac{1}{4} \mathbf{Z}_i = \frac{1}{4} (80 \Omega \angle 0^\circ) = 20 \Omega \angle 0^\circ$

26. a. $\mathbf{E}_2 = \frac{N_2}{N_1} \mathbf{E}_1 = \frac{15 \text{ t}}{90 \text{ t}} (60 \text{ V} \angle 0^\circ) = 10 \text{ V} \angle 0^\circ$
 $\mathbf{E}_3 = \frac{N_3}{N_1} \mathbf{E}_1 = \frac{45 \text{ t}}{90 \text{ t}} (60 \text{ V} \angle 0^\circ) = 30 \text{ V} \angle 0^\circ$
 $\mathbf{I}_2 = \frac{\mathbf{E}_2}{\mathbf{Z}_2} = \frac{10 \text{ V} \angle 0^\circ}{8 \Omega \angle 0^\circ} = 1.25 \text{ A} \angle 0^\circ$
 $\mathbf{I}_3 = \frac{\mathbf{E}_3}{\mathbf{Z}_3} = \frac{30 \text{ V} \angle 0^\circ}{5 \Omega \angle 0^\circ} = 6 \text{ A} \angle 0^\circ$

b. $\frac{1}{R_1} = \frac{1}{(N_1/N_2)^2 R_2} + \frac{1}{(N_1/N_3)^2 R_3}$
 $= \frac{1}{(90 \text{ t}/15 \text{ t})^2 8 \Omega} + \frac{1}{(90 \text{ t}/45 \text{ t})^2 5 \Omega}$
 $\frac{1}{R_1} = \frac{1}{288 \Omega} + \frac{1}{20 \Omega} = 0.05347 \text{ S}$
 $R_1 = 18.70 \Omega$

27. a. $\mathbf{E}_2 = \frac{N_2}{N_1} \mathbf{E}_1 = \left(\frac{40 \text{ t}}{120 \text{ t}} \right) (120 \text{ V} \angle 60^\circ) = 40 \text{ V} \angle 60^\circ$
 $\mathbf{I}_2 = \frac{\mathbf{E}_2}{\mathbf{Z}_2} = \frac{40 \text{ V} \angle 60^\circ}{12 \Omega \angle 0^\circ} = 3.33 \text{ A} \angle 60^\circ$
 $\mathbf{E}_3 = \frac{N_3}{N_1} \mathbf{E}_1 = \left(\frac{30 \text{ t}}{120 \text{ t}} \right) (120 \text{ V} \angle 60^\circ) = 30 \text{ V} \angle 60^\circ$
 $\mathbf{I}_3 = \frac{\mathbf{E}_3}{\mathbf{Z}_3} = \frac{30 \text{ V} \angle 60^\circ}{10 \Omega \angle 0^\circ} = 3 \text{ A} \angle 60^\circ$

b.

$$\begin{aligned}\frac{1}{R_1} &= \frac{1}{(N_1/N_2)^2 R_2} + \frac{1}{(N_1/N_3)^2 R_3} \\ &= \frac{1}{(120\text{ t}/40\text{ t})^2 12\Omega} + \frac{1}{(120\text{ t}/30\text{ t})^2 10\Omega} \\ \frac{1}{R_1} &= \frac{1}{108\Omega} + \frac{1}{160\Omega} = 0.0155 \text{ S} \\ R_1 &= \frac{1}{0.0155 \text{ S}} = \mathbf{64.52 \Omega}\end{aligned}$$

28. $\mathbf{Z}_M = \mathbf{Z}_{M_{12}} = \omega M_{12} \angle 90^\circ$

$$\begin{aligned}\mathbf{E} - \mathbf{I}_1 \mathbf{Z}_1 - \mathbf{I}_1 \mathbf{Z}_{L_1} - \mathbf{I}_1(-\mathbf{Z}_m) - \mathbf{I}_2(+\mathbf{Z}_m) - \mathbf{I}_1 \mathbf{Z}_{L_2} + \mathbf{I}_2 \mathbf{Z}_{L_2} - \mathbf{I}_1(-\mathbf{Z}_m) &= 0 \\ \mathbf{E} - \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_{L_1} - \mathbf{Z}_m + \mathbf{Z}_{L_2} - \mathbf{Z}_m) - \mathbf{I}_2(\mathbf{Z}_m - \mathbf{Z}_{L_2}) &= 0 \\ \text{or } \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_{L_1} + \mathbf{Z}_{L_2} - 2\mathbf{Z}_m) + \mathbf{I}_2(\mathbf{Z}_m - \mathbf{Z}_{L_2}) &= \mathbf{E} \\ \hline -\mathbf{I}_2 \mathbf{Z}_2 - \mathbf{Z}_{L_2} (\mathbf{I}_2 - \mathbf{I}_1) - \mathbf{I}_1(+\mathbf{Z}_m) &= 0 \\ \text{or } \mathbf{I}_1(\mathbf{Z}_m - \mathbf{Z}_{L_2}) + \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_{L_2}) &= 0\end{aligned}$$

29.

$$\begin{aligned}\mathbf{E}_1 - \mathbf{I}_1 \mathbf{Z}_1 - \mathbf{I}_1 \mathbf{Z}_{L_1} - \mathbf{I}_2(-\mathbf{Z}_{M_{12}}) - \mathbf{I}_3(+\mathbf{Z}_{M_{13}}) &= 0 \\ \text{or } \mathbf{E}_1 - \mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_{L_1}] + \mathbf{I}_2 \mathbf{Z}_{M_{12}} - \mathbf{I}_3 \mathbf{Z}_{M_{13}} &= 0 \\ \hline -\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}) + \mathbf{I}_3 \mathbf{Z}_2 - \mathbf{I}_1(-\mathbf{Z}_{M_{12}}) &= 0 \\ \text{or } -\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}) + \mathbf{I}_3 \mathbf{Z}_2 + \mathbf{I}_1 \mathbf{Z}_{M_{12}} &= 0\end{aligned}$$

$$\begin{aligned}\hline -\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}) + \mathbf{I}_2 \mathbf{Z}_2 - \mathbf{I}_1(+\mathbf{Z}_{M_{13}}) &= 0 \\ \text{or } -\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}) + \mathbf{I}_2 \mathbf{Z}_2 - \mathbf{I}_1 \mathbf{Z}_{M_{13}} &= 0 \\ \hline \therefore [\mathbf{Z}_1 + \mathbf{Z}_{L_1}] \mathbf{I}_1 - \mathbf{Z}_{M_{12}} \mathbf{I}_2 + \mathbf{Z}_{M_{13}} \mathbf{I}_3 &= \mathbf{E}_1 \\ \mathbf{Z}_{M_{12}} \mathbf{I}_1 - [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}] \mathbf{I}_2 + \mathbf{Z}_2 \mathbf{I}_3 &= 0 \\ \mathbf{Z}_{M_{13}} \mathbf{I}_1 + \mathbf{Z}_2 \mathbf{I}_2 + [\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}] \mathbf{I}_3 &= 0\end{aligned}$$

Chapter 23

1. a. $E_\phi = E_L/\sqrt{3} = 208 \text{ V}/1.732 = \mathbf{120.1 \text{ V}}$ b. $V_\phi = E_\phi = \mathbf{120.1 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{R_\phi} = \frac{120.1 \text{ V}}{10 \Omega} = \mathbf{12.01 \text{ A}}$ d. $I_L = I_\phi = \mathbf{12.01 \text{ A}}$

2. a. $E_\phi = E_L/\sqrt{3} = 208 \text{ V}/1.732 = \mathbf{120.1 \text{ V}}$ b. $V_\phi = E_\phi = \mathbf{120.1 \text{ V}}$

c. $\mathbf{Z}_\phi = 12 \Omega - j16 \Omega = 20 \Omega \angle -53.13^\circ$ d. $I_L = I_\phi = \mathbf{6 \text{ A}}$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \text{ V}}{20 \Omega} \cong \mathbf{6 \text{ A}}$

3. a. $E_\phi = \mathbf{120.1 \text{ V}}$ b. $V_\phi = \mathbf{120.1 \text{ V}}$

c. $\mathbf{Z}_\phi = (10 \Omega \angle 0^\circ \parallel (10 \Omega \angle -90^\circ)) = 7.071 \Omega \angle -45^\circ$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \text{ V}}{7.071 \Omega} = \mathbf{16.98 \text{ A}}$

d. $I_L = \mathbf{16.98 \text{ A}}$

4. a. $\theta_2 = -120^\circ, \theta_3 = 120^\circ$

b. $\mathbf{V}_{an} = 120 \text{ V} \angle 0^\circ, \mathbf{V}_{bn} = 120 \text{ V} \angle -120^\circ, \mathbf{V}_{cn} = 120 \text{ V} \angle 120^\circ$

c. $\mathbf{I}_{an} = \frac{\mathbf{V}_{an}}{\mathbf{Z}_{an}} = \frac{120 \text{ V} \angle 0^\circ}{20 \Omega \angle 0^\circ} = \mathbf{6 \text{ A} \angle 0^\circ}$

$\mathbf{I}_{bn} = \frac{\mathbf{V}_{bn}}{\mathbf{Z}_{bn}} = \frac{120 \text{ V} \angle -120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{6 \text{ A} \angle -120^\circ}$

$\mathbf{I}_{cn} = \frac{\mathbf{V}_{cn}}{\mathbf{Z}_{cn}} = \frac{120 \text{ V} \angle 120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{6 \text{ A} \angle 120^\circ}$

d. $I_L = I_\phi = \mathbf{6 \text{ A}}$ e. $V_L = \sqrt{3} V_\phi = \sqrt{3} (120 \text{ V}) = \mathbf{207.8 \text{ V}}$

5. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$

b. $\mathbf{V}_{an} = 120 \text{ V} \angle 0^\circ, \mathbf{V}_{bn} = 120 \text{ V} \angle -120^\circ, \mathbf{V}_{cn} = 120 \text{ V} \angle 120^\circ$

c. $\mathbf{Z}_\phi = 9 \Omega + j12 \Omega = 15 \Omega \angle 53.13^\circ$

$\mathbf{I}_{an} = \frac{120 \text{ V} \angle 0^\circ}{15 \Omega \angle 53.13^\circ} = \mathbf{8 \text{ A} \angle -53.13^\circ}, \mathbf{I}_{bn} = \frac{120 \text{ V} \angle -120^\circ}{15 \Omega \angle 53.13^\circ} = \mathbf{8 \text{ A} \angle -173.13^\circ}$

$\mathbf{I}_{cn} = \frac{120 \text{ V} \angle 120^\circ}{15 \Omega \angle 53.13^\circ} = \mathbf{8 \text{ A} \angle 66.87^\circ}$

$$\text{e. } I_L = I_\phi = \mathbf{8 \text{ A}} \quad \text{f. } E_L = \sqrt{3} E_\phi = (1.732)(120 \text{ V}) = \mathbf{207.85 \text{ V}}$$

6. a, b. The same as problem 4.

$$\text{c. } \mathbf{Z}_\phi = 6 \Omega \angle 0^\circ \parallel 8 \Omega \angle -90^\circ = 4.8 \Omega \angle -36.87^\circ$$

$$\mathbf{I}_{an} = \frac{\mathbf{V}_{an}}{\mathbf{Z}_{an}} = \frac{120 \text{ V} \angle 0^\circ}{4.8 \Omega \angle -36.87^\circ} = \mathbf{25 \text{ A} \angle 36.87^\circ}$$

$$\mathbf{I}_{bn} = \frac{\mathbf{V}_{bn}}{\mathbf{Z}_{bn}} = \frac{120 \text{ V} \angle -120^\circ}{4.8 \Omega \angle -36.87^\circ} = \mathbf{25 \text{ A} \angle -83.13^\circ}$$

$$\mathbf{I}_{cn} = \frac{\mathbf{V}_{cn}}{\mathbf{Z}_{cn}} = \frac{120 \text{ V} \angle 120^\circ}{4.8 \Omega \angle -36.87^\circ} = \mathbf{25 \text{ A} \angle 156.87^\circ}$$

$$\text{d. } I_L = I_\phi = \mathbf{25 \text{ A}} \quad \text{e. } V_L = \sqrt{3} V_\phi = \sqrt{3} (120 \text{ V}) = \mathbf{207.84 \text{ V}}$$

$$7. \quad V_\phi = V_{an} = V_{bn} = V_{cn} = \frac{V_L}{\sqrt{3}} = \frac{220 \text{ V}}{1.732} = \mathbf{127.0 \text{ V}}$$

$$\mathbf{Z}_\phi = 10 \Omega - j10 \Omega = 14.142 \Omega \angle -45^\circ$$

$$I_\phi = I_{an} = I_{bn} = I_{cn} = \frac{V_\phi}{Z_\phi} = \frac{127 \text{ V}}{14.142 \Omega} = \mathbf{8.98 \text{ A}}$$

$$I_L = I_{Aa} = I_{Bb} = I_{Cc} = I_\phi = \mathbf{8.98 \text{ A}}$$

$$8. \quad \mathbf{Z}_\phi = 12 \Omega + j16 \Omega = 20 \Omega \angle 53.13^\circ$$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{50 \text{ V}}{20 \Omega} = \mathbf{2.5 \text{ A}}$$

$$Z_{T_\phi} = 13 \Omega + j16 \Omega = 20.62 \Omega \angle 50.91^\circ$$

$$V_\phi = I_\phi Z_{T_\phi} = (2.5 \text{ A})(20.62 \Omega) = 51.55 \text{ V}$$

$$V_L = \sqrt{3} V_\phi = (\sqrt{3})(51.55 \text{ V}) = \mathbf{89.29 \text{ V}}$$

$$9. \quad \text{a. } \mathbf{E}_{AN} = \frac{22 \text{ kV}}{\sqrt{3}} \angle -30^\circ = \mathbf{12.7 \text{ kV} \angle -30^\circ}$$

$$\mathbf{E}_{BN} = \frac{22 \text{ kV}}{\sqrt{3}} \angle -150^\circ = \mathbf{12.7 \text{ kV} \angle -150^\circ}$$

$$\mathbf{E}_{CN} = \frac{22 \text{ kV}}{\sqrt{3}} \angle 90^\circ = \mathbf{12.7 \text{ kV} \angle 90^\circ}$$

$$\begin{aligned}
b, c. \quad \mathbf{I}_{Aa} = \mathbf{I}_{an} &= \frac{\mathbf{E}_{AN}}{\mathbf{Z}_{AN}} = \frac{12.7 \text{ kV} \angle -30^\circ}{(30 \Omega + j40 \Omega) + (0.4 \text{ k}\Omega + j1 \text{k}\Omega)} \\
&= \frac{12.7 \text{ kV} \angle -30^\circ}{430 \Omega + j1040 \Omega} = \frac{12.7 \text{ kV} \angle -30^\circ}{1125.39 \Omega \angle 67.54^\circ} \\
&= \mathbf{11.29 \text{ A} \angle -97.54^\circ} \\
\mathbf{I}_{Bb} = \mathbf{I}_{bn} &= \frac{\mathbf{E}_{BN}}{\mathbf{Z}_{BN}} = \frac{12.7 \text{ kV} \angle -150^\circ}{1125.39 \Omega \angle 67.54^\circ} = \mathbf{11.29 \text{ A} \angle -217.54^\circ} \\
\mathbf{I}_{Cc} = \mathbf{I}_{cn} &= \frac{\mathbf{E}_{CN}}{\mathbf{Z}_{CN}} = \frac{12.7 \text{ kV} \angle 90^\circ}{1125.39 \Omega \angle 67.54^\circ} = \mathbf{11.29 \text{ A} \angle 22.46^\circ}
\end{aligned}$$

$$\begin{aligned}
d. \quad \mathbf{V}_{an} = \mathbf{I}_{an} \mathbf{Z}_{an} &= (11.29 \text{ A} \angle -97.54^\circ)(400 + j1000) \\
&= (11.29 \text{ A} \angle -97.54^\circ)(1077.03 \Omega \angle 68.2^\circ) \\
&= \mathbf{12.16 \text{ kV} \angle -29.34^\circ} \\
\mathbf{V}_{bn} = \mathbf{I}_{bn} \mathbf{Z}_{bn} &= (11.29 \text{ A} \angle -217.54^\circ)(1077.03 \angle 68.2^\circ) \\
&= \mathbf{12.16 \text{ kV} \angle -149.34^\circ} \\
\mathbf{V}_{cn} = \mathbf{I}_{cn} \mathbf{Z}_{cn} &= (11.29 \text{ A} \angle 22.46^\circ)(1077.03 \angle 68.2^\circ) \\
&= \mathbf{12.16 \text{ kV} \angle 90.66^\circ}
\end{aligned}$$

10. a. $E_\phi = E_L / \sqrt{3} = 208 \text{ V} / 1.732 = \mathbf{120.1 \text{ V}}$ b. $V_\phi = E_L = \mathbf{208 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{208 \text{ V}}{20 \Omega} = \mathbf{10.4 \text{ A}}$ d. $I_L = \sqrt{3} I_\phi = (1.732)(10.4 \text{ A}) = \mathbf{18 \text{ A}}$

11. a. $E_\phi = E_L / \sqrt{3} = 208 \text{ V} / 1.732 = \mathbf{120.1 \text{ V}}$ b. $V_\phi = E_L = \mathbf{208 \text{ V}}$

c. $\mathbf{Z}_\phi = 6.8 \Omega + j14 \Omega = 15.564 \Omega \angle 64.09^\circ$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{208 \text{ V}}{15.564 \Omega} = \mathbf{13.36 \text{ A}}$

d. $I_L = \sqrt{3} I_\phi = (1.732)(13.36 \text{ A}) = \mathbf{23.14 \text{ A}}$

12. $\mathbf{Z}_\phi = 18 \Omega \angle 0^\circ \parallel 18 \Omega \angle -90^\circ = 12.728 \Omega \angle -45^\circ$

a. $E_\phi = V_L / \sqrt{3} = 208 \text{ V} / \sqrt{3} = \mathbf{120.09 \text{ V}}$ b. $V_\phi = \mathbf{208 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{208 \text{ V}}{12.728 \Omega} = \mathbf{16.34 \text{ A}}$

d. $I_L = \sqrt{3} I_\phi = (1.732)(16.34 \text{ A}) = \mathbf{28.30 \text{ A}}$

13. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$

b. $\mathbf{V}_{ab} = \mathbf{208 \text{ V} \angle 0^\circ}, \mathbf{V}_{bc} = \mathbf{208 \text{ V} \angle -120^\circ}, \mathbf{V}_{ca} = \mathbf{208 \text{ V} \angle 120^\circ}$

c. —

d. $\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{208 \text{ V} \angle 0^\circ}{22 \Omega \angle 0^\circ} = \mathbf{9.46 \text{ A} \angle 0^\circ}$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{208 \text{ V} \angle 120^\circ}{22 \Omega \angle 0^\circ} = \mathbf{9.46 \text{ A} \angle -120^\circ}$$
$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{208 \text{ V} \angle 120^\circ}{22 \Omega \angle 0^\circ} = \mathbf{9.46 \text{ A} \angle 120^\circ}$$

e. $I_L = \sqrt{3} I_\phi = (1.732)(9.46 \text{ A}) = \mathbf{16.38 \text{ A}}$

f. $E_\phi = E_L / \sqrt{3} = 208 \text{ V} / 1.732 = \mathbf{120.1 \text{ V}}$

14. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$

b. $\mathbf{V}_{ab} = 208 \text{ V} \angle 0^\circ, \mathbf{V}_{bc} = 208 \text{ V} \angle -120^\circ, \mathbf{V}_{ca} = 208 \text{ V} \angle 120^\circ$

c. —

d. $\mathbf{Z}_\phi = 100 \Omega - j100 \Omega = 141.42 \Omega \angle -45^\circ$

$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{208 \text{ V} \angle 0^\circ}{141.42 \Omega \angle -45^\circ} = \mathbf{1.47 \text{ A} \angle 45^\circ}$$
$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{208 \text{ V} \angle -120^\circ}{141.42 \Omega \angle -45^\circ} = \mathbf{1.47 \text{ A} \angle -75^\circ}$$
$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{208 \text{ V} \angle 120^\circ}{141.42 \Omega \angle -45^\circ} = \mathbf{1.47 \text{ A} \angle 165^\circ}$$

e. $I_L = \sqrt{3} I_\phi = (1.732)(1.471 \text{ A}) = \mathbf{2.55 \text{ A}}$

f. $E_\phi = E_L / \sqrt{3} = 208 \text{ V} / 1.732 = \mathbf{120.1 \text{ V}}$

15. a, b. The same as problem 13.

c. —

d. $\mathbf{Z}_\phi = 3 \Omega \angle 0^\circ \parallel 4 \Omega \angle 90^\circ = 2.4 \Omega \angle 36.87^\circ$

$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{208 \text{ V} \angle 0^\circ}{2.4 \Omega \angle 36.87^\circ} = \mathbf{86.67 \text{ A} \angle -36.87^\circ}$$
$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{208 \text{ V} \angle -120^\circ}{2.4 \Omega \angle 36.87^\circ} = \mathbf{86.67 \text{ A} \angle -156.87^\circ}$$
$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{208 \text{ V} \angle 120^\circ}{2.4 \Omega \angle 36.87^\circ} = \mathbf{86.67 \text{ A} \angle 83.13^\circ}$$

e. $I_L = \sqrt{3} I_\phi = (1.732)(86.67 \text{ A}) = \mathbf{150.11 \text{ A}}$ f. $E_\phi = \mathbf{120.1 \text{ V}}$

16. $V_{ab} = V_{bc} = V_{ca} = \mathbf{220 \text{ V}}$
 $\mathbf{Z}_\phi = 10 \Omega + j10 \Omega = 14.142 \Omega \angle 45^\circ$
 $I_{ab} = I_{bc} = I_{ca} = \frac{V_\phi}{Z_\phi} = \frac{220 \text{ V}}{14.142 \Omega} = \mathbf{15.56 \text{ A}}$

17. a. $\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{16 \text{ kV} \angle 0^\circ}{300 \Omega + j1000 \Omega} = \frac{16 \text{ kV} \angle 0^\circ}{1044.03 \Omega \angle 73.30^\circ}$
 $\mathbf{I}_{ab} = \mathbf{15.33 \text{ A} \angle -73.30^\circ}$
 $\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{16 \text{ kV} \angle -120^\circ}{1044.03 \Omega \angle 73.30^\circ} = \mathbf{15.33 \text{ A} \angle -193.30^\circ}$
 $\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{16 \text{ kV} \angle 120^\circ}{1044.03 \Omega \angle 73.30^\circ} = \mathbf{15.33 \text{ A} \angle 46.7^\circ}$

b. $\mathbf{I}_{Aa} - \mathbf{I}_{ab} + \mathbf{I}_{ca} = 0$
 $\mathbf{I}_{Aa} = \mathbf{I}_{ab} - \mathbf{I}_{ca} = 15.33 \text{ A} \angle -73.30^\circ - 15.33 \text{ A} \angle 46.7^\circ$
 $= (4.41 \text{ A} - j14.68 \text{ A}) - (10.51 \text{ A} + j11.16 \text{ A})$
 $= 4.41 \text{ A} - 10.51 \text{ A} - j(14.68 \text{ A} + 11.16 \text{ A})$
 $= -6.11 \text{ A} - j25.84 \text{ A} = \mathbf{26.55 \text{ A} \angle -103.30^\circ}$
 $\mathbf{I}_{Bb} + \mathbf{I}_{ab} = \mathbf{I}_{bc}$
 $\mathbf{I}_{Bb} = \mathbf{I}_{bc} - \mathbf{I}_{ab} = 15.33 \text{ A} \angle -193.30^\circ - 15.33 \text{ A} \angle -73.30^\circ$
 $= \mathbf{26.55 \text{ A} \angle 136.70^\circ}$
 $\mathbf{I}_{Cc} + \mathbf{I}_{bc} = \mathbf{I}_{ca}$
 $\mathbf{I}_{Cc} = \mathbf{I}_{ca} - \mathbf{I}_{bc} = 15.33 \text{ A} \angle 46.7^\circ - 15.33 \text{ A} \angle -193.30^\circ$
 $= \mathbf{26.55 \text{ A} \angle 16.70^\circ}$

c. $\mathbf{E}_{AB} = \mathbf{I}_{Aa}(10 \Omega + j20 \Omega) + \mathbf{V}_{ab} - \mathbf{I}_{Bb}(22.361 \Omega \angle 63.43^\circ)$
 $= (26.55 \text{ A} \angle -103.30^\circ)(22.361 \Omega \angle 63.43^\circ) + 16 \text{ kV} \angle 0^\circ$
 $- (26.55 \text{ A} \angle 136.70^\circ)(22.361 \Omega \angle 63.43^\circ)$
 $= (455.65 \text{ V} - j380.58 \text{ V}) + 16,000 \text{ V} - (-557.42 \text{ V} - j204.32 \text{ V})$
 $= 17.01 \text{ kV} - j176.26 \text{ V}$
 $= \mathbf{17.01 \text{ kV} \angle -0.59^\circ}$

$$\begin{aligned}\mathbf{E}_{BC} &= \mathbf{I}_{Bb}(22.361 \Omega \angle 63.43^\circ) + \mathbf{V}_{bc} - \mathbf{I}_{Cc}(22.361 \Omega \angle 63.53^\circ) \\ &= (26.55 \text{ A} \angle 136.70^\circ)(22.361 \Omega \angle 63.53^\circ) + 16 \text{ kV} \angle -120^\circ \\ &\quad - (26.55 \text{ A} \angle 16.70^\circ)(22.361 \Omega \angle 63.53^\circ) \\ &= \mathbf{17.01 \text{ kV} \angle -120.59^\circ}\end{aligned}$$

$$\begin{aligned}\mathbf{E}_{CA} &= \mathbf{I}_{Cc}(22.361 \Omega \angle 63.43^\circ) + \mathbf{V}_{ca} - \mathbf{I}_{Aa}(22.361 \Omega \angle 63.43^\circ) \\ &= \mathbf{17.01 \text{ kV} \angle 119.41^\circ}\end{aligned}$$

18. a. $E_\phi = E_L = \mathbf{208 \text{ V}}$ b. $V_\phi = \frac{E_L}{\sqrt{3}} = \frac{208 \text{ V}}{1.732} = \mathbf{120.1 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \text{ V}}{30 \Omega} = \mathbf{4.00 \text{ A}}$ d. $I_L = I_\phi \cong \mathbf{4 \text{ A}}$

19. a. $E_\phi = E_L = \mathbf{208 \text{ V}}$ b. $V_\phi = E_L \sqrt{3} = \mathbf{120.09 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.09 \text{ V}}{16.971 \Omega} = \mathbf{7.08 \text{ A}}$ d. $I_L = I_\phi = \mathbf{7.08 \text{ A}}$

20. a, b. The same as problem 18.

c. $\mathbf{Z}_\phi = 15 \Omega \angle 0^\circ \parallel 20 \Omega \angle -90^\circ = 12 \Omega \angle -36.87^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \text{ V}}{12 \Omega} \cong \mathbf{10 \text{ A}}$$

d. $I_L = I_\phi \cong \mathbf{10 \text{ A}}$

21. $V_{an} = V_{bn} = V_{cn} = \frac{120 \text{ V}}{\sqrt{3}} = \frac{120 \text{ V}}{1.732} = \mathbf{69.28 \text{ V}}$

$$I_{an} = I_{bn} = I_{cn} = \frac{69.28 \text{ V}}{24 \Omega} = \mathbf{2.89 \text{ A}}$$

$$I_{Aa} = I_{Bb} = I_{Cc} = \mathbf{2.89 \text{ A}}$$

22. $V_{an} = V_{bn} = V_{cn} = \frac{120 \text{ V}}{\sqrt{3}} = \mathbf{69.28 \text{ V}}$

$$\mathbf{Z}_\phi = 10 \Omega + j20 \Omega = 22.36 \Omega \angle 63.43^\circ$$

$$I_{an} = I_{bn} = I_{cn} = \frac{\mathbf{V}_\phi}{\mathbf{Z}_\phi} = \frac{69.28 \text{ V}}{22.36 \Omega} = \mathbf{3.10 \text{ A}}$$

$$I_{Aa} = I_{Bb} = I_{Cc} = I_\phi = \mathbf{3.10 \text{ A}}$$

23. $V_{an} = V_{bn} = V_{cn} = \mathbf{69.28 \text{ V}}$

$$\mathbf{Z}_\phi = 20 \Omega \angle 0^\circ \parallel 15 \Omega \angle -90^\circ = 12 \Omega \angle -53.13^\circ$$

$$I_{an} = I_{bn} = I_{cn} = \frac{69.28 \text{ V}}{12 \Omega} = \mathbf{5.77 \text{ A}}$$

$$I_{Aa} = I_{Bb} = I_{Cc} = \mathbf{5.77 \text{ A}}$$

24. a. $E_\phi = E_L = \mathbf{440 \text{ V}}$

b. $V_\phi = E_L = E_\phi = \mathbf{440 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440 \text{ V}}{220 \Omega} = \mathbf{2 \text{ A}}$

d. $I_L = \sqrt{3} I_\phi = (1.732)(2 \text{ A}) = \mathbf{3.46 \text{ A}}$

25. a. $E_\phi = E_L = \mathbf{440 \text{ V}}$ b. $V_\phi = E_L = \mathbf{440 \text{ V}}$

c. $\mathbf{Z}_\phi = 12 \Omega - j9 \Omega = 15 \Omega \angle -36.87^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440 \text{ V}}{15 \Omega} = \mathbf{29.33 \text{ A}}$$

d. $I_L = \sqrt{3} I_\phi = (1.732)(29.33 \text{ A}) = \mathbf{50.8 \text{ A}}$

26. a, b. The same as problem 24.

c. $\mathbf{Z}_\phi = 22 \Omega \angle 0^\circ \parallel 22 \Omega \angle 90^\circ = 15.56 \Omega \angle 45^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440 \text{ V}}{15.56 \Omega} = \mathbf{28.28 \text{ A}}$$

d. $I_L = \sqrt{3} I_\phi = (1.732)(28.28 \text{ A}) = \mathbf{48.98 \text{ A}}$

27. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$

b. $\mathbf{V}_{ab} = 100 \text{ V} \angle 0^\circ, \mathbf{V}_{bc} = 100 \text{ V} \angle -120^\circ, \mathbf{V}_{ca} = 100 \text{ V} \angle 120^\circ$

c. —

d. $\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{100 \text{ V} \angle 0^\circ}{20 \Omega \angle 0^\circ} = \mathbf{5 \text{ A} \angle 0^\circ}$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{100 \text{ V} \angle -120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{5 \text{ A} \angle -120^\circ}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{100 \text{ V} \angle 120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{5 \text{ A} \angle 120^\circ}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3} (5 \text{ A}) = \mathbf{8.66 \text{ A}}$

28. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$

b. $\mathbf{V}_{ab} = 100 \text{ V} \angle 0^\circ, \mathbf{V}_{bc} = 100 \text{ V} \angle -120^\circ, \mathbf{V}_{ca} = 100 \text{ V} \angle 120^\circ$

c. —

d. $\mathbf{Z}_\phi = 12 \Omega + j16 \Omega = 20 \Omega \angle 53.13^\circ$

$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{100 \text{ V} \angle 0^\circ}{20 \Omega \angle 53.13^\circ} = \mathbf{5 \text{ A} \angle -53.13^\circ}$$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{100 \text{ V} \angle -120^\circ}{20 \Omega \angle 53.13^\circ} = \mathbf{5 \text{ A} \angle -173.13^\circ}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{100 \text{ V} \angle 120^\circ}{20 \Omega \angle 53.13^\circ} = \mathbf{5 \text{ A} \angle 66.87^\circ}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3} I_\phi = (\sqrt{3})(5 \text{ A}) = \mathbf{8.66 \text{ A}}$

29. a. $\theta_2 = -120^\circ, \theta_3 = 120^\circ$

b. $\mathbf{V}_{ab} = 100 \text{ V} \angle 0^\circ, \mathbf{V}_{bc} = 100 \text{ V} \angle -120^\circ, \mathbf{V}_{ca} = 100 \text{ V} \angle 120^\circ$

c. —

d. $\mathbf{Z}_\phi = 20 \Omega \angle 0^\circ \parallel 20 \Omega \angle -90^\circ = 14.14 \Omega \angle -45^\circ$

$$\mathbf{I}_{ab} = \frac{100 \text{ V} \angle 0^\circ}{14.14 \Omega \angle -45^\circ} = \mathbf{7.07 \text{ A} \angle 45^\circ}$$

$$\mathbf{I}_{bc} = \frac{100 \text{ V} \angle -120^\circ}{14.14 \Omega \angle -45^\circ} = \mathbf{7.07 \text{ A} \angle -75^\circ}$$

$$\mathbf{I}_{ca} = \frac{100 \text{ V} \angle 120^\circ}{14.14 \Omega \angle -45^\circ} = \mathbf{7.07 \text{ A} \angle 165^\circ}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = (\sqrt{3})(7.07 \text{ A}) = \mathbf{12.25 \text{ A}}$

30. $P_T = 3I_\phi^2 R_\phi = 3(6 \text{ A})^2 12 \Omega = \mathbf{1296 \text{ W}}$

$$Q_T = 3I_\phi^2 X_\phi = 3(6 \text{ A})^2 16 \Omega = \mathbf{1728 \text{ VAR(C)}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{2160 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{1296 \text{ W}}{2160 \text{ VA}} = \mathbf{0.6 \text{ (leading)}}$$

31. $V_\phi = 120 \text{ V}, I_\phi = 120 \text{ V}/20 \Omega = 6 \text{ A}$

$$P_T = 3I_\phi^2 R_\phi = 3(6 \text{ A})^2 20 \Omega = \mathbf{2160 \text{ W}}$$

$$Q_T = \mathbf{0 \text{ VAR}}$$

$$S_T = P_T = \mathbf{2160 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{2160 \text{ W}}{2160 \text{ VA}} = \mathbf{1}$$

32. $P_T = 3I_\phi^2 R_\phi = 3(8.98 \text{ A})^2 10 \Omega = \mathbf{2419.21 \text{ W}}$

$$Q_T = 3I_\phi^2 X_\phi = 3(8.98 \text{ A})^2 10 \Omega = \mathbf{2419.21 \text{ VAR(C)}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3421.28 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{2419.21 \text{ W}}{3421.28 \text{ VA}} = \mathbf{0.7071 \text{ (leading)}}$$

$$33. \quad V_\phi = 208 \text{ V}$$

$$P_T = 3 \left(\frac{V_\phi^2}{R_\phi} \right) = 3 \cdot \frac{(208 \text{ V})^2}{18 \Omega} = \mathbf{7210.67 \text{ W}}$$

$$Q_T = 3 \left(\frac{V_\phi^2}{X_\phi} \right) = 3 \cdot \frac{(208 \text{ V})^2}{18 \Omega} = \mathbf{7210.67 \text{ VAR}(C)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{10,197.42 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{7210.67 \text{ W}}{10,197.42 \text{ VA}} = \mathbf{0.707 \text{ (leading)}}$$

$$34. \quad P_T = 3I_\phi^2 R_\phi = 3(1.471 \text{ A})^2 100 \Omega = \mathbf{649.15 \text{ W}}$$

$$Q_T = 3I_\phi^2 X_\phi = 3(1.471 \text{ A})^2 100 \Omega = \mathbf{649.15 \text{ VAR}(C)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{918.04 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{649.15 \text{ W}}{918.04 \text{ VA}} = \mathbf{0.7071 \text{ (leading)}}$$

$$35. \quad P_T = 3I_\phi^2 R_\phi = 3(15.56 \text{ A})^2 10 \Omega = \mathbf{7.26 \text{ kW}}$$

$$Q_T = 3I_\phi^2 X_\phi = 3(15.56 \text{ A})^2 10 \Omega = \mathbf{7.26 \text{ kVAR}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{10.27 \text{ kVA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{7.263 \text{ kW}}{10.272 \text{ kVA}} = \mathbf{0.7071 \text{ (lagging)}}$$

$$36. \quad P_T = 3 \frac{V_\phi^2}{R_\phi} = \frac{3(120.1 \text{ V})^2}{15 \Omega} = \mathbf{2884.80 \text{ W}}$$

$$Q_T = 3 \frac{V_\phi^2}{X_\phi} = \frac{3(120.1 \text{ V})^2}{20 \Omega} = \mathbf{2163.60 \text{ VAR}(C)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3605.97 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{2884.80 \text{ W}}{3605.97 \text{ VA}} = \mathbf{0.8 \text{ (leading)}}$$

$$37. \quad Z_\phi = 10 \Omega + j20 \Omega = 22.36 \Omega \angle 63.43^\circ$$

$$V_\phi = \frac{V_L}{\sqrt{3}} = \frac{120 \text{ V}}{1.732} = 69.28 \text{ V}$$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{69.28 \text{ V}}{22.36 \Omega} = 3.098 \text{ A}$$

$$P_T = 3I_\phi^2 R_\phi = 3(3.098 \text{ A})^2 10 \Omega = \mathbf{287.93 \text{ W}}$$

$$Q_T = 3I_\phi^2 X_\phi = 3(3.098 \text{ A})^2 20 \Omega = \mathbf{575.86 \text{ VAR}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{643.83 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{287.93 \text{ W}}{643.83 \text{ VA}} = \mathbf{0.447 \text{ (lagging)}}$$

38. $P_T = 3 \frac{V_\phi^2}{R_\phi} = \frac{3(440 \text{ V})^2}{22 \Omega} = \mathbf{26.4 \text{ kW}}$

$$Q_T = P_T = \mathbf{26.4 \text{ kVAR(L)}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{37.34 \text{ kVA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{26.4 \text{ kW}}{37.34 \text{ kVA}} = \mathbf{0.707 \text{ (lagging)}}$$

39. $\mathbf{Z}_\phi = 12 \Omega + j16 \Omega = 20 \Omega \angle 53.13^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{100 \text{ V}}{20 \Omega} = 5 \text{ A}$$

$$P_T = 3I_\phi^2 R_\phi = 3(5 \text{ A})^2 12 \Omega = \mathbf{900 \text{ W}}$$

$$Q_T = 3I_\phi^2 X_\phi = 3(5 \text{ A})^2 16 \Omega = \mathbf{1200 \text{ VAR(L)}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{1500 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{900 \text{ W}}{1500 \text{ VA}} = \mathbf{0.6 \text{ (lagging)}}$$

40. $P_T = \sqrt{3} E_L I_L \cos \theta$

$$4800 \text{ W} = (1.732)(200 \text{ V})I_L (0.8)$$

$$I_L = 17.32 \text{ A}$$

$$I_\phi = \frac{I_L}{\sqrt{3}} = \frac{17.32 \text{ A}}{1.732} = 10 \text{ A}$$

$$\theta = \cos^{-1} 0.8 = 36.87^\circ$$

$$\mathbf{Z}_\phi = \frac{\mathbf{V}_\phi}{\mathbf{I}_\phi} = \frac{200 \text{ V} \angle 0^\circ}{10 \text{ A} \angle -36.87^\circ} = 20 \Omega \angle 36.87^\circ = \mathbf{16 \Omega + j12 \Omega}$$

41. $P_T = \sqrt{3} E_L I_L \cos \theta$

$$1200 \text{ W} = \sqrt{3} (208 \text{ V})I_L(0.6) \Rightarrow I_L = 5.55 \text{ A}$$

$$V_\phi = \frac{V_L}{\sqrt{3}} = \frac{208 \text{ V}}{1.732} = 120.1 \text{ V}$$

$$\theta = \cos^{-1} 0.6 = 53.13^\circ \text{ (leading)}$$

$$\mathbf{Z}_\phi = \frac{\mathbf{V}_\phi}{\mathbf{I}_\phi} = \frac{120.1 \text{ V} \angle 0^\circ}{5.55 \text{ A} \angle 53.13^\circ} = 21.64 \Omega \angle -53.13^\circ = \underbrace{12.98 \Omega}_R - j\underbrace{17.31 \Omega}_{X_C}$$

42. Δ : $\mathbf{Z}_\phi = 15 \Omega + j20 \Omega = 25 \Omega \angle 53.13^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{125 \text{ V}}{25 \Omega} = 5 \text{ A}$$

$$P_T = 3I_\phi^2 R_\phi = 3(5 \text{ A})^2 15 \Omega = 1125 \text{ W}$$

$$Q_T = 3I_\phi^2 X_\phi = 3(5 \text{ A})^2 20 \Omega = 1500 \text{ VAR}(L)$$

Y: $V_\phi = V_L / \sqrt{3} = 125 \text{ V} / \sqrt{3} = 72.17 \text{ V}$

$$\mathbf{Z}_\phi = 3 \Omega - j4 \Omega = 5 \Omega \angle -53.13^\circ$$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{72.17 \text{ V}}{5 \Omega} = 14.43 \text{ A}$$

$$P_T = 3I_\phi^2 R_\phi = 3(14.43 \text{ A})^2 3 \Omega = 1874.02 \text{ W}$$

$$Q_T = 3I_\phi^2 X_\phi = 3(14.43 \text{ A})^2 4 \Omega = 2498.7 \text{ VAR}$$

$$P_T = 1125 \text{ W} + 1874.02 \text{ W} = 2999.02 \text{ W}$$

$$Q_T = 1500 \text{ VAR}(L) - 2498.7 \text{ VAR}(C) = 998.7 \text{ VAR}(C)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 3161 \text{ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{2999.02 \text{ W}}{3161 \text{ VA}} = 0.949 \text{ (leading)}$$

43. a. $E_\phi = \frac{16 \text{ kV}}{\sqrt{3}} = 9,237.6 \text{ V}$

b. $I_L = I_\phi = 80 \text{ A}$

c. $P_{\phi_L} = \frac{1200 \text{ kW}}{3} = 400 \text{ kW}$

$$P_{4\Omega} = (80 \text{ A})^2 4 \Omega = 25.6 \text{ kW}$$

$$P_T = 3P_\phi = 3(25.6 \text{ kW} + 400 \text{ kW}) = 1276.8 \text{ kW}$$

d. $F_p = \frac{P_T}{S_T}, S_T = \sqrt{3} V_L I_L = \sqrt{3} (16 \text{ kV})(80 \text{ A}) = 2,217.025 \text{ kVA}$

$$F_p = \frac{1,276.8 \text{ kW}}{2,217.025 \text{ kVA}} = 0.576 \text{ lagging}$$

e. $\theta_L = \cos^{-1} 0.576 = 54.83^\circ \text{ (lagging)}$

$$\mathbf{I}_{Aa} = \underbrace{\frac{\mathbf{E}_{AN} \angle 0^\circ}{Z_T \angle 54.83^\circ}}_{\uparrow} \Rightarrow \underbrace{80 \text{ A}}_{\text{given}} \angle -54.83^\circ$$

for entire load

f.
$$\begin{aligned}\mathbf{V}_{an} &= \mathbf{E}_{AN} - \mathbf{I}_{Aa}(4 \Omega + j20 \Omega) \\ &= 9237.6 \text{ V} \angle 0^\circ - (80 \text{ A} \angle -54.83^\circ)(20.396 \Omega \angle 78.69^\circ) \\ &= 9237.6 \text{ V} \angle 0^\circ - 1631.68 \text{ V} \angle 23.86^\circ \\ &= 9237.6 \text{ V} - (1492.22 \text{ V} + j660 \text{ V}) \\ &= 7745.38 \text{ V} - j660 \text{ V} \\ &= \mathbf{7773.45 \text{ V} \angle -4.87^\circ}\end{aligned}$$

g.
$$\begin{aligned}\mathbf{Z}_\phi &= \frac{\mathbf{V}_{an}}{\mathbf{I}_{Aa}} = \frac{7773.45 \text{ V} \angle -4.87^\circ}{80 \text{ A} \angle -54.83^\circ} = 97.168 \Omega \angle 49.95^\circ \\ &= \underbrace{62.52 \Omega}_R + j \underbrace{74.38 \Omega}_C\end{aligned}$$

h. $F_p(\text{entire system}) = \mathbf{0.576 \text{ (lagging)}}$
 $F_p(\text{load}) = \mathbf{0.643 \text{ (lagging)}}$

i. $\eta = \frac{P_o}{P_i} = \frac{P_i - P_{\text{lost}}}{P_i} = \frac{1276.8 \text{ kW} - 3(25.6 \text{ kW})}{1276.8 \text{ kW}} = 0.9398 \Rightarrow \mathbf{93.98\%}$

44. a. —

b. $V_\phi = \frac{220 \text{ V}}{\sqrt{3}} = 127.02 \text{ V}, \quad \mathbf{Z}_\phi = 10 \Omega - j10 \Omega = 14.14 \Omega \angle -45^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{127.02 \text{ V}}{14.14 \Omega} = 8.98 \text{ A}$$

$$P_T = 3I_\phi^2 R_\phi = 3(8.98 \text{ A})^2 10 \Omega = \mathbf{2419.2 \text{ W}}$$

$$\text{Each wattmeter: } \frac{2419.2 \text{ W}}{3} = \mathbf{806.4 \text{ W}}$$

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

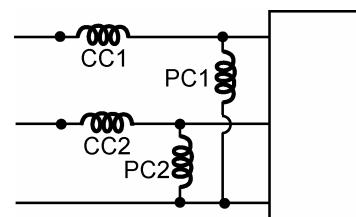
46. a. —

b. $P_T = P_\ell + P_h = 85 \text{ W} + 200 \text{ W} = \mathbf{285 \text{ W}}$

c. $0.2 \Rightarrow \frac{P_\ell}{P_h} = 0.5$

$$P_h = \frac{P_\ell}{0.5} = \frac{100 \text{ W}}{0.5} = \mathbf{200 \text{ W}}$$

$$P_T = P_h - P_\ell = 200 \text{ W} - 100 \text{ W} = \mathbf{100 \text{ W}}$$



48. a. $\mathbf{I}_{ab} = \frac{\mathbf{E}_{AB}}{R\angle 0^\circ} = \frac{208 \text{ V} \angle 0^\circ}{10 \Omega \angle 0^\circ} = \mathbf{20.8 \text{ A} \angle 0^\circ}$

$$\mathbf{I}_{bc} = \frac{\mathbf{E}_{BC}}{R\angle 0^\circ} = \frac{208 \text{ V} \angle -120^\circ}{10 \Omega \angle 0^\circ} = \mathbf{20.8 \text{ A} \angle -120^\circ}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{E}_{CA}}{R\angle 0^\circ} = \frac{208 \text{ V} \angle 120^\circ}{10 \Omega \angle 0^\circ} = \mathbf{20.8 \text{ A} \angle 120^\circ}$$

b. $\mathbf{I}_{Aa} + \mathbf{I}_{ca} - \mathbf{I}_{ab} = 0$
 $\mathbf{I}_{Aa} = \mathbf{I}_{ab} - \mathbf{I}_{ca}$
 $= 20.8 \text{ A} \angle 0^\circ - 20.8 \text{ A} \angle 120^\circ$
 $= 20.8 \text{ A} - (-10.4 \text{ A} + j18.01 \text{ A})$
 $= 31.2 \text{ A} - j18.01 \text{ A}$
 $= \mathbf{36.02 \text{ A} \angle -30^\circ}$

$\mathbf{I}_{Bb} + \mathbf{I}_{ab} - \mathbf{I}_{bc} = 0$
 $\mathbf{I}_{Bb} = \mathbf{I}_{bc} - \mathbf{I}_{ab}$
 $= 20.8 \text{ A} \angle -120^\circ - 20.8 \text{ A} \angle 0^\circ$
 $= (-10.4 \text{ A} - j18.01 \text{ A}) - 20.8 \text{ A}$
 $= -31.2 \text{ A} - j18.01 \text{ A}$
 $= \mathbf{36.02 \text{ A} \angle -150^\circ}$

$\mathbf{I}_{Cc} + \mathbf{I}_{bc} - \mathbf{I}_{ca} = 0$
 $\mathbf{I}_{Cc} = \mathbf{I}_{ca} - \mathbf{I}_{bc}$
 $= 20.8 \text{ A} \angle 120^\circ - 20.8 \text{ A} \angle -120^\circ$
 $= (-10.4 \text{ A} + j18.01 \text{ A}) - (-10.4 \text{ A} - j18.01 \text{ A})$
 $= -10.4 \text{ A} + 10.4 \text{ A} + j18.01 \text{ A} + j18.01 \text{ A}$
 $= \mathbf{32.02 \text{ A} \angle 90^\circ}$

c. $P_1 = V_{ac} I_{Aa} \cos \frac{V_{ca}}{I_{Aa}}, \quad \mathbf{V}_{ac} = V_{ca} \angle \theta - 180^\circ = 208 \text{ V} \angle 120^\circ - 180^\circ$
 $= 208 \text{ V} \angle -60^\circ$
 $\mathbf{I}_{Aa} = 36.02 \text{ A} \angle -30^\circ$
 $= (208 \text{ V})(36.02 \text{ A}) \cos 30^\circ$
 $= \mathbf{6488.4 \text{ W}}$

$P_2 = V_{bc} I_{Bb} \cos \frac{V_{bc}}{I_{Bb}}, \quad \mathbf{V}_{bc} = 208 \text{ V} \angle -120^\circ, \quad \mathbf{I}_{Bb} = 36.02 \text{ A} \angle -150^\circ$
 $= (208 \text{ V})(36.02 \text{ A}) \cos 30^\circ$
 $= \mathbf{6488.4 \text{ W}}$

d. $P_T = P_1 + P_2 = 6488.4 \text{ W} + 6488.4 \text{ W}$
 $= \mathbf{12,976.8 \text{ W}}$

49. a. $V_\phi = E_\phi = \frac{E_L}{\sqrt{3}} = 120.09 \text{ V}$

b. $I_{an} = \frac{V_{an}}{Z_{an}} = \frac{120.09 \text{ V}}{14.142 \Omega} = 8.49 \text{ A}$

$$I_{bn} = \frac{V_{bn}}{Z_{bn}} = \frac{120.09 \text{ V}}{16.971 \Omega} = 7.08 \text{ A}$$

$$I_{cn} = \frac{V_{cn}}{Z_{cn}} = \frac{120.09 \text{ V}}{2.828 \Omega} = 42.47 \text{ A}$$

c. $P_T = I_{an}^2 10 \Omega + I_{bn}^2 12 \Omega + I_{cn}^2 2 \Omega$
 $= (8.49 \text{ A})^2 10 \Omega + (7.08 \text{ A})^2 12 \Omega + (42.47 \text{ A})^2 2 \Omega$
 $= 720.80 \text{ W} + 601.52 \text{ W} + 3.61 \text{ kW}$
 $= 4.93 \text{ kW}$

$$Q_T = P_T = 4.93 \text{ kVAR}(L)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 6.97 \text{ kVA}$$

$$F_p = \frac{P_T}{S_T} = 0.707 \text{ (lagging)}$$

d. $\mathbf{E}_{an} = 120.09 \text{ V} \angle -30^\circ, \mathbf{E}_{bn} = 120.09 \text{ V} \angle -150^\circ, \mathbf{E}_{cn} = 120.09 \text{ V} \angle 90^\circ$

$$\mathbf{I}_{an} = \frac{\mathbf{E}_{an}}{\mathbf{Z}_{an}} = \frac{120.09 \text{ V} \angle -30^\circ}{10 \Omega + j10 \Omega} = \frac{120.09 \text{ V} \angle -30^\circ}{14.142 \Omega \angle 45^\circ} = 8.49 \text{ A} \angle -75^\circ$$

$$\mathbf{I}_{bn} = \frac{\mathbf{E}_{bn}}{\mathbf{Z}_{bn}} = \frac{120.09 \text{ V} \angle -150^\circ}{12 \Omega + j12 \Omega} = \frac{120.09 \text{ V} \angle -150^\circ}{16.971 \Omega \angle 45^\circ} = 7.08 \text{ A} \angle -195^\circ$$

$$\mathbf{I}_{cn} = \frac{\mathbf{E}_{cn}}{\mathbf{Z}_{cn}} = \frac{120.09 \text{ V} \angle 90^\circ}{2 \Omega + j2 \Omega} = \frac{120.09 \text{ V} \angle 90^\circ}{2.828 \Omega \angle 45^\circ} = 42.47 \text{ A} \angle 45^\circ$$

e. $\mathbf{I}_N = \mathbf{I}_{an} + \mathbf{I}_{bn} + \mathbf{I}_{cn}$

$$\begin{aligned} &= 8.49 \text{ A} \angle -75^\circ + 7.08 \text{ A} \angle -195^\circ + 42.47 \text{ A} \angle 45^\circ \\ &= (2.02 \text{ A} - j8.20 \text{ A}) + (-6.84 \text{ A} + j1.83 \text{ A}) + (30.30 \text{ A} + j30.30 \text{ A}) \\ &= 25.66 \text{ A} - j23.93 \text{ A} \\ &= 35.09 \text{ A} \angle -43.00^\circ \end{aligned}$$

50. $\mathbf{Z}_1 = 12 \Omega - j16 \Omega = 20 \Omega \angle -53.13^\circ, \mathbf{Z}_2 = 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ$
 $\mathbf{Z}_3 = 20 \Omega \angle 0^\circ$

$$\mathbf{E}_{AB} = 200 \text{ V} \angle 0^\circ, \mathbf{E}_{BC} = 200 \text{ V} \angle -120^\circ, \mathbf{E}_{CA} = 200 \text{ V} \angle 120^\circ$$

$$\begin{aligned} \mathbf{Z}_\Delta &= \mathbf{Z}_1 \mathbf{Z}_2 + \mathbf{Z}_1 \mathbf{Z}_3 + \mathbf{Z}_2 \mathbf{Z}_3 \\ &= (20 \Omega \angle -53.13^\circ)(5 \Omega \angle 53.13^\circ) + (20 \Omega \angle -53.13^\circ)(20 \Omega \angle 0^\circ) \\ &\quad + (5 \Omega \angle 53.13^\circ)(20 \Omega \angle 0^\circ) \\ &= 100 \Omega \angle 0^\circ + 400 \Omega \angle -53.13^\circ + 100 \Omega \angle 53.13^\circ \\ &= 100 \Omega + (240 \Omega - j320 \Omega) + (60 \Omega + j80 \Omega) \\ &= 400 \Omega - j240 \Omega \\ &= 466.48 \Omega \angle -30.96^\circ \end{aligned}$$

$$\mathbf{I}_{an} = \frac{\mathbf{E}_{AB}\mathbf{Z}_3 - \mathbf{E}_{CA}\mathbf{Z}_2}{\mathbf{Z}_\Delta} = \frac{(200 \text{ V} \angle 0^\circ)(20 \Omega \angle 0^\circ) - (200 \text{ V} \angle 120^\circ)(5 \Omega \angle 53.13^\circ)}{\mathbf{Z}_\Delta}$$

$$= \frac{4000 \text{ A} \angle 0^\circ - 1000 \text{ A} \angle 173.13^\circ}{466.48 \angle -30.96^\circ} = \mathbf{10.71 \text{ A} \angle 29.59^\circ}$$

$$\mathbf{I}_{bn} = \frac{\mathbf{E}_{BC}\mathbf{Z}_1 - \mathbf{E}_{AB}\mathbf{Z}_3}{\mathbf{Z}_\Delta} = \frac{(200 \text{ V} \angle -120^\circ)(20 \Omega \angle -53.13^\circ) - (200 \text{ V} \angle 0^\circ)(20 \Omega \angle 0^\circ)}{\mathbf{Z}_\Delta}$$

$$= \frac{4000 \text{ A} \angle -173.13^\circ - 4000 \text{ A} \angle 0^\circ}{466.48 \angle -30.96^\circ} = \mathbf{17.12 \text{ A} \angle -145.61^\circ}$$

$$\mathbf{I}_{cn} = \frac{\mathbf{E}_{CA}\mathbf{Z}_2 - \mathbf{E}_{BC}\mathbf{Z}_1}{\mathbf{Z}_\Delta} = \frac{(200 \text{ V} \angle 120^\circ)(5 \Omega \angle 53.13^\circ) - (200 \text{ V} \angle -120^\circ)(20 \Omega \angle -53.13^\circ)}{\mathbf{Z}_\Delta}$$

$$= \frac{1000 \text{ A} \angle 173.13^\circ - 4000 \text{ A} \angle -173.13^\circ}{466.48 \angle -30.96^\circ} = \mathbf{6.51 \text{ A} \angle 42.32^\circ}$$

$$P_T = I_{an}^2 12 \Omega + I_{bn}^2 4 \Omega + I_{cn}^2 20 \Omega$$

$$= 1376.45 \text{ W} + 1172.38 \text{ W} + 847.60 \text{ W} = \mathbf{3396.43 \text{ W}}$$

$$Q_T = I_{an}^2 16 \Omega + I_{bn}^2 3 \Omega = 1835.27 \text{ VAR}(C) + 879.28 \text{ VAR}(L) = \mathbf{955.99 \text{ VAR}(C)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3508.40 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{3396.43 \text{ W}}{3508.40 \text{ VA}} = \mathbf{0.968 \text{ (leading)}}$$

Chapter 24

1. a. **positive-going** b. $V_b = 2 \text{ V}$ c. $t_p = 0.2 \text{ ms}$

d. Amplitude = $8 \text{ V} - 2 \text{ V} = 6 \text{ V}$

e. % tilt = $\frac{V_1 - V_2}{V} \times 100\%$

$$V = \frac{8 \text{ V} + 7.5 \text{ V}}{2} = 7.75 \text{ V}$$

$$\% \text{ tilt} = \frac{8 \text{ V} - 7.5 \text{ V}}{7.75 \text{ V}} \times 100\% = 6.5\%$$

2. a. **negative-going** b. $+7 \text{ mV}$ c. $3 \mu\text{s}$

d. -8 mV (from base line level)

e. $V = \frac{-8 \text{ mV} - 7 \text{ mV}}{2} = \frac{-15 \text{ mV}}{2} = -7.5 \text{ mV}$

$$\% \text{ Tilt} = \frac{V_1 - V_2}{V} \times 100\% = \frac{-8 \text{ mV} - (-7 \text{ mV})}{-7.5 \text{ mV}} \times 100\%$$

$$= \frac{-1 \text{ mV}}{-7.5 \text{ mV}} \times 100\% = 13.3\%$$

f. $T = 15 \mu\text{s} - 7 \mu\text{s} = 8 \mu\text{s}$

$$\text{prf} = \frac{1}{T} = \frac{1}{8 \mu\text{s}} = 125 \text{ kHz}$$

g. Duty cycle = $\frac{t_p}{T} \times 100\% = \frac{3 \mu\text{s}}{8 \mu\text{s}} \times 100\% = 37.5\%$

3. a. **positive-going** b. $V_b = 10 \text{ mV}$ c. $t_p = \left(\frac{8}{10}\right)4 \text{ ms} = 3.2 \text{ ms}$

d. Amplitude = $(30 - 10)\text{mV} = 20 \text{ mV}$

e. % tilt = $\frac{V_1 - V_2}{V} \times 100\%$

$$V = \frac{30 \text{ mV} + 28 \text{ mV}}{2} = 29 \text{ mV}$$

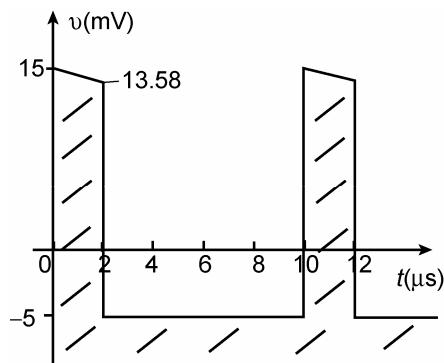
$$\% \text{ tilt} = \frac{30 \text{ mV} - 28 \text{ mV}}{29 \text{ mV}} \times 100\% \approx 6.9\%$$

4. $t_r \cong (0.2 \text{ div.})(2 \text{ ms/div.}) = \mathbf{0.4 \text{ ms}}$
 $t_f \cong (0.4 \text{ div.})(2 \text{ ms/div.}) = \mathbf{0.8 \text{ ms}}$

5. $\text{tilt} = \frac{V_1 - V_2}{V} = 0.1 \text{ with } V = \frac{V_1 + V_2}{2}$

Substituting V into top equation,

$$\frac{\frac{V_1 - V_2}{V_1 + V_2}}{2} = 0.1 \text{ leading to } V_2 = \frac{0.95 V_1}{1.05} \text{ or } V_2 = 0.905(15 \text{ mV}) = 13.58 \text{ mV}$$



6. a. $t_r = 80\% \text{ of straight line segment}$
 $= 0.8(2 \mu\text{s}) = \mathbf{1.6 \mu\text{s}}$

b. $t_f = 80\% \text{ of } 4 \mu\text{s interval}$
 $= 0.8(4 \mu\text{s}) = \mathbf{3.2 \mu\text{s}}$

c. At 50% level (10 mV)
 $t_p = (8 - 1)\mu\text{s} = \mathbf{7 \mu\text{s}}$

d. $\text{prf} = \frac{1}{T} = \frac{1}{20 \mu\text{s}} = \mathbf{50 \text{ kHz}}$

7. a. $T = (4.8 - 2.4)\text{div.}[50 \mu\text{s/div.}] = \mathbf{120 \mu\text{s}}$ b. $f = \frac{1}{T} = \frac{1}{120 \mu\text{s}} = 8.33 \text{ kHz}$
c. Maximum Amplitude: $(2.2 \text{ div.})(0.2 \text{ V/div.}) = 0.44 \text{ V} = \mathbf{440 \text{ mV}}$
Minimum Amplitude: $(0.4 \text{ div.})(0.2 \text{ V/div.}) = 0.08 \text{ V} = \mathbf{80 \text{ mV}}$

8. $T = (3.6 - 2.0)\text{ms} = 1.6 \text{ ms}$
 $\text{prf} = \frac{1}{T} = \frac{1}{1.6 \text{ ms}} = \mathbf{625 \text{ Hz}}$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{0.2 \text{ ms}}{1.6 \text{ ms}} \times 100\% = \mathbf{12.5\%}$$

9. $T = (15 - 7)\mu s = 8 \mu s$

$$\text{prf} = \frac{1}{T} = \frac{1}{8 \mu s} = \mathbf{125 \text{ kHz}}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{(20 - 15)\mu s}{8 \mu s} \times 100\% = \frac{5}{8} \times 100\% = \mathbf{62.5\%}$$

10. $T = (3.6 \text{ div.})(2 \text{ ms/div.}) = 7.2 \text{ ms}$

$$\text{prf} = \frac{1}{T} = \frac{1}{7.2 \text{ ms}} = \mathbf{138.89 \text{ Hz}}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{1.6 \text{ div.}}{3.6 \text{ div.}} \times 100\% = \mathbf{44.4\%}$$

11. a. $T = (9 - 1)\mu s = \mathbf{8 \mu s}$

b. $t_p = (3 - 1)\mu s = \mathbf{2 \mu s}$

c. $\text{prf} = \frac{1}{T} = \frac{1}{8 \mu s} = \mathbf{125 \text{ kHz}}$

d. $V_{av} = (\text{Duty cycle})(\text{Peak value}) + (1 - \text{Duty cycle})(V_b)$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{2 \mu s}{8 \mu s} \times 100\% = 25\%$$

$$V_{av} = (0.25)(6 \text{ mV}) + (1 - 0.25)(-2 \text{ mV}) \\ = 1.5 \text{ mV} - 1.5 \text{ mV} = \mathbf{0 \text{ V}}$$

or

$$V_{av} = \frac{(2 \mu s)(6 \text{ mV}) - (2 \mu s)(6 \text{ mV})}{8 \mu s} = \mathbf{0 \text{ V}}$$

e. $V_{eff} = \sqrt{\frac{(36 \times 10^{-6})(2 \mu s) + (4 \times 10^{-6})(6 \mu s)}{8 \mu s}} = \mathbf{3.46 \text{ mV}}$

12. Eq. 24.5 cannot be applied due to tilt in the waveform.

(Method of Section 13.6)

Between 2 and 3.6 ms

$$V_{av} = \frac{(3.4 \text{ ms} - 2 \text{ ms})(2 \text{ V}) + (3.6 \text{ ms} - 3.4 \text{ ms})(7.5 \text{ V}) + \frac{1}{2}(3.6 \text{ ms} - 3.4 \text{ ms})(0.5 \text{ V})}{3.6 \text{ ms} - 2 \text{ ms}} \\ = \frac{(1.4 \text{ ms})(2 \text{ V}) + (0.2 \text{ ms})(7.5 \text{ V}) + \frac{1}{2}(0.2 \text{ ms})(0.5 \text{ V})}{1.6 \text{ ms}} \\ = \frac{2.8 \text{ V} + 1.5 \text{ V} + 0.05 \text{ V}}{1.6} = \mathbf{2.719 \text{ V}}$$

13. Ignoring tilt and using 20 mV level to define t_p

$$t_p = (2.8 \text{ div.} - 1.2 \text{ div.})(2 \text{ ms/div.}) = 3.2 \text{ ms}$$

$$T = (\text{at } 10 \text{ mV level}) = (4.6 \text{ div.} - 1 \text{ div.})(2 \text{ ms/div.}) = 7.2 \text{ ms}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{3.2 \text{ ms}}{7.2 \text{ ms}} \times 100\% = 44.4\%$$

$$\begin{aligned} V_{av} &= (\text{Duty cycle})(\text{peak value}) + (1 - \text{Duty cycle})(V_b) \\ &= (0.444)(30 \text{ mV}) + (1 - 0.444)(10 \text{ mV}) \\ &= 13.320 \text{ mV} + 5.560 \text{ mV} \\ &= \mathbf{18.88 \text{ mV}} \end{aligned}$$

14. $V_{av} = (\text{Duty cycle})(\text{Peak value}) + (1 - \text{Duty cycle})(V_b)$

$$\text{Duty cycle} = \frac{t_p}{T} \text{ (decimal form)}$$

$$= \frac{(8-1)\mu\text{s}}{20 \mu\text{s}} = 0.35$$

$$\begin{aligned} V_{av} &= (0.35)(20 \text{ mV}) + (1 - 0.35)(0) \\ &= 7 \text{ mV} + 0 \\ &= \mathbf{7 \text{ mV}} \end{aligned}$$

15. Using methods of Section 13.8:

$$A_1 = b_1 h_1 = [(0.2 \text{ div.})(50 \mu\text{s/div.})][(2 \text{ div.})(0.2 \text{ V/div.})] = 4 \mu\text{sV}$$

$$A_2 = b_2 h_2 = [(0.2 \text{ div.})(50 \mu\text{s/div.})][(2.2 \text{ div.})(0.2 \text{ V/div.})] = 4.4 \mu\text{sV}$$

$$A_3 = b_3 h_3 = [(0.2 \text{ div.})(50 \mu\text{s/div.})][(1.4 \text{ div.})(0.2 \text{ V/div.})] = 2.8 \mu\text{sV}$$

$$A_4 = b_4 h_4 = [(0.2 \text{ div.})(50 \mu\text{s/div.})][(1 \text{ div.})(0.2 \text{ V/div.})] = 2.0 \mu\text{sV}$$

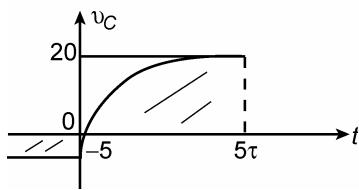
$$A_5 = b_5 h_5 = [(0.2 \text{ div.})(50 \mu\text{s/div.})][(0.4 \text{ div.})(0.2 \text{ V/div.})] = 0.8 \mu\text{sV}$$

$$V_{av} = \frac{(4 + 4.4 + 2.8 + 2.0 + 0.8)\mu\text{sV}}{120 \mu\text{s}} = \mathbf{117 \text{ mV}}$$

16. Using the defined polarity of Fig. 24.57 for v_C , $V_i = -5 \text{ V}$, $V_f = +20 \text{ V}$ and $\tau = RC = (10 \text{ k}\Omega)(0.02 \mu\text{F}) = 0.2 \text{ ms}$

$$\begin{aligned} \text{a. } v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= -5 + (20 - (-5))(1 - e^{-t/0.2 \text{ ms}}) \\ &= -5 + 25(1 - e^{-t/0.2 \text{ ms}}) \\ &= -5 + 25 - 25e^{-t/0.2 \text{ ms}} \\ v_C &= \mathbf{20 \text{ V} - 25 \text{ V}e^{-t/0.2 \text{ ms}}} \end{aligned}$$

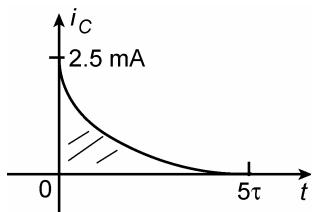
b.



c. $I_i = 0$

$$i_C = \frac{E - v_C}{R} = \frac{20 \text{ V} - [20 \text{ V} - 25 \text{ V} e^{-t/0.2 \text{ ms}}]}{10 \text{ k}\Omega} = 2.5 \text{ mA} e^{-t/0.2 \text{ ms}}$$

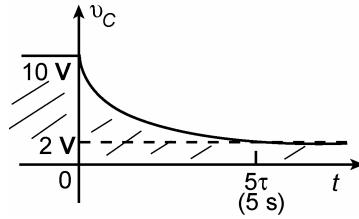
d.



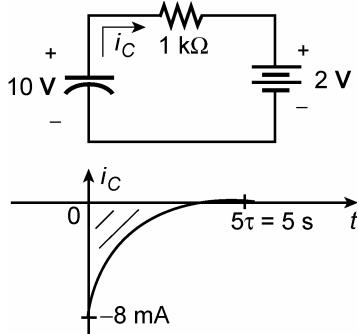
$$\begin{aligned} 17. \quad v_C &= V_i + (V_f - V_i)(1 - e^{-t/RC}) & \tau &= RC = (2 \text{ k}\Omega)(10 \mu\text{F}) \\ &= 8 + (4 - 8)(1 - e^{-t/20 \text{ ms}}) & &= 20 \text{ ms} \\ &= 8 - 4(1 - e^{-t/20 \text{ ms}}) \\ &= 8 - 4 + 4e^{-t/20 \text{ ms}} \\ &= 4 + 4e^{-t/20 \text{ ms}} \\ v_C &= 4 \text{ V}(1 + e^{-t/20 \text{ ms}}) \end{aligned}$$

18. $V_i = 10 \text{ V}, V_f = 2 \text{ V}, \tau = RC = (1 \text{ k}\Omega)(1000 \mu\text{F}) = 1 \text{ s}$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= 10 \text{ V} + (2 \text{ V} - 10 \text{ V})(1 - e^{-t}) \\ &= 10 - 8(1 - e^{-t}) \\ &= 10 - 8 + 8e^{-t} \\ v_C &= 2 \text{ V} + 8 \text{ V} e^{-t} \end{aligned}$$



19. $V_i = 10 \text{ V}, I_i = 0 \text{ A}$



Using the defined direction of i_C

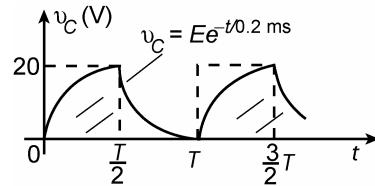
$$\begin{aligned} i_C &= \frac{-(10 \text{ V} - 2 \text{ V})}{1 \text{ k}\Omega} e^{-t/\tau} \\ \tau &= RC = (1 \text{ k}\Omega)(1000 \mu\text{F}) = 1 \text{ s} \\ i_C &= -\frac{8 \text{ V}}{1 \text{ k}\Omega} e^{-t} \\ \text{and } i_C &= -8 \text{ mA} e^{-t} \end{aligned}$$

20. $\tau = RC = (5 \text{ k}\Omega)(0.04 \mu\text{F}) = 0.2 \text{ ms}$ (throughout)
 $v_C = E(1 - e^{-t/\tau}) = 20 \text{ V}(1 - e^{-t/0.2 \text{ ms}})$
(Starting at $t = 0$ for each plot)

a. $T = \frac{1}{f} = \frac{1}{500 \text{ Hz}} = 2 \text{ ms}$

$$\frac{T}{2} = 1 \text{ ms}$$

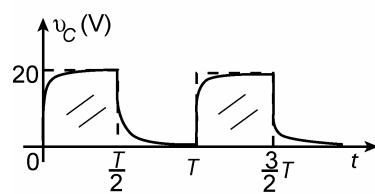
$$5\tau = 1 \text{ ms} = \frac{T}{2}$$



b. $T = \frac{1}{f} = \frac{1}{100 \text{ Hz}} = 10 \text{ ms}$

$$\frac{T}{2} = 5 \text{ ms}$$

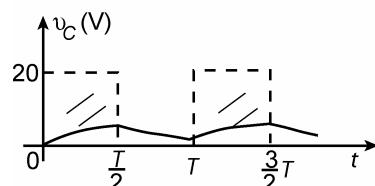
$$5\tau = 1 \text{ ms} = \frac{1}{5} \left(\frac{T}{2} \right)$$



c. $T = \frac{1}{f} = \frac{1}{5 \text{ Hz}} = 0.2 \text{ ms}$

$$\frac{T}{2} = 0.1 \text{ ms}$$

$$5\tau = 1 \text{ ms} = 10 \left(\frac{T}{2} \right)$$



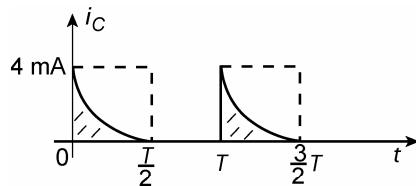
21. The mathematical expression for i_C is the same for each frequency!

$$\tau = RC = (5 \text{ k}\Omega)(0.04 \mu\text{F}) = 0.2 \text{ ms}$$

and $i_C = \frac{20 \text{ V}}{5 \text{ k}\Omega} e^{-t/0.2 \text{ ms}} = 4 \text{ mA} e^{-t/0.2 \text{ ms}}$

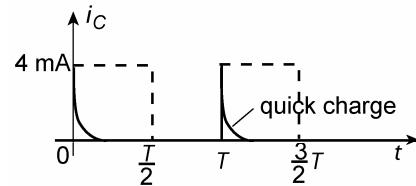
a. $T = \frac{1}{500 \text{ Hz}} = 2 \text{ ms}, \frac{T}{2} = 1 \text{ ms}$

$$5\tau = 5(0.2 \text{ ms}) = 1 \text{ ms} = \frac{T}{2}$$



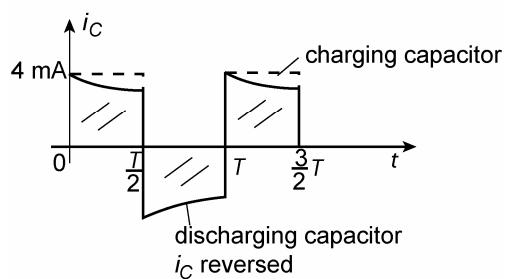
b. $T = \frac{1}{100 \text{ Hz}} = 10 \text{ ms}, \frac{T}{2} = 5 \text{ ms}$

$$5\tau = 1 \text{ ms} = \frac{1}{5} \left(\frac{T}{2} \right)$$



c. $T = \frac{1}{5000 \text{ Hz}} = 0.2 \text{ ms}, \frac{T}{2} = 0.1 \text{ ms}$

$$5\tau = 1 \text{ ms} = 10 \left(\frac{T}{2} \right)$$



22. $\tau = 0.2 \text{ ms}$ as above

$$T = \frac{1}{500 \text{ Hz}} = 2 \text{ ms}$$

$$5\tau = 1 \text{ ms} = \frac{T}{2}$$

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

$$\frac{T}{2} \rightarrow T : V_i = 20 \text{ V}, V_f = -20 \text{ V}$$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= 20 + (-20 - 20)(1 - e^{-t/0.2 \text{ ms}}) \\ &= 20 - 40(1 - e^{-t/0.2 \text{ ms}}) \\ &= 20 - 40 + 40e^{-t/0.2 \text{ ms}} \\ v_C &= \mathbf{-20 \text{ V} + 40 \text{ V}e^{-t/0.2 \text{ ms}}} \end{aligned}$$

$$T \rightarrow \frac{3}{2}T : V_i = -20 \text{ V}, V_f = +20 \text{ V}$$

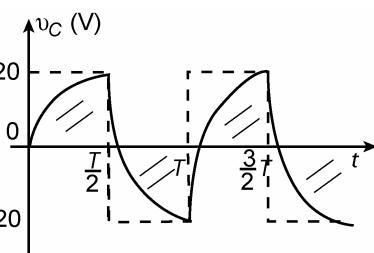
$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= -20 + (20 - (-20))(1 - e^{-t/\tau}) \\ &= -20 + 40(1 - e^{-t/\tau}) \\ &= -20 + 40 - 40e^{-t/\tau} \\ v_C &= \mathbf{20 \text{ V} - 40 \text{ V}e^{-t/0.2 \text{ ms}}} \end{aligned}$$

23. $v_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$

$$V_i = 20 \text{ V}, V_f = 20 \text{ V}$$

$$\begin{aligned} v_C &= 20 + (20 - 20)(1 - e^{-t/RC}) \\ &= \mathbf{20 \text{ V}} \text{ (for } 0 \rightarrow \frac{T}{2} \text{)} \end{aligned}$$

$$\text{For } \frac{T}{2} \rightarrow T, v_i = 0 \text{ V and } v_C = \mathbf{20 \text{ V}e^{-t/\tau}}$$



$$\tau = RC = 0.2 \text{ ms}$$

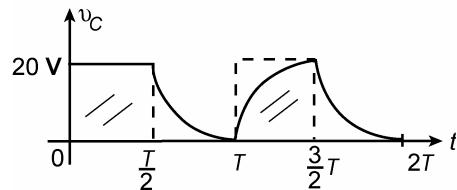
$$\text{with } \frac{T}{2} = 1 \text{ ms and } 5\tau = \frac{T}{2}$$

$$\text{For } T \rightarrow \frac{3}{2}T, v_i = 20 \text{ V}$$

$$v_C = \mathbf{20 \text{ V}(1 - e^{-t/\tau})}$$

$$\text{For } \frac{3}{2}T \rightarrow 2T, v_i = 0 \text{ V}$$

$$v_C = \mathbf{20 \text{ V}e^{-t/\tau}}$$



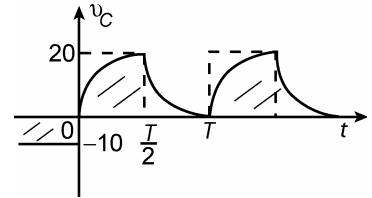
24. $\tau = RC = 0.2 \text{ ms}$

$$5\tau = 1 \text{ ms} = \frac{T}{2}$$

$$V_i = -10 \text{ V}, V_f = +20 \text{ V}$$

$$0 \rightarrow \frac{T}{2}:$$

$$\begin{aligned} v_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau}) \\ &= -10 + (20 - (-10))(1 - e^{-t/0.2}) \\ &= -10 + 30(1 - e^{-t/0.2}) \\ &= -10 + 30 - 30e^{-t/0.2} \\ v_C &= +20 \text{ V} - 30 \text{ V} e^{-t/0.2 \text{ ms}} \end{aligned}$$



$$\frac{T}{2} \rightarrow T: \quad V_i = 20 \text{ V}, V_f = 0 \text{ V}$$

$$v_C = 20 \text{ V} e^{-t/0.2 \text{ ms}}$$

25. $\mathbf{Z}_p:$ $X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(10 \text{ kHz})(3 \text{ pF})} = 5.31 \text{ M}\Omega$

$$\mathbf{Z}_p = \frac{(9 \text{ M}\Omega \angle 0^\circ)(5.31 \text{ M}\Omega \angle -90^\circ)}{9 \text{ M}\Omega - j5.31 \text{ M}\Omega} = 4.573 \text{ M}\Omega \angle -59.5^\circ$$

$\mathbf{Z}_s:$ $C_T = 18 \text{ pF} + 9 \text{ pF} = 27 \text{ pF}$

$$X_C = \frac{1}{2\pi f C_T} = \frac{1}{2\pi(10 \text{ kHz})(27 \text{ pF})} = 0.589 \text{ M}\Omega$$

$$\mathbf{Z}_s = \frac{(1 \text{ M}\Omega \angle 0^\circ)(0.589 \text{ M}\Omega \angle -90^\circ)}{1 \text{ M}\Omega - j0.589 \text{ M}\Omega} = 0.507 \text{ M}\Omega \angle -59.5^\circ$$

$$\begin{aligned} \mathbf{V}_{\text{scope}} &= \frac{\mathbf{Z}_s \mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.507 \text{ M}\Omega \angle -59.5^\circ)(100 \text{ V} \angle 0^\circ)}{(0.257 \text{ M}\Omega - j0.437 \text{ M}\Omega) + (2.324 \text{ M}\Omega - j3.939 \text{ M}\Omega)} \\ &= \frac{50.7 \times 10^6 \text{ V} \angle -59.5^\circ}{5.07 \times 10^6 \angle -59.5^\circ} = 10 \text{ V} \angle 0^\circ = \frac{1}{10}(100 \text{ V} \angle 0^\circ) \end{aligned}$$

$$\theta_{\mathbf{Z}_s} = \theta_{\mathbf{Z}_p} = -59.5^\circ$$

26. $\mathbf{Z}_p:$ $X_C = \frac{1}{\omega C} = \frac{1}{(10^5 \text{ rad/s})(3 \text{ pF})} = 3.333 \text{ M}\Omega$

$$\mathbf{Z}_p = \frac{(9 \text{ M}\Omega \angle 0^\circ)(3.333 \text{ M}\Omega)}{9 \text{ M}\Omega - j3.333 \text{ M}\Omega} = 3.126 \text{ M}\Omega \angle -69.68^\circ$$

$\mathbf{Z}_s:$ $X_C = \frac{1}{\omega C} = \frac{1}{(10^5 \text{ rad/s})(27 \text{ pF})} = 0.370 \text{ M}\Omega$

$$\mathbf{Z}_s = \frac{(1 \text{ M}\Omega \angle 0^\circ)(0.370 \text{ M}\Omega \angle -90^\circ)}{1 \text{ M}\Omega - j0.370 \text{ M}\Omega} = 0.347 \text{ M}\Omega \angle -69.68^\circ$$

$$\checkmark \theta_{\mathbf{Z}_p} = \theta_{\mathbf{Z}_s}$$

$$\begin{aligned}
\mathbf{V}_{\text{scope}} &= \frac{\mathbf{Z}_s \mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.347 \text{ M}\Omega \angle -69.68^\circ)(100 \text{ V} \angle 0^\circ)}{(0.121 \text{ M}\Omega - j0.325 \text{ M}\Omega) + (1.086 \text{ M}\Omega - j2.931 \text{ M}\Omega)} \\
&= \frac{34.70 \times 10^6 \text{ V} \angle -69.68^\circ}{3.470 \times 10^6 \angle -69.68^\circ} \\
&\approx \mathbf{10 \text{ V} \angle 0^\circ} = \frac{1}{10}(100 \text{ V} \angle 0^\circ)
\end{aligned}$$

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

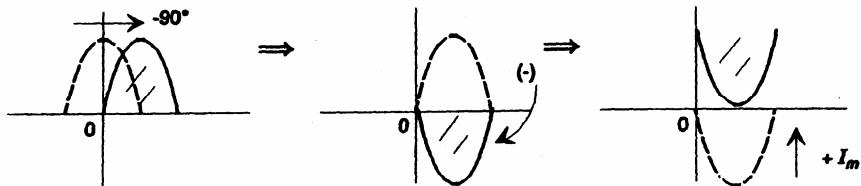
III: a. yes b. yes c. no d. yes e. yes

IV: a. no b. no c. yes d. yes e. yes

2. b. $i = \frac{2I_m}{\pi} \left(1 + \frac{2}{3} \cos(2\omega t - 90^\circ) - \frac{2}{15} \cos(4\omega t - 90^\circ) + \frac{2}{35} \cos(6\omega t - 90^\circ) + \dots \right)$

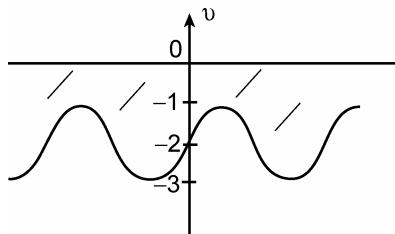
c. $\frac{2I_m}{\pi} - \frac{I_m}{2} = \frac{2I_m}{\pi} \left[1 - \frac{\pi}{4} \right]$
 $i = \frac{2I_m}{\pi} \left[1 - \frac{\pi}{4} + \frac{2}{3} \cos(2\omega t - 90^\circ) - \frac{2}{15} \cos(4\omega t - 90^\circ) + \frac{2}{35} \cos(6\omega t - 90^\circ) + \dots \right]$

d.

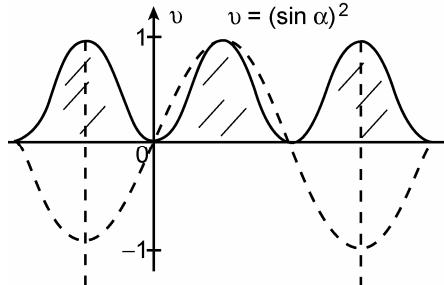


$$i = \frac{-2I_m}{\pi} \left[1 - \frac{\pi}{4} + \frac{2}{3} \cos(2\omega t - 90^\circ) - \frac{2}{15} \cos(4\omega t - 90^\circ) + \frac{2}{35} \cos(6\omega t - 90^\circ) + \dots \right]$$

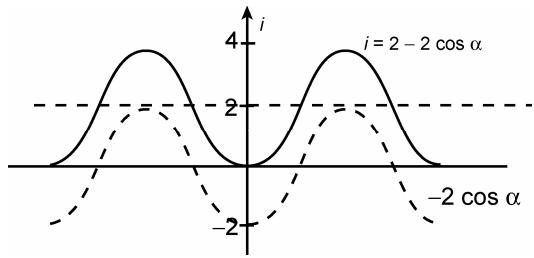
3. a. $v = -4 + 2 \sin \alpha$



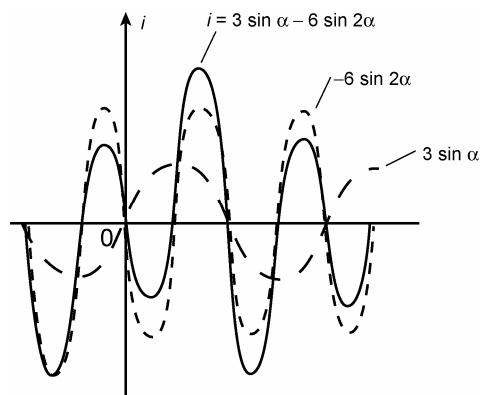
b. $v = (\sin \alpha)^2$



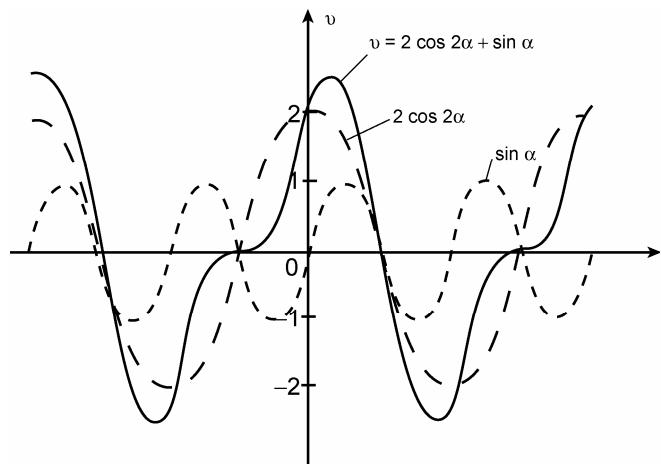
c. $i = 2 - 2 \cos \alpha$



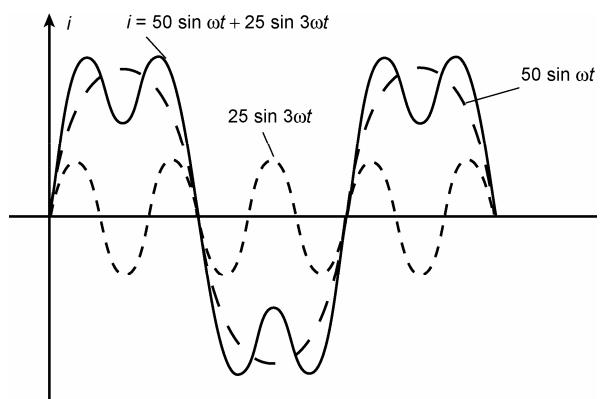
4. a.



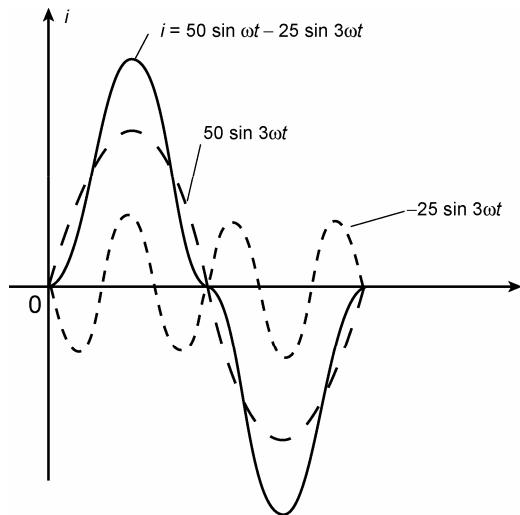
b.



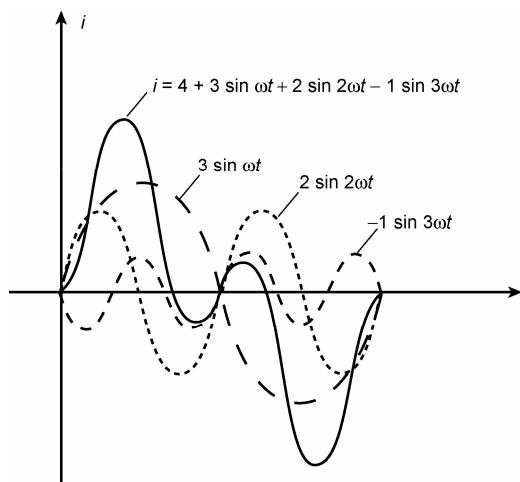
5. a.



b.



c.



6. a. $V_{av} = \mathbf{100\ V}$

$$V_{eff} = \sqrt{(100\ V)^2 + \frac{(50\ V)^2 + (25\ V)^2}{2}} = \mathbf{107.53\ V}$$
- b. $I_{av} = \mathbf{3\ A}$

$$I_{eff} = \sqrt{(3\ A)^2 + \frac{(2\ A)^2 + (0.8\ A)^2}{2}} = \mathbf{3.36\ A}$$
7. a. $V_{eff} = \sqrt{\frac{(20\ V)^2 + (15\ V)^2 + (10\ V)^2}{2}} = \mathbf{19.04\ V}$
- b. $I_{eff} = \sqrt{\frac{(6\ A)^2 + (2\ A)^2 + (1\ A)^2}{2}} = \mathbf{4.53\ A}$
8. $P_T = V_0 I_0 + V_1 I_1 \cos \theta_1 + \dots + V_n I_n \cos \theta_n$
 $= (100\ V)(3\ A) + \frac{(50\ V)(2\ A)}{2} \cos 53^\circ + \frac{(25\ V)(0.8\ A)}{2} \cos 70^\circ$
 $= 300 + (50)(0.6018) + (10)(0.3420)$
 $= \mathbf{333.52\ W}$
9. $P = \frac{(20\ V)(6\ A)}{2} \cos 20^\circ + \frac{(15\ V)(2\ A)}{2} \cos 30^\circ + \frac{(10\ V)(1\ A)}{2} \cos 60^\circ$
 $= 60(0.9397) + 15(0.866) + 5(0.5)$
 $= \mathbf{71.87\ W}$
10. a. DC: $E = 18\ V, I_o = \frac{E}{R} = \frac{18\ V}{12\ \Omega} = 1.5\ A$
 $\omega = 400\ rad/s: \quad X_L = \omega L = (400\ rad/s)(0.02\ H) = 8\ \Omega$
 $\mathbf{Z} = 12\ \Omega + j8\ \Omega = 14.42\ \Omega \angle 33.69^\circ$
 $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{30\ V/\sqrt{2} \angle 0^\circ}{14.42\ \Omega \angle 33.69^\circ} = \frac{2.08\ A}{\sqrt{2}} \angle -33.69^\circ$
 $i = 1.5 + \sqrt{2} \left(\frac{2.08}{\sqrt{2}} \right) \sin(400t - 33.69^\circ)$
 $i = \mathbf{1.5 + 2.08 \sin(400t - 33.69^\circ)}$
- b. $I_{eff} = \sqrt{(1.5\ A)^2 + \frac{(2.08\ A)^2}{2}} = \mathbf{2.10\ A}$

c. DC: $v_R = E = 18 \text{ V}$, $\mathbf{V}_R = \left(\frac{2.08 \text{ A}}{\sqrt{2}} \angle -33.69^\circ \right) (12 \Omega \angle 0^\circ)$
 $= \frac{24.96 \text{ V}}{\sqrt{2}} \angle -33.69^\circ$

$$v_R = 18 + \sqrt{2} \left(\frac{24.96}{\sqrt{2}} \right) \sin(400t - 33.69^\circ)$$

$$v_R = \mathbf{18 + 24.96 \sin(400t - 33.69^\circ)}$$

d. $V_{R_{\text{eff}}} = \sqrt{(18 \text{ V})^2 + \frac{(24.96 \text{ V})^2}{2}} = \mathbf{25.21 \text{ V}}$

e. DC: $V_L = 0 \text{ V}$

$$\omega = 400 \text{ rad/s: } \mathbf{V}_L = \left(\frac{2.08 \text{ A}}{\sqrt{2}} \angle -33.69^\circ \right) (8 \Omega \angle 90^\circ)$$

$$= \frac{16.64 \text{ A}}{\sqrt{2}} \angle 56.31^\circ$$

$$v_L = \mathbf{0 + 16.64 \sin(400t + 56.31^\circ)}$$

f. $V_{L_{\text{eff}}} = \sqrt{0^2 + \frac{(16.64 \text{ V})^2}{2}} = \mathbf{11.77 \text{ V}}$

g. $P = I_{\text{eff}}^2 R = (2.101 \text{ A})^2 12 \Omega = \mathbf{52.97 \text{ W}}$

11. a. DC: $I_{\text{DC}} = \frac{24 \text{ V}}{12 \Omega} = 2 \text{ A}$

$\omega = 400 \text{ rad/s:}$

$$\mathbf{Z} = 12 \Omega + j(400 \text{ rad/s})(0.02 \text{ H}) = 12 \Omega + j8 \Omega = 14.422 \Omega \angle 33.69^\circ$$

$$\mathbf{I} = \frac{30 \text{ V} \angle 0^\circ}{14.422 \Omega \angle 33.69^\circ} = 2.08 \text{ A} \angle -33.69^\circ \text{ (peak values)}$$

$\omega = 800 \text{ rad/s:}$

$$\mathbf{Z} = 12 \Omega + j(800 \text{ rad/s})(0.02 \text{ H}) = 12 \Omega + j16 \Omega = 20 \Omega \angle 53.13^\circ$$

$$\mathbf{I} = \frac{10 \text{ V} \angle 0^\circ}{20 \Omega \angle 53.13^\circ} = 0.5 \text{ A} \angle -53.13^\circ \text{ (peak values)}$$

$$i = \mathbf{2 + 2.08 \sin(400t - 33.69^\circ) + 0.5 \sin(800t - 53.13^\circ)}$$

b. $I_{\text{eff}} = \sqrt{(2 \text{ A})^2 + \frac{(2.08 \text{ A})^2 + (0.5 \text{ A}^2)}{2}} = \mathbf{2.51 \text{ A}}$

c. $v_R = iR = i(12 \Omega)$
 $= \mathbf{24 + 24.96 \sin(400t - 33.69^\circ) + 6 \sin(800t - 53.13^\circ)}$

d. $V_{\text{eff}} = \sqrt{(24 \text{ V})^2 + \frac{(24.96 \text{ V})^2 + (6 \text{ V})^2}{2}} = \mathbf{30.09 \text{ V}}$

e. DC: $V_L = 0 \text{ V}$
 $\omega = 400 \text{ rad/s: } \mathbf{V}_L = (2.08 \text{ A} \angle -33.69^\circ)(8 \Omega \angle 90^\circ)$
 $= 16.64 \text{ V} \angle 56.31^\circ$
 $\omega = 800 \text{ rad/s: } \mathbf{V}_L = (0.5 \text{ A} \angle -53.13^\circ)(16 \Omega \angle 90^\circ)$
 $= 8 \text{ V} \angle 36.87^\circ$
 $v_L = 0 + 16.64 \sin(400t + 56.31^\circ) + 8 \sin(800t + 36.87^\circ)$

f. $V_{\text{eff}} = \sqrt{(0)^2 + \frac{(16.64 \text{ V})^2 + (8 \text{ V})^2}{2}} = 13.06 \text{ V}$

g. $P_T = I_{\text{eff}}^2 R = (2.508 \text{ A})^2 12 \Omega = 75.48 \text{ W}$

12. a. DC: $I = -\frac{60 \text{ V}}{12 \Omega} = -5 \text{ A}$
 $\omega = 300 \text{ rad/s: } X_L = \omega L = (300 \text{ rad/s})(0.02 \text{ H}) = 6 \Omega$
 $\mathbf{Z} = 12 \Omega + j16 \Omega = 13.42 \Omega \angle 26.57^\circ$
 $\mathbf{E} = (0.707)(20 \text{ V}) \angle 0^\circ = 14.14 \text{ V} \angle 0^\circ$
 $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{14.14 \text{ V} \angle 0^\circ}{13.42 \Omega \angle 26.57^\circ} = 1.054 \text{ A} \angle -26.57^\circ$
 $\omega = 600 \text{ rad/s: } X_L = \omega L = (600 \text{ rad/s})(0.02 \text{ H}) = 12 \Omega$
 $\mathbf{Z} = 12 \Omega + j12 \Omega = 16.97 \Omega \angle 45^\circ$
 $\mathbf{E} = -(0.707)(10 \text{ V}) \angle 0^\circ = -7.07 \text{ V} \angle 0^\circ$
 $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = -\frac{7.07 \text{ V} \angle 0^\circ}{16.97 \Omega \angle 45^\circ} = -0.417 \text{ A} \angle -45^\circ$
 $i = -5 + (1.414)(1.054)\sin(300t - 26.57^\circ) - (1.414)(0.417)\sin(600t - 45^\circ)$
 $i = -5 + 1.49 \sin(300t - 26.57^\circ) - 0.59 \sin(600t - 45^\circ)$

b. $I_{\text{eff}} = \sqrt{(10 \text{ A})^2 + \frac{(1.49 \text{ A})^2 + (0.59 \text{ A})^2}{2}} = 10.06 \text{ A}$

c. DC: $V = IR = (-5 \text{ A})(12 \Omega) = -60 \text{ V}$
 $\omega = 300 \text{ rad/s: } \mathbf{V}_R = (1.054 \text{ A} \angle -26.57^\circ)(12 \Omega \angle 0^\circ)$
 $= 12.648 \text{ V} \angle -26.57^\circ$
 $\omega = 600 \text{ rad/s: } \mathbf{V}_R = (-0.417 \text{ A} \angle -45^\circ)(12 \Omega \angle 0^\circ)$
 $= -5 \text{ V} \angle -45^\circ$
 $v_R = -60 + (1.414)(12.648)\sin(300t - 26.57^\circ) - (1.414)(5)\sin(600t - 45^\circ)$
 $v_R = -60 + 17.88 \sin(300t - 26.57^\circ) - 7.07 \sin(600t - 45^\circ)$

d. $V_{R_{\text{eff}}} = \sqrt{(60 \text{ V})^2 + \frac{(17.88 \text{ V})^2 + (7.07 \text{ V})^2}{2}} = 61.52 \text{ V}$

e. DC: $V_L = 0 \text{ V}$
 $\omega = 300 \text{ rad/s: } \mathbf{V}_L = (1.054 \text{ A} \angle -26.57^\circ)(6 \Omega \angle 90^\circ) = 6.324 \text{ V} \angle 63.43^\circ$
 $\omega = 600 \text{ rad/s: } \mathbf{V}_L = (-0.417 \text{ A} \angle -45^\circ)(6 \Omega \angle 90^\circ) = -2.502 \text{ V} \angle 45^\circ$
 $v_L = 0 + (1.414)(6.324)\sin(300t + 63.43^\circ) - (1.414)(2.502)\sin(600t + 45^\circ)$
 $v_L = \mathbf{8.94 \sin(300t + 63.43^\circ) - 3.54 \sin(600t + 45^\circ)}$

f. $V_{L_{\text{eff}}} = \sqrt{\frac{(8.94 \text{ V})^2 + (3.54 \text{ V})^2}{2}} = \mathbf{6.8 \text{ V}}$

g. $P = I_{\text{eff}}^2 R = (10.06 \text{ A})^2 12 \Omega = \mathbf{1214.44 \text{ W}}$

13. a. DC: $I = \mathbf{0 \text{ A}}$
 $\omega = 400 \text{ rad/s: } X_C = \frac{1}{\omega C} = \frac{1}{(400 \text{ rad/s})(125 \mu\text{F})} = 20 \Omega$
 $\mathbf{Z} = 15 \Omega - j20 \Omega = 25 \Omega \angle -53.13^\circ$
 $\mathbf{E} = (0.707)(30 \text{ V}) \angle 0^\circ = 21.21 \text{ V} \angle 0^\circ$
 $\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{21.21 \text{ V} \angle 0^\circ}{25 \Omega \angle -53.13^\circ} = 0.848 \text{ A} \angle 53.13^\circ$
 $i = 0 + (1.414)(0.848)\sin(400t + 53.13^\circ)$
 $i = \mathbf{1.2 \sin(400t + 53.13^\circ)}$

b. $I_{\text{eff}} = \sqrt{\frac{(1.2 \text{ A})^2}{2}} = \mathbf{0.85 \text{ A}}$ as above

c. DC: $V_R = 0 \text{ V}$
 $\omega = 400 \text{ rad/s: } \mathbf{V}_R = (0.848 \text{ A} \angle 53.13^\circ)(15 \Omega \angle 0^\circ) = 12.72 \text{ V} \angle 53.13^\circ$
 $v_R = 0 + (1.414)(12.72)\sin(400t + 53.13^\circ)$
 $v_R = \mathbf{18 \sin(400t + 53.13^\circ)}$

d. $V_{R_{\text{eff}}} = \sqrt{\frac{(18 \text{ V})^2}{2}} = \mathbf{12.73 \text{ V}}$

e. DC: $V_C = 18 \text{ V}$
 $\omega = 400 \text{ rad/s: } \mathbf{V}_C = (0.848 \text{ A} \angle 53.13^\circ)(20 \Omega \angle -90^\circ)$
 $= 16.96 \text{ V} \angle -36.87^\circ$
 $v_C = 18 + (1.414)(16.96)\sin(400t - 36.87^\circ)$
 $v_C = \mathbf{18 + 23.98 \sin(400t - 36.87^\circ)}$

f. $V_{C_{\text{eff}}} = \sqrt{(18 \text{ V})^2 + \frac{(23.98 \text{ V})^2}{2}} = \mathbf{24.73 \text{ V}}$

g. $P = I_{\text{eff}}^2 R = (0.848 \text{ A})^2 15 \Omega = \mathbf{10.79 \text{ W}}$

14. a. $e = \frac{200}{\pi} + \frac{400}{3\pi} \cos 2\omega t - \frac{400}{15\pi} \cos 4\omega t$
 $= 63.69 + 42.46 \sin(2\omega t + 90^\circ) - 8.49 \sin(4\omega t + 90^\circ)$
 $\omega = 377 \text{ rad/s:}$
 $e = 63.69 + 42.46 \sin(754t + 90^\circ) - 8.49 \sin(1508t + 90^\circ)$
DC: $X_L = 0 \therefore V_L = 0 \text{ V}$
 $\omega = 754 \text{ rad/s: } X_C = \frac{1}{\omega C} = \frac{1}{(754 \text{ rad/s})(1 \mu\text{F})} = 1330 \Omega$
 $X_L = \omega L = (754 \text{ rad/s})(0.1 \text{ H}) = 75.4 \Omega$
 $\mathbf{Z}' = (1 \text{ k}\Omega \angle 0^\circ) \parallel 75.4 \Omega \angle 90^\circ = 75.19 \Omega \angle 85.69^\circ$
 $\mathbf{E} = (0.707)(42.46 \text{ V}) \angle 90^\circ = 30.02 \text{ V} \angle 90^\circ$
 $\mathbf{V}_o = \frac{\mathbf{Z}'(\mathbf{E})}{\mathbf{Z}' + \mathbf{Z}_C} = \frac{(75.19 \Omega \angle 85.69^\circ)(30.02 \text{ V} \angle 90^\circ)}{75.19 \Omega \angle 85.69^\circ + 1330 \Omega \angle -90^\circ} = 1.799 \text{ V} \angle -94.57^\circ$
 $\omega = 1508 \text{ rad/s: } X_C = \frac{1}{\omega C} = \frac{1}{(1508 \text{ rad/s})(1 \mu\text{F})} = 6631.13 \Omega$
 $X_L = \omega L = (1508 \text{ rad/s})(0.1 \text{ H}) = 150.8 \Omega$
 $\mathbf{Z}' = (1 \text{ k}\Omega \angle 0^\circ) \parallel 150.8 \Omega \angle 90^\circ = 149.12 \Omega \angle 81.42^\circ$
 $\mathbf{E} = (0.707)(8.49 \text{ V}) \angle 90^\circ = 6 \text{ V} \angle 90^\circ$
 $\mathbf{V}_o = \frac{\mathbf{Z}'(\mathbf{E})}{\mathbf{Z}' + \mathbf{Z}_C} = \frac{(149.12 \Omega \angle 81.42^\circ)(6 \text{ V} \angle 90^\circ)}{149.12 \Omega \angle 81.42^\circ + 6631.13 \Omega \angle -90^\circ} = 1.73 \text{ V} \angle -101.1^\circ$
 $v_o = 0 + 1.414(1.799)\sin(754t - 94.57^\circ) - 1.414(1.73)\sin(1508t - 101.1^\circ)$
 $v_o = \mathbf{2.54 \sin(754t - 94.57^\circ) - 2.45 \sin(1508t - 101.1^\circ)}$
- b. $V_{o_{\text{eff}}} = \sqrt{\frac{(2.54 \text{ V})^2 + (2.45 \text{ V})^2}{2}} = \mathbf{2.50 \text{ V}}$
- c. $P = \frac{(V_{\text{eff}})^2}{R} = \frac{(2.50 \text{ V})^2}{1 \text{ k}\Omega} = \mathbf{6.25 \text{ mW}}$
15. $i = 0.318I_m + 0.500 I_m \sin \omega t - 0.212I_m \cos 2\omega t - 0.0424I_m \cos 4\omega t + \dots$ ($I_m = 10 \text{ mA}$)
 $i = 3.18 \times 10^{-3} + 5 \times 10^{-3} \sin \omega t - 2.12 \times 10^{-3} \sin(2\omega t + 90^\circ)$
 $- 0.424 \times 10^{-3} \sin(4\omega t + 90^\circ) + \dots$
 $i \approx 3.18 \times 10^{-3} + 5 \times 10^{-3} \sin \omega t - 2.12 \times 10^{-3} \sin(2\omega t + 90^\circ)$
DC: $I_o = 0 \text{ A}, V_o = 0 \text{ V}$
 $\omega = 377 \text{ rad/s: } X_L = \omega L = (377 \text{ rad/s})(1.2 \text{ mH}) = 0.452 \Omega$
 $X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(200 \mu\text{F})} = 13.26 \Omega$
 $\mathbf{Z}' = 200 \Omega - j13.26 \Omega = 200.44 \Omega \angle -3.79^\circ$
 $\mathbf{I} = (0.707)(5 \times 10^{-3}) \text{ A} \angle 0^\circ = 3.54 \text{ mA} \angle 0^\circ$
 $\mathbf{I}_o = \frac{\mathbf{Z}_L \mathbf{I}}{\mathbf{Z}_L + \mathbf{Z}'} = \frac{(0.452 \Omega \angle 90^\circ)(3.54 \text{ mA} \angle 0^\circ)}{j0.452 \Omega + 200 \Omega - j13.26 \Omega} = 7.98 \mu\text{A} \angle 93.66^\circ$

$$\mathbf{V}_o = (7.98 \mu\text{A} \angle 93.66^\circ)(200 \Omega \angle 0^\circ) = 1.596 \text{ mV} \angle 93.66^\circ$$

$$\omega = 754 \text{ rad/s}; X_L = \omega L = (754 \text{ rad/s})(1.2 \text{ mH}) = 0.905 \Omega$$

$$X_C = \frac{1}{\omega C} = \frac{1}{(754 \text{ rad/s})(200 \mu\text{F})} = 6.63 \Omega$$

$$\mathbf{Z}' = 200 \Omega - j6.63 \Omega = 200.11 \Omega \angle -1.9^\circ$$

$$\mathbf{I} = (0.707)(2.12 \text{ mA}) \angle 90^\circ = 1.5 \text{ mA} \angle 90^\circ$$

$$\mathbf{I}_o = \frac{\mathbf{Z}_L \mathbf{I}}{\mathbf{Z}_L + \mathbf{Z}'} = \frac{(0.905 \Omega \angle 90^\circ)(1.5 \text{ mA} \angle 90^\circ)}{j0.905 \Omega + 200 \Omega - j6.63 \Omega} = 6.8 \mu\text{A} \angle 181.64^\circ$$

$$\mathbf{V}_o = (6.8 \mu\text{A} \angle 181.64^\circ)(200 \Omega \angle 0^\circ) = 1.36 \text{ mA} \angle 181.64^\circ$$

$$v_o = 0 + (1.414)(1.596 \times 10^{-3})\sin(377t + 93.66^\circ) - (1.414)(1.360 \times 10^{-3})\sin(754t + 181.64^\circ)$$

$$v_o = \mathbf{2.26 \times 10^{-3} \sin(377t + 93.66^\circ) + 1.92 \times 10^{-3} \sin(754t + 181.64^\circ)}$$

16. a. $60 + 70 \sin \omega t + 20 \sin(2\omega t + 90^\circ) + 10 \sin(3\omega t + 60^\circ)$
 $+20 + 30 \sin \omega t - 20 \sin(2\omega t + 90^\circ) + 5 \sin(3\omega t + 90^\circ)$
DC: $60 + 20 = 80$
 $\omega: 70 + 30 = 100 \Rightarrow 100 \sin \omega t$
 $2\omega: 0$
 $3\omega: 10 \angle 60^\circ + 5 \angle 90^\circ = 5 + j8.66 + j5 = 5 + j13.66 = 14.55 \angle 69.9^\circ$
Sum = $\mathbf{80 + 100 \sin \omega t + 14.55 \sin(3\omega t + 69.9^\circ)}$

b. $20 + 60 \sin \alpha + 10 \sin(2\alpha - 180^\circ) + 5 \sin(3\alpha + 180^\circ)$
 $-5 + 10 \sin \alpha + 0 - 4 \sin(3\alpha - 30^\circ)$
DC: $20 - 5 = 15$
 $\alpha: 60 + 10 = 70 \Rightarrow 70 \sin \alpha$
 $2\alpha: 10 \sin(2\alpha - 180^\circ)$
 $3\alpha: 5 \angle 180^\circ - 4 \angle -30^\circ = -5 - [3.46 - j2] = -8.46 + j2$
 $= 8.69 \angle 166.7^\circ$
Sum = $\mathbf{15 + 70 \sin \alpha + 10 \sin(2\alpha - 180^\circ) + 8.69 \sin(3\alpha + 166.7^\circ)}$

17. $i_T = i_1 + i_2$
 $= 10 + 30 \sin 20t - 0.5 \sin(40t + 90^\circ)$
 $+20 + 4 \sin(20t + 90^\circ) + 0.5 \sin(40t + 30^\circ)$
DC: $10 \text{ A} + 20 \text{ A} = 30 \text{ A}$
 $\omega = 20 \text{ rad/s}; 30 \text{ A} \angle 0^\circ + 4 \text{ A} \angle 90^\circ = 30 \text{ A} + j4 \text{ A} = 30.27 \text{ A} \angle 7.59^\circ$
 $\omega = 40 \text{ rad/s}; -0.5 \text{ A} \angle 90^\circ + 0.5 \text{ A} \angle 30^\circ$
 $= -j0.5 \text{ A} + 0.433 \text{ A} + j0.25 \text{ A}$
 $= 0.433 \text{ A} - j0.25 \text{ A} = 0.5 \text{ A} \angle -30^\circ$
 $i_T = \mathbf{30 + 30.27 \sin(20t + 7.59^\circ) + 0.5 \sin(40t - 30^\circ)}$

$$\begin{aligned}
 18. \quad e &= v_1 + v_2 \\
 &= 20 - 200 \sin 600t + 100 \sin(1200t + 90^\circ) + 75 \sin 1800t \\
 &\quad - 10 + 150 \sin(600t + 30^\circ) + 0 + 50 \sin(1800t + 60^\circ) \\
 \text{DC: } 20 \text{ V} - 10 \text{ V} &= 10 \text{ V} \\
 \omega: 600 \text{ rad/s: } -200 \text{ V} \angle 0^\circ + 150 \text{ V} \angle 30^\circ &= 102.66 \text{ V} \angle 133.07^\circ \\
 \omega = 1200 \text{ rad/s: } 100 \sin(1200t + 90^\circ) & \\
 \omega = 1800 \text{ rad/s: } 75 \text{ V} \angle 0^\circ + 50 \text{ V} \angle 60^\circ &= 108.97 \text{ V} \angle 23.41^\circ \\
 e &= \mathbf{10 + 102.66 \sin(600t + 133.07^\circ) + 100 \sin(1200t + 90^\circ) + 108.97 \sin(1800t + 23.41^\circ)}
 \end{aligned}$$

