Instructor's Resource Manual
to accompany

Introductory Circuit Analysis

Eleventh Edition

Robert L. Boylestad

PEARSON Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

Contents

Chapter 1

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

5. $$4\,\cancel{\text{min}}\left[\frac{1\,\text{h}}{60\,\cancel{\text{min}}}\right] = \mathbf{0.067\ h}$$
$$\upsilon = \frac{d}{t} = \frac{31\,\text{mi}}{1.067\,\text{h}} = \mathbf{29.05\ mph}$$

6. a. $$\frac{95\,\cancel{\text{mi}}}{\cancel{\text{h}}}\left[\frac{5{,}280\,\text{ft}}{\cancel{\text{mi}}}\right]\left[\frac{1\,\cancel{\text{h}}}{60\,\cancel{\text{min}}}\right]\left[\frac{1\,\cancel{\text{min}}}{60\,\text{s}}\right] = \mathbf{139.33\ ft/s}$$
b. $$t = \frac{d}{\upsilon} = \frac{60\,\text{ft}}{139.33\,\text{ft/s}} = \mathbf{0.431\ s}$$
c. $$\upsilon = \frac{d}{t} = \frac{60\,\cancel{\text{ft}}}{1\,\cancel{\text{s}}}\left[\frac{60\,\cancel{\text{s}}}{1\,\cancel{\text{min}}}\right]\left[\frac{60\,\cancel{\text{min}}}{1\,\text{h}}\right]\left[\frac{1\,\text{mi}}{5{,}280\,\cancel{\text{ft}}}\right] = \mathbf{40.91\ mph}$$

7. –

8. –

9. –

10. MKS, CGS, $°\text{C} = \frac{5}{9}(°\text{F} - 32) = \frac{5}{9}(68 - 32) = \frac{5}{9}(36) = \mathbf{20°}$
SI: K = 273.15 + °C = 273.15 + 20 = **293.15**

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

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

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

14. a. $\mathbf{15 \times 10^{3}}$ b. $\mathbf{30 \times 10^{-3}}$ c. $\mathbf{2.4 \times 10^{6}}$ d. $\mathbf{150 \times 10^{3}}$
e. $\mathbf{4.02 \times 10^{-4}}$ f. $\mathbf{2 \times 10^{-10}}$

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. $\dfrac{(10^2)(10^{-4})}{10^3} = 10^{-2}/10^3 = \mathbf{1.0 \times 10^{-5}}$
c. $\dfrac{(10^{-3})^2(10^2)}{10^4} = \dfrac{(10^{-6})(10^2)}{10^4} = \dfrac{10^{-4}}{10^4} = \mathbf{1.0 \times 10^{-8}}$
d. $\dfrac{(10^3)(10^4)}{10^{-4}} = 10^7/10^{-4} = \mathbf{1.0 \times 10^{11}}$

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. $\dfrac{\left[(10^2)(10^{-2})\right]^{-3}}{\left[(10^2)^2\right]\left[10^{-3}\right]} = \dfrac{1}{(10^4)(10^{-3})} = \dfrac{1}{10} = \mathbf{1.0 \times 10^{-1}}$

23. a. $\dfrac{(3\times10^2)^2(10^2)}{3\times10^4} = (9 \times 10^4)(10^2)/(3 \times 10^4) = (9 \times 10^6)/(3 \times 10^4) = 3 \times 10^2 = \mathbf{300}$

b. $\dfrac{(4\times10^4)^2}{(20)^3} = \dfrac{16\times10^8}{8\times10^3} = 2 \times 10^5 = \mathbf{200.0 \times 10^3}$

c. $\dfrac{(6\times10^4)^2}{(2\times10^{-2})^2} = \dfrac{36\times10^8}{4\times10^{-4}} = \mathbf{9.0 \times 10^{12}}$

d. $\dfrac{(27\times10^{-6})^{1/3}}{2\times10^5} = \dfrac{3\times10^{-2}}{2\times10^5} = 1.5 \times 10^{-7} = \mathbf{150.0 \times 10^{-9}}$

e. $\dfrac{(4\times10^3)^2(3\times10^2)}{2\times10^{-4}} = \dfrac{(16\times10^6)(3\times10^2)}{2\times10^{-4}} = \dfrac{48\times10^8}{2\times10^{-4}} = \mathbf{24.0 \times 10^{12}}$

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. $\dfrac{\left[(3\times10^{-3})^3\right]\left[1.60\times10^2\right]^2\left[(2\times10^2)(8\times10^{-4})\right]^{1/2}}{(7\times10^{-5})^2}$

$= \dfrac{(27\times10^{-9})(2.56\times10^4)(16\times10^{-2})^{1/2}}{49\times10^{-10}}$

$= \dfrac{(69.12\times10^{-5})(4\times10^{-1})}{49\times10^{-10}} = \dfrac{276.48\times10^{-6}}{49\times10^{-10}}$

$= 5.64 \times 10^4 = \mathbf{56.4 \times 10^3}$

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

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

c.
−2 +3 +3
$50 \times 10^5 = \underline{5000} \times 10^3 = \underline{5} \times 10^6 = \underline{0.005} \times 10^9$
+2 −3 −3

d. $30 \times 10^{-8} \overset{+5}{\underset{-5}{=}} \underline{0.0003} \times 10^{-3} \overset{-3}{\underset{+3}{=}} \underline{0.3} \times 10^{-6} \overset{-3}{\underset{+3}{=}} \underline{300} \times 10^{-9}$

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

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

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

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

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

f. $260 \times \overbrace{10^{3} \times 10^{-3}}^{10^{0}}\ \text{m} \underset{-3}{=} \underline{0.26} \times \overset{\text{increase by 3}}{10^{3}}\ \text{m} = \mathbf{0.26\ km}$

26. a. $1.5\ \cancel{\text{min}}\left[\dfrac{60\ \text{s}}{1\ \cancel{\text{min}}}\right] = \mathbf{90\ s}$

b. $0.04\ \cancel{\text{h}}\left[\dfrac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}}\right]\left[\dfrac{60\ \text{s}}{1\ \cancel{\text{min}}}\right] = \mathbf{144\ s}$

c. $0.05\ \cancel{\text{s}}\left[\dfrac{1\ \mu\text{s}}{10^{-6}\ \cancel{\text{s}}}\right] = \mathbf{0.05 \times 10^{6}\ \mu s = 50 \times 10^{3}\ \mu s}$

d. $0.16\ \cancel{\text{m}}\left[\dfrac{1\ \text{mm}}{10^{-3}\ \cancel{\text{m}}}\right] = 0.16 \times 10^{3}\ \text{mm} = \mathbf{160\ mm}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

30. $$299{,}792{,}458\ \frac{\cancel{\text{m}}}{\cancel{\text{s}}}\left[\frac{39.37\,\cancel{\text{in.}}}{1\,\cancel{\text{m}}}\right]\left[\frac{1\,\cancel{\text{ft}}}{12\,\cancel{\text{in.}}}\right]\left[\frac{1\text{ mi}}{5280\,\cancel{\text{ft}}}\right]\left[\frac{60\,\cancel{\text{s}}}{1\,\cancel{\text{min}}}\right]\left[\frac{60\,\cancel{\text{min}}}{1\text{ h}}\right]$$

$= 670{,}615{,}288.1$ mph $\cong$ **670.62 × 10^6 mph**

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

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

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

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

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

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

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

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

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

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

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

difference = **20.22 minutes**

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

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

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

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

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

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

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

41. a. $5\,\cancel{\text{J}}\left[\frac{1\,\text{Btu}}{1054.35\,\cancel{\text{J}}}\right]$ = **4.74×10^{-3} 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. $1.4\ \cancel{\text{days}}\left[\frac{86{,}400\,\text{s}}{1\,\cancel{\text{day}}}\right]$ = **1.21×10^5 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 pints**

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

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

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

45. MODE = DEGREES: cos 50° = **0.64**

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

47. $\sqrt{}\left(400/(6^2+10)\right)$ **= 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. $F = k\dfrac{Q_1Q_2}{r^2} = \dfrac{(9\times10^9)(1\,\text{C})(2\,\text{C})}{(1\,\text{m})^2}$ = **18 × 10^9 N**

b. $F = k\dfrac{Q_1Q_2}{r^2} = \dfrac{(9\times10^9)(1\,\text{C})(2\,\text{C})}{(3\,\text{m})^2}$ = **2 × 10^9 N**

c. $F = k\dfrac{Q_1Q_2}{r^2} = \dfrac{(9\times10^9)(1\,\text{C})(2\,\text{C})}{(10\,\text{m})^2}$ = **0.18 × 10^9 N**

d. Exponentially, $\dfrac{r_3}{r_1} = \dfrac{10\text{ m}}{1\text{ m}}$ = 10 while $\dfrac{F_1}{F_2} = \dfrac{18\times10^9\text{ N}}{0.18\times10^9\text{ N}}$ = **100**

3. a. r = 1 mi:

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

$$F = \frac{kQ_1Q_2}{r^2} = \frac{(9\times10^9)(8\times10^{-6}\text{ C})(40\times10^{-6}\text{ C})}{(1609.35\text{ m})^2} = \frac{2880\times10^{-3}}{2.59\times10^6}$$

$= \mathbf{1.11\ \mu N}$

b. r =10 ft:

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

$$F = \frac{kQ_1Q_2}{r^2} = \frac{2880\times10^{-3}}{(3.05\text{ m})^2} = \frac{2880\times10^{-3}}{9.30} = \mathbf{0.31\ N}$$

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

$$F = \frac{kQ_1Q_2}{r^2} = \frac{2880\times10^{-3}}{(1.59\times10^{-3}\text{ m})^2} = \frac{2880\times10^{-3}}{2.53\times10^{-6}} = 1138.34\times10^3\text{ N}$$

$= \mathbf{1138.34\ kN}$

4. –

5. $F = \dfrac{kQ_1Q_2}{r^2} \Rightarrow r = \sqrt{\dfrac{kQ_1Q_2}{F}} = \sqrt{\dfrac{(9\times10^9)(20\times10^{-6})^2}{3.6\times10^4}}$ = **10 mm**

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

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

b. $Q_1/Q_2 = 1/2 \Rightarrow Q_2 = 2Q_1$

$7.2 = kQ_1Q_2 = (9 \times 10^9)(Q_1)(2Q_1) = 9 \times 10^9\left(2Q_1^2\right)$

$\dfrac{7.2}{18\times 10^9} = Q_1^2 \Rightarrow Q_1 = \sqrt{\dfrac{7.2}{18\times 10^9}} =$ **20 μC**

$Q_2 = 2Q_1 = 2(2 \times 10^{-5}\text{ C}) =$ **40 μC**

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

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

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

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

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

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

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

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

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

16. $21.847 \times 10^{18}\ \cancel{\text{electrons}}\left[\dfrac{1\text{C}}{6.242\times 10^{18}\ \cancel{\text{electrons}}}\right] = 3.5\text{ C}$

$I = \dfrac{Q}{t} = \dfrac{3.5\text{ C}}{12\text{ s}} = 0.29\text{ A}$

17. $Q = It = (4\text{ mA})(90\text{ s}) = 360\text{ mC}$

$360\text{ m}\cancel{\text{C}}\left[\dfrac{6.242\times 10^{18}\text{ electrons}}{1\cancel{\text{C}}}\right] =$ **2.25 × 10**^{18} **electrons**

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

19. $0.84 \times 10^{16}\ \cancel{\text{electrons}}\left[\dfrac{1\text{ C}}{6.242\times10^{18}\ \cancel{\text{electrons}}}\right] = 1.346\text{ mC}$

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

20. a. $Q = It = (2\text{ mA})(0.01\ \mu\text{s}) = 2 \times 10^{-11}\text{ C}$

$2 \times 10^{-11}\ \cancel{\text{C}}\left[\dfrac{6.242\times10^{18}\ \cancel{\text{electrons}}}{1\ \cancel{\text{C}}}\right]\left[\dfrac{1\ \text{¢}}{\cancel{\text{electron}}}\right]$

$= 1.25 \times 10^{8}\ \text{¢} = \$1.25 \times 10^{6} = \mathbf{1.25\ million}$

b. $Q = It = (100\ \mu\text{A})(1.5\text{ ns}) = 1.5 \times 10^{-13}\text{ C}$

$1.5 \times 10^{-13}\ \cancel{\text{C}}\left[\dfrac{6.242\times10^{18}\ \cancel{\text{electrons}}}{1\ \cancel{\text{C}}}\right]\left[\dfrac{\$1}{\cancel{\text{electron}}}\right] = \mathbf{0.94\ million}$

(a) > (b)

21. $Q = It = (200 \times 10^{-3}\text{ A})(30\text{ s}) = 6\text{ C}$

$V = \dfrac{W}{Q} = \dfrac{40\text{ J}}{6\text{ C}} = \mathbf{6.67\ V}$

22. $Q = It = \left[\dfrac{420\text{ C}}{\cancel{\text{min}}}\right](0.5\ \cancel{\text{min}}) = 210\text{ C}$

$V = \dfrac{W}{Q} = \dfrac{742\text{ J}}{210\text{ C}} = \mathbf{3.53\ V}$

23. $Q = \dfrac{W}{V} = \dfrac{0.4\text{ J}}{24\text{ V}} = 0.0167\text{ C}$

$I = \dfrac{Q}{t} = \dfrac{0.0167\text{ C}}{5\times10^{-3}\text{ s}} = \mathbf{3.34\ A}$

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

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

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

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

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

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

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

$I_2/I_1 = 1.5$ 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 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 C**

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

Chapter 3

1. a. 0.5 in. = **500 mils**

   b. $0.02\,\cancel{\text{in.}}\left[\dfrac{1000\text{ mils}}{1\,\cancel{\text{in.}}}\right]$ = **20 mils**

   c. $\dfrac{1}{4}$ in. = $0.25\,\cancel{\text{in.}}\left[\dfrac{1000\text{ mils}}{1\,\cancel{\text{in.}}}\right]$ = **250 mils**

   d. 1 in. = **1000 mils**

   e. $0.02\,\cancel{\text{ft}}\left[\dfrac{12\,\cancel{\text{in.}}}{1\,\cancel{\text{ft}}}\right]\left[\dfrac{10^3\text{ mils}}{1\,\cancel{\text{in.}}}\right]$ = **240 mils**

   f. $0.1\,\cancel{\text{cm}}\left[\dfrac{1\,\cancel{\text{in.}}}{2.54\,\cancel{\text{cm}}}\right]\left[\dfrac{1000\text{ mils}}{1\,\cancel{\text{in.}}}\right]$ = **39.37 mils**

2. a. $A_{\text{CM}} = (30\text{ mils})^2 =$ **900 CM**

   b. 0.016 in. = 16 mils, $A_{\text{CM}} = (16\text{ mils})^2 =$ **256 CM**

   c. $\dfrac{1}{8}''$ = 0.125" = 125 mils, $A_{\text{CM}} = (125\text{ mils})^2 =$ $\mathbf{15.63 \times 10^3}$ **CM**

   d. $1\,\cancel{\text{cm}}\left[\dfrac{1\,\cancel{\text{in.}}}{2.54\,\cancel{\text{cm}}}\right]\left[\dfrac{1000\text{ mils}}{1\,\cancel{\text{in.}}}\right]$ = 393.7 mils, $A_{\text{CM}} = (393.7\text{ mils})^2 =$ $\mathbf{155 \times 10^3}$ **CM**

   e. $0.02\,\cancel{\text{ft}}\left[\dfrac{12\,\cancel{\text{in.}}}{1\,\cancel{\text{ft}}}\right]\left[\dfrac{1000\text{ mils}}{1\,\cancel{\text{in.}}}\right]$ = 240 mils, $A_{\text{CM}} = (240\text{ mils})^2 =$ $\mathbf{57.60 \times 10^3}$ **CM**

   f. $0.0042\,\cancel{\text{m}}\left[\dfrac{39.37\text{ in.}}{1\,\cancel{\text{m}}}\right]$ = 0.1654 in. = 165.4 mils, $A_{\text{CM}} = (165.4\text{ mils})^2 =$ $\mathbf{27.36 \times 10^3}$ **CM**

3. $A_{\text{CM}} = (d_{\text{mils}})^2 \rightarrow d_{\text{mils}} = \sqrt{A_{\text{CM}}}$

   a. $d = \sqrt{1600\text{ CM}}$ = 40 mils = **0.04 in.**

   b. $d = \sqrt{820\text{ CM}}$ = 28.64 mils = **0.029 in.**

   c. $d = \sqrt{40{,}000\text{ CM}}$ = 200 mils = **0.2 in.**

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

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

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

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

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

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

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

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

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

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

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

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

b. larger

c. smaller

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

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

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

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

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

11. a. $3'' = 3000$ mils, $1/2'' = 0.5$ in. $= 500$ mils
Area $= (3 \times 10^3 \text{ mils})(5 \times 10^2 \text{ mils}) = 15 \times 10^5$ sq. mils

$$15 \times 10^5 \text{ sq } \cancel{\text{mils}} \left[\frac{4/\pi \text{ CM}}{1 \text{ sq } \cancel{\text{mil}}}\right] = 19.108 \times 10^5 \text{ CM}$$

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

b. $$R = \rho\frac{l}{A} = \frac{(17)(4')}{19.108 \times 10^5 \text{ CM}} = \mathbf{35.59\ \mu\Omega}$$

Aluminum bus-bar has almost 64% higher resistance.

c. increases

d. decreases

12. $l_2 = 2l_1$, $A_2 = A_1/4$, $\rho_2 = \rho_1$

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

and $R_2 = 8R_1 = 8(0.2\ \Omega) = 1.6\ \Omega$
$\Delta R = 1.6\ \Omega - 0.2\ \Omega = \mathbf{1.4\ \Omega}$

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

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

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

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

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

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

b. Resistance: #14:#11 = 1.136 Ω:0.567 Ω ≅ **2:1**

c. Area: #14:#11 = 4106.8 CM:8234.0 CM ≅ **1:2**

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

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

b. #18:#8 = 11.49 Ω:1.13 Ω = 10.17:1 ≅ **10:1**

c. #18:#8 = 1624.3 CM:16,509 CM = 1:10.16 ≅ **1:10**

16. a. $A = \rho\dfrac{l}{R} = \dfrac{(10.37)(30')}{6\text{ m}\Omega} = \dfrac{311.1\,\text{CM}}{6\times10^{-3}} = 51{,}850\text{ CM} \Rightarrow \#3$

but 110 A ⇒ **#2**

b. $A = \rho\dfrac{l}{R} = \dfrac{(10.37)(30')}{3\text{ m}\Omega} = \dfrac{311.1\,\text{CM}}{3\times10^{-3}} = 103{,}700\text{ CM} \Rightarrow \mathbf{\#0}$

17. a. A/CM = 230 A/211,600 CM = **1.09 mA/CM**

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

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

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

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

$l = \dfrac{RA}{\rho} = \dfrac{(2\ \Omega)(0.035\text{ cm}^2)}{1.724\times10^{-6}} = 40{,}603\text{ cm} = \mathbf{406.03\ m}$

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

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

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

b. $R = \rho\dfrac{\ell}{A} = \dfrac{(2.825\times10^{-6})(121.92\text{ cm})}{(1.27\text{ cm})(7.62\text{ cm})} = \mathbf{35.59\ \mu\Omega}$

c. increases

d. decreases

20. $R_s = \dfrac{\rho}{d} = 100 \Rightarrow d = \dfrac{\rho}{100} = \dfrac{250\times 10^{-6}}{100} = \mathbf{2.5}\ \boldsymbol{\mu}\mathbf{cm}$

21. $R = R_s \dfrac{l}{w} \Rightarrow w = \dfrac{R_s\, l}{R} = \dfrac{(150\,\Omega)(1/2\text{ in.})}{500\,\Omega} = \mathbf{0.15\ in.}$

22. a. $d = 1$ in. $= 1000$ mils

$A_{\text{CM}} = (10^3 \text{ mils})^2 = 10^6$ CM

$\rho_1 = \dfrac{RA}{l} = \dfrac{(1\,\text{m}\Omega)(10^6\ \text{CM})}{10^3\ \text{ft}} = \mathbf{1\ CM\text{-}\Omega/ft}$

b. 1 in. = 2.54 cm

$A = \dfrac{\pi d^2}{4} = \dfrac{\pi(2.54\text{ cm})^2}{4} = 5.067\text{ cm}^2$

$l = 1000\text{ ft}\left[\dfrac{12\text{ in.}}{1\text{ ft}}\right]\left[\dfrac{2.54\text{ cm}}{1\text{ in.}}\right] = 30{,}480\text{ cm}$

$\rho_2 = \dfrac{RA}{l} = \dfrac{(1\,\text{m}\Omega)(5.067\text{ cm}^2)}{30{,}480\text{ cm}} = \mathbf{1.66 \times 10^{-7}\ \Omega\text{-cm}}$

c. $k = \dfrac{\rho_2}{\rho_1} = \dfrac{1.66\times 10^{-7}\ \Omega\text{-cm}}{1\text{ CM-}\Omega/\text{ft}} = \mathbf{1.66 \times 10^{-7}}$

23. $\dfrac{234.5+10}{2\,\Omega} = \dfrac{234.5+80}{R_2}$, $\quad R_2 = \dfrac{(314.5)(2\,\Omega)}{244.5} = \mathbf{2.57\ \Omega}$

24. $\dfrac{236+0}{0.02\ \Omega} = \dfrac{236+100}{R_2}$

$R_2 = \dfrac{(0.02\ \Omega)(336)}{236} = \mathbf{0.028\ \Omega}$

25. $\text{C} = \dfrac{5}{9}(°\text{F}-32) = \dfrac{5}{9}(32-32) = 0°\ (=32°\text{F})$

$\text{C} = \dfrac{5}{9}(70-32) = 21.11° \quad (=70°\text{F})$

$\dfrac{234.5°+21.11°}{4\ \Omega} = \dfrac{234.5°+0°}{R_2}$

$R_2 = \dfrac{(234.5)(4\ \Omega)}{255.61} = \mathbf{3.67\ \Omega}$

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

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

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

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

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

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

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

$212°\text{F} = 100\ °\text{C}$

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

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

b. $\dfrac{\Delta R}{\Delta T}=\dfrac{2.63\ \text{m}\Omega-2\ \text{m}\Omega}{100°\text{C}-20°\text{C}}=\dfrac{0.63\ \text{m}\Omega}{80°\text{C}} = 7.88\ \mu\Omega/°\text{C}$ or $\mathbf{7.88\times10^{-5}\ \Omega/10°C}$

29. a. $\dfrac{234.5+4}{1\ \Omega}=\dfrac{234.5+t_2}{1.1\ \Omega}, \quad t_2 = \mathbf{27.85°C}$

b. $\dfrac{234.5+4}{1\ \Omega}=\dfrac{234.5+t_2}{0.1\ \Omega}, \quad t_2 = \mathbf{-210.65°C}$

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

$50 = 273.15 + °\text{C}$

$°\text{C} = -223.15°$

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

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

b. $\text{K} = 273.15 + °\text{C}$

$38.65 = 273.15 + °\text{C}$

$°\text{C} = -234.5°$

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

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

Recall: $-234.5° =$
Inferred absolute zero
$R = \mathbf{0\ \Omega}$

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

31. a. $\alpha_{20} = \dfrac{1}{|T_i| + 20°\text{C}} = \dfrac{1}{234.5 + 20} = \dfrac{1}{254.5} = 0.003929 \cong \mathbf{0.00393}$

b. $R = R_{20}[1 + \alpha_{20}(t - 20°\text{C})]$
$1\ \Omega = 0.8\ \Omega[1 + 0.00393(t - 20°)]$
$1.25 = 1 + 0.00393t - 0.0786$
$1.25 - 0.9214 = 0.00393t$
$0.3286 = 0.00393t$
$t = \dfrac{0.3286}{0.00393} = \mathbf{83.61°C}$

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

33. Table: 1000′ of #12 copper wire = 1.588 Ω @ 20°C
$\text{C}° = \dfrac{5}{9}(\text{F}° - 32) = \dfrac{5}{9}(115 - 32) = 46.11°\text{C}$
$R = R_{20}[1 + \alpha_{20}(t - 20°\text{C})]$
$= 1.588\ \Omega[1 + 0.00393(46.11 - 20)]$
$= \mathbf{1.75\ \Omega}$

34. $\Delta R = \dfrac{R_{\text{nominal}}}{10^6}(\text{PPM})(\Delta \text{T}) = \dfrac{22\ \Omega}{10^6}(200)(65° - 20°) = 0.198\ \Omega$
$R = R_{\text{nominal}} + \Delta R = \mathbf{22.198\ \Omega}$

35. $\Delta R = \dfrac{R_{\text{nominal}}}{10^6}(\text{PPM})(\Delta \text{T}) = \dfrac{100\ \Omega}{10^6}(100)(50° - 20°) = 0.30\ \Omega$
$R = R_{\text{nominal}} + \Delta R = 100\ \Omega + 0.30\ \Omega = \mathbf{100.30\ \Omega}$

36. –

37. –

38. #12: Area = 6529 CM
$d = \sqrt{6529\ \text{CM}} = 80.8\ \text{mils} = 0.0808\ \cancel{\text{in.}} \left[\dfrac{2.54\ \text{cm}}{1\ \cancel{\text{in.}}}\right] = 0.205\ \text{cm}$
$A = \dfrac{\pi d^2}{4} = \dfrac{\pi(0.205\ \text{cm})^2}{4} = 0.033\ \text{cm}^2$
$I = \dfrac{1\ \text{MA}}{\cancel{\text{cm}^2}}[0.033\ \cancel{\text{cm}^2}] = \mathbf{33\ kA >>} 20\ \text{A}$

39. –

40. a. 2 times larger b. 4 times larger

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

42. **6.25 kΩ** and **18.75 kΩ**

43. –

44. a. 560 kΩ ± 5%, 560 kΩ ± 28 kΩ, **532 kΩ ↔ 588 kΩ**
b. 220 Ω ± 10%, 220 Ω ± 22 Ω, **198 Ω ↔ 242 Ω**
c. 100 Ω ± 20%, 100 Ω ± 20 Ω, **80 Ω ↔ 120 Ω**

45. a. 120 Ω = Brown, Red, Brown, Silver
b. 8.2 Ω = Gray, Red, Gold, Silver
c. 6.8 kΩ = Blue, Gray, Red, Silver
d. 3.3 MΩ = Orange, Orange, Green, Silver

46. $$\left.\begin{array}{l} 10\,\Omega \pm 20\% \Rightarrow 8\,\Omega - 12\,\Omega \\ 15\,\Omega \pm 20\% \Rightarrow 12\,\Omega - 18\,\Omega \end{array}\right\}\text{ no overlap, continuance}$$

47. $$\left.\begin{array}{l} 10\,\Omega \pm 10\% \Rightarrow 10\,\Omega \pm 1\,\Omega = 9\,\Omega - 11\,\Omega \\ 15\,\Omega \pm 10\% \Rightarrow 15\,\Omega \pm 1.5\,\Omega = 13.5\,\Omega - 16.5\,\Omega \end{array}\right\}\text{ No overlap}$$

48. a. 621 = 62×10^1 Ω = 620 Ω = **0.62 kΩ**
b. 333 = 33×10^3 Ω = **33 kΩ**
c. Q2 = 3.9×10^2 Ω = **390 Ω**
d. C6 = 1.2×10^6 Ω = **1.2 MΩ**

49. a. $G = \dfrac{1}{R} = \dfrac{1}{120\,\Omega}$ = **8.33 mS**

b. $G = \dfrac{1}{4\,\text{k}\Omega}$ = **0.25 mS**

c. $G = \dfrac{1}{2.2\,\text{M}\Omega}$ = **0.46 μS**
$G_a > G_b > G_c$ vs. $R_c > R_b > R_a$

50. a. Table 3.2, Ω/1000′ = 1.588 Ω
$G = \dfrac{1}{R} = \dfrac{1}{1.588\,\Omega}$ = **629.72 mS**
or $G = \dfrac{A}{\rho l} = \dfrac{6529.9\text{ CM (Table 3.2)}}{(10.37)(1000')}$ = **629.69 mS** (Cu)

b. $G = \dfrac{6529.9\text{ CM}}{(17)(1000')}$ = **384.11 mS** (Al)

c. $G = \dfrac{6529.9\text{ CM}}{(74)(1000')}$ = **88.24 mS** (Fe)

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

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

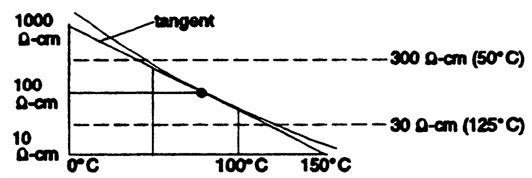
$G_2 = 5G_1 = 5(100\text{ S}) = \mathbf{500\ S}$

52. –

53. –

54. –

55. a. –50°C specific resistance ≅ 10^5 Ω-cm
50°C specific resistance ≅ 500 Ω-cm
200°C specific resistance ≅ 7 Ω-cm



b. negative

c. No

d. $\rho = \dfrac{\Delta\Omega - \text{cm}}{\Delta T} = \dfrac{300 - 30}{125 - 50} = \dfrac{270\ \Omega - \text{ cm}}{75°\text{ C}}$ ≅ **3.6 Ω-cm/°C**

56. a. Log scale: 10 fc ⇒ **3 kΩ**
100 fc ⇒ **0.4 kΩ**

b. negative

c. no—log scales imply linearity

d. 1 kΩ ⇒ ≅ 30 fc
10 kΩ ⇒ ≅ 2 fc

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

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

57. a. @ 0.5 mA, V ≅ **195 V**
@ 1 mA, V ≅ **200 V**
@ 5 mA, V ≅ **215 V**

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

c. 5 mA:0.5 mA = **10:1**
compared to
215 V: 200 V = **1.08:1**

Chapter 4

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

15. –

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

17. –

18. –

19. –

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

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

22. a. $8\ \cancel{\text{h}}\left[\dfrac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}}\right]\left[\dfrac{60 \text{ s}}{1\ \cancel{\text{min}}}\right] = 28{,}800 \text{ s}$

$W = Pt = (2 \text{ W})(28{,}000 \text{ s}) = \mathbf{57.6\ kJ}$

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

23. $I = \dfrac{Q}{t} = \dfrac{300 \text{ C}}{1\ \cancel{\text{min}}}\left[\dfrac{1\ \cancel{\text{min}}}{60 \text{ s}}\right] = 5 \text{ C/s} = 5 \text{ A}$

$P = I^2R = (5 \text{ A})^2\ 10\ \Omega = \mathbf{250\ W}$

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

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

25. $I = \dfrac{48 \text{ C}}{\cancel{\text{min}}}\left[\dfrac{1\ \cancel{\text{min}}}{60 \text{ s}}\right] = 0.8 \text{ A}$

$P = EI = (6 \text{ V})(0.8 \text{ A}) = \mathbf{4.8\ W}$

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

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

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

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

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

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

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

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

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

no

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

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

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

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

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

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

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

b. Ah rating = (0.13 mA)(500 h) = **66.5 mAh**

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

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

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

b. Energy doubles, power the same

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

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

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

41. $\text{kWh} = \dfrac{(24\text{ W})(3\text{ h})}{1000} = 72 \times 10^{-3}\text{ kWh}$

$(72 \times 10^{-3}\text{ kWh})(9¢/\text{kWh}) = \mathbf{0.65¢}$

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

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

c. $P_{\text{lost}} = P_i - P_o = P_i - \eta P_i = P_i(1-\eta) = 120\text{ kW}(1-0.82) = 21.6\text{ kW}$

$\text{kWh}_{\text{lost}} = \dfrac{Pt}{1000} = \dfrac{(21.6\text{ kW})(10\text{ h})}{1000} = \mathbf{216\ kWh}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

47. $$\text{kWh} = \frac{(860\text{ W})(6\text{ h}) + (4800\text{ W})(1/2\text{ h}) + (900\text{ W})\left(20\ \cancel{\text{min}}\left(\dfrac{1\text{ h}}{60\ \cancel{\text{min}}}\right)\right) + (110\text{ W})(3.5\text{ h})}{1000}$$

$$= \frac{5160\text{ Wh} + 2400\text{ Wh} + 300\text{ Wh} + 385\text{ Wh}}{1000} = 8.245\text{ kWh}$$

$(8.245\text{ kWh})(9¢/\text{kWh}) = \mathbf{74.21¢}$

48. $$\text{kWh} = \frac{(200\text{ W})(4\text{ h}) + (1200\text{ W})\left(20\ \cancel{\text{min}}\left(\dfrac{1\text{ h}}{60\ \cancel{\text{min}}}\right)\right) + (70\text{ W})(1.5\text{ h}) + (150\text{ W})\left(130\ \cancel{\text{min}}\left(\dfrac{1\text{ h}}{60\ \cancel{\text{min}}}\right)\right)}{1000}$$

$$= \frac{800\text{ Wh} + 400\text{ Wh} + 105\text{ Wh} + 325\text{ Wh}}{1000} = \mathbf{1.63\text{ kWh}}$$

$(1.63\text{ kWh})(9¢/\text{kWh}) = \mathbf{14.67¢}$

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

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. $P_i = EI = (120\text{ V})(2.4\text{ A}) = 288\text{ W}$

$P_i = P_o + P_{\text{lost}},\ P_{\text{lost}} = P_i - P_o = 288\text{ W} - 50\text{ W} = \mathbf{238\ W}$

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

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

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

b. $P_i = EI = 1657.78\text{ W}$

$(110\text{ V})I = 1657.78\text{ W}$

$I = \dfrac{1657.78\text{ W}}{110\text{ V}} = \mathbf{15.07\ A}$

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

$P_i = EI = 2131.43\text{ W}$

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

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

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

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

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. $\eta_1 = \eta_2 = .08$

$\eta_T = (\eta_1)(\eta_2) = (0.8)(0.8) = 0.64$

$\eta_T = \dfrac{W_o}{W_i} \Rightarrow W_o = \eta_T W_i = (0.64)(60\text{ J}) = \mathbf{38.4\ J}$

59. $\eta_T = \eta_1 \cdot \eta_2 = 0.72 = 0.9\eta_2$

$\eta_2 = \dfrac{0.72}{0.9} = 0.8 \Rightarrow \mathbf{80\%}$

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

b. $\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 = (0.98)(0.87)(0.90) = 0.7673 \Rightarrow$ **76.73%**

$\dfrac{76.73\% - 17.9\%}{17.9\%} \times 100\% =$ **328.66%**

61. $\eta_T = \dfrac{P_o}{P_i} = \eta_1 \cdot \eta_2 = \eta_1 \cdot 2\eta_1 = 2\eta_1^2$

$\eta_1^2 = \dfrac{P_o}{2P_i} \Rightarrow \eta_1 = \sqrt{\dfrac{P_o}{2P_i}} = \sqrt{\dfrac{128 \text{ W}}{2(400 \text{ W})}} = 0.4$

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

$\therefore\ \eta_2 =$ **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. $R_T = 0.1\ \text{k}\Omega + 0.39\ \text{k}\Omega + 1.2\ \text{k}\Omega = \mathbf{1.69\ k\Omega}$
   b. $R_T = 1.2\ \Omega + 2.7\ \Omega + 8.2\ \Omega = \mathbf{12.1\ \Omega}$
   c. $R_T = 8.2\ \text{k}\Omega + 10\ \text{k}\Omega + 9.1\ \text{k}\Omega + 1.8\ \text{k}\Omega + 2.7\ \text{k}\Omega = \mathbf{31.8\ k\Omega}$
   d. $R_T = 47\ \Omega + 820\ \Omega + 91\ \Omega + 1.2\ \text{k}\Omega = \mathbf{2158.0\ \Omega}$

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

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

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

6. a. **1.2 kΩ**
   b. 3.3 kΩ + 4.3 kΩ = **7.6 kΩ**
   c. **0 Ω**
   d. **∞ Ω**

7. a. $R_T = 10\ \Omega + 12\ \Omega + 18\ \Omega = \mathbf{40\ \Omega}$
   b. $I_s = \dfrac{E}{R_T} = \dfrac{120\ \text{V}}{40\ \Omega} = \mathbf{3\ A}$
   c. $V_1 = I_1R_1 = (3\ \text{A})(10\ \Omega) = \mathbf{30\ V}$, $V_2 = I_2R_2 = (3\ \text{A})(12\ \Omega) = \mathbf{36\ V}$,
   $V_3 = I_3R_3 = (3\ \text{A})(18\ \Omega) = \mathbf{54\ V}$

8. a. the most: R_3, the least: R_1
   b. R_3, $R_T = 1.2\ \text{k}\Omega + 6.8\ \text{k}\Omega + 82\ \text{k}\Omega = \mathbf{90\ k\Omega}$
   $I_s = \dfrac{E}{R_T} = \dfrac{45\ \text{V}}{90\ \text{k}\Omega} = \mathbf{0.5\ mA}$
   c. $V_1 = I_1R_1 = (0.5\ \text{mA})(1.2\ \text{k}\Omega) = \mathbf{0.6\ V}$, $V_2 = I_2R_2 = (0.5\ \text{mA})(6.8\ \text{k}\Omega) = \mathbf{3.4\ V}$,
   $V_3 = I_3R_3 = (0.5\ \text{mA})(82\ \text{k}\Omega) = \mathbf{41\ V}$, results agree with part (a)

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

10. a. a. $I = \dfrac{V}{R} = \dfrac{5.2\text{ V}}{1.3\,\Omega} = \mathbf{4\ A}$

b. $E = IR_T = (4\text{ A})(9\ \Omega) = \mathbf{36\ V}$

c. $R_T = 9\ \Omega = 4.7\ \Omega + 1.3\ \Omega + R, \quad R = \mathbf{3\ \Omega}$

d. $V_{4.7\,\Omega} = (4\text{ A})(4.7\ \Omega) = \mathbf{18.8\ V}$

$V_{1.3\,\Omega} = (4\text{ A})(1.3\ \Omega) = \mathbf{5.2\ V}$

$V_{3\,\Omega} = (4\text{ A})(3\ \Omega) = \mathbf{12\ V}$

b. a. $I = \dfrac{V}{R} = \dfrac{6.6\text{ V}}{2.2\text{ k}\Omega} = \mathbf{3\ mA}$

b. $V_{3.3\,\text{k}\Omega} = (3\text{ mA})(3.3\text{ k}\Omega) = 9.9\text{ V}$

$E = 6.6\text{ V} + 9\text{ V} + 9.9\text{ V} = \mathbf{25.5\ V}$

c. $R = \dfrac{V}{I} = \dfrac{9\text{ V}}{3\text{ mA}} = \mathbf{3\ k\Omega}$

d. $V_{2.2\,\text{k}\Omega} = \mathbf{6.6\ V}$, $V_{3\,\text{k}\Omega} = \mathbf{9\ V}$, $V_{3.3\,\text{k}\Omega} = \mathbf{9.9\ V}$

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

b. $R_T = 1\text{ k}\Omega + 2.4\text{ k}\Omega + 5.6\text{ k}\Omega = 9\text{ k}\Omega$

$I = \dfrac{E}{R_T} = \dfrac{22.5\text{ V}}{9\text{ k}\Omega} = \mathbf{2.5\ mA}$, $V = 2.5\text{ mA}(2.4\text{ k}\Omega + 5.6\text{ k}\Omega) = \mathbf{20\ V}$

c. $R_T = 10\text{ k}\Omega + 22\text{ k}\Omega + 33\text{ k}\Omega + 10\text{ M}\Omega = 10.065\text{ M}\Omega$

$I = \dfrac{E}{R_T} = \dfrac{100\text{ V}}{10.065\text{ M}\Omega} = \mathbf{9.94\ \mu A}$

$V = (9.935\ \mu\text{A})(10\text{ M}\Omega) = \mathbf{99.35\ V}$

12. a. $R_T = 3\text{ k}\Omega + 1\text{ k}\Omega + 2\text{ k}\Omega = \mathbf{6\ k\Omega}$

$I_s = \dfrac{E}{R_T} = \dfrac{120\text{ V}}{6\text{ k}\Omega} = \mathbf{20\ mA}$

$V_{R_1} = (20\text{ mA})(3\text{ k}\Omega) = \mathbf{60\ V}$

$V_{R_2} = (20\text{ mA})(1\text{ k}\Omega) = \mathbf{20\ V}$

$V_{R_3} = (20\text{ mA})(2\text{ k}\Omega) = \mathbf{40\ V}$

b. $P_{R_1} = I_1^2R_1 = (20\text{ mA})^2 \cdot 3\text{ k}\Omega = \mathbf{1.2\ W}$

$P_{R_2} = I_2^2R_2 = (20\text{ mA})^2 \cdot 1\text{ k}\Omega = \mathbf{0.4\ W}$

$P_{R_3} = I_3^2R_3 = (20\text{ mA})^2 \cdot 2\text{ k}\Omega = \mathbf{0.8\ W}$

c. $P_T = P_{R_1} + P_{R_2} + P_{R_3} = 1.2\text{ W} + 0.4\text{ W} + 0.8\text{ W} = \mathbf{2.4\ W}$

d. $P_T = EI_s = (120\text{ V})(20\text{ mA}) = \mathbf{2.4\ W}$

e. the same

f. R_1 – the largest

g. dissipated

h. R_1: 2 W, R_2 : 1/2 W, R_3: 1 W

13. a. $R_T = 22\ \Omega + 10\ \Omega + 47\ \Omega + 3\ \Omega = \mathbf{82.0\ \Omega}$

$$I_s = \frac{E}{R_T} = \frac{20.5\text{ V}}{82.0\ \Omega} = \mathbf{250\ mA}$$

$$V_{R_1} = I_1R_1 = (250\text{ mA})(22\ \Omega) = \mathbf{5.50\ V}$$
$$V_{R_2} = I_2R_2 = (250\text{ mA})(10\ \Omega) = \mathbf{2.50\ V}$$
$$V_{R_3} = I_3R_3 = (250\text{ mA})(47\ \Omega) = \mathbf{11.75\ V}$$
$$V_{R_4} = I_4R_4 = (250\text{ mA})(3\ \Omega) = \mathbf{0.75\ V}$$

b. $P_{R_1} = I_1^2R_1 = (250\text{ mA})^2 \cdot 22\ \Omega = \mathbf{1.38\ W}$

$P_{R_2} = I_2^2R_2 = (250\text{ mA})^2 \cdot 10\ \Omega = \mathbf{625.00\ mW}$

$P_{R_3} = I_3^2R_3 = (250\text{ mA})^2 \cdot 47\ \Omega = \mathbf{2.94\ W}$

$P_{R_4} = I_4^2R_4 = (250\text{ mA})^2 \cdot 3\ \Omega = \mathbf{187.50\ mW}$

c. $P_T = P_{R_1} + P_{R_2} + P_{R_3} + P_{R_4} = 1.38\text{ W} + 625.00\text{ mW} + 2.94\text{ W} + 187.50\text{ mW} = \mathbf{5.13\ W}$

d. $P = EI_s = (20.5\text{ V})(250\text{ mA}) = \mathbf{5.13\ W}$

e. the same

f. 47 Ω – the largest

g. dissipated

h. R_1: 2 W; R_2: 1/2 W, R_3: 5 W, R_4: 1/2 W

14. a. $P = 21\text{ W} = (1\text{ A})^2 \cdot R, \quad R = \mathbf{21\ \Omega}$

$V_1 = I_1R_1 = (1\text{ A})(2\ \Omega) = \mathbf{2\ V}$, $V_2 = I_2R_2 = (1\text{ A})(1\ \Omega) = \mathbf{1\ V}$

$V_3 = I_3R_3 = (1\text{ A})(21\ \Omega) = \mathbf{21\ V}$

$E = V_1 + V_2 + V_3 = 2\text{ V} + 1\text{ V} + 21\text{ V} = \mathbf{24\ V}$

b. $P = 4\text{ W} = I^2 \cdot 1\ \Omega$, $I = \sqrt{4} = \mathbf{2\ A}$

$P = 8\text{ W} = I^2R_1 = (2\text{ A})^2R_1, \quad R_1 = \mathbf{2\ \Omega}$

$R_T = 16\ \Omega = 2\ \Omega + R_2 + 1\ \Omega = 3\ \Omega + R_2, \quad R_2 = \mathbf{13\ \Omega}$

$E = IR_T = (2\text{ A})(16\ \Omega) = \mathbf{32\ V}$

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

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

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

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

d. All go out!

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$E = \mathbf{42\ V}$

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. $$V_3 = \frac{R_3E}{R_T} = \frac{(8.2\text{ k}\Omega)(60\text{ V})}{0.1\text{ k}\Omega + 1\text{ k}\Omega + 8.2\text{ k}\Omega} = \mathbf{52.90\text{ V}}$$

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. $V = \dfrac{40\ \Omega(30\text{ V})}{40\ \Omega + 20\ \Omega} = \mathbf{20\ V}$

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

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

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

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

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

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

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

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

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

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

$V_2 = \dfrac{6\text{ V}}{2} = \mathbf{3\ V}$

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

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

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

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

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

b. $100\text{ V} = \dfrac{(6\ \Omega + R)140\text{ V}}{3\ \Omega + 6\ \Omega + R}$

$300\ \Omega + 600\ \Omega + 100R = 840\ \Omega + 140\text{ R}$

$140R - 100R = -840\ \Omega + 900\ \Omega$

$40R = 60\ \Omega$

$R = \dfrac{60\ \Omega}{40} = \mathbf{1.5\ \Omega}$

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

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

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

31. a. $R_{\text{bulb}} = \dfrac{8\text{ V}}{50\text{ mA}} = 160\ \Omega$

$V_{\text{bulb}} = 8\text{ V} = \dfrac{R_{\text{bulb}}(12\text{ V})}{R_{\text{bulb}} + R_x} = \dfrac{160\ \Omega(12\text{ V})}{160\ \Omega + R_x}$, $R_x = \mathbf{80\ \Omega}$ in series with the bulb

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

32. $V_{R_1} + V_{R_2} = 72\text{ V}$

$\dfrac{1}{5}V_{R_2} + V_{R_2} = 72\text{ V}$

$V_{R_2}\left[1 + \dfrac{1}{5}\right] = 72\text{ V}$, $V_{R_2} = \dfrac{72\text{ V}}{1.2} = 60\text{ V}$

$R_2 = \dfrac{V_{R_2}}{I_{R_2}} = \dfrac{60\text{ V}}{4\text{ mA}} = \mathbf{15\ k\Omega}$, $R_1 = \dfrac{V_{R_1}}{I_{R_1}} = \dfrac{72\text{ V} - 60\text{ V}}{4\text{ mA}} = \dfrac{12\text{ V}}{4\text{ mA}} = \mathbf{3\ k\Omega}$

33. $R_T = R_1 + R_2 + R_3 = 2R_3 + 7R_3 + R_3 = 10R_3$

$V_{R_3} = \dfrac{R_3(60\text{ V})}{10R_3} = \mathbf{6\ V}$, $V_{R_1} = 2V_{R_3} = 2\,(6\text{ V}) = \mathbf{12\ V}$, $V_{R_2} = 7V_{R_3} = 7(6\text{ V}) = \mathbf{42\ V}$

34. a. $V_{R_3} = 4V_{R_2} = 4(3V_{R_1}) = 12V_{R_1}$

$E = V_{R_1} + 3V_{R_1} + 12V_{R_1}$ $\therefore R_T = R_1 + 3R_1 + 12R_1 = 16R_1 = \dfrac{64\text{ V}}{10\text{ mA}} = 6.4\text{ k}\Omega$

$R_1 = \dfrac{6.4\text{ k}\Omega}{16} = \mathbf{400\ \Omega}$, $R_2 = 3R_1 = \mathbf{1.2\ k\Omega}$, $R_3 = 12R_1 = \mathbf{4.8\ k\Omega}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

40. $V_{R_2} = 48\text{ V} - 12\text{ V} = 36\text{ V}$

$R_2 = \dfrac{V_{R_2}}{I} = \dfrac{36\text{ V}}{16\text{ mA}} = \mathbf{2.25\ k\Omega}$

$V_{R_3} = 12\text{ V} - 0\text{ V} = 12\text{ V}$

$R_3 = \dfrac{V_{R_3}}{I} = \dfrac{12\text{ V}}{16\text{ mA}} = \mathbf{0.75\ k\Omega}$

$V_{R_4} = 20\text{ V}$

$R_4 = \dfrac{V_{R_4}}{I} = \dfrac{20\text{ V}}{16\text{ mA}} = \mathbf{1.25\ k\Omega}$

$V_{R_1} = E - V_{R_2} - V_{R_3} - V_{R_4}$

$= 100\text{ V} - 36\text{ V} - 12\text{ V} - 20\text{ V} = 32\text{ V}$

$R_1 = \dfrac{V_{R_1}}{I} = \dfrac{32\text{ V}}{16\text{ mA}} = \mathbf{2\ k\Omega}$

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

$V_{2\text{k}\Omega} = IR = (2\text{ mA})(2\text{ k}\Omega) = 4\text{ V}$

$V_{4\text{k}\Omega} = IR = (2\text{ mA})(4\text{ k}\Omega) = 8\text{ V}$

$V_{6\text{k}\Omega} = IR = (2\text{ mA})(6\text{ k}\Omega) = 12\text{ V}$

a. $V_a = \mathbf{44\ V}$, $V_b = 44\text{ V} - 4\text{ V} = \mathbf{40\ V}$, $V_c = 44\text{ V} - 4\text{ V} - 8\text{ V} = \mathbf{32\ V}$
$V_d = \mathbf{20\ V}$

b. $V_{ab} = V_{2\text{k}\Omega} = \mathbf{4\ V}$, $V_{cb} = -V_{4\text{k}\Omega} = \mathbf{-8\ V}$
$V_{cd} = V_{6\text{k}\Omega} = \mathbf{12\ V}$

c. $V_{ad} = V_a - V_d = 44\text{ V} - 20\text{ V} = \mathbf{24\ V}$
$V_{ca} = V_c - V_a = 32\text{ V} - 44\text{ V} = \mathbf{-12\ V}$

42. $V_0 = \mathbf{0\ V}$

$V_4 = -12\text{ V} + 2\text{ V} = 0,\ V_4 = \mathbf{+10\ V}$

$V_7 = \mathbf{4\ V}$

$V_{10} = \mathbf{20\ V}$

$V_{23} = \mathbf{+6\ V}$

$V_{30} = \mathbf{-8\ V}$

$V_{67} = \mathbf{0\ V}$

$V_{56} = \mathbf{-6\ V}$

$I = \dfrac{V_4}{4\ \Omega} = \dfrac{V_{23}}{4\ \Omega} = \dfrac{6\text{ V}}{4\ \Omega} = 1.5\text{ A}\uparrow$

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

44. a. $V_L = I_L R_L$ = (2 A)(28 Ω) = 56 V
V_{int} = 60 V – 56 V = 4 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 V)(3.58 A) = **42.96 W**
$P_{\text{int}} = I^2 R_{\text{int}} = (3.58\text{ A})^2\ 0.05\ \Omega$ = **0.64 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. $R_T = \dfrac{(9.1\ \Omega)(18\ \Omega)}{9.1\ \Omega + 18\ \Omega} = \mathbf{6.04\ \Omega}$

   b. $R_T = \dfrac{1}{\dfrac{1}{1\ \text{k}\Omega} + \dfrac{1}{2\ \text{k}\Omega} + \dfrac{1}{3\ \text{k}\Omega}} = \dfrac{1}{1\times 10^{-3}\text{S} + 0.5\times 10^{-3}\ \text{S} + 0.333\times 10^{-3}\text{S}}$

   $= \dfrac{1}{1.833\times 10^{-3}\text{S}} = \mathbf{545.55\ \Omega}$

   c. $R_T = \dfrac{1}{\dfrac{1}{100\ \Omega} + \dfrac{1}{1\ \text{k}\Omega} + \dfrac{1}{10\ \text{k}\Omega}} = \dfrac{1}{10\times 10^{-3}\text{S} + 1\times 10^{-3}\text{S} + 0.1\times 10^{-3}\text{S}} = \dfrac{1}{11.1\times 10^{-3}\text{S}}$

   $= \mathbf{90.09\ \Omega}$

   d. $R'_T = \dfrac{18\ \text{k}\Omega}{3} = 6\ \text{k}\Omega$

   $R_T = \dfrac{(6\ \text{k}\Omega)(6\ \text{M}\Omega)}{6\ \text{k}\Omega + 6\ \text{M}\Omega} = \mathbf{5.99\ k\Omega}$

   e. $R'_T = \dfrac{22\ \Omega}{4} = 5.5\ \Omega,\ R_{T''} = \dfrac{10\ \Omega}{2} = 5\ \Omega$

   $R_T = \dfrac{(5.5\ \Omega)(5\ \Omega)}{5.5\ \Omega + 5\ \Omega} = \mathbf{2.62\ \Omega}$

   f. $R_T = \dfrac{1}{\dfrac{1}{1\ \Omega} + \dfrac{1}{1\ \text{k}\Omega} + \dfrac{1}{1\ \text{M}\Omega}} = \dfrac{1}{1000\times 10^{-3}\text{S} + 1\times 10^{-3}\text{S} + 0.001\times 10^{-3}\text{S}}$

   $= \dfrac{1}{1001.001\times 10^{-3}\text{S}} = \mathbf{0.99\ \Omega}$

4. a. $R_T = \dfrac{1}{\dfrac{1}{1\ \text{k}\Omega} + \dfrac{1}{1.2\ \text{k}\Omega} + \dfrac{1}{0.3\ \text{k}\Omega}} = \dfrac{1}{1\times 10^{-3}\text{S} + 0.833\times 10^{-3}\text{S} + 3.333\times 10^{-3}\text{S}}$

   $= \dfrac{1}{5.166\times 10^{-3}\text{S}} = \mathbf{193.57\ \Omega}$

b. $R_T = \dfrac{1}{\dfrac{1}{1\text{ k}\Omega}+\dfrac{1}{1.2\text{ k}\Omega}+\dfrac{1}{2.2\text{ k}\Omega}+\dfrac{1}{1\text{ k}\Omega}} = \dfrac{1}{1\times10^{-3}\text{S}+0.833\times10^{-3}\text{S}+0.455\times10^{-3}\text{S}+1\times10^{-3}\text{S}}$

$= \dfrac{1}{3.288\times10^{-3}\text{S}} = \mathbf{304.14\ \Omega}$

5. a. $R_T' = 3\ \Omega \parallel 6\ \Omega = 2\ \Omega$

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

b. $R_T' = \dfrac{6\text{ k}\Omega}{3} = 2\text{ k}\Omega$

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

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

d. $R_T = 628.93\ \Omega = \dfrac{1}{\dfrac{1}{1.2\text{ k}\Omega}+\dfrac{1}{R}+\dfrac{1}{2.2\text{ k}\Omega}} = \dfrac{1}{833.33\times10^{-3}\text{S}+\dfrac{1}{R}+454.55\times10^{-3}\ \text{S}}$

$811.32\times10^{-3} + \dfrac{628.93\ \Omega}{R} = 1$

$R = \dfrac{628.93\ \Omega}{1-811.32\times10^{-3}} = \mathbf{3.3\text{ k}\Omega}$

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

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

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

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

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

c. $R_T = \dfrac{1}{\dfrac{1}{1.2\text{ k}\Omega}+\dfrac{1}{22\text{ k}\Omega}+\dfrac{1}{220\text{ k}\Omega}+\dfrac{1}{2.2\text{ M}\Omega}}$

$= \dfrac{1}{833.333\times10^{-6}\text{S}+45.455\times10^{-6}\text{S}+4.545\times10^{-6}\text{S}+0.455\times10^{-6}\text{S}}$

$= \dfrac{1}{883.788\times10^{-6}\text{S}} = \mathbf{1.131\text{ k}\Omega}$

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

e. R_T reduced.

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

b. $\mathbf{\infty\ \Omega}$

c. $\mathbf{\infty\ \Omega}$

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

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

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

and $R_1 = 3.2(20\ \Omega) = \mathbf{64\ \Omega}$

$R_2 = 5R_1 = 5(64\ \Omega) = \mathbf{320\ \Omega}$

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

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

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

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

$0.1\text{ S} = \dfrac{1}{R_1} + 0.09167\text{ S}$

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

$R_1 = \dfrac{1}{0.00833\text{ S}} = \mathbf{120\ \Omega}$

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

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

c. $I_s = \dfrac{E}{R_T} = \dfrac{36\text{ V}}{6\ \Omega} = \mathbf{6\ A}$

$I_1 = \dfrac{V_{R_1}}{R_1} = \dfrac{36\text{ V}}{8\ \Omega} = \mathbf{4.5\ A}$

$I_2 = \dfrac{V_{R_2}}{R_2} = \dfrac{36\text{ V}}{24\ \Omega} = \mathbf{1.5\ A}$

d. $I_s = I_1 + I_2$

$6\text{ A} = 4.5\text{ A} + 1.5\text{ A} = 6\text{ A}$ (checks)

11. a. $R_T = \dfrac{1}{\dfrac{1}{3\,\Omega}+\dfrac{1}{9\,\Omega}+\dfrac{1}{36\,\Omega}} = \dfrac{1}{0.333\,\text{S}+0.111\,\text{S}+0.028\,\text{S}}$

$= \dfrac{1}{472\times10^{-3}\text{S}} = \mathbf{2.12\ \Omega}$

b. $V_{R_1} = V_{R_2} = V_{R_3} = \mathbf{18\ V}$

c. $I_s = \dfrac{E}{R_T} = \dfrac{18\text{ V}}{2.12\ \Omega} = \mathbf{8.5\ A}$

$I_1 = \dfrac{V_{R_1}}{R_1} = \dfrac{18\text{ V}}{3\ \Omega} = \mathbf{6\ A}$, $I_2 = \dfrac{V_{R_2}}{R_2} = \dfrac{18\text{ V}}{9\ \Omega} = \mathbf{2\ A}$, $I_3 = \dfrac{V_{R_3}}{R_3} = \dfrac{18\text{ V}}{36\ \Omega} = \mathbf{0.5\ A}$

d. I_s = 8.5 A = 6 A + 2 A + 0.5 A = 8.5 A (checks)

12. a. $R_T = \dfrac{1}{\dfrac{1}{10\text{ k}\Omega}+\dfrac{1}{1.2\text{ k}\Omega}+\dfrac{1}{6.8\text{ k}\Omega}} = \dfrac{1}{100\times10^{-6}\text{S}+833.333\times10^{-6}\text{S}+147.059\times10^{-6}\text{S}}$

$= \dfrac{1}{1.080\times10^{-3}\text{S}} = \mathbf{925.93\ \Omega}$

b. $V_{R_1} = V_{R_2} = V_{R_3} = \mathbf{24\ V}$

c. $I_s = \dfrac{E}{R_T} = \dfrac{24\text{ V}}{925.93\ \Omega} = \mathbf{25.92\ mA}$

$I_{R_1} = \dfrac{V_{R_2}}{R_1} = \dfrac{24\text{ V}}{10\text{ k}\Omega} = \mathbf{2.4\ mA}$, $I_{R_2} = \dfrac{V_{R_2}}{R_2} = \dfrac{24\text{ V}}{1.2\text{ k}\Omega} = \mathbf{20\ mA}$,

$I_{R_3} = \dfrac{V_{R_3}}{R_3} = \dfrac{24\text{ V}}{6.8\text{ k}\Omega} = \mathbf{3.53\ mA}$

d. I_T = **25.92 mA** = 2.4 mA + 20 mA + 3.53 mA = **25.93 mA** (checks)

13. a. $R_T \cong 1\text{ k}\Omega$

b. $R_T = \dfrac{1}{\dfrac{1}{10\text{ k}\Omega}+\dfrac{1}{22\text{ k}\Omega}+\dfrac{1}{1.2\text{ k}\Omega}+\dfrac{1}{56\text{ k}\Omega}}$

$= \dfrac{1}{100\times10^{-6}\text{S}+45.46\times10^{-6}\text{S}+833.333\times10^{-6}\text{S}+17.86\times10^{-6}\text{S}}$

$= \dfrac{1}{996.65\times10^{-6}\text{S}} = \mathbf{1.003\ k\Omega}$, very close

c. I_3 the most, I_4 the least

d. $I_{R_1} = \dfrac{V_{R_1}}{R_1} = \dfrac{44\text{ V}}{10\text{ k}\Omega} = \mathbf{4.4\ mA}$, $I_{R_2} = \dfrac{V_{R_2}}{R_2} = \dfrac{44\text{ V}}{22\text{ k}\Omega} = \mathbf{2\ mA}$

$I_{R_3} = \dfrac{V_{R_3}}{R_3} = \dfrac{44\text{ V}}{1.2\text{ k}\Omega} = \mathbf{36.67\ mA}$, $I_{R_4} = \dfrac{V_{R_4}}{R_4} = \dfrac{44\text{ V}}{56\text{ k}\Omega} = \mathbf{0.79\ mA}$

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

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

f. always greater

14. –

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

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

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

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

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

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

$E = V_{R_3} = I_3R_3 = (9\text{ A})(4\ \Omega) = \mathbf{36\text{ V}}$

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

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

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

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

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

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

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

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

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

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

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

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

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

19. a. $R_T = \dfrac{1}{\dfrac{1}{1\,\text{k}\Omega}+\dfrac{1}{33\,\text{k}\Omega}+\dfrac{1}{8.2\,\text{k}\Omega}} = \dfrac{1}{1000\times10^{-6}\text{S}+30.303\times10^{-6}\text{S}+121.951\times10^{-6}\text{S}}$

$= \dfrac{1}{1.152\times10^{-3}\text{S}} = \mathbf{867.86\ \Omega}$

$I_{R_1} = \dfrac{V_{R_1}}{R_1} = \dfrac{100\text{ V}}{1\,\text{k}\Omega} = \mathbf{100\ mA},\ I_{R_2} = \dfrac{V_{R_2}}{R_2} = \dfrac{100\text{ V}}{33\,\text{k}\Omega} = \mathbf{3.03\ mA}$

$I_{R_3} = \dfrac{V_{R_3}}{R_3} = \dfrac{100\text{ V}}{8.2\,\text{k}\Omega} = \mathbf{12.2\ mA}$

b. $P_{R_1} = V_{R_1}\cdot I_{R_1}$ = (100 V)(100 mA) = **10 W**

$P_{R_2} = V_{R_2}\cdot I_{R_2}$ = (100 V)(3.03 mA) = **0.30 W**

$P_{R_3} = V_{R_3}\cdot I_{R_3}$ = (100 V)(12.2 mA) = **1.22 W**

c. $I_s = \dfrac{E}{R_T} = \dfrac{100\text{ V}}{867.86\ \Omega}$ = 115.23 mA

$P_s = E_sI_s$ = (100 V)(115.23 mA) = **11.52 W**

d. P_s = **11.52 W** = 10 W + 0.30 W + 1.22 W = **11.52 W** (checks)

e. R_1 = the smallest parallel resistor

20. a. $I_{\text{bulb}} = \dfrac{E}{R_{\text{bulb}}} = \dfrac{120\text{ V}}{1.8\,\text{k}\Omega} = \mathbf{66.667\ mA}$

b. $R_T = \dfrac{R}{N} = \dfrac{1.8\,\text{k}\Omega}{8} = \mathbf{225\ \Omega}$

c. $I_s = \dfrac{E}{R_T} = \dfrac{120\text{ V}}{225\,\Omega} = \mathbf{0.533\ A}$

d. $P = \dfrac{V^2}{R} = \dfrac{(120\text{ V})^2}{1.8\,\text{k}\Omega} = \mathbf{8\ W}$

e. P_s = 8(8 W) = **64 W**

f. none, I_s drops by 66.667 mA

21. $R_T = \dfrac{1}{\dfrac{1}{5\ \Omega}+\dfrac{1}{10\ \Omega}+\dfrac{1}{20\ \Omega}} = \dfrac{1}{200\times10^{-3}\text{S}+100\times10^{-3}\text{S}+50\times10^{-3}\text{S}}$

$= \dfrac{1}{350\times10^{-3}\text{S}} = 2.86\ \Omega$

$I_s = \dfrac{E}{R_T} = \dfrac{60\text{ V}}{2.86\ \Omega} = 20.98\text{ A}$

$P = E\cdot I_s$ = (60 V)(20.98 A) = **1.26 kW**

22. a. $P_1 = 10(60 \text{ W}) = 600 \text{ W} = E \cdot I_1 = 120 \text{ V} \cdot I_1, I_1 = \dfrac{600 \text{ W}}{120 \text{ V}} = \mathbf{5\ A}$

$P_2 = 400 \text{ W} = 120 \text{ V} \cdot I_2, \quad I_2 = \dfrac{400 \text{ W}}{120 \text{ V}} = \mathbf{3.33\ A}$

$P_3 = 200 \text{ W} = 120 \text{ V} \cdot I_3, \quad I_3 = \dfrac{200 \text{ W}}{120 \text{ V}} = \mathbf{1.67\ A}$

$P_4 = 110 \text{ W} = 120 \text{ V} \cdot I_4, \quad I_4 = \dfrac{110 \text{ W}}{120 \text{ V}} = \mathbf{0.92\ A}$

b. $I_s = 5 \text{ A} + 3.33 \text{ A} + 1.67 \text{ A} + 0.92 \text{ A} = \mathbf{10.92\ A}$ (no)

c. $R_T = \dfrac{E}{I_s} = \dfrac{120 \text{ V}}{10.92 \text{ A}} = \mathbf{10.99\ \Omega}$

d. $P_s = E \cdot I_s = (120 \text{ V})(10.92 \text{ A}) = 1.31 \text{ kW}$
$P_s = \mathbf{1.31\ kW} = 600 \text{ W} + 400 \text{ W} + 200 \text{ W} + 110 \text{ W} = \mathbf{1.31\ kW}$ (the same)

23. a. $8\ \Omega \parallel 12\ \Omega = 4.8\ \Omega,\ 4.8\ \Omega \parallel 4\ \Omega = 2.182\ \Omega$

$I_1 = \dfrac{24 \text{ V} + 8 \text{ V}}{2.182\ \Omega} = \mathbf{14.67\ A}$

b. $P_4 = \dfrac{V^2}{R} = \dfrac{(24 \text{ V} + 8 \text{ V})^2}{4\ \Omega} = \mathbf{256\ W}$

c. $I_2 = I_1 = \mathbf{14.67\ A}$

24. $I_1 = 12.6 \text{ mA} - 8.5 \text{ mA} = \mathbf{4.1\ mA}$
$I_2 = 8.5 \text{ mA} - 4 \text{ mA} = \mathbf{4.5\ mA}$

25. a. $9 \text{ A} + 2 \text{ A} + I_1 = 12 \text{ A}, \quad I_1 = 12 \text{ A} - 11 \text{ A} = \mathbf{1\ A}$
$I_2 + 1 \text{ A} = 1 \text{ A} + 3 \text{ A}, \quad I_2 = 4 \text{ A} - 1 \text{ A} = \mathbf{3\ A}$

b. $6 \text{ A} = 2 \text{ A} + I_1, \quad I_1 = 6 \text{ A} - 2 \text{ A} = \mathbf{4\ A}$
$4 \text{ A} + 5 \text{ A} = I_2, \quad I_2 = \mathbf{9\ A}$
$9 \text{ A} = I_3 + 3 \text{ A}, \quad I_3 = 9 \text{ A} - 3 \text{ A} = \mathbf{6\ A}$
$3 \text{ A} + 10 \text{ A} = I_4, \quad I_4 = \mathbf{13\ A}$

26. a. $I_1 + 5 \text{ mA} = 8 \text{ mA}, \quad I_1 = \mathbf{3\ mA}$
$5 \text{ mA} = I_2 + 3.5 \text{ mA}, \quad I_2 = \mathbf{1.5\ mA}$
$I_1 = 3 \text{ mA} = I_3 + 1 \text{ mA}, \quad I_3 = \mathbf{2\ mA}$
$I_4 = \mathbf{5\ mA}$

b. $I_3 = 1.5\ \mu\text{A} + 0.5\ \mu\text{A} = \mathbf{2.0\ \mu A}$
$6\ \mu\text{A} = I_2 + I_3 = I_2 + 2\ \mu\text{A}, \quad I_2 = \mathbf{4\ \mu A}$
$I_2 + 1.5\ \mu\text{A} = I_4, \quad I_4 = 4\ \mu\text{A} + 1.5\ \mu\text{A} = \mathbf{5.5\ \mu A}$
$I_1 = \mathbf{6\ \mu A}$

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

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

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

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

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

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

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

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

b. $E = I_1R_1 = (2\text{ A})(6\ \Omega) = \mathbf{12\text{ V}}$

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

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

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

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

c. $I_1 = \dfrac{64\text{ V}}{1\text{ k}\Omega} = \mathbf{64\text{ mA}}$

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

$I_s = I_1 + I_2 + I_3$

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

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

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

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

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

$I_1 = \dfrac{E}{R_1} = \dfrac{30\text{ V}}{30\,\Omega} = \mathbf{1\text{ A}}$

Because $R_3 = R_2$, $I_3 = I_2$, and $I_s = I_1 + I_2 + I_3 = I_1 + 2I_2$

$$2\text{ A} = 1\text{ A} + 2I_2$$

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

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

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

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

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

$I_3 = \dfrac{4\,\Omega}{2\,\Omega} I_1 = 2I_1 = \mathbf{12\text{ A}}$

$I_4 = \dfrac{4\,\Omega}{40\,\Omega} I_1 = \dfrac{1}{10} I_1 = \mathbf{0.6\text{ A}}$

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

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

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

b. $R_T = \dfrac{1}{\dfrac{1}{2.2\text{ k}\Omega} + \dfrac{1}{1.2\text{ k}\Omega} + \dfrac{1}{0.2\text{ k}\Omega}} = \dfrac{1}{454.55\times10^{-6}\text{S} + 833.33\times10^{-6}\text{S} + 5000\times10^{-6}\text{S}}$

$= \dfrac{1}{6{,}288\times10^{-6}\text{S}} = 159.03\,\Omega$

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

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

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

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

c. $R_T = \dfrac{1}{\dfrac{1}{4\,\Omega}+\dfrac{1}{8\,\Omega}+\dfrac{1}{12\,\Omega}} = \dfrac{1}{250\times10^{-3}\text{S}+125\times10^{-3}\text{S}+83.333\times10^{-3}\text{S}}$

$= \dfrac{1}{458.333\times10^{-3}} = 2.18\,\Omega$

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

$I_2 = \dfrac{2.18\,\Omega}{8\,\Omega}(6\text{ A}) = \mathbf{1.64\ A}$

$I_3 = \dfrac{2.18\,\Omega}{12\,\Omega}(6\text{ A}) = \mathbf{1.09\ A}$

$I_4 = \mathbf{6\ A}$

d. $I_1 = I_2 = \dfrac{20\,\Omega(9\text{ A})}{20\,\Omega+10\,\Omega} = \mathbf{6\ A}$

$I_3 = 9\text{ A} - I_1 = 9\text{ A} - 6\text{ A} = \mathbf{3\ A}$
$I_4 = \mathbf{9\ A}$

31. a. $I_1 \cong \dfrac{9}{10}(10\text{ A}) = \mathbf{9\ A}$

b. $I_1/I_2 = 10\,\Omega/1\,\Omega = 10,\qquad I_2 = \dfrac{I_1}{10} = \dfrac{9\text{ A}}{10} \cong \mathbf{0.9\ A}$

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

d. $I_1/I_4 = 100\text{ k}\Omega/1\,\Omega = 100{,}000$, $\quad I_4 = I_1/100{,}000 = 9\text{ A}/100{,}000 \cong$ **90 μA**

e. very little effect, 1/100,000

f. $R_T = \dfrac{1}{\dfrac{1}{1\,\Omega}+\dfrac{1}{10\,\Omega}+\dfrac{1}{1\text{ k}\Omega}+\dfrac{1}{100\text{ k}\Omega}}$

$= \dfrac{1}{1\text{ S}+0.1\text{ S}+1\times10^{-3}\text{ S}+10\times10^{-6}\text{ S}}$

$= \dfrac{1}{1.10\text{ S}} = 0.91\,\Omega$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

35. a. $P_L = V_L I_L$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

c. $R_m = 400\text{ k}\Omega$

$R'_T = 400\text{ k}\Omega \parallel 200\text{ k}\Omega = 133.333\text{ k}\Omega$

$V_2 = \dfrac{(133.333\text{ k}\Omega)(20\text{ V})}{133.333\text{ k}\Omega + 100\text{ k}\Omega} = \mathbf{11.43\text{ V}}$ (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. $V_{ab} = \mathbf{20\text{ V}}$

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

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

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

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

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

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

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

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

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

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

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

4 V supply connected in reverse so that

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

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

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

4. a. $R'_T = R_3 \parallel R_4 = \dfrac{12\ \Omega}{2} = 6\ \Omega$, $R''_T = R_2 \parallel R'_T = \dfrac{6\ \Omega}{2} = 3\ \Omega$
   $R_T = R_1 + R''_T = 4\ \Omega + 3\ \Omega = \mathbf{7\ \Omega}$
   b. $I_s = \dfrac{E}{R_T} = \dfrac{14\text{ V}}{7\ \Omega} = \mathbf{2\ A}$, $I_2 = \dfrac{1}{2}I_s = \dfrac{2\text{ A}}{2} = \mathbf{1\ A}$
   $I_3 = \dfrac{1\text{ A}}{2} = \mathbf{0.5\ A}$
   c. $I_5 = \mathbf{1\ A}$
   d. $V_2 = I_2R_2 = (1\text{ A})(6\ \Omega) = \mathbf{6\ V}$
   $V_4 = V_2 = \mathbf{6\ V}$

5. a. $R'_T = R_1 \parallel R_2 = 10\ \Omega \parallel 15\ \Omega = 6\ \Omega$
   $R_T = R'_T \parallel (R_3 + R_4) = 6\ \Omega \parallel (10\ \Omega + 2\ \Omega) = 6\ \Omega \parallel 12\ \Omega = \mathbf{4\ \Omega}$
   b. $I_s = \dfrac{E}{R_T} = \dfrac{36\text{ V}}{4\ \Omega} = \mathbf{9\ A}$, $I_1 = \dfrac{E}{R'_T} = \dfrac{36\text{ V}}{6\ \Omega} = \mathbf{6\ A}$
   $I_2 = \dfrac{E}{R_3 + R_4} = \dfrac{36\text{ V}}{10\ \Omega + 2\ \Omega} = \dfrac{36\text{ V}}{12\ \Omega} = \mathbf{3\ A}$
   c. $V_4 = I_4 R_4 = I_2R_4 = (3\text{ A})(2\ \Omega) = \mathbf{6\ V}$

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

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

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

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

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

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

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

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

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

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

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

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

$= 4\ \Omega \parallel 4\ \Omega = 2\ \Omega$

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

$= 10\ \Omega \parallel 10\ \Omega = 5\ \Omega$

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

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

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

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

c. $I_8 = \dfrac{(R_4 \parallel R_5)(I_3)}{(R_4 \parallel R_5) + (R_7 + R_8)}$

$= \dfrac{(4\ \Omega \parallel 8\ \Omega)(4\text{ A})}{(4\ \Omega \parallel 8\ \Omega) + (6\ \Omega + 2\ \Omega)}$

$= \dfrac{(2.67)(4\text{ A})}{2.67\ \Omega + 8\ \Omega} = \mathbf{1\text{ A}}$

d. $\quad -I_8R_8 - V_x + I_9R_9 = 0$

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

9. $\quad I_1 = \dfrac{20\text{ V}}{5\,\Omega} = \mathbf{4\ A}$

$R_T = 16\ \Omega \parallel 25\ \Omega = 9.756\ \Omega$

$I_2 = \dfrac{7\text{ V}}{9.756\,\Omega} = \mathbf{0.72\ A}$

10. a, b. $\quad I_1 = \dfrac{24\text{ V}}{4\,\Omega} = \mathbf{6\ A}\downarrow,\ I_3 = \dfrac{8\text{ V}}{10\,\Omega} = \mathbf{0.8\ A}\uparrow$

$I_2 = \dfrac{24\text{ V} + 8\text{ V}}{2\,\Omega} = \dfrac{32\text{ V}}{2\,\Omega} = \mathbf{16\ A}$

$I = I_1 + I_2 = 6\text{ A} + 16\text{ A} = \mathbf{22\ A}\downarrow$

11. a. $\quad R' = R_4 + R_5 = 14\ \Omega + 6\ \Omega = 20\ \Omega$

$R'' = R_2 \parallel R' = 20\ \Omega \parallel 20\ \Omega = 10\ \Omega$

$R''' = R'' + R_1 = 10\ \Omega + 10\ \Omega = 20\ \Omega$

$R_T = R_3 \parallel R''' = 5\ \Omega \parallel 20\ \Omega = \mathbf{4\ \Omega}$

$I_s = \dfrac{E}{R_T} = \dfrac{20\text{ V}}{4\,\Omega} = \mathbf{5\ A}$

$I_1 = \dfrac{20\text{ V}}{R_1 + R''} = \dfrac{20\text{ V}}{10\,\Omega + 10\,\Omega} = \dfrac{20\text{ V}}{20\,\Omega} = \mathbf{1\ A}$

$I_3 = \dfrac{20\text{ V}}{5\,\Omega} = \mathbf{4\ A}$

$I_4 = \dfrac{I_1}{2} = (\text{since } R' = R_2) = \dfrac{1\text{ A}}{2} = \mathbf{0.5\ A}$

b. $\quad V_a = I_3R_3 - I_4R_5 = (4\text{ A})(5\ \Omega) - (0.5\text{ A})(6\ \Omega) = 20\text{ V} - 3\text{ V} = \mathbf{17\ V}$

$V_{bc} = \left(\dfrac{I_1}{2}\right)R_2 = (0.5\text{ A})(20\ \Omega) = \mathbf{10\ V}$

12. a. $\quad I_1 = \dfrac{E}{R_1 + R_4 \parallel (R_2 + R_3 \parallel R_5)} = \dfrac{20\text{ V}}{3\,\Omega + 3\,\Omega \parallel (3\,\Omega + 6\,\Omega \parallel 6\,\Omega)}$

$= \dfrac{20\text{ V}}{3\,\Omega + 3\,\Omega \parallel (3\,\Omega + 3\,\Omega)} = \dfrac{20\text{ V}}{3\,\Omega + 3\,\Omega \parallel 6\,\Omega} = \dfrac{20\text{ V}}{3\,\Omega + 2\,\Omega}$

$= \mathbf{4\ A}$

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

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

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

c. $I_4 = I_1 - I_2 = 4\ \text{A} - 1.33\ \text{A} = 2.67\ \text{A}$

$$V_a = I_4R_4 = (2.67\ \text{A})(3\ \Omega) = \mathbf{8\ V}$$
$$V_b = I_3R_3 = (0.67\ \text{A})(6\ \Omega) = \mathbf{4\ V}$$

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

$I_C = I_E = \mathbf{2\ mA}$

b. $I_B = \dfrac{V_{R_B}}{R_B} = \dfrac{V_{CC} - (V_{BE} + V_E)}{R_B} = \dfrac{8\ \text{V} - (0.7\ \text{V} + 2\ \text{V})}{220\ \text{k}\Omega}$

$$= \frac{8\ \text{V} - 2.7\ \text{V}}{220\ \text{k}\Omega} = \frac{5.3\ \text{V}}{220\ \text{k}\Omega} = \mathbf{24\ \mu A}$$

c. $V_B = V_{BE} + V_E = \mathbf{2.7\ V}$

$V_C = V_{CC} - I_CR_C = 8\ \text{V} - (2\ \text{mA})(2.2\ \text{k}\Omega) = 8\ \text{V} - 4.4\ \text{V} = \mathbf{3.6\ V}$

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

$V_{BC} = V_B - V_C = 2.7\ \text{V} - 3.6\ \text{V} = \mathbf{-0.9\ V}$

14. a. $I_G = 0 \therefore V_G = \dfrac{270\ \text{k}\Omega(16\ \text{V})}{270\ \text{k}\Omega + 2000\ \text{k}\Omega} = \mathbf{1.9\ V}$

$$V_G - V_{GS} - V_S = 0$$
$$V_S = V_G - V_{GS} = 1.9\ \text{V} - (-1.75\ \text{V}) = \mathbf{3.65\ V}$$

b. $I_1 = I_2 = \dfrac{16\ \text{V}}{270\ \text{k}\Omega + 2000\ \text{k}\Omega} = \mathbf{7.05\ \mu A}$

$I_D = I_S = \dfrac{V_S}{R_S} = \dfrac{3.65\ \text{V}}{1.5\ \text{k}\Omega} = \mathbf{2.43\ mA}$

c. $V_{DS} = V_{DD} - I_DR_D - I_SR_S = V_{DD} - I_D(R_D + R_S)$ since $I_D = I_S$

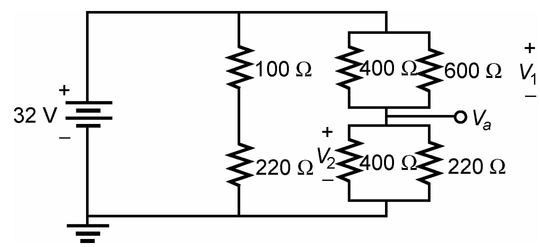
$= 16\ \text{V} - (2.43\ \text{mA})(4\ \text{k}\Omega) = 16\ \text{V} - 9.72\ \text{V} = \mathbf{6.28\ V}$

d. $V_{DD} - I_DR_D - V_{DG} - V_G = 0$

$V_{DG} = V_{DD} - I_DR_D - V_G$

$= 16\ \text{V} - (2.43\ \text{mA})(2.5\ \text{k}\Omega) - 1.9\ \text{V} = 16\ \text{V} - 6.08\ \text{V} - 1.9\ \text{V} = \mathbf{8.02\ V}$

15. a. Network redrawn:



$100\ \Omega + 220\ \Omega = 320\ \Omega$
$400\ \Omega \parallel 600\ \Omega = 240\ \Omega$
$400\ \Omega \parallel 220\ \Omega = 141.94\ \Omega$
$240\ \Omega + 141.94\ \Omega = 381.94\ \Omega$

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

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

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. $I_{600\Omega} = \dfrac{20.11\text{ V}}{600\,\Omega} = 33.52\text{ mA}$

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

$I + I_{600\Omega} = I_{220\Omega}$
$I = I_{200\Omega} - I_{600\Omega}$
$= 54.05\text{ mA} - 33.52\text{ mA}$
$= \mathbf{20.53\ mA} \rightarrow$

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

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"
$R' = R_3 + R_4 \parallel R_5 + R_6 \parallel R_7$
$= 10\ \Omega + 6\ \Omega \parallel 6\ \Omega + 6\ \Omega \parallel 3\ \Omega$
$= 10\ \Omega + 3\ \Omega + 2\ \Omega$
$= 15\ \Omega$

$R_T = R_1 + R_2 \parallel R'$
$= 10\ \Omega + 30\ \Omega \parallel 15\ \Omega = 10\ \Omega + 10\ \Omega$
$= 20\ \Omega$

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

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

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

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

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

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

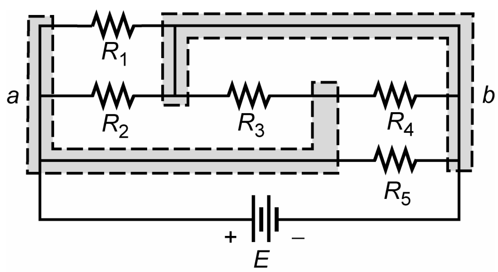
$V_8 = \mathbf{0\text{ V}}$

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

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

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

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



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

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

$$\underbrace{4\,\Omega \parallel 4\,\Omega} \parallel 32\,\Omega$$

$$2\,\Omega \parallel 32\,\Omega = \mathbf{1.88\,\Omega}$$

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

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

d. $I_s = I_1 + I_2 + I_3 + I_4 + I_5$

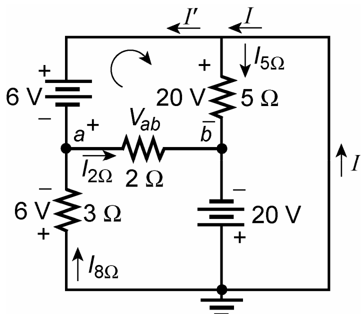
$$= \frac{32\text{ V}}{16\,\Omega} + \frac{32\text{ V}}{8\,\Omega} + \frac{32\text{ V}}{4\,\Omega} + \frac{32\text{ V}}{32\,\Omega} + \frac{32\text{ V}}{16\,\Omega}$$

$= 2\text{ A} + 4\text{ A} + 8\text{ A} + 1\text{ A} + 2\text{ A}$

$= 17\text{ A}$

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

20. a.



KVL: $+6\text{ V} - 20\text{ V} + V_{ab} = 0$
$V_{ab} = +20\text{ V} - 6\text{ V} = \mathbf{14\ V}$

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

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

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

$I' + I_{3\Omega} = I_{2\Omega}$
and $I' = I_{2\Omega} - I_{3\Omega} = 7\text{ A} - 2\text{ A} = 5\text{ A}$
$I = I' + I_{5\Omega} = 5\text{ A} + 4\text{ A} = \mathbf{9\ A}$

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

$+18\text{ V} + 20\text{ V} - V_{8\Omega} = 0$
$V_{8\Omega} = 38\text{ V}$
$I_{8\Omega} = \dfrac{38\text{ V}}{8\,\Omega} = 4.75\text{ A}$
$I_{3\Omega} = \dfrac{18\text{ V}}{3\,\Omega + 6\,\Omega} = \dfrac{18\text{ V}}{9\,\Omega} = 2\text{ A}$

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

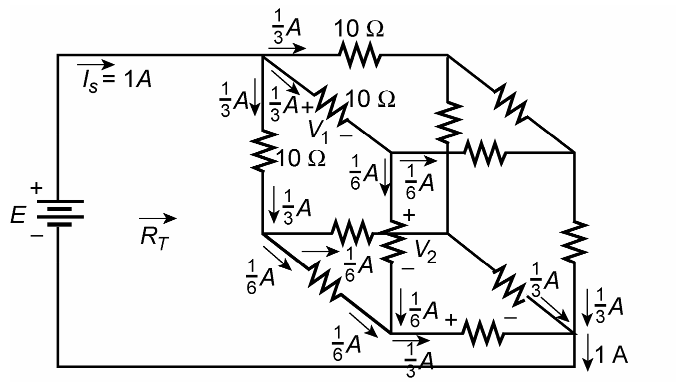
b. $V = (I_{3\Omega})(6\,\Omega) + 20\text{ V} = (2\text{ A})(6\,\Omega) + 20\text{ V} = 12\text{ V} + 20\text{ V} = \mathbf{32\ V}$

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

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

KVL: $120 = I_1 12 + I_3R_3 = \left(\dfrac{R_3}{10} + 2\right)12 + 2R_3$
and $120 = 1.2R_3 + 24 + 2R_3$
$3.2R_3 = 96\ \Omega$
$R_3 = \dfrac{96\ \Omega}{3.2} = \mathbf{30\ \Omega}$

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.



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

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

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

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

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

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

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

6 kΩ resistor "open"

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

25. a. $R'_T = R_5 \parallel (R_6 + R_7) = 6\,\Omega \parallel 3\,\Omega = 2\,\Omega$

$R''_T = R_3 \parallel (R_4 + R'_T) = 4\,\Omega \parallel (2\,\Omega + 2\,\Omega) = 2\,\Omega$

$R_T = R_1 + R_2 + R''_T = 3\,\Omega + 5\,\Omega + 2\,\Omega = 10\,\Omega$

$$I = \frac{240\text{ V}}{10\,\Omega} = \mathbf{24\ A}$$

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

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

c. $V_3 = I_3R_3 = (I - I_4)R_3 = (24\text{ A} - 12\text{ A})4\ \Omega = \mathbf{48\ V}$
$V_5 = I_5R_5 = (I_4 - I_7)R_5 = (4\text{ A})6\ \Omega = \mathbf{24\ V}$
$V_7 = I_7R_7 = (8\text{ A})2\ \Omega = \mathbf{16\ V}$

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

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

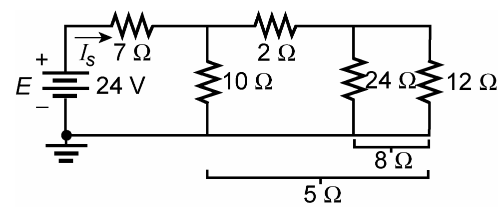
b. $I = 2\text{ V}/5.53\ \Omega = \mathbf{361.66\ mA}$

c. $I_3 = \dfrac{2\ \Omega(I)}{2\ \Omega + 6.56\ \Omega} = \dfrac{2\ \Omega(361.66\text{ mA})}{2\ \Omega + 6.56\ \Omega} = \mathbf{84.50\ mA}$

$I_8 = \dfrac{2\ \Omega(84.5\text{ mA})}{2\ \Omega + 7\ \Omega} = \mathbf{18.78\ mA}$

27. The 12 Ω resistors are in parallel.

Network redrawn:



$R_T = 12\ \Omega$

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

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

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

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

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

b. $I_1 = 12\text{ V}/6\ \Omega = 2\text{ A}$

$I_3 = \dfrac{6\ \Omega(2\text{ A})}{6\ \Omega + 6\ \Omega} = 1\text{ A}$

$I_4 = \dfrac{1\text{ A}}{2} = \mathbf{0.5\ A}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$P_1 = I_1^2 R_1 = (40\text{ mA})^2 0.5\text{ k}\Omega = \mathbf{0.8\ W}$ (1 watt resistor)
$P_2 = I_2^2 R_2 = (30\text{ mA})^2 2\text{ k}\Omega = \mathbf{1.8\ W}$ (2 watt resistor)
$P_3 = I_3^2 R_3 = (10\text{ mA})^2 4\text{ k}\Omega = \mathbf{0.4\ W}$ (1/2 watt or 1 watt resistor)
$P_4 = I_4^2 R_4 = (36\text{ mA})^2 1\text{ k}\Omega = \mathbf{1.3\ W}$ (2 watt resistor)
$P_5 = I_5^2 R_5 = (40\text{ mA})^2 0.6\text{ k}\Omega = \mathbf{0.96\ W}$ (1 watt resistor)

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

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

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

$$R_2 = \frac{3\text{ V}(1\text{ k}\Omega)}{12\text{ V}} = 0.25\text{ k}\Omega = \mathbf{250\ \Omega}$$
$$R_1 = 1\text{ k}\Omega - 0.25\text{ k}\Omega = 0.75\text{ k}\Omega = \mathbf{750\ \Omega}$$

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

$$V_{R_1} = 9\text{ V} = \frac{R_1(12\text{ V})}{R_1 + (R_2 \| R_L)}$$
$$9R_1 + 9(R_2 \| R_L) = 12R_1$$
$$\left.\begin{aligned} R_1 &= 3(R_2 \| R_L) \\ R_1 + R_2 &= 1\text{ k}\Omega \end{aligned}\right\} 2\text{ eq. } 2\text{ unk}(R_L = 10\text{ k}\Omega)$$
$$R_1 = \frac{3R_2R_L}{R_2 + R_L} \Rightarrow \frac{3R_2\ 10\text{ k}\Omega}{R_2 + 10\text{ k}\Omega}$$
and $R_1(R_2 + 10\text{ k}\Omega) = 30\text{ k}\Omega\ R_2$
$$R_1R_2 + 10\text{ k}\Omega\ R_1 = 30\text{ k}\Omega\ R_2$$
$$R_1 + R_2 = 1\text{ k}\Omega:\ (1\text{ k}\Omega - R_2)R_2 + 10\text{ k}\Omega\ (1\text{ k}\Omega - R_2) = 30\text{ k}\Omega\ R_2$$
$$R_2^2 + 39\text{ k}\Omega\ R_2 - 10\text{ k}\Omega^2 = 0$$
$$R_2 = 0.255\text{ k}\Omega,\ \cancel{-39.255}\text{ k}\Omega$$
$$R_2 = \mathbf{255\ \Omega}$$
$$R_1 = 1\text{ k}\Omega - R_2 = \mathbf{745\ \Omega}$$

32. a. $V_{ab} = \dfrac{80\ \Omega(40\text{ V})}{100\ \Omega} = \mathbf{32\ V}$
$V_{bc} = 40\text{ V} - 32\text{ V} = \mathbf{8\ V}$

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

$20\ \Omega \| 10\text{ k}\Omega = 19.96\ \Omega$
$$V_{ab} = \frac{74.07\ \Omega(40\text{ V})}{74.07\ \Omega + 19.96\ \Omega} = \mathbf{31.51\ V}$$
$V_{bc} = 40\text{ V} - 31.51\text{ V} = \mathbf{8.49\ V}$

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

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

The applied loads dissipate less than 20 mW of power.

33. a. I_{CS} = **1 mA**

b. $R_{\text{shunt}} = \dfrac{R_m I_{CS}}{I_{\max} - I_{CS}} = \dfrac{(100\,\Omega)(1\text{ mA})}{20\text{ A} - 1\text{ mA}} \cong \dfrac{0.1}{20}$ Ω = **5 mΩ**

34. 25 mA: $R_{\text{shunt}} = \dfrac{(1\text{ k}\Omega)(50\,\mu\text{A})}{25\text{ mA} - 0.05\text{ mA}}$ ≅ **2 Ω**

50 mA: $R_{\text{shunt}} = \dfrac{(1\text{ k}\Omega)(50\,\mu\text{A})}{50\text{ mA} - 0.05\text{ mA}}$ = **1 Ω**

100 mA: R_{shunt} ≅ **0.5 Ω**

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

b. Ω/V = 1/I_{CS} = 1/50 μA = **20,000**

36. 5 V: $R_s = \dfrac{5\text{ V} - (1\text{ mA})(100\,\Omega)}{1\text{ mA}}$ = **4.9 kΩ**

50 V: $R_s = \dfrac{50\text{ V} - 0.1\text{ V}}{1\text{ mA}}$ = **49.9 kΩ**

500 V: $R_s = \dfrac{500\text{ V} - 0.1\text{ V}}{1\text{ mA}}$ = **499.9 kΩ**

37. 10 MΩ = (0.5 V)(Ω/V) ⇒ Ω/V = 20×10^6

I_{CS} = 1/(Ω/V) = $\dfrac{1}{20 \times 10^6}$ = **0.05 μA**

38. a. $R_s = \dfrac{E}{I_m} - R_m - \dfrac{\text{zero adjust}}{2} = \dfrac{3\text{ V}}{100\,\mu\text{A}}$ − 1 kΩ − $\dfrac{2\text{ k}\Omega}{2}$ = **28 kΩ**

b. $xI_m = \dfrac{E}{R_{\text{series}}} + R_m + \dfrac{\text{zero adjust}}{2} + R_{\text{unk}}$

$$R_{\text{unk}} = \frac{E}{xI_m} - \left(R_{\text{series}} + R_m + \frac{\text{zero adjust}}{2}\right)$$

$$= \frac{3\text{ V}}{x100\,\mu\text{A}} - 30\text{ k}\Omega \Rightarrow \frac{30\times10^3}{x} - 30\times10^3$$

$x = \frac{3}{4}$, R_{unk} = **10 kΩ**; $x = \frac{1}{2}$, R_{unk} = **30 kΩ**; $x = \frac{1}{4}$, R_{unk} = **90 kΩ**

39. –

40. a. Carefully redrawing the network will reveal that all three resistors are in parallel and $R_T = \dfrac{R}{N} = \dfrac{12\,\Omega}{3}$ = **4 Ω**

b. Again, all three resistors are in parallel and $R_T = \dfrac{R}{N} = \dfrac{18\,\Omega}{3}$ = **6 Ω**

Chapter 8

1. a. $I_2 = I_3 =$ **10 mA**

   b. $V_1 = I_1R_1 = (10\text{ mA})(1\text{ k}\Omega) =$ **10 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 V**

2. a. $I_2 = \dfrac{R_s(I)}{R_s + R_1 + R_2} = \dfrac{10\text{ k}\Omega(4\text{ A})}{10\text{ k}\Omega + 10\,\Omega} =$ **3.996 A, $I_2 \cong I$**

   b. $V_2 = I_2R_2 = (3.996\text{ A})(6\,\Omega) =$ **23.98 V**

   c. $V_s = I_2(R_1 + R_2) = (3.996\text{ A})(10\,\Omega) =$ **39.96 V**

3. $V_{R_1} = IR_1 = (6\text{ A})(3\,\Omega) = 18\text{ V}$

   $E + V_{R_1} - V_s = 0,\quad V_s = E + V_{R_1} = 10\text{ V} + 18\text{ V} =$ **28 V**

4. a. $V_s = E =$ **24 V**

   b. $I_2 = \dfrac{E}{R_1 + R_2} = \dfrac{24\text{ V}}{1\,\Omega + 3\,\Omega} = \dfrac{24\text{ V}}{4\,\Omega} =$ **6 A**

   c. $I + I_s = I_2,\quad I_s = I_2 - I = 6\text{ A} - 2\text{ A} =$ **4 A**

5. $V_1 = V_2 = V_s = IR_T = 0.6\text{ A}[6\,\Omega \parallel 24\,\Omega \parallel 24\,\Omega] = 0.6\text{ A}[6\,\Omega \parallel 12\,\Omega] = 2.4\text{ V}$

   $I_2 = \dfrac{V_2}{R_2} = \dfrac{2.4\text{ V}}{24\,\Omega} =$ **0.1 A**

   $V_3 = \dfrac{R_3V_s}{R_3 + R_4} = \dfrac{16\,\Omega(2.4\text{ V})}{24\,\Omega} =$ **1.6 V**

6. a. $I_1 = \dfrac{E}{R_1} = \dfrac{24\text{ V}}{2\,\Omega} =$ **12 A**, $I_{R_2} = \dfrac{E}{R_2 + R_3} = \dfrac{24\text{ V}}{6\,\Omega + 2\,\Omega} = \dfrac{24\,\Omega}{8\,\Omega} = 3\text{ A}$

   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 A**

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

   VDR: $V_3 = \dfrac{R_3E}{R_2 + R_3} = \dfrac{2\,\Omega(24\text{ V})}{6\,\Omega + 2\,\Omega} = \dfrac{48\text{ V}}{8\,\Omega} =$ **6 V**

7. a. $I = \dfrac{E}{R_s} = \dfrac{18\text{ V}}{6\,\Omega} =$ **3 A**, $R_p = R_s =$ **6 Ω**

   b. $I = \dfrac{E}{R_s} = \dfrac{9\text{ V}}{2.2\text{ k}\Omega} =$ **4.09 mA**, $R_p = R_s =$ **2.2 kΩ**

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

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

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

b. $E_s = IR = (12\text{ A})(100\ \Omega) = \mathbf{1.2\ kV}$
$R_s = 100\ \Omega$
$I = \dfrac{E_s}{R_s + R_L} = \dfrac{1.2\text{ kV}}{100\ \Omega + 2\ \Omega} = \mathbf{11.76\ A}$

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

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

c. $\underset{+-}{V_{ab}} = I_1R_3 = (458.78\text{ mA})(39\ \Omega) = \mathbf{17.89\ V}$

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

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

12. $I_T\uparrow = 7\text{ A} - 3\text{ A} = 4\text{ A}$
CDR: $I_1 = \dfrac{R_2(I_T)}{R_1 + R_2} = \dfrac{6\ \Omega(4\text{ A})}{4\ \Omega + 6\ \Omega} = \mathbf{2.4\ A}$
$V_2 = I_1R_1 = (2.4\text{ A})(4\ \Omega) = \mathbf{9.6\ V}$

13. a. Conversions: $I_1 = E_1/R_1 = 9\text{ V}/3\ \Omega = \mathbf{3\ A}$, $R_1 = \mathbf{3\ \Omega}$
$I_2 = E_2/R_2 = 20\text{ V}/2\ \Omega = \mathbf{10\ A},\ R_2 = \mathbf{2\ \Omega}$

b. $I_T\downarrow = 10\text{ A} - 3\text{A} = 7\text{ A}$, $R_T = 3\ \Omega \parallel 6\ \Omega \parallel 2\ \Omega \parallel 12\ \Omega$
$= 2\ \Omega \parallel 2\ \Omega \parallel 12\ \Omega$
$= 1\ \Omega \parallel 12\ \Omega$
$= 0.92\ \Omega$
$\underset{+-}{V_{ab}}$ $V_{ab} = -I_TR_T = -(7\text{ A})(0.92\ \Omega) = \mathbf{-6.44\ V}$

c. $I_3\uparrow = \dfrac{6.44\text{ V}}{6\ \Omega} = \mathbf{1.07\ A}$

14. a. $I = \dfrac{E}{R_2} = \dfrac{12\text{ V}}{2.2\text{ k}\Omega} = \mathbf{5.45\ mA}$, $R_p = \mathbf{2.2\ k\Omega}$

b. $I_T\uparrow = 8\text{ mA} + 5.45\text{ mA} - 3\text{ mA} = 10.45\text{ mA}$
$R' = 6.8\text{ k}\Omega \parallel 2.2\text{ k}\Omega = 1.66\text{ k}\Omega$
$V_1 = I_T R' = (10.45\text{ mA})(1.66\text{ k}\Omega) = \mathbf{17.35\ V}$

c. $V_1 = V_2 + 12\text{ V} \Rightarrow V_2 = V_1 - 12\text{ V} = 17.35\text{ V} - 12\text{ V}$
$= \mathbf{5.35\ V}$

d. $I_2 = \dfrac{V_2}{R_2} = \dfrac{5.35\text{ V}}{2.2\text{ k}\Omega} = \mathbf{2.43\ mA}$

15. a. $I_1 \downarrow I_3\ I_2$

$$\begin{aligned} 4 - 4I_1 - 8I_3 &= 0 \\ 6 - 2I_2 - 8I_3 &= 0 \\ I_1 + I_2 &= I_3 \end{aligned}$$

$I_1 = -\mathbf{\dfrac{1}{7}\ A}, I_2 = \mathbf{\dfrac{5}{7}\ A}, I_3 = \mathbf{\dfrac{4}{7}\ A}$

$I_{R_1} = I_1 = -\mathbf{\dfrac{1}{7}\ A}, I_{R_2} = I_2 = \mathbf{\dfrac{5}{7}\ A}, I_{R_3} = I_3 = \mathbf{\dfrac{4}{7}\ A}$

b. $I_1 \uparrow I_3\ I_2$

$$\begin{aligned} 10 + 12 - 3I_3 - 4I_1 &= 0 \\ 12 - 3I_3 - 12I_2 &= 0 \\ I_1 + I_2 &= I_3 \end{aligned}$$

$I_1 = \mathbf{3.06\ A}$
$I_2 = \mathbf{0.19\ A}$
$I_3 = \mathbf{3.25\ A}$

$I_{R_1} = I_1 = \mathbf{3.06\ A},\ I_{R_2} = I_2 = \mathbf{0.19\ A}$
$I_{R_3} = I_3 = \mathbf{3.25\ A}$

16. (I): $I_1 \downarrow I_3\ I_2$

$$\begin{aligned} 10 - I_1\,5.6\text{ k}\Omega - I_3\,2.2\text{ k}\Omega + 20 &= 0 \\ -20 + I_3\,2.2\text{ k}\Omega + I_2\,3.3\text{ k}\Omega - 30 &= 0 \\ I_1 + I_2 &= I_3 \end{aligned}$$

$I_1 = I_{R_1} = \mathbf{1.45\ mA}, I_2 = I_{R_2} = \mathbf{8.51\ mA}, I_3 = I_{R_3} = \mathbf{9.96\ mA}$

(II): I_1, I_3, $\uparrow I_2$

$$\begin{aligned} -1.2\text{ k}\Omega\, I_1 + 9 - 8.2\text{ k}\Omega\, I_3 &= 0 \\ -10.2\text{ k}\Omega\, I_2 + 8.2\text{ k}\Omega\, I_3 + 6 &= 0 \\ I_2 + I_3 &= I_1 \end{aligned}$$

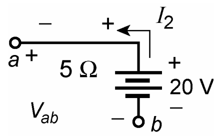
$I_1 = \mathbf{2.03\ mA}, I_2 = \mathbf{1.23\ mA}, I_3 = \mathbf{0.8\ mA}$

$I_{R_1} = I_1 = \mathbf{2.03\ mA}$
$I_{R_2} = I_3 = \mathbf{0.8\ mA}$
$I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23\ mA}$

17. (I): $\overrightarrow{I_1} \downarrow I_3 \downarrow I_2$

$$-25 - 2I_1 - 3I_3 + 60 = 0$$
$$-60 + 3I_3 + 6 - 5I_2 - 20 = 0$$
$$I_1 = I_2 + I_3$$

$I_2 =$ **–8.55 A**



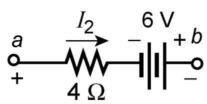
$$V_{\underset{+-}{ab}} = 20\text{ V} - I_2\, 5\ \Omega = 20\text{ V} - (8.55\text{ A})(5\ \Omega) = \mathbf{-22.75\ V}$$

(II): Source conversion: $E = IR_1 = (3\text{ A})(3\ \Omega) = 9\text{ V}$, $R_1 = 3\ \Omega$

$\overrightarrow{I_2} \downarrow I_4 \downarrow I_3$

$$9 + 6 - 3I_2 - 4I_2 - 6I_4 = 0$$
$$+ 6I_4 - 8I_3 - 4 = 0$$
$$I_2 = I_3 + I_4$$

$I_2 =$ **1.27 A**



$$V_{\underset{+-}{ab}} = I_2\, 4\ \Omega - 6\text{ V} = (1.27\text{ A})4\ \Omega - 6\text{ V} = \mathbf{-0.92\ V}$$

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.
$$E_1 - I_1R_1 - I_2R_2 = 0$$
$$I_2R_2 - I_3R_3 - I_4R_4 = 0$$
$$I_4R_4 - I_5R_5 - E_2 = 0$$
$$I_1 = I_2 + I_3$$
$$I_3 = I_4 + I_5$$

b.
$$E_1 - I_2(R_1 + R_2) - I_3R_1 = 0$$
$$I_2R_2 - I_3(R_3 + R_4) + I_5R_4 = 0$$
$$I_3R_4 - I_5(R_4 + R_5) - E_2 = 0$$

c.
$$\begin{aligned}
&I_2(R_1 + R_2) + I_3R_1 &&+ \ 0 &&= E_1\\
&I_2(R_2) \quad - I_3(R_3 + R_4) &&+ I_5R_4 &&= 0\\
&0 \quad + I_3R_4 &&- I_5(R_4 + R_5) &&= E_2
\end{aligned}$$

$$3I_2 + 2I_3 + 0 = 10$$
$$1I_2 - 9I_3 + 5I_5 = 0$$
$$0 + 5I_3 - 8I_5 = 6$$

d. $I_3 = I_{R_3} =$ **–63.69 mA**

19. a. $20\text{ V} - I_B(270\text{ k}\Omega) - 0.7\text{ V} - I_E(0.51\text{ k}\Omega) = 0$
$I_E(0.51\text{ k}\Omega) + 8\text{ V} + I_C(2.2\text{ k}\Omega) - 20\text{ V} = 0$
$I_E = I_B + I_C$

$I_B = \mathbf{63.02\ \mu A}$, $I_C = \mathbf{4.42\ mA}$, $I_E = \mathbf{4.48\ mA}$

b. $V_B = 20\text{ V} - I_B(270\text{ k}\Omega) = 20\text{ V} - (63.02\ \mu\text{A})(270\text{ k}\Omega) = 20\text{ V} - 17.02\text{ V} = \mathbf{2.98\ V}$
$V_E = I_E R_E = (4.48\text{ mA})(510\ \Omega) = \mathbf{2.28\ V}$
$V_C = 20\text{ V} - I_C(2.2\text{ k}\Omega) = 20\text{ V} - (4.42\text{ mA})(2.2\text{ k}\Omega) = 20\text{ V} - 9.72\text{ V} = \mathbf{10.28\ V}$

c. $\beta \cong I_C/I_B = 4.42\text{ mA}/63.02\ \mu\text{A} = \mathbf{70.14}$

20. a. $I_1 \curvearrowright\ I_2 \curvearrowright$

$4 - 4I_1 - 8(I_1 - I_2) = 0$
$-8(I_2 - I_1) - 2I_2 - 6 = 0$

$I_1 = -\dfrac{1}{7}\text{ A}$, $I_2 = -\dfrac{5}{7}\text{ A}$

$I_{R_1} = I_1 = -\dfrac{1}{7}\text{ A}$

$I_{R_2} = I_2 = -\dfrac{5}{7}\text{ A}$

$I_{R_3} = I_1 - I_2 = \left(-\dfrac{1}{7}\text{ A}\right) - \left(-\dfrac{5}{7}\text{ A}\right) = \dfrac{4}{7}\text{ A (dir. of } I_1)$

b. $I_1 \curvearrowright\ I_2 \curvearrowright$

$-10 - 4I_1 - 3(I_1 - I_2) - 12 = 0$
$12 - 3(I_2 - I_1) - 12I_2 = 0$

$I_1 = \mathbf{-3.06\ A}$, $I_2 = \mathbf{0.19\ A}$

$I_{R_1} = I_1 = \mathbf{-3.06\ A}$
$I_{R_3} = I_2 = \mathbf{0.19\ A}$
$I_{R_2} = I_1 - I_2 = (-3.06\text{ A}) - (0.19\text{ A}) = \mathbf{-3.25\ A}$

21. (I): $I_1 \curvearrowright\ I_2 \curvearrowright$

$10 - I_1(5.6\text{ k}\Omega) - 2.2\text{ k}\Omega(I_1 - I_2) + 20 = 0$
$-20 - 2.2\text{ k}\Omega(I_2 - I_1) - I_2\ 3.3\text{ k}\Omega - 30 = 0$

$I_1 = \mathbf{1.45\ mA}$, $I_2 = \mathbf{8.51\ mA}$
$I_{R_1} = I_1 = \mathbf{1.45\ mA}$, $I_{R_2} = I_2 = \mathbf{8.51\ mA}$
$I_{R_3} = I_2 - I_1 = \mathbf{7.06\ mA}$ (direction of I_2)

(II): I_1 I_2

$$-I_1(1.2\text{ k}\Omega) + 9 - 8.2\text{ k}\Omega(I_1 - I_2) = 0$$
$$-I_2(1.1\text{ k}\Omega) + 6 - I_2\,(9.1\text{ k}\Omega) - 8.2\text{ k}\Omega(I_2 - I_1) = 0$$

$I_1 = \mathbf{2.03\text{ mA}}$, $I_2 = \mathbf{1.23\text{ mA}}$

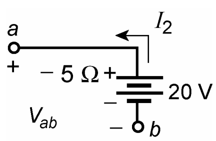
$I_{R_1} = I_1 = \mathbf{2.03\text{ mA}}$, $I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23\text{ mA}}$

$I_{R_2} = I_1 - I_2 = 2.03\text{ mA} - 1.23\text{ mA} = \mathbf{0.80\text{ mA}}$ (direction of I_1)

22. (I): I_1 I_2

$$-25 - 2I_1 - 3(I_1 - I_2) + 60 = 0$$
$$-60 - 3(I_2 - I_1) + 6 - 5I_2 - 20 = 0$$

$I_1 = \mathbf{1.87\text{ A}}$, $I_2 = \mathbf{-8.55\text{ A}}$



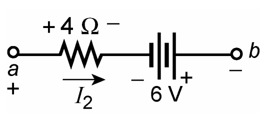
$$\underset{+-}{V_{ab}} = 20 - I_2\,5 = 20 - (8.55\text{ A})(5) = 20\text{ V} - 42.75\text{ V}$$
$$= \mathbf{-22.75\text{ V}}$$

(II): Source conversion: $E = 9$ V, $R = 3\ \Omega$

I_2 I_3

$$9 - 3I_2 - 4I_2 + 6 - 6(I_2 - I_3) = 0$$
$$-6(I_3 - I_2) - 8I_3 - 4 = 0$$

$I_2 = \mathbf{1.27\text{ A}}$, $I_3 = \mathbf{0.26\text{ A}}$



$$\underset{+-}{V_{ab}} = I_2\,4 - 6 = (1.27\text{ A})(4\ \Omega) - 6\text{ V}$$
$$= 5.08\text{ V} - 6\text{ V}$$
$$= \mathbf{-0.92\text{ V}}$$

23. (a): I_1 I_2 I_3

$$10 - I_1 2 - 1(I_1 - I_2) = 0$$
$$-1(I_2 - I_1) - I_2\,4 - 5(I_2 - I_3) = 0$$
$$-5(I_3 - I_2) - I_3\,3 - 6 = 0$$

$$\begin{aligned} 3I_1 - 1I_2 + 0 &= 10 \\ -1I_1 + 10I_2 - 5I_3 &= 0 \\ 0 - 5I_2 + 8I_3 &= -6 \end{aligned}$$

$I_2 = I_{R_3} = \mathbf{-63.69\text{ mA}}$

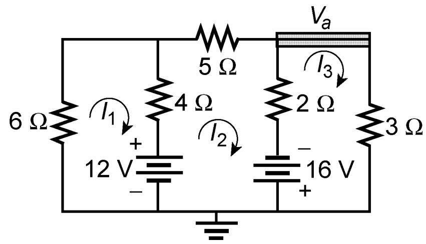
24. a. I_1 I_2

$$-1I_1 - 4 - 5I_1 + 6 - 1(I_1 - I_2) = 0$$
$$-1(I_2 - I_1) - 6 - 3I_2 - 15 - 10I_2 = 0$$

$I_1 = I_{5\Omega} = \mathbf{72.16\text{ mA}}$

$$V_a = -4 - (72.16\text{ mA})(6\ \Omega)$$
$$= -4 - 0.433\text{ V}$$
$$= \mathbf{-4.43\text{ V}}$$

b. Network redrawn:



$$-6I_1 - 4(I_1 - I_2) - 12 = 0$$
$$12 - 4(I_2 - I_1) - 5I_2 - 2(I_2 - I_3) + 16 = 0$$
$$-16 - 2(I_3 - I_2) - 3I_3 = 0$$

$I_2 = I_{5\Omega} = \mathbf{1.95\ A}$

$$V_a = (I_3)(3\ \Omega)$$
$$= (-2.42\ \text{mA})(3\ \Omega)$$
$$= \mathbf{-7.26\ V}$$

25. (I): $I_1 \circlearrowright\ I_2 \circlearrowright\ I_3 \circlearrowright$

$$I_1(2.2\ \text{k}\Omega + 9.1\ \text{k}\Omega) - 9.1\ \text{k}\Omega\ I_2 = 18$$
$$I_2(9.1\ \text{k}\Omega + 7.5\ \text{k}\Omega + 6.8\ \text{k}\Omega) - 9.1\ \text{k}\Omega\ I_1 - 6.8\ \text{k}\Omega\ I_3 = -18$$
$$I_3(6.8\ \text{k}\Omega + 3.3\ \text{k}\Omega) - I_2\ 6.8\ \text{k}\Omega = -3$$

$I_1 = \mathbf{1.21\ mA}$, $I_2 = \mathbf{-0.48\ mA}$, $I_3 = \mathbf{-0.62\ mA}$

(II): $I_1 \circlearrowright$ $I_3 \circlearrowright\ I_2 \circlearrowright$

$$16 - 4I_1 - 3(I_1 - I_2) - 12 - 4(I_1 - I_3) = 0$$
$$12 - 3(I_2 - I_1) - 10\ I_2 - 15 - 4(I_2 - I_3) = 0$$
$$-16 - 4(I_3 - I_1) - 4(I_3 - I_2) - 7I_3 = 0$$

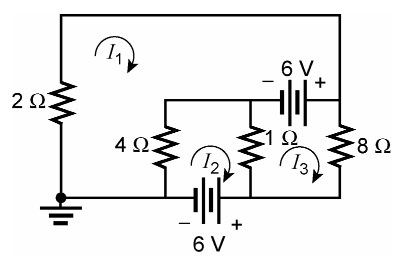
$I_1 = \mathbf{-0.24\ A}$, $I_2 = \mathbf{-0.52\ A}$, $I_3 = \mathbf{-1.28\ A}$

26. a. $I_1 \circlearrowright\ I_2 \circlearrowright$ $I_4 \circlearrowright\ I_3 \circlearrowright$

$$-6.8\ \text{k}\Omega\ I_1 - 4.7\ \text{k}\Omega(I_1 - I_2) + 6 - 2.2\ \text{k}\Omega(I_1 - I_4) = 0$$
$$-6 - 4.7\ \text{k}\Omega(I_2 - I_1) - 2.7\ \text{k}\Omega\ I_2 - 8.2\ \text{k}\Omega\ (I_2 - I_3) = 0$$
$$-1.1\ \text{k}\Omega\ I_3 - 22\ \text{k}\Omega(I_3 - I_4) - 8.2\ \text{k}\Omega(I_3 - I_2) - 9 = 0$$
$$5 - 1.2\ \text{k}\Omega\ I_4 - 2.2\ \text{k}\Omega(I_4 - I_1) - 22\ \text{k}\Omega(I_4 - I_3) = 0$$

$I_1 = \mathbf{0.03\ mA}$, $I_2 = \mathbf{-0.88\ mA}$, $I_3 = \mathbf{-0.97\ mA}$, $I_4 = \mathbf{-0.64\ mA}$

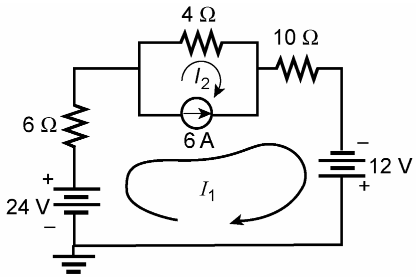
b. Network redrawn:

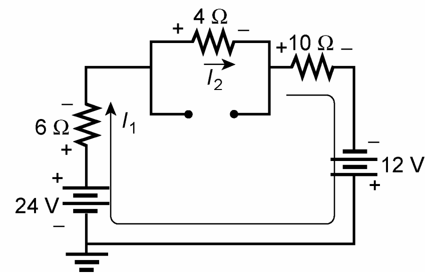


$$-2I_1 - 6 - 4I_1 + 4I_2 = 0$$
$$-4I_2 + 4I_1 - 1I_2 + 1I_3 - 6 = 0$$
$$-1I_3 + 1I_2 + 6 - 8I_3 = 0$$

$I_1 = \mathbf{-3.8\ A}$, $I_2 = \mathbf{-4.20\ A}$, $I_3 = \mathbf{0.20\ A}$

27. a.





$$24\text{ V} - 6I_1 - 4I_2 - 10I_1 + 12\text{ V} = 0$$

and $16I_1 + 4I_2 = 36$

$I_1 - I_2 = 6\text{ A}$

$I_1 = I_2 + 6\text{ A}$

$16[I_2 + 6\text{ A}] + 4I_2 = 36$

$16I_2 + 96 + 4I_2 = 36$

$20I_2 = -60$

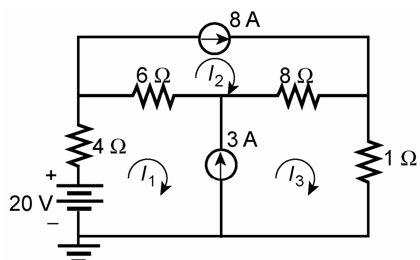
$I_2 = \mathbf{-3\text{ A}}$

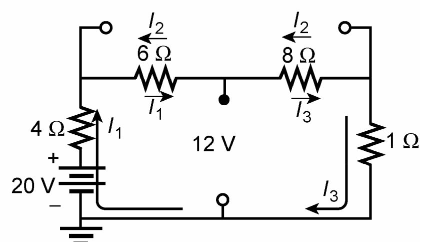
$I_1 = I_2 + 6\text{ A} = -3\text{ A} + 6\text{ A} = \mathbf{3\text{ A}}$

$I_{24\text{V}} = I_{6\Omega} = I_{10\Omega} = I_{12\text{V}} = \mathbf{3\text{ A}}$ (CW)

$I_{4\Omega} = \mathbf{3\text{ A}}$ (CCW)

b.





$$20\text{ V} - 4I_1 - 6(I_1 - I_2) - 8(I_3 - I_2) - 1I_3 = 0$$

$10I_1 - 14I_2 + 9I_3 = 20$

$I_3 - I_1 = 3\text{ A}$

$I_2 = 8\text{ A}$

$10I_1 - 14(8\text{ A}) + 9[I_1 + 3\text{ A}] = 20$

$19I_1 = 105$

$I_1 = 5.526\text{ A}$

$I_3 = I_1 + 3\text{ A} = 5.526\text{ A} + 3\text{ A} = 8.526\text{ A}$

$I_2 = 8\text{ A}$

$I_{20\text{V}} = I_{4\Omega} = \mathbf{5.53\text{ A}}$ (dir. of I_1)

$I_{6\Omega} = I_2 - I_1 = \mathbf{2.47\text{ A}}$ (dir. of I_2)

$I_{8\Omega} = I_3 - I_2 = \mathbf{0.53\text{ A}}$ (dir. of I_3)

$I_{1\Omega} = \mathbf{8.53\text{ A}}$ (dir. of I_3)

28. a. $I_1 \curvearrowright$ $I_2 \curvearrowright$

$$(4 + 8)I_1 - 8I_2 = 4$$
$$(8 + 2)I_2 - 8I_1 = -6$$

$$I_1 = -\frac{1}{7}\text{ A},\ I_2 = -\frac{5}{7}\text{ A}$$

b. $I_1 \curvearrowright$ $I_2 \curvearrowright$

$$(4 + 3)I_1 - 3I_2 = -10 - 12$$
$$(3 + 12)I_2 - 3I_1 = 12$$

$I_1 =$ **–3.06 A**, $I_2 =$ **0.19 A**

29. (I): $I_1 \curvearrowright$ $I_2 \curvearrowright$

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 mA**, $I_2 =$ **–8.51 mA**

c. $I_{R_1} = I_1 =$ **1.45 mA**, $I_{R_2} = I_2 =$ **–8.51 mA**
$I_{R_3} = I_1 + I_2 = 8.51\text{ mA} + 1.44\text{ mA} =$ **9.96 mA** (direction of I_1)

(II): $I_1 \curvearrowright$
$I_2 \curvearrowright$

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 mA**, $I_2 =$ **1.23 mA**

c. $I_{R_1} = I_1 =$ **2.03 mA**, $I_{R_3} = I_{R_4} = I_2 =$ **1.23 mA**
$I_{R_2} = I_1 - I_2 = 2.03\text{ mA} - 1.23\text{ mA} =$ **0.80 mA** (direction of I_1)

30. (I): $I_1 \curvearrowright$ $I_2 \curvearrowright$

$$(2 + 3)I_1 - 3I_2 = -25 + 60$$
$$(3 + 5)I_2 - 3I_1 = -60 + 6 - 20$$

b. $I_1 =$ **1.87 A**, $I_2 =$ **–8.55 A**

c. $I_{R_1} = I_1 =$ **1.87 A**, $I_{R_2} = I_2 =$ **–8.55 A**
$I_{R_3} = I_1 - I_2 = 1.87\text{ A} - (-8.55\text{ A}) =$ **10.42 A** (direction of I_1)

(II): a. $I_2 \curvearrowright$ $I_3 \curvearrowright$

$$(3 + 4 + 6)I_2 - 6I_3 = 9 + 6$$
$$(6 + 8)I_3 - 6I_2 = -4$$

b. I_2 = **1.27 A**, I_3 = **0.26 A**

c. $I_{R_2} = I_2 =$ **1.27 A**, $I_{R_3} = I_3 =$ **0.26 A**
$I_{R_4} = I_2 - I_3 = 1.27\text{ A} - 0.26\text{ A} =$ **1.01 A**
$I_{R_1} = 3\text{ A} - I_2 = 3\text{ A} - 1.27\text{ A} =$ **1.73 A**

31. I_1 I_2 I_3

$I_1(2 + 1) - 1I_2 = 10$
$I_2(1 + 4 + 5) - 1I_1 - 5I_3 = 0$
$I_3(5 + 3) - 5I_2 = -6$

$I_2 = I_{R_3} =$ **–63.69 mA** (exact match with problem 18)

32. From Sol. 24(b)
I_1 I_2 I_3

$I_1(6 + 4) - 4I_2 = -12$
$I_2(4 + 5 + 2) - 4I_1 - 2I_3 = 12 + 16$
$I_3(2 + 3) - 2I_2 = -16$

$I_{5\Omega} = I_2 =$ **1.95 A**
$I_3 = -2.42\text{ A}$, $\therefore$ $V_a = (I_3)(3\ \Omega) = (-2.42\text{ A})(3\ \Omega) =$ **–7.26 V**

33. (I): I_1 I_2 I_3

$(2.2\text{ k}\Omega + 9.1\text{ k}\Omega)I_1 - 9.1\text{ k}\Omega I_2 = 18$
$(9.1\text{ k}\Omega + 7.5\text{ k}\Omega + 6.8\text{ k}\Omega)I_2 - 9.1\text{ k}\Omega\ I_1 - 6.8\text{ k}\Omega I_3 = -18$
$(6.8\text{ k}\Omega + 3.3\text{ k}\Omega)I_3 - 6.8\text{ k}\Omega I_2 = -3$

I_1 = **1.21 mA**, I_2 = **–0.48 mA**, I_3 = **–0.62 mA**

(II): I_1 I_3 I_2

$(4\ \Omega + 4\ \Omega + 3\ \Omega)I_1 - 3\ \Omega\ I_2 - 4\ \Omega\ I_3 = 16 - 12$
$(4\ \Omega + 3\ \Omega + 10\ \Omega)I_2 - 3I_1 - 4\ \Omega\ I_3 = 12 - 15$
$(4\ \Omega + 4\ \Omega + 7\ \Omega)I_3 - 4I_1 - 4I_2 = -16$

I_1 = **–0.24 A**, I_2 = **–0.52 A**, I_3 = **–1.28 A**

34. a. I_1 I_2 I_4 I_3

$I_1(6.8\text{ k}\Omega + 4.7\text{ k}\Omega + 2.2\text{ k}\Omega) - 4.7\text{ k}\Omega\ I_2 - 2.2\text{ k}\Omega\ I_4 = 6$
$I_2(2.7\text{ k}\Omega + 8.2\text{ k}\Omega + 4.7\text{ k}\Omega) - 4.7\text{ k}\Omega\ I_1 - 8.2\text{ k}\Omega\ I_3 = -6$
$I_3(8.2\text{ k}\Omega + 1.1\text{ k}\Omega + 22\text{ k}\Omega) - 22\text{ k}\Omega\ I_4 - 8.2\text{ k}\Omega\ I_2 = -9$
$I_4(2.2\text{ k}\Omega + 22\text{ k}\Omega + 1.2\text{ k}\Omega) - 2.2\text{ k}\Omega\ I_1 - 22\text{ k}\Omega\ I_3 = 5$

I_1 = **0.03 mA**, I_2 = **–0.88 mA**, I_3 = **–0.97 mA**, I_4 = **–0.64 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 A**, I_2 = **–4.20 A**, I_3 = **0.20 A**

35. a. V_1 V_2

$$V_1\left[\frac{1}{2}+\frac{1}{5}+\frac{1}{2}\right]-\frac{1}{2}V_2=5 \qquad V_1=\mathbf{8.08\ V}$$

$$V_2=\mathbf{9.39\ V}$$

$$V_2\left[\frac{1}{2}+\frac{1}{4}\right]-\frac{1}{2}V_1=3$$

Symmetry is present

b. V_1 V_2

$$V_1\left[\frac{1}{2}+\frac{1}{4}\right]-\frac{1}{4}V_2=4-2 \qquad V_1=\mathbf{4.80\ V}$$

$$V_2=\mathbf{6.40\ V}$$

$$V_2\left[\frac{1}{4}+\frac{1}{20}+\frac{1}{5}\right]-\frac{1}{4}V_1=2$$

Symmetry is present

36. (I): V_1 V_2

$$V_1\left[\frac{1}{3}+\frac{1}{6}+\frac{1}{4}\right]-\frac{1}{4}V_2=-5-3$$

$$V_2\left[\frac{1}{8}+\frac{1}{4}\right]-\frac{1}{4}V_1=3-4$$

$V_1=\mathbf{-14.86\ V}$, $V_2=\mathbf{-12.57\ V}$

$V_{R_1}=V_{R_4}=\mathbf{-14.86\ V}$

$V_{R_2}=\mathbf{-12.57\ V}$

${}^{+}V_{R_3}{}^{-}$ = 12 V + 12.57 V – 14.86 V = **9.71 V**

(II): V_1 V_2

$$V_1\left[\frac{1}{5}+\frac{1}{3}+\frac{1}{2}\right]-\frac{1}{3}V_2-\frac{1}{2}V_2=-6$$

$$V_2\left[\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{8}\right]-\frac{1}{3}V_1-\frac{1}{2}V_1=7$$

$V_1=\mathbf{-2.56\ V}$, $V_2=\mathbf{4.03\ V}$

$V_{R_1}=\mathbf{-2.56\ V}$

$V_{R_2}=V_{R_5}=\mathbf{4.03\ V}$

$V_{R_4}=V_{R_3}$ = 4.03 V + 2.56 V = **6.59 V**

37. (I): a. V_1 V_2

$$V_1\left[\frac{1}{2.2\text{ k}\Omega}+\frac{1}{9.1\text{ k}\Omega}+\frac{1}{7.5\text{ k}\Omega}\right]-\frac{1}{7.5\text{ k}\Omega}V_2=-1.98\text{ mA}$$

$$V_2\left[\frac{1}{7.5\text{ k}\Omega}+\frac{1}{6.8\text{ k}\Omega}+\frac{1}{3.3\text{ k}\Omega}\right]-\frac{1}{7.5\text{ k}\Omega}V_1=0.91\text{ mA}$$

b. $V_1 = \mathbf{-2.65\ V}$, $V_2 = \mathbf{0.95\ V}$

c. $V_{R_3} = V_1 = \mathbf{-2.65\ V}$, $V_{R_5} = V_2 = \mathbf{0.95\ V}$, $V_{R_4} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = \mathbf{3.60\ V}$

R_1 $\overset{+}{\underset{-}{V_{R_1}}}$ $= 18\text{ V} - 2.65\text{ V} = \mathbf{15.35\ V}$

R_2 $\overset{-}{\underset{+}{V_{R_2}}}$ $= 3\text{ V} - 0.95\text{ V} = \mathbf{2.05\ V}$

(II): a. V_1 V_2 V_3

$$V_1\left[\frac{1}{4}+\frac{1}{4}+\frac{1}{7}\right]-\frac{1}{4}V_2-\frac{1}{4}V_3=4$$

$$V_2\left[\frac{1}{4}+\frac{1}{3}+\frac{1}{10}\right]-\frac{1}{4}V_1-\frac{1}{3}V_3=4+1.5$$

$$V_3\left[\frac{1}{4}+\frac{1}{3}+\frac{1}{4}\right]-\frac{1}{4}V_1-\frac{1}{3}V_3=-4-4$$

b. $V_1 = \mathbf{8.88\ V}$, $V_2 = \mathbf{9.83\ V}$, $V_3 = \mathbf{-3.01\ V}$

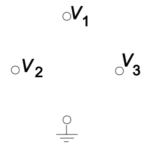
c. $V_{R_6} = V_1 = \mathbf{8.88\ V}$, $V_{R_4} = V_3 = \mathbf{-3.01\ V}$, $V_{R_5} = \overset{(+)}{V_2}\ \overset{(-)}{V_1} = \mathbf{0.95\ V}$

$-V_{R_1}+$ R_1 $\qquad V_{R_1} = 16\text{ V} - V_1 + V_3 = \mathbf{4.12\ V}$

$-V_{R_2}+$ R_2 $\qquad V_{R_2} = V_2 - V_3 - 12\text{ V} = \mathbf{0.84\ V}$

R_3 - + $\qquad V_{R_3} = 15\text{ V} - V_2 = \mathbf{5.17\ V}$

38. (I):



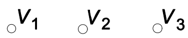
$$V_1\left[\frac{1}{3}+\frac{1}{6}+\frac{1}{6}\right]-\frac{1}{6}V_2-\frac{1}{6}V_3=5$$

$$V_2\left[\frac{1}{6}+\frac{1}{4}+\frac{1}{5}\right]-\frac{1}{6}V_1-\frac{1}{5}V_3=-3$$

$$V_3\left[\frac{1}{6}+\frac{1}{5}+\frac{1}{7}\right]-\frac{1}{5}V_2-\frac{1}{6}V_1=0$$

V_1 = **7.24 V**, V_2 = **–2.45 V**, V_3 = **1.41 V**

(II): Source conversion: $I = 4$ A, $R = 4\ \Omega$



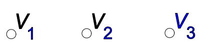
$$V_1\left[\frac{1}{9}+\frac{1}{20}+\frac{1}{20}\right]-\frac{1}{20}V_2-\frac{1}{20}V_3=-2$$

$$V_2\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{18}\right]-\frac{1}{20}V_1-\frac{1}{20}V_3=0$$

$$V_3\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{4}\right]-\frac{1}{20}V_2-\frac{1}{20}V_1=4$$

V_1 = **–6.64 V**, V_2 = **1.29 V**, V_3 = **10.66 V**

39. (I)



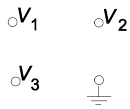
$$\left[\frac{1}{2}+\frac{1}{2}\right]V_1-\frac{1}{2}V_2+0=-5$$

$$\left[\frac{1}{2}+\frac{1}{9}+\frac{1}{7}+\frac{1}{2}\right]V_2-\frac{1}{2}V_1-\frac{1}{2}V_3=0$$

$$\left[\frac{1}{2}+\frac{1}{2}+\frac{1}{4}\right]V_3-\frac{1}{2}V_2=5$$

V_1 = **–5.31 V**, V_2 = **–0.62 V**, V_3 = **3.75 V**

(II)



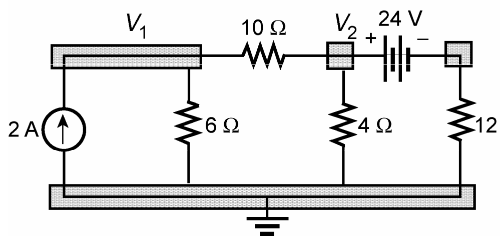
$$V_1\left[\frac{1}{2}+\frac{1}{6}\right]-\frac{1}{6}V_3=-5$$

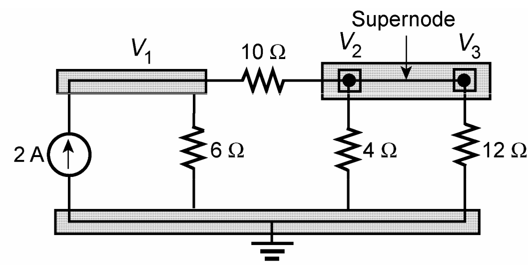
$$V_2\left[\frac{1}{4}\right]=5-2$$

$$V_3\left[\frac{1}{6}+\frac{1}{5}\right]-\frac{1}{6}V_1=2$$

$V_1 = \mathbf{-6.92\ V}$, $V_2 = \mathbf{12\ V}$, $V_3 = \mathbf{2.3\ V}$

40. a.





$$\Sigma I_i = \Sigma I_o$$

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:

$$V_2 - V_3 = 24\text{ V or } V_3 = V_2 - 24\text{ V}$$

2 eq. 2 unknowns:

$$\frac{V_1}{6\,\Omega}+\frac{V_1-V_2}{10\,\Omega} = 2\text{ A}$$

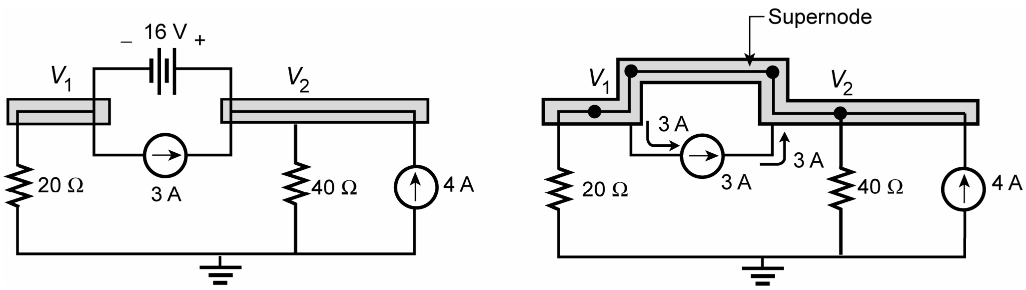
$$\frac{V_2-V_1}{10\,\Omega}+\frac{V_2}{4\,\Omega}+\frac{V_2-24\text{ V}}{12\,\Omega} = 0$$

$$0.267V_1 - 0.1V_2 = 2$$
$$+0.1V_1 - 0.433V_2 = -2$$

$V_1 = \mathbf{10.08\ V}$, $V_2 = \mathbf{6.94\ V}$

$V_3 = V_2 - 24\text{ V} = \mathbf{-17.06\ V}$

b.



Supernode: $\Sigma I_i = \Sigma I_o$

$$3\text{ A} + 4\text{ A} = 3\text{ A} + \frac{V_1}{20\,\Omega} + \frac{V_2}{40\,\Omega}$$

2 eq. 2 unk. $\begin{cases} 4\text{ A} = \dfrac{V_1}{20\,\Omega} + \dfrac{V_2}{40\,\Omega} \\ V_2 - V_1 = 16\text{ V} \end{cases}$

Subt. $V_2 = 16\text{ V} + V_1$

$$4\text{ A} = \frac{V_1}{20\,\Omega} + \frac{(16\text{ V} + V_1)}{40\,\Omega}$$

and $V_1 = \mathbf{48\ V}$

$V_2 = 16\text{ V} + V_1 = \mathbf{64\ V}$

41. a. V_1 V_2

$$V_1\left[\frac{1}{2} + \frac{1}{5} + \frac{1}{2}\right] - \frac{1}{2}V_2 = 5$$

$$V_2\left[\frac{1}{2} + \frac{1}{4}\right] - \frac{1}{2}V_1 = 3$$

$V_1 = \mathbf{8.08\ V}$, $V_2 = \mathbf{9.39\ V}$

Symmetry present

b. V_1 V_2

$$V_1\left[\frac{1}{2} + \frac{1}{4}\right] - \frac{1}{4}V_2 = 4 - 2$$

$$V_2\left[\frac{1}{4} + \frac{1}{20} + \frac{1}{5}\right] - \frac{1}{4}V_1 = 2$$

$V_1 = \mathbf{4.8\ V}$, $V_2 = \mathbf{6.4\ V}$

Symmetry present

42. (I): a. Note the solution to problem 36(I).

b. $V_1 =$ **−14.86 V**, $V_2 =$ **−12.57 V**

c. $V_{R_1} = V_{R_4} = V_1 =$ **−14.86 V**, $V_{R_2} = V_2 =$ **−12.57 V**

$+V_{R_3}-$

R_3

$$V_{R_3} = V_1 - V_2 + 12\text{ V} = (-14.86\text{ V}) - (-12.57\text{ V}) + 12\text{ V} = \mathbf{9.71\ V}$$

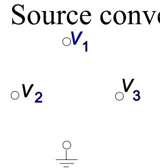
(II): a. Note the solution to problem 36(II).

b. $V_1 =$ **−2.56 V**, $V_2 =$ **4.03 V**

c. $V_{R_1} = V_1 =$ **−2.56 V**, $V_{R_2} = V_{R_5} = V_2 =$ **4.03 V**

$$V_{R_3} = V_{R_4} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = \mathbf{6.59\ V}$$

43. (I): a. Source conversion: $I = 5$ A, $R = 3\ \Omega$



$$V_1\left[\frac{1}{3}+\frac{1}{6}+\frac{1}{6}\right]-\frac{1}{6}V_2-\frac{1}{6}V_3 = 5$$

$$V_2\left[\frac{1}{6}+\frac{1}{4}+\frac{1}{5}\right]-\frac{1}{6}V_1-\frac{1}{5}V_3 = -3$$

$$V_3\left[\frac{1}{6}+\frac{1}{5}+\frac{1}{7}\right]-\frac{1}{5}V_2-\frac{1}{6}V_1 = 0$$

b. $V_1 =$ **7.24 V**, $V_2 =$ **−2.45 V**, $V_3 =$ **1.41 V**

c. R_1 V_{R_1} (− above, + below) $= 15\text{ V} - 7.24\text{ V} =$ **7.76 V**

$V_{R_2} = V_2 =$ **−2.45 V**, $V_{R_3} = V_3 =$ **1.41 V**

$$V_{R_4} = \overset{(+)}{V_3} - \overset{(-)}{V_2} = 1.41\text{ V} - (-2.45\text{ V}) = \mathbf{3.86\ V}$$

$$V_{R_5} = V_1 - V_2 = 7.24\text{ V} - (-2.45\text{ V}) = \mathbf{9.69\ V}$$

$$V_{R_6} = V_1 - V_3 = 7.24\text{ V} - 1.41\text{ V} = \mathbf{5.83\ V}$$

(II): a. Source conversion: $I = 4$ A, $R = 4\ \Omega$

V_1 V_2 V_3

$$V_1\left[\frac{1}{9}+\frac{1}{20}+\frac{1}{20}\right]-\frac{1}{20}V_2-\frac{1}{20}V_3=-2$$

$$V_2\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{18}\right]-\frac{1}{20}V_1-\frac{1}{20}V_3=0$$

$$V_3\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{4}\right]-\frac{1}{20}V_2-\frac{1}{20}V_1=4$$

b. $V_1 = \mathbf{-6.64\ V}$, $V_2 = \mathbf{1.29\ V}$, $V_3 = \mathbf{10.66\ V}$

c. $V_{R_1} = V_1 = \mathbf{-6.64\ V}$, R_2 $\overset{-}{\underset{+}{V_{R_2}}} = 16\text{ V} - 10.66\text{ V} = \mathbf{5.34\ V}$

$V_{R_3} = V_2 = \mathbf{1.29\ V}$, $V_{R_4} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = 1.29\text{ V} - (-6.64\text{ V}) = \mathbf{7.93\ V}$

$V_{R_5} = \overset{(+)}{V_3} - \overset{(-)}{V_2} = 10.66\text{ V} - 1.29\text{ V} = \mathbf{9.37\ V}$

$V_{R_6} = \overset{(+)}{V_3} - \overset{(-)}{V_1} = 10.66\text{ V} - (-6.64\text{ V}) = \mathbf{17.30\ V}$

44. a. Note the solution to problem 39(I).
$V_1 = \mathbf{-5.31\ V}$, $V_2 = \mathbf{-0.62\ V}$, $V_3 = \mathbf{3.75\ V}$
$V_{5\text{A}} = V_1 = \mathbf{-5.31\ V}$

b. Note the solution to problem 39(II).
$V_1 = \mathbf{-6.92\ V}$, $V_2 = \mathbf{12\ V}$, $V_3 = \mathbf{2.3\ V}$
$V_{2\text{A}} = \overset{(+)}{V_2} - \overset{(-)}{V_3} = \mathbf{9.7\ V}$, $V_{5\text{A}} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = \mathbf{18.92\ V}$

45. a. I_1 I_2 I_3

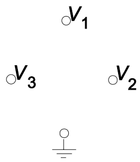
$$I_1(6 + 5 + 10) - 5I_2 - 10I_3 = 6$$
$$I_2(5 + 5 + 5) - 5I_1 - 5I_3 = 0$$
$$I_3(5 + 10 + 20) - 10I_1 - 5I_2 = 0$$

$I_1 = \mathbf{0.39\ A}$, $I_2 = \mathbf{0.18\ A}$, $I_3 = \mathbf{0.14\ A}$

b. $I_5 = I_2 - I_3 = \mathbf{40\ mA}$ (direction of I_2)

c, d. no

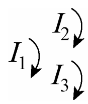
46. Source conversion: $I = 1$ A, $R = 6\ \Omega$



$$\left[\frac{1}{6}+\frac{1}{5}+\frac{1}{5}\right]V_1-\frac{1}{5}V_2-\frac{1}{5}V_3=1$$
$$\left[\frac{1}{5}+\frac{1}{5}+\frac{1}{20}\right]V_2-\frac{1}{5}V_1-\frac{1}{5}V_3=0$$
$$\left[\frac{1}{5}+\frac{1}{5}+\frac{1}{10}\right]V_3-\frac{1}{5}V_1-\frac{1}{5}V_2=0$$

V_{R_5} = **196.70 mV**, **no**

47. a.



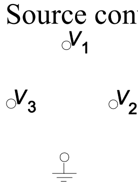
$I_1(2\text{ k}\Omega + 33\text{ k}\Omega + 3.3\text{ k}\Omega) - 33\text{ k}\Omega\, I_2 - 3.3\text{ k}\Omega\, I_3 = 24$
$I_2(33\text{ k}\Omega + 56\text{ k}\Omega + 36\text{ k}\Omega) - 33\text{ k}\Omega\, I_1 - 36\text{ k}\Omega\, I_3 = 0$
$I_3(3.3\text{ k}\Omega + 36\text{ k}\Omega + 5.6\text{ k}\Omega) - 36\text{ k}\Omega\, I_2 - 3.3\text{ k}\Omega\, I_1 = 0$

I_1 = **0.97 mA**, $I_2 = I_3$ = **0.36 mA**

b. $I_5 = I_2 - I_3 = 0.36\text{ mA} - 0.36\text{ mA} = \mathbf{0}$

c, d. yes

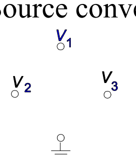
48. Source conversion: $I = 12$ A, $R = 2\text{ k}\Omega$



$$\left[\frac{1}{2\text{ k}\Omega}+\frac{1}{33\text{ k}\Omega}+\frac{1}{56\text{ k}\Omega}\right]V_1-\frac{1}{56\text{ k}\Omega}V_2-\frac{1}{33\text{ k}\Omega}V_3=12$$
$$\left[\frac{1}{56\text{ k}\Omega}+\frac{1}{36\text{ k}\Omega}+\frac{1}{5.6\text{ k}\Omega}\right]V_2-\frac{1}{56\text{ k}\Omega}V_1-\frac{1}{36\text{ k}\Omega}V_3=0$$
$$\left[\frac{1}{33\text{ k}\Omega}+\frac{1}{3.3\text{ k}\Omega}+\frac{1}{36\text{ k}\Omega}\right]V_3-\frac{1}{33\text{ k}\Omega}V_1-\frac{1}{36\text{ k}\Omega}V_2=0$$

I_{R_5} = **0 A, yes**

49. Source conversion: $I = 9$ mA, $R = 1\text{ k}\Omega$



$$V_1\left[\frac{1}{1\text{ k}\Omega}+\frac{1}{100\text{ k}\Omega}+\frac{1}{200\text{ k}\Omega}\right]-\frac{1}{100\text{ k}\Omega}V_2-\frac{1}{200\text{ k}\Omega}V_3 = 4\text{ mA}$$
$$V_2\left[\frac{1}{100\text{ k}\Omega}+\frac{1}{200\text{ k}\Omega}+\frac{1}{1\text{ k}\Omega}\right]-\frac{1}{100\text{ k}\Omega}V_1-\frac{1}{1\text{ k}\Omega}V_3=-9\text{ mA}$$
$$V_3\left[\frac{1}{200\text{ k}\Omega}+\frac{1}{100\text{ k}\Omega}+\frac{1}{1\text{ k}\Omega}\right]-\frac{1}{200\text{ k}\Omega}V_1-\frac{1}{1\text{ k}\Omega}V_2=9\text{ mA}$$

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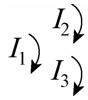
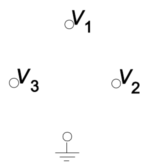
50. a.



$$(1\text{ k}\Omega + 2\text{ k}\Omega + 2\text{ k}\Omega)I_1 - 2\text{ k}\Omega\ I_2 - 2\text{ k}\Omega\ I_3 = 10$$
$$(2\text{ k}\Omega + 2\text{ k}\Omega + 2\text{ k}\Omega)I_2 - 2\text{ k}\Omega\ I_1 - 2\text{ k}\Omega\ I_3 = 0$$
$$(2\text{ k}\Omega + 2\text{ k}\Omega + 2\text{ k}\Omega)I_3 - 2\text{ k}\Omega\ I_1 - 2\text{ k}\Omega\ I_2 = 0$$

$I_1 = I_{10\text{V}} = \mathbf{3.33\ mA}$

Source conversion: $I = 10\text{ V}/1\text{ k}\Omega = 10\text{ mA}$, $R = 1\text{ k}\Omega$

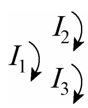


$$V_1\left[\frac{1}{1\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}\right]-\frac{1}{2\,\text{k}\Omega}V_2-\frac{1}{2\,\text{k}\Omega}V_3=10\text{ mA}$$
$$V_2\left[\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}\right]-\frac{1}{2\,\text{k}\Omega}V_1-\frac{1}{2\,\text{k}\Omega}V_3=0$$
$$V_3\left[\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}\right]-\frac{1}{2\,\text{k}\Omega}V_2-\frac{1}{2\,\text{k}\Omega}V_1=0$$

$V_1 = 6.67\text{ V} = E - IR_s = 10\text{ V} - I(1\text{ k}\Omega)$

$$I = \frac{10 - 6.67\text{ V}}{1\,\text{k}\Omega} = \mathbf{3.33\ mA}$$

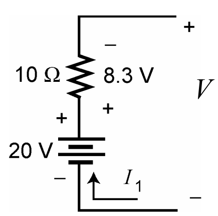
b.



Source conversion: $E = 20\text{ V}$, $R = 10\ \Omega$

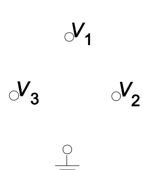
$$(10 + 10 + 20)I_1 - 10I_2 - 20I_3 = 20$$
$$(10 + 20 + 20)I_2 - 10I_1 - 20I_3 = 0$$
$$(20 + 20 + 10)I_3 - 20I_1 - 20I_2 = 0$$

$I_1 = I_{20\text{V}} = 0.83\text{ A}$



$$V = 20\text{ V} - 8.3\text{ V}$$
$$= 11.7\text{ V}$$

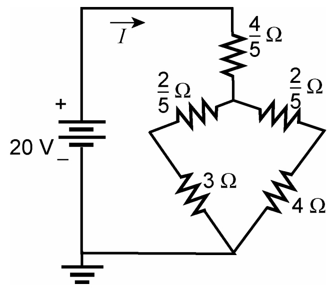
$$I_s = \frac{V}{R_s} = \frac{11.70\text{ V}}{10\,\Omega} = \mathbf{1.17A}$$



$$V_1\left[\frac{1}{10}+\frac{1}{10}+\frac{1}{20}\right]-\left[\frac{1}{20}\right]V_2-\left[\frac{1}{10}\right]V_3=2$$
$$V_2\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{10}\right]-\left[\frac{1}{20}\right]V_1-\left[\frac{1}{20}\right]V_3=0$$
$$V_3\left[\frac{1}{10}+\frac{1}{20}+\frac{1}{20}\right]-\left[\frac{1}{10}\right]V_1-\left[\frac{1}{20}\right]V_2=0$$

$$I_{R_s} = \frac{V_1}{R_s} = \mathbf{1.17\ A}$$

51. a.

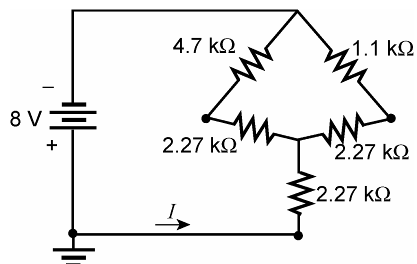


$$I = \frac{20\text{ V}}{\frac{4}{5}\ \Omega + \left[\frac{2}{5}\ \Omega + 3\ \Omega\right] \| \left[\frac{2}{5}\ \Omega + 4\ \Omega\right]}$$

$$= \frac{20\text{ V}}{\frac{4}{5}\ \Omega + (3.14\ \Omega) \| (4.4\ \Omega)}$$

$= \mathbf{7.36\ A}$

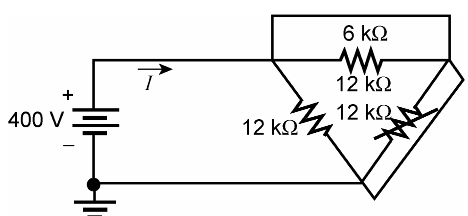
b.



$R_T = 2.27\text{ k}\Omega + [4.7\text{ k}\Omega + 2.27\text{ k}\Omega] \| [1.1\text{ k}\Omega + 2.27\text{ k}\Omega]$
$= 2.27\text{ k}\Omega + [6.97\text{ k}\Omega] \| [3.37\text{ k}\Omega]$
$= 2.27\text{ k}\Omega + 2.27\text{ k}\Omega$
$= 4.54\text{ k}\Omega$

$$I = \frac{8\text{ V}}{4.54\text{ k}\Omega} = \mathbf{1.76\ mA}$$

52. a.



(Y-Δ conversion)

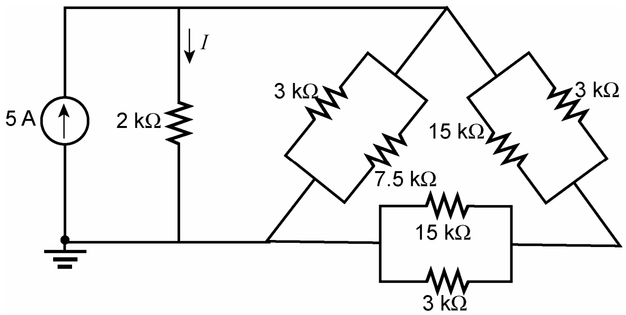
$$I = \frac{400\text{ V}}{12\text{ k}\Omega \| 12\text{ k}\Omega \| 6\text{ k}\Omega} = \frac{400\text{ V}}{3\text{ k}\Omega}$$

$= \mathbf{133.33\ mA}$

b. $$I = \frac{42\text{ V}}{(18\ \Omega \| 18\ \Omega) \| \left[(18\ \Omega \| 18\ \Omega) + (18\ \Omega \| 18\ \Omega)\right]} = \frac{42\text{ V}}{9\ \Omega \| \left[9\ \Omega + 9\ \Omega\right]}$$

$= \mathbf{7\ A}$ (Y–Δ conversion)

53.

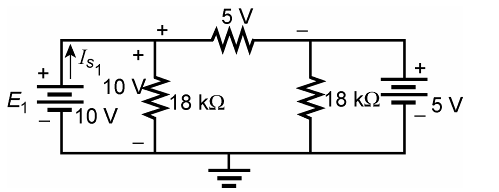


$3\text{ k}\Omega \parallel 7.5\text{ k}\Omega = 2.14\text{ k}\Omega$
$3\text{ k}\Omega \parallel 15\text{ k}\Omega = 2.5\text{ k}\Omega$

$R'_T = 2.14\text{ k}\Omega \parallel (2.5\text{ k}\Omega + 2.5\text{ k}\Omega) = 1.5\text{ k}\Omega$

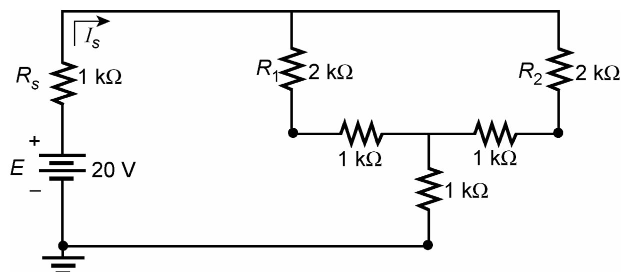
CDR: $\quad I = \dfrac{(1.5\text{ k}\Omega)(5\text{ A})}{1.5\text{ k}\Omega + 2\text{ k}\Omega} = \mathbf{2.14\ A}$

54.



$$I_{s_1} = \frac{10\text{ V}}{18\text{ k}\Omega} + \frac{5\text{ V}}{18\text{ k}\Omega} = \frac{15\text{ V}}{18\text{ k}\Omega} = \mathbf{0.83\ mA}$$

55.

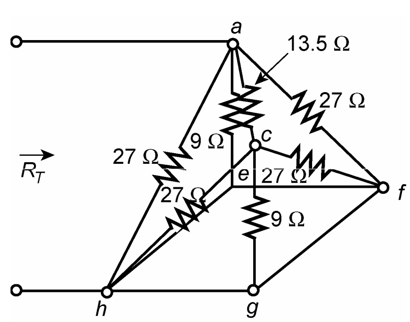


$R' = R_1 + 1\text{ k}\Omega = 3\text{ k}\Omega$
$R'' = R_2 + 1\text{ k}\Omega = 3\text{ k}\Omega$
$R'_T = \dfrac{3\text{ k}\Omega}{2} = 1.5\text{ k}\Omega$

$R_T = 1\text{ k}\Omega + 1.5\text{ k}\Omega + 1\text{ k}\Omega = 3.5\text{ k}\Omega$

$$I_s = \frac{E}{R_T} = \frac{20\text{ V}}{3.5\text{ k}\Omega} = \mathbf{5.71\ mA}$$

56.



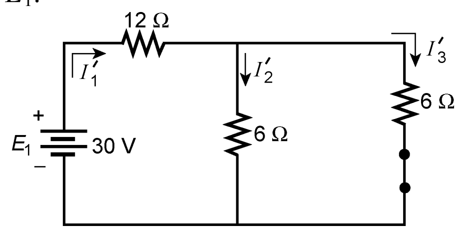
c – g: $27\ \Omega \parallel 9\ \Omega \parallel 27\ \Omega = 5.4\ \Omega$

a – h: $27\ \Omega \parallel 9\ \Omega \parallel 27\ \Omega = 5.4\ \Omega$

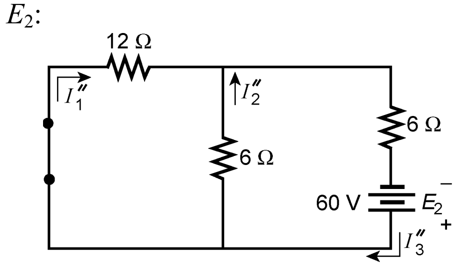
$R_T = 5.4\ \Omega \parallel (13.5\ \Omega + 5.4\ \Omega)$
$= 5.4\ \Omega \parallel 18.9\Omega$
$= \mathbf{4.2\ \Omega}$

Chapter 9

1. a. E_1:



E_2:



$$I'_1 = \frac{30\text{ V}}{12\,\Omega + 6\,\Omega \parallel 6\,\Omega} = \frac{30\text{ V}}{12\,\Omega + 3\,\Omega} = 2\text{ A}$$

$$I'_2 = I'_3 = \frac{I_1'}{2} = 1\text{ A}$$

$$I''_3 = \frac{60\text{ V}}{6\,\Omega + 6\,\Omega \parallel 12\,\Omega} = \frac{60\text{ V}}{6\,\Omega + 4\,\Omega} = 6\text{ A}$$

$$I''_1 = \frac{6\,\Omega(I_3'')}{6\,\Omega + 12\,\Omega} = 2\text{ A}$$

$$I''_2 = \frac{12\,\Omega(I_3'')}{12\,\Omega + 6\,\Omega} = 4\text{ A}$$

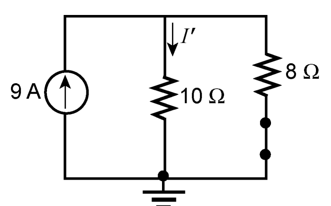
$I_1 = I'_1 + I''_1 = 2\text{ A} + 2\text{ A} = \mathbf{4\text{ A}}$ (dir. of I_1')
$I_2 = I_2'' - I_2' = 4\text{ A} - 1\text{ A} = \mathbf{3\text{ A}}$ (dir. of I_2'')
$I_3 = I'_3 + I''_3 = 1\text{ A} + 6\text{ A} = \mathbf{7\text{ A}}$ (dir. of I_3')

b. E_1: $P'_1 = I_1'^2 R_1 = (2\text{ A})^2\, 12\,\Omega = \mathbf{48\text{ W}}$
E_2: $P''_1 = I_1''^2 R_1 \text{I}'' R_1 = (2\text{ A})^2\, 12\,\Omega = \mathbf{48\text{ W}}$

c. $P_1 = I_1^2 R_1 = (4\text{ A})^2\, 12\,\Omega = \mathbf{192\text{ W}}$

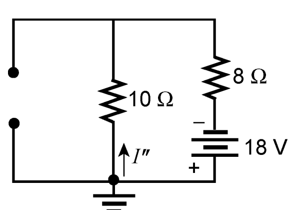
d. $P'_1 + P''_1 = 48\text{ W} + 48\text{ W} = 96\text{ W} \neq 192\text{ W} = P_1$

2. I:



$$I' = \frac{8\,\Omega(9\text{ A})}{8\,\Omega + 10\,\Omega} = 4\text{ A}$$

E:

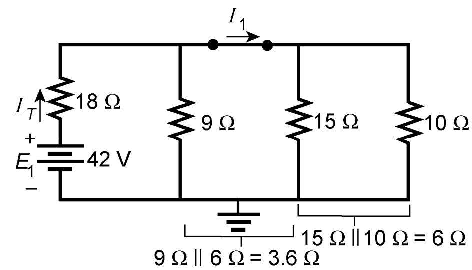


$$I'' = \frac{18\text{ V}}{10\,\Omega + 8\,\Omega} = 1\text{ A}$$

$I = I' - I'' = 4\text{ A} - 1\text{ A} = \mathbf{3\text{ A}}$ **(dir of I')**

3.

E_1:

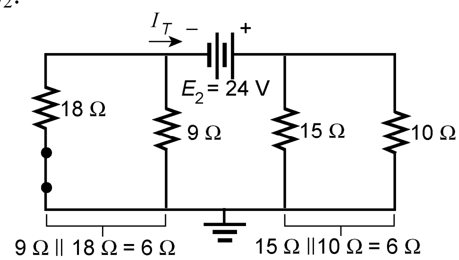


$$I_T = \frac{42\text{ V}}{18\,\Omega + 3.6\,\Omega} = 1.944\text{ A}$$

$$I_1 = \frac{9\,\Omega(I_T)}{9\,\Omega + 6\,\Omega} = \frac{9\,\Omega(1.944\text{ A})}{15\,\Omega}$$

$$= 1.17\text{ A}$$

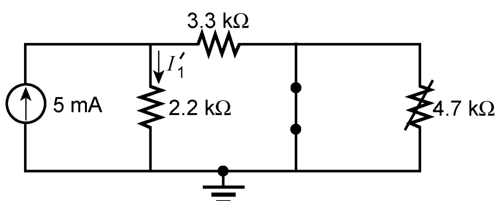
E_2:



$$I_T = \frac{E_2}{R_T} = \frac{24\text{ V}}{12\,\Omega} = 2\text{ A}$$

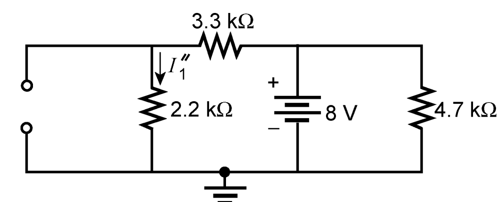
$I_{24\text{V}} = I_T + I_1 = 2\text{ A} + 1.17\text{ A} =$ **3.17 A (dir. of I_1)**

4.



$$I_1' = \frac{3.3\text{ k}\Omega(5\text{ mA})}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega} = \frac{16.5\text{ mA}}{5.5}$$

$$= 3\text{ mA}$$

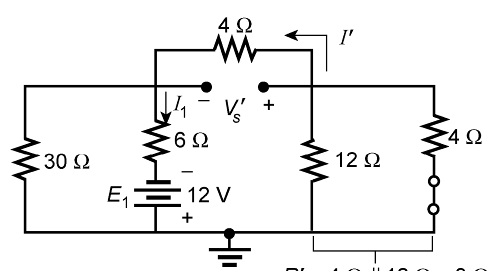


$$I''_1 = \frac{8\text{ V}}{3.3\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{8\text{ V}}{5.5\text{ k}\Omega}$$

$$= 1.45\text{ mA}$$

$I_1 = I'_1 + I''_1 = 3\text{ mA} + 1.45\text{ mA} =$ **4.45 mA**

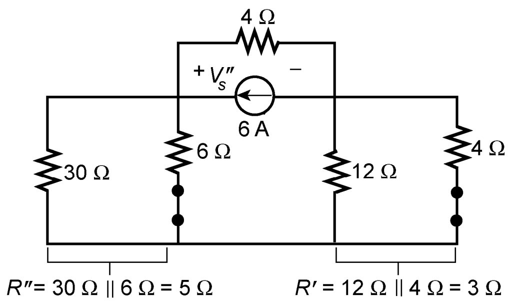
5. E_1:

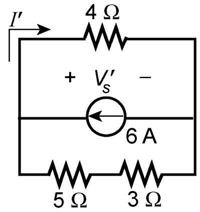


$$I_1 = \frac{E_1}{R_T} = \frac{12\text{ V}}{6\,\Omega + 5.88\,\Omega} = 1.03\text{ A}$$

$$I' = \frac{30\ \Omega(I_1)}{30\ \Omega + 7\ \Omega} = \frac{30\ \Omega(1.03\ \text{A})}{37\ \Omega}$$
$$= 835.14\ \text{mA}$$
$$V_s' = I'(4\ \Omega) = (835.14\ \text{mA})(4\ \Omega)$$
$$= 3.34\ \text{V}$$

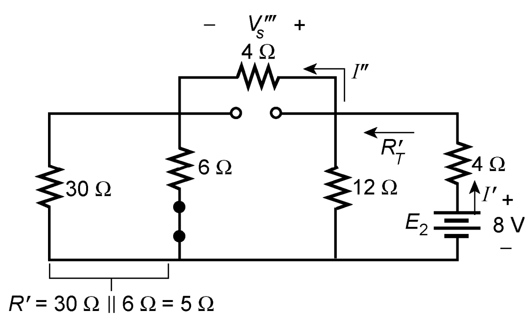
I:





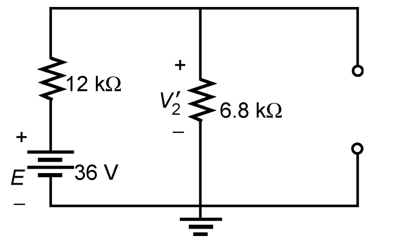
$$I' = \frac{8\,\Omega(6\,\text{A})}{8\,\Omega + 4\,\Omega} = 4\,\text{A}$$
$$V_s'' = I'(4\ \Omega) = 4\ \text{A}(4\ \Omega) = 16\ \text{V}$$

E_2:



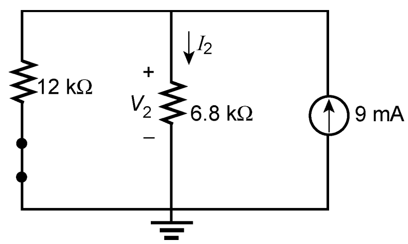
$$R'_T = 12\ \Omega \parallel (4\ \Omega + 5\ \Omega) = 12\ \Omega \parallel 9\ \Omega = 5.14\ \Omega$$
$$I' = \frac{E_2}{R_T} = \frac{8\ \text{V}}{4\,\Omega + 5.14\,\Omega} = 0.875\ \text{A}$$
$$I'' = \frac{12\,\Omega(I')}{12\,\Omega + 9\,\Omega} = \frac{12\,\Omega(0.875\ \text{A})}{21\,\Omega} = 0.5\ \text{A}$$
$$V_s''' = I''(4\ \Omega) = 0.5\ \text{A}(4\ \Omega) = 2\ \text{V}$$
$$V_s = V_s'' - V_s' - V_s''' = 16\ \text{V} - 3.34\ \text{V} - 2\ \text{V} = \mathbf{10.66\ V}$$

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:



$$I_2 = \frac{12\text{ k}\Omega(9\text{ mA})}{12\text{ k}\Omega + 6.8\text{ k}\Omega} = 5.75\text{ mA}$$

$V_2'' = I_2R_2 = (5.75\text{ mA})(6.8\text{ k}\Omega) = 39.10\text{ V}$

$V_2 = V_2' + V_2'' = 13.02\text{ V} + 39.10\text{ V} = \mathbf{52.12\text{ V}}$

7. a. $R_{Th} = R_3 + R_1 \parallel R_2 = 4\ \Omega + 6\ \Omega \parallel 3\ \Omega = 4\ \Omega + 2\ \Omega = \mathbf{6\ \Omega}$

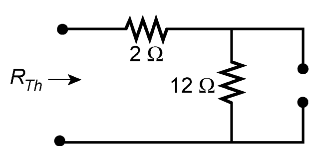
$$E_{Th} = \frac{R_2E}{R_2 + R_1} = \frac{3\ \Omega(18\text{ V})}{3\ \Omega + 6\ \Omega} = 6\text{ V}$$

b. $$I_1 = \frac{E_{Th}}{R_{Th} + R} = \frac{6\text{ V}}{6\ \Omega + 2\ \Omega} = \mathbf{0.75\text{ A}}$$

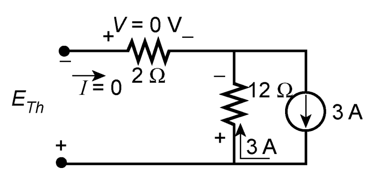
$$I_2 = \frac{6\text{ V}}{6\ \Omega + 30\ \Omega} = \mathbf{166.67\text{ mA}}$$

$$I_3 = \frac{6\text{ V}}{6\ \Omega + 100\ \Omega} = \mathbf{56.60\text{ mA}}$$

8. a.



$R_{Th} = 2\ \Omega + 12\ \Omega = \mathbf{14\ \Omega}$

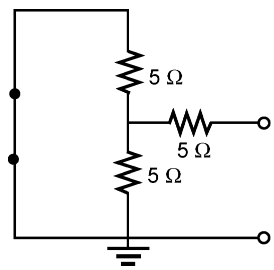


$E_{Th} = IR = (3\text{ A})(12\ \Omega) = \mathbf{36\text{ V}}$

b. $R = 2\ \Omega$: $P = \left(\dfrac{E_{Th}}{R_{Th} + R}\right)^2 R = \left(\dfrac{36\text{ V}}{14\ \Omega + 2\ \Omega}\right)^2 2\ \Omega = \mathbf{10.13\ W}$

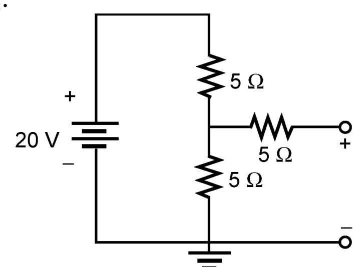
$R = 100\ \Omega$: $P = \left(\dfrac{36\text{ V}}{14\ \Omega + 100\ \Omega}\right)^2 100\ \Omega = \mathbf{9.97\ W}$

9. a. R_{Th}:



$\leftarrow R_{Th} = 5\ \Omega + 5\ \Omega \parallel 5\ \Omega = \mathbf{7.5\ \Omega}$

E_{Th}:

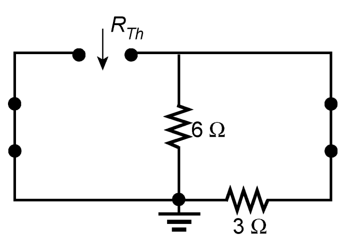


$E_{Th} = \dfrac{20\text{ V}}{2} = \mathbf{10\ V}$

b. $R = 2\ \Omega$: $P = \left(\dfrac{E_{Th}}{R_{Th} + R}\right)^2 R = \left(\dfrac{10\text{ V}}{7.5\ \Omega + 2\ \Omega}\right)^2 2\ \Omega = \mathbf{2.22\ W}$

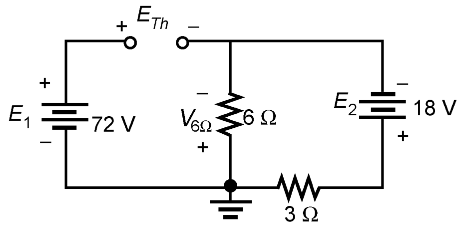
$R = 100\ \Omega$: $P = \left(\dfrac{10\text{ V}}{7.5\ \Omega + 100\ \Omega}\right)^2 100\ \Omega = \mathbf{0.87\ W}$

10. R_{Th}:



$R_{Th} = 6\ \Omega \parallel 3\ \Omega = \mathbf{2\ \Omega}$

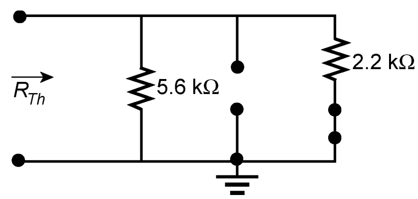
E_{Th}:



$V_{6\Omega} = \dfrac{6\ \Omega(18\text{ V})}{6\ \Omega + 3\ \Omega} = 12\text{ V}$

$E_{Th} = 72\text{ V} + 12\text{ V} = \mathbf{84\ V}$

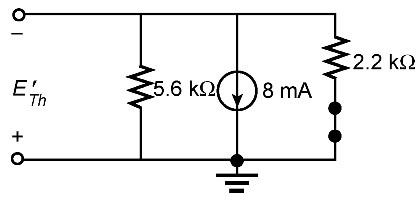
11. R_{Th}:



$R_{Th} = 5.6\text{ k}\Omega \parallel 2.2\text{ k}\Omega = \mathbf{1.58\text{ k}\Omega}$

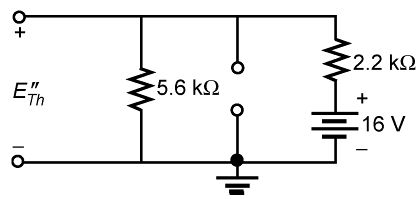
E_{Th}: Superposition:

I:



$$\begin{aligned} E'_{Th} &= IR_T \\ &= 8\text{ mA}(5.6\text{ k}\Omega \parallel 2.2\text{ k}\Omega) \\ &= 8\text{ mA}(1.579\text{ k}\Omega) \\ &= 12.64\text{ V} \end{aligned}$$

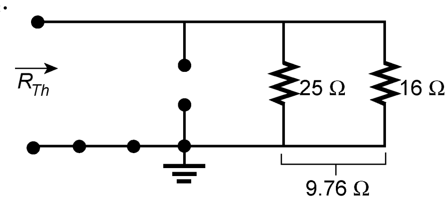
E:



$$\begin{aligned} E''_{Th} &= \frac{5.6\text{ k}\Omega(16\text{ V})}{5.6\text{ k}\Omega + 2.2\text{ k}\Omega} \\ &= 11.49\text{ V} \end{aligned}$$

$$\begin{array}{l} + \\ E_{Th} = 11.49\text{ V} - 12.64\text{ V} = \mathbf{-1.15\text{ V}} \\ - \end{array}$$

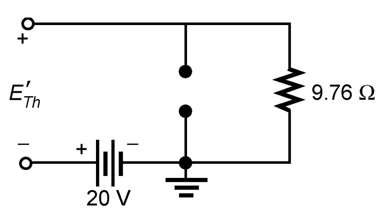
12. a. R_{Th}:



$R_{Th} = 25\ \Omega \parallel 16\ \Omega = \mathbf{9.76\ \Omega}$

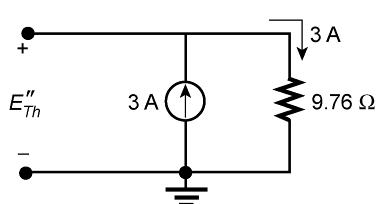
E_{Th}: Superposition:

E:



$E'_{Th} = -20\text{ V}$

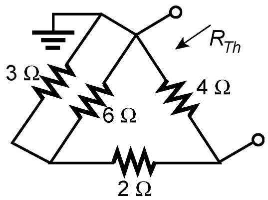
I:



$E''_{Th} = (3\text{ A})(9.76\ \Omega) = 29.28\text{ V}$

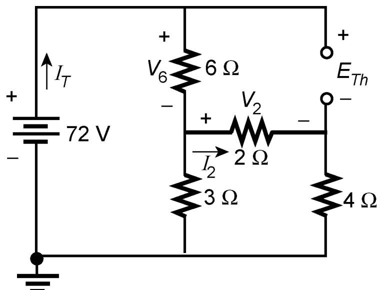
$E_{Th} = E''_{Th} - E'_{Th} = 29.28\text{ V} - 20\text{ V} = \mathbf{9.28\text{ V}}$

b. R_{Th}:



$$R_{Th} = 4\ \Omega \parallel (2\ \Omega + 6\ \Omega \parallel 3\ \Omega) = \mathbf{2\ \Omega}$$

E_{Th}:

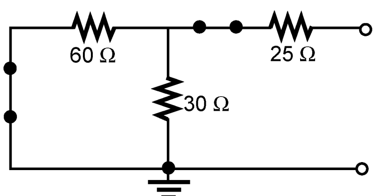


$$I_T = \frac{72\text{ V}}{6\,\Omega + 3\,\Omega \parallel (2\,\Omega + 4\,\Omega)} = 9\text{ A}$$

$$I_2 = \frac{3\,\Omega(I_T)}{3\,\Omega + 6\,\Omega} = \frac{3\,\Omega(9\text{ A})}{9\,\Omega} = 3\text{ A}$$

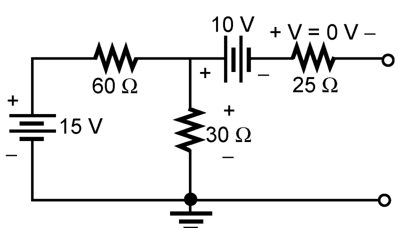
$$E_{Th} = V_6 + V_2 = (I_T)(6\ \Omega) + I_2(2\ \Omega)$$
$$= (9\text{ A})(6\ \Omega) + (3\text{ A})(2\ \Omega) = \mathbf{60\ V}$$

13. (I): R_{Th}:



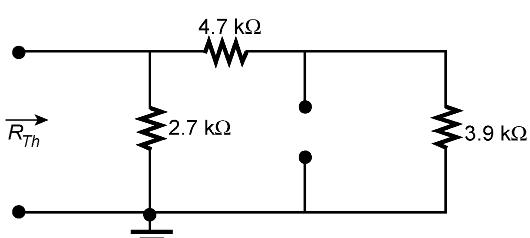
$\leftarrow R_{Th} = 25\ \Omega + 60\ \Omega \parallel 30\ \Omega = \mathbf{45\ \Omega}$

E_{Th}:



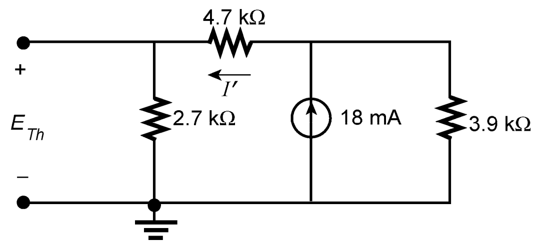
$$E_{Th} = V_{30\Omega} - 10\text{ V} - 0$$
$$= \frac{30\ \Omega(15\text{ V})}{30\ \Omega + 60\ \Omega} - 10\text{ V}$$
$$= 5\text{ V} - 10\text{ V} = \mathbf{-5\ V}$$

(II): R_{Th}:



$R_{Th} = 2.7\text{ k}\Omega \parallel (4.7\text{ k}\Omega + 3.9\text{ k}\Omega) = 2.7\text{ k}\Omega \parallel 8.6\text{ k}\Omega = \mathbf{2.06\ k\Omega}$

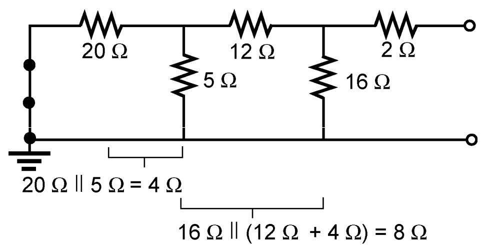
E_{Th}:



$$I' = \frac{3.9\text{ k}\Omega(18\text{ mA})}{3.9\text{ k}\Omega + 7.4\text{ k}\Omega} = 6.21\text{ mA}$$

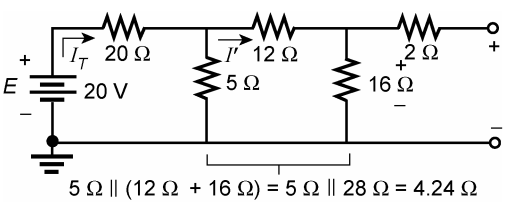
$E_{Th} = I'(2.7\text{ k}\Omega) = (6.21\text{ mA})(2.7\text{ k}\Omega) = \mathbf{16.77\text{ V}}$

14. (I): R_{Th}:



$\leftarrow R_{Th} = 2\ \Omega + 8\ \Omega = \mathbf{10\ \Omega}$

E_{Th}:



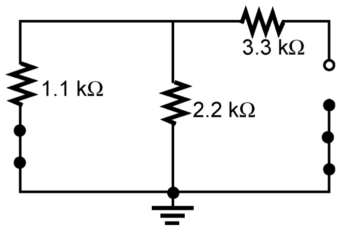
$E_{Th} = V_{16\Omega}$

$$I_T = \frac{20\text{ V}}{20\ \Omega + 4.24\ \Omega} = 825.08\text{ mA}$$

$$I' = \frac{5\ \Omega(I_T)}{5\ \Omega + 28\ \Omega} = \frac{5\ \Omega(825.08\text{ mA})}{33\ \Omega} = 125.01\text{ mA}$$

$E_{Th} = V_{16\Omega} = (I')(16\ \Omega) = (125.01\text{ mA})(16\ \Omega) = \mathbf{2\text{ V}}$

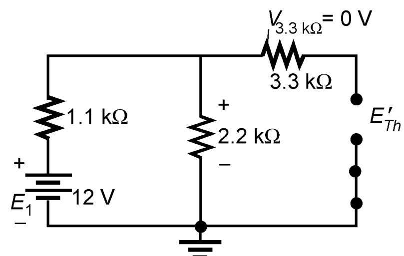
(II): R_{Th}:



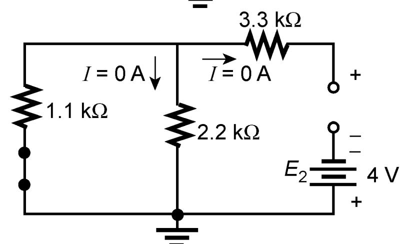
$\leftarrow R_{Th} = 3.3\text{ k}\Omega + 2.2\text{ k}\Omega \parallel 1.1\text{ k}\Omega$
$= 3.3\text{ k}\Omega + 0.73\text{ k}\Omega$
$= \mathbf{4.03\text{ k}\Omega}$

E_{Th}: Superposition:

E_1:



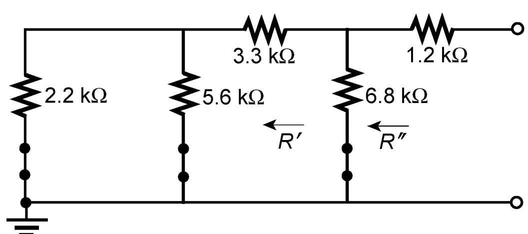
$$E'_{Th} = V_{2.2\text{k}\Omega} = \frac{2.2\text{ k}\Omega(12\text{ V})}{2.2\text{ k}\Omega + 1.1\text{ k}\Omega} = 8\text{ V}$$



$E_{Th}'' = E_2 = 4$ V

$E_{Th} = E'_{Th} + E''_{Th} = 8\text{ V} + 4\text{ V} = \mathbf{12\text{ V}}$

15. R_{Th}:



$\leftarrow R_{Th} = 2.2\text{ k}\Omega \parallel 5.6\text{ k}\Omega = 1.58\text{ k}\Omega$
$R' = 1.58\text{ k}\Omega + 3.3\text{ k}\Omega$
$= 4.88\text{ k}\Omega$

$R'' = 4.88\text{ k}\Omega \parallel 6.8\text{ k}\Omega = 2.84\text{ k}\Omega$
$R_{Th} = 1.2\text{ k}\Omega + R'' = 1.2\text{ k}\Omega + 2.84\text{ k}\Omega = \mathbf{4.04\text{ k}\Omega}$

E_{Th}: Source conversions:

$$I_1 = \frac{22\text{ V}}{2.2\text{ k}\Omega} = 10\text{ mA},\ R_s = 2.2\text{ k}\Omega$$

$$I_2 = \frac{12\text{ V}}{5.6\text{ k}\Omega} = 2.14\text{ mA},\ R_s = 5.6\text{ k}\Omega$$

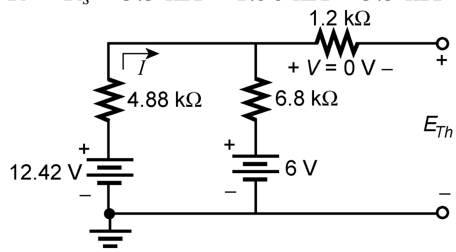
Combining parallel current sources: $I'_T = I_1 - I_2 = 10\text{ mA} - 2.14\text{ mA} = 7.86\text{ mA}$

$2.2\text{ k}\Omega \parallel 5.6\text{ k}\Omega = 1.58\text{ k}\Omega$

Source conversion:

$E = (7.86\text{ mA})(1.58\text{ k}\Omega) = 12.42\text{ V}$

$R' = R_s + 3.3\text{ k}\Omega = 1.58\text{ k}\Omega + 3.3\text{ k}\Omega = 4.88\text{ k}\Omega$

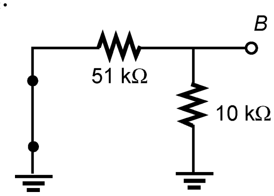


$$I = \frac{12.42\text{ V} - 6\text{ V}}{4.88\text{ k}\Omega + 6.8\text{ k}\Omega} = \frac{6.42\text{ V}}{11.68\text{ k}\Omega} = 549.66\ \mu\text{A}$$

$$V_{6.8\text{k}\Omega} = I(6.8\text{ k}\Omega) = (549.66\ \mu\text{A})(6.8\text{ k}\Omega) = 3.74\text{ V}$$

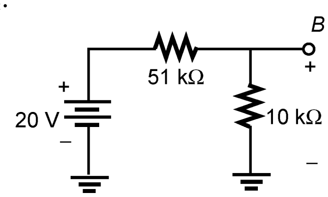
$$E_{Th} = 6\text{ V} + V_{6.8\text{k}\Omega} = 6\text{ V} + 3.74\text{ V} = \mathbf{9.74\text{ V}}$$

16. a. R_{Th}:



$\leftarrow R_{Th} = 51\text{ k}\Omega \parallel 10\text{ k}\Omega = \mathbf{8.36\text{ k}\Omega}$

E_{Th}:



$$E_{Th} = \frac{10\text{ k}\Omega(20\text{ V})}{10\text{ k}\Omega + 51\text{ k}\Omega} = 3.28\text{ V}$$

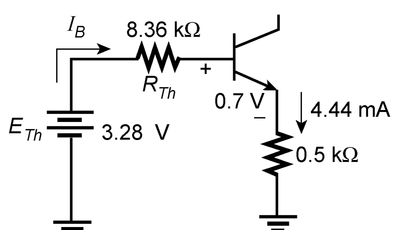
b. $I_E R_E + V_{CE} + I_C R_C = 20\text{ V}$

but $I_C = I_E$

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.



$$E_{Th} - I_B R_{Th} - V_{BE} - V_E = 0$$

$$\text{and } I_B = \frac{E_{Th} - V_{BE} - V_E}{R_{Th}} = \frac{3.28\text{ V} - 0.7\text{ V} - (4.44\text{ mA})(0.5\text{ k}\Omega)}{8.36\text{ k}\Omega}$$

$$= \frac{2.58\text{ V} - 2.22\text{ V}}{8.36\text{ k}\Omega} = \frac{0.36\text{ V}}{8.36\text{ k}\Omega} = \mathbf{43.06\ \mu A}$$

d. $V_C = 20\text{ V} - I_C R_C = 20\text{ V} - (4.44\text{ mA})(2.2\text{ k}\Omega)$
$= 20\text{ V} - 9.77\text{ V}$
$= \mathbf{10.23\ V}$

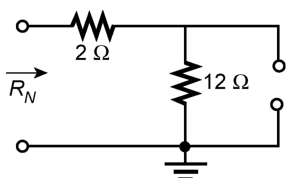
17. a. $E_{Th} = \mathbf{20\ V}$

$I = 1.6\text{ mA} = \dfrac{E_{Th}}{R_{Th}} = \dfrac{20\text{ V}}{R_{Th}}, R_{Th} = \dfrac{20\text{ V}}{1.6\text{ mA}} = \mathbf{12.5\ k\Omega}$

b. $E_{Th} = \mathbf{60\ mV}$, $R_{Th} = \mathbf{2.72\ k\Omega}$

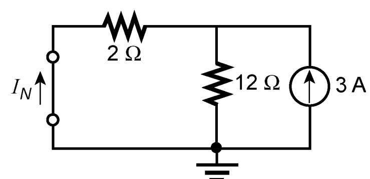
c. $E_{Th} = \mathbf{16\ V}$, $R_{Th} = \mathbf{2.2\ k\Omega}$

18. R_N:



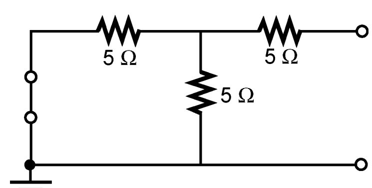
$R_N = 2\ \Omega + 12\ \Omega = \mathbf{14\ \Omega}$

I_N:



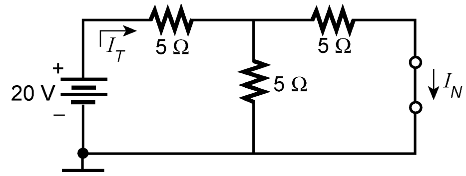
$$I_N = \frac{12\ \Omega(3\text{ A})}{12\ \Omega + 2\ \Omega} = 2.57\text{ A}$$

19. a. R_N:



$\leftarrow R_N = 5\ \Omega + \dfrac{5\ \Omega}{2} = \mathbf{7.5\ \Omega}$

I_N:

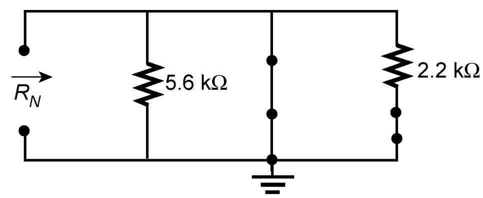


$$I_T = \frac{20\text{ V}}{5\ \Omega + \frac{5\ \Omega}{2}} = 2.67\text{ A}$$

$$I_N = \frac{I_T}{2} = \mathbf{1.34\ A}$$

b. $E_{Th} = I_N R_N = (1.34\text{ A})(7.5\ \Omega) = 10.05\text{ V} \cong \mathbf{10\ V}$, $R_{Th} = R_N = \mathbf{7.5\ \Omega}$

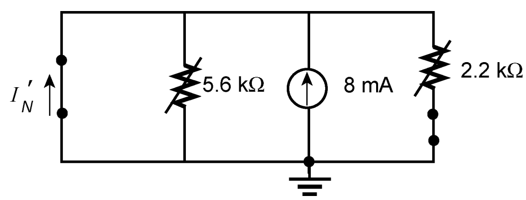
20. R_N:



$R_N = 5.6\text{ k}\Omega \parallel 2.2\text{ k}\Omega = \mathbf{1.58\text{ k}\Omega}$

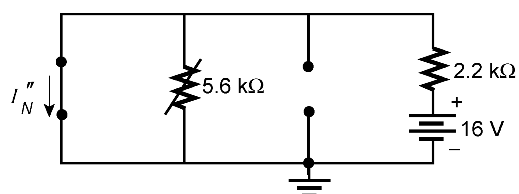
I_N:

I:



$I'_N = 8\text{ mA}$

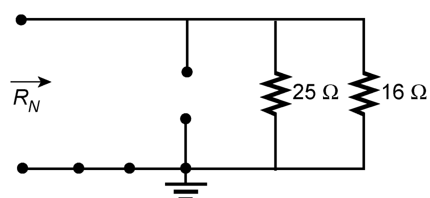
E:



$I''_N = \dfrac{16\text{ V}}{2.2\text{ k}\Omega} = 7.27\text{ mA}$

$I_N \uparrow = 8\text{ mA} - 7.27\text{ mA} = \mathbf{0.73\text{ mA}}$

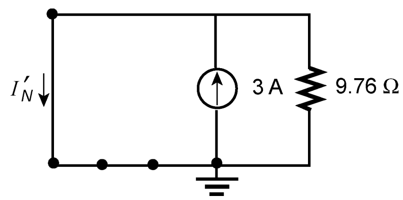
21. (I): (a)



$R_N = 25\ \Omega \parallel 16\ \Omega = \mathbf{9.76\ \Omega}$

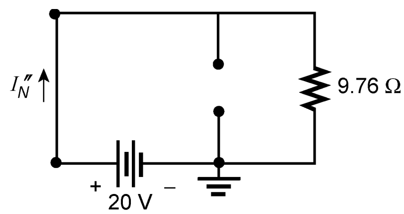
I_N: Superposition:

I:



$I'_N = 3\text{ A}$

E:

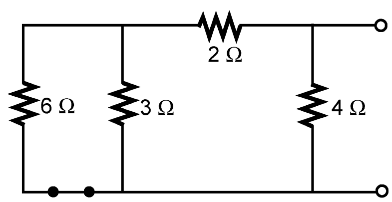


$$I''_N = \frac{20\text{ V}}{9.76\,\Omega} = 2.05\text{ A}$$

$I_N = I'_N - I''_N = 3\text{ A} - 2.05\text{ A} = \mathbf{0.95\text{ A}}$ (direction of I'_N)

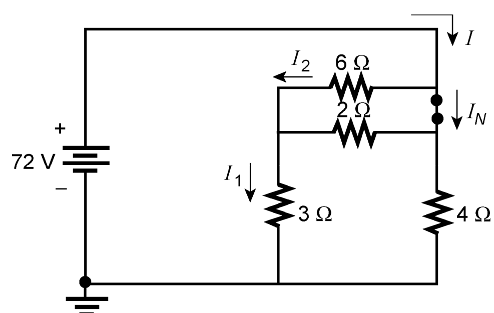
b. $E_{Th} = I_N R_N = (0.95\text{ A})(9.76\,\Omega) = \mathbf{9.27\text{ V}} \cong 9.28\text{ V}$, $R_{Th} = R_N = \mathbf{9.76\,\Omega}$

(II): a. R_N:



$\leftarrow R_N = 4\,\Omega \parallel (2\,\Omega + 2\,\Omega) = \mathbf{2\,\Omega}$

I_N:

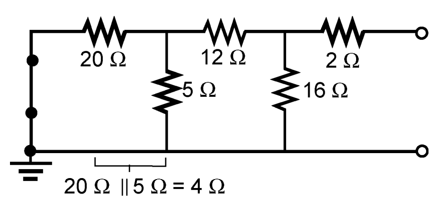


$$I = \frac{72\text{ V}}{4\,\Omega \parallel (3\,\Omega + 6\,\Omega \parallel 2\,\Omega)}$$
$$= \frac{72\text{ V}}{2.118\,\Omega} \cong 34\text{ A}$$
$$I_1 = \frac{4\,\Omega(I)}{4\,\Omega + 4.5\,\Omega} = 16\text{ A}$$
$$I_2 = \frac{2\,\Omega(I_1)}{2\,\Omega + 6\,\Omega} = 4\text{ A}$$

$I_N = I - I_2 = 34\text{ A} - 4\text{ A} = \mathbf{30\text{ A}}$

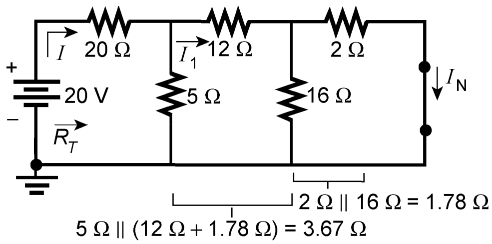
b. $E_{Th} = I_N R_N = (30\text{ A})(2\,\Omega) = \mathbf{60\text{ V}}$, $R_{Th} = R_N = \mathbf{2\,\Omega}$

22. (I) R_N:



$\leftarrow R_N = 2\,\Omega + 16\,\Omega \parallel (12\,\Omega + 4\,\Omega)$
$= 2\,\Omega + 16\,\Omega \parallel 16\,\Omega$
$= 2\,\Omega + 8\,\Omega = \mathbf{10\,\Omega}$

I_N:

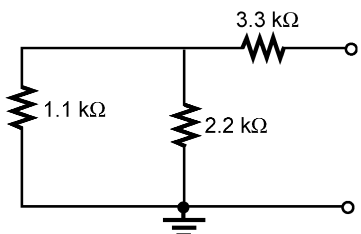


$$I = \frac{E}{R_T} = \frac{20\text{ V}}{20\,\Omega + 3.67\,\Omega} = 0.845\text{ A}$$

$$I_1 = \frac{5\,\Omega(0.845\text{ A})}{5\,\Omega + 13.78\,\Omega} = 0.225\text{ A}$$

$$I_N = \frac{16\,\Omega(0.225\text{ A})}{16\,\Omega + 2\,\Omega} = \mathbf{0.2\text{ A}}$$

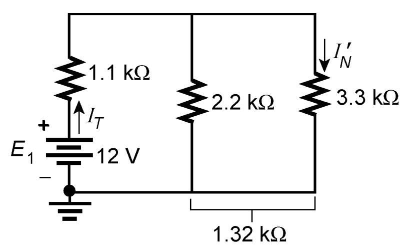
(II): R_N:



$\leftarrow R_N = 3.3\text{ k}\Omega + 1.1\text{ k}\Omega \parallel 2.2\text{ k}\Omega$
$= 3.3\text{ k}\Omega + 0.733\text{ k}\Omega$
$= \mathbf{4.03\text{ k}\Omega}$

I_N: Superposition:

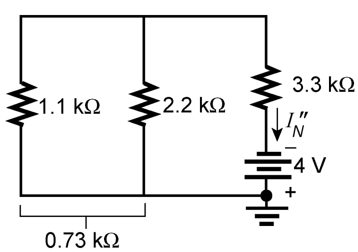
E_1:



$$I_T = \frac{12\text{ V}}{1.1\text{ k}\Omega + 1.32\text{ k}\Omega} = 4.96\text{ mA}$$

$$I'_N = \frac{2.2\text{ k}\Omega(4.96\text{ mA})}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega} = 1.98\text{ mA}$$

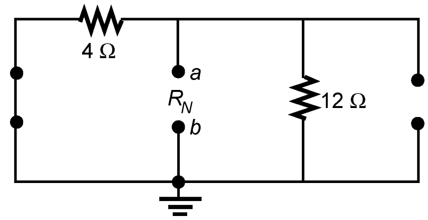
E_2:



$$I''_N = \frac{4\text{ V}}{3.3\text{ k}\Omega + 0.73\text{ k}\Omega} = 0.99\text{ mA}$$

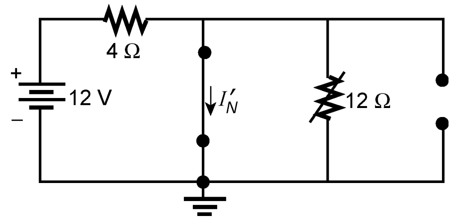
$I_N = I'_N + I''_N = 1.98\text{ mA} + 0.99\text{ mA} = \mathbf{2.97\text{ mA}}$

23. a. R_N:



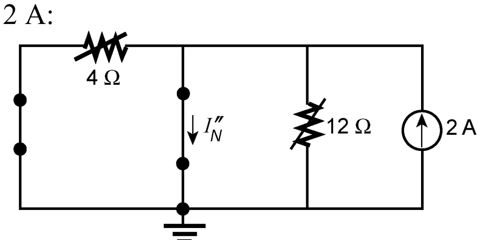
$R_N = 4\ \Omega \parallel 12\ \Omega = \mathbf{3\ \Omega}$

$E = 12$ V:



$$I'_N = \frac{12\text{ V}}{4\,\Omega} = 3\text{ A}$$

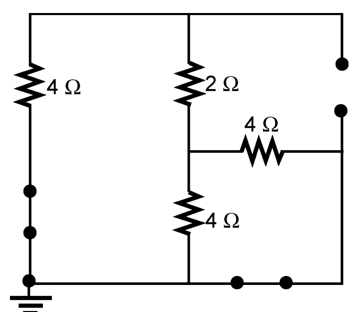
$I = 2$ A:



$I''_N = 2$ A

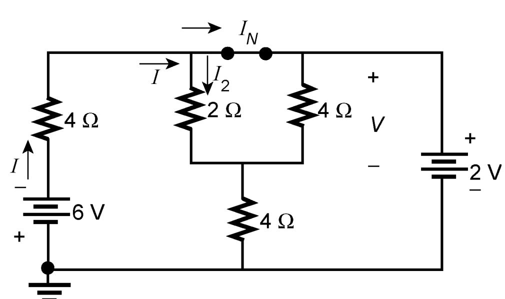
$I_N = I'_N + I''_N = 3\text{ A} + 2\text{ A} = \mathbf{5\text{ A}}$

b. R_N:



$$\leftarrow R_N = (2\ \Omega + 4\ \Omega \parallel 4\ \Omega) \parallel 4\ \Omega$$
$$= (2\ \Omega + 2\ \Omega) \parallel 4\ \Omega$$
$$= \frac{4\,\Omega}{2} = \mathbf{2\ \Omega}$$

I_N:



$$I = \frac{V_{4\Omega}}{4\,\Omega} = \frac{6\text{ V} - 2\text{ V}}{4\,\Omega} = \frac{4\text{ V}}{4\,\Omega}$$
$$= 1\text{ A}$$
$$V = \frac{(4\,\Omega \parallel 2\,\Omega)(2\text{ V})}{(4\,\Omega \parallel 2\,\Omega) + 4\,\Omega}$$
$$= 0.5\text{ V}$$
$$I_2 = \frac{V}{R} = \frac{0.5\text{ V}}{2\,\Omega} = 0.25\text{ A}$$

$I_N = I - I_2 = 1\text{ A} - 0.25\text{ A} = \mathbf{0.75\ A}$

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) $P_{\max} = E_{Th}^2 / 4R_{Th} = (9.28\text{ V})^2/4(9.76\ \Omega) = \mathbf{2.21\ W}$

(II): (b) $P_{\max} = E_{Th}^2 / 4R_{Th} = (60\text{ V})^2/4(2\ \Omega) = \mathbf{450\ W}$

25. (I): (a) $R = R_{Th} = \mathbf{10\ \Omega}$ (from problem 14)

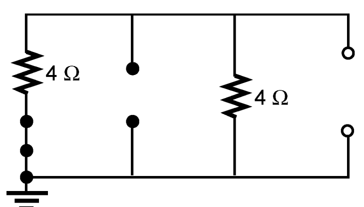
(II): (a) $R = R_{Th} = \mathbf{4.03\ k\Omega}$ (from problem 14)

(I): (b) $P_{\max} = E_{Th}^2 / 4R_{Th} = (2\text{ V})^2/4(10\ \Omega) = \mathbf{100\ mW}$

(II): (b) $P_{\max} = E_{Th}^2 / 4R_{Th} = (12\text{ V})^2/4(4.03\text{ k}\Omega) = \mathbf{8.93\ mW}$

26. $R_L = R_{Th} = \mathbf{4.04\ k\Omega}$ (from problem 15)
$E_{Th} = \mathbf{9.74\ V}$ (from problem 15)
$P_{\max} = E_{Th}^2 / 4R_{Th} = (9.74\text{ V})^2/4(4.04\text{ k}\Omega) = \mathbf{5.87\ mW}$

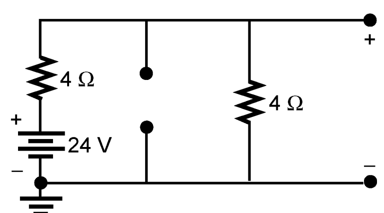
27. a.



$\leftarrow R = R_{Th} = 4\ \Omega \parallel 4\ \Omega = \mathbf{2\ \Omega}$

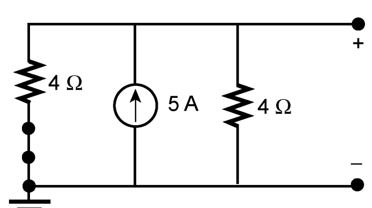
b. E_{Th}:

E:



$$E'_{Th} = \frac{24\text{ V}}{2} = 12\text{ V}$$

I:

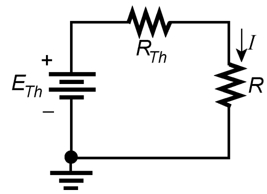


$E''_{Th} = IR_T = (5\text{ A})(4\ \Omega \parallel 4\ \Omega)$
$= (5\text{ A})(2\ \Omega) = 10\text{ V}$

$E_{Th} = E'_{Th} + E''_{Th} = 12\text{ V} + 10\text{ V} = \mathbf{22\ V}$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(22\text{ V})^2}{4(2\ \Omega)} = \mathbf{60.5\ W}$$

c.



$$P = I^2R = \left(\frac{E_{Th}}{R_{Th}+R}\right)^2 R$$

$R = \frac{1}{4}(2\,\Omega) = 0.5\,\Omega$, P = **38.72 W**

$R = \frac{1}{2}(2\,\Omega) = 1\,\Omega$, P = **53.78 W**

$R = \frac{3}{4}(2\,\Omega) = 1.5\,\Omega$, P = **59.27 W**

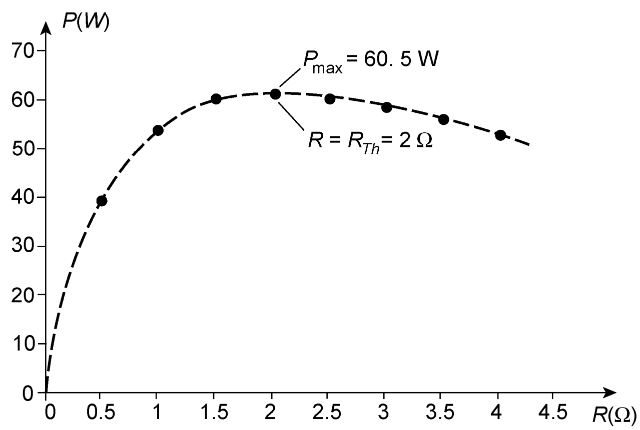
R **= 2 Ω**, P = **60.5 W**

$R = \frac{5}{4}(2\,\Omega) = 2.5\,\Omega$, P = **59.75 W**

$R = \frac{3}{2}(2\,\Omega) = 3\,\Omega$, P = **58 W**

$R = \frac{7}{4}(2\,\Omega) = 3.5\,\Omega$, P = **56 W**

$R = 2(2\,\Omega) = 4\,\Omega$, P = **53.78 W**

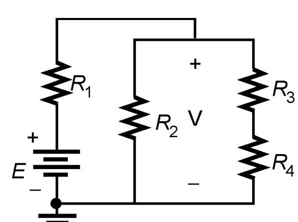


28. $$P_{\max} = \left(\frac{E_{Th}}{R_{Th}+R_4}\right)^2 R_4$$

with R_1 = **0 Ω** $\quad$ E_{Th} is a maximum and R_{Th} a minimum

$\therefore$ $P_{\max}$ a **maximum**

29. a.

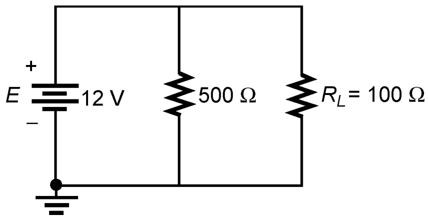


V, and therefore V_4, will be its largest value when R_2 is as large as possible. Therefore choose R_2 = open-circuit (∞ Ω).

Then $P_4 = \frac{V_4^2}{R_4}$ will be a maximum.

b. No, examine each individually.

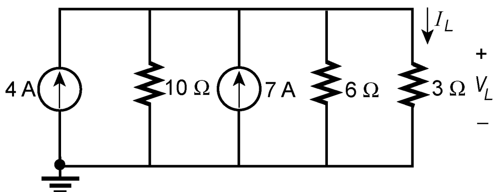
30.



Since R_L fixed, maximum power to R_L when V_{R_L} a maximum as defined by $P_L = \dfrac{V_{R_L}^2}{R_L}$

$$\therefore\ R = \mathbf{500\ \Omega} \text{ and } P_{\max} = \frac{(12\text{ V})^2}{100\,\Omega} = \mathbf{1.44\ W}$$

31.



$I_T\uparrow = 4\text{ A} + 7\text{ A} = 11\text{ A}$
$R_T = 10\ \Omega \parallel 6\ \Omega \parallel 3\ \Omega = 1.67\ \Omega$
$V_L = I_T R_T = (11\text{ A})(1.67\ \Omega) = \mathbf{18.37\ V}$
$$I_L = \frac{V_L}{R_L} = \frac{18.37\text{ V}}{3\,\Omega} = \mathbf{6.12\ A}$$

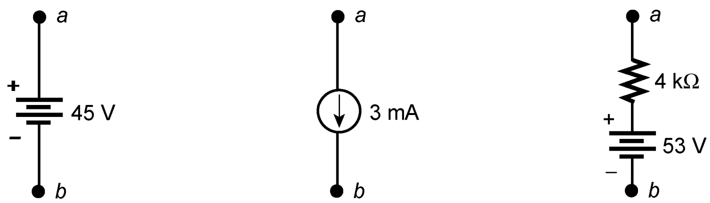
32. $$E_{eq} = \frac{-5\text{ V}/2.2\text{ k}\Omega + 20\text{ V}/8.2\text{ k}\Omega}{1/2.2\text{ k}\Omega + 1/8.2\text{ k}\Omega} = 0.2879\text{ V}$$
$$R_{eq} = \frac{1}{1/2.2\text{ k}\Omega + 1/8.2\text{ k}\Omega} = 1.7346\text{ k}\Omega$$
$$I_L = \frac{E_{eq}}{R_{eq} + R_L} = \frac{0.2879\text{ V}}{1.7346\text{ k}\Omega + 5.6\text{ k}\Omega} = \mathbf{39.3\ \mu A}$$
$V_L = I_L R_L = (39.3\ \mu\text{A})(5.6\text{ k}\Omega) = \mathbf{220\ mV}$

33. $I_T\downarrow = 5\text{ A} - 0.4\text{ A} - 0.2\text{ A} = 4.40\text{ A}$
$R_T = 200\ \Omega \parallel 80\ \Omega \parallel 50\ \Omega \parallel 50\ \Omega = 17.39\ \Omega$
$V_L = I_T R_T = (4.40\text{ A})(17.39\ \Omega) = \mathbf{75.52\ V}$
$$I_L = \frac{V_L}{R_L} = \frac{76.52\text{ V}}{200\ \Omega} = \mathbf{0.38\ A}$$

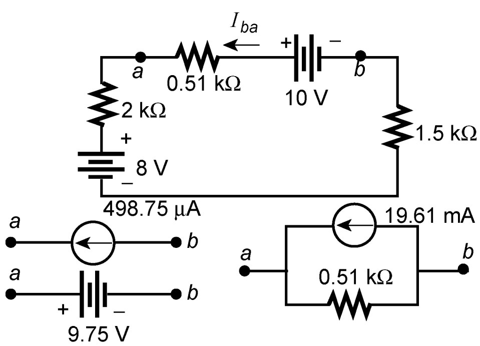
34. $$I_{eq} = \frac{(4\text{ A})(4.7\,\Omega) + (1.6\text{ A})(3.3\,\Omega)}{4.7\,\Omega + 3.3\,\Omega} = \frac{18.8\text{ V} + 5.28\text{ V}}{8\ \Omega} = 3.01\text{ A}$$
$R_{eq} = 4.7\ \Omega + 3.3\ \Omega = 8\ \Omega$
$$I_L = \frac{R_{eq}(I_{eq})}{R_{eq} + R_L} = \frac{8\,\Omega(3.01\text{ A})}{8\,\Omega + 2.7\,\Omega} = \mathbf{2.25\ A}$$
$V_L = I_L R_L = (2.25\text{ A})(2.7\ \Omega) = \mathbf{6.08\ V}$

35.
$$\overleftarrow{I}_{eq} = \frac{(4\text{ mA})(8.2\text{ k}\Omega)+(8\text{ mA})(4.7\text{ k}\Omega)-(10\text{ mA})(2\text{ k}\Omega)}{8.2\text{ k}\Omega+4.7\text{ k}\Omega+2\text{ k}\Omega}$$
$$= \frac{32.8\text{ V} + 37.6\text{ V} - 20\text{ V}}{14.9\text{ k}\Omega} = 3.38\text{ mA}$$
$$R_{eq} = 8.2\text{ k}\Omega + 4.7\text{ k}\Omega + 2\text{ k}\Omega = 14.9\text{ k}\Omega$$
$$I_L = \frac{R_{eq}I_{eq}}{R_{eq}+R_L} = \frac{(14.9\text{ k}\Omega)(3.38\text{ mA})}{14.9\text{ k}\Omega+6.8\text{ k}\Omega} = \mathbf{2.32\text{ mA}}$$
$$V_L = I_L R_L = (2.32\text{ mA})(6.8\text{ k}\Omega) = \mathbf{15.78\text{ V}}$$

36. $15\text{ k}\Omega \parallel (8\text{ k}\Omega + 7\text{ k}\Omega) = 15\text{ k}\Omega \parallel 15\text{ k}\Omega = 7.5\text{ k}\Omega$
$$V_{ab} = \frac{7.5\text{ k}\Omega(60\text{ V})}{7.5\text{ k}\Omega+2.5\text{ k}\Omega} = 45\text{ V}$$
$$I_{ab} = \frac{45\text{ V}}{15\text{ k}\Omega} = 3\text{ mA}$$

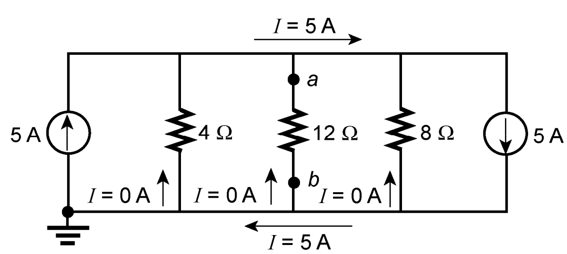


37.



$$I_{ba} = \frac{10\text{ V} - 8\text{ V}}{2\text{ k}\Omega+0.51\text{ k}\Omega+1.5\text{ k}\Omega}$$
$$= \mathbf{498.75\ \mu A}$$
$$V_{0.51\text{k}\Omega} = (498.75\ \mu\text{A})(0.51\text{ k}\Omega)$$
$$= 0.25\text{ V}$$
$$\underset{+-}{V_{ab}} = 10\text{ V} - 0.25\text{ V} = 9.75\text{ V}$$

38.



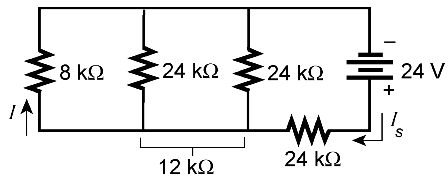
$\therefore R_2$ = short-circuit, open-circuit, any value

$V_{ab} = 0$ V (short)
$I_{ab} = 0$ A (open)

R_2 any resistive value

39. a. $I_s = \dfrac{24\text{ V}}{8\text{ k}\Omega + \dfrac{24\text{ k}\Omega}{3}} = 1.5\text{ mA},\ I = \dfrac{I_s}{3} = \mathbf{0.5\ mA}$

b.

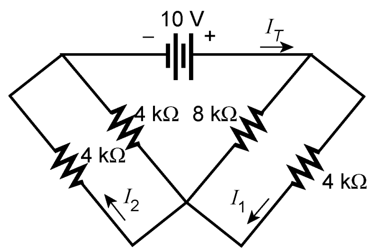


$$I_s = \frac{24\text{ V}}{24\text{ k}\Omega + 8\text{ k}\Omega \,\|\, 12\text{ k}\Omega} = 0.83\text{ mA}$$

$$I = \frac{12\text{ k}\Omega(I_s)}{12\text{ k}\Omega + 8\text{ k}\Omega} = \mathbf{0.5\ mA}$$

c. yes

40. (a)

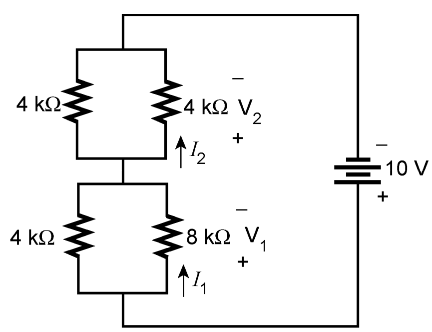


$$I_T = \frac{10\text{ V}}{4\text{ k}\Omega \,\|\, 8\text{ k}\Omega + 4\text{ k}\Omega \,\|\, 4\text{ k}\Omega} = \frac{10\text{ V}}{2.67\text{ k}\Omega + 2\text{ k}\Omega} = \frac{10\text{ V}}{4.67\text{ k}\Omega} = 2.14\text{ mA}$$

$I_1 = \dfrac{8\,\Omega(I_T)}{8\,\Omega + 4\,\Omega} = 1.43\text{ mA},\ I_2 = I_T/2 = 1.07\text{ mA}$

$I = I_1 - I_2 = 1.43\text{ mA} - 1.07\text{ mA} = \mathbf{0.36\ mA}$

(b)



$$V_1 = \frac{(8\text{ k}\Omega \,\|\, 4\text{ k}\Omega)(10\text{ V})}{8\text{ k}\Omega \,\|\, 4\text{ k}\Omega + 4\text{ k}\Omega \,\|\, 4\text{ k}\Omega} = 5.72\text{ V}$$

$I_1 = \dfrac{V_1}{8\text{ k}\Omega} = 0.71\text{ mA}$

$V_2 = E - V_1 = 10\text{ V} - 5.72\text{ V} = 4.28\text{ V}$

$I_2 = \dfrac{V_2}{4\text{ k}\Omega} = 1.07\text{ mA}$

$I = I_2 - I_1 = 1.07\text{ mA} - 0.71\text{ mA} = \mathbf{0.36\ mA}$

41. a. $I_{R_2} = \dfrac{R_1(I)}{R_1 + R_2 + R_3} = \dfrac{3\,\Omega(6\text{ A})}{3\,\Omega + 2\,\Omega + 4\,\Omega} = 2\text{ A}$

$V = I_{R_2}R_2 = (2\text{ A})(2\,\Omega) = \mathbf{4\ V}$

b. $I_{R_1} = \dfrac{R_2(I)}{R_1 + R_2 + R_3} = \dfrac{2\,\Omega(6\text{ A})}{3\,\Omega + 2\,\Omega + 4\,\Omega} = 1.33\text{ A}$

$V = I_{R_1}R_1 = (1.33\text{ A})(3\,\Omega) = \mathbf{4\ V}$

Chapter 10

1. (a) $\mathscr{E} = k\dfrac{Q_1}{r^2} = \dfrac{(9\times10^9)(4\ \mu\text{C})}{(2\text{ m})^2}$ = **9 × 10³ N/C**

   (b) $\mathscr{E} = k\dfrac{Q_1}{r^2} = \dfrac{(9\times10^9)(4\ \mu\text{C})}{(1\text{ mm})^2}$ = **36 × 10⁹ N/C**

   $\mathscr{E}(1\text{ mm}) : \mathscr{E}(2\text{ m}) = 4\times10^6 : 1$

2. $\mathscr{E} = \dfrac{kQ}{r^2} \Rightarrow r = \sqrt{\dfrac{kQ}{\mathscr{E}}} = \sqrt{\dfrac{(9\times10^9)(2\ \mu\text{C})}{72\text{ N/C}}}$ = **15.81 m**

3. $C = \dfrac{Q}{V} = \dfrac{1200\ \mu\text{C}}{10\text{ V}}$ = **120 µF**

4. $Q = CV = (0.15\ \mu\text{F})(45\text{ V})$ = **6.75 µC**

5. $\mathscr{E} = \dfrac{V}{d} = \dfrac{100\text{ mV}}{2\text{ mm}}$ = **50 V/m**

6. $d = 10\ \cancel{\text{mils}}\left[\dfrac{10^{-3}\ \cancel{\text{in.}}}{1\ \cancel{\text{mil}}}\right]\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.254\text{ mm}$

   $\mathscr{E} = \dfrac{V}{d} = \dfrac{100\text{ mV}}{0.254\text{ mm}}$ = **393.70 V/m**

7. $V = \dfrac{Q}{C} = \dfrac{160\ \mu\text{C}}{4\ \mu\text{F}} = 40\text{ V}$

   $\mathscr{E} = \dfrac{V}{d} = \dfrac{40\text{ V}}{5\text{ mm}}$ = **8 × 10³ V/m**

8. $C = 8.85\times10^{-12}\varepsilon_r\dfrac{A}{d} = 8.85\times10^{-12}(1)\dfrac{(0.1\text{ m}^2)}{2\text{ mm}}$ = **442.50 pF**

9. $C = 8.85\times10^{-12}\ \varepsilon_r\dfrac{A}{d} = 8.85\times10^{-12}(2.5)\dfrac{(0.1\text{ m}^2)}{2\text{ mm}}$ = **1.11 nF**

10. $C = 8.85\times10^{-12}\varepsilon_r\dfrac{A}{d} \Rightarrow d = \dfrac{8.85\times10^{-12}(4)(0.15\text{ m}^2)}{2\ \mu\text{F}}$ = **2.66 µm**

11. $C = \varepsilon_r C_o \Rightarrow \varepsilon_r = \dfrac{C}{C_o} = \dfrac{6\text{ nF}}{1200\text{ pF}}$ = **5 (mica)**

12. a. $C = 8.85 \times 10^{-12}(1)\dfrac{(0.08\text{ m}^2)}{0.2\text{ mm}} = \mathbf{3.54\ nF}$

b. $\mathscr{E} = \dfrac{V}{d} = \dfrac{200\text{ V}}{0.2\text{ mm}} = \mathbf{10^6\ V/m}$

c. $Q = CV = (3.54\text{ nF})(200\text{ V}) = \mathbf{0.71\ \mu C}$

13. a. $\mathscr{E} = \dfrac{V}{d} = \dfrac{200\text{ V}}{0.2\text{ mm}} = \mathbf{10^6\ V/m}$

b. $Q = \varepsilon \mathscr{E} A = \varepsilon_r \varepsilon_o \mathscr{E} A = (7)(8.85 \times 10^{-12})(10^6\text{ V/m})(0.08\text{ m}^2) = \mathbf{4.96\ \mu C}$

c. $C = \dfrac{Q}{V} = \dfrac{4.96\ \mu\text{C}}{200\text{ V}} = \mathbf{24.80\ nF}$

14. a. $C = \dfrac{1}{2}(5\ \mu\text{F}) = \mathbf{2.5\ \mu F}$

b. $C = 2(5\ \mu\text{F}) = \mathbf{10\ \mu F}$

c. $C = 20(5\ \mu\text{F}) = \mathbf{100\ \mu F}$

d. $C = \dfrac{(4)\left(\frac{1}{3}\right)}{\left(\frac{1}{4}\right)}(5\ \mu\text{F}) = \mathbf{26.67\ \mu F}$

15. $d = \dfrac{8.85 \times 10^{-12}\varepsilon_r A}{C} = \dfrac{(8.85 \times 10^{-12})(5)(0.02\text{ m}^2)}{0.006\ \mu\text{F}} = 0.1475\text{ mm} = 147.5\ \mu\text{m}$

$d = 0.1475\ \cancel{\text{mm}}\left[\dfrac{10^{-3}\ \cancel{\text{m}}}{1\ \cancel{\text{mm}}}\right]\left[\dfrac{39.37\ \cancel{\text{in.}}}{1\ \cancel{\text{m}}}\right]\left[\dfrac{1000\text{ mils}}{1\ \cancel{\text{in.}}}\right] = 5.807\text{ mils}$

$5.807\ \cancel{\text{mils}}\left[\dfrac{5000\text{ V}}{\cancel{\text{mil}}}\right] = \mathbf{29.04\ kV}$

16. mica: $\dfrac{1200\text{ V}}{\dfrac{5000\text{ V}}{\cancel{\text{mil}}}} = 1200\text{ V}\left[\dfrac{\cancel{\text{mil}}}{5000\text{ V}}\right] = 0.24\text{ mils}$

$0.24\text{ mils}\left[\dfrac{\cancel{1''}}{1000\text{ mils}}\right]\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = \mathbf{6.10\ \mu m}$

17. $\dfrac{200}{1 \times 10^6}(22\ \mu\text{F})/°\text{C} = 4400\text{ pF}/°\text{C}$

$\dfrac{4400\text{ pF}}{°\text{C}}[\Delta\text{T}] = \dfrac{4400\text{ pF}}{°\text{C}}[80°\text{C}] = \mathbf{0.35\ \mu F}$

18. J = ±5%, Size ⇒ 40 pF ± 2 pF, **38 pF → 42 pF**

19. M = ±20%, Size ⇒ 220 μF ± 44 μF, **176 μF → 264 μF**

20. K = ±10%, Size ⇒ 33,000 pF ± 3300 pF, **29,700 pF → 36,300 pF**

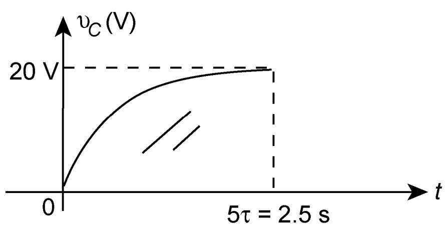
21. a. $\tau = RC = (10^5\ \Omega)(5.1\ \mu\text{F}) = \mathbf{0.51\ s}$

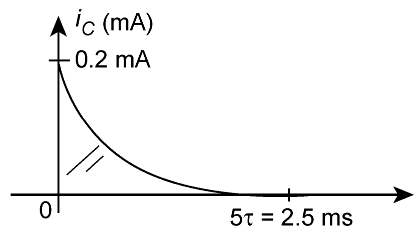
b. $\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{20\ V(1 - e^{-t/0.51\ s})}$

c. $1\tau = 0.632(20\text{ V}) = \mathbf{12.64\ V}$, $3\tau = 0.95(20\text{ V}) = \mathbf{19\ V}$
$5\tau = 0.993(20\text{ V}) = \mathbf{19.87\ V}$

d. $i_C = \dfrac{20\text{ V}}{100\text{ k}\Omega} e^{-t/\tau} = \mathbf{0.2\ mA}\boldsymbol{e^{-t/0.51\ s}}$
$\upsilon_R = Ee^{-t/\tau} = \mathbf{20\ V}\boldsymbol{e^{-t/0.51\ s}}$

e.





22. a. $\tau = RC = (10^6\ \Omega)(5.1\ \mu\text{F}) = \mathbf{5.1\ s}$

b. $\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{20\ V(1 - e^{-t/5.1s})}$

c. $1\tau = \mathbf{12.64\ V}$, $3\tau = \mathbf{19\ V}$, $5\tau = \mathbf{19.87\ V}$

d. $i_C = \dfrac{20\text{ V}}{1\text{ M}\Omega} e^{-t/\tau} = \mathbf{20\ \mu A}\ \boldsymbol{e^{-t/5.1s}}$
$\upsilon_R = Ee^{-t/\tau} = \mathbf{20V}\ \boldsymbol{e^{-t/5.1s}}$

e. Same as problem 21 with $5\tau = 25$ s and $I_m = 20\ \mu$A

23. a. $\tau = RC = (2.2\text{ k}\Omega + 3.3\text{ k}\Omega)1\ \mu\text{F} = (5.5\text{ k}\Omega)(1\ \mu\text{F}) = \mathbf{5.5\ ms}$

b. $\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{100\ V(1 - e^{-t/5.5\ ms})}$

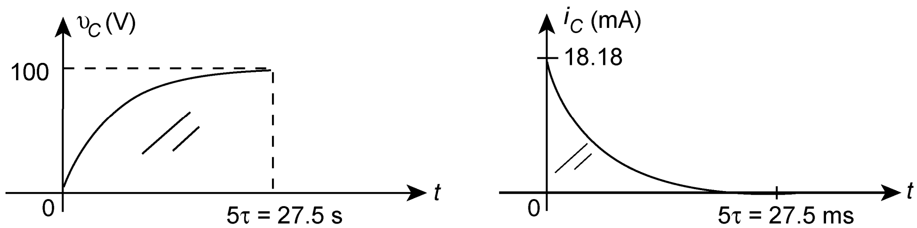
c. $1\tau = \mathbf{63.21\ V}$, $3\tau = \mathbf{95.02\ V}$, $5\tau = \mathbf{99.33\ V}$

d. $i_C = \dfrac{E}{R_T} e^{-t/\tau} = \dfrac{100\text{ V}}{5.5\text{ k}\Omega} e^{-t/\tau} = \mathbf{18.18\ mA}\boldsymbol{e^{-t/5.5\ ms}}$

$$V_{R_2} = \frac{3.3\text{ k}\Omega(100\text{ V})}{3.3\text{ k}\Omega + 2.2\text{ k}\Omega} = 60\text{ V}$$

$\upsilon_R = \upsilon_{R_2} = \mathbf{60\ V}\boldsymbol{e^{-t/5.5\ ms}}$

e.

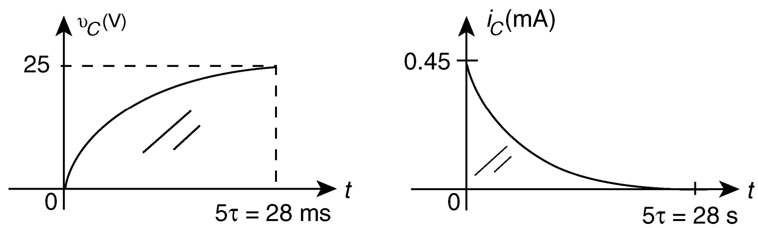


24. a. $\tau = RC = (56\text{ k}\Omega)(0.1\ \mu\text{F}) = \mathbf{5.6\ ms}$

b. $\upsilon_C = E(1 - e^{-t/\tau}) = 25\text{ V}(1 - e^{-t/5.6\text{ms}})$

c. $i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{25\text{ V}}{56\text{ k}\Omega}e^{-t/\tau} = \mathbf{0.45\ mA}\boldsymbol{e^{-t/5.6\text{ms}}}$

d.



25. a. **5 ms**

b. $\upsilon_C = 60\text{ mV}(1 - e^{-2\text{ms}/5\text{ms}}) = 60\text{ mV}(1 - e^{-0.4}) = 60\text{ mV}(1 - 0.670)$
$= 60\text{ mV}(0.330) = \mathbf{19.8\ mV}$

c. $\upsilon_C = 60\text{ mV}(1 - e^{-100\text{ms}/5\text{ms}}) = 60\text{ mV}(1 - e^{-20}) = 60\text{ mV}(1 - 2.06 \times 10^{-9})$
$\cong 60\text{ mV}(1) = \mathbf{60\ mV}$

26. a. $\tau = 40\text{ ms},\ 5\tau = 5(40\text{ ms}) = \mathbf{200\ ms}$

b. $\tau = RC,\ R = \dfrac{\tau}{C} = \dfrac{40\text{ ms}}{10\ \mu\text{F}} = \mathbf{4\ k\Omega}$

c. $\upsilon_C\,(20\text{ ms}) = 12\text{ V}(1 - e^{-20\text{ ms}/40\text{ms}}) = 12\text{ V}(1 - e^{-0.5})$
$= 12\text{ V}(1 - 0.607) = 12\text{ V}(0.393) = \mathbf{4.72\ V}$

d. $\upsilon_C = 12\text{ V}(1 - e^{-10}) = 12\text{ V}(1 - 45 \times 10^{-6}) \cong \mathbf{12.0\ V}$

e. $Q = CV = (10\ \mu\text{F})(12\text{ V}) = \mathbf{120\ \mu C}$

f. $\tau = RC = (1000 \times 10^6\ \Omega)(10\ \mu\text{F}) = 10 \times 10^3\text{ s}$

$$5\tau = 50 \times 10^3\ \cancel{\text{s}}\left[\frac{1\ \cancel{\text{min}}}{60\ \cancel{\text{s}}}\right]\left[\frac{1\text{ h}}{60\ \cancel{\text{min}}}\right] = \mathbf{13.89\ h}$$

27. a. $\tau = RC = (2\text{ k}\Omega)(100\ \mu\text{F}) = \mathbf{200\ ms}$

b. $\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{8\ V(1 - e^{-t/200ms})}$

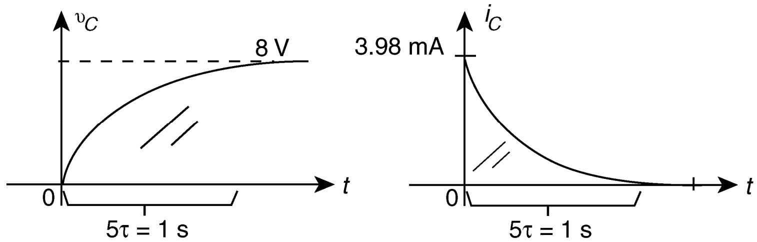
$i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{8\text{ V}}{2\text{ k}\Omega}e^{-t/200\text{ms}} = \mathbf{4\ mA}\boldsymbol{e^{-t/200\text{ms}}}$

c. $\upsilon_C(1\text{ s}) = 8\text{ V}(1 - e^{-1\text{s}/200\text{ms}}) = 8\text{ V}(1 - e^{-5})$
$= 8\text{ V}(1 - 6.738 \times 10^{-3}) = 8\text{ V}(0.9933) = \mathbf{7.95\ V}$
$i_C\,(1\text{ s}) = 4\text{ mA}e^{-5} = 4\text{ mA}(6.738 \times 10^{-3}) = \mathbf{26.95\ \mu A}$

d. $\upsilon_C = \mathbf{7.95\ V}\boldsymbol{e}^{-t/200\text{ms}}$

$i_C = \dfrac{7.95\text{ V}}{2\text{ k}\Omega}e^{-t/200\text{ms}} = \mathbf{3.98\ mA}\boldsymbol{e}^{\boldsymbol{-t/200}\textbf{ms}}$

e.



28. a. $\tau = RC = (3\text{ k}\Omega + 2\text{ k}\Omega)(2\ \mu\text{F}) = 10\text{ ms}$

$\upsilon_C = \mathbf{50\ V(1 -} \boldsymbol{e}^{\boldsymbol{-t/10}\textbf{ms}}\mathbf{)}$

$i_C = \dfrac{50\text{ V}}{5\text{ k}\Omega}e^{-t/10\text{ms}} = \mathbf{10\ mA}^{\boldsymbol{-t/10}\textbf{ms}}$

$\upsilon_{R_1} = i_C \cdot R_1 = (10\text{ mA})(3\text{ k}\Omega)e^{-t/10\text{ms}} = \mathbf{30\ V}\boldsymbol{e}^{\boldsymbol{-t/10}\textbf{ms}}$

b. 100ms: $e^{-10} = 45.4 \times 10^{-6}$

$\upsilon_C = 50\text{ V}(1 - 45.4 \times 10^{-6}) = \mathbf{50\ V}$

$i_C = 10\text{ mA}(45.4 \times 10^{-6}) = \mathbf{0.45\ \mu A}$

$\upsilon_{R_1} = 30\text{ V}(45.4 \times 10^{-6}) = \mathbf{1.36\ mV}$

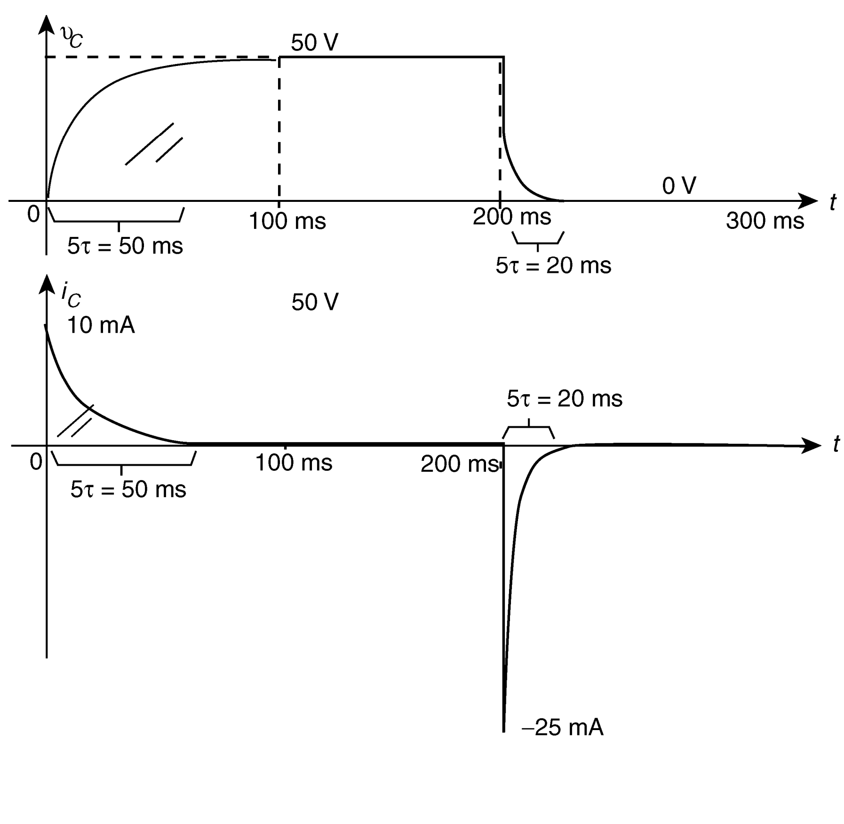
c. 200 ms: $\tau' = R_2C = (2\text{ k}\Omega)(2\ \mu\text{F}) = 4\text{ ms}$

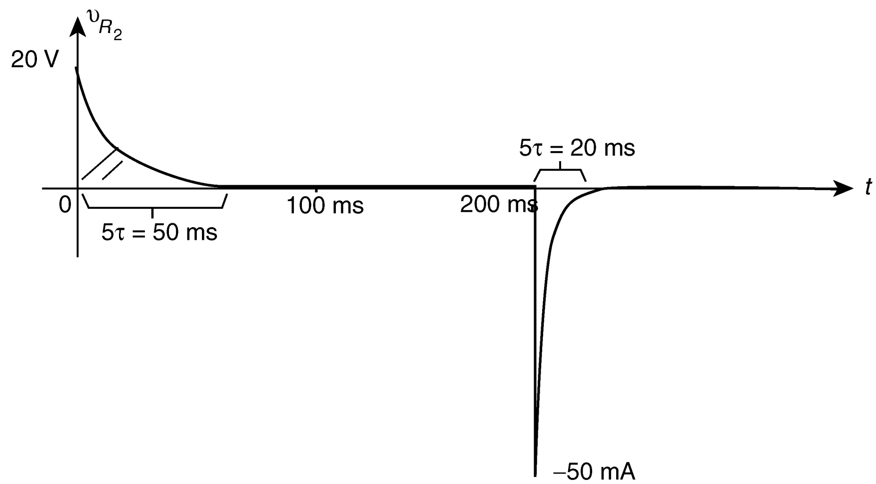
$\upsilon_C = \mathbf{50\ V}\boldsymbol{e}^{\boldsymbol{-t/4}\textbf{ms}}$

$i_C = -\dfrac{50\text{ V}}{2\text{ k}\Omega}e^{-t/4\text{ms}} = \mathbf{-25\ mA}\boldsymbol{e}^{\boldsymbol{-t/4}\textbf{ms}}$

$\upsilon_{R_2} = \upsilon_C = \mathbf{-50\ V}\boldsymbol{e}^{-t/4\text{ms}}$

d.





29. a. $\tau = RC = (5\ \text{k}\Omega)(20\ \mu\text{F}) = 100$ ms

$v_C = \mathbf{50\ V(1 - e^{-t/100ms})}$

$i_C = \dfrac{50\ \text{V}}{5\ \text{k}\Omega}e^{-t/100\text{ms}} = \mathbf{10\ mAe^{-t/100ms}}$

$v_{R_1} = i_C \cdot R_1 = (10\ \text{mA})(3\ \text{k}\Omega)\ e^{-t/100\text{ms}} = \mathbf{30\ Ve^{-t/100ms}}$

b. 100 ms: $e^{-1} = 0.368$

$v_C = 50\ \text{V}(1 - 0.368) = 50\ \text{V}(0.632) = \mathbf{31.6\ V}$

$i_C = 10\ \text{mA}(0.368) = \mathbf{3.68\ mA}$

$v_{R_1} = 30\ \text{V}(0.368) = \mathbf{11.04\ V}$

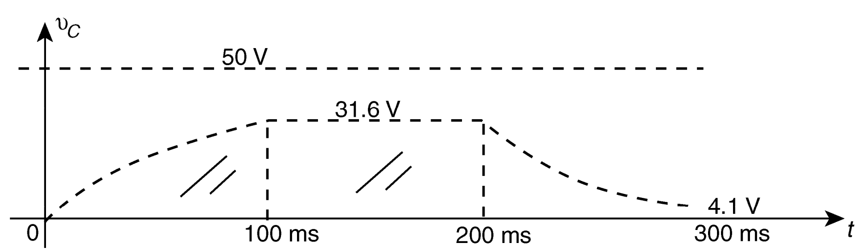
c. 200 ms: $\tau' = R_2C = (2\ \text{k}\Omega)(20\ \mu\text{F}) = 40$ ms

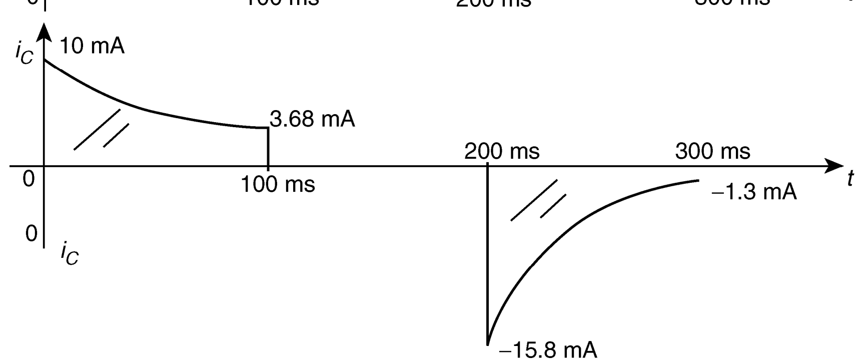
$v_C = \mathbf{31.6\ Ve^{-t/40ms}}$

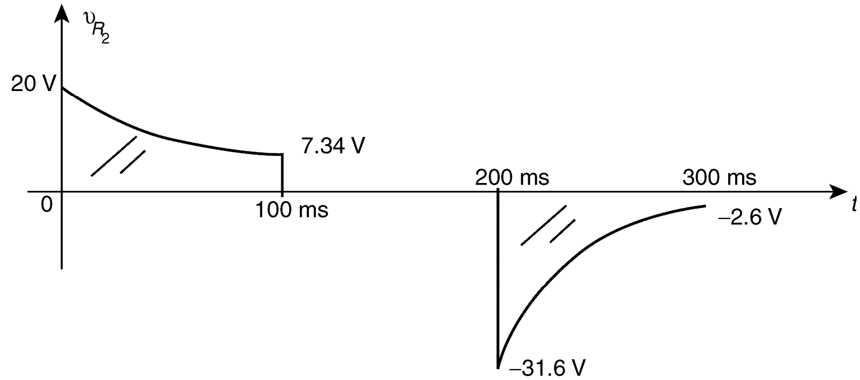
$i_C = -\dfrac{31.6\ \text{V}}{2\ \text{k}\Omega}e^{-t/40\text{ms}} = \mathbf{-15.8\ mAe^{-t/40ms}}$

$v_{R_2} = -v_C = \mathbf{-31.6\ Ve^{-t/40ms}}$

d.







30. a. $\tau = R_1C = (10^5\ \Omega)(10\ \text{pF}) = 1\ \mu\text{s}$

$$\boldsymbol{\upsilon_C = 80\ \text{V}\left(1 - e^{-t/1\mu s}\right)}$$

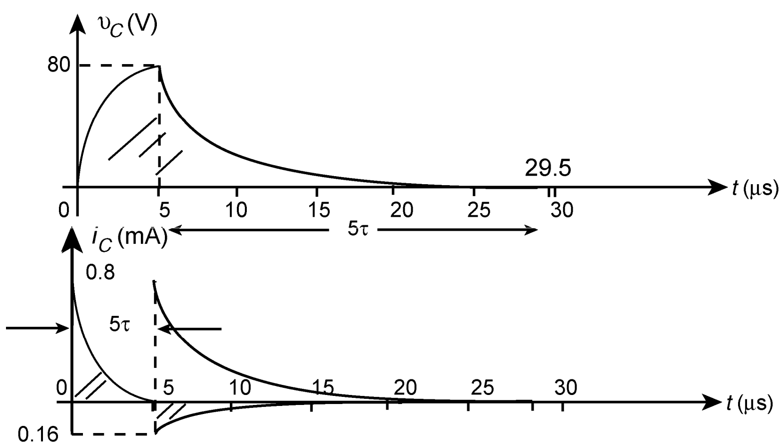
$$i_C = \frac{80\ \text{V}}{100\ \text{k}\Omega}e^{-t/\tau} = \mathbf{0.8\ mA}\boldsymbol{e^{-t/1\mu s}}$$

b. $\tau' = R'C = (490\ \text{k}\Omega)(10\ \text{pF}) = 4.9\ \mu\text{s}$

$$\upsilon_C = 80\ \text{V}e^{-t/\tau'} = \mathbf{80\ V}\boldsymbol{e^{-t/4.9\times 10^{-6}}}$$

$$i_C = \frac{80\ \text{V}}{490\ \text{k}\Omega}e^{-t/\tau'} = \mathbf{0.16\ mA}\boldsymbol{e^{-t/4.9\times 10^{-6}}}$$

c.



31. a. $\tau = RC = (2\ \text{m}\Omega)(1000\ \mu\text{F}) = 2\ \mu\text{s}$

$$5\tau = \mathbf{10\ \mu s}$$

b. $I_m = \dfrac{V}{R} = \dfrac{6\ \text{V}}{2\ \text{m}\Omega} = \mathbf{3\ kA}$

c. yes

32. a. $\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$\tau = RC = (10\text{ k}\Omega)(2\ \mu\text{F}) = 20\text{ ms},\ \ V_f = 50\text{ V},\ \ V_i = -10\text{ V}$

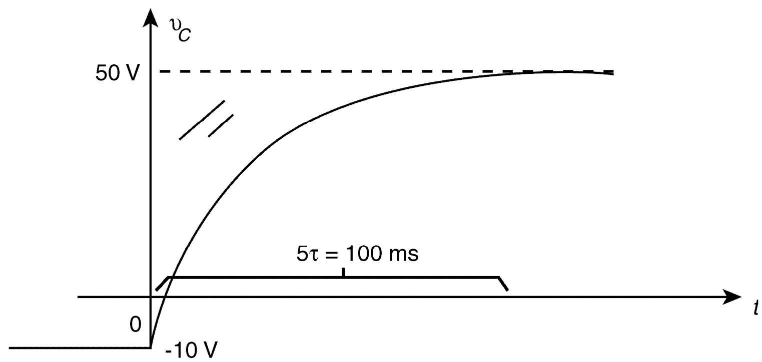
$\upsilon_C = 50\text{ V} + (-10\text{ V} - (+50\text{ V}))e^{-t/20\text{ms}}$

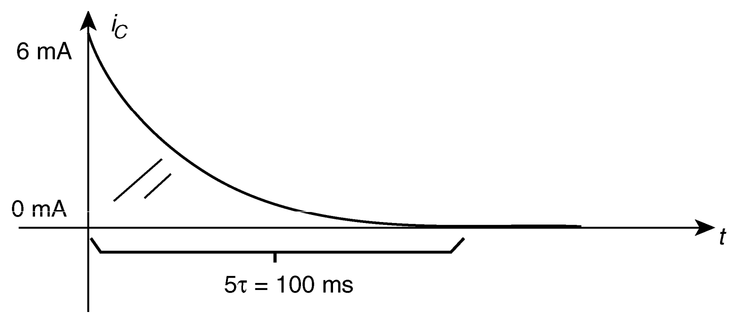
$\upsilon_C = \mathbf{50\ V - 60\ V}\boldsymbol{e^{-t/20\text{ms}}}$

b. Initially $V_R = E + \upsilon_C = 50\text{ V} + 10\text{ V} = 60\text{ V}$

$$i_C = \frac{V_R}{R}e^{-t/\tau} = \frac{60\text{ V}}{10\text{ k}\Omega}e^{-t/20\text{ms}} = \mathbf{6\ mA}\ \boldsymbol{e^{-t/20\text{ms}}}$$

c.





33. $\tau = RC = (2.2\text{ k}\Omega)(2000\ \mu\text{F}) = 4.4\text{ s}$

$\upsilon_C = V_C e^{-t/\tau} = \mathbf{40\ V}\boldsymbol{e^{-t/4.4\text{ s}}}$

$$I_C = \frac{V_C}{R}e^{-t/\tau} = \frac{40\text{ V}}{2.2\text{ k}\Omega}e^{-t/4.4\text{ s}} = \mathbf{18.18\ mA}\boldsymbol{e^{-t/4.4\text{ s}}}$$

$\upsilon_R = \upsilon_C = \mathbf{40\ V}\boldsymbol{e^{-t/4.4\text{s}}}$

34. $\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

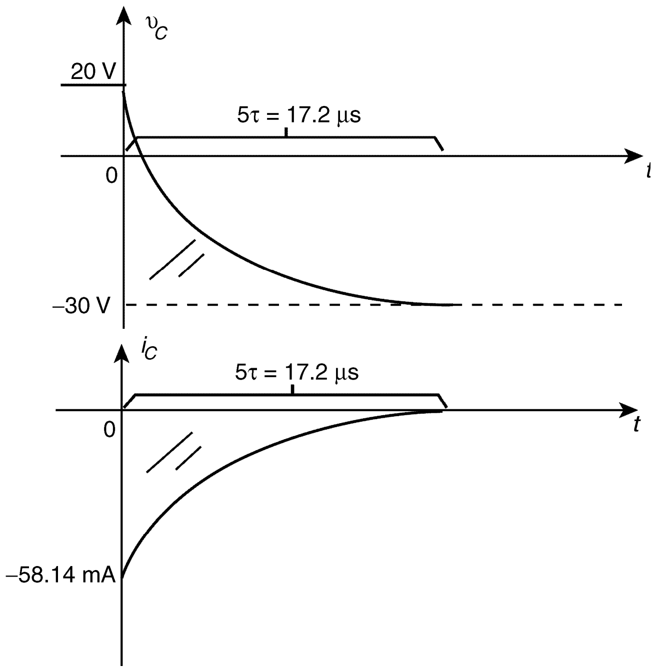
$\tau = RC = (860\ \Omega)(4000\text{ pF}) = 3.44\ \mu\text{s},\ \ V_f = -30\text{ V},\ \ V_i = 20\text{ V}$

$\upsilon_C = -30\text{ V} + (20\text{ V} - (-30\text{ V}))e^{-t/3.44\mu\text{s}}$

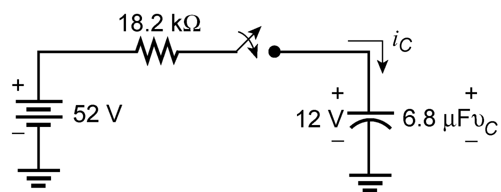
$\upsilon_C = \mathbf{-30\ V + 50\ V}\boldsymbol{e^{-t/3.44\mu\text{s}}}$

$$I_m = \frac{20\text{ V} + 30\text{ V}}{860\ \Omega} = 58.14\text{ mA}$$

$i_C = \mathbf{-58.14\ mA}\boldsymbol{e^{-t/3.44\mu\text{s}}}$



35. a.



$\tau = RC = (18.2\text{ k}\Omega)(6.8\ \mu\text{F}) = 123.8\text{ ms}$

$\upsilon_C = V_f + (V_i - V_f)\, e^{-t/\tau}$

$= 52\text{ V} + (12\text{ V} - 52\text{ V})e^{-t/123.8\text{ ms}}$

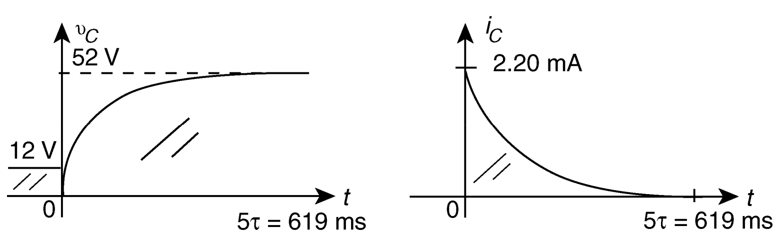
$\upsilon_C = \mathbf{52\ V - 40\ V}\boldsymbol{e^{-t/123.8\text{ ms}}}$

$\upsilon_R(0+) = 52\text{ V} - 12\text{ V} = 40\text{ V}$

$i_C = \dfrac{40\text{ V}}{18.2\text{ k}\Omega}\, e^{-t/123.8\text{ ms}}$

$= \mathbf{2.20\ mA}\boldsymbol{e^{-t/123.8\text{ ms}}}$

b.



36. a. $\upsilon_C = 12\text{ V}(1 - e^{-10\mu\text{s}/20\ \mu\text{s}}) = 12\text{ V}(1 - e^{-0.5}) = 12\text{ V}(1 - 0.607)$

$= 12\text{ V}(0.393) = \mathbf{4.72\ V}$

b. $\upsilon_C = 12\text{ V}(1 - e^{-10\,\tau/\tau}) = 12\text{ V}(1 - e^{-10}) = 12\text{ V}(1 - 45.4 \times 10^{-6})$

$\cong \mathbf{12\ V}$

c. $6\text{ V} = 12\text{ V}(1 - e^{-t/20\ \mu\text{s}})$

$0.5 = 1 - e^{-t/20\ \mu\text{s}}$

$-0.5 = -e^{-t/20\ \mu\text{s}}$

$0.5 = e^{-t/20\ \mu\text{s}}$

$\log_e 0.5 = \log_e e^{-t/20\ \mu\text{s}}$

$-0.693 = -t/20\ \mu\text{s}$

$t = 0.693\ (20\ \mu\text{s}) = \mathbf{13.86\ \mu s}$

d. $\upsilon_C = 11.98\text{ V} = 12\text{ V}(1 - e^{t/20\ \mu\text{s}})$
$0.998 = 1 - e^{-t/20\ \mu\text{s}}$
$-0.002 = -e^{-t/20\ \mu\text{s}}$
$0.002 = -e^{-t/20\ \mu\text{s}}$
$\log_e 0.002 = -t/20\ \mu\text{s}$
$-6.215 = -t/20\ \mu\text{s}$
$t = (6.215)(20\ \mu\text{s}) = \mathbf{124.3\ \mu s}$

37. $\tau = RC = (33\text{ k}\Omega)(20\ \mu\text{F}) = 0.66\text{ s}$
$\upsilon_C = 12\text{ V}(1 - e^{-t/0.66\text{ s}})$
$8\text{ V} = 12\text{ V}(1 - e^{-t/0.66\text{ s}})$
$8\text{ V} = 12\text{ V} - 12\text{ V}e^{-t/0.66\text{ s}}$
$-4\text{ V} = -12\text{ V}e^{-t/0.66\text{ s}}$
$0.333 = e^{-t/0.66\text{ s}}$
$\log_e 0.333 = -t/0.66\text{ s}$
$-1.0996 = -t/0.66\text{ s}$
$t = 1.0996(0.66\text{ s}) = \mathbf{0.73\ s}$

38. $$t = -\tau \log_e\left(1 - \frac{\upsilon_C}{E}\right)$$

$$10\text{ s} = -\tau \underbrace{\log_e\left(\underbrace{1 - \frac{12\text{ V}}{20\text{ V}}}_{.4}\right)}_{-916.29 \times 10^{-3}}$$

$$\tau = \frac{10\text{ s}}{0.916} = 10.92\text{ s}$$

$$\tau = RC \Rightarrow R = \frac{\tau}{C} = \frac{10.92\text{ s}}{200\ \mu\text{F}} = \mathbf{54.60\ k\Omega}$$

39. a. $\tau = (R_1 + R_2)C = (20\text{ k}\Omega)(6\ \mu\text{F}) = 0.12\text{ s}$
$\upsilon_C = E(1 - e^{-t/\tau})$
$60\text{ V} = 80\text{ V}(1 - e^{-t/0.12\text{s}})$
$0.75 = 1 - e^{-t/0.12\text{s}}$
$0.25 = e^{-t/0.12\text{s}}$
$t = -(0.12\text{ s})(-1.39)$
$= \mathbf{166.80\ ms}$

b. $$i_C = \frac{E}{R}e^{-t/\tau}$$

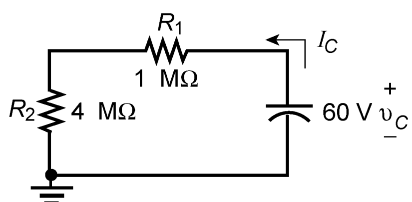
$$i_C = \frac{80\text{ V}}{20\text{ k}\Omega}e^{-\frac{166.80\text{ ms}}{0.12\text{s}}} = 4\text{ mA}e^{-1.39}$$
$= (4\text{ mA})(249.08 \times 10^{-3})$
$\cong \mathbf{1\ mA}$

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. $\tau = RC = (1\text{ M}\Omega)(0.2\ \mu\text{F}) = 0.2\text{ s}$
$\upsilon_C = \mathbf{60\text{ V}(1 - e^{-t/0.2s})}$
$i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{60\text{ V}}{1\text{ M}\Omega}e^{-t/0.2\text{s}} = \mathbf{60\ \mu\text{A}e^{-t/0.2s}}$
$\upsilon_{R_1} = Ee^{-t/\tau} = \mathbf{60\text{ V}e^{-t/0.2s}}$

υ_C: 0.5 s = **55.07 V**
1 s = **59.58 V**

i_C: 0.5 s = **4.93 V**
1 s = **0.40 V**

b. 

$\tau' = RC = (1\text{ M}\Omega + 4\text{ M}\Omega)(0.2\ \mu\text{F})$
$= (5\text{ M}\Omega)(0.2\ \mu\text{F})$
$= 1\text{ s}$
$i_C = \dfrac{60\text{ V}}{5\text{ M}\Omega}e^{-t} = \mathbf{12\ \mu\text{A}e^{-t}}$

$$\begin{aligned}8\ \mu\text{A} &= 12\ \mu\text{A}e^{-t}\\ 0.667 &= e^{-t}\\ \log_e 0.667 &= -t\\ -0.41 &= -t\\ t &= \mathbf{0.41\text{ s}}\end{aligned}$$

$$\begin{aligned}\upsilon_C &= 60\text{ V}e^{-t\tau'}\\ 10\text{ V} &= 60\text{ V}e^{-t}\\ 0.167 &= e^{-t}\\ \log_e 0.167 &= -t\\ -1.79 &= -t\\ t &= 1.79\text{ s}\end{aligned}$$

Longer = 1.79 s – 0.41 s = **1.38 s**

41. a. $\upsilon_m = \upsilon_R = Ee^{-t/\tau} = 60\text{ V}e^{-1\tau/\tau} = 60\text{ V}e^{-1}$
$= 60\text{ V}(0.3679)$
$= \mathbf{22.07\text{ V}}$

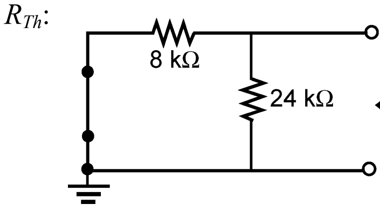
b. $i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{60\text{ V}}{10\text{ M}\Omega}e^{-2\tau/\tau} = 6\ \mu\text{A}e^{-2}$
$= 6\ \mu\text{A}(0.1353)$
$= \mathbf{0.81\ \mu A}$

c. $\upsilon_C = E(1 - e^{-t/\tau})$ $\qquad \tau = RC = (10\text{ M}\Omega)(0.2\ \mu\text{F}) = 2\text{ s}$

$$50\text{ V} = 60\text{ V}(1 - e^{-t/2\text{ s}})$$
$$0.8333 = 1 - e^{-t/2\text{ s}}$$
$$\log_e 0.1667 = -t/2\text{ s}$$
$$t = -(2\text{ s})(-1.792)$$
$$= \mathbf{3.58\text{ s}}$$

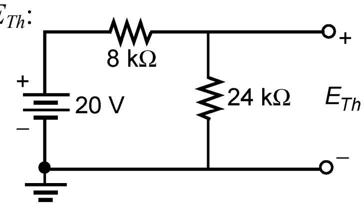
42. a. Thevenin's theorem:

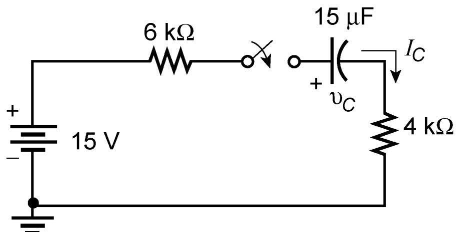
R_{Th}:



$\leftarrow R_{Th} = 8\text{ k}\Omega \parallel 24\text{ k}\Omega = 6\text{ k}\Omega$

E_{Th}:





$$E_{Th} = \frac{24\text{ k}\Omega(20\text{ V})}{24\text{ k}\Omega + 8\text{ k}\Omega} = 15\text{ V}$$

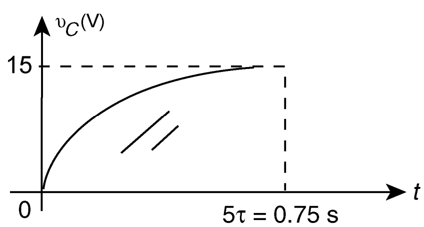
$\tau = RC = (10\text{ k}\Omega)(15\ \mu\text{F}) = 0.15\text{ s}$

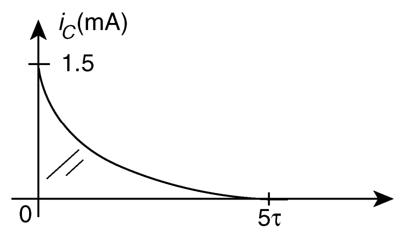
$\upsilon_C = E(1 - e^{-t/\tau})$

$= \mathbf{15\text{ V}(1 - e^{-t/0.15\text{ s}})}$

$$i_C = \frac{E}{R}e^{-t/\tau} = \frac{15\text{ V}}{10\text{ k}\Omega}e^{-t/0.15} = \mathbf{1.5\text{ mA}e^{-t/0.15\text{ s}}}$$

b.





43. a. Source conversion and combining series resistors:

$\tau = RC = (8.3\text{ k}\Omega)(2.2\ \mu\text{F}) = 18.26\text{ ms}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 27.2\text{ V} + (2\text{ V} - 27.2\text{ V})e^{-t/18.26\text{ ms}}$

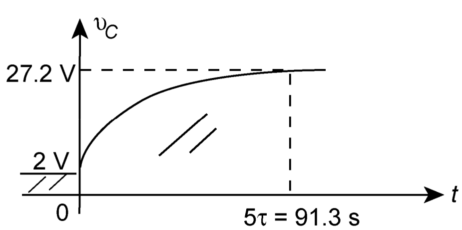
$\upsilon_C = \mathbf{27.2\text{ V} - 25.2\text{ V}e^{-t/18.26\text{ ms}}}$

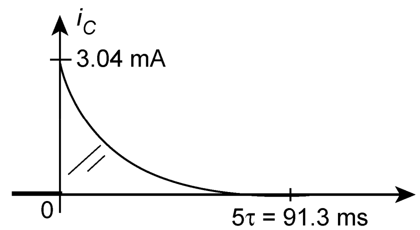
$\upsilon_R(0+) = 27.2\text{ V} - 2\text{ V} = 25.2\text{ V}$

$$i_C = \frac{25.2\text{ V}}{8.3\text{ k}\Omega}e^{-t/18.26\text{ms}}$$

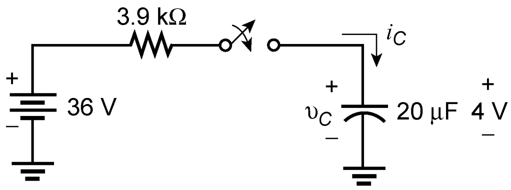
$i_C = \mathbf{3.04\text{ mA}e^{-t/18.26\text{ ms}}}$

b.



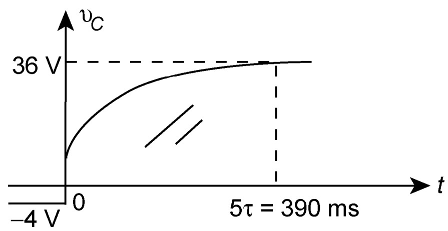


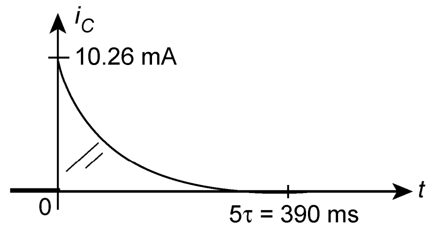
44. a. $R_{Th} = 3.9\text{ k}\Omega + 0\ \Omega \parallel 1.8\text{ k}\Omega = 3.9\text{ k}\Omega$
$E_{Th} = 36\text{ V}$



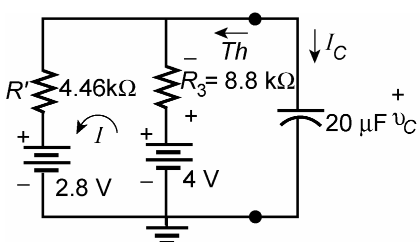
$\tau = RC = (3.9\text{ k}\Omega)(20\ \mu\text{F}) = 78\text{ ms}$
$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$
$= 36\text{ V} + (-4\text{ V} - 36\text{ V})e^{-t/78\text{ ms}}$
$\boldsymbol{\upsilon_C = 36\text{ V} - 40\text{ V}e^{-t/78\text{ ms}}}$
$\upsilon_R(0+) = 36\text{ V} + 4\text{ V} = 40\text{ V}$
$$i_C = \frac{40\text{ V}}{3.9\text{ k}\Omega}e^{-t/78\text{ ms}}$$
$\boldsymbol{i_C = 10.26\text{ mA}e^{-t/78\text{ ms}}}$

b.

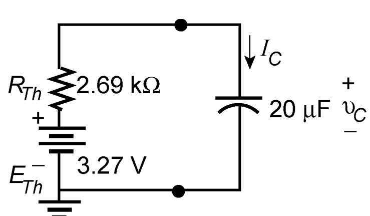




45. Source conversion:
$E = IR_1 = (5\text{ mA})(0.56\text{ k}\Omega) = 2.8\text{ V}$
$R' = R_1 + R_2 = 0.56\text{ k}\Omega + 3.9\text{ k}\Omega = 4.46\text{ k}\Omega$

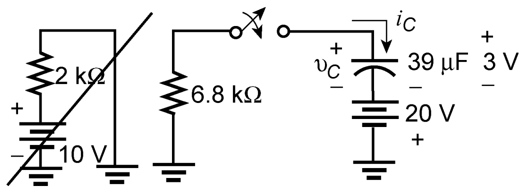


$R_{Th} = 4.46\text{ k}\Omega \parallel 6.8\text{ k}\Omega = 2.69\text{ k}\Omega$
$$I = \frac{4\text{ V} - 2.8\text{ V}}{6.8\text{ k}\Omega + 4.46\text{ k}\Omega} = \frac{1.2\text{ V}}{11.26\text{ k}\Omega} = 0.107\text{ mA}$$
$E_{Th} = 4\text{ V} - (0.107\text{ mA})(6.8\text{ k}\Omega)$
$= 4\text{ V} - 0.727\text{ V}$
$= 3.27\text{ V}$



$\upsilon_C = 3.27\text{ V}(1 - e^{-t/\tau})$
$\tau = RC = (2.69\text{ k}\Omega)(20\ \mu\text{F})$
$= 53.80\text{ ms}$
$\boldsymbol{\upsilon_C = 3.27\text{ V}(1 - e^{-t/53.80\text{ ms}})}$
$$i_C = \frac{3.27\text{ V}}{2.69\text{ k}\Omega}e^{-t/\tau}$$
$\boldsymbol{= 1.22\text{ mA}\ e^{-t/53.80\text{ ms}}}$

46. a.



$\tau = RC = (6.8\text{ k}\Omega)(39\ \mu\text{F}) = 265.2\text{ ms}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 20\text{ V} + (3\text{ V} - 20\text{ V})e^{-t/265.2\text{ ms}}$

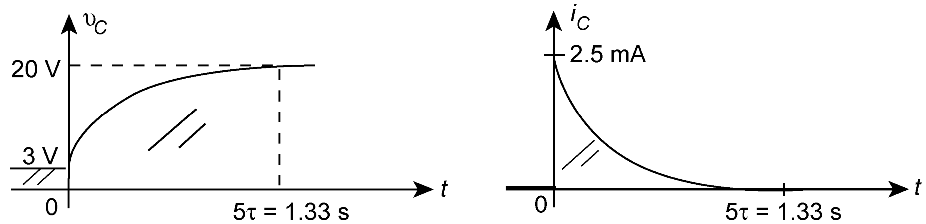
$\upsilon_C = \mathbf{20\ V - 17\ V}e^{-t/265.2\text{ ms}}$

$\upsilon_R(0+) = 20\text{ V} - 3\text{ V} = 17\text{ V}$

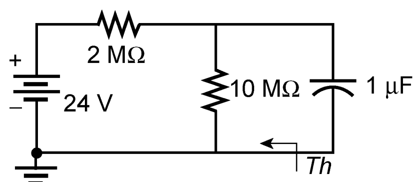
$$i_C = \frac{17\text{ V}}{6.8\text{ k}\Omega}e^{-t/265.2\text{ ms}}$$

$i_C = \mathbf{2.5\ mA}e^{-t/265.2\text{ ms}}$

b.



47. a.



$R_{Th} = 2\text{ M}\Omega \parallel 10\text{ M}\Omega = 1.67\text{ M}\Omega$

$$E_{Th} = \frac{10\text{ M}\Omega(24\text{ V})}{10\text{ M}\Omega + 2\text{ M}\Omega} = 20\text{ V}$$

$\upsilon_C = E_{Th}(1 - e^{-t/\tau})$

$= 20\text{ V}(1 - e^{-4\tau/\tau})$

$= 20\text{ V}(1 - e^{-4})$

$= 20\text{ V}(1 - 0.0183)$

$= \mathbf{19.63\ V}$

$\tau = R_{Th}C = (1.67\text{ M}\Omega)(1\ \mu\text{F}) = 1.67\text{ s}$

$$i_C = \frac{E}{R}e^{-t/\tau}$$

$$3\ \mu\text{A} = \frac{20\text{ V}}{1.67\text{ M}\Omega}e^{-t/1.67\text{s}}$$

$0.25 = e^{-t/1.67\text{s}}$

$\log_e 0.25 = -t/1.67\text{ s}$

$t = -(1.67\text{ s})(-1.39)$

$= \mathbf{2.32\ s}$

c. $\upsilon_{\text{meter}} = \upsilon_C$

$\upsilon_C = E_{Th}(1 - e^{-t/\tau})$

$10\text{ V} = 20\text{ V}(1 - e^{-t/1.67\text{s}})$

$0.5 = 1 - e^{-t/1.67\text{s}}$

$-0.5 = -e^{-t/1.67\text{s}}$

$\log_e 0.5 = -t/1.67\text{ s}$

$t = -(1.67\text{ s})(-0.69)$

$= \mathbf{1.15\ s}$

48. $i_{C_{ao}} = C\dfrac{\Delta \upsilon_C}{\Delta t}$

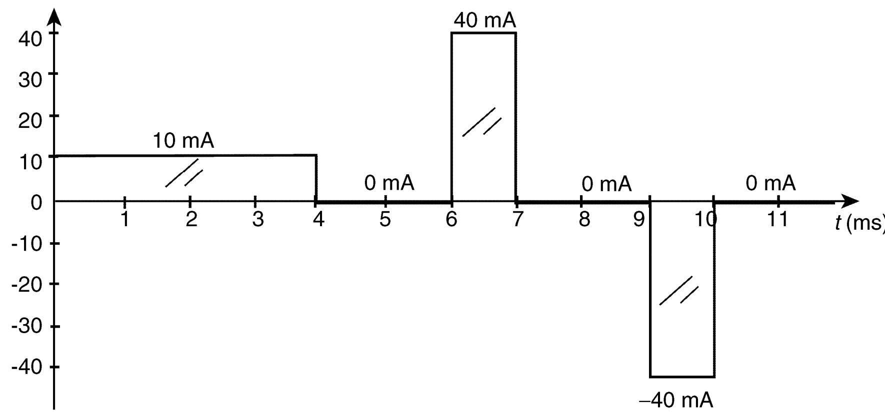
$0 \to 4$ ms: $i_C = 2 \times 10^{-6}\dfrac{(20\text{ V})}{4\text{ ms}} = \mathbf{10\ mA}$

$4 \to 6$ ms: $i_C = 2 \times 10^{-6}\dfrac{(0\text{ V})}{2\text{ ms}} = \mathbf{0\ mA}$

$6 \to 7$ ms: $i_C = 2 \times 10^{-6}\dfrac{(20\text{ V})}{1\text{ ms}} = \mathbf{40\ mA}$

$7 \to 9$ ms: $i_C = 2 \times 10^{-6}\dfrac{(0\text{ V})}{2\text{ ms}} = \mathbf{0\ mA}$

$9 \to 11$ ms: $i_C = -2 \times 10^{-6}\dfrac{(40\text{ V})}{2\text{ ms}} = \mathbf{-40\ mA}$



49. $i_{C_{ao}} = C\dfrac{\Delta \upsilon_C}{\Delta t}$

$0 \to 20\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(-5\text{ V})}{20\ \mu\text{s}} = \mathbf{-1.18\ A}$

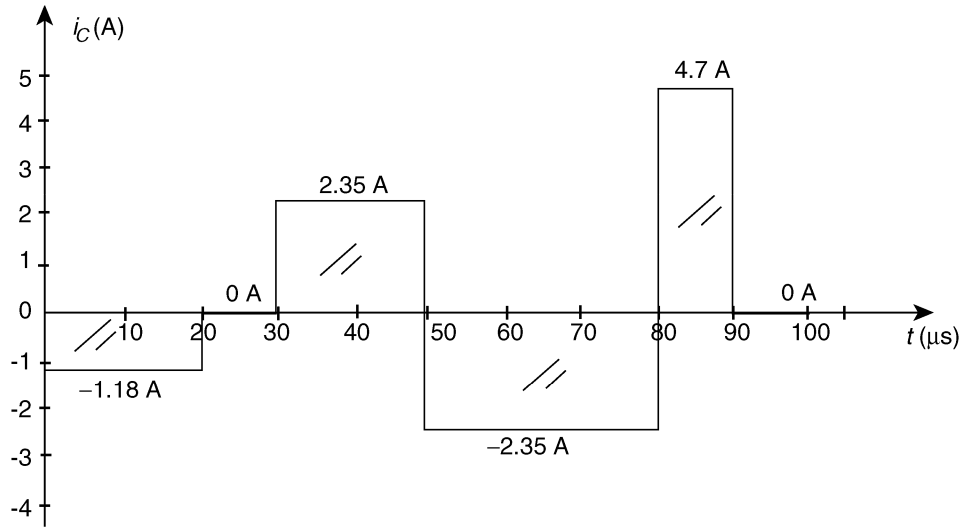
$20 \to 30\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(0\text{ V})}{10\ \mu\text{s}} = \mathbf{0\ A}$

$30 \to 50\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(+10\text{ V})}{20\ \mu\text{s}} = \mathbf{+2.35\ A}$

$50 \to 80\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(-15\text{ V})}{30\ \mu\text{s}} = \mathbf{-2.35\ A}$

$80 \to 90\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(+10\text{ V})}{10\ \mu\text{s}} = \mathbf{+4.7\ A}$

$90\ \mu\text{s} \to 100\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(0\text{ V})}{10\ \mu\text{s}} = \mathbf{0\ A}$



50. $i_C = C\dfrac{\Delta\upsilon_C}{\Delta t} \Rightarrow \Delta\upsilon_C = \dfrac{\Delta t}{C}(i_C)$

$0 \to 2$ ms: $i_C = 0$ mA $\Delta\upsilon_C = \mathbf{0\ V}$

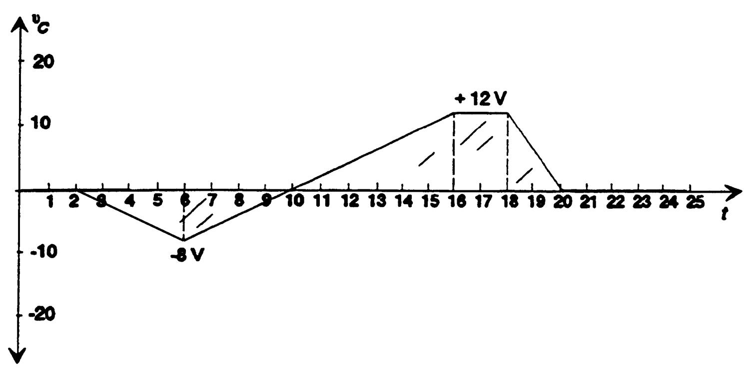
$2 \to 6$ ms: $i_C = -80$ mA $\Delta\upsilon_C = \dfrac{(2\text{ ms})}{20\ \mu\text{F}}(-80\text{ mA}) = \mathbf{-8\ V}$

$6 \to 16$ ms: $i_C = +40$ mA $\Delta\upsilon_C = \dfrac{(10\text{ ms})}{20\ \mu\text{F}}(40\text{ mA}) = \mathbf{+20\ V}$

$16 \to 18$ ms: $i_C = 0$ mA $\Delta\upsilon_C = \mathbf{0\ V}$

$18 \to 20$ ms: $i_C = -120$ mA $\Delta\upsilon_C = \dfrac{(2\text{ ms})}{20\ \mu\text{F}}(-120\text{ mA}) = \mathbf{-12\ V}$

$20 \to 25$ ms: $i_C = 0$ mA $\Delta\upsilon_C = \mathbf{0\ V}$



51. $C_T = 6\ \mu\text{F} + 4\ \mu\text{F} + 3\ \mu\text{F} \parallel 6\ \mu\text{F} = 10\ \mu\text{F} + 2\ \mu\text{F} = \mathbf{12\ \mu F}$

52. $C_T' = 6\ \mu\text{F} \parallel 12\ \mu\text{F} = 4\ \mu\text{F}$

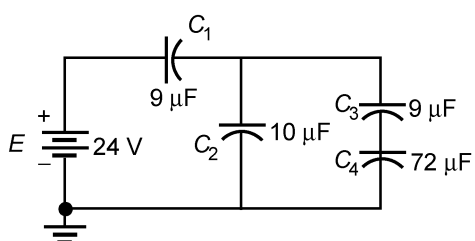
$C_T'' = C_T' + 12\ \mu\text{F} = 4\ \mu\text{F} + 12\ \mu\text{F} = 16\ \mu\text{F}$

$C_T = 6\ \mu\text{F} \parallel C_T'' = \dfrac{6\ \mu\text{F}\cdot C_T''}{6\ \mu\text{F} + C_T''} = \dfrac{(6\ \mu\text{F})(16\ \mu\text{F})}{6\ \mu\text{F} + 16\ \mu\text{F}} = \mathbf{4.36\ \mu F}$

53. $V_1 =$ **10 V**, $Q_1 = V_1C_1 = (10\text{ V})(6\ \mu\text{F}) =$ **60 μC**
$C_T = 6\ \mu\text{F} \parallel 12\ \mu\text{F} = 4\ \mu\text{F}$, $Q_T = C_TE = (4\ \mu\text{F})(10\text{ V}) = 40\ \mu\text{C}$
$Q_2 = Q_3 =$ **40 μC**
$V_2 = \dfrac{Q_2}{C_2} = \dfrac{40\mu\text{C}}{6\mu\text{F}} = \mathbf{6.67\ V}$
$V_3 = \dfrac{Q_3}{C_3} = \dfrac{40\mu\text{C}}{12\mu\text{F}} = \mathbf{3.33\ V}$

54. $C_T = 1200\text{ pF} \parallel (200\text{ pF} + 400\text{ pF}) \parallel 600\text{ pF}$
$= 1200\text{ pF} \parallel 600\text{ pF} \parallel 600\text{ pF} = 1200\text{ pF} \parallel 300\text{ pF}$
$= 240\text{ pF}$
$Q_T = C_TE = (240\text{ pF})(40\text{ V}) = 9.60\text{ nC}$
$Q_1 = Q_4 = Q_T =$ **9.60 nC**
$V_1 = \dfrac{Q_1}{C_1} = \dfrac{9.60\text{ nC}}{1200\text{ pF}} = \mathbf{8.00\ V}$, $V_4 = \dfrac{Q_4}{C_4} = \dfrac{9.60\text{ nC}}{600\text{ pF}} = \mathbf{16.00\ V}$
$V_2 = V_3 = E - V_1 - V_4 = 40\text{ V} - 8\text{ V} - 16\text{ V} =$ **16 V**
$Q_2 = C_2V_2 = (200\text{ pF})(16\text{ V}) =$ **3.20 nC**, $Q_3 = C_3V_3 = (400\text{ pF})(16\text{ V}) =$ **6.40 nC**

55.



$\dfrac{(9\ \mu\text{F})(72\ \mu\text{F})}{9\ \mu\text{F} + 72\ \mu\text{F}} = 8\ \mu\text{F}$
$8\ \mu\text{F} + 10\ \mu\text{F} = 18\ \mu\text{F}$
$\dfrac{(9\ \mu\text{F})(18\ \mu\text{F})}{9\ \mu\text{F} + 18\ \mu\text{F}} = 6\ \mu\text{F}$

$C_T = \dfrac{Q}{V} = \dfrac{Q}{E} \Rightarrow Q = C_TE = (6\ \mu\text{F})(24\text{ V}) = 144\ \mu\text{C}$

$Q_1 =$ **144 μC**
$V_1 = \dfrac{Q_1}{C_1} = \dfrac{144\ \mu\text{C}}{9\ \mu\text{F}} = \mathbf{16\ V}$
$V_2 = E - V_1 = 24\text{ V} - 16\text{ V} =$ **8 V**
$Q_2 = C_2V_2 = 10\ \mu\text{F}(8\text{ V}) =$ **80 μC**
$Q_{3-4} = C'V = (8\ \mu\text{F})(8\text{ V}) = 64\ \mu\text{C}$
$Q_3 = Q_4 =$ **64 μC**
$V_3 = \dfrac{Q_3}{C_3} = \dfrac{64\ \mu\text{C}}{9\ \mu\text{F}} = \mathbf{7.11\ V}$
$V_4 = \dfrac{Q_4}{C_4} = \dfrac{64\ \mu\text{C}}{72\ \mu\text{F}} = \mathbf{0.89\ V}$

56. $V_{4\text{k}\Omega} = \dfrac{4\text{ k}\Omega(48\text{ V})}{4\text{ k}\Omega + 2\text{ k}\Omega} = \mathbf{32\ V} = V_{0.08\mu\text{F}}$
$Q_{0.08\mu\text{F}} = (0.08\ \mu\text{F})(32\text{ V}) =$ **2.56 μC**
$V_{0.04\mu\text{F}} =$ **48 V**
$Q_{0.04\mu\text{F}} = (0.04\ \mu\text{F})(48\text{ V}) =$ **1.92 μC**

57. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(120\text{ pF})(12\text{ V})^2 = \mathbf{8{,}640\ pJ}$

58. $W = \frac{Q^2}{2C} \Rightarrow Q = \sqrt{2CW} = \sqrt{2(6\ \mu\text{F})(1200\text{ J})} = \mathbf{0.12\ C}$

59. a. $V_{6\mu\text{F}} = V_{12\mu\text{F}} = \frac{3\text{ k}\Omega(24\text{ V})}{3\text{ k}\Omega + 6\text{ k}\Omega} = 8\text{ V}$

$W_{6\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(6\ \mu\text{F})(8\text{ V})^2 = \mathbf{0.19\ mJ}$

$W_{12\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(12\ \mu\text{F})(8\text{ V})^2 = \mathbf{0.38\ mJ}$

b. $C_T = \frac{(6\ \mu\text{F})(12\ \mu\text{F})}{6\ \mu\text{F} + 12\ \mu\text{F}} = 4\ \mu\text{F}$

$Q_T = C_T V = (4\ \mu\text{F})(8\text{ V}) = 32\ \mu\text{C}$

$Q_{6\mu\text{F}} = Q_{12\mu\text{F}} = 32\ \mu\text{C}$

$V_{6\mu\text{F}} = \frac{Q}{C} = \frac{32\ \mu\text{C}}{6\ \mu\text{F}} = 5.33\text{ V}$

$V_{12\mu\text{F}} = \frac{Q}{C} = \frac{32\ \mu\text{C}}{12\ \mu\text{F}} = 2.67\text{ V}$

$W_{6\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(6\ \mu\text{F})(5.33\text{ V})^2 = \mathbf{85.23\ \mu J}$

$W_{12\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(12\ \mu\text{F})(2.67\text{ V})^2 = \mathbf{42.77\ \mu J}$

60. a. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(1000\ \mu\text{F})(100\text{ V})^2 = \mathbf{5\ pJ}$

b. $Q = CV = (1000\ \mu\text{F})(100\text{ V}) = \mathbf{0.1\ C}$

c. $I = Q/t = 0.1\text{ C}/(1/2000) = \mathbf{200\ A}$

d. $P = V_{av}I_{av} = W/t = 5\text{ J}(1/2000\text{ s}) = \mathbf{10{,}000\ W}$

e. $t = Q/I = 0.1\text{ C}/10\text{ mA} = \mathbf{10\ s}$

Chapter 11

1. a. $B = \dfrac{\Phi}{A} = \dfrac{4\times10^{-4}\text{ Wb}}{0.01\text{ m}^2} = 4 \times 10^{-2}\text{ Wb/m}^2 = \mathbf{0.04\text{ Wb/m}^2}$

   b. **0.04 T**

   c. $F = NI = (40\text{ t})(2.2\text{ A}) = \mathbf{88\text{ At}}$

   d. $0.04\cancel{T}\left[\dfrac{10^4\text{ gauss}}{1\cancel{T}}\right] = \mathbf{0.4 \times 10^3\text{ gauss}}$

2. $A = \dfrac{\pi d^2}{4} = \dfrac{\pi(5\text{ mm})^2}{4} = 19.63 \times 10^{-6}\text{ m}^2$

   $L = \dfrac{N^2\mu A}{\ell} = \dfrac{(200\text{ t})^2(4\pi\times10^{-7})(19.63\times10^{-6}\text{ m}^2)}{100\text{ mm}} = \mathbf{9.87\ \mu H}$

3. $d = 0.2\ \cancel{\text{in.}}\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 5.08\text{ mm}$

   $A = \dfrac{\pi d^2}{4} = \dfrac{(\pi)(5.08\text{ mm})^2}{4} = 20.27 \times 10^{-6}\text{ m}^2$

   $\ell = 1.6\ \cancel{\text{in.}}\left(\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right) = 40.64\text{ mm}$

   $L = \dfrac{N^2\mu_r\mu_o A}{\ell} = \dfrac{(200\text{ t})^2(500)(4\pi\times10^{-7})(20.27\times10^{-6}\text{ m}^2)}{40.64\text{ mm}} = \mathbf{12.54\text{ mH}}$

4. $L = N^2\dfrac{\mu_r\mu_o}{\ell} = \dfrac{(200\text{ t})^2(1000)(4\pi\times10^{-7})(1.5\times10^{-4}\text{ m}^2)}{0.15\text{ m}} = \mathbf{50.27\text{ mH}}$

5. $L = \dfrac{N^2\mu_r\mu_o A}{\ell}$

   a. $L' = (3)^2L_o = 9L_o = 9(5\text{ mH}) = \mathbf{45\text{ mH}}$

   b. $L' = \dfrac{1}{3}L_o = \dfrac{1}{3}(5\text{ mH}) = \mathbf{1.67\text{ mH}}$

   c. $L' = \dfrac{(2)(2)^2}{\frac{1}{2}}L_o = 16\ (5\text{ mH}) = \mathbf{80\text{ mH}}$

   d. $L' = \dfrac{\left(\frac{1}{2}\right)^2\frac{1}{2}(1500)L_o}{\frac{1}{2}} = 375(5\text{ mH}) = \mathbf{1875\text{ mH}}$

6. a. $12 \times 10^3\ \mu\text{H} \pm 5\% \Rightarrow 12{,}000\ \mu\text{H} \pm 600\ \mu\text{H} \Rightarrow \mathbf{11{,}400\ \mu H \rightarrow 12{,}600\ \mu H}$

   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. $e = N\dfrac{d\phi}{dt}$ = (50 t)(120 mWb/s) = **6.0 V**

8. $e = N\dfrac{d\phi}{dt} \Rightarrow \dfrac{d\phi}{dt} = \dfrac{e}{N} = \dfrac{20\text{ V}}{200\text{ t}}$ = **100 mWb/s**

9. $e = N\dfrac{d\phi}{dt} \Rightarrow N = e\left(\dfrac{1}{\dfrac{d\phi}{dt}}\right) = 42\text{ mV}\left(\dfrac{1}{3\text{ m Wb/s}}\right)$ = **14 turns**

10. a. $e = L\dfrac{di_L}{dt}$ = (5 H)(1 A/s) = **5 V**

b. $e = L\dfrac{di_L}{dt}$ = (5 H)(60 mA/s) = **0.3 V**

$e = L\dfrac{di_L}{dt} = (5\text{ H})\left[\dfrac{0.5\text{ A}}{\cancel{\text{ms}}}\right]\left[\dfrac{1000\ \cancel{\text{ms}}}{1\text{ s}}\right]$ = **2.5 kV**

11. $e = L\dfrac{di_L}{dt} = (50\text{ mH})\left(\dfrac{0.1\text{ mA}}{\mu\text{s}}\right)$ = **5 V**

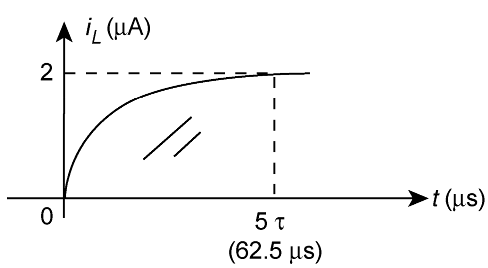
12. a. $\tau = \dfrac{L}{R} = \dfrac{250\text{ mH}}{20\text{ k}\Omega}$ = **12.5 μs**

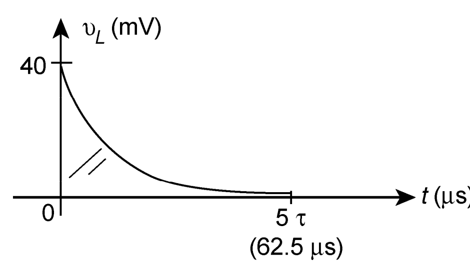
b. $i_L = \dfrac{E}{R}(1 - e^{-t/\tau}) = \dfrac{40\text{ mV}}{20\text{ k}\Omega}(1 - e^{-t/\tau})$
= **2 μA(1 − $e^{-t/12.5\mu s}$)**

c. $\upsilon_L = Ee^{-t/\tau}$ = **40 mV$e^{-t/12.5\ \mu s}$**
$\upsilon_R = i_R R = i_L R = E(1 - e^{-t/\tau})$ = **40 mV(1 − $e^{-t/12.5\ \mu s}$)**

d. i_L: 1τ = **1.26 μA**, , 3τ = **1.9 μA**, 5τ = **1.99 μA**
υ_L: 1τ = **14.72 V**, 3τ = **1.99 V**, 5τ = **0.27 V**

e.





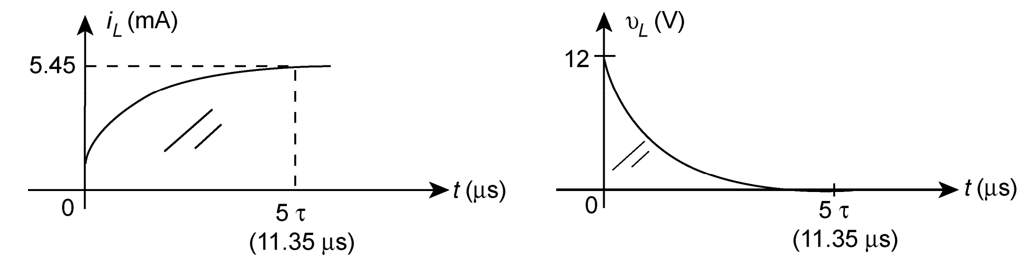
13. a. $\tau = \dfrac{L}{R} = \dfrac{5\text{ mH}}{2.2\text{ k}\Omega} = \mathbf{2.27\ \mu s}$

b. $i_L = \dfrac{E}{R}(1 - e^{-t/\tau}) = \dfrac{12\text{ V}}{2.2\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{5.45\ mA(1 - e^{-t/2.27\ \mu s})}$

c. $\upsilon_L = Ee^{-t/\tau} = \mathbf{12\ Ve^{-t/2.27\ \mu s}}$
$\upsilon_R = i_R R = i_L R = E(1 - e^{-t/\tau}) = \mathbf{12\ V(1 - e^{-t/2.27\ \mu s})}$

d. i_L: $1\tau = \mathbf{3.45\ mA}$, , $3\tau = \mathbf{5.18\ mA}$, $5\tau = \mathbf{5.41\ mA}$
υ_L: $1\tau = \mathbf{4.42\ V}$, $3\tau = \mathbf{0.60\ V}$, $5\tau = \mathbf{0.08\ V}$

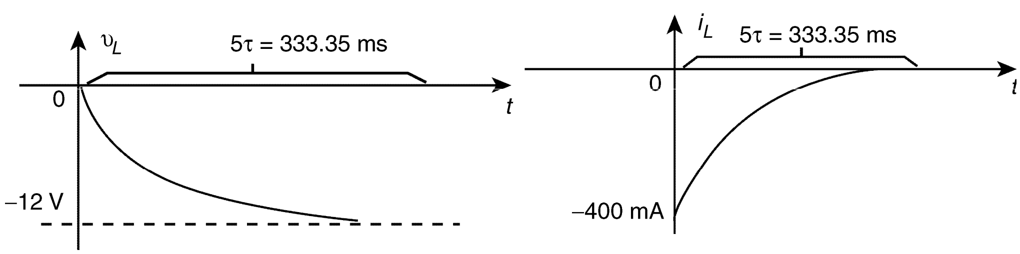
e.



14. a. $\tau = \dfrac{L}{R} = \dfrac{2\text{ H}}{(20\ \Omega + 10\ \Omega)} = \dfrac{2\text{ H}}{30\ \Omega} = \mathbf{66.67\ ms}$

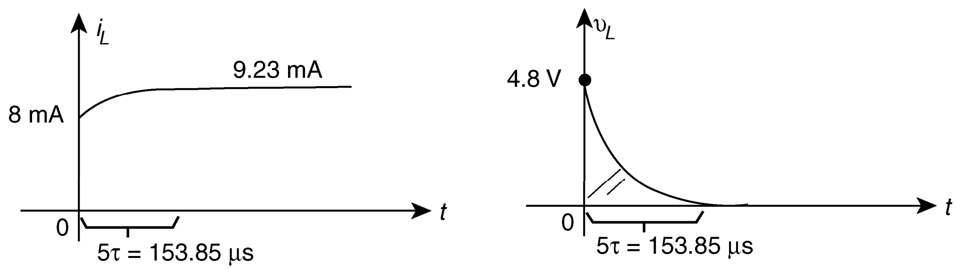
b. $\upsilon_L = -E(1 - e^{-t/\tau}) = \mathbf{-12\ V(1 - e^{-t/66.67ms})}$
$i_L = -\dfrac{E}{R}e^{-t/\tau} = -\dfrac{12\text{ V}}{30\ \Omega}e^{-t/66.67\text{ms}} = \mathbf{-400\ mA}\boldsymbol{e}^{-t/66.67\text{ ms}}$

c.



15. a. $i_L = I_f + (I_i - I_f)e^{-t/\tau}$
$I_i = 8\text{ mA},\ I_f = \dfrac{E}{R} = \dfrac{36\text{ V}}{3.9\text{ k}\Omega} = \mathbf{9.23\ mA},\ \ \tau = \dfrac{L}{R} = \dfrac{120\text{ mH}}{3.9\text{ k}\Omega} = 30.77\ \mu\text{s}$
$i_L = 9.23\text{ mA} + (8\text{ mA} - 9.23\text{ mA})e^{-t/30.77\ \mu s}$
$i_L = \mathbf{9.23\ mA - 1.23\ mA}\boldsymbol{e}^{\boldsymbol{-t/30.77\ \mu s}}$
$+E - \upsilon_L - \upsilon_R = 0$ and $\upsilon_L = E - \upsilon_R$
$\upsilon_R = i_R R = i_L R = (8\text{ mA})(3.9\text{ k}\Omega) = 31.2\text{ V}$
$\upsilon_L = E - \upsilon_R = 36\text{ V} - 31.2\text{ V} = 4.8\text{ V}$
$\upsilon_L = \mathbf{4.8\ V}\boldsymbol{e}^{\boldsymbol{-t/30.77\ \mu s}}$

b.



16. a. $I_i = -8 \text{ mA}, \; I_f = 9.23 \text{ mA}, \; \tau = \dfrac{L}{R} = \dfrac{120 \text{ mH}}{3.9 \text{ k}\Omega} = 30.77\ \mu\text{s}$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$= 9.23 \text{ mA} + (-8 \text{ mA} - 9.23 \text{ mA})e^{-t/30.77\ \mu s}$

$i_L = \mathbf{9.23\ mA - 17.23\ mA}\ \boldsymbol{e^{-t/30.77\ \mu s}}$

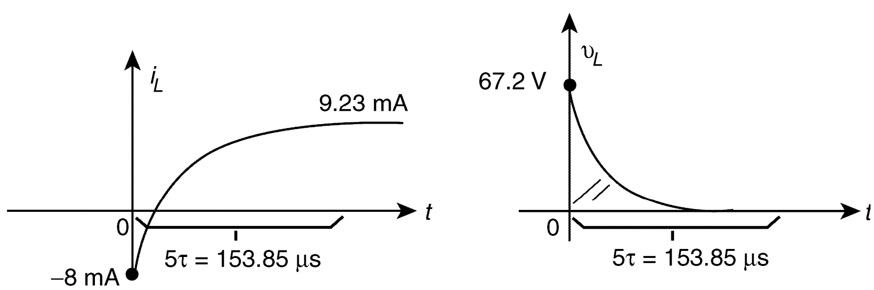
$+E - \upsilon_L - \upsilon_R = 0$ (at $t = 0^-$)

but, $\upsilon_R = i_R R = -i_L R = (-8 \text{ mA})(3.9 \text{ k}\Omega) = -31.2 \text{ V}$

$\upsilon_L = E - \upsilon_R = 36 \text{ V} - (-31.2 \text{ V}) = 67.2 \text{ V}$

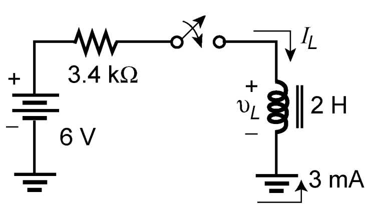
$\upsilon_L = \mathbf{67.2\ V}\ \boldsymbol{e^{-t/30.77\ \mu s}}$

b.



c. Final levels are the same. Transition period defined by 5τ is also the same.

17. a. Source conversion:



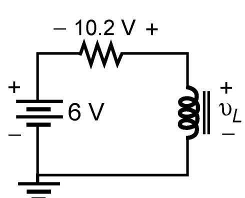
$\tau = \dfrac{L}{R} = \dfrac{2 \text{ H}}{3.4 \text{ k}\Omega} = 588.2\ \mu\text{s}$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$I_f = \dfrac{6 \text{ V}}{3.4 \text{ k}\Omega} = 1.76 \text{ mA}$

$i_L = 1.76 \text{ mA} + (-3 \text{ mA} - 1.76 \text{ mA})e^{-t/588.2\mu s}$

$i_L = \mathbf{1.76\ mA - 4.76\ mA}\ \boldsymbol{e^{-t/588.2\mu s}}$



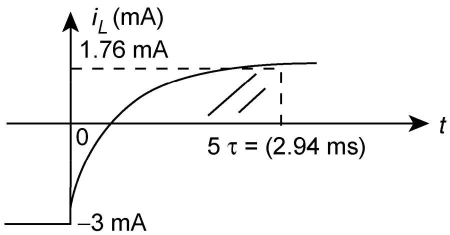
$\upsilon_R(0+) = 3 \text{ mA}(3.4 \text{ k}\Omega) = 10.2 \text{ V}$

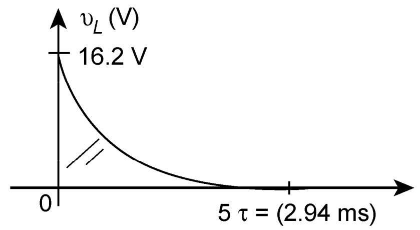
KVL: $+6 \text{ V} + 10.2 \text{ V} - \upsilon_L(0+) = 0$

$\upsilon_L(0+) = 16.2 \text{ V}$

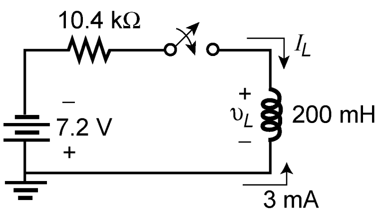
$\upsilon_L = \mathbf{16.2\ V}\boldsymbol{e^{-t/588.2\mu s}}$

b.





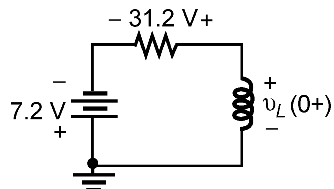
18. a.



$$I_f = -\frac{7.2\text{ V}}{10.4\text{ k}\Omega} = -0.69\text{ mA}$$

$$\tau = \frac{L}{R} = \frac{200\text{ mH}}{10.4\text{ k}\Omega} = 19.23\ \mu\text{s}$$

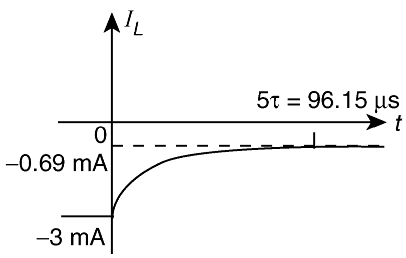
$$i_L = I_f + (I_i - I_f)e^{-t/\tau}$$
$$= -0.69\text{ mA} + (-3\text{ mA} - (-0.69\text{ mA}))e^{-t/19.23\ \mu\text{s}}$$
$$\boldsymbol{i_L = -0.69\text{ mA} - 2.31\text{ mA}e^{-t/19.23\ \mu\text{s}}}$$

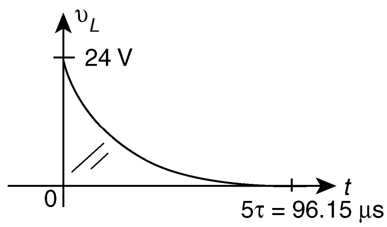


KVL: $-7.2\text{ V} + 31.2\text{ V} - \upsilon_L(0+) = 0$

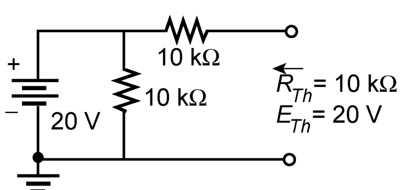
$$\upsilon_L(0+) = 24\text{ V}$$
$$\upsilon_L = \mathbf{24\ V}e^{-t/19.23\ \mu s}$$

b.





19. a.



$$\tau = \frac{L}{R} = \frac{10\text{ mH}}{10\text{ k}\Omega} = 1\ \mu\text{s}$$

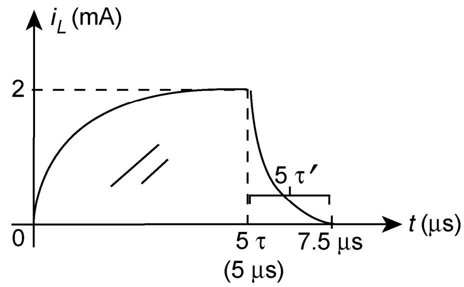
$$\upsilon_L = \mathbf{20\ V}e^{-t/1\mu s},\ i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \mathbf{2\ mA(1 - e^{-t/1\mu s})}$$

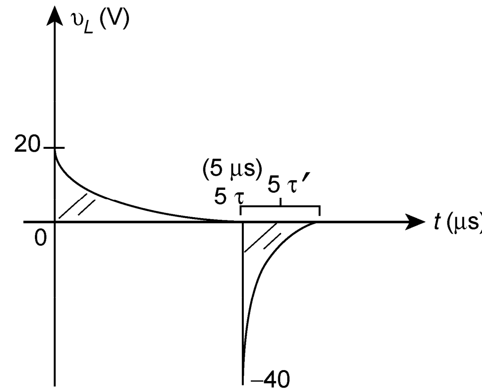
b. $5\tau \Rightarrow$ steady state

$$\tau' = \frac{L}{R} = \frac{10\text{ mH}}{10\text{ k}\Omega} = 1\ \mu\text{s}$$

$$i_L = I_m e^{-t/\tau'} = \mathbf{2\ mA}\boldsymbol{e^{-t/1\mu s}}$$

$$\upsilon_L = -(2\text{ mA})(20\text{ k}\Omega)e^{-t/\tau} = \mathbf{-40\ V}\boldsymbol{e^{-t/1\mu s}}$$





20. a. $\tau = \dfrac{L}{R} = \dfrac{1\text{ mH}}{2\text{ k}\Omega} = 0.5\ \mu\text{s}$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{12\text{ V}}{2\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{6\ mA(1 - e^{-t/0.5\mu s})}$$

$$\upsilon_L = Ee^{-t/\tau} = \mathbf{12\ V}\ \boldsymbol{e^{-t/0.5\mu s}}$$

b. $i_L = 6\text{ mA}(1 - e^{-t/0.5\mu s}) = 6\text{ mA}(1 - e^{-1\mu s/0.5\mu s})$
$= 6\text{ mA}(1 - e^{-2}) = 5.19\text{ mA}$

$i_L = I'_m e^{-t/\tau'}$ $\qquad \tau' = \dfrac{L}{R} = \dfrac{1\text{ mH}}{12\text{ k}\Omega} = 83.3\text{ ns}$

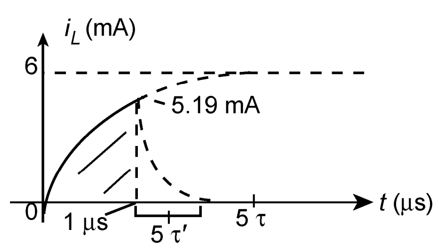
$i_L = \mathbf{5.19\ mA}\boldsymbol{e^{-t/83.3ns}}$

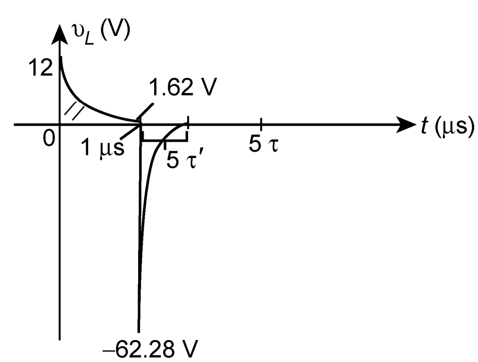
$t = 1\ \mu\text{s}$: $\upsilon_L = 12\text{ V}e^{-t/0.5\mu s} = 12\text{ V}e^{-2} = 12\text{ V}(0.1353) = 1.62\text{ V}$

$V'_L = (5.19\text{ mA})(12\text{ k}\Omega) = 62.28\text{ V}$

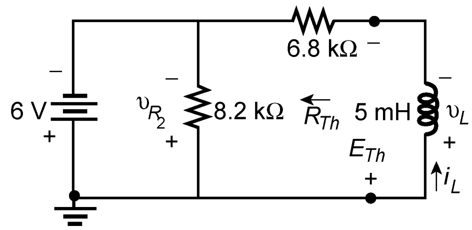
$\upsilon_L = \mathbf{-62.28\ V}\boldsymbol{e^{-t/83.3ns}}$

c.

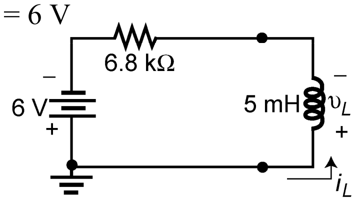




21. a.



$R_{Th} = 6.8\ \text{k}\Omega$
$E_{Th} = 6\ \text{V}$

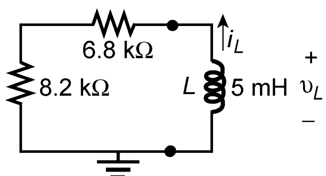


$$\tau = \frac{L}{R} = \frac{5\ \text{mH}}{6.8\ \text{k}\Omega} = 0.74\ \mu\text{s}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{6\ \text{V}}{6.8\ \text{k}\Omega}(1 - e^{-t/\tau}) = \mathbf{0.88\ mA(1 - e^{-t/0.74\mu s})}$$

$\upsilon_L = Ee^{-t/\tau} = \mathbf{6\ V}e^{-t/0.74\mu s}$

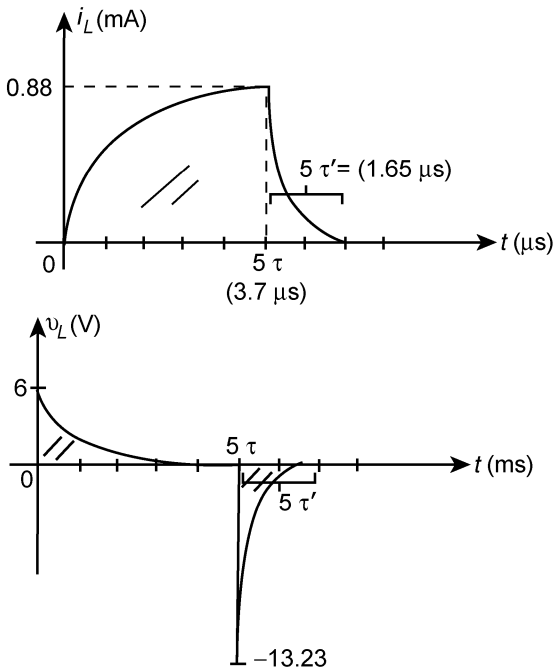
b. Assume steady state and $I_L = 0.88$ mA



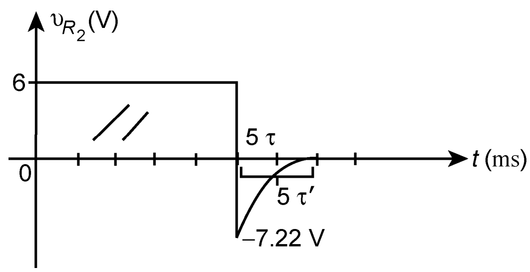
$$\tau' = \frac{L}{R} = \frac{5\ \text{mH}}{15\ \text{k}\Omega} = 0.33\ \mu\text{s}$$

$i_L = I_m e^{-t/\tau'} = \mathbf{0.88\ mA}\ e^{-t/0.33\mu s}$
$\upsilon_L = -V_m e^{-t/\tau'}$
$V_m = I_m R = (0.88\ \text{mA})(15\ \text{k}\Omega) = 13.23\ \text{V}$
$\upsilon_L = \mathbf{-13.23\ V}e^{-t/0.33\mu s}$

c.



d. $V_{R_{2\max}} = I_m R_2 = (0.88\text{ mA})(8.2\text{ k}\Omega) = 7.22\text{ V}$



22. a. $R_{Th} = 2\text{ k}\Omega + 3\text{ k}\Omega \parallel 6\text{ k}\Omega = 2\text{ k}\Omega + 2\text{ k}\Omega = 4\text{ k}\Omega$

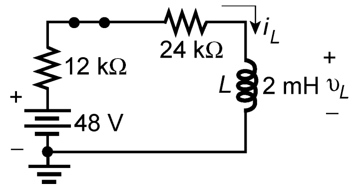
$$E_{Th} = \frac{6\text{ k}\Omega(12\text{ V})}{6\text{ k}\Omega + 3\text{ k}\Omega} = 8\text{ V},\quad \tau = \frac{L}{R} = \frac{100\text{ mH}}{4\text{ k}\Omega} = 25\ \mu\text{s}$$

$$I_f = \frac{E_{Th}}{R_{Th}} = \frac{8\text{ V}}{4\text{ k}\Omega} = 2\text{ mA}$$

$\boldsymbol{i_L = 2\textbf{ mA}(1 - e^{-t/25\mu s})}$
$\boldsymbol{\upsilon_L = 8\textbf{ V}e^{-t/25\mu s}}$

b. $i_L = 2\text{ mA}(1 - e^{-1}) = \mathbf{1.26\ mA}$
$\upsilon_L = 8\text{ V}e^{-1} = \mathbf{2.94\ V}$

23. a. Source conversion: $E = IR = (4\text{ mA})(12\text{ k}\Omega) = 48\text{ V}$



$$\tau = \frac{L}{R} = \frac{2\text{ mH}}{36\text{ k}\Omega} = 55.56\text{ ns}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{48\text{ V}}{36\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{1.33\text{ mA}(1 - e^{-t/55.56ns})}$$

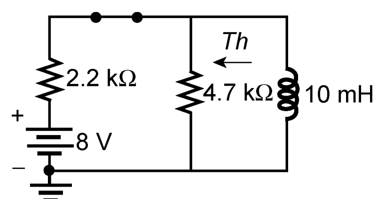
$$\upsilon_L = Ee^{-t/\tau} = \mathbf{48\text{ V}e^{-t/55.56ns}}$$

b. $t = 100$ ns:

$$i_L = 1.33\text{ mA}(1 - e^{-100ns/55.56ns}) = 1.33\text{ mA}(1 - \underbrace{e^{-1.8}}_{0.165}) = \mathbf{1.11\text{ mA}}$$

$$\upsilon_L = \mathbf{48\text{ V}e^{-1.8} = 7.93\text{ V}}$$

24. a.



$$R_{Th} = 2.2\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 1.50\text{ k}\Omega$$

$$E_{Th} = \frac{4.7\text{ k}\Omega(8\text{ V})}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega} = 5.45\text{ V}$$

$$\tau = \frac{L}{R} = \frac{10\text{ mH}}{1.50\text{ k}\Omega} = 6.67\ \mu\text{s}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{5.45\text{ V}}{1.5\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{3.63\text{ mA}(1 - e^{-t/6.67\mu s})}$$

$$\upsilon_L = Ee^{-t/\tau} = \mathbf{5.45\text{ V}e^{-t/6.67\mu s}}$$

b. $t = 10\ \mu$s:

$$i_L = 3.63\text{ mA}(1 - e^{-10\mu s/6.67\mu s}) = 3.63\text{ mA}(1 - \underbrace{e^{-1.4}}_{0.246})$$

$$= \mathbf{2.74\text{ mA}}$$

$$\upsilon_L = 5.45\text{ V}(0.246) = \mathbf{1.34\text{ V}}$$

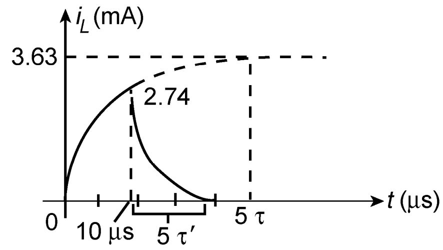
c. $$\tau' = \frac{L}{R} = \frac{10\text{ mH}}{4.7\text{ k}\Omega} = 2.13\ \mu\text{s}$$

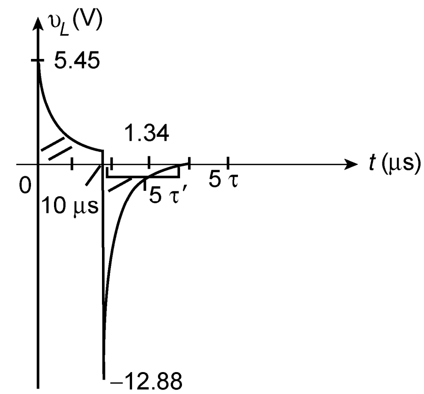
$$i_L = \mathbf{2.74\text{ mA}e^{-t/2.13\mu s}}$$

At $t = 10\ \mu$s

$$V_L = (2.74\text{ mA})(4.7\text{ k}\Omega) = 12.88\text{ V}$$

$$\upsilon_L = \mathbf{-12.88\text{ V}e^{-t/2.13\mu s}}$$





25. a. $\upsilon_L = Ee^{-t/\tau}$ $\quad\tau = \dfrac{L}{R_1 + R_3} = \dfrac{0.6\text{ H}}{100\ \Omega + 20\ \Omega} = \dfrac{0.6\text{ H}}{120\ \Omega} = 5\text{ ms}$

$\upsilon_L = 36\text{ V}e^{-t/5\text{ ms}}$

$\upsilon_L = 36\text{ V}e^{-25\text{ ms}/5\text{ ms}} = 36\text{ V}e^{-5} = 36\text{ V}(0.00674) = \mathbf{0.24\ V}$

b. $\upsilon_L = 36\text{ V}e^{-1\text{ ms}/5\text{ ms}} = 36\text{ V}e^{-0.2} = 36\text{ V}(0.819) = \mathbf{29.47\ V}$

c. $\upsilon_{R_1} = i_{R_1}R_1 = i_L R_1 = \left(\dfrac{E}{R_1 + R_3}(1 - e^{-t/\tau})\right)R_1$

$= \left(\dfrac{36\text{ V}}{120\ \Omega}(1 - e^{-t/5\text{ms}})\right)100\ \Omega$

$= (300\text{ mA}(1 - e^{-t/5\text{ ms}}))100\ \Omega$

$= 30\text{ V}(1 - e^{-5\text{ ms}/5\text{ ms}}) = 30\text{ V}(1 - e^{-1})$

$= 30\text{ V}(1 - 0.368) = \mathbf{18.96\ V}$

d. $i_L = 300\text{ mA}(1 - e^{-t/5\text{ ms}})$

$100\text{ mA} = 300\text{ mA}(1 - e^{-t/5\text{ ms}})$

$0.333 = 1 - e^{-t/5\text{ ms}}$

$0.667 = e^{-t/5\text{ ms}}$

$\log_e 0.667 = -t/5\text{ ms}$

$0.405 = t/5\text{ ms}$

$t = 0.405(5\text{ ms}) = \mathbf{2.03\ ms}$

26. a. $I_i = \dfrac{16\text{ V}}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega} = 2\text{ mA}$

$t = 0$ s: Thevenin:

$R_{Th} = 3.3\text{ k}\Omega + 1\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 3.3\text{ k}\Omega + 0.82\text{ k}\Omega = 4.12\text{ k}\Omega$

$E_{Th} = \dfrac{1\text{ k}\Omega(16\text{ V})}{1\text{ k}\Omega + 4.7\text{ k}\Omega} = 2.81\text{ V}$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$$I_f = \frac{2.81\text{ V}}{4.12\text{ k}\Omega} = 0.68\text{ mA},\ \tau = \frac{L}{R} = \frac{2\text{ H}}{4.12\text{ k}\Omega} = 0.49\text{ ms}$$

$i_L = 0.68\text{ mA} + (2\text{ mA} - 0.68\text{ mA})e^{-t/0.49\text{ ms}}$

$i_L = \mathbf{0.68\text{ mA} + 1.32\text{ mA}e^{-t/0.49\text{ ms}}}$

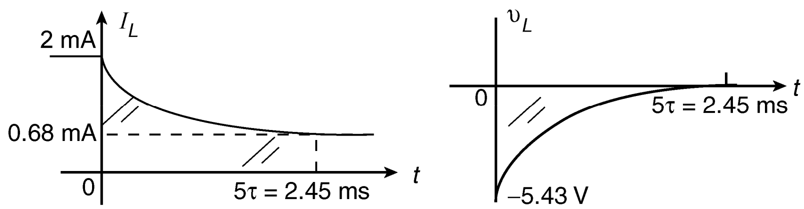
$\upsilon_R(0+) = 2\text{ mA}(4.12\text{ k}\Omega) = 8.24\text{ V}$

KVL(0+): $2.81\text{ V} - 8.24\text{ V} - \upsilon_L = 0$

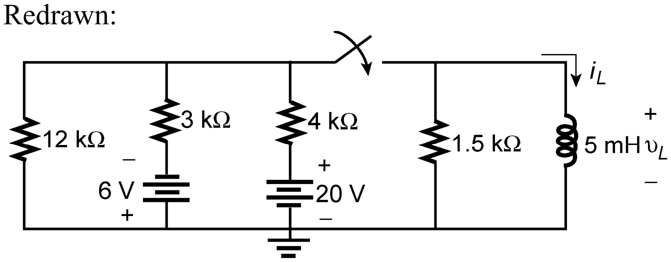
$\upsilon_L = -5.43\text{ V}$

$\upsilon_L = \mathbf{-5.43\text{ V}e^{-t/0.49\text{ ms}}}$

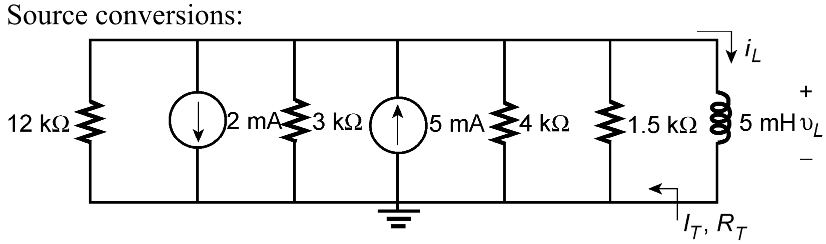
b.



27. a. Redrawn:



Source conversions:



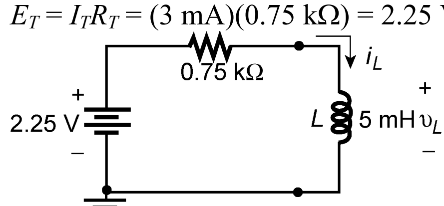
$I_T = 5\text{ mA} - 2\text{ mA} = 3\text{ mA}\uparrow$

$$\frac{1}{R_T} = \frac{1}{12\text{ k}\Omega} + \frac{1}{3\text{ k}\Omega} + \frac{1}{4\text{ k}\Omega} + \frac{1}{1.5\text{ k}\Omega}$$

and $R_T = 0.75\text{ k}\Omega$

Source conversion:

$E_T = I_T R_T = (3\text{ mA})(0.75\text{ k}\Omega) = 2.25\text{ V}$



$$\tau = \frac{L}{R} = \frac{5\text{ mH}}{0.75\text{ k}\Omega} = 6.67\ \mu\text{s}$$

$$i_L = \frac{2.25\text{ V}}{0.75\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{3\text{ mA}(1 - e^{-t/6.67\ \mu s})}$$

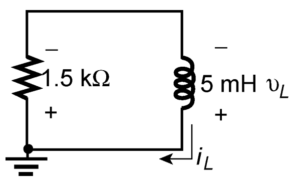
$\upsilon_L = \mathbf{2.25\text{ V}e^{-t/6.67\ \mu s}}$

b. 2τ: 0.865 I_m, 0.135 V_m

i_L: 0.865(3 mA) = **2.60 mA**

υ_L: 0.135(2.25 V) = **0.30 V**

c.



$$\tau' = \frac{L}{R} = \frac{5\text{ mH}}{1.5\text{ k}\Omega} = 3.33\ \mu\text{s}$$

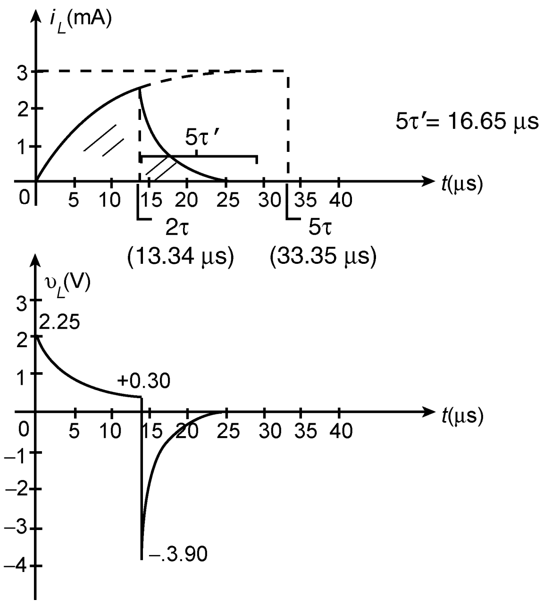
$i_L = \mathbf{2.60\ mA}\ e^{-t/3.33\ \mu s}$

$i_L(0+) = 2.60$ mA

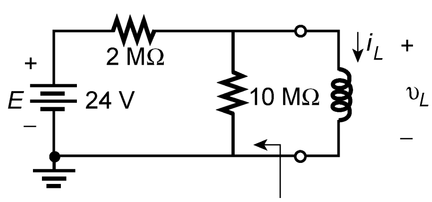
$\upsilon_R(0+) = (2.60\text{ mA})(1.5\text{ k}\Omega) = 3.90$ V

$\upsilon_L = \mathbf{-3.90\ V}e^{-t/3.33\ \mu s}$

d.



28. a.



$R_{\text{Th}} = 2\text{ M}\Omega \parallel 10\text{ M}\Omega = 1.67\text{ M}\Omega$

$$E_{Th} = \frac{10\text{ M}\Omega(24\text{ V})}{10\text{ M}\Omega + 2\text{ M}\Omega} = 20\text{ V}$$

$$I_L(0^-) = \frac{E_{Th}}{R_{Th}} = \frac{20\text{ V}}{1.67\text{ M}\Omega} = \mathbf{12\ \mu A}$$

$$\tau' = \frac{L}{R_{\text{meter}}} = \frac{5\text{ H}}{10\text{ M}\Omega} = 5\mu\text{s}$$

$i_L = 12\ \mu\text{A}e^{-t/5\ \mu s}$

$10\ \mu\text{A} = 12\ \mu\text{A}e^{-t/5\ \mu s}$

$0.833 = e^{-t/5\ \mu s}$

$\log_e 0.833 = -t/5\ \mu\text{s}$

$0.183 = t/5\ \mu s$

$t = 0.183(5\ \mu s) = \mathbf{0.92\ \mu s}$

b. $\upsilon_L\,(0^+) = i_L(0^+)R_m = (12\ \mu A)(10\ M\Omega) = 120\ V$

$\upsilon_L = 120\ Ve^{-t/5\mu s} = 120\ Ve^{-10\mu s/5\mu s} = 120\ Ve^{-2} = 120\ V(0.135) = \mathbf{16.2\ V}$

c. $\upsilon_L = 120\ Ve^{-5\tau/\tau} = 120\ Ve^{-5} = 120\ V(6.74 \times 10^{-3}) = \mathbf{0.81\ V}$

29. a. $I_i = -\dfrac{24\ V}{2.2\ k\Omega} = -10.91\ mA$

Switch open: $I_f = -\dfrac{24\ V}{2.2\ k\Omega + 4.7\ k\Omega} = -\dfrac{24\ V}{6.9\ k\Omega} = -3.48\ mA$

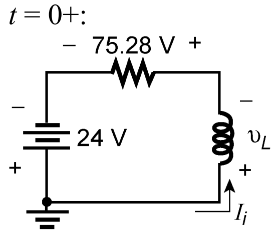
$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$\tau = \dfrac{L}{R} = \dfrac{1.2\ H}{6.9\ k\Omega} = 173.9\ \mu s$

$i_L = -3.48\ mA + (-10.91\ mA - (-3.48\ mA))e^{-t/173.9\ \mu s}$

$i_L = \mathbf{-3.48\ mA - 7.43\ mA}e^{-t/173.9\ \mu s}$

$t = 0+$:



$\upsilon_R(0+) = (10.91\ mA)(6.9\ k\Omega) = 75.28\ V$

KVL: $-24\ V + 75.28\ V - \upsilon_L = 0$

$\upsilon_L = 51.28\ V$

$\upsilon_L = \mathbf{51.28\ V}e^{-t/173.9\ \mu s}$

30. a. $i_L = 100\ mA(1 - e^{-1ms/20ms}) = 100\ mA(1 - e^{-1/20})$

$= 100\ mA(1 - e^{-0.05}) = 100\ mA(1 - 951.23 \times 10^{-3}) = 100\ mA(48.77 \times 10^{-3})$

$= \mathbf{4.88\ mA}$

b. $i_L = 100\ mA(1 - e^{-100ms/20ms}) = 100\ mA(1 - e^{-5})$

$= \mathbf{99.33\ mA}$

c. $50\ mA = 100\ mA(1 - e^{-t/\tau})$

$0.5 = 1 - e^{-t/\tau}$

$-0.5 = -e^{-t/\tau}$

$0.5 = e^{-t/\tau}$

$\log_e 0.5 = -t/\tau$

$t = -(\tau)(\log_e 0.5) = -(20\ ms)(\log_e 0.5) = -(20\ ms)(-693.15 \times 10^{-3})$

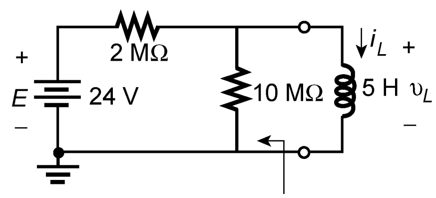
$= \mathbf{13.86\ ms}$

d. $$99\text{ mA} = 100\text{ mA}(1 - e^{-t/20\text{ ms}})$$
$$0.99 = 1 - e^{-t/20\text{ms}}$$
$$-0.01 = -e^{-t/20\text{ms}}$$
$$0.01 = e^{-t/20\text{ms}}$$
$$\log_e 0.01 = -t/20\text{ ms}$$
$$t = -(20\text{ ms})(\log_e 0.01) = -(20\text{ ms})(-4.605) = \mathbf{92.1ms}$$

31. a. $L \Rightarrow$ open circuit equivalent

$$V_L = \frac{10\text{ M}\Omega(24\text{ V})}{10\text{ M}\Omega + 2\text{ M}\Omega} = \mathbf{20\text{ V}}$$

b.



$$R_{Th} = 2\text{ M}\Omega \parallel 10\text{ M}\Omega = 1.67\text{ M}\Omega$$
$$E_{Th} = \frac{10\text{ M}\Omega(24\text{ V})}{10\text{ M}\Omega + 2\text{ M}\Omega} = 20\text{ V}$$

$$I_{L_{\text{final}}} = \frac{E_{Th}}{R_{Th}} = \frac{20\text{ V}}{1.67\text{ M}\Omega} = \mathbf{12\ \mu A}$$

c. $$i_L = 12\ \mu\text{A}(1 - e^{-t/3\ \mu\text{s}}) \qquad \tau = \frac{L}{R} = \frac{5\text{ H}}{1.67\text{ M}\Omega} = 3\ \mu\text{s}$$

$$10\ \mu\text{A} = 12\ \mu\text{A}(1 - e^{-t/3\ \mu\text{s}})$$
$$0.8333 = 1 - e^{-t/3\ \mu\text{s}}$$
$$0.1667 = e^{-t/3\ \mu\text{s}}$$
$$\log_e(0.1667) = -t/3\ \mu\text{s}$$
$$1.792 = t/3\ \mu\text{s}$$
$$t = 1.792(3\ \mu\text{s}) = \mathbf{5.38\ \mu s}$$

d. $$\upsilon_L = 20\text{ V } e^{-t/3\ \mu\text{s}} = 20\text{ V } e^{-12\ \mu\text{s}/3\ \mu\text{s}} = 20\text{ V } e^{-4}$$
$$= 20\text{ V}(0.0183) = \mathbf{0.37\text{ V}}$$

32. $e_L = L\dfrac{\Delta i}{\Delta t}$: $0 - 3$ ms, $e_L = \mathbf{0\text{ V}}$

$$3 - 8\text{ ms},\ e_L = (200\text{ mH})\left(\frac{40\times10^{-3}\text{ A}}{5\times10^{-3}\text{ s}}\right) = \mathbf{1.6\text{ V}}$$

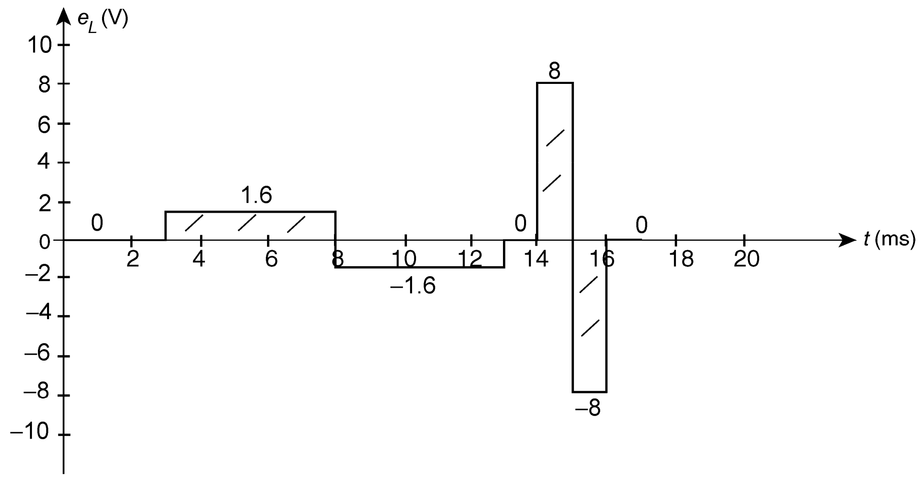
$$8 - 13\text{ ms},\ e_L = -(200\text{ mH})\left(\frac{40\times10^{-3}\text{ A}}{5\times10^{-3}\text{ s}}\right) = \mathbf{-1.6\text{ V}}$$

$13 - 14$ ms, $e_L = \mathbf{0\text{ V}}$

$$14 - 15\text{ ms},\ e_L = (200\text{ mH})\left(\frac{40\times10^{-3}\text{ A}}{5\times10^{-3}\text{ s}}\right) = \mathbf{8\text{ V}}$$

$15 - 16$ ms, $e_L = \mathbf{-8\ V}$

$16 - 17$ ms, $e_L = \mathbf{0\ V}$



33. $\upsilon_L = L\dfrac{\Delta i_L}{\Delta t}$

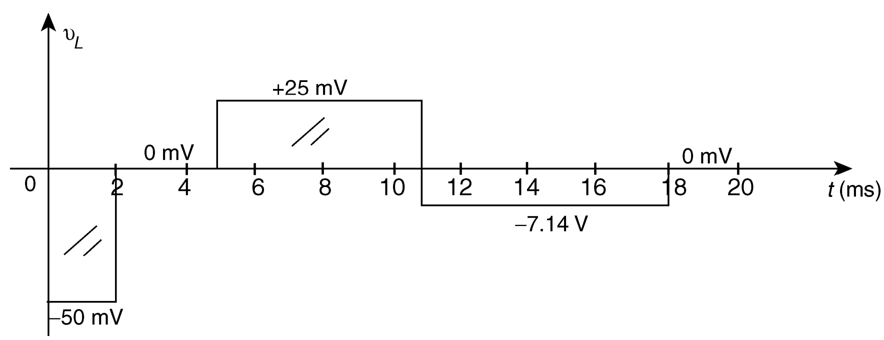
$0 \to 2$ ms: $\upsilon_L = (5\text{ mH})\left(-\dfrac{20\text{ mA}}{2\text{ ms}}\right) = \mathbf{-50\ mV}$

$2 \to 5$ ms: $\Delta i_L = 0$ mA, $\upsilon_L = 0$ V

$5 \to 11$ ms: $\upsilon_L = (5\text{ mH})\left(\dfrac{+30\text{ mA}}{6\text{ ms}}\right) = \mathbf{+25\ mV}$

$11 \to 18$ ms: $\upsilon_L = (5\text{ mH})\left(\dfrac{-10\text{ mA}}{7\text{ ms}}\right) = \mathbf{-7.14\ V}$

$18 \to$: $\Delta i_L = 0$ mA, $\upsilon_L = \mathbf{0\ V}$



34. $L = 10$ mH, 4 mA at $t = 0$ s

$\upsilon_L = L\dfrac{\Delta i}{\Delta t} \Rightarrow \Delta i = \dfrac{\Delta t}{L}\upsilon_L$

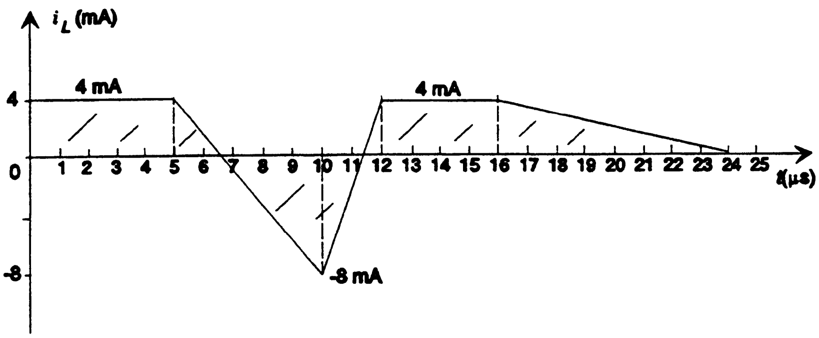
$0 - 5\ \mu$s: $\upsilon_L = 0$ V, $\Delta i_L = 0$ mA and $i_L = \mathbf{4\ mA}$

$5 - 10\ \mu$s: $\Delta i_L = \dfrac{5\ \mu\text{s}}{10\text{ mH}}(-24\text{ V}) = \mathbf{-12\ mA}$

$10 - 12\ \mu\text{s}$: $\Delta i_L = \dfrac{2\ \mu\text{s}}{10\ \text{mH}}(+60\ \text{V}) = \mathbf{+12\ mA}$

$12 - 16\ \mu\text{s}$: $\upsilon_L = 0\ \text{V}$, $\Delta i_L = 0$ mA and $i_L = \mathbf{4\ mA}$

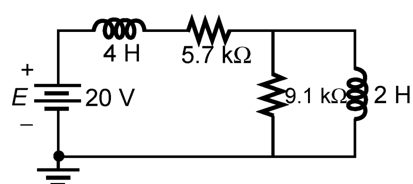
$16 - 24\ \mu\text{s}$: $\Delta i_L = \dfrac{8\ \mu\text{s}}{10\ \text{mH}}(-5\ \text{V}) = \mathbf{-4\ mA}$



35. a. $L_T = L_1 + L_2 \parallel (L_3 + L_4) = 6\ \text{H} + 6\ \text{H} \parallel (6\ \text{H} + 6\ \text{H})$
$= 6\ \text{H} + 6\ \text{H} \parallel 12\ \text{H} = 6\ \text{H} + 4\ \text{H} = \mathbf{10\ H}$

b. $L_T = (L_1 + L_2 \parallel L_3) \parallel L_4 = (4\ \text{H} + 4\ \text{H} \parallel 4\ \text{H}) \parallel 4\ \text{H}$
$= (4\ \text{H} + 2\ \text{H}) \parallel 4\ \text{H} = 6\ \text{H} \parallel 4\ \text{H} = \mathbf{2.4\ H}$

36. $L'_T = 6\ \text{H} \parallel (1\ \text{H} + 2\ \text{H}) = 6\ \text{H} \parallel 3\ \text{H} = 2\ \text{H}$



37. $L'_T = 6\ \text{mH} + 14\ \text{mH} \parallel 35\ \text{mH} = 6\ \text{mH} + 10\ \text{mH} = \mathbf{16\ mH}$
$C'_T = 9\ \mu\text{F} + 10\ \mu\text{F} \parallel 90\ \mu\text{F} = 9\ \mu\text{F} + 9\ \mu\text{F} = \mathbf{18\ \mu F}$
16 mH in series with 18 μF

38. a. $R'_T = 2\ \text{k}\Omega \parallel 8\ \text{k}\Omega = 1.6\ \text{k}\Omega$, $L'_T = 4\ \text{H} \parallel 6\ \text{H} = 2.4\ \text{H}$

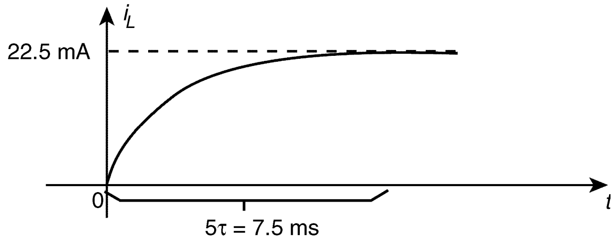
$$\tau = \frac{L'_T}{R'_T} = \frac{2.4\ \text{H}}{1.6\ \text{k}\Omega} = 1.5\ \text{ms}$$

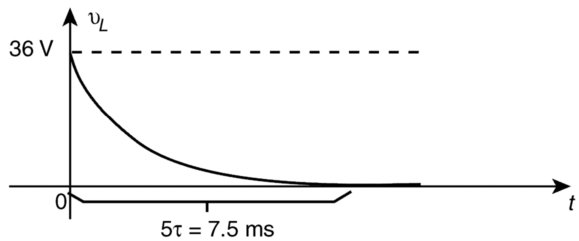
$$i_L = \frac{E}{R'_T}(1 - e^{-t/\tau})$$

$$= \frac{36\ \text{V}}{1.6\ \text{k}\Omega}(1 - e^{-t/1.5\text{ms}}) = \mathbf{22.5\ mA(1 - e^{-t/1.5ms})}$$

$\upsilon_L = Ee^{-t/\tau} = \mathbf{36\ V}\boldsymbol{e}^{-t/1.5\text{ms}}$

b.





39. a. Source conversion: $E = 16$ V, $R_s = 2$ kΩ

$R_{Th} = 2\text{ k}\Omega + 2\text{ k}\Omega \parallel 8\text{ k}\Omega = 2\text{ k}\Omega + 16\text{ k}\Omega = 3.6\text{ k}\Omega$

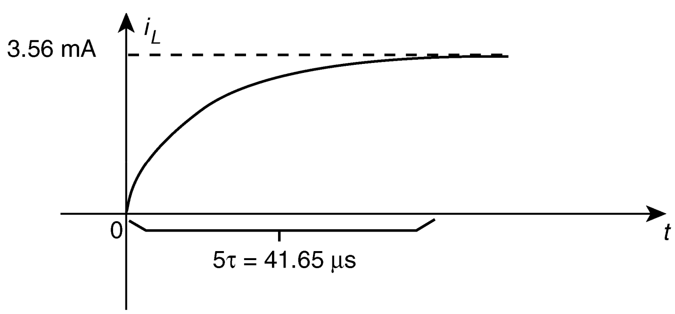
$$E_{Th} = \frac{8\text{ k}\Omega(16\text{ V})}{8\text{ k}\Omega + 2\text{ k}\Omega} = 12.8\text{ V}$$

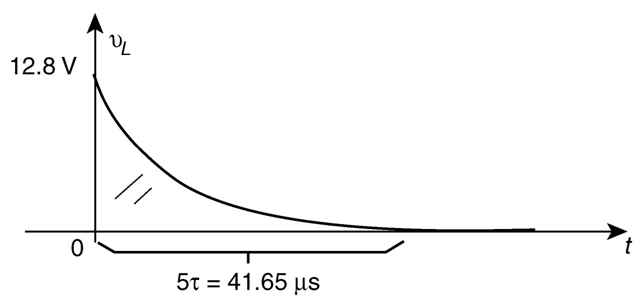
$$I_m = \frac{E_{Th}}{R_{Th}} = \frac{12.8\text{ V}}{3.6\text{ k}\Omega} = 3.56\text{ mA}, \quad \tau = \frac{L}{R} = \frac{30\text{ mH}}{3.6\text{ k}\Omega} = 8.33\ \mu\text{s}$$

$i_L = \mathbf{3.56\ mA(1 - e^{-t/8.33\mu s})}$

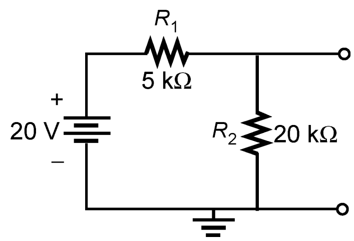
$\upsilon_L = E_{Th}e^{-t/\tau} = \mathbf{12.8\ Ve^{-t/8.33\mu s}}$

b.





40. a.



$\leftarrow R_{Th} = 5\text{ k}\Omega \parallel 20\text{ k}\Omega = 4\text{ k}\Omega$

$$E_{Th} = \frac{20\text{ k}\Omega(20\text{ V})}{20\text{ k}\Omega + 5\text{ k}\Omega} = 16\text{ V}$$

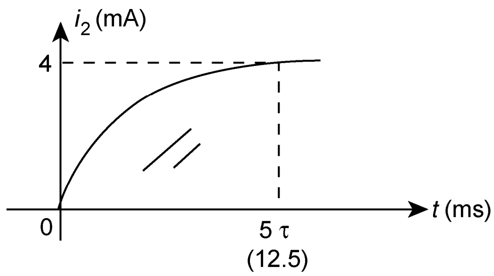
$L_T = 5\text{ H} + 6\text{ H} \parallel 30\text{ H} = 5\text{ H} + 5\text{ H} = \mathbf{10\text{ H}}$

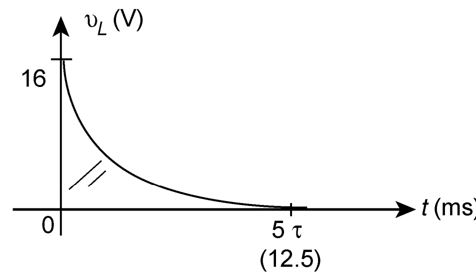
$$\tau = \frac{L_T}{R} = \frac{10\text{ H}}{4\text{ k}\Omega} = 2.5\text{ ms}$$

$\upsilon_L = \mathbf{16V}\boldsymbol{e^{-t/2.5\text{ ms}}}$

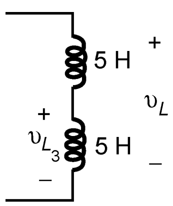
$$i_L = \frac{16\text{ V}}{4\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{4\text{ mA}(1 - e^{-t/2.5\text{ ms}})}$$

b.





c.



$$\upsilon_{L_3} = \frac{\upsilon_L}{2} = \mathbf{8\text{ V}\,e^{-t/2.5\text{ ms}}}$$

41. $$I_{R_1} = \frac{E}{R_1} = \frac{20\text{ V}}{4\,\Omega} = 5\text{ A}$$

$$I_2 = I_{R_2} = \frac{E}{R_2 + R_3} = \frac{20\text{ V}}{6\,\Omega + 4\,\Omega} = \frac{20\text{ V}}{10\,\Omega} = \mathbf{2\text{ A}}$$

$I_1 = I_{R_1} + I_2 = 5\text{ A} + 2\text{ A} = \mathbf{7\text{ A}}$

42. $I_1 = I_2 = \mathbf{0\text{ A}}$
$V_1 = V_2 = E = \mathbf{60\text{ V}}$

43. $I_1 = \dfrac{12\text{ V}}{4\,\Omega} = \mathbf{3\text{ A}},\ I_2 = \mathbf{0\text{ A}}$
$V_1 = \mathbf{12\text{ V}},\ V_2 = \mathbf{0\text{ V}}$

44. $V_1 = \dfrac{(3\ \Omega + 3\ \Omega \parallel 6\ \Omega)(50\ \text{V})}{(3\ \Omega + 3\ \Omega \parallel 6\ \Omega) + 20\ \Omega} = \dfrac{(3\ \Omega + 2\ \Omega)(50\ \text{V})}{(3\ \Omega + 2\ \Omega) + 20\ \Omega} = \mathbf{10\ V}$

$R_T = 20\ \Omega + 3\ \Omega + 3\ \Omega \parallel 6\ \Omega = 23\ \Omega + 2\ \Omega = 25\ \Omega$

$I_s = I_1 = \dfrac{50\ \text{V}}{25\ \Omega} = \mathbf{2\ A}$

$I_{5\Omega} = 0\ \text{A},\ \therefore\ I_2 = \dfrac{6\ \Omega(I_s)}{6\ \Omega + 3\ \Omega} = \dfrac{6\ \Omega(2\ \text{A})}{6\ \Omega + 3\ \Omega} = \mathbf{1.33\ A}$

$V_2 = \dfrac{(3\ \Omega \parallel 6\ \Omega)(50\ \text{V})}{(3\ \Omega \parallel 6\ \Omega) + 20\ \Omega + 3\ \Omega} = \dfrac{2\ \Omega(50\ \text{V})}{2\ \Omega + 23\ \Omega}$

$= \mathbf{4\ V}$

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. $B = \dfrac{\Phi}{A} = \dfrac{4\times10^{-4}\text{ Wb}}{0.01\text{ m}^2} = \mathbf{0.04\ T}$

4. a. $\Re = \dfrac{l}{\mu A} = \dfrac{0.06\text{ m}}{\mu 2\times10^{-4}\text{ m}^2} = \dfrac{300}{\mu\text{m}}$

   b. $\Re = \dfrac{l}{\mu A} = \dfrac{0.0762\text{ m}}{\mu 5\times10^{-4}\text{ m}^2} = \dfrac{152.4}{\mu\text{m}}$

   c. $\Re = \dfrac{l}{\mu\text{A}} = \dfrac{0.1\text{ m}}{\mu 1\times10^{-4}\text{ m}^2} = \dfrac{1000}{\mu\text{m}}$

   from the above $\Re_{(c)} > \Re_{(a)} > \Re_{(b)}$

5. $\Re = \dfrac{\mathscr{F}}{\Phi} = \dfrac{400\text{ At}}{4.2\times10^{-4}\text{ Wb}} = \mathbf{952.4 \times 10^3\ At/Wb}$

6. $\Re = \dfrac{\mathscr{F}}{\Phi} = \dfrac{120\text{ gilberts}}{72{,}000\text{ maxwells}} = \mathbf{1.67 \times 10^{-3}\ rels\ (CGS)}$

7. $6\ \cancel{\text{in.}}\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.1524\text{ m}$

   $H = \dfrac{\mathscr{F}}{l} = \dfrac{400\text{ At}}{0.1524\text{ m}} = \mathbf{2624.67\ At/m}$

8. $\mu = \dfrac{2B}{H} = \dfrac{2(1200\times10^{-4}\text{ T})}{600\text{ At/m}} = \mathbf{4 \times 10^{-4}\ Wb/Am}$

9. $B = \dfrac{\Phi}{A} = \dfrac{10\times10^{-4}\text{ Wb}}{3\times10^{-3}\text{ m}^2} = 0.33\text{ T}$
   Fig. 12.7: $H \cong 800$ At/m
   $NI = Hl \Rightarrow I = Hl/N = (800\text{ At/m})(0.2\text{ m})/75\text{ t} = \mathbf{2.13\ A}$

10. $B = \dfrac{\Phi}{A} = \dfrac{3\times10^{-4}\text{ Wb}}{5\times10^{-4}\text{ m}^2} = 0.6\text{ T}$

Fig. 12.7, H_{iron} = 2500 At/m

Fig. 12.8, H_{steel} = 70 At/m

$NI = Hl_{(iron)} + Hl_{(steel)}$

$(100\text{ t})I = (H_{iron} + H_{steel})l$

$(100\text{ t})I = (2500\text{ At/m} + 70\text{ At/m})0.3\text{ m}$

$I = \dfrac{771\text{ A}}{100} = \mathbf{7.71\text{ A}}$

11. a. $N_1I_1 + N_2I_2 = Hl$

$B = \dfrac{\Phi}{A} = \dfrac{12\times10^{-4}\text{ Wb}}{12\times10^{-4}\text{ m}^2} = 1\text{ T}$

Fig. 12.7: $H \cong 750$ 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. $\mu = \dfrac{B}{H} = \dfrac{1\text{ T}}{750\text{ At/m}} = \mathbf{13.34\times10^{-4}\text{ Wb/Am}}$

12. a. $80{,}000\ \cancel{\text{lines}}\left[\dfrac{1\text{ Wb}}{10^8\ \cancel{\text{lines}}}\right] = 8\times10^4\times10^{-8}\text{ Wb} = 8\times10^{-4}\text{ Wb}$

$l_{(cast\ steel)} = 5.5\ \cancel{\text{in.}}\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.14\text{ m}$

$l_{(sheet\ steel)} = 0.5\ \cancel{\text{in.}}\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.013\text{ m}$

$\text{Area} = 1\ \cancel{\text{in.}}^2\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right]\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 6.45\times10^{-4}\text{ m}^2$

$B = \dfrac{\Phi}{A} = \dfrac{8\times10^{-4}\text{ Wb}}{6.45\times10^{-4}\text{ m}^2} = 1.24\text{ T}$

Fig 12.8: $H_{sheet\ steel} \cong 460$ At/m, Fig. 12.7: $H_{cast\ steel} \cong 1275$ At/m

$NI = Hl_{(sheet\ steel)} + Hl_{(cast\ iron)}$

$= (460\text{ At/m})(0.013\text{ m}) + (1275\text{ At/m})(0.14\text{ m})$

$= 5.98\text{ At} + 178.50\text{ At}$

$NI = \mathbf{184.48\text{ At}}$

b. Cast steel: $\mu = \dfrac{B}{H} = \dfrac{1.24\text{ T}}{1275\text{ At/m}} = \mathbf{9.73\times10^{-4}\text{ Wb/Am}}$

Sheet steel: $\mu = \dfrac{B}{H} = \dfrac{1.24\text{ T}}{460\text{ At/m}} = \mathbf{26.96\times10^{-4}\text{ Wb/Am}}$

13. $N_1I + N_2 = \underbrace{Hl}_{\text{cast steel}} + \underbrace{Hl}_{\text{cast iron}}$

$(20\text{ t})I + (30\text{ t})I = $ "

$(50\text{ t})I = $ "

$$B = \frac{\Phi}{A} \text{ with } 0.25\ \cancel{\text{in.}}^2 \left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right]\left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 1.6 \times 10^{-4}\text{ m}^2$$

$$B = \frac{0.8 \times 10^{-4}\text{ Wb}}{1.6 \times 10^{-4}\text{ m}^2} = 0.5\text{ T}$$

Fig. 12.8: $H_{\text{cast steel}} \cong 280$ At/m

Fig. 12.7: $H_{\text{cast iron}} \cong 1500$ At/m

$$l_{\text{cast steel}} = 5.5\ \cancel{\text{in.}}\left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.14\text{ m}$$

$$l_{\text{cast iron}} = 2.5\ \cancel{\text{in.}}\left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.064\text{ m}$$

$(50\text{ t})I = (280\text{ At/m})(0.14\text{ m}) + (1500\text{ At/m})(0.064\text{ m})$

$50I = 39.20 + 96.00 = 135.20$

$I = \mathbf{2.70\ A}$

14. a. $l_{ab} = l_{ef} = 0.05$ m, $l_{af} = 0.02$ m, $l_{bc} = l_{de} = 0.0085$ m

$NI = 2H_{ab}l_{ab} + 2H_{bc}l_{bc} + H_{fa}l_{fa} + H_gl_g$

$$B = \frac{\Phi}{A} = \frac{2.4 \times 10^{-4}\text{ Wb}}{2 \times 10^{-4}\text{ m}^2} = 1.2\text{ T} \Rightarrow H \cong 360\text{ At/m (Fig. 12.8)}$$

$100I = 2(360\text{ At/m})(0.05\text{ m}) + 2(360\text{ At/m})(0.0085\text{ m})$
$+ (360\text{ At/m})(0.02\text{ m}) + 7.97 \times 10^5(1.2\text{ T})(0.003\text{ m})$
$= 36\text{ At} + 6.12\text{ At} + 7.2\text{ At} + 2869\text{ At}$

$100I = 2918.32$ At

$I \cong \mathbf{29.18\ A}$

b. air gap: metal = 2869 At:49.72 At = **58.17:1**

$$\mu_{\text{sheet steel}} = \frac{B}{H} = \frac{1.2\text{ T}}{360\text{ At/m}} = \mathbf{3.33 \times 10^{-3}\ Wb/Am}$$

$\mu_{\text{air}} = \mathbf{4\pi \times 10^{-7}\ Wb/Am}$

$\mu_{\text{sheet steel}}\mathbf{:}\ \mu_{\text{air}} = 3.33 \times 10^{-3}\text{ Wb/Am}\mathbf{:}4\pi \times 10^{-7} \cong \mathbf{2627:1}$

15. $4\ \cancel{\text{cm}}\left[\frac{1\text{ m}}{100\ \cancel{\text{cm}}}\right] = 0.04\text{ m}$

$$f = \frac{1}{2}NI\frac{d\phi}{dx} = \frac{1}{2}(80\text{ t})(0.9\text{ A})\frac{(8 \times 10^{-4}\text{ Wb} - 0.5 \times 10^{-4}\text{ Wb})}{\frac{1}{2}(0.04\text{ m})} = \frac{36(7.5 \times 10^{-4})}{0.02}$$

$= \mathbf{1.35\ N}$

16. $C = 2\pi r = (6.28)(0.3\text{ m}) = 1.88\text{ m}$

$$B = \frac{\Phi}{A} = \frac{2\times10^{-4}\text{ Wb}}{1.3\times10^{-4}\text{ m}^2} = 1.54\text{ T}$$

Fig. 12.7: $H_{\text{sheet steel}} \cong 2100\text{ At/m}$

$H_g = 7.97\times10^5 B_g = (7.97\times10^5)(1.54\text{ T}) = 1.23\times10^6\text{ At/m}$

$N_1I_1 + N_2I_2 = H_gl_g + Hl_{(\text{sheet steel})}$

$(200\text{ t})I_1 + (40\text{ t})(0.3\text{ A}) = (1.23\times10^6\text{ At/m})(2\text{ mm}) + (2100\text{ At/m})(1.88\text{ m})$

$I_1 = \mathbf{31.98\text{ A}}$

17. a. $0.2\,\cancel{\text{cm}}\left[\dfrac{1\text{ m}}{100\,\cancel{\text{cm}}}\right] = 2\times10^{-3}\text{ m}$

$$A = \frac{\pi d^2}{4} = \frac{(3.14)(0.01\text{ m})^2}{4} = 0.79\times10^{-4}\text{ m}^2$$

$NI = H_gl_g,\ H_g = 7.96\times10^5\,B_g$

$$(200\text{ t})I = \left[(7.96\times10^5)\left(\frac{0.2\times10^{-4}\text{ Wb}}{0.79\times10^{-4}\text{ m}^2}\right)\right]2\times10^{-3}\text{ m}$$

$I = \mathbf{2.02\text{ A}}$

b. $$B_g = \frac{\Phi}{A} = \frac{2\times10^{-4}\text{ Wb}}{0.79\times10^{-4}\text{ m}^2} = 0.25\text{ T}$$

$$F \cong \frac{1}{2}\frac{B_g^2A}{\mu_o} = \frac{1}{2}\frac{(0.25\text{ T})^2(0.79\times10^{-4}\text{ m}^2)}{4\pi\times10^{-7}}$$

$\cong$ **2 N**

18. **Table:**

Section	Φ(Wb)	A(m²)	*B*(T)	*H*	*l*(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	

$B_{bc} = B_{cd} = B_g = B_{ef} = B_{fg} = \dfrac{\Phi}{A} = \dfrac{2\times10^{-4}\ \text{Wb}}{5\times10^{-4}\ \text{m}^2} = 0.4\ \text{T}$

Air gap: $H_g = 7.97 \times 10^5(0.4\ \text{T}) = 3.19 \times 10^5\ \text{At/m}$

$H_g l_g = (3.19 \times 10^5\ \text{At/m})(2\ \text{mm}) = 638\ \text{At}$

Fig 12.8: $H_{bc} = H_{cd} = H_{ef} = H_{fg} = 55\ \text{At/m}$

$H_{bc}l_{bc} = H_{fg}l_{fg} = (55\ \text{At/m})(0.1\ \text{m}) = 5.5\ \text{At}$

$H_{cd}l_{cd} = H_{ef}l_{ef} = (55\ \text{At/m})(0.099\ \text{m}) = 5.45\ \text{At}$

For loop 2: $\sum \mathscr{F} = 0$

$H_{bc}l_{bc} + H_{cd}l_{cd} + H_g l_g + H_{ef}l_{ef} + H_{fg}l_{fg} - H_{gb}l_{gb} = 0$

$5.5\ \text{At} + 5.45\ \text{At} + 638\ \text{At} + 5.45\ \text{At} + 5.50\ \text{At} - H_{gb}l_{gb} = 0$

$H_{gb}l_{gb} = 659.90\ \text{At}$

and $H_{gb} = \dfrac{659.90\ \text{At}}{0.2\ \text{m}} = 3300\ \text{At/m}$

Fig 12.7: $B_{gb} \cong 1.55\ \text{T}$

with $\Phi_2 = B_{gb}A = (1.55\ \text{T})(2 \times 10^{-4}\ \text{m}^2) = 3.1 \times 10^{-4}\ \text{Wb}$

$\Phi_T = \Phi_1 + \Phi_2$

$= 2 \times 10^{-4}\ \text{Wb} + 3.1 \times 10^{-4}\ \text{Wb}$

$= 5.1 \times 10^{-4}\ \text{Wb} = \Phi_{ab} = \Phi_{ha} = \Phi_{gh}$

$B_{ab} = B_{ha} = B_{gh} = \dfrac{\Phi_T}{A} = \dfrac{5.1\times10^{-4}\ \text{Wb}}{5\times10^{-4}\ \text{m}^2} = 1.02\ \text{T}$

B–H curve: (Fig 12.8):

$H_{ab} = H_{ha} = H_{gh} \cong 180\ \text{At/m}$

$H_{ab}l_{ab} = (180\ \text{At/m})(0.2\ \text{m}) = 36\ \text{At}$

$H_{ha}l_{ha} = (180\ \text{At/m})(0.2\ \text{m}) = 36\ \text{At}$

$H_{gh}l_{gh} = (180\ \text{At/m})(0.2\ \text{m}) = 36\ \text{At}$

which **completes** the table!

Loop #1: $\sum \mathscr{F} = 0$

$NI = H_{ab}l_{ab} + H_{bg}l_{bg} + H_{gh}l_{gh} + H_{ah}l_{ah}$

$(200\ \text{t})I = 36\ \text{At} + 659.49\ \text{At} + 36\ \text{At} + 36\ \text{At}$

$(200\ \text{t})I = 767.49\ \text{At}$

$I \cong$ **3.84 A**

19. $NI = Hl$

$l = 2\pi r = (6.28)(0.08\ \text{m}) = 0.50\ \text{m}$

$(100\ \text{t})(2\ \text{A}) = H(0.50\ \text{m})$

$H = 400\ \text{At/m}$

Fig. 12.8: $B \cong 0.68\ \text{T}$

$\Phi = BA = (0.68\ \text{T})(0.009\ \text{m}^2)$

$\Phi =$ **6.12 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)
$300 \text{ At} = (270 \text{ At/m})(0.8 \text{ m}) + 637.6(0.47 \text{ T})$
$300 \text{ At} \neq 515.67 \text{ At}$
$\therefore$ Poor approximation!
$\dfrac{300 \text{ At}}{515.67 \text{ At}} \times 100\% \cong 58\%$
Reduce Φ to 58%
$0.58(0.94 \times 10^{-4} \text{ Wb}) = 0.55 \times 10^{-4} \text{ Wb}$
$B = \dfrac{\Phi}{A} = \dfrac{0.55 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{ m}^2} = 0.28 \text{ T} \Rightarrow H \cong 190 \text{ At/m}$ (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 $10\% = 0.55 \times 10^{-4} \text{ Wb} - 0.1(0.55 \times 10^{-4} \text{ Wb})$
$= 0.495 \times 10^{-4} \text{ Wb}$
$B = \dfrac{\Phi}{A} = \dfrac{0.495 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{m}^2} = 0.25 \text{ T} \Rightarrow H \cong 175 \text{ At/m}$ (Fig. 12.7)
$300 \text{ At} = (175 \text{ At/m})(0.8) + 637.6(0.28 \text{ T})$
$300 \text{ At} \neq 318.53 \text{ At}$ but within 5% $\therefore$ OK
$\Phi \cong \mathbf{0.55 \times 10^{-4}\ Wb}$

21. a. $1\tau = 0.632 \text{ T}_{max}$
$\text{T}_{max} \cong 1.5 \text{ T}$ 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)
$\therefore \boldsymbol{B = 1.5\ \mathrm{T}(1 - e^{-H/700\ \mathrm{At/m}})}$

b. $H = 900 \text{ At/m}$:
$B = 1.5 \text{ T}\left(1 - e^{-\frac{900 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.09\ T}$
Graph: $\cong$ **1.1 T**
$H = 1800 \text{ At/m}$:
$B = 1.5 \text{ T}\left(1 - e^{-\frac{1800 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.39\ T}$
Graph: $\cong$ **1.38 T**
$H = 2700 \text{ At/m}$:
$B = 1.5\left(1 - e^{-\frac{2700 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.47\ T}$
Graph: $\cong$ **1.47 T**
Excellent comparison!

c. $B = 1.5\ \text{T}(1 - e^{-H/700\ \text{At/m}}) = 1.5\ \text{T} - 1.5\ \text{T}e^{-H/700\ \text{At/m}}$

$B - 1.5\ \text{T} = -1.5\ \text{T}e^{-H/700\ \text{At/m}}$

$1.5 - B = 1.5\ \text{T}e^{-H/700\ \text{At/m}}$

$$\frac{1.5\ \text{T} - B}{1.5\ \text{T}} = e^{-H/700\ \text{At/m}}$$

$$\log_e\left(1 - \frac{B}{1.5\ \text{T}}\right) = \frac{-H}{700\ \text{At/m}}$$

and $H = -700 \log_e\left(1 - \dfrac{B}{1.5\ \text{T}}\right)$

d. $B = 1$ T:

$$H = -700 \log_e\left(1 - \frac{1\ \text{T}}{1.5\ \text{T}}\right) = \mathbf{769.03\ At/m}$$

Graph: $\cong$ **750 At/m**

$B = 1.4$ T:

$$H = -700 \log_e\left(1 - \frac{1.4\ \text{T}}{1.5\ \text{T}}\right) = \mathbf{1895.64\ At/m}$$

Graph: $\cong$ **1920 At/m**

e. $H = -700 \log_e\left(1 - \dfrac{B}{1.5\ \text{T}}\right)$

$= -700 \log_e\left(1 - \dfrac{0.2\ \text{T}}{1.5\ \text{T}}\right)$

$= 100.2$ At/m

$$I = \frac{Hl}{N} = \frac{(100.2\ \text{At/m})(0.16\ \text{m})}{400\ \text{t}} = \mathbf{40.1\ mA}$$

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 μs: **40 V**, 11 μs: **–40 V**
   c. **80 V**
   d. **4 μs**
   e. **3 cycles**

3. a. **8 mV**
   b. 3 μs: **–8 mV**, 9 μs: **0 mV**
   c. **16 mV**
   d. **4.5 μs**
   e. $\dfrac{10\ \mu\text{S}}{4.5\ \mu\text{S/cycle}} = \mathbf{2.22\ cycles}$

4. a. $T = \dfrac{1}{f} = \dfrac{1}{25\text{ Hz}} = \mathbf{40\ ms}$
   b. $T = \dfrac{1}{f} = \dfrac{1}{40\text{ mHz}} = \mathbf{25\ ns}$
   c. $T = \dfrac{1}{f} = \dfrac{1}{25\text{ kHz}} = \mathbf{40\ \mu s}$
   d. $T = \dfrac{1}{f} = \dfrac{1}{1\text{ Hz}} = \mathbf{1\ s}$

5. a. $f = \dfrac{1}{T} = \dfrac{0}{\frac{1}{60}\text{ s}} = \mathbf{60\ Hz}$
   b. $f = \dfrac{1}{T} = \dfrac{1}{0.01\text{ s}} = \mathbf{100\ Hz}$
   c. $f = \dfrac{1}{T} = \dfrac{1}{40\text{ ms}} = \mathbf{25\ Hz}$
   d. $f = \dfrac{1}{T} = \dfrac{1}{25\ \mu\text{s}} = \mathbf{40\ kHz}$

6. $T = \dfrac{1}{20\text{ Hz}} = 0.05\text{ s}$, $5(0.05\text{ s}) = \mathbf{0.25\ s}$

7. $T = \dfrac{24\ \text{ms}}{80\,\text{cycles}} = \mathbf{0.3\ ms}$

8. $f = \dfrac{42\,\text{cycles}}{6\,\text{s}} = \mathbf{7\ Hz}$

9. a. $V_{\text{peak}} = (3\ \text{div.})(50\ \text{mV/div}) = \mathbf{150\ mV}$

b. $T = (\ 4\ \text{div.})(10\ \mu\text{s/div.}) = \mathbf{40\ \mu s}$

c. $f = \dfrac{1}{T} = \dfrac{1}{40\ \mu\text{s}} = \mathbf{25\ kHz}$

10. a. Radians $= \left(\dfrac{\pi}{180°}\right)45° = \dfrac{\boldsymbol{\pi}}{\mathbf{4}}\,\mathbf{rad}$

b. Radians $= \left(\dfrac{\pi}{180°}\right)60° = \dfrac{\boldsymbol{\pi}}{\mathbf{3}}\,\mathbf{rad}$

c. Radians $= \left(\dfrac{\pi}{180°}\right)270° = \mathbf{1.5}\boldsymbol{\pi}\,\mathbf{rad}$

d. Radians $= \left(\dfrac{\pi}{180°}\right)170° = \mathbf{0.94}\boldsymbol{\pi}\,\mathbf{rad}$

11. a. Degrees $= \left(\dfrac{180°}{\pi}\right)\dfrac{\pi}{4} = \mathbf{45°}$

b. Degrees $= \left(\dfrac{180°}{\pi}\right)\dfrac{\pi}{6} = \mathbf{30°}$

c. Degrees $= \left(\dfrac{180°}{\pi}\right)\dfrac{1}{10}\pi = \mathbf{18°}$

d. Degrees $= \left(\dfrac{180°}{\pi}\right)0.6\ \pi = \mathbf{108°}$

12. a. $\omega = \dfrac{2\pi}{T} = \dfrac{2\pi}{2\,\text{s}} = \mathbf{3.14\ rad/s}$

b. $\omega = \dfrac{2\pi}{0.3\times10^{-3}\ \text{s}} = \mathbf{20.94 \times 10^3\ rad/s}$

c. $\omega = \dfrac{2\pi}{4\times10^{-6}\ \text{s}} = \mathbf{1.57 \times 10^6\ rad/s}$

d. $\omega = \dfrac{2\pi}{1/25\,\text{s}} = \mathbf{157.1\ rad/s}$

13. a. $\omega = 2\pi f = 2\pi(50\ \text{Hz}) = \mathbf{314.16\ rad/s}$

b. $\omega = 2\pi f = 2\pi(600\ \text{Hz}) = \mathbf{3769.91\ rad/s}$

c. $\omega = 2\pi f = 2\pi(2\ \text{kHz}) = \mathbf{12.56 \times 10^3\ rad/s}$

d. $\omega = 2\pi f = 2\pi(0.004\ \text{MHz}) = \mathbf{25.13 \times 10^3\ rad/s}$

14. a. $\omega = 2\pi f = \dfrac{2\pi}{T} \Rightarrow f = \dfrac{\omega}{2\pi}$

$T = \dfrac{2\pi}{\omega} = \dfrac{1}{f}$

$f = \dfrac{\omega}{2\pi} = \dfrac{754 \text{ rad/s}}{2\pi}$ = **120 Hz, *T* = 8.33 ms**

b. $f = \dfrac{\omega}{2\pi} = \dfrac{8.4 \text{ rad/s}}{2\pi}$ = **1.34 Hz, *T* = 746.27 ms**

c. $f = \dfrac{\omega}{2\pi} = \dfrac{6000 \text{ rad/s}}{2\pi}$ = **954.93 Hz, *T* = 1.05 ms**

d. $f = \dfrac{\omega}{2\pi} = \dfrac{1/16 \text{ rad/s}}{2\pi}$ = **9.95×10^{-3} Hz, *T* = 100.5 ms**

15. $(45°)\left(\dfrac{\pi}{180°}\right) = \dfrac{\pi}{4}$ radians

$t = \dfrac{\theta}{\omega} = \dfrac{\pi/4 \text{ rad}}{2\pi f} = \dfrac{\pi/4 \text{ rad}}{2\pi(60 \text{ Hz})} = \dfrac{1}{(8)(60)} = \dfrac{1}{480}$ = **2.08 ms**

16. $(30°)\left(\dfrac{\pi}{180°}\right) = \dfrac{\pi}{6}$, $\alpha = \omega t \Rightarrow \omega = \dfrac{\alpha}{t} = \dfrac{\pi/6}{5 \times 10^{-3} \text{ s}}$ = **104.7 rad/s**

17. a. Amplitude = **20**, $f = \dfrac{\omega}{2\pi} = \dfrac{377 \text{ rad/s}}{2\pi}$ = **60 Hz**

b. Amplitude = **5**, $f = \dfrac{\omega}{2\pi} = \dfrac{754 \text{ rad/s}}{2\pi}$ = **120 Hz**

c. Amplitude = **10^6**, $f = \dfrac{\omega}{2\pi} = \dfrac{10{,}000 \text{ rad/s}}{2\pi}$ = **1591.55 Hz**

d. Amplitude = **–6.4**, $f = \dfrac{\omega}{2\pi} = \dfrac{942 \text{ rad/s}}{2\pi}$ = **149.92 Hz**

18. –

19. –

20. $T = \dfrac{2\pi}{\omega} = \dfrac{2\pi}{157}$ = 40 ms, $\dfrac{1}{2}$ cycle = **20 ms**

21. $i = 0.5 \sin 72° = 0.5(0.9511)$ = **0.48 A**

22. $1.2\pi\left(\frac{180°}{\pi}\right) = 216°$

$\upsilon = 20 \sin 216° = 20(-0.588) = \mathbf{-11.76\ V}$

23. $6 \times 10^{-3} = 30 \times 10^{-3} \sin \alpha$

$0.2 = \sin \alpha$

$\alpha = \sin^{-1} 0.2 = \mathbf{11.54°}$ and $180° - 11.54° = \mathbf{168.46°}$

24. $\upsilon = V_m \sin \alpha$

$40 = V_m \sin 30° = V_m (0.5)$

$\therefore V_m = \frac{40}{0.5} = \mathbf{80\ V}$

$\frac{30°}{360°} = \frac{1\text{ ms}}{T}$

$T = 1\text{ ms}\left(\frac{360}{30}\right) = \mathbf{12\ ms}$

$f = \frac{1}{T} = \frac{1}{12 \times 10^{-3}\text{ s}} = \mathbf{83.33\ Hz}$

$\omega = 2\pi f = (2\pi)(83.33\text{ Hz}) = \mathbf{523.58\ rad/s}$

and $\upsilon = \mathbf{80 \sin 523.58}\boldsymbol{t}$

25. –

26. –

27. a. $\omega = 2\pi f = 377$ rad/s

$\upsilon = \mathbf{25 \sin (\omega \boldsymbol{t} + 30°)}$

b. $\pi - \frac{2}{3}\pi = \frac{\pi}{3} = 60°$, $\omega = 2\pi f = 6.28 \times 10^3$ rad/s

$i = \mathbf{3 \times 10^{-3} \sin(6.28 \times 10^3 \boldsymbol{t} - 60°)}$

28. a. $\omega = 2\pi f = 2\pi(40\text{ Hz}) = 251.33$ rad/s

$\upsilon = \mathbf{0.01 \sin (251.33\boldsymbol{t} - 110°)}$

b. $\omega = 2\pi f = 2\pi(10\text{ kHz}) = 62.83 \times 10^3$ rad/s, $\frac{3}{4}\pi\left(\frac{180°}{\pi}\right) = 135°$

$i = \mathbf{2 \times 10^{-3} \sin (62.83 \times 10^3 \boldsymbol{t} + 135°)}$

29. $\boldsymbol{\upsilon}$ **leads** $\boldsymbol{i}$ **by 10°**

30. $\boldsymbol{i}$ **leads** $\boldsymbol{\upsilon}$ **by 70°**

31. $\boldsymbol{i}$ **leads** $\boldsymbol{\upsilon}$ **by 80°**

32. $$\left.\begin{array}{l} \upsilon = 2 \sin (\omega t \underbrace{- 30° + 90°}_{+60°}) \\ i = 5 \sin(\omega t + 60°) \end{array}\right\} \textbf{ in phase}$$

33. $$\left.\begin{array}{l} \upsilon = 4 \sin(\omega t + 90° + 90° + 180° = 4 \sin\omega t \\ i = \sin(\omega t + 10° + 180°) = \sin(\omega t + 190°) \end{array}\right\} \boldsymbol{i} \textbf{ leads } \boldsymbol{\upsilon} \textbf{ by 190°}$$

34. $T = \dfrac{1}{f} = \dfrac{1}{1000\text{ Hz}} = 1\text{ ms}$

$t_1 = \dfrac{120°}{180°}\left(\dfrac{T}{2}\right) = \dfrac{2}{3}\left(\dfrac{1\text{ ms}}{2}\right) = \mathbf{\dfrac{1}{3}\ ms}$

35. $\omega = 2\pi f = 50{,}000\text{ rad/s}$

$f = \dfrac{50{,}000}{2\pi} = 7957.75\text{ Hz}$

$T = \dfrac{1}{f} = 125.66\ \mu\text{s}$

$t_1 = \dfrac{40°}{180°}\left(\dfrac{T}{2}\right) = 0.222(62.83\ \mu\text{s}) = \mathbf{13.95\ \mu s}$

36. a. $T = (8\ \cancel{\text{div.}})(1\text{ ms}/\cancel{\text{div.}}) = \mathbf{8\ ms}$ (both waveforms)

b. $f = \dfrac{1}{T} = \dfrac{1}{8\text{ ms}} = \mathbf{125\ Hz\ (both)}$

c. Peak = (2.5 div)(0.5 V/div.) = 1.25 V
$V_{\text{rms}} = 0.707(1.25\text{ V}) = \mathbf{0.884\ V}$

d. Phase shift = 4.6 div., T = 8 div.
$\theta = \dfrac{4.6\text{ div.}}{8\text{ div.}} \times 360° = \mathbf{207°}$ ***i* leads *e***
or ***e* leads *i* by 153°**

37. $G = \dfrac{(6\text{ V})(1\text{ s}) + (3\text{ V})(1\text{ s}) - (3\text{ V})(1\text{ s})}{3\text{ s}} = \dfrac{6\text{ V}}{3} = \mathbf{2\ V}$

38. $G = \dfrac{\left[\dfrac{1}{2}(4\text{ ms})(20\text{ mA})\right] - (2\text{ ms})(5\text{ mA})}{8\text{ ms}} = \dfrac{40\text{ mA} - 10\text{ mA}}{8} = \dfrac{30\text{ mA}}{8} = \mathbf{3.87\ mA}$

39. $G = \dfrac{2A_m - (5\text{ mA})(\pi)}{2\pi} = \dfrac{2(20\text{ mA}) - (5\text{ mA})(\pi)}{2\pi} = \dfrac{40\text{ mA} - 15.708\text{ mA}}{2\pi} = \mathbf{3.87\ mA}$

40. a. $T = (2\text{ div.})(50\ \mu\text{s}) = \mathbf{100\ \mu s}$

b. $f = \dfrac{1}{T} = \dfrac{1}{100\ \mu\text{s}} = \mathbf{10\ kHz}$

c. Average = (–1.5 div.)(0.2 V/div.) = **–0.3 V**

41. a. $T = (4\text{ div.})(10\ \mu\text{s/div.}) = \mathbf{40\ \mu s}$

b. $f = \dfrac{1}{T} = \dfrac{1}{40\ \mu\text{s}} = \mathbf{25\ kHz}$

c. $$G = \frac{(2.5\text{ div.})(1.5\cancel{\text{div.}}) + (1\text{ div.})(0.5\cancel{\text{div.}}) + (1\text{ div.})(0.6\cancel{\text{div.}}) + (2.5\text{ div.})(0.4\cancel{\text{div.}}) + (1\text{ div.})(1\cancel{\text{div.}})}{4\cancel{\text{div.}}}$$
$$= \frac{3.75\text{ div.} + 0.5\text{ div.} + 0.6\text{ div.} + 1\text{ div.} + 1\text{ div.}}{4}$$
$$= \frac{6.85\text{ div.}}{4} = 1.713\text{ div.}$$
$1.713\ \cancel{\text{div.}}(10\text{ mV}/\cancel{\text{div.}}) = \mathbf{17.13\ mV}$

42. a. $V_{\text{rms}} = 0.7071(140\text{ V}) = \mathbf{98.99\ V}$
b. $I_{\text{rms}} = 0.7071(6\text{ mA}) = \mathbf{4.24\ mA}$
c. $V_{\text{rms}} = 0.7071(40\ \mu\text{V}) = \mathbf{28.28\ \mu V}$

43. a. $\upsilon = \mathbf{14.14\sin 377}\boldsymbol{t}$
b. $i = \mathbf{70.7 \times 10^{-3}\sin 377}\boldsymbol{t}$
c. $\upsilon = \mathbf{2.83 \times 10^{3}\sin 377}\boldsymbol{t}$

44. $$V_{\text{rms}} = \frac{\sqrt{(2\text{ V})^2(4\text{ s}) + (-2\text{ V})^2(1\text{ s}) + (3\text{ V})^2\left(\frac{1}{2}\text{s}\right)}}{12\text{ s}} = \mathbf{1.43\ V}$$

45. $$V_{\text{rms}} = \sqrt{\frac{(3\text{ V})^2(2\text{ s}) + (2\text{ V})^2(2\text{ s}) + (1\text{ V})^2(2\text{ s}) + (-1\text{ V})^2(2\text{ s}) + (-3\text{ V})^2(2\text{ s}) + (-2\text{ V})^2(2\text{ s})}{12\text{ s}}}$$
$= \mathbf{+2.16\ V}$

46. $$G = \frac{(10\text{ V})(4\text{ ms}) - (10\text{ V})(4\text{ ms})}{8\text{ ms}} = \frac{0}{8\text{ ms}} = \mathbf{0\ V}$$
$$V_{\text{rms}} = \sqrt{\frac{(10\text{ V})^2(4\text{ ms}) + (-10\text{ V})^2(4\text{ ms})}{8\text{ ms}}} = \mathbf{10\ V}$$

47. a. $T = (4\text{ div.})(10\ \mu\text{s/div.}) = \mathbf{40\ \mu s}$
$$f = \frac{1}{T} = \frac{1}{40\ \mu\text{s}} = \mathbf{25\ kHz}$$
Av. = (1 div.)(20 mV/div.) **= 20 mV**
Peak = (2 div.)(20 mV/div.) = **40 mV**
$$\text{rms} = \sqrt{V_0^2 + \frac{V_{\max}^2}{2}} = \sqrt{(20\text{ mV})^2 + \frac{(40\text{ mV})^2}{2}} = \mathbf{34.64\ mV}$$

b. $T = (2 \text{ div.})(50\ \mu\text{s}) = \mathbf{100\ \mu s}$

$f = \dfrac{1}{T} = \dfrac{1}{100\ \mu\text{s}} = \mathbf{10\ kHz}$

Av. = (–1.5 div.)(0.2 V/div.) **= –0.3 V**

Peak = (1.5 div.)(0.2 V/div.) = **0.3 mV**

$\text{rms} = \sqrt{V_0^2 + \dfrac{V_{\max}^2}{2}} = \sqrt{(.3\text{ V})^2 + \dfrac{(.3\text{ V})^2}{2}} = \mathbf{367.42\ mV}$

48. a. $V_{dc} = IR = (4\text{ mA})(2\text{ k}\Omega) = 8\text{ V}$

Meter indication = 2.22(8 V) = **17.76 V**

b. $V_{\text{rms}} = 0.707(16\text{ V}) = \mathbf{11.31\ V}$

Chapter 14

1. –

2. –

3. a. $(377)(10)\cos 377t = \mathbf{3770\cos 377}\boldsymbol{t}$

   b. $(754)(0.6)\cos(754t + 20°) = \mathbf{452.4\cos(754}\boldsymbol{t}\mathbf{ + 20°)}$

   c. $(\sqrt{2}\,20)(157)\cos(157t - 20°) = \mathbf{4440.63\cos(157}\boldsymbol{t}\mathbf{ - 20°)}$

   d. $(-200)(1)\cos(t + 180°) = -200\cos(t + 180°) = \mathbf{200\cos}\ \boldsymbol{t}$

4. a. $I_m = V_m/R = 150\text{ V}/5\ \Omega = 30\text{ A}$, $i = \mathbf{30\sin 200}\boldsymbol{t}$

   b. $I_m = V_m/R = 30\text{ V}/5\ \Omega = 6\text{ A}$, $i = \mathbf{6\sin(377}\boldsymbol{t}\mathbf{ + 20°)}$

   c. $I_m = V_m/R = 40\text{ V}/5\ \Omega = 8\text{ A}$, $i = \mathbf{8\sin(\boldsymbol{\omega t} + 100°)}$

   d. $I_m = V_m/R = 80\text{ V}/5\ \Omega = 16\text{ A}$, $i = \mathbf{16\sin(\boldsymbol{\omega t} + 220°)}$

5. a. $V_m = I_mR = (0.1\text{ A})(7 \times 10^3\ \Omega) = 700\text{ V}$
   $\upsilon = \mathbf{700\sin 1000}\boldsymbol{t}$

   b. $V_m = I_mR = (2 \times 10^{-3}\text{ A})((7 \times 10^3\ \Omega) = 14.8\text{ V}$
   $\upsilon = \mathbf{14.8\sin(400}\boldsymbol{t}\mathbf{ - 120°)}$

   c. $i = 6 \times 10^{-6}\sin(\omega t - 2° + 90°) = 6 \times 10^{-6}\sin(\omega t + 88°)$
   $V_m = I_mR = (6 \times 10^{-6}\text{ A})((7 \times 10^3\ \Omega) = 42 \times 10^{-3}\text{ V}$
   $\upsilon = \mathbf{42 \times 10^{-3}\sin(\boldsymbol{\omega t} + 88°)}$

   d. $i = 0.004\sin(\omega t + 90° + 90° + 180°) = 0.004\sin(\omega t + 360°) = 0.0004\sin\omega t$
   $V_m = I_mR = (4 \times 10^{-3}\text{ A})((7 \times 10^3\ \Omega) = 28\text{ V}$
   $\upsilon = \mathbf{28\sin}\ \boldsymbol{\omega t}$

6. a. $\mathbf{0\ \Omega}$

   b. $X_L = 2\pi fL = 2\pi Lf = (6.28)(2\text{ H})f = 12.56f = 12.56(10\text{ Hz}) = \mathbf{125.6\ \Omega}$

   c. $X_L = 12.56f = 12.56(60\text{ Hz}) = \mathbf{753.6\ \Omega}$

   d. $X_L = 12.56f = 12.56(2000\text{ Hz}) = \mathbf{25.13\ k\Omega}$

   e. $X_L = 12.56f = 12.56(10^5\text{ Hz}) = \mathbf{1.256\ M\Omega}$

7. a. $L = \dfrac{X_L}{2\pi f} = \dfrac{20\ \Omega}{2\pi(2\ \text{Hz})} = \mathbf{1.59\ H}$

b. $L = \dfrac{X_L}{2\pi f} = \dfrac{1000\ \Omega}{2\pi(60\ \text{Hz})} = \mathbf{2.65\ H}$

c. $L = \dfrac{X_L}{2\pi f} = \dfrac{5280\ \Omega}{2\pi(500\ \text{Hz})} = \mathbf{1.68\ H}$

8. a. $X_L = 2\pi fL \Rightarrow f = \dfrac{X_L}{2\pi L} = \dfrac{X_L}{(6.28)(10\ \text{H})} = \dfrac{X_L}{62.8}$

$f = \dfrac{100\ \Omega}{62.8} = \mathbf{1.59\ Hz}$

b. $f = \dfrac{X_L}{62.8} = \dfrac{3770\ \Omega}{62.8} = \mathbf{60.03\ Hz}$

c. $f = \dfrac{X_L}{62.8} = \dfrac{15{,}700\ \Omega}{62.8} = \mathbf{250\ Hz}$

d. $f = \dfrac{X_L}{62.8} = \dfrac{243\ \Omega}{62.8} = \mathbf{3.87\ Hz}$

9. a. $V_m = I_m X_L = (5\ \text{A})(20\ \Omega) = 100\ \text{V}$
$\upsilon = \mathbf{100\ sin(\boldsymbol{\omega t} + 90°)}$

b. $V_m = I_m X_L = (40 \times 10^{-3}\ \text{A})(20\ \Omega) = 0.8\ \text{V}$
$\upsilon = \mathbf{0.8\ sin(\boldsymbol{\omega t} + 150°)}$

c. $i = 6\sin(\omega t + 150°)$, $V_m = I_m X_L = (6\ \text{A})(20\ \Omega) = 120\ \text{V}$
$\upsilon = 120\sin(\omega t + 240°) = \mathbf{120\ sin(\boldsymbol{\omega t} - 120°)}$

d. $i = 3\sin(\omega t + 100°)$, $V_m = I_m X_L = (3\ \text{A})(20\ \Omega) = 60\ \text{V}$
$\upsilon = \mathbf{60\ sin(\boldsymbol{\omega t} + 190°)}$

10. a. $X_L = \omega L = (100\ \text{rad/s})(0.1\ \text{H}) = 10\ \Omega$
$V_m = I_m X_L = (10\ \text{A})(10\ \Omega) = 100\ \text{V}$
$\upsilon = \mathbf{100\ sin(100\boldsymbol{t} + 90°)}$

b. $X_L = \omega L = (377\ \text{rad/s})(0.1\ \text{H}) = 37.7\ \Omega$
$V_m = I_m X_L = (6 \times 10^{-3}\ \text{A})(37.7\ \Omega) = 226.2\ \text{mV}$
$\upsilon = \mathbf{226.2 \times 10^{-3}\ sin(377\boldsymbol{t} + 90°)}$

c. $X_L = \omega L = (400\ \text{rad/s})(0.1\ \text{H}) = 40\ \Omega$
$V_m = I_m X_L = (5 \times 10^{-6}\ \text{A})(40\ \Omega) = 200\ \mu\text{V}$
$\upsilon = \mathbf{200 \times 10^{-6}\ sin(400\boldsymbol{t} + 110°)}$

d. $i = 4 \sin(20t + 200°)$
$X_L = \omega L = (20 \text{ rad/s})(0.1 \text{ H}) = 2\ \Omega$
$V_m = I_m X_L = (4 \text{ A})(2\ \Omega) = 8 \text{ V}$
$\upsilon = 8 \sin(20t + 290°) = \mathbf{8 \sin(20}\boldsymbol{t}\mathbf{ - 70°)}$

11. a. $I_m = \dfrac{V_m}{X_L} = \dfrac{120 \text{ V}}{50\ \Omega} = 2.4 \text{ A}$, $i = \mathbf{2.4 \sin(\boldsymbol{\omega t} - 90°)}$

b. $I_m = \dfrac{V_m}{X_L} = \dfrac{30 \text{ V}}{50\ \Omega} = 0.6 \text{ A}$, $i = \mathbf{0.6 \sin(\boldsymbol{\omega t} - 70°)}$

c. $\upsilon = 40 \sin(\omega t + 100°)$
$I_m = \dfrac{V_m}{X_L} = \dfrac{40 \text{ V}}{50\ \Omega} = 0.8 \text{ A}$, $i = \mathbf{0.8 \sin(\boldsymbol{\omega t} + 10°)}$

d. $\upsilon = 80 \sin(377t + 220°)$
$I_m = \dfrac{V_m}{X_L} = \dfrac{80 \text{ V}}{50\ \Omega} = 1.6 \text{ A}$, $i = \mathbf{1.6 \sin(377\boldsymbol{t} + 130°)}$

12. a. $X_L = \omega L = (60 \text{ rad/s})(0.2 \text{ H}) = 12\ \Omega$
$I_m = V_m/X_L = 1.5 \text{ V}/12\ \Omega = 0.125 \text{ A}$
$i = \mathbf{0.125 \sin(60\boldsymbol{t} - 90°)}$

b. $X_L = \omega L = (10 \text{ rad/s})(0.2 \text{ H}) = 2\ \Omega$
$I_m = V_m/X_L = 16 \text{ mV}/2\ \Omega = 8 \text{ mA}$
$i = 8 \times 10^{-3} \sin(t + 2° - 90°) = \mathbf{8 \times 10^{-3} \sin(\boldsymbol{t} - 88°)}$

c. $\upsilon = 4.8 \sin(0.05t + 230°)$
$X_L = \omega L = (0.05 \text{ rad/s})(0.2 \text{ H}) = 0.01\ \Omega$
$I_m = V_m/X_L = 4.8 \text{ V}/0.01\ \Omega = 480 \text{ A}$
$i = 480 \sin(0.05t + 230° - 90°) = \mathbf{480 \sin(0.05\boldsymbol{t} + 140°)}$

d. $\upsilon = 9 \times 10^{-3} \sin(377t + 90°)$
$X_L = \omega L = (377 \text{ rad/s})(0.2 \text{ H}) = 75.4\ \Omega$
$I_m = V_m/X_L = 9 \text{ mV}/75.4\ \Omega = 0.119 \text{ mA}$
$i = \mathbf{0.119 \times 10^{-3} \sin 377\boldsymbol{t}}$

13. a. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(0 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{\infty\ \Omega}$

b. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(60 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{530.79\ \Omega}$

c. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(120 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{265.39\ \Omega}$

d. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(2\text{ kHz})(5\times10^{-6}\text{ F})} = \mathbf{15.92\ \Omega}$

e. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(2\times10^{6}\text{ Hz})(5\times10^{-6}\text{ F})} = \mathbf{62.83\ \Omega}$

14. a. $C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{6.28(60\text{ Hz})(250\ \Omega)} = \mathbf{10.62\ \mu F}$

b. $C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{6.28(312\text{ Hz})(55\ \Omega)} = \mathbf{9.28\ \mu F}$

c. $C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{6.28(25\text{ Hz})(10\ \Omega)} = \mathbf{636.94\ \mu F}$

15. a. $f = \dfrac{1}{2\pi CX_C} = \dfrac{1}{2\pi(50\times10^{-6}\text{ F})(100\ \Omega)} = \mathbf{31.83\ Hz}$

b. $f = \dfrac{1}{2\pi CX_C} = \dfrac{1}{2\pi(50\times10^{-6}\text{ F})(684\ \Omega)} = \mathbf{4.66\ Hz}$

c. $f = \dfrac{1}{2\pi CX_C} = \dfrac{1}{2\pi(50\times10^{-6}\text{ F})(342\ \Omega)} = \mathbf{9.31\ Hz}$

d. $f = \dfrac{1}{2\pi CX_C} = \dfrac{1}{2\pi(50\times10^{-6}\text{ F})(2000\ \Omega)} = \mathbf{1.59\ Hz}$

16. a. $I_m = V_m/X_C = 120\text{ V}/2.5\ \Omega = 48\text{ A}$
$i = \mathbf{48\ sin(\omega \mathit{t} + 90°)}$

b. $I_m = V_m/X_C = 0.4\text{ V}/2.5\ \Omega = 0.16\text{ A}$
$i = \mathbf{0.16\ sin(\omega \mathit{t} + 110°)}$

c. $\upsilon = 8\sin(\omega t + 100°)$
$I_m = V_m/X_C = 8\text{ V}/2.5\ \Omega = 3.2\text{ A}$
$i = \mathbf{3.2\ sin(\omega \mathit{t} + 190°)}$

d. $\upsilon = -70\sin(\omega t + 40°) = 70\sin(\omega t + 220°)$
$I_m = V_m/X_C = 70\text{ V}/2.5\ \Omega = 28\text{ A}$
$i = 28\sin(\omega t + 310°) = \mathbf{28\ sin(\omega \mathit{t} - 50°)}$

17. a. $\upsilon = 30 \sin 200t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(200)(1\times10^{-6})} = 5\text{ k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{30\text{ V}}{5\text{ k}\Omega} = 6\text{ mA}$, $i = \mathbf{6 \times 10^{-3} \sin(200}\boldsymbol{t}\mathbf{ + 90°)}$

b. $\upsilon = 60 \times 10^{-3} \sin 377t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(377)(1\times10^{-6})} = 2.65\text{ k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{60\times10^{-3}\text{ V}}{2{,}650\,\Omega} = 22.64\ \mu\text{A}$, $i = \mathbf{22.64 \times 10^{-6} \sin(377}\boldsymbol{t}\mathbf{ + 90°)}$

c. $\upsilon = 120 \sin(374t + 210°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(374)(1\times10^{-6})} = 2.67\text{ k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{120\text{ V}}{2{,}670\,\Omega} = 44.94\text{ mA}$, $i = \mathbf{44.94 \times 10^{-3} \sin(374}\boldsymbol{t}\mathbf{ + 300°)}$

d. $\upsilon = 70 \sin(800t + 70°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(800)(1\times10^{-6})} = 1.25\text{ k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{70\text{ V}}{1250\,\Omega} = 56\text{ mA}$, $i = \mathbf{56 \times 10^{-3} \sin(\omega}\boldsymbol{t}\mathbf{ + 160°)}$

18. a. $V_m = I_m X_C = (50 \times 10^{-3}\text{ A})(10\ \Omega) = 0.5\text{ V}$
$\upsilon = \mathbf{0.5 \sin(\omega}\boldsymbol{t}\mathbf{ - 90°)}$

b. $V_m = I_m X_C = (2 \times 10^{-6})(10\ \Omega) = 20\ \mu\text{V}$
$\upsilon = \mathbf{20 \times 10^{-6} \sin(\omega}\boldsymbol{t}\mathbf{ - 30°)}$

c. $i = -6 \sin(\omega t - 30°) = 6 \sin(\omega t + 150°)$
$V_m = I_m X_C = (6\text{ A})(10\ \Omega) = 60\text{ V}$
$\upsilon = \mathbf{60 \sin(\omega}\boldsymbol{t}\mathbf{ + 60°)}$

d. $i = 3 \sin(\omega t + 100°)$
$V_m = I_m X_C = (3\text{ A})(10\ \Omega) = 30\text{ V}$
$\upsilon = \mathbf{30 \sin(\omega}\boldsymbol{t}\mathbf{ + 10°)}$

19. a. $i = 0.2 \sin 300t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(300)(0.5\times10^{-6})} = 6.67\text{ k}\Omega$

$V_m = I_m X_C = (0.2\text{ A})(6{,}670\ \Omega) = 1334\text{ V}$, $\upsilon = \mathbf{1334 \sin(300}\boldsymbol{t}\mathbf{ - 90°)}$

b. $i = 8 \times 10^{-3} \sin 377t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(377)(0.5\times10^{-6})} = 5.31\text{ k}\Omega$

$V_m = I_m X_C = (8 \times 10^{-3}\text{ A})(5.31 \times 10^{3}\ \Omega) = 42.48\text{ V}$
$\upsilon = \mathbf{42.48 \sin(377}\boldsymbol{t}\mathbf{ - 90°)}$

c. $i = 60 \times 10^{-3} \sin(754t + 90°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(754)(0.5 \times 10^{-6})} = 2.65\text{ k}\Omega$

$V_m = I_m X_C = (60 \times 10^{-3}\text{ A})(2.65 \times 10^3\ \Omega) = 159\text{ V}$
υ = **159 sin 754*t***

d. $i = 80 \times 10^{-3} \sin(1600t - 80°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(1600)(0.5 \times 10^{-6})} = 1.25\text{ k}\Omega$

$V_m = I_m X_C = (80 \times 10^{-3}\text{ A})(1.25 \times 10^3\ \Omega) = 100\text{ V}$
υ = **100 sin(1600*t* – 170°)**

20. a. υ leads i by 90° $\Rightarrow L$, $X_L = V_m/I_m = 550\text{ V}/11\text{ A} = 50\ \Omega$

$$L = \frac{X_L}{\omega} = \frac{50\ \Omega}{377\text{ rad/s}} = \mathbf{132.63\ mH}$$

b. υ leads i by 90° $\Rightarrow L$, $X_L = V_m/I_m = 36\text{ V}/4\text{ A} = 9\ \Omega$

$$L = \frac{1}{\omega X_L} = \frac{1}{(754\text{ rad/s})(9\ \Omega)} = \mathbf{147.36\ \mu H}$$

c. υ and i are in phase $\Rightarrow R$

$$R = \frac{V_m}{I_m} = \frac{10.5\text{ V}}{1.5\text{ A}} = \mathbf{7\ \Omega}$$

21. a. $$\left.\begin{array}{r} i = 5\sin(\omega t + 90°) \\ \upsilon = 2000\sin\omega t \end{array}\right\}\ i \text{ leads } \upsilon \text{ by } 90° \Rightarrow \boldsymbol{C}$$

$$X_C = \frac{V_m}{I_m} = \frac{2000\text{ V}}{5\text{ A}} = 400\ \Omega$$

b. $$\left.\begin{array}{r} i = 2\sin(157t + 60°) \\ \upsilon = 80\sin(157t + 150°) \end{array}\right\}\ \upsilon \text{ leads } i \text{ by } 90° \Rightarrow \boldsymbol{L}$$

$$X_L = \frac{V_m}{I_m} = \frac{80\text{ V}}{2\text{ A}} = 40\ \Omega,\ L = \frac{X_L}{\omega} = \frac{40\ \Omega}{157\text{ rad/s}} = \mathbf{254.78\ mH}$$

c. $$\left.\begin{array}{r} \upsilon = 35\sin(\omega t - 20°) \\ i = 7\sin(\omega t - 20°) \end{array}\right\}\ \text{in phase} \Rightarrow \boldsymbol{R}$$

$$R = \frac{V_m}{I_m} = \frac{35\text{ V}}{7\text{ A}} = \mathbf{5\ \Omega}$$

22. –

23. –

24. $X_C = \dfrac{1}{2\pi fC} = R \Rightarrow f = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(2\times10^3\ \Omega)(1\times10^{-6}\ \text{F})} = \dfrac{1}{12.56\times10^{-3}}$

$\cong$ **79.62 Hz**

25. $X_L = 2\pi fL = R$

$$L = \frac{R}{2\pi f} = \frac{10{,}000\ \Omega}{2\pi(5\times10^3\ \text{Hz})} = \mathbf{318.47\ mH}$$

26. $X_C = X_L$

$$\frac{1}{2\pi fC} = 2\pi fL$$

$$f^2 = \frac{1}{4\pi^2 LC}$$

and $f = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(10\times10^{-3}\ \text{H})(1\times10^{-6}\ \text{F})}} = \mathbf{1.59\ kHz}$

27. $X_C = X_L$

$$\frac{1}{2\pi fC} = 2\pi fL \Rightarrow C = \frac{1}{4\pi^2 f^2 L} = \frac{1}{4(9.86)(2500\times10^6)(2\times10^{-3})} = \mathbf{5.07\ nF}$$

28. a. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(550\ \text{V})(11\ \text{A})}{2}\cos 90° = (\ )(0) =$ **0 W**

b. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(36\ \text{V})(4\ \text{A})}{2}\cos 90° = (\ )(0) =$ **0 W**

c. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(10.5\ \text{V})(1.5\ \text{A})}{2}\cos 0° =$ **7.88 W**

29. a. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(5\ \text{A})(2000\ \text{V})}{2}\cos 90° =$ **0 W**

b. $\cos\theta = 0 \Rightarrow$ **0 W**

c. $P = \dfrac{(35\ \text{V})(7\ \text{A})}{2}\cos 0° =$ **122.5 W**

30. a. $P = \dfrac{(60\ \text{V})(15\ \text{A})}{2}\cos 30° =$ **389.7 W**, $F_p =$ **0.866**

b. $P = \dfrac{(50\ \text{V})(2\ \text{A})}{2}\cos 0° =$ **50 W**, $F_p =$ **1.0**

c. $P = \dfrac{(50\text{ V})(3\text{ A})}{2}\cos 10° = \mathbf{73.86\ W}$, $F_p = \mathbf{0.985}$

d. $P = \dfrac{(75\text{ V})(0.08\text{ A})}{2}\cos 40° = \mathbf{2.30\ W}$, $F_p = \mathbf{0.766}$

31. $R = \dfrac{V_m}{I_m} = \dfrac{48\text{ V}}{8\text{ A}} = 6\ \Omega$, $P = I^2R = \left(\dfrac{8\text{ A}}{\sqrt{2}}\right)^2 6\ \Omega = \mathbf{192\ W}$

$$P = \frac{V_m I_m}{2}\cos\theta = \frac{(48\text{ V})(8\text{ A})}{2}\cos 0° = \mathbf{192\ W}$$

$$P = VI\cos\theta = \left(\frac{48\text{ V}}{\sqrt{2}}\right)\left(\frac{8\text{ A}}{\sqrt{2}}\right)\cos 0° = \mathbf{192\ W}$$

All the same!

32. $P = 100$ W: $F_p = \cos\theta = P/VI = 100\text{ W}/(150\text{ V})(2\text{ A}) = \mathbf{0.333}$
$P = 0$ W: $F_p = \cos\theta = \mathbf{0}$
$P = 300$ W: $F_p = \dfrac{300}{300} = \mathbf{1}$

33. $P = \dfrac{V_m I_m}{2}\cos\theta$

$500\text{ W} = \dfrac{(50\text{ V})I_m}{2}\ (0.5) \Rightarrow I_m = 40\text{ A}$

$i = \mathbf{40\ sin(\omega t - 50°)}$

34. a. $I_m = E_m/R = 30\text{ V}/6.8\ \Omega = 4.41\text{ A}$, $i = \mathbf{4.41\ sin(377t + 20°)}$

b. $P = I^2R = \left(\dfrac{4.41\text{ A}}{\sqrt{2}}\right)^2 3\ \Omega = \mathbf{29.18\ W}$

c. $T = \dfrac{2\pi}{\omega} = \dfrac{6.28}{377\text{ rad/s}} = \mathbf{16.67\ ms}$
$6(16.67\text{ ms}) = 100.02\text{ ms} \cong \mathbf{0.1\ s}$

35. a. $I_m = \dfrac{V_m}{X_L} = \dfrac{100\text{ V}}{25\ \Omega} = 4\text{ A}$, $i = \mathbf{4\ sin(314t - 30°)}$

b. $L = \dfrac{X_L}{\omega} = \dfrac{25\ \Omega}{314\text{ rad/s}} = \mathbf{79.62\ mH}$

c. $L \Rightarrow \mathbf{0\ W}$

36. a. $E_m = I_m X_C = (30 \times 10^{-3}\text{ A})(2.4\text{ k}\Omega) = 72\text{ V}$

$e = 72\sin(377t - 20° - 90°) = \mathbf{72\sin(377}\boldsymbol{t}\mathbf{ - 110°)}$

b. $C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377\text{ rad/s})(2.4\text{ k}\Omega)} = \mathbf{1.11\ \mu F}$

c. $P = 0\text{ W}$

37. a. $X_{C_1} = \dfrac{1}{2\pi f C_1} = \dfrac{1}{\omega C_1} = \dfrac{1}{(10^4\text{ rad/s})(2\,\mu\text{F})} = 50\ \Omega$

$X_{C_2} = \dfrac{1}{\omega C_2} = \dfrac{1}{(10^4)(10\,\mu F)} = 10\ \Omega$

$\mathbf{E} = 100\text{ V}\angle 60°$ $\quad \mathbf{I}_1 = \dfrac{\mathbf{E}}{\mathbf{Z}_{C_1}} = \dfrac{120\text{ V}\angle 60°}{50\,\Omega\angle -90°} = 2.4\text{ A}\angle 150°$

$\mathbf{I}_2 = \dfrac{\mathbf{E}}{\mathbf{Z}_{C_2}} = \dfrac{120\text{ V}\angle 60°}{10\,\Omega\angle -90°} = 12\text{ A}\angle 150°$

$i_1 = \sqrt{2}\ 2.4\sin(10^4 t + 150°) = \mathbf{3.39\sin(10^4}\boldsymbol{t}\mathbf{ + 150°)}$

$i_2 = \sqrt{2}\ 12\sin(10^4 t + 150°) = \mathbf{16.97\sin(10^4}\boldsymbol{t}\mathbf{ + 150°)}$

b. $\mathbf{I}_s = \mathbf{I}_1 + \mathbf{I}_2 = 2.4\text{ A}\angle 150° + 12\text{ A}\angle 150° = 14.4\text{ A}\angle 150°$

$i_s = \sqrt{2}\ 14.4\sin(10^4 t + 150°) = \mathbf{20.36\sin(10^4}\boldsymbol{t}\mathbf{ + 150°)}$

38. a. $L_1 \parallel L_2 = 60\text{ mH} \parallel 120\text{ mH} = 40\text{ mH}$

$X_{L_T} = 2\pi f L_T = 2\pi(10^3\text{ Hz})(40\text{ mH}) = 251.33\ \Omega$

$V_m = I_m X_{L_T} = \left(\sqrt{2}\ 24\text{ A}\right)(251.33\,\Omega) = \sqrt{2}\ 6.03\text{ kV}$

and $\upsilon_s = \sqrt{2}\ 6.03\text{ kV}\sin(10^3 t + 30° + 90°)$

or $\upsilon_s = \mathbf{8..53 \times 10^3\sin(10^3}\boldsymbol{t}\mathbf{ + 120°)}$

b. $I_{m_1} = \dfrac{V_m}{X_{L_1}}$, $X_{L_1} = 2\pi f L_1 = 2\pi(10^3\text{ Hz})(60\text{ mH}) = 376.99\ \Omega$

$I_{m_1} = \dfrac{8.53 \times 10^3}{376.99\,\Omega} = 22.63\text{ A}$

and $i_1 = \mathbf{22.63\sin(10^3}\boldsymbol{t}\mathbf{ + 30°)}$

$X_{L_2} = 2\pi f L_2 = 2\pi(10^3\text{ Hz})(120\text{ mH}) = 753.98\ \Omega$

$I_{m_2} = \dfrac{8.53 \times 10^3}{753.98\,\Omega} = 11.31\text{ A}$

and $i_2 = \mathbf{11.31\sin(10^3}\boldsymbol{t}\mathbf{ + 30°)}$

39. a. $\mathbf{5.0 \angle 36.87°}$ b. $\mathbf{2.83 \angle 45°}$
c. $\mathbf{17.09 \angle 69.44°}$ d. $\mathbf{1.0 \times 10^{3} \angle 84.29°}$
e. $\mathbf{1077.03 \angle 21.80°}$ f. $\mathbf{6.58 \times 10^{-3} \angle 81.25°}$
g. $\mathbf{11.78 \angle -49.82°}$ h. $\mathbf{8.94 \angle -153.43°}$
i. $\mathbf{61.85 \angle -104.04°}$ j. $\mathbf{101.73 \angle -39.94°}$
k. $\mathbf{4{,}326.66 \angle 123.69°}$ l. $\mathbf{25.5 \times 10^{-3} \angle -78.69°}$

40. a. $\mathbf{5.196 + \mathit{j}3.0}$ b. $\mathbf{6.946 + \mathit{j}39.39}$
c. $\mathbf{2530.95 + \mathit{j}6953.73}$ d. $\mathbf{3.96 \times 10^{-4} + \mathit{j}5.57 \times 10^{-5}}$
e. $\mathbf{\mathit{j}0.04}$ f. $\mathbf{6.91 \times 10^{-3} + \mathit{j}6.22 \times 10^{-3}}$
g. $\mathbf{-56.29 + \mathit{j}32.50}$ h. $\mathbf{-0.85 + \mathit{j}0.85}$
i. $\mathbf{-469.85 - \mathit{j}171.01}$ j. $\mathbf{5177.04 - \mathit{j}3625.0}$
k. $\mathbf{-4.31 - \mathit{j}6.16}$ l. $\mathbf{-6.93 \times 10^{-3} - \mathit{j}4.00 \times 10^{-3}}$

41. a. $\mathbf{15.03 \angle 86.19}$ b. $\mathbf{60.21 \angle 4.76°}$
c. $\mathbf{0.30 \angle 88.09°}$ d. $\mathbf{223.61 \angle -63.43°}$
e. $\mathbf{86.18 \angle 93.73°}$ f. $\mathbf{38.69 \angle -94.0°}$

42. a. $\mathbf{12.95 + \mathit{j}1.13}$ b. $\mathbf{8.37 + \mathit{j}159.78}$
c. $\mathbf{7.00 \times 10^{-6} + \mathit{j}2.44 \times 10^{-7}}$ d. $\mathbf{-8.69 + \mathit{j}0.46}$
e. $\mathbf{75.82 - \mathit{j}5.30}$ f. $\mathbf{-34.51 - \mathit{j}394.49}$

43. a. $\mathbf{11.8 + \mathit{j}7.0}$ b. $\mathbf{151.90 + \mathit{j}49.90}$
c. $\mathbf{4.72 \times 10^{-6} + \mathit{j}71}$ d. $\mathbf{5.20 + \mathit{j}1.60}$
e. $\mathbf{209.30 + \mathit{j}311.0}$ f. $\mathbf{-21.20 + \mathit{j}12.0}$

g. $6 \angle 20° + 8 \angle 80° = (5.64 + j2.05) + (1.39 + j7.88) = \mathbf{7.03 + \mathit{j}9.93}$

h. $(29.698 + j29.698) + (31.0 + j53.69) - (-35 + j60.62) = \mathbf{95.7 + \mathit{j}22.77}$

44. a. $\mathbf{-12.0 + \mathit{j}34.0}$ b. $\mathbf{86.80 + \mathit{j}312.40}$
c. $\mathbf{56. \times 10^{-3} - \mathit{j}\, 8 \times 10^{-3}}$ d. $\mathbf{698.00 \angle -114°}$
e. $\mathbf{8.00 \angle 20°}$ f. $\mathbf{49.68 \angle -64.0°}$
g. $\mathbf{40 \times 10^{-3} \angle 40°}$ h. $\mathbf{-16{,}740 \angle 160°}$

45. a. **6.0 ∠–50°** b. **200 × 10^{-6} ∠60°**

c. **109 ∠–170.0°** d. **76.47 ∠–80**

e. **4∠0°**

f. **5.93 ∠–134.47°**

g. (0.05 + j0.25)/(8 –j60) = 0.255∠78.69°/60.53 ∠–82.41° = **4.21 × 10^{-3} ∠161.10°**

h. **9.30 ∠–43.99°**

46. a. $\dfrac{10 - j5}{1 + j0}$ = **10.0 – j5.0**

b. $\dfrac{8\angle 60°}{102 + j400} = \dfrac{8\angle 60°}{412.80\angle 75.69°}$ = **19.38 × 10^{-3} ∠–15.69°**

c. $\dfrac{(6\angle 20°)(120\angle -40°)(8.54\angle 69.44°)}{2\angle -30°} = \dfrac{6.15\times 10^{3}\angle 49.44°}{2\angle -30°}$ = **3.07 × 10^{3} ∠79.44°**

d. $\dfrac{(0.16\angle 120°)(300\angle 40°)}{9.487\angle 71.565°} = \dfrac{48\angle 160°}{9.487\angle 71.565°}$ = **5.06 ∠88.44°**

e. $\left(\dfrac{1}{4\times 10^{-4}\angle 20°}\right)\left(\dfrac{8}{j(j^{2})}\right)\left(\dfrac{1}{36 - j30}\right)$

$\left(2500\angle -20°\right)\left(\dfrac{8}{-j}\right)\left(\dfrac{1}{46.861\angle -39.81°}\right)$

(2500 ∠–20°)(8j)(0.0213 ∠39.81°) = **426 ∠109.81°**

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 ∠20°)(x ∠–60°) = 30.64 – j25.72

10x ∠–40° = 40 ∠–40°

10 x = 40

x = **4**

c. $\begin{array}{r} 5x + j10 \\ 2 - jy \\ \hline \end{array}$

$10x + j20 - j5xy - j^2 10y = 90 - j70$
$(10x + 10y) + j(20 - 5xy) = 90 - j70$
$10x + 10y = 90$
$x + y = 9$
$x = 9 - y \Rightarrow$

$20 - 5xy = -70$
$20 - 5(9 - y)y = -70$
$5y(9 - y) = 90$
$y^2 - 9y + 18 = 0$

$$y = \frac{-(-9) \pm \sqrt{(-9)^2 - 4(1)(18)}}{2}$$

$$y = \frac{9 \pm 3}{2} = 6, 3$$

For $y = 6, x = 3$
$y = 3, x = 6$
($x = 3, y = 6$) or ($x = 6, y = 3$)

d. $\dfrac{80 \angle 0°}{40 \angle \theta} = 4 \angle -\theta = 3.464 - j2 = 4 \angle -30°$
$\boldsymbol{\theta = 30°}$

48. a. **160.0 ∠30°** b. **25×10^{-3} ∠–40°**

c. **70.71 ∠–90°** d. **14.14 ∠0°**

e. **4.24×10^{-6} ∠90°** f. **2.55×10^{-6} ∠70°**

49. a. **56.57 sin(377*t* + 20°)** b. **169.68 sin (377*t* + 10°)**

c. **11.31×10^{-3} sin(377*t* + 120°)** d. **7.07 sin(377*t* + 90°)**

e. **1696.8 sin(377*t* – 50°)** f. **6000 sin(377*t* – 180°)**

50. (Using peak values)
$e_{in} = \upsilon_a + \upsilon_b \Rightarrow \upsilon_a = e_{\text{in}} - \upsilon_b$
$= 60 \text{ V} \angle 20° - 20 \text{ V} \angle -20°$
$= 46.49 \text{ V} \angle 36.05°$
and e_{in} = 46.49 sin (377*t* + 36.05°)

51. $i_s = i_1 + i_2 \Rightarrow i_1 = i_s - i_2$
(Using peak values) $= (20 \times 10^{-6} \text{ A} \angle 60°) - (6 \times 10^{-6} \text{ A} \angle -30°) = 20.88 \times 10^{-6} \text{ A} \angle 76.70°$
i_1 = **20.88×10^{-6}** sin (ωt + 76.70°)

52. $e = \upsilon_a + \upsilon_b + \upsilon_c$
$= 60 \text{ V} \angle 30° + 30 \text{ V} \angle 60° + 40 \text{ V} \angle 120°$
$= 102.07 \text{ V} \angle 62.61°$
and e = **102.07 sin(ω*t* + 62.61°)**

53. (Using effective values)

$$\mathbf{I}_s = \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3 = 4.24\text{ mA } \angle 180° + 5.66\text{ mA } \angle -180° + 11.31\text{ mA } \angle -180°$$
$$= -4.24\text{ mA} - 5.66\text{ mA} - 11.31\text{ mA}$$
$$= 21.21 \times 10^{-3} \sin (377t + 180°)$$
$$i_s = \mathbf{-21.21 \times 10^{-3} \sin 377}\boldsymbol{t}$$

Chapter 15

1. a. $R \angle 0° = \mathbf{6.8\ \Omega \angle 0° = 6.8\ \Omega}$

   b. $X_L = \omega L = (377 \text{ rads/s})(1.2 \text{ H}) = 452.4\ \Omega$
   $X_L \angle 90° = \mathbf{452.4\ \Omega \angle 90° = +j452.4\ \Omega}$

   c. $X_L = 2\pi fL = (6.28)(50 \text{ Hz})(0.05 \text{ H}) = 15.7\ \Omega$
   $X_L \angle 90° = \mathbf{15.7\ \Omega \angle 90° = +j15.7\ \Omega}$

   d. $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(100 \text{ rad/s})(10 \times 10^{-6} \text{ F})} = 1\text{ k}\Omega$
   $X_C \angle -90° = \mathbf{1\ k\Omega \angle -90° = -j1\ k\Omega}$

   e. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10 \times 10^{3} \text{ Hz})(0.05 \times 10^{-6} \text{ F})} = 318.47\ \Omega$
   $X_C \angle -90° = \mathbf{318.47\ \Omega \angle -90° = -j318.47\ \Omega}$

   f. $R \angle 0° = \mathbf{220\ \Omega \angle 0° = 220\ \Omega}$

2. a. $\mathbf{V} = 10.61 \text{ V} \angle 10°$, $\mathbf{I} = \dfrac{V\angle\theta}{R\angle 0°} = \dfrac{10.61 \text{ V} \angle 10°}{3\ \Omega \angle 0°} = 3.54 \text{ A} \angle 10°$
   $\boldsymbol{i = 5 \sin(\omega t + 10°)}$

   b. $\mathbf{V} = 39.60 \text{ V} \angle 10°$, $\mathbf{I} = \dfrac{V\angle\theta}{X_L\angle 90°} = \dfrac{39.60 \text{ V} \angle 10°}{7\ \Omega \angle 90°} = 5.66 \text{ A} \angle -80°$
   $\boldsymbol{i = 8 \sin(\omega t - 80°)}$

   c. $\mathbf{V} = 17.68 \text{ V} \angle -20°$, $\mathbf{I} = \dfrac{V\angle\theta}{X_C\angle -90°} = \dfrac{17.68 \text{ V} \angle -20°}{100\ \Omega \angle -90°} = 0.1768 \text{ A} \angle 70°$
   $\boldsymbol{i = 0.25 \sin(\omega t + 70°)}$

   d. $\mathbf{V} = 2.828 \text{ mV} \angle -120°$, $\mathbf{I} = \dfrac{V\angle\theta}{R\angle 0°} = \dfrac{2.828 \text{ mV} \angle -120°}{5.1\text{ k}\Omega \angle 0°} = 0.555\ \mu\text{A} \angle -120°$
   $\boldsymbol{i = 0.785 \times 10^{-6} \sin(\omega t - 120°)}$

   e. $\mathbf{V} = 11.312 \text{ V} \angle 60°$, $\mathbf{I} = \dfrac{V\angle\theta}{X_L\angle 90°} = \dfrac{11.312 \text{ V} \angle 60°}{(377 \text{ rad/s})(0.2 \text{ H} \angle 90°)} = 150.03 \text{ mA} \angle -30°$
   $\boldsymbol{i = 106.09 \times 10^{-3} \sin(377t - 30°)}$

   f. $\mathbf{V} = 84.84 \text{ V} \angle 0°$, $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(5 \text{ kHz})(2\ \mu\text{F})} = 15.924\ \Omega$
   $\mathbf{I} = \dfrac{V\angle\theta}{X_C\angle -90°} = \dfrac{84.84 \text{ V} \angle 0°}{15.924\ \Omega \angle -90°} = 5.328 \text{ A} \angle 90°$
   $\boldsymbol{i = 7.534 \sin(\omega t + 90°)}$

3. a. $\mathbf{I} = (0.707)(4 \text{ mA} \angle 0°) = 2.828 \text{ mA} \angle 0°$
$\mathbf{V} = (I \angle 0°)(R \angle 0°) = 2.828 \text{ mA} \angle 0°)(22\ \Omega \angle 0°) = 62.216 \text{ mV} \angle 0°$
$\upsilon = \mathbf{88 \times 10^{-3} \sin \omega t}$

b. $\mathbf{I} = (0.707)(1.5 \text{ A} \angle 60°) = 1.061 \text{ A} \angle 60°$
$X_L = \omega L = (1000 \text{ rad/s})(0.016 \text{ H}) = 16\ \Omega$

$\mathbf{V} = (I \angle \theta)(X_L \angle 90°) = (1.061 \text{ A} \angle 60°)(16\ \Omega \angle 90°) = 16.98 \text{ V} \angle 150°$
$\upsilon = \mathbf{16.98 \sin(1000t + 150°)}$

c. $\mathbf{I} = (0.707)(2 \text{ mA} \angle 40°) = 1.414 \text{ mA} \angle 40°$
$$X_C = \frac{1}{\omega C} = \frac{1}{(157 \text{rad/s})(0.05 \times 10^{-6} \text{ F})} = 127.39 \text{ k}\Omega$$

$\mathbf{V} = (I \angle \theta)(X_C \angle -90°) = 1.414 \text{ mA} \angle 40°)(127.39 \text{ k}\Omega \angle -90°) = 180.13 \text{ V} \angle -50°$
$V_p = \sqrt{2}(180.13 \text{ V}) = 254.7 \text{ V}$
and $\upsilon = \mathbf{254.7 \sin (157t - 50°)}$

4. a. $\mathbf{Z}_T = \mathbf{6.8\ \Omega + \mathit{j}8.2\ \Omega = 10.65\ \Omega \angle 50.33°}$

b. $\mathbf{Z}_T = 2\ \Omega - j6\ \Omega + 10\ \Omega = \mathbf{12\ \Omega - \mathit{j}6\ \Omega = 13.42\ \Omega \angle -26.57°}$

c. $\mathbf{Z}_T = 1 \text{ k}\Omega + j3 \text{ k}\Omega + 4 \text{ k}\Omega + j7 \text{ k}\Omega = \mathbf{5 \text{ k}\Omega + \mathit{j}10 \text{ k}\Omega = 11.18 \text{ k}\Omega \angle 63.44°}$

5. a. $\mathbf{Z}_T = \mathbf{3\ \Omega + \mathit{j}4\ \Omega - \mathit{j}5\ \Omega = 3\ \Omega - \mathit{j}1\ \Omega = 3.16\ \Omega \angle -18.43°}$

b. $\mathbf{Z}_T = 1 \text{ k}\Omega + j8 \text{ k}\Omega - j4 \text{ k}\Omega = \mathbf{1 \text{ k}\Omega + \mathit{j}4 \text{ k}\Omega} = \mathbf{4.12 \text{ k}\Omega \angle 75.96°}$

c. $L_T = 240 \text{ mH}$
$X_L = \omega L = 2\pi fL = 2\pi(10^3 \text{ Hz})(240 \times 10^{-3} \text{ H}) = 1.51 \text{ k}\Omega$
$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10^3 \text{ Hz})(0.1 \times 10^{-6} \text{ F})} = 1.59 \text{ k}\Omega$$
$= 470\ \Omega + j1.51 \text{ k}\Omega - j1.59 \text{ k}\Omega$
$= \mathbf{470\ \Omega - \mathit{j}80\ \Omega} = \mathbf{476.76\ \Omega \angle -9.66°}$

6. a. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120 \text{ V} \angle 0°}{60 \text{ A} \angle 70°} = 2\ \Omega \angle -70° = \mathbf{0.684\ \Omega - \mathit{j}1.879\ \Omega = \mathit{R} - \mathit{jX_C}}$$

b. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{80 \text{ V} \angle 320°}{20 \text{ mA} \angle 40°} = 4 \text{ k}\Omega \angle 280° = \mathbf{4 \text{ k}\Omega \angle -80° = 0.695 \text{ k}\Omega - \mathit{j}3.939\ \Omega}$$
$$= \mathbf{\mathit{R} - \mathit{jX_C}}$$

c. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{8 \text{ kV} \angle 0°}{0.2 \text{ A} \angle -60°} = 40 \text{ k}\Omega \angle 60° = \mathbf{20 \text{ k}\Omega + \mathit{j}34.64 \text{ k}\Omega = \mathit{R} + \mathit{jX_L}}$$

7. a. $\mathbf{Z}_T = 8\ \Omega + j6\ \Omega = \mathbf{10\ \Omega \angle 36.87°}$

c. $\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 100\ \text{V} \angle 0°/10\ \Omega \angle 36.87° = \mathbf{10\ A \angle -36.87°}$
$\mathbf{V}_R = (I \angle \theta)(R \angle 0°) = (10\ \text{A} \angle -36.87°)(8\ \Omega \angle 0°) = \mathbf{80\ V \angle -36.87°}$
$\mathbf{V}_L = (I \angle \theta)(X_L \angle 90°) = (10\ \text{A} \angle -36.87°)(6\ \Omega \angle 90°) = \mathbf{60\ V \angle 53.13°}$

f. $P = I^2R = (10\ \text{A})^2\ 8\ \Omega = \mathbf{800\ W}$

g. $F_p = \cos\theta_T = R/Z_T = 8\ \Omega/10\ \Omega = \mathbf{0.8\ lagging}$

h. $\upsilon_R = \mathbf{113.12\ sin(\boldsymbol{\omega t} - 36.87°)}$
$\upsilon_L = \mathbf{84.84\ sin(\boldsymbol{\omega t} + 53.13°)}$
$i = \mathbf{14.14\ sin\ (\boldsymbol{\omega t} - 36.87°)}$

8. a. $\mathbf{Z}_T = 6\ \Omega - j30\ \Omega = \mathbf{30.59\ \Omega \angle -78.69°}$

c. $$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{120\ \text{V} \angle 20°}{30.59\ \Omega \angle -78.69°} = \mathbf{3.92\ A \angle 98.69°}$$

$\mathbf{V}_R = (I \angle\theta)(R \angle 0°) = (3.92\ \text{A} \angle 98.69°)(6\ \Omega \angle 0°) = \mathbf{23.52\ V \angle 98.69°}$
$\mathbf{V}_C = (I \angle\theta)(X_C \angle -90°) = (3.92\ \text{A} \angle 98.69°)(30\ \Omega \angle -90°) = \mathbf{117.60\ V \angle 8.69°}$

f. $P = I^2R = (3.92\ \text{A})^2\ 6\ \Omega = \mathbf{92.2\ \ W}$

g. $F_p = R/Z_T = 6\ \Omega/30.59\ \Omega = \mathbf{0.196\ leading}$

h. $i = \mathbf{5.54\ sin(377\boldsymbol{t} + 98.69°)}$
$\upsilon_R = \mathbf{33.26\ sin(377\boldsymbol{t} + 98.69°)}$
$\upsilon_C = \mathbf{166.29\ sin(377\boldsymbol{t} + 8.69°)}$

9. a. $$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10^3\ \text{Hz})(0.2 \times 10^{-6}\ \text{F})} = 795.77\ \Omega$$

$\mathbf{Z}_T = 2.2\ \text{k}\Omega - j795.77\ \Omega = \mathbf{2.34\ k\Omega \angle -19.89°}$

b. $\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 14.14\ \text{V} \angle 0°/2.34\ \text{k}\Omega \angle -19.89° = \mathbf{6.04\ mA \angle 19.89°}$

c. $\mathbf{V}_R = (I \angle\theta)(R \angle 0°) = (6.04\ \text{mA} \angle 19.89°)(2.2 \times 10^3\ \Omega \angle 0°) = \mathbf{13.29\ V \angle 19.89°}$
$\mathbf{V}_C = (I \angle\theta)(X_C \angle -90°) = (6.04\ \text{mA} \angle 19.89°)(795.77\ \Omega \angle -90°)$
$= \mathbf{4.81\ V \angle -70.11°}$

d. $P = I^2R = (6.04\ \text{mA})^2\ 2.2\ \text{k}\Omega = \mathbf{80.26\ mW}$
$F_p = \cos\theta_T = \cos 19.89° = \mathbf{0.94\ leading}$

10. a. $\mathbf{Z}_T = 4\ \Omega + j6\ \Omega - j10\ \Omega = 4\ \Omega - j4\ \Omega = \mathbf{5.66\ \Omega\ \angle{-45°}}$

c. $X_L = \omega L \Rightarrow L = \dfrac{X_L}{\omega} = \dfrac{6\ \Omega}{377\ \text{rad/s}} = \mathbf{16\ mH}$

$X_C = \dfrac{1}{\omega C} \Rightarrow C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377\ \text{rad/s})(10\ \Omega)} = \mathbf{265\ \mu F}$

d. $\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{50\ \text{V}\ \angle 0°}{5.66\ \Omega\ \angle -45°} = \mathbf{8.83\ A\ \angle 45°}$

$\mathbf{V}_R = (I\ \angle\theta)(R\ \angle 0°) = (8.83\ \text{A}\ \angle 45°)(4\ \Omega\ \angle 0°) = \mathbf{35.32\ V\ \angle 45°}$
$\mathbf{V}_L = (I\ \angle\theta)(X_L\ \angle 90°) = (8.83\ \text{A}\ \angle 45°)(6\ \Omega\ \angle 90°) = \mathbf{52.98\ V\ \angle 135°}$
$\mathbf{V}_C = (I\ \angle\theta)(X_C\ \angle{-90°}) = (8.83\ \text{A}\ \angle 45°)(10\ \Omega\ \angle{-90°}) = \mathbf{88.30\ V\ \angle{-45°}}$

f. $\mathbf{E} = \mathbf{V}_R + \mathbf{V}_L + \mathbf{V}_C$
$50\ \text{V}\ \angle 0° = 35.32\ \text{V}\ \angle 45° + 52.98\ \text{V}\ \angle 135° + 88.30\ \text{V}\ \angle{-45°}$
$50\ \text{V}\ \angle 0° = 49.95\ \text{V}\ \angle 0° \cong 50\ \text{V}\ \angle 0°$

g. $P = I^2R = (8.83\ \text{A})^2\ 4\ \Omega = \mathbf{311.88\ W}$

h. $F_p = \cos\theta_T = \dfrac{R}{Z_T} = 4\ \Omega/5.66\ \Omega =$ **0.707 leading**

i. $i = \mathbf{12.49\ sin(377\mathit{t} + 45°)}$
$e = \mathbf{70.7\ sin\ 377\mathit{t}}$
$\upsilon_R = \mathbf{49.94\ sin(377\mathit{t} + 45°)}$
$\upsilon_L = \mathbf{74.91\ sin(377\mathit{t} + 135°)}$
$\upsilon_C = \mathbf{124.86\ sin(377\mathit{t} - 45°)}$

11. a. $\mathbf{Z}_T = 1.8\ \text{k}\Omega + j2\ \text{k}\Omega - j0.6\ \text{k}\Omega = \mathbf{1.8\ k\Omega + \mathit{j}1.2\ k\Omega = 2.16\ k\Omega\ \angle 33.69°}$

c. $X_C = \dfrac{1}{\omega C} \Rightarrow C = \dfrac{1}{\omega X_C} = \dfrac{1}{(314\ \text{rad/s})(0.6\ \text{k}\Omega)} = \mathbf{5.31\ \mu F}$

$X_L = \omega L \Rightarrow L = \dfrac{X_L}{\omega} = \dfrac{2\times 10^3\ \Omega}{314\ \text{rad/s}} = \mathbf{6.37\ H}$

d. $\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 4.242\ \text{V}\ \angle 60°/2.16\ \text{k}\Omega\ \angle 33.69° = \mathbf{1.96\ mA\ \angle 26.31°}$
$\mathbf{V}_R = (I\ \angle\theta)(R\ \angle 0°) = (1.96\ \text{mA}\ \angle 26.31°)(1.8\ \text{k}\Omega\ \angle 0°) = \mathbf{3.53\ V\ \angle 26.31°}$
$\mathbf{V}_L = (I\ \angle\theta)(X_L\ \angle 90°) = (1.96\ \text{mA}\ \angle 26.31°)(2\ \text{k}\Omega\ \angle 90°) = \mathbf{2.68\ V\ \angle 116.31°}$
$\mathbf{V}_C = (I\ \angle\theta)(X_C\ \angle{-90°}) = (1.96\ \text{mA}\ \angle 26.31°)(0.6\ \text{k}\Omega\ \angle{-90°}) = \mathbf{1.18\ V\ \angle{-63.69°}}$

g. $P = I^2R = (1.96\ \text{mA})^2\ 1.8\ \text{k}\Omega = \mathbf{6.91\ mW}$

h. $F_p = \cos\theta_T = \cos 33.69° =$ **0.832 lagging**

i. $i = \mathbf{2.77 \times 10^{-3} \sin(\omega t + 26.31°)}$
$\upsilon_R = \mathbf{4.99 \sin(\omega t + 26.31°)}$
$\upsilon_L = \mathbf{3.79 \sin(\omega t + 116.31°)}$
$\upsilon_C = \mathbf{1.67 \sin(\omega t - 63.69°)}$

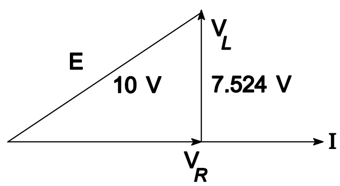
12. $V_{80\Omega}(\text{rms}) = 0.7071\left(\dfrac{45.27\text{ V}}{2}\right) = 16\text{ V}$

$$V_{\text{scope}} = \frac{80\,\Omega\;(20\text{ V})}{80\,\Omega + R} = 16\text{ V}$$
$$1600 = 1280 + 16\,R$$
$$R = \frac{320}{16} = \mathbf{20\ \Omega}$$

13. a. $V_L(\text{rms}) = 0.7071\left(\dfrac{21.28\text{ V}}{2}\right) = 7.524\text{ V}$

$$X_L = \frac{V_L}{I_L} = \frac{7.524\text{ V}}{29.94\text{ mA}} = 251.303\ \Omega$$
$$X_L = 2\pi fL \Rightarrow L = \frac{X_L}{2\pi f} = \frac{251.303\,\Omega}{2\pi(1\text{ kHz})} = 39.996\text{ mH} \cong \mathbf{40\text{ mH}}$$

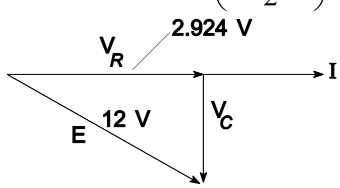
b.



$$E^2 = V_R^2 + V_L^2$$
$$V_R = \sqrt{E^2 - V_L^2}$$
$$= \sqrt{(100\text{ V}) - (56.611)} = \sqrt{43.389} = 6.587\text{ V}$$

$$R = \frac{V_R}{I_R} = \frac{6.587\text{ V}}{29.94\text{ mA}} = \mathbf{220\ \Omega}$$

14. $V_R(\text{rms}) = 0.7071\left(\dfrac{8.27\text{ V}}{2}\right) = 2.924\text{ V}$



$$V_C = \sqrt{E^2 - V_R^2}$$
$$= \sqrt{144 - 8.55} = \sqrt{135.45} = 11.638\text{ V}$$

$$I_C = I_R = \frac{2.924\text{ V}}{10\text{ k}\Omega} = 292.4\ \mu\text{A}$$
$$X_C = \frac{V_C}{I_C} = \frac{11.638\text{ V}}{292.4\ \mu\text{A}} = 39.802\text{ k}\Omega$$
$$X_C = \frac{1}{2\pi fC} \Rightarrow C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(40\text{ kHz})(39.802\text{ k}\Omega)} = 99.967\text{ pF} \cong \mathbf{100\text{ pF}}$$

15. a. $\mathbf{V}_1 = \dfrac{(2\,\text{k}\Omega \angle 0°)(120\text{ V} \angle 60°)}{2\,\text{k}\Omega + j8\,\text{k}\Omega} = \dfrac{240\text{ V} \angle 60°}{8.25 \angle 75.96°} = \mathbf{29.09\ V \angle{-15.96°}}$

$\mathbf{V}_2 = \dfrac{(8\,\text{k}\Omega \angle 90°)(120\text{ V} \angle 60°)}{8.25\,\text{k}\Omega \angle 75.96°} = \mathbf{116.36\ V \angle 74.04°}$

b. $\mathbf{V}_1 = \dfrac{(40\,\Omega \angle 90°)(60\text{ V} \angle 5°)}{6.8\,\Omega + j40\,\Omega + 22\,\Omega} = \dfrac{2400\text{ V} \angle 95°}{28.8 + j40} = \mathbf{48.69\ V \angle 40.75°}$

$\mathbf{V}_2 = \dfrac{(22\,\Omega \angle 0°)(60\text{ V} \angle 5°)}{49.29\,\Omega \angle 54.25°} = \dfrac{1.32\text{ kV} \angle 5°}{49.29\,\Omega \angle 54.25°} = \mathbf{26.78\ V \angle{-49.25°}}$

16. a. $\mathbf{V}_1 = \dfrac{(20\,\Omega \angle 90°)(20\text{ V} \angle 70°)}{20\,\Omega + j20\,\Omega - j40\,\Omega} = \mathbf{14.14\ V \angle{-155°}}$

$\mathbf{V}_2 = \dfrac{(40\,\Omega \angle -90°)(20\text{ V} \angle 70°)}{28.28\,\Omega \angle -45°} = \mathbf{28.29\ V \angle 25°}$

b. $\mathbf{Z}_T = 4.7\text{ k}\Omega + j30\text{ k}\Omega + 3.3\text{ k}\Omega - j10\text{ k}\Omega = 8\text{ k}\Omega + j20\text{ k}\Omega = 21.541\text{ k}\Omega \angle 68.199°$

$\mathbf{Z}'_T = 3.3\text{ k}\Omega + j30\text{ k}\Omega - j10\text{ k}\Omega = 3.3\text{ k}\Omega + j20\text{ k}\Omega = 20.27\text{ k}\Omega \angle 80.631°$

$\mathbf{V}_1 = \dfrac{\mathbf{Z}'_T\mathbf{E}}{\mathbf{Z}_T} = \dfrac{(20.27\,\text{k}\Omega \angle 80.631°)(120\text{ V} \angle 0°)}{21.541\,\text{k}\Omega \angle 68.199°} = \mathbf{112.92\ V \angle 12.432°}$

$\mathbf{V}_2 = \dfrac{\mathbf{Z}''_T\mathbf{E}}{\mathbf{Z}_T}$ $\quad \mathbf{Z}''_T = 3.3\text{ k}\Omega - j10\text{ k}\Omega = 10.53\text{ k}\Omega \angle{-71.737°}$

$= \dfrac{(10.53\,\text{k}\Omega \angle -71.737°)(120\text{ V} \angle 0°)}{21.541\,\text{k}\Omega \angle 68.199°} = \mathbf{58.66\ V \angle{-139.94°}}$

17. a. $X_L = \omega L = (377\text{ rad/s})(0.4\text{ H}) = 150.8\ \Omega$

$X_C = \dfrac{1}{\omega C} = \dfrac{1}{(377\text{ rad/s})(4\,\mu\text{F})} = 663\ \Omega$

$\mathbf{Z}_T = 30\ \Omega + j150.8\ \Omega - j663\ \Omega = 30\ \Omega - j512.2\ \Omega = \mathbf{513.08\ \Omega \angle{-86.65°}}$

$\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{20\text{ V} \angle 40°}{513.08\,\Omega \angle -86.65°} = \mathbf{39\ mA \angle 126.65°}$

$\mathbf{V}_R = (I \angle \theta)(R \angle 0°) = (39\text{ mA} \angle 126.65°)(30\ \Omega \angle 0°) = \mathbf{1.17\ V \angle 126.65°}$

$\mathbf{V}_C = (39\text{ mA} \angle 126.65°)(0.663\text{ k}\Omega \angle{-90°}) = \mathbf{25.86\ V \angle 36.65°}$

b. $\cos\theta_T = \dfrac{R}{Z_T} = \dfrac{30\,\Omega}{513.08\,\Omega} = \mathbf{0.058\ leading}$

c. $P = I^2R = (39\text{ mA})^2\, 30\ \Omega = \mathbf{45.63\ mW}$

f. $\mathbf{V}_R = \dfrac{(30\,\Omega \angle 0°)(20\text{ V} \angle 40°)}{\mathbf{Z}_T} = \dfrac{600\text{ V} \angle 40°}{513.08\ \Omega \angle -86.65°} = \mathbf{1.17\ V \angle 126.65°}$

$\mathbf{V}_C = \dfrac{(0.663\,\text{k}\Omega \angle -90°)(20\text{ V} \angle 40°)}{513.08\,\Omega \angle -86.65°} = \mathbf{25.84\ V \angle 36.65°}$

g. $\mathbf{Z}_T = \mathbf{30\ \Omega - \mathit{j}512.2\ \Omega} = R - jX_C$

18. a. $X_L = \omega L = (377 \text{ rad/s})(0.4 \text{ H}) = 150.8\ \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(220 \times 10^{-6} \text{ F})} = 12.06\ \Omega$$

$\mathbf{Z}_T = 30\ \Omega + j150.8\ \Omega - j12.06\ \Omega$
$= 30\ \Omega + j138.74\ \Omega = 141.95\ \Omega \angle 77.80°$

$\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 20 \text{ V} \angle 40°/141.95\ \Omega \angle 77.80° = \mathbf{140.89\ mA \angle{-37.80°}}$

$\mathbf{V}_R = (I \angle \theta)(R \angle 0°) = (140.89 \text{ mA} \angle{-37.80°})(30\ \Omega \angle 0°) = \mathbf{4.23\ V \angle{-37.80°}}$

$\mathbf{V}_C = (I \angle \theta)(X_C \angle{-90°}) = (140.89 \text{ mA} \angle{-37.80°})(12.06\ \Omega \angle{-90°})$
$= \mathbf{1.70\ V \angle{-127.80°}}$

b. $F_p = \cos \theta_T = R/Z_T = 30\ \Omega/141.95\ \Omega =$ **0.211 lagging**

c. $P = I^2R = (140.89 \text{ mA})^2\ 30\ \Omega =$ **595.50 mW**

f. $$\mathbf{V}_R = \frac{(30\ \Omega \angle 0°)(20 \text{ V} \angle 40°)}{141.95\ \Omega \angle 77.80°} = \mathbf{4.23\ V \angle{-37.80°}}$$

$$\mathbf{V}_C = \frac{(12.06\ \Omega \angle -90°)(20 \text{ V} \angle 40°)}{141.95\ \Omega \angle 77.80°} = \mathbf{1.70\ V \angle{-127.80°}}$$

g. $\mathbf{Z}_T = 30\ \Omega + j138.74\ \Omega = R + jX_L$

19. $P = VI \cos \theta \Rightarrow 8000 \text{ W} = (200 \text{ V})(I)(0.8)$

$$I = \frac{8000 \text{ A}}{160} = 50 \text{ A}$$

$0.8 = \cos \theta$
$\theta = 36.87°$

$\mathbf{V} = 200 \text{ V} \angle 0°,\ I = 50 \text{ A} \angle{-36.87°}$

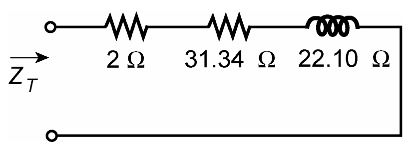
$$\mathbf{Z}_T = \frac{\mathbf{V}}{\mathbf{I}} = \frac{200 \text{ V} \angle 0°}{50 \text{ A} \angle -36.87°} = 4\ \Omega \angle 36.87° = \mathbf{3.2\ \Omega + \mathit{j}2.4\ \Omega}$$

20. $P = VI \cos \theta \Rightarrow 300 \text{ W} = (120 \text{ V})(3 \text{ A}) \cos \theta$
$\cos \theta = 0.833 \Rightarrow \theta = \mathbf{33.59°}$

$\mathbf{V} = 120 \text{ V} \angle 0°,\ \mathbf{I} = 3 \text{ A} \angle{-33.59°}$

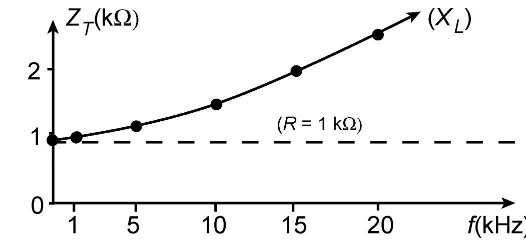
$$\mathbf{Z}_T = \frac{\mathbf{V}}{\mathbf{I}} = \frac{120 \text{ V} \angle 0°}{3 \text{ A} \angle -33.59°} = 40\ \Omega \angle 33.59° = \mathbf{33.34\ \Omega + \mathit{j}22.10\ \Omega}$$

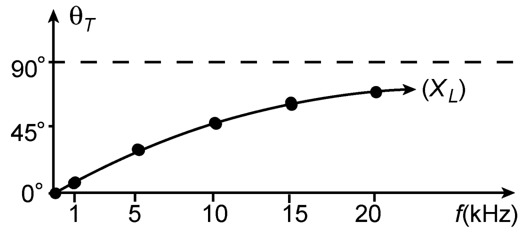
$R_T = 33.34\ \Omega = 2\ \Omega + R \Rightarrow R = 31.34\ \Omega$



21. a. $\mathbf{Z}_T = \sqrt{R^2 + X_L^2}\ \angle\tan^{-1}X_L/R$

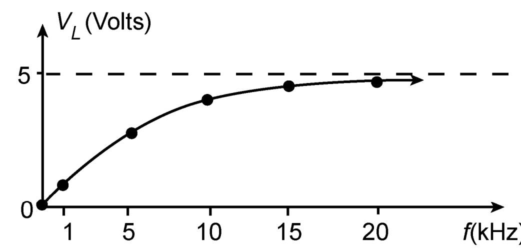
f	Z_T	θ_T
0 Hz	1.0 kΩ	0.0°
1 kHz	1.008 kΩ	7.16°
5 kHz	1.181 kΩ	32.14°
10 kHz	1.606 kΩ	51.49°
15 kHz	2.134 kΩ	62.05°
20 kHz	2.705 kΩ	68.3°





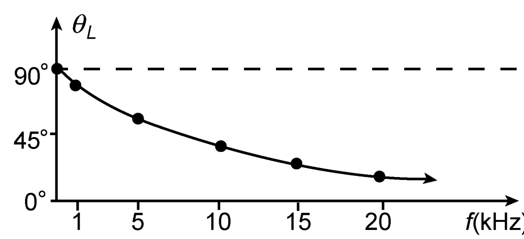
b. $V_L = \dfrac{X_L E}{Z_T}$

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



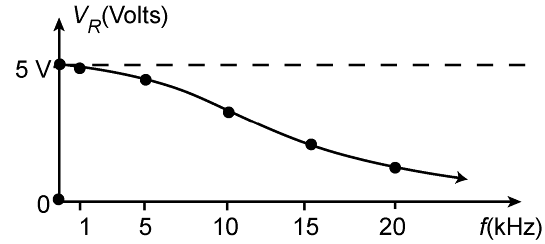
c.

f	$\theta_L = 90° - \tan^{-1} X_L/R$
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.

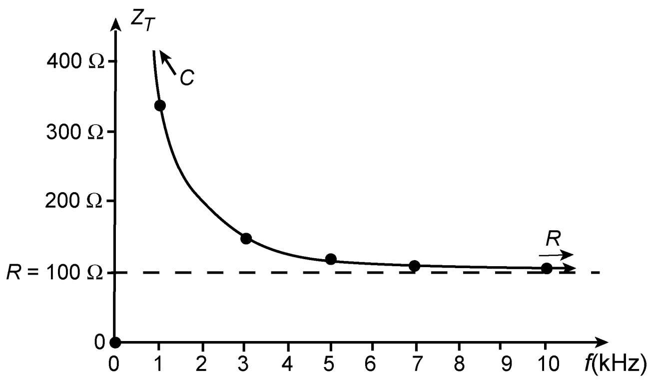
f	$V_R = RE/Z_T$
0 Hz	5.0 V
1 kHz	4.96 V
5 kHz	4.23 V
10 kHz	3.11 V
15 kHz	2.34 V
20 kHz	1.848 V

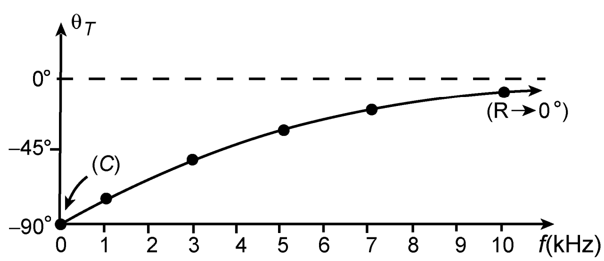


22. a. $\mathbf{Z}_T = \sqrt{R^2 + X_C^2} \angle -\tan^{-1} X_C/R$

$|Z_T| = \sqrt{R^2 + X_C^2}$, $\theta_T = -\tan^{-1} X_C/R$

f	$\lvert \mathbf{Z}_T \rvert$	θ_T
0 kHz	∞ Ω	–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°

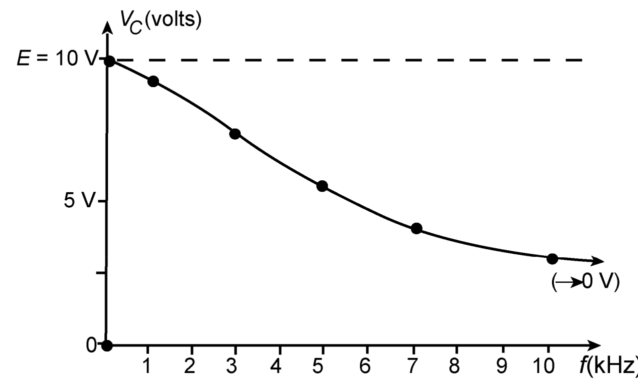




b. $\mathbf{V}_C = \dfrac{(X_C\angle -90°)(E\angle 0°)}{R - jX_C} = \dfrac{X_C E}{\sqrt{R^2 + X_C^2}}\ \angle -90° + \tan^{-1} X_C/R$

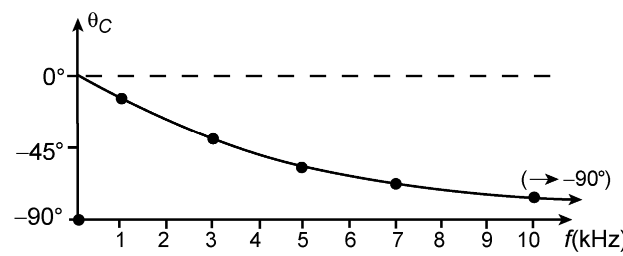
$$|V_C| = \frac{X_C E}{\sqrt{R^2 + X_C^2}}$$

f	$\lvert V_C \rvert$
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



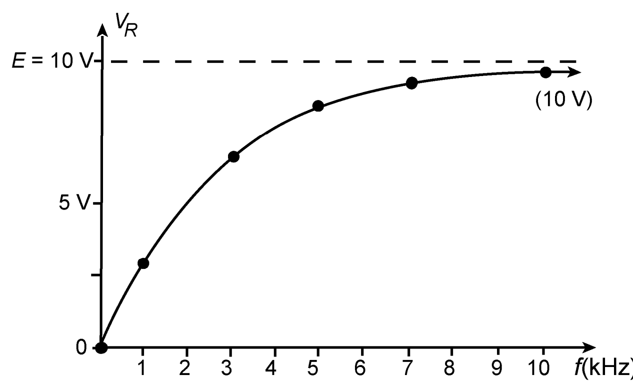
c. $\theta_C = -90° + \tan^{-1} X_C/R$

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°



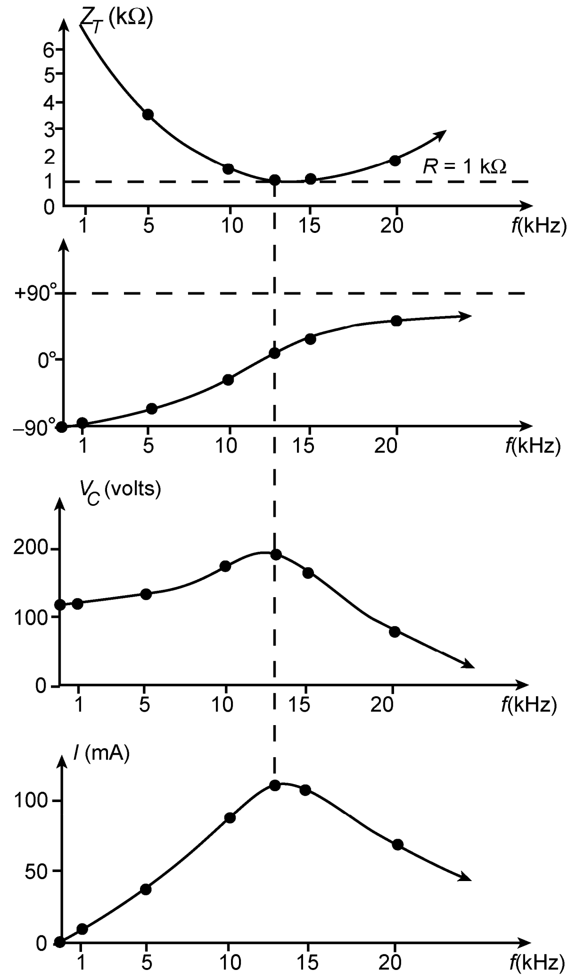
d. $|V_R| = \dfrac{RE}{\sqrt{R^2 + X_C^2}}$

f	$\lvert V_R \rvert$
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. $\mathbf{Z}_T = \sqrt{R^2 + (X_L - X_C)^2} \angle \tan^{-1}(X_L - X_C)/R$

f	Z_T	θ_T
0 Hz	∞ Ω	–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°
20 kHz	1,818.24 Ω	+56.63°



b. $|V_C| = \dfrac{X_C E}{Z_T}$

f	$\lvert V_C \rvert$
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. $|I| = \dfrac{E}{Z_T}$

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. $X_C = \dfrac{1}{2\pi fC} = R \Rightarrow f = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(220\ \Omega)(0.47\ \mu\text{F})} = \mathbf{1.54\ kHz}$

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. $f = 100$ Hz: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(100\ \text{Hz})(0.47\ \mu\text{F})} = 3.39\ \text{k}\Omega$

$Z_T \cong X_C$

$f = 10$ kHz: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10\ \text{kHz})(0.47\ \mu\text{F})} = 33.86\ \Omega$

$Z_T \cong R$

d. –

e. $f = 40$ kHz: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(40\ \text{kHz})(0.47\ \mu\text{F})} = 8.47\ \text{k}\Omega$

$\theta = -\tan^{-1}\dfrac{X_C}{R} = -\tan^{-1}\dfrac{8.47\ \Omega}{220\ \Omega} = \mathbf{-2.2°}$

25. a. $\mathbf{Z}_T = \mathbf{91\ \Omega\ \angle 0°} = R\ \angle 0°$, $\mathbf{Y}_T = \mathbf{10.99\ mS\ \angle 0°} = G\ \angle 0°$

b. $\mathbf{Z}_T = \mathbf{200\ \Omega\ \angle 90°} = X_L\ \angle 90°$, $\mathbf{Y}_T = \mathbf{5\ mS\ \angle -90°} = B_L\ \angle -90°$

c. $\mathbf{Z}_T = \mathbf{0.2\ k\Omega\ \angle -90°} = X_C\ \angle -90°$, $\mathbf{Y}_T = \mathbf{5.00\ mS\ \angle 90°} = B_C\ \angle 90°$

d. $\mathbf{Z}_T = \dfrac{(10\ \Omega\angle 0°)(60\ \Omega\ \angle 90°)}{10\ \Omega + j60\ \Omega} = \mathbf{9.86\ \Omega\ \angle 9.46° = 9.73\ \Omega + \mathit{j}1.62\ \Omega} = R + jX_L$

$\mathbf{Y}_T = \mathbf{0.10\ S\ \angle -9.46° = 0.1\ S - \mathit{j}0.02\ S} = G - jB_L$

e. $22\ \Omega \parallel 2.2\ \Omega = 2\ \Omega$

$\mathbf{Z}_T = \dfrac{(2\ \Omega\angle 0°)(6\ \Omega\ \angle -90°)}{2\ \Omega - j6\ \Omega} = \dfrac{12\ \Omega\ \angle -90°}{6.32\ \Omega\ \angle -71.57°} = \mathbf{1.90\ \Omega\ \angle -18.43°}$

$= \mathbf{1.80\ \Omega - \mathit{j}0.6\ \Omega} = R - jX_C$

$\mathbf{Y}_T = \mathbf{0.53\ S\ \angle 18.43° = 0.5\ S + \mathit{j}0.17\ S} = G + jB_C$

f. $\mathbf{Y}_T = \dfrac{1}{3\ \text{k}\Omega\ \angle 0°} + \dfrac{1}{6\ \text{k}\Omega\ \angle 90°} + \dfrac{1}{9\ \text{k}\Omega\ \angle -90°}$

$= 0.333 \times 10^{-3}\ \angle 0° + 0.167 \times 10^{-3}\ \angle -90° + 0.111 \times 10^{-3}\ \angle 90°$

$= \mathbf{0.333 \times 10^{-3}\ S - \mathit{j}0.056 \times 10^{-3}\ S = 0.34\ mS\ \angle -9.55°}$

$= G - jB_L$

$\mathbf{Z}_T = \dfrac{1}{\mathbf{Y}_T} = \mathbf{2.94\ k\Omega\ \angle 9.55° = 2.90\ k\Omega + \mathit{j}0.49\ k\Omega}$

26. a. $\mathbf{Z}_T = 4.7\ \Omega + j8\ \Omega = \mathbf{9.28\ \Omega \angle 59.57°}$, $\mathbf{Y}_T = \mathbf{0.108\ S \angle{-59.57°}}$

$\mathbf{Y}_T = \mathbf{54.7\ mS - \mathit{j}93.12\ mS} = G - jB_L$

b. $\mathbf{Z}_T = 33\ \Omega + 20\ \Omega - j70\ \Omega = \mathbf{53\ \Omega - \mathit{j}70\ \Omega} = \mathbf{87.80\ \Omega \angle{-52.87°}}$

$\mathbf{Y}_T = \mathbf{11.39\ mS \angle 52.87°} = \mathbf{6.88\ mS + \mathit{j}9.08\ mS} = G + jB_C$

c. $\mathbf{Z}_T = 200\ \Omega + j500\ \Omega - j600\ \Omega = \mathbf{200\ \Omega - \mathit{j}100\ \Omega} = \mathbf{223.61\ \Omega \angle{-26.57°}}$

$\mathbf{Y}_T = \mathbf{4.47\ mS \angle 26.57°} = \mathbf{4\ mS + \mathit{j}2\ mS} = G + jB_C$

27. a. $\mathbf{Y}_T = \dfrac{\mathbf{I}}{\mathbf{E}} = \dfrac{60\text{ A}\angle 70°}{120\text{ V}\angle 0°} = 0.5\text{ S}\angle 70° = 0.171\text{ S} + j0.470\text{ S} = G + jB_C$

$R = \dfrac{1}{G} = \mathbf{5.85\ \Omega}$, $X_C = \dfrac{1}{B_C} = \mathbf{2.13\ \Omega}$

b. $\mathbf{Y}_T = \dfrac{\mathbf{I}}{\mathbf{E}} = \dfrac{20\text{ mA}\angle 40°}{80\text{ V}\angle 320°} = 0.25\text{ mS}\angle{-280°} = 0.25\text{ mS}\angle 80°$

$= 0.043\text{ mS} + j0.246\text{ mS} = G + jB_C$

$R = \dfrac{1}{G} = \mathbf{23.26\ k\Omega}$, $X_C = \dfrac{1}{B_C} = \mathbf{4.07\ k\Omega}$

c. $\mathbf{Y}_T = \dfrac{\mathbf{I}}{\mathbf{E}} = \dfrac{0.2\text{ A}\angle -60°}{8\text{ kV}\angle 0°} = 0.25\text{ mS}\angle{-60°} = 0.0125\text{ mS} - j0.02165\text{ mS} = G - jB_L$

$R = \dfrac{1}{G} = \mathbf{80\ k\Omega}$, $X_L = \dfrac{1}{B_L} = \mathbf{46.19\ k\Omega}$

28. a. $\mathbf{Y}_T = \dfrac{1}{10\ \Omega\angle 0°} + \dfrac{1}{20\ \Omega\angle 90°} = 0.1\text{ S} - j0.05\text{ S} = \mathbf{111.8\ mS \angle{-26.57°}}$

c. $\mathbf{E} = \mathbf{I}_s/\mathbf{Y}_T = 2\text{ A}\angle 0°/111.8\text{ mS}\angle{-26.57°} = \mathbf{17.89\ V \angle 26.57°}$

$\mathbf{I}_R = \dfrac{E\angle\theta}{R\angle 0°} = 17.89\text{ V}\angle 26.57°/10\ \Omega\angle 0° = \mathbf{1.79\ A \angle 26.57°}$

$\mathbf{I}_L = \dfrac{E\angle\theta}{X_L\angle 90°} = 17.89\text{ V}\angle 26.57°/20\ \Omega\angle 90° = \mathbf{0.89\ A \angle{-63.43°}}$

f. $P = I^2R = (1.79\text{ A})^2\ 10\ \Omega = \mathbf{32.04\ W}$

g. $F_p = \dfrac{G}{Y_T} = \dfrac{0.1\text{ S}}{111.8\text{ mS}} = $ **0.894 lagging**

h. $e = \mathbf{25.30\ sin(377\mathit{t} + 26.57°)}$
$i_R = \mathbf{2.53\ sin(377\mathit{t} + 26.57°)}$
$i_L = \mathbf{1.26\ sin(377\mathit{t} - 63.43°)}$
$i_s = \mathbf{2.83\ sin\ 377\mathit{t}}$

29. a. $\mathbf{Y}_T = \dfrac{1}{10\,\text{k}\Omega\,\angle 0°} + \dfrac{1}{20\,\text{k}\Omega\,\angle -90°} = 0.1\text{ mS }\angle 0° + 0.05\text{ mS }\angle{-90°}$

$= \mathbf{0.112\ mS\ \angle 26.57°}$

c. $\mathbf{E} = \dfrac{\mathbf{I}_s}{\mathbf{Y}_\text{T}} = \dfrac{2\text{ mA }\angle 20°}{0.1118\text{ mS }\angle 26.565°} = \mathbf{17.89\ V\ \angle{-6.57°}}$

$\mathbf{I}_R = \dfrac{\mathbf{E}}{\mathbf{Z}_R} = \dfrac{17.89\text{ V }\angle -6.57°}{10\,\text{k}\Omega\,\angle 0°} = \mathbf{1.79\ mA\ \angle{-6.57°}}$

$\mathbf{I}_C = \dfrac{\mathbf{E}}{\mathbf{Z}_C} = \dfrac{17.89\text{ V }\angle -6.57°}{20\,\text{k}\Omega\,\angle -90°} = \mathbf{0.90\ mA\ \angle 83.44°}$

e. $\mathbf{I}_s = \mathbf{I}_R + \mathbf{I}_C$

$2\text{ mA }\angle 20° = 1.79\text{ mA }\angle{-6.57°} + 0.90\text{ mA }\angle 83.44°$

$= 1.88\text{ mA} + j0.69\text{ mA}$

$2\text{ mA }\angle 20° \overset{\checkmark}{=} 2\text{ mA }\angle 20.15°$

f. $P = I^2R = (1.79\text{ mA})^2\ 10\text{ k}\Omega = \mathbf{32.04\ mW}$

g. $F_p = \dfrac{G}{Y_T} = \dfrac{0.1\text{ mS}}{0.1118\text{ mS}} = \mathbf{0.894\ leading}$

h. $\omega = 2\pi f = 377$ rad/s

$\boldsymbol{i_s = 2.83 \times 10^{-3}\sin(\omega t + 20°)}$

$\boldsymbol{i_R = 2.53 \times 10^{-3}\sin(\omega t - 6.57°)}$

$\boldsymbol{i_C = 1.27 \times 10^{-3}\sin(\omega t + 83.44°)}$

$e = \mathbf{25.3}\ \boldsymbol{\sin(\omega t - 6.57°)}$

30. a. $\mathbf{Y}_T = \dfrac{1}{12\,\Omega\,\angle 0°} + \dfrac{1}{10\,\Omega\,\angle 90°} = 0.083\text{ S} - j0.1\text{ S} = \mathbf{129.96\ mS\ \angle{-50.31°}}$

c. $\mathbf{I}_s = \mathbf{E}\mathbf{Y}_T = (60\text{ V }\angle 0°)(0.13\text{ S}\angle{-50.31°}) = \mathbf{7.8\ A\ \angle{-50.31°}}$

$\mathbf{I}_R = \dfrac{E\angle\theta}{R\angle 0°} = 60\text{ V }\angle 0°/12\ \Omega\ \angle 0° = \mathbf{5\ A}\ \angle 0°$

$\mathbf{I}_L = \dfrac{E\angle\theta}{X_L\angle 90°} = 60\text{ V }\angle 0°/10\ \Omega\ \angle 90° = \mathbf{6\ A\ \angle{-90°}}$

f. $P = I^2R = (5\text{ A})^2\ 12\ \Omega = \mathbf{300\ W}$

g. $F_p = G/Y_T = 0.083\text{ S}/0.13\text{ S} = \mathbf{0.638\ lagging}$

h. $e = \mathbf{84.84\ sin\ 377}\boldsymbol{t}$

$i_R = \mathbf{7.07\ sin\ 377}\boldsymbol{t}$

$i_L = \mathbf{8.484\ sin(377}\boldsymbol{t}\mathbf{ - 90°)}$

$i_s = \mathbf{11.03\ sin(377}\boldsymbol{t}\mathbf{ - 50.31°)}$

31. a. $\mathbf{Y}_T = \dfrac{1}{1.2\,\Omega\,\angle 0°} + \dfrac{1}{2\,\Omega\,\angle 90°} + \dfrac{1}{5\,\Omega\,\angle -90°}$

$= 0.833\text{ S}\,\angle 0° + 0.5\text{ S}\,\angle -90° + 0.2\text{ S}\,\angle 90°$

$= 0.833\text{ S} - j0.3\text{ S} = \mathbf{0.89\ S\ \angle -19.81°}$

$\mathbf{Z}_T = 1.12\,\Omega\,\angle\,19.81°$

c. $X_C = \dfrac{1}{\omega C} \Rightarrow C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377\text{ rad/s})(5\,\Omega)} = \mathbf{531\ \mu F}$

$X_L = \omega L \Rightarrow L = \dfrac{X_L}{\omega} = \dfrac{2\,\Omega}{377\text{ rad/s}} = \mathbf{5.31\ mH}$

d. $\mathbf{E} = \dfrac{\mathbf{I}_s}{\mathbf{Y}_T} = \dfrac{(0.707)(3\text{ A})\,\angle 60°}{0.885\text{ S}\,\angle -19.81°} = \dfrac{2.121\text{ A}\,\angle 60°}{0.885\text{ S}\,\angle -19.81°} = \mathbf{2.40\ V\ \angle 79.81°}$

$\mathbf{I}_R = \dfrac{E\,\angle\theta}{R\,\angle 0°} = \dfrac{2.397\text{ V}\,\angle 79.81°}{1.2\,\Omega\,\angle 0°} = \mathbf{2.00\ A\ \angle 79.81°}$

$\mathbf{I}_L = \dfrac{E\,\angle\theta}{X_L\,\angle 90°} = \dfrac{2.397\text{ V}\,\angle 79.81°}{2\,\Omega\,\angle 90°} = \mathbf{1.20\ A\ \angle -10.19°}$

$\mathbf{I}_C = \dfrac{E\,\angle\theta}{X_C\,\angle -90°} = \dfrac{2.397\text{ V}\,\angle 79.81°}{5\,\Omega\,\angle -90°} = \mathbf{0.48\ A\ \angle 169.81°}$

f. $\mathbf{I}_s = \mathbf{I}_R + \mathbf{I}_L + \mathbf{I}_C$

$2.121\text{ A}\,\angle 60° = 2.00\text{ A}\,\angle 79.81° + 1.20\text{ A}\,\angle -10.19° + 0.48\text{ A}\,\angle 169.81°$

$2.121\text{ A}\,\angle 60° \overset{\checkmark}{=} 2.13\text{ A}\,\angle 60.01°$

g. $P = I^2R = (2.00\text{ A})^2\,1.2\,\Omega = \mathbf{4.8\ W}$

h. $F_p = \dfrac{G}{Y_T} = \dfrac{0.833\text{ S}}{0.885\text{ S}} = \mathbf{0.941\ lagging}$

i. $e = \mathbf{3.39\ sin(377\mathit{t} + 79.81°)}$

$i_R = \mathbf{2.83\ sin(377\mathit{t} + 79.81°)}$

$i_L = \mathbf{1.70\ sin(377\mathit{t} - 10.19°)}$

$i_C = \mathbf{0.68\ sin(377\mathit{t} + 169.81°)}$

32. a. $\mathbf{Y}_T = \dfrac{1}{3\text{ k}\Omega\,\angle 0°} + \dfrac{1}{4\text{ k}\Omega\,\angle 90°} + \dfrac{1}{8\text{ k}\Omega\,\angle -90°}$

$= 0.333\text{ mS}\,\angle 0° + 0.25\text{ mS}\,\angle -90° + 0.125\text{ mS}\,\angle 90°$

$= \mathbf{0.333\ mS + \mathit{j}0.125\ mS = 0.356\ mS\ \angle 20.57°}$

c. $X_L = \omega L \Rightarrow L = X_L/\omega = 4000\,\Omega/377\text{ rad/s} = \mathbf{10.61\ H}$

$X_C = \dfrac{1}{\omega C} \Rightarrow C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377\text{ rad/s})(8\text{ k}\Omega)} = \mathbf{0.332\ \mu F}$

d. $\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 3.535 \text{ mA } \angle{-20°}/0.356 \text{ mS } \angle 20.57° = \mathbf{9.93 \text{ V } \angle{-40.57°}}$

$\mathbf{I}_R = \dfrac{E \angle \theta}{R \angle 0°} = 9.93 \text{ V}\angle{-40.57°}/3 \text{ k}\Omega \angle 0° = \mathbf{3.31 \text{ mA } \angle{-40.57°}}$

$\mathbf{I}_L = \dfrac{E \angle \theta}{X_L \angle 90°} = 9.93 \text{ V}\angle{-40.57°}/4 \text{ k}\Omega \angle 90° = \mathbf{2.48 \text{ mA } \angle{-130.57°}}$

$\mathbf{I}_C = \dfrac{E \angle \theta}{X_C \angle -90°} = 9.93 \text{ V}\angle{-40.57°}/8 \text{ k}\Omega \angle{-90°} = \mathbf{1.24 \text{ mA } \angle 49.43°}$

g. $P = I^2R = (3.31 \text{ mA})^2 3 \text{ k}\Omega = \mathbf{32.87 \text{ mW}}$

h. $F_p = G/Y_T = 0.333 \text{ mS}/0.356 \text{ mS} = \mathbf{0.935 \text{ leading}}$

i. $e = \mathbf{14.04 \sin(377t - 40.57°)}$
$i_R \cong \mathbf{4.68 \times 10^{-3} \sin(377t - 40.57°)}$
$i_L \cong \mathbf{3.51 \times 10^{-3} \sin(377t - 130.57°)}$
$i_C = \mathbf{1.75 \times 10^{-3} \sin(377t + 49.43°)}$

33. a. $\mathbf{Y}_T = \dfrac{1}{5 \ \Omega \angle -90°} + \dfrac{1}{22 \ \Omega \angle 0°} + \dfrac{1}{10 \ \Omega \angle 90°}$
$= 0.2 \text{ S } \angle 90° + 0.045 \text{ S } \angle 0° + 0.1 \text{ S } \angle{-90°}$
$= 0.045 \text{ S} + j0.1 \text{ S} = \mathbf{0.110 \text{ S } \angle 65.77°}$
$\mathbf{Z}_T = \mathbf{9.09 \ \Omega \angle -65.77°}$

c. $C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377 \text{ rad/s})(5 \ \Omega)} = \mathbf{636.9 \ \mu F}$

$L = \dfrac{X_L}{\omega} = \dfrac{10 \ \Omega}{314 \text{ rad/s}} = \mathbf{31.8 \text{ mH}}$

d. $\mathbf{E} = (0.707)(35.4 \text{ V}) \angle 60° = \mathbf{25.03 \text{ V } \angle 60°}$
$\mathbf{I}_s = \mathbf{E}\mathbf{Y}_T = (25.03 \text{ V } \angle 60°)(0.11 \text{ S } \angle 65.77°) = \mathbf{2.75 \text{ A } \angle 125.77°}$

$\mathbf{I}_C = \dfrac{E \angle \theta}{X_C \angle -90°} = \dfrac{25.03 \text{ V } \angle 60°}{5 \angle -90°} = \mathbf{5 \text{ A } \angle 150°}$

$\mathbf{I}_R = \dfrac{E \angle \theta}{R \angle 0°} = \dfrac{25.03 \text{ V } \angle 60°}{22 \ \Omega \angle 0°} = \mathbf{1.14 \text{ A } \angle 60°}$

$\mathbf{I}_L = \dfrac{E \angle \theta}{X_L \angle 90°} = \dfrac{25.03 \text{ V } \angle 60°}{10 \ \Omega \angle 90°} = \mathbf{2.50 \text{ A } \angle{-30°}}$

f. $\mathbf{I}_s = \mathbf{I}_C + \mathbf{I}_R + \mathbf{I}_L$
$2.75 \text{ A } \angle 125.77° = 5 \text{ A } \angle 150° + 1.14 \text{ A } \angle 60° + 2.50 \text{ A } \angle{-30°}$
$= (-4.33 + j2.5) + (0.57 + j0.9) + (2.17 - j1.25)$
$= -1.59 + j2.24$
$\overset{\checkmark}{=} 2.75 \angle 125.4°$

g. $P = I^2R = (1.14 \text{ A})^2 \ 22 \ \Omega = \mathbf{28.59 \text{ W}}$

h. $F_p = \dfrac{G}{Y_T} = \dfrac{0.045\text{ S}}{0.110\text{ S}} = \mathbf{0.409\ leading}$

i. $e = \mathbf{35.4\ sin(314}\boldsymbol{t}\mathbf{ + 60°)}$
$i_s = \mathbf{3.89\ sin(314}\boldsymbol{t}\mathbf{ + 125.77°)}$
$i_C = \mathbf{7.07\ sin(314}\boldsymbol{t}\mathbf{ + 150°)}$
$i_R = \mathbf{1.61\ sin(314}\boldsymbol{t}\mathbf{ + 60°)}$
$i_L = \mathbf{3.54\ sin(314}\boldsymbol{t}\mathbf{ - 30°)}$

34. a. $\mathbf{I}_1 = \dfrac{(80\ \Omega \angle 90°)(20\text{ A} \angle 40°)}{22\ \Omega + j80\ \Omega} = \dfrac{1600\text{ A} \angle 130°}{82.97 \angle 74.62°} = \mathbf{19.28\ A \angle 55.38°}$

$\mathbf{I}_2 = \dfrac{(22\ \Omega \angle 0°)(20\text{ A} \angle 40°)}{82.97\ \Omega \angle 74.62°} = \dfrac{440\text{ A} \angle 40°}{82.97 \angle 74.62°} = \mathbf{5.30\ A \angle{-34.62°}}$

b. $\mathbf{I}_1 = \dfrac{(12\ \Omega - j6\ \Omega)(6\text{ A} \angle 30°)}{12\ \Omega - j6\ \Omega + j4\ \Omega} = \dfrac{(13.42 \angle -26.57°)(6\text{ A} \angle 30°)}{12 - j2}$

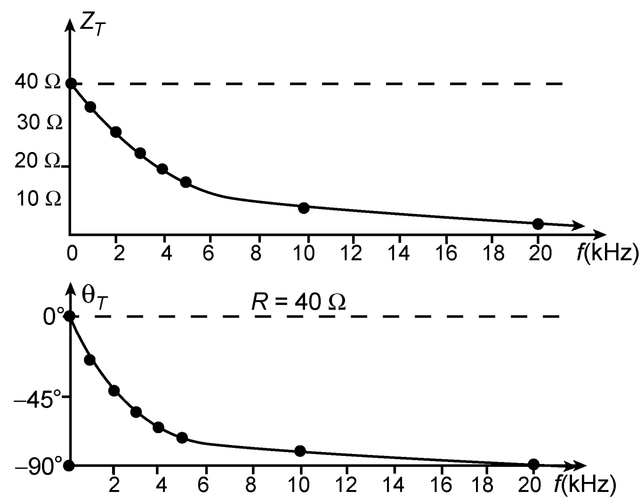
$= \dfrac{80.52\text{ A}\angle 3.43°}{12.17\angle -9.46°} = \mathbf{6.62\ A \angle 12.89°}$

$\mathbf{I}_2 = \dfrac{(4\ \Omega \angle 90°)(6\text{ A} \angle 30°)}{12.17\ \Omega\angle -9.46°} = \dfrac{24\text{ A} \angle 120°}{12.17 \angle -9.46°} = \mathbf{1.97\ A \angle 129.46°}$

35. a. $\mathbf{Z}_T = \dfrac{(R \angle 0°)(X_C \angle -90°)}{R - jX_C} = \dfrac{RX_C}{\sqrt{R^2 + X_C^2}} \angle -90° + \tan^{-1} X_C/R$

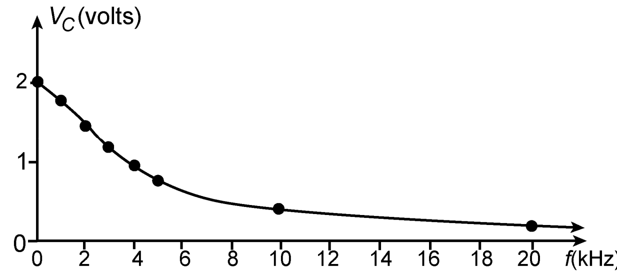
$|Z_T| = \dfrac{RX_C}{\sqrt{R^2 + X_C^2}} \quad \theta_T = -90° + \tan^{-1} X_C/\text{R}$

f	$\lvert Z_T \rvert$	θ_T
0 Hz	40.0 Ω	0.0°
1 kHz	35.74 Ω	–26.67°
2 kHz	28.22 Ω	–45.14°
3 kHz	22.11 Ω	–56.44°
4 kHz	17.82 Ω	–63.55°
5 kHz	14.79 Ω	–68.30°
10 kHz	7.81 Ω	–78.75°
20 kHz	3.959 Ω	–89.86°



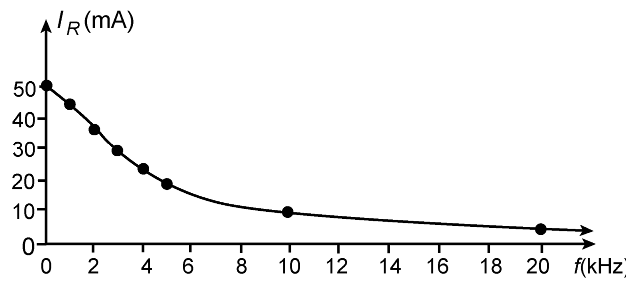
b. $|V_C| = \dfrac{IRX_C}{\sqrt{R^2 + X_C^2}} = I[Z_T(f)]$

f	$\lvert V_C \rvert$
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. $|I_R| = \left|\dfrac{V_C}{R}\right|$

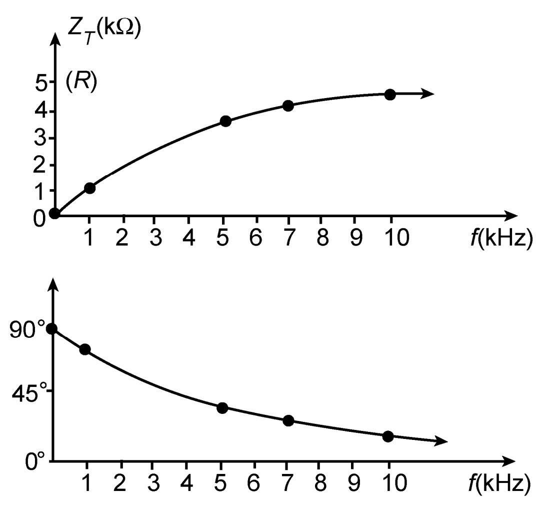
f	$\lvert I_R \rvert$
0 kHz	50.0 mA
1 kHz	44.7 mA
2 kHz	35.3 mA
3 kHz	27.64 mA
4 kHz	22.28 mA
5 kHz	18.50 mA
10 kHz	9.78 mA
20 kHz	4.95 mA



36. a. $\mathbf{Z}_T = \dfrac{\mathbf{Z}_R \mathbf{Z}_L}{\mathbf{Z}_R + \mathbf{Z}_L} = \dfrac{(R \angle 0°)(X_L \angle 90°)}{R + jX_L} = \dfrac{RX_L}{\sqrt{R^2 + X_L^2}} \angle 90° - \tan^{-1} X_L/R$

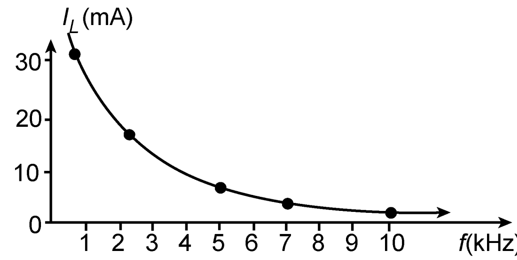
$|\mathbf{Z}_T| = \dfrac{RX_L}{\sqrt{R^2 + X_L^2}}\ \theta_T = 90° - \tan^{-1} X_L/R$

f	$\lvert Z_T \rvert$	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°

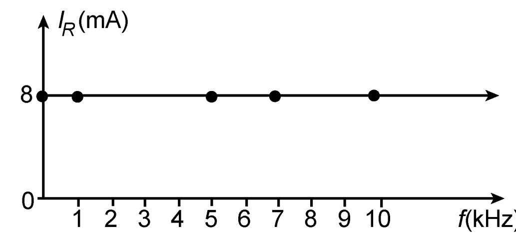


b. $|I_L| = \dfrac{E}{X_L}$

f	$\lvert I_L \rvert$
0 Hz	∞
1 kHz	31.75 mA
5 kHz	6.37 mA
7 kHz	4.55 mA
10 kHz	3.18 mA

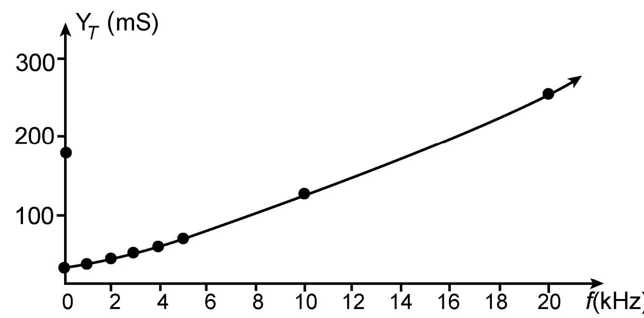


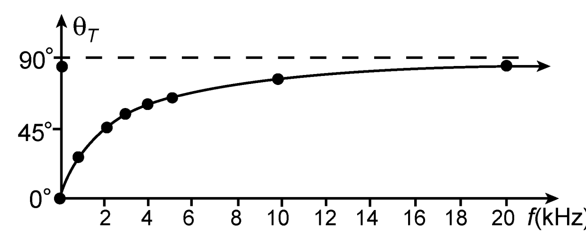
c. $I_R = \dfrac{E}{R} = \dfrac{40\text{ V}}{5\text{ k}\Omega} = 8\text{ mA (constant)}$



37. $\mathbf{Y}_T = \dfrac{\sqrt{R^2 + X_C^2}}{RX_C} \angle 90° - \tan^{-1} X_C/R$

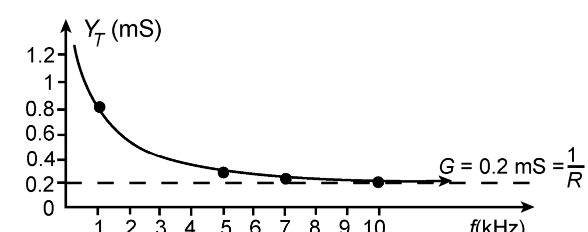
f	$\lvert Y_T \rvert$	θ_T
0 Hz	25.0 mS	0.0°
1 kHz	27.98 mS	26.67°
2 kHz	35.44 mS	45.14°
3 kHz	45.23 mS	56.44°
4 kHz	56.12 mS	63.55°
5 kHz	67.61 mS	68.30°
10 kHz	128.04 mS	78.75°
20 kHz	252.59 mS	89.86°

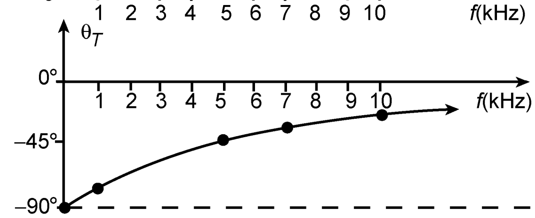




38. $Y_T = \dfrac{1}{Z_T}$ (use data of Prob. 36), $\theta_{T_Y} = -\theta_{T_Z}$

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°

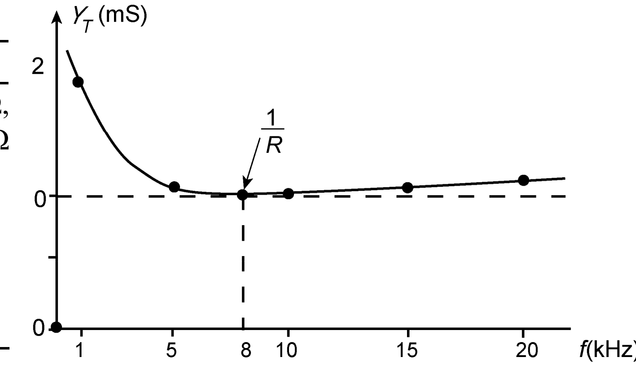




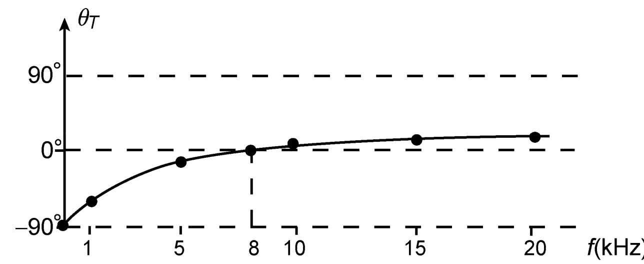
39. a. $\mathbf{Y}_T = G \angle 0° + B_L \angle{-90°} + B_C \angle 90°$

$$= \sqrt{G^2 + (B_C - B_L)^2} \angle \tan^{-1} \frac{B_C - B_L}{G}$$

f	$\lvert Y_T \rvert$
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

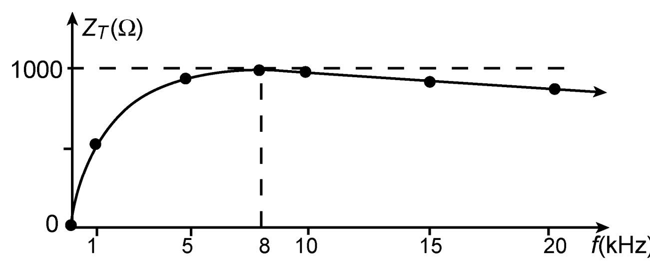


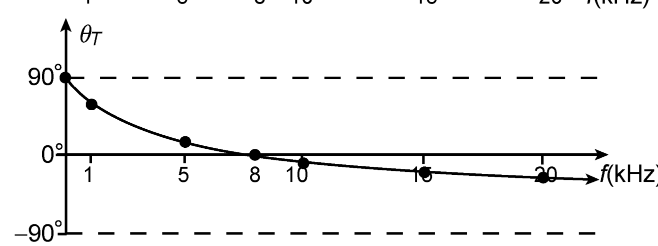
f	$\lvert \theta_T \rvert$
0 Hz	–90.0°
1 kHz	–57.42°
5 kHz	–10.87°
10 kHz	+5.26°
15 kHz	+15.16°
20 kHz	+22.95°



b. $Z_T = \dfrac{1}{Y_T}, \theta_{T_Z} = -\theta_{T_Y}$

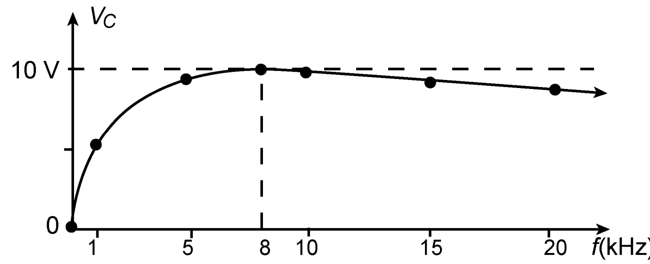
f	Z_T	θ_T
0 kHz	0.0 Ω	90.0°
1 kHz	538.5 Ω	57.42°
5 kHz	982.32 Ω	10.87°
10 kHz	996.02 Ω	–5.26°
15 kHz	965.25 Ω	–15.16°
20 kHz	921.66 Ω	–22.95°





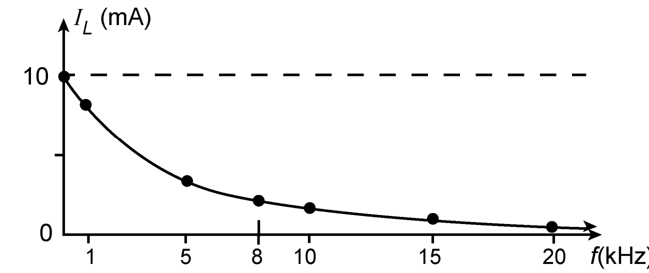
c. $V_C(f) = I[Z_T(f)]$

f	$\lvert V_C \rvert$
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. $I_L = \dfrac{V_C(f)}{X_L}$

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. $$R_p = \frac{R_s^2 + X_s^2}{R_s} = \frac{(20\,\Omega)^2 + (40\,\Omega)^2}{20\,\Omega} = \mathbf{100\,\Omega}\ (R)$$

$$X_p = \frac{R_s^2 + X_s^2}{X_s} = \frac{2000\,\Omega}{40} = \mathbf{50\,\Omega}\ (C)$$

b. $$R_p = \frac{R_s^2 + X_s^2}{R_s} = \frac{(2\,\text{k}\Omega)^2 + (3\,\text{k}\Omega)^2}{2\,\text{k}\Omega} = \mathbf{6.5\,k\Omega}\ (R)$$

$$X_p = \frac{R_s^2 + X_s^2}{X_s} = \frac{(2\,\text{k}\Omega)^2 + (3\,\text{k}\Omega)^2}{3\,\text{k}\Omega} = \mathbf{4.33\,k\Omega}\ (C)$$

41. a. $$R_s = \frac{R_p X_p^2}{X_p^2 + R_p^2} = \frac{(8.2\,\text{k}\Omega)(20\,\text{k}\Omega)^2}{(20\,\text{k}\Omega)^2 + (8.2\,\text{k}\Omega)^2} = \mathbf{7.02\,k\Omega}$$

$$X_s = \frac{R_p^2 X_p}{X_p^2 + R_p^2} = \frac{(8.2\,\text{k}\Omega)^2(20\,\text{k}\Omega)}{467.24\,\text{k}\Omega} = \mathbf{2.88\,k\Omega}$$

$\mathbf{Z}_T = \mathbf{7.02\,k\Omega - \mathit{j}2.88\,k\Omega}$

b. $$R_s = \frac{R_p X_p^2}{X_p^2 + R_p^2} = \frac{(68\,\Omega)(40\,\Omega)^2}{(40\,\Omega)^2 + (68\,\Omega)^2} = \mathbf{17.48\,\Omega}$$

$$X_s = \frac{R_p^2 X_p}{X_p^2 + R_p^2} = \frac{(68\,\Omega)^2(40\,\Omega)}{6224\,\Omega^2} = \mathbf{29.72\,\Omega}$$

$\mathbf{Z}_T = \mathbf{17.48\,\Omega + \mathit{j}29.72\,\Omega}$

42. a. $C_T = 2\ \mu\text{F}$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3\text{ Hz})(2\ \mu\text{F})} = 79.62\ \Omega$$

$$X_L = \omega L = 2\pi(10^3\text{ Hz})(10\text{ mH}) = 62.80\ \Omega$$

$$\mathbf{Y}_T = \frac{1}{220\ \Omega\ \angle 0°} + \frac{1}{79.62\ \Omega\ \angle -90°} + \frac{1}{62.8\ \Omega\ \angle 90°}$$

$= 4.55\text{ mS}\ \angle 0° + 12.56\text{ mS}\ \angle 90° + 15.92\text{ mS}\ \angle{-90°}$
$= \mathbf{4.55\ mS} - \boldsymbol{j}\mathbf{3.36\ mS = 5.66\ mS\ \angle{-36.44°}}$

$\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 1\text{ A}\ \angle 0°/5.66\text{ mS}\ \angle{-36.44°} = \mathbf{176.68\ V\ \angle 36.44°}$

$$\mathbf{I}_R = \frac{E\angle\theta}{R\angle 0°} = 176.68\text{ V}\ \angle 36.44°/220\ \Omega\ \angle 0° = \mathbf{0.803\ A\ \angle 36.44°}$$

$$\mathbf{I}_L = \frac{E\angle\theta}{X_L\angle 90°} = 176.68\text{ V}\ \angle 36.44°/62.80\ \angle 90° = \mathbf{2.813\ A\ \angle{-53.56°}}$$

b. $F_p = G/Y_T = 4.55\text{ mS}/5.66\text{ mS} = $ **0.804 lagging**

e. $P = I^2R = (0.803\text{ A})^2\ 220\ \Omega = \mathbf{141.86\ W}$

f. $\mathbf{I}_s = \mathbf{I}_R + 2\mathbf{I}_C + \mathbf{I}_L$

and $\mathbf{I}_C = \dfrac{\mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L}{2}$

$$= \frac{1\text{ A}\ \angle 0° - 0.803\text{ A}\ \angle 36.44° - 2.813\text{ A}\ \angle -53.56°}{2}$$

$$= \frac{1-(0.646+j0.477)-(1.671-j2.263)}{2} = \frac{-1.317+j1.786}{2}$$

$\mathbf{I}_C = -0.657 + j0.893 = \mathbf{1.11\ A\ \angle 126.43°}$

g. $$\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{5.66\text{ mS}\ \angle -36.44°} = 176.7\ \Omega\ \angle 36.44°$$

$= \mathbf{142.15\ \Omega} + \boldsymbol{j}\mathbf{104.96\ \Omega} = R + jX_L$

43. a. $(R = 220\ \Omega)\ \|\ (L = 1\text{ H})\ \|\ (C = 2\ \mu\text{F})$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3\text{ Hz})(2\ \mu\text{F})} = 79.62\ \Omega$$

$$X_L = \omega L = 2\pi(10^3\text{ Hz})(1\text{ H}) = 6.28\text{ k}\Omega$$

$$\mathbf{Y}_T = \frac{1}{220\ \Omega\ \angle 0°} + \frac{1}{6.28\times 10^3\ \Omega\ \angle 90°} + \frac{1}{79.62\ \Omega\ \angle -90°}$$

$= 0.0045 - j0.1592 \times 10^{-3} + j0.0126$
$= 4.5 \times 10^{-3} - j0.1592 \times 10^{-3} + j12.6 \times 10^{-3}$
$= \mathbf{4.5\ mS} + \boldsymbol{j}\mathbf{12.44\ mS = 13.23\ mS\ \angle 70.11°}$

$\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 1\text{ A }\angle 0°/13.23\text{ mS }\angle 70.11° = \mathbf{75.6\text{ V }\angle{-70.11°}}$

$\mathbf{I}_R = \dfrac{E\angle\theta}{R\angle 0°} = 75.6\text{ V }\angle{-70.11°}/220\ \Omega\ \angle 0° = \mathbf{0.34\text{ A }\angle{-70.11°}}$

$\mathbf{I}_L = \dfrac{E\angle\theta}{X_L\angle 90°} = 75.6\text{ V }\angle{-70.11°}/6.28\text{ k}\Omega\ \angle 90° = \mathbf{12.04\text{ mA }\angle{-160.11°}}$

b. $F_p = \dfrac{G}{Y_T} = \dfrac{4.5\text{ mS}}{13.23\text{ mS}} = \mathbf{0.340\ leading}$

c. $P = I^2R = (0.34\text{A})^2\ 220\ \Omega = \mathbf{25.43\ W}$

f. $2\mathbf{I}_C = \mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L$

$$\mathbf{I}_C = \frac{\mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L}{2} = \frac{1\text{ A }\angle 0° - 0.34\text{ A }\angle -70.11° - 12.04\text{ mA }\angle -160.11°}{2}$$

$$= \frac{1-(0.12-j0.32)-(-11.32\times10^{-3}-j4.1\times10^{-3})}{2}$$

$$= \frac{0.89+j0.32}{2}$$

$\mathbf{I}_C = 0.45 + j0.16 = \mathbf{0.47\text{ A }\angle 19.63°}$

g. $\mathbf{Z}_T = \dfrac{1}{\mathbf{Y}_\text{T}} = \dfrac{1}{13.23\text{ mS}\angle 70.11°} = 75.59\ \Omega\ \angle{-70.11°} = \mathbf{25.72\ \Omega - \mathit{j}71.08\ \Omega}$

$R = \mathbf{25.72\ \Omega}$, $X_C = \mathbf{71.08\ \Omega}$

44. $P = VI\cos\theta = 3000\text{ W}$

$$\cos\theta = \frac{3000\text{ W}}{VI} = \frac{3000\text{ W}}{(100\text{ V})(40\text{ A})} = \frac{3000}{4000} = 0.75\text{ (lagging)}$$

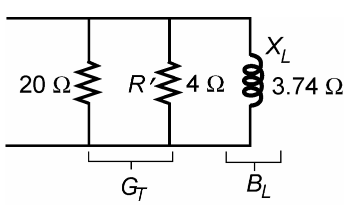
$\theta = \cos^{-1} 0.75 = 41.41°$

$$\mathbf{Y}_T = \frac{\mathbf{I}}{\mathbf{E}} = \frac{40\text{ A }\angle -41.41°}{100\text{ V }\angle 0°} = 0.4\text{ S }\angle{-41.41°} = 0.3\text{ S} - j0.265\text{ S} = G_T - jB_L$$

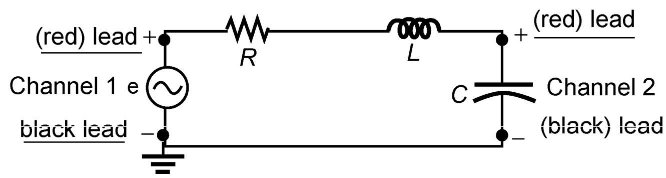
$$G_T = 0.3\text{ S} = \frac{1}{20\ \Omega} + \frac{1}{R'} = 0.05\text{ S} + \frac{1}{R'}$$

and $R' = \dfrac{1}{0.25\text{ S}} = 4\ \Omega$

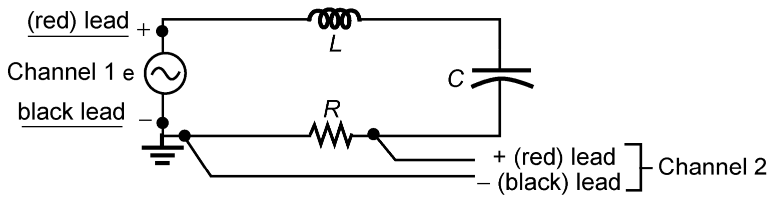
$X_L = \dfrac{1}{B_L} = \dfrac{1}{0.265\text{ S}} = \mathbf{3.74\ \Omega}$



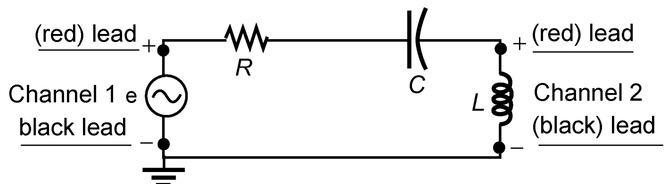
45. a.



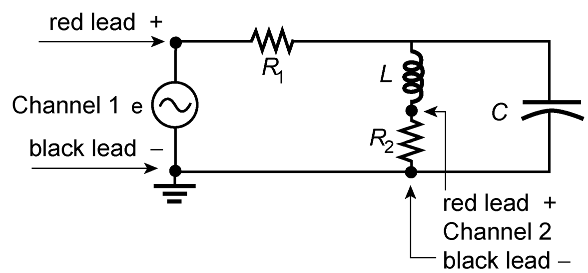
b.



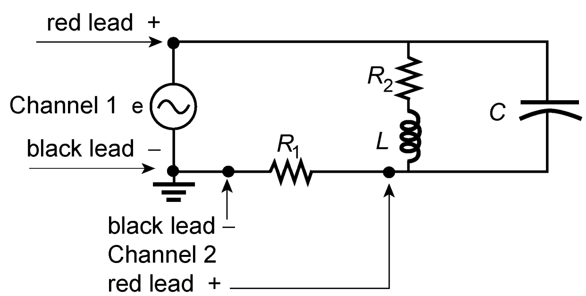
c.



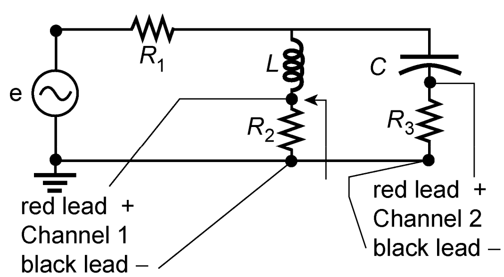
46. a. e and υ_{R_2}



b. e and i_s



c. i_L and i_C



47. (I): (a) $\theta_{\text{div.}} = 0.8$ div., $\theta_T = 4$ div.

$$\theta = \frac{0.8\text{ div.}}{4\text{ div.}} \times 360° = 72°$$

$\boldsymbol{\upsilon_1}$ **leads** $\boldsymbol{\upsilon_2}$ **by 72°**

(b) υ_1: peak-to-peak = (5 div.)(0.5 V/div.) = **2.5 V**

$$V_1(\text{rms}) = 0.7071\left(\frac{2.5\text{ V}}{2}\right) = \mathbf{0.88\text{ V}}$$

υ_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) $\theta_{\text{div.}} = 2.2$ div., $\theta_T = 6$ div.

$$\theta = \frac{2.2\text{ div.}}{6\text{ div.}} \times 360° = 132°$$

$\boldsymbol{\upsilon_1}$ **leads** $\boldsymbol{\upsilon_2}$ **by 132°**

(b) υ_1: peak-to-peak = (2.8 div.)(2 V/div.) = **5.6 V**

$$V_1(\text{rms}) = 0.7071\left(\frac{5.6\text{ V}}{2}\right) = \mathbf{1.98\text{ V}}$$

υ_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. $\mathbf{Z}_T = 2\ \Omega + j6\ \Omega + 8\ \Omega\ \angle{-90^\circ} \parallel 12\ \Omega\ \angle{-90^\circ}$

$$= 2\ \Omega + j6\ \Omega + \frac{(8\ \Omega \angle -90^\circ)(12\ \Omega \angle -90^\circ)}{-j8\Omega - j12\Omega} = 2\ \Omega + j6\ \Omega + \frac{96\ \Omega \angle -180^\circ}{20 \angle -90^\circ}$$

$$= 2\ \Omega + j6\ \Omega + 4.8\ \Omega\ \angle{-90^\circ} = 2\ \Omega + j6\ \Omega - j4.8\ \Omega = 2\ \Omega + j\ 1.2\ \Omega$$

$\mathbf{Z}_T = \mathbf{2.33\ \Omega\ \angle 30.96^\circ}$

b. $\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{12\ \text{V} \angle 0^\circ}{2.33\ \Omega \angle 30.96^\circ} = \mathbf{5.15\ A\ \angle{-30.96^\circ}}$

c. $\mathbf{I}_1 = \mathbf{I} = \mathbf{5.15\ A\ \angle{-30.96^\circ}}$

d. $(\text{CDR})\mathbf{I}_2 = \dfrac{(12\ \Omega \angle -90^\circ)(5.15\ \text{A} \angle -30.96^\circ)}{-j12\ \Omega - j8\ \Omega} = \dfrac{61.80\ \text{A} \angle -120.96^\circ}{20 \angle -90^\circ} = \mathbf{3.09\ A\ \angle{-30.96^\circ}}$

$\mathbf{I}_3 = \dfrac{(8\ \Omega \angle -90^\circ)(5.15\ \text{A} \angle -30.96^\circ)}{20\ \Omega \angle -90^\circ} = \dfrac{41.2\ \text{A} \angle -120.96^\circ}{20 \angle -90^\circ} = \mathbf{2.06\ A\ \angle{-30.96^\circ}}$

e. $\mathbf{V}_L = (I \angle \theta)(X_L \angle 90^\circ) = (5.15\ \text{A} \angle -30.96^\circ)(6\ \Omega \angle 90^\circ) = \mathbf{30.9\ V\ \angle 59.04^\circ}$

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. $\mathbf{I}_s = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{30\ \text{V} \angle 0^\circ}{7.38\ \Omega \angle 48.57^\circ} = \mathbf{4.07\ A\ \angle{-48.57^\circ}}$

c. $\mathbf{I}_C = \dfrac{\mathbf{Z}_{R_2} \mathbf{I}_s}{\mathbf{Z}_{R_2} + \mathbf{Z}_C} = \dfrac{(2\ \Omega \angle 0^\circ)(4.07\ \text{A} \angle -48.57^\circ)}{2\ \Omega - j8\ \Omega}$

$= \dfrac{8.14\ \text{A} \angle -48.57^\circ}{8.25 \angle -75.96^\circ} = \mathbf{0.987\ A\ \angle 27.39^\circ}$

d. $\mathbf{V}_L = \dfrac{\mathbf{Z}_L \mathbf{E}}{\mathbf{Z}_T} = \dfrac{(6\ \Omega \angle 90^\circ)(30\ \text{V} \angle 0^\circ)}{7.38\ \Omega \angle 48.57^\circ} = \dfrac{180\ \text{V} \angle 90^\circ}{7.38\ \Omega \angle 48.57^\circ}$

$= \mathbf{24.39\ V\ \angle 41.43^\circ}$

3. a. $\mathbf{Z}_T = 12\ \Omega\ \angle 90^\circ \parallel (9.1\ \Omega - j12\ \Omega) = 12\ \Omega\ \angle 90^\circ \parallel 15.06\ \Omega\ \angle{-52.826^\circ}$

$= \dfrac{180.72\ \Omega \angle 37.17^\circ}{9.10 \angle 0^\circ}$

$= \mathbf{19.86\ \Omega\ \angle 37.17^\circ}$

$\mathbf{Y}_T = \dfrac{1}{\mathbf{Z}_T} = \dfrac{1}{19.86\ \Omega\ \angle 37.17^\circ} = \mathbf{50.35\ mS\ \angle{-37.17^\circ}}$

b. $\mathbf{I}_s = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{60\text{ V} \angle 30°}{19.86\ \Omega \angle 37.17°} = \mathbf{3.02\ A\ \angle{-7.17°}}$

c. (CDR) $\mathbf{I}_2 = \dfrac{(12\ \Omega \angle 90°)(3.02\text{ A} \angle -7.17°)}{j12\ \Omega + 9.1\ \Omega - j12\ \Omega} = \dfrac{36.24\text{ A} \angle 82.83°}{9.1 \angle 0°}$

$= \mathbf{3.98\ A\ \angle 82.83°}$

d. (VDR) $\mathbf{V}_C = \dfrac{(12\ \Omega \angle -90°)(60\text{ V} \angle 30°)}{9.1\ \Omega - j12\ \Omega} = \dfrac{720\text{ V} \angle -60°}{15.06 \angle -52.826°}$

$= \mathbf{47.81\ V\ \angle{-7.17°}}$

e. $P = EI\cos\theta = (60\text{ V})(3.02\text{ A})\cos(30° - 7.17°)$
$= 181.20(0.922) = \mathbf{167.07\ W}$

4. a. $\mathbf{Z}_T = 2\ \Omega + \dfrac{(4\ \Omega \angle -90°)(6\Omega \angle 90°)}{-j4\ \Omega + j6\ \Omega} + \dfrac{(4\ \Omega \angle 0°)(3\ \Omega \angle 90°)}{4\ \Omega + j3\ \Omega}$

$= 2\ \Omega + \dfrac{24\ \Omega \angle 0°}{2 \angle 90°} + \dfrac{12\ \Omega \angle 90°}{5 \angle 36.87°}$
$= 2\ \Omega + 12\ \Omega \angle{-90°} + 2.4 \angle 53.13°$
$= 2\ \Omega - j12\ \Omega + 1.44\ \Omega + j1.92\ \Omega$
$= \mathbf{3.44\ \Omega - \mathit{j}10.08\ \Omega = 10.65\ \Omega\ \angle{-71.16°}}$

b. $\mathbf{V}_2 = \mathbf{I}(2.4\ \Omega \angle 53.13°) = (5\text{ A} \angle 0°)(2.4\ \Omega \angle 53.13°) = \mathbf{12\ V\ \angle 53.13°}$

$\mathbf{I}_L = \dfrac{(4\ \Omega \angle 0°)(\mathbf{I})}{4\ \Omega + j3\ \Omega} = \dfrac{(4\ \Omega \angle 0°)(5\text{ A} \angle 0°)}{5\ \Omega \angle 36.87°} = \dfrac{20\text{ A} \angle 0°}{5 \angle 36.87°} = \mathbf{4\ A\ \angle{-36.87°}}$

c. $F_p = \dfrac{R}{\mathbf{Z}_T} = \dfrac{3.44\ \Omega}{10.65\ \Omega} = \mathbf{0.323\ (leading)}$

5. a. $400\ \Omega \angle{-90°} \parallel 400\ \Omega \angle{-90°} = \dfrac{400\ \Omega \angle -90°}{2} = 200\ \Omega \angle{-90°}$

$\mathbf{Z}' = 200\ \Omega - j200\ \Omega = 282.843\ \Omega \angle{-45°}$
$\mathbf{Z}'' = -j200\ \Omega + j560\ \Omega = +j360\ \Omega = 360\ \Omega \angle 90°$

$\mathbf{Z}_T = \mathbf{Z}' \parallel \mathbf{Z}'' = \dfrac{(282.843\ \Omega \angle -45°)(360\ \Omega \angle 90°)}{(200\ \Omega - j200\ \Omega) + \ j360\ \Omega} = \dfrac{101.83\text{ k}\Omega\angle 45°}{256.12 \angle 38.66°}$

$= 397.59\ \Omega \angle 6.34°$

$\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{100\text{ V} \angle 0°}{397.59\ \Omega \angle 6.34°} = \mathbf{0.25\ A\ \angle{-6.34°}}$

b. $\mathbf{V}_C = \dfrac{(200\ \Omega \angle -90°)(100\text{ V} \angle 0°)}{200\ \Omega - j200\ \Omega} = \dfrac{20{,}000\text{ V} \angle -90°}{282.843 \angle -45°} = \mathbf{70.71\ V\ \angle{-45°}}$

c. $P = EI\cos\theta = (100\text{ V})(0.25\text{ A})\cos 6.34°$
$= (25)(0.994) = \mathbf{24.85\ W}$

6. a. $\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega = 5\ \Omega\ \angle 53.13°$

$$\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{120\text{ V}\ \angle 60°}{5\ \Omega\ \angle 53.13°} = \mathbf{24\ A\ \angle 6.87°}$$

b. $$\mathbf{V}_C = \frac{(13\ \Omega\ \angle -90°)(120\text{ V}\ \angle 60°)}{-j13\ \Omega + j7\ \Omega} = \frac{1560\text{ V}\ \angle -30°}{6\ \angle -90°} = \mathbf{260\ V\ \angle 60°}$$

c. $V_{R_1} = (I_1\ \angle\theta)R\ \angle 0° = (24\text{ A}\ \angle 6.87°)(3\ \Omega\ \angle 0°) = 72\text{ V}\ \angle 6.87°$

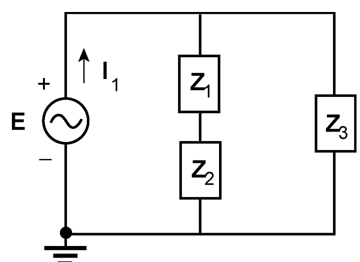
$\underset{+-}{\mathbf{V}_{ab}} + V_{R_1} - \mathbf{V}_C = 0$

$\underset{+-}{\mathbf{V}_{ab}} = \mathbf{V}_C - V_{R_1} = 260\text{ V}\ \angle 60° - 72\text{ V}\ \angle 6.87°$

$= (130\text{ V} + j225.167\text{ V}) - (71.483\text{ V} + j8.612\text{ V})$

$= \mathbf{58.52\ V + \mathit{j}216.56\ V = 224.33\ V\ \angle 74.88°}$

7. a.



$\mathbf{Z}_1 = 10\ \Omega\ \angle 0°$

$\mathbf{Z}_2 = 80\ \Omega\ \angle 90° \parallel 20\ \Omega\ \angle 0°$

$$= \frac{1600\ \Omega\ \angle 90°}{20 + j80} = \frac{1600\ \Omega\ \angle 90°}{82.462\ \angle 75.964°}$$

$= 19.403\ \Omega\ \angle 14.036°$

$\mathbf{Z}_3 = 60\ \Omega\ \angle -90°$

$\mathbf{Z}_T = (\mathbf{Z}_1 + \mathbf{Z}_2) \parallel \mathbf{Z}_3$

$= (10\ \Omega + 18.824\ \Omega + j4.706\ \Omega) \parallel 60\ \Omega\ \angle -90°$

$$= 29.206\ \Omega\ \angle 9.273° \parallel 6\ \Omega\ \angle -90° = \frac{1752.36\ \Omega\ \angle -80.727°}{28.824 + j4.706 - j60}$$

$$= \frac{1752.36\ \Omega\ \angle -80.727°}{62.356\ \angle -62.468°} = \mathbf{28.103\ \Omega\ \angle -18.259°}$$

$$\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{40\text{ V}\ \angle 0°}{28.103\ \Omega\ \angle -18.259°} = \mathbf{1.42\ A\ \angle 18.26°}$$

b. $$\mathbf{V}_1 = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(19.403\ \Omega\ \angle 14.036°)(40\text{ V}\ \angle 0°)}{29.206\ \Omega\ \angle 9.273°} = \frac{776.12\text{ V}\ \angle 14.036°}{29.206\ \angle 9.273°}$$

$= \mathbf{26.57\ V\ \angle 4.76°}$

c. $P = EI\cos\theta = (40\text{ V})(1.423\text{ A})\cos 18.259°$

$= \mathbf{54.07\ W}$

8. a. $\mathbf{Z}_1 = 2\ \Omega + j1\ \Omega = 2.236\ \Omega\ \angle 26.565°$, $\mathbf{Z}_2 = 3\ \Omega\ \angle 0°$

$\mathbf{Z}_3 = 16\ \Omega + j15\ \Omega - j7\ \Omega = 16\ \Omega + j8\ \Omega = 17.889\ \Omega\ \angle 26.565°$

$$\mathbf{Y}_T = \frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} = \frac{1}{2.236\ \Omega\ \angle 26.565°} + \frac{1}{3\ \Omega\ \angle 0°} + \frac{1}{17.889\ \Omega\ \angle 26.565°}$$
$$= 0.447\ \text{S}\ \angle -26.565° + 0.333\ \text{S}\ \angle 0° + 0.056\ \text{S}\ \angle -26.565°$$
$$= (0.4\ \text{S} - j0.2\ \text{S}) + (0.333\ \text{S}) + (0.05\ \text{S} - j0.025\ \text{S})$$
$$= 0.783\ \text{S} - j0.225\ \text{S} = \mathbf{0.82\ S\ \angle -16.03°}$$
$$\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{0.82\ \text{S}\ \angle -16.03°} = \mathbf{1.23\ \Omega\ \angle 16.03°}$$

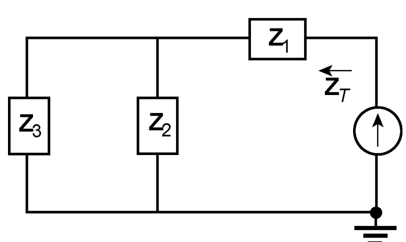
b $$\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{60\ \text{V}\ \angle 0°}{2.236\ \Omega\ \angle 26.565°} = \mathbf{26.83\ A\ \angle -26.57°}$$
$$\mathbf{I}_2 = \frac{\mathbf{E}}{\mathbf{Z}_2} = \frac{60\ \text{V}\ \angle 0°}{3\ \Omega\ \angle 0°} = \mathbf{20\ A\ \angle 0°}$$
$$\mathbf{I}_3 = \frac{\mathbf{E}}{\mathbf{Z}_3} = \frac{60\ \text{V}\ \angle 0°}{17.889\ \Omega\ \angle 26.565°} = \mathbf{3.35\ A\ \angle -26.57°}$$

c. $$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60\ \text{V}\ \angle 0°}{1.227\ \Omega\ \angle 16.032°} = \mathbf{48.9\ A\ \angle -16.03°}$$

$$\mathbf{I}_s \stackrel{?}{=} \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3$$
$$48.9\ \text{A}\ \angle -16.03° \stackrel{?}{=} 26.83\ \text{A}\ \angle -26.57° + 20\ \text{A}\ \angle 0° + 3.35\ \text{A}\ \angle -26.57°$$
$$= (24\ \text{A} - j12\ \text{A}) + (20\ \text{A}) + (3\ \text{A} - j1.5\ \text{A})$$
$$\stackrel{\checkmark}{=} 47\ \text{A} + j13.5\ \text{A} = \mathbf{48.9\ A\ \angle -16.03°}\ \text{(checks)}$$

d. $$F_p = \frac{G}{Y_T} = \frac{0.783\ \text{S}}{0.820\ \text{S}} = \mathbf{0.955\ (lagging)}$$

9. a.



$$\mathbf{Z}' = 3\ \Omega\ \angle 0° \parallel 4\ \Omega\ \angle -90° = \frac{12\ \Omega\ \angle -90°}{3 - j4}$$
$$= \frac{12\ \Omega\ \angle -90°}{5\ \angle -53.13°} = 2.4\ \Omega\ \angle -36.87°$$
$$\mathbf{Z}_3 = 2\ \mathbf{Z}' + j7\ \Omega$$
$$= 4.8\ \Omega\ \angle -36.87° + j7\ \Omega$$
$$= 3.84\ \Omega - j2.88\ \Omega + j7\ \Omega$$
$$= 3.84\ \Omega + j4.12\ \Omega$$
$$= 5.63\ \Omega\ \angle 47.02°$$

$$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3 = 8.8\ \Omega + 8.2\ \Omega\ \angle 0° \parallel 5.63\ \Omega\ \angle 47.02°$$
$$= 8.8\ \Omega + \frac{46.18\ \Omega\ \angle 47.02°}{8.2 + 3.84 + j4.12} = 8.8\ \Omega + \frac{46.18\ \Omega\ \angle 47.02°}{12.73\ \angle 18.89°}$$
$$= 8.8\ \Omega + 3.63\ \Omega\ \angle 28.13° = 8.8\ \Omega + 3.20\ \Omega + j1.71\ \Omega$$
$$= 12\ \Omega + j1.71\ \Omega = \mathbf{12.12\ \Omega\ \angle 8.11°}$$
$$\mathbf{Y}_T = \frac{1}{\mathbf{Z}_T} = \mathbf{82.51\ mS\ \angle{-8.11°}}$$

b. $\mathbf{V}_1 = \mathbf{I}\mathbf{Z}_1 = (3\ \text{A}\ \angle 30°)(6.8\ \Omega\ \angle 0°) = \mathbf{20.4\ V\ \angle 30°}$
$\mathbf{V}_2 = \mathbf{I}(\mathbf{Z}_2 \parallel \mathbf{Z}_3) = (3\ \text{A}\ \angle 30°)(3.63\ \Omega\ \angle 28.13°)$
$= \mathbf{10.89\ V\ \angle 58.13°}$

c. $$\mathbf{I}_3 = \frac{\mathbf{V}_2}{\mathbf{Z}_3} = \frac{10.89\ \text{V}\ \angle 58.13°}{5.63\ \Omega\ \angle 47.02°} = \mathbf{1.93\ A\ \angle 11.11°}$$

10. a. $X_{L_1} = \omega L_1 = 2\pi(10^3\ \text{Hz})(0.1\ \text{H}) = 628\ \Omega$
$X_{L_2} = \omega L_2 = 2\pi(10^3\ \text{Hz})(0.2\ \text{H}) = 1.256\ \text{k}\Omega$
$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3\ \text{Hz})(1\ \mu\text{F})} = 0.159\ \text{k}\Omega$$
$$\mathbf{Z}_T = R\ \angle 0° + X_{L_1}\ \angle 90° + X_C\ \angle{-90°} \parallel X_{L_2}\ \angle 90°$$
$$= 300\ \Omega + j628\ \Omega + 0.159\ \text{k}\Omega\ \angle{-90°} \parallel 1.256\ \text{k}\Omega\ \angle 90°$$
$$= 300\ \Omega + j628\ \Omega - j182\ \Omega$$
$$= \mathbf{300\ \Omega + \mathit{j}446\ \Omega = 537.51\ \Omega\ \angle 56.07°}$$
$$\mathbf{Y}_T = \frac{1}{\mathbf{Z}_T} = \frac{1}{537.51\ \Omega\ \angle 56.07°} = \mathbf{1.86\ mS\ \angle{-56.07°}}$$

b. $$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50\ \text{V}\ \angle 0°}{537.51\ \Omega\ \angle 56.07°} = \mathbf{93\ mA\ \angle{-56.07°}}$$

c. (CDR): $$\mathbf{I}_1 = \frac{\mathbf{Z}_{L_2}\mathbf{I}_s}{\mathbf{Z}_{L_2} + \mathbf{Z}_C} = \frac{(1.256\ \text{k}\Omega\ \angle 90°)(93\ \text{mA}\ \angle -56.07°)}{+j1.256\ \text{k}\Omega - j0.159\ \text{k}\Omega}$$
$$= \frac{116.81\ \text{mA}\ \angle 33.93°}{1.097\ \angle 90°} = \mathbf{106.48\ mA\ \angle{-56.07°}}$$
$$\mathbf{I}_2 = \frac{\mathbf{Z}_C\mathbf{I}_s}{\mathbf{Z}_{L_2} + \mathbf{Z}_C} = \frac{(0.159\ \text{k}\Omega\ \angle -90°)(93\ \text{mA}\ \angle -56.07°)}{1.097\ \text{k}\Omega\ \angle 90°}$$
$$= \frac{14.79\ \text{mA}\ \angle -146.07°}{1.097\ \angle 90°} = 13.48\ \text{mA}\ \angle{-236.07°}$$
$$= \mathbf{13.48\ mA\ \angle 123.93°}$$

d. $\mathbf{V}_1 = (I_2 \angle\theta)(X_{L_2} \angle 90°) = (13.48 \text{ mA} \angle 123.92°)(1.256 \text{ k}\Omega \angle 90°)$

$= \mathbf{16.93 \text{ V} \angle 213.93°}$

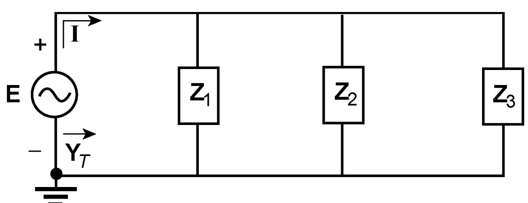
$\underset{+-}{\mathbf{V}_{ab}} = \mathbf{E} - (I_s \angle\theta)(R \angle 0°) = 50 \text{ V} \angle 0° - (93 \text{ mA} \angle -56.07°)(300\ \Omega \angle 0°)$

$= 50 \text{ V} - 27.9 \text{ V} \angle -56.07°$

$= 50 \text{ V} - (15.573 \text{ V} - j23.149 \text{ V})$
$= 34.43 \text{ V} + j23.149 \text{ V} = \mathbf{41.49 \text{ V} \angle 33.92°}$

e. $P = I_s^2 R = (93 \text{ mA})^2 300\ \Omega = \mathbf{2.595 \text{ W}}$

f. $F_p = \dfrac{R}{Z_T} = \dfrac{300\ \Omega}{537.51\ \Omega} = \mathbf{0.558 \text{ (lagging)}}$

11. 

$\mathbf{Z}_1 = 2\ \Omega - j2\ \Omega = 2.828\ \Omega \angle -45°$
$\mathbf{Z}_2 = 3\ \Omega - j9\ \Omega + j6\ \Omega$
$= 3\ \Omega - j3\ \Omega = 4.243\ \Omega \angle -45°$
$\mathbf{Z}_3 = 10\ \Omega \angle 0°$

$\mathbf{Y}_T = \dfrac{1}{\mathbf{Z}_1} + \dfrac{1}{\mathbf{Z}_2} + \dfrac{1}{\mathbf{Z}_3} = \dfrac{1}{2.828\ \Omega \angle -45°} + \dfrac{1}{4.243\ \Omega \angle -45°} + \dfrac{1}{10\ \Omega \angle 0°}$
$= 0.354 \text{ S} \angle 45° + 0.236 \text{ S} \angle 45° + 0.1 \text{ S} \angle 0° = 0.59 \text{ S} \angle 45° + 0.1 \text{ S} \angle 0°$
$= 0.417 \text{ S} + j0.417 \text{ S} + 0.1 \text{ S}$
$\mathbf{Y}_T = 0.517 \text{ S} + j\,0.417 \text{ S} = \mathbf{0.66 \text{ S} \angle 38.89°}$

$\mathbf{Z}_T = \dfrac{1}{\mathbf{Y}_T} = \dfrac{1}{0.66 \text{ S} \angle 38.89°} = \mathbf{1.52\ \Omega \angle -38.89°}$

$\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{50 \text{ V} \angle 0°}{1.52\ \Omega \angle -38.89°} = \mathbf{32.89 \text{ A} \angle 38.89°}$

12. $\mathbf{Z}' = 12\ \Omega - j20\ \Omega = 23.32\ \Omega \angle -59.04°$
$X_L \angle 90° \parallel \mathbf{Z}' = 20\ \Omega \angle 90° \parallel 23.32\ \Omega \angle -59.04° = 33.34\ \Omega \angle 19.99°$
$\mathbf{Z}'' = R_3 \angle 0° + X_L \angle 90° \parallel \mathbf{Z}' = 12\ \Omega + 33.34\ \Omega \angle 19.99°$
$= 12\ \Omega + (31.33\ \Omega - j11.40\ \Omega)$
$= 43.33\ \Omega - j11.40\ \Omega = 44.80\ \Omega \angle 14.74°$
$R_2 \angle 0° \parallel \mathbf{Z}'' = 20\ \Omega \angle 0° \parallel 44.80\ \Omega \angle 14.74° = 13.93\ \Omega \angle 4.54°$
$\mathbf{Z}_T = R_1 \angle 0° + R_2 \angle 0° \parallel \mathbf{Z}'' = 12\ \Omega + 13.93 \angle 4.54°$
$= 12\ \Omega + (13.89\ \Omega + j1.10\ \Omega)$
$= 25.89\ \Omega + j1.10\ \Omega = \mathbf{25.91\ \Omega \angle 2.43°}$

$\mathbf{I}_s = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{100 \text{ V} \angle 0°}{25.91\ \Omega \angle 2.43°} = \mathbf{3.86 \text{ A} \angle -2.43°}$

$\mathbf{I}_{R_1} = \mathbf{I}$

$$\mathbf{I}_{R_3} = \frac{R_2 \angle 0^\circ \ \mathbf{I}_s}{R_2 \angle 0^\circ + \mathbf{Z}''} = \frac{(20\ \Omega \angle 0^\circ)(3.86\text{ A} \angle -2.43^\circ)}{\underbrace{20\ \Omega + 43.33\ \Omega}_{63.33\ \Omega} + j11.40\ \Omega} = \frac{77.20\text{ A} \angle -2.43^\circ}{64.35 \angle 10.20^\circ}$$

$= 1.20\text{ A} \angle -12.63^\circ$

$$\mathbf{I}_4 = \frac{X_L \angle 90^\circ \mathbf{I}_{R_3}}{X_L \angle 90^\circ + \mathbf{Z}'} = \frac{(20\ \Omega \angle 90^\circ)(1.20\text{ A} \angle -12.63^\circ)}{j20\ \Omega + 12\ \Omega - j20\ \Omega} = \frac{24.00\text{ A} \angle 77.37^\circ}{12 \angle 0^\circ}$$

$= \mathbf{2.00\text{ A} \angle 77.37^\circ}$

13. $R_3 + R_4 = 2.7\text{ k}\Omega + 4.3\text{ k}\Omega = 7\text{ k}\Omega$
$R' = 3\text{ k}\Omega \parallel 7\text{ k}\Omega = 2.1\text{ k}\Omega$
$Z' = 2.1\text{ k}\Omega - j10\ \Omega$

(CDR) $\mathbf{I}'$ (of 10 Ω cap.) $= \dfrac{(40\text{ k}\Omega \angle 0^\circ)(20\text{ mA} \angle 0^\circ)}{40\text{ k}\Omega + 2.1\text{ k}\Omega - j10\ \Omega}$

$= 19\text{ mA} \angle +0.014^\circ$ as expected since $R_1 \gg \mathbf{Z}'$

(CDR) $\mathbf{I}_4 = \dfrac{(3\text{ k}\Omega \angle 0^\circ)(19\text{ mA} \angle 0.014^\circ)}{3\text{ k}\Omega + 7\text{ k}\Omega} = \dfrac{57\text{ mA} \angle 0.014^\circ}{10}$

$= 5.7\text{ mA} \angle 0.014^\circ$

$P = I^2R = (5.7\text{ mA})^2\ 4.3\text{ k}\Omega = \mathbf{139.71\text{ mW}}$

14. $\mathbf{Z}' = X_{C_2} \angle -90^\circ \parallel R_1 \angle 0^\circ = 2\ \Omega \angle -90^\circ \parallel 1\ \Omega \angle 0^\circ$

$= \dfrac{2\ \Omega \angle -90^\circ}{1 - j2} = \dfrac{2\ \Omega \angle -90^\circ}{2.236 \angle -63.435^\circ}$

$= 0.894\ \Omega \angle -26.565^\circ$

$\mathbf{Z}'' = X_{L_2} \angle 90^\circ + \mathbf{Z}' = +j8\ \Omega + 0.894\ \Omega \angle -26.565^\circ$

$= +j8\ \Omega + (0.8\ \Omega - j4\ \Omega)$

$= 0.8\ \Omega + j4 = 4.079\ \Omega \angle 78.69^\circ$

$$\mathbf{I}_{X_{L_2}} = \frac{X_{C_1} \angle -90^\circ \mathbf{I}}{X_{C_1} \angle -90^\circ + \mathbf{Z}''} = \frac{(2\ \Omega \angle -90^\circ)(0.5\text{ A} \angle 0^\circ)}{-j2\ \Omega + (0.8\ \Omega + j4\ \Omega)} = \frac{1\text{ A} \angle -90^\circ}{0.8 + j2}$$

$$= \frac{1\text{ A} \angle -90^\circ}{2.154 \angle 68.199^\circ} = 0.464\text{ A} \angle -158.99^\circ$$

$$\mathbf{I}_1 = \frac{X_{C_2} \angle -90^\circ \mathbf{I}_{X_{C_2}}}{X_{C_2} \angle -90^\circ + R_1} = \frac{(2\ \Omega \angle -90^\circ)(0.464\text{ A} \angle -158.99^\circ)}{-j2\ \Omega + 1\ \Omega} = \frac{0.928\text{ A} \angle -248.99^\circ}{2.236 \angle -63.435^\circ}$$

$= \mathbf{0.42\text{ A} \angle 174.45^\circ}$

Chapter 17

1. –

2. a. $\mathbf{Z} = 2.2\ \Omega + 5.6\ \Omega + j8.2\ \Omega = 7.8\ \Omega + j8.2\ \Omega = \mathbf{11.32\ \Omega\ \angle 46.43^\circ}$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{20\text{ V}\angle 20^\circ}{11.32\ \Omega\angle 46.43^\circ} = \mathbf{1.77\ A\ \angle{-26.43^\circ}}$$

b. $\mathbf{Z} = -j5\ \Omega + 2\ \Omega\ \angle 0^\circ \parallel 5\ \Omega\ \angle 90^\circ = -j5\ \Omega + 1.72\ \Omega + j0.69\ \Omega = \mathbf{4.64\ \Omega\ \angle{-68.24^\circ}}$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{60\text{ V}\angle 30^\circ}{4.64\ \Omega\angle -68.24^\circ} = \mathbf{12.93\ A\ \angle 98.24^\circ}$$

3. a. $\mathbf{Z} = 15\ \Omega - j16\ \Omega = \mathbf{21.93\ \Omega\ \angle{-46.85^\circ}}$

$\mathbf{E} = \mathbf{IZ} = (0.5\text{ A}\ \angle 60^\circ)(21.93\ \Omega\ \angle{-46.85^\circ})$

$= \mathbf{10.97\ V\ \angle 13.15^\circ}$

b. $\mathbf{Z} = 10\ \Omega\ \angle 0^\circ \parallel 6\ \Omega\ \angle 90^\circ = \mathbf{5.15\ \Omega\ \angle 59.04^\circ}$

$\mathbf{E} = \mathbf{IZ} = (2\text{ A}\ \angle 120^\circ)(5.15\ \Omega\ \angle 59.04^\circ)$

$= \mathbf{10.30\ V\ \angle 179.04^\circ}$

4. a. $$\mathbf{I} = \frac{\mu\mathbf{V}}{R} = \frac{16\ \mathbf{V}}{4\times 10^3} = \mathbf{4 \times 10^{-3}\ V}$$

$\mathbf{Z = 4\ k\Omega\ \angle 0^\circ}$

b. $\mathbf{V} = (h\mathbf{I})(R) = (50\ \mathbf{I})(50\text{ k}\Omega) = \mathbf{2.5 \times 10^6\ I}$

$\mathbf{Z = 50\ k\Omega\ \angle 0^\circ}$

5. a. Clockwise mesh currents:

$\mathbf{E} - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_1\mathbf{Z}_2 + \mathbf{I}_2\mathbf{Z}_2 = 0$

$-\mathbf{I}_2\mathbf{Z}_2 + \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_2\mathbf{Z}_3 - \mathbf{E}_2 = 0$

$[\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1$

$-\mathbf{Z}_2\mathbf{I}_1 + [\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{I}_2 = -\mathbf{E}_2$

$\mathbf{Z}_1 = R_1\ \angle 0^\circ = 4\ \Omega\ \angle 0^\circ$

$\mathbf{Z}_2 = X_L\ \angle 90^\circ = 6\ \Omega\ \angle 90^\circ$

$\mathbf{Z}_3 = X_C\ \angle{-90^\circ} = 8\ \Omega\ \angle{-90^\circ}$

$\mathbf{E}_1 = 10\text{ V}\ \angle 0^\circ$, $\mathbf{E}_2 = 40\text{ V}\ \angle 60^\circ$

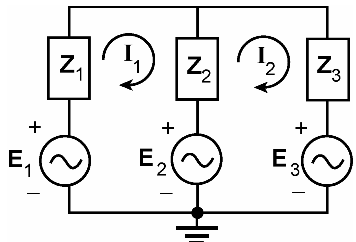
$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\begin{vmatrix} \mathbf{E}_1 & -\mathbf{Z}_2 \\ -\mathbf{E}_2 & [\mathbf{Z}_2 + \mathbf{Z}_3] \end{vmatrix}}{\begin{vmatrix} [\mathbf{Z}_1 + \mathbf{Z}_2] & -\mathbf{Z}_2 \\ -\mathbf{Z}_2 & [\mathbf{Z}_2 + \mathbf{Z}_3] \end{vmatrix}} = \frac{[\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{E}_1 - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{5.15\ A\ \angle{-24.5^\circ}}$$

b. By interchanging the right two branches, the general configuration of part (a) will result and

$$\mathbf{I}_{50\Omega} = \mathbf{I}_1 = \frac{[\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{E}_1 - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3}$$
$$= \mathbf{0.44\ A\ \angle 143.48^\circ}$$

$\mathbf{Z}_1 = R_1 = 50\ \Omega\ \angle 0^\circ$
$\mathbf{Z}_2 = X_C\ \angle -90^\circ = 60\ \Omega\ \angle -90^\circ$
$\mathbf{Z}_3 = X_L\ \angle 90^\circ = 20\ \Omega\ \angle 90^\circ$
$\mathbf{E}_1 = 5\ \text{V}\ \angle 30^\circ$, $\mathbf{E}_2 = 20\ \text{V}\ \angle 0^\circ$

6. a.



$\mathbf{Z}_1 = 12\ \Omega + j12\ \Omega = 16.971\ \Omega\ \angle 45^\circ$
$\mathbf{Z}_2 = 3\ \Omega\ \angle 0^\circ$
$\mathbf{Z}_3 = -j1\ \Omega$
$\mathbf{E}_1 = 20\ \text{V}\ \angle 50^\circ$
$\mathbf{E}_2 = 60\ \text{V}\ \angle 70^\circ$
$\mathbf{E}_3 = 40\ \text{V}\ \angle 0^\circ$

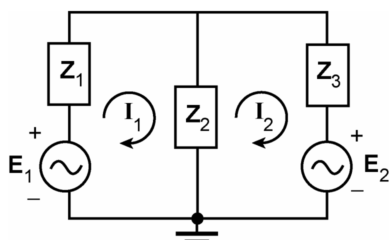
$\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_2] - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1 - \mathbf{E}_2$
$\mathbf{I}_2[\mathbf{Z}_2 + \mathbf{Z}_3] - \mathbf{Z}_2\mathbf{I}_1 = \mathbf{E}_2 - \mathbf{E}_3$

$(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1 - \mathbf{E}_2$
$-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 = \mathbf{E}_2 - \mathbf{E}_3$

Using determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{(\mathbf{E}_1 - \mathbf{E}_2)(\mathbf{Z}_2 + \mathbf{Z}_3) + \mathbf{Z}_2(\mathbf{E}_2 - \mathbf{E}_3)}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{2.55\ A\ \angle 132.72^\circ}$$

b.



Source conversion:

$\mathbf{E}_1 = \mathbf{IZ} = (6\ \text{A}\ \angle 0^\circ)(2\ \Omega\ \angle 0^\circ)$
$= 12\ \text{V}\ \angle 0^\circ$
$\mathbf{Z}_1 = 2\ \Omega + 20\ \Omega + j20\ \Omega = 22\ \Omega + j20\ \Omega$
$= 29.732\ \Omega\ \angle 42.274^\circ$
$\mathbf{Z}_2 = -j10\ \Omega = 10\ \Omega\ \angle -90^\circ$
$\mathbf{Z}_3 = 10\ \Omega\ \angle 0^\circ$

$\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_2] - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1$
$\mathbf{I}_2[\mathbf{Z}_2 + \mathbf{Z}_3] - \mathbf{Z}_2\mathbf{I}_1 = -\mathbf{E}_2$

$(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1$
$-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 = -\mathbf{E}_2$

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\mathbf{E}_1(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{0.495\ A\ \angle 72.26^\circ}$$

7. a. Clockwise mesh currents:

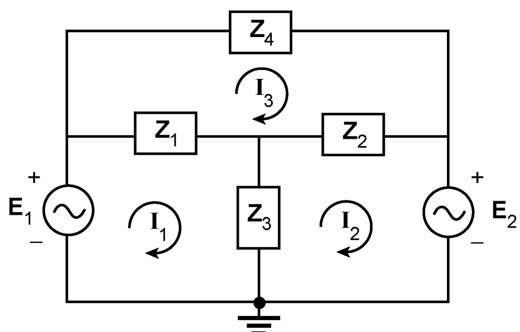
$\mathbf{Z}_1 = 4\ \Omega + j3\ \Omega$, $\mathbf{Z}_2 = -j1\ \Omega$
$\mathbf{Z}_3 = +j6\ \Omega$, $\mathbf{Z}_4 = !j2\ \Omega$
$\mathbf{Z}_5 = 8\ \Omega$
$\mathbf{E}_1 = 60\text{ V}\ \angle 0°$, $\mathbf{E}_2 = 120\text{ V}\ \angle 120°$

$$\mathbf{E}_1 - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_1\mathbf{Z}_2 + \mathbf{I}_2\mathbf{Z}_2 = 0$$
$$-\mathbf{I}_2\mathbf{Z}_2 + \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_2\mathbf{Z}_3 - \mathbf{I}_2\mathbf{Z}_4 + \mathbf{I}_3\mathbf{Z}_4 = 0$$
$$-\mathbf{I}_3\mathbf{Z}_4 + \mathbf{I}_2\mathbf{Z}_4 - \mathbf{I}_3\mathbf{Z}_5 - \mathbf{E}_2 = 0$$

$$\begin{array}{llll}
[\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{I}_1 & -\mathbf{Z}_2\ \mathbf{I}_2 & +0 & = \mathbf{E}_1 \\
-\mathbf{Z}_2\ \mathbf{I}_1 & +[\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4]\mathbf{I}_2 & -\ \mathbf{Z}_4\ \mathbf{I}_3 & = 0 \\
0 & -\ \mathbf{Z}_4\ \mathbf{I}_2 & +[\mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{I}_3 & = -\mathbf{E}_2
\end{array}$$

$$\mathbf{I}_{R_1} = \mathbf{I}_3 = \frac{[\mathbf{Z}_2\mathbf{Z}_4]\mathbf{E}_1 + \left[\mathbf{Z}_2^2 - [\mathbf{Z}_1 + \mathbf{Z}_2]\ [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4]\right]\mathbf{E}_2}{[\mathbf{Z}_1 + \mathbf{Z}_2][\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4][\mathbf{Z}_4 + \mathbf{Z}_5] - [\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{Z}_4^2 - [\mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{Z}_2^2}$$
$$= \mathbf{13.07\ A\ \angle -33.71°}$$

b.



$\mathbf{Z}_1 = 15\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 15\ \Omega\ \angle 0°$
$\mathbf{Z}_3 = -j10\ \Omega = 10\ \Omega\ \angle -90°$
$\mathbf{Z}_4 = 3\ \Omega + j4\ \Omega = 5\ \Omega\ \angle 53.13°$
$\mathbf{E}_1 = 220\text{ V}\ \angle 0°$
$\mathbf{E}_2 = 100\text{ V}\ \angle 90°$

$$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_3) - \mathbf{I}_2\mathbf{Z}_3 - \mathbf{I}_3\mathbf{Z}_1 = \mathbf{E}_1$$
$$\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{I}_1\mathbf{Z}_3 - \mathbf{I}_3\mathbf{Z}_2 = -\mathbf{E}_2$$
$$\mathbf{I}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_2\mathbf{Z}_2 = 0$$

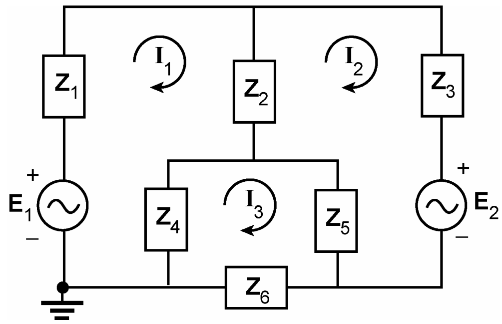
$$\begin{array}{llll}
\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_3) & - \mathbf{I}_2\mathbf{Z}_3 & - \mathbf{I}_3\mathbf{Z}_1 & = \mathbf{E}_1 \\
-\mathbf{I}_1\mathbf{Z}_3 & + \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) & - \mathbf{I}_3\mathbf{Z}_2 & = -\mathbf{E}_2 \\
-\mathbf{I}_1\mathbf{Z}_1 & - \mathbf{I}_2\mathbf{Z}_2 & + \mathbf{I}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) & = 0
\end{array}$$

Applying determinants:

$$\mathbf{I}_3 = \frac{-(\mathbf{Z}_1 + \mathbf{Z}_3)(\mathbf{Z}_2)\mathbf{E}_2 - \mathbf{Z}_1\mathbf{Z}_3\mathbf{E}_2 + \mathbf{E}_1\left[\mathbf{Z}_2\mathbf{Z}_3 + \mathbf{Z}_1(\mathbf{Z}_2 + \mathbf{Z}_3)\right]}{(\mathbf{Z}_1 + \mathbf{Z}_3)\left[(\mathbf{Z}_2 + \mathbf{Z}_3)(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{Z}_2^2\right] + \mathbf{Z}_3\left[\mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{Z}_1\mathbf{Z}_2\right] - \mathbf{Z}_1\left[-\mathbf{Z}_2\mathbf{Z}_3 - \mathbf{Z}_1(\mathbf{Z}_2 + \mathbf{Z}_3)\right]}$$
$$= \mathbf{48.33\ A\ \angle -77.57°}$$

or $\mathbf{I}_3 = \dfrac{\mathbf{E}_1 - \mathbf{E}_2}{\mathbf{Z}_4}$ if one carefully examines the network!

8. a.



$\mathbf{Z}_1 = 5\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 5\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 4\ \Omega\ \angle 0°$, $\mathbf{Z}_4 = 6\ \Omega\ \angle{-90°}$
$\mathbf{Z}_5 = 4\ \Omega\ \angle 0°$, $\mathbf{Z}_6 = 6\ \Omega + j8\ \Omega$
$\mathbf{E}_1 = 20\ \text{V}\ \angle 0°$, $\mathbf{E}_2 = 40\ \text{V}\ \angle 60°$

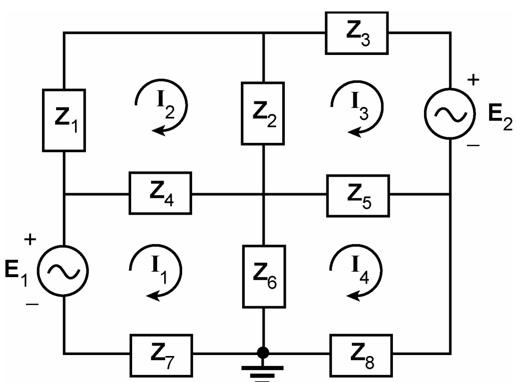
$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_3\mathbf{Z}_4 = \mathbf{E}_1$
$\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5) - \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_3\mathbf{Z}_5 = -\mathbf{E}_2$
$\mathbf{I}_3(\mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6) - \mathbf{I}_1\mathbf{Z}_4 - \mathbf{I}_2\mathbf{Z}_5 = 0$

$$\begin{aligned}
&(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4)\,\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 - \mathbf{Z}_4\mathbf{I}_3 = \mathbf{E}_1 \\
&-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5)\mathbf{I}_2 - \mathbf{Z}_5\mathbf{I}_3 = -\mathbf{E}_2 \\
&-\mathbf{Z}_4\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_2 + (\mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6)\mathbf{I}_3 = 0
\end{aligned}$$

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:

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\mathbf{E}_1(\mathbf{Z}''\mathbf{Z}''' - \mathbf{Z}_5^2) - \mathbf{E}_2(\mathbf{Z}_2\mathbf{Z}''' + \mathbf{Z}_4\mathbf{Z}_5)}{\mathbf{Z}'(\mathbf{Z}''\mathbf{Z}''' - \mathbf{Z}_5^2) - \mathbf{Z}_2(\mathbf{Z}_2\mathbf{Z}''' + \mathbf{Z}_4\mathbf{Z}_5) - \mathbf{Z}_4(\mathbf{Z}_2\mathbf{Z}_5 + \mathbf{Z}_4\mathbf{Z}'')}$$
$$= \mathbf{3.04\ A\ \angle 169.12°}$$

b.



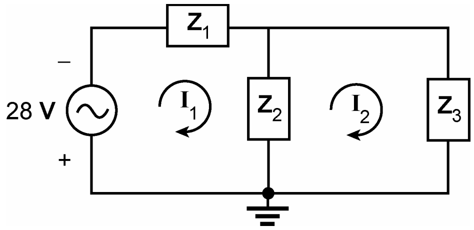
$\mathbf{Z}_1 = 10\ \Omega + j20\ \Omega$ | $\mathbf{Z}_2 = -j20\ \Omega$
$\mathbf{Z}_3 = 80\ \Omega\ \angle 0°$ | $\mathbf{Z}_4 = 6\ \Omega\ \angle 0°$
$\mathbf{Z}_5 = 15\ \Omega\ \angle 90°$ | $\mathbf{Z}_6 = 10\ \Omega\ \angle 0°$
$\mathbf{Z}_7 = 5\ \Omega\ \angle 0°$ | $\mathbf{Z}_8 = 5\ \Omega - j20\ \Omega$
$\mathbf{E}_1 = 25\ \text{V}\ \angle 0°$ | $\mathbf{E}_2 = 75\ \text{V}\ \angle 20°$

$\mathbf{I}_1(\mathbf{Z}_4 + \mathbf{Z}_6 + \mathbf{Z}_7) - \mathbf{I}_2\mathbf{Z}_4 - \mathbf{I}_4\mathbf{Z}_6 = \mathbf{E}_1$
$\mathbf{I}_2(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_1\mathbf{Z}_4 - \mathbf{I}_3\mathbf{Z}_2 = 0$
$\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5) - \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_4\mathbf{Z}_5 = -\mathbf{E}_2$
$\mathbf{I}_4(\mathbf{Z}_5 + \mathbf{Z}_6 + \mathbf{Z}_8) - \mathbf{I}_1\mathbf{Z}_6 - \mathbf{I}_3\mathbf{Z}_5 = 0$

$$\begin{aligned}
&(\mathbf{Z}_4 + \mathbf{Z}_6 + \mathbf{Z}_7)\,\mathbf{I}_1 - \mathbf{Z}_4\mathbf{I}_2 + 0 - \mathbf{Z}_6\mathbf{I}_4 = \mathbf{E}_1 \\
&-\mathbf{Z}_4\mathbf{I}_1 + (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4)\mathbf{I}_2 - \mathbf{Z}_2\mathbf{I}_3 + 0 = 0 \\
&0 - \mathbf{Z}_2\ \mathbf{I}_2 + (\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5)\mathbf{I}_3 - \mathbf{Z}_5\mathbf{I}_4 = -\mathbf{E}_2 \\
&-\mathbf{Z}_6\mathbf{I}_1 + 0 - \mathbf{Z}_5\mathbf{I}_3 + (\mathbf{Z}_5 + \mathbf{Z}_6 + \mathbf{Z}_7)\mathbf{I}_4 = 0
\end{aligned}$$

Applying determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_{80\Omega} = \mathbf{0.68\ A\ \angle{-162.9°}}$$

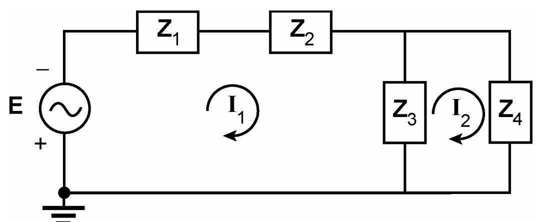
9. 

$\mathbf{Z}_1 = 5\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 10\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_3 = 1\ \text{k}\Omega + j4\ \text{k}\Omega = 4.123\ \text{k}\Omega\ \angle 75.96°$

$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2) - \mathbf{Z}_2\mathbf{I}_2 = -28\ \text{V}$
$\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{Z}_2\mathbf{I}_1 = 0$

$(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = -28\ \text{V}$
$-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 = 0$

$$\mathbf{I}_L = \mathbf{I}_2 = \frac{-\mathbf{Z}_2\, 28\ \text{V}}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{-3.17 \times 10^{-3}\ V\ \angle 137.29°}$$

10. a. 

Source Conversion:
$\mathbf{E} = (I\ \angle\theta)(R_p\ \angle 0°)$
$= (50\ \mathbf{I})(40\ \text{k}\Omega\ \angle 0°)$
$= 2 \times 10^6\ \mathbf{I}\ \angle 0°$
$\mathbf{Z}_1 = R_s = R_p = 40\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = -j0.2\ \text{k}\Omega$
$\mathbf{Z}_3 = 8\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_4 = 4\ \text{k}\Omega\ \angle 90°$

$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{Z}_3\mathbf{I}_2 = -\mathbf{E}$
$\mathbf{I}_2(\mathbf{Z}_3 + \mathbf{Z}_4) - \mathbf{Z}_3\mathbf{I}_1 = 0$

$(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_1 - \mathbf{Z}_3\mathbf{I}_2 = -\mathbf{E}$
$-\mathbf{Z}_3\mathbf{I}_1 + (\mathbf{Z}_3 + \mathbf{Z}_4)\mathbf{I}_2 = 0$

$$\mathbf{I}_L = \mathbf{I}_2 = \frac{-\mathbf{Z}_3\mathbf{E}}{(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3)(\mathbf{Z}_3 + \mathbf{Z}_4) - \mathbf{Z}_3^2} = \mathbf{42.91\ I\ \angle 149.31°}$$

11. $6\mathbf{V}_x - \mathbf{I}_1\ 1\ \text{k}\Omega - 10\ \text{V}\ \angle 0° = 0$
$10\ \text{V}\angle 0° - \mathbf{I}_2\ 4\ \text{k}\Omega - \mathbf{I}_2\ 2\ \text{k}\Omega = 0$

$\mathbf{V}_x = \mathbf{I}_2\ 2\ \text{k}\Omega$

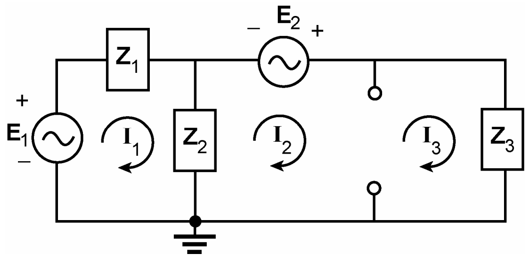
$-\mathbf{I}_1\ 1\ \text{k}\Omega + \mathbf{I}_2\ 12\ \text{k}\Omega = 10\ \text{V}\ \angle 0°$
$-\mathbf{I}_2\ 6\ \text{k}\Omega = -10\ \text{V}\ \angle 0°$

$$\mathbf{I}_2 = \mathbf{I}_{2\text{k}\Omega} = \frac{10\ \text{V}\ \angle 0°}{6\ \text{k}\Omega} = \mathbf{1.67\ mA\ \angle 0°} = \mathbf{I}_{2\text{k}\Omega}$$

$-\mathbf{I}_1\ 1\ \text{k}\Omega + (1.667\ \text{mA}\ \angle 0°)(12\ \text{k}\Omega) = 10\ \text{V}\ \angle 0°$
$-\mathbf{I}_1\ 1\ \text{k}\Omega + 20\ \text{V}\ \angle 0° = 10\ \text{V}\ \angle 0°$
$-\mathbf{I}_1\ 1\ \text{k}\Omega = -10\ \text{V}\ \angle 0°$

$$\mathbf{I}_1 = \mathbf{I}_{1k\Omega} = \frac{10\text{ V }\angle 0°}{1\text{ k}\Omega} = \mathbf{10\text{ mA }\angle 0°}$$

12.



$\mathbf{E}_1 = 5\text{ V }\angle 0°$
$\mathbf{E}_2 = 20\text{ V }\angle 0°$
$\mathbf{Z}_1 = 2.2\text{ k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega\ \angle 90°$
$\mathbf{Z}_3 = 10\text{ k}\Omega\ \angle 0°$
$\mathbf{I} = 4\text{ mA }\angle 0°$

$$\mathbf{E}_1 - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{Z}_2(\mathbf{I}_1 - \mathbf{I}_2) = 0$$
$$-\mathbf{Z}_2(\mathbf{I}_2 - \mathbf{I}_1) + \mathbf{E}_2 - \mathbf{I}_3\mathbf{Z}_3 = 0$$

$$\mathbf{I}_3 - \mathbf{I}_2 = \mathbf{I}$$

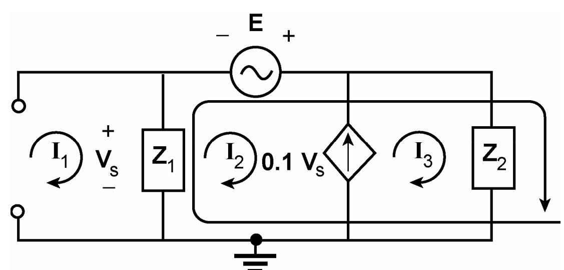
Substituting, we obtain:

$$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2) - \mathbf{I}_2\mathbf{Z}_2 = \mathbf{E}_1$$
$$\mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) = \mathbf{I}\mathbf{Z}_3 - \mathbf{E}_2$$

Determinants:

$\mathbf{I}_1 = 1.39\text{ mA }\angle{-126.48°}$, $\mathbf{I}_2 = 1.341\text{ mA }\angle{-10.56°}$, $\mathbf{I}_3 = 2.693\text{ mA }\angle{-174.8°}$
$\mathbf{I}_{10k\Omega} = \mathbf{I}_3 = \mathbf{2.693\text{ mA }\angle{-174.8°}}$

13.



$\mathbf{Z}_1 = 1\text{ k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 4\text{ k}\Omega + j6\text{ k}\Omega$
$\mathbf{E} = 10\text{ V }\angle 0°$

$$-\mathbf{Z}_1(\mathbf{I}_2 - \mathbf{I}_1) + \mathbf{E} - \mathbf{I}_3\mathbf{Z}_3 = 0$$
$$\mathbf{I}_1 = 6\text{ mA }\angle 0°,\ 0.1\ \mathbf{V}_s = \mathbf{I}_3 - \mathbf{I}_2,\ \mathbf{V}_s = (\mathbf{I}_1 - \mathbf{I}_2)\mathbf{Z}_1$$

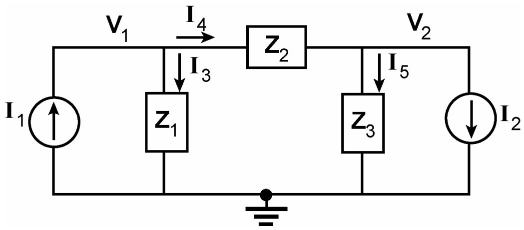
Substituting:

$$(1\text{ k}\Omega)\mathbf{I}_2 + (4\text{ k}\Omega + j6\text{ k}\Omega)\mathbf{I}_3 = 16\text{ V }\angle 0°$$
$$(99\ \Omega)\mathbf{I}_2 + \quad \mathbf{I}_3 = 0.6\text{ V }\angle 0°$$

Determinants:

$$\mathbf{I}_3 = \mathbf{I}_{6\text{ k}\Omega} = \mathbf{1.38\text{ mA }\angle{-56.31°}}$$

14. a.



$\mathbf{Z}_1 = 4\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 2\ \Omega\ \angle -90°$
$\mathbf{I}_1 = 3\text{ A}\ \angle 0°$
$\mathbf{I}_2 = 5\text{ A}\ \angle 30°$

$\mathbf{I}_1 = \mathbf{I}_3 + \mathbf{I}_4$

$$\mathbf{I}_1 = \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} \Rightarrow \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2}\right] - \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}\right] = \mathbf{I}_1$$

or $\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{V}_2[\mathbf{Y}_2] = \mathbf{I}_1$

$\mathbf{I}_4 = \mathbf{I}_5 + \mathbf{I}_2$

$$\frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} = \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \mathbf{I}_2 \Rightarrow \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3}\right] - \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_2}\right] = -\mathbf{I}_2$$

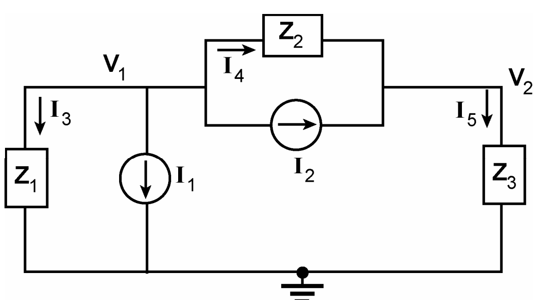
or $\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{V}_1[\mathbf{Y}_2] = -\mathbf{I}_2$

$$\begin{aligned} [\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 \qquad &- \mathbf{Y}_2\mathbf{V}_2 = \mathbf{I}_1 \\ -\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 &+ \mathbf{Y}_3]\mathbf{V}_2 = -\mathbf{I}_2 \end{aligned}$$

$$\mathbf{V}_1 = \frac{[\mathbf{Y}_2 + \mathbf{Y}_3]\,\mathbf{I}_1 - \mathbf{Y}_2\,\mathbf{I}_2}{\mathbf{Y}_1\,\mathbf{Y}_2 + \mathbf{Y}_1\,\mathbf{Y}_3 + \mathbf{Y}_2\,\mathbf{Y}_3} = \mathbf{14.68\text{ V}\ \angle 68.89°}$$

$$\mathbf{V}_2 = \frac{-[\mathbf{Y}_1 + \mathbf{Y}_2]\,\mathbf{I}_2 + \mathbf{Y}_2\,\mathbf{I}_1}{\mathbf{Y}_1\,\mathbf{Y}_2 + \mathbf{Y}_1\,\mathbf{Y}_3 + \mathbf{Y}_2\,\mathbf{Y}_3} = \mathbf{12.97\text{ V}\ \angle 155.88°}$$

b.



$\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega = 5\ \angle 53.13°$
$\mathbf{Z}_2 = 2\ \Omega\ \angle 0°$
$\mathbf{Z}_3 = 6\ \Omega\ \angle 0° \parallel 8\ \Omega\ \angle -90°$
$\quad = 4.8\ \Omega\ \angle -36.87°$
$\mathbf{I}_1 = 0.6\text{ A}\ \angle 20°$
$\mathbf{I}_2 = 4\text{ A}\ \angle 80°$

$0 = \mathbf{I}_1 + \mathbf{I}_3 + \mathbf{I}_4 + \mathbf{I}_2$

$$0 = \mathbf{I}_1 + \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} + \mathbf{I}_2$$

$$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2}\right] - \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}\right] = -\mathbf{I}_1 - \mathbf{I}_2$$

or $\quad \mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{V}_2[\mathbf{Y}_2] = -\mathbf{I}_1 - \mathbf{I}_2$

$\mathbf{I}_2 + \mathbf{I}_4 = \mathbf{I}_5$

$$\mathbf{I}_2 + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} = \frac{\mathbf{V}_2}{\mathbf{Z}_3}$$

$$\mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}\right]-\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_2}\right]=+\mathbf{I}_2$$

or $\mathbf{V}_2[\mathbf{Y}_2+\mathbf{Y}_3]-\mathbf{V}_1[\mathbf{Y}_2]=\mathbf{I}_2$

and $[\mathbf{Y}_1+\mathbf{Y}_2]\mathbf{V}_1-\mathbf{Y}_2\mathbf{V}_2=-\mathbf{I}_1-\mathbf{I}_2$

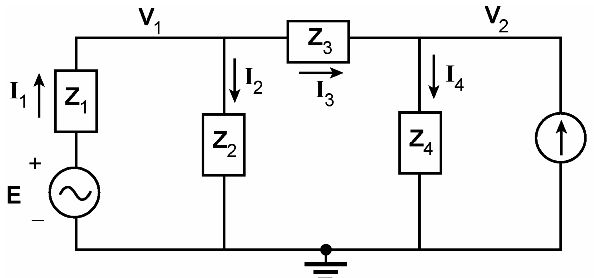
$-\mathbf{Y}_2\mathbf{V}_1+[\mathbf{Y}_2+\mathbf{Y}_3]\mathbf{V}_2=\mathbf{I}_2$

Applying determinants:

$$\mathbf{V}_1=\frac{-[\mathbf{Y}_2+\mathbf{Y}_3][\mathbf{I}_1+\mathbf{I}_2]+\mathbf{Y}_2\mathbf{I}_2}{\mathbf{Y}_1\mathbf{Y}_2+\mathbf{Y}_1\mathbf{Y}_3+\mathbf{Y}_2\mathbf{Y}_3}=\mathbf{5.12\ V\ \angle{-79.36°}}$$

$$\mathbf{V}_2=\frac{\mathbf{Y}_1\mathbf{I}_2-\mathbf{I}_1\mathbf{Y}_2}{\mathbf{Y}_1\mathbf{Y}_2+\mathbf{Y}_1\mathbf{Y}_3+\mathbf{Y}_2\mathbf{Y}_3}=\mathbf{2.71\ V\ \angle 39.96°}$$

15. a.



$\mathbf{Z}_1 = 5\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = 6\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 4\ \Omega\ \angle{-90°}$
$\mathbf{Z}_4 = 2\ \Omega\ \angle 0°$
$\mathbf{E} = 30\ \text{V}\ \angle 50°$
$\mathbf{I} = 0.04\ \text{A}\ \angle 90°$

$\mathbf{I}_1=\mathbf{I}_2+\mathbf{I}_3$

$$\frac{\mathbf{E}_1-\mathbf{V}_1}{\mathbf{Z}_1}=\frac{\mathbf{V}_1}{\mathbf{Z}_2}+\frac{(\mathbf{V}_1-\mathbf{V}_2)}{\mathbf{Z}_3}\Rightarrow \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1}+\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}\right]-\frac{\mathbf{V}_2}{\mathbf{Z}_3}=\frac{\mathbf{E}_1}{\mathbf{Z}_1}$$

or $\mathbf{V}_1[\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3]-\mathbf{Y}_3\mathbf{V}_2=\mathbf{E}_1\mathbf{Y}_1$

$\mathbf{I}_3+\mathbf{I}=\mathbf{I}_4$

$$\frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_3}+\mathbf{I}=\frac{\mathbf{V}_2}{\mathbf{Z}_4}\Rightarrow \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_4}\right]-\frac{\mathbf{V}_1}{\mathbf{Z}_3}=\mathbf{I}$$

or $\mathbf{V}_2[\mathbf{Y}_3+\mathbf{Y}_4]-\mathbf{V}_1\mathbf{Y}_3=\mathbf{I}$

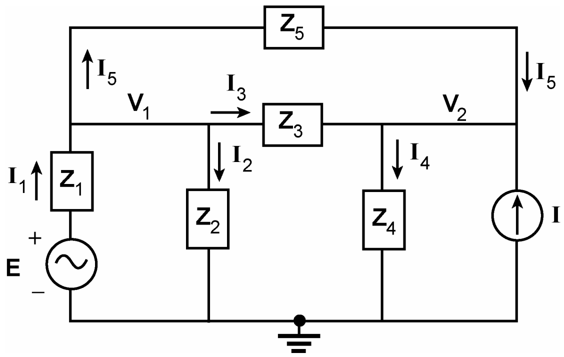
resulting in

$\mathbf{V}_1[\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3]-\mathbf{V}_2\mathbf{Y}_3=\mathbf{E}_1\mathbf{Y}_1$

$-\mathbf{V}_1[\mathbf{Y}_3]+\mathbf{V}_2[\mathbf{Y}_3+\mathbf{Y}_4]=+\mathbf{I}$

Using determinants:

$\mathbf{V}_1=\mathbf{19.86\ V\ \angle 43.8°}$ and $\mathbf{V}_2=\mathbf{8.94\ V\ \angle 106.9°}$

b. 

$\mathbf{Z}_1 = 10\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = 10\ \Omega\ \angle 0°$
$\mathbf{Z}_3 = 4\ \Omega\ \angle 90°$
$\mathbf{Z}_4 = 2\ \Omega\ \angle 0°$
$\mathbf{Z}_5 = 8\ \Omega\ \angle -90°$
$\mathbf{E} = 50\ \text{V}\ \angle 120°$
$\mathbf{I} = 0.8\ \text{A}\ \angle 70°$

$\mathbf{I}_1 = \mathbf{I}_2 + \mathbf{I}_5$

$$\frac{\mathbf{E}-\mathbf{V}_1}{\mathbf{Z}_1} = \frac{\mathbf{V}_1}{\mathbf{Z}_2} + \frac{(\mathbf{V}_1-\mathbf{V}_2)}{\mathbf{Z}_5} + \frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_3} \Rightarrow \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1}+\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_5}\right]-\mathbf{V}_2\left[\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_5}\right]=\frac{\mathbf{E}}{\mathbf{Z}_1}$$

or $\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_5] - \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_5] = \mathbf{E}_1\mathbf{Y}_1$

$\mathbf{I}_3 + \mathbf{I}_5 = \mathbf{I}_4 + \mathbf{I}$

$$\frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_3}+\frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_5}=\frac{\mathbf{V}_2}{\mathbf{Z}_4}+\mathbf{I} \Rightarrow \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_4}+\frac{1}{\mathbf{Z}_5}\right]-\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_5}\right]=-\mathbf{I}$$

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

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_5] - \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_5] = \mathbf{E}_1\mathbf{Y}_1$$
$$-\mathbf{V}_1[\mathbf{Y}_3 + \mathbf{Y}_5] + \mathbf{V}_2[\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_5] = -\mathbf{I}$$

Applying determinants:

$\mathbf{V}_1 = \mathbf{19.78\ V\ \angle 132.48°}$ and $\mathbf{V}_2 = \mathbf{13.37\ V\ \angle 98.78°}$

16. $$\mathbf{I} = \frac{\mathbf{V}_1}{\mathbf{Z}_1}+\frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_2}$$
$$0 = \frac{\mathbf{V}_2-\mathbf{V}_1}{\mathbf{Z}_2}+\frac{\mathbf{V}_2}{\mathbf{Z}_3}+\frac{\mathbf{V}_2-\mathbf{E}}{\mathbf{Z}_4}$$

$\mathbf{Z}_1 = 2\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = 20\ \Omega + j\,20\ \Omega$
$\mathbf{Z}_3 = 10\ \Omega\ \angle -90°$
$\mathbf{Z}_4 = 10\ \Omega\ \angle 0°$
$\mathbf{I} = 6\ \text{A}\ \angle 0°$
$\mathbf{E} = 30\ \text{V}\ \angle 0°$

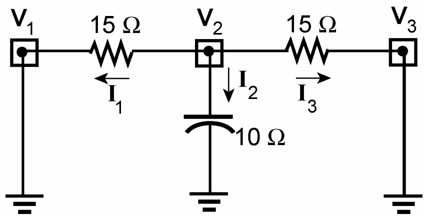
Rearranging:

$$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1}+\frac{1}{\mathbf{Z}_2}\right]-\frac{1}{\mathbf{Z}_2}\mathbf{V}_2 = \mathbf{I}$$
$$\frac{-\mathbf{V}_1}{\mathbf{Z}_2}+\mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_4}\right] = \frac{\mathbf{E}}{\mathbf{Z}_4}$$

Determinants and substituting:

$\mathbf{V}_1 = \mathbf{11.74\ V\ \angle -4.61°}$, $\mathbf{V}_2 = \mathbf{22.53\ V\ \angle -36.48°}$

17.



(Note that $3 + j4$ branch has no effect on nodal voltages)

$\sum \mathbf{I}_i = \sum \mathbf{I}_o$

$0 = \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3$

$$= \frac{\mathbf{V}_2 - \mathbf{V}_1}{15\,\Omega} + \frac{\mathbf{V}_2}{10\,\Omega \angle -90°} + \frac{\mathbf{V}_2 - \mathbf{V}_3}{15\,\Omega}$$

Through manipulation:

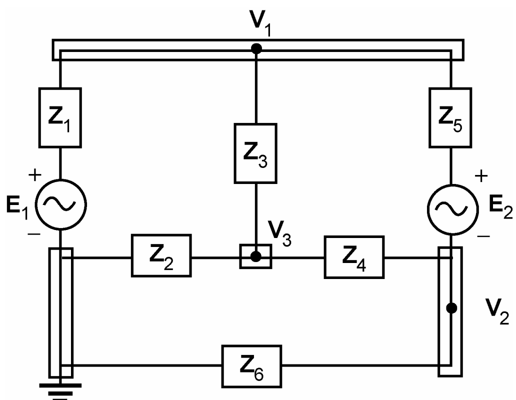
$$\mathbf{V}_2[2 + j1.5] - \mathbf{V}_1 - \mathbf{V}_3 = 0$$

but $\mathbf{V}_1 = \mathbf{220\ V \angle 0°}$ and $\mathbf{V}_3 = \mathbf{100\ V \angle 90°}$

and $\mathbf{V}_2 = \dfrac{220 + j100}{2 + j1.5} = \mathbf{96.66\ V\angle -12.43°}$

with $\mathbf{V}_3 = 0\text{V} \angle 0°$

18.



$\mathbf{Z}_1 = 5\ \Omega \angle 0°$
$\mathbf{Z}_2 = 6\ \Omega \angle -90°$
$\mathbf{Z}_3 = 5\ \Omega \angle 90°$
$\mathbf{Z}_4 = 4\ \Omega \angle 0°$
$\mathbf{Z}_5 = 4\ \Omega \angle 0°$
$\mathbf{Z}_6 = 6\ \Omega + j8\ \Omega$
$\mathbf{E}_1 = 20\ \text{V} \angle 0°$
$\mathbf{E}_2 = 40\ \text{V} \angle 60°$

node $\mathbf{V}_1$: $\dfrac{\mathbf{V}_1 - \mathbf{E}_1}{\mathbf{Z}_1} + \dfrac{\mathbf{V}_1 - \mathbf{V}_3}{\mathbf{Z}_3} + \dfrac{\mathbf{V}_1 - \mathbf{E}_2 - \mathbf{V}_2}{\mathbf{Z}_5} = 0$

node $\mathbf{V}_2$: $\dfrac{\mathbf{V}_2 + \mathbf{E}_2 - \mathbf{V}_1}{\mathbf{Z}_5} + \dfrac{\mathbf{V}_2 - \mathbf{V}_3}{\mathbf{Z}_4} + \dfrac{\mathbf{V}_2}{\mathbf{Z}_6} = 0$

node $\mathbf{V}_3$: $\dfrac{\mathbf{V}_3}{\mathbf{Z}_2} + \dfrac{\mathbf{V}_3 - \mathbf{V}_1}{\mathbf{Z}_3} + \dfrac{\mathbf{V}_3 - \mathbf{V}_2}{\mathbf{Z}_4} = 0$

Rearranging:

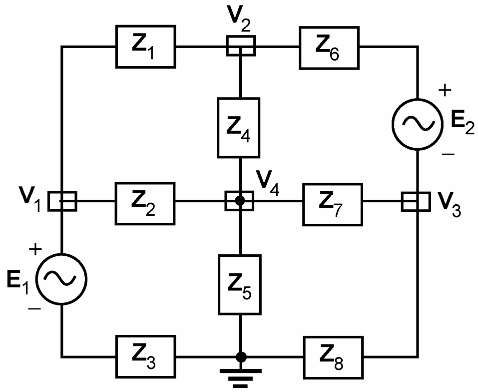
$$\mathbf{V}_1\left(\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_5}\right) - \frac{\mathbf{V}_2}{\mathbf{Z}_5} - \frac{\mathbf{V}_3}{\mathbf{Z}_3} = \frac{\mathbf{E}_1}{\mathbf{Z}_1} + \frac{\mathbf{E}_2}{\mathbf{Z}_5}$$

$$\mathbf{V}_2\left(\frac{1}{\mathbf{Z}_5} + \frac{1}{\mathbf{Z}_4} + \frac{1}{\mathbf{Z}_6}\right) - \frac{\mathbf{V}_1}{\mathbf{Z}_5} - \frac{\mathbf{V}_3}{\mathbf{Z}_4} = -\frac{\mathbf{E}_2}{\mathbf{Z}_5}$$

$$\mathbf{V}_3\left(\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_4}\right) - \frac{\mathbf{V}_1}{\mathbf{Z}_3} - \frac{\mathbf{V}_2}{\mathbf{Z}_4} = 0$$

Determinants: $\mathbf{V}_1 = \mathbf{5.84\ V \angle 29.4°}$, $\mathbf{V}_2 = \mathbf{28.06\ V \angle -89.15°}$, $\mathbf{V}_3 = \mathbf{31.96\ V \angle -77.6°}$

19.



$\mathbf{E}_1 = 25\text{ V}\angle 0°$
$\mathbf{E}_2 = 75\text{ V}\angle 20°$

$\mathbf{Z}_1 = 10\ \Omega + j20\ \Omega$
$\mathbf{Z}_2 = 6\ \Omega\angle 0°$
$\mathbf{Z}_3 = 5\ \Omega\angle 0°$
$\mathbf{Z}_4 = 20\ \Omega\angle -90°$
$\mathbf{Z}_5 = 10\ \Omega\angle 0°$
$\mathbf{Z}_6 = 80\ \Omega\angle 0°$
$\mathbf{Z}_7 = 15\ \Omega\angle 90°$
$\mathbf{Z}_8 = 5\ \Omega - j20\ \Omega$

$$\mathbf{V}_1\text{:}\quad \frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_1}+\frac{\mathbf{V}_1-\mathbf{V}_4}{\mathbf{Z}_2}+\frac{\mathbf{V}_1-\mathbf{E}_1}{\mathbf{Z}_3}=0$$

$$\mathbf{V}_2\text{:}\quad \frac{\mathbf{V}_2-\mathbf{V}_1}{\mathbf{Z}_1}+\frac{\mathbf{V}_2-\mathbf{V}_4}{\mathbf{Z}_4}+\frac{\mathbf{V}_2-\mathbf{E}_2-\mathbf{V}_3}{\mathbf{Z}_6}=0$$

$$\mathbf{V}_3\text{:}\quad \frac{\mathbf{V}_3+\mathbf{E}_2-\mathbf{V}_2}{\mathbf{Z}_6}+\frac{\mathbf{V}_3-\mathbf{V}_4}{\mathbf{Z}_7}+\frac{\mathbf{V}_3}{\mathbf{Z}_8}=0$$

$$\mathbf{V}_4\text{:}\quad \frac{\mathbf{V}_4-\mathbf{V}_1}{\mathbf{Z}_2}+\frac{\mathbf{V}_4-\mathbf{V}_2}{\mathbf{Z}_4}+\frac{\mathbf{V}_4-\mathbf{V}_3}{\mathbf{Z}_7}+\frac{\mathbf{V}_4}{\mathbf{Z}_5}=0$$

Rearranging:

$$\mathbf{V}_1\left(\frac{1}{\mathbf{Z}_1}+\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}\right)-\frac{\mathbf{V}_2}{\mathbf{Z}_1}-\frac{\mathbf{V}_4}{\mathbf{Z}_2}=\frac{\mathbf{E}_1}{\mathbf{Z}_3}$$

$$\mathbf{V}_2\left(\frac{1}{\mathbf{Z}_1}+\frac{1}{\mathbf{Z}_4}+\frac{1}{\mathbf{Z}_6}\right)-\frac{\mathbf{V}_1}{\mathbf{Z}_1}-\frac{\mathbf{V}_4}{\mathbf{Z}_4}-\frac{\mathbf{V}_3}{\mathbf{Z}_6}=\frac{\mathbf{E}_2}{\mathbf{Z}_6}$$

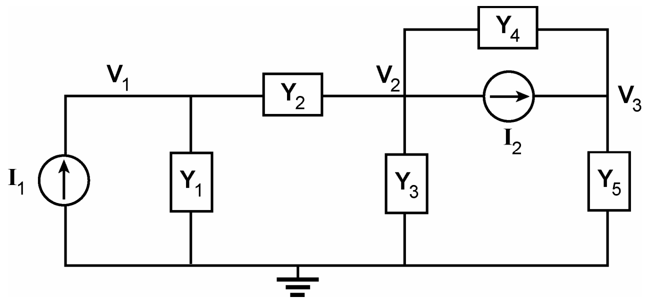
$$\mathbf{V}_3\left(\frac{1}{\mathbf{Z}_6}+\frac{1}{\mathbf{Z}_7}+\frac{1}{\mathbf{Z}_8}\right)-\frac{\mathbf{V}_2}{\mathbf{Z}_6}-\frac{\mathbf{V}_4}{\mathbf{Z}_7}=-\frac{\mathbf{E}_2}{\mathbf{Z}_6}$$

$$\mathbf{V}_4\left(\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_4}+\frac{1}{\mathbf{Z}_7}+\frac{1}{\mathbf{Z}_5}\right)-\frac{\mathbf{V}_1}{\mathbf{Z}_2}-\frac{\mathbf{V}_2}{\mathbf{Z}_4}-\frac{\mathbf{V}_3}{\mathbf{Z}_7}=0$$

Setting up and then using determinants:

$\mathbf{V}_1 = \mathbf{14.62\ V\angle -5.86°}$, $\mathbf{V}_2 = \mathbf{35.03\ V\angle -37.69°}$
$\mathbf{V}_3 = \mathbf{32.4\ V\angle -73.34°}$, $\mathbf{V}_4 = \mathbf{5.67\ V\angle 23.53°}$

20. a.



$\mathbf{Y}_1 = \dfrac{1}{4\,\Omega\,\angle 0°} = 0.25\text{ S }\angle 0°$

$\mathbf{Y}_2 = \dfrac{1}{1\,\Omega\,\angle 90°} = 1\text{ S }\angle -90°$

$\mathbf{Y}_3 = \dfrac{1}{5\,\Omega\,\angle 0°} = 0.2\text{ S }\angle 0°$

$\mathbf{Y}_4 = \dfrac{1}{4\,\Omega\,\angle -90°} = 0.25\text{ S }\angle 90°$

$\mathbf{Y}_5 = \dfrac{1}{8\,\Omega\,\angle 90°} = 0.125\text{ S }\angle -90°$

$\mathbf{I}_1 = 2\text{ A }\angle 30°$

$\mathbf{I}_2 = 3\text{ A }\angle 150°$

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{Y}_2\mathbf{V}_2 = \mathbf{I}_1$$
$$\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_3 = -\mathbf{I}_2$$
$$\mathbf{V}_3[\mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_4\mathbf{V}_2 = \mathbf{I}_2$$

$$\begin{array}{lllll}
[\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 & - \mathbf{Y}_2\,\mathbf{V}_2 & + 0 & = \mathbf{I}_1 \\
-\mathbf{Y}_2\mathbf{V}_1 & + [\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4]\mathbf{V}_2 & - \mathbf{Y}_4\,\mathbf{V}_3 & = -\mathbf{I}_2 \\
0 & - \mathbf{Y}_4\mathbf{V}_2 & + [\mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_3 & = \mathbf{I}_2
\end{array}$$

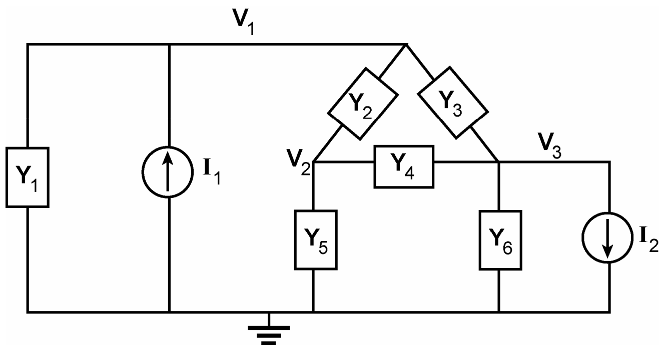
$$\mathbf{V}_1 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4)(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_4^2\right] - \mathbf{I}_2[\mathbf{Y}_2\mathbf{Y}_5]}{\left[\mathbf{Y}_1 + \mathbf{Y}_2\right]\left[(\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4)(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_4^2\right] - \mathbf{Y}_2^2(\mathbf{Y}_4 + \mathbf{Y}_5) = \mathbf{Y}_\Delta}$$

$= \mathbf{5.74\text{ V }\angle 122.76°}$

$$\mathbf{V}_2 = \frac{\mathbf{I}_1\mathbf{Y}_2(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{I}_2\mathbf{Y}_5(\mathbf{Y}_1 + \mathbf{Y}_2)}{\mathbf{Y}_\Delta} = \mathbf{4.04\text{ V }\angle 145.03°}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}_2\left[(\mathbf{Y}_1 + \mathbf{Y}_2)(\mathbf{Y}_3 + \mathbf{Y}_4) - \mathbf{Y}_2^2\right] - \mathbf{Y}_2\mathbf{Y}_4\mathbf{I}_1}{\mathbf{Y}_\Delta} = \mathbf{25.94\text{ V }\angle 78.07°}$$

b.



$$\mathbf{Y}_1 = \frac{1}{4\ \Omega \angle 0°} = 0.25\ \text{S} \angle 0°$$
$$\mathbf{Y}_2 = \frac{1}{6\ \Omega \angle 0°} = 0.167\ \text{S} \angle 0°$$
$$\mathbf{Y}_3 = \frac{1}{8\ \Omega \angle 0°} = 0.125\ \text{S} \angle 0°$$
$$\mathbf{Y}_4 = \frac{1}{2\ \Omega \angle -90°} = 0.5\ \text{S} \angle 90°$$
$$\mathbf{Y}_5 = \frac{1}{5\ \Omega \angle 90°} = 0.2\ \text{S} \angle -90°$$
$$\mathbf{Y}_6 = \frac{1}{4\ \Omega \angle 90°} = 0.25\ \text{S} \angle -90°$$
$\mathbf{I}_1 = 4\ \text{A} \angle 0°$
$\mathbf{I}_2 = 6\ \text{A} \angle 90°$

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{Y}_2\mathbf{V}_2 - \mathbf{Y}_3\mathbf{V}_3 = \mathbf{I}_1$$
$$\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_3 = 0$$
$$\mathbf{V}_3[\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6] - \mathbf{Y}_3\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_2 = -\mathbf{I}_2$$

$$\begin{array}{lll}
[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{V}_1 & -\ \mathbf{Y}_2\mathbf{V}_2 & -\ \mathbf{Y}_3\mathbf{V}_3 = \mathbf{I}_1 \\
-\mathbf{Y}_2\mathbf{V}_1 + & [\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_2 & -\ \mathbf{Y}_4\mathbf{V}_3 = 0 \\
-\mathbf{Y}_3\mathbf{V}_1 & -\ \mathbf{Y}_4\mathbf{V}_2 + & [\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6]\mathbf{V}_3 = -\mathbf{I}_2
\end{array}$$

$$\mathbf{V}_1 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6)-\mathbf{Y}_4^2\right]-\mathbf{I}_2\left[\mathbf{Y}_2\mathbf{Y}_4+\mathbf{Y}_3(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_5)\right]}{\mathbf{Y}_\Delta=(\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3)\left[(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6)-\mathbf{Y}_4^2\right]-\mathbf{Y}_2\left[\mathbf{Y}_2(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6)+\mathbf{Y}_3\mathbf{Y}_4\right]-\mathbf{Y}_3\left[\mathbf{Y}_2\mathbf{Y}_4+\mathbf{Y}_3(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)\right]}$$
$$= \mathbf{15.13\ V \angle 1.29°}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_2)(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6)+\mathbf{Y}_3\mathbf{Y}_4\right]+\mathbf{I}_2\left[\mathbf{Y}_4(\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3)-\mathbf{Y}_2\mathbf{Y}_3\right]}{\mathbf{Y}_\Delta} = \mathbf{17.24\ V \angle 3.73°}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_3)(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)+\mathbf{Y}_2\mathbf{Y}_4\right]+\mathbf{I}_2\left[\mathbf{Y}_2^2-(\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3)(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)\right]}{\mathbf{Y}_\Delta}$$
$$= \mathbf{10.59\ V \angle -0.11°}$$

21. Left node: $\mathbf{V}_1$

$$\Sigma \mathbf{I}_i = \Sigma \mathbf{I}_o$$
$$4\mathbf{I}_x = \mathbf{I}_x + 5\ \text{mA} \angle 0° + \frac{\mathbf{V}_1 - \mathbf{V}_2}{2\ \text{k}\Omega}$$

Right node: $\mathbf{V}_2$

$$\Sigma \mathbf{I}_i = \Sigma \mathbf{I}_o$$
$$8\ \text{mA} \angle 0° = \frac{\mathbf{V}_2}{1\ \text{k}\Omega} + \frac{\mathbf{V}_2 - \mathbf{V}_1}{2\ \text{k}\Omega} + 4\mathbf{I}_x$$

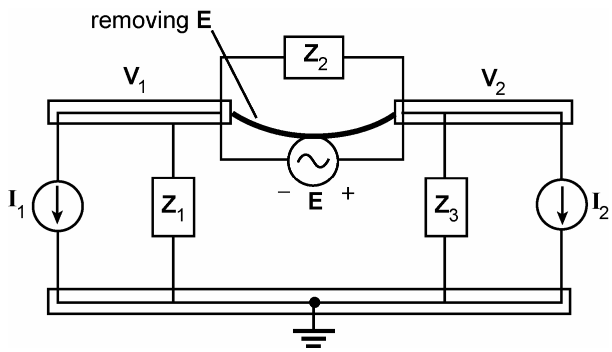
Insert $\mathbf{I}_x = \dfrac{\mathbf{V}_1}{4\ \text{k}\Omega \angle -90°}$

Rearrange, reduce and 2 equations with 2 unknowns result:

$$\mathbf{V}_1[1.803 \angle 123.69°] + \mathbf{V}_2 = 10$$
$$\mathbf{V}_1[2.236 \angle 116.57°] + 3\,\mathbf{V}_2 = 16$$

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

22.



$\mathbf{Z}_1 = 1\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 2\ \text{k}\Omega\ \angle 90°$
$\mathbf{Z}_3 = 3\ \text{k}\Omega\ \angle{-90°}$
$\mathbf{I}_1 = 12\ \text{mA}\ \angle 0°$
$\mathbf{I}_2 = 4\ \text{mA}\ \angle 0°$
$\mathbf{E} = 10\ \text{V}\ \angle 0°$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$0 = \mathbf{I}_1 + \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \mathbf{I}_2$$

and $\dfrac{\mathbf{V}_1}{\mathbf{Z}_1} + \dfrac{\mathbf{V}_2}{\mathbf{Z}_3} = -\mathbf{I}_1 - \mathbf{I}_2$

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 $\mathbf{V}_1$:

$\mathbf{V}_1 = \mathbf{15.4\ V\ \angle 178.2°}$
with $\mathbf{V}_2 = \mathbf{V}_C = \mathbf{5.41\ V\ \angle 174.87°}$

23. Left node: $\mathbf{V}_1$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$2\ \text{mA}\ \angle 0° = 12\ \text{mA}\ \angle 0° + \frac{\mathbf{V}_1}{2\ \text{k}\Omega} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{1\ \text{k}\Omega}$$

and $1.5\ \mathbf{V}_1 - \mathbf{V}_2 = -10$

Right node: $\mathbf{V}_2$

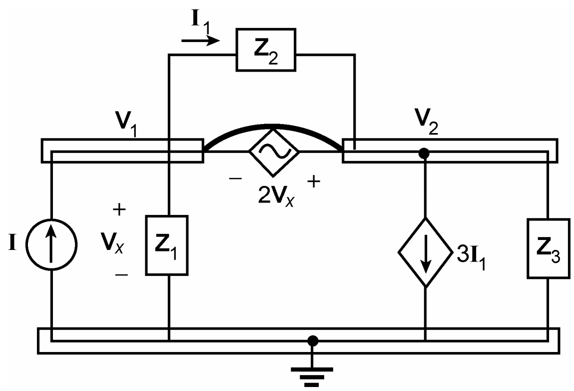
$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$0 = 2\ \text{mA}\ \angle 0° + \frac{\mathbf{V}_2 - \mathbf{V}_1}{1\ \text{k}\Omega} - \frac{\mathbf{V}_2 - 6\ \mathbf{V}_x}{3.3\ \text{k}\Omega}$$

and $2.7\ \mathbf{V}_1 - 3.7\ \mathbf{V}_2 = -6.6$

Using determinants: $\mathbf{V}_1 = \mathbf{V}_{2k\Omega} = \mathbf{-10.67\ V\ \angle 0° = 10.67\ V\ \angle 180°}$
$\mathbf{V}_2 = \mathbf{-6\ V\ \angle 0° = 6\ V\ \angle 180°}$

24.



$\mathbf{Z}_1 = 2\text{ k}\Omega \angle 0°$
$\mathbf{Z}_2 = 1\text{ k}\Omega\angle 0°$
$\mathbf{Z}_3 = 1\text{ k}\Omega \angle 0°$
$\mathbf{I} = 5\text{ mA} \angle 0°$

$\mathbf{V}_1$: $\mathbf{I} = \dfrac{\mathbf{V}_1}{\mathbf{Z}_1} + 3\mathbf{I}_1 + \dfrac{\mathbf{V}_2}{\mathbf{Z}_3}$

with $\mathbf{I}_1 = \dfrac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2}$

and $\mathbf{V}_2 - \mathbf{V}_1 = 2\mathbf{V}_x = 2\mathbf{V}_1$ or $\mathbf{V}_2 = 3\mathbf{V}_1$

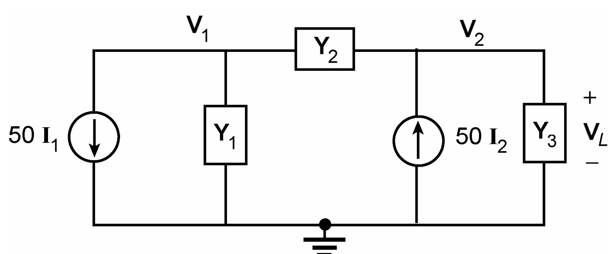
Substituting will result in:

$$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{3}{\mathbf{Z}_2}\right] + 3\,\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_3} - \frac{3}{\mathbf{Z}_2}\right] = \mathbf{I}$$

or $$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} - \frac{6}{\mathbf{Z}_2} + \frac{3}{\mathbf{Z}_3}\right] = \mathbf{I}$$

and $\mathbf{V}_1 = \mathbf{V}_x = \mathbf{-2\ V \angle 0°}$
with $\mathbf{V}_2 = \mathbf{-6\ V \angle 0°}$

25.



$\mathbf{I}_1 = \dfrac{E_i\angle\theta}{R_1 \angle 0°} = 1 \times 10^{-3}\ \mathbf{E}_i$

$\mathbf{Y}_1 = \dfrac{1}{50\text{ k}\Omega} = 0.02\text{ mS} \angle 0°$

$\mathbf{Y}_2 = \dfrac{1}{1\text{ k}\Omega} = 1\text{ mS} \angle 0°$

$\mathbf{Y}_3 = 0.02\text{ mS} \angle 0°$
$\mathbf{I}_2 = (\mathbf{V}_1 - \mathbf{V}_2)\mathbf{Y}_2$

$\mathbf{V}_1(\mathbf{Y}_1 + \mathbf{Y}_2) - \mathbf{Y}_2\mathbf{V}_2 = -50\mathbf{I}_1$
$\mathbf{V}_2(\mathbf{Y}_2 + \mathbf{Y}_3) - \mathbf{Y}_2\mathbf{V}_1 = 50\mathbf{I}_2 = 50(\mathbf{V}_1 - \mathbf{V}_2)\mathbf{Y}_2 = 50\mathbf{Y}_2\mathbf{V}_1 - 50\mathbf{Y}_2\mathbf{V}_2$

$(\mathbf{Y}_1 + \mathbf{Y}_2)\mathbf{V}_1 - \mathbf{Y}_2\mathbf{V}_2 = -50\mathbf{I}_1$
$-51\mathbf{Y}_2\mathbf{V}_1 + (51\mathbf{Y}_2 + \mathbf{Y}_3)\mathbf{V}_2 = 0$

$$\mathbf{V}_L = \mathbf{V}_2 = \frac{-(50)(51)\mathbf{Y}_2\mathbf{I}_1}{(\mathbf{Y}_1 + \mathbf{Y}_2)(51\mathbf{Y}_2 + \mathbf{Y}_3) - 51\mathbf{Y}_2^2} = \mathbf{-2451.92\ E}_i$$

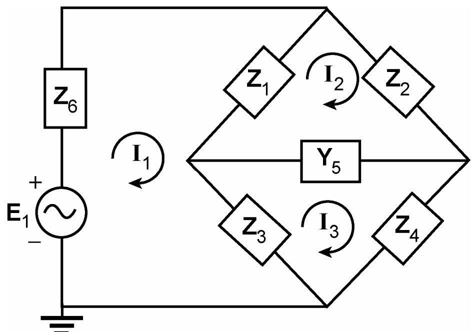
26. a. yes

$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$

$$\frac{5\times 10^3 \angle 0°}{2.5 \times 10^3 \angle 90°} = \frac{8\times 10^3 \angle 0°}{4\times 10^3 \angle 90°}$$

$$2 \angle -90° = 2 \angle -90° \text{ (balanced)}✓$$

b. $\mathbf{Z}_1 = 5\ \text{k}\Omega \angle 0°$, $\mathbf{Z}_2 = 8\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_3 = 2.5\ \text{k}\Omega \angle 90°$, $\mathbf{Z}_4 = 4\ \text{k}\Omega \angle 90°$
$\mathbf{Z}_5 = 5\ \text{k}\Omega \angle -90°$, $\mathbf{Z}_6 = 1\ \text{k}\Omega \angle 0°$



$$\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6] - \mathbf{Z}_1\mathbf{I}_2 - \mathbf{Z}_3\mathbf{I}_3 = \mathbf{E}$$
$$\mathbf{I}_2[\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5] - \mathbf{Z}_1\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_3 = 0$$
$$\mathbf{I}_3[\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5] - \mathbf{Z}_3\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_2 = 0$$

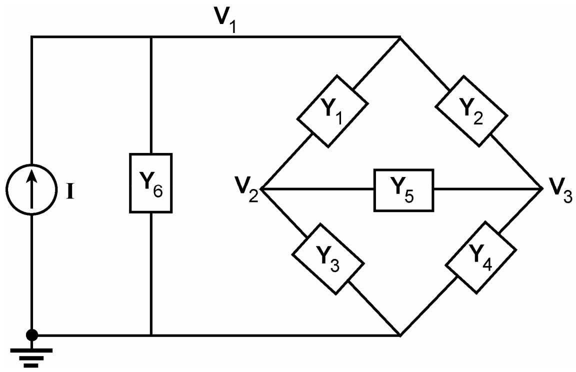
$$\begin{aligned}
&[\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6]\mathbf{I}_1 && - \mathbf{Z}_1\mathbf{I}_2 && - \mathbf{Z}_3\mathbf{I}_3 = \mathbf{E}\\
&-\mathbf{Z}_1\mathbf{I}_1 && + [\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5]\mathbf{I}_2 && - \mathbf{Z}_5\mathbf{I}_3 = 0\\
&-\mathbf{Z}_3\mathbf{I}_1 && - \mathbf{Z}_5\mathbf{I}_2 && + [\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{I}_3 = 0
\end{aligned}$$

$$\mathbf{I}_2 = \frac{\mathbf{E}[\mathbf{Z}_1(\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5) + \mathbf{Z}_3\mathbf{Z}_5]}{\mathbf{Z}_\Delta = (\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6)[(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)(\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5) - \mathbf{Z}_5^2] - \mathbf{Z}_1[\mathbf{Z}_1(\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5) - \mathbf{Z}_3\mathbf{Z}_5] - \mathbf{Z}_3[\mathbf{Z}_1\mathbf{Z}_5 + \mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)]}$$

$$\mathbf{I}_3 = \frac{\mathbf{E}[\mathbf{Z}_1\mathbf{Z}_5 + \mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)]}{\mathbf{Z}_\Delta}$$

$$\mathbf{I}_{Z_5} = \mathbf{I}_2 - \mathbf{I}_3 = \frac{\mathbf{E}[\mathbf{Z}_1\mathbf{Z}_4 - \mathbf{Z}_3\mathbf{Z}_2]}{\mathbf{Z}_\Delta} = \frac{E[20\times 10^6 \angle 90° - 20\times 10^6 \angle 90°]}{\mathbf{Z}_\Delta} = \mathbf{0\ A}$$

c.



$$\mathbf{I} = \frac{\mathbf{E}_s}{\mathbf{R}_s} = \frac{10\text{ V}\angle 0^\circ}{1\text{ k}\Omega\angle 0^\circ} = 10\text{ mA}\angle 0^\circ$$

$$\mathbf{Y}_1 = \frac{1}{5\text{ k}\Omega\angle 0^\circ} = 0.2\text{ mS}\angle 0^\circ$$

$$\mathbf{Y}_2 = \frac{1}{8\text{ k}\Omega\angle 0^\circ} = 0.125\text{ mS}\angle 0^\circ$$

$$\mathbf{Y}_3 = \frac{1}{2.5\text{ k}\Omega\angle 90^\circ} = 0.4\text{ mS}\angle -90^\circ$$

$$\mathbf{Y}_4 = \frac{1}{4\text{ k}\Omega\angle 90^\circ} = 0.25\text{ mS}\angle -90^\circ$$

$$\mathbf{Y}_5 = \frac{1}{5\text{ k}\Omega\angle -90^\circ} = 0.2\text{ mS}\angle 90^\circ$$

$$\mathbf{Y}_6 = \frac{1}{1\text{ k}\Omega\angle 0^\circ}$$

$$\mathbf{V}_2 = 1\text{ mS}\angle 0^\circ$$

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6] - \mathbf{Y}_1\mathbf{V}_2 - \mathbf{Y}_2\mathbf{V}_3 = \mathbf{I}$$
$$\mathbf{V}_2[\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5] - \mathbf{Y}_1\mathbf{V}_1 - \mathbf{Y}_5\mathbf{V}_3 = 0$$
$$\mathbf{V}_3[\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_5\mathbf{V}_2 = 0$$

$$\begin{aligned}
&[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6]\mathbf{V}_1 && - \mathbf{Y}_1\mathbf{V}_2 && - \mathbf{Y}_2\mathbf{V}_3 = \mathbf{I}\\
&-\mathbf{Y}_1\mathbf{V}_1 && + [\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5]\mathbf{V}_2 && - \mathbf{Y}_5\mathbf{V}_3 = 0\\
&-\mathbf{Y}_2\mathbf{V}_1 && - \mathbf{Y}_5\mathbf{V}_2 && + [\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_3 = 0
\end{aligned}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}\left[\mathbf{Y}_1(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_5\right]}{\mathbf{Y}_\Delta = (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6)[(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_5^2] - \mathbf{Y}_1[\mathbf{Y}_1(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_5] - \mathbf{Y}_2[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)]}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}\left[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)\right]}{\mathbf{Y}_\Delta}$$

$$\mathbf{V}_{Z_5} = \mathbf{V}_2 - \mathbf{V}_3 = \frac{\mathbf{I}\left[\mathbf{Y}_1\mathbf{Y}_4 - \mathbf{Y}_4\mathbf{Y}_3\right]}{\mathbf{Y}_\Delta} = \frac{\mathbf{I}\left[0.05\times 10^{-3}\angle -90^\circ - 0.05\times 10^{-3}\angle -90^\circ\right]}{\mathbf{Y}_\Delta}$$

$$= \mathbf{0\ V}$$

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 $\mathbf{I}_{X_C} = \mathbf{1.76\ mA\angle -71.54^\circ}$

c. The solution to 26(c) resulted in

$$\mathbf{V}_3 = \mathbf{V}_{X_C} = \frac{\mathbf{I}\left[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1+\mathbf{Y}_3+\mathbf{Y}_5)\right]}{\mathbf{Y}_\Delta}$$

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 $\mathbf{Y}_1 = 0.2 \text{ mS} \angle 0°$, $\mathbf{Y}_2 = 0.125 \text{ mS} \angle 0°$, $\mathbf{Y}_3 = 0.4 \text{ mS} \angle -90°$

$\mathbf{Y}_4 = 0.25 \text{ mS} \angle -90°$, $\mathbf{Y}_5 = 0.2 \text{ mS} \angle 90°$

Source conversion: $\mathbf{Y}_6 = 1 \text{ mS} \angle 0°$, $\mathbf{I} = 10 \text{ mA} \angle 0°$

and $\mathbf{V}_3 = \mathbf{7.03\ V \angle -18.46°}$

28. $\mathbf{Z}_1\mathbf{Z}_4 = \mathbf{Z}_3\mathbf{Z}_2$

$(R_1 - jX_C)\left(R_x + jX_{L_x}\right) = R_3R_2$ $\qquad X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^3 \text{ rad/s})(1\,\mu\text{F})} = 1 \text{ k}\Omega$

$(1 \text{ k}\Omega - j1 \text{ k}\Omega)\left(R_x + jX_{L_x}\right) = (0.1 \text{ k}\Omega)(0.1 \text{ k}\Omega) = 10 \text{ k}\Omega$

and $R_x + jX_{L_x} = \dfrac{10\times10^3\ \Omega}{1\times10^3 - j1\times10^3} = \dfrac{10\times10^3}{1.414\times10^3\ \angle -45°} = 5\ \Omega + j5\ \Omega$

$\therefore R_x = \mathbf{5\ \Omega}$, $L_x = \dfrac{X_{L_x}}{\omega} = \dfrac{5\,\Omega}{10^3 \text{ rad/s}} = \mathbf{5\ mH}$

29. $X_{C_1} = \dfrac{1}{\omega C} = \dfrac{1}{(1000 \text{ rad/s})(3\,\mu\text{F})} = \dfrac{1}{3}\text{k}\Omega$

$\mathbf{Z}_1 = R_1 \parallel X_{C_1} \angle -90° = (2 \text{ k}\Omega \angle 0°) \parallel 2\dfrac{1}{3} \text{ k}\Omega \angle -90° = 328.8\ \Omega \angle -80.54°$

$\mathbf{Z}_2 = R_2 \angle 0° = 0.5 \text{ k}\Omega \angle 0°$, $\mathbf{Z}_3 = R_3 \angle 0° = 4 \text{ k}\Omega \angle 0°$

$\mathbf{Z}_4 = R_x + j X_{L_x} = 1 \text{ k}\Omega + j6 \text{ k}\Omega$

$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$

$$\frac{328.8\,\Omega \angle -80.54°}{4 \text{ k}\Omega \angle 0°} \stackrel{?}{=} \frac{0.5 \text{ k}\Omega \angle 0°}{6.083\,\Omega \angle 80.54°}$$

$$82.2 \angle -80.54° \stackrel{\checkmark}{=} 82.2 \angle -80.54° \textbf{ (balanced)}$$

30. Apply Eq. **17.6.**

31. For balance:

$$R_1(R_x + jX_{L_x}) = R_2(R_3 + jX_{L_3})$$

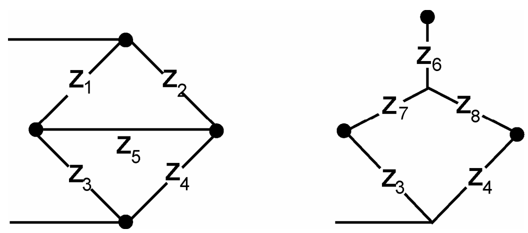
$$R_1R_x + jR_1X_{L_x} = R_2R_3 + jR_2X_{L_3}$$

$$\therefore\ R_1R_x = R_2R_3 \text{ and } R_x = \frac{R_2R_3}{R_1}$$

$$R_1X_{L_x} = R_2X_{L_3} \text{ and } R_1\omega L_x = R_2\omega L_3$$

$$\text{so that } L_x = \boldsymbol{\frac{R_2L_3}{R_1}}$$

32. a.



$\mathbf{Z}_1 = 8\ \Omega\ \angle -90° = -j8\ \Omega$
$\mathbf{Z}_2 = 4\ \Omega\ \angle 90° = +j4\ \Omega$
$\mathbf{Z}_3 = 8\ \Omega\ \angle 90° = +j8\ \Omega$
$\mathbf{Z}_4 = 6\ \Omega\ \angle -90° = -j6\ \Omega$
$\mathbf{Z}_5 = 5\ \Omega\ \angle 0°$

$$\mathbf{Z}_6 = \frac{\mathbf{Z}_1\mathbf{Z}_2}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 5\ \Omega\ \angle 38.66°$$

$$\mathbf{Z}_7 = \frac{\mathbf{Z}_1\mathbf{Z}_5}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 6.25\ \Omega\ \angle -51.34°$$

$$\mathbf{Z}_8 = \frac{\mathbf{Z}_2\mathbf{Z}_5}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 3.125\ \Omega\ \angle 128.66°$$

$$\mathbf{Z}' = \mathbf{Z}_7 + \mathbf{Z}_3 = 3.9\ \Omega + j3.12\ \Omega = 4.99\ \Omega\ \angle 38.66°$$

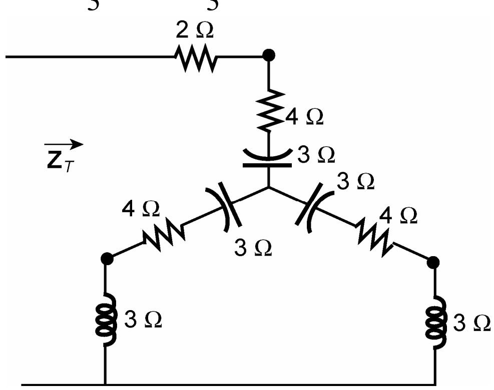
$$\mathbf{Z}'' = \mathbf{Z}_8 + \mathbf{Z}_4 = -1.95\ \Omega - j3.56\ \Omega = 4.06\ \Omega\ \angle -118.71°$$

$$\mathbf{Z}' \parallel \mathbf{Z}'' = 10.13\ \Omega\ \angle -67.33° = 3.90\ \Omega - j9.35\ \Omega$$

$$\mathbf{Z}_T = \mathbf{Z}_6 + \mathbf{Z}' \parallel \mathbf{Z}'' = 7.80\ \Omega - j6.23\ \Omega = 9.98\ \Omega\ \angle -38.61°$$

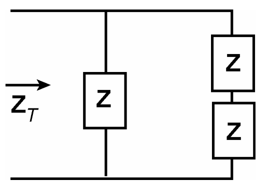
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{120\ \text{V}\ \angle 0°}{9.98\ \Omega\ \angle -38.61°} = \mathbf{12.02\ A\ \angle 38.61°}$$

b. $$\mathbf{Z}_Y = \frac{\mathbf{Z}_\Delta}{3} = \frac{12\ \Omega - j9\ \Omega}{3} = 4\ \Omega - j3\ \Omega$$



$$\mathbf{Z}_T = 2\ \Omega + 4\ \Omega + j3\ \Omega + [4\ \Omega - \cancel{j3}\ \Omega + \cancel{j3}\ \Omega] \parallel [4\ \Omega - \cancel{j}3\ \Omega + \cancel{j}3\ \Omega]$$
$$= 6\ \Omega - j3\ \Omega + 2\ \Omega$$
$$= 8\ \Omega - j3\ \Omega = 8.544\ \Omega\ \angle -20.56°$$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60\ \text{V}\ \angle 0°}{8.544\ \Omega\ \angle -20.56°} = \mathbf{7.02\ A\ \angle 20.56°}$$

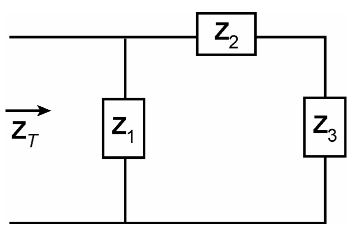
33. a.



$$\mathbf{Z}_\Delta = 3\mathbf{Z}_Y = 3(3\ \Omega\ \angle 90°) = 9\ \Omega\ \angle 90°$$
$$\mathbf{Z} = 9\ \Omega\ \angle 90° \parallel (12\ \Omega - j16\ \Omega)$$
$$= 9\ \Omega\ \angle 90° \parallel 20\ \Omega\ \angle 53.13°$$
$$= 12.96\ \Omega\ \angle 67.13°$$

$$\mathbf{Z}_T = \mathbf{Z} \parallel \mathbf{2Z} = \frac{2\mathbf{Z}^2}{\mathbf{Z} + 2\mathbf{Z}} = \frac{2}{3}\mathbf{Z} = \frac{2}{3}\ [12.96\ \Omega\ \angle 67.13°] = 8.64\ \Omega\ \angle 67.13°$$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100\ \text{V}\ \angle 0°}{8.64\ \Omega\ \angle 67.13°} = \mathbf{11.57\ A\ \angle -67.13°}$$

b. $\mathbf{Z}_\Delta = 3\mathbf{Z}_Y = 3(5\ \Omega) = 15\ \Omega$

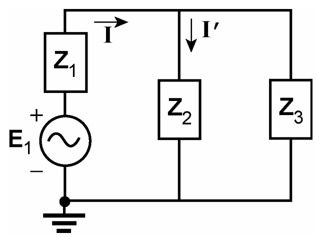


$$\mathbf{Z}_1 = 15\ \Omega\ \angle 0° \parallel 5\ \Omega\ \angle -90°$$
$$= 4.74\ \Omega\ \angle -71.57°$$
$$\mathbf{Z}_2 = 15\ \Omega\ \angle 0° \parallel 6\ \Omega\ \angle 90°$$
$$= 5.57\ \Omega\ \angle 68.2° = 2.07\ \Omega + j5.17\ \Omega$$
$$\mathbf{Z}_3 = \mathbf{Z}_1 = 4.74\ \Omega\ \angle -71.57°$$
$$= 1.5\ \Omega - j4.5\ \Omega$$

$$\mathbf{Z}_T = \mathbf{Z}_1 \parallel (\mathbf{Z}_2 + \mathbf{Z}_3) = (4.74\ \Omega\ \angle -71.57°) \parallel (2.07\ \Omega + j5.17\ \Omega + 1.5\ \Omega - j4.5\ \Omega)$$
$$= (4.74\ \Omega\ \angle -7.57°) \parallel (3.63\ \Omega\ \angle 10.63°)$$
$$= 2.71\ \Omega\ \angle -23.87°$$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100\ \text{V}\ \angle 0°}{2.71\ \Omega\ \angle -23.87°} = \mathbf{36.9\ A\ \angle 23.87°}$$

Chapter 18

1. a.

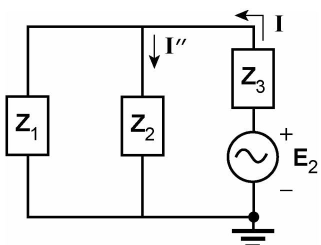


$\mathbf{Z}_1 = 3\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 8\ \Omega\ \angle 90°$, $\mathbf{Z}_3 = 6\ \Omega\ \angle -90°$

$\mathbf{Z}_2 \parallel \mathbf{Z}_3 = 8\ \Omega\ \angle 90° \parallel 6\ \Omega\ \angle -90° = 24\ \Omega\ \angle -90°$

$$\mathbf{I} = \frac{\mathbf{E}_1}{\mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3} = \frac{30\text{ V}\ \angle 30°}{3\ \Omega - j24\ \Omega} = 1.24\text{ A}\ \angle 112.875°$$

$$\mathbf{I}' = \frac{\mathbf{Z}_3\mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(6\ \Omega\ \angle -90°)(1.24\text{ A}\ \angle 112.875°)}{2\ \Omega\ \angle 90°} = 3.72\text{ A}\ \angle -67.125°$$



$\mathbf{Z}_1 \parallel \mathbf{Z}_2 = 3\ \Omega\ \angle 0° \parallel 8\ \Omega\ \angle 90° = 2.809\ \Omega\ \angle 20.556°$

$$\mathbf{I} = \frac{\mathbf{E}_2}{\mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2} = \frac{60\text{ V}\ \angle 10°}{-j6\ \Omega + 2.630\ \Omega + j0.986\ \Omega}$$

$= 10.597\text{ A}\ \angle 72.322°$

$$\mathbf{I}'' = \frac{\mathbf{Z}_1\mathbf{I}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(3\ \Omega\ \angle 0°)(10.597\text{ A}\ \angle 72.322°)}{3\ \Omega + j8\ \Omega} = 3.721\text{ A}\ \angle 2.878°$$

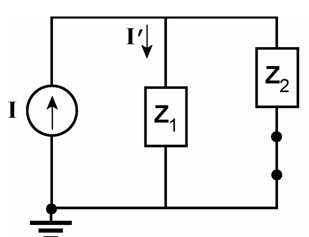
$\mathbf{I}_{L_1} = \mathbf{I}' + \mathbf{I}'' = 3.72\text{ A}\ \angle -67.125° + 3.721\text{ A}\ \angle 2.878°$

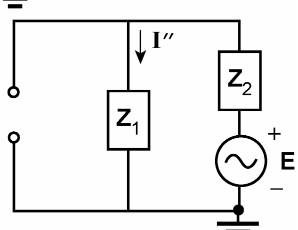
$= 1.446\text{ A} - j3.427\text{ A} + 3.716\text{ A} + j0.187\text{ A}$

$= 5.162\text{ A} - j3.24\text{ A}$

$= \mathbf{6.09\ A\ \angle -32.12°}$

b.





$\mathbf{Z}_1 = 8\ \Omega\ \angle 90°$, $\mathbf{Z}_2 = 5\ \Omega\ \angle -90°$

$\mathbf{I} = 0.3\text{ A}\ \angle 60°$, $\mathbf{E} = 10\text{ V}\ \angle 0°$

$$\mathbf{I}' = \frac{\mathbf{Z}_2\mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(5\ \Omega\ \angle -90°)(0.3\text{ A}\ \angle 60°)}{+j8\ \Omega - j5\ \Omega}$$

$= 0.5\text{A}\ \angle -120°$

$$\mathbf{I}'' = \frac{\mathbf{E}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{10\text{ V}\ \angle 0°}{3\ \Omega\ \angle 90°} = 3.33\text{ A}\ \angle -90°$$

$\mathbf{I}_{Z_1} = \mathbf{I}_{L_1} = \mathbf{I}' + \mathbf{I}''$

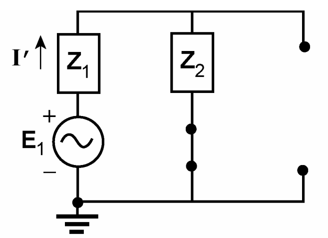
$= 0.5\text{ A}\ \angle -120° + 3.33\text{ A}\ \angle -90°$

$= -0.25\text{ A} - j0.433\text{ A} - j3.33\text{ A}$

$= -0.25\text{ A} - j3.763\text{ A}$

$= \mathbf{3.77\ A\ \angle -93.8°}$

2. a. $\mathbf{E}_1$:



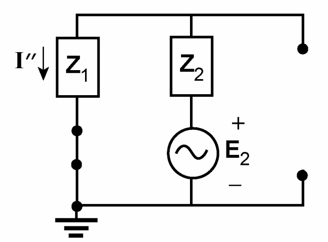
$\mathbf{E}_1 = 20\text{ V}\angle 0°, \quad \mathbf{Z}_1 = 4\ \Omega + j3\ \Omega = 5\ \Omega\angle 36.87°$

$\mathbf{Z}_2 = 1\ \Omega\angle 0°$

$$\mathbf{I}' = \frac{\mathbf{E}_1}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{20\text{ V}\angle 0°}{4\,\Omega + j3\,\Omega + 1\,\Omega}$$

$$= 3.43\text{ A}\angle{-30.96°}$$

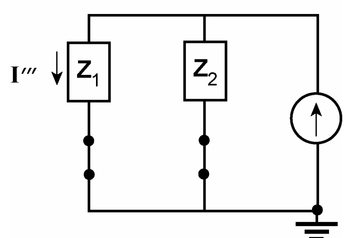
$\mathbf{E}_2$:



$$\mathbf{I}'' = \frac{\mathbf{E}_2}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{120\text{ V}\angle 0°}{5.83\,\Omega\angle 30.96°}$$

$$= 20.58\text{ A}\angle{-30.96°}$$

$\mathbf{I}$:



$$\mathbf{I}''' = \frac{\mathbf{Z}_2\mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(1\,\Omega\angle 0°)(0.5\text{ A}\angle 60°)}{5.83\,\Omega\angle 30.96°}$$

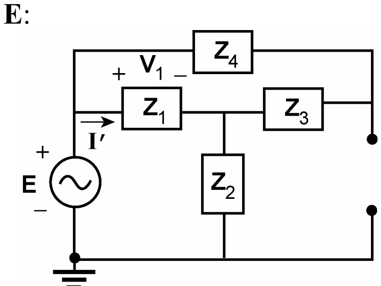
$$= 0.0858\text{ A}\angle 29.04°$$

$\uparrow\mathbf{I}_L = \mathbf{I}' - \mathbf{I}'' - \mathbf{I}'''$

$= (3.43\text{ A}\angle{-30.96°}) - (20.58\text{ A}\angle{-30.96°}) - (0.0858\text{ A}\angle 29.04°)$

$=$ **$17.20\text{ A}\angle 149.30°$** or **$17.20\text{ A}\angle{-30.70°}$**$\downarrow$

b. $\mathbf{E}$:



$\mathbf{Z}_1 = 3\ \Omega\angle 90°,\ \mathbf{Z}_2 = 7\ \Omega\angle{-90°}$

$\mathbf{E} = 10\text{ V}\angle 90°$

$\mathbf{Z}_3 = 6\ \Omega\angle{-90°},\ \mathbf{Z}_4 = 4\ \Omega\angle 0°$

$\mathbf{Z}' = \mathbf{Z}_1 \| (\mathbf{Z}_3 + \mathbf{Z}_4)$

$= 3\ \Omega\angle 90° \| (4\ \Omega - j6\ \Omega)$

$= 3\ \Omega\angle 90° \| 7.21\ \Omega\angle{-56.31°}$

$= 4.33\ \Omega\angle 70.56°$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'\mathbf{E}}{\mathbf{Z}' + \mathbf{Z}_2}$$

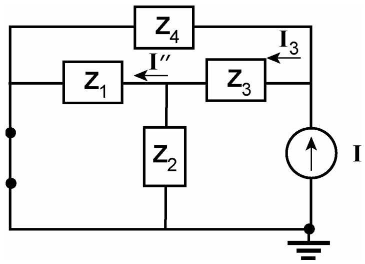
$$= \frac{(4.33\,\Omega\angle 70.56°)(10\text{ V}\angle 90°)}{(1.44\,\Omega + j4.08\,\Omega) - j7\Omega}$$

$$= \frac{43.3\text{ V}\angle 160.56°}{3.26\angle{-63.75°}} = 13.28\text{ V}\angle 224.31°$$

$$\mathbf{I}' = \frac{\mathbf{V}_1}{\mathbf{Z}_1} = \frac{13.28\text{ V}\angle 224.31°}{3\,\Omega\angle 90°}$$

$$= 4.43\text{ A}\angle 134.31°$$

I:

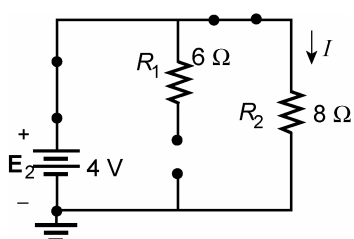


$$\mathbf{Z}'' = \mathbf{Z}_3 + \mathbf{Z}_1 \| \mathbf{Z}_2$$
$$= -j6\ \Omega + 3\ \Omega\ \angle 90° \parallel 7\ \Omega\ \angle -90°$$
$$= -j6\ \Omega + 5.25\ \Omega\ \angle 90°$$
$$= -j6\ \Omega + j5.25\ \Omega$$
$$= -j0.75\ \Omega = 0.75\ \Omega \angle -90°$$

CDR: $$\mathbf{I}_3 = \frac{\mathbf{Z}_4\mathbf{I}}{\mathbf{Z}_4 + \mathbf{Z}''} = \frac{(4\ \Omega\ \angle 0°)(0.6\ \text{A}\ \angle 120°)}{4\ \Omega - j0.75\ \Omega} = \frac{2.4\ \text{A}\ \angle 120°}{4.07\ \angle -10.62°}$$
$$= 0.59\ \text{A}\ \angle 130.62°$$
$$\mathbf{I}'' = \frac{\mathbf{Z}_2\mathbf{I}_3}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(7\ \Omega\ \angle -90°)(0.59\ \text{A}\ \angle 130.62°)}{-j7\ \Omega + j3\ \Omega} = \frac{4.13\ \text{A}\ \angle 40.62°}{4\ \angle -90°}$$
$$= 1.03\ \text{A}\ \angle 130.62°$$

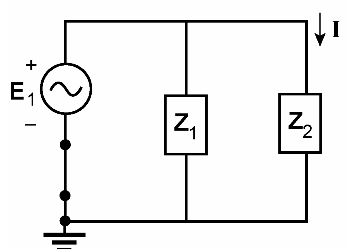
$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}''$ (direction of $\mathbf{I}'$)
$$= 4.43\ \text{A}\ \angle 134.31° - 1.03\ \text{A}\ \angle 130.62°$$
$$= (-3.09\ \text{A} + j3.17\ \text{A}) - (-0.67\ \text{A} + j0.78\ \text{A}) = -2.42\ \text{A} + j2.39\ \text{A}$$
$$= \mathbf{3.40\ A\ \angle 135.36°}$$

3. DC:



$$I_{DC} = \frac{4\ \text{V}}{8\ \Omega} = 0.5\ \text{A}$$

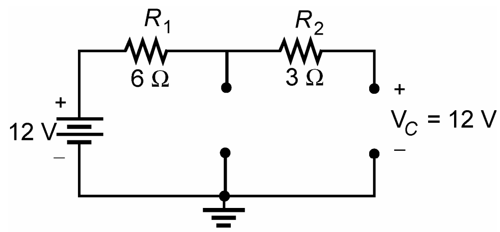
AC:



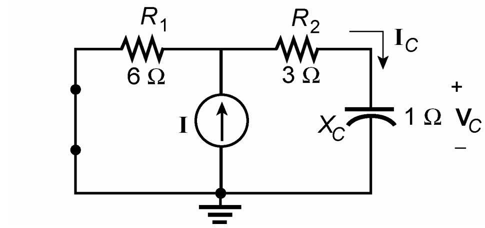
$$\mathbf{Z}_2 = R_2 + jX_L = 8\ \Omega + j4\ \Omega$$
$$= 8.944\ \Omega\ \angle 26.565°$$
$$\mathbf{I} = \frac{\mathbf{E}_1}{\mathbf{Z}_2} = \frac{10\ \text{V}\ \angle 0°}{8.944\ \Omega\ \angle 26.565°}$$
$$= 1.118\ \text{A}\ \angle -26.565°$$

$$\mathbf{I = 0.5\ A + 1.118\ A\ \angle -26.57°}$$
$$i = \mathbf{0.5\ A + 1.58\ sin(\omega t - 26.57°)}$$

4. DC:



AC:



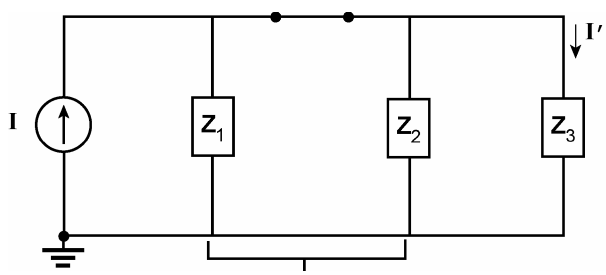
$$\mathbf{I}_C = \frac{(6\,\Omega\,\angle 0°)(\mathbf{I})}{6\,\Omega + 3\,\Omega - j1\,\Omega} = \frac{(6\,\Omega\,\angle 0°)(4\text{ A}\,\angle 0°)}{9\,\Omega - j1\,\Omega} = \frac{24\text{ A}\,\angle 0°}{9.055\angle -6.34°} = 2.65\text{ A}\,\angle 6.34°$$

$\mathbf{V}_C = \mathbf{I}_C\mathbf{X}_C = (2.65\text{ A}\,\angle 6.34°)(1\,\Omega\,\angle{-90°}) = 2.65\text{ V}\,\angle{-83.66°}$

$= \mathbf{12\ V + 2.65\ V\,\angle{-83.66°}}$

$\upsilon_C = \mathbf{12\ V + 3.75\ sin(\omega \mathit{t} - 83.66°)}$

5.

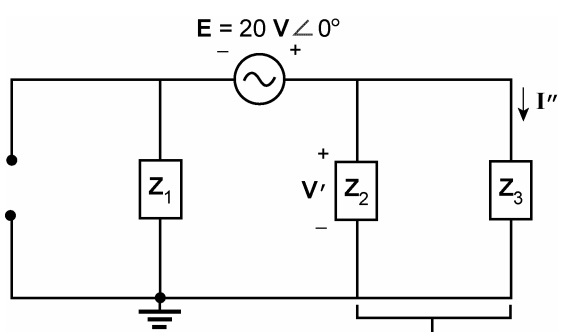


$\mathbf{E} = 20\text{ V}\,\angle 0°$
$\mathbf{Z}_1 = 10\text{ k}\Omega\,\angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega - j5\text{ k}\Omega$
$= 7.071\text{ k}\Omega\,\angle{-45°}$
$\mathbf{Z}_3 = 5\text{ k}\Omega\,\angle 90°$
$\mathbf{I} = 5\text{ mA}\,\angle 0°$

$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 10\text{ k}\Omega\,\angle 0° \parallel 7.071\text{ k}\Omega\,\angle{-45°} = 4.472\text{ k}\Omega\,\angle{-26.57°}$

(CDR) $$\mathbf{I}' = \frac{\mathbf{Z}'\mathbf{I}}{\mathbf{Z}' + \mathbf{Z}_3} = \frac{(4.472\text{ k}\Omega\,\angle -26.57°)(5\text{ mA}\,\angle 0°)}{4\text{ k}\Omega - j2\text{ k}\Omega + j5\text{ k}\Omega} = \frac{22.36\text{ mA}\,\angle -26.57°}{5\,\angle 36.87°}$$

$= 4.472\text{ mA}\,\angle{-63.44°}$



$\mathbf{Z}'' = \mathbf{Z}_2 \parallel \mathbf{Z}_3$
$= 7.071\text{ k}\Omega\,\angle{-45°} \parallel 5\text{ k}\Omega\,\angle 90°$
$= 7.071\text{ k}\Omega\,\angle 45°$

(VDR) $\quad \mathbf{V}' = \dfrac{\mathbf{Z}''\mathbf{E}}{\mathbf{Z}'' + \mathbf{Z}_1} = \dfrac{(7.071\text{ k}\Omega \angle 45°)(20\text{ V} \angle 0°)}{(5\text{ k}\Omega + j5\text{ k}\Omega) + (10\text{ k}\Omega)} = \dfrac{141.42\text{ V} \angle 45°}{15.81 \angle 18.435°}$

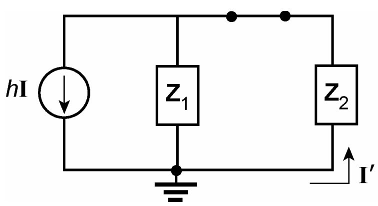
$= 8.945\text{ V} \angle 26.565°$

$\mathbf{I}'' = \dfrac{\mathbf{V}'}{\mathbf{Z}_3} = \dfrac{8.945\text{ V} \angle 26.565°}{5\text{ k}\Omega \angle 90°} = 1.789\text{ mA} \angle -63.435° = 0.8\text{ mA} - j1.6\text{ mA}$

$\mathbf{I} = \mathbf{I}' + \mathbf{I}'' = (2\text{ mA} - j4\text{ mA}) + (0.8\text{ mA} - j1.6\text{ mA}) = 2.8\text{ mA} - j5.6\text{ mA}$

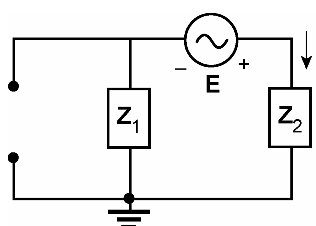
$= \mathbf{6.26\text{ mA} \angle -63.43°}$

6.



$\mathbf{Z}_1 = 20\text{ k}\Omega \angle 0°$
$\mathbf{Z}_2 = 10\text{ k}\Omega \angle 90°$
$\mathbf{I} = 2\text{ mA} \angle 0°$
$\mathbf{E} = 10\text{ V} \angle 0°$

$$\mathbf{I}' = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20\text{ k}\Omega \angle 0°)(100)(2\text{ mA} \angle 0°)}{20\text{ k}\Omega + j10\text{ k}\Omega} = 0.179\text{ A} \angle -26.57°$$



$\mathbf{I}'' = \dfrac{\mathbf{E}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \dfrac{10\text{ V} \angle 0°}{22.36\text{ k}\Omega \angle 26.57°}$

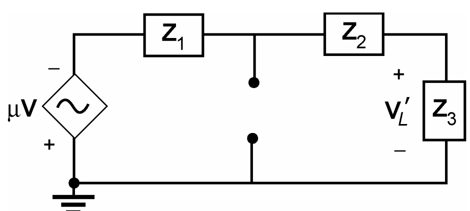
$= 0.447\text{ mA} \angle -26.57°$

$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}''$ (direction of $\mathbf{I}'$)

$= 179\text{ mA} \angle -26.57° - 0.447\text{ mA} \angle -26.57°$

$= \mathbf{178.55\text{ mA} \angle -26.57°}$

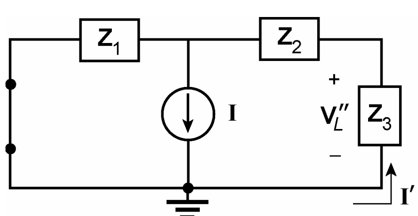
7. $\mu\mathbf{V}$:



$\mathbf{Z}_1 = 5\text{ k}\Omega \angle 0°$, $\mathbf{Z}_2 = 1\text{ k}\Omega \angle -90°$
$\mathbf{Z}_3 = 4\text{ k}\Omega \angle 0°$
$\mathbf{V} = 2\text{ V} \angle 0°$, $\mu = 20$

$$\mathbf{V}'_L = \frac{-\mathbf{Z}_3(\mu\mathbf{V})}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3} = \frac{-(4\text{ k}\Omega \angle 0°)(20)(2\text{ V} \angle 0°)}{5\text{ k}\Omega - j1\text{ k}\Omega + 4\text{ k}\Omega} = -17.67\text{ V} \angle 6.34°$$

I:



CDR: $\mathbf{I}' = \dfrac{\mathbf{Z}_1\mathbf{I}}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3}$

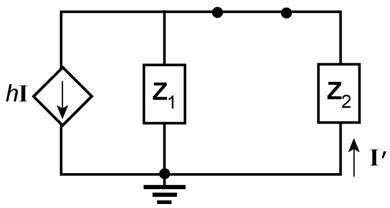
$= \dfrac{(5\text{ k}\Omega \angle 0°)(2\text{ mA} \angle 0°)}{9.056\text{ k}\Omega \angle -6.34°}$

$= 1.104\text{ mA} \angle 6.34°$

$\mathbf{V}''_L = -\mathbf{I}'\mathbf{Z}_3 = -(1.104\text{ mA} \angle 6.34°)(4\text{ k}\Omega \angle 0°) = -4.416\text{ V} \angle 6.34°$

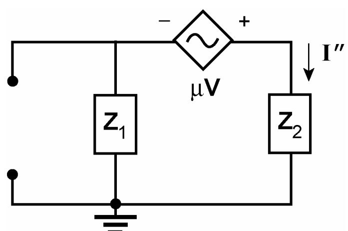
$\mathbf{V}_L = \mathbf{V}'_L + \mathbf{V}''_L = -17.67\text{ V} \angle 6.34° - 4.416\text{ V} \angle 6.34° = \mathbf{-22.09\text{ V} \angle 6.34°}$

8.



$\mathbf{Z}_1 = 20\text{ k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega + j5\text{ k}\Omega$

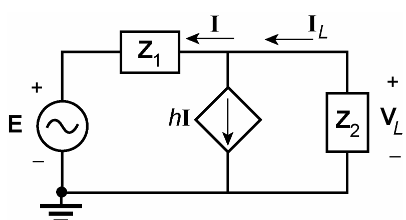
$$\mathbf{I}' = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20\text{ k}\Omega\ \angle 0°)(100)(1\text{ mA}\ \angle 0°)}{20\text{ k}\Omega + 5\text{ k}\Omega + j5\text{ k}\Omega} = 78.45\text{ mA}\ \angle{-11.31°}$$



$$\mathbf{I}'' = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(10\text{ V}\ \angle 0°)}{25.495\text{ k}\Omega\ \angle 11.31°}$$
$$= 7.845\text{ mA}\ \angle{-11.31°}$$

$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}''$ (direction of $\mathbf{I}'$)
$= 78.45\text{ mA}\ \angle{-11.31°} - 7.845\text{ mA}\ \angle{-11.31°}$
$= \mathbf{70.61\ mA\ \angle{-11.31°}}$

9.



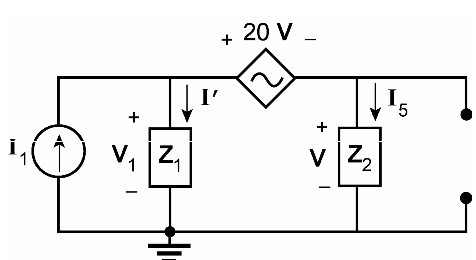
$\mathbf{Z}_1 = 2\text{ k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 2\text{ k}\Omega\ \angle 0°$
$\mathbf{V}_L = -\mathbf{I}_L\mathbf{Z}_2$
$\mathbf{I}_L = h\mathbf{I} + \mathbf{I} = (h+1)\mathbf{I}$
$\mathbf{V}_L = -(h+1)\mathbf{I}\mathbf{Z}_2$
and by KVL: $\mathbf{V}_L = \mathbf{I}\mathbf{Z}_1 + \mathbf{E}$
so that $\mathbf{I} = \dfrac{\mathbf{V}_L - \mathbf{E}}{\mathbf{Z}_1}$

$$\mathbf{V}_L = -(h+1)\mathbf{I}\mathbf{Z}_2 = -(h+1)\left[\frac{\mathbf{V}_L - \mathbf{E}}{\mathbf{Z}_1}\right]\mathbf{Z}_2$$

Subt. for $\mathbf{Z}_1$, $\mathbf{Z}_2$

$$\mathbf{V}_L = -(h+1)(\mathbf{V}_L - \mathbf{E})$$
$$\mathbf{V}_L(2+h) = \mathbf{E}(h+1)$$
$$\mathbf{V}_L = \frac{(h+1)}{(h+2)}\mathbf{E} = \frac{51}{52}\ (20\text{ V}\ \angle 53°) = \mathbf{19.62\ V\ \angle 53°}$$

10. $\mathbf{I}_1$:



$\mathbf{I}_1 = 1\text{ mA}\ \angle 0°$
$\mathbf{Z}_1 = 2\text{ k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega\ \angle 0°$

KVL: $\mathbf{V}_1 - 20\text{ }\mathbf{V} - \mathbf{V} = 0$ $\qquad \mathbf{I}' = \dfrac{\mathbf{V}_1}{\mathbf{Z}_1}\ \therefore\ \mathbf{I}' = \dfrac{21\mathbf{V}}{\mathbf{Z}_1}$ or $\mathbf{V} = \dfrac{\mathbf{Z}_1}{21}\mathbf{I}'$

$\mathbf{V}_1 = 21\ \mathbf{V}$

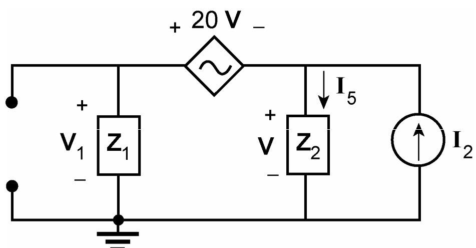
$$\mathbf{V} = \mathbf{I}_5\mathbf{Z}_2 = [\mathbf{I}_1 - \mathbf{I}']\mathbf{Z}_2$$

$$\frac{\mathbf{Z}_1}{21}\mathbf{I}' = \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}'\mathbf{Z}_2$$

$$\mathbf{I}'\left[\frac{\mathbf{Z}_1}{21} + \mathbf{Z}_2\right] = \mathbf{I}_1\mathbf{Z}_2$$

$$\text{and } \mathbf{I}' = \frac{\mathbf{Z}_2}{\dfrac{\mathbf{Z}_1}{21} + \mathbf{Z}_2}[\mathbf{I}_1] = \frac{(5\,\text{k}\Omega\,\angle 0°)(1\,\text{mA}\,\angle 0°)}{\left(\dfrac{2\,\text{k}\Omega\,\angle 0°}{21}\right) + 5\,\text{k}\Omega\,\angle 0°} = 0.981\text{ mA }\angle 0°$$

$\mathbf{I}_2$:



$$\mathbf{V}_1 = 20\text{ V} + \text{V} = 21\text{ V}$$

$$\mathbf{I}'' = \frac{\mathbf{V}_1}{\mathbf{Z}_1} = \frac{21\text{ V}}{\mathbf{Z}_1} \Rightarrow \mathbf{V} = \frac{\mathbf{Z}_1}{21}\mathbf{I}''$$

$$\mathbf{I}_5 = \frac{\mathbf{V}}{\mathbf{Z}_2} = \frac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}\mathbf{I}''$$

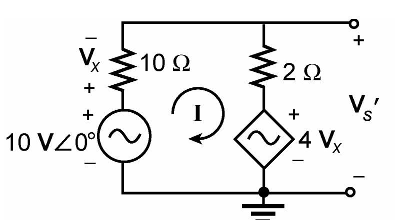
$$\mathbf{I}'' = \mathbf{I}_2 - \mathbf{I}_5 = \mathbf{I}_2 - \frac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}\mathbf{I}''$$

$$\mathbf{I}''\left[1 + \frac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}\right] = \mathbf{I}_2$$

$$\mathbf{I}'' = \frac{\mathbf{I}_2}{1 + \dfrac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}} = \frac{2\text{ mA }\angle 0°}{1 + \dfrac{2\,\text{k}\Omega}{21(5\,\text{k}\Omega)}} = 1.963\text{ mA }\angle 0°$$

$$\mathbf{I} = \mathbf{I}' + \mathbf{I}'' = 0.981\text{ mA }\angle 0° + 1.963\text{ mA }\angle 0°$$
$$= \mathbf{2.94\text{ mA }\angle 0°}$$

11. $\mathbf{E}_1$:



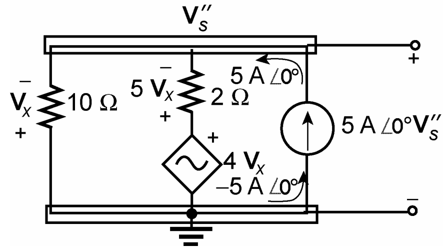
$$10\text{ V }\angle 0° - \mathbf{I}\,10\,\Omega - \mathbf{I}\,2\,\Omega - 4\,\mathbf{V}_x = 0$$
$$\text{with } \mathbf{V}_x = \mathbf{I}\,10\,\Omega$$

Solving for **I**:

$$\mathbf{I} = \frac{10\text{ V }\angle 0°}{52\,\Omega} = 192.31\text{ mA }\angle 0°$$

$$\mathbf{V}_s' = 10\text{ V }\angle 0° - \mathbf{I}(10\,\Omega) = 10\text{ V} - (192.31\text{ mA }\angle 0°)(10\,\Omega\,\angle 0°) = 8.08\text{ V }\angle 0°$$

I:



$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$5 \text{ A } \angle 0° + \frac{\mathbf{V}_x}{10\,\Omega} + \frac{5\,\mathbf{V}_x}{2\,\Omega} = 0$$

$$5 \text{ A} + 0.1\,\mathbf{V}_x + 2.5\,\mathbf{V}_x = 0$$

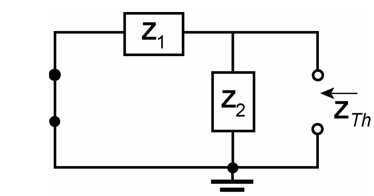
$$2.6\,\mathbf{V}_x = -5 \text{ A}$$

$$\mathbf{V}_x = -\frac{5}{2.6}\mathbf{V} = -1.923 \text{ V}$$

$$\mathbf{V}_s'' = -\mathbf{V}_x = -(-1.923 \text{ V}) = 1.923 \text{ V } \angle 0°$$

$$\mathbf{V}_s = \mathbf{V}_s' + \mathbf{V}_s'' = 8.08 \text{ V } \angle 0° + 1.923 \text{ V } \angle 0° = \mathbf{10\ V\ \angle 0°}$$

12. a. $\mathbf{Z}_{Th}$:



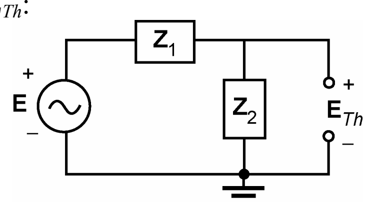
$\mathbf{Z}_1 = 3\ \Omega \angle 0°$, $\mathbf{Z}_2 = 4\ \Omega \angle 90°$

$\mathbf{E} = 100 \text{ V } \angle 0°$

$\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (3\ \Omega \angle 0° \parallel 4\ \Omega \angle 90°)$

$= \mathbf{2.4\ \Omega \angle 36.87° = 1.92\ \Omega + \mathit{j}1.44\ \Omega}$

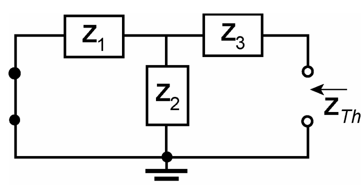
$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(4\,\Omega \angle 90°)(100 \text{ V } \angle 0°)}{5\,\Omega \angle 53.13°}$$

$= \mathbf{80\ V\ \angle 36.87°}$

b. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_{Th} = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2$

$= +j6 \text{ k}\Omega + (2 \text{ k}\Omega \angle 0° \parallel 3 \text{ k}\Omega \angle -90°)$

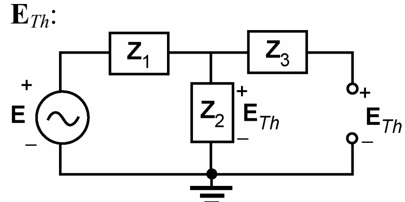
$= +j6 \text{ k}\Omega + 1.664 \text{ k}\Omega \angle -33.69°$

$= +j6 \text{ k}\Omega + 1.385 \text{ k}\Omega - j0.923 \text{ k}\Omega$

$= 1.385 \text{ k}\Omega + j5.077 \text{ k}\Omega$

$= \mathbf{5.26\ k\Omega \angle 74.74°}$

$\mathbf{E}_{Th}$:

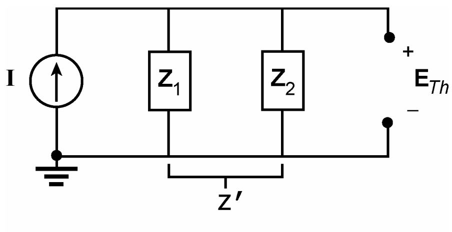


$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(3 \text{ k}\Omega \angle -90°)(20 \text{ V } \angle 0°)}{2 \text{ k}\Omega - j3 \text{ k}\Omega}$$

$$= \frac{60 \text{ V } \angle -90°}{3.606 \angle -56.31°} = \mathbf{16.64\ V\ \angle -33.69°}$$

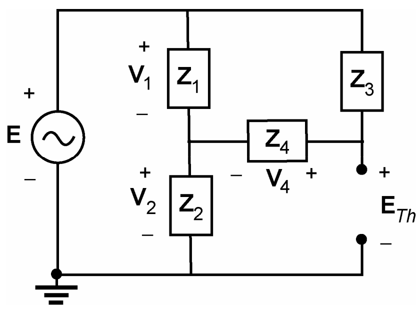
13. a. From #27. $\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$

$\mathbf{Z}_{Th} = \mathbf{Z}_N = \mathbf{21.31\ \Omega\ \angle 32.2°}$



$\mathbf{E}_{Th} = \mathbf{IZ}' = \mathbf{IZ}_{Th}$
$= (0.1\text{ A } \angle 0°)(21.31\ \Omega\ \angle 32.12°)$
$= \mathbf{2.13\ V\ \angle 32.2°}$

b. From #27. $\mathbf{Z}_{Th} = \mathbf{Z}_N = \mathbf{6.81\ \Omega\ \angle{-54.23°} = 3.98\ \Omega - \mathit{j}5.53\ \Omega}$



$\mathbf{Z}_1 = 2\ \Omega\ \angle 0°$, $\mathbf{Z}_3 = 8\ \Omega\ \angle{-90°}$
$\mathbf{Z}_2 = 4\ \Omega\ \angle 90°$, $\mathbf{Z}_4 = 10\ \Omega\ \angle 0°$
$\mathbf{E} = 50\text{ V } \angle 0°$
$\mathbf{E}_{Th} = \mathbf{V}_2 + \mathbf{V}_4$

$$\mathbf{V}_2 = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1 \parallel (\mathbf{Z}_3 + \mathbf{Z}_4)}$$

$$= \frac{(4\ \Omega\ \angle 90°)(50\text{ V } \angle 0°)}{+j4\ \Omega + 2\ \Omega\ \angle 0° \parallel (10\ \Omega - j8\ \Omega)}$$

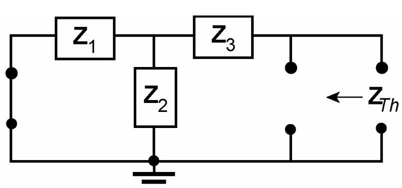
$= 47.248\text{ V } \angle 24.7°$

$\mathbf{V}_1 = \mathbf{E} - \mathbf{V}_2 = 50\text{ V } \angle 0° - 47.248\text{ V } \angle 24.7° = 20.972\text{ V } \angle{-70.285°}$

$$\mathbf{V}_4 = \frac{\mathbf{Z}_4\mathbf{V}_1}{\mathbf{Z}_4 + \mathbf{Z}_3} = \frac{(10\ \Omega\ \angle 0°)(20.972\text{ V } \angle -70.285°)}{10\ \Omega - j8\ \Omega} = 16.377\text{ V } \angle{-31.625°}$$

$\mathbf{E}_{Th} = \mathbf{V}_2 + \mathbf{V}_4 = 47.248\text{ V } \angle 24.7° + 16.377\text{ V } \angle{-31.625°}$
$= (42.925\text{ V} + j19.743\text{ V}) + (13.945\text{ V} - j8.587\text{ V})$
$= 56.870\text{ V} + j11.156\text{ V} = \mathbf{57.95\ V\ \angle 11.10°}$

14. a. $\mathbf{Z}_{Th}$:

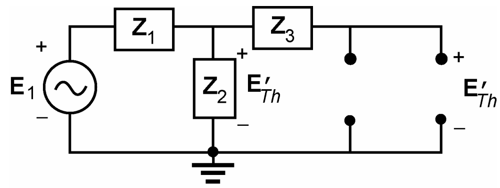


$\mathbf{Z}_1 = 10\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 8\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 8\ \Omega\ \angle{-90°}$

$\mathbf{Z}_{Th} = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= -j8\ \Omega + 10\ \Omega\ \angle 0° \angle \parallel 8\ \Omega\ \angle 90°$
$= -j8\ \Omega + 6.247\ \Omega\ \angle 51.34°$
$= -j8\ \Omega + 3.902\ \Omega + j4.878\ \Omega$
$= 3.902\ \Omega - j3.122\ \Omega$
$= \mathbf{5.00\ \Omega\ \angle{-38.66°}}$

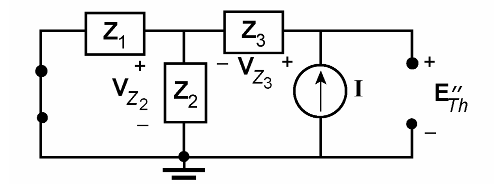
$\mathbf{E}_{Th}$: Superposition:

($\mathbf{E}_1$)



$$\mathbf{E}'_{Th} = \frac{(8\ \Omega \angle 90^\circ)(120\ \text{V} \angle 0^\circ)}{10\ \Omega + j8\ \Omega}$$
$$= \frac{960\ \text{V} \angle 90^\circ}{12.806 \angle 38.66^\circ}$$
$$= 74.965\ \text{V} \angle 51.34^\circ$$

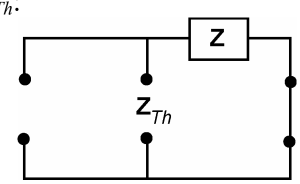
($\mathbf{I}$)



$$\mathbf{E}''_{Th} = \mathbf{V}_{Z_2} + \mathbf{V}_{Z_3}$$
$$= \mathbf{IZ}_3 + \mathbf{I}(\mathbf{Z}_1 \parallel \mathbf{Z}_2)$$
$$= \mathbf{I}(\mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2)$$
$$= (0.5\ \text{A} \angle 60^\circ)(-j8\ \Omega + 10\ \Omega \angle 0^\circ \parallel 8\ \Omega \angle 90^\circ)$$
$$= (0.5\ \text{A} \angle 60^\circ)(-j8\ \Omega + 3.902\ \Omega + j4.878\ \Omega)$$
$$= (0.5\ \text{A} \angle 60^\circ)(3.902\ \Omega - j3.122\ \Omega)$$
$$= (0.5\ \text{A} \angle 60^\circ)(4.997\ \Omega \angle -38.663^\circ)$$
$$= 2.499\ \text{V} \angle 21.337^\circ$$

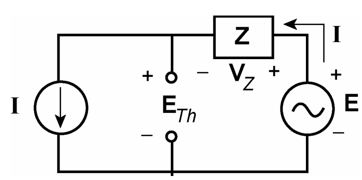
$$\mathbf{E}_{Th} = \mathbf{E}'_{Th} + \mathbf{E}''_{Th}$$
$$= 74.965\ \text{V} \angle 51.34^\circ + 2.449\ \text{V} \angle 21.337^\circ$$
$$= (46.83\ \text{V} + j58.538\ \text{V}) + (2.328\ \text{V} + j0.909\ \text{V})$$
$$= 49.158\ \text{V} + j59.447\ \text{V} = \mathbf{77.14\ V \angle 50.41^\circ}$$

b. $\mathbf{Z}_{Th}$:



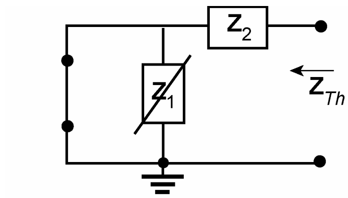
$$\mathbf{Z}_{Th} = \mathbf{Z} = 10\ \Omega - j10\ \Omega = \mathbf{14.14\ \Omega \angle -45^\circ}$$

$\mathbf{E}_{Th}$:

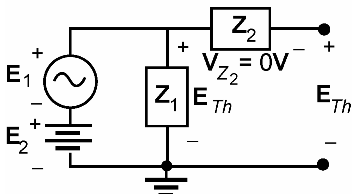


$$\mathbf{E}_{Th} = \mathbf{E} - \mathbf{V}_Z$$
$$= 20\ \text{V} \angle 40^\circ - \mathbf{IZ}$$
$$= 20\ \text{V} \angle 40^\circ - (0.6\ \text{A} \angle 90^\circ)(14.14\ \Omega \angle -45^\circ)$$
$$= 20\ \text{V} \angle 40^\circ - 8.484\ \text{V} \angle 45^\circ$$
$$= (15.321\ \text{V} + j12.856\ \text{V}) - (6\ \text{V} + j6\ \text{V})$$
$$= 9.321\ \text{V} + j6.856\ \text{V}$$
$$= \mathbf{11.57\ V \angle 36.34^\circ}$$

15. a.



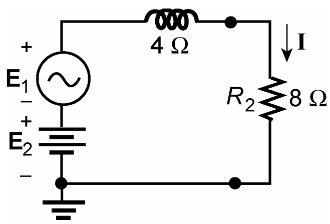
$\mathbf{Z}_1 = 6\ \Omega - j2\ \Omega = 6.325\ \Omega \angle{-18.435°}$
$\mathbf{Z}_2 = 4\ \Omega \angle 90°$
$\mathbf{Z}_{Th} = \mathbf{Z}_2 = \mathbf{4\ \Omega \angle 90°}$



By inspection:

$\mathbf{E}_{Th} = \mathbf{E}_2 + \mathbf{E}_1$
$= \mathbf{4\ V + 10\ V \angle 0°}$
DC AC

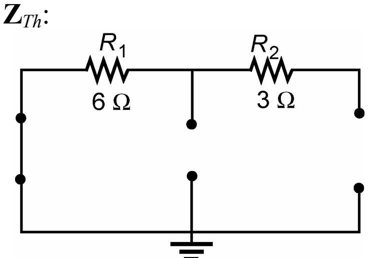
b.



$$\mathbf{I} = \frac{E_2}{R_2} + \frac{\mathbf{E}_1}{R_2 + jX_L}$$
$$= \frac{4\ \text{V}}{8\ \Omega} + \frac{10\ \text{V} \angle 0°}{8\ \Omega + j4\ \Omega}$$
$$= 0.5\ \text{A} + \frac{10\ \text{V} \angle 0°}{8.944\ \Omega \angle 26.565°}$$
$$= 0.5\ \text{A} + 1.118\ \text{A} \angle{-26.565°}$$
(dc) (ac)

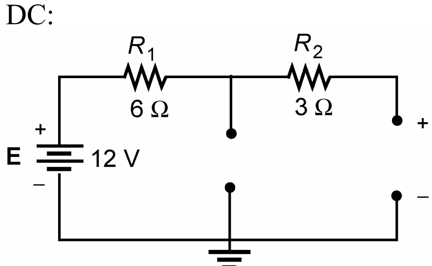
$\boldsymbol{i = 0.5 + 1.58 \sin(\omega t - 26.57°)}$

16. a. $\mathbf{Z}_{Th}$:



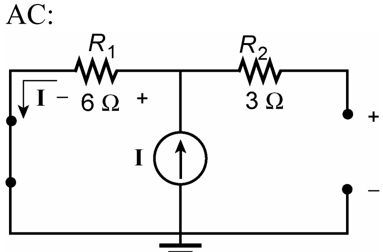
$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_{R_1} + \mathbf{Z}_{R_2} = 6\ \Omega + 3\ \Omega = \mathbf{9\ \Omega}$

DC:



$\mathbf{E}'_{Th} = 12\ \text{V}$

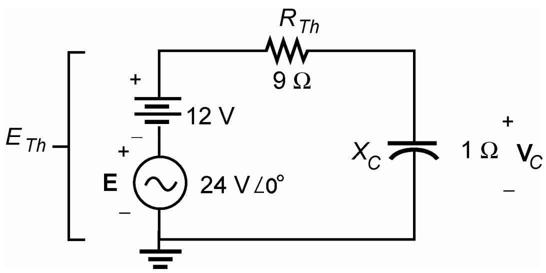
AC:



$\leftarrow \mathbf{E}''_{Th} = \mathbf{I}\mathbf{Z}_{R_1} = (4\ \text{A} \angle 0°)(6\ \Omega \angle 0°) = 24\ \text{V} \angle 0°$

$\mathbf{E}_{Th} = 12\ \text{V} + 24\ \text{V} \angle 0°$
(DC) (AC)

b.



DC: $\mathbf{V}_C = 12\text{ V}$

AC: $\mathbf{V}_C = \dfrac{\mathbf{Z}_C\mathbf{E}}{\mathbf{Z}_C + \mathbf{Z}_{R_{Th}}}$

$$= \frac{(1\,\Omega\angle -90°)(24\text{ V}\angle 0°)}{-j1\,\Omega + 9\,\Omega}$$

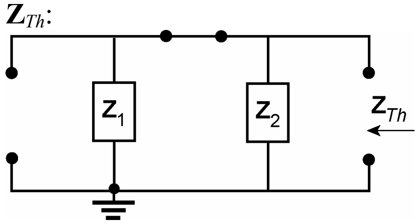
$$= \frac{24\text{ V}\angle -90°}{9.055\angle -6.34°}$$

$\mathbf{V}_C = 2.65\text{ V}\angle -83.66°$

$\upsilon_C = 12\text{ V} + 2.65\text{ V}\angle -83.66°$

$= \mathbf{12\ V + 3.75\ sin(\omega \mathit{t} - 83.66°)}$

17. a. $\mathbf{Z}_{Th}$:

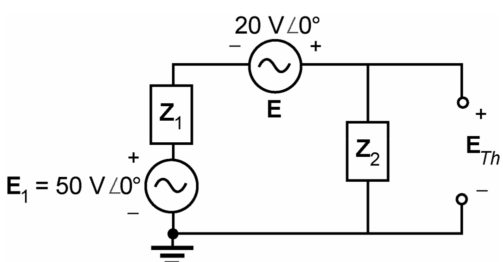


$\mathbf{Z}_1 = 10\text{ k}\Omega\angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega - j5\text{ k}\Omega$
$= 7.071\text{ k}\Omega\angle -45°$

$\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (10\text{ k}\Omega\angle 0°) \parallel (7.071\text{ k}\Omega\angle -45°) = \mathbf{4.47\ k\Omega\angle -26.57°}$

Source conversion:

$\mathbf{E}_1 = (I\angle\theta)(R_1\angle 0°) = (5\text{ mA}\angle 0°)(10\text{ k}\Omega\angle 0°) = 50\text{ V}\angle 0°$



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2(\mathbf{E} + \mathbf{E}_1)}{\mathbf{Z}_2 + \mathbf{Z}_1}$$

$$= \frac{(7.071\text{ k}\Omega\angle -45°)(20\text{ V}\angle 0° + 50\text{ V}\angle 0°)}{(5\text{ k}\Omega - j5\text{ k}\Omega) + (10\text{ k}\Omega)}$$

$$= \frac{(7.071\text{ k}\Omega\angle -45°)(70\text{ V}\angle 0°)}{(15\text{ k}\Omega - j5\text{ k}\Omega)}$$

$$= \frac{494.97\text{ V}\angle -45°}{15.811\angle -18.435°}$$

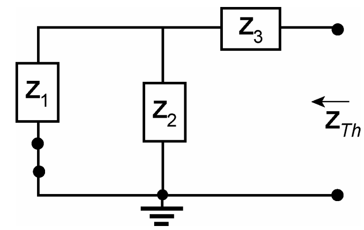
$= \mathbf{31.31\ V\angle -26.57°}$

b. $$\mathbf{I} = \frac{\mathbf{E}_{Th}}{\mathbf{Z}_{Th} + \mathbf{Z}_L} = \frac{31.31\text{ V}\angle -26.565°}{4.472\text{ k}\Omega\angle -26.565° + 5\text{ k}\Omega\angle 90°}$$

$$= \frac{31.31\text{ V}\angle -26.565°}{4\text{ k}\Omega - j2\text{ k}\Omega + j5\text{ k}\Omega} = \frac{31.31\text{ V}\angle -26.565°}{4\text{ k}\Omega + j3\text{ k}\Omega}$$

$$= \frac{31.31\text{ V}\angle -26.565°}{5\text{ k}\Omega\angle 36.87°} = \mathbf{6.26\ mA\angle 63.44°}$$

18.

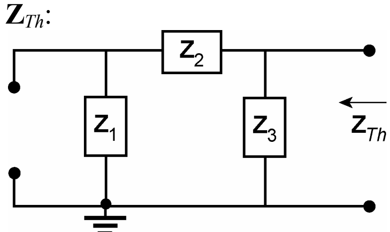


$\mathbf{Z}_1 = 10\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_2 = 10\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_3 = 1\ \text{k}\Omega \angle -90°$

$$\mathbf{Z}_{Th} = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 5\ \text{k}\Omega - j1\ \text{k}\Omega \cong \mathbf{5.1\ k\Omega \angle{-11.31°}}$$

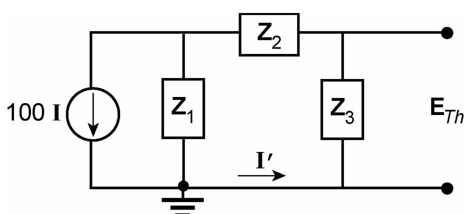
$\mathbf{E}_{Th}$: (VDR) $$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2(20\ \mathbf{V})}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(10\ \text{k}\Omega \angle 0°)(20\ \mathbf{V})}{10\ \text{k}\Omega + 10\ \text{k}\Omega} = \mathbf{10\ V}$$

19. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 40\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_2 = 0.2\ \text{k}\Omega \angle -90°$
$\mathbf{Z}_3 = 5\ \text{k}\Omega \angle 0°$

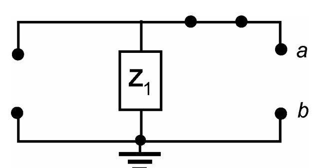
$$\mathbf{Z}_{Th} = \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2) = 5\ \text{k}\Omega \angle 0° \parallel (40\ \text{k}\Omega - j0.2\ \text{k}\Omega) = \mathbf{4.44\ k\Omega \angle{-0.03°}}$$



$$\mathbf{I}' = \frac{\mathbf{Z}_1(100\,\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(40\ \text{k}\Omega \angle 0°)(100\,\mathbf{I})}{45\ \text{k}\Omega \angle -0.255°} = 88.89\ \mathbf{I} \angle 0.255°$$

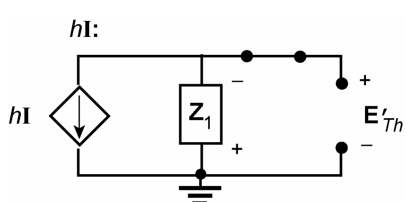
$$\mathbf{E}_{Th} = -\mathbf{I}'\mathbf{Z}_3 = -(88.89\ \mathbf{I} \angle 0.255°)(5\ \text{k}\Omega \angle 0°) = \mathbf{-444.45 \times 10^3\ I \angle 0.26°}$$

20. $\mathbf{Z}_{Th}$:



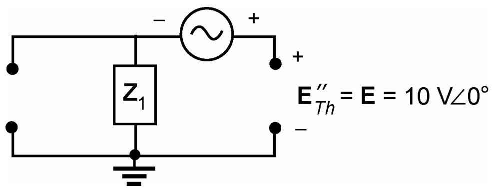
$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 = \mathbf{20\ k\Omega \angle 0°}$

$\mathbf{E}_{Th}$:



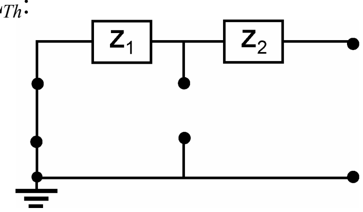
$$\begin{aligned}\mathbf{E}'_{Th} &= -(h\mathbf{I})(\mathbf{Z}_1)\\ &= -(100)(2\ \text{mA} \angle 0°)(20\ \text{k}\Omega \angle 0°)\\ &= -4\ \text{kV} \angle 0°\end{aligned}$$

E:



$$\mathbf{E}_{Th} = \mathbf{E}'_{Th} + \mathbf{E}''_{Th}$$
$$= -4\text{ kV}\angle 0° + 10\text{ V}\angle 0°$$
$$= \mathbf{-3990\ V\ \angle 0°}$$

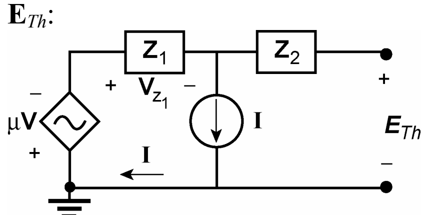
21. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 5\text{ k}\Omega\angle 0°$ $\qquad$ $\mathbf{Z}_2 = -j1$

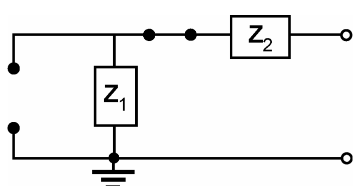
$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 + \mathbf{Z}_2 = 5\text{ k}\Omega - j1\text{ k}\Omega$$
$$= \mathbf{5.10\ k\Omega\ \angle -11.31°}$$

$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = -\left[\mu\mathbf{V} + \mathbf{V}_{Z_1}\right]$$
$$= -\mu\mathbf{V} - \mathbf{I}\mathbf{Z}_1$$
$$= -(20)(2\text{ V}\angle 0°) - (2\text{ mA}\angle 0°)(5\text{ k}\Omega\angle 0°)$$
$$= \mathbf{-50\ V\ \angle 0°}$$

22. $\mathbf{Z}_{Th}$:

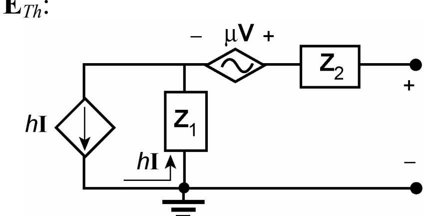


$\mathbf{Z}_1 = 20\text{ k}\Omega\angle 0°$

$\mathbf{Z}_2 = 5\text{ k}\Omega\angle 0°$

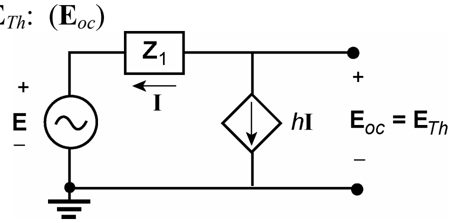
$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 + \mathbf{Z}_2 = \mathbf{25\ k\Omega\ \angle 0°}$$

$\mathbf{E}_{Th}$:



$$\mathrm{E}_{Th} = \mu\mathbf{V} - (h\mathbf{I})(\mathbf{Z}_1)$$
$$= (20)(10\text{ V}\angle 0°) - (100)(1\text{ mA}\angle 0°)(20\text{ k}\Omega\angle 0°)$$
$$= \mathbf{-1800\ V\ \angle 0°}$$

23. $\mathbf{E}_{Th}$: $(\mathbf{E}_{oc})$



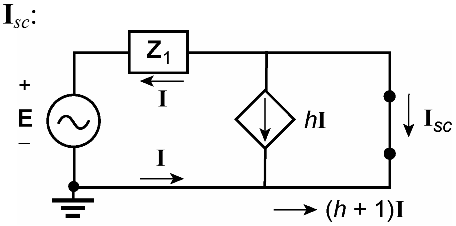
$h\mathbf{I} = -\mathbf{I}$ $\quad\quad$ $\mathbf{Z}_1 = 2\text{ k}\Omega \angle 0°$

$\therefore \mathbf{I} = 0$

and $\quad h\mathbf{I} = 0$

with $\quad \mathbf{E}_{oc} = \mathbf{E}_{Th} = \mathbf{E} = \mathbf{20\ V \angle 53°}$

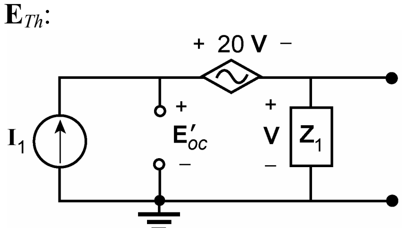
$\mathbf{I}_{sc}$:



$$\mathbf{I}_{sc} = -(h + 1)\mathbf{I}$$
$$= -(h + 1)(10\text{ mA} \angle 53°)$$
$$= -510\text{ mA} \angle 53°$$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{20\text{ V} \angle 53°}{-510\text{ mA} \angle 53°} = \mathbf{-39.22\ \Omega \angle 0°}$$

24. $\mathbf{E}_{Th}$:



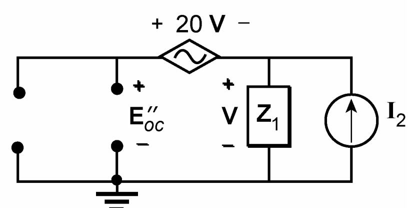
$\mathbf{E}'_{oc} = 21\text{ V}$ $\quad\quad$ $\mathbf{Z}_1 = 5\text{ k}\Omega \angle 0°$

$\mathbf{V} = \mathbf{I}_1\mathbf{Z}_1 = (1\text{ mA} \angle 0°)(5\text{ k}\Omega \angle 0°)$

$= 5\text{ V} \angle 0°$

$\mathbf{E}'_{oc} = \mathbf{E}'_{Th} = 21(5\text{ V} \angle 0°)$

$= 105\text{ V} \angle 0°$



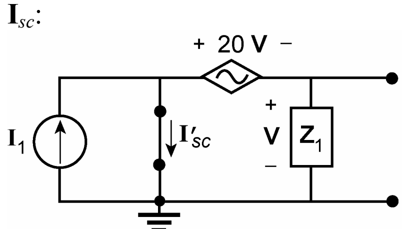
$\mathbf{V} = \mathbf{I}_2\mathbf{Z}_1$

$= (2\text{ mA} \angle 0°)(5\text{ k}\Omega \angle 0°)$

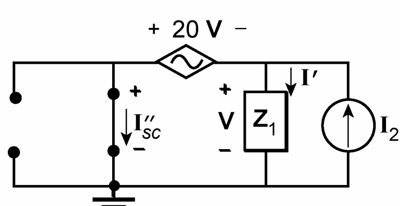
$= 10\text{ V} \angle 0°$

$\mathbf{E}''_{oc} = \mathbf{E}''_{Th} = \mathbf{V} + 20\ \mathbf{V} = 21\text{ V} = 210\text{ V} \angle 0°$

$\mathbf{I}_{sc}$:



$\mathbf{I}'_{sc} = \mathbf{I}_1$



$20\text{ V} = \mathbf{V} \therefore \mathbf{V} = 0\text{ V}$

and $\mathbf{I}' = 0\text{ A}$

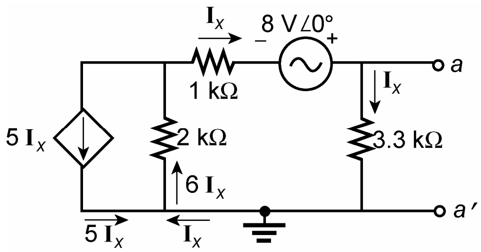
$\therefore \ \mathbf{I}''_{sc} = \mathbf{I}_2$

$\mathbf{I}_{sc} = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 3\text{ mA} \angle 0°$

$\mathbf{E}_{oc} = \mathbf{E}'_{oc} + \mathbf{E}''_{oc} = 315\text{ V} \angle 0° = \mathbf{E}_{Th}$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{315\text{ V} \angle 0°}{3\text{ mA} \angle 0°} = \mathbf{105\ k\Omega \angle 0°}$$

25. $\mathbf{E}_{oc}$:
($\mathbf{E}_{Th}$)

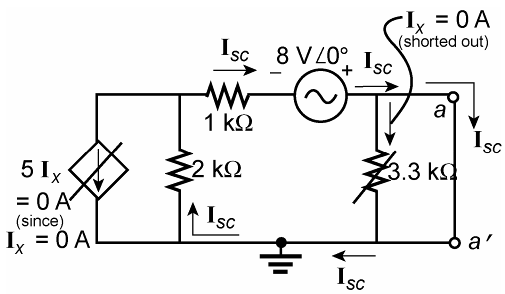


KVL: $-6\,\mathbf{I}_x(2\text{ k}\Omega) - \mathbf{I}_x(1\text{ k}\Omega) + 8\text{ V}\angle 0° - \mathbf{I}_x(3.3\text{ k}\Omega) = 0$

$$\mathbf{I}_x = \frac{8\text{ V}\angle 0°}{16.3\text{ k}\Omega} = 0.491\text{ mA}\angle 0°$$

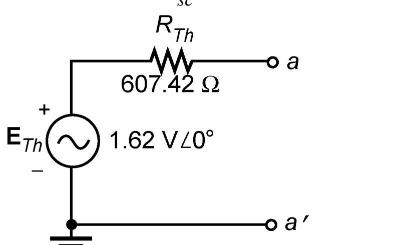
$$\mathbf{E}_{oc} = \mathbf{E}_{Th} = \mathbf{I}_x(3.3\text{ k}\Omega) = \mathbf{1.62\text{ V}\angle 0°}$$

$\mathbf{I}_{sc}$:



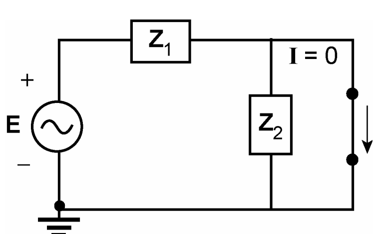
$$\mathbf{I}_{sc} = \frac{8\text{ V}}{3\text{ k}\Omega} = 2.667\text{ mA}\angle 0°$$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{1.62\text{ V}\angle 0°}{2.667\text{ mA}\angle 0°} = \mathbf{607.42\ \Omega\angle 0°}$$



26. a. From Problem 12(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 1.92\ \Omega + j1.44\ \Omega = \mathbf{2.4\ \Omega\angle 36.87°}$

$\mathbf{I}_N$:



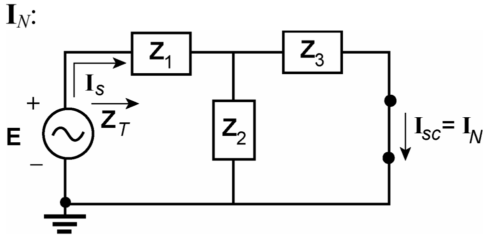
$\mathbf{Z}_1 = 3\ \Omega\angle 0°$, $\mathbf{Z}_2 = 4\ \Omega\angle 90°$

$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{100\text{ V}\angle 0°}{3\ \Omega\angle 0°}$$

$$= \mathbf{33.33\text{ A}\angle 0°}$$

b. From Problem 12(b): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 5.263\text{ k}\Omega\ \angle 74.74° = \mathbf{1.39\text{ k}\Omega + j5.08\text{ k}\Omega}$

$\mathbf{I}_N$:

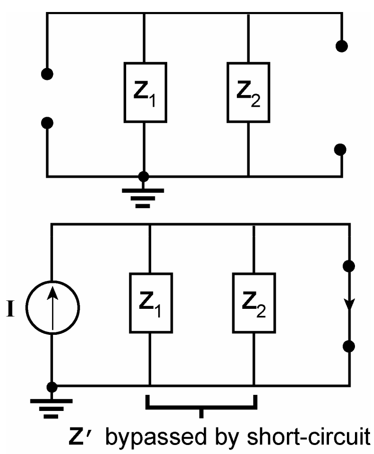


$\mathbf{Z}_1 = 2\text{ k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 3\text{ k}\Omega\ \angle -90°$
$\mathbf{Z}_3 = 6\text{ k}\Omega \angle 90°$

$$\begin{aligned}\mathbf{Z}_T &= \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3\\ &= 2\text{ k}\Omega + 3\text{ k}\Omega\ \angle -90° \parallel 6\text{ k}\Omega\ \angle 90°\\ &= 2\text{ k}\Omega + 6\text{ k}\Omega\ \angle -90°\\ &= 2\text{ k}\Omega - j6\text{ k}\Omega\\ &= 6.325\text{ k}\Omega\ \angle -71.565°\end{aligned}$$

$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{20\text{ V}\ \angle 0°}{6.325\text{ k}\Omega\ \angle -71.565°}$$
$$= 3.162\text{ mA}\ \angle 71.565°$$
$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{Z}_2\mathbf{I}_s}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(3\text{ k}\Omega\ \angle -90°)(3.162\text{ mA}\ \angle 71.565°)}{-j3\text{ k}\Omega + j6\text{ k}\Omega}$$
$$= \frac{9.486\text{ mA}\ \angle -18.435°}{3\ \angle 90°} = \mathbf{3.16\text{ mA}\ \angle -108.44°}$$

27. a.

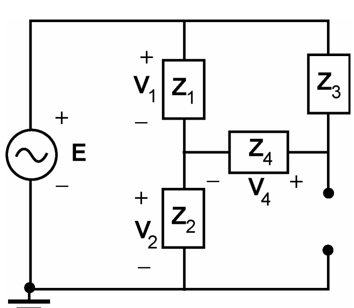


$\mathbf{Z}_1 = 20\ \Omega + j20\ \Omega = 28.284\ \Omega\ \angle 45°$
$\mathbf{Z}_2 = 68\ \Omega\ \angle 0°$

$\leftarrow \mathbf{Z}_N = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= (28.284\ \Omega\ \angle 45°) \parallel (68\ \Omega\ \angle 0°)$
$\mathbf{= 21.31\ \Omega\ \angle 32.2°}$

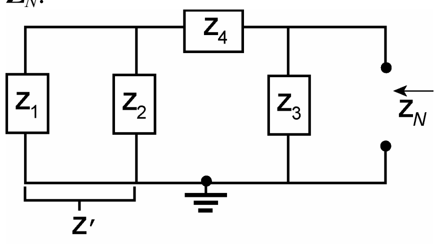
$\leftarrow \mathbf{I}_{sc} = \mathbf{I} = \mathbf{I}_N = 0.1\text{ A}\ \angle 0°$

b.

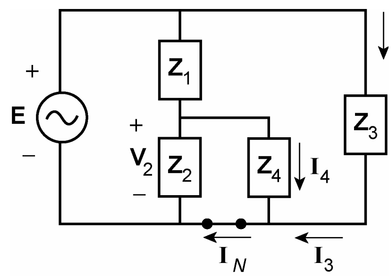


$\mathbf{Z}_1 = 2\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 4\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 8\ \Omega\ \angle -90°$, $\mathbf{Z}_4 = 10\ \Omega\ \angle 0°$
$\mathbf{E} = 50\text{ V}\ \angle 0°$

$\mathbf{Z}_N$:



$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 2\ \Omega\ \angle 0° \parallel 4\ \Omega\ \angle 90°$
$\quad = 1.789\ \Omega\ \angle 26.565° = 1.6\ \Omega + j0.8\ \Omega$
$\mathbf{Z}' + \mathbf{Z}_4 = 1.6\ \Omega + j0.8\ \Omega + 10\ \Omega = 11.6\ \Omega + j0.8\ \Omega = 11.628\ \Omega\ \angle 3.945°$
$\mathbf{Z}_N = \mathbf{Z}_3 \parallel (\mathbf{Z}' + \mathbf{Z}_4) = (8\ \Omega\ \angle -90°) \parallel (11.628\ \Omega\ \angle 3.945°) = \mathbf{6.81\ \Omega\ \angle -54.23°}$
$\quad = \mathbf{3.98\ \Omega - j5.53\ \Omega}$



$$\mathbf{I}_3 = \frac{\mathbf{E}}{\mathbf{Z}_3} = \frac{50\text{ V}\ \angle 0°}{8\ \Omega\ \angle -90°} = 6.250\text{ A}\ \angle 90°$$

$\mathbf{Z}' = \mathbf{Z}_2 \parallel \mathbf{Z}_4 = 4\ \Omega\ \angle 90° \parallel 10\ \Omega\ \angle 0°$
$\quad = 3.714\ \Omega\ \angle 68.2°$

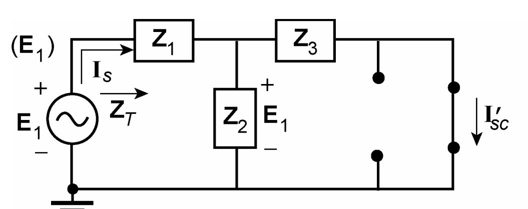
$$\mathbf{V}_2 = \frac{\mathbf{Z}'\mathbf{E}}{\mathbf{Z}' + \mathbf{Z}_1} = \frac{(3.714\ \Omega\ \angle 68.2°)(50\text{ V}\ \angle 0°)}{1.378\ \Omega + j3.448\ \Omega + 2\ \Omega}$$
$$= \frac{185.7\text{ V}\ \angle 68.2°}{4.827\ \angle 45.588°} = 38.471\text{ V}\ \angle 22.612°$$

$$\mathbf{I}_4 = \frac{\mathbf{V}_2}{\mathbf{Z}_4} = \frac{38.471\text{ V}\ \angle 22.612°}{10\ \Omega\ \angle 0°} = 3.847\text{ A}\ \angle 22.612°$$

$\mathbf{I}_N = \mathbf{I}_3 + \mathbf{I}_4 = 6.250\text{ A}\ \angle 90° + 3.847\text{ A}\ \angle 22.612°$
$\quad = +j6.25\text{ A} + 3.551\text{ A} + j1.479\text{ A} = 3.551\text{ A} + j7.729\text{ A}$
$\quad = \mathbf{8.51\text{ A}\ \angle 65.32°}$

28. a. From Problem 14(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{5.00\ \Omega\ \angle -38.66°}$

$\mathbf{I}_N$: Superposition:



$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3$
$\quad = 10\ \Omega + 8\ \Omega\ \angle 90° \parallel 8\ \Omega\ \angle -90°$

$$= 10\ \Omega + \frac{64\ \Omega\ \angle 0°}{0}$$

$\quad$ = very large impedance

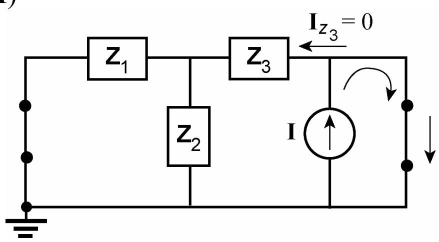
$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = 0\text{ A}$$

and $\mathbf{V}_{Z_1} = 0\text{ V}$

with $\mathbf{V}_{Z_2} = \mathbf{V}_{Z_3} = \mathbf{E}_1 = 120\text{ V}\ \angle 0°$

$$\text{so that } \mathbf{I}'_{sc} = \frac{\mathbf{E}_1}{\mathbf{Z}_3} = \frac{120\text{ V}\ \angle 0°}{8\ \Omega\ \angle -90°}$$
$$= 15\text{ A}\ \angle 90°$$

(I)

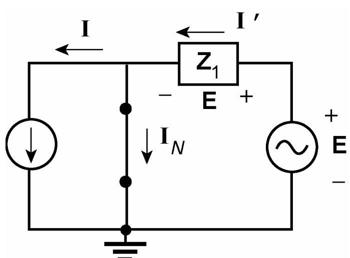


$\mathbf{I}''_{sc} = \mathbf{I} = 0.5 \text{ A} \angle 60°$

$\mathbf{I}_N = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = +j15 \text{ A} + 0.5 \text{ A} \angle 60° = +j15 \text{ A} + 0.25 \text{ A} + j0.433 \text{ A}$
$= 0.25 \text{ A} + j15.433 \text{ A} = \mathbf{15.44 \text{ A} \angle 89.07°}$

b. From Problem 14(b): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 10\ \Omega - j10\ \Omega = \mathbf{14.14\ \Omega \angle -45°}$

$\mathbf{I}_N$:



$\mathbf{I}_N = \mathbf{I}' - \mathbf{I}$

$= \dfrac{\mathbf{E}}{\mathbf{Z}} - \mathbf{I}$

$= \dfrac{20 \text{ V} \angle 40°}{14.142\ \Omega \angle -45°} - 0.6 \text{ A} \angle 90°$

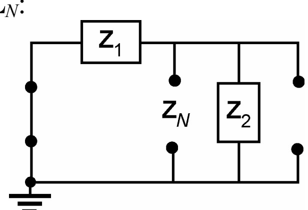
$= 1.414 \text{ A} \angle 85° - j0.6 \text{ A}$

$= 0.123 \text{ A} + j1.409 \text{ A} - j0.6 \text{ A}$

$= 0.123 \text{ A} + j0.809 \text{ A}$

$= \mathbf{0.82 \text{ A} \angle 81.35°}$

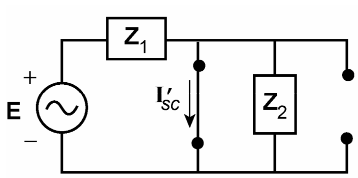
29. a. $\mathbf{Z}_N$:



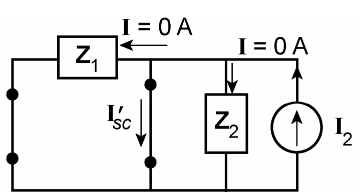
$\mathbf{E} = 20 \text{ V} \angle 0°$, $\mathbf{I}_2 = 0.4 \text{ A} \angle 20°$
$\mathbf{Z}_1 = 6\ \Omega + j8\ \Omega = 10\ \Omega \angle 53.13°$
$\mathbf{Z}_2 = \Omega - j12\ \Omega = 15\ \Omega \angle -53.13°$
$\mathbf{Z}_N = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (10\ \Omega \angle 53.13°) \parallel (15\ \Omega \angle -53.13°)$
$= \mathbf{9.66\ \Omega \angle 14.93°}$

$\mathbf{I}_N$:

(E)



($\mathbf{I}_2$)



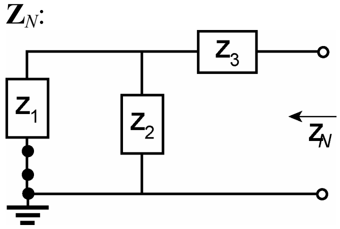
$\mathbf{I}'_{sc} = \mathbf{E}/\mathbf{Z}_1 = 20 \text{ V} \angle 0°/10\ \Omega \angle 53.13°$

$\mathbf{I}''_{sc} = \mathbf{I}_2 = 0.4 \text{ A} \angle 20°$

$= 2 \text{ A} \angle -53.13°$

$\mathbf{I}_N = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 2 \text{ A} \angle -53.13° + 0.4 \text{ A} \angle 20°$
$= \mathbf{2.15 \text{ A} \angle -42.87°}$

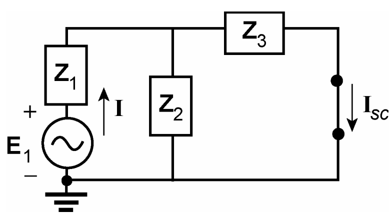
b. $\mathbf{Z}_N$:



$\mathbf{E}_1 = 120\text{ V} \angle 30°$, $\mathbf{Z}_1 = 3\ \Omega \angle 0°$
$\mathbf{Z}_2 = 8\ \Omega - j8\ \Omega$, $\mathbf{Z}_3 = 4\ \Omega \angle 90°$

$$\begin{aligned}\mathbf{Z}_N &= \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2\\ &= 4\ \Omega \angle 90° + (3\ \Omega \angle 0°) \parallel (8\ \Omega - j8\ \Omega)\\ &= \mathbf{4.37\ \Omega \angle 55.67° = 2.47\ \Omega + \mathit{j}3.61\ \Omega}\end{aligned}$$

$\mathbf{I}_N$:



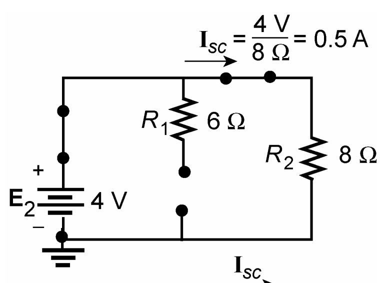
$$\begin{aligned}\mathbf{I} &= \frac{\mathbf{E}_1}{\mathbf{Z}_T} = \frac{120\text{ V} \angle 30°}{\mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3}\\ &= \frac{120\text{ V} \angle 30°}{3\ \Omega + (8\ \Omega - j8\ \Omega) \parallel 4\ \Omega \angle 90°}\\ &= \frac{120\text{ V} \angle 30°}{6.65\ \Omega \angle 46.22°}\\ &= 18.05\text{ A} \angle -16.22°\end{aligned}$$

$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{Z}_2(\mathbf{I})}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(8\ \Omega - j8\ \Omega)(18.05\text{ A} \angle -16.22°)}{8\ \Omega - j8\ \Omega + j4\ \Omega} = \mathbf{22.83\text{ A} \angle -34.65°}$$

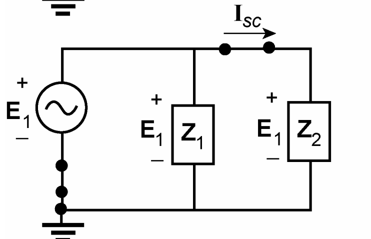
30. a. $\mathbf{Z}_N = 8\ \Omega \angle \mathbf{0°}$

$\mathbf{I}_N$:

DC



AC

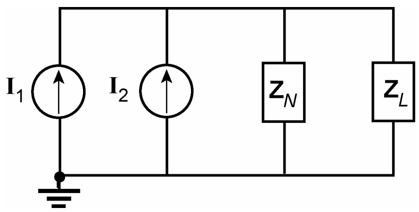


$\mathbf{Z}_1 = 6\ \Omega - j2\ \Omega$
$\mathbf{Z}_2 = 8\ \Omega \angle 0°$

$$\mathbf{I}_{sc} = \frac{\mathbf{E}_1}{\mathbf{Z}_2} = \frac{10\text{ V} \angle 0°}{8\ \Omega \angle 0°} = 1.25\text{ A} \angle 0°$$

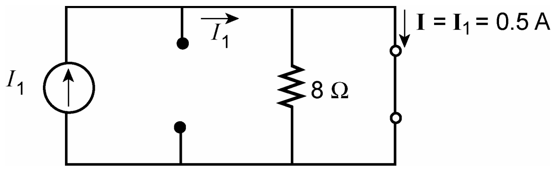
$\mathbf{I}_N = 0.5\text{ A} + 1.25\text{ A} \angle 0°$

b.



$\mathbf{Z}_N = 8\ \Omega\ \angle 0°$
$\mathbf{Z}_L = 4\ \Omega\ \angle 90°$

DC:



AC:

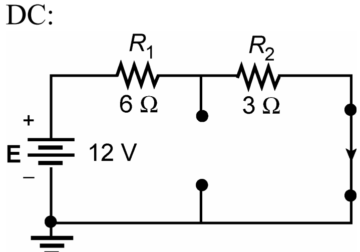
$$\mathbf{I} = \frac{\mathbf{Z}_N(\mathbf{I}_2)}{\mathbf{Z}_N + \mathbf{Z}_L} = \frac{(8\ \Omega\ \angle 0°)(1.25\ \text{A}\ \angle 0°)}{8\ \Omega + j4\ \Omega} = \mathbf{1.118\ A\ \angle{-26.57°}}$$

$$\underset{\text{(dc)}}{I_{8\Omega} = 0.5\ \text{A}} + \underset{\text{(ac)}}{1.118\ \text{A}\ \angle{-26.57°}}$$

$i = \mathbf{0.5 + 1.58\ sin(\omega \mathit{t} - 26.57°)}$

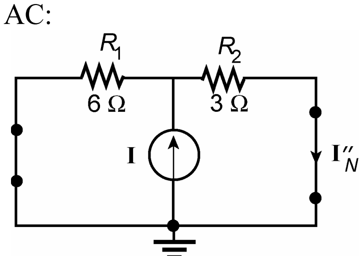
31. a. From #16 $\mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{9\ \Omega\ \angle 0°}$

DC:



$$\mathbf{I}'_N = \frac{E}{R_T} = \frac{12\ \text{V}}{9\ \Omega} = 1.33\ \text{A}$$

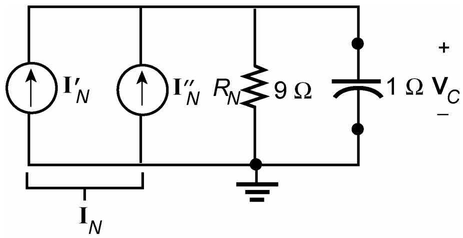
AC:



$$\mathbf{I}''_N = \frac{R_1\mathbf{I}}{R_1 + R_2} = \frac{(6\ \Omega\ \angle 0°)(4\ \text{A}\ \angle 0°)}{9\ \Omega\ \angle 0°}$$
$$= \frac{24\ \text{V}\ \angle 0°}{9\ \Omega\ \angle 0°} = 2.67\ \text{A}\ \angle 0°$$

$\mathbf{I}_N = \mathbf{1.33\ A + 2.67\ A\ \angle 0°}$

b.



DC: $V_C = IR$
$= (1.33\text{ A})(9\ \Omega)$
$= 12\text{ V}$

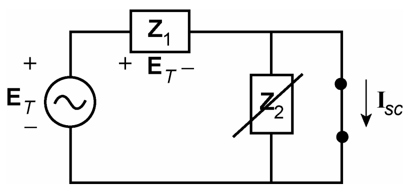
AC: $\mathbf{Z}' = 9\ \Omega \angle 0° \parallel 1\ \Omega \angle -90°$
$= 0.994\ \Omega \angle -83.66°$

$\mathbf{V}_C = \mathbf{IZ}' = (2.667\text{ A} \angle 0°)(0.994\ \Omega \angle -83.66°)$
$= 2.65\text{ V} \angle -83.66°$
$V_C = \mathbf{12\ V + 2.65\ V \angle -83.66°}$

32. a. Note Problem 17(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{4.47\ k\Omega \angle -26.57°}$

Using the same source conversion: $\mathbf{E}_1 = 50\text{ V} \angle 0°$

Defining $\mathbf{E}_T = \mathbf{E}_1 + \mathbf{E} = 50\text{ V} \angle 0° + 20\text{ V} \angle 0° = 70\text{ V} \angle 0°$



$\mathbf{Z}_1 = 10\text{ k}\Omega \angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega - j5\text{ k}\Omega = 7.071\text{ k}\Omega \angle -45°$

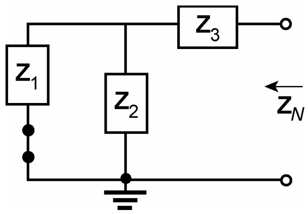
$$\mathbf{I}_{sc} = \frac{\mathbf{E}_T}{\mathbf{Z}_1} = \frac{70\text{ V} \angle 0°}{10\text{ k}\Omega \angle 0°} = 7\text{ mA} \angle 0°$$

$\mathbf{I}_N = \mathbf{I}_{sc} = \mathbf{7\ mA \angle 0°}$

b.
$$\mathbf{I} = \frac{\mathbf{Z}_N(\mathbf{I}_N)}{\mathbf{Z}_N + \mathbf{Z}_L} = \frac{(4.472\text{ k}\Omega \angle -26.565°)(7\text{ mA} \angle 0°)}{4.472\text{ k}\Omega \angle -26.565° + 5\text{ k}\Omega \angle 90°}$$
$$= \frac{31.30\text{ mA} \angle -26.565°}{4 - j2 + j5} = \frac{31.30\text{ mA} \angle -26.565°}{4 + j3}$$
$$= \frac{31.30\text{ mA} \angle -26.565°}{5 \angle 36.87°} = \mathbf{6.26\ mA \angle 63.44°} \text{ as obtained in Problem 17.}$$

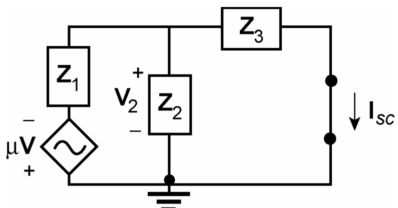
33.

$\mathbf{Z}_N$:



$\mathbf{Z}_1 = 10\text{ k}\Omega \angle 0°$, $\mathbf{Z}_2 = 10\text{ k}\Omega \angle 0$
$\mathbf{Z}_3 = -j1\text{ k}\Omega$
$\mathbf{Z}_N = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 5\text{ k}\Omega - j1\text{ k}\Omega$
$= \mathbf{5.1\ k\Omega \angle{-11.31°}}$

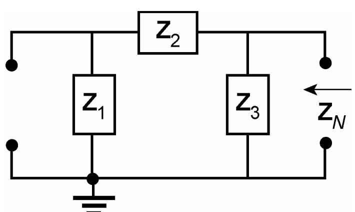
$\mathbf{I}_N$:



$$\mathbf{V}_2 = \frac{-(\mathbf{Z}_2 \parallel \mathbf{Z}_3)20\text{ V}}{(\mathbf{Z}_2 \parallel \mathbf{Z}_3) + \mathbf{Z}_1}$$
$$= \frac{-(0.995\text{ k}\Omega \angle -84.29°)(20\text{ V})}{0.1\text{ k}\Omega - j0.99\text{ k}\Omega + 10\text{ k}\Omega}$$
$$V_2 = -1.961\text{ V} \angle{-78.69°}$$

$$\mathbf{I}_N = \mathbf{I}_{sc} = \frac{\mathbf{V}_2}{\mathbf{Z}_3} = \frac{-1.961\text{ V} \angle -78.69°}{1\text{ k}\Omega \angle -90°} = \mathbf{-1.96 \times 10^{-3}\ V \angle 11.31°}$$

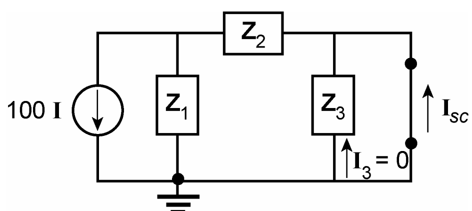
34. $\mathbf{Z}_N$:



$\mathbf{Z}_1 = 40\text{ k}\Omega \angle 0°$, $\mathbf{Z}_2 = 0.2\text{ k}\Omega \angle{-90°}$
$\mathbf{Z}_3 = 5\text{ k}\Omega \angle 0°$

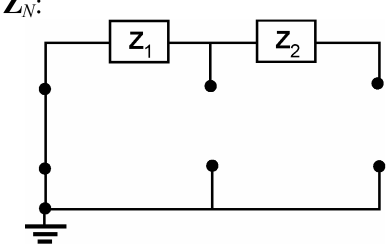
$\mathbf{Z}_N = \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2)$
$= 5\text{ k}\Omega \angle 0° \parallel (40\text{ k}\Omega - j0.2\text{ k}\Omega)$
$= \mathbf{4.44\ k\Omega \angle{-0.03°}}$

$\mathbf{I}_N$:



$$\mathbf{I}_N = \mathbf{I}_{sc} = \frac{\mathbf{Z}_1(100\,\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2}$$
$$= \frac{(40\text{ k}\Omega \angle 0°)(100\,\mathbf{I})}{40\text{ k}\Omega \angle -0.286°}$$
$$= \mathbf{100\ I \angle 0.29°}$$

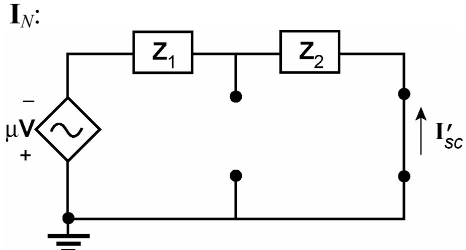
35. $\mathbf{Z}_N$:



$\mathbf{Z}_1 = 5\text{ k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 1\text{ k}\Omega\ \angle -90°$

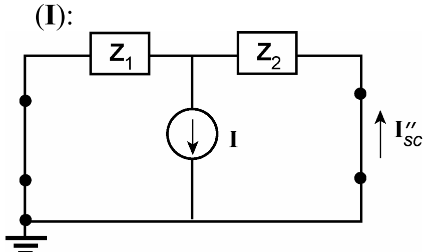
$\leftarrow \mathbf{Z}_N = \mathbf{Z}_1 + \mathbf{Z}_2 = 5\text{ k}\Omega - j1\text{ k}\Omega$
$\qquad \mathbf{= 5.1\ k\Omega\ \angle -11.31°}$

$\mathbf{I}_N$:



$$\mathbf{I}'_{sc} = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(2\text{ V}\ \angle 0°)}{5.1\text{ k}\Omega\ \angle -11.31°}$$
$$= 7.843\text{ mA}\ \angle 11.31°$$

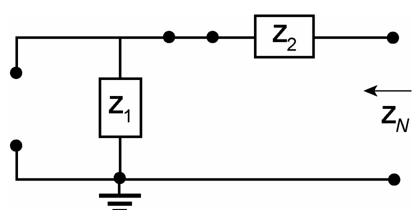
(**I**):



$$\mathbf{I}''_{sc} = \frac{\mathbf{Z}_1(\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2}$$
$$= \frac{(5\text{ k}\Omega\ \angle 0°)(2\text{ mA}\ \angle 0°)}{5.1\text{ k}\Omega\ \angle -11.31°}$$
$$= 1.96\text{ mA}\ \angle 11.31°$$

$\mathbf{I}_N = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 7.843\text{ mA}\ \angle 11.31° + 1.96\text{ mA}\ \angle 11.31°$
$\quad = \mathbf{9.81\ mA\ \angle 11.31°}$

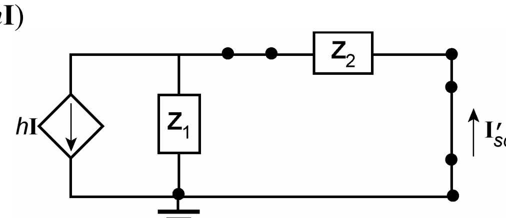
36. $\mathbf{Z}_N$:



$\mathbf{Z}_1 = 20\text{ k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 5\text{ k}\Omega\ \angle 0°$
$\mathbf{V} = 10\text{ V}\ \angle 0°$, $\mu = 20$, $h = 100$
$\mathbf{I} = 1\text{ mA}\ \angle 0°$

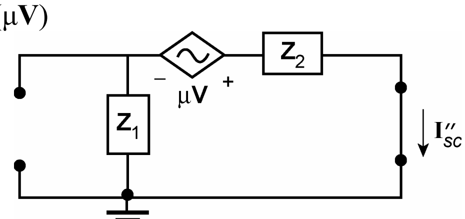
$\mathbf{Z}_N = \mathbf{Z}_1 + \mathbf{Z}_2 = \mathbf{25\ k\Omega\ \angle 0°}$

$\mathbf{I}_N$: ($h\mathbf{I}$)



$$\mathbf{I}'_{sc} = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2}$$
$$= \frac{(20\text{ k}\Omega\ \angle 0°)(h\mathbf{I})}{20\text{ k}\Omega\ \angle 0° + 5\text{ k}\Omega \angle 0°}$$
$$= 80\text{ mA}\ \angle 0°$$

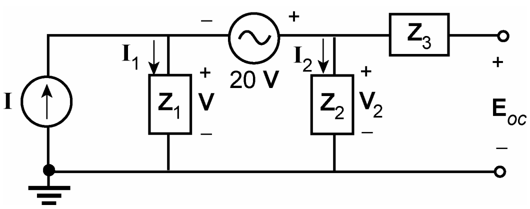
(μ**V**)



$$\mathbf{I}''_{sc} = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(10\text{ V}\ \angle 0°)}{25\text{ k}\Omega}$$
$$= 8\text{ mA}\ \angle 0°$$

$\mathbf{I}_N$ (direction of $\mathbf{I}'_{sc}$) $= \mathbf{I}'_{sc} - \mathbf{I}''_{sc} = 80\text{ mA}\ \angle 0° - 8\text{ mA}\ \angle 0° = \mathbf{72\ mA\ \angle 0°}$

37.



$\mathbf{Z}_1 = 1\text{ k}\Omega \angle 0°$
$\mathbf{Z}_2 = 3\text{ k}\Omega \angle 0°$
$\mathbf{Z}_3 = 4\text{ k}\Omega \angle 0°$

$\mathbf{V}_2 = 21\ \mathbf{V} = \mathbf{E}_{oc} \Rightarrow \mathbf{V} = \dfrac{\mathbf{E}_{oc}}{21}$

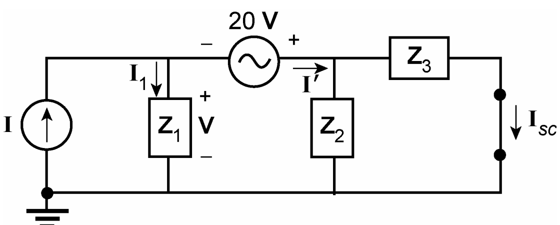
$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2,\ \mathbf{I}_1 = \dfrac{\mathbf{V}}{\mathbf{Z}_1} = \dfrac{\mathbf{E}_{oc}}{21\,\mathbf{Z}_1}$

$$\mathbf{I}_2 = \frac{\mathbf{E}_{oc}}{\mathbf{Z}_2},\ \mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2 = \frac{\mathbf{E}_{oc}}{21\,\mathbf{Z}_1} + \frac{\mathbf{E}_{oc}}{\mathbf{Z}_2} = \mathbf{E}_{oc}\left[\frac{1}{21\,\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2}\right]$$

$$\mathbf{I} = \mathbf{E}_{oc}\left[\frac{\mathbf{Z}_2 + 21\ \mathbf{Z}_1}{21\ \mathbf{Z}_1\mathbf{Z}_2}\right]$$

and $$\mathbf{E}_{oc} = \frac{21\,\mathbf{Z}_1\mathbf{Z}_2\mathbf{I}}{\mathbf{Z}_2 + 21\mathbf{Z}_1} = \frac{(21)(1\text{ k}\Omega \angle 0°)(3\text{ k}\Omega \angle 0°)(2\text{ mA} \angle 0°)}{3\text{ k}\Omega + 21(1\text{ k}\Omega \angle 0°)}$$

$\mathbf{E}_{Th} = \mathbf{E}_{oc} = 5.25\text{ V} \angle 0°$



$\mathbf{I}_{sc} = \dfrac{\mathbf{V}_3}{\mathbf{Z}_3} = \dfrac{21\,\mathbf{V}}{\mathbf{Z}_3} \Rightarrow \mathbf{V} = \dfrac{\mathbf{Z}_3}{21}\mathbf{I}_{sc}$

$\mathbf{V} = \mathbf{I}_1\mathbf{Z}_1$

$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}'$

$$\mathbf{I}_{sc} = \frac{\mathbf{Z}_2\mathbf{I}'}{\mathbf{Z}_2 + \mathbf{Z}_3} \Rightarrow \mathbf{I}' = \left(\frac{\mathbf{Z}_2 + \mathbf{Z}_3}{\mathbf{Z}_2}\right)\mathbf{I}_{sc}$$

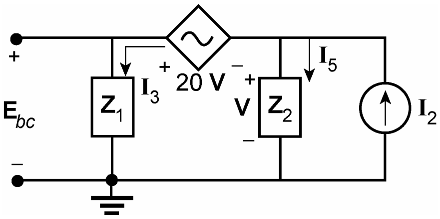
$$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}' = \frac{\mathbf{V}}{\mathbf{Z}_1} + \left(\frac{\mathbf{Z}_2 + \mathbf{Z}_3}{\mathbf{Z}_2}\right)\mathbf{I}_{sc} = \left[\frac{\mathbf{Z}_3}{21\ \mathbf{Z}_1} + \frac{\mathbf{Z}_2 + \mathbf{Z}_3}{\mathbf{Z}_2}\right]\mathbf{I}_{sc}$$

$$\mathbf{I}_{sc} = \frac{\mathbf{I}}{\dfrac{\mathbf{Z}_3}{21\ \mathbf{Z}_1} + \dfrac{\mathbf{Z}_3 + \mathbf{Z}_2}{\mathbf{Z}_2}} = \frac{2\text{ mA} \angle 0°}{\dfrac{4\text{ k}\Omega}{21\text{ k}\Omega} + \dfrac{7\text{ k}\Omega}{3\text{ k}\Omega}} = 0.79\text{ mA} \angle 0°$$

$\therefore$ $\mathbf{I}_N = \mathbf{0.79\ mA \angle 0°}$

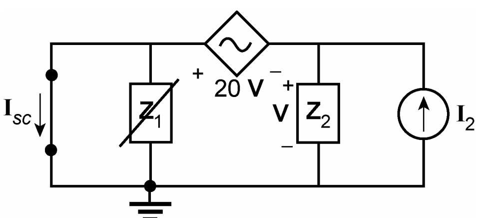
$$\mathbf{Z}_N = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{5.25\text{ V} \angle 0°}{0.79\text{ mA} \angle 0°} = \mathbf{6.65\ k\Omega \angle 0°}$$

38.



$\mathbf{Z}_1 = 2\text{ k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega\ \angle 0°$

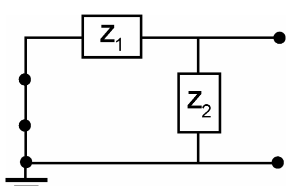
$$\mathbf{I}_2 = \mathbf{I}_3 + \mathbf{I}_5$$
$$\mathbf{V} = \mathbf{I}_5\mathbf{Z}_2 = (\mathbf{I}_2 - \mathbf{I}_3)\mathbf{Z}_2$$
$$\mathbf{E}_{oc} = \mathbf{E}_{Th} = 21\ \mathbf{V} = 21(\mathbf{I}_2 - \mathbf{I}_3)\mathbf{Z}_2$$
$$= 21\left(\mathbf{I}_2 - \frac{\mathbf{E}_{oc}}{\mathbf{Z}_1}\right)\mathbf{Z}_2$$
$$\mathbf{E}_{oc}\left[1 + 21\frac{\mathbf{Z}_2}{\mathbf{Z}_1}\right] = 21\ \mathbf{Z}_2\mathbf{I}_2$$
$$\mathbf{E}_{oc} = \frac{21\,\mathbf{Z}_2\mathbf{I}_2}{1 + 21\dfrac{\mathbf{Z}_2}{\mathbf{Z}_1}} = \frac{21(5\text{ k}\Omega\ \angle 0°)(2\text{ mA}\ \angle 0°)}{1 + 21\left(\dfrac{5\text{ k}\Omega\ \angle 0°}{2\text{ k}\Omega\ \angle 0°}\right)}$$
$$\mathbf{E}_{Th} = \mathbf{E}_{oc} = 3.925\text{ V}\ \angle 0°$$



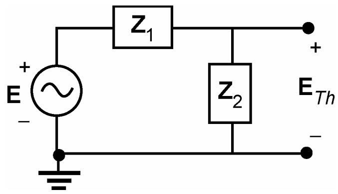
$20\ \mathbf{V} \neq -\mathbf{V}\ \therefore\ \mathbf{V} = 0$
and $\mathbf{I}_N = \mathbf{I}_{sc} = \mathbf{I}_2 = \mathbf{2\text{ mA}\ \angle 0°}$

$$\mathbf{Z}_N = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{3.925\text{ V}\ \angle 0°}{2\text{ mA}\ \angle 0°} = \mathbf{1.96\text{ k}\Omega}$$

39. a.

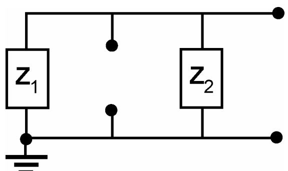


$\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega,\ \mathbf{Z}_2 = -j6\ \Omega$
$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= 5\ \Omega\ \angle 53.13° \parallel 6\ \Omega\ \angle -90°$
$= 8.32\ \Omega\ \angle -3.18°$
$\mathbf{Z}_L = \mathbf{8.32\ \Omega\ \angle 3.18° = 8.31\ \Omega - j0.46\ \Omega}$

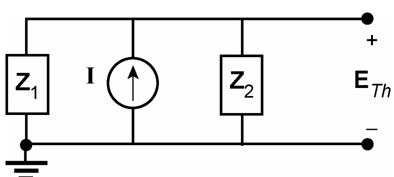


$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2\,\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1}$$
$$= \frac{(6\,\Omega\,\angle -90°)(120\text{ V}\,\angle 0°)}{3.61\,\Omega\,\angle -33.69°}$$
$$= \mathbf{199.45\text{ V}\,\angle{-56.31°}}$$
$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(3.124\text{ V})^2}{4(8.31\,\Omega)} = \mathbf{1198.2\text{ W}}$$

b.

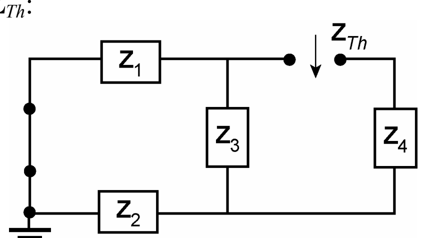


$\mathbf{Z}_1 = 3\,\Omega + j4\,\Omega = 5\,\Omega\,\angle 53.13°$
$\mathbf{Z}_2 = 2\,\Omega\,\angle 0°$
$\leftarrow \mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= 5\,\Omega\,\angle 53.13° \parallel 2\,\Omega\,\angle 0°$
$$= \frac{10\,\Omega\,\angle 53.13°}{2 + 3\; + j4}$$
$$= \frac{10\,\Omega\,\angle 53.13°}{5 + j4}$$
$$= \frac{10\,\Omega\,\angle 53.13°}{6.403\,\angle 38.66°}$$
$= \mathbf{1.56\,\Omega\,\angle 14.47°}$
$\mathbf{Z}_{Th} = 1.56\,\Omega\,\angle 14.47°$
$= 1.51\,\Omega + j0.39\,\Omega$
$\mathbf{Z}_L = \mathbf{1.51\;\;\Omega - \mathit{j}0.39\,\Omega}$



$\mathbf{E}_{Th} = \mathbf{I}(\mathbf{Z}_1 \parallel \mathbf{Z}_2)$
$= (2\text{ A}\,\angle 30°)(1.562\,\Omega\,\angle 14.47°)$
$= \mathbf{3.12\text{ V}\,\angle 44.47°}$
$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(3.12\text{ V})^2}{4(1.51\,\Omega)} = \mathbf{1.61\text{ W}}$$

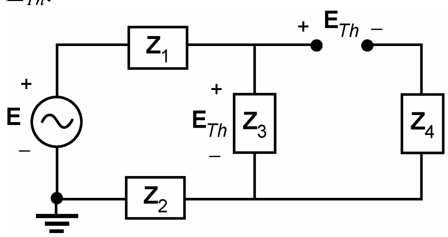
40. a. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 4\,\Omega\,\angle 90°$, $\mathbf{Z}_2 = 10\,\Omega\,\angle 0°$
$\mathbf{Z}_3 = 5\,\Omega\,\angle{-90°}$, $\mathbf{Z}_4 = 6\,\Omega\,\angle{-90°}$
$\mathbf{E} = 60\text{ V}\,\angle 60°$

$\mathbf{Z}_{Th} = \mathbf{Z}_4 + \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2) = -j6\,\Omega + (5\,\Omega\,\angle{-90°}) \parallel (10\,\Omega + j4\,\Omega)$
$= 2.475\,\Omega - j4.754\,\Omega$
$= 11.04\,\Omega\,\angle{-77.03°}$
$\mathbf{Z}_L = \mathbf{11.04\,\Omega\,\angle 77.03°}$

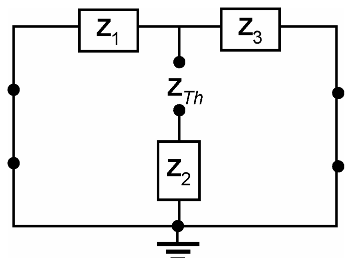
$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_3(\mathbf{E})}{\mathbf{Z}_3 + \mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(5\,\Omega\,\angle -90°)(60\text{ V}\,\angle 60°)}{-j5\,\Omega + j4\,\Omega + 10\,\Omega} = \mathbf{29.85\ V\ \angle{-24.29°}}$$

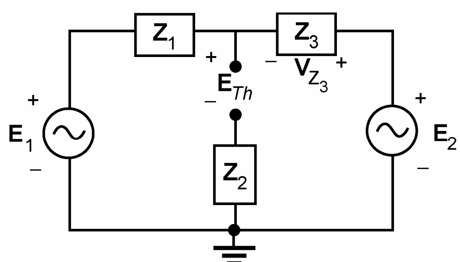
$P_{\max} = E_{Th}^2/4R_{Th} = (29.85\text{ V})^2/4(2.475\ \Omega) = \mathbf{90\ W}$

b.



$\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega = 5\ \Omega\ \angle 53.13°$
$\mathbf{Z}_2 = -j8\ \Omega$
$\mathbf{Z}_3 = 12\ \Omega + j9\ \Omega$

$\mathbf{Z}_{Th} = \mathbf{Z}_2 + \mathbf{Z}_1 \parallel \mathbf{Z}_3 = -j8\ \Omega + (5\ \Omega\ \angle 53.13°) \parallel (15\ \Omega\ \angle 36.87°)$
$= 5.71\ \Omega\ \angle{-64.30°} = 2.475\ \Omega - j5.143\ \Omega$
$\mathbf{Z}_L = \mathbf{5.71\ \Omega\ \angle 64.30° = 2.48\ \Omega + \mathit{j}5.15\ \Omega}$



$\mathbf{E}_{Th} + \mathbf{V}_{Z_3} - \mathbf{E}_2 = 0$
$\mathbf{E}_{Th} = \mathbf{E}_2 - \mathbf{V}_{Z_3}$

$$\mathbf{V}_{Z_3} = \frac{\mathbf{Z}_3(\mathbf{E}_2 - \mathbf{E}_1)}{\mathbf{Z}_3 + \mathbf{Z}_1} = 168.97\text{ V}\ \angle 112.53°$$

$\mathbf{E}_{Th} = \mathbf{E}_2 - \mathbf{V}_{Z_3} = 200\text{ V}\ \angle 90° - 168.97\text{ V}\ \angle 112.53° = \mathbf{78.24\ V\ \angle 34.16°}$
$P_{\max} = E_{Th}^2/4R_{Th} = (78.24\text{ V})^2/4(2.475\ \Omega) = \mathbf{618.33\ W}$

41. $\mathbf{I} = \dfrac{E\angle 0°}{R_1\angle 0°} = \dfrac{1\text{ V}\ \angle 0°}{1\text{ k}\Omega\ \angle 0°} = 1\text{ mA}\ \angle 0°$

$\mathbf{Z}_{Th} = 40\text{ k}\Omega\ \angle 0°$
$\mathbf{E}_{Th} = (50\ \mathbf{I})(40\text{ k}\Omega\ \angle 0°) = (50)(1\text{ mA}\ \angle 0°)(40\text{ k}\Omega\ \angle 0°) = 2000\text{ V}\ \angle 0°$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(2\text{ kV})^2}{4(40\text{ k}\Omega)} = \mathbf{25\ W}$$

42. a. $\mathbf{Z}_{Th} = \mathbf{Z}_N = 8\ \Omega\ \angle 0°$ (Problem 30(b))

$\mathbf{Z}_L = \mathbf{8\ \Omega\ \angle 0°}$

$\mathbf{E}_{Th} = \mathbf{I}_N \cdot \mathbf{Z}_N$: DC: $\mathbf{E}_{Th} = \mathbf{I}'_N \cdot \mathbf{Z}_N = (0.5\text{ A})(8\ \Omega) = 4\text{ V}$

AC: $\mathbf{E}_{Th} = \mathbf{I}'_N \cdot \mathbf{Z}_N = (1.25\text{ A}\ \angle 0°)(8\ \Omega\ \angle 0°) = 10\text{ V}$

b. $P_{\max} = \dfrac{E_{Th}^2}{4R_{Th}} = \dfrac{(4\text{ V})^2}{4(8\ \Omega)} + \dfrac{(10\text{ V})^2}{4(8\ \Omega)} = 0.5\text{ W} + 3.13\text{ W} = \mathbf{3.63\ W}$

43. From #16, $\mathbf{Z}_{Th} = 9\ \Omega$, $\mathbf{E}_{Th} = 12\text{ V} + 24\text{ V}\ \angle 0°$

a. $\therefore\ \mathbf{Z}_L = 9\ \Omega$

b. $P_{\max} = \dfrac{E_{Th}^2}{4R_{Th}} = \dfrac{(12\text{ V})^2}{4(9\ \Omega)} + \dfrac{(24\text{ V})^2}{4(9\ \Omega)} = 4\text{ W} + 16\text{ W} = \mathbf{20\ W}$

or $E_{Th} = \sqrt{V_0^2 + V_{1_{\text{eff}}}^2} = 26.833\text{ V}$

and $P_{\max} = \dfrac{E_{Th}^2}{4R_{Th}} = \dfrac{(26.833\text{ V})^2}{4(9\ \Omega)} = \mathbf{20\ W}$

44. a. Problem 17(a):

$\mathbf{Z}_{Th} = 4.47\text{ k}\Omega\ \angle{-26.57°} = 4\text{ k}\Omega - j2\text{ k}\Omega$

$\mathbf{Z}_L = \mathbf{4\ k\Omega + \mathit{j}2\ k\Omega}$

$\mathbf{E}_{Th} = \mathbf{31.31\ V\ \angle{-26.57°}}$

b. $P_{\max} = E_{Th}^2/4R_{Th} = (31.31\text{ V})^2/4(4\text{ k}\Omega) = \mathbf{61.27\ mW}$

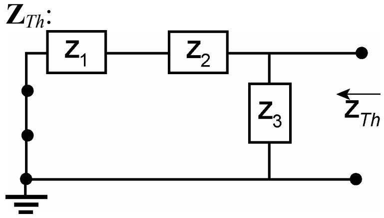
45. a. $\mathbf{Z}_{Th} = 2\text{ k}\Omega\ \angle 0° \parallel 2\text{ k}\Omega\ \angle{-90°} = 1\text{ k}\Omega - j1\text{ k}\Omega$

$$R_L = \sqrt{R_{Th}^2 + (X_{Th} + X_{\text{Load}})^2}$$
$$= \sqrt{(1\text{ k}\Omega)^2 + (-1\text{ k}\Omega + 2\text{ k}\Omega)^2}$$
$$= \sqrt{(1\text{ k}\Omega)^2 + (1\text{ k}\Omega)^2}$$
$$= \mathbf{1.41\ k\Omega}$$

b. $R_{\text{av}} = (R_{Th} + R_{\text{Load}})/2 = (1\text{ k}\Omega + 1.41\text{ k}\Omega)/2 = 1.21\text{ k}\Omega$

$P_{\max} = \dfrac{E_{Th}^2}{4R_{\text{av}}} = \dfrac{(50\text{ V})^2}{4(1.21\text{ k}\Omega)} = \mathbf{516.53\ mW}$

46. **a.** $\mathbf{Z}_{Th}$:



$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10\text{ kHz})(4\text{ nF})}$$
$$\cong 3978.87\ \Omega$$
$$X_L = 2\pi fL = 2\pi(10\text{ kHz})(30\text{ mH})$$
$$\cong 1884.96\ \Omega$$
$\mathbf{Z}_1 = 1\text{ k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 1884.96\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 3978.87\ \Omega\ \angle{-90°}$

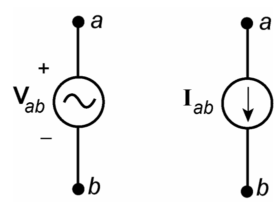
$$\mathbf{Z}_{Th} = (\mathbf{Z}_1 + \mathbf{Z}_2) \parallel \mathbf{Z}_3 = (1\text{ k}\Omega + j1884.96\ \Omega) \parallel 3978.87\ \Omega\ \angle{-90°})$$
$$= 2133.79\ \Omega\ \angle 62.05° \parallel 3978.87\ \Omega\ \angle{-90°})$$
$$= 3658.65\ \Omega\ \angle 36.52°$$

$$\therefore\quad \mathbf{Z}_L = \mathbf{3658.65\ \Omega\ \angle{-36.52°} = 2940.27\ \Omega - \mathit{j}2177.27\ \Omega}$$
$$C = \frac{1}{2\pi fX_C} = \frac{1}{2\pi(10\text{ kHz})(2177.27\ \Omega)} = \mathbf{7.31\ nF}$$

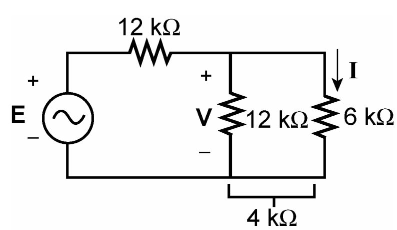
b. $R_L = R_{Th} = \mathbf{2940.27\ \Omega}$

c. $$\mathbf{E}_{Th} = \frac{\mathbf{Z}_3(\mathbf{E})}{\mathbf{Z}_3 + \mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(3978.87\ \Omega\ \angle -90°)(2\text{ V}\angle 0°)}{1\text{ k}\Omega + j1884.96\ \Omega - j3978.87\Omega} = 3.43\text{ V}\angle{-25.53°})$$
$$P_{\max} = E_{Th}^2/4R_{Th} = (3.43\text{ V})^2/4(2940.27\ \Omega) = \mathbf{1\ mW}$$

47. $$\mathbf{I}_{ab} = \frac{(4\text{ k}\Omega\ \angle 0°)(4\text{ mA}\ \angle 0°)}{4\text{ k}\Omega + 8\text{ k}\Omega} = \mathbf{1.33\ mA\ \angle 0°}$$
$$\mathbf{V}_{ab} = (\mathbf{I}_{ab})(8\text{ k}\Omega\ \angle 0°) = \mathbf{10.67\ V\ \angle 0°}$$

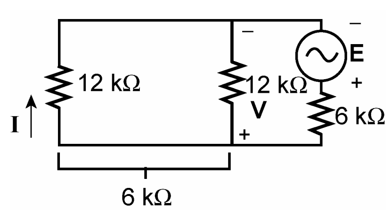


48. a.



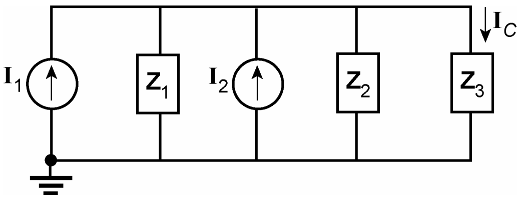
$$\mathbf{V} = \frac{4\text{ k}\Omega(\mathbf{E})}{4\text{ k}\Omega + 12\text{ k}\Omega} = \frac{1}{4}(20\text{ V}\ \angle 0°)$$
$$= 5\text{ V}\ \angle 0°$$
$$\mathbf{I} = \frac{5\text{ V}\ \angle 0°}{6\text{ k}\Omega} = \mathbf{0.83\ mA\ \angle 0°}$$

b.



$$\mathbf{V} = \frac{6\text{ k}\Omega(\mathbf{E})}{6\text{ k}\Omega + 6\text{ k}\Omega} = \frac{1}{2}(20\text{ V}\ \angle 0°)$$
$$= 10\text{ V}\ \angle 0°$$
$$\mathbf{I} = \frac{10\text{ V}\ \angle 0°}{12\text{ k}\Omega} = \mathbf{0.83\ mA\ \angle 0°}$$

49.



$$\mathbf{I}_1 = \frac{100\text{ V}\angle 0^\circ}{2\text{ k}\Omega\angle 0^\circ} = 50\text{ mA}\angle 0^\circ$$

$$\mathbf{I}_2 = \frac{50\text{ V}\angle 0^\circ}{4\text{ k}\Omega\angle 90^\circ}$$

$$= 12.5\text{ mA}\angle -90^\circ$$

$\mathbf{Z}_1 = 2\text{ k}\Omega\angle 0^\circ$

$\mathbf{Z}_2 = 4\text{ k}\Omega\angle 90^\circ$

$\mathbf{Z}_3 = 4\text{ k}\Omega\angle -90^\circ$

$\mathbf{I}_T = \mathbf{I}_1 - \mathbf{I}_2 = (50\text{ mA}\angle 0^\circ - 12.5\text{ mA}\angle -90^\circ) = 50\text{ mA} + j12.5\text{ mA}$

$= 51.54\text{ mA}\angle 14.04^\circ$

$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (2\text{ k}\Omega\angle 0^\circ) \parallel (4\text{ k}\Omega\angle 90^\circ) = 1.79\text{ k}\Omega\angle 26.57^\circ$

$$\mathbf{I}_C = \frac{\mathbf{Z}'\mathbf{I}_T}{\mathbf{Z}' + \mathbf{Z}_3} = \frac{(1.79\text{ k}\Omega\angle 26.57^\circ)(51.54\text{ mA}\angle 14.04^\circ)}{1.6\text{ k}\Omega + j0.8\text{ k}\Omega - j4\text{ k}\Omega}$$

$= \mathbf{25.77\text{ mA}\angle 104.04^\circ}$

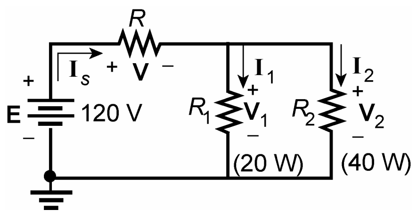
Chapter 19

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. $S_T = EI_s,\quad I_s = \dfrac{S_T}{E} = \dfrac{120\text{ VA}}{240\text{ V}} = \mathbf{0.5\text{ A}}$

d.



$P = I_s^2 R,\ R = \dfrac{P}{I_s^2} = \dfrac{60\text{ W}}{(0.5\text{ A})^2} = 240\ \Omega$

$V = I_sR = (0.5\text{ A})(240\ \Omega) = 120\text{ V}$

$V_1 = V_2 = E - V = 240\text{ V} - 120\text{ V} = 120\text{ V}$

$P_1 = \dfrac{V_1^2}{R_1},\ R_1 = \dfrac{V_1^2}{P_1} = \dfrac{(120\text{ V})^2}{20\text{ W}} = \mathbf{720\ \Omega}$

$P_2 = \dfrac{V_2^2}{R_2},\ R_2 = \dfrac{V_2^2}{P_2} = \dfrac{(120\text{ V})^2}{40\text{ W}} = \mathbf{360\ \Omega}$

e. $I_1 = \dfrac{V_1}{R_1} = \dfrac{120\text{ V}}{720\ \Omega} = \mathbf{0.17\text{ A}},\ I_2 = \dfrac{V_2}{R_2} = \dfrac{120\text{ V}}{360\ \Omega} = \mathbf{0.33\text{ A}}$

2. a. $\mathbf{Z}_T = 3\ \Omega - j5\ \Omega + j9\ \Omega = 3\ \Omega + j4\ \Omega = 5\ \Omega\ \angle 53.13°$

$\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{50\text{ V}\ \angle 0°}{5\ \Omega\ \angle 53.13°} = 10\text{ A}\ \angle -53.13°$

R: $P = I^2R = (10\text{ A})^2\ 3\ \Omega = \mathbf{300\text{ W}}$
L: $P = \mathbf{0\text{ W}}$
C: $P = \mathbf{0\text{ W}}$

b. R: $Q = \mathbf{0\text{ VAR}}$
C: $Q_C = I^2X_C = (10\text{ A})^2\ 5\ \Omega = \mathbf{500\text{ VAR}}$
L: $Q_L = I^2X_L = (10\text{ A})^2\ 9\ \Omega = \mathbf{900\text{ VAR}}$

c. R: $S = \mathbf{300\text{ VA}}$
C: $S = \mathbf{500\text{ VA}}$
L: $S = \mathbf{900\text{ VA}}$

d. $P_T = 300\text{ W}$
$Q_T = Q_L - Q_C = \mathbf{400\text{ VAR}(\mathit{L})}$
$S_T = \sqrt{P_T^2 + Q_T^2} = EI = (50\text{ V})(10\text{ A}) = \mathbf{500\text{ VA}}$
$F_p = \dfrac{P_T}{S_T} = \dfrac{300\text{ W}}{500\text{ VA}} = \mathbf{0.6\ lagging}$

e. –

f. $W_R = \dfrac{VI}{f_1}$: $W_R = 2\left[\dfrac{VI}{f_2}\right] = 2\left[\dfrac{VI}{2f_1}\right] = \dfrac{VI}{f_1}$

$V = IR = (10\text{ A})(3\ \Omega) = 30\text{ V}$

$W_R = \dfrac{(30\text{ V})(10\text{ A})}{60\text{ Hz}} = \mathbf{5\ J}$

g. $V_C = IX_C = (10\text{ A})(5\ \Omega) = 50\text{ V}$

$W_C = \dfrac{VI}{\omega_1} = \dfrac{(50\text{ V})(10\text{ A})}{(2\pi)(60\text{ Hz})} = \mathbf{1.33\ J}$

$V_L = IX_L = (10\text{ A})(9\ \Omega) = 90\text{ V}$

$W_L = \dfrac{VI}{\omega_1} = \dfrac{(90\text{ V})(10\text{ A})}{376.8} = \mathbf{2.39\ J}$

3. a. $P_T = 0 + 100\text{ W} + 300\text{ W} = \mathbf{400\ W}$

$Q_T = 200\text{ VAR}(L) - 600\text{ VAR}(C) + 0 = \mathbf{-400\ VAR(\mathit{C})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{565.69\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{400\text{ W}}{565.69\text{ VA}} = \mathbf{0.707\ (leading)}$

b. –

c. $P_T = EI_s \cos\theta_T$

$400\text{ W} = (100\text{ V})I_s(0.7071)$

$I_s = \dfrac{400\text{ W}}{70.71\text{ V}} = 5.66\text{ A}$

$\mathbf{I}_s = 5.66\text{ A}\ \angle 135°$

4. a. $P_T = 600\text{ W} + 500\text{ W} + 100\text{ W} = \mathbf{1200\ W}$

$Q_T = 1200\text{ VAR}(L) + 600\text{ VAR}(L) - 600\text{ VAR}(C) = \mathbf{1200\ VAR(\mathit{L})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \sqrt{(1200\text{ W})^2 + (1200\text{ VAR})^2} = \mathbf{1697\ VA}$

b. $F_p = \dfrac{P_T}{S_T} = \dfrac{1200\text{ W}}{1697\text{ VA}} = \mathbf{0.7071\ (lagging)}$

c. –

d. $I_s = \dfrac{S_T}{E} = \dfrac{1697\text{ VA}}{200\text{ V}} = 8.485\text{ A},\ 0.7071 \Rightarrow 45°\text{ (lagging)}$

$\mathbf{I}_s = \mathbf{8.49\ A\ \angle{-45°}}$

5. a. $P_T = 200\text{ W} + 200\text{ W} + 0 + 100\text{ W} = \mathbf{500\ W}$

$Q_T = 100\text{ VAR}(L) + 100\text{ VAR}(L) - 200\text{ VAR}(C) - 200\text{ VAR}(C) = \mathbf{-200\ VAR(\mathit{C})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{538.52\ VA}$

b. $F_p = \dfrac{P_T}{S_T} = \dfrac{500\text{ W}}{538.52\text{ VA}} = \mathbf{0.928\ (leading)}$

c. –

d. $P_T = EI_s \cos\theta_T$

$500\text{ W} = (50\text{ V})I_s(0.928)$

$I_s = \dfrac{500\text{ W}}{46.4\text{ V}} = 10.776\text{ A}$

$\mathbf{I}_s = \mathbf{10.78\ A\ \angle 21.88^\circ}$

6. a. $\mathbf{I}_R = \dfrac{60\text{ V}\angle 30^\circ}{20\,\Omega\angle 0^\circ} = 3\text{ A}\angle 30^\circ$

$P = I^2R = (3\text{ A})^2\,20\,\Omega = \mathbf{180\ W}$

$Q_R = \mathbf{0\ VAR}$

$S = P = \mathbf{180\ VA}$

b. $\mathbf{I}_L = \dfrac{60\text{ V}\angle 30^\circ}{10\,\Omega\angle 90^\circ} = 6\text{ A}\angle -60^\circ$

$P_L = \mathbf{0\ W}$

$Q_L = I^2X_L = (6\text{ A})^2\,10\,\Omega = \mathbf{360\ VAR(\mathit{L})}$

$S = Q = \mathbf{360\ VA}$

c. $P_T = 180\text{ W} + 400\text{ W} = \mathbf{580\ W}$

$Q_T = 600\text{ VAR}(L) + 360\text{ VAR}(L) = \mathbf{960\ VAR(\mathit{L})}$

$S_T = \sqrt{(580\text{ W})^2 + (960\text{ VAR})^2} = \mathbf{1121.61\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{580\text{ W}}{1121.61\text{ VA}} = \mathbf{0.517\ (lagging)}\quad \theta = 58.87^\circ$

d. $S_T = EI_s$

$I_s = \dfrac{S_T}{E} = \dfrac{1121.61\text{ VA}}{60\text{ V}} = 18.69\text{ A}$

$\theta_{I_s} = 30^\circ - 58.87^\circ = -28.87^\circ$

$\mathbf{I}_s = \mathbf{18.69\ A\ \angle -28.87^\circ}$

7. a. R: $P = \dfrac{E^2}{R} = \dfrac{(20\text{ V})^2}{2\,\Omega} = \mathbf{200\ W}$

$P_{L,C} = \mathbf{0\ W}$

b. R: $Q = \mathbf{0\ VAR}$

C: $Q_C = \dfrac{E^2}{X_C} = \dfrac{(20\text{ V})^2}{5\,\Omega} = \mathbf{80\ VAR(\mathit{C})}$

L: $Q_L = \dfrac{E^2}{X_L} = \dfrac{(20\text{ V})^2}{4\,\Omega} = \mathbf{100\ VAR(\mathit{L})}$

c. R: $S = \mathbf{200\ VA}$
C: $S = \mathbf{80\ VA}$
L: $S = \mathbf{100\ VA}$

d. $P_T = 200\text{ W} + 0 + 0 = \mathbf{200\ W}$
$Q_T = 0 + 80\text{ VAR}(C) + 100\text{ VAR}(L) = \mathbf{20\ VAR(\mathit{L})}$
$S_T = \sqrt{(200\text{ W})^2 + (20\text{ VAR})^2} = \mathbf{200\ VA}$
$F_p = \dfrac{P_T}{S_T} = \dfrac{200\text{ W}}{200.998\text{ VA}} = \mathbf{0.995\ (lagging)} \Rightarrow 5.73°$

e. –

f. $I_s = \dfrac{S_T}{E} = \dfrac{200.998\text{ VA}}{20\text{ V}} = 10.05\text{ A}$
$\mathbf{I}_s = 10.05\text{ A}\angle{-5.73°}$

8. a. $R - L$: $\mathbf{I} = \dfrac{50\text{ V}\angle 60°}{5\,\Omega\angle 53.13°} = 10\text{ A}\angle 6.87°$
$P_R = I^2R = (10\text{ A})^2\, 3\,\Omega = \mathbf{300\ W}$
$P_L = \mathbf{0\ W}$
$P_C = \mathbf{0\ W}$

b. $Q_R = \mathbf{0\ VAR}$
$Q_L = I^2X_L = (10\text{ A})^2\, 4\,\Omega = \mathbf{400\ VAR}$
$\mathbf{I}_C = \dfrac{50\text{ V}\angle 60°}{10\,\Omega\angle -90°} = 5\text{ A}\angle 150°$
$Q_C = I^2X_C = (5\text{ A})^2\, 10\,\Omega = \mathbf{250\ VAR}$

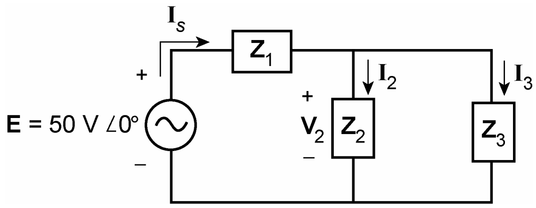
c. $S_R = P = \mathbf{300\ VA}$
$S_L = Q_L = \mathbf{400\ VA}$
$S_C = Q_C = \mathbf{250\ VA}$

d. $P_T = P_R = \mathbf{300\ W}$
$Q_T = 400\text{ VAR}(L) - 250\text{ VAR}(C) = \mathbf{150\ VAR(\mathit{L})}$
$S_T = \sqrt{(300\text{ W})^2 + (150\text{ VAR})^2} = \mathbf{335.41\ VA}$
$F_p = \dfrac{P_T}{S_T} = \dfrac{300\text{ W}}{335.41\text{ VA}} = \mathbf{0.894\ (lagging)}$

e. –

f. $I_s = \dfrac{S_T}{E} = \dfrac{335.41\text{ VA}}{50\text{ V}} = 6.71\text{ A}$
$0.894 \Rightarrow 26.62°$ lagging
$\theta = 60° - 26.62° = 33.38°$
$\mathbf{I}_s = \mathbf{6.71\ A\ \angle 33.38°}$

9. a–c.



$X_L = \omega L = (400 \text{ rad/s})(0.1 \text{ H}) = 40\ \Omega$

$X_C = \dfrac{1}{\omega C} = \dfrac{1}{(400 \text{ rad/s})(100\ \mu\text{F})}$

$= 25\ \Omega$

$\mathbf{Z}_1 = 40\ \Omega \angle 90°$, $\mathbf{Z}_2 = 25\ \Omega \angle -90°$

$\mathbf{Z}_3 = 30\ \Omega \angle 0°$

$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3 = +j40\ \Omega + (25\ \Omega \angle -90°) \parallel (30\ \Omega \angle 0°)$
$= +j40\ \Omega + 19.21\ \Omega \angle -50.19°$
$= +j40\ \Omega + 12.3\ \Omega - j14.76\ \Omega$
$= 12.3\ \Omega + j25.24\ \Omega$
$= 28.08\ \Omega \angle 64.02°$

$\mathbf{I}_s = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{50 \text{ V} \angle 0°}{28.08\ \Omega \angle 64.02°} = 1.78 \text{ A} \angle -64.02°$

$\mathbf{V}_2 = \mathbf{I}_s(\mathbf{Z}_2 \parallel \mathbf{Z}_3) = (1.78 \text{ A} \angle -64.02°)(19.21\ \Omega \angle -50.19°)$
$= 34.19 \text{ V} \angle -114.21°$

$\mathbf{I}_2 = \dfrac{\mathbf{V}_2}{\mathbf{Z}_2} = \dfrac{34.19 \text{ V} \angle -114.21°}{25\ \Omega \angle -90°} = 1.37 \text{ A} \angle -24.21°$

$\mathbf{I}_3 = \dfrac{\mathbf{V}_2}{\mathbf{Z}_3} = \dfrac{34.19 \text{ V} \angle -114.21°}{30\ \Omega \angle 0°} = 1.14 \text{ A} \angle -114.21°$

$\mathbf{Z}_1$: $P = \mathbf{0\ W}$, $Q_L = I_s^2 X_L = (1.78 \text{ A})^2\, 40\ \Omega = $ **126.74 VAR(L), S = 126.74 VA**

$\mathbf{Z}_2$: $P = \mathbf{0\ W}$, $Q_C = I_2^2 X_C = (1.37 \text{ A})^2\, 25\ \Omega = $ **46.92 VAR(C), S = 46.92 VA**

$\mathbf{Z}_3$: $P = I_3^2 R = (1.14 \text{ A})^2\, 30\ \Omega = $ **38.99 W**, $Q_R = $ **0 VAR, S = 38.99 VA**

d. $P_T = 0 + 0 + 38.99 \text{ W} = $ **38.99 W**

$Q_T = +126.74 \text{ VAR}(L) - 46.92 \text{ VAR}(C) + 0 = $ **79.82 VAR(L)**

$S_T = \sqrt{P_T^2 + Q_T^2} = $ **88.83 VA**

$F_p = \dfrac{P_T}{S_T} = \dfrac{38.99 \text{ W}}{88.83 \text{ VA}} = $ **0.439 (lagging)**

e. –

f. $W_R = \dfrac{V_R I_R}{2f_1} = \dfrac{V_2 I_3}{2f_1} = \dfrac{(34.19 \text{ V})(1.14 \text{ A})}{2(63.69 \text{ Hz})} = \mathbf{0.31\ J}$

$f_1 = \dfrac{\omega_1}{2\pi} = \dfrac{400 \text{ rad/s}}{6.28} = 63.69 \text{ Hz}$

g. $W_L = \dfrac{V_L I_L}{\omega_1} = \dfrac{(I_s X_L) I_s}{\omega_1} = \dfrac{I_s^2 X_L}{\omega_1} = \dfrac{(1.78 \text{ A})^2\, 40\ \Omega}{400 \text{ rad/s}} = \mathbf{0.32\ J}$

$W_C = \dfrac{V_C I_C}{\omega_1} = \dfrac{V_2 I_2}{\omega_1} = \dfrac{(34.19 \text{ V})(1.37 \text{ A})}{400 \text{ rad/s}} = \mathbf{0.12\ J}$

10. a. $I_s = \dfrac{S_T}{E} = \dfrac{10{,}000\text{ VA}}{200\text{ V}} = 50\text{ A}$

$0.5 \Rightarrow 60°$ leading

$\therefore$ $\mathbf{I}_s$ leads $\mathbf{E}$ by 60°

$\mathbf{Z}_T = \dfrac{\mathbf{E}}{\mathbf{I}_s} = \dfrac{200\text{ V}\angle 0°}{50\text{ A}\angle 60°} = 4\ \Omega\ \angle{-60°} = 2\ \Omega - j3.464\ \Omega = R - jX_C$

b. $F_p = \dfrac{P_T}{S_T} \Rightarrow P_T = F_p S_T = (0.5)(10{,}000\text{ VA}) = \mathbf{5000\ W}$

11. a. $I = \dfrac{S_T}{E} = \dfrac{5000\text{ VA}}{120\text{ V}} = 41.67\text{ A}$

$F_p = 0.8 \Rightarrow 36.87°$ (lagging)

$\mathbf{E} = 120\text{ V}\angle 0°$, $\mathbf{I} = 41.67\text{ A}\angle{-36.87°}$

$\mathbf{Z} = \dfrac{\mathbf{E}}{\mathbf{I}} = \dfrac{120\text{ V}\angle 0°}{41.67\text{ A}\angle -36.87°} = 2.88\ \Omega\ \angle 36.87° = \mathbf{2.30\ \Omega + \mathit{j}1.73\ \Omega} = R + jX_L$

b. $P = S\cos\theta = (5000\text{ VA})(0.8) = \mathbf{4000\ W}$

12. a. $P_T = 0 + 300\text{ W} = \mathbf{300\ W}$

$Q_T = 600\text{ VAR}(C) + 200(L) = \mathbf{400\ VAR(\mathit{C})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{500\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{300\text{ W}}{500\text{ VA}} = \mathbf{0.6\ (leading)}$

b. $I_s = \dfrac{S_T}{E} = \dfrac{500\text{ VA}}{30\text{ V}} = 16.67\text{ A}$

$F_p = 0.6 \Rightarrow 53.13°$

$\mathbf{I}_s = \mathbf{16.67\ A\ \angle 53.13°}$

c. –

d. Load: 600 VAR(C), 0 W

$R = 0,\ L = 0,\ Q_C = I^2X_C \Rightarrow X_C = \dfrac{Q_C}{I^2} = \dfrac{600\text{ VAR}}{(16.67\text{ A})^2} = \mathbf{2.159\ \Omega}$

Load: 200 VAR(L), 300 W

$C = 0,\ R = P/I^2 = 300\text{ W}/(16.67\text{ A})^2 = \mathbf{1.079\ \Omega}$

$X_L = \dfrac{Q_L}{I^2} = \dfrac{200\text{ VAR}}{(16.67\text{ A})^2} = \mathbf{0.7197\ \Omega}$

$\mathbf{Z}_T = !j2.159\ \Omega + 1.0796\ \Omega + j0.7197\ \Omega$

$= \mathbf{1.08\ \Omega - \mathit{j}1.44\ \Omega}$

13. a. $P_T = 0 + 300\text{ W} + 600\text{ W} = \mathbf{900\ W}$

$Q_T = 500\text{ VAR}(C) + 0 + 500\text{ VAR}(L) = \mathbf{0\ VAR}$

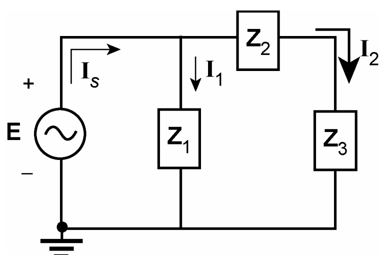
$S_T = P_T = \mathbf{900\ VA}$

$F_p = \dfrac{P_T}{S_T} = \mathbf{1}$

b. $I_s = \dfrac{S_T}{E} = \dfrac{900\text{ VA}}{100\text{ V}} = 9\text{ A}, \mathbf{I}_s = \mathbf{9\ A\ \angle 0°}$

c. –

d.



$\mathbf{Z}_1$: $Q_C = \dfrac{V^2}{X_C} \Rightarrow X_C = \dfrac{V^2}{Q_C} = \dfrac{10^4}{500} = \mathbf{20\ \Omega}$

$\mathbf{I}_1 = \dfrac{\mathbf{E}}{\mathbf{Z}_1} = \dfrac{100\text{ V}\angle 0°}{20\,\Omega\angle -90°} = 5\text{A}\angle 90°$

$\mathbf{I}_2 = \mathbf{I}_s - \mathbf{I}_1 = 9\text{ A} - j5\text{ A} = 10.296\text{ A}\angle{-29.05°}$

$\mathbf{Z}_2$: $R = \dfrac{P}{I^2} = \dfrac{300\text{ W}}{(10.296\text{ A})^2} = \dfrac{300}{106} = \mathbf{2.83\ \Omega}$

$X_{L,C} = \mathbf{0\ \Omega}$

$\mathbf{Z}_3$: $R = \dfrac{P}{I_2^2} = \dfrac{600\text{ W}}{(10.296\text{ A})^2} = \mathbf{5.66\ \Omega}$

$X_L = \dfrac{Q}{I_2^2} = \dfrac{500}{(10.296\text{ A})^2} = \mathbf{4.72\ \Omega}, X_C = \mathbf{0\ \Omega}$

14. a. $P_T = 200\text{ W} + 30\text{ W} + 0 = \mathbf{230\ W}$

$Q_T = 0 + 40\text{ VAR}(L) + 100\text{ VAR}(L) = \mathbf{140\ VAR(\mathit{L})}$

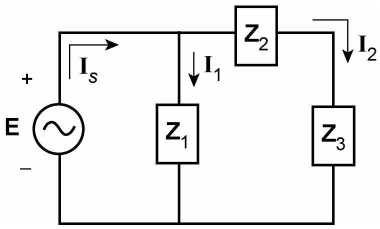
$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{269.26\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{230\text{ W}}{269.26\text{ VA}} = \mathbf{0.854\ (lagging)} \Rightarrow 31.35°$

b. $I_s = \dfrac{S_T}{E} = \dfrac{269.26\text{ VA}}{100\text{ V}} = 2.6926\text{ A}$

$\mathbf{I}_s = \mathbf{2.69\ A\ \angle{-31.35°}}$

c.



$\mathbf{Z}_1$: $R = \dfrac{V^2}{P} = \dfrac{10^4}{200} = 50\ \Omega$

$X_L, X_C = 0\ \Omega$

$\mathbf{I}_1 = \dfrac{100\text{ V}\angle 0°}{50\ \Omega\angle 0°} = 2\text{ A}\angle 0°$

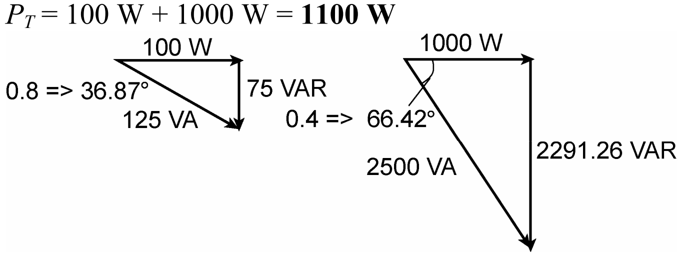
$$\begin{aligned}\mathbf{I}_2 &= \mathbf{I}_s - \mathbf{I}_1\\ &= 2.6926\text{ A}\angle{-31.35°} - 2\text{ A}\angle 0°\\ &= 2.299\text{ A} - j1.40\text{ A} - 2.0\text{ A}\\ &= 0.299\text{ A} - j1.40\text{ A}\\ &= 1.432\text{ A}\angle{-77.94°}\end{aligned}$$

$\mathbf{Z}_2$: $R = \dfrac{P}{I_2^2} = \dfrac{30\text{ W}}{(1.432\text{ A})^2} = \mathbf{14.63\ \Omega}$, $X_L = \dfrac{Q}{I_2^2} = \dfrac{40\text{ VAR}}{(1.432\text{ A})^2} = \mathbf{19.50\ \Omega}$

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

$\mathbf{Z}_3$: $X_L = \dfrac{Q}{I_2^2} = \dfrac{100\text{ VAR}}{(1.432\text{ A})^2} = \mathbf{48.76\ \Omega}$, $R = \mathbf{0\ \Omega}$, $X_C = \mathbf{0\ \Omega}$

15. a. $P_T = 100\text{ W} + 1000\text{ W} = \mathbf{1100\ W}$



$Q_T = 75\text{ VAR}(C) + 2291.26\text{ VAR}(C) = \mathbf{2366.26\ VAR(\mathit{C})}$

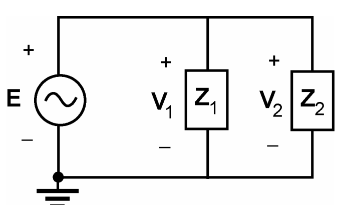
$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{2609.44\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{1100\text{ W}}{2609.44\text{ VA}} = \mathbf{0.422\ (leading)} \Rightarrow 65.04°$

b. $S_T = EI \Rightarrow E = \dfrac{S_T}{I} = \dfrac{2609.44\text{ VA}}{5\text{ A}} = 521.89\text{ V}$

$\mathbf{E} = \mathbf{521.89\ V\angle{-65.07°}}$

c.



$I_{Z_1} = \dfrac{S}{V_1} = \dfrac{S}{E} = \dfrac{125\text{ VA}}{521.89\text{ V}} = 0.2395\text{ A}$

$I_{Z_2} = \dfrac{S}{V_2} = \dfrac{S}{E} = \dfrac{2500\text{ VA}}{521.89\text{ V}} = 4.79\text{ A}$

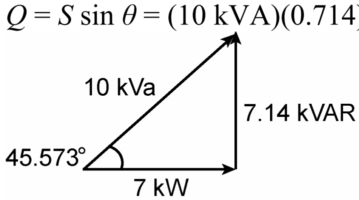
$\mathbf{Z}_1$: $R = \dfrac{P}{I_{Z_1}^2} = \dfrac{100\text{ W}}{(0.2395)^2} = \mathbf{1743.38\ \Omega}$

$Q = I_{Z_1}^2 X_C \Rightarrow X_C = \dfrac{Q}{I_{Z_1}^2} = \dfrac{75\text{ VAR}}{(0.2395\text{ A})^2} = \mathbf{1307.53\ \Omega}$

$\mathbf{Z}_2$: $R = \dfrac{P}{I_{Z_1}^2 X_C} = \dfrac{1000\text{ W}}{(4.790\text{ A})^2} = \mathbf{43.59\ \Omega}$

$X_C = \dfrac{Q}{I_{Z_1}^2 X_C} = \dfrac{2291.26\text{ VAR}}{(4.790\text{ A})^2} = \mathbf{99.88\ \Omega}$

16. a. $0.7 \Rightarrow 45.573°$
$P = S\cos\theta = (10\text{ kVA})(0.7) = 7\text{ kW}$
$Q = S\sin\theta = (10\text{ kVA})(0.714) = 7.14\text{ kVAR}(L)$



b. $Q_C = 7.14\text{ kVAR} = \dfrac{V^2}{X_C}$

$X_C = \dfrac{V^2}{Q_C} = \dfrac{(208\text{ V})^2}{7.14\text{ kVAR}} = 6.059\ \Omega$

$X_C = \dfrac{1}{2\pi fC} \Rightarrow C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{(2\pi)(60\text{ Hz})(6.059\ \Omega)} = \mathbf{438\ \mu F}$

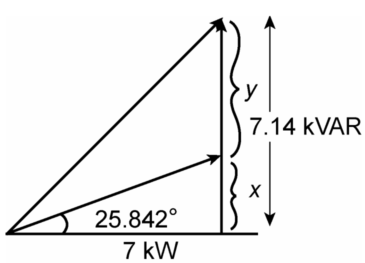
c. Uncompensated:

$I_s = \dfrac{S_T}{E} = \dfrac{10{,}000\text{ VA}}{208\text{ V}} = \mathbf{48.08\ A}$

Compensated:

$I_s = \dfrac{S_T}{E} = \dfrac{P_T}{E} = \dfrac{7{,}000\text{ W}}{208\text{ V}} = \mathbf{33.65\ A}$

d.



$\cos\theta = 0.9$
$\theta = \cos^{-1}0.9 = 25.842°$
$\tan\theta = \dfrac{x}{7\text{ kW}}$
$x = (7\text{ kW})(\tan 25.842°)$
$= (7\text{ kW})(0.484)$
$= 3.39\text{ kVAR}$
$y = (7.14 - 3.39)\text{ kVAR}$
$= 3.75\text{ kVAR}$

$$Q_C = 3.75\text{ kVAR} = \frac{V^2}{X_C}$$

$$X_C = \frac{V^2}{Q_C} = \frac{(208\text{ V})^2}{3.75\text{ kVAR}} = 11.537\ \Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60\text{ Hz})(11.537\ \Omega)} = \mathbf{230\ \mu F}$$

Uncompensated:

$I_s = \mathbf{48.08\ A}$

Compensated:

$$S_T = \sqrt{(7\text{ kW})^2 + (3.39\text{ kVAR})^2} = 7.778\text{ kVA}$$

$$I_s = \frac{S_T}{E} = \frac{7.778\text{ kVA}}{208\text{ V}} = \mathbf{37.39\ A}$$

17. a. $P_T = 5\text{ kW},\ Q_T = 6\text{ kVAR}(L)$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{7.81\ kVA}$$

b. $$F_p = \frac{P_T}{S_T} = \frac{5\text{ kW}}{7.81\text{ kVA}} = \mathbf{0.640\ (lagging)}$$

c. $$I_s = \frac{S_T}{E} = \frac{7{,}810\text{ VA}}{120\text{ V}} = \mathbf{65.08\ A}$$

d. $$X_C = \frac{1}{2\pi f C},\ Q_C = I^2 X_C = \frac{E^2}{X_C} = \frac{(120\text{ V})^2}{X_C}$$

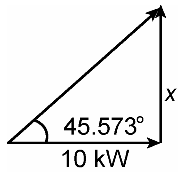
and $$X_C = \frac{(120\text{ V})^2}{Q_C} = \frac{14{,}400}{6000} = 2.4\ \Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60\text{ Hz})(2.4\ \Omega)} = \mathbf{1105\ \mu F}$$

e. $S_T = EI_s = P_T$

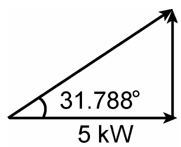
$$\therefore\ I_s = \frac{P_T}{E} = \frac{5000\text{ W}}{120\text{ V}} = \mathbf{41.67\ A}$$

18. a. Load 1: $P = 20{,}000$ W, $Q = 0$ VAR
Load 2: $\theta = \cos^{-1}0.7 = 45.573°$



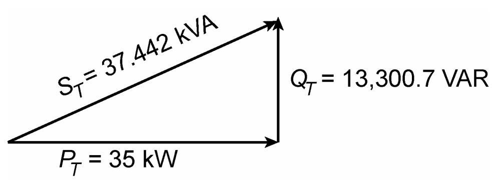
$$\tan\theta = \frac{x}{10\text{ kW}}$$
$x = (10\text{ kW})\tan 45.573°$
$= (10\text{ kW})(1.02)$
$= \mathbf{10{,}202\ VAR(}\boldsymbol{L}\mathbf{)}$

Load 3: $\theta = \cos^{-1}0.85 = 31.788°$



$$\tan\theta = \frac{x}{5\text{ kW}}$$
$x = (5\text{ kW})\tan 31.788°$
$= (5\text{ kW})(0.62)$
$= 3098.7\text{ VAR}(L)$

$P_T = 20{,}000\text{ W} + 10{,}000\text{ W} + 5{,}000\text{ W} = \mathbf{35\ kW}$
$Q_T = 0 + 10{,}202\text{ VAR} + 3098.7\text{ VAR} = \mathbf{13{,}300.7\ VAR(}\boldsymbol{L}\mathbf{)}$
$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{37{,}442\ VA = 37.442\ kVA}$



b. $Q_C = Q_L = 13{,}300.7$ VAR
$$X_C = \frac{E^2}{Q_C} = \frac{(10^3\text{ V})^2}{13{,}300.7\text{ VAR}} = 75.184\ \Omega$$
$$C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60\text{ Hz})(75.184\ \Omega)} = \mathbf{35.28\ \mu F}$$

c. Uncompensated:
$$I_s = \frac{S_T}{E} = \frac{37.442\text{ kVA}}{1\text{ kV}} = \mathbf{37.44\ A}$$

Compensated:
$S_T = P_T = 35$ kW
$$I_s = \frac{S_T}{E} = \frac{35\text{ kW}}{1\text{ kV}} = \mathbf{35\ A}$$

19. a. $\mathbf{Z}_T = R_1 + R_2 + R_3 + jX_L - jX_C$
$= 2\ \Omega + 3\ \Omega + 1\ \Omega + j3\ \Omega - j12\ \Omega = 6\ \Omega - j9\ \Omega = 10.82\ \Omega\ \angle -56.31°$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50\text{ V}\ \angle 0°}{10.82\ \Omega\ \angle -56.31°} = 4.62\text{ A}\ \angle 56.31°$$
$P = VI\cos\theta = (50\text{ V})(4.62\text{ A})\cos 56.31° = \mathbf{128.14\ W}$

b. a-b: $P = I^2R = (4.62\text{ A})^2\ 2\ \Omega = \mathbf{42.69\ W}$
b-c: $P = I^2R = (4.62\text{ A})^2\ 3\ \Omega = \mathbf{64.03\ W}$
a-c: $42.69\text{ W} + 64.03\text{ W} = \mathbf{106.72\ W}$
a-d: **106.72 W**
c-d: **0 W**
d-e: **0 W**
f-e: $P = I^2R = (4.62\text{ A})^2\ 1\ \Omega = \mathbf{21.34\ W}$

20. a. $S_T = 660\text{ VA} = EI_s$

$$I_s = \frac{660\text{ VA}}{120\text{ V}} = 5.5\text{ A}$$

$\theta = \cos^{-1}0.6 = 53.13°$

$\therefore \mathbf{E} = 120\text{ V}\angle 0°,\ \mathbf{I}_s = 5.5\text{ A}\angle{-53.13°}$

$P = EI\cos\theta = (120\text{ V})(5.5\text{ A})(0.6) = \mathbf{396\ W}$

Wattmeter = **396 W**, Ammeter = **5.5 A**, Voltmeter = **120 V**

b. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120\text{ V}\angle 0°}{5.5\text{ A}\angle -53.13°} = \mathbf{21.82\ \Omega\angle 53.13° = 13.09\ \Omega + \mathit{j}17.46\ \Omega} = R + jX_L$$

21. a. $$R = \frac{P}{I^2} = \frac{80\text{ W}}{(4\text{ A})^2} = \mathbf{5\ \Omega},\ \mathbf{Z}_T = \frac{E}{I} = \frac{200\text{ V}}{4\text{ A}} = 50\ \Omega$$

$$X_L = \sqrt{Z_T^2 - R^2} = \sqrt{(50\ \Omega)^2 - (5\ \Omega)^2} = 49.75\ \Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{49.75\ \Omega}{(2\pi)(60\text{ Hz})} = \mathbf{132.03\ mH}$$

b. $$R = \frac{P}{I^2} = \frac{90\text{ W}}{(3\text{ A})^2} = \mathbf{10\ \Omega}$$

c. $$R = \frac{P}{I^2} = \frac{60\text{ W}}{(2\text{ A})^2} = \mathbf{15\ \Omega},\ Z_T = \frac{E}{I} = \frac{200\text{ V}}{2\text{ A}} = 100\ \Omega$$

$$X_L = \sqrt{Z_T^2 - R^2} = \sqrt{(100\ \Omega)^2\ -\ (15\ \Omega)^2} = 98.87\ \Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{98.87\ \Omega}{376.8} = \mathbf{262.39\ mH}$$

22. a. $X_L = 2\pi fL = (6.28)(50\text{ Hz})(0.08\text{ H}) = 25.12\ \Omega$

$$Z_T = \sqrt{R^2 + X_L^2} = \sqrt{(4\ \Omega)^2 + (25.12\ \Omega)^2} = 25.44\ \Omega$$

$$I = \frac{E}{Z_T} = \frac{60\text{ V}}{25.44\ \Omega} = 2.358\text{ A}$$

$P = I^2R = (2.358\text{ A})^2\ 4\ \Omega = \mathbf{22.24\ W}$

b. $I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{30\text{ W}}{7\,\Omega}} = \mathbf{2.07\ A}$

$Z_T = \dfrac{E}{I} = \dfrac{60\text{ V}}{2.07\text{ A}} = 28.99\ \Omega$

$X_L = \sqrt{(28.99\ \Omega)^2 - (7\ \Omega)^2} = 28.13\ \Omega$

$L = \dfrac{X_L}{2\pi f} = \dfrac{28.13\ \Omega}{(2\pi)(50\text{ Hz})} = \mathbf{89.54\ mH}$

c. $P = I^2R = (1.7\text{ A})^2\ 10\ \Omega = \mathbf{28.9\ W}$

$Z_T = \dfrac{E}{I} = \dfrac{60\text{ V}}{1.7\text{ A}} = 35.29\ \Omega$

$X_L = \sqrt{(35.29\ \Omega)^2 - (10\ \Omega)^2} = 33.84\ \Omega$

$L = \dfrac{X_L}{2\pi f} = \dfrac{38.84\,\Omega}{314} = \mathbf{107.77\ mH}$

Chapter 20

1. a. $\omega_s = \dfrac{1}{\sqrt{LC}} = \dfrac{1}{\sqrt{1\text{ H})(16\,\mu\text{F})}} = \mathbf{250\ rad/s}$

$f_s = \dfrac{\omega_s}{2\pi} = \dfrac{250\text{ rad/s}}{2\pi} = \mathbf{39.79\ Hz}$

b. $\omega_s = \dfrac{1}{\sqrt{(0.5\text{ H})(0.16\,\mu\text{F})}} = \mathbf{3535.53\ rad/s}$

$f_s = \dfrac{\omega_s}{2\pi} = \dfrac{3535.53\text{ rad/s}}{2\pi} = \mathbf{562.7\ Hz}$

c. $\omega_s = \dfrac{1}{\sqrt{(0.28\text{ mH})(7.46\,\mu\text{F})}} = \mathbf{21{,}880\ rad/s}$

$f_s = \dfrac{\omega_s}{2\pi} = \dfrac{21{,}880\text{ rad/s}}{2\pi} = \mathbf{3482.31\ Hz}$

2. a. $X_C = \mathbf{30\ \Omega}$ b. $Z_{T_s} = \mathbf{10\ \Omega}$ c. $I = \dfrac{E}{Z_{T_s}} = \dfrac{50\text{ mV}}{10\,\Omega} = \mathbf{5\ mA}$

d. $V_R = IR = (5\text{ mA})(10\ \Omega) = \mathbf{50\ mV} = E$
$V_L = IX_L = (5\text{ mA})(30\ \Omega) = \mathbf{150\ mV}$
$V_C = IX_C = (5\text{ mA})(30\ \Omega) = \mathbf{150\ mV}$
$V_L = V_C$

e. $Q_s = \dfrac{X_L}{R} = \dfrac{30\,\Omega}{10\,\Omega} = \mathbf{3}$ (low Q) f. $P = I^2R = (5\text{ mA})^2\ 10\ \Omega = \mathbf{0.25\ mW}$

3. a. $X_L = \mathbf{40\ \Omega}$

b. $I = \dfrac{E}{Z_{T_s}} = \dfrac{20\text{ mV}}{2\,\Omega} = \mathbf{10\ mA}$

c. $V_R = IR = (10\text{ mA})(2\ \Omega) = \mathbf{20\ mV} = E$
$V_L = IX_L = (10\text{ mA})(40\ \Omega) = \mathbf{400\ mV}$
$V_C = IX_C = (10\text{ mA})(40\ \Omega) = \mathbf{400\ mV}$
$V_L = V_C = 20\ V_R$

d. $Q_s = \dfrac{X_L}{R} = \dfrac{40\,\Omega}{2\,\Omega} = \mathbf{20}$ (high Q)

e. $X_L = 2\pi fL,\ L = \dfrac{X_L}{2\pi f} = \dfrac{40\,\Omega}{2\pi(5\text{ kHz})} = \mathbf{1.27\ mH}$

$X_C = \dfrac{1}{2\pi fC},\ C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{2\pi(5\text{ kHz})(40\,\Omega)} = \mathbf{795.77\ nF}$

f. $BW = \dfrac{f_s}{Q_s} = \dfrac{5\text{ kHz}}{20} = \mathbf{250\ Hz}$

g. $f_2 = f_s + \dfrac{BW}{2} = 5\text{ kHz} + \dfrac{0.25\text{ kHz}}{2} = \mathbf{5.13\ kHz}$

$f_1 = f_s - \dfrac{BW}{2} = 5\text{ kHz} - \dfrac{0.25\text{ kHz}}{2} = \mathbf{4.88\ kHz}$

4. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} \Rightarrow L = \dfrac{1}{(2\pi f_s)^2 C} = \dfrac{1}{(2\pi\ 1.8\text{ kHz})^2\ 2\ \mu\text{F}} = \mathbf{3.91\ mH}$

b. $X_L = 2\pi fL = 2\pi(1.8\text{ kHz})(3.91\text{ mH}) = \mathbf{44.2\ \Omega}$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1.8\text{ kHz})(2\ \mu\text{F})} = \mathbf{44.2\ \Omega}$

$X_L = X_C$

c. $E_{\text{rms}} = (0.707)(20\text{ mV}) = 14.14\text{ mV}$

$I_{\text{rms}} = \dfrac{E_{\text{rms}}}{R} = \dfrac{14.14\text{ mV}}{4.7\ \Omega} = \mathbf{3.01\ mA}$

d. $P = I^2R = (3.01\text{ mA})^2\ 4.7\ \Omega = \mathbf{42.58\ \mu W}$

e. $S_T = P_T = \mathbf{42.58\ \mu VA}$

f. $F_p = \mathbf{1}$

g. $Q_s = \dfrac{X_L}{R} = \dfrac{44.2\ \Omega}{4.7\ \Omega} = \mathbf{9.4}$

$BW = \dfrac{f_s}{Q_s} = \dfrac{1.8\text{ kHz}}{9.4} = \mathbf{191.49\ Hz}$

h. $$f_2 = \frac{1}{2\pi}\left[\frac{R}{2L} + \frac{1}{2}\sqrt{\left(\frac{R}{L}\right)^2 + \frac{4}{LC}}\right]$$

$$= \frac{1}{2\pi}\left[\frac{4.7\ \Omega}{2(3.91\text{ mH})} + \frac{1}{2}\sqrt{\left(\frac{4.7\ \Omega}{3.91\text{ mH}}\right)^2 + \frac{4}{(3.91\text{ mH})(2\ \mu\text{F})}}\right]$$

$$= \frac{1}{2\pi}\left[601.02 + 11.324\times10^3\right]$$

$= \mathbf{1897.93\ Hz}$

$$f_1 = \frac{1}{2\pi}\left[-\frac{R}{2L} + \frac{1}{2}\sqrt{\left(\frac{R}{L}\right)^2 + \frac{4}{LC}}\right]$$

$$= \frac{1}{2\pi}\left[-601.02 + 11.324\times10^3\right]$$

$= \mathbf{1.71\ kHz}$

$P_{\text{HPF}} = \dfrac{1}{2}P_{\max} = \dfrac{1}{2}(42.58\ \mu\text{W}) = \mathbf{21.29\ \mu W}$

5. a. $BW = f_s/Q_s = 6000 \text{ Hz}/15 = \mathbf{400\ Hz}$

b. $f_2 = f_s + \dfrac{BW}{2} = 6000 \text{ Hz} + 200 \text{ Hz} = \mathbf{6200\ Hz}$

$f_1 = f_s - \dfrac{BW}{2} = 6000 \text{ Hz} - 200 \text{ Hz} = \mathbf{5800\ Hz}$

c. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_sR = (15)(3\ \Omega) = \mathbf{45\ \Omega} = X_C$

d. $P_{\text{HPF}} = \dfrac{1}{2}P_{\max} = \dfrac{1}{2}(I^2R) = \dfrac{1}{2}(0.5\text{ A})^2\,3\Omega = \mathbf{375\ mW}$

6. a. $L = \dfrac{X_L}{2\pi f} = \dfrac{200\,\Omega}{2\pi(10^4\text{ Hz})} = 3.185\text{ mH}$

$BW = \dfrac{R}{2\pi L} = \dfrac{5\,\Omega}{2\pi(3.185\text{ mH})} \cong \mathbf{250\ Hz}$

or $Q_s = \dfrac{X_L}{R} = \dfrac{X_C}{R} = \dfrac{200\,\Omega}{5\,\Omega} = 40$, $BW = \dfrac{f_s}{Q_s} = \dfrac{10{,}000\text{ Hz}}{40} = \mathbf{250\ Hz}$

b. $f_2 = f_s + BW/2 = 10{,}000\text{ Hz} + 250\text{ Hz}/2 = \mathbf{10{,}125\ Hz}$
$f_1 = f_s - BW/2 = 10{,}000\text{ Hz} - 125\text{ Hz} = \mathbf{9{,}875\ Hz}$

c. $Q_s = \dfrac{X_L}{R} = \dfrac{200\,\Omega}{5\,\Omega} = \mathbf{40}$

d. $\mathbf{I} = \dfrac{E\angle 0°}{R\angle 0°} = \dfrac{30\text{ V}\angle 0°}{5\,\Omega\angle 0°} = 6\text{ A}\angle 0°$, $\mathbf{V}_L = (I\angle 0°)(X_L\angle 90°)$

$= (6\text{ A}\angle 0°)(200\ \Omega\angle 90°)$
$= \mathbf{1200\ V\angle 90°}$

$\mathbf{V}_C = (I\angle 0°)(X_C\angle -90°) = \mathbf{1200\ V\angle -90°}$

e. $P = I^2R = (6\text{ A})^2\,5\ \Omega = \mathbf{180\ W}$

7. a. $BW = \dfrac{f_s}{Q_s} \Rightarrow Q_s = f_s/BW = 2000\text{ Hz}/200\text{ Hz} = \mathbf{10}$

b. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_sR = (10)(2\ \Omega) = \mathbf{20\ \Omega}$

c. $L = \dfrac{X_L}{2\pi f} = \dfrac{20\,\Omega}{(6.28)(2\text{ kHz})} = \mathbf{1.59\ mH}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{(6.28)(2\text{ kHz})(20\,\Omega)} = \mathbf{3.98\ \mu F}$

d. $f_2 = f_s + BW/2 = 2000\text{ Hz} + 100\text{ Hz} = \mathbf{2100\ Hz}$
$f_1 = f_s - BW/2 = 2000\text{ Hz} - 100\text{ Hz} = \mathbf{1900\ Hz}$

8. a. $BW = 6000\text{ Hz} - 5400\text{ Hz} = \mathbf{600\ Hz}$

b. $BW = f_s/Q_s \Rightarrow f_s = Q_s BW = (9.5)(600\text{ Hz}) = \mathbf{5700\ Hz}$

c. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = X_C = Q_s R = (9.5)(2\ \Omega) = \mathbf{19\ \Omega}$

d. $L = \dfrac{X_L}{2\pi f} = \dfrac{19\ \Omega}{2\pi(5700\text{ Hz})} = \mathbf{0.53\ mH}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{2\pi(5.7\text{ kHz})(19\ \Omega)} = \mathbf{1.47\ \mu F}$

9. $I_M = \dfrac{E}{R} \Rightarrow R = \dfrac{E}{I_M} = \dfrac{5\text{ V}}{500\text{ mA}} = \mathbf{10\ \Omega}$

$BW = f_s/Q_s \Rightarrow Q_s = f_s/BW = 8400\text{ Hz}/120\text{ Hz} = 70$

$Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_s R = (70)(10\ \Omega) = \mathbf{700\ \Omega}$

$X_C = X_L = \mathbf{700\ \Omega}$

$L = \dfrac{X_L}{2\pi f} = \dfrac{700\ \Omega}{(2\pi)(8.4\text{ kHz})} = \mathbf{13.26\ mH}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{(2\pi)(8.4\text{ kHz})(0.7\text{ k}\Omega)} = \mathbf{27.07\ nF}$

$f_2 = f_s + BW/2 = 8400\text{ Hz} + 120\text{ Hz}/2 = \mathbf{8460\ Hz}$
$f_1 = f_s - BW/2 = 8400\text{ Hz} - 60\text{ Hz} = \mathbf{8340\ Hz}$

10. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_s R = 20(2\ \Omega) = \mathbf{40\ \Omega} = X_C$

$BW = \dfrac{f_s}{Q_s} \Rightarrow f_s = Q_s BW = (20)(400\text{ Hz}) = \mathbf{8\ kHz}$

$L = \dfrac{X_L}{2\pi f} = \dfrac{40\ \Omega}{2\pi(8\text{ kHz})} = \mathbf{795.77\ \mu H}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{2\pi(8\text{ kHz})(40\ \Omega)} = \mathbf{497.36\ nF}$

$f_2 = f_s + BW/2 = 8000\text{ Hz} + 400\text{ Hz}/2 = \mathbf{8200\ Hz}$
$f_1 = f_s - BW/2 = 8000\text{ Hz} - 200\text{ Hz} = \mathbf{7800\ Hz}$

11. a. $f_s = \dfrac{\omega_s}{2\pi} = \dfrac{2\pi \times 10^6\text{ rad/s}}{2\pi} = \mathbf{1\ MHz}$

b. $\dfrac{f_2 - f_1}{f_s} = 0.16 \Rightarrow BW = f_2 - f_1 = 0.16 f_s = 0.16(1\text{ MHz}) = \mathbf{160\ kHz}$

c. $P = \dfrac{V_R^2}{R} \Rightarrow R = \dfrac{V_R^2}{P} = \dfrac{(120\text{ V})^2}{20\text{ W}} = \mathbf{720\ \Omega}$

$BW = \dfrac{R}{2\pi L} \;\Rightarrow\; L = \dfrac{R}{2\pi BW} = \dfrac{720\,\Omega}{(6.28)(160\text{ kHz})} = \mathbf{0.716\ mH}$

$f_s = \dfrac{1}{2\pi\sqrt{LC}} \Rightarrow C = \dfrac{1}{4\pi^2 f_s^2 L} = \dfrac{1}{4\pi^2(10^6\text{ Hz})^2(0.716\text{ mH})} = \mathbf{35.38\ pF}$

d. $Q_\ell = \dfrac{X_L}{R_\ell} = 80 \Rightarrow R_\text{P} = \dfrac{X_L}{80} = \dfrac{2\pi f_s L}{80} = \dfrac{2\pi(10^6\text{ Hz})(0.716\text{ mH})}{80} = \mathbf{56.23\ \Omega}$

12. a. $Q_\ell = \dfrac{X_L}{R_\ell}$

$R_\ell = \dfrac{X_L}{Q_\ell} = \dfrac{2\pi fL}{Q_\ell} = \dfrac{2\pi(1\text{MHz})(100\,\mu\text{H})}{12.5} = 50.27\ \Omega$

$\dfrac{f_2 - f_1}{f_s} = \dfrac{1}{Q_s} = 0.2$

$Q_s = \dfrac{1}{0.2} = 5 = \dfrac{X_L}{R} = \dfrac{2\pi fL}{R} = \dfrac{2\pi(1\text{ MHz})(100\,\mu\text{H})}{R} = \dfrac{628.32\,\Omega}{R}$

$R = \dfrac{628.32\,\Omega}{5} = 125.66$

$R = R_d + R_\ell$

$125.66\ \Omega = R_d + 50.27\ \Omega$

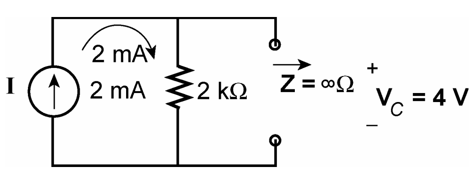
and $R_d = 125.66\ \Omega - 50.27\ \Omega = \mathbf{75.39\ \Omega}$

c. $X_C = \dfrac{1}{2\pi fC} = X_L$

$C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{2\pi(1\text{ MHz})(628.32\,\Omega)} = \mathbf{253.3\ pF}$

13. a. $f_p = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{2}{2\pi\sqrt{(0.1\text{ mH})(10\text{ nF})}} = \mathbf{159.16\ kHz}$

b.



c. $I_L = \dfrac{V_L}{X_L} = \dfrac{4\text{ V}}{2\pi f_p L} = \dfrac{4\text{ V}}{100\,\Omega} = \mathbf{40\ mA}$

$I_C = \dfrac{V_L}{X_C} = \dfrac{4\text{ V}}{1/2\pi f_p C} = \dfrac{4\text{ V}}{100\,\Omega} = \mathbf{40\ mA}$

d. $Q_p = \dfrac{R_s}{X_{L_p}} = \dfrac{2\text{ k}\Omega}{2\pi f_p L} = \dfrac{2\text{ k}\Omega}{100\,\Omega} = \mathbf{20}$

14. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(0.5\text{ mH})(30\text{ nF})}} = \mathbf{41.09\ kHz}$

b. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{2\pi fL}{R_\ell} = \dfrac{2\pi(41.09\text{ kHz})(0.5\text{ mH})}{8\,\Omega} = \mathbf{16.14} \geq 10$ (yes)

c. Since $Q_\ell \geq 10, f_p \cong f_s = \mathbf{41.09\ kHz}$

d. $X_L = 2\pi f_p L = 2\pi(41.09\text{ kHz})(0.5\text{ mH}) = \mathbf{129.1\ \Omega}$

$X_C = \dfrac{2}{2\pi f_p C} = \dfrac{2}{2\pi(41.09\text{ kHz})(30\text{ nF})} = \mathbf{129.1\ \Omega}$

$X_L = X_C$

e. $Z_{T_p} = Q_\ell^2 R_\ell = (16.14)^2\ 8\ \Omega = \mathbf{2.084\ k\Omega}$

f. $V_C = IZ_{T_p} = (10\text{ mA})(2.084\text{ k}\Omega) = \mathbf{20.84\ V}$

g. $Q_\ell \geq 10,\ Q_p = Q_\ell = \mathbf{16.14}$

$BW = \dfrac{f_p}{Q_p} = \dfrac{41.09\text{ kHz}}{16.14} = \mathbf{2545.85\ Hz}$

h. $I_L = I_C = Q_\ell I_T = (16.14)(10\text{ mA}) = \mathbf{161.4\ mA}$

15. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(0.1\text{ mH})(2\,\mu\text{F})}} = \mathbf{11{,}253.95\ Hz}$

b. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{2\pi f_s L}{R_\ell} = \dfrac{2\pi(11{,}253.95\text{ Hz})(0.1\text{ mH})}{4\,\Omega} = \mathbf{1.77}$ (low Q_ℓ)

c. $f_p = f_s\sqrt{1 - \dfrac{R_\ell^2 C}{L}} = 11{,}253.95\text{ Hz}\ \sqrt{1 - \dfrac{(4\,\Omega)^2\ 2\,\mu\text{F}}{0.1\text{ mH}}} = 11{,}253.95\text{ Hz}(0.825)$

$= \mathbf{9{,}280.24\ Hz}$

$f_m = f_s\sqrt{1 - \dfrac{1}{4}\left[\dfrac{R_\ell^2 C}{L}\right]} = 11{,}253.95\text{ Hz}\ \sqrt{1 - \dfrac{1}{4}\left[\dfrac{(4\,\Omega)^2\ 2\,\mu\text{F}}{0.1\text{ mH}}\right]}$

$= 11{,}253.95\text{ Hz}(0.996) = \mathbf{10{,}794.41\ Hz}$

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. $V_C = IZ_{T_p} = (2 \text{ mA})(12.5\ \Omega) = \mathbf{25\ mV}$

g. Since $R_s = \infty\ \Omega$ $$Q_p = Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_p L}{R_\ell} = \frac{2\pi(9{,}280.24\text{ Hz})(0.1\text{ mH})}{4\ \Omega} = \mathbf{1.46}$$

$$BW = \frac{f_p}{Q_p} = \frac{9{,}280.24\text{ Hz}}{1.46} = \mathbf{6.36\ kHz}$$

h. $$I_C = \frac{V_C}{X_C} = \frac{25\text{ mV}}{8.57\ \Omega} = \mathbf{2.92\ mA}$$

$$I_L = \frac{V_L}{Z_{R-L}} = \frac{V_C}{R_\ell + jX_L} = \frac{25\text{ mV}}{4\ \Omega + j5.83\ \Omega} = \frac{25\text{ mV}}{7.07\ \Omega} = \mathbf{3.54\ mA}$$

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. $\mathbf{E} = \mathbf{IZ}_{T_p} = (5 \text{ mA} \angle 0°)(342.11\ \Omega \angle 0°) = 1.711 \text{ V} \angle 0°$

$$\mathbf{I}_C = \frac{\mathbf{E}}{X_C \angle -90°} = \frac{1.711\text{ V}\angle 0°}{104\ \Omega \angle -90°} = \mathbf{16.45\ mA\ \angle 90°}$$

$\mathbf{Z}_L = 20\ \Omega + j100\ \Omega = 101.98\ \Omega \angle 78.69°$

$$\mathbf{I}_L = \frac{\mathbf{E}}{\mathbf{Z}_L} = \frac{1.711\text{ V}\angle 0°}{101.98\ \Omega \angle 78.69°} = \mathbf{16.78\ mA\ \angle -78.69°}$$

d. $$L = \frac{X_L}{2\pi f} = \frac{100\ \Omega}{2\pi(20\text{ kHz})} = \mathbf{795.77\ \mu H}$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(20\text{ kHz})(104\ \Omega)} = \mathbf{76.52\ nF}$$

e. $Q_p = \dfrac{R}{X_C} = \dfrac{342.11\,\Omega}{104\,\Omega} = \mathbf{3.29}$

$BW = f_p/Q_p = 20{,}000\text{ Hz}/3.29 = \mathbf{6079.03\ Hz}$

17. a. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{30\,\Omega}{2\,\Omega} = 15$ (use approximate approach): $X_C = X_L = \mathbf{30\ \Omega}$

b. $Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell = 450\,\Omega \parallel (15)^2\,2\,\Omega = 450\,\Omega \parallel 450\,\Omega = \mathbf{225\ \Omega}$

c. $\mathbf{E} = \mathbf{I}\,\mathbf{Z}_{T_p} = (80\text{ mA}\angle 0°)(225\,\Omega\angle 0°) = \mathbf{18\ V\angle 0°}$

$\mathbf{I}_C = \dfrac{\mathbf{E}}{X_C\angle -90°} = \dfrac{18\text{ V}\angle 0°}{30\,\Omega\angle -90°} = \mathbf{0.6\ A\angle 90°}$

$\mathbf{I}_L = \dfrac{\mathbf{E}}{\mathbf{Z}_{R\text{-}L}} = \dfrac{18\text{ V}\angle 0°}{2\,\Omega + j30\,\Omega} = \dfrac{18\text{ V}\angle 0°}{30.07\,\Omega\angle 86.19°} \cong \mathbf{0.6\ A\angle -86.19°}$

d. $X_L = 2\pi f_p L,\ L = \dfrac{X_L}{2\pi f_p} = \dfrac{30\,\Omega}{2\pi(20\times 10^3\text{ Hz})} = \mathbf{0.239\ mH}$

$X_C = \dfrac{1}{2\pi f_p C},\ C = \dfrac{1}{2\pi f_p X_C} = \dfrac{1}{2\pi(20\times 10^3\text{ Hz})(30\,\Omega)} = \mathbf{265.26\ nF}$

e. $Q_p = \dfrac{Z_{T_p}}{X_L} = \dfrac{225\,\Omega}{30\,\Omega} = \mathbf{7.5},\ BW = \dfrac{f_p}{Q_p} = \dfrac{20{,}000\text{ Hz}}{7.5} = \mathbf{2.67\ kHz}$

18. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(80\,\mu\text{H})(0.03\,\mu\text{F})}} = \mathbf{102.73\ kHz}$

$f_p = f_s\sqrt{1 - \dfrac{R_\ell^2 C}{L}} = 102.73\text{ kHz}\sqrt{1 - \dfrac{(1.5\,\Omega)^2\,0.03\,\mu\text{F}}{80\,\mu\text{H}}} = 102.73\text{ kHz}(.99958)$

$= \mathbf{102.69\ kHz}$

$f_m = f_s\sqrt{1 - \dfrac{1}{4}\left[\dfrac{R_\ell^2 C}{L}\right]} = 102.73\text{ kHz}(0.99989) = \mathbf{102.72\ kHz}$

Since $f_s \cong f_p \cong f_m \Rightarrow$ high Q_p

b. $X_L = 2\pi f_p L = 2\pi(102.69\text{ kHz})(80\,\mu\text{H}) = \mathbf{51.62\ \Omega}$

$X_C = \dfrac{1}{2\pi f_p C} = \dfrac{1}{2\pi(102.69\text{ kHz})(0.03\,\mu\text{F})} = \mathbf{51.66\ \Omega}$

$X_L \cong X_C$

c. $Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{51.62\,\Omega}{1.5\,\Omega} = 34.41$$

$$Z_{T_p} = 10\text{ k}\Omega \parallel (34.41)^2 1.5\,\Omega = 10\text{ k}\Omega \parallel 1.776\text{ k}\Omega = \mathbf{1.51\ k\Omega}$$

d. $$Q_p = \frac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \frac{Z_{T_p}}{X_L} = \frac{1.51\text{ k}\Omega}{51.62\,\Omega} = \mathbf{29.25}$$

$$BW = \frac{f_p}{Q_p} = \frac{102.69\text{ kHz}}{29.25} = \mathbf{3.51\ kHz}$$

e. $$I_T = \frac{R_s I_s}{R_s + Q_\ell^2 R_\ell} = \frac{10\text{ k}\Omega(10\text{ mA})}{10\text{ k}\Omega + 1.78\text{ k}\Omega} = 8.49\text{ mA}$$

$$I_C = I_L \cong Q_\ell I_T = (34.41)(8.49\text{ mA}) = \mathbf{292.14\ mA}$$

f. $V_C = IZ_{T_p} = (10\text{ mA})(1.51\text{ k}\Omega) = \mathbf{15.1\ V}$

19. a. $$f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.5\text{ mH})(1\,\mu\text{F})}} = \mathbf{7.12\ kHz}$$

$$f_p = f_s\sqrt{1 - \frac{R_\ell^2 C}{L}} = 7.12\text{ kHz}\sqrt{1 - \frac{(8\,\Omega)^2(1\,\mu\text{F})}{0.5\text{ mH}}} = 7.12\text{ kHz}(0.9338) = \mathbf{6.65\ kHz}$$

$$f_m = f_s\sqrt{1 - \frac{1}{4}\left[\frac{R_\ell^2 C}{L}\right]} = 7.12\text{ kHz}\sqrt{1 - \frac{1}{4}\left[\frac{(8\,\Omega)^2(1\,\mu\text{F})}{0.5\text{ mH}}\right]} = 7.12\text{ kHz}\ (0.9839)$$

$$= \mathbf{7.01\ kHz}$$

Low Q_p

b. $X_L = 2\pi f_p L = 2\pi(6.647\text{ kHz})(0.5\text{ mH}) = 20.88\,\Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6.647\text{ kHz})(1\,\mu\text{F})} = 23.94\,\Omega$$

$X_C > X_L$ (low Q)

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. $$Q_p = \frac{Z_{T_p}}{X_{L_p}} = \frac{55.56\,\Omega}{23.94\,\Omega} = \mathbf{2.32}$$

$$BW = \frac{f_p}{Q_p} = \frac{6.647\text{ kHz}}{2.32} = \mathbf{2.87\ kHz}$$

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. $$Z_{T_p} = \frac{R_\ell^2 + X_L^2}{R_\ell} = 50\text{ k}\Omega$$

$$(50\ \Omega)^2 + X_L^2 = (50\text{ k}\Omega)(50\ \Omega)$$

$$X_L = \sqrt{250\times10^4 - 2.5\times10^3} = \mathbf{1580.3\ \Omega}$$

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. $$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi fL}{R_\ell} \Rightarrow R_\ell = \frac{2\pi fL}{Q_\ell} = \frac{2\pi(3558.81\text{ Hz})(0.2\text{ H})}{20} = 223.61\ \Omega$$

$$Z_{T_p} = R_s \parallel R_p = R_s \parallel Q_\ell^2 R_\ell = 40\text{ k}\Omega \parallel (20)^2\ 223.61\ \Omega$$

$$Z_{T_p} = 27.64\text{ k}\Omega$$

$$V_C = IZ_{T_p} = (5\text{ mA})(27.64\text{ k}\Omega) = \mathbf{138.2\text{ V}}$$

c. $P = I^2R = (5\text{ mA})^2 27.64\text{ k}\Omega = \mathbf{691\text{ mW}}$

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. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{400\ \Omega}{8\ \Omega} = \mathbf{50}$

c. $Q_p = \dfrac{R}{X_L} = \dfrac{R_s \parallel R_p}{X_L} = \dfrac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \dfrac{20\text{ k}\Omega \parallel (50)^2\ 8\ \Omega}{400\ \Omega} = \dfrac{10\text{ k}\Omega}{400\ \Omega} = \mathbf{25}$

$BW = \dfrac{f_p}{Q_p} \Rightarrow f_p = Q_p BW = (25)(1000\text{ Hz}) = \mathbf{25\ kHz}$

d. $V_{C_{\max}} = IZ_{T_p} = (0.1\text{ mA})(10\text{ k}\Omega) = \mathbf{1\ V}$

e. $f_2 = f_p + BW/2 = 25\text{ kHz} + \dfrac{1\text{ kHz}}{2} = \mathbf{25.5\ kHz}$

$f_1 = f_p - BW/2 = 25\text{ kHz} - \dfrac{1\text{ kHz}}{2} = \mathbf{24.5\ kHz}$

23. a. $X_C = \dfrac{R_\ell^2 + X_L^2}{X_L} \Rightarrow X_L^2 - X_L X_C + R_\ell^2 = 0$

$$X_L^2 - 100\ X_L + 144 = 0$$

$$X_L = \frac{-(-100) \pm \sqrt{(100)^2 - 4(1)(144)}}{2}$$

$$= 50\ \Omega \pm \frac{\sqrt{10^4 - 576}}{2} = 50\ \Omega \pm 48.54\ \Omega$$

$$X_L = \mathbf{98.54\ \Omega} \text{ or } 1.46\ \Omega$$

b. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{98.54\ \Omega}{12\ \Omega} = \mathbf{8.21}$

c. $Q_p = \dfrac{R_s \parallel R_p}{X_{L_p}} = \dfrac{40\text{ k}\Omega \parallel \dfrac{R_\ell^2 + X_L^2}{R_\ell}}{X_C} = \dfrac{40\text{ k}\Omega \parallel \dfrac{(12\ \Omega)^2 + (98.54\ \Omega)^2}{12\ \Omega}}{100\ \Omega}$

$= \dfrac{40\text{ k}\Omega \parallel 821.18\ \Omega}{100\ \Omega} = \dfrac{804.66\ \Omega}{100\ \Omega} = \mathbf{8.05}$

$BW = f_p/Q_p \Rightarrow f_p = Q_p BW = (8.05)(1\text{ kHz}) = \mathbf{8.05\ kHz}$

d. $V_{C_{\max}} = IZ_{T_p} = (6\text{ mA})(804.66\ \Omega) = \mathbf{4.83\ V}$

e. $f_2 = f_p + BW/2 = 8.05\text{ kHz} + \dfrac{1\text{ kHz}}{2} = \mathbf{8.55\ kHz}$

$f_1 = f_p - BW/2 = 8.05\text{ kHz} - \dfrac{1\text{ kHz}}{2} = \mathbf{7.55\ kHz}$

24. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(0.5\text{ mH})(30\text{ nF})}} = \mathbf{41.09\ kHz}$

$$f_p = f_s\sqrt{1-\frac{R_\ell^2 C}{L}} = 41.09\text{ kHz}\ \sqrt{1-\frac{(6\,\Omega)^2\ 30\text{ nF}}{0.5\text{ mH}}} = 41.09\text{ kHz}(0.9978) = \mathbf{41\ kHz}$$

$$f_m = f_s\sqrt{1-\frac{1}{4}\left[\frac{R_\ell^2 C}{L}\right]} = 41.09\text{ kHz}\sqrt{1-\frac{1}{4}\left[\frac{(6\,\Omega)^2(30\text{ nF})}{0.5\text{ mH}}\right]} = 41.09\text{ kHz}(0.0995)$$

$$= \mathbf{41.07\ kHz}$$

High Q_p

b. $\mathbf{I} = \dfrac{80\text{ V}\ \angle 0°}{20\text{ k}\Omega\ \angle 0°} = 4\text{ mA}\ \angle 0°,\ R_s = 20\text{ k}\Omega$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi fL}{R_\ell} = \frac{2\pi(41\text{ kHz})(0.5\text{ mH})}{6\,\Omega} = \mathbf{21.47}\ (\text{high } Q \text{ coil})$$

$$Q_p = \frac{R_s \,\|\, R_p}{X_{L_p}} = \frac{R_s \,\|\, \dfrac{R_\ell^2 + X_L^2}{R_\ell}}{\dfrac{R_\ell^2 + X_L^2}{X_L}} = \frac{20\text{ k}\Omega \,\|\, \dfrac{(6\,\Omega)^2 + (128.81\,\Omega)^2}{6\,\Omega}}{\dfrac{(6\,\Omega)^2 + (128.81\,\Omega)^2}{128.81\,\Omega}}$$

$$= \frac{20\text{ k}\Omega \,\|\, 2.771\text{ k}\Omega}{129.09\,\Omega} = \frac{2.434\text{ k}\Omega}{129.09\,\Omega} = \mathbf{18.86\ (high\ } \boldsymbol{Q_p}\mathbf{)}$$

c. $Z_{T_p} = R_s \,\|\, R_p = 20\text{ k}\Omega \,\|\, 2.771\text{ k}\Omega = \mathbf{2.43\ k\Omega}$

d. $V_C = IZ_{T_p} = (4\text{ mA})(2.43\text{ k}\Omega) = \mathbf{9.74\ V}$

e. $BW = \dfrac{f_p}{Q_p} = \dfrac{41\text{ kHz}}{18.86} = \mathbf{2.17\ kHz}$

f. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(41\text{ kHz})(30\text{ nF})} = \mathbf{129.39\ \Omega}$

$$I_C = \frac{V_C}{X_C} = \frac{9.736\text{ V}}{129.39\,\Omega} = \mathbf{75.25\ mA}$$

$$I_L = \frac{V_C}{|R + jX_L|} = \frac{9.736\text{ V}}{6\,\Omega + j128.81\,\Omega} = \frac{9.736\text{ V}}{128.95\,\Omega} = \mathbf{75.50\ mA}$$

25. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{2\pi f_p L}{R_\ell} \Rightarrow R_\ell = \dfrac{2\pi f_p L}{Q_\ell} = \dfrac{2\pi(20\text{ kHz})(2\text{ mH})}{80} = \mathbf{3.14\ \Omega}$

$BW = f_p/Q_p \Rightarrow Q_p = f_p/BW = 20\text{ kHz}/1.8\text{ kHz} = \mathbf{11.11}$

High $Q \therefore$ $f_p \cong f_s = \dfrac{1}{2\pi\sqrt{LC}} \Rightarrow C = \dfrac{1}{4\pi^2 f_p^2 L} = \dfrac{1}{4\pi^2(20\text{ kHz})^2\ 2\text{ mH}} = \mathbf{31.66\ nF}$

$Q_p = \dfrac{R}{X_C} \Rightarrow R = Q_p X_C = \dfrac{Q_p}{2\pi f_p C} = \dfrac{11.11}{2\pi(20\text{ kHz})(31.66\text{ nF})} = \mathbf{2.79\ k\Omega}$

$R_p = Q_\ell^2 R_\ell = (80)^2\, 3.14\ \Omega = 20.1\ \text{k}\Omega$

$$R = R_s \parallel R_p = \frac{R_s R_p}{R_s + R_p} \Rightarrow R_s = \frac{R_p R}{R_p - R} = \frac{(20.1\,\text{k}\Omega)(2.793\,\text{k}\Omega)}{20.1\,\text{k}\Omega - 2.793\,\text{k}\Omega} = \mathbf{3.24\ k\Omega}$$

26. $$V_{C_{\max}} = IZ_{T_p} \Rightarrow Z_{T_p} = \frac{V_{C_{\max}}}{I} = \frac{1.8\ \text{V}}{0.2\ \text{mA}} = 9\ \text{k}\Omega$$

$$Q_p = \frac{R}{X_L} = \frac{R_s \parallel R_p}{X_L} = \frac{R_p}{X_L} \Rightarrow X_L = \frac{R_p}{Q_p} = \frac{9\ \text{k}\Omega}{30} = \mathbf{300\ \Omega} = X_C$$

$$BW = \frac{f_p}{Q_p} \Rightarrow f_p = Q_p BW = (30)(500\ \text{Hz}) = \mathbf{15\ kHz}$$

$$L = \frac{X_L}{2\pi f} = \frac{300\ \Omega}{2\pi(15\ \text{kHz})} = \mathbf{3.18\ mH}$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(15\ \text{kHz})(300\ \Omega)} = \mathbf{35.37\ nF}$$

$$Q_p = Q_\ell\,(R_s = \infty\ \Omega) = \frac{X_L}{R_\ell} \Rightarrow R_\ell = \frac{X_L}{Q_p} = \frac{300\ \Omega}{30} = \mathbf{10\ \Omega}$$

27. a. $$f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(200\ \mu\text{H})(2\ \text{nF})}} = 251.65\ \text{kHz}$$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi(251.65\ \text{kHz})(200\ \mu\text{H})}{20\ \Omega} = 15.81 \geq 10$$

$\therefore f_p = f_s = \mathbf{251.65\ kHz}$

b. $Z_{T_p} = R_s \parallel Q_\ell^2 R_\ell = 40\ \text{k}\Omega \parallel (15.81)^2\ 20\ \Omega = \mathbf{4.44\ k\Omega}$

c. $$Q_p = \frac{R_s \parallel Q_\ell^2 R_\ell}{X_L} = \frac{4.444\ \text{k}\Omega}{316.23\ \Omega} = \mathbf{14.05}$$

d. $$BW = \frac{f_p}{Q_p} = \frac{251.65\ \text{kHz}}{14.05} = \mathbf{17.91\ kHz}$$

e. **20 μH, 20 nF**

f_s the same since product LC the same

$f_s = 251.65$ 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:

$$f_p = f_s\sqrt{1 - \frac{R_\ell^2 C}{L}} = (251.65\ \text{kHz})\sqrt{1 - \frac{(20\ \Omega)^2(20\ \text{nF})}{20\ \mu\text{H}}}$$

$$= (251.65\ \text{kHz})(0.775) = \mathbf{194.93\ kHz}$$

$X_L = 2\pi f_p L = 2\pi(194.93 \text{ kHz})(20 \text{ μH}) = 24.496 \ \Omega$

$$R_p = \frac{R_\ell^2 + X_L^2}{R_\ell} = \frac{(20\,\Omega)^2 + (24.496\,\Omega)^2}{20\,\Omega} = 50\ \Omega$$

$Z_{T_p} = R_s \parallel R_p = 40 \text{ k}\Omega \parallel 50\ \Omega = \mathbf{49.94\ \Omega}$

$$Q_p = \frac{R}{X_L} = \frac{49.94\,\Omega}{24.496\,\Omega} = \mathbf{2.04}$$

$$BW = \frac{f_p}{Q_p} = \frac{194.93 \text{ kHz}}{2.04} = \mathbf{95.55 \text{ kHz}}$$

f. **0.4 mH, 1 nF**

$f_s = 251.65$ 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 $\dfrac{L}{C} = \dfrac{200\,\mu\text{H}}{2 \text{ nF}} = \mathbf{100 \times 10^3}$

part (e) $\dfrac{L}{C} = \dfrac{20\,\mu\text{H}}{20 \text{ nF}} = \mathbf{1 \times 10^3}$

part (f) $\dfrac{L}{C} = \dfrac{0.4 \text{ mH}}{1 \text{ nF}} = \mathbf{400 \times 10^3}$

h. Yes, as $\dfrac{L}{C}$ 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: $d_1 = \frac{3}{16}'' = 0.1875''$, $d_2 = 1''$

$$\text{Value} = 10^3 \times 10^{0.1875''/1''}$$
$$= 10^3 \times 1.54$$
$$= \mathbf{1.54\ kHz}$$

right: $d_1 = \frac{3}{4}'' = 0.75''$, $d_2 = 1''$

$$\text{Value} = 10^3 \times 10^{0.75''/1''}$$
$$= 10^3 \times 5.623$$
$$= \mathbf{5.62\ kHz}$$

b. bottom: $d_1 = \frac{5}{16}'' = 0.3125''$, $d_2 = \frac{15}{16}'' = 0.9375''$

$$\text{Value} = 10^{-1} \times 10^{0.3125''/0.9375''} = 10^{-1} \times 10^{0.333}$$
$$= 10^{-1} \times 2.153$$
$$= \mathbf{0.22\ V}$$

top: $d_1 = \frac{11}{16}'' = 0.6875''$, $d_2 = 0.9375''$

$$\text{Value} = 10^{-1} \times 10^{0.6875''/0.9375''} = 10^{-1} \times 10^{0.720}$$
$$= 10^{-1} \times 5.248$$
$$= \mathbf{0.52\ V}$$

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. $\mathbf{10^{12}}$ c. **1.59** d. **1.1**

e. $\mathbf{10^{10}}$ 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. bels $= \log_{10} \dfrac{P_2}{P_1} = \log_{10} \dfrac{280 \text{ mW}}{4 \text{ mW}} = \log_{10} 70 = \mathbf{1.85}$

b. dB $= 10 \log_{10} \dfrac{P_2}{P_1} = 10(\log_{10} 70) = 10(1.845) = \mathbf{18.45}$

10. $\text{dB} = 10 \log_{10} \dfrac{P_2}{P_1}$

$6 \text{ dB} = 10 \log_{10} \dfrac{100 \text{ W}}{P_1}$

$0.6 = \log_{10} x$

$x = 3.981 = \dfrac{100 \text{ W}}{P_1}$

$P_1 = \dfrac{100 \text{ W}}{3.981} = \mathbf{25.12\ W}$

11. $\text{dB} = 10 \log_{10} \dfrac{P_2}{P_1} = 10 \log_{10} \dfrac{40 \text{ W}}{2 \text{ W}} = 10 \log_{10} 20 = \mathbf{13.01}$

12. $\text{dB}_m = 10 \log_{10} \dfrac{P}{1 \text{ mW}}$

$\text{dB}_m = 10 \log_{10} \dfrac{120 \text{ mW}}{1 \text{ mW}} = 10 \log_{10} 120 = \mathbf{20.79}$

13. $\text{dB}_v = 20 \log_{10} \dfrac{V_2}{V_1} = 20 \log_{10} \dfrac{8.4 \text{ V}}{0.1 \text{ V}} = 20 \log_{10} 84 = \mathbf{38.49}$

14. $\text{dB}_v = 20 \log_{10} \dfrac{V_2}{V_1}$

$22 = 20 \log_{10} \dfrac{V_o}{20 \text{ mV}}$

$1.1 = \log_{10} x$

$x = 12.589 = \dfrac{V_o}{20 \text{ mV}}$

$V_o = \mathbf{251.79\ mV}$

15. $\text{dB}_s = 20 \log_{10} \dfrac{P}{0.0002\ \mu\text{bar}}$

$\text{dB}_s = 20 \log_{10} \dfrac{0.001\ \mu\text{bar}}{0.0002\ \mu\text{bar}} = \mathbf{13.98}$

$\text{dB}_s = 20 \log_{10} \dfrac{0.016\ \mu\text{bar}}{0.0002\ \mu\text{bar}} = \mathbf{38.06}$

Increase = $\mathbf{24.08\ dB_s}$

16. $60\text{ dB}_s \Rightarrow 90\text{ dB}_s$
quiet loud

$$60\text{ dB}_s = 20\log_{10}\frac{P_1}{0.002\ \mu\text{bar}} = 20\log_{10}x$$

$$3 = \log_{10}x$$
$$x = \mathbf{1000}$$

$$90\text{ dB}_s = 20\log_{10}\frac{P_2}{0.002\ \mu\text{bar}} = 20\log_{10}y$$

$$4.5 = \log_{10}y$$
$$y = \mathbf{31.623 \times 10^3}$$

$$\frac{x}{y} = \frac{\dfrac{P_1}{0.002\ \cancel{\mu\text{bar}}}}{\dfrac{P_2}{0.002\ \cancel{\mu\text{bar}}}} = \frac{P_1}{P_2} = \frac{\cancel{10^3}}{31.623 \times \cancel{10^3}}$$

and $P_2 = \mathbf{31.62\ P_1}$

18. a. $$8\text{ dB} = 20\log_{10}\frac{V_2}{0.775\text{ V}}$$

$$0.4 = \log_{10}\frac{V_2}{0.775\text{ V}}$$

$$\frac{V_2}{0.775\text{ V}} = 2.512$$

$$V_2 = (2.512)(0.775\text{ V}) = 1.947\text{ V}$$

$$P = \frac{V^2}{R} = \frac{(1.947\text{ V})^2}{600\ \Omega} = \mathbf{6.32\ mW}$$

b. $$-5\text{ dB} = 20\log_{10}\frac{V_2}{0.775\text{ V}}$$

$$-0.25 = \log_{10}\frac{V_2}{0.775\text{ V}}$$

$$\frac{V_2}{0.775\text{ V}} = 0.562$$

$$V_2 = (0.562)(0.775\text{ V}) = 0.436\text{ V}$$

$$P = \frac{V^2}{R} = \frac{(0.436\text{ V})^2}{600\ \Omega} = \mathbf{0.32\ mW}$$

19. a. $$A_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}}\angle{-90^\circ} + \tan^{-1} X_C/R = \frac{1}{\sqrt{\left(\dfrac{R}{X_C}\right)^2 + 1}}\ \angle{-\tan^{-1} R/X_C}$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2\text{ k}\Omega)(0.02\ \mu\text{F})} = \mathbf{3617.16\ Hz}$$

$f = f_c$: $\quad A_v = \dfrac{V_o}{V_i} = \mathbf{0.707}$

$f = 0.1f_c$: $\quad$ At f_c, $X_C = R = 2.2\text{ k}\Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi 0.1 f_c C} = \frac{1}{0.1}\left[\frac{1}{2\pi f_c C}\right] = 10\left[2.2\text{ k}\Omega\right] = 22\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{\left(\frac{R}{X_C}\right)^2 + 1}} = \frac{1}{\sqrt{\left(\frac{2.2\text{ k}\Omega}{22\text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(.1)^2 + 1}} = \mathbf{0.995}$$

$f = 0.5f_c = \frac{1}{2}f_c$:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi\left(\frac{f_c}{2}\right)C} = 2\left[\frac{1}{2\pi f_c C}\right] = 2\left[2.2\text{ k}\Omega\right] = 4.4\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{\left(\frac{2.2\text{ k}\Omega}{4.4\text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(0.5)^2 + 1}} = \mathbf{0.894}$$

$f = 2f_c$:

$$X_C = \frac{1}{2\pi(2f_c)C} = \frac{1}{2}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{2}\left[2.2\text{ k}\Omega\right] = 1.1\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{\left(\frac{2.2\text{ k}\Omega}{1.1\text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(2)^2 + 1}} = \mathbf{0.447}$$

$f = 10f_c$:

$$X_C = \frac{1}{2\pi(10f_c)C} = \frac{1}{10}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{10}\left[2.2\text{ k}\Omega\right] = 0.22\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{\left(\frac{2.2\text{ k}\Omega}{0.22\text{ k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(10)^2 + 1}} = \mathbf{0.0995}$$

b. $\theta = -\tan^{-1} R/X_C$

$f = f_c$: $\theta = -\tan^{-1} = \mathbf{-45°}$

$f = 0.1f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/22\text{ k}\Omega = -\tan^{-1}\frac{1}{10} = \mathbf{-5.71°}$

$f = 0.5f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/4.4\text{ k}\Omega = -\tan^{-1}\frac{1}{2} = \mathbf{-26.57°}$

$f = 2f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/1.1\text{ k}\Omega = -\tan^{-1} 2 = -\mathbf{63.43°}$

$f = 10f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/0.22\text{ k}\Omega = -\tan^{-1} 10 = \mathbf{-84.29°}$

20. a. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(1\text{ k}\Omega)(0.01\,\mu\text{F})} = 15.915\text{ kHz}$

$f = 2f_c = 31.83\text{ kHz}$

$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(31.83\text{ kHz})(0.01\,\mu\text{F})} = 500\ \Omega$

$A_\upsilon = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{500\ \Omega}{\sqrt{(1\text{ k}\Omega)^2 + (0.5\text{ k}\Omega)^2}} = 0.4472$

$V_o = 0.4472V_i = 0.4472(10\text{ mV}) = \mathbf{4.47\text{ mV}}$

b. $f = \dfrac{1}{10} f_c = \dfrac{1}{10}(15{,}915 \text{ kHz}) = 1.5915 \text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.5915 \text{ kHz})(0.01\,\mu\text{F})} = 10 \text{ k}\Omega$$

$$A_\upsilon = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{10\text{ k}\Omega}{\sqrt{(1\text{ k}\Omega)^2 + (10\text{ k}\Omega)^2}} = 0.995$$

$V_o = 0.995V_i = 0.995(10 \text{ mV}) = \mathbf{9.95 \text{ mV}}$

c. Yes, at $f = f_c$, $V_o = 7.07$ mV

at $f = \dfrac{1}{10} f_c$, $V_o = 9.95$ mV (much higher)

at $f = 2f_c$, $V_o = 4.47$ mV (much lower)

21. $f_c = 500 \text{ Hz} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(1.2\text{ k}\Omega)C}$

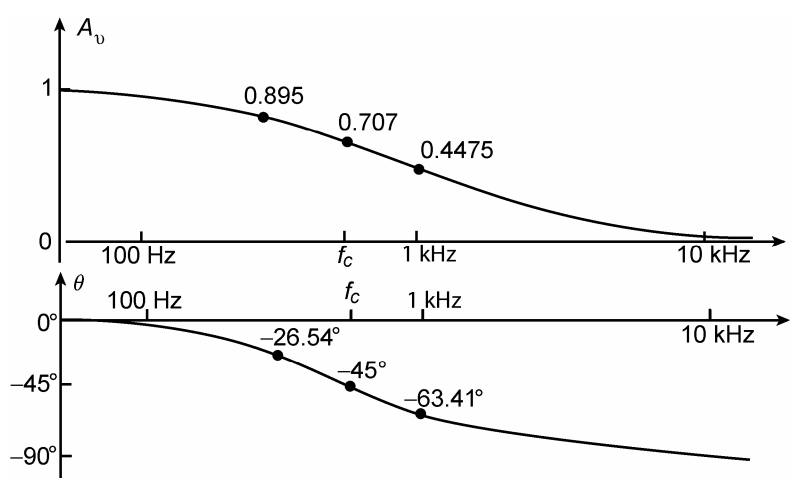
$$C = \frac{1}{2\pi R f_c} = \frac{1}{2\pi(1.2\text{ k}\Omega)(500 \text{ Hz})} = \mathbf{0.265\ \mu F}$$

$$A_\upsilon = \frac{V_o}{V_i} = \frac{1}{\sqrt{\left(\dfrac{R}{X_C}\right)^2 + 1}}$$

At $f = 250$ Hz, $X_C = 2402.33\ \Omega$ and $A_\upsilon = 0.895$
At $f = 1000$ Hz, $X_C = 600.58\ \Omega$ and $A_\upsilon = 0.4475$
$\theta = -\tan^{-1} R/X_C$

At $f = 250 \text{ Hz} = \dfrac{1}{2} f_c$, $\theta = -26.54°$

At $f = 1$ kHz $= 2f_c$, $\theta = -63.41°$



22. a. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(4.7\text{ k}\Omega)(500\text{ pF})} = \mathbf{67.73\ kHz}$

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. $f = 10f_c = 677.26\text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(677.26\text{ kHz})(500\text{ pF})} \cong 470\ \Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{470\ \Omega}{\sqrt{(4.7\text{ k}\Omega)^2 + (470\ \Omega)^2}} = \mathbf{0.0995} \cong 0.1$$

d. $A_v = \dfrac{V_o}{V_i} = 0.01 = \dfrac{X_C}{\sqrt{R^2 + X_C^2}}$

$$\sqrt{R^2 + X_C^2} = \frac{X_C}{0.01} = 100\ X_C$$

$$R^2 + X_C^2 = 10^4\ X_C^2$$

$$R^2 = 10^4\ X_C^2 - X_C^2 = 9{,}999\ X_C^2$$

$$X_C = \frac{R}{\sqrt{9{,}999}} = \frac{4.7\text{ k}\Omega}{99.995} \cong 47\ \Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(47\ \Omega)(500\text{ pF})} = \mathbf{6.77\ MHz}$$

23. a. $A_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{R}{\sqrt{R^2 + X_C^2}} \angle \tan^{-1} X_C/R = \dfrac{1}{\sqrt{1 + \left(\dfrac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2\text{ k}\Omega)(20\text{ nF})} = \mathbf{3.62\ kHz}$$

$f = f_c$: $A_v = \dfrac{V_o}{V_i} = \mathbf{0.707}$

$f = 2f_c$: At f_c, $X_C = R = 2.2\text{ k}\Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(2f_c)C} = \frac{1}{2}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{2}\left[2.2\text{ k}\Omega\right] = 1.1\text{ k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left(\dfrac{1.1\text{ k}\Omega}{2.2\text{ k}\Omega}\right)^2}} = \mathbf{0.894}$$

$$f = \frac{1}{2}f_c: \qquad X_C = \frac{1}{2\pi\left(\frac{f_c}{2}\right)C} = 2\left[\frac{1}{2\pi f_c C}\right] = 2\left[2.2\text{ k}\Omega\right] = 4.4\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{1+\left(\frac{4.4\text{ k}\Omega}{2.2\text{ k}\Omega}\right)^2}} = \mathbf{0.447}$$

$$f = 10f_c: \qquad X_C = \frac{1}{2\pi(10f_c)C} = \frac{1}{10}\left[\frac{1}{2\pi f_c C}\right] = \frac{2.2\text{ k}\Omega}{10} = 0.22\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{1+\left(\frac{0.22\text{ k}\Omega}{2.2\text{ k}\Omega}\right)^2}} = \mathbf{0.995}$$

$$f = \frac{1}{10}f_c: \qquad X_C = \frac{1}{2\pi\left(\frac{f_c}{10}\right)C} = 10\left[\frac{1}{2\pi f_c C}\right] = 10\left[2.2\text{ k}\Omega\right] = 22\text{ k}\Omega$$

$$A_\upsilon = \frac{1}{\sqrt{1+\left(\frac{22\text{ k}\Omega}{2.2\text{ k}\Omega}\right)^2}} = \mathbf{0.0995}$$

b. $f = f_c$, $\qquad \theta = \mathbf{45°}$

$f = 2f_c$, $\qquad \theta = \tan^{-1}(X_C/R) = \tan^{-1} 1.1\text{ k}\Omega/2.2\text{ k}\Omega = \tan^{-1}\frac{1}{2} = \mathbf{26.57°}$

$f = \frac{1}{2}f_c$, $\qquad \theta = \tan^{-1}\frac{4.4\text{ k}\Omega}{2.2\text{ k}\Omega} = \tan^{-1} 2 = \mathbf{63.43°}$

$f = 10f_c$, $\qquad \theta = \tan^{-1}\frac{0.22\text{ k}\Omega}{2.2\text{ k}\Omega} = \mathbf{5.71°}$

$f = \frac{1}{10}f_c$, $\qquad \theta = \tan^{-1}\frac{22\text{ k}\Omega}{2.2\text{ k}\Omega} = \mathbf{84.29°}$

24. a. $f = f_c$: $A_\upsilon = \frac{V_o}{V_i} = \mathbf{0.707}$

b. $$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(10\text{ k}\Omega)(1000\text{ pF})} = 15.915\text{ kHz}$$

$f = 4f_c = 4(15.915\text{ kHz}) = 63.66\text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(63.66\text{ kHz})(1000\text{ pF})} = 2.5\text{ k}\Omega$$

$$A_\upsilon = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10\text{ k}\Omega}{\sqrt{(10\text{ k}\Omega)^2 + (2.5\text{ k}\Omega)^2}} = \mathbf{0.970} \text{ (significant rise)}$$

c. $f = 100f_c = 100(15.915\text{ kHz}) = 1591.5\text{ kHz} \cong 1.592\text{ MHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.592\text{ MHz})(1000\text{ pF})} = 99.972\ \Omega$$

$$A_\upsilon = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10\text{ k}\Omega}{\sqrt{(10\text{ k}\Omega)^2 + (99.972\ \Omega)^2}} = 0.99995 \cong 1$$

d. At $f = f_c$, $V_o = 0.707V_i = 0.707(10\text{ mV}) = 7.07\text{ mV}$

$$P_o = \frac{V_o^2}{R} = \frac{(7.07\text{ mV})^2}{10\text{ k}\Omega} \cong \mathbf{5\ nW}$$

25. $$\mathbf{A}_\upsilon = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1}{\sqrt{1 + \left(\frac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$$

$$f_c = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi(2\text{ kHz})(0.1\ \mu\text{F})} = 795.77\ \Omega$$

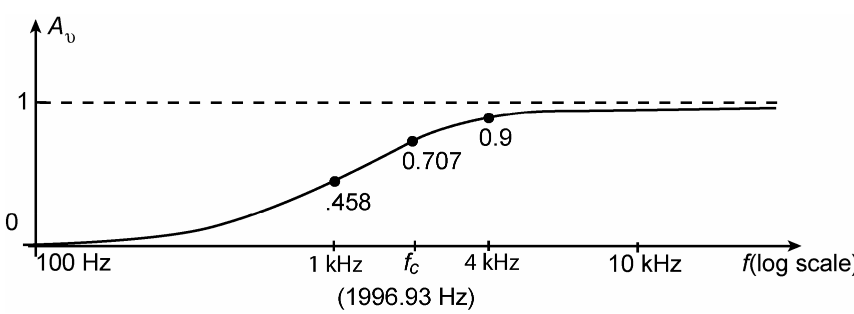
$$R = 795.77\ \Omega \Rightarrow \underbrace{750\ \Omega + 47\ \Omega}_{\text{nominal values}} = 797\ \Omega$$

$$\therefore f_c = \frac{1}{2\pi(797\ \Omega)(0.1\ \mu\text{F})} = \mathbf{1996.93\ Hz} \text{ using nominal values}$$

At $f = 1\text{ kHz}$, $A_\upsilon = 0.458$
$f = 4\text{ kHz}$, $A_\upsilon \cong 0.9$

$$\theta = \tan^{-1}\frac{X_C}{R}$$

$f = 1\text{ kHz}$, $\theta = 63.4°$
$f = 4\text{ kHz}$, $\theta = 26.53°$



26. a. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(100\,\text{k}\Omega)(20\,\text{pF})} =$ **79.58 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. $f = 100f_c = 100(79.577\text{ kHz}) \cong 7.96\text{ MHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(7.96\,\text{MHz})(20\,\text{pF})} = 999.72\ \Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{100\,\text{k}\Omega}{\sqrt{(100\,\text{k}\Omega)^2 + (999.72\,\Omega)^2}} = \mathbf{0.99995} \cong 1$$

d. $A_v = \dfrac{V_o}{V_i} = 0.5 = \dfrac{R}{\sqrt{R^2 + X_C^2}}$

$$\sqrt{R^2 + X_C^2} = 2R$$

$$R^2 + X_C^2 = 4R^2$$

$$X_C^2 = 4R^2 - R^2 = 3R^2$$

$$X_C = \sqrt{3R^2} = \sqrt{3}R = \sqrt{3}\,(100\text{ k}\Omega) = 173.2\text{ k}\Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(173.2\,\text{k}\Omega)(20\,\text{pF})}$$

$f =$ **45.95 kHz**

27. a. low-pass section: $f_{c_1} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(0.1\,\text{k}\Omega)(2\,\mu\text{F})} =$ **795.77 Hz**

high-pass section: $f_{c_2} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(10\,\text{k}\Omega)(8\,\text{nF})} =$ **1989.44 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 $f_{c_1} = 795.77$ Hz:

$$V_{R_1} = 0.707\ V_i$$

$$X_{C_2} = \frac{1}{2\pi fC_2} = 25\text{ k}\Omega$$

$$|V_o| = \frac{25\,\text{k}\Omega(V_{R_1})}{\sqrt{(10\,\text{k}\Omega)^2 + (25\,\text{k}\Omega)^2}} = 0.9285\ V_{R_1}$$

$V_o = (0.9285)(0.707\ V_i) =$ **0.66 V_i**

At $f_{c_2} = 1989.44$ Hz:

$$V_o = 0.707\ V_{R_1}$$

$$X_{C_1} = \frac{1}{2\pi f C_1} = 40\ \Omega$$

$$|V_{R_1}| = \frac{R_1 V_i}{\sqrt{R_1^2 + X_{C_1}^2}} = \frac{100\ \Omega(V_i)}{\sqrt{(100\ \Omega)^2 + (40\ \Omega)^2}} = 0.928\ V_i$$

$$|V_o| = (0.707)(0.928\ V_i) = \mathbf{0.66\ V_i}$$

At $f = 795.77\text{ Hz} + \dfrac{(1989.44\text{ Hz} - 795.77\text{ Hz})}{2} = 1392.60\text{ Hz}$

$X_{C_1} = 57.14\ \Omega$, $X_{C_2} = 14.29\text{ k}\Omega$

$$|V_{R_1}| = \frac{100\ \Omega(V_i)}{\sqrt{(100\ \Omega)^2 + (57.14\ \Omega)^2}} = 0.868\ V_i$$

$$|V_o| = \frac{14.29\text{ k}\Omega\left(V_{R_1}\right)}{\sqrt{(10\text{ k}\Omega)^2 + (14.29\text{ k}\Omega)^2}} = 0.8193\ V_{R_1}$$

$V_o = 0.8193(0.868\ V_i) = \mathbf{0.71 V_i}$

and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.71}$ ($\cong$ maximum value)

After plotting the points it was determined that the gain should also be determined at $f = 500$ Hz and 4 kHz:

$f = 500$ Hz: $X_{C_1} = 159.15\ \Omega$, $X_{C_2} = 39.8\text{ k}\Omega$,
$V_{R_1} = 0.532\ V_i$, $V_o = 0.97\ V_{R_1}$
$V_o = \mathbf{0.52\ V_i}$

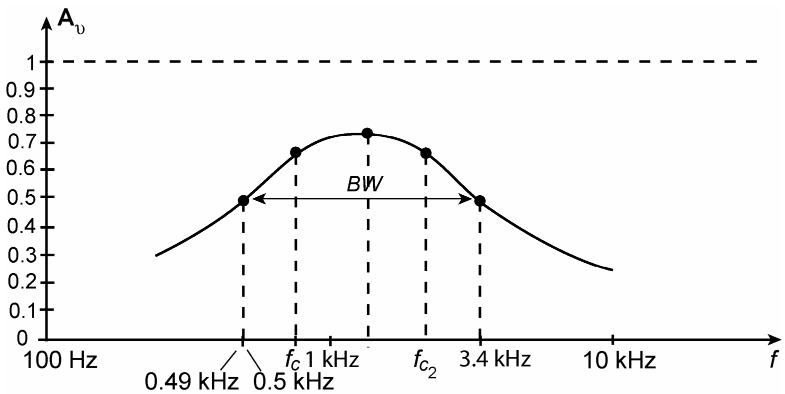
$f = 4$ kHz: $X_{C_1} = 19.89\ \Omega$, $X_{C_2} = 4.97\text{ k}\Omega$,
$V_{R_1} = 0.981\ V_i$, $V_o = 0.445\ V_{R_1}$
$V_o = \mathbf{0.44\ V_i}$

b. Using $0.707(.711) = 0.5026 \cong 0.5$ to define the bandwidth

$BW = 3.4\text{ kHz} - 0.49\text{ kHz} = 2.91\text{ kHz}$

and $BW \cong$ **2.9 kHz**

with $f_{\text{center}} = 490\text{ Hz} + \left(\dfrac{2.9\text{ kHz}}{2}\right) = \mathbf{1940\ Hz}$



28. $f_1 = \dfrac{1}{2\pi R_1 C_1} = 4$ kHz

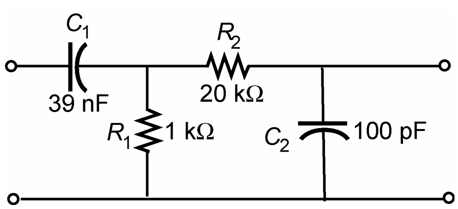
Choose $R_1 = 1\text{ k}\Omega$

$$C_1 = \frac{1}{2\pi f_1 R_1} = \frac{1}{2\pi(4\text{ kHz})(1\text{ k}\Omega)} = 39.8\text{ nF} \therefore \text{ Use } \mathbf{39\text{ nF}}$$

$f_2 = \dfrac{1}{2\pi R_2 C_2} = 80$ kHz

Choose $R_2 = 20\text{ k}\Omega$

$$C_2 = \frac{1}{2\pi f_2 R_2} = \frac{1}{2\pi(80\text{ kHz})(20\text{ k}\Omega)} = 99.47\text{ pF} \therefore \text{ Use } 100\text{ pF}$$



Center frequency $= 4\text{ kHz} + \dfrac{80\text{ kHz} - 4\text{ kHz}}{2} = 42$ kHz

At $f = 42$ kHz, $X_{C_1} = 97.16\ \Omega$, $X_{C_2} = 37.89\text{ k}\Omega$

Assuming $\boldsymbol{Z}_2 \gg \boldsymbol{Z}_1$

$$|V_{R_1}| = \frac{R_1(V_i)}{\sqrt{R_1^2 + X_{C_1}^2}} = 0.995V_i$$

$$|V_o| = \frac{X_{C_2}(V_{R_1})}{\sqrt{R_2^2 + X_{C_1}^2}} = 0.884V_i$$

$V_o = 0.884V_{R_1} = 0.884(0.995V_i) = \mathbf{0.88\ V_i}$

as $f = f_1$: $V_{R_1} = 0.707V_i$, $X_{C_2} = 221.05\text{ k}\Omega$

and $V_o = 0.996V_{R_1}$

so that $V_o = 0.996V_{R_1} = 0.996(0.707V_i) = 0.704V_i$

Although $A_\upsilon = 0.88$ is less than the desired level of 1, f_1 and f_2 do define a band of frequencies for which $A_\upsilon \geq 0.7$ and the power to the load is significant.

29. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(5\text{ mH})(500\text{ pF})}}$ = **100.66 kHz**

b. $Q_s = \dfrac{X_L}{R + R_\ell} = \dfrac{2\pi(100.658\text{ kHz})(5\text{ mH})}{160\,\Omega + 12\,\Omega}$ = **18.39**

$BW = \dfrac{f_s}{Q_s} = \dfrac{100.658\text{ kHz}}{18.39}$ = **5,473.52 Hz**

c. At $f = f_s$: $V_{o_{\max}} = \dfrac{R}{R + R_\ell}V_i = \dfrac{160\,\Omega(1\text{ V})}{172\,\Omega}$ = 0.93 V and $A_\upsilon = \dfrac{V_o}{V_i}$ = **0.93**

Since $Q_s \geq 10$, $f_1 = f_s - \dfrac{BW}{2}$ = 100.658 kHz − $\dfrac{5{,}473.52\text{ Hz}}{2}$ = 97,921.24 Hz

$f_2 = f_s + \dfrac{BW}{2}$ = 103,394.76 Hz

At f = 95 kHz: $X_L = 2\pi fL = 2\pi(95 \times 10^3\text{ Hz})(5\text{ mH}) = 2.98\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(95\times10^3\text{ Hz})(500\text{ pF})} = 3.35\text{ k}\Omega$

$\mathbf{V}_o = \dfrac{160\,\Omega(1\text{ V}\angle 0°)}{172 + j2.98\text{ k}\Omega - j3.35\text{ k}\Omega} = \dfrac{160\text{ V}\angle 0°}{172 - j370}$

$= \dfrac{160\text{ V}\angle 0°}{480\angle -65.07°}$ = **0.39 V∠65.07°**

At f = 105 kHz: $X_L = 2\pi fL = 2\pi(105\text{ kHz})(5\text{ mH}) = 3.3\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(105\text{ kHz})(500\text{ pF})} = 3.03\text{ k}\Omega$

$\mathbf{V}_o = \dfrac{160\,(1\text{ V}\angle 0°)}{172 + j3.3\text{ k}\Omega - j3.03\text{ k}\Omega} = \dfrac{160\text{ V}\angle 0°}{172 + j270}$

$= \dfrac{160\text{ V}\angle 0°}{320\angle 57.50°}$ = **0.5∠–57.50°**

d. $f = f_s$: $V_{o_{\max}}$ = **0.93 V**

$f = f_1$ = 97,921.24 Hz, V_o = 0.707(0.93 V) = **0.66 V**

$f = f_2$ = 103,394.76 Hz, V_o = 0.707(0.93 V) = **0.66 V**

30. a. $f_p = \dfrac{1}{2\pi\sqrt{LC}}\sqrt{1 - \dfrac{R_\ell^2 C}{L}} \cong$ **159.15 kHz**

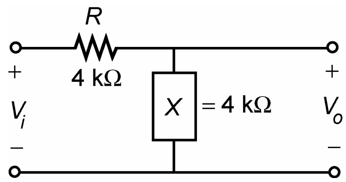
$Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{2\pi f_p L}{R_\ell} = \dfrac{2\pi(159.15\text{ kHz})(1\text{ mH})}{16\,\Omega} = 62.5 \gg 10$

$Z_{T_p} = Q_\ell^2 R_\ell = (62.5)^2\ 16\,\Omega = 62.5\text{ k}\Omega \gg 4\text{ k}\Omega$

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 $A_v = \dfrac{V_o}{V_i} = 0.707$, $|X| = R$ for the following configuration



For frequencies near f_p, $X_L \gg R_\ell$ and $\mathbf{Z}_L = R_\ell + jX_L \cong X_L$
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 $X_C = \dfrac{1}{2\pi f_1 C}$ 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, $f_1 = 140.4$ kHz
and $\dfrac{BW}{2} = 159.15\ \text{kHz} - 140.4\ \text{kHz} = 18.75\ \text{kHz}$
with $BW = 2(18.75\ \text{kHz}) = \mathbf{37.5\ kHz}$

b. $Q_p = \dfrac{f_p}{BW} = \dfrac{159.15\ \text{kHz}}{37.5\ \text{kHz}} = \mathbf{4.24}$

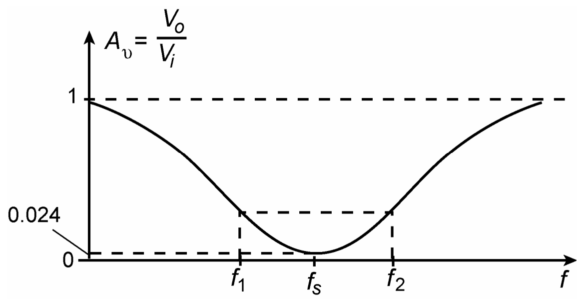
31. a. $$Q_s = \frac{X_L}{R + R_\ell} = \frac{5000\,\Omega}{400\,\Omega + 10\,\Omega} = \frac{5000\,\Omega}{410\,\Omega} = \mathbf{12.2}$$

b. $$BW = \frac{f_s}{Q_s} = \frac{5000\text{ Hz}}{12.2} = \mathbf{409.84\ Hz}$$

$$f_1 = 5000\text{ Hz} - \frac{409.84\text{ Hz}}{2} = \mathbf{4.80\ kHz}$$

$$f_2 = 5000\text{ Hz} + \frac{410\text{ Hz}}{2} = \mathbf{5.20\ kHz}$$

c.



At resonance

$$V_o = \frac{10\,\Omega(V_i)}{10\,\Omega + 400\,\Omega} = 0.024\ V_i$$

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, $V_o = \dfrac{32\text{ k}\Omega\, V_i}{32\text{ k}\Omega + 1\text{ k}\Omega} = 0.97V_i$

and $A_v = \dfrac{V_o}{V_i} = 0.97$

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

$f_1 = 16.4$ kHz

with $\dfrac{BW}{2} = 20\text{ kHz} - 16.4\text{ kHz} = 3.6\text{ kHz}$

and $BW = 2(3.6\text{ kHz}) = \mathbf{7.2\ kHz}$

$$Q_p = \frac{f_p}{BW} = \frac{20\text{ kHz}}{7.2\text{ kHz}} = \mathbf{2.78}$$

b. –

c. At resonance

$$Z_{T_p} = 32\text{ k}\Omega \parallel 100\text{ k}\Omega = 24.24\text{ k}\Omega$$

with $V_o = \dfrac{24.24\text{ k}\Omega\, V_i}{24.24\text{ k}\Omega + 1\text{ k}\Omega} = 0.96V_i$

and $A_v = \dfrac{V_o}{V_i} = 0.96$ vs 0.97 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

$$Z_{T_p} = 32\text{ k}\Omega \parallel 20\text{ k}\Omega = 12.31\text{ k}\Omega$$

with $V_o = \dfrac{12.31\text{ k}\Omega\, V_i}{12.31\text{ k}\Omega + 1\text{ k}\Omega} = 0.925V_i$ vs 0.97 V_i 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. $f_p = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(400\,\mu\text{H})(120\text{ pF})}}$ = **726.44 kHz** (band-stop)

$$X_{L_s}\angle 90° + \left(X_{L_p}\angle 90° \parallel X_C\angle -90°\right) = 0$$

$$jX_{L_s} + \frac{\left(X_{L_p}\angle 90°\right)\left(X_C\angle -90°\right)}{jX_{L_p} - jX_C} = 0$$

$$jX_{L_s} + \frac{X_{L_p}X_C}{j\left(X_{L_p} - X_C\right)} = 0$$

$$jX_{L_s} - j\frac{X_{L_p}X_C}{\left(X_{L_p} - X_C\right)} = 0$$

$$X_{L_s} - \frac{X_{L_p}X_C}{X_{L_p} - X_C} = 0$$

$$X_{L_s}X_C - X_{L_s}X_{L_p} + X_{L_p}X_C = 0$$

$$\frac{\omega L_s}{\omega C} - \omega L_s + \frac{\omega L_p}{\omega C} = 0$$

$$L_sL_p\omega^2 - \frac{1}{C}\left[L_s + L_p\right] = 0$$

$$\omega = \sqrt{\frac{L_s + L_p}{CL_sL_p}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{L_s + L_p}{CL_sL_p}} = \frac{1}{2\pi}\sqrt{\frac{460\times10^{-6}}{28.8\times10^{-19}}} = \mathbf{2.01\ MHz}\ \text{(pass-band)}$$

34. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} \Rightarrow L_s = \dfrac{1}{4\pi^2 f_s^2 C} = \dfrac{1}{4\pi^2(100\text{ kHz})^2(200\text{ pF})} = 12.68\text{ mH}$

$X_L = 2\pi fL = 2\pi(30\text{ kHz})(12.68\text{ mH}) = 2388.91\ \Omega$

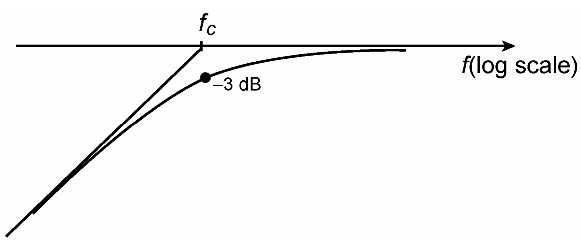
$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(30\text{ kHz})(200\text{ pF})} = 26.54\text{ k}\Omega$

$X_C - X_L = 26.54\text{ k}\Omega - 2388.91\ \Omega = 24.15\text{ k}\Omega(C)$

$X_{L_p} = X_{C_{(\text{net})}} = 24.15\text{ k}\Omega$

$L_p = \dfrac{X_L}{2\pi f} = \dfrac{24.15\text{ k}\Omega}{2\pi(30\text{ kHz})} = \mathbf{128.19\ mH}$

35. a, b. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(0.47\text{ k}\Omega)(0.05\ \mu\text{F})} = \mathbf{772.55\ Hz}$



c. $f = \frac{1}{2}f_c$: $A_{v_{\text{dB}}} = 20\log_{10}\dfrac{1}{\sqrt{1+(f_c/f)^2}} = 20\log_{10}\dfrac{1}{\sqrt{1+(2)^2}} = \mathbf{-7\ dB}$

$f = 2f_c$: $A_{v_{\text{dB}}} = 20\log_{10}\dfrac{1}{\sqrt{1+(0.5)^2}} = \mathbf{-0.969\ dB}$

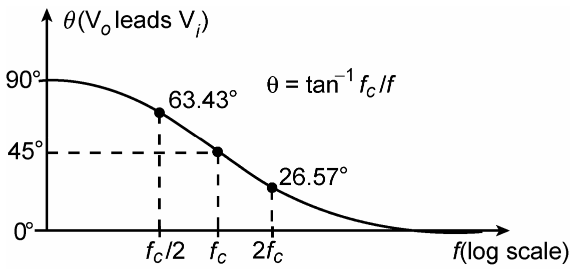
$f = \frac{1}{10}f_c$: $A_{v_{\text{dB}}} = 20\log_{10}\dfrac{1}{\sqrt{1+(10)^2}} = \mathbf{-20.04\ dB}$

$f = 10f_c$: $A_{v_{\text{dB}}} = 20\log_{10}\dfrac{1}{\sqrt{1+(0.1)^2}} = \mathbf{-0.043\ dB}$

d. $f = \frac{1}{2}f_c$: $A_v = \dfrac{1}{\sqrt{1+(f_c/f)^2}} = \dfrac{1}{\sqrt{1+(2)^2}} = \mathbf{0.447}$

$f = 2f_c$: $A_v = \dfrac{1}{\sqrt{1+(0.5)^2}} = \mathbf{0.894}$

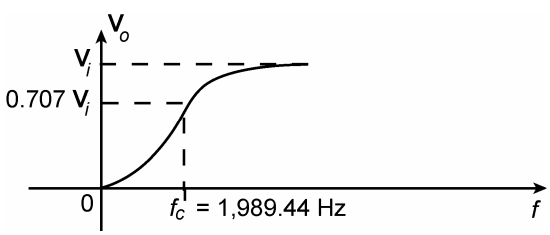
e.



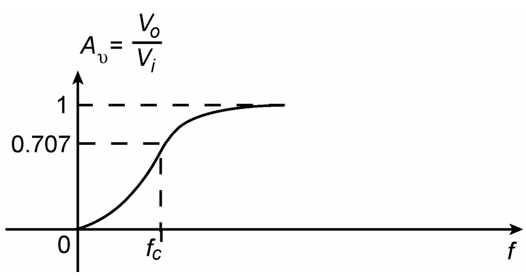
36. a. $$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(6\,\text{k}\Omega \| 12\,\text{k}\Omega)0.01\,\mu\text{F}} = \frac{1}{2\pi(4\,\text{k}\Omega)(0.01\,\mu\text{F})} = \mathbf{1989.44\ Hz}$$

$$\frac{V_o}{V_i} = \frac{1}{\sqrt{1+(f_c/f)^2}}$$

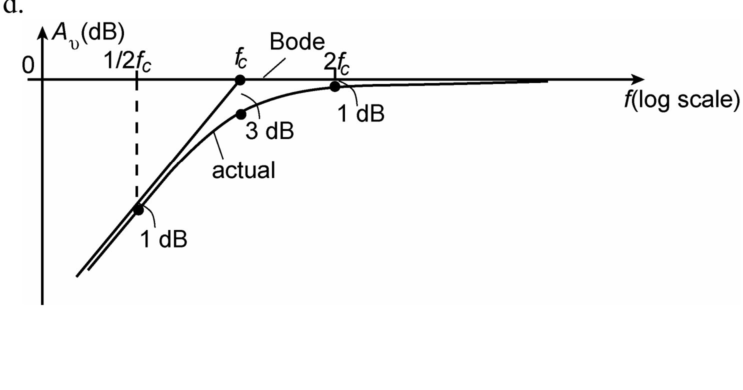
and $V_o = \left(\dfrac{1}{\sqrt{1+(f_c/f)^2}}\right)V_i$



b.



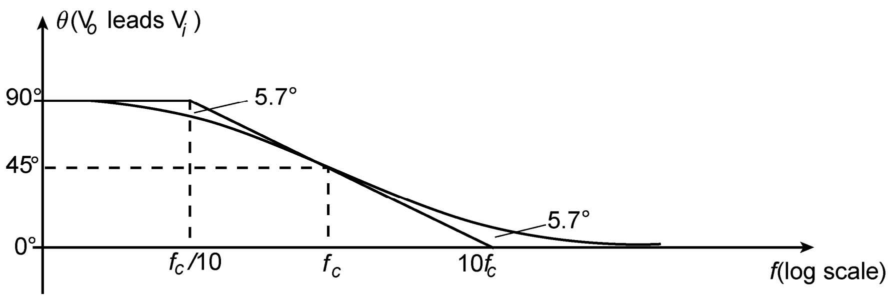
c. & d.



e. Remember the log scale! $1.5f_c$ is not midway between f_c and $2f_c$

$$A_{\upsilon_{\text{dB}}} = 20 \log_{10} A_\upsilon$$
$$-1.5 = 20 \log_{10} A_\upsilon$$
$$-0.075 = \log_{10} A_\upsilon$$
$$A_\upsilon = \frac{V_o}{V_i} = \mathbf{0.84}$$

f. $\theta = \tan^{-1} f_c/f$



37. a, b. $$\mathbf{A}_\upsilon = \frac{\mathbf{V}_o}{\mathbf{V}_i} = A_\upsilon \angle\theta = \frac{1}{\sqrt{1+(f/f_c)^2}} \angle -\tan^{-1} f/f_c$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(12\text{ k}\Omega)(1\text{ nF})} = \mathbf{13.26\ kHz}$$

c. $f = f_c/2 = 6.63$ kHz

$$A_{\upsilon_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1+(0.5)^2}} = \mathbf{-0.97\ dB}$$

$f = 2f_c = 26.52$ kHz

$$A_{\upsilon_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1+(2)^2}} = \mathbf{-6.99\ dB}$$

$f = f_c/10 = 1.326$ kHz

$$A_{\upsilon_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1+(0.1)^2}} = \mathbf{-0.04\ dB}$$

$f = 10f_c = 132.6$ kHz

$$A_{\upsilon_{\text{dB}}} = 20 \log_{10} \frac{1}{\sqrt{1+(10)^2}} = \mathbf{-20.04\ dB}$$

d. $f = f_c/2$: $\quad A_\upsilon = \dfrac{1}{\sqrt{1+(0.5)^2}} = \mathbf{0.894}$

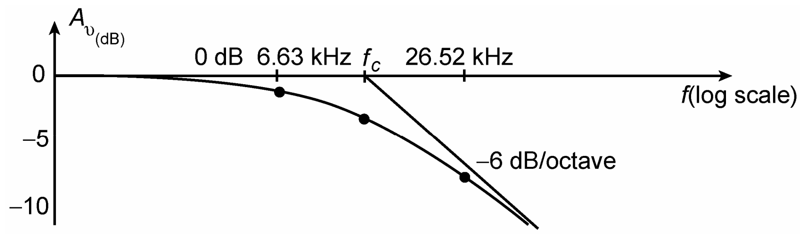
$f = 2f_c$: $\quad A_\upsilon = \dfrac{1}{\sqrt{1+(2)^2}} = \mathbf{0.447}$

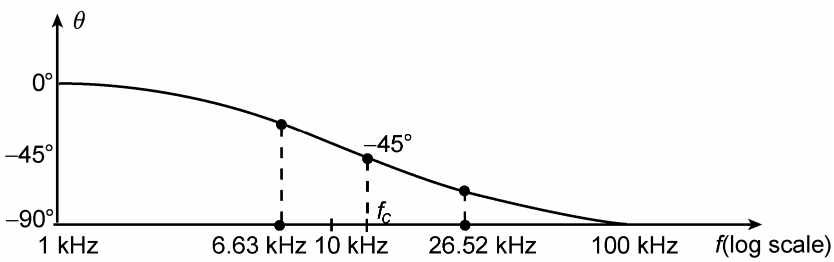
e. $\theta = \tan^{-1} f/f_c$

$f = f_c/2$: $\theta = -\tan^{-1} 0.5 = -26.57°$

$f = f_c$: $\theta = -\tan^{-1} 1 = -45°$

$f = 2f_c$: $\theta = -\tan^{-1} 2 = -63.43°$





38. a. $R_2 \parallel X_C = \dfrac{(R_2)(-jX_C)}{R_2 - jX_C} = -j\dfrac{R_2X_C}{R_2 - jX_C}$

$$\mathbf{V}_o = \frac{\left(\dfrac{-jR_2X_C}{R_2 - jX_C}\right)\mathbf{V}_i}{R_1 - j\dfrac{R_2X_C}{R_2 - jX_C}} = -j\frac{R_2X_C\mathbf{V}_i}{R_1(R_2 - jX_C) - jR_2X_C}$$

$$= \frac{-jR_2X_C\mathbf{V}_i}{R_1R_2 - jR_1X_C - jR_2X_C} = \frac{-jR_2X_C\mathbf{V}_i}{R_1R_2 - j(R_1 + R_2)X_C}$$

$$= \frac{R_2X_C\mathbf{V}_i}{jR_1R_2 + (R_1 + R_2)X_C} = \frac{R_2\mathbf{V}_i}{j\dfrac{R_1R_2}{X_C} + (R_1 + R_2)}$$

$$= \frac{R_2\mathbf{V}_i}{R_1 + R_2 + j\dfrac{R_1R_2}{X_C}} = \frac{\left(\dfrac{R_2}{R_1 + R_2}\right)\mathbf{V}_i}{1 + j\left(\dfrac{R_1R_2}{R_1 + R_2}\right)\dfrac{1}{X_C}}$$

and $\mathbf{A}_\upsilon = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{\dfrac{R_2}{R_1 + R_2}}{1 + j\omega\left(\dfrac{R_1R_2}{R_1 + R_2}\right)C}$

or $\mathbf{A}_\upsilon = \dfrac{R_2}{R_1 + R_2}\left[\dfrac{1}{1 + j2\pi f(R_1 \parallel R_2)C}\right]$

defining $f_c = \dfrac{1}{2\pi(R_1 \| R_2)C}$

$$\mathbf{A}_\upsilon = \frac{R_2}{R_1+R_2}\left[\frac{1}{1+j\,f/f_c}\right]$$

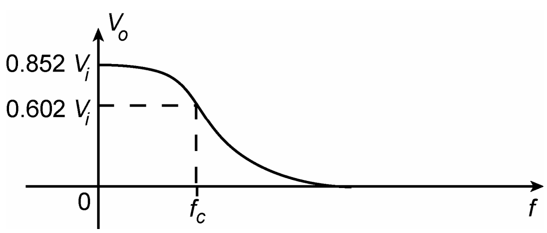
and $\mathbf{A}_\upsilon = \dfrac{R_2}{R_1+R_2}\left[\dfrac{1}{\sqrt{1+(f/f_c)^2}}\angle -\tan^{-1} f/f_c\right]$

with $|V_o| = \dfrac{R_2}{R_1+R_2}\left[\dfrac{1}{\sqrt{1+(f/f_c)^2}}\right]|V_i|$

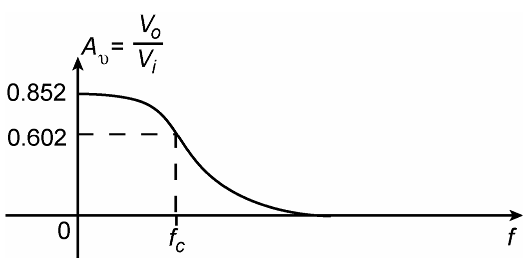
for $f \ll f_c$, $V_o = \dfrac{R_2}{R_1+R_2}V_i = \dfrac{27\text{ k}\Omega}{4.7\text{ k}\Omega + 27\text{ k}\Omega}V_i = 0.852V_i$

at $f = f_c$: $V_o = 0.852[0.707]V_i = 0.602V_i$

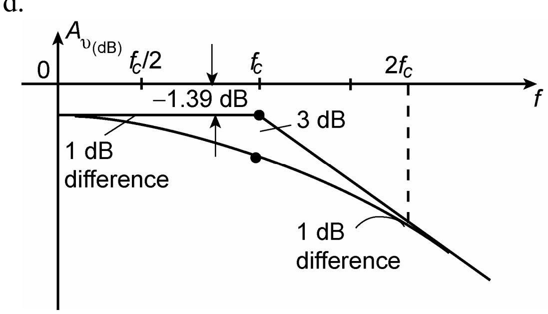
$f_c = \dfrac{1}{2\pi(R_1 \| R_2)C}$ = **994.72 Hz**



b.



c. & d.



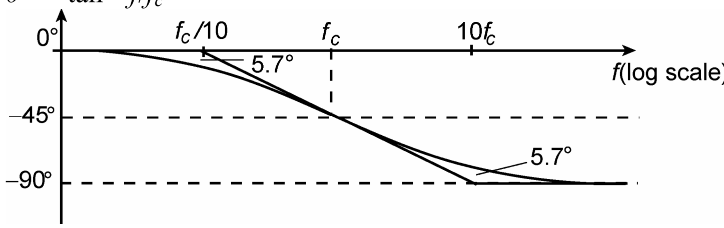
$$-20\log_{10}\frac{R_1+R_2}{R_2} = -20\log_{10}\frac{4.7\text{ k}\Omega + 27\text{ k}\Omega}{27\text{ k}\Omega}$$

$$= -20\log_{10}1.174 = -1.39\text{ dB}$$

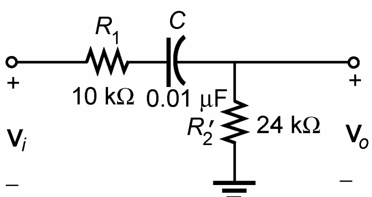
e. $A_{v_{dB}} \cong -1.39\text{ dB} - 0.5\text{ dB} = -1.89\text{ dB}$

$$A_{v_{dB}} = 20\log_{10} A_v$$
$$-1.89 = 20\log_{10} A_v$$
$$0.0945 = \log_{10} A_v$$
$$A_v = \frac{V_o}{V_i} = \mathbf{0.80}$$

f. $\theta = -\tan^{-1} f/f_c$



39.

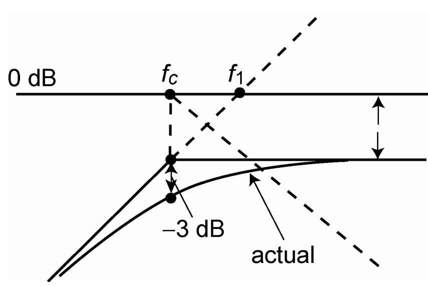


a. From Section 21.11,

$$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{j\,f/f_1}{1 + jf/f_c}$$

$$f_1 = \frac{1}{2\pi R_2' C} = \frac{1}{2\pi(24\text{ k}\Omega)(0.01\,\mu\text{F})} = 663.15\text{ Hz}$$

$$f_c = \frac{1}{2\pi\left(R_1 + R_2'\right)C} = \frac{1}{2\pi(10\text{ k}\Omega + 24\text{ k}\Omega)(0.01\,\mu\text{F})} = 468.1\text{ Hz}$$



$$20\log_{10}\frac{f}{f_1} = 20\log_{10}\frac{f_c}{f_1}$$
$$= 20\ \log_{10}\frac{468.1\text{ Hz}}{663.15\text{ Hz}}$$
$$= \mathbf{-3.03\text{ dB}}$$

b. $\theta = 90° - \tan^{-1}\dfrac{f}{f_1} = +\tan^{-1}\dfrac{f_1}{f}$

$f = f_1$: $\theta = 45°$

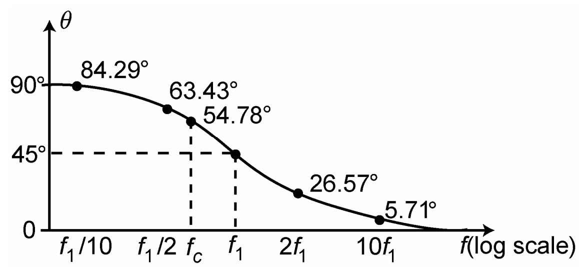
$f = f_c$: $\theta = 54.78°$

$f = \dfrac{1}{2}f_1 = 331.58$ Hz, $\theta = 63.43°$

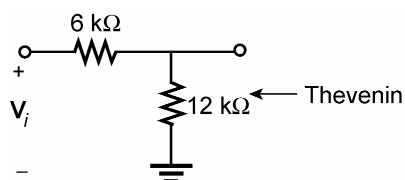
$f = \dfrac{1}{10}f_1 = 66.31$ Hz, $\theta = 84.29°$

$f = 2f_1 = 1{,}326.3$ Hz, $\theta = 26.57°$

$f = 10f_1 = 6{,}631.5$ Hz, $\theta = 5.71°$

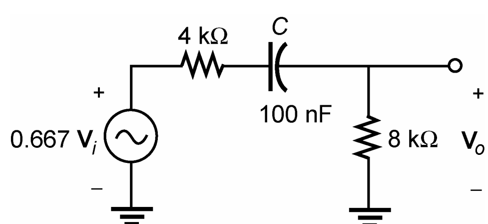


40. a.



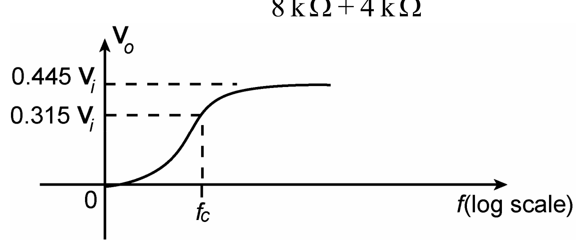
$$\mathbf{V}_{Th} = \frac{12\,\text{k}\Omega\,\mathbf{V}_i}{12\,\text{k}\Omega + 6\,\text{k}\Omega} = 0.667\,\mathbf{V}_i$$

$R_{Th} = 6\text{ k}\Omega \parallel 12\text{ k}\Omega = 4\text{ k}\Omega$



$f = \infty$ Hz: ($C \Rightarrow$ short circuit)

$$\mathbf{V}_o = \frac{8\,\text{k}\Omega\,(0.667\,\mathbf{V}_i)}{8\,\text{k}\Omega + 4\,\text{k}\Omega} = 0.445\,\mathbf{V}_i$$



voltage-divider rule: $\mathbf{V}_o = \dfrac{R_2(0.667\,\mathbf{V}_i)}{R_1 + R_2 - jX_C} = \dfrac{0.667\,R_2\mathbf{V}_i}{R_1 + R_2 - jX_C}$

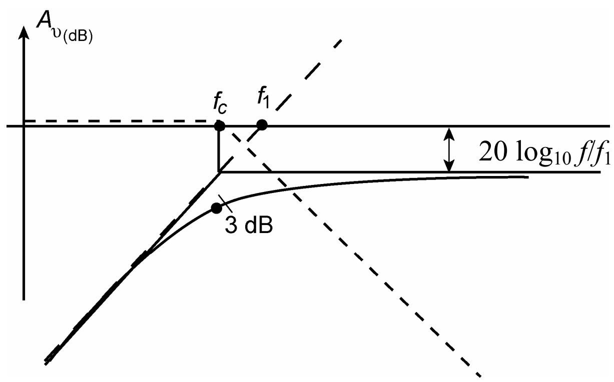
and $\mathbf{A}_\upsilon = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{0.667R_2}{R_1 + R_2 - jX_C} = \dfrac{j2\pi f(0.667R_2)C}{1 + j2\pi f(R_1 + R_2)C}$

so that $\mathbf{A}_\upsilon = \dfrac{j\ f/f_1}{1 + j\ f/f_c}$ with $f_1 = \dfrac{1}{2\pi 0.667 R_2 C} = \dfrac{1}{2\pi 0.667(8\text{ k}\Omega)(100\text{ nF})}$

$= 298.27\text{ Hz}$

and $f_c = \dfrac{1}{2\pi(R_1 + R_2)C} = \dfrac{1}{2\pi(4\text{ k}\Omega + 8\text{ k}\Omega)(100\text{ nF})}$

$= 132.63\text{ Hz}$

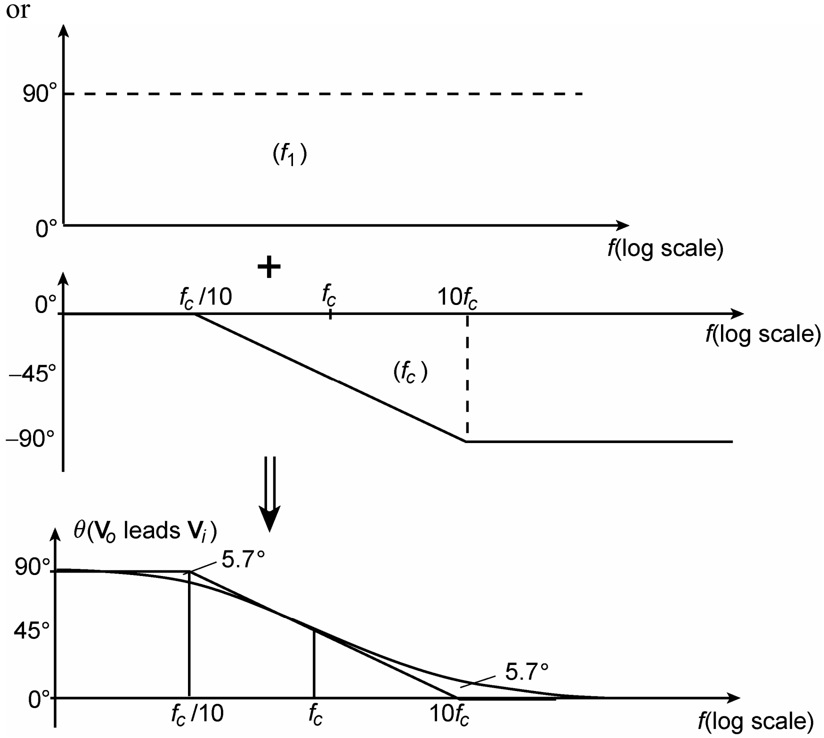


$20\log_{10} f/f_1 = 20\log_{10}\dfrac{132.63\text{ Hz}}{298.27\text{ Hz}}$

$= 20\log_{10} 0.445 = -7.04\text{ dB}$

b. $\theta = 90° - \tan^{-1} f/f_c = +\tan^{-1} f_c/f = \tan^{-1} 132.6\text{ Hz}/f$

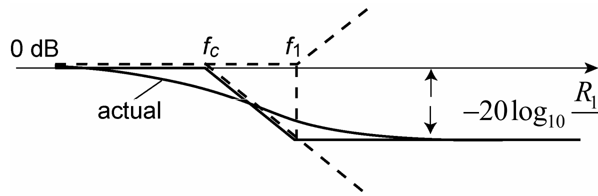
or



41. a. $\mathbf{A}_v = \dfrac{1 + j\dfrac{f}{f_1}}{1 + j\dfrac{f}{f_c}}$

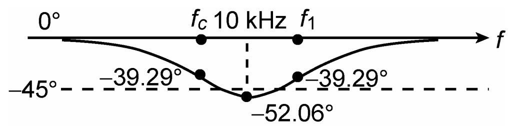
$$f_1 = \frac{1}{2\pi R_2 C} = \frac{1}{2\pi(10\text{ k}\Omega)(800\text{ pF})} = 19{,}894.37\text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 + R_2)C} = \frac{1}{2\pi(10\text{ k}\Omega + 90\text{ k}\Omega)(800\text{ pF})}$$
$$= 1{,}989.44\text{ Hz}$$



$$-20\log_{10}\frac{R_1 + R_2}{R_2} = -20\log_{10} 10 = \mathbf{20\,dB}$$

b.



$$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$$

$f = 10$ kHz

$$\theta = \tan^{-1}\frac{10\text{ kHz}}{19.89\text{ kHz}} - \tan^{-1}\frac{10\text{ kHz}}{1.989\text{ kHz}} = 26.69° - 78.75° = \mathbf{-52.06°}$$

$f = f_c$: ($f_1 = 10\,f_c$)

$$\theta = \tan^{-1}\frac{f_c}{10\,f_c} - \tan^{-1}\frac{f_c}{f_c} = \tan^{-1} 0.1 \tan^{-1} 1 = 5.71° - 45° = \mathbf{-39.29°}$$

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 $\left(-20\log\dfrac{12\text{ k}\Omega + 6\text{ k}\Omega}{6\text{ k}\Omega} = -9.54\text{ dB}\right)$

(b) Note Fig. 21.67.

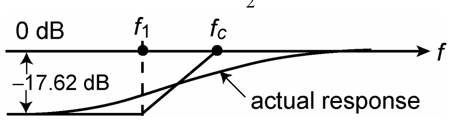
From 0° to –26.50° at f_c and f_1
$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$
At $f = 1500$ Hz (between f_c and f_1)
$\theta = \tan^{-1} 1500\text{ Hz}/2652.58\text{ Hz} - \tan^{-1} 1500\text{ Hz}/884.19\text{ Hz}$
$= 29.49° - 59.48° = -30°$

43. a. $$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1 - jf_1/f}{1 - jf_c/f}$$

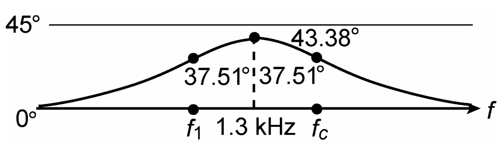
$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3\text{ k}\Omega)(0.05\ \mu\text{F})} = 964.58\text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \parallel R_2)C} = \frac{1}{2\pi\underbrace{(3.3\text{ k}\Omega \parallel 0.5\text{ k}\Omega)}_{0.434\text{ k}\Omega}(0.05\ \mu\text{F})} = \mathbf{7{,}334.33\ Hz}$$

$$-20\log_{10}\frac{R_1 + R_2}{R_2} = -20\log_{10}\frac{3.3\text{ k}\Omega + 0.5\text{ k}\Omega}{0.5\text{ k}\Omega} = -20\log_{10} 7.6 = -17.62\text{ dB}$$



b.



$$\theta = -\tan^{-1}\frac{f_1}{f} + \tan^{-1}\frac{f_c}{f}$$

$f = 1.3$ kHz: $$\theta = -\tan^{-1}\frac{964.58\text{ kHz}}{1.3\text{ kHz}} + \tan^{-1}\frac{7334.33\text{ Hz}}{1.3\text{ kHz}}$$
$$= -36.57° + 79.95° = 43.38°$$

44. a. Note Section 21.13.

$$\mathbf{A}_v = \frac{1 - j(f_1/f)}{1 - j(f_c/f)}$$

$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3\text{ k}\Omega)(0.05\ \mu\text{F})} = \mathbf{964.58\ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \parallel R_2)C} = \frac{1}{2\pi\underbrace{(3.3\text{ k}\Omega \parallel 0.5\text{ k}\Omega)}_{0.434\text{ k}\Omega}0.05\ \mu\text{F}} = \mathbf{7334.33\ Hz}$$

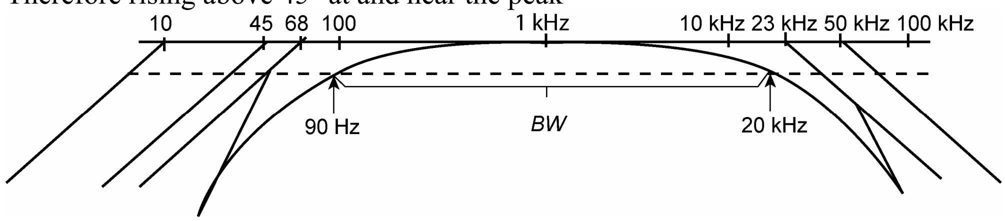
Note Fig. 21.72.

$$-20\log_{10}\frac{R_1+R_2}{R_2} = -20\log_{10}\frac{3.3\text{ k}\Omega + 0.5\text{ k}\Omega}{0.5\text{ k}\Omega} = -17.62\text{ dB}$$

Asymptote at -17.62 dB from $0 \to f_1$
+6 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
$\theta = -\tan^{-1} 964.58\text{ Hz}/3.0\text{ kHz} + \tan^{-1} 7334.33\text{ Hz}/3.0\text{ kHz}$
$= -17.82° + 67.75° = 49.93° \cong 50°$

Therefore rising above 45° at and near the peak



50 kHz vs 23 kHz → 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

$$A'_{v\text{dB}} = -20\log_{10}\sqrt{1+\left(\frac{10\text{ Hz}}{f}\right)^2} - 20\log_{10}\sqrt{1+\left(\frac{45\text{ Hz}}{f}\right)^2} - 20\log_{10}\sqrt{1+\left(\frac{68\text{ Hz}}{f}\right)^2}$$

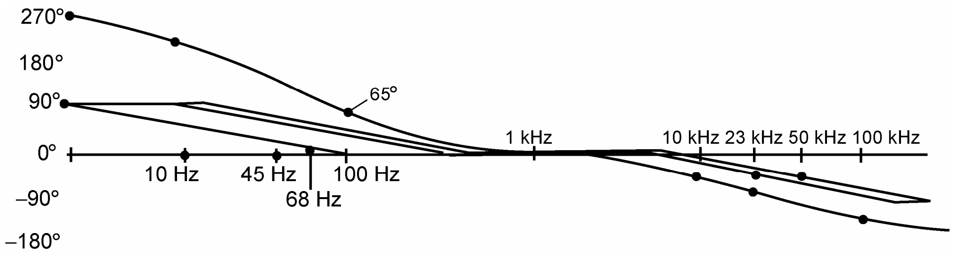
$= -0.0532\text{ dB} - 0.969\text{ dB} - 1.96\text{ dB}$
$= -2.98\text{ dB}$ (excellent)

High frequency cutoff: Try 20 kHz

$$A'_{v\text{dB}} = -20\log_{10}\sqrt{1+\left(\frac{f}{23\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1+\left(\frac{f}{50\text{ kHz}}\right)^2}$$

$= -2.445\text{ dB} - 0.6445\text{ dB}$
$= -3.09\text{ dB}$ (excellent

$\therefore$ $BW = 20\text{ kHz} - 90\text{ Hz} =$ **19,910 Hz** $\cong 20$ kHz
$f_1 =$ **90 Hz**, $f_2 =$ **20 kHz**



Testing: $f = 100$ Hz

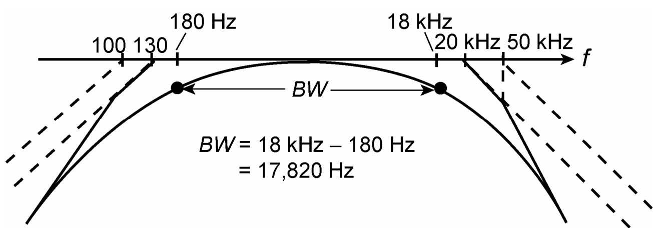
$$\theta = \tan^{-1}\frac{10\text{ Hz}}{f} + \tan^{-1}\frac{45\text{ Hz}}{f} + \tan^{-1}\frac{68\text{ Hz}}{f} - \tan^{-1}\frac{f}{23\text{ kHz}} - \tan^{-1}\frac{f}{50\text{ kHz}}$$

$= \tan^{-1} 0.1 + \tan^{-1} 0.45 + \tan^{-1} 0.68 - \tan^{-1} 0.00435 - \tan^{-1} .002$

$= 5.71° + 24.23° + 34.22° - 0.249° - 0.115°$

$=$ **63.8°** vs about 65° on the plot

45. a. $$\frac{A_\upsilon}{A_{\upsilon_{\max}}} = \frac{1}{\left(1 - j\dfrac{100\text{ Hz}}{f}\right)\left(1 - j\dfrac{130\text{ Hz}}{f}\right)\left(1 + j\dfrac{f}{20\text{ kHz}}\right)\left(1 + j\dfrac{f}{50\text{ kHz}}\right)}$$



Proximity of 100 Hz to 130 Hz will raise lower cutoff frequency above 130 Hz:

Testing: $f = 180$ Hz: (with lower terms only)

$$A_{\upsilon_{\text{dB}}} = -20\log_{10}\sqrt{1 + \left(\frac{100}{f}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{130}{f}\right)^2}$$

$$= -20\log_{10}\sqrt{1 + \left(\frac{100}{180}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{130}{180}\right)^2}$$

$= 1.17\text{ dB} - 1.82\text{ dB} =$ **–2.99 dB** $\cong -3$ dB

Proximity of 50 kHz to 20 kHz will lower high cutoff frequency below 20 kHz:

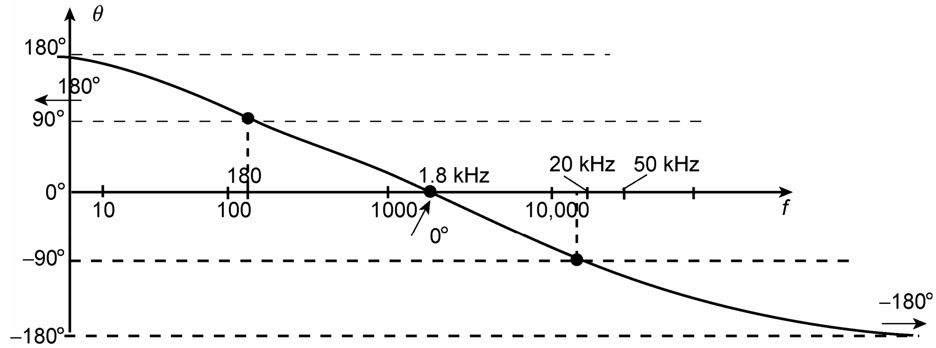
Testing: $f = 18$ kHz: (with upper terms only)

$$A_{\upsilon_{\text{dB}}} = -20\log_{10}\sqrt{1 + \left(\frac{f}{20\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{f}{50\text{ kHz}}\right)^2}$$

$$= -20\log_{10}\sqrt{1 + \left(\frac{18\text{ kHz}}{20\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{13\text{ kHz}}{20\text{ kHz}}\right)^2}$$

$= -2.576\text{ dB} - 0.529\text{ dB} =$ **–3.105 dB**

b.

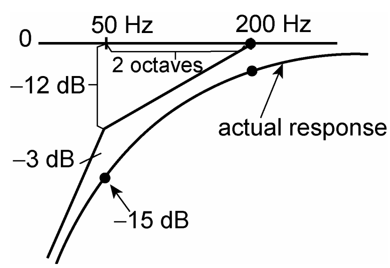


Testing: $f = 1.8$ kHz:

$$\theta = \tan^{-1}\frac{100}{1.8\,\text{kHz}} + \tan^{-1}\frac{130}{1.8\,\text{kHz}} - \tan^{-1}\frac{1.8\,\text{kHz}}{20\,\text{kHz}} - \tan^{-1}\frac{1.8\,\text{kHz}}{50\,\text{kHz}}$$
$$= 3.18° + 4.14° - 5.14° - 2.06°$$
$$= \mathbf{0.12°} \cong \mathbf{0°}$$

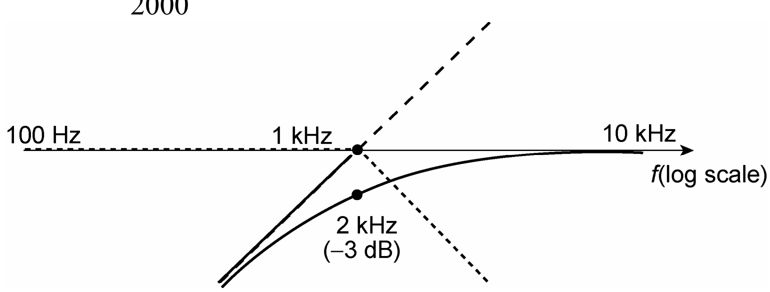
47. $f_{\text{low}} = f_{\text{high}} - BW = 36\text{ kHz} - 35.8\text{ kHz} = 0.2\text{ kHz} = 200\text{ Hz}$

$$A_\upsilon = \frac{-120}{\left(1 - j\dfrac{50}{f}\right)\left(1 - j\dfrac{200}{f}\right)\left(1 + j\dfrac{f}{36\,\text{kHz}}\right)}$$



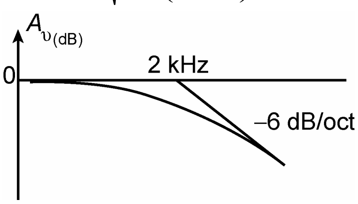
48. $$\mathbf{A}_\upsilon = \frac{0.05}{0.05 - j\dfrac{100}{f}} = \frac{1}{1 - j\dfrac{100}{0.05\,f}} = \frac{1}{1 - j\dfrac{2000}{f}} = \frac{+jf}{+jf + 2000}$$

$$= \frac{+j\dfrac{f}{2000}}{1 + j\dfrac{f}{2000}} \text{ and } f_1 = 2000\text{ Hz}$$

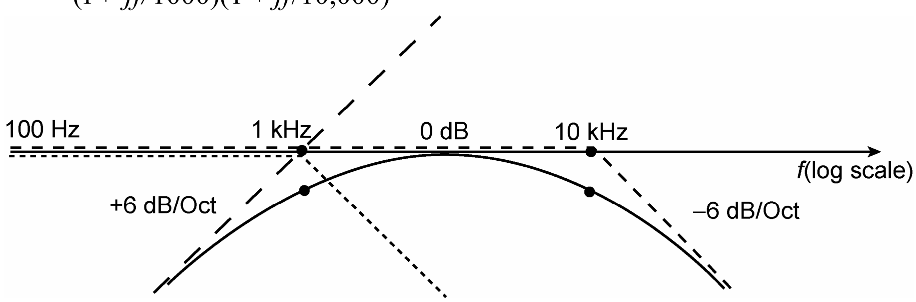


49. $\mathbf{A}_\upsilon = \dfrac{200}{200 + j0.1f} = \dfrac{1}{1 + j\dfrac{0.1f}{200}} = \dfrac{1}{1 + j\dfrac{f}{2000}}$

$A_{\upsilon_{\text{dB}}} = 20 \log_{20} \dfrac{1}{\sqrt{1 + \left(\dfrac{f}{2000}\right)^2}}, \quad \dfrac{f}{2000} = 1$ and $f =$ **2 kHz**

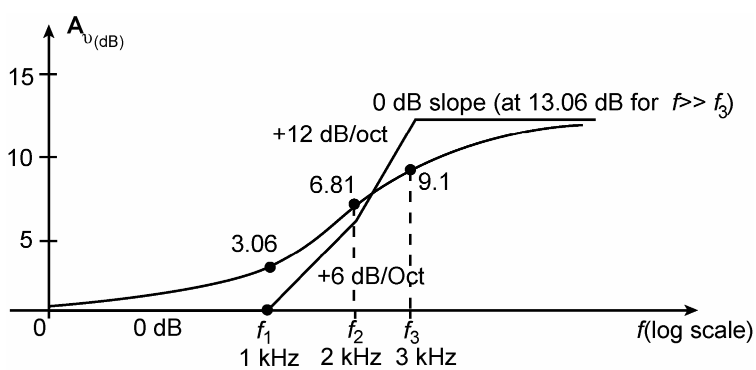


50. $\mathbf{A}_\upsilon = \dfrac{jf/1000}{(1 + jf/1000)(1 + jf/10{,}000)}$

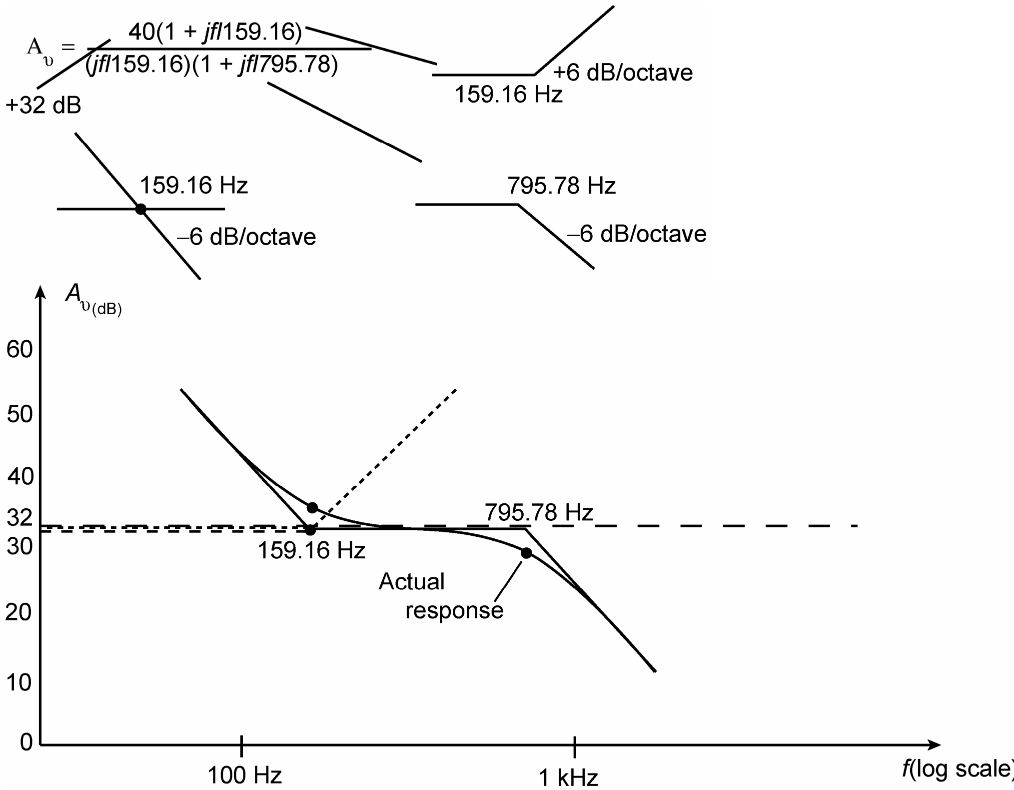


51. $\mathbf{A}_\upsilon = \dfrac{\left(1 + j\dfrac{f}{1000}\right)\left(1 + j\dfrac{f}{2000}\right)}{\left(1 + j\dfrac{f}{3000}\right)^2}$

$\mathbf{A}_{\upsilon_{\text{dB}}} = 20 \log_{10}\sqrt{1 + \left(\dfrac{f_1}{1000}\right)^2} + 20 \log_{10}\sqrt{1 + \left(\dfrac{f_2}{2000}\right)^2} + 40 \log_{10} \dfrac{1}{\sqrt{1 + \left(\dfrac{f_3}{3000}\right)^2}}$



52. $\dfrac{j\omega}{1000} = j\dfrac{2\pi f}{1000} = j\dfrac{f}{\dfrac{1000}{2\pi}} = j\dfrac{f}{159.16\text{ Hz}}, \quad \dfrac{j\omega}{5000} = j\dfrac{f}{795.78\text{ Hz}}$



53. a. Woofer − 400 Hz:

$$X_L = 2\pi fL = 2\pi(400\text{ Hz})(4.7\text{ mH}) = 11.81\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(400\text{ Hz})(39\ \mu\text{F})} = 10.20\ \Omega$$

$$R \parallel X_C = 8\ \Omega\ \angle 0° \parallel 10.20\angle{-90°} = 6.3\ \Omega\ \angle{-38.11°}$$

$$\mathbf{V}_o = \frac{(R \parallel X_C)(\mathbf{V}_i)}{(R \parallel X_C) + jX_L} = \frac{(6.3\ \Omega\angle{-38.11°})(\mathbf{V}_i)}{(6.3\ \Omega\angle{-38.11°}) + j\,11.81\ \Omega}$$

$$\mathbf{V}_o = 0.673\ \angle{-96.11°}\ \mathbf{V}_i$$

and $A_\upsilon = \dfrac{V_o}{V_i}$ = **0.673** vs desired 0.707 (off by less than 5%)

Tweeter − 5 kHz:

$$X_L = 2\pi fL = 2\pi(5\text{ kHz})(0.39\text{ mH}) = 12.25\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(5\text{ kHz})(2.7\ \mu\text{F})} = 11.79\ \Omega$$

$$R \parallel X_L = 8\ \Omega\ \angle 0° \parallel 12.25\ \Omega\ \angle 90° = 6.7\ \Omega\ \angle 33.15°$$

$$\mathbf{V}_o = \frac{(6.7\ \Omega\angle 33.15°)(\mathbf{V}_i)}{(6.7\ \Omega\angle 33.15°) - j\,11.79\ \Omega}$$

$$\mathbf{V}_o = 0.678\ \angle 88.54°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.678}$ vs 0.707 (off by less than 5%)

b. Woofer − 3 kHz:

$$X_L = 2\pi fL = 2\pi(3\text{ kHz})(4.7\text{ mH}) = 88.59\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3\text{ kHz})(39\ \mu\text{F})} = 1.36\ \Omega$$

$$R \parallel X_C = 8\ \Omega\ \angle 0° \parallel 1.36\ \Omega\ \angle{-90°} = 1.341\ \Omega\ \angle{-80.35°}$$

$$\mathbf{V}_o = \frac{(R \parallel X_C)(\mathbf{V}_i)}{(R \parallel X_C) + jX_L} = \frac{(1.341\,\Omega\ \angle -80.35°)(\mathbf{V}_i)}{(1.341\,\Omega\ \angle -80.35°) + j\,88.59\,\Omega}$$

$$\mathbf{V}_o = 0.015\ \angle{-170.2°}\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.015}$ vs desired 0 (excellent)

Tweeter − 3 kHz:

$$X_L = 2\pi fL = 2\pi(3\text{ kHz})(0.39\text{ mH}) = 7.35\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3\text{ kHz})(2.7\ \mu\text{F})} = 19.65\ \Omega$$

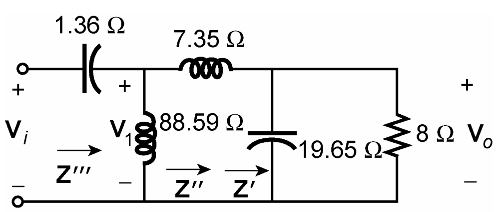
$$R \parallel X_L = 8\ \Omega\ \angle 0° \parallel 7.35\ \Omega\ \angle 90° = 5.42\ \Omega\ \angle 47.42°$$

$$\mathbf{V}_o = \frac{(R \parallel X_L)(\mathbf{V}_i)}{(R \parallel X_L) + jX_C} = \frac{(5.42\,\Omega\ \angle 47.42°)(\mathbf{V}_i)}{(5.42\,\Omega\ \angle 47.42°) - j\,19.65\,\Omega}$$

$$\mathbf{V}_o = 0.337\ \angle 124.24°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.337}$ (acceptable since relatively close to cut frequency for tweeter)

c. Mid-range speaker − 3 kHz:



$$\mathbf{Z}' = 7.41\ \Omega\ \angle -22.15°$$

$$\mathbf{Z}'' = 8.24\ \Omega\ \angle\ 33.58°$$

$$\mathbf{Z}''' = 7.816\ \Omega\ \angle\ 37.79°$$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'''\mathbf{V}_i}{\mathbf{Z}''' - jX_C} = \frac{(7.816\,\Omega\ \angle 37.79°)\mathbf{V}_i}{7.816\,\Omega\ \angle 37.79° - j1.36\,\Omega} = 1.11\ \angle 8.83°\ \mathbf{V}_i$$

$$\mathbf{V}_o = \frac{\mathbf{Z}'\mathbf{V}_1}{\mathbf{Z}' + jX_L} = \frac{(7.41\,\Omega\ \angle -22.15°)\mathbf{V}_i}{7.41\,\Omega\ \angle -22.15° + j7.35\,\Omega} = 0.998\ \angle{-46.9°}\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.998}$ (excellent)

Chapter 22

1. a. $M = k\sqrt{L_p L_s} \Rightarrow L_s = \dfrac{M^2}{L_p k^2} = \dfrac{(80\text{ mH})^2}{(50\text{ mH})(0.8)^2} = \mathbf{0.2\ H}$

   b. $e_p = N_p \dfrac{d\phi_p}{dt} = (20)(0.08\text{ Wb/s}) = \mathbf{1.6\ V}$

   $e_s = kN_s \dfrac{d\phi_p}{dt} = (0.8)(80\text{ t})(0.08\text{ Wb/s}) = \mathbf{5.12\ V}$

   c. $e_p = L_p \dfrac{di_p}{dt} = (50\text{ mH})(0.03 \times 10^3\text{ A/s}) = \mathbf{15\ V}$

   $e_s = M\dfrac{di_p}{dt} = (80\text{ mH})(0.03 \times 10^3\text{ A/s}) = \mathbf{24\ V}$

2. a. $k = 1$

   (a) $L_s = \dfrac{M^2}{L_p k^2} = \dfrac{(80\text{ mH})^2}{(50\text{ mH})(1)^2} = \mathbf{128\ mH}$

   (b) $e_p = \mathbf{1.6\ V}$, $e_s = kN_s\dfrac{d\phi_p}{dt} = (1)(80\text{ t})(0.08\text{ Wb/s}) = \mathbf{6.4\ V}$

   (c) $e_p = \mathbf{15\ V}$, $e_s = \mathbf{24\ V}$

   b. $k = 0.2$

   (a) $L_s = \dfrac{M^2}{L_p k^2} = \dfrac{(80\text{ mH})^2}{(50\text{ mH})(0.2)^2} = \mathbf{3.2\ H}$

   (b) $e_p = \mathbf{1.6\ V}$, $e_s = kN_s\dfrac{d\phi_p}{dt} = (0.2)(80\text{ t})(0.08\text{ Wb/s}) = \mathbf{1.28\ V}$

   (c) $e_p = \mathbf{15\ V}$, $e_s = \mathbf{24\ V}$

3. a. $L_s = \dfrac{M^2}{L_p k^2} = \dfrac{(80\text{ mH})^2}{(50\text{ mH})(0.9)^2} = \mathbf{158.02\ mH}$

   b. $e_p = N_p\dfrac{d\phi_p}{dt} = (300\text{ t})(0.08\text{ Wb/s}) = \mathbf{24\ V}$

   $e_s = kN_s\dfrac{d\phi_p}{dt} = (0.9)(25\text{ t})(0.08\text{ Wb/s}) = \mathbf{1.8\ V}$

   c. e_p and e_s the same as problem 1: $e_p = \mathbf{15\ V}$, $e_s = \mathbf{24\ V}$

4. a. $E_s = \dfrac{N_s}{N_p} E_p = \dfrac{64\text{ t}}{8\text{ t}}(25\text{ V}) = \mathbf{200\ V}$

b. $\Phi_{\max} = \dfrac{E_p}{4.4 fN_p} = \dfrac{25\text{ V}}{4.44(60\text{ Hz})(8\text{ t})} = \mathbf{11.73\ mWb}$

5. a. $E_s = \dfrac{N_s}{N_p} E_p = \dfrac{30\text{ t}}{240\text{ t}}(25\text{ V}) = \mathbf{3.13\ V}$

b. $\Phi_{m(\max)} = \dfrac{E_p}{4.44\ fN_p} = \dfrac{25\text{ V}}{(4.44)(60\text{ Hz})(240\text{ t})} = \mathbf{391.02\ \mu Wb}$

6. $E_p = \dfrac{N_p}{N_s} E_s = \dfrac{60\text{ t}}{720\text{ t}}\ (240\text{ V}) = \mathbf{20\ V}$

7. $f = \dfrac{E_p}{(4.44) N_p \Phi_{m(\max)}} = \dfrac{25\text{ V}}{(4.44)(8\text{ t})(12.5\text{ mWb})} = \mathbf{56.31\ Hz}$

8. a. $I_L = aI_p = \left(\dfrac{1}{5}\right)(2\text{ A}) = \mathbf{0.4\ A}$

$V_L = I_L Z_L = \left(\dfrac{2}{5}\text{ A}\right)(2\ \Omega) = \mathbf{0.8\ V}$

b. $Z_{\text{in}} = a^2 Z_L = \left(\dfrac{1}{5}\right)^2 2\ \Omega = \mathbf{0.08\ \Omega}$

9. $Z_p = \dfrac{V_g}{I_p} = \dfrac{1600\text{ V}}{4\text{ A}} = \mathbf{400\ \Omega}$

10. $V_g = aV_L = \left(\dfrac{1}{4}\right)(1200\text{ V}) = \mathbf{300\ V}$

$I_p = \dfrac{V_g}{Z_i} = \dfrac{300\text{ V}}{4\ \Omega} = \mathbf{75\ A}$

11. $I_L = I_s = \dfrac{V_L}{Z_L} = \dfrac{240\text{ V}}{20\ \Omega} = 12\text{ A}$

$\dfrac{I_s}{I_p} = a = \dfrac{N_p}{N_s} \Rightarrow \dfrac{12\text{ A}}{0.05\text{ A}} = \dfrac{N_p}{50}$

$N_p = \dfrac{50(12)}{0.05} = \mathbf{12{,}000\ turns}$

12. a. $a = \dfrac{N_p}{N_s} = \dfrac{400\text{ t}}{1200\text{ t}} = \dfrac{1}{3}$

$Z_i = a^2 Z_L = \left(\dfrac{1}{3}\right)^2 [9\ \Omega + j12\ \Omega] = 1\ \Omega + j1.333\ \Omega = 1.667\ \Omega \angle 53.13°$

$I_p = V_g/Z_i = 100\text{ V}/1.667\ \Omega = \mathbf{60\ A}$

b. $I_L = aI_p = \dfrac{1}{3}(60\text{ A}) = \mathbf{20\ A}$, $V_L = I_L Z_L = (20\text{ A})(15\ \Omega) = \mathbf{300\ V}$

13. a. $Z_p = a^2 Z_L \Rightarrow a = \sqrt{\dfrac{Z_p}{Z_L}}$

$Z_p = \dfrac{V_p}{I_p} = \dfrac{10\text{ V}}{20\text{ V}/72\ \Omega} = 36\ \Omega$

$a = \sqrt{\dfrac{36\ \Omega}{4\ \Omega}} = \mathbf{3}$

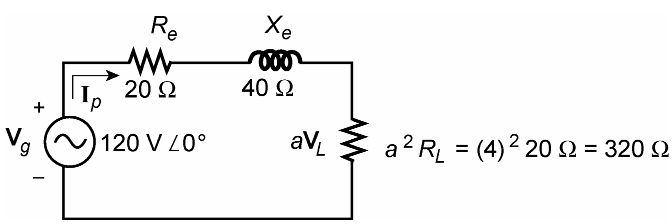
b. $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p} = \dfrac{1}{3} \Rightarrow V_s = \dfrac{1}{3}V_p = \dfrac{1}{3}(10\text{ V}) = \mathbf{3\frac{1}{3}\ V}$

$P = \dfrac{V_s^2}{Z_s} = \dfrac{(3.33\text{ V})^2}{4\ \Omega} = \mathbf{2.78\ W}$

14. a. $R_e = R_p + a^2 R_s = 4\ \Omega + (4)^2\ 1\ \Omega = \mathbf{20\ \Omega}$

b. $X_e = X_p + a^2 X_s = 8\ \Omega + (4)^2\ 2\ \Omega = \mathbf{40\ \Omega}$

c.



d. $\mathbf{I}_p = \dfrac{\mathbf{V}_g}{\mathbf{Z}_p} = \dfrac{120\text{ V}\angle 0°}{20\ \Omega + 320\ \Omega + j40\ \Omega} = \dfrac{120\text{ V}\angle 0°}{340\ \Omega + j40\ \Omega} = \mathbf{0.351\ A \angle -6.71°}$

e. $a\mathbf{V}_L = \dfrac{a^2 R_L \mathbf{V}_g}{(R_e + a^2 R_L) + jX_e} = \mathbf{I}_p a^2 R_L$

or $\mathbf{V}_L = a\mathbf{I}_p R_L \angle 0° = (4)(0.351\text{ A}\angle -6.71°)(20\ \Omega\angle 0°) = \mathbf{28.1\ V \angle -6.71°}$

f. –

g. $V_L = \dfrac{N_s}{N_p}V_g = \dfrac{1}{4}(120\text{ V}) = \mathbf{30\ V}$

15. a. $a = \dfrac{N_p}{N_s} = \dfrac{4\text{ t}}{1\text{ t}} = 4$

$R_e = R_p + a^2R_s = 4\ \Omega + (4)^2\ 1\ \Omega = 20\ \Omega$

$X_e = X_p + a^2X_s = 8\ \Omega + (4)^2\ 2\ \Omega = 40\ \Omega$

$\mathbf{Z}_p = \mathbf{Z}_{R_e} + \mathbf{Z}_{X_e} + a^2\mathbf{Z}_{X_L} = 20\ \Omega + j40\ \Omega + j(4)^2\ 20\ \Omega$

$= 20\ \Omega + j40\ \Omega + j320\ \Omega = 20\ \Omega + j360\ \Omega =$ **$360.56\ \Omega\ \angle 86.82°$**

b. $\mathbf{I}_p = \dfrac{\mathbf{V}_g}{\mathbf{Z}_p} = \dfrac{120\text{ V}\ \angle 0°}{360.56\ \Omega\ \angle 86.82°} = 332.82\text{ mA}\ \angle{-86.82°}$

c. $\mathbf{V}_{R_e} = (I\angle\theta)(R_e\angle 0°) = (332.82\text{ mA}\ \angle{-86.82°})(20\ \Omega\ \angle 0°)$

$=$ **$6.66\text{ V}\ \angle{-86.82°}$**

$\mathbf{V}_{X_e} = (I\angle\theta)(X_e\angle 90°) = (332.82\text{ mA}\ \angle{-86.32°})(40\ \Omega\ \angle 90°)$

$=$ **$13.31\text{ V}\ \angle 3.18°$**

$\mathbf{V}_{X_L} = \mathbf{I}(a^2 Z_{X_L}) = (332.82\text{ mA}\ \angle{-86.82°})(320\ \Omega\ \angle 90°)$

$=$ **$106.50\text{ V}\ \angle 3.18°$**

16. a. $a = N_p/N_s = 4\text{ t}/1\text{ t} = 4$, $R_e = R_p + a^2R_s = 4\ \Omega + (4)^2\ 1\ \Omega = 20\ \Omega$

$X_e = X_p + a^2X_s = 8\ \Omega + (4)^2\ 2\ \Omega = 40\ \Omega$

$\mathbf{Z}_p = R_e + jX_e - ja^2X_C = 20\ \Omega + j40\ \Omega - j(4)^2\ 20\ \Omega$

$= 20\ \Omega - j280\ \Omega =$ **$280.71\ \Omega\ \angle{-85.91°}$**

b. $\mathbf{I}_p = \dfrac{\mathbf{V}_g}{\mathbf{Z}_p} = \dfrac{120\text{ V}\ \angle 0°}{280.71\ \Omega\ \angle{-85.91°}} =$ **$0.43\text{ A}\ \angle 85.91°$**

c. $\mathbf{V}_{R_e} = (I_p\angle\theta)(R_e\angle 0°) = (0.427\text{ A}\ \angle 85.91°)(20\ \Omega\ \angle 0°) =$ **$8.54\text{ V}\ \angle 85.91°$**

$\mathbf{V}_{X_e} = (I_p\angle\theta)(X_e\angle 90°) = (0.427\text{ A}\ \angle 85.91°)(40\ \Omega\ \angle 90°) =$ **$17.08\text{ V}\ \angle 175.91°$**

$\mathbf{V}_{X_C} = (I_p\angle\theta)(a^2X_C\angle{-90°}) = (0.427\text{ A}\ \angle 85.91°)(320\ \Omega\ \angle{-90°}) =$ **$136.64\text{ V}\ \angle{-4.09°}$**

17. –

18. Coil 1: $L_1 - M_{12}$

Coil 2: $L_2 - M_{12}$

$L_T = L_1 + L_2 - 2M_{12} = 4\text{ H} + 7\text{ H} - 2(1\text{ H}) =$ **9 H**

19. $L_{T(+)} = L_1 + L_2 + 2M_{12}$

$M_{12} = k\sqrt{L_1L_2} = (0.8)\sqrt{(200\text{ mH})(600\text{ mH})} =$ **277 mH**

$L_{T(+)} = 200\text{ mH} + 600\text{ mH} + 2(277\text{ mH}) =$ **1.35 H**

20. $M_{23} = k\sqrt{L_2L_3} = 1\sqrt{(1\text{ H})(4\text{ H})} = 2\text{ H}$

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. $\mathbf{E}_1 - \mathbf{I}_1[\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}] - \mathbf{I}_2[\mathbf{Z}_m] = 0$

$\mathbf{I}_2[\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}] + \mathbf{I}_1[\mathbf{Z}_m] = 0$

$\mathbf{I}_1(\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}) + \mathbf{I}_2(\mathbf{Z}_m) = \mathbf{E}_1$

$\mathbf{I}_1(\mathbf{Z}_m) + \mathbf{I}_2(\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}) = 0$ $\qquad X_m = -\omega M \angle 90°$

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22. $\mathbf{Z}_i = \mathbf{Z}_p + \dfrac{(\omega M)^2}{\mathbf{Z}_s + \mathbf{Z}_L} = R_p + jX_{L_p} + \dfrac{(\omega M)^2}{R_s + jX_{L_s} + R_L}$

$R_p = 2\ \Omega,\ X_{L_p} = \omega L_p = (10^3\text{ rad/s})(8\text{ H}) = 8\text{ k}\Omega$

$R_s = 1\ \Omega,\ X_{L_s} = \omega L_s = (10^3\text{ rad/s})(2\text{ H}) = 2\text{ k}\Omega$

$M = k\sqrt{L_pL_s} = 0.05\sqrt{(8\text{ H})(2\text{ H})} = 0.2\text{ H}$

$\mathbf{Z}_i = 2\ \Omega + j8\text{ k}\Omega + \dfrac{(10^3\text{ rad/s}\cdot 0.2\text{ H})^2}{1\,\Omega + j2\text{ k}\Omega + 20\,\Omega}$

$= 2\ \Omega + j8\text{ k}\Omega + \dfrac{4\times 10^4\,\Omega}{21 + j2\times 10^3}$

$= 2\ \Omega + j8\text{ k}\Omega + 0.21\ \Omega - j19.99\ \Omega = 2.21\ \Omega + j7980\ \Omega$

$\mathbf{Z}_i = \mathbf{7980\ \Omega \angle 89.98°}$

23. a. $a = \dfrac{N_p}{N_s} = \dfrac{V_p}{V_s} = \dfrac{2400\text{ V}}{120\text{ V}} = \mathbf{20}$

b. $10{,}000\text{ VA} = V_sI_s \Rightarrow I_s = \dfrac{10{,}000\text{ VA}}{V_s} = \dfrac{10{,}000\text{ VA}}{120\text{ V}} = \mathbf{83.33\text{ A}}$

c. $I_p = \dfrac{10{,}000\text{ VA}}{V_p} = \dfrac{10{,}000\text{ VA}}{2400\text{ V}} = \mathbf{4.17\text{ A}}$

d. $a = \dfrac{V_p}{V_s} = \dfrac{120\text{ V}}{2400\text{ V}} = 0.05 = \dfrac{1}{20}$

$I_s = \dfrac{10{,}000\text{ VA}}{2400\text{ V}} = \mathbf{4.17\text{ A}}$, $I_p = \mathbf{83.33\text{ A}}$

24. $I_s = I_1 = \mathbf{2\ A}$, $E_p = V_L = \mathbf{40\ V}$
$E_s = V_s - V_L = 200\text{ V} - 40\text{ V} = \mathbf{160\ V}$
$V_g I_1 = V_L I_L \Rightarrow I_L = V_g/V_L \cdot I_1 = \dfrac{200\text{ V}}{40\text{ V}}(2\text{ A}) = \mathbf{10\ A}$
$I_p + I_1 = I_L \Rightarrow I_p = I_L - I_1 = 10\text{ A} - 2\text{A} = \mathbf{8\ A}$

25. a. $\mathbf{E}_s = \dfrac{N_s}{N_p}\mathbf{E}_p$
$= \dfrac{25\text{ t}}{100\text{ t}}(100\text{ V}\angle 0°) = \mathbf{25\ V\ \angle 0°} = \mathbf{V}_L$
$\mathbf{I}_s = \dfrac{\mathbf{E}_s}{\mathbf{Z}_L} = \dfrac{25\text{ V}\angle 0°}{5\,\Omega\angle 0°} = \mathbf{5\ A\ \angle 0°} = \mathbf{I}_L$

b. $\mathbf{Z}_i = a^2\mathbf{Z}_L = \left(\dfrac{N_p}{N_s}\right)^2\mathbf{Z}_L = \left(\dfrac{100\text{ t}}{25\text{ t}}\right)^2 5\,\Omega\angle 0° = (4)^2\, 5\,\Omega\angle 0° = \mathbf{80\ \Omega\ \angle 0°}$

c. $\mathbf{Z}_{1/2} = \dfrac{1}{4}\mathbf{Z}_i = \dfrac{1}{4}(80\,\Omega\angle 0°) = \mathbf{20\ \Omega\ \angle 0°}$

26. a. $\mathbf{E}_2 = \dfrac{N_2}{N_1}\mathbf{E}_1 = \dfrac{15\text{ t}}{90\text{ t}}(60\text{ V}\angle 0°) = \mathbf{10\ V\ \angle 0°}$
$\mathbf{E}_3 = \dfrac{N_3}{N_1}\mathbf{E}_1 = \dfrac{45\text{ t}}{90\text{ t}}(60\text{ V}\angle 0°) = \mathbf{30\ V\ \angle 0°}$
$\mathbf{I}_2 = \dfrac{\mathbf{E}_2}{\mathbf{Z}_2} = \dfrac{10\text{ V}\angle 0°}{8\,\Omega\angle 0°} = \mathbf{1.25\ A\ \angle 0°}$
$\mathbf{I}_3 = \dfrac{\mathbf{E}_3}{\mathbf{Z}_3} = \dfrac{30\text{ V}\angle 0°}{5\,\Omega\angle 0°} = \mathbf{6\ A\ \angle 0°}$

b. $\dfrac{1}{R_1} = \dfrac{1}{(N_1/N_2)^2 R_2} + \dfrac{1}{(N_1/N_3)^2 R_3}$
$= \dfrac{1}{(90\text{ t}/15\text{ t})^2\, 8\,\Omega} + \dfrac{1}{(90\text{ t}/45\text{ t})^2\, 5\,\Omega}$
$\dfrac{1}{R_1} = \dfrac{1}{288\,\Omega} + \dfrac{1}{20\,\Omega} = 0.05347\text{ S}$
$R_1 = \mathbf{18.70\ \Omega}$

27. a. $\mathbf{E}_2 = \dfrac{N_2}{N_1}\mathbf{E}_1 = \left(\dfrac{40\text{ t}}{120\text{ t}}\right)(120\text{ V}\angle 60°) = \mathbf{40\ V\ \angle 60°}$
$\mathbf{I}_2 = \dfrac{\mathbf{E}_2}{\mathbf{Z}_2} = \dfrac{40\text{ V}\angle 60°}{12\,\Omega\angle 0°} = \mathbf{3.33\ A\ \angle 60°}$
$\mathbf{E}_3 = \dfrac{N_3}{N_1}\mathbf{E}_1 = \left(\dfrac{30\text{ t}}{120\text{ t}}\right)(120\text{ V}\angle 60°) = \mathbf{30\ V\ \angle 60°}$
$\mathbf{I}_3 = \dfrac{\mathbf{E}_3}{\mathbf{Z}_3} = \dfrac{30\text{ V}\angle 60°}{10\,\Omega\angle 0°} = \mathbf{3\ A\ \angle 60°}$

b. $$\frac{1}{R_1} = \frac{1}{(N_1/N_2)^2 R_2} + \frac{1}{(N_1/N_3)^2 R_3}$$
$$= \frac{1}{(120\text{ t}/40\text{ t})^2 12\,\Omega} + \frac{1}{(120\text{ t}/30\text{ t})^2 10\,\Omega}$$
$$\frac{1}{R_1} = \frac{1}{108\,\Omega} + \frac{1}{160\,\Omega} = 0.0155\text{ S}$$
$$R_1 = \frac{1}{0.0155\text{ S}} = \mathbf{64.52\ \Omega}$$

28. $\mathbf{Z}_M = \mathbf{Z}_{M_{12}} = \omega M_{12} \angle 90°$

$$\mathbf{E} - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_1\mathbf{Z}_{L_1} - \mathbf{I}_1(-\mathbf{Z}_m) - \mathbf{I}_2(+\mathbf{Z}_m) - \mathbf{I}_1\mathbf{Z}_{L_2} + \mathbf{I}_2\mathbf{Z}_{L_2} - \mathbf{I}_1(-\mathbf{Z}_m) = 0$$
$$\mathbf{E} - \mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_{L_1} - \mathbf{Z}_m + \mathbf{Z}_{L_2} - \mathbf{Z}_m) - \mathbf{I}_2(\mathbf{Z}_m - \mathbf{Z}_{L_2}) = 0$$
or $$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_{L_1} + \mathbf{Z}_{L_2} - 2\,\mathbf{Z}_m) + \mathbf{I}_2(\mathbf{Z}_m - \mathbf{Z}_{L_2}) = \mathbf{E}$$

$$-\mathbf{I}_2\mathbf{Z}_2 - \mathbf{Z}_{L_2}(\mathbf{I}_2 - \mathbf{I}_1) - \mathbf{I}_1(+\mathbf{Z}_m) = 0$$
or $$\mathbf{I}_1(\mathbf{Z}_m - \mathbf{Z}_{L_2}) + \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_{L_2}) = 0$$

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29. $$\mathbf{E}_1 - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_1\mathbf{Z}_{L_1} - \mathbf{I}_2(-\mathbf{Z}_{M_{12}}) - \mathbf{I}_3(+\mathbf{Z}_{M_{13}}) = 0$$
or $$\mathbf{E}_1 - \mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_{L_1}] + \mathbf{I}_2\mathbf{Z}_{M_{12}} - \mathbf{I}_3\mathbf{Z}_{M_{13}} = 0$$

$$-\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}) + \mathbf{I}_3\mathbf{Z}_2 - \mathbf{I}_1(-\mathbf{Z}_{M_{12}}) = 0$$
or $$-\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}) + \mathbf{I}_3\mathbf{Z}_2 + \mathbf{I}_1\mathbf{Z}_{M_{12}} = 0$$

$$-\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}) + \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_1(+\mathbf{Z}_{M_{13}}) = 0$$
or $$-\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}) + \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_1\mathbf{Z}_{M_{13}} = 0$$

$\therefore$
$$\begin{aligned}
&[\mathbf{Z}_1 + \mathbf{Z}_{L_1}]\mathbf{I}_1 - \mathbf{Z}_{M_{12}}\mathbf{I}_2 + \mathbf{Z}_{M_{13}}\mathbf{I}_3 = \mathbf{E}_1\\
&\mathbf{Z}_{M_{12}}\mathbf{I}_1 - [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}]\mathbf{I}_2 + \mathbf{Z}_2\mathbf{I}_3 = 0\\
&\mathbf{Z}_{M_{13}}\mathbf{I}_1 \quad \mathbf{Z}_2\mathbf{I}_2 + [\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}]\mathbf{I}_3 = 0
\end{aligned}$$

Chapter 23

1. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\ V}$ b. $V_\phi = E_\phi = \mathbf{120.1\ V}$

c. $I_\phi = \dfrac{V_\phi}{R_\phi} = \dfrac{120.1\text{ V}}{10\ \Omega} = \mathbf{12.01\ A}$ d. $I_L = I_\phi = \mathbf{12.01\ A}$

2. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\ V}$ b. $V_\phi = E_\phi = \mathbf{120.1\ V}$

c. $\mathbf{Z}_\phi = 12\ \Omega - j16\ \Omega = 20\ \Omega \angle -53.13°$ d. $I_L = I_\phi = \mathbf{6\ A}$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.1\text{ V}}{20\ \Omega} \cong \mathbf{6\ A}$

3. a. $E_\phi = \mathbf{120.1\ V}$ b. $V_\phi = \mathbf{120.1\ V}$

c. $\mathbf{Z}_\phi = (10\ \Omega \angle 0° \parallel (10\ \Omega \angle -90°) = 7.071\ \Omega \angle -45°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.1\text{ V}}{7.071\ \Omega} = \mathbf{16.98\ A}$

d. $I_L = \mathbf{16.98\ A}$

4. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{120°}$

b. $\mathbf{V}_{an} = \mathbf{120\ V \angle 0°}$, $\mathbf{V}_{bn} = \mathbf{120\ V \angle -120°}$, $\mathbf{V}_{cn} = \mathbf{120\ V \angle 120°}$

c. $\mathbf{I}_{\text{an}} = \dfrac{\mathbf{V}_{an}}{\mathbf{Z}_{an}} = \dfrac{120\text{ V} \angle 0°}{20\ \Omega \angle 0°} = \mathbf{6\ A \angle 0°}$

$\mathbf{I}_{\text{bn}} = \dfrac{\mathbf{V}_{bn}}{\mathbf{Z}_{bn}} = \dfrac{120\text{ V} \angle -120°}{20\ \Omega \angle 0°} = \mathbf{6\ A \angle -120°}$

$\mathbf{I}_{\text{cn}} = \dfrac{\mathbf{V}_{cn}}{\mathbf{Z}_{cn}} = \dfrac{120\text{ V} \angle 120°}{20\ \Omega \angle 0°} = \mathbf{6\ A \angle 120°}$

d. $I_L = I_\phi = \mathbf{6A}$ e. $V_L = \sqrt{3}\ V_\phi = \sqrt{3}\,(120\text{ V}) = \mathbf{207.8\ V}$

5. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

b. $\mathbf{V}_{an} = \mathbf{120\ V \angle 0°}$, $\mathbf{V}_{bn} = \mathbf{120\ V \angle -120°}$, $\mathbf{V}_{cn} = \mathbf{120\ V \angle 120°}$

c. $\mathbf{Z}_\phi = 9\ \Omega + j12\ \Omega = 15\ \Omega \angle 53.13°$

$\mathbf{I}_{an} = \dfrac{120\text{ V} \angle 0°}{15\ \Omega \angle 53.13°} = \mathbf{8\ A \angle -53.13°}$, $\mathbf{I}_{bn} = \dfrac{120\text{ V} \angle -120°}{15\ \Omega \angle 53.13°} = \mathbf{8\ A \angle -173.13°}$

$\mathbf{I}_{cn} = \dfrac{120\text{ V} \angle 120°}{15\ \Omega \angle 53.13°} = \mathbf{8\ A \angle 66.87°}$

e. $I_L = I_\phi = \mathbf{8\ A}$

f. $E_L = \sqrt{3}\ E_\phi = (1.732)(120\text{ V}) = \mathbf{207.85\ V}$

6. a, b. The same as problem 4.

c. $\mathbf{Z}_\phi = 6\ \Omega \angle 0° \parallel 8\ \Omega \angle -90° = 4.8\ \Omega \angle -36.87°$

$$\mathbf{I}_{an} = \frac{\mathbf{V}_{an}}{\mathbf{Z}_{an}} = \frac{120\text{ V} \angle 0°}{4.8\ \Omega \angle -36.87°} = \mathbf{25\ A \angle 36.87°}$$

$$\mathbf{I}_{bn} = \frac{\mathbf{V}_{bn}}{\mathbf{Z}_{bn}} = \frac{120\text{ V} \angle -120°}{4.8\ \Omega \angle -36.87°} = \mathbf{25\ A \angle -83.13°}$$

$$\mathbf{I}_{cn} = \frac{\mathbf{V}_{cn}}{\mathbf{Z}_{cn}} = \frac{120\text{ V} \angle 120°}{4.8\ \Omega \angle -36.87°} = \mathbf{25\ A \angle 156.87°}$$

d. $I_L = I_\phi = \mathbf{25\ A}$

e. $V_L = \sqrt{3}\ V_\phi = \sqrt{3}\ (120\text{ V}) = \mathbf{207.84\ V}$

7. $$V_\phi = V_{an} = V_{bn} = V_{cn} = \frac{V_L}{\sqrt{3}} = \frac{220\text{ V}}{1.732} = \mathbf{127.0\ V}$$

$\mathbf{Z}_\phi = 10\ \Omega - j10\ \Omega = 14.42\ \Omega \angle -45°$

$$I_\phi = I_{an} = I_{bn} = I_{cn} = \frac{V_\phi}{Z_\phi} = \frac{127\text{ V}}{14.142\ \Omega} = \mathbf{8.98\ A}$$

$I_L = I_{Aa} = I_{Bb} = I_{Cc} = I_\phi = \mathbf{8.98\ A}$

8. $\mathbf{Z}_\phi = 12\ \Omega + j16\ \Omega = 20\ \Omega \angle 53.13°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{50\text{ V}}{20\ \Omega} = \mathbf{2.5\ A}$$

$Z_{T_\phi} = 13\ \Omega + j16\ \Omega = 20.62\ \Omega \angle 50.91°$

$V_\phi = I_\phi\ Z_{T_\phi} = (2.5\text{ A})(20.62\ \Omega) = 51.55\text{ V}$

$V_L = \sqrt{3}\ V_\phi = \left(\sqrt{3}\right)(51.55\text{ V}) = \mathbf{89.29\ V}$

9. a. $$\mathbf{E}_{AN} = \frac{22\text{ kV}}{\sqrt{3}} \angle -30° = \mathbf{12.7\ kV \angle -30°}$$

$$\mathbf{E}_{BN} = \frac{22\text{ kV}}{\sqrt{3}} \angle -150° = \mathbf{12.7\ kV \angle -150°}$$

$$\mathbf{E}_{CN} = \frac{22\text{ kV}}{\sqrt{3}} \angle 90° = \mathbf{12.7\ kV \angle 90°}$$

b, c. $\mathbf{I}_{Aa} = \mathbf{I}_{an} = \dfrac{\mathbf{E}_{AN}}{\mathbf{Z}_{AN}} = \dfrac{12.7\text{ kV}\angle -30°}{(30\,\Omega + j40\,\Omega) + (0.4\text{ k}\Omega + j1\text{ k}\Omega)}$

$= \dfrac{12.7\text{ kV}\angle -30°}{430\,\Omega + j1040\,\Omega} = \dfrac{12.7\text{ kV}\angle -30°}{1125.39\,\Omega\angle 67.54°}$

$= \mathbf{11.29\ A\ \angle{-97.54°}}$

$\mathbf{I}_{Bb} = \mathbf{I}_{bn} = \dfrac{\mathbf{E}_{BN}}{\mathbf{Z}_{BN}} = \dfrac{12.7\text{ kV}\angle -150°}{1125.39\,\Omega\angle 67.54°} = \mathbf{11.29\ A\ \angle{-217.54°}}$

$\mathbf{I}_{Cc} = \mathbf{I}_{cn} = \dfrac{\mathbf{E}_{CN}}{\mathbf{Z}_{CN}} = \dfrac{12.7\text{ kV}\angle 90°}{1125.39\,\Omega\angle 67.54°} = \mathbf{11.29\ A\ \angle 22.46°}$

d. $\mathbf{V}_{an} = \mathbf{I}_{an}\mathbf{Z}_{an} = (11.29\text{ A}\angle -97.54°)(400 + j1000)$

$= (11.29\text{ A}\angle -97.54°)(1077.03\,\Omega\angle 68.2°)$

$= \mathbf{12.16\ kV\ \angle{-29.34°}}$

$\mathbf{V}_{bn} = \mathbf{I}_{bn}\mathbf{Z}_{bn} = (11.29\text{ A}\angle -217.54°)(1077.03\angle 68.2°)$

$= \mathbf{12.16\ kV\ \angle{-149.34°}}$

$\mathbf{V}_{cn} = \mathbf{I}_{cn}\mathbf{Z}_{cn} = (11.29\text{ A}\angle 22.46°)(1077.03\angle 68.2°)$

$= \mathbf{12.16\ kV\ \angle 90.66°}$

10. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\ V}$ b. $V_\phi = E_L = \mathbf{208\ V}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{208\text{ V}}{20\,\Omega} = \mathbf{10.4\ A}$ d. $I_L = \sqrt{3}\ I_\phi = (1.732)(10.4\text{ A}) = \mathbf{18\ A}$

11. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\ V}$ b. $V_\phi = E_L = \mathbf{208\ V}$

c. $\mathbf{Z}_\phi = 6.8\,\Omega + j14\,\Omega = 15.564\,\Omega\angle 64.09°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{208\text{ V}}{15.564\,\Omega} = \mathbf{13.36\ A}$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(13.36\text{ A}) = \mathbf{23.14\ A}$

12. $\mathbf{Z}_\phi = 18\,\Omega\angle 0° \parallel 18\,\Omega\angle -90° = 12.728\,\Omega\angle -45°$

a. $E_\phi = V_L/\sqrt{3} = 208\text{ V}/\sqrt{3} = \mathbf{120.09\ V}$ b. $V_\phi = \mathbf{208\ V}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{208\text{ V}}{12.728\,\Omega} = \mathbf{16.34\ A}$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(16.34\text{ A}) = \mathbf{28.30\ A}$

13. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

b. $\mathbf{V}_{ab} = \mathbf{208\ V\ \angle 0°}$, $\mathbf{V}_{bc} = \mathbf{208\ V\ \angle{-120°}}$, $\mathbf{V}_{ca} = \mathbf{208\ V\ \angle 120°}$

c. –

d. $\mathbf{I}_{ab} = \dfrac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \dfrac{208\text{ V}\angle 0°}{22\,\Omega\angle 0°} = \mathbf{9.46\text{ A}\angle 0°}$

$\mathbf{I}_{bc} = \dfrac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \dfrac{208\text{ V}\angle 120°}{22\,\Omega\angle 0°} = \mathbf{9.46\text{ A}\angle{-120}°}$

$\mathbf{I}_{ca} = \dfrac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \dfrac{208\text{ V}\angle 120°}{22\,\Omega\angle 0°} = \mathbf{9.46\text{ A}\angle 120°}$

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. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

b. $\mathbf{V}_{ab} = \mathbf{208\text{ V}\angle 0°}$, $\mathbf{V}_{bc} = \mathbf{208\text{ V}\angle{-120}°}$, $\mathbf{V}_{ca} = \mathbf{208\text{ V}\angle 120°}$

c. –

d. $\mathbf{Z}_\phi = 100\,\Omega - j100\,\Omega = 141.42\,\Omega\angle{-45}°$

$\mathbf{I}_{ab} = \dfrac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \dfrac{208\text{ V}\angle 0°}{141.42\,\Omega\angle -45°} = \mathbf{1.47\text{ A}\angle 45°}$

$\mathbf{I}_{bc} = \dfrac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \dfrac{208\text{ V}\angle -120°}{141.42\,\Omega\angle -45°} = \mathbf{1.47\text{ A}\angle{-75}°}$

$\mathbf{I}_{ca} = \dfrac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \dfrac{208\text{ V}\angle 120°}{141.42\,\Omega\angle -45°} = \mathbf{1.47\text{ A}\angle 165°}$

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. $\mathbf{Z}_\phi = 3\,\Omega\angle 0° \parallel 4\,\Omega\angle 90° = 2.4\,\Omega\angle 36.87°$

$\mathbf{I}_{ab} = \dfrac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \dfrac{208\text{ V}\angle 0°}{2.4\,\Omega\angle 36.87°} = \mathbf{86.67\text{ A}\angle{-36.87}°}$

$\mathbf{I}_{bc} = \dfrac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \dfrac{208\text{ V}\angle -120°}{2.4\,\Omega\angle 36.87°} = \mathbf{86.67\text{ A}\angle{-156.87}°}$

$\mathbf{I}_{ca} = \dfrac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \dfrac{208\text{ V}\angle 120°}{2.4\,\Omega\angle 36.87°} = \mathbf{86.67\text{ A}\angle 83.13°}$

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. $V_{ab} = V_{bc} = V_{ca} = \mathbf{220\text{ V}}$

$\mathbf{Z}_\phi = 10\ \Omega + j10\ \Omega = 14.142\ \Omega\angle 45°$

$$I_{ab} = I_{bc} = I_{ca} = \frac{V_\phi}{Z_\phi} = \frac{220\text{ V}}{14.142\ \Omega} = \mathbf{15.56\text{ A}}$$

17. a. $$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\boldsymbol{Z}_{ab}} = \frac{16\text{ kV}\angle 0°}{300\ \Omega + j1000\ \Omega} = \frac{16\text{ kV}\angle 0°}{1044.03\ \Omega\angle 73.30°}$$

$\mathbf{I}_{ab} = \mathbf{15.33\text{ A}\angle{-73.30°}}$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{16\text{ kV}\angle{-120°}}{1044.03\ \Omega\angle 73.30°} = \mathbf{15.33\text{ A}\angle{-193.30°}}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{16\text{ kV}\angle 120°}{1044.03\ \Omega\angle 73.30°} = \mathbf{15.33\text{ A}\angle 46.7°}$$

b. $\mathbf{I}_{Aa} - \mathbf{I}_{ab} + \mathbf{I}_{ca} = 0$

$\mathbf{I}_{Aa} = \mathbf{I}_{ab} - \mathbf{I}_{ca} = 15.33\text{ A}\angle{-73.30°} - 15.33\text{ A}\angle 46.7°$

$= (4.41\text{ A} - j14.68\text{ A}) - (10.51\text{ A} + j11.16\text{ A})$

$= 4.41\text{ A} - 10.51\text{ A} - j(14.68\text{ A} + 11.16\text{ A})$

$= -6.11\text{ A} - j25.84\text{ A} = \mathbf{26.55\text{ A}\angle{-103.30°}}$

$\mathbf{I}_{Bb} + \mathbf{I}_{ab} = \mathbf{I}_{bc}$

$\mathbf{I}_{Bb} = \mathbf{I}_{bc} - \mathbf{I}_{ab} = 15.33\text{ A}\angle{-193.30°} - 15.33\text{ A}\angle{-73.30°}$

$= \mathbf{26.55\text{ A}\angle 136.70°}$

$\mathbf{I}_{Cc} + \mathbf{I}_{bc} = \mathbf{I}_{ca}$

$\mathbf{I}_{Cc} = \mathbf{I}_{ca} - \mathbf{I}_{bc} = 15.33\text{ A}\angle 46.7° - 15.33\text{ A}\angle{-193.30°}$

$= \mathbf{26.55\text{ A}\angle 16.70°}$

c. $\mathbf{E}_{AB} = \mathbf{I}_{Aa}(10\ \Omega + j20\ \Omega) + \mathbf{V}_{ab} - \mathbf{I}_{Bb}(22.361\ \Omega\angle 63.43°)$

$= (26.55\text{ A}\angle{-103.30°})(22.361\ \Omega\angle 63.43°) + 16\text{ kV}\angle 0°$

$- (26.55\text{ A}\angle 136.70°)(22.361\ \Omega\angle 63.43°)$

$= (455.65\text{ V} - j380.58\text{ V}) + 16{,}000\text{ V} - (-557.42\text{ V} - j204.32\text{ V})$

$= 17.01\text{ kV} - j176.26\text{ V}$

$= \mathbf{17.01\text{ kV}\angle{-0.59°}}$

$\mathbf{E}_{BC} = \mathbf{I}_{Bb}(22.361\ \Omega\angle 63.43°) + \mathbf{V}_{bc} - \mathbf{I}_{Cc}(22.361\ \Omega\angle 63.53°)$

$= (26.55\text{ A}\angle 136.70°)(22.361\ \Omega\angle 63.53°) + 16\text{ kV}\angle{-120°}$

$- (26.55\text{ A}\angle 16.70°)(22.361\ \Omega\angle 63.53°)$

$= \mathbf{17.01\text{ kV}\angle{-120.59°}}$

$\mathbf{E}_{CA} = \mathbf{I}_{Cc}(22.361\ \Omega\angle 63.43°) + \mathbf{V}_{ca} - \mathbf{I}_{Aa}(22.361\ \Omega\angle 63.43°)$

$= \mathbf{17.01\text{ kV}\angle 119.41°}$

18. a. $E_\phi = E_L = \mathbf{208\ V}$

b. $V_\phi = \dfrac{E_L}{\sqrt{3}} = \dfrac{208\text{ V}}{1.732} = \mathbf{120.1\ V}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.1\text{ V}}{30\,\Omega} = \mathbf{4.00\ A}$

d. $I_L = I_\phi \cong \mathbf{4\ A}$

19. a. $E_\phi = E_L = \mathbf{208\ V}$

b. $V_\phi = E_L \sqrt{3} = \mathbf{120.09\ V}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.09\text{ V}}{16.971\,\Omega} = \mathbf{7.08\ A}$

d. $I_L = I_\phi = \mathbf{7.08\ A}$

20. a, b. The same as problem 18.

c. $\mathbf{Z}_\phi = 15\ \Omega\ \angle 0° \parallel 20\ \Omega\ \angle{-90°} = 12\ \Omega\ \angle{-36.87°}$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1\text{ V}}{12\,\Omega} \cong \mathbf{10\ A}$$

d. $I_L = I_\phi \cong \mathbf{10\ A}$

21. $V_{an} = V_{bn} = V_{cn} = \dfrac{120\text{ V}}{\sqrt{3}} = \dfrac{120\text{ V}}{1.732} = \mathbf{69.28\ V}$

$I_{an} = I_{bn} = I_{cn} = \dfrac{69.28\text{ V}}{24\,\Omega} = \mathbf{2.89\ A}$

$I_{Aa} = I_{Bb} = I_{Cc} = \mathbf{2.89\ A}$

22. $V_{an} = V_{bn} = V_{cn} = \dfrac{120\text{ V}}{\sqrt{3}} = \mathbf{69.28\ V}$

$\mathbf{Z}_\phi = 10\ \Omega + j20\ \Omega = 22.36\ \Omega\angle 63.43°$

$I_{an} = I_{bn} = I_{cn} = \dfrac{\mathbf{V}_\phi}{\mathbf{Z}_\phi} = \dfrac{69.28\text{ V}}{22.36\,\Omega} = \mathbf{3.10\ A}$

$I_{Aa} = I_{Bb} = I_{Cc} = I_\phi = \mathbf{3.10\ A}$

23. $V_{an} = V_{bn} = V_{cn} = \mathbf{69.28\ V}$

$\mathbf{Z}_\phi = 20\ \Omega\ \angle 0° \parallel 15\ \Omega\ \angle{-90°} = 12\ \Omega\ \angle{-53.13°}$

$I_{an} = I_{bn} = I_{cn} = \dfrac{69.28\text{ V}}{12\,\Omega} = \mathbf{5.77\ A}$

$I_{Aa} = I_{Bb} = I_{Cc} = \mathbf{5.77\ A}$

24. a. $E_\phi = E_L = \mathbf{440\ V}$

b. $V_\phi = E_L = E_\phi = \mathbf{440\ V}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{440\text{ V}}{220\,\Omega} = \mathbf{2\ A}$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(2\text{ A}) = \mathbf{3.46\ A}$

25. a. $E_\phi = E_L =$ **440 V** b. $V_\phi = E_L =$ **440 V**

c. $\mathbf{Z}_\phi = 12\ \Omega - j9\ \Omega = 15\ \Omega \angle -36.87°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440\text{ V}}{15\ \Omega} = \mathbf{29.33\ A}$$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(29.33\text{ A}) =$ **50.8 A**

26. a, b. The same as problem 24.

c. $\mathbf{Z}_\phi = 22\ \Omega \angle 0° \parallel 22\ \Omega \angle 90° = 15.56\ \Omega \angle 45°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440\text{ V}}{15.56\ \Omega} = \mathbf{28.28\ A}$$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(28.28\text{ A}) =$ **48.98 A**

27. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

b. $\mathbf{V}_{ab} = \mathbf{100\ V \angle 0°}$, $\mathbf{V}_{bc} = \mathbf{100\ V \angle -120°}$, $\mathbf{V}_{ca} = \mathbf{100\ V \angle 120°}$

c. –

d.
$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{100\text{ V} \angle 0°}{20\ \Omega \angle 0°} = \mathbf{5\ A \angle 0°}$$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{100\text{ V} \angle -120°}{20\ \Omega \angle 0°} = \mathbf{5\ A \angle -120°}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{100\text{ V} \angle 120°}{20\ \Omega \angle 0°} = \mathbf{5\ A \angle 120°}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3}\ (5\text{ A}) =$ **8.66 A**

28. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

b. $\mathbf{V}_{ab} = \mathbf{100\ V \angle 0°}$, $\mathbf{V}_{bc} = \mathbf{100\ V \angle -120°}$, $\mathbf{V}_{ca} = \mathbf{100\ V \angle 120°}$

c. –

d. $\mathbf{Z}_\phi = 12\ \Omega + j16\ \Omega = 20\ \Omega \angle 53.13°$

$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{100\text{ V} \angle 0°}{20\ \Omega \angle 53.13°} = \mathbf{5\ A \angle -53.13°}$$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{100\text{ V} \angle -120°}{20\ \Omega \angle 53.13°} = \mathbf{5\ A \angle -173.13°}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{100\text{ V}\angle 120°}{20\,\Omega\angle 53.13°} = \mathbf{5\text{ A}\angle 66.87°}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3}\ I_\phi = (1.732)(5\text{ A}) = \mathbf{8.66\text{ A}}$

29. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{120°}$

b. $\mathbf{V}_{ab} = \mathbf{100\text{ V}\angle 0°}$, $\mathbf{V}_{bc} = \mathbf{100\text{ V}\angle -120°}$, $\mathbf{V}_{ca} = \mathbf{100\text{ V}\angle 120°}$

c. –

d. $\mathbf{Z}_\phi = 20\,\Omega\angle 0° \parallel 20\,\Omega\angle -90° = 14.14\,\Omega\angle -45°$

$$\mathbf{I}_{ab} = \frac{100\text{ V}\angle 0°}{14.14\,\Omega\angle -45°} = \mathbf{7.07\text{ A}\angle 45°}$$

$$\mathbf{I}_{bc} = \frac{100\text{ V}\angle -120°}{14.14\,\Omega\angle -45°} = \mathbf{7.07\text{ A}\angle -75°}$$

$$\mathbf{I}_{ca} = \frac{100\text{ V}\angle 120°}{14.14\,\Omega\angle -45°} = \mathbf{7.07\text{ A}\angle 165°}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = \left(\sqrt{3}\right)(7.07\text{ A}) = \mathbf{12.25\text{ A}}$

30. $P_T = 3I_\phi^2 R_\phi = 3(6\text{ A})^2\ 12\,\Omega = \mathbf{1296\text{ W}}$

$Q_T = 3I_\phi^2 X_\phi = 3(6\text{ A})^2\ 16\,\Omega = \mathbf{1728\text{ VAR}(\mathit{C})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{2160\text{ VA}}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{1296\text{ W}}{2160\text{ VA}} = \mathbf{0.6\text{ (leading)}}$

31. $V_\phi = 120\text{ V}$, $I_\phi = 120\text{ V}/20\,\Omega = 6\text{ A}$

$P_T = 3I_\phi^2 R_\phi = 3(6\text{ A})^2\ 20\,\Omega = \mathbf{2160\text{ W}}$

$Q_T = \mathbf{0\text{ VAR}}$

$S_T = P_T = \mathbf{2160\text{ VA}}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{2160\text{ W}}{2160\text{ VA}} = \mathbf{1}$

32. $P_T = 3I_\phi^2 R_\phi = 3(8.98\text{ A})^2\ 10\,\Omega = \mathbf{2419.21\text{ W}}$

$Q_T = 3I_\phi^2 X_\phi = 3(8.98\text{ A})^2\ 10\,\Omega = \mathbf{2419.21\text{ VAR}(\mathit{C})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3421.28\text{ VA}}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{2419.21\text{ W}}{3421.28\text{ VA}} = \mathbf{0.7071\text{ (leading)}}$

33. $V_\phi = 208\text{ V}$

$$P_T = 3\left(\frac{V_\phi^2}{R_\phi}\right) = 3\cdot\frac{(208\text{ V})^2}{18\,\Omega} = \mathbf{7210.67\ W}$$

$$Q_T = 3\left(\frac{V_\phi^2}{X_\phi}\right) = 3\cdot\frac{(208\text{ V})^2}{18\,\Omega} = \mathbf{7210.67\ VAR(}\boldsymbol{C}\mathbf{)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{10{,}197.42\ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{7210.67\text{ W}}{10{,}197.42\text{ VA}} = \mathbf{0.707\ (leading)}$$

34. $P_T = 3I_\phi^2 R_\phi = 3(1.471\text{ A})^2\ 100\ \Omega = \mathbf{649.15\ W}$

$$Q_T = 3I_\phi^2 X_\phi = 3(1.471\text{ A})^2\ 100\ \Omega = \mathbf{649.15\ VAR(}\boldsymbol{C}\mathbf{)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{918.04\ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{649.15\text{ W}}{918.04\text{ VA}} = \mathbf{0.7071\ (leading)}$$

35. $P_T = 3I_\phi^2 R_\phi = 3(15.56\text{ A})^2\ 10\ \Omega = \mathbf{7.26\ kW}$

$$Q_T = 3I_\phi^2 X_\phi = 3(15.56\text{ A})^2\ 10\ \Omega = \mathbf{7.26\ kVAR}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{10.27\ kVA}$$

$$F_p = \frac{P_T}{S_T} = \frac{7.263\text{ kW}}{10.272\text{ kVA}} = \mathbf{0.7071\ (lagging)}$$

36. $P_T = 3\dfrac{V_\phi^2}{R_\phi} = \dfrac{3(120.1\text{ V})^2}{15\,\Omega} = \mathbf{2884.80\ W}$

$$Q_T = 3\frac{V_\phi^2}{X_\phi} = \frac{3(120.1\text{ V})^2}{20\,\Omega} = \mathbf{2163.60\ VAR(}\boldsymbol{C}\mathbf{)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3605.97\ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{2884.80\text{ W}}{3605.97\text{ VA}} = \mathbf{0.8\ (leading)}$$

37. $\mathbf{Z}_\phi = 10\ \Omega + j20\ \Omega = 22.36\ \Omega\ \angle 63.43°$

$$V_\phi = \frac{V_L}{\sqrt{3}} = \frac{120\text{ V}}{1.732} = 69.28\text{ V}$$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{69.28\text{ V}}{22.36\,\Omega} = 3.098\text{ A}$$

$$P_T = 3I_\phi^2 R_\phi = 3(3.098\text{ A})^2\ 10\ \Omega = \mathbf{287.93\ W}$$

$Q_T = 3I_\phi^2 X_\phi = 3(3.098\text{ A})^2\ 20\ \Omega = \mathbf{575.86\ VAR}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{643.83\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{287.93\text{ W}}{643.83\text{ VA}} = \mathbf{0.447\ (lagging)}$

38. $P_T = 3\dfrac{V_\phi^2}{R_\phi} = \dfrac{3(440\text{ V})^2}{22\ \Omega} = \mathbf{26.4\ kW}$

$Q_T = P_T = \mathbf{26.4\ kVAR(\mathit{L})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{37.34\ kVA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{26.4\text{ kW}}{37.34\text{ kVA}} = \mathbf{0.707\ (lagging)}$

39. $\mathbf{Z}_\phi = 12\ \Omega + j16\ \Omega = 20\ \Omega\ \angle 53.13°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{100\text{ V}}{20\ \Omega} = 5\text{ A}$

$P_T = 3I_\phi^2 R_\phi = 3(5\text{ A})^2\ 12\ \Omega = \mathbf{900\ W}$

$Q_T = 3I_\phi^2 X_\phi = 3(5\text{ A})^2\ 16\ \Omega = \mathbf{1200\ VAR(\mathit{L})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{1500\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{900\text{ W}}{1500\text{ VA}} = \mathbf{0.6\ (lagging)}$

40. $P_T = \sqrt{3}\, E_L I_L \cos\theta$

$4800\text{ W} = (1.732)(200\text{ V})I_L\,(0.8)$

$I_L = 17.32\text{ A}$

$I_\phi = \dfrac{I_L}{\sqrt{3}} = \dfrac{17.32\text{ A}}{1.732} = 10\text{ A}$

$\theta = \cos^{-1} 0.8 = 36.87°$

$\mathbf{Z}_\phi = \dfrac{\mathbf{V}_\phi}{\mathbf{I}_\phi} = \dfrac{200\text{ V}\ \angle 0°}{10\text{ A}\ \angle -36.87°} = 20\ \Omega\ \angle 36.87° = \mathbf{16\ \Omega + \mathit{j}12\ \Omega}$

41. $P_T = \sqrt{3}\, E_L I_L \cos\theta$

$1200\text{ W} = \sqrt{3}\,(208\text{ V})I_L(0.6) \Rightarrow I_L = 5.55\text{ A}$

$V_\phi = \dfrac{V_L}{\sqrt{3}} = \dfrac{208\text{ V}}{1.732} = 120.1\text{ V}$

$\theta = \cos^{-1} 0.6 = 53.13°$ (leading)

$\mathbf{Z}_\phi = \dfrac{\mathbf{V}_\phi}{\mathbf{I}_\phi} = \dfrac{120.1\text{ V}\ \angle 0°}{5.55\text{ A}\ \angle 53.13°} = 21.64\ \Omega\ \angle -53.13° = \underbrace{12.98\ \Omega}_{R} - j\underbrace{17.31\ \Omega}_{X_C}$

42. Δ: $\mathbf{Z}_\phi = 15\ \Omega + j20\ \Omega = 25\ \Omega\angle 53.13°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{125\ \text{V}}{25\ \Omega} = 5\ \text{A}$$

$P_T = 3I_\phi^2 R_\phi = 3(5\ \text{A})^2\ 15\ \Omega = \mathbf{1125\ W}$

$Q_T = 3I_\phi^2 X_\phi = 3(5\ \text{A})^2\ 20\ \Omega = \mathbf{1500\ VAR(\mathit{L})}$

Y: $V_\phi = V_L/\sqrt{3} = 125\ \text{V}/1.732 = \mathbf{72.17\ V}$

$\mathbf{Z}_\phi = 3\ \Omega - j4\ \Omega = 5\ \Omega\angle -53.13°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{72.17\ \text{V}}{5\ \Omega} = \mathbf{14.43\ A}$$

$P_T = 3I_\phi^2 R_\phi = 3(14.43\ \text{A})^2\ 3\ \Omega = \mathbf{1874.02\ W}$

$Q_T = 3I_\phi^2 X_\phi = 3(14.43\ \text{A})^2\ 4\ \Omega = \mathbf{2498.7\ VAR}$

$P_T = 1125\ \text{W} + 1874.02\ \text{W} = \mathbf{2999.02\ W}$

$Q_T = 1500\ \text{VAR}(L) - 2498.7\ \text{VAR}(C) = \mathbf{998.7\ VAR(\mathit{C})}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3161\ VA}$

$$F_p = \frac{P_T}{S_T} = \frac{2999.02\ \text{W}}{3161\ \text{VA}} = \mathbf{0.949\ (leading)}$$

43. a. $E_\phi = \dfrac{16\ \text{kV}}{\sqrt{3}} = \mathbf{9{,}237.6\ V}$ b. $I_L = I_\phi = \mathbf{80\ A}$

c. $P_{\phi_L} = \dfrac{1200\ \text{kW}}{3} = 400\ \text{kW}$

$P_{4\Omega} = (80\ \text{A})^2 4\ \Omega = 25.6\ \text{kW}$

$P_T = 3P_\phi = 3(25.6\ \text{kW} + 400\ \text{kW}) = \mathbf{1276.8\ kW}$

d. $F_p = \dfrac{P_T}{S_T}$, $S_T = \sqrt{3}\ V_L I_L = \sqrt{3}\ (16\ \text{kV})(80\ \text{A}) = 2{,}217.025\ \text{kVA}$

$$F_p = \frac{1{,}276.8\ \text{kW}}{2{,}217.025\ \text{kVA}} = \mathbf{0.576\ lagging}$$

e. $\theta_L = \cos^{-1} 0.576 = 54.83°$ (lagging)

$$\mathbf{I}_{Aa} = \frac{\mathbf{E}_{AN}\angle 0°}{\underbrace{Z_T\angle 54.83°}_{\substack{\uparrow \\ \text{for entire load}}}} \Rightarrow \underbrace{\mathbf{80A}}_{\text{given}} \angle \mathbf{-54.83°}$$

f. $\mathbf{V}_{an} = \mathbf{E}_{AN} - \mathbf{I}_{Aa}(4\ \Omega + j20\ \Omega)$

$= 9237.6\ \text{V}\ \angle 0° - (80\ \text{A}\ \angle -54.83°)(20.396\ \Omega\ \angle 78.69°)$

$= 9237.6\ \text{V}\ \angle 0° - 1631.68\ \text{V}\ \angle 23.86°$

$= 9237.6\ \text{V} - (1492.22\ \text{V} + j660\ \text{V})$

$= 7745.38\ \text{V} - j660\ \text{V}$

$= \mathbf{7773.45\ V\ \angle -4.87°}$

g. $$\mathbf{Z}_\phi = \frac{\mathbf{V}_{an}}{\mathbf{I}_{Aa}} = \frac{7773.45\ \text{V}\ \angle -4.87°}{80\ \text{A}\ \angle -54.83°} = 97.168\ \Omega\ \angle 49.95°$$

$$= \underbrace{62.52\ \Omega}_{R} + j\underbrace{74.38\ \Omega}_{X_C}$$

h. F_p(entire system) = **0.576 (lagging)**

F_p(load) = **0.643 (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. $V_\phi = \dfrac{220\ \text{V}}{\sqrt{3}} = 127.02\ \text{V}$, $\mathbf{Z}_\phi = 10\ \Omega - j10\ \Omega = 14.14\ \Omega\angle -45°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{127.02\ \text{V}}{14.14\ \Omega} = 8.98\ \text{A}$

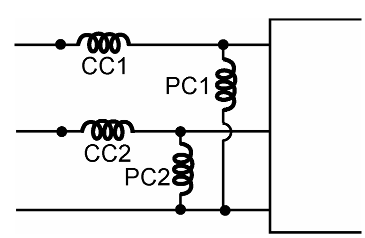
$P_T = 3I_\phi^2 R_\phi = 3(8.98\ \text{A})^2\ 10\ \Omega = \mathbf{2419.2\ W}$

Each wattmeter: $\dfrac{2419.2\ \text{W}}{3} = \mathbf{806.4\ W}$

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

46. a. –

b. $P_T = P_\ell + P_h = 85\ \text{W} + 200\ \text{W} = \mathbf{285\ W}$



c. $0.2 \Rightarrow \dfrac{P_\ell}{P_h} = 0.5$

$P_h = \dfrac{P_\ell}{0.5} = \dfrac{100\ \text{W}}{0.5} = \mathbf{200\ W}$

$P_T = P_h - P_\ell = 200\ \text{W} - 100\ \text{W} = \mathbf{100\ W}$

48. a. $\mathbf{I}_{ab} = \dfrac{\mathbf{E}_{AB}}{R\angle 0°} = \dfrac{208\text{ V}\angle 0°}{10\,\Omega\angle 0°} = \mathbf{20.8\ A\ \angle 0°}$

$\mathbf{I}_{bc} = \dfrac{\mathbf{E}_{BC}}{R\angle 0°} = \dfrac{208\text{ V}\angle -120°}{10\,\Omega\angle 0°} = \mathbf{20.8\ A\ \angle{-120°}}$

$\mathbf{I}_{ca} = \dfrac{\mathbf{E}_{CA}}{R\angle 0°} = \dfrac{208\text{ V}\angle 120°}{10\,\Omega\angle 0°} = \mathbf{20.8\ A\ \angle 120°}$

b. $\mathbf{I}_{Aa} + \mathbf{I}_{ca} - \mathbf{I}_{ab} = 0$
$\mathbf{I}_{Aa} = \mathbf{I}_{ab} - \mathbf{I}_{ca}$
$= 20.8\text{ A}\angle 0° - 20.8\text{ A}\angle 120°$
$= 20.8\text{ A} - (-10.4\text{ A} + j18.01\text{ A})$
$= 31.2\text{ A} - j18.01\text{ A}$
$= \mathbf{36.02\ A\ \angle{-30°}}$
$\mathbf{I}_{Bb} + \mathbf{I}_{ab} - \mathbf{I}_{bc} = 0$
$\mathbf{I}_{Bb} = \mathbf{I}_{bc} - \mathbf{I}_{ab}$
$= 20.8\text{ A}\angle{-120°} - 20.8\text{ A}\angle 0°$
$= (-10.4\text{ A} - j18.01\text{ A}) - 20.8\text{ A}$
$= -31.2\text{ A} - j18.01\text{ A}$
$= \mathbf{36.02\ A\ \angle{-150°}}$
$\mathbf{I}_{Cc} + \mathbf{I}_{bc} - \mathbf{I}_{ca} = 0$
$\mathbf{I}_{Cc} = \mathbf{I}_{ca} - \mathbf{I}_{bc}$
$= 20.8\text{ A}\angle 120° - 20.8\text{ A}\angle{-120°}$
$= (-10.4\text{ A} + j18.01\text{ A}) - (-10.4\text{ A} - j18.01\text{ A})$
$= -10.4\text{ A} + 10.4\text{ A} + j18.01\text{ A} + j18.01\text{ A}$
$= \mathbf{32.02\ A\ \angle 90°}$

c. $P_1 = V_{ac}I_{Aa}\cos\theta_{\mathbf{I}_{Aa}}^{\mathbf{V}_{ca}}$, $\mathbf{V}_{ac} = V_{ca}\angle\theta - 180° = 208\text{ V}\angle 120° - 180°$
$= 208\text{ V}\angle{-60°}$
$\mathbf{I}_{Aa} = 36.02\text{ A}\angle{-30°}$
$= (208\text{ V})(36.02\text{ A})\cos 30°$
$= \mathbf{6488.4\ W}$
$P_2 = V_{bc}I_{Bb}\cos\theta_{\mathbf{I}_{Bb}}^{\mathbf{V}_{bc}}$, $\mathbf{V}_{bc} = 208\text{ V}\angle{-120°}$, $\mathbf{I}_{Bb} = 36.02\text{ A}\angle{-150°}$
$= (208\text{ V})(36.02\text{ A})\cos 30°$
$= \mathbf{6488.4\ W}$

d. $P_T = P_1 + P_2 = 6488.4\text{ W} + 6488.4\text{ W}$
$= \mathbf{12{,}976.8\ W}$

49. a. $V_\phi = E_\phi = \dfrac{E_L}{\sqrt{3}} = \mathbf{120.09\ V}$

b. $I_{an} = \dfrac{V_{an}}{Z_{an}} = \dfrac{120.09\text{ V}}{14.142\,\Omega} = \mathbf{8.49\ A}$

$I_{bn} = \dfrac{V_{bn}}{Z_{bn}} = \dfrac{120.09\text{ V}}{16.971\,\Omega} = \mathbf{7.08\ A}$

$I_{cn} = \dfrac{V_{cn}}{Z_{cn}} = \dfrac{120.09\text{ V}}{2.828\,\Omega} = \mathbf{42.47\ A}$

c. $P_T = I_{an}^2\,10\,\Omega + I_{bn}^2\,12\,\Omega + I_{cn}^2\,2\,\Omega$
$= (8.49\text{ A})^2\,10\,\Omega + (7.08\text{ A})^2\,12\,\Omega + (42.47\text{ A})^2\,2\,\Omega$
$= 720.80\text{ W} + 601.52\text{ W} + 3.61\text{ kW}$
$= \mathbf{4.93\ kW}$
$Q_T = P_T = \mathbf{4.93\ kVAR}(\boldsymbol{L})$
$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{6.97\ kVA}$
$F_p = \dfrac{P_T}{S_T} = \mathbf{0.707\ (lagging)}$

d. $\mathbf{E}_{an} = 120.09\text{ V}\angle{-30^\circ}$, $\mathbf{E}_{bn} = 120.09\text{ V}\angle{-150^\circ}$, $\mathbf{E}_{cn} = 120.09\text{ V}\angle 90^\circ$

$\mathbf{I}_{an} = \dfrac{\mathbf{E}_{an}}{\mathbf{Z}_{an}} = \dfrac{120.09\text{ V}\angle{-30^\circ}}{10\,\Omega + j10\,\Omega} = \dfrac{120.09\text{ V}\angle{-30^\circ}}{14.142\,\Omega\angle 45^\circ} = \mathbf{8.49\ A\ \angle{-75^\circ}}$

$\mathbf{I}_{bn} = \dfrac{\mathbf{E}_{bn}}{\mathbf{Z}_{bn}} = \dfrac{120.09\text{ V}\angle{-150^\circ}}{12\,\Omega + j12\,\Omega} = \dfrac{120.09\text{ V}\angle{-150^\circ}}{16.971\,\Omega\angle 45^\circ} = \mathbf{7.08\ A\ \angle{-195^\circ}}$

$\mathbf{I}_{cn} = \dfrac{\mathbf{E}_{cn}}{\mathbf{Z}_{cn}} = \dfrac{120.09\text{ V}\angle 90^\circ}{2\,\Omega + j2\,\Omega} = \dfrac{120.09\text{ V}\angle 90^\circ}{2.828\,\Omega\angle 45^\circ} = \mathbf{42.47\ A\ \angle 45^\circ}$

e. $\mathbf{I}_N = \mathbf{I}_{an} + \mathbf{I}_{bn} + \mathbf{I}_{cn}$
$= 8.49\text{ A}\angle{-75^\circ} + 7.08\text{ A}\angle{-195^\circ} + 42.47\text{ A}\angle 45^\circ$
$= (2.02\text{ A} - j8.20\text{ A}) + (-6.84\text{ A} + j1.83\text{ A}) + (30.30\text{ A} + j30.30\text{ A})$
$= 25.66\text{ A} - j23.93\text{ A}$
$= \mathbf{35.09\ A\ \angle{-43.00^\circ}}$

50. $\mathbf{Z}_1 = 12\,\Omega - j16\,\Omega = 20\,\Omega\angle{-53.13^\circ}$, $\mathbf{Z}_2 = 3\,\Omega + j4\,\Omega = 5\,\Omega\angle 53.13^\circ$
$\mathbf{Z}_3 = 20\,\Omega\angle 0^\circ$

$\mathbf{E}_{AB} = 200\text{ V}\angle 0^\circ$, $\mathbf{E}_{BC} = 200\text{ V}\angle{-120^\circ}$, $\mathbf{E}_{CA} = 200\text{ V}\angle 120^\circ$
$\mathbf{Z}_\Delta = \mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3$
$= (20\,\Omega\angle{-53.13^\circ})(5\,\Omega\angle 53.13^\circ) + (20\,\Omega\angle{-53.13^\circ})(20\,\Omega\angle 0^\circ)$
$+ (5\,\Omega\angle 53.13^\circ)(20\,\Omega\angle 0^\circ)$
$= 100\,\Omega\angle 0^\circ + 400\,\Omega\angle{-53.13^\circ} + 100\,\Omega\angle 53.13^\circ$
$= 100\,\Omega + (240\,\Omega - j320\,\Omega) + (60\,\Omega + j80\,\Omega)$
$= 400\,\Omega - j240\,\Omega$
$= 466.48\,\Omega\angle{-30.96^\circ}$

$$\mathbf{I}_{an} = \frac{\mathbf{E}_{AB}\mathbf{Z}_3 - \mathbf{E}_{CA}\mathbf{Z}_2}{\mathbf{Z}_\Delta} = \frac{(200\text{ V}\angle 0^\circ)(20\ \Omega\angle 0^\circ) - (200\text{ V}\angle 120^\circ)(5\ \Omega\angle 53.13^\circ)}{\mathbf{Z}_\Delta}$$

$$= \frac{4000\text{ A}\angle 0^\circ - 1000\text{ A}\angle 173.13^\circ}{466.48\angle -30.96^\circ} = \mathbf{10.71\text{ A}\angle 29.59^\circ}$$

$$\mathbf{I}_{bn} = \frac{\mathbf{E}_{BC}\mathbf{Z}_1 - \mathbf{E}_{AB}\mathbf{Z}_3}{\mathbf{Z}_\Delta} = \frac{(200\text{ V}\angle -120^\circ)(20\ \Omega\angle -53.13^\circ) - (200\text{ V}\angle 0^\circ)(20\ \Omega\angle 0^\circ)}{\mathbf{Z}_\Delta}$$

$$= \frac{4000\text{ A}\angle -173.13^\circ - 4000\text{ A}\angle 0^\circ}{466.48\angle -30.96^\circ} = \mathbf{17.12\text{ A}\angle -145.61^\circ}$$

$$\mathbf{I}_{cn} = \frac{\mathbf{E}_{CA}\mathbf{Z}_2 - \mathbf{E}_{BC}\mathbf{Z}_1}{\mathbf{Z}_\Delta} = \frac{(200\text{ V}\angle 120^\circ)(5\ \Omega\angle 53.13^\circ) - (200\text{ V}\angle -120^\circ)(20\ \Omega\angle -53.13^\circ)}{\mathbf{Z}_\Delta}$$

$$= \frac{1000\text{ A}\angle 173.13^\circ - 4000\text{ A}\angle -173.13^\circ}{466.48\angle -30.96^\circ} = \mathbf{6.51\text{ A}\angle 42.32^\circ}$$

$$P_T = I_{an}^2\, 12\ \Omega + I_{bn}^2\, 4\ \Omega + I_{cn}^2\, 20\ \Omega$$

$$= 1376.45\text{ W} + 1172.38\text{ W} + 847.60\text{ W} = \mathbf{3396.43\text{ W}}$$

$$Q_T = I_{an}^2\, 16\ \Omega + I_{bn}^2\, 3\ \Omega = 1835.27\text{ VAR}(C) + 879.28\text{ VAR}(L) = \mathbf{955.99\text{ VAR}(\mathit{C})}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3508.40\text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{3396.43\text{ W}}{3508.40\text{ VA}} = \mathbf{0.968\text{ (leading)}}$$

Chapter 24

1. a. **positive-going** b. V_b = **2 V** c. t_p = **0.2 ms**

   d. Amplitude = 8 V – 2 V = **6 V**

   e. $\% \text{ tilt} = \dfrac{V_1 - V_2}{V} \times 100\%$

   $$V = \frac{8\text{ V} + 7.5\text{ V}}{2} = 7.75\text{ V}$$

   $$\% \text{ tilt} = \frac{8\text{ V} - 7.5\text{ V}}{7.75\text{ V}} \times 100\% = \mathbf{6.5\%}$$

2. a. **negative-going** b. **+7 mV** c. **3 μs**

   d. **–8 mV** (from base line level)

   e. $$V = \frac{-8\text{ mV} - 7\text{ mV}}{2} = \frac{-15\text{ mV}}{2} = -7.5\text{ mV}$$

   $$\% \text{ Tilt} = \frac{V_1 - V_2}{V} \times 100\% = \frac{-8\text{ mV} - (-7\text{ mV})}{-7.5\text{ mV}} \times 100\%$$

   $$= \frac{-1\text{ mV}}{-7.5\text{ mV}} \times 100\% = \mathbf{13.3\%}$$

   f. $T = 15\ \mu\text{s} - 7\ \mu\text{s} = 8\ \mu\text{s}$

   $$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu\text{s}} = \mathbf{125\ kHz}$$

   g. $$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{3\ \mu\text{s}}{8\ \mu\text{s}} \times 100\% = \mathbf{37.5\%}$$

3. a. **positive-going** b. V_b = **10 mV** c. $t_p = \left(\dfrac{8}{10}\right) 4\text{ ms} = \mathbf{3.2\ ms}$

   d. Amplitude = (30 – 10)mV = **20 mV**

   e. $\% \text{ tilt} = \dfrac{V_1 - V_2}{V} \times 100\%$

   $$V = \frac{30\text{ mV} + 28\text{ mV}}{2} = 29\text{ mV}$$

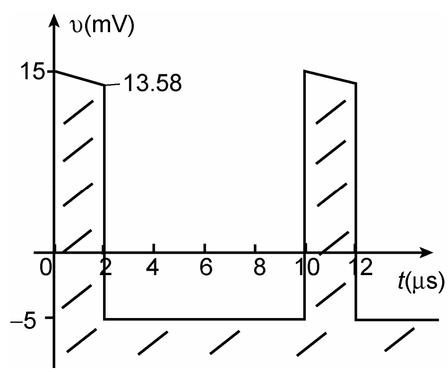
   $$\% \text{ tilt} = \frac{30\text{ mV} - 28\text{ mV}}{29\text{ mV}} \times 100\% \cong \mathbf{6.9\%}$$

4. $t_r \cong$ (0.2 div.)(2 ms/div.) = **0.4 ms**
$t_f \cong$ (0.4 div.)(2 ms/div.) = **0.8 ms**

5. tilt = $\dfrac{V_1 - V_2}{V}$ = 0.1 with $V = \dfrac{V_1 + V_2}{2}$

Substituting V into top equation,

$$\frac{V_1 - V_2}{\frac{V_1 + V_2}{2}} = 0.1 \text{ leading to } V_2 = \frac{0.95\,V_1}{1.05} \text{ or } V_2 = 0.905(15\text{ mV}) = 13.58\text{ mV}$$



6. a. t_r = 80% of straight line segment
= 0.8(2 μs) = **1.6 μs**

b. t_f = 80% of 4 μs interval
= 0.8(4 μs) = **3.2 μs**

c. At 50% level (10 mV)
t_p = (8 – 1)μs = **7 μs**

d. prf = $\dfrac{1}{T} = \dfrac{1}{20\,\mu\text{s}}$ = **50 kHz**

7. a. $T = (4.8 - 2.4)\text{div.}\left[50\,\mu\text{s/div.}\right]$ = **120 μs**

b. $f = \dfrac{1}{T} = \dfrac{1}{120\,\mu\text{s}}$ = 8.33 kHz

c. Maximum Amplitude: (2.2 div.)(0.2 V/div.) = 0.44 V = **440 mV**
Minimum Amplitude: (0.4 div.)(0.2 V/div.) = 0.08 V = **80 mV**

8. T = (3.6 – 2.0)ms = 1.6 ms

prf = $\dfrac{1}{T} = \dfrac{1}{1.6\text{ ms}}$ = **625 Hz**

Duty cycle = $\dfrac{t_p}{T} \times 100\% = \dfrac{0.2\text{ ms}}{1.6\text{ ms}}$ × 100% = **12.5%**

9. $T = (15 - 7)\mu\text{s} = 8\ \mu\text{s}$

$$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu\text{s}} = \mathbf{125\ kHz}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{(20-15)\mu s}{8\ \mu s} \times 100\% = \frac{5}{8} \times 100\% = \mathbf{62.5\%}$$

10. $T = (3.6\text{ div.})(2\text{ ms/div.}) = 7.2\text{ ms}$

$$\text{prf} = \frac{1}{T} = \frac{1}{7.2\text{ ms}} = \mathbf{138.89\ Hz}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{1.6\text{ div.}}{3.6\text{ div.}} \times 100\% = \mathbf{44.4\%}$$

11. a. $T = (9 - 1)\mu\text{s} = \mathbf{8\ \mu s}$

b. $t_p = (3 - 1)\mu\text{s} = \mathbf{2\ \mu s}$

c. $$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu\text{s}} = \mathbf{125\ kHz}$$

d. $V_{\text{av}} = (\text{Duty cycle})(\text{Peak value}) + (1 - \text{Duty cycle})(V_b)$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{2\ \mu\text{s}}{8\ \mu\text{s}} \times 100\% = 25\%$$

$$\begin{aligned} V_{\text{av}} &= (0.25)(6\text{ mV}) + (1 - 0.25)(-2\text{ mV}) \\ &= 1.5\text{ mV} - 1.5\text{ mV} = \mathbf{0\ V} \end{aligned}$$

or

$$V_{\text{av}} = \frac{(2\ \mu\text{s})(6\text{ mV}) - (2\ \mu\text{s})(6\text{ mV})}{8\ \mu\text{s}} = \mathbf{0\ V}$$

e. $$V_{\text{eff}} = \sqrt{\frac{(36\times10^{-6})(2\ \mu\text{s}) + (4\times10^{-6})(6\ \mu\text{s})}{8\ \mu\text{s}}} = \mathbf{3.46\ mV}$$

12. Eq. 24.5 cannot be applied due to tilt in the waveform.
(Method of Section 13.6)
Between 2 and 3.6 ms

$$V_{\text{av}} = \frac{(3.4\text{ ms} - 2\text{ ms})(2\text{ V}) + (3.6\text{ ms} - 3.4\text{ ms})(7.5\text{ V}) + \frac{1}{2}(3.6\text{ ms} - 3.4\text{ ms})(0.5\text{ V})}{3.6\text{ ms} - 2\text{ ms}}$$

$$= \frac{(1.4\text{ ms})(2\text{ V}) + (0.2\text{ ms})(7.5\text{ V}) + \frac{1}{2}(0.2\text{ ms})(0.5\text{ V})}{1.6\text{ ms}}$$

$$= \frac{2.8\text{ V} + 1.5\text{ V} + 0.05\text{ V}}{1.6} = \mathbf{2.719\ V}$$

13. Ignoring tilt and using 20 mV level to define t_p

t_p = (2.8 div. – 1.2 div.)(2 ms/div.) = 3.2 ms

T = (at 10 mV level) = (4.6 div. – 1 div.)(2 ms/div.) = 7.2 ms

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{3.2\text{ ms}}{7.2\text{ ms}} \times 100\% = 44.4\%$$

V_{av} = (Duty cycle)(peak value) + (1 – Duty cycle)(V_b)
= (0.444)(30 mV) + (1 – 0.444)(10 mV)
= 13.320 mV + 5.560 mV
= **18.88 mV**

14. V_{av} = (Duty cycle)(Peak value) + (1 – Duty cycle)(V_b)

$$\text{Duty cycle} = \frac{t_p}{T} \text{ (decimal form)}$$

$$= \frac{(8-1)\mu\text{s}}{20\ \mu\text{s}} = 0.35$$

V_{av} = (0.35)(20 mV) + (1 – 0.35)(0)
= 7 mV + 0
= **7 mV**

15. Using methods of Section 13.8:

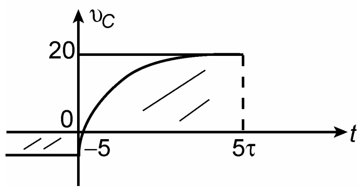
$A_1 = b_1h_1$ = [(0.2 div.)(50 μs/div.)][(2 div.)(0.2 V/div.)] = 4 μsV
$A_2 = b_2h_2$ = [(0.2 div.)(50 μs/div.)][(2.2 div.)(0.2 V/div.)] = 4.4 μsV
$A_3 = b_3h_3$ = [(0.2 div.)(50 μs/div.)][(1.4 div.)(0.2 V/div.)] = 2.8 μsV
$A_4 = b_4h_4$ = [(0.2 div.)(50 μs/div.)][(1 div.)(0.2 V/div.)] = 2.0 μsV
$A_5 = b_5h_5$ = [(0.2 div.)(50 μs/div.)][(0.4 div.)(0.2 V/div.)] = 0.8 μsV

$$V_{av} = \frac{(4+4.4+2.8+2.0+0.8)\mu\text{sV}}{120\ \mu\text{s}} = \mathbf{117\ mV}$$

16. Using the defined polarity of Fig. 24.57 for υ_C, $V_i = -5$ V, $V_f = +20$ V and $\tau = RC$ = (10 kΩ)(0.02 μF) = 0.2 ms

a. $\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$
$= -5 + (20 - (-5))(1 - e^{-t/0.2\text{ ms}})$
$= -5 + 25(1 - e^{-t/0.2\text{ ms}})$
$= -5 + 25 - 25e^{-t/0.2\text{ ms}}$
$\upsilon_C = \mathbf{20\ V - 25\ V}e^{-t/0.2\text{ ms}}$

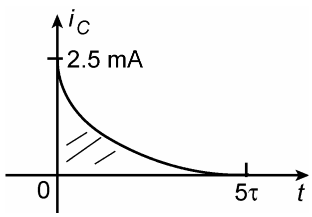
b.



c. $I_i = 0$

$$i_C = \frac{E - \upsilon_C}{R} = \frac{20\text{ V} - \left[20\text{ V} - 25\text{ V}\,e^{-t/0.2\text{ ms}}\right]}{10\text{ k}\Omega} = \mathbf{2.5\ mA}\boldsymbol{e^{-t/0.2\text{ ms}}}$$

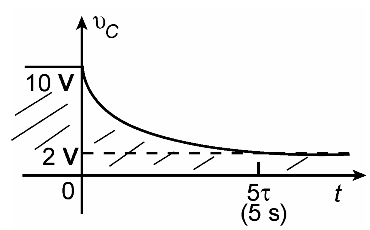
d.



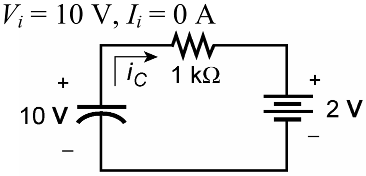
17. $\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$
$= 8 + (4 - 8)(1 - e^{-t/20\text{ ms}})$
$= 8 - 4(1 - e^{-t/20\text{ ms}})$
$= 8 - 4 + 4e^{-t/20\text{ ms}}$
$= 4 + 4e^{-t/20\text{ ms}}$
$\upsilon_C = \mathbf{4\ V(1 + }\boldsymbol{e^{-t/20\text{ ms}}}\mathbf{)}$

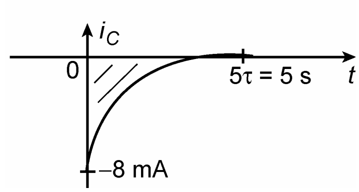
$\tau = RC = (2\text{ k}\Omega)(10\ \mu\text{F})$
$= 20\text{ ms}$

18. $V_i = 10\text{ V}$, $V_f = 2\text{ V}$, $\tau = RC = (1\text{ k}\Omega)(1000\ \mu\text{F}) = 1\text{ s}$
$\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$
$= 10\text{ V} + (2\text{ V} - 10\text{ V})(1 - e^{-t})$
$= 10 - 8(1 - e^{-t})$
$= 10 - 8 + 8e^{-t}$
$\upsilon_C = \mathbf{2\ V + 8\ V}\boldsymbol{e^{-t}}$



19. $V_i = 10\text{ V}$, $I_i = 0\text{ A}$





Using the defined direction of i_C

$$i_C = \frac{-(10\text{ V} - 2\text{ V})}{1\text{ k}\Omega}e^{-t/\tau}$$

$\tau = RC = (1\text{ k}\Omega)(1000\ \mu\text{F}) = 1\text{ s}$

$$i_C = -\frac{8\text{ V}}{1\text{ k}\Omega}e^{-t}$$

and $i_C = \mathbf{-8mA}\boldsymbol{e^{-t}}$

20. $\tau = RC = (5\text{ k}\Omega)(0.04\ \mu\text{F}) = 0.2\text{ ms}$ (throughout)

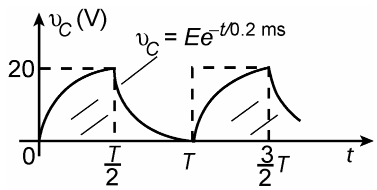
$\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{20\ V(1 - e^{-t/0.2\ ms})}$

(Starting at $t = 0$ for each plot)

a. $T = \dfrac{1}{f} = \dfrac{1}{500\text{ Hz}} = 2\text{ ms}$

$\dfrac{T}{2} = 1\text{ ms}$

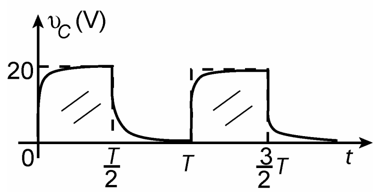
$5\tau = 1\text{ ms} = \dfrac{T}{2}$



b. $T = \dfrac{1}{f} = \dfrac{1}{100\text{ Hz}} = 10\text{ ms}$

$\dfrac{T}{2} = 5\text{ ms}$

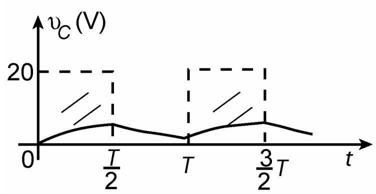
$5\tau = 1\text{ ms} = \dfrac{1}{5}\left(\dfrac{T}{2}\right)$



c. $T = \dfrac{1}{f} = \dfrac{1}{5\text{ Hz}} = 0.2\text{ ms}$

$\dfrac{T}{2} = 0.1\text{ ms}$

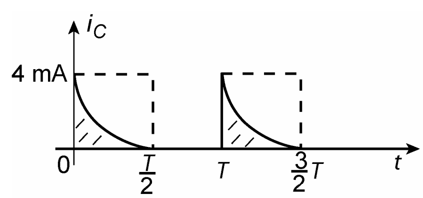
$5\tau = 1\text{ ms} = 10\left(\dfrac{T}{2}\right)$



21. The mathematical expression for i_C is the same for each frequency!

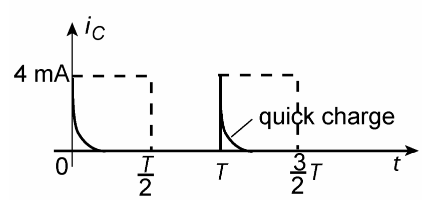
$\tau = RC = (5\text{ k}\Omega)(0.04\ \mu\text{F}) = 0.2\text{ ms}$

and $i_C = \dfrac{20\text{ V}}{5\text{ k}\Omega} e^{-t/0.2\text{ ms}} = \mathbf{4\ mAe^{-t/0.2\ ms}}$



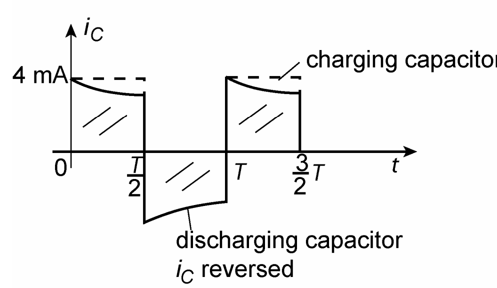
a. $T = \dfrac{1}{500\text{ Hz}} = 2\text{ ms}, \dfrac{T}{2} = 1\text{ ms}$

$5\tau = 5(0.2\text{ ms}) = 1\text{ ms} = \dfrac{T}{2}$



b. $T = \dfrac{1}{100\text{ Hz}} = 10\text{ ms}, \dfrac{T}{2} = 5\text{ ms}$

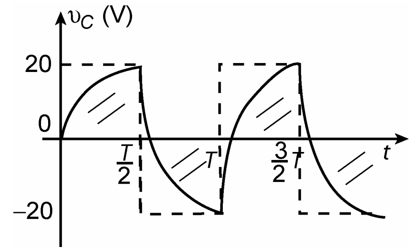
$5\tau = 1\text{ ms} = \dfrac{1}{5}\left(\dfrac{T}{2}\right)$



c. $T = \dfrac{1}{5000\text{ Hz}} = 0.2\text{ ms}, \dfrac{T}{2} = 0.1\text{ ms}$

$5\tau = 1\text{ ms} = 10\left(\dfrac{T}{2}\right)$

22. $\tau = 0.2$ ms as above



$$T = \frac{1}{500\text{ Hz}} = 2\text{ ms}$$

$$5\tau = 1\text{ ms} = \frac{T}{2}$$

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

$\frac{T}{2} \to T$: $V_i = 20$ V, $V_f = -20$ V

$$\begin{aligned}\upsilon_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau})\\ &= 20 + (-20 - 20)(1 - e^{-t/0.2\text{ ms}})\\ &= 20 - 40(1 - e^{-t/0.2\text{ ms}})\\ &= 20 - 40 + 40e^{-t/0.2\text{ ms}}\end{aligned}$$

$\upsilon_C = \mathbf{-20\ V + 40\ V}\boldsymbol{e^{-t/0.2\text{ ms}}}$

$T \to \frac{3}{2}T$: $V_i = -20$ V, $V_f = +20$ V

$$\begin{aligned}\upsilon_C &= V_i + (V_f - V_i)(1 - e^{-t/\tau})\\ &= -20 + (20 - (-20))(1 - e^{-t/\tau})\\ &= -20 + 40(1 - e^{-t/\tau})\\ &= -20 + 40 - 40e^{-t/\tau}\end{aligned}$$

$\upsilon_C = \mathbf{20\ V - 40\ V}\boldsymbol{e^{-t/0.2\text{ ms}}}$

23. $\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$

$V_i = 20$ V, $V_f = 20$ V

$\upsilon_C = 20 + (20 - 20)(1 - e^{-t/RC})$

$= \mathbf{20\ V}$ (for $0 \to \frac{T}{2}$)

For $\frac{T}{2} \to T$, $\upsilon_i = 0$ V and $\upsilon_C = \mathbf{20\ V}\boldsymbol{e^{-t/\tau}}$

$\tau = RC = 0.2$ ms

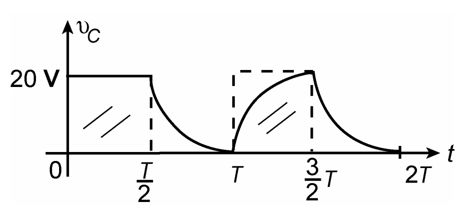
with $\frac{T}{2} = 1$ ms and $5\tau = \frac{T}{2}$

For $T \to \frac{3}{2}T$, $\upsilon_i = 20$ V

$\upsilon_C = \mathbf{20\ V(1 - }\boldsymbol{e^{-t/\tau}}\mathbf{)}$

For $\frac{3}{2}T \to 2T$, $\upsilon_i = 0$ V

$\upsilon_C = \mathbf{20\ V}\boldsymbol{e^{-t/\tau}}$



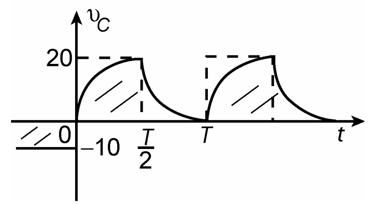
24. $\tau = RC = 0.2$ ms

$5\tau = 1 \text{ ms} = \dfrac{T}{2}$

$V_i = -10$ V, $V_f = +20$ V

$0 \rightarrow \dfrac{T}{2}$:

$$\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$$
$$= -10 + (20 - (-10))(1 - e^{-t/\tau})$$
$$= -10 + 30(1 - e^{-t/\tau})$$
$$= -10 + 30 - 30e^{-t/\tau}$$
$$\upsilon_C = \mathbf{+20\ V - 30\ V}\boldsymbol{e^{-t/0.2\ ms}}$$



$\dfrac{T}{2} \rightarrow T$: $V_i = 20$ V, $V_f = 0$ V

$$\upsilon_C = \mathbf{20\ V}\boldsymbol{e^{-t/0.2\ ms}}$$

25. $\mathbf{Z}_p$: $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10\,\text{kHz})(3\,\text{pF})} = 5.31\ \text{M}\Omega$

$$\mathbf{Z}_p = \frac{(9\,\text{M}\Omega\,\angle 0°)(5.31\,\text{M}\Omega\,\angle -90°)}{9\,\text{M}\Omega - j5.31\,\text{M}\Omega} = 4.573\ \text{M}\Omega\ \angle -59.5°$$

$\mathbf{Z}_s$: $C_T = 18\text{ pF} + 9\text{ pF} = 27\text{ pF}$

$$X_C = \frac{1}{2\pi fC_T} = \frac{1}{2\pi(10\,\text{kHz})(27\,\text{pF})} = 0.589\ \text{M}\Omega$$

$$\mathbf{Z}_s = \frac{(1\,\text{M}\Omega\,\angle 0°)(0.589\,\text{M}\Omega\,\angle -90°)}{1\,\text{M}\Omega - j0.589\,\text{M}\Omega} = 0.507\ \text{M}\Omega\ \angle -59.5°$$

$$\mathbf{V}_{\text{scope}} = \frac{\mathbf{Z}_s\mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.507\,\text{M}\Omega\,\angle -59.5°)(100\,\text{V}\,\angle 0°)}{(0.257\,\text{M}\Omega - j0.437\,\text{M}\Omega) + (2.324\,\text{M}\Omega - j3.939\,\text{M}\Omega)}$$
$$= \frac{50.7\times 10^6\ \text{V}\ \angle -59.5°}{5.07\times 10^6\ \angle -59.5°} = \mathbf{10\ V\ \angle 0°} = \frac{1}{10}(100\ \text{V}\ \angle 0°)$$

$$\theta_{\mathbf{Z}_s} = \theta_{\mathbf{Z}_p} = \mathbf{-59.5°}$$

26. $\mathbf{Z}_p$: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^5\ \text{rad/s})(3\,\text{pF})} = 3.333\ \text{M}\Omega$

$$\mathbf{Z}_p = \frac{(9\,\text{M}\Omega\,\angle 0°)(3.333\,\text{M}\Omega)}{9\,\text{M}\Omega - j3.333\,\text{M}\Omega} = 3.126\ \text{M}\Omega\ \angle -69.68°$$

$\mathbf{Z}_s$: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^5\ \text{rad/s})(27\,\text{pF})} = 0.370\ \text{M}\Omega$

$$\mathbf{Z}_s = \frac{(1\,\text{M}\Omega\,\angle 0°)(0.370\,\text{M}\Omega\,\angle -90°)}{1\,\text{M}\Omega - j0.370\,\text{M}\Omega} = 0.347\ \text{M}\Omega\ \angle -69.68°$$

$$\checkmark\ \theta_{\mathbf{Z}_p} = \theta_{\mathbf{Z}_s}$$

$$\mathbf{V}_{\text{scope}} = \frac{\mathbf{Z}_s \mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.347\ \text{M}\Omega\ \angle -69.68^\circ)(100\ \text{V}\ \angle 0^\circ)}{(0.121\ \text{M}\Omega - j0.325\ \text{M}\Omega) + (1.086\ \text{M}\Omega - j2.931\ \text{M}\Omega)}$$

$$= \frac{34.70 \times 10^6\ \text{V}\ \angle -69.68^\circ}{3.470 \times 10^6\ \angle -69.68^\circ}$$

$$\cong \mathbf{10\ V\ \angle 0^\circ} = \frac{1}{10}(100\ \text{V}\ \angle 0^\circ)$$

Chapter 25

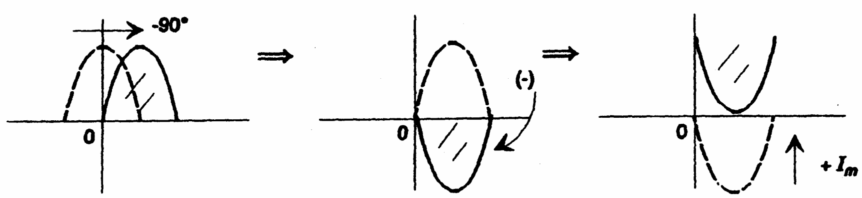
1.	I:	a. no		b. no		c. yes		d. no		e. yes
	II:	a. yes		b. yes		c. yes		d. yes		e. no
	III:	a. yes		b. yes		c. no		d. yes		e. yes
	IV:	a. no		b. no		c. yes		d. yes		e. yes

2. b. $$i = \frac{2I_m}{\pi}\left(1 + \frac{2}{3}\cos(2\omega t - 90°) - \frac{2}{15}\cos(4\omega t - 90°) + \frac{2}{35}\cos(6\omega t - 90°) + \ldots\right)$$

c. $$\frac{2I_m}{\pi} - \frac{I_m}{2} = \frac{2I_m}{\pi}\left[1 - \frac{\pi}{4}\right]$$

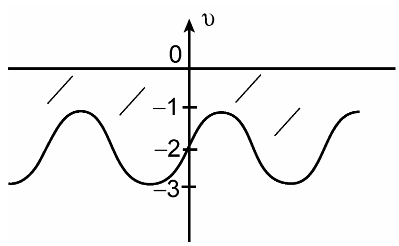
$$i = \frac{2I_m}{\pi}\left[1 - \frac{\pi}{4} + \frac{2}{3}\cos(2\omega t - 90°) - \frac{2}{15}\cos(4\omega t - 90°) + \frac{2}{35}\cos(6\omega t - 90°) + \ldots\right]$$

d.

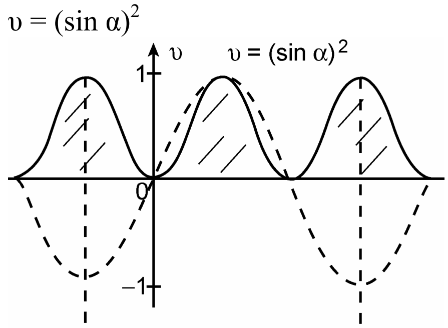


$$i = \frac{-2I_m}{\pi}\left[1 - \frac{\pi}{4} + \frac{2}{3}\cos(2\omega t - 90°) - \frac{2}{15}\cos(4\omega t - 90°) + \frac{2}{35}\cos(6\omega t - 90°) + \ldots\right]$$

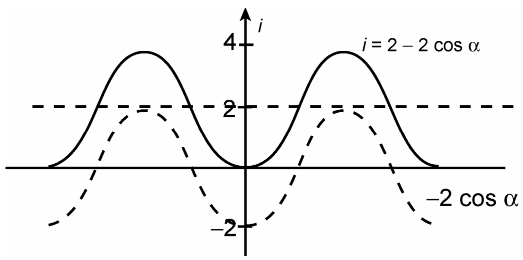
3. a. $\upsilon = -4 + 2\sin\alpha$



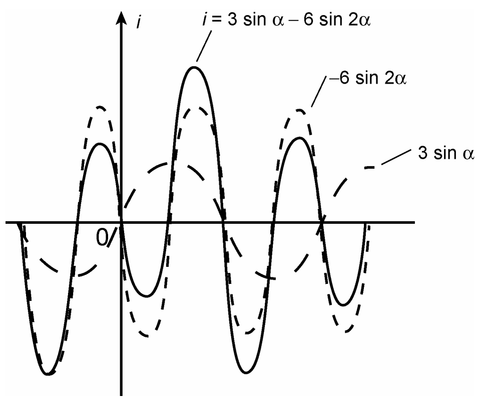
b. $\upsilon = (\sin\alpha)^2$



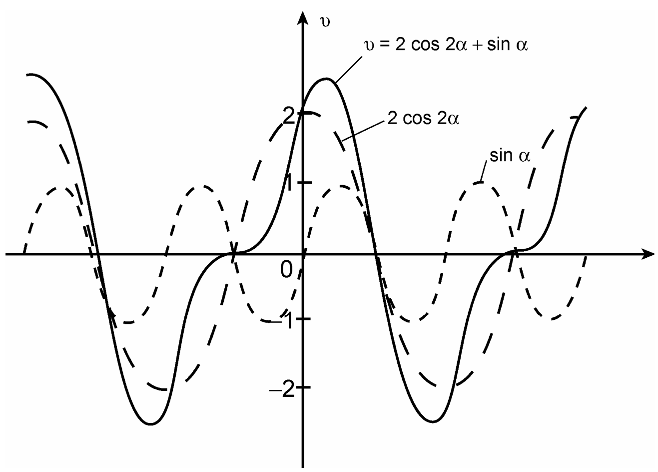
c. $i = 2 - 2\cos\alpha$



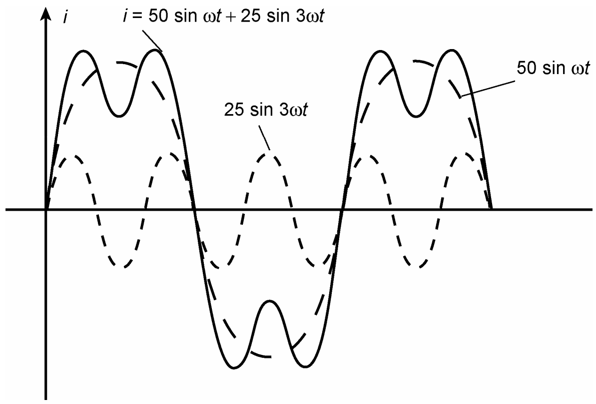
4. a.



b.

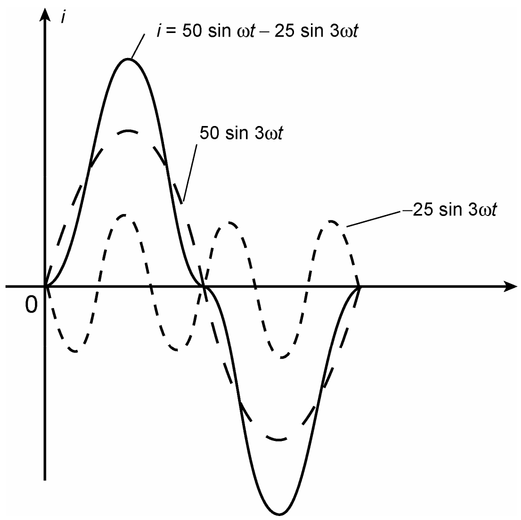


5. a.



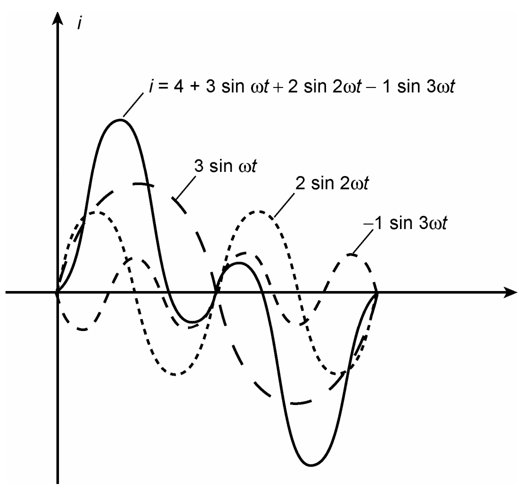
i
$i = 50 \sin \omega t + 25 \sin 3\omega t$
$50 \sin \omega t$
$25 \sin 3\omega t$

b.



i
$i = 50 \sin \omega t - 25 \sin 3\omega t$
$50 \sin 3\omega t$
$-25 \sin 3\omega t$
0

c.



i
$i = 4 + 3 \sin \omega t + 2 \sin 2\omega t - 1 \sin 3\omega t$
$3 \sin \omega t$
$2 \sin 2\omega t$
$-1 \sin 3\omega t$

6. a. $V_{av} = \mathbf{100\ V}$

$$V_{eff} = \sqrt{(100\text{ V})^2 + \frac{(50\text{ V})^2 + (25\text{ V})^2}{2}} = \mathbf{107.53\ V}$$

b. $I_{av} = \mathbf{3\ A}$

$$I_{eff} = \sqrt{(3\text{ A})^2 + \frac{(2\text{ A})^2 + (0.8\text{ A})^2}{2}} = \mathbf{3.36\ A}$$

7. a. $$V_{eff} = \sqrt{\frac{(20\text{ V})^2 + (15\text{ V})^2 + (10\text{ V})^2}{2}} = \mathbf{19.04\ V}$$

b. $$I_{eff} = \sqrt{\frac{(6\text{ A})^2 + (2\text{ A})^2 + (1\text{ A})^2}{2}} = \mathbf{4.53\ A}$$

8. $P_T = V_0I_0 + V_1I_1 \cos\theta_1 + \ldots + V_nI_n \cos\theta_n$

$$= (100\text{ V})(3\text{ A}) + \frac{(50\text{ V})(2\text{ A})}{2}\cos 53° + \frac{(25\text{ V})(0.8\text{ A})}{2}\cos 70°$$

$= 300 + (50)(0.6018) + (10)(0.3420)$

$= \mathbf{333.52\ W}$

9. $$P = \frac{(20\text{ V})(6\text{ A})}{2}\cos 20° + \frac{(15\text{ V})(2\text{ A})}{2}\cos 30° + \frac{(10\text{ V})(1\text{ A})}{2}\cos 60°$$

$= 60(0.9397) + 15(0.866) + 5(0.5)$

$= \mathbf{71.87\ W}$

10. a. DC: $E = 18\text{ V},\ I_o = \dfrac{E}{R} = \dfrac{18\text{ V}}{12\ \Omega} = 1.5\text{ A}$

$\omega = 400\text{ rad/s}$: $X_L = \omega L = (400\text{ rad/s})(0.02\text{ H}) = 8\ \Omega$

$\mathbf{Z} = 12\ \Omega + j8\ \Omega = 14.42\ \Omega\ \angle 33.69°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{30\text{ V}/\sqrt{2}\ \angle 0°}{14.42\ \Omega\ \angle 33.69°} = \frac{2.08\text{ A}}{\sqrt{2}}\ \angle -33.69°$$

$$i = 1.5 + \sqrt{2}\left(\frac{2.08}{\sqrt{2}}\right)\sin(400t - 33.69°)$$

$i = \mathbf{1.5 + 2.08\ sin(400}\boldsymbol{t}\mathbf{ - 33.69°)}$

b. $$I_{eff} = \sqrt{(1.5\text{ A})^2 + \frac{(2.08\text{ A})^2}{2}} = \mathbf{2.10\ A}$$

c. DC: $\upsilon_R = E = 18$ V, $\mathbf{V}_R = \left(\dfrac{2.08\text{ A}}{\sqrt{2}}\angle -33.69°\right)(12\,\Omega\angle 0°)$

$$= \frac{24.96\text{ V}}{\sqrt{2}}\angle -33.69°$$

$$\upsilon_R = 18 + \sqrt{2}\left(\frac{24.96}{\sqrt{2}}\right)\sin(400t - 33.69°)$$

υ_R = **18 + 24.96 sin(400*t* – 33.69°)**

d. $V_{R_{\text{eff}}} = \sqrt{(18\text{ V})^2 + \dfrac{(24.96\text{ V})^2}{2}} = \mathbf{25.21\ V}$

e. DC: $V_L = 0$ V

$\omega = 400$ rad/s: $\mathbf{V}_L = \left(\dfrac{2.08\text{ A}}{\sqrt{2}}\angle -33.69°\right)(8\,\Omega\angle 90°)$

$$= \frac{16.64\text{ A}}{\sqrt{2}}\angle 56.31°$$

υ_L = **0 + 16.64 sin(400*t* + 56.31°)**

f. $V_{L_{\text{eff}}} = \sqrt{0^2 + \dfrac{(16.64\text{ V})^2}{2}} = \mathbf{11.77\ V}$

g. $P = I_{\text{eff}}^2 R = (2.101\text{ A})^2\, 12\,\Omega = \mathbf{52.97\ W}$

11. a. DC: $I_{DC} = \dfrac{24\text{ V}}{12\,\Omega} = 2$ A

$\omega = 400$ rad/s:

$\mathbf{Z} = 12\,\Omega + j(400\text{ rad/s})(0.02\text{ H}) = 12\,\Omega + j8\,\Omega = 14.422\,\Omega\angle 33.69°$

$\mathbf{I} = \dfrac{30\text{ V}\angle 0°}{14.422\,\Omega\angle 33.69°} = 2.08\text{ A}\angle -33.69°$ (peak values)

$\omega = 800$ rad/s:

$\mathbf{Z} = 12\,\Omega + j(800\text{ rad/s})(0.02\text{ H}) = 12\,\Omega + j16\,\Omega = 20\,\Omega\angle 53.13°$

$\mathbf{I} = \dfrac{10\text{ V}\angle 0°}{20\,\Omega\angle 53.13°} = 0.5\text{ A}\angle -53.13°$ (peak values)

i = **2 + 2.08 sin(400*t* – 33.69°) + 0.5 sin(800*t* – 53.13°)**

b. $I_{\text{eff}} = \sqrt{(2\text{ A})^2 + \dfrac{(2.08\text{ A})^2 + (0.5\text{ A}^2)}{2}} = \mathbf{2.51\ A}$

c. $\upsilon_R = iR = i(12\,\Omega)$

= **24 + 24.96 sin(400*t* – 33.69°) + 6 sin(800*t* – 53.13°)**

d. $V_{\text{eff}} = \sqrt{(24\text{ V})^2 + \dfrac{(24.96\text{ V})^2 + (6\text{ V})^2}{2}} = \mathbf{30.09\ V}$

e. DC: $V_L = 0$ V

$\omega = 400$ rad/s: $\mathbf{V}_L = (2.08 \text{ A} \angle -33.69°)(8 \ \Omega \angle 90°)$
$= 16.64 \text{ V} \angle 56.31°$

$\omega = 800$ rad/s: $\mathbf{V}_L = (0.5 \text{ A} \angle -53.13°)(16 \ \Omega \angle 90°)$
$= 8 \text{ V} \angle 36.87°$

$\boldsymbol{\upsilon_L = 0 + 16.64 \sin(400t + 56.31°) + 8 \sin(800t + 36.87°)}$

f. $$V_{\text{eff}} = \sqrt{(0)^2 + \frac{(16.64 \text{ V})^2 + (8 \text{ V})^2}{2}} = \mathbf{13.06 \text{ V}}$$

g. $P_T = I_{\text{eff}}^2 R = (2.508 \text{ A})^2 \, 12 \ \Omega = \mathbf{75.48 \text{ W}}$

12. a. DC: $I = -\dfrac{60 \text{ V}}{12 \ \Omega} = -5 \text{ A}$

$\omega = 300$ rad/s: $X_L = \omega L = (300 \text{ rad/s})(0.02 \text{ H}) = 6 \ \Omega$

$\mathbf{Z} = 12 \ \Omega + j16 \ \Omega = 13.42 \ \Omega \angle 26.57°$

$\mathbf{E} = (0.707)(20 \text{ V}) \angle 0° = 14.14 \text{ V} \angle 0°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{14.14 \text{ V} \angle 0°}{13.42 \ \Omega \angle 26.57°} = 1.054 \text{ A} \angle -26.57°$$

$\omega = 600$ rad/s: $X_L = \omega L = (600 \text{ rad/s})(0.02 \text{ H}) = 12 \ \Omega$

$\mathbf{Z} = 12 \ \Omega + j12 \ \Omega = 16.97 \ \Omega \angle 45°$

$\mathbf{E} = -(0.707)(10 \text{ V}) \angle 0° = -7.07 \text{ V} \angle 0°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = -\frac{7.07 \text{ V} \angle 0°}{16.97 \ \Omega \angle 45°} = -0.417 \text{ A} \angle -45°$$

$i = -5 + (1.414)(1.054)\sin(300t - 26.57°) - (1.414)(0.417)\sin(600t - 45°)$

$\boldsymbol{i = -5 + 1.49 \sin(300t - 26.57°) - 0.59 \sin(600t - 45°)}$

b. $$I_{\text{eff}} = \sqrt{(10 \text{ A})^2 + \frac{(1.49 \text{ A})^2 + (0.59 \text{ A})^2}{2}} = \mathbf{10.06 \text{ A}}$$

c. DC: $V = IR = (-5 \text{ A})(12 \ \Omega) = -60$ V

$\omega = 300$ rad/s: $\mathbf{V}_R = (1.054 \text{ A} \angle -26.57°)(12 \ \Omega \angle 0°)$
$= 12.648 \text{ V} \angle -26.57°$

$\omega = 600$ rad/s: $\mathbf{V}_R = (-0.417 \text{ A} \angle -45°)(12 \ \Omega \angle 0°)$
$= -5 \text{ V} \angle -45°$

$\upsilon_R = -60 + (1.414)(12.648)\sin(300t - 26.57°) - (1.414)(5)\sin(600t - 45°)$

$\boldsymbol{\upsilon_R = -60 + 17.88 \sin(300t - 26.57°) - 7.07 \sin(600t - 45°)}$

d. $$V_{R_{\text{eff}}} = \sqrt{(60 \text{ V})^2 + \frac{(17.88 \text{ V})^2 + (7.07 \text{ V})^2}{2}} = \mathbf{61.52 \text{ V}}$$

e. DC: $V_L = 0$ V

$\omega = 300$ rad/s: $\mathbf{V}_L = (1.054 \text{ A} \angle{-26.57°})(6\ \Omega \angle 90°) = 6.324 \text{ V} \angle 63.43°$

$\omega = 600$ rad/s: $\mathbf{V}_L = (-0.417 \text{ A} \angle{-45°})(6\ \Omega \angle 90°) = -2.502 \text{ V} \angle 45°$

$\upsilon_L = 0 + (1.414)(6.324)\sin(300t + 63.43°) - (1.414)(2.502)\sin(600t + 45°)$

$\upsilon_L =$ **$8.94 \sin(300t + 63.43°) - 3.54 \sin(600t + 45°)$**

f. $$V_{L_{\text{eff}}} = \sqrt{\frac{(8.94\text{ V})^2 + (3.54\text{ V})^2}{2}} = \mathbf{6.8\ V}$$

g. $P = I_{\text{eff}}^2 R = (10.06\text{ A})^2\ 12\ \Omega =$ **1214.44 W**

13. a. DC: $I =$ **0 A**

$\omega = 400$ rad/s: $$X_C = \frac{1}{\omega C} = \frac{1}{(400 \text{ rad/s})(125\ \mu\text{F})} = 20\ \Omega$$

$\mathbf{Z} = 15\ \Omega - j20\ \Omega = 25\ \Omega \angle{-53.13°}$

$\mathbf{E} = (0.707)(30\text{ V}) \angle 0° = 21.21\text{ V} \angle 0°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{21.21\text{ V}\angle 0°}{25\ \Omega \angle -53.13°} = 0.848 \text{ A} \angle 53.13°$$

$i = 0 + (1.414)(0.848)\sin(400t + 53.13°)$

$i =$ **$1.2 \sin(400t + 53.13°)$**

b. $$I_{\text{eff}} = \sqrt{\frac{(1.2\text{ A})^2}{2}} = \mathbf{0.85\ A} \text{ as above}$$

c. DC: $V_R = 0$ V

$\omega = 400$ rad/s: $\mathbf{V}_R = (0.848 \text{ A} \angle 53.13°)(15\ \Omega \angle 0°) = 12.72 \text{ V} \angle 53.13°$

$\upsilon_R = 0 + (1.414)(12.72)\sin(400t + 53.13°)$

$\upsilon_R =$ **$18 \sin(400t + 53.13°)$**

d. $$V_{R_{\text{eff}}} = \sqrt{\frac{(18\text{ V})^2}{2}} = \mathbf{12.73\ V}$$

e. DC: $V_C = 18$ V

$\omega = 400$ rad/s: $\mathbf{V}_C = (0.848 \text{ A} \angle 53.13°)(20\ \Omega \angle{-90°})$

$= 16.96 \text{ V} \angle{-36.87°}$

$\upsilon_C = 18 + (1.414)(16.96)\sin(400t - 36.87°)$

$\upsilon_C =$ **$18 + 23.98 \sin(400t - 36.87°)$**

f. $$V_{C_{\text{eff}}} = \sqrt{(18\text{ V})^2 + \frac{(23.98\text{ V})^2}{2}} = \mathbf{24.73\ V}$$

g. $P = I_{\text{eff}}^2 R = (0.848\text{ A})^2\ 15\ \Omega =$ **10.79 W**

14. a. $e = \frac{200}{\pi} + \frac{400}{3\pi}\cos 2\omega t - \frac{400}{15\pi}\cos 4\omega t$

$= 63.69 + 42.46 \sin(2\omega t + 90°) - 8.49 \sin(4\omega t + 90°)$

$\omega = 377$ rad/s:

$e = 63.69 + 42.46 \sin(754t + 90°) - 8.49 \sin(1508t + 90°)$

DC: $X_L = 0 \;\therefore\; V_L = 0$ V

$\omega = 754$ rad/s: $X_C = \frac{1}{\omega C} = \frac{1}{(754 \text{ rad/s})(1\,\mu\text{F})} = 1330\ \Omega$

$X_L = \omega L = (754 \text{ rad/s})(0.1 \text{ H}) = 75.4\ \Omega$

$\mathbf{Z}' = (1\text{ k}\Omega \angle 0°) \parallel 75.4\ \Omega \angle 90° = 75.19\ \Omega \angle 85.69°$

$\mathbf{E} = (0.707)(42.46 \text{ V}) \angle 90° = 30.02 \text{ V} \angle 90°$

$\mathbf{V}_o = \frac{\mathbf{Z}'(\mathbf{E})}{\mathbf{Z}' + \mathbf{Z}_C} = \frac{(75.19\ \Omega \angle 85.69°)(30.02 \text{ V} \angle 90°)}{75.19\ \Omega \angle 85.69° + 1330\ \Omega \angle -90°} = 1.799 \text{ V} \angle -94.57°$

$\omega = 1508$ rad/s: $X_C = \frac{1}{\omega C} = \frac{1}{(1508 \text{ rad/s})(1\,\mu\text{F})} = 6631.13\ \Omega$

$X_L = \omega L = (1508 \text{ rad/s})(0.1 \text{ H}) = 150.8\ \Omega$

$\mathbf{Z}' = (1\text{ k}\Omega \angle 0°) \parallel 150.8\ \Omega \angle 90° = 149.12\ \Omega \angle 81.42°$

$\mathbf{E} = (0.707)(8.49 \text{ V}) \angle 90° = 6 \text{ V} \angle 90°$

$\mathbf{V}_o = \frac{\mathbf{Z}'(\mathbf{E})}{\mathbf{Z}' + \mathbf{Z}_C} = \frac{(149.12\ \Omega \angle 81.42°)(6 \text{ V} \angle 90°)}{149.12\ \Omega \angle 81.42° + 6631.13\ \Omega \angle -90°}$

$= 1.73 \text{ V} \angle -101.1°$

$\upsilon_o = 0 + 1.414(1.799)\sin(754t - 94.57°) - 1.414(1.73)\sin(1508t - 101.1°)$

$\boldsymbol{\upsilon_o = 2.54 \sin(754t - 94.57°) - 2.45 \sin(1508t - 101.1°)}$

b. $V_{o_{\text{eff}}} = \sqrt{\frac{(2.54 \text{ V})^2 + (2.45 \text{ V})^2}{2}} = \mathbf{2.50\ V}$

c. $P = \frac{(V_{\text{eff}})^2}{\text{R}} = \frac{(2.50 \text{ V})^2}{1\text{ k}\Omega} = \mathbf{6.25\ mW}$

15. $i = 0.318I_m + 0.500\, I_m \sin \omega t - 0.212I_m \cos 2\omega t - 0.0424I_m \cos 4\omega t + \ldots\ (I_m = 10 \text{ mA})$

$i = 3.18 \times 10^{-3} + 5 \times 10^{-3} \sin \omega t - 2.12 \times 10^{-3} \sin(2\omega t + 90°)$

$- 0.424 \times 10^{-3} \sin(4\omega t + 90°) + \ldots$

$i \cong 3.18 \times 10^{-3} + 5 \times 10^{-3} \sin \omega t - 2.12 \times 10^{-3} \sin(2\omega t + 90°)$

DC: $I_o = 0$ A, $V_o = 0$ V

$\omega = 377$ rad/s; $X_L = \omega L = (377 \text{ rad/s})(1.2 \text{ mH}) = 0.452\ \Omega$

$X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(200\,\mu\text{F})} = 13.26\ \Omega$

$\mathbf{Z}' = 200\ \Omega - j13.26\ \Omega = 200.44\ \Omega \angle -3.79°$

$\mathbf{I} = (0.707)(5 \times 10^{-3})\text{A} \angle 0° = 3.54 \text{ mA} \angle 0°$

$\mathbf{I}_o = \frac{\mathbf{Z}_L \mathbf{I}}{\mathbf{Z}_L + \mathbf{Z}'} = \frac{(0.452\ \Omega \angle 90°)(3.54 \text{ mA} \angle 0°)}{j0.452\ \Omega + 200\ \Omega - j13.26\ \Omega} = 7.98\ \mu\text{A} \angle 93.66°$

$\mathbf{V}_o = (7.98\ \mu\text{A} \angle 93.66°)(200\ \Omega \angle 0°) = 1.596\ \text{mV} \angle 93.66°$

$\omega = 754$ rad/s: $X_L = \omega L = (754\ \text{rad/s})(1.2\ \text{mH}) = 0.905\ \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(754\ \text{rad/s})(200\ \mu\text{F})} = 6.63\ \Omega$$

$$\mathbf{Z}' = 200\ \Omega - j6.63\ \Omega = 200.11\ \Omega \angle -1.9°$$

$$\mathbf{I} = (0.707)(2.12\ \text{mA}) \angle 90° = 1.5\ \text{mA} \angle 90°$$

$$\mathbf{I}_o = \frac{\mathbf{Z}_L \mathbf{I}}{\mathbf{Z}_L + \mathbf{Z}'} = \frac{(0.905\ \Omega \angle 90°)(1.5\ \text{mA} \angle 90°)}{j0.905\ \Omega + 200\ \Omega - j6.63\ \Omega} = 6.8\ \mu\text{A} \angle 181.64°$$

$\mathbf{V}_o = (6.8\ \mu\text{A} \angle 181.64°)(200\ \Omega \angle 0°) = 1.36\ \text{mA} \angle 181.64°$

$\upsilon_o = 0 + (1.414)(1.596 \times 10^{-3})\sin(377t + 93.66°)$

$\qquad - (1.414)(1.360 \times 10^{-3})\sin(754t + 181.64°)$

$\upsilon_o = \mathbf{2.26 \times 10^{-3} \sin(377}\boldsymbol{t}\mathbf{ + 93.66°) + 1.92 \times 10^{-3} \sin(754}\boldsymbol{t}\mathbf{ + 1.64°)}$

16. a. $\quad 60 + 70 \sin \omega t + 20 \sin(2\omega t + 90°) + 10 \sin(3\omega t + 60°)$

$+20 + 30 \sin \omega t - 20 \sin(2\omega t + 90°) + 5 \sin(3\omega t + 90°)$

DC: $60 + 20 = 80$

ω: $70 + 30 = 100 \Rightarrow 100 \sin \omega t$

2ω: 0

3ω: $10 \angle 60° + 5\angle 90° = 5 + j8.66 + j5 = 5 + j13.66 = 14.55 \angle 69.9°$

Sum = $\mathbf{80 + 100 \sin \omega}\boldsymbol{t}\mathbf{ + 14.55 \sin(3\omega}\boldsymbol{t}\mathbf{ + 69.9°)}$

b. $\quad 20 + 60 \sin \alpha + 10 \sin(2\alpha - 180°) + 5 \sin(3\alpha + 180°)$

$-5 + 10 \sin \alpha + \qquad 0 \qquad\qquad - 4 \sin(3\alpha - 30°)$

DC: $20 - 5 = 15$

α: $60 + 10 = 70 \Rightarrow 70 \sin \alpha$

2α: $10 \sin(2\alpha - 180°)$

3α: $5 \angle 180° - 4 \angle -30° = -5 - [3.46 - j2] = -8.46 + j2$

$\qquad = 8.69 \angle 166.7°$

Sum = $\mathbf{15 + 70 \sin \alpha + 10 \sin(2\alpha - 180°) + 8.69 \sin(3\alpha + 166.7°)}$

17. $i_T = i_1 + i_2$

$\quad = 10 + 30 \sin 20t \qquad - 0.5 \sin(40t + 90°)$

$\quad +20 + 4 \sin(20t + 90°) + 0.5 \sin(40t + 30°)$

DC: $10\ \text{A} + 20\ \text{A} = 30\ \text{A}$

$\omega = 20$ rad/s: $30\ \text{A} \angle 0° + 4\ \text{A} \angle 90° = 30\ \text{A} + j4\ \text{A} = 30.27\ \text{A} \angle 7.59°$

$\omega = 40$ rad/s: $-0.5\ \text{A} \angle 90° + 0.5\ \text{A} \angle 30°$

$\qquad = -j0.5\ \text{A} + 0.433\ \text{A} + j0.25\ \text{A}$

$\qquad = 0.433\ \text{A} - j0.25\ \text{A} = 0.5\ \text{A} \angle -30°$

$i_T = \mathbf{30 + 30.27 \sin(20}\boldsymbol{t}\mathbf{ + 7.59°) + 0.5 \sin(40}\boldsymbol{t}\mathbf{ - 30°)}$

18. $e = \upsilon_1 + \upsilon_2$

$= \quad 20 - 200 \sin 600t + 100 \sin(1200t + 90°) + 75 \sin 1800t$

$\quad -10 + 150 \sin(600t + 30°) \quad + 0 \quad + 50 \sin(1800t + 60°)$

DC: 20 V − 10 V = 10 V

ω: 600 rad/s: $-200\text{ V} \angle 0° + 150\text{ V} \angle 30° = 102.66\text{ V} \angle 133.07°$

$\omega = 1200$ rad/s: $100 \sin(1200t + 90°)$

$\omega = 1800$ rad/s: $75\text{ V} \angle 0° + 50\text{ V} \angle 60° = 108.97\text{ V} \angle 23.41°$

$e =$ **$10 + 102.66 \sin(600t + 133.07°) + 100 \sin(1200t + 90°) + 108.97 \sin(1800t + 23.41°)$**