Instructor's Resource Manual
to accompany

Introductory Circuit Analysis

Eleventh Edition

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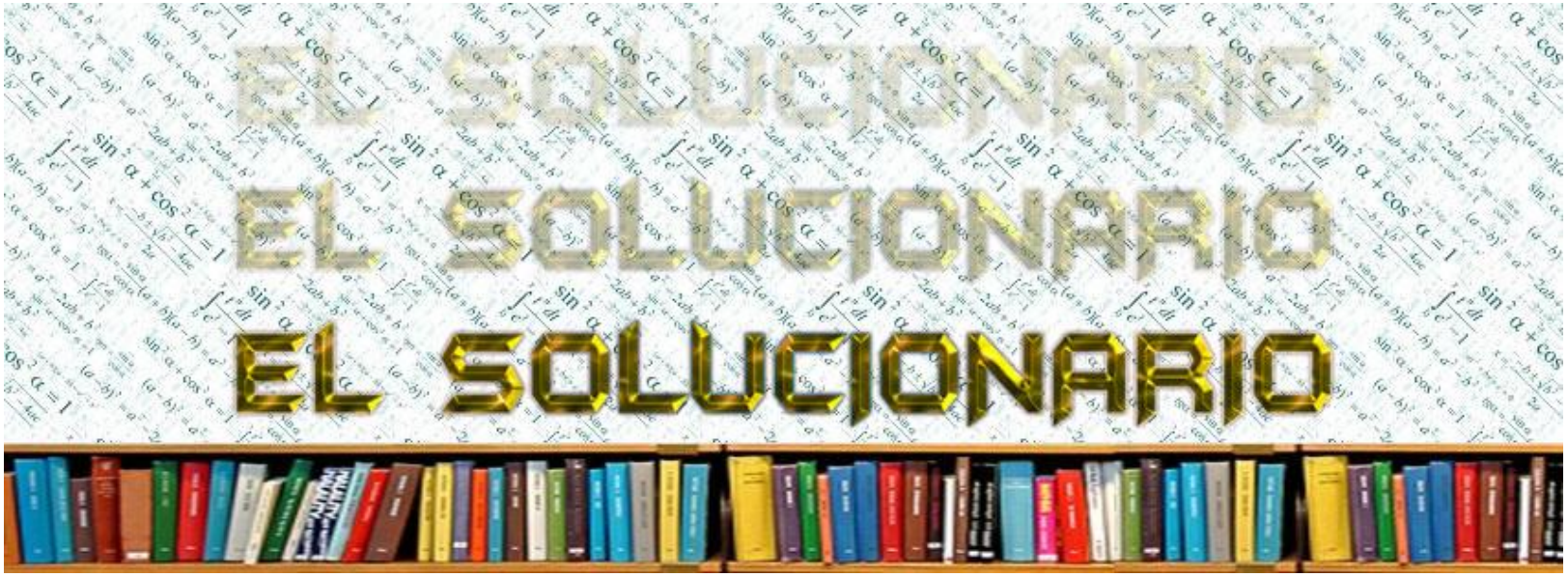

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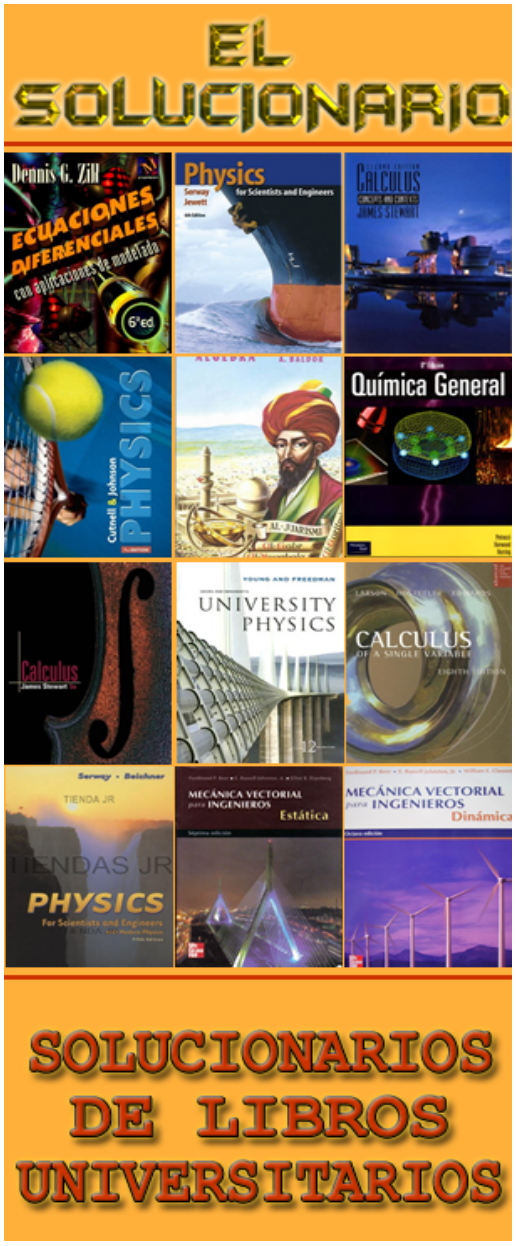

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Contents

CHAPTER 1	1
CHAPTER 2	9
CHAPTER 3	13
CHAPTER 4	22
CHAPTER 5	29
CHAPTER 6	39
CHAPTER 7	52
CHAPTER 8	65
CHAPTER 9	86
CHAPTER 10	106
CHAPTER 11	124
CHAPTER 12	143
CHAPTER 13	150
CHAPTER 14	157
CHAPTER 15	170
CHAPTER 16	195
CHAPTER 17	202
CHAPTER 18	222
CHAPTER 19	253
CHAPTER 20	266
CHAPTER 21	280
CHAPTER 22	311
CHAPTER 23	318
CHAPTER 24	333
CHAPTER 25	342
TEST ITEM FILE	353

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Chapter 1

1. –

2. –

3. –

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

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

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

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

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

7. –

8. –

9. –

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

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

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

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. $\mathbf{2 \times 10^{-10}}$

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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. $\dfrac{(10^3)(10^4)}{10^{-4}} = 10^7/10^{-4} = \mathbf{1.0 \times 10^{11}}$

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e. $(1 \times 10^{-4})^3(10^2)/10^6 = (10^{-12})(10^2)/10^6 = 10^{-10}/10^6 = \mathbf{1.0 \times 10^{-16}}$

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

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

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

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

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

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

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. $$\frac{\left[(3\times10^{-3})^3\right]\left[1.60\times10^2\right]^2\left[(2\times10^2)(8\times10^{-4})\right]^{1/2}}{(7\times10^{-5})^2}$$
$$= \frac{(27\times10^{-9})(2.56\times10^4)(16\times10^{-2})^{1/2}}{49\times10^{-10}}$$
$$= \frac{(69.12\times10^{-5})(4\times10^{-1})}{49\times10^{-10}} = \frac{276.48\times10^{-6}}{49\times10^{-10}}$$
$= 5.64 \times 10^4 = \mathbf{56.4 \times 10^3}$

24. a. $6 \times 10^3 = \underline{0.006} \times 10^{+6}$ (+3 over the exponents; −3 under the exponents)

b. $4 \times 10^{-3} = \underline{4000} \times 10^{-6}$ (−3 over the exponents; +3 under the exponents)

c. $50 \times 10^5 = \underline{5000} \times 10^3 = \underline{5} \times 10^6 = \underline{0.005} \times 10^9$ (−2, +3, +3 over the exponents; +2, −3, −3 under the exponents)

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

+5, −3, −3 / −5, +3, +3

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

−3 / +3

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

+3 / −3

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

−3 / +3

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

+6 / −6

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

−3 / +3

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

10^0, increase by 3 / −3

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

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

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

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

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

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

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

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

$= 670{,}615{,}288.1\text{ mph} \cong \mathbf{670.62 \times 10^6\ mph}$

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

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

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

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

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

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

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

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

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

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

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

difference = **20.22 minutes**

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

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

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

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

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

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

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

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

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

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

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

42. $6(4 + 8) = \mathbf{72}$

43. $(20 + 32)/4 = \mathbf{13}$

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

45. MODE = DEGREES: $\cos 50° = \mathbf{0.64}$

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

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

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

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

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

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Chapter 2

1. –

2. a. $F = k\dfrac{Q_1Q_2}{r^2} = \dfrac{(9\times10^9)(1\text{ C})(2\text{ C})}{(1\text{ m})^2} = \mathbf{18\times10^9\ N}$

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

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

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

3. a. $r = 1$ mi:

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

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

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

   b. $r = 10$ ft:

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

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

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

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

   $$= \mathbf{1138.34\ kN}$$

4. –

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

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

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

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

$\dfrac{7.2}{18\times10^9} = Q_1^2 \Rightarrow Q_1 = \sqrt{\dfrac{7.2}{18\times10^9}} = \mathbf{20\ \mu C}$

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

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

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

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

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

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

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

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

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

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

16. $21.847 \times 10^{18}\ \cancel{\text{electrons}}\left[\dfrac{1\text{ C}}{6.242\times10^{18}\ \cancel{\text{electrons}}}\right] = 3.5\text{ C}$

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

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

$360\ \text{m}\cancel{\text{C}}\left[\dfrac{6.242\times10^{18}\text{ electrons}}{1\ \cancel{\text{C}}}\right] = \mathbf{2.25 \times 10^{18}\ electrons}$

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

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

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

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

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

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

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

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

(a) > (b)

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

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

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

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

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

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

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

25. Ah = (0.8 A)(75 h) = **60.0 Ah**

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

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

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

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

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

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

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

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

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

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

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

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

29. –

30. –

31. –

32. –

33. –

34. –

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

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

36. $Q = It = (10 \times 10^{-3}\text{ A})(20\text{ s}) = \mathbf{200\text{ mC}}$

$W = VQ = (12.5\text{ V})(200 \times 10^{-3}\text{ C}) = \mathbf{2.5\text{ J}}$

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

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

   c. $\dfrac{1}{8}$" = 0.125" = 125 mils, $A_{CM} = (125 \text{ mils})^2$ = **15.63×10^3 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, $A_{CM} = (393.7 \text{ mils})^2$ = **155×10^3 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, $A_{CM} = (240 \text{ mils})^2$ = **57.60×10^3 CM**

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

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

   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.**

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

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

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

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

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

7. $\dfrac{1}{32}'' = 0.03125'' = 31.25$ mils, $A_{\text{CM}} = (31.25\text{ mils})^2 = 976.56$ 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. $$A_{\text{CM}} = \rho\frac{l}{A} = \frac{(10.37)(300')}{3.3\,\Omega} = \mathbf{942.73\ CM}$$

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

b. larger

c. smaller

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

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

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

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

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

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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

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

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

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

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

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

$\Delta R = 1.6\ \Omega - 0.2\ \Omega = \mathbf{1.4\ \Omega}$

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

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

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: $$450 \text{ ft}\left[\frac{1.260\ \Omega}{1000 \text{ ft}}\right] = \mathbf{0.567\ \Omega}$$

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

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

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

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

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

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. $A = \rho\frac{l}{R} = \frac{(10.37)(30')}{6\ \text{m}\Omega} = \frac{311.1\,\text{CM}}{6\times10^{-3}} = 51{,}850\ \text{CM} \Rightarrow \#3$
but 110 A ⇒ **#2**

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

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

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

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

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

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

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

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

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

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

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

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c. increases

d. decreases

20. $R_s = \dfrac{\rho}{d} = 100 \Rightarrow d = \dfrac{\rho}{100} = \dfrac{250\times10^{-6}}{100} = \mathbf{2.5\ \mu cm}$

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

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

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

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

$\rho_2 = \dfrac{RA}{l} = \dfrac{(1\,\text{m}\Omega)(5.067\text{ cm}^2)}{30{,}480\text{ cm}} = \mathbf{1.66\times10^{-7}\ \Omega\text{-cm}}$

c. $k = \dfrac{\rho_2}{\rho_1} = \dfrac{1.66\times10^{-7}\ \Omega\text{-cm}}{1\text{ CM-}\Omega/\text{ft}} = \mathbf{1.66\times10^{-7}}$

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

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

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

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

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

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

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

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

28. a. 68°F = 20°C, 32°F = 0°C

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

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

212°F = 100 °C

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

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

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

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

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

30. a. K = 273.15 + °C

50 = 273.15 + °C

°C = –223.15°

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

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

b. K = 273.15 + °C

38.65 = 273.15 + °C

°C = –234.5°

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

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

Recall: –234.5° =
Inferred absolute zero
R = **0 Ω**

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

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

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

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

48. a. $621 = 62 \times 10^1\ \Omega = 620\ \Omega =$ **0.62 kΩ**
    b. $333 = 33 \times 10^3\ \Omega =$ **33 kΩ**
    c. $Q2 = 3.9 \times 10^2\ \Omega =$ **390 Ω**
    d. $C6 = 1.2 \times 10^6\ \Omega =$ **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)

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

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

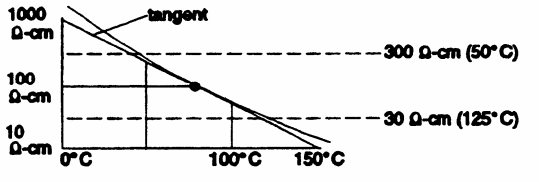
$G_2 = 5G_1 = 5(100\ \text{S}) = \mathbf{500\ S}$

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

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

57. a. @ 0.5 mA, $V \cong$ **195 V**
@ 1 mA, $V \cong$ **200 V**
@ 5 mA, $V \cong$ **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**

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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. $I = \dfrac{V}{R} = \dfrac{12\text{ V}}{40\times10^{-3}\ \Omega} = \mathbf{300\ A}$

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

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

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

15. –

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16. b. (0.13 mA)(500 h) = **65 mAh**

17. –

18. –

19. –

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

36. a. $P = EI$ and $I = \frac{P}{E} = \frac{0.4\times10^{-3}\text{ W}}{3\text{ V}} = \mathbf{0.13\text{ mA}}$

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

37. $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{100\text{ W}}{20\text{ k}\Omega}} = \sqrt{5\times10^{-3}} = \mathbf{70.71\text{ mA}}$

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

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

b. Energy doubles, power the same

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

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

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

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

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

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

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

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

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

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

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

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

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

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

c. 1 kJ = 1 Ws, $\therefore$ **216 kJ**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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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%**

$$\frac{76.73\% - 17.9\%}{17.9\%} \times 100\% = \textbf{328.66\%}$$

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

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

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

$\therefore$ $\eta_2 =$ **40%**, $\eta_2 =$ **80%**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

b. $P_{R_1} = I_1^2R_1 = (250\text{ mA})^2 \cdot 22\ \Omega = \mathbf{1.38\text{ W}}$
$P_{R_2} = I_2^2R_2 = (250\text{ mA})^2 \cdot 10\ \Omega = \mathbf{625.00\text{ mW}}$
$P_{R_3} = I_3^2R_3 = (250\text{ mA})^2 \cdot 47\ \Omega = \mathbf{2.94\text{ W}}$
$P_{R_4} = I_4^2R_4 = (250\text{ mA})^2 \cdot 3\ \Omega = \mathbf{187.50\text{ mW}}$

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

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

e. the same

f. 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. $P = 21\text{ W} = (1\text{ A})^2 \cdot R, \quad R = \mathbf{21\ \Omega}$
$V_1 = I_1R_1 = (1\text{ A})(2\ \Omega) = \mathbf{2\text{ V}}$, $V_2 = I_2R_2 = (1\text{ A})(1\ \Omega) = \mathbf{1\text{ V}}$
$V_3 = I_3R_3 = (1\text{ A})(21\ \Omega) = \mathbf{21\text{ V}}$
$E = V_1 + V_2 + V_3 = 2\text{ V} + 1\text{ V} + 21\text{ V} = \mathbf{24\text{ V}}$

b. $P = 4\text{ W} = I^2 \cdot 1\ \Omega$, $I = \sqrt{4} = \mathbf{2\text{ A}}$
$P = 8\text{ W} = I^2R_1 = (2\text{ A})^2R_1, \quad R_1 = \mathbf{2\ \Omega}$
$R_T = 16\ \Omega = 2\ \Omega + R_2 + 1\ \Omega = 3\ \Omega + R_2, \quad R_2 = \mathbf{13\ \Omega}$
$E = IR_T = (2\text{ A})(16\ \Omega) = \mathbf{32\text{ V}}$

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

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

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

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

d. All go out!

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

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

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

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

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

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

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

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

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

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

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

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

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

$E = \mathbf{42\ V}$

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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. $\dfrac{1\text{ V}}{2\,\Omega} = \dfrac{50\text{ V}}{R_2},\ R_2 = \dfrac{(50\text{ V})(2\,\Omega)}{1\text{ V}} = \mathbf{100\ \Omega}$
$\dfrac{1\text{ V}}{2\,\Omega} = \dfrac{100\text{ V}}{R_3},\ R_3 = \dfrac{(100\text{ V})(2\,\Omega)}{1\text{ V}} = \mathbf{200\ \Omega}$

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. $V_3 = \dfrac{R_3 E}{R_T} = \dfrac{(8.2\text{ k}\Omega)(60\text{ V})}{0.1\text{ k}\Omega + 1\text{ k}\Omega + 8.2\text{ k}\Omega} = \mathbf{52.90\text{ V}}$

d. $V' = \dfrac{(R_2 + R_3)E}{R_T} = \dfrac{(1\text{ k}\Omega + 8.2\text{ k}\Omega)(60\text{ V})}{9.3\text{ k}\Omega} = \mathbf{59.35\text{ V}}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$V_7 = \mathbf{4\text{ V}}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

c. not for most applications.

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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. $R_T = \dfrac{1}{\frac{1}{1\,\text{k}\Omega} + \frac{1}{2\,\text{k}\Omega} + \frac{1}{3\,\text{k}\Omega}} = \dfrac{1}{1\times10^{-3}\text{S} + 0.5\times10^{-3}\,\text{S} + 0.333\times10^{-3}\text{S}}$

   $= \dfrac{1}{1.833\times10^{-3}\text{S}} = \mathbf{545.55\ \Omega}$

   c. $R_T = \dfrac{1}{\frac{1}{100\,\Omega} + \frac{1}{1\,\text{k}\Omega} + \frac{1}{10\,\text{k}\Omega}} = \dfrac{1}{10\times10^{-3}\text{S} + 1\times10^{-3}\text{S} + 0.1\times10^{-3}\text{S}} = \dfrac{1}{11.1\times10^{-3}\text{S}}$

   $= \mathbf{90.09\ \Omega}$

   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. $R_T = \dfrac{1}{\frac{1}{1\,\Omega} + \frac{1}{1\,\text{k}\Omega} + \frac{1}{1\,\text{M}\Omega}} = \dfrac{1}{1000\times10^{-3}\text{S} + 1\times10^{-3}\text{S} + 0.001\times10^{-3}\text{S}}$

   $= \dfrac{1}{1001.001\times10^{-3}\text{S}} = \mathbf{0.99\ \Omega}$

4. a. $R_T = \dfrac{1}{\frac{1}{1\,\text{k}\Omega} + \frac{1}{1.2\,\text{k}\Omega} + \frac{1}{0.3\,\text{k}\Omega}} = \dfrac{1}{1\times10^{-3}\text{S} + 0.833\times10^{-3}\text{S} + 3.333\times10^{-3}\text{S}}$

   $= \dfrac{1}{5.166\times10^{-3}\text{S}} = \mathbf{193.57\ \Omega}$

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

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

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

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

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

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

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

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

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

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

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

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

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

6. a. 1.2 kΩ
b. about 1 kΩ
c. $$R_T = \frac{1}{\frac{1}{1.2\,\text{k}\Omega}+\frac{1}{22\,\text{k}\Omega}+\frac{1}{220\,\text{k}\Omega}+\frac{1}{2.2\,\text{M}\Omega}}$$

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

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

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

e. R_T reduced.

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

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

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

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

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

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

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 A = 4.5 A + 1.5 A = 6 A (checks)

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

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

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

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

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

d. $I_s = 8.5\text{ A} = 6\text{ A} + 2\text{ A} + 0.5\text{ A} = 8.5\text{ A}$ (checks)

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

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

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

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

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

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

d. $I_T = \mathbf{25.92\ mA} = 2.4\text{ mA} + 20\text{ mA} + 3.53\text{ mA} = \mathbf{25.93\ mA}$ (checks)

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

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

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

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

c. I_3 the most, I_4 the least

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$P_s = E_s I_s = (100\text{ V})(115.23\text{ mA}) = \mathbf{11.52\ W}$

d. $P_s = \mathbf{11.52\ W} = 10\text{ W} + 0.30\text{ W} + 1.22\text{ W} = \mathbf{11.52\ W}$ (checks)

e. R_1 = the smallest parallel resistor

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

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

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

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

e. $P_s = 8(8\text{ W}) = \mathbf{64\ W}$

f. none, I_s drops by 66.667 mA

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

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

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

$P = E \cdot I_s = (60\text{ V})(20.98\text{ A}) = \mathbf{1.26\ kW}$

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

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

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

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

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. $8\ \Omega\ \|\ 12\ \Omega = 4.8\ \Omega,\ 4.8\ \Omega\ \|\ 4\ \Omega = 2.182\ \Omega$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$I_s = I_1 + I_2 + I_3$

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

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

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

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

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

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

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

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

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

$I_3 = \mathbf{0.5\ A}$

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

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

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

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

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

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

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

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

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

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

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

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

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

$I_4 = \mathbf{18\ mA}$

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

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

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)

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

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

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

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

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

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

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

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

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)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4 V supply connected in reverse so that

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

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

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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. $V_4 = I_4\,R_4 = I_2R_4 = (3\text{ A})(2\ \Omega) = \mathbf{6\ V}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$I_1 = \dfrac{20\text{ V}}{R_1 + R''} = \dfrac{20\text{ V}}{10\ \Omega + 10\ \Omega} = \dfrac{20\text{ V}}{20\ \Omega} = \mathbf{1\ A}$

$I_3 = \dfrac{20\text{ V}}{5\ \Omega} = \mathbf{4\ A}$

$I_4 = \dfrac{I_1}{2} = (\text{since } R' = R_2) = \dfrac{1\text{ A}}{2} = \mathbf{0.5\ A}$

b. $V_a = I_3R_3 - I_4R_5 = (4\text{ A})(5\ \Omega) - (0.5\text{ A})(6\ \Omega) = 20\text{ V} - 3\text{ V} = \mathbf{17\ V}$

$V_{bc} = \left(\dfrac{I_1}{2}\right)R_2 = (0.5\text{ A})(20\ \Omega) = \mathbf{10\ V}$

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

$= \dfrac{20\text{ V}}{3\ \Omega + 3\ \Omega \parallel (3\ \Omega + 3\ \Omega)} = \dfrac{20\text{ V}}{3\ \Omega + 3\ \Omega \parallel 6\ \Omega} = \dfrac{20\text{ V}}{3\ \Omega + 2\ \Omega}$

$= \mathbf{4\ A}$

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

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

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

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. $V_{DD} - I_DR_D - V_{DG} - V_G = 0$

$V_{DG} = V_{DD} - I_DR_D - V_G$

$= 16\ \text{V} - (2.43\ \text{mA})(2.5\ \text{k}\Omega) - 1.9\ \text{V} = 16\ \text{V} - 6.08\ \text{V} - 1.9\ \text{V} = \mathbf{8.02\ V}$

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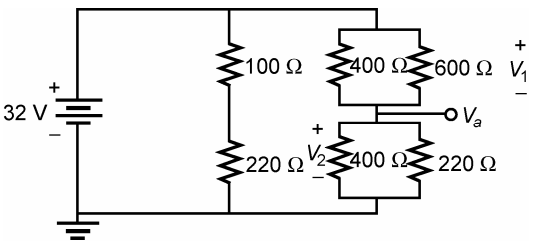
15. a. Network redrawn:



$100\ \Omega + 220\ \Omega = 320\ \Omega$
$400\ \Omega \parallel 600\ \Omega = 240\ \Omega$
$400\ \Omega \parallel 220\ \Omega = 141.94\ \Omega$
$240\ \Omega + 141.94\ \Omega = 381.94\ \Omega$

$R_T = 320\ \Omega \parallel 381.94\ \Omega =$ **174.12 Ω**

b. $V_a = \dfrac{141.94\,\Omega(32\text{ V})}{141.94\,\Omega + 240\,\Omega} =$ **11.89 V**

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

d. $V_2 = V_a =$ **11.89 V**

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

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

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

$I = I_{200\Omega} - I_{600\Omega}$

$= 54.05\text{ mA} - 33.52\text{ mA}$

$=$ **20.53 mA** $\rightarrow$

16. a. $I = \dfrac{E_1}{R_2 + R_3} = \dfrac{9\text{ V}}{7\,\Omega + 8\,\Omega} =$ **0.6 A**

b. $E_1 - V_1 + E_2 = 0$

$V_1 = E_1 + E_2 = 9\text{ V} + 19\text{ V} =$ **28 V**

17. a. R_8 "shorted out"

$R' = R_3 + R_4 \parallel R_5 + R_6 \parallel R_7$

$= 10\ \Omega + 6\ \Omega \parallel 6\ \Omega + 6\ \Omega \parallel 3\ \Omega$

$= 10\ \Omega + 3\ \Omega + 2\ \Omega$

$= 15\ \Omega$

$R_T = R_1 + R_2 \parallel R'$

$= 10\ \Omega + 30\ \Omega \parallel 15\ \Omega = 10\ \Omega + 10\ \Omega$

$= 20\ \Omega$

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

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

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

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

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

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

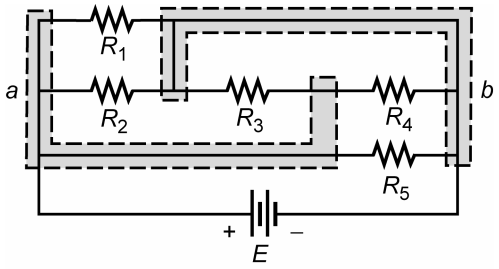
$V_8 = \mathbf{0\ V}$

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

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

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

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, $V_1 = V_4 = E = \mathbf{32\ V}$

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

d. $I_s = I_1 + I_2 + I_3 + I_4 + I_5$

$$= \frac{32\text{ V}}{16\,\Omega} + \frac{32\text{ V}}{8\,\Omega} + \frac{32\text{ V}}{4\,\Omega} + \frac{32\text{ V}}{32\,\Omega} + \frac{32\text{ V}}{16\,\Omega}$$

$= 2\text{ A} + 4\text{ A} + 8\text{ A} + 1\text{ A} + 2\text{ A}$

$= 17\text{ A}$

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

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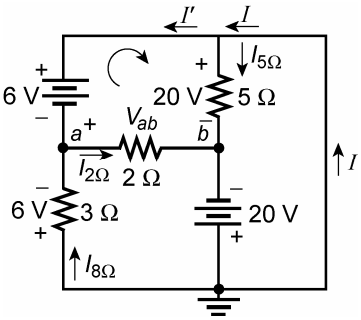
20. a.



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

22. $I_2R_2 = I_3R_3$ and $I_2 = \dfrac{I_3R_3}{R_2} = \dfrac{2R_3}{20} = \dfrac{R_3}{10}$ (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 $120 = 1.2R_3 + 24 + 2R_3$

$3.2R_3 = 96\ \Omega$

$R_3 = \dfrac{96\ \Omega}{3.2} = \mathbf{30\ \Omega}$

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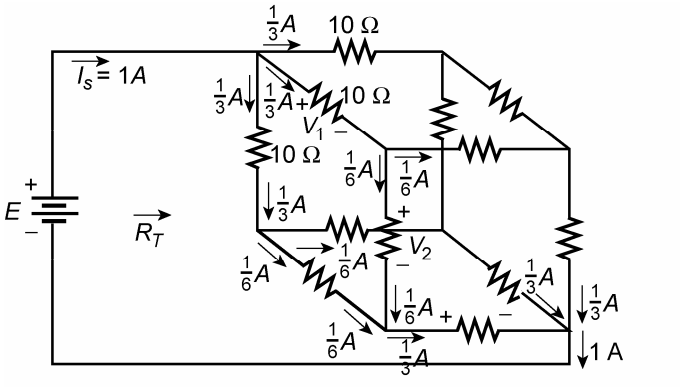
23. Assuming $I_s = 1$ A, the current I_s will divide as determined by the load appearing in each branch. Since balanced I_s will split equally between all three branches.



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

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

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

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

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

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"

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

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

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

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

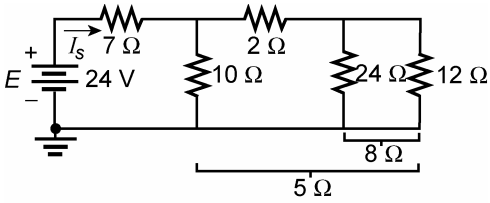
26. a. $R'_T = R_4 \parallel (R_6 + R_7 + R_8) = 2\ \Omega \parallel 7\ \Omega = 1.56\ \Omega$
$R''_T = R_2 \parallel (R_3 + R_5 + R'_T) = 2\ \Omega \parallel (4\ \Omega + 1\ \Omega + 1.56\ \Omega) = 1.53\ \Omega$
$R_T = R_1 + R''_T = 4\ \Omega + 1.53\ \Omega = \mathbf{5.53\ \Omega}$

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. $I_{10} = \dfrac{12\text{ A}}{2} = \mathbf{6\ A}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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$P_1 = I_1^2 R_1 = (40\text{ mA})^2 0.5\text{ k}\Omega = \mathbf{0.8\ W}$ (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. $80\ \Omega \| 1\text{ k}\Omega = 74.07\ \Omega$

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

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

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

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

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

The applied loads dissipate less than 20 mW of power.

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

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

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

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

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

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

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

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

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

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

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

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

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

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b. $xI_m = \dfrac{E}{R_{\text{series}}} + R_m + \dfrac{\text{zero adjust}}{2} + R_{\text{unk}}$

$$R_{\text{unk}} = \frac{E}{xI_m} - \left(R_{\text{series}} + R_m + \frac{\text{zero adjust}}{2} \right)$$

$$= \frac{3\text{ V}}{x100\ \mu\text{A}} - 30\text{ k}\Omega \Rightarrow \frac{30 \times 10^3}{x} - 30 \times 10^3$$

$x = \dfrac{3}{4}$, $R_{\text{unk}} =$ **10 kΩ**; $x = \dfrac{1}{2}$, $R_{\text{unk}} =$ **30 kΩ**; $x = \dfrac{1}{4}$, $R_{\text{unk}} =$ **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 $R_{\text{T}} = \dfrac{R}{N} = \dfrac{18\,\Omega}{3} =$ **6 Ω**

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Chapter 8

1. a. $I_2 = I_3 = \mathbf{10\ mA}$
   b. $V_1 = I_1R_1 = (10\text{ mA})(1\text{ k}\Omega) = \mathbf{10\ V}$
   c. $R_T = 1\text{ k}\Omega + 2.2\text{ k}\Omega + 0.56\text{ k}\Omega = 3.76\text{ k}\Omega$
   $V_s = IR_T = (10\text{ mA})(3.76\text{ k}\Omega) = \mathbf{37.6\ V}$

2. a. $I_2 = \dfrac{R_s(I)}{R_s + R_1 + R_2} = \dfrac{10\text{ k}\Omega(4\text{ A})}{10\text{ k}\Omega + 10\ \Omega} = \mathbf{3.996\ A,}\ \boldsymbol{I_2 \cong I}$
   b. $V_2 = I_2R_2 = (3.996\text{ A})(6\ \Omega) = \mathbf{23.98\ V}$
   c. $V_s = I_2(R_1 + R_2) = (3.996\text{ A})(10\ \Omega) = \mathbf{39.96\ V}$

3. $V_{R_1} = IR_1 = (6\text{ A})(3\ \Omega) = 18\text{ V}$
   $E + V_{R_1} - V_s = 0,\quad V_s = E + V_{R_1} = 10\text{ V} + 18\text{ V} = \mathbf{28\ V}$

4. a. $V_s = E = \mathbf{24\ V}$
   b. $I_2 = \dfrac{E}{R_1 + R_2} = \dfrac{24\text{ V}}{1\ \Omega + 3\ \Omega} = \dfrac{24\text{ V}}{4\ \Omega} = \mathbf{6\ A}$
   c. $I + I_s = I_2,\quad I_s = I_2 - I = 6\text{ A} - 2\text{ A} = \mathbf{4\ A}$

5. $V_1 = V_2 = V_s = IR_T = 0.6\text{ A}[6\ \Omega \parallel 24\ \Omega \parallel 24\ \Omega] = 0.6\text{ A}[6\ \Omega \parallel 12\ \Omega] = 2.4\text{ V}$
   $I_2 = \dfrac{V_2}{R_2} = \dfrac{2.4\text{ V}}{24\ \Omega} = \mathbf{0.1\ A}$
   $V_3 = \dfrac{R_3V_s}{R_3 + R_4} = \dfrac{16\ \Omega(2.4\text{ V})}{24\ \Omega} = \mathbf{1.6\ V}$

6. a. $I_1 = \dfrac{E}{R_1} = \dfrac{24\text{ V}}{2\ \Omega} = \mathbf{12\ A},\ I_{R_2} = \dfrac{E}{R_2 + R_3} = \dfrac{24\text{ V}}{6\ \Omega + 2\ \Omega} = \dfrac{24\ \Omega}{8\ \Omega} = 3\text{ A}$
   KCL: $I + I_s - I_1 - I_{R_2} = 0$
   $I_s = I_1 + I_{R_2} - I = 12\text{ A} + 3\text{ A} - 4\text{ A} = \mathbf{11\ A}$

   b. $V_s = E = 24\text{ V}$
   VDR: $V_3 = \dfrac{R_3E}{R_2 + R_3} = \dfrac{2\ \Omega(24\text{ V})}{6\ \Omega + 2\ \Omega} = \dfrac{48\text{ V}}{8\ \Omega} = \mathbf{6\ V}$

7. a. $I = \dfrac{E}{R_s} = \dfrac{18\text{ V}}{6\ \Omega} = \mathbf{3\ A},\ R_p = R_s = \mathbf{6\ \Omega}$

   b. $I = \dfrac{E}{R_s} = \dfrac{9\text{ V}}{2.2\text{ k}\Omega} = \mathbf{4.09\ mA},\ R_p = R_s = \mathbf{2.2\ k\Omega}$

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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. $I = \dfrac{E}{R_2} = \dfrac{12\text{ V}}{2.2\text{ k}\Omega} = \mathbf{5.45\ mA}$, $R_p = \mathbf{2.2\ k\Omega}$

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b. $I_T\uparrow = 8\text{ mA} + 5.45\text{ mA} - 3\text{ mA} = 10.45\text{ mA}$
$R' = 6.8\text{ k}\Omega \parallel 2.2\text{ k}\Omega = 1.66\text{ k}\Omega$
$V_1 = I_T R' = (10.45\text{ mA})(1.66\text{ k}\Omega) = \mathbf{17.35\text{ V}}$

c. $V_1 = V_2 + 12\text{ V} \Rightarrow V_2 = V_1 - 12\text{ V} = 17.35\text{ V} - 12\text{ V}$
$= \mathbf{5.35\text{ V}}$

d. $I_2 = \dfrac{V_2}{R_2} = \dfrac{5.35\text{ V}}{2.2\text{ k}\Omega} = \mathbf{2.43\text{ mA}}$

15. a. $\overrightarrow{I_1}\downarrow\overleftarrow{I_3}\,I_2$

$4 - 4I_1 - 8I_3 = 0$
$6 - 2I_2 - 8I_3 = 0$
$I_1 + I_2 = I_3$

$I_1 = -\mathbf{\frac{1}{7}}\,\mathbf{A}, I_2 = \mathbf{\frac{5}{7}}\,\mathbf{A}, I_3 = \mathbf{\frac{4}{7}}\,\mathbf{A}$

$I_{R_1} = I_1 = -\mathbf{\frac{1}{7}}\,\mathbf{A}, I_{R_2} = I_2 = \mathbf{\frac{5}{7}}\,\mathbf{A}, I_{R_3} = I_3 = \mathbf{\frac{4}{7}}\,\mathbf{A}$

b. $I_1\uparrow\,\overleftarrow{I_3}\,I_2$

$10 + 12 - 3I_3 - 4I_1 = 0$
$12 - 3I_3 - 12I_2 = 0$
$I_1 + I_2 = I_3$

$I_1 = \mathbf{3.06\text{ A}}$
$I_2 = \mathbf{0.19\text{ A}}$
$I_3 = \mathbf{3.25\text{ A}}$

$I_{R_1} = I_1 = \mathbf{3.06\text{ A}}, \; I_{R_2} = I_2 = \mathbf{0.19\text{ A}}$
$I_{R_3} = I_3 = \mathbf{3.25\text{ A}}$

16. (I): $\overrightarrow{I_1}\downarrow\overleftarrow{I_3}\,I_2$

$10 - I_1\,5.6\text{ k}\Omega - I_3\,2.2\text{ k}\Omega + 20 = 0$
$-20 + I_3\,2.2\text{ k}\Omega + I_2\,3.3\text{ k}\Omega - 30 = 0$
$I_1 + I_2 = I_3$

$I_1 = I_{R_1} = \mathbf{1.45\text{ mA}}, I_2 = I_{R_2} = \mathbf{8.51\text{ mA}}, I_3 = I_{R_3} = \mathbf{9.96\text{ mA}}$

(II): $\overrightarrow{I_1}$, $\overleftarrow{I_3}$, $\uparrow I_2$

$-1.2\text{ k}\Omega\,I_1 + 9 - 8.2\text{ k}\Omega\,I_3 = 0$
$-10.2\text{ k}\Omega\,I_2 + 8.2\text{ k}\Omega\,I_3 + 6 = 0$
$I_2 + I_3 = I_1$

$I_1 = \mathbf{2.03\text{ mA}}, I_2 = \mathbf{1.23\text{ mA}}, I_3 = \mathbf{0.8\text{ mA}}$

$I_{R_1} = I_1 = \mathbf{2.03\text{ mA}}$
$I_{R_2} = I_3 = \mathbf{0.8\text{ mA}}$
$I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23\text{ mA}}$

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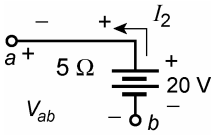
17. (I): I_1 ↓ I_3 ↓ I_2

$-25 - 2I_1 - 3I_3 + 60 = 0$
$-60 + 3I_3 + 6 - 5I_2 - 20 = 0$
$I_1 = I_2 + I_3$

$I_2 = \mathbf{-8.55\ A}$



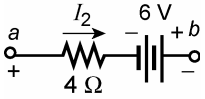
V_{ab} (+ a, – b) $= 20\ \text{V} - I_2\ 5\ \Omega = 20\ \text{V} - (8.55\ \text{A})(5\ \Omega) = \mathbf{-22.75\ V}$

(II): Source conversion: $E = IR_1 = (3\ \text{A})(3\ \Omega) = 9\ \text{V}$, $R_1 = 3\ \Omega$

I_2 ↓ I_4 ↓ I_3

$9 + 6 - 3I_2 - 4I_2 - 6I_4 = 0$
$+ 6I_4 - 8I_3 - 4 = 0$
$I_2 = I_3 + I_4$

$I_2 = \mathbf{1.27\ A}$



V_{ab} (+ a, – b) $= I_2\ 4\ \Omega - 6\ \text{V} = (1.27\ \text{A})4\ \Omega - 6\ \text{V} = \mathbf{-0.92\ V}$

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.
$I_2(R_1 + R_2) + I_3R_1 + 0 = E_1$
$I_2(R_2) - I_3(R_3 + R_4) + I_5R_4 = 0$
$0 + I_3R_4 - I_5(R_4 + R_5) = E_2$

$3I_2 + 2I_3 + 0 = 10$
$1I_2 - 9I_3 + 5I_5 = 0$
$0 + 5I_3 - 8I_5 = 6$

d. $I_3 = I_{R_3} = \mathbf{-63.69\ mA}$

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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 I_2
$4 - 4I_1 - 8(I_1 - I_2) = 0$
$-8(I_2 - I_1) - 2I_2 - 6 = 0$

$I_1 = -\frac{1}{7}\text{ A}$, $I_2 = -\frac{5}{7}\text{ A}$

$I_{R_1} = I_1 = -\frac{1}{7}\text{ A}$

$I_{R_2} = I_2 = -\frac{5}{7}\text{ A}$

$I_{R_3} = I_1 - I_2 = \left(-\frac{1}{7}\text{ A}\right) - \left(-\frac{5}{7}\text{ A}\right) = \frac{4}{7}\text{ A}\ (\text{dir. of } I_1)$

b. I_1 I_2
$-10 - 4I_1 - 3(I_1 - I_2) - 12 = 0$
$12 - 3(I_2 - I_1) - 12I_2 = 0$

$I_1 = \mathbf{-3.06\ A}$, $I_2 = \mathbf{0.19\ A}$

$I_{R_1} = I_1 = \mathbf{-3.06\ A}$
$I_{R_3} = I_2 = \mathbf{0.19\ A}$
$I_{R_2} = I_1 - I_2 = (-3.06\text{ A}) - (0.19\text{ A}) = \mathbf{-3.25\ A}$

21. (I): I_1 I_2
$10 - I_1(5.6\text{ k}\Omega) - 2.2\text{ k}\Omega(I_1 - I_2) + 20 = 0$
$-20 - 2.2\text{ k}\Omega(I_2 - I_1) - I_2\ 3.3\text{ k}\Omega - 30 = 0$

$I_1 = \mathbf{1.45\ mA}$, $I_2 = \mathbf{8.51\ mA}$
$I_{R_1} = I_1 = \mathbf{1.45\ mA}$, $I_{R_2} = I_2 = \mathbf{8.51\ mA}$
$I_{R_3} = I_2 - I_1 = \mathbf{7.06\ mA}$ (direction of I_2)

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(II): $\overline{I_1}$, $\overline{I_2}$

$$-I_1(1.2\ \text{k}\Omega) + 9 - 8.2\ \text{k}\Omega(I_1 - I_2) = 0$$
$$-I_2(1.1\ \text{k}\Omega) + 6 - I_2(9.1\ \text{k}\Omega) - 8.2\ \text{k}\Omega(I_2 - I_1) = 0$$

$I_1 = \mathbf{2.03\ mA}$, $I_2 = \mathbf{1.23\ mA}$

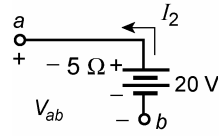
$I_{R_1} = I_1 = \mathbf{2.03\ mA}$, $I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23\ mA}$

$I_{R_2} = I_1 - I_2 = 2.03\ \text{mA} - 1.23\ \text{mA} = \mathbf{0.80\ mA}$ (direction of I_1)

22. (I): $\overline{I_1}$, $\overline{I_2}$

$$-25 - 2I_1 - 3(I_1 - I_2) + 60 = 0$$
$$-60 - 3(I_2 - I_1) + 6 - 5I_2 - 20 = 0$$

$I_1 = \mathbf{1.87\ A}$, $I_2 = \mathbf{-8.55\ A}$



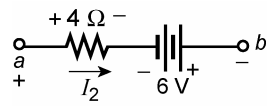
$$V_{ab} = 20 - I_2\,5 = 20 - (8.55\ \text{A})(5) = 20\ \text{V} - 42.75\ \text{V}$$
$$= \mathbf{-22.75\ V}$$

(II): Source conversion: $E = 9$ V, $R = 3\ \Omega$

$\overline{I_2}$, $\overline{I_3}$

$$9 - 3I_2 - 4I_2 + 6 - 6(I_2 - I_3) = 0$$
$$-6(I_3 - I_2) - 8I_3 - 4 = 0$$

$I_2 = \mathbf{1.27\ A}$, $I_3 = \mathbf{0.26\ A}$



$$V_{ab} = I_2\,4 - 6 = (1.27\ \text{A})(4\ \Omega) - 6\ \text{V}$$
$$= 5.08\ \text{V} - 6\ \text{V}$$
$$= \mathbf{-0.92\ V}$$

23. (a): I_1, I_2, I_3

$$10 - I_1 2 - 1(I_1 - I_2) = 0$$
$$-1(I_2 - I_1) - I_2\,4 - 5(I_2 - I_3) = 0$$
$$-5(I_3 - I_2) - I_3\,3 - 6 = 0$$

$$3I_1 - 1I_2 + 0 = 10$$
$$-1I_1 + 10I_2 - 5I_3 = 0$$
$$0 - 5I_2 + 8I_3 = -6$$

$I_2 = I_{R_3} = \mathbf{-63.69\ mA}$

24. a. $\overline{I_1}$, $\overline{I_2}$

$$-1I_1 - 4 - 5I_1 + 6 - 1(I_1 - I_2) = 0$$
$$-1(I_2 - I_1) - 6 - 3I_2 - 15 - 10I_2 = 0$$

$I_1 = I_{5\Omega} = \mathbf{72.16\ mA}$

$$V_a = -4 - (72.16\ \text{mA})(6\ \Omega)$$
$$= -4 - 0.433\ \text{V}$$
$$= \mathbf{-4.43\ V}$$

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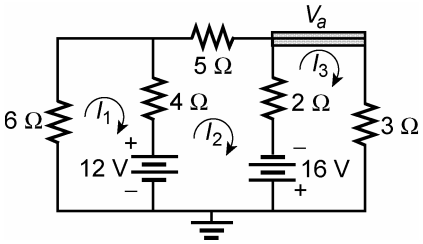
b. Network redrawn:



$-6I_1 - 4(I_1 - I_2) - 12 = 0$
$12 - 4(I_2 - I_1) - 5I_2 - 2(I_2 - I_3) + 16 = 0$
$-16 - 2(I_3 - I_2) - 3I_3 = 0$

$I_2 = I_{5\Omega} =$ **1.95 A**

$V_a = (I_3)(3\ \Omega)$
$= (-2.42\ \text{mA})(3\ \Omega)$
$=$ **–7.26 V**

25. (I): I_1 I_2 I_3

$I_1(2.2\ \text{k}\Omega + 9.1\ \text{k}\Omega) - 9.1\ \text{k}\Omega\ I_2 = 18$
$I_2(9.1\ \text{k}\Omega + 7.5\ \text{k}\Omega + 6.8\ \text{k}\Omega) - 9.1\ \text{k}\Omega\ I_1 - 6.8\ \text{k}\Omega\ I_3 = -18$
$I_3(6.8\ \text{k}\Omega + 3.3\ \text{k}\Omega) - I_2\ 6.8\ \text{k}\Omega = -3$

$I_1 =$ **1.21 mA**, $I_2 =$ **–0.48 mA**, $I_3 =$ **–0.62 mA**

(II): I_1, I_3, I_2

$16 - 4I_1 - 3(I_1 - I_2) - 12 - 4(I_1 - I_3) = 0$
$12 - 3(I_2 - I_1) - 10\ I_2 - 15 - 4(I_2 - I_3) = 0$
$-16 - 4(I_3 - I_1) - 4(I_3 - I_2) - 7I_3 = 0$

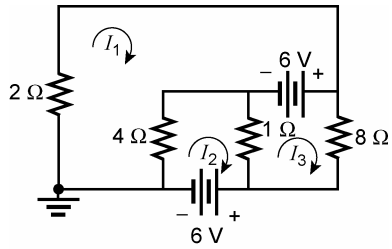
$I_1 =$ **–0.24 A**, $I_2 =$ **–0.52 A**, $I_3 =$ **–1.28 A**

26. a. I_1 I_2 I_4 I_3

$-6.8\ \text{k}\Omega\ I_1 - 4.7\ \text{k}\Omega(I_1 - I_2) + 6 - 2.2\ \text{k}\Omega(I_1 - I_4) = 0$
$-6 - 4.7\ \text{k}\Omega(I_2 - I_1) - 2.7\ \text{k}\Omega\ I_2 - 8.2\ \text{k}\Omega\ (I_2 - I_3) = 0$
$-1.1\ \text{k}\Omega\ I_3 - 22\ \text{k}\Omega(I_3 - I_4) - 8.2\ \text{k}\Omega(I_3 - I_2) - 9 = 0$
$5 - 1.2\ \text{k}\Omega\ I_4 - 2.2\ \text{k}\Omega(I_4 - I_1) - 22\ \text{k}\Omega(I_4 - I_3) = 0$

$I_1 =$ **0.03 mA**, $I_2 =$ **–0.88 mA**, $I_3 =$ **–0.97 mA**, $I_4 =$ **–0.64 mA**

b. Network redrawn:



$-2I_1 - 6 - 4I_1 + 4I_2 = 0$
$-4I_2 + 4I_1 - 1I_2 + 1I_3 - 6 = 0$
$-1I_3 + 1I_2 + 6 - 8I_3 = 0$

$I_1 =$ **–3.8 A**, $I_2 =$ **–4.20 A**, $I_3 =$ **0.20 A**

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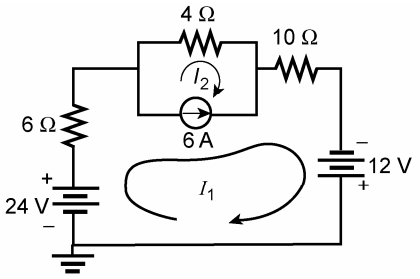
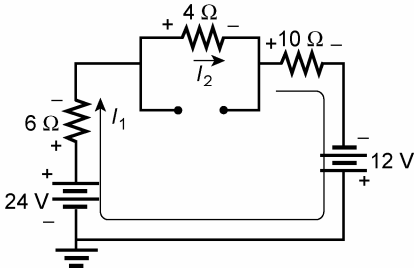
27. a.





$24\text{ V} - 6I_1 - 4I_2 - 10I_1 + 12\text{ V} = 0$

and $16I_1 + 4I_2 = 36$

$I_1 - I_2 = 6\text{ A}$

$I_1 = I_2 + 6\text{ A}$

$16[I_2 + 6\text{ A}] + 4I_2 = 36$

$16I_2 + 96 + 4I_2 = 36$

$20I_2 = -60$

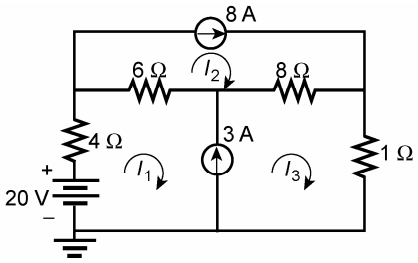
$I_2 = \mathbf{-3\text{ A}}$

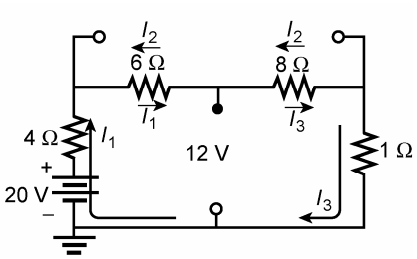
$I_1 = I_2 + 6\text{ A} = -3\text{ A} + 6\text{ A} = \mathbf{3\text{ A}}$

$I_{24\text{V}} = I_{6\Omega} = I_{10\Omega} = I_{12\text{V}} = \mathbf{3\text{ A}}$ (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)

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28. a. $\overline{I_1}\downarrow\ \overline{I_2}\downarrow$

$$(4 + 8)I_1 - 8I_2 = 4$$
$$(8 + 2)I_2 - 8I_1 = -6$$

b. $\overline{I_1}\downarrow\ \overline{I_2}\downarrow$

$$I_1 = -\frac{1}{7}\text{A}\ ,\ I_2 = -\frac{5}{7}\text{A}$$

$$(4 + 3)I_1 - 3I_2 = -10 - 12$$
$$(3 + 12)I_2 - 3I_1 = 12$$

$I_1 = \mathbf{-3.06\ A}$, $I_2 = \mathbf{0.19\ A}$

29. (I): $\overline{I_1}\downarrow\ \overline{I_2}\downarrow$

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. $I_1 = \mathbf{1.45\ mA}$, $I_2 = \mathbf{-8.51\ mA}$

c. $I_{R_1} = I_1 = \mathbf{1.45\ mA}$, $I_{R_2} = I_2 = \mathbf{-8.51\ mA}$
$I_{R_3} = I_1 + I_2 = 8.51\ \text{mA} + 1.44\ \text{mA} = \mathbf{9.96\ mA}$ (direction of I_1)

(II): $I_1\downarrow$
$I_2\downarrow$

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. $I_1 = \mathbf{2.03\ mA}$, $I_2 = \mathbf{1.23\ mA}$

c. $I_{R_1} = I_1 = \mathbf{2.03\ mA}$, $I_{R_3} = I_{R_4} = I_2 = \mathbf{1.23\ mA}$
$I_{R_2} = I_1 - I_2 = 2.03\ \text{mA} - 1.23\ \text{mA} = \mathbf{0.80\ mA}$ (direction of I_1)

30. (I): $\overline{I_1}\downarrow\ \overline{I_2}\downarrow$

$$(2 + 3)I_1 - 3I_2 = -25 + 60$$
$$(3 + 5)I_2 - 3I_1 = -60 + 6 - 20$$

b. $I_1 = \mathbf{1.87\ A}$, $I_2 = \mathbf{-8.55\ A}$

c. $I_{R_1} = I_1 = \mathbf{1.87\ A}$, $I_{R_2} = I_2 = \mathbf{-8.55\ A}$
$I_{R_3} = I_1 - I_2 = 1.87\ \text{A} - (-8.55\ \text{A}) = \mathbf{10.42\ A}$ (direction of I_1)

(II): a. $\overline{I_2}\downarrow\ \overline{I_3}\downarrow$

$$(3 + 4 + 6)I_2 - 6I_3 = 9 + 6$$
$$(6 + 8)I_3 - 6I_2 = -4$$

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b. $I_2 = \mathbf{1.27\ A}$, $I_3 = \mathbf{0.26\ A}$

c. $I_{R_2} = I_2 = \mathbf{1.27\ A}$, $I_{R_3} = I_3 = \mathbf{0.26\ A}$
$I_{R_4} = I_2 - I_3 = 1.27\ \text{A} - 0.26\ \text{A} = \mathbf{1.01\ A}$
$I_{R_1} = 3\ \text{A} - I_2 = 3\ \text{A} - 1.27\ \text{A} = \mathbf{1.73\ A}$

31. $I_1 \circlearrowright\ I_2 \circlearrowright\ I_3 \circlearrowright$

$I_1(2 + 1) - 1I_2 = 10$
$I_2(1 + 4 + 5) - 1I_1 - 5I_3 = 0$
$I_3(5 + 3) - 5I_2 = -6$

$I_2 = I_{R_3} = \mathbf{-63.69\ mA}$ (exact match with problem 18)

32. From Sol. 24(b)

$I_1 \circlearrowright\ I_2 \circlearrowright\ I_3 \circlearrowright$

$I_1(6 + 4) - 4I_2 = -12$
$I_2(4 + 5 + 2) - 4I_1 - 2I_3 = 12 + 16$
$I_3(2 + 3) - 2I_2 = -16$

$I_{5\Omega} = I_2 = \mathbf{1.95\ A}$
$I_3 = -2.42\ \text{A}, \therefore V_a = (I_3)(3\ \Omega) = (-2.42\ \text{A})(3\ \Omega) = \mathbf{-7.26\ V}$

33. (I): $I_1 \circlearrowright\ I_2 \circlearrowright\ I_3 \circlearrowright$

$(2.2\ \text{k}\Omega + 9.1\ \text{k}\Omega)I_1 - 9.1\ \text{k}\Omega I_2 = 18$
$(9.1\ \text{k}\Omega + 7.5\ \text{k}\Omega + 6.8\ \text{k}\Omega)I_2 - 9.1\ \text{k}\Omega\ I_1 - 6.8\ \text{k}\Omega I_3 = -18$
$(6.8\ \text{k}\Omega + 3.3\ \text{k}\Omega)I_3 - 6.8\ \text{k}\Omega I_2 = -3$

$I_1 = \mathbf{1.21\ mA}$, $I_2 = \mathbf{-0.48\ mA}$, $I_3 = \mathbf{-0.62\ mA}$

(II): $I_1 \circlearrowright$, $I_3 \circlearrowright\ I_2 \circlearrowright$

$(4\ \Omega + 4\ \Omega + 3\ \Omega)I_1 - 3\ \Omega\ I_2 - 4\ \Omega\ I_3 = 16 - 12$
$(4\ \Omega + 3\ \Omega + 10\ \Omega)I_2 - 3I_1 - 4\ \Omega\ I_3 = 12 - 15$
$(4\ \Omega + 4\ \Omega + 7\ \Omega)I_3 - 4I_1 - 4I_2 = -16$

$I_1 = \mathbf{-0.24\ A}$, $I_2 = \mathbf{-0.52\ A}$, $I_3 = \mathbf{-1.28\ A}$

34. a. $I_1 \circlearrowright\ I_2 \circlearrowright$, $I_4 \circlearrowright\ I_3 \circlearrowright$

$I_1(6.8\ \text{k}\Omega + 4.7\ \text{k}\Omega + 2.2\ \text{k}\Omega) - 4.7\ \text{k}\Omega\ I_2 - 2.2\ \text{k}\Omega\ I_4 = 6$
$I_2(2.7\ \text{k}\Omega + 8.2\ \text{k}\Omega + 4.7\ \text{k}\Omega) - 4.7\ \text{k}\Omega\ I_1 - 8.2\ \text{k}\Omega\ I_3 = -6$
$I_3(8.2\ \text{k}\Omega + 1.1\ \text{k}\Omega + 22\ \text{k}\Omega) - 22\ \text{k}\Omega\ I_4 - 8.2\ \text{k}\Omega\ I_2 = -9$
$I_4(2.2\ \text{k}\Omega + 22\ \text{k}\Omega + 1.2\ \text{k}\Omega) - 2.2\ \text{k}\Omega\ I_1 - 22\ \text{k}\Omega\ I_3 = 5$

$I_1 = \mathbf{0.03\ mA}$, $I_2 = \mathbf{-0.88\ mA}$, $I_3 = \mathbf{-0.97\ mA}$, $I_4 = \mathbf{-0.64\ mA}$

b. From Sol. 26(b):

$I_1(2 + 4) - 4I_2 = -6$
$I_2(4 + 1) - 4I_1 - 1I_3 = -6$
$I_3(1 + 8) - 1I_2 = 6$

$I_1 = \mathbf{3.8\ A}$, $I_2 = \mathbf{-4.20\ A}$, $I_3 = \mathbf{0.20\ A}$

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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**

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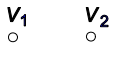
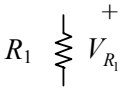
37. (I): a. 

$$V_1\left[\frac{1}{2.2\,\text{k}\Omega}+\frac{1}{9.1\,\text{k}\Omega}+\frac{1}{7.5\,\text{k}\Omega}\right]-\frac{1}{7.5\,\text{k}\Omega}V_2=-1.98\,\text{mA}$$

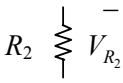
$$V_2\left[\frac{1}{7.5\,\text{k}\Omega}+\frac{1}{6.8\,\text{k}\Omega}+\frac{1}{3.3\,\text{k}\Omega}\right]-\frac{1}{7.5\,\text{k}\Omega}V_1=0.91\,\text{mA}$$

b. $V_1 = \mathbf{-2.65\ V}$, $V_2 = \mathbf{0.95\ V}$

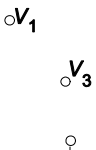
c. $V_{R_3} = V_1 = \mathbf{-2.65\ V}$, $V_{R_5} = V_2 = \mathbf{0.95\ V}$, $V_{R_4} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = \mathbf{3.60\ V}$



R_1 $V_{R_1} = 18\ \text{V} - 2.65\ \text{V} = \mathbf{15.35\ V}$



R_2 $V_{R_2} = 3\ \text{V} - 0.95\ \text{V} = \mathbf{2.05\ V}$

(II): a. 

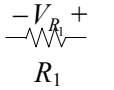
$$V_1\left[\frac{1}{4}+\frac{1}{4}+\frac{1}{7}\right]-\frac{1}{4}V_2-\frac{1}{4}V_3=4$$

$$V_2\left[\frac{1}{4}+\frac{1}{3}+\frac{1}{10}\right]-\frac{1}{4}V_1-\frac{1}{3}V_3=4+1.5$$

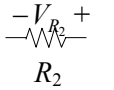
$$V_3\left[\frac{1}{4}+\frac{1}{3}+\frac{1}{4}\right]-\frac{1}{4}V_1-\frac{1}{3}V_3=-4-4$$

b. $V_1 = \mathbf{8.88\ V}$, $V_2 = \mathbf{9.83\ V}$, $V_3 = \mathbf{-3.01\ V}$

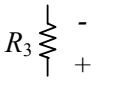
c. $V_{R_6} = V_1 = \mathbf{8.88\ V}$, $V_{R_4} = V_3 = \mathbf{-3.01\ V}$, $V_{R_5} = \overset{(+)}{V_2}\ \overset{(-)}{V_1} = \mathbf{0.95\ V}$



$V_{R_1} = 16\ \text{V} - V_1 + V_3 = \mathbf{4.12\ V}$



$V_{R_2} = V_2 - V_3 - 12\ \text{V} = \mathbf{0.84\ V}$



$V_{R_3} = 15\ \text{V} - V_2 = \mathbf{5.17\ V}$

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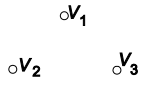
38. (I):



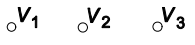
$$V_1\left[\frac{1}{3}+\frac{1}{6}+\frac{1}{6}\right]-\frac{1}{6}V_2-\frac{1}{6}V_3=5$$

$$V_2\left[\frac{1}{6}+\frac{1}{4}+\frac{1}{5}\right]-\frac{1}{6}V_1-\frac{1}{5}V_3=-3$$

$$V_3\left[\frac{1}{6}+\frac{1}{5}+\frac{1}{7}\right]-\frac{1}{5}V_2-\frac{1}{6}V_1=0$$

$V_1 =$ **7.24 V**, $V_2 =$ **–2.45 V**, $V_3 =$ **1.41 V**

(II): Source conversion: $I = 4$ A, $R = 4\ \Omega$



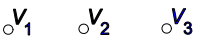
$$V_1\left[\frac{1}{9}+\frac{1}{20}+\frac{1}{20}\right]-\frac{1}{20}V_2-\frac{1}{20}V_3=-2$$

$$V_2\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{18}\right]-\frac{1}{20}V_1-\frac{1}{20}V_3=0$$

$$V_3\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{4}\right]-\frac{1}{20}V_2-\frac{1}{20}V_1=4$$

$V_1 =$ **–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**

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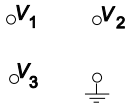
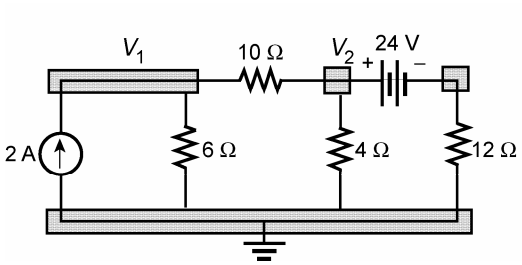
(II) 

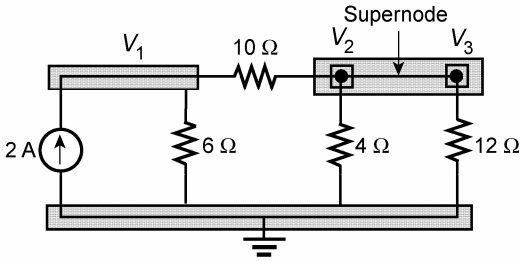
$$V_1\left[\frac{1}{2}+\frac{1}{6}\right]-\frac{1}{6}V_3=-5$$

$$V_2\left[\frac{1}{4}\right]=5-2$$

$$V_3\left[\frac{1}{6}+\frac{1}{5}\right]-\frac{1}{6}V_1=2$$

$V_1 =$ **–6.92 V**, $V_2 =$ **12 V**, $V_3 =$ **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:

$$\frac{V_1}{6\,\Omega}+\frac{V_1-V_2}{10\,\Omega}=2\text{ A}$$

$$\frac{V_2-V_1}{10\,\Omega}+\frac{V_2}{4\,\Omega}+\frac{V_2-24\text{ V}}{12\,\Omega}=0$$

$$0.267V_1 - 0.1V_2 = 2$$
$$+0.1V_1 - 0.433V_2 = -2$$

$V_1 =$ **10.08 V**, $V_2 =$ **6.94 V**
$V_3 = V_2 - 24\text{ V} =$ **–17.06 V**

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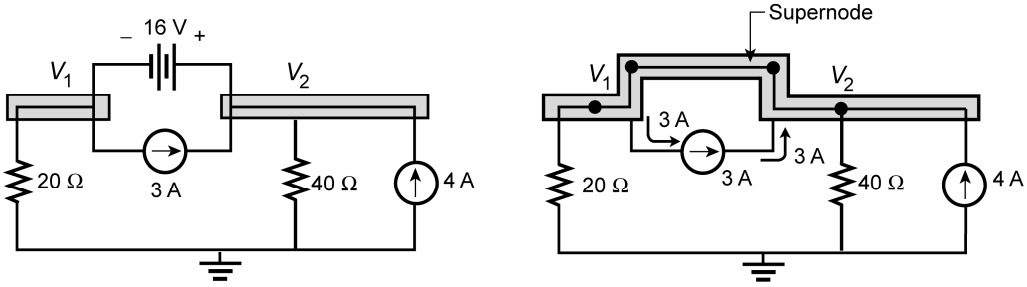
b.



$$\Sigma I_i = \Sigma I_o$$

Supernode:

$$3\text{ A} + 4\text{ A} = 3\text{ A} + \frac{V_1}{20\,\Omega} + \frac{V_2}{40\,\Omega}$$

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 $V_1 =$ **48 V**

$V_2 = 16\text{ V} + V_1 =$ **64 V**

---

41. a. V_1 V_2

$$V_1\left[\frac{1}{2} + \frac{1}{5} + \frac{1}{2}\right] - \frac{1}{2}V_2 = 5$$

$$V_2\left[\frac{1}{2} + \frac{1}{4}\right] - \frac{1}{2}V_1 = 3$$

$V_1 =$ **8.08 V**, $V_2 =$ **9.39 V**

Symmetry present

b. V_1 V_2

$$V_1\left[\frac{1}{2} + \frac{1}{4}\right] - \frac{1}{4}V_2 = 4 - 2$$

$$V_2\left[\frac{1}{4} + \frac{1}{20} + \frac{1}{5}\right] - \frac{1}{4}V_1 = 2$$

$V_1 =$ **4.8 V**, $V_2 =$ **6.4 V**

Symmetry present

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42. (I): a. Note the solution to problem 36(I).

b. $V_1 = \mathbf{-14.86\ V}$, $V_2 = \mathbf{-12.57\ V}$

c. $V_{R_1} = V_{R_4} = V_1 = \mathbf{-14.86\ V}$, $V_{R_2} = V_2 = \mathbf{-12.57\ V}$

$+V_{R_3}-$ across 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. $V_1 = \mathbf{-2.56\ V}$, $V_2 = \mathbf{4.03\ V}$

c. $V_{R_1} = V_1 = \mathbf{-2.56\ V}$, $V_{R_2} = V_{R_5} = V_2 = \mathbf{4.03\ V}$

(+) (–)

$V_{R_3} = V_{R_4} = V_2 - V_1 = \mathbf{6.59\ V}$

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. $V_1 = \mathbf{7.24\ V}$, $V_2 = \mathbf{-2.45\ V}$, $V_3 = \mathbf{1.41\ V}$

c. R_1 V_{R_1} (–, +) $= 15\ \text{V} - 7.24\ \text{V} = \mathbf{7.76\ V}$

$V_{R_2} = V_2 = \mathbf{-2.45\ V}$, $V_{R_3} = V_3 = \mathbf{1.41\ V}$

(+) (–)

$V_{R_4} = V_3 - V_2 = 1.41\ \text{V} - (-2.45\ \text{V}) = \mathbf{3.86\ V}$

$V_{R_5} = V_1 - V_2 = 7.24\ \text{V} - (-2.45\ \text{V}) = \mathbf{9.69\ V}$

$V_{R_6} = V_1 - V_3 = 7.24\ \text{V} - 1.41\ \text{V} = \mathbf{5.83\ V}$

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(II): a. Source conversion: $I = 4$ A, $R = 4\ \Omega$

$$V_1\left[\frac{1}{9}+\frac{1}{20}+\frac{1}{20}\right]-\frac{1}{20}V_2-\frac{1}{20}V_3=-2$$

$$V_2\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{18}\right]-\frac{1}{20}V_1-\frac{1}{20}V_3=0$$

$$V_3\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{4}\right]-\frac{1}{20}V_2-\frac{1}{20}V_1=4$$

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 $\overset{-}{V_{R_2}}\ {}^{+}$ $= 16\ \text{V} - 10.66\ \text{V} = \mathbf{5.34\ V}$

$V_{R_3} = V_2 = \mathbf{1.29\ V}$, $V_{R_4} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = 1.29\ \text{V} - (-6.64\ \text{V}) = \mathbf{7.93\ V}$

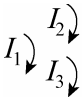
$V_{R_5} = \overset{(+)}{V_3} - \overset{(-)}{V_2} = 10.66\ \text{V} - 1.29\ \text{V} = \mathbf{9.37\ V}$

$V_{R_6} = \overset{(+)}{V_3} - \overset{(-)}{V_1} = 10.66\ \text{V} - (-6.64\ \text{V}) = \mathbf{17.30\ V}$

44. a. Note the solution to problem 39(I).
$V_1 = \mathbf{-5.31\ V}$, $V_2 = \mathbf{-0.62\ V}$, $V_3 = \mathbf{3.75\ V}$
$V_{5A} = V_1 = \mathbf{-5.31\ V}$

b. Note the solution to problem 39(II).
$V_1 = \mathbf{-6.92\ V}$, $V_2 = \mathbf{12\ V}$, $V_3 = \mathbf{2.3\ V}$
$V_{2A} = \overset{(+)}{V_2} - \overset{(-)}{V_3} = \mathbf{9.7\ V}$, $V_{5A} = \overset{(+)}{V_2} - \overset{(-)}{V_1} = \mathbf{18.92\ V}$

45. a.



$$I_1(6 + 5 + 10) - 5I_2 - 10I_3 = 6$$
$$I_2(5 + 5 + 5) - 5I_1 - 5I_3 = 0$$
$$I_3(5 + 10 + 20) - 10I_1 - 5I_2 = 0$$

$I_1 = \mathbf{0.39\ A}$, $I_2 = \mathbf{0.18\ A}$, $I_3 = \mathbf{0.14\ A}$

b. $I_5 = I_2 - I_3 = \mathbf{40\ mA}$ (direction of I_2)

c, d. no

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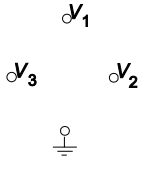
46. Source conversion: $I = 1$ A, $R = 6\ \Omega$



$$\left[\frac{1}{6}+\frac{1}{5}+\frac{1}{5}\right]V_1-\frac{1}{5}V_2-\frac{1}{5}V_3=1$$

$$\left[\frac{1}{5}+\frac{1}{5}+\frac{1}{20}\right]V_2-\frac{1}{5}V_1-\frac{1}{5}V_3=0$$

$$\left[\frac{1}{5}+\frac{1}{5}+\frac{1}{10}\right]V_3-\frac{1}{5}V_1-\frac{1}{5}V_2=0$$

V_{R_5} = **196.70 mV**, **no**

47. a.



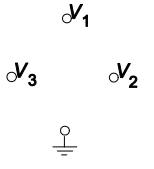
$$I_1(2\ \text{k}\Omega + 33\ \text{k}\Omega + 3.3\ \text{k}\Omega) - 33\ \text{k}\Omega\, I_2 - 3.3\ \text{k}\Omega\, I_3 = 24$$
$$I_2(33\ \text{k}\Omega + 56\ \text{k}\Omega + 36\ \text{k}\Omega) - 33\ \text{k}\Omega\, I_1 - 36\ \text{k}\Omega\, I_3 = 0$$
$$I_3(3.3\ \text{k}\Omega + 36\ \text{k}\Omega + 5.6\ \text{k}\Omega) - 36\ \text{k}\Omega\, I_2 - 3.3\ \text{k}\Omega\, I_1 = 0$$

I_1 = **0.97 mA**, $I_2 = I_3$ = **0.36 mA**

b. $I_5 = I_2 - I_3 = 0.36\ \text{mA} - 0.36\ \text{mA} =$ **0**

c, d. yes

48. Source conversion: $I = 12$ A, $R = 2\ \text{k}\Omega$



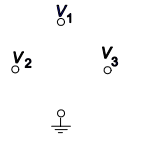
$$\left[\frac{1}{2\ \text{k}\Omega}+\frac{1}{33\ \text{k}\Omega}+\frac{1}{56\ \text{k}\Omega}\right]V_1-\frac{1}{56\ \text{k}\Omega}V_2-\frac{1}{33\ \text{k}\Omega}V_3=12$$

$$\left[\frac{1}{56\ \text{k}\Omega}+\frac{1}{36\ \text{k}\Omega}+\frac{1}{5.6\ \text{k}\Omega}\right]V_2-\frac{1}{56\ \text{k}\Omega}V_1-\frac{1}{36\ \text{k}\Omega}V_3=0$$

$$\left[\frac{1}{33\ \text{k}\Omega}+\frac{1}{3.3\ \text{k}\Omega}+\frac{1}{36\ \text{k}\Omega}\right]V_3-\frac{1}{33\ \text{k}\Omega}V_1-\frac{1}{36\ \text{k}\Omega}V_2=0$$

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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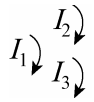
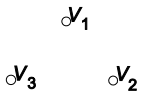
50. a.



$$(1\ \text{k}\Omega + 2\ \text{k}\Omega + 2\ \text{k}\Omega)I_1 - 2\ \text{k}\Omega\, I_2 - 2\ \text{k}\Omega\, I_3 = 10$$
$$(2\ \text{k}\Omega + 2\ \text{k}\Omega + 2\ \text{k}\Omega)I_2 - 2\ \text{k}\Omega\, I_1 - 2\ \text{k}\Omega\, I_3 = 0$$
$$(2\ \text{k}\Omega + 2\ \text{k}\Omega + 2\ \text{k}\Omega)I_3 - 2\ \text{k}\Omega\, I_1 - 2\ \text{k}\Omega\, I_2 = 0$$

$$I_1 = I_{10\text{V}} = \mathbf{3.33\ mA}$$

Source conversion: $I = 10\ \text{V}/1\ \text{k}\Omega = 10\ \text{mA}$, $R = 1\ \text{k}\Omega$

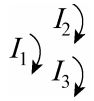


$$V_1\left[\frac{1}{1\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}\right]-\frac{1}{2\,\text{k}\Omega}V_2-\frac{1}{2\,\text{k}\Omega}V_3=10\ \text{mA}$$
$$V_2\left[\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}\right]-\frac{1}{2\,\text{k}\Omega}V_1-\frac{1}{2\,\text{k}\Omega}V_3=0$$
$$V_3\left[\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}+\frac{1}{2\,\text{k}\Omega}\right]-\frac{1}{2\,\text{k}\Omega}V_2-\frac{1}{2\,\text{k}\Omega}V_1=0$$

$V_1 = 6.67\ \text{V} = E - IR_s = 10\ \text{V} - I(1\ \text{k}\Omega)$

$$I = \frac{10 - 6.67\ \text{V}}{1\,\text{k}\Omega} = \mathbf{3.33\ mA}$$

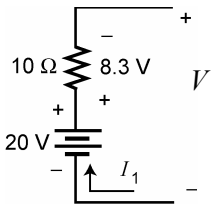
b.



Source conversion: $E = 20\ \text{V}$, $R = 10\ \Omega$

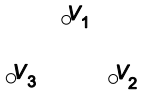
$$(10 + 10 + 20)I_1 - 10I_2 - 20I_3 = 20$$
$$(10 + 20 + 20)I_2 - 10I_1 - 20I_3 = 0$$
$$(20 + 20 + 10)I_3 - 20I_1 - 20I_2 = 0$$

$I_1 = I_{20\text{V}} = 0.83\ \text{A}$



$$V = 20\ \text{V} - 8.3\ \text{V}$$
$$= 11.7\ \text{V}$$

$$I_s = \frac{V}{R_s} = \frac{11.70\ \text{V}}{10\,\Omega} = \mathbf{1.17A}$$



$$V_1\left[\frac{1}{10}+\frac{1}{10}+\frac{1}{20}\right]-\left[\frac{1}{20}\right]V_2-\left[\frac{1}{10}\right]V_3=2$$
$$V_2\left[\frac{1}{20}+\frac{1}{20}+\frac{1}{10}\right]-\left[\frac{1}{20}\right]V_1-\left[\frac{1}{20}\right]V_3=0$$
$$V_3\left[\frac{1}{10}+\frac{1}{20}+\frac{1}{20}\right]-\left[\frac{1}{10}\right]V_1-\left[\frac{1}{20}\right]V_2=0$$

$$I_{R_s} = \frac{V_1}{R_s} = \mathbf{1.17\ A}$$

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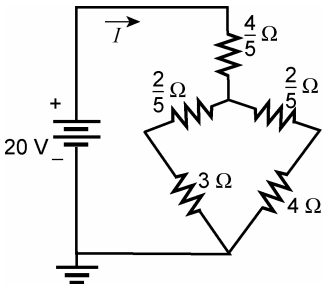
51. a.

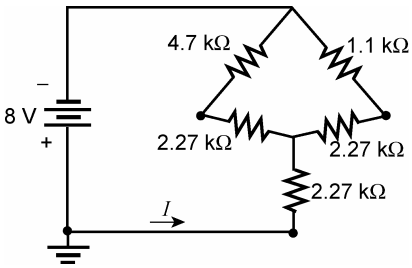


$$I = \frac{20\ \text{V}}{\frac{4}{5}\Omega + \left[\frac{2}{5}\Omega + 3\,\Omega\right] \| \left[\frac{2}{5}\Omega + 4\,\Omega\right]}$$

$$= \frac{20\ \text{V}}{\frac{4}{5}\Omega + (3.14\,\Omega) \| (4.4\,\Omega)}$$

$$= \mathbf{7.36\ A}$$

b.



$R_T = 2.27\ \text{k}\Omega + [4.7\ \text{k}\Omega + 2.27\ \text{k}\Omega] \| [1.1\ \text{k}\Omega + 2.27\ \text{k}\Omega]$

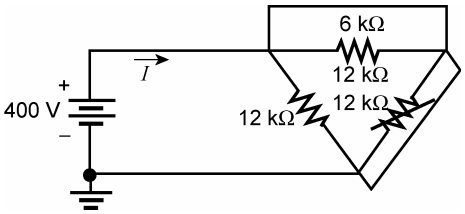
$= 2.27\ \text{k}\Omega + [6.97\ \text{k}\Omega] \| [3.37\ \text{k}\Omega]$

$= 2.27\ \text{k}\Omega + 2.27\ \text{k}\Omega$

$= 4.54\ \text{k}\Omega$

$$I = \frac{8\ \text{V}}{4.54\ \text{k}\Omega} = \mathbf{1.76\ mA}$$

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)

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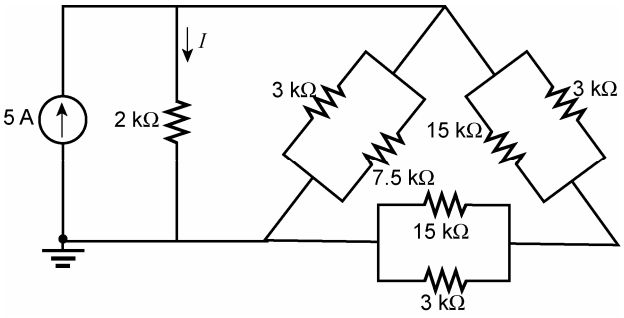
53.

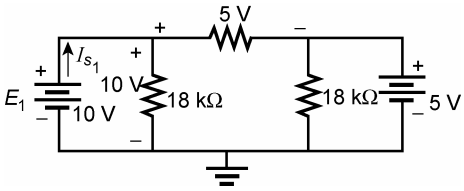


$3\ \text{k}\Omega \parallel 7.5\ \text{k}\Omega = 2.14\ \text{k}\Omega$
$3\ \text{k}\Omega \parallel 15\ \text{k}\Omega = 2.5\ \text{k}\Omega$

$R'_T = 2.14\ \text{k}\Omega \parallel (2.5\ \text{k}\Omega + 2.5\ \text{k}\Omega) = 1.5\ \text{k}\Omega$

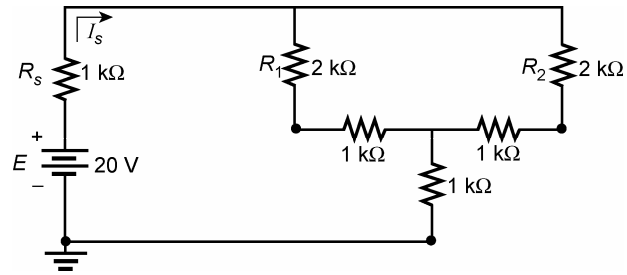
CDR: $I = \dfrac{(1.5\ \text{k}\Omega)(5\ \text{A})}{1.5\ \text{k}\Omega + 2\ \text{k}\Omega} = \mathbf{2.14\ A}$

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.

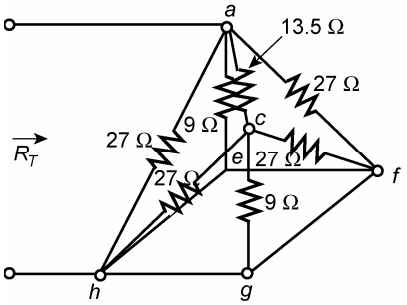


$R' = R_1 + 1\ \text{k}\Omega = 3\ \text{k}\Omega$
$R'' = R_2 + 1\ \text{k}\Omega = 3\ \text{k}\Omega$
$R'_T = \dfrac{3\ \text{k}\Omega}{2} = 1.5\ \text{k}\Omega$

$R_T = 1\ \text{k}\Omega + 1.5\ \text{k}\Omega + 1\ \text{k}\Omega = 3.5\ \text{k}\Omega$

$$I_s = \frac{E}{R_T} = \frac{20\ \text{V}}{3.5\ \text{k}\Omega} = \mathbf{5.71\ mA}$$

56.



c – g: $27\ \Omega \parallel 9\ \Omega \parallel 27\ \Omega = 5.4\ \Omega$

a – h: $27\ \Omega \parallel 9\ \Omega \parallel 27\ \Omega = 5.4\ \Omega$

$R_T = 5.4\ \Omega \parallel (13.5\ \Omega + 5.4\ \Omega)$
$= 5.4\ \Omega \parallel 18.9\Omega$
$= \mathbf{4.2\ \Omega}$

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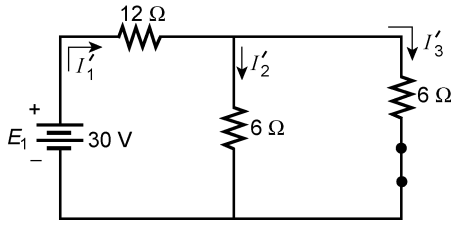
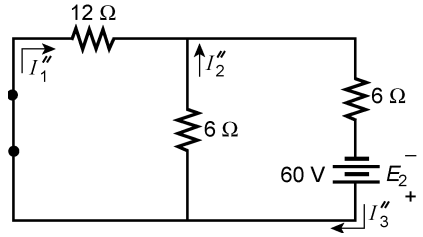
Chapter 9

1. a. E_1:



E_2:



$$I'_1 = \frac{30\text{ V}}{12\,\Omega + 6\,\Omega \,||\, 6\,\Omega} = \frac{30\text{ V}}{12\,\Omega + 3\,\Omega} = 2\text{ A}$$

$$I'_2 = I'_3 = \frac{I'_1}{2} = 1\text{ A}$$

$$I''_3 = \frac{60\text{ V}}{6\,\Omega + 6\,\Omega \,||\, 12\,\Omega} = \frac{60\text{ V}}{6\,\Omega + 4\,\Omega} = 6\text{ A}$$

$$I''_1 = \frac{6\,\Omega(I''_3)}{6\,\Omega + 12\,\Omega} = 2\text{ A}$$

$$I''_2 = \frac{12\,\Omega(I''_3)}{12\,\Omega + 6\,\Omega} = 4\text{ A}$$

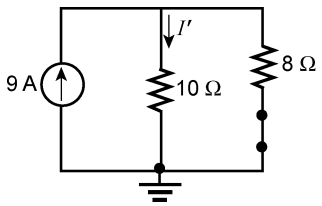
$I_1 = I'_1 + I''_1 = 2\text{ A} + 2\text{ A} = \mathbf{4\ A}$ (dir. of I'_1)
$I_2 = I''_2 - I'_2 = 4\text{ A} - 1\text{ A} = \mathbf{3\ A}$ (dir. of I''_2)
$I_3 = I'_3 + I''_3 = 1\text{ A} + 6\text{ A} = \mathbf{7\ A}$ (dir. of I'_3)

b. E_1: $P'_1 = I'^2_1 R_1 = (2\text{ A})^2\ 12\ \Omega = \mathbf{48\ W}$
E_2: $P''_1 = I''^2_1 R_1 \text{I''} R_1 = (2\text{ A})^2\ 12\ \Omega = \mathbf{48\ W}$

c. $P_1 = I_1^2 R_1 = (4\text{ A})^2\ 12\ \Omega = \mathbf{192\ W}$

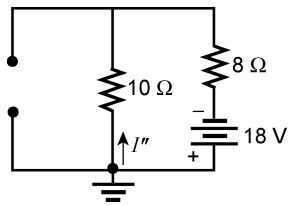
d. $P'_1 + P''_1 = 48\text{ W} + 48\text{ W} = 96\text{ W} \neq 192\text{ W} = P_1$

2. I:



$$I' = \frac{8\,\Omega(9\text{ A})}{8\,\Omega + 10\,\Omega} = 4\text{ A}$$

E:



$$I'' = \frac{18\text{ V}}{10\,\Omega + 8\,\Omega} = 1\text{ A}$$

$I = I' - I'' = 4\text{ A} - 1\text{ A} = \mathbf{3\ A\ (dir\ of\ } \boldsymbol{I'}\mathbf{)}$

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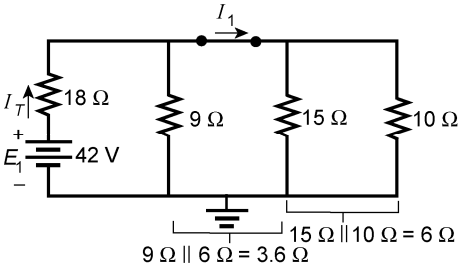
3.

E_1:

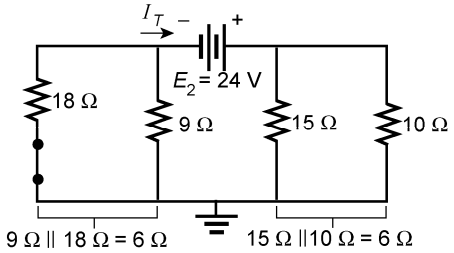


$$I_T = \frac{42\text{ V}}{18\,\Omega + 3.6\,\Omega} = 1.944\text{ A}$$

$$I_1 = \frac{9\,\Omega(I_T)}{9\,\Omega + 6\,\Omega} = \frac{9\,\Omega(1.944\text{ A})}{15\,\Omega}$$

$$= 1.17\text{ A}$$

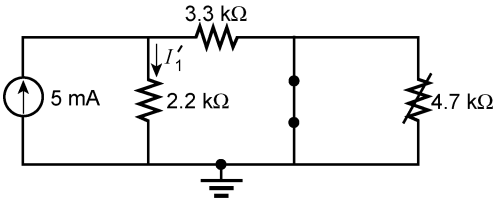
E_2:



$$I_T = \frac{E_2}{R_T} = \frac{24\text{ V}}{12\,\Omega} = 2\text{ A}$$

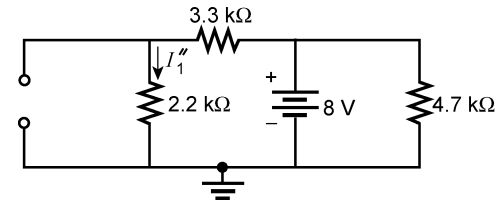
$I_{24V} = I_T + I_1 = 2\text{ A} + 1.17\text{ A} =$ **3.17 A (dir. of I_1)**

4.



$$I'_1 = \frac{3.3\,\text{k}\Omega(5\text{ mA})}{2.2\,\text{k}\Omega + 3.3\,\text{k}\Omega} = \frac{16.5\text{ mA}}{5.5}$$

$$= 3\text{ mA}$$

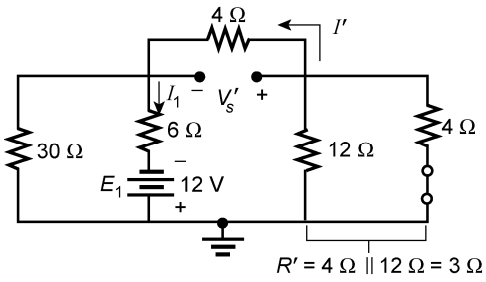


$$I''_1 = \frac{8\text{ V}}{3.3\,\text{k}\Omega + 2.2\,\text{k}\Omega} = \frac{8\text{ V}}{5.5\,\text{k}\Omega}$$

$$= 1.45\text{ mA}$$

$I_1 = I'_1 + I''_1 = 3\text{ mA} + 1.45\text{ mA} =$ **4.45 mA**

5. E_1:



$$I_1 = \frac{E_1}{R_T} = \frac{12\text{ V}}{6\,\Omega + 5.88\,\Omega} = 1.03\text{ A}$$

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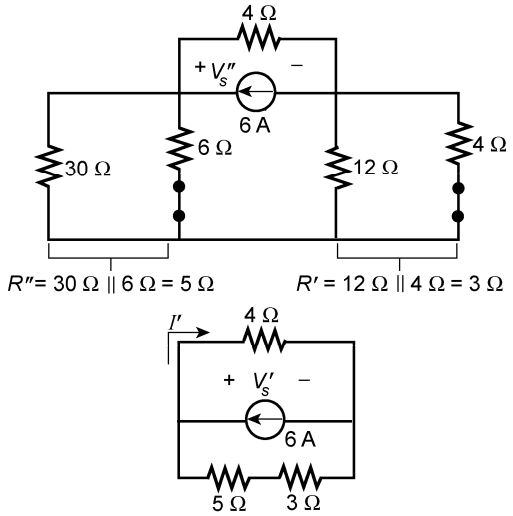
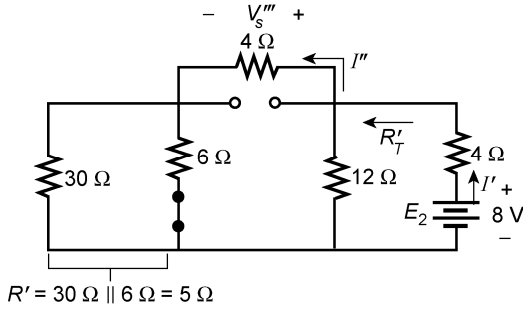
$$I' = \frac{30\ \Omega(I_1)}{30\ \Omega + 7\ \Omega} = \frac{30\ \Omega(1.03\ \text{A})}{37\ \Omega}$$
$$= 835.14\ \text{mA}$$
$$V_s' = I'(4\ \Omega) = (835.14\ \text{mA})(4\ \Omega)$$
$$= 3.34\ \text{V}$$

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:



$$R'_T = 12\ \Omega \parallel (4\ \Omega + 5\ \Omega) = 12\ \Omega \parallel 9\ \Omega = 5.14\ \Omega$$
$$I' = \frac{E_2}{R_T} = \frac{8\ \text{V}}{4\ \Omega + 5.14\ \Omega} = 0.875\ \text{A}$$
$$I'' = \frac{12\ \Omega(I')}{12\ \Omega + 9\ \Omega} = \frac{12\ \Omega(0.875\ \text{A})}{21\ \Omega} = 0.5\ \text{A}$$
$$V_s''' = I''(4\ \Omega) = 0.5\ \text{A}(4\ \Omega) = 2\ \text{V}$$
$$V_s = V_s'' - V_s' - V_s''' = 16\ \text{V} - 3.34\ \text{V} - 2\ \text{V} = \mathbf{10.66\ V}$$

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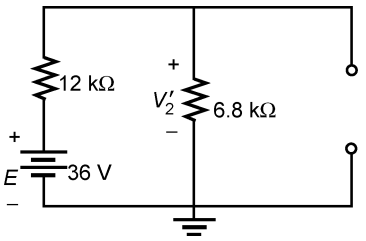
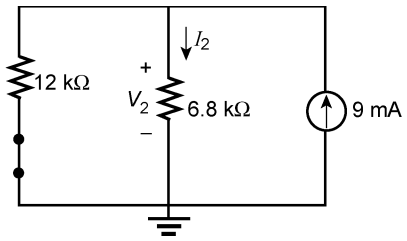
6. *E*:



$$V'_2 = \frac{6.8\,\text{k}\Omega(36\,\text{V})}{6.8\,\text{k}\Omega + 12\,\text{k}\Omega} = 13.02\ \text{V}$$

I:



$$I_2 = \frac{12\,\text{k}\Omega(9\,\text{mA})}{12\,\text{k}\Omega + 6.8\,\text{k}\Omega} = 5.75\ \text{mA}$$

$V_2'' = I_2 R_2 = (5.75\ \text{mA})(6.8\ \text{k}\Omega) = 39.10\ \text{V}$

$V_2 = V_2' + V_2'' = 13.02\ \text{V} + 39.10\ \text{V} = \mathbf{52.12\ V}$

7. a. $R_{Th} = R_3 + R_1 \,||\, R_2 = 4\ \Omega + 6\ \Omega \,||\, 3\ \Omega = 4\ \Omega + 2\ \Omega = \mathbf{6\ \Omega}$

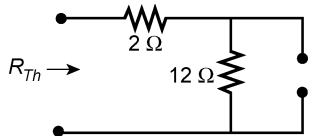
$$E_{Th} = \frac{R_2 E}{R_2 + R_1} = \frac{3\,\Omega(18\,\text{V})}{3\,\Omega + 6\,\Omega} = 6\ \text{V}$$

b. $$I_1 = \frac{E_{Th}}{R_{Th} + R} = \frac{6\ \text{V}}{6\,\Omega + 2\,\Omega} = \mathbf{0.75\ A}$$

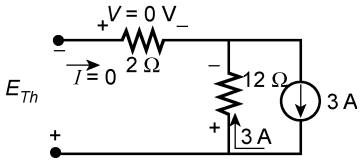
$$I_2 = \frac{6\ \text{V}}{6\,\Omega + 30\,\Omega} = \mathbf{166.67\ mA}$$

$$I_3 = \frac{6\ \text{V}}{6\,\Omega + 100\,\Omega} = \mathbf{56.60\ mA}$$

8. a.



$R_{Th} = 2\ \Omega + 12\ \Omega = \mathbf{14\ \Omega}$



$E_{Th} = IR = (3\ \text{A})(12\ \Omega) = \mathbf{36\ V}$

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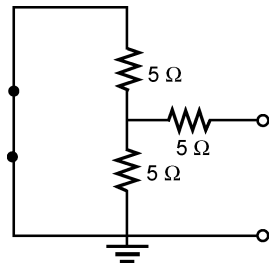
b. $R = 2\ \Omega$: $P = \left(\dfrac{E_{Th}}{R_{Th}+R}\right)^2 R = \left(\dfrac{36\ \text{V}}{14\ \Omega + 2\ \Omega}\right)^2 2\ \Omega = \mathbf{10.13\ W}$

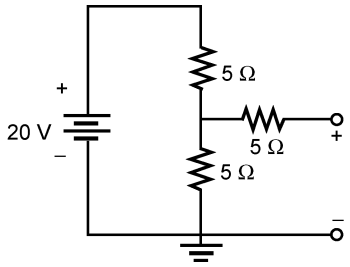
$R = 100\ \Omega$: $P = \left(\dfrac{36\ \text{V}}{14\ \Omega + 100\ \Omega}\right)^2 100\ \Omega = \mathbf{9.97\ W}$

9. a. R_{Th}:



$\leftarrow R_{Th} = 5\ \Omega + 5\ \Omega \parallel 5\ \Omega = \mathbf{7.5\ \Omega}$

E_{Th}:

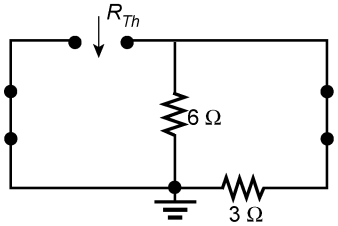


$E_{Th} = \dfrac{20\ \text{V}}{2} = \mathbf{10\ V}$

b. $R = 2\ \Omega$: $P = \left(\dfrac{E_{Th}}{R_{Th}+R}\right)^2 R = \left(\dfrac{10\ \text{V}}{7.5\ \Omega + 2\ \Omega}\right)^2 2\ \Omega = \mathbf{2.22\ W}$

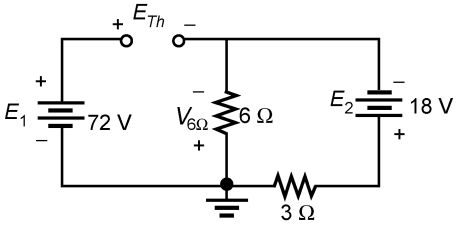
$R = 100\ \Omega$: $P = \left(\dfrac{10\ \text{V}}{7.5\ \Omega + 100\ \Omega}\right)^2 100\ \Omega = \mathbf{0.87\ W}$

10. R_{Th}:



$R_{Th} = 6\ \Omega \parallel 3\ \Omega = \mathbf{2\ \Omega}$

E_{Th}:



$V_{6\Omega} = \dfrac{6\ \Omega(18\ \text{V})}{6\ \Omega + 3\ \Omega} = 12\ \text{V}$

$E_{Th} = 72\ \text{V} + 12\ \text{V} = \mathbf{84\ V}$

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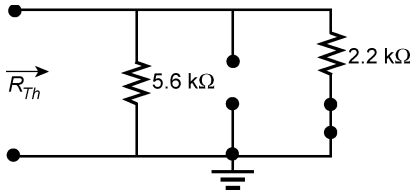
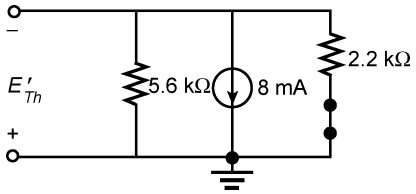
11. R_{Th}:



$R_{Th} = 5.6\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega = \mathbf{1.58\ k\Omega}$

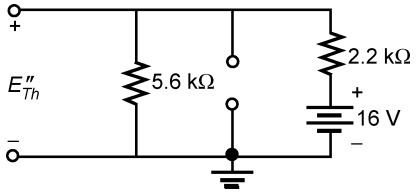
E_{Th}: Superposition:

I:



$E'_{Th} = IR_T$
$= 8\ \text{mA}(5.6\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega)$
$= 8\ \text{mA}(1.579\ \text{k}\Omega)$
$= 12.64\ \text{V}$

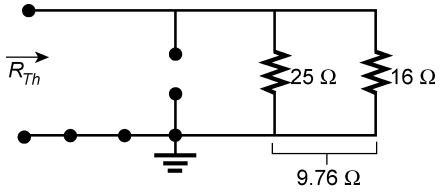
E:



$$E''_{Th} = \frac{5.6\ \text{k}\Omega(16\ \text{V})}{5.6\ \text{k}\Omega + 2.2\ \text{k}\Omega} = 11.49\ \text{V}$$

$E_{Th} = 11.49\ \text{V} - 12.64\ \text{V} = \mathbf{-1.15\ V}$

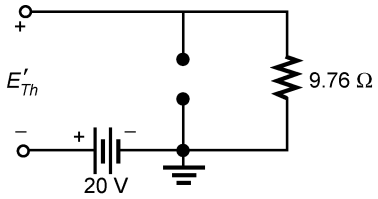
12. a. R_{Th}:



$R_{Th} = 25\ \Omega \parallel 16\ \Omega = \mathbf{9.76\ \Omega}$

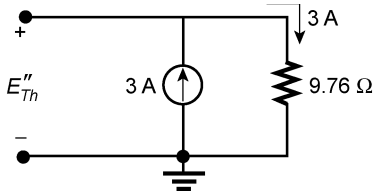
E_{Th}: Superposition:

E:



$E'_{Th} = -20\ \text{V}$

I:



$E''_{Th} = (3\ \text{A})(9.76\ \Omega) = 29.28\ \text{V}$

$E_{Th} = E''_{Th} - E'_{Th} = 29.28\ \text{V} - 20\ \text{V} = \mathbf{9.28\ V}$

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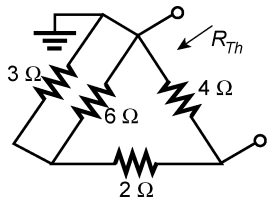
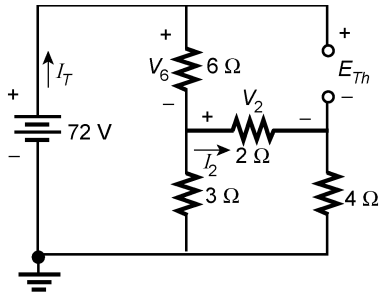
b. R_{Th}:



$R_{Th} = 4\ \Omega \,||\, (2\ \Omega + 6\ \Omega \,||\, 3\ \Omega) = \mathbf{2\ \Omega}$

E_{Th}:

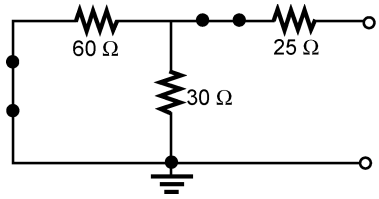


$$I_T = \frac{72\ \text{V}}{6\ \Omega + 3\ \Omega \,||\, (2\ \Omega + 4\ \Omega)} = 9\ \text{A}$$

$$I_2 = \frac{3\ \Omega(I_T)}{3\ \Omega + 6\ \Omega} = \frac{3\ \Omega(9\ \text{A})}{9\ \Omega} = 3\ \text{A}$$

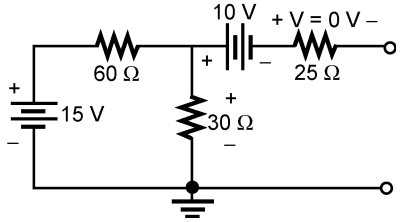
$E_{Th} = V_6 + V_2 = (I_T)(6\ \Omega) + I_2(2\ \Omega)$
$= (9\ \text{A})(6\ \Omega) + (3\ \text{A})(2\ \Omega) = \mathbf{60\ V}$

13. (I): R_{Th}:



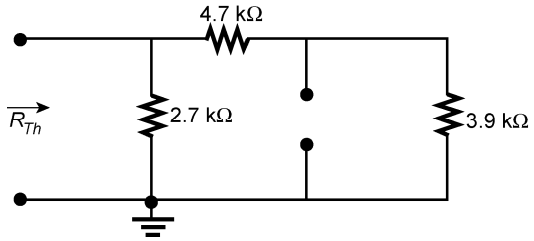
$\leftarrow R_{Th} = 25\ \Omega + 60\ \Omega \,||\, 30\ \Omega = \mathbf{45\ \Omega}$

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}:



$R_{Th} = 2.7\ \text{k}\Omega \,||\, (4.7\ \text{k}\Omega + 3.9\ \text{k}\Omega) = 2.7\ \text{k}\Omega \,||\, 8.6\ \text{k}\Omega = \mathbf{2.06\ k\Omega}$

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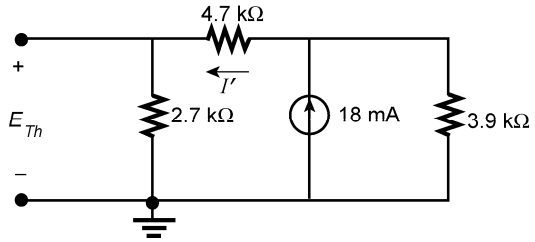
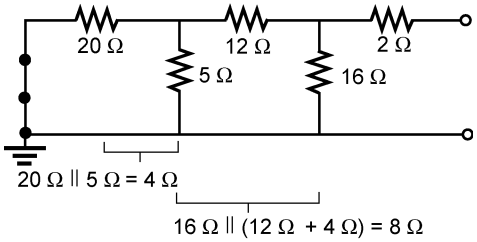
E_{Th}:



$$I' = \frac{3.9\,\text{k}\Omega(18\text{ mA})}{3.9\,\text{k}\Omega + 7.4\,\text{k}\Omega} = 6.21\text{ mA}$$

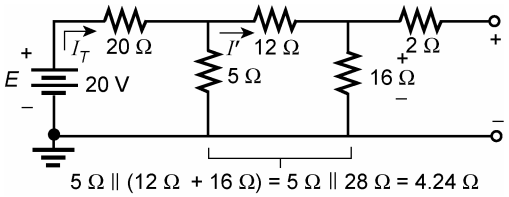
$E_{Th} = I'(2.7\text{ k}\Omega) = (6.21\text{ mA})(2.7\text{ k}\Omega) = \mathbf{16.77\text{ V}}$

14. (I): R_{Th}:



$\leftarrow R_{Th} = 2\ \Omega + 8\ \Omega = \mathbf{10\ \Omega}$

E_{Th}:



$E_{Th} = V_{16\Omega}$

$$I_T = \frac{20\text{ V}}{20\,\Omega + 4.24\,\Omega} = 825.08\text{ mA}$$

$$I' = \frac{5\,\Omega(I_T)}{5\,\Omega + 28\,\Omega} = \frac{5\,\Omega(825.08\text{ mA})}{33\,\Omega} = 125.01\text{ mA}$$

$E_{Th} = V_{16\Omega} = (I')(16\ \Omega) = (125.01\text{ mA})(16\ \Omega) = \mathbf{2\text{ V}}$

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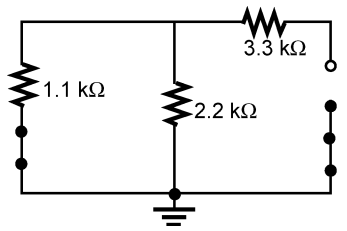
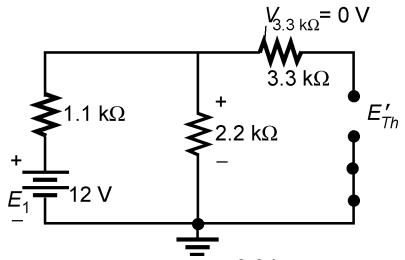
(II): R_{Th}:



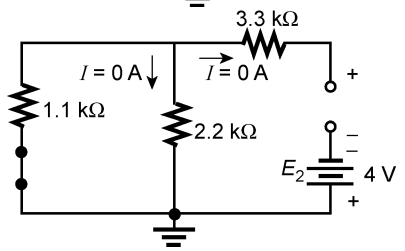
$\leftarrow R_{Th} = 3.\ 3\ \text{k}\Omega + 2.2\ \text{k}\Omega \parallel 1.1\ \text{k}\Omega$
$= 3.3\ \text{k}\Omega + 0.73\ \text{k}\Omega$
$= \mathbf{4.03\ k\Omega}$

E_{Th}: Superposition:

E_1:



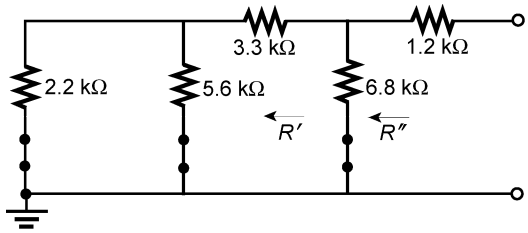
$E'_{Th} = V_{2.2\text{k}\Omega} = \dfrac{2.2\ \text{k}\Omega(12\ \text{V})}{2.2\ \text{k}\Omega + 1.1\ \text{k}\Omega}$
$= 8\ \text{V}$



$E''_{Th} = E_2 = 4\ \text{V}$

$E_{Th} = E'_{Th} + E''_{Th} = 8\ \text{V} + 4\ \text{V} = \mathbf{12\ V}$

15. R_{Th}:



$\leftarrow R_{Th} = 2.2\ \text{k}\Omega \parallel 5.6\ \text{k}\Omega = 1.58\ \text{k}\Omega$
$R' = 1.58\ \text{k}\Omega + 3.3\ \text{k}\Omega$
$= 4.88\ \text{k}\Omega$

$R'' = 4.88\ \text{k}\Omega \parallel 6.8\ \text{k}\Omega = 2.84\ \text{k}\Omega$
$R_{Th} = 1.2\ \text{k}\Omega + R'' = 1.2\ \text{k}\Omega + 2.84\ \text{k}\Omega = \mathbf{4.04\ k\Omega}$

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: $I'_T = I_1 - I_2 = 10\ \text{mA} - 2.14\ \text{mA} = 7.86\ \text{mA}$

$$2.2\ \text{k}\Omega \parallel 5.6\ \text{k}\Omega = 1.58\ \text{k}\Omega$$

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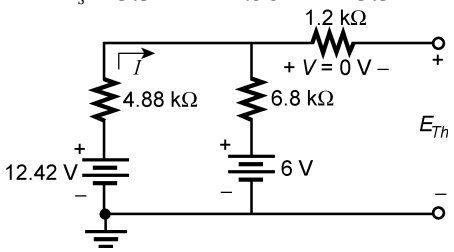
Source conversion:

$E = (7.86\text{ mA})(1.58\text{ k}\Omega) = 12.42\text{ V}$

$R' = R_s + 3.3\text{ k}\Omega = 1.58\text{ k}\Omega + 3.3\text{ k}\Omega = 4.88\text{ k}\Omega$

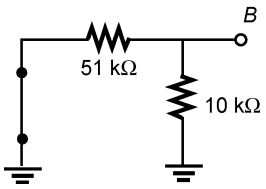


$$I = \frac{12.42\text{ V} - 6\text{ V}}{4.88\text{ k}\Omega + 6.8\text{ k}\Omega} = \frac{6.42\text{ V}}{11.68\text{ k}\Omega} = 549.66\ \mu\text{A}$$

$$V_{6.8\text{k}\Omega} = I(6.8\text{ k}\Omega) = (549.66\ \mu\text{A})(6.8\text{ k}\Omega) = 3.74\text{ V}$$

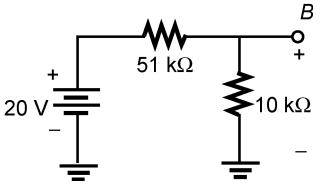
$$E_{Th} = 6\text{ V} + V_{6.8\text{k}\Omega} = 6\text{ V} + 3.74\text{ V} = \mathbf{9.74\text{ V}}$$

16. a. R_{Th}:



$\leftarrow R_{Th} = 51\text{ k}\Omega \parallel 10\text{ k}\Omega = \mathbf{8.36\text{ k}\Omega}$

E_{Th}:



$$E_{Th} = \frac{10\text{ k}\Omega(20\text{ V})}{10\text{ k}\Omega + 51\text{ k}\Omega} = 3.28\text{ V}$$

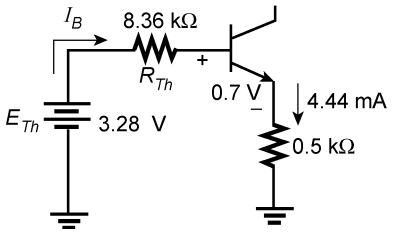
b. $I_E R_E + V_{CE} + I_C R_C = 20\text{ V}$

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.



$E_{Th} - I_B R_{Th} - V_{BE} - V_E = 0$

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$$\text{and } I_B = \frac{E_{Th} - V_{BE} - V_E}{R_{Th}} = \frac{3.28\text{ V} - 0.7\text{ V} - (4.44\text{ mA})(0.5\text{ k}\Omega)}{8.36\text{ k}\Omega}$$

$$= \frac{2.58\text{ V} - 2.22\text{ V}}{8.36\text{ k}\Omega} = \frac{0.36\text{ V}}{8.36\text{ k}\Omega} = \mathbf{43.06\ \mu A}$$

d. $V_C = 20\text{ V} - I_C R_C = 20\text{ V} - (4.44\text{ mA})(2.2\text{ k}\Omega)$
$= 20\text{ V} - 9.77\text{ V}$
$= \mathbf{10.23\text{ V}}$

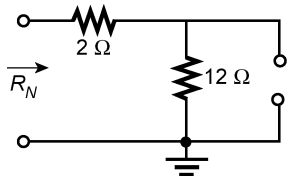
17. a. $E_{Th} = \mathbf{20\text{ V}}$

$$I = 1.6\text{ mA} = \frac{E_{Th}}{R_{Th}} = \frac{20\text{ V}}{R_{Th}}, R_{Th} = \frac{20\text{ V}}{1.6\text{ mA}} = \mathbf{12.5\ k\Omega}$$

b. $E_{Th} = \mathbf{60\text{ mV}}$, $R_{Th} = \mathbf{2.72\ k\Omega}$

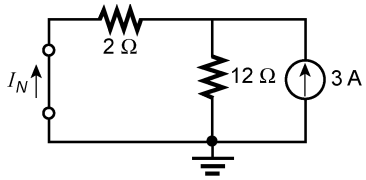
c. $E_{Th} = \mathbf{16\text{ V}}$, $R_{Th} = \mathbf{2.2\ k\Omega}$

18. R_N:



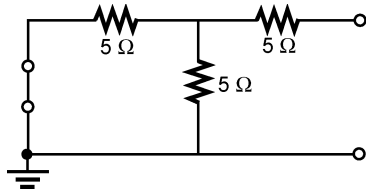
$$R_N = 2\ \Omega + 12\ \Omega = \mathbf{14\ \Omega}$$

I_N:



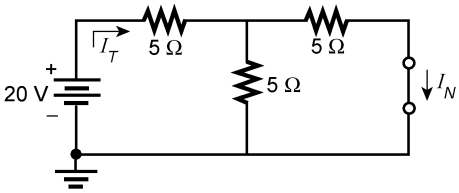
$$I_N = \frac{12\ \Omega(3\text{ A})}{12\ \Omega + 2\ \Omega} = 2.57\text{ A}$$

19. a. R_N:



$$\leftarrow R_N = 5\ \Omega + \frac{5\ \Omega}{2} = \mathbf{7.5\ \Omega}$$

I_N:



$$I_T = \frac{20\text{ V}}{5\ \Omega + \frac{5\ \Omega}{2}} = 2.67\text{ A}$$

$$I_N = \frac{I_T}{2} = \mathbf{1.34\text{ A}}$$

b. $E_{Th} = I_N R_N = (1.34\text{ A})(7.5\ \Omega) = 10.05\text{ V} \cong \mathbf{10\text{ V}}$, $R_{Th} = R_N = \mathbf{7.5\ \Omega}$

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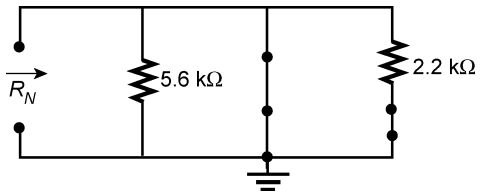
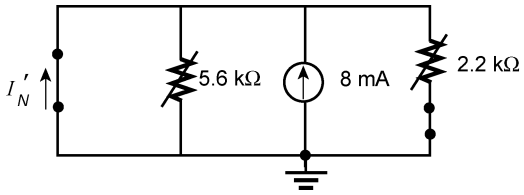
20. R_N:



$R_N = 5.6\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega = \mathbf{1.58\ k\Omega}$

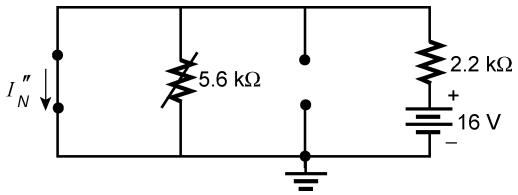
I_N:

I:



$I'_N = 8\ \text{mA}$

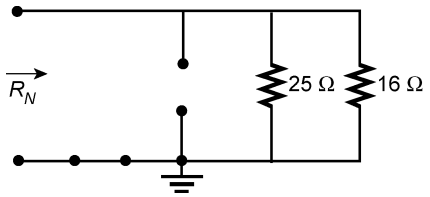
E:



$$I''_N = \frac{16\ \text{V}}{2.2\ \text{k}\Omega} = 7.27\ \text{mA}$$

$I_N\uparrow = 8\ \text{mA} - 7.27\ \text{mA} = \mathbf{0.73\ mA}$

21. (I): (a)



$R_N = 25\ \Omega \parallel 16\ \Omega = \mathbf{9.76\ \Omega}$

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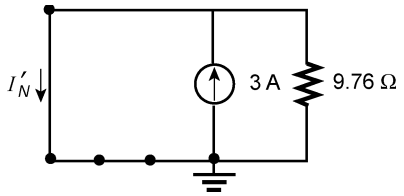
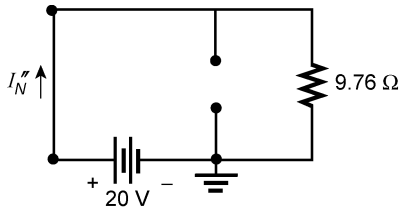
I_N: Superposition:

I:



$I'_N = 3$ A

E:

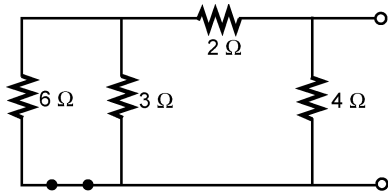


$$I''_N = \frac{20\text{ V}}{9.76\,\Omega} = 2.05\text{ A}$$

$I_N = I'_N - I''_N = 3\text{ A} - 2.05\text{ A} = \mathbf{0.95\ A}$ (direction of I'_N)

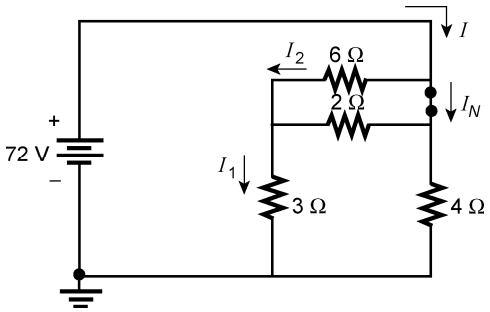
b. $E_{Th} = I_N R_N = (0.95\text{ A})(9.76\ \Omega) = \mathbf{9.27\ V} \cong 9.28$ V, $R_{Th} = R_N = \mathbf{9.76\ \Omega}$

(II): a. R_N:



$\leftarrow R_N = 4\ \Omega \,||\, (2\ \Omega + 2\ \Omega) = \mathbf{2\ \Omega}$

I_N:



$$I = \frac{72\text{ V}}{4\,\Omega \,||\, (3\,\Omega + 6\,\Omega \,||\, 2\,\Omega)}$$

$$= \frac{72\text{ V}}{2.118\,\Omega} \cong 34\text{ A}$$

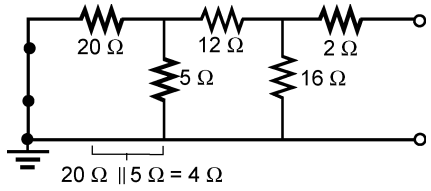
$$I_1 = \frac{4\,\Omega(I)}{4\,\Omega + 4.5\,\Omega} = 16\text{ A}$$

$$I_2 = \frac{2\,\Omega(I_1)}{2\,\Omega + 6\,\Omega} = 4\text{ A}$$

$I_N = I - I_2 = 34\text{ A} - 4\text{ A} = \mathbf{30\ A}$

b. $E_{Th} = I_N R_N = (30\text{ A})(2\ \Omega) = \mathbf{60\ V}$, $R_{Th} = R_N = \mathbf{2\ \Omega}$

22. (I) R_N:



$$\leftarrow R_N = 2\ \Omega + 16\ \Omega \,||\, (12\ \Omega + 4\ \Omega)$$
$$= 2\ \Omega + 16\ \Omega \,||\, 16\ \Omega$$
$$= 2\ \Omega + 8\ \Omega = \mathbf{10\ \Omega}$$

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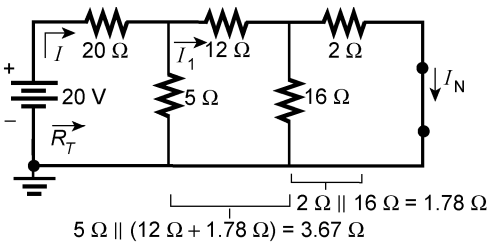
I_N:

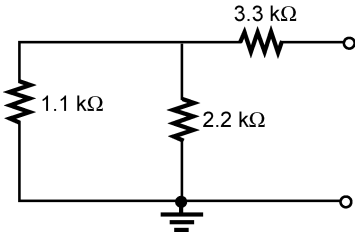


$$I = \frac{E}{R_T} = \frac{20\text{ V}}{20\,\Omega + 3.67\,\Omega} = 0.845\text{ A}$$

$$I_1 = \frac{5\,\Omega(0.845\text{ A})}{5\,\Omega + 13.78\,\Omega} = 0.225\text{ A}$$

$$I_N = \frac{16\,\Omega(0.225\text{ A})}{16\,\Omega + 2\,\Omega} = \mathbf{0.2\text{ A}}$$

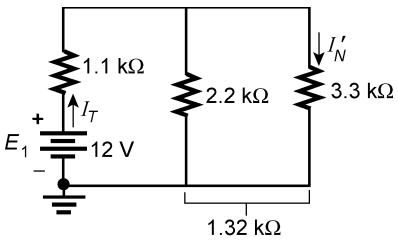
(II): R_N:



$\leftarrow R_N = 3.3\text{ k}\Omega + 1.1\text{ k}\Omega \parallel 2.2\text{ k}\Omega$
$= 3.3\text{ k}\Omega + 0.733\text{ k}\Omega$
$= \mathbf{4.03\text{ k}\Omega}$

I_N: Superposition:

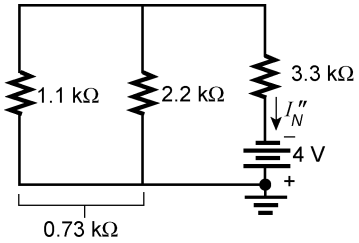
E_1:



$$I_T = \frac{12\text{ V}}{1.1\text{ k}\Omega + 1.32\text{ k}\Omega} = 4.96\text{ mA}$$

$$I'_N = \frac{2.2\text{ k}\Omega(4.96\text{ mA})}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega} = 1.98\text{ mA}$$

E_2:



$$I''_N = \frac{4\text{ V}}{3.3\text{ k}\Omega + 0.73\text{ k}\Omega} = 0.99\text{ mA}$$

$I_N = I'_N + I''_N = 1.98\text{ mA} + 0.99\text{ mA} = \mathbf{2.97\text{ mA}}$

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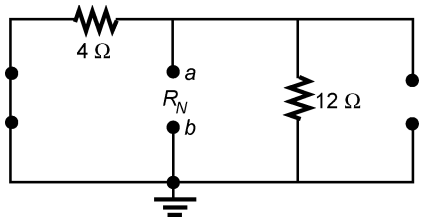
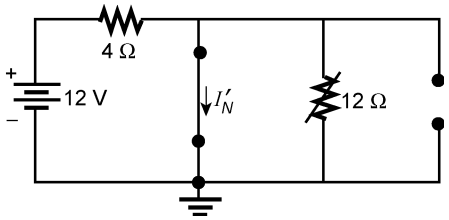
23. a. R_N:



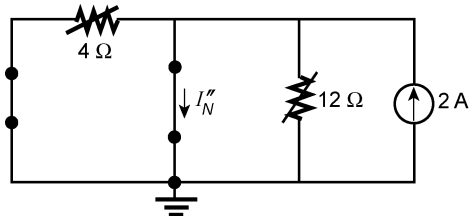
$R_N = 4\ \Omega \parallel 12\ \Omega = \mathbf{3\ \Omega}$

$E = 12$ V:



$$I'_N = \frac{12\ \text{V}}{4\ \Omega} = 3\ \text{A}$$

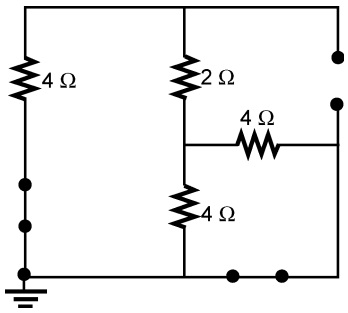
$I = 2$ A:



$I''_N = 2$ A

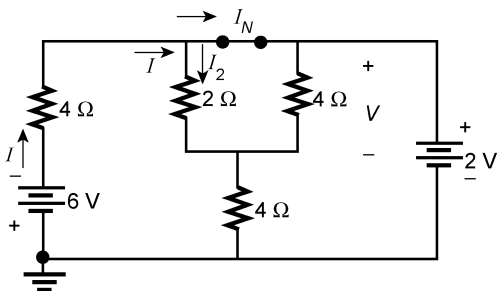
$I_N = I'_N + I''_N = 3\ \text{A} + 2\ \text{A} = \mathbf{5\ A}$

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:



$$I = \frac{V_{4\Omega}}{4\ \Omega} = \frac{6\ \text{V} - 2\ \text{V}}{4\ \Omega} = \frac{4\ \text{V}}{4\ \Omega}$$
$$= 1\ \text{A}$$
$$V = \frac{(4\ \Omega \parallel 2\ \Omega)(2\ \text{V})}{(4\ \Omega \parallel 2\ \Omega) + 4\ \Omega}$$
$$= 0.5\ \text{V}$$
$$I_2 = \frac{V}{R} = \frac{0.5\ \text{V}}{2\ \Omega} = 0.25\ \text{A}$$

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$I_N = I - I_2 = 1\text{ A} - 0.25\text{ A} = \mathbf{0.75\ A}$

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)

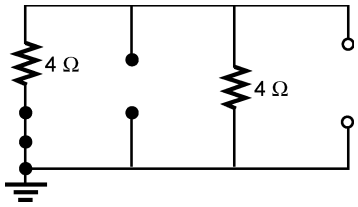
(II): (a) $R = R_{Th} = \mathbf{4.03\ k\Omega}$ (from problem 14)

(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)
$P_{\max} = E_{Th}^2 / 4R_{Th} = (9.74\text{ V})^2/4(4.04\ \text{k}\Omega) = \mathbf{5.87\ mW}$

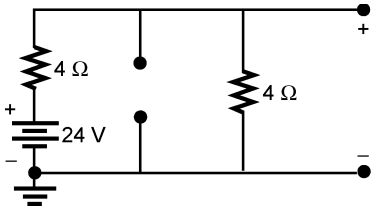
27. a.



$\leftarrow R = R_{Th} = 4\ \Omega \parallel 4\ \Omega = \mathbf{2\ \Omega}$

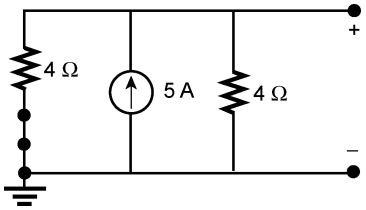
b. E_{Th}:

E:



$$E'_{Th} = \frac{24\text{ V}}{2} = 12\text{ V}$$

I:



$E''_{Th} = IR_T = (5\text{ A})(4\ \Omega \parallel 4\ \Omega)$
$= (5\text{ A})(2\ \Omega) = 10\text{ V}$

$E_{Th} = E'_{Th} + E''_{Th} = 12\text{ V} + 10\text{ V} = \mathbf{22\ V}$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(22\text{ V})^2}{4(2\ \Omega)} = \mathbf{60.5\ W}$$

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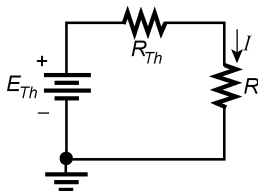
c.



$$P = I^2R = \left(\frac{E_{Th}}{R_{Th} + R}\right)^2 R$$

$R = \frac{1}{4}(2\,\Omega) = 0.5\ \Omega$, 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**

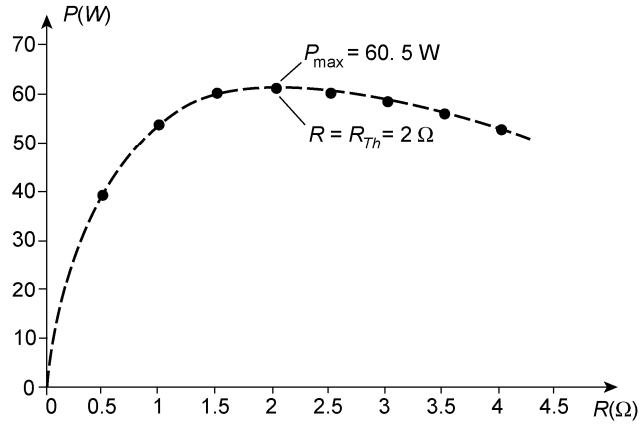
R = **2 Ω**, P = **60.5 W**

$R = \frac{5}{4}(2\,\Omega) = 2.5\ \Omega$, 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**

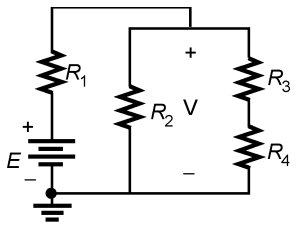


28. $P_{\max} = \left(\frac{E_{Th}}{R_{Th} + R_4}\right)^2 R_4$

with R_1 = **0 Ω** 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 ($\infty\ \Omega$).

Then $P_4 = \frac{V_4^2}{R_4}$ will be a maximum.

b. No, examine each individually.

30.

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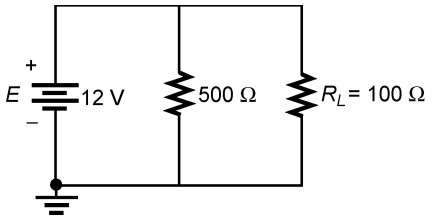
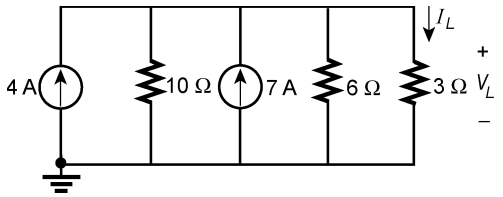


Since R_L fixed, maximum power to R_L when V_{R_L} a maximum as defined by $P_L = \dfrac{V_{R_L}^2}{R_L}$

$$\therefore R = \mathbf{500\ \Omega} \text{ and } P_{\max} = \frac{(12\text{ V})^2}{100\,\Omega} = \mathbf{1.44\ W}$$

31.



$I_T\uparrow = 4\text{ A} + 7\text{ A} = 11\text{ A}$
$R_T = 10\ \Omega \parallel 6\ \Omega \parallel 3\ \Omega = 1.67\ \Omega$
$V_L = I_T R_T = (11\text{ A})(1.67\ \Omega) = \mathbf{18.37\ V}$
$I_L = \dfrac{V_L}{R_L} = \dfrac{18.37\text{ V}}{3\,\Omega} = \mathbf{6.12\ A}$

32. $E_{\text{eq}} = \dfrac{-5\text{ V}/2.2\text{ k}\Omega + 20\text{ V}/8.2\text{ k}\Omega}{1/2.2\text{ k}\Omega + 1/8.2\text{ k}\Omega} = 0.2879\text{ V}$

$R_{\text{eq}} = \dfrac{1}{1/2.2\text{ k}\Omega + 1/8.2\text{ k}\Omega} = 1.7346\text{ k}\Omega$

$I_L = \dfrac{E_{\text{eq}}}{R_{\text{eq}} + R_L} = \dfrac{0.2879\text{ V}}{1.7346\text{ k}\Omega + 5.6\text{ k}\Omega} = \mathbf{39.3\ \mu A}$

$V_L = I_L R_L = (39.3\ \mu\text{A})(5.6\text{ k}\Omega) = \mathbf{220\ mV}$

33. $I_T\downarrow = 5\text{ A} - 0.4\text{ A} - 0.2\text{ A} = 4.40\text{ A}$
$R_T = 200\ \Omega \parallel 80\ \Omega \parallel 50\ \Omega \parallel 50\ \Omega = 17.39\ \Omega$
$V_L = I_T R_T = (4.40\text{ A})(17.39\ \Omega) = \mathbf{75.52\ V}$
$I_L = \dfrac{V_L}{R_L} = \dfrac{76.52\text{ V}}{200\ \Omega} = \mathbf{0.38\ A}$

34. $I_{\text{eq}} = \dfrac{(4\text{ A})(4.7\ \Omega) + (1.6\text{ A})(3.3\,\Omega)}{4.7\ \Omega + 3.3\,\Omega} = \dfrac{18.8\text{ V} + 5.28\text{ V}}{8\ \Omega} = 3.01\text{ A}$

$R_{\text{eq}} = 4.7\ \Omega + 3.3\ \Omega = 8\ \Omega$

$I_L = \dfrac{R_{\text{eq}}(I_{\text{eq}})}{R_{\text{eq}} + R_L} = \dfrac{8\,\Omega(3.01\text{ A})}{8\,\Omega + 2.7\,\Omega} = \mathbf{2.25\ A}$

$V_L = I_L R_L = (2.25\text{ A})(2.7\ \Omega) = \mathbf{6.08\ V}$

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35. $\overleftarrow{I_{eq}} = \dfrac{(4\text{ mA})(8.2\text{ k}\Omega) + (8\text{ mA})(4.7\text{ k}\Omega) - (10\text{ mA})(2\text{ k}\Omega)}{8.2\text{ k}\Omega + 4.7\text{ k}\Omega + 2\text{ k}\Omega}$

$= \dfrac{32.8\text{ V} + 37.6\text{ V} - 20\text{ V}}{14.9\text{ k}\Omega} = 3.38\text{ mA}$

$R_{eq} = 8.2\text{ k}\Omega + 4.7\text{ k}\Omega + 2\text{ k}\Omega = 14.9\text{ k}\Omega$

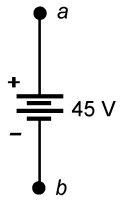
$I_L = \dfrac{R_{eq}I_{eq}}{R_{eq} + R_L} = \dfrac{(14.9\text{ k}\Omega)(3.38\text{ mA})}{14.9\text{ k}\Omega + 6.8\text{ k}\Omega} = \mathbf{2.32\text{ mA}}$

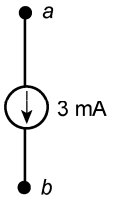
$V_L = I_L R_L = (2.32\text{ mA})(6.8\text{ k}\Omega) = \mathbf{15.78\text{ V}}$

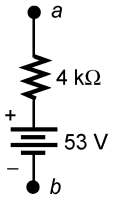
36. $15\text{ k}\Omega \parallel (8\text{ k}\Omega + 7\text{ k}\Omega) = 15\text{ k}\Omega \parallel 15\text{ k}\Omega = 7.5\text{ k}\Omega$

$V_{ab} = \dfrac{7.5\text{ k}\Omega(60\text{ V})}{7.5\text{ k}\Omega + 2.5\text{ k}\Omega} = 45\text{ V}$

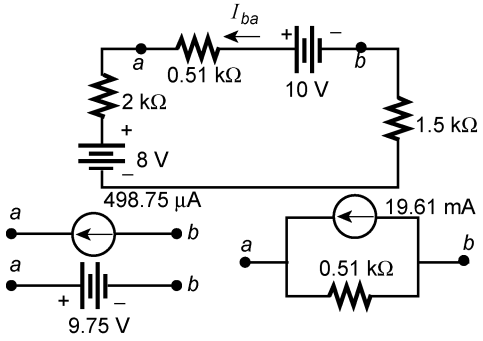
$I_{ab} = \dfrac{45\text{ V}}{15\text{ k}\Omega} = 3\text{ mA}$







37.



$I_{ba} = \dfrac{10\text{ V} - 8\text{ V}}{2\text{ k}\Omega + 0.51\text{ k}\Omega + 1.5\text{ k}\Omega}$

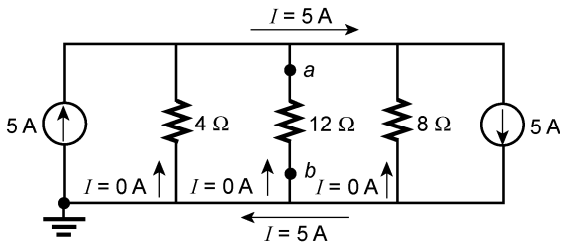
$= \mathbf{498.75\ \mu A}$

$V_{0.51\text{k}\Omega} = (498.75\ \mu\text{A})(0.51\text{ k}\Omega)$

$= 0.25\text{ V}$

$V_{ab} = 10\text{ V} - 0.25\text{ V} = 9.75\text{ V}$

38.



$V_{ab} = 0$ V (short)

$I_{ab} = 0$ A (open)

R_2 any resistive value

$\therefore R_2$ = short-circuit, open-circuit, any value

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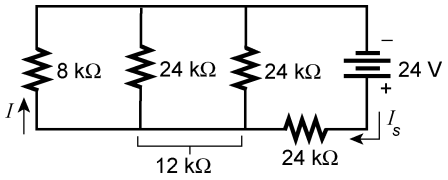
39. a. $I_s = \dfrac{24\text{ V}}{8\text{ k}\Omega + \dfrac{24\text{ k}\Omega}{3}} = 1.5\text{ mA}, I = \dfrac{I_s}{3} = \mathbf{0.5\text{ mA}}$

b.

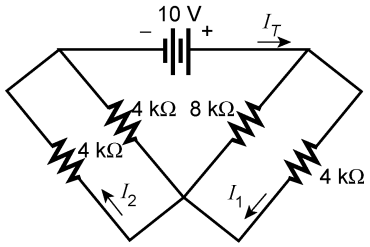


$$I_s = \frac{24\text{ V}}{24\text{ k}\Omega + 8\text{ k}\Omega \,||\, 12\text{ k}\Omega} = 0.83\text{ mA}$$

$$I = \frac{12\text{ k}\Omega(I_s)}{12\text{ k}\Omega + 8\text{ k}\Omega} = \mathbf{0.5\text{ mA}}$$

c. yes

40. (a)

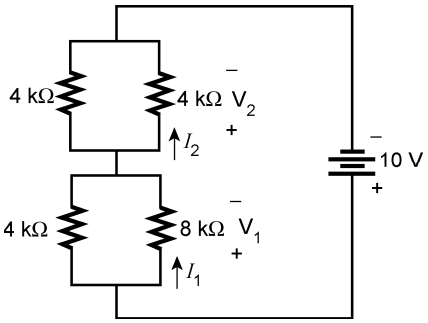


$$I_T = \frac{10\text{ V}}{4\text{ k}\Omega \,||\, 8\text{ k}\Omega + 4\text{ k}\Omega \,||\, 4\text{ k}\Omega} = \frac{10\text{ V}}{2.67\text{ k}\Omega + 2\text{ k}\Omega} = \frac{10\text{ V}}{4.67\text{ k}\Omega} = 2.14\text{ mA}$$

$$I_1 = \frac{8\,\Omega(I_T)}{8\,\Omega + 4\,\Omega} = 1.43\text{ mA}, I_2 = I_T/2 = 1.07\text{ mA}$$

$I = I_1 - I_2 = 1.43\text{ mA} - 1.07\text{ mA} = \mathbf{0.36\text{ mA}}$

(b)



$$V_1 = \frac{(8\text{ k}\Omega \,||\, 4\text{ k}\Omega)(10\text{ V})}{8\text{ k}\Omega \,||\, 4\text{ k}\Omega + 4\text{ k}\Omega \,||\, 4\text{ k}\Omega} = 5.72\text{ V}$$

$$I_1 = \frac{V_1}{8\text{ k}\Omega} = 0.71\text{ mA}$$

$V_2 = E - V_1 = 10\text{ V} - 5.72\text{ V} = 4.28\text{ V}$

$$I_2 = \frac{V_2}{4\text{ k}\Omega} = 1.07\text{ mA}$$

$I = I_2 - I_1 = 1.07\text{ mA} - 0.71\text{ mA} = \mathbf{0.36\text{ mA}}$

41. a. $I_{R_2} = \dfrac{R_1(I)}{R_1 + R_2 + R_3} = \dfrac{3\,\Omega(6\text{ A})}{3\,\Omega + 2\,\Omega + 4\,\Omega} = 2\text{ A}$

$V = I_{R_2} R_2 = (2\text{ A})(2\,\Omega) = \mathbf{4\text{ V}}$

b. $I_{R_1} = \dfrac{R_2(I)}{R_1 + R_2 + R_3} = \dfrac{2\,\Omega(6\text{ A})}{3\,\Omega + 2\,\Omega + 4\,\Omega} = 1.33\text{ A}$

$V = I_{R_1} R_1 = (1.33\text{ A})(3\,\Omega) = \mathbf{4\text{ V}}$

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Chapter 10

1. (a) $\mathscr{E} = k\dfrac{Q_1}{r^2} = \dfrac{(9\times10^9)(4\ \mu\text{C})}{(2\text{ m})^2} = \mathbf{9 \times 10^3\ N/C}$

   (b) $\mathscr{E} = k\dfrac{Q_1}{r^2} = \dfrac{(9\times10^9)(4\ \mu\text{C})}{(1\text{ mm})^2} = \mathbf{36 \times 10^9\ N/C}$

   $\mathscr{E}$(1 mm): $\mathscr{E}$ (2 m) = 4×10^6: 1

2. $\mathscr{E} = \dfrac{kQ}{r^2} \Rightarrow r = \sqrt{\dfrac{kQ}{\mathscr{E}}} = \sqrt{\dfrac{(9\times10^9)(2\ \mu\text{C})}{72\text{ N/C}}} = \mathbf{15.81\ m}$

3. $C = \dfrac{Q}{V} = \dfrac{1200\ \mu\text{C}}{10\text{ V}} = \mathbf{120\ \mu F}$

4. $Q = CV = (0.15\ \mu\text{F})(45\text{ V}) = \mathbf{6.75\ \mu C}$

5. $\mathscr{E} = \dfrac{V}{d} = \dfrac{100\text{ mV}}{2\text{ mm}} = \mathbf{50\ V/m}$

6. $d = 10\ \cancel{\text{mils}}\left[\dfrac{10^{-3}\ \cancel{\text{in.}}}{1\ \cancel{\text{mil}}}\right]\left[\dfrac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.254\text{ mm}$

   $\mathscr{E} = \dfrac{V}{d} = \dfrac{100\text{ mV}}{0.254\text{ mm}} = \mathbf{393.70\ V/m}$

7. $V = \dfrac{Q}{C} = \dfrac{160\ \mu\text{C}}{4\ \mu\text{F}} = 40\text{ V}$

   $\mathscr{E} = \dfrac{V}{d} = \dfrac{40\text{ V}}{5\text{ mm}} = \mathbf{8 \times 10^3\ V/m}$

8. $C = 8.85 \times 10^{-12}\varepsilon_r\dfrac{A}{d} = 8.85 \times 10^{-12}(1)\dfrac{(0.1\text{ m}^2)}{2\text{ mm}} = \mathbf{442.50\ pF}$

9. $C = 8.85 \times 10^{-12}\ \varepsilon_r\dfrac{A}{d} = 8.85 \times 10^{-12}(2.5)\dfrac{(0.1\text{ m}^2)}{2\text{ mm}} = \mathbf{1.11\ nF}$

10. $C = 8.85 \times 10^{-12}\varepsilon_r\dfrac{A}{d} \Rightarrow d = \dfrac{8.85\times10^{-12}(4)(0.15\text{ m}^2)}{2\ \mu\text{F}} = \mathbf{2.66\ \mu m}$

11. $C = \varepsilon_r C_o \Rightarrow \varepsilon_r = \dfrac{C}{C_o} = \dfrac{6\text{ nF}}{1200\text{ pF}} = \mathbf{5\ (mica)}$

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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. $C = \dfrac{(4)\left(\dfrac{1}{3}\right)}{\left(\dfrac{1}{4}\right)}(5\ \mu\text{F}) = \mathbf{26.67\ \mu F}$

15. $d = \dfrac{8.85 \times 10^{-12}\varepsilon_r A}{C} = \dfrac{(8.85 \times 10^{-12})(5)(0.02\ \text{m}^2)}{0.006\ \mu\text{F}} = 0.1475\ \text{mm} = 147.5\ \mu\text{m}$

$$d = 0.1475\ \cancel{\text{mm}}\left[\frac{10^{-3}\ \cancel{\text{m}}}{1\ \cancel{\text{mm}}}\right]\left[\frac{39.37\ \cancel{\text{in.}}}{1\ \cancel{\text{m}}}\right]\left[\frac{1000\ \text{mils}}{1\ \cancel{\text{in.}}}\right] = 5.807\ \text{mils}$$

$$5.807\ \cancel{\text{mils}}\left[\frac{5000\ \text{V}}{\cancel{\text{mil}}}\right] = \mathbf{29.04\ kV}$$

16. mica: $\dfrac{1200\ \text{V}}{\dfrac{5000\ \text{V}}{\cancel{\text{mil}}}} = 1200\ \text{V}\left[\dfrac{\cancel{\text{mil}}}{5000\ \text{V}}\right] = 0.24\ \text{mils}$

$$0.24\ \text{mils}\left[\frac{1\ \cancel{\text{mil}}}{1000\ \text{mils}}\right]\left[\frac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right] = \mathbf{6.10\ \mu m}$$

17. $\dfrac{200}{1 \times 10^6}(22\ \mu\text{F})/°\text{C} = 4400\ \text{pF}/°\text{C}$

$$\frac{4400\ \text{pF}}{°\text{C}}[\Delta\text{T}] = \frac{4400\ \text{pF}}{°\text{C}}[80°\text{C}] = \mathbf{0.35\ \mu F}$$

18. J = ±5%, Size ⇒ 40 pF ± 2 pF, **38 pF → 42 pF**

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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**

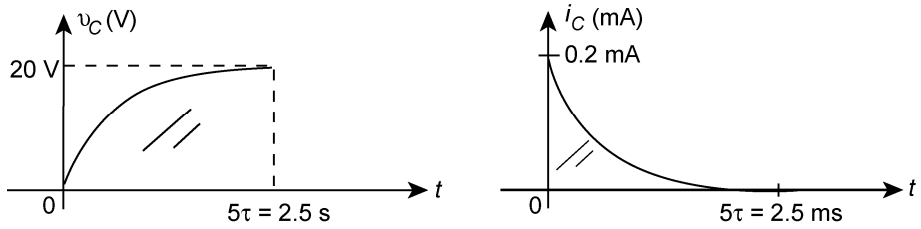
21. a. $\tau = RC = (10^5\ \Omega)(5.1\ \mu\text{F}) = \mathbf{0.51\ s}$

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. $i_C = \dfrac{20\ \text{V}}{100\ \text{k}\Omega}e^{-t/\tau} = \mathbf{0.2\ mA}e^{-t/0.51\ \text{s}}$
$\upsilon_R = Ee^{-t/\tau} = \mathbf{20\ V}e^{-t/0.51\ \text{s}}$

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. $i_C = \dfrac{20\ \text{V}}{1\ \text{M}\Omega}e^{-t/\tau} = \mathbf{20\ \mu A}\ e^{-t/5.1s}$
$\upsilon_R = Ee^{-t/\tau} = \mathbf{20V}\ e^{-t/5.1s}$

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. $i_C = \dfrac{E}{R_T}e^{-t/\tau} = \dfrac{100\ \text{V}}{5.5\ \text{k}\Omega}e^{-t/\tau} = \mathbf{18.18\ mA}e^{-t/5.5\ \text{ms}}$

$V_{R_2} = \dfrac{3.3\ \text{k}\Omega(100\ \text{V})}{3.3\ \text{k}\Omega + 2.2\ \text{k}\Omega} = 60\ \text{V}$

$\upsilon_R = \upsilon_{R_2} = \mathbf{60\ V}e^{-t/5.5\ \text{ms}}$

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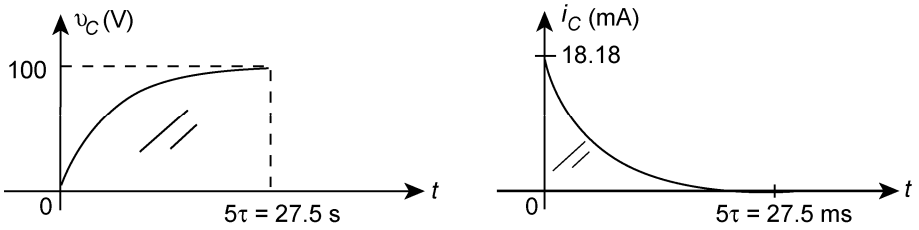
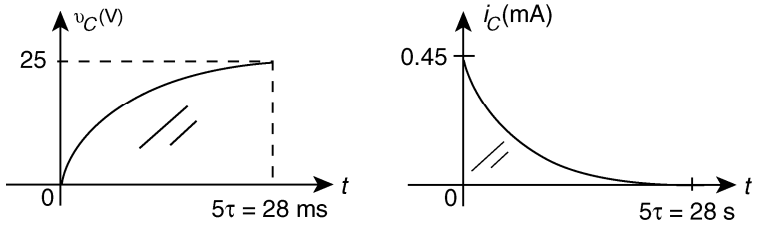
e.



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. $i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{25\ \text{V}}{56\ \text{k}\Omega}e^{-t/\tau} = \mathbf{0.45\ mA}e^{-t/5.6\text{ms}}$

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. $\tau = RC = (1000 \times 10^6\ \Omega)(10\ \mu\text{F}) = 10 \times 10^3\ \text{s}$

$5\tau = 50 \times 10^3\ \text{s}\left[\dfrac{1\ \text{min}}{60\ \text{s}}\right]\left[\dfrac{1\ \text{h}}{60\ \text{min}}\right] = \mathbf{13.89\ h}$

27. a. $\tau = RC = (2\ \text{k}\Omega)(100\ \mu\text{F}) = \mathbf{200\ ms}$

b. $\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{8\ V(1 - e^{-t/200\text{ms}})}$

$i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{8\ \text{V}}{2\ \text{k}\Omega}e^{-t/200\text{ms}} = \mathbf{4\ mA}e^{-t/200\text{ms}}$

c. $\upsilon_C(1\ \text{s}) = 8\ \text{V}(1 - e^{-1\text{s}/200\text{ms}}) = 8\ \text{V}(1 - e^{-5})$
$= 8\ \text{V}(1 - 6.738 \times 10^{-3}) = 8\ \text{V}(0.9933) = \mathbf{7.95\ V}$
$i_C\ (1\ \text{s}) = 4\ \text{mA}e^{-5} = 4\ \text{mA}(6.738 \times 10^{-3}) = \mathbf{26.95\ \mu A}$

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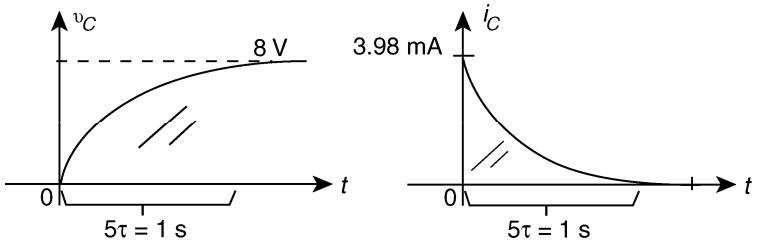
d. $\upsilon_C = \mathbf{7.95\ V}e^{-t/200\text{ms}}$

$$i_C = \frac{7.95\text{ V}}{2\text{ k}\Omega}e^{-t/200\text{ms}} = \mathbf{3.98\ mA}e^{\mathbf{-t/200ms}}$$

e.



28. a. $\tau = RC = (3\text{ k}\Omega + 2\text{ k}\Omega)(2\ \mu\text{F}) = 10\text{ ms}$

$\upsilon_C = \mathbf{50\ V(1 - }e^{\mathbf{-t/10ms}}\mathbf{)}$

$$i_C = \frac{50\text{ V}}{5\text{ k}\Omega}e^{-t/10\text{ms}} = \mathbf{10\ mA}^{\mathbf{-t/10ms}}$$

$\upsilon_{R_1} = i_C \cdot R_1 = (10\text{ mA})(3\text{ k}\Omega)e^{-t/10\text{ms}} = \mathbf{30\ V}e^{\mathbf{-t/10ms}}$

b. 100ms: $e^{-10} = 45.4 \times 10^{-6}$

$\upsilon_C = 50\text{ V}(1 - 45.4 \times 10^{-6}) = \mathbf{50\ V}$

$i_C = 10\text{ mA}(45.4 \times 10^{-6}) = \mathbf{0.45\ \mu A}$

$\upsilon_{R_1} = 30\text{ V}(45.4 \times 10^{-6}) = \mathbf{1.36\ mV}$

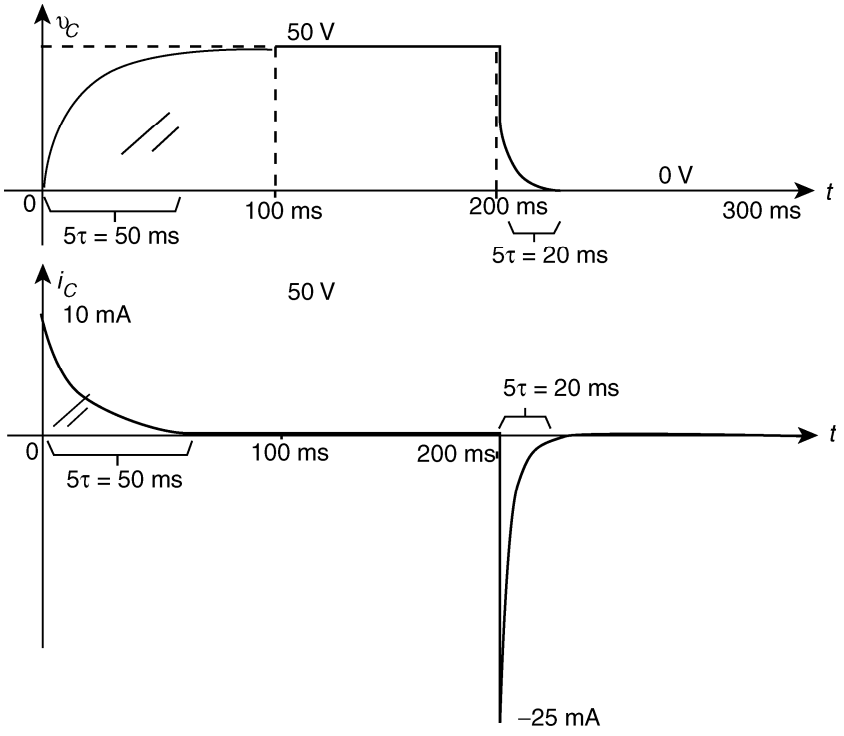
c. 200 ms: $\tau' = R_2C = (2\text{ k}\Omega)(2\ \mu\text{F}) = 4\text{ ms}$

$\upsilon_C = \mathbf{50\ V}e^{\mathbf{-t/4ms}}$

$$i_C = -\frac{50\text{ V}}{2\text{ k}\Omega}e^{-t/4\text{ms}} = \mathbf{-25\ mA}e^{\mathbf{-t/4ms}}$$

$\upsilon_{R_2} = \upsilon_C = \mathbf{-50\ V}e^{-t/4\text{ms}}$

d.



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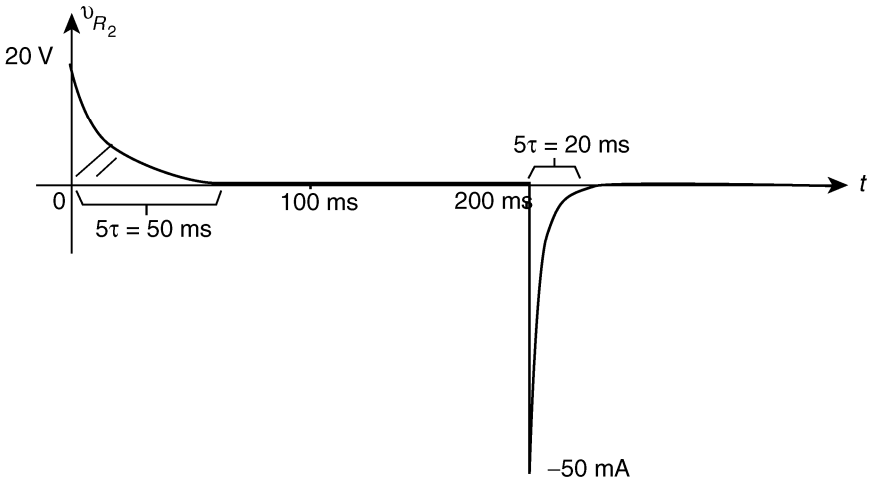


29. a. $\tau = RC = (5\ \text{k}\Omega)(20\ \mu\text{F}) = 100\ \text{ms}$

$\upsilon_C = \mathbf{50\ V(1 - e^{-t/100ms})}$

$i_C = \dfrac{50\ \text{V}}{5\ \text{k}\Omega} e^{-t/100\text{ms}} = \mathbf{10\ mA}e^{\mathbf{-t/100ms}}$

$\upsilon_{R_1} = i_C \cdot R_1 = (10\ \text{mA})(3\ \text{k}\Omega)\ e^{-t/100\text{ms}} = \mathbf{30\ V}e^{\mathbf{-t/100ms}}$

b. 100 ms: $e^{-1} = 0.368$

$\upsilon_C = 50\ \text{V}(1 - 0.368) = 50\ \text{V}(0.632) = \mathbf{31.6\ V}$

$i_C = 10\ \text{mA}(0.368) = \mathbf{3.68\ mA}$

$\upsilon_{R_1} = 30\ \text{V}(0.368) = \mathbf{11.04\ V}$

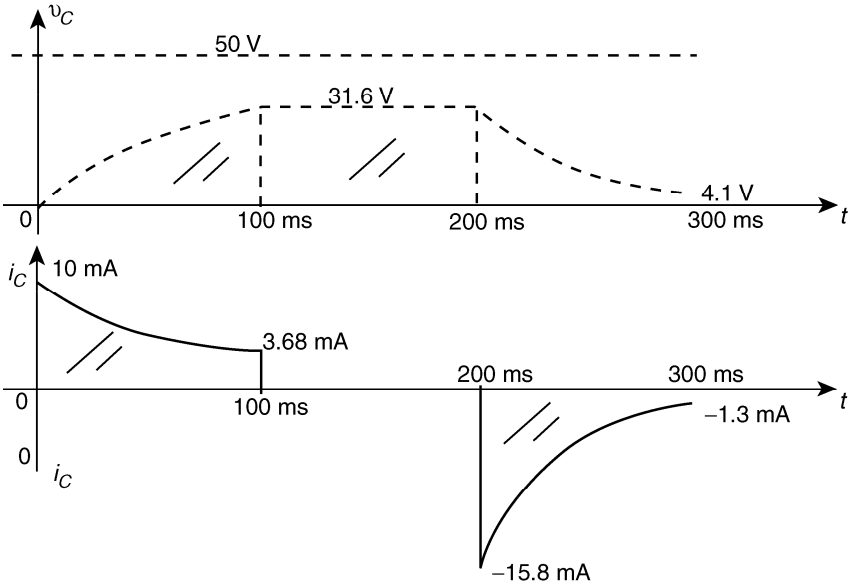
c. 200 ms: $\tau' = R_2C = (2\ \text{k}\Omega)(20\ \mu\text{F}) = 40\ \text{ms}$

$\upsilon_C = \mathbf{31.6\ V}e^{\mathbf{-t/40ms}}$

$i_C = -\dfrac{31.6\ \text{V}}{2\ \text{k}\Omega} e^{-t/40\text{ms}} = \mathbf{-15.8\ mA}e^{\mathbf{-t/40ms}}$

$\upsilon_{R_2} = -\upsilon_C = \mathbf{-31.6\ V}e^{\mathbf{-t/40ms}}$

d.



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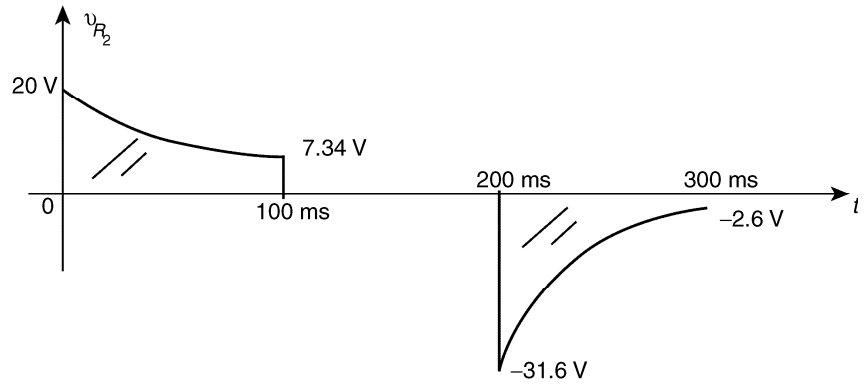


30. a. $\tau = R_1C = (10^5\ \Omega)(10\ \text{pF}) = 1\ \mu\text{s}$

$$\boldsymbol{\upsilon_C = 80\ \text{V}\left(1 - e^{-t/1\mu\text{s}}\right)}$$

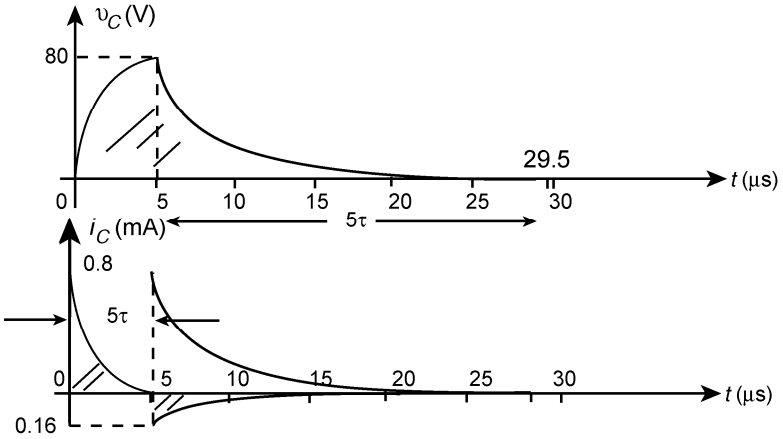
$$i_C = \frac{80\ \text{V}}{100\ \text{k}\Omega}e^{-t/\tau} = \mathbf{0.8\ mA}e^{-t/1\mu\text{s}}$$

b. $\tau' = R'C = (490\ \text{k}\Omega)(10\ \text{pF}) = 4.9\ \mu\text{s}$

$$\upsilon_C = 80\ \text{V}e^{-t/\tau'} = \mathbf{80\ V}e^{-t/4.9\times10^{-6}}$$

$$i_C = \frac{80\ \text{V}}{490\ \text{k}\Omega}e^{-t/\tau'} = \mathbf{0.16\ mA}e^{-t/4.9\times10^{-6}}$$

c.



31. a. $\tau = RC = (2\ \text{m}\Omega)(1000\ \mu\text{F}) = 2\ \mu\text{s}$

$$5\tau = \mathbf{10\ \mu s}$$

b. $$I_m = \frac{V}{R} = \frac{6\ \text{V}}{2\ \text{m}\Omega} = \mathbf{3\ kA}$$

c. yes

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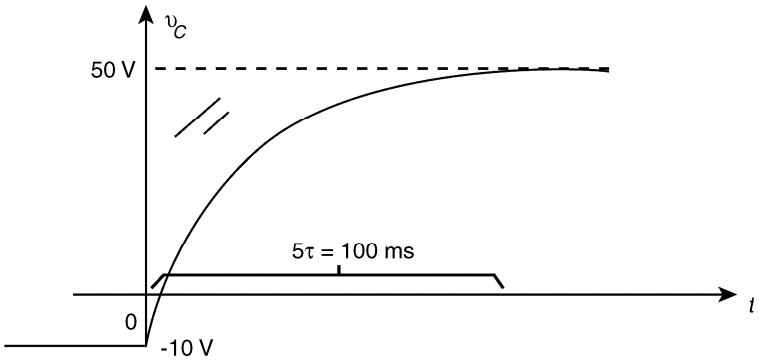
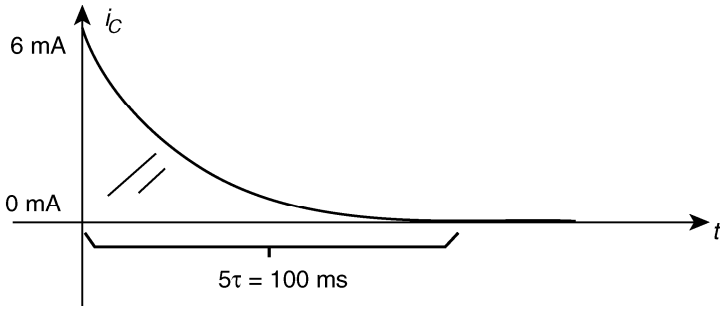
32. a. $\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$
$\tau = RC = (10\ \text{k}\Omega)(2\ \mu\text{F}) = 20\ \text{ms},\ V_f = 50\ \text{V},\ V_i = -10\ \text{V}$
$\upsilon_C = 50\ \text{V} + (-10\ \text{V} - (+50\ \text{V}))e^{-t/20\text{ms}}$
$\upsilon_C = \mathbf{50\ V - 60\ V}e^{\mathbf{-t/20ms}}$

b. Initially $V_R = E + \upsilon_C = 50\ \text{V} + 10\ \text{V} = 60\ \text{V}$
$$i_C = \frac{V_R}{R}e^{-t/\tau} = \frac{60\ \text{V}}{10\ \text{k}\Omega}e^{-t/20\text{ms}} = \mathbf{6\ mA}\ e^{\mathbf{-t/20ms}}$$

c.





33. $\tau = RC = (2.2\ \text{k}\Omega)(2000\ \mu\text{F}) = 4.4\ \text{s}$
$\upsilon_C = V_C e^{-t/\tau} = \mathbf{40\ V}e^{\mathbf{-t/4.4\ s}}$
$$I_C = \frac{V_C}{R}e^{-t/\tau} = \frac{40\ \text{V}}{2.2\ \text{k}\Omega}e^{-t/4.4\ \text{s}} = \mathbf{18.18\ mA}e^{\mathbf{-t/4.4\ s}}$$
$\upsilon_R = \upsilon_C = \mathbf{40\ V}e^{\mathbf{-t/4.4s}}$

34. $\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$
$\tau = RC = (860\ \Omega)(4000\ \text{pF}) = 3.44\ \mu\text{s},\ V_f = -30\ \text{V},\ V_i = 20\ \text{V}$
$\upsilon_C = -30\ \text{V} + (20\ \text{V} - (-30\ \text{V}))e^{-t/3.44\mu\text{s}}$
$\upsilon_C = \mathbf{-30\ V + 50\ V}e^{\mathbf{-t/3.44\mu s}}$
$$I_m = \frac{20\ \text{V} + 30\ \text{V}}{860\ \Omega} = 58.14\ \text{mA}$$
$i_C = \mathbf{-58.14\ mA}e^{\mathbf{-t/3.44\mu s}}$

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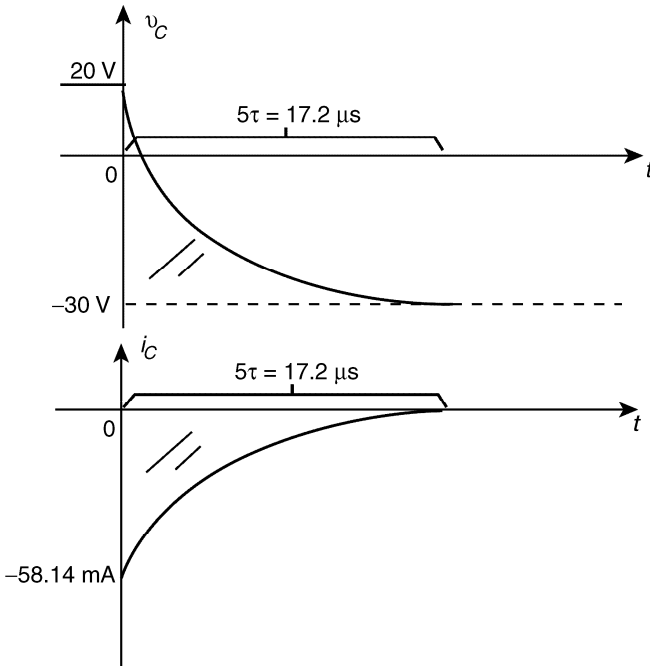
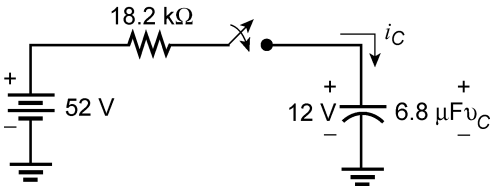


35. a.



$\tau = RC = (18.2\ \text{k}\Omega)(6.8\ \mu\text{F}) = 123.8\ \text{ms}$

$\upsilon_C = V_f + (V_i - V_f)\, e^{-t/\tau}$

$= 52\ \text{V} + (12\ \text{V} - 52\ \text{V})e^{-t/123.8\ \text{ms}}$

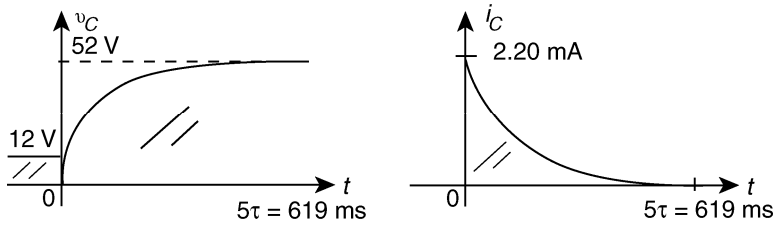
$\upsilon_C = \mathbf{52\ V - 40\ V}e^{\mathbf{-t/123.8\ ms}}$

$\upsilon_R(0+) = 52\ \text{V} - 12\ \text{V} = 40\ \text{V}$

$$i_C = \frac{40\ \text{V}}{18.2\ \text{k}\Omega}\, e^{-t/123.8\ \text{ms}}$$

$= \mathbf{2.20\ mA}e^{\mathbf{-t/123.8\ ms}}$

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. $6\ \text{V} = 12\ \text{V}(1 - e^{-t/20\,\mu\text{s}})$

$0.5 = 1 - e^{-t/20\,\mu\text{s}}$

$-0.5 = -e^{-t/20\,\mu\text{s}}$

$0.5 = e^{-t/20\,\mu\text{s}}$

$\log_e 0.5 = \log_e e^{-t/20\,\mu\text{s}}$

$-0.693 = -t/20\ \mu\text{s}$

$t = 0.693\ (20\ \mu\text{s}) = \mathbf{13.86\ \mu s}$

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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. $$t = -\tau \log_e\left(1 - \frac{\upsilon_C}{E}\right)$$

$$10\text{ s} = -\tau \log_e\left(\underbrace{1 - \underbrace{\frac{12\text{ V}}{20\text{ V}}}_{.4}}_{-916.29 \times 10^{-3}}\right)$$

$$\tau = \frac{10\text{ s}}{0.916} = 10.92\text{ s}$$

$$\tau = RC \Rightarrow R = \frac{\tau}{C} = \frac{10.92\text{ s}}{200\ \mu\text{F}} = \mathbf{54.60\ k\Omega}$$

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. $$i_C = \frac{E}{R}e^{-t/\tau}$$

$$i_C = \frac{80\text{ V}}{20\text{ k}\Omega}e^{-\frac{166.80\text{ ms}}{0.12\text{s}}} = 4\text{ mA}e^{-1.39}$$

$= (4\text{ mA})(249.08 \times 10^{-3})$

$\cong \mathbf{1\ mA}$

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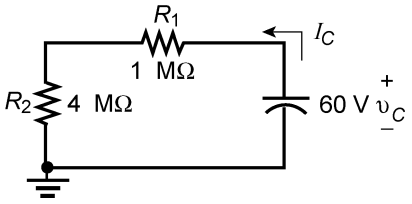
c. $i_s = i_C = 4\text{ mA}e^{-t/\tau} = 4\text{ mA}e^{-2\tau/\tau} = 4\text{ mA}e^{-2}$
$= 4\text{ mA}(135.34 \times 10^{-3})$
$= 0.54\text{ mA}$
$P_s = EI_s = (80\text{ V})(0.54\text{ mA})$
$= \mathbf{43.20\text{ mW}}$

40. a. $\tau = RC = (1\text{ M}\Omega)(0.2\ \mu\text{F}) = 0.2\text{ s}$
$\upsilon_C = \mathbf{60\text{ V}(1 - e^{-t/0.2\text{s}})}$
$i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{60\text{ V}}{1\text{ M}\Omega}e^{-t/0.2\text{s}} = \mathbf{60\ \mu A}e^{-t/0.2\text{s}}$
$\upsilon_{R_1} = Ee^{-t/\tau} = \mathbf{60\text{ V}}e^{-t/0.2\text{s}}$

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.



$\tau' = RC = (1\text{ M}\Omega + 4\text{ M}\Omega)(0.2\ \mu\text{F})$
$= (5\text{ M}\Omega)(0.2\ \mu\text{F})$
$= 1\text{ s}$
$i_C = \dfrac{60\text{ V}}{5\text{ M}\Omega}e^{-t} = \mathbf{12\ \mu A}e^{-t}$

$8\ \mu\text{A} = 12\ \mu\text{A}e^{-t}$
$0.667 = e^{-t}$
$\log_e 0.667 = -t$
$-0.41 = -t$
$t = \mathbf{0.41\text{ s}}$

$\upsilon_C = 60\text{ V}e^{-t\tau'}$
$10\text{ V} = 60\text{ V}e^{-t}$
$0.167 = e^{-t}$
$\log_e 0.167 = -t$
$-1.79 = -t$
$t = 1.79\text{ s}$
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. $i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{60\text{ V}}{10\text{ M}\Omega}e^{-2\tau/\tau} = 6\ \mu\text{A}e^{-2}$
$= 6\ \mu\text{A}(0.1353)$
$= \mathbf{0.81\ \mu A}$

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c. $\upsilon_C = E(1 - e^{-t/\tau})$ $\tau = RC = (10\ \text{M}\Omega)(0.2\ \mu\text{F}) = 2\ \text{s}$

$50\ \text{V} = 60\ \text{V}(1 - e^{-t/2\ \text{s}})$

$0.8333 = 1 - e^{-t/2\ \text{s}}$

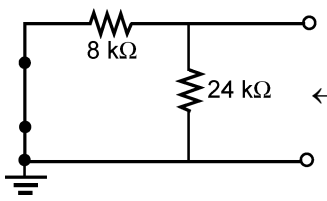
$\log_e 0.1667 = -t/2\ \text{s}$

$t = -(2\ \text{s})(-1.792)$

$= \mathbf{3.58\ s}$

42. a. Thevenin's theorem:

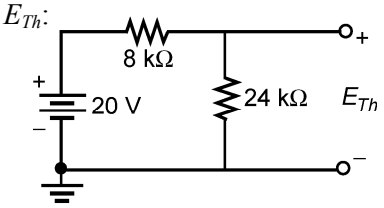
R_{Th}:



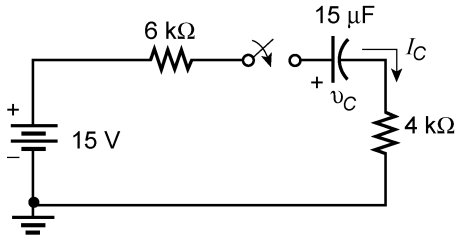
$\leftarrow R_{Th} = 8\ \text{k}\Omega \parallel 24\ \text{k}\Omega$

$= 6\ \text{k}\Omega$

E_{Th}:



$$E_{Th} = \frac{24\ \text{k}\Omega(20\ \text{V})}{24\ \text{k}\Omega + 8\ \text{k}\Omega} = 15\ \text{V}$$



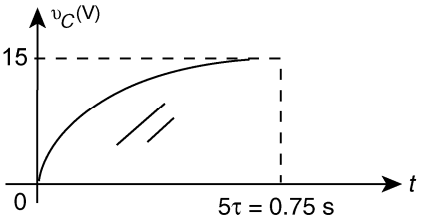
$\tau = RC = (10\ \text{k}\Omega)(15\ \mu\text{F}) = 0.15\ \text{s}$

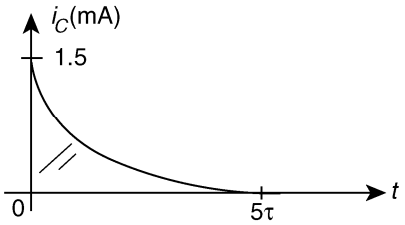
$\upsilon_C = E(1 - e^{-t/\tau})$

$= \mathbf{15\ V(1 - e^{-t/0.15\ s})}$

$$i_C = \frac{E}{R}e^{-t/\tau} = \frac{15\ \text{V}}{10\ \text{k}\Omega}e^{-t/0.15} = \mathbf{1.5\ mA}e^{\mathbf{-t/0.15\ s}}$$

b.





43. a. Source conversion and combining series resistors:

$\tau = RC = (8.3\ \text{k}\Omega)(2.2\ \mu\text{F}) = 18.26\ \text{ms}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 27.2\ \text{V} + (2\ \text{V} - 27.2\ \text{V})e^{-t/18.26\ \text{ms}}$

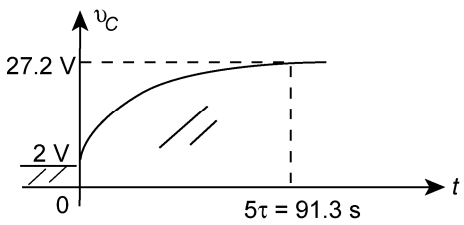
$\upsilon_C = \mathbf{27.2\ V - 25.2\ V}e^{\mathbf{-t/18.26\ ms}}$

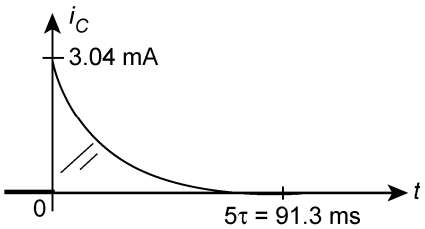
$\upsilon_R(0+) = 27.2\ \text{V} - 2\ \text{V} = 25.2\ \text{V}$

$$i_C = \frac{25.2\ \text{V}}{8.3\ \text{k}\Omega}e^{-t/18.26\text{ms}}$$

$i_C = \mathbf{3.04\ mA}e^{\mathbf{-t/18.26\ ms}}$

b.





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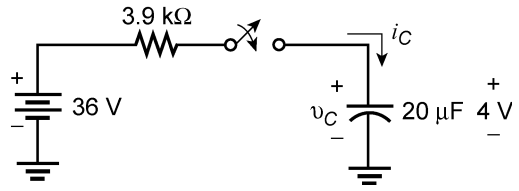
44. a. $R_{Th} = 3.9\ \text{k}\Omega + 0\ \Omega \parallel 1.8\ \text{k}\Omega = 3.9\ \text{k}\Omega$

$E_{Th} = 36\ \text{V}$



$\tau = RC = (3.9\ \text{k}\Omega)(20\ \mu\text{F}) = 78\ \text{ms}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 36\ \text{V} + (-4\ \text{V} - 36\ \text{V})e^{-t/78\ \text{ms}}$

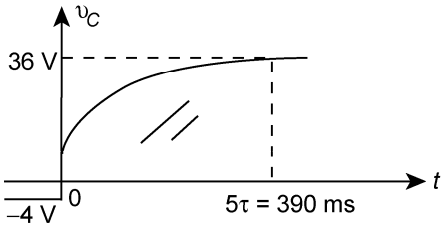
$\upsilon_C = \mathbf{36\ V - 40\ V}e^{\mathbf{-t/78\ ms}}$

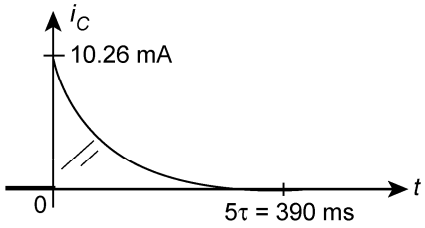
$\upsilon_R(0+) = 36\ \text{V} + 4\ \text{V} = 40\ \text{V}$

$$i_C = \frac{40\ \text{V}}{3.9\ \text{k}\Omega}e^{-t/78\ \text{ms}}$$

$i_C = \mathbf{10.26\ mA}e^{\mathbf{-t/78\ ms}}$

b.

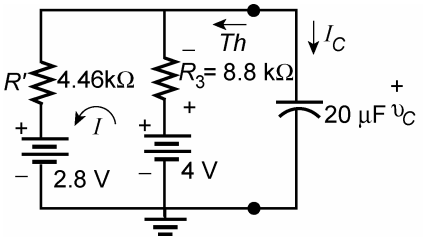




45. Source conversion:

$E = IR_1 = (5\ \text{mA})(0.56\ \text{k}\Omega) = 2.8\ \text{V}$

$R' = R_1 + R_2 = 0.56\ \text{k}\Omega + 3.9\ \text{k}\Omega = 4.46\ \text{k}\Omega$



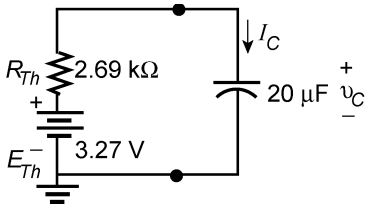
$R_{Th} = 4.46\ \text{k}\Omega \parallel 6.8\ \text{k}\Omega = 2.69\ \text{k}\Omega$

$$I = \frac{4\ \text{V} - 2.8\ \text{V}}{6.8\ \text{k}\Omega + 4.46\ \text{k}\Omega} = \frac{1.2\ \text{V}}{11.26\ \text{k}\Omega} = 0.107\ \text{mA}$$

$E_{Th} = 4\ \text{V} - (0.107\ \text{mA})(6.8\ \text{k}\Omega)$

$= 4\ \text{V} - 0.727\ \text{V}$

$= 3.27\ \text{V}$



$\upsilon_C = 3.27\ \text{V}(1 - e^{-t/\tau})$

$\tau = RC = (2.69\ \text{k}\Omega)(20\ \mu\text{F})$

$= 53.80\ \text{ms}$

$\upsilon_C = \mathbf{3.27\ V(1 - }e^{\mathbf{-t/53.80\ ms}}\mathbf{)}$

$$i_C = \frac{3.27\ \text{V}}{2.69\ \text{k}\Omega}e^{-t/\tau}$$

$= \mathbf{1.22\ mA}\ e^{\mathbf{-t/53.80\ ms}}$

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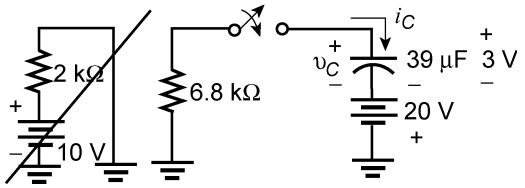
46. a.



$\tau = RC = (6.8\ \text{k}\Omega)(39\ \mu\text{F}) = 265.2\ \text{ms}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 20\ \text{V} + (3\ \text{V} - 20\ \text{V})e^{-t/265.2\ \text{ms}}$

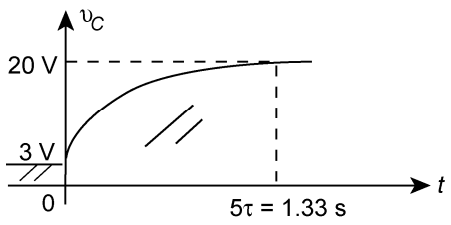
$\upsilon_C = \mathbf{20\ V\ -17\ V}e^{\mathbf{-t/265.2\ ms}}$

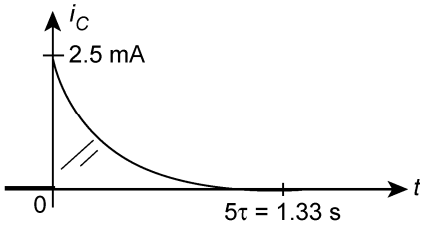
$\upsilon_R(0+) = 20\ \text{V} - 3\ \text{V} = 17\ \text{V}$

$$i_C = \frac{17\ \text{V}}{6.8\ \text{k}\Omega}e^{-t/265.2\ \text{ms}}$$

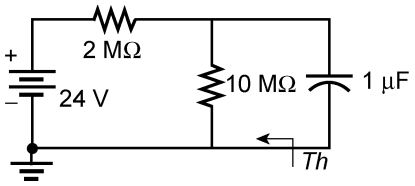
$i_C = \mathbf{2.5\ mA}e^{\mathbf{-t/265.2\ ms}}$

b.





47. a.



$R_{Th} = 2\ \text{M}\Omega \parallel 10\ \text{M}\Omega = 1.67\ \text{M}\Omega$

$$E_{Th} = \frac{10\ \text{M}\Omega(24\ \text{V})}{10\ \text{M}\Omega + 2\ \text{M}\Omega} = 20\ \text{V}$$

$\upsilon_C = E_{Th}(1 - e^{-t/\tau})$

$= 20\ \text{V}(1 - e^{-4\,t/\tau})$

$= 20\ \text{V}(1 - e^{-4})$

$= 20\ \text{V}(1 - 0.0183)$

$= \mathbf{19.63\ V}$

$\tau = R_{Th}C = (1.67\ \text{M}\Omega)(1\ \mu\text{F}) = 1.67\ \text{s}$

$$i_C = \frac{E}{R}e^{-t/\tau}$$

$$3\ \mu\text{A} = \frac{20\ \text{V}}{1.67\ \text{M}\Omega}e^{-t/1.67\text{s}}$$

$$0.25 = e^{-t/1.67\text{s}}$$

$$\log_e 0.25 = -t/1.67\ \text{s}$$

$$t = -(1.67\ \text{s})(-1.39)$$

$$= \mathbf{2.32\ s}$$

c. $\upsilon_{\text{meter}} = \upsilon_C$

$$\upsilon_C = E_{Th}(1 - e^{-t/\tau})$$

$$10\ \text{V} = 20\ \text{V}(1 - e^{-t/1.67\text{s}})$$

$$0.5 = 1 - e^{-t/1.67\text{s}}$$

$$-0.5 = -e^{-t/1.67\text{s}}$$

$$\log_e 0.5 = -t/1.67\ \text{s}$$

$$t = -(1.67\ \text{s})(-0.69)$$

$$= \mathbf{1.15\ s}$$

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48. $i_{C_{ao}} = C\dfrac{\Delta v_C}{\Delta t}$

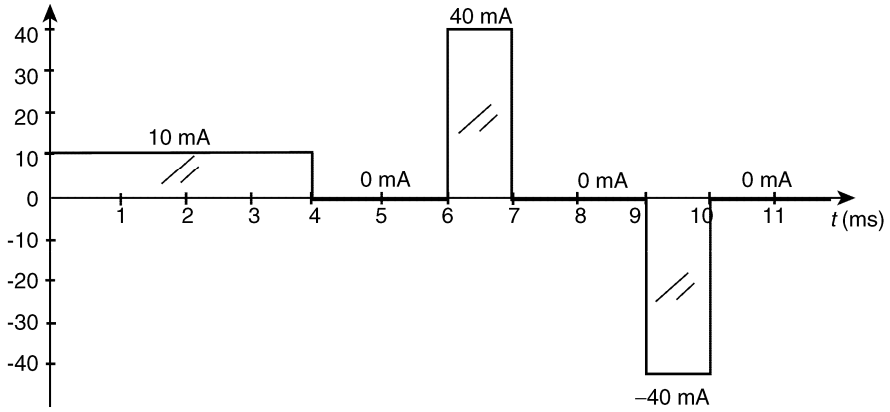
$0 \rightarrow 4$ ms: $i_C = 2 \times 10^{-6}\dfrac{(20\text{ V})}{4\text{ ms}} = \mathbf{10\ mA}$

$4 \rightarrow 6$ ms: $i_C = 2 \times 10^{-6}\dfrac{(0\text{ V})}{2\text{ ms}} = \mathbf{0\ mA}$

$6 \rightarrow 7$ ms: $i_C = 2 \times 10^{-6}\dfrac{(20\text{ V})}{1\text{ ms}} = \mathbf{40\ mA}$

$7 \rightarrow 9$ ms: $i_C = 2 \times 10^{-6}\dfrac{(0\text{ V})}{2\text{ ms}} = \mathbf{0\ mA}$

$9 \rightarrow 11$ ms: $i_C = -2 \times 10^{-6}\dfrac{(40\text{ V})}{2\text{ ms}} = \mathbf{-40\ mA}$



49. $i_{C_{ao}} = C\dfrac{\Delta v_C}{\Delta t}$

$0 \rightarrow 20\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(-5\text{ V})}{20\ \mu\text{s}} = \mathbf{-1.18\ A}$

$20 \rightarrow 30\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(0\text{ V})}{10\ \mu\text{s}} = \mathbf{0\ A}$

$30 \rightarrow 50\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(+10\text{ V})}{20\ \mu\text{s}} = \mathbf{+2.35\ A}$

$50 \rightarrow 80\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(-15\text{ V})}{30\ \mu\text{s}} = \mathbf{-2.35\ A}$

$80 \rightarrow 90\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(+10\text{ V})}{10\ \mu\text{s}} = \mathbf{+4.7\ A}$

$90\ \mu\text{s} \rightarrow 100\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(0\text{ V})}{10\ \mu\text{s}} = \mathbf{0\ A}$

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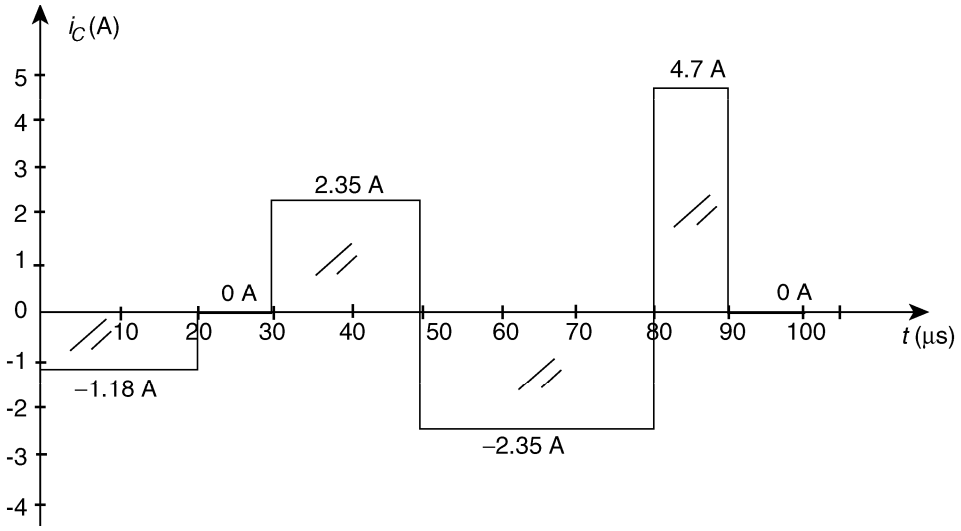


50. $i_C = C\dfrac{\Delta v_C}{\Delta t} \Rightarrow \Delta v_C = \dfrac{\Delta t}{C}(i_C)$

$0 \rightarrow 2$ ms: $i_C = 0$ mA $\quad \Delta v_C = \mathbf{0\ V}$

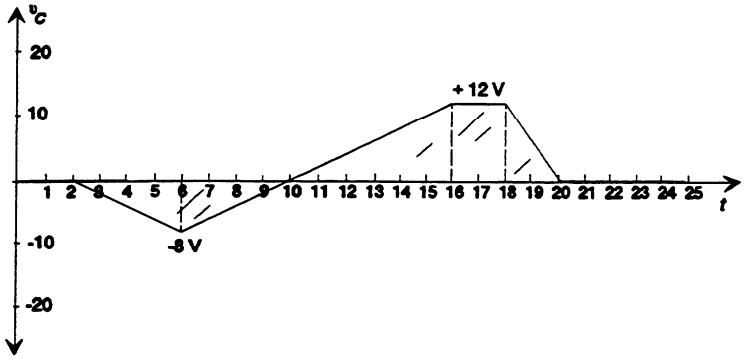
$2 \rightarrow 6$ ms: $i_C = -80$ mA $\quad \Delta v_C = \dfrac{(2\text{ ms})}{20\ \mu\text{F}}(-80\text{ mA}) = \mathbf{-8\ V}$

$6 \rightarrow 16$ ms: $i_C = +40$ mA $\quad \Delta v_C = \dfrac{(10\text{ ms})}{20\ \mu\text{F}}(40\text{ mA}) = \mathbf{+20\ V}$

$16 \rightarrow 18$ ms: $i_C = 0$ mA $\quad \Delta v_C = \mathbf{0\ V}$

$18 \rightarrow 20$ ms: $i_C = -120$ mA $\quad \Delta v_C = \dfrac{(2\text{ ms})}{20\ \mu\text{F}}(-120\text{ mA}) = \mathbf{-12\ V}$

$20 \rightarrow 25$ ms: $i_C = 0$ mA $\quad \Delta v_C = \mathbf{0\ V}$



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. $C_T' = 6\ \mu\text{F} \parallel 12\ \mu\text{F} = 4\ \mu\text{F}$

$C_T'' = C_T' + 12\ \mu\text{F} = 4\ \mu\text{F} + 12\ \mu\text{F} = 16\ \mu\text{F}$

$C_T = 6\ \mu\text{F} \parallel C_T'' = \dfrac{6\ \mu\text{F} \cdot C_T''}{6\ \mu\text{F} + C_T''} = \dfrac{(6\ \mu\text{F})(16\ \mu\text{F})}{6\ \mu\text{F} + 16\ \mu\text{F}} = \mathbf{4.36\ \mu F}$

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53. $V_1 = \mathbf{10\ V}$, $Q_1 = V_1C_1 = (10\ \text{V})(6\ \mu\text{F}) = \mathbf{60\ \mu C}$
$C_T = 6\ \mu\text{F} \parallel 12\ \mu\text{F} = 4\ \mu\text{F}$, $Q_T = C_TE = (4\ \mu\text{F})(10\ \text{V}) = 40\ \mu\text{C}$
$Q_2 = Q_3 = \mathbf{40\ \mu C}$

$$V_2 = \frac{Q_2}{C_2} = \frac{40\mu\text{C}}{6\mu\text{F}} = \mathbf{6.67\ V}$$

$$V_3 = \frac{Q_3}{C_3} = \frac{40\mu\text{C}}{12\mu\text{F}} = \mathbf{3.33\ V}$$

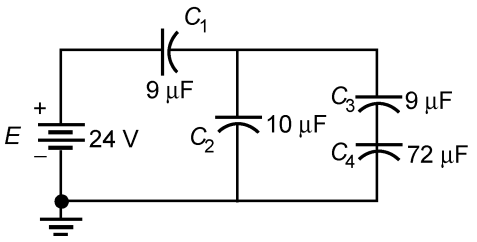
54. $C_T = 1200\ \text{pF} \parallel (200\ \text{pF} + 400\ \text{pF}) \parallel 600\ \text{pF}$
$= 1200\ \text{pF} \parallel 600\ \text{pF} \parallel 600\ \text{pF} = 1200\ \text{pF} \parallel 300\ \text{pF}$
$= 240\ \text{pF}$
$Q_T = C_TE = (240\ \text{pF})(40\ \text{V}) = 9.60\ \text{nC}$
$Q_1 = Q_4 = Q_T = \mathbf{9.60\ nC}$

$$V_1 = \frac{Q_1}{C_1} = \frac{9.60\ \text{nC}}{1200\ \text{pF}} = \mathbf{8.00\ V},\quad V_4 = \frac{Q_4}{C_4} = \frac{9.60\ \text{nC}}{600\ \text{pF}} = \mathbf{16.00\ V}$$

$V_2 = V_3 = E - V_1 - V_4 = 40\ \text{V} - 8\ \text{V} - 16\ \text{V} = \mathbf{16\ V}$

$Q_2 = C_2V_2 = (200\ \text{pF})(16\ \text{V}) = \mathbf{3.20\ nC}$, $Q_3 = C_3V_3 = (400\ \text{pF})(16\ \text{V}) = \mathbf{6.40\ nC}$

55.



$$\frac{(9\ \mu\text{F})(72\ \mu\text{F})}{9\ \mu\text{F} + 72\ \mu\text{F}} = 8\ \mu\text{F}$$

$$8\ \mu\text{F} + 10\ \mu\text{F} = 18\ \mu\text{F}$$

$$\frac{(9\ \mu\text{F})(18\ \mu\text{F})}{9\ \mu\text{F} + 18\ \mu\text{F}} = 6\ \mu\text{F}$$

$$C_T = \frac{Q}{V} = \frac{Q}{E} \Rightarrow Q = C_TE = (6\ \mu\text{F})(24\ \text{V}) = 144\ \mu\text{C}$$

$Q_1 = \mathbf{144\ \mu C}$

$$V_1 = \frac{Q_1}{C_1} = \frac{144\ \mu\text{C}}{9\ \mu\text{F}} = \mathbf{16\ V}$$

$V_2 = E - V_1 = 24\ \text{V} - 16\ \text{V} = \mathbf{8\ V}$
$Q_2 = C_2V_2 = 10\ \mu\text{F}(8\ \text{V}) = \mathbf{80\ \mu C}$
$Q_{3-4} = C'V = (8\ \mu\text{F})(8\ \text{V}) = 64\ \mu\text{C}$
$Q_3 = Q_4 = \mathbf{64\ \mu C}$

$$V_3 = \frac{Q_3}{C_3} = \frac{64\ \mu\text{C}}{9\ \mu\text{F}} = \mathbf{7.11\ V}$$

$$V_4 = \frac{Q_4}{C_4} = \frac{64\ \mu\text{C}}{72\ \mu\text{F}} = \mathbf{0.89\ V}$$

56. $$V_{4\text{k}\Omega} = \frac{4\ \text{k}\Omega(48\ \text{V})}{4\ \text{k}\Omega + 2\ \text{k}\Omega} = \mathbf{32\ V} = V_{0.08\mu\text{F}}$$
$Q_{0.08\mu\text{F}} = (0.08\ \mu\text{F})(32\ \text{V}) = \mathbf{2.56\ \mu C}$
$V_{0.04\mu\text{F}} = \mathbf{48\ V}$
$Q_{0.04\mu\text{F}} = (0.04\ \mu\text{F})(48\ \text{V}) = \mathbf{1.92\ \mu C}$

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57. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(120\text{ pF})(12\text{ V})^2 = \mathbf{8{,}640\text{ pJ}}$

58. $W = \frac{Q^2}{2C} \Rightarrow Q = \sqrt{2CW} = \sqrt{2(6\ \mu\text{F})(1200\text{ J})} = \mathbf{0.12\text{ C}}$

59. a. $V_{6\mu\text{F}} = V_{12\mu\text{F}} = \frac{3\text{ k}\Omega(24\text{ V})}{3\text{ k}\Omega + 6\text{ k}\Omega} = 8\text{ V}$

$W_{6\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(6\ \mu\text{F})(8\text{ V})^2 = \mathbf{0.19\text{ mJ}}$

$W_{12\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(12\ \mu\text{F})(8\text{ V})^2 = \mathbf{0.38\text{ mJ}}$

b. $C_T = \frac{(6\ \mu\text{F})(12\ \mu\text{F})}{6\ \mu\text{F} + 12\ \mu\text{F}} = 4\ \mu\text{F}$

$Q_T = C_T V = (4\ \mu\text{F})(8\text{ V}) = 32\ \mu\text{C}$

$Q_{6\mu\text{F}} = Q_{12\mu\text{F}} = 32\ \mu\text{C}$

$V_{6\mu\text{F}} = \frac{Q}{C} = \frac{32\ \mu\text{C}}{6\ \mu\text{F}} = 5.33\text{ V}$

$V_{12\mu\text{F}} = \frac{Q}{C} = \frac{32\ \mu\text{C}}{12\ \mu\text{F}} = 2.67\text{ V}$

$W_{6\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(6\ \mu\text{F})(5.33\text{ V})^2 = \mathbf{85.23\ \mu J}$

$W_{12\mu\text{F}} = \frac{1}{2}CV^2 = \frac{1}{2}(12\ \mu\text{F})(2.67\text{ V})^2 = \mathbf{42.77\ \mu J}$

60. a. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(1000\ \mu\text{F})(100\text{ V})^2 = \mathbf{5\text{ pJ}}$

b. $Q = CV = (1000\ \mu\text{F})(100\text{ V}) = \mathbf{0.1\text{ C}}$

c. $I = Q/t = 0.1\text{ C}/(1/2000) = \mathbf{200\text{ A}}$

d. $P = V_{av}I_{av} = W/t = 5\text{ J}(1/2000\text{ s}) = \mathbf{10{,}000\text{ W}}$

e. $t = Q/I = 0.1\text{ C}/10\text{ mA} = \mathbf{10\text{ s}}$

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Chapter 11

1. a. $B = \dfrac{\Phi}{A} = \dfrac{4\times10^{-4}\ \text{Wb}}{0.01\ \text{m}^2} = 4 \times 10^{-2}\ \text{Wb/m}^2 = \mathbf{0.04\ Wb/m^2}$

   b. **0.04 T**

   c. $F = NI = (40\ \text{t})(2.2\ \text{A}) = \mathbf{88\ At}$

   d. $0.04 \cancel{T}\left[\dfrac{10^4\ \text{gauss}}{1 \cancel{T}}\right] = \mathbf{0.4 \times 10^3\ gauss}$

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. $d = 0.2\ \cancel{\text{in.}}\left[\dfrac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right] = 5.08\ \text{mm}$

   $A = \dfrac{\pi d^2}{4} = \dfrac{(\pi)(5.08\ \text{mm})^2}{4} = 20.27 \times 10^{-6}\ \text{m}^2$

   $\ell = 1.6\ \cancel{\text{in.}}\left(\dfrac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right) = 40.64\ \text{mm}$

   $L = \dfrac{N^2 \mu_r \mu_o A}{\ell} = \dfrac{(200\ \text{t})^2(500)(4\pi\times10^{-7})(20.27\times10^{-6}\ \text{m}^2)}{40.64\ \text{mm}} = \mathbf{12.54\ mH}$

4. $L = N^2 \dfrac{\mu_r \mu_o}{\ell} = \dfrac{(200\ \text{t})^2(1000)(4\pi\times10^{-7})(1.5\times10^{-4}\ \text{m}^2)}{0.15\ \text{m}} = \mathbf{50.27\ mH}$

5. $L = \dfrac{N^2 \mu_r \mu_o A}{\ell}$

   a. $L' = (3)^2 L_o = 9L_o = 9(5\ \text{mH}) = \mathbf{45\ mH}$

   b. $L' = \dfrac{1}{3} L_o = \dfrac{1}{3}(5\ \text{mH}) = \mathbf{1.67\ mH}$

   c. $L' = \dfrac{(2)(2)^2}{\frac{1}{2}} L_o = 16\ (5\ \text{mH}) = \mathbf{80\ mH}$

   d. $L' = \dfrac{\left(\frac{1}{2}\right)^2 \frac{1}{2}(1500)L_o}{\frac{1}{2}} = 375(5\ \text{mH}) = \mathbf{1875\ mH}$

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. $47\ \mu\text{H} \pm 10\% \Rightarrow 47\ \mu\text{H} \pm 4.7\ \mu\text{H} \Rightarrow \mathbf{42.3\ \mu F \rightarrow 51.7\ \mu F}$

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7. $e = N\dfrac{d\phi}{dt} = (50\text{ t})(120\text{ mWb/s}) = \mathbf{6.0\ V}$

8. $e = N\dfrac{d\phi}{dt} \Rightarrow \dfrac{d\phi}{dt} = \dfrac{e}{N} = \dfrac{20\text{ V}}{200\text{ t}} = \mathbf{100\ mWb/s}$

9. $e = N\dfrac{d\phi}{dt} \Rightarrow N = e\left(\dfrac{1}{\dfrac{d\phi}{dt}}\right) = 42\text{ mV}\left(\dfrac{1}{3\text{ m Wb/s}}\right) = \mathbf{14\ turns}$

10. a. $e = L\dfrac{di_L}{dt} = (5\text{ H})(1\text{ A/s}) = \mathbf{5\ V}$

b. $e = L\dfrac{di_L}{dt} = (5\text{ H})(60\text{ mA/s}) = \mathbf{0.3\ V}$

$e = L\dfrac{di_L}{dt} = (5\text{ H})\left[\dfrac{0.5\text{ A}}{\cancel{\text{ms}}}\right]\left[\dfrac{1000\ \cancel{\text{ms}}}{1\text{ s}}\right] = \mathbf{2.5\ kV}$

11. $e = L\dfrac{di_L}{dt} = (50\text{ mH})\left(\dfrac{0.1\,\text{mA}}{\mu\text{s}}\right) = \mathbf{5\ V}$

12. a. $\tau = \dfrac{L}{R} = \dfrac{250\,\text{mH}}{20\,\text{k}\Omega} = \mathbf{12.5\ \mu s}$

b. $i_L = \dfrac{E}{R}(1 - e^{-t/\tau}) = \dfrac{40\text{ mV}}{20\text{ k}\Omega}(1 - e^{-t/\tau})$

$= \mathbf{2\ \mu A(1 - e^{-t/12.5\mu s})}$

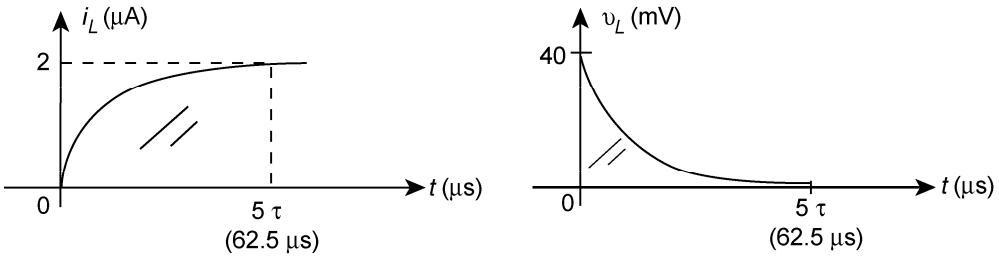
c. $\upsilon_L = Ee^{-t/\tau} = \mathbf{40\ mV}e^{\mathbf{-t/12.5\ \mu s}}$

$\upsilon_R = i_R R = i_L R = E(1 - e^{-t/\tau}) = \mathbf{40\ mV(1 - e^{-t/12.5\ \mu s})}$

d. i_L: $1\tau = \mathbf{1.26\ \mu A}$, , $3\tau = \mathbf{1.9\ \mu A}$, $5\tau = \mathbf{1.99\ \mu A}$

υ_L: $1\tau = \mathbf{14.72\ V}$, $3\tau = \mathbf{1.99\ V}$, $5\tau = \mathbf{0.27\ V}$

e.



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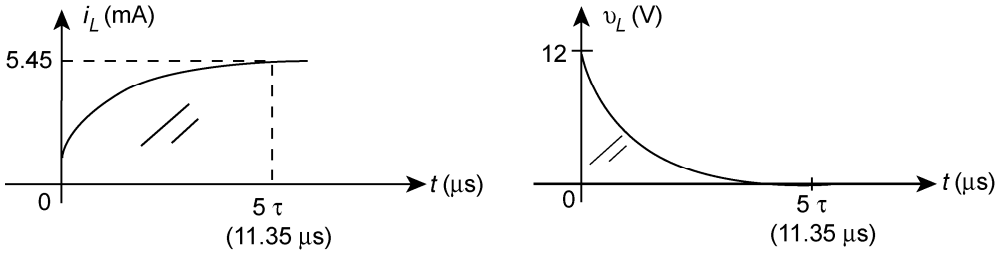
13. a. $\tau = \dfrac{L}{R} = \dfrac{5\text{ mH}}{2.2\text{ k}\Omega} = \mathbf{2.27\ \mu s}$

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. $\upsilon_L = Ee^{-t/\tau} = \mathbf{12\ V}e^{\mathbf{-t/2.27\ \mu s}}$
$\upsilon_R = i_R R = i_L R = E(1 - e^{-t/\tau}) = \mathbf{12\ V(1 - e^{-t/2.27\ \mu s})}$

d. i_L: $1\tau = \mathbf{3.45\ mA}$, , $3\tau = \mathbf{5.18\ mA}$, $5\tau = \mathbf{5.41\ mA}$
υ_L: $1\tau = \mathbf{4.42\ V}$, $3\tau = \mathbf{0.60\ V}$, $5\tau = \mathbf{0.08\ V}$

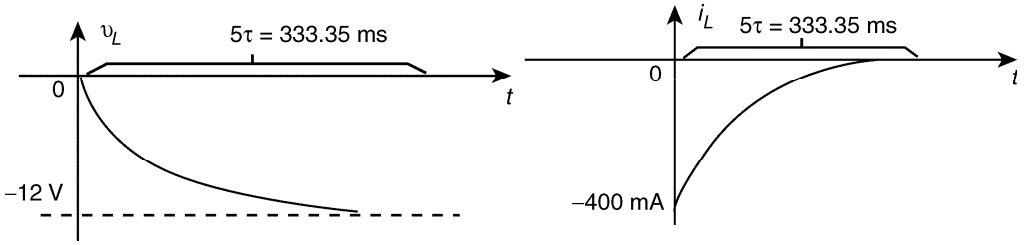
e.



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. $\upsilon_L = -E(1 - e^{-t/\tau}) = \mathbf{-12\ V(1 - e^{-t/66.67ms})}$
$i_L = -\dfrac{E}{R}e^{-t/\tau} = -\dfrac{12\text{ V}}{30\ \Omega}e^{-t/66.67\text{ ms}} = \mathbf{-400\ mA}e^{-t/66.67\text{ ms}}$

c.



15. a. $i_L = I_f + (I_i - I_f)e^{-t/\tau}$
$I_i = 8\text{ mA}$, $I_f = \dfrac{E}{R} = \dfrac{36\text{ V}}{3.9\text{ k}\Omega} = \mathbf{9.23\ mA}$, $\tau = \dfrac{L}{R} = \dfrac{120\text{ mH}}{3.9\text{ k}\Omega} = 30.77\ \mu s$
$i_L = 9.23\text{ mA} + (8\text{ mA} - 9.23\text{ mA})e^{-t/30.77\ \mu s}$
$i_L = \mathbf{9.23\ mA - 1.23\ mA}e^{\mathbf{-t/30.77\ \mu s}}$
$+E - \upsilon_L - \upsilon_R = 0$ and $\upsilon_L = E - \upsilon_R$
$\upsilon_R = i_R R = i_L R = (8\text{ mA})(3.9\text{ k}\Omega) = 31.2\text{ V}$
$\upsilon_L = E - \upsilon_R = 36\text{ V} - 31.2\text{ V} = 4.8\text{ V}$
$\upsilon_L = \mathbf{4.8\ V}e^{\mathbf{-t/30.77\ \mu s}}$

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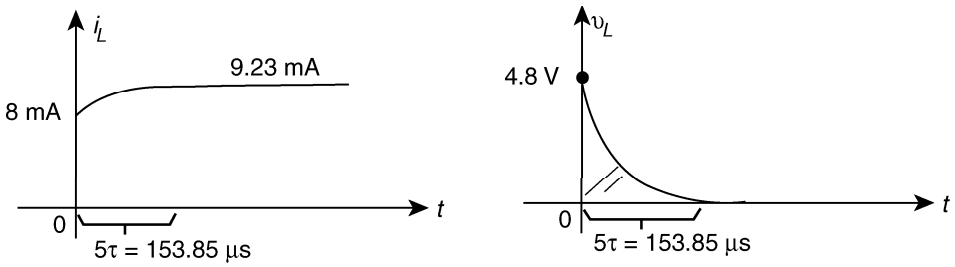
b.



16. a. $I_i = -8$ mA, $I_f = 9.23$ mA, $\tau = \dfrac{L}{R} = \dfrac{120\text{ mH}}{3.9\text{ k}\Omega} = 30.77\ \mu\text{s}$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$= 9.23\text{ mA} + (-8\text{ mA} - 9.23\text{ mA})e^{-t/30.77\ \mu\text{s}}$

$i_L =$ **9.23 mA – 17.23 mA** $e^{-t/30.77\ \mu\text{s}}$

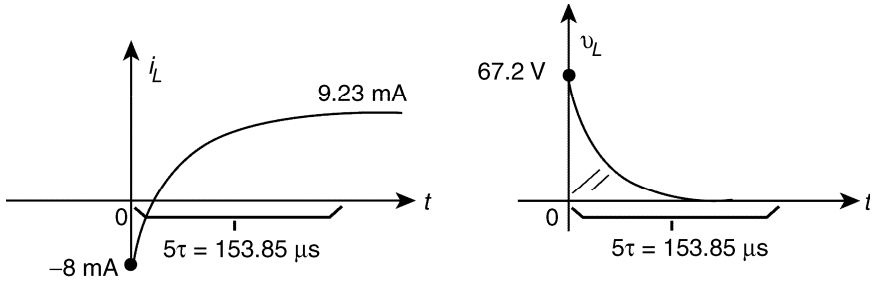
$+E - \upsilon_L - \upsilon_R = 0$ (at $t = 0^-$)

but, $\upsilon_R = i_R R = -i_L R = (-8\text{ mA})(3.9\text{ k}\Omega) = -31.2$ V

$\upsilon_L = E - \upsilon_R = 36\text{ V} - (-31.2\text{ V}) = 67.2$ V

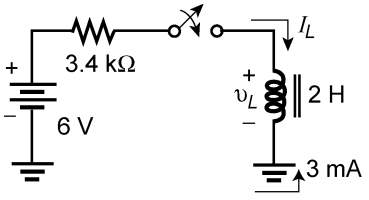
$\upsilon_L =$ **67.2 V** $e^{-t/30.77\ \mu\text{s}}$

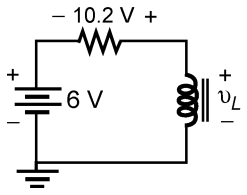
b.



c. Final levels are the same. Transition period defined by 5τ is also the same.

17. a. Source conversion:





$\tau = \dfrac{L}{R} = \dfrac{2\text{ H}}{3.4\text{ k}\Omega} = 588.2\ \mu\text{s}$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$I_f = \dfrac{6\text{ V}}{3.4\text{ k}\Omega} = 1.76$ mA

$i_L = 1.76\text{ mA} + (-3\text{ mA} - 1.76\text{ mA})e^{-t/588.2\mu\text{s}}$

$i_L =$ **1.76 mA – 4.76 mA** $e^{-t/588.2\mu\text{s}}$

$\upsilon_R(0+) = 3\text{ mA}(3.4\text{ k}\Omega) = 10.2$ V

KVL: $+6\text{ V} + 10.2\text{ V} - \upsilon_L(0+) = 0$

$\upsilon_L(0+) = 16.2$ V

$\upsilon_L =$ **16.2 V** $e^{-t/588.2\mu\text{s}}$

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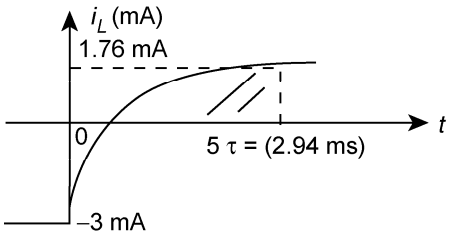
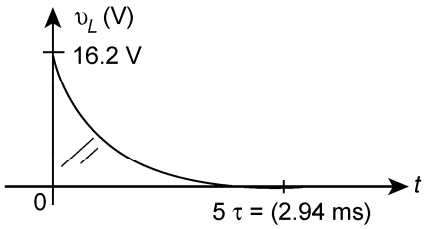
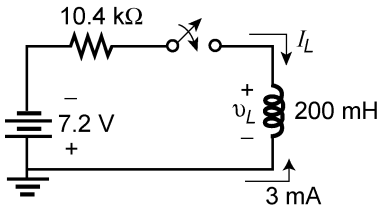
b.





18. a.



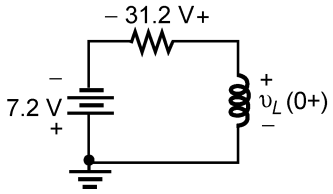
$$I_f = -\frac{7.2\text{ V}}{10.4\text{ k}\Omega} = -0.69\text{ mA}$$

$$\tau = \frac{L}{R} = \frac{200\text{ mH}}{10.4\text{ k}\Omega} = 19.23\ \mu\text{s}$$

$$i_L = I_f + (I_i - I_f)e^{-t/\tau}$$

$$= -0.69\text{ mA} + (-3\text{ mA} - (-0.69\text{ mA}))e^{-t/19.23\ \mu\text{s}}$$

$$i_L = \mathbf{-0.69\text{ mA} - 2.31\text{ mA}}e^{\mathbf{-t/19.23\ \mu s}}$$

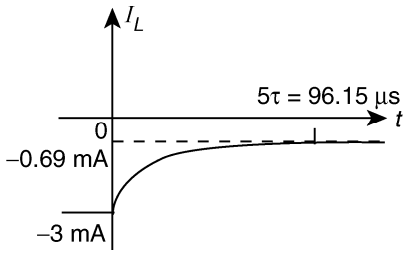


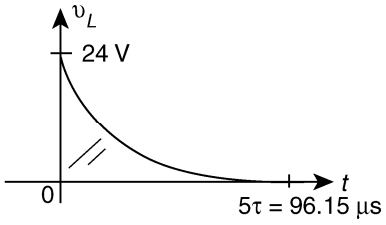
KVL: $-7.2\text{ V} + 31.2\text{ V} - \upsilon_L(0+) = 0$

$$\upsilon_L(0+) = 24\text{ V}$$

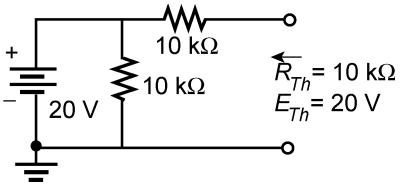
$$\upsilon_L = \mathbf{24\text{ V}}e^{\mathbf{-t/19.23\ \mu s}}$$

b.





19. a.



$$\tau = \frac{L}{R} = \frac{10\text{ mH}}{10\text{ k}\Omega} = 1\ \mu\text{s}$$

$$\upsilon_L = \mathbf{20\text{ V}}e^{\mathbf{-t/1\mu s}},\ i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \mathbf{2\text{ mA}(1 - }e^{\mathbf{-t/1\mu s}}\mathbf{)}$$

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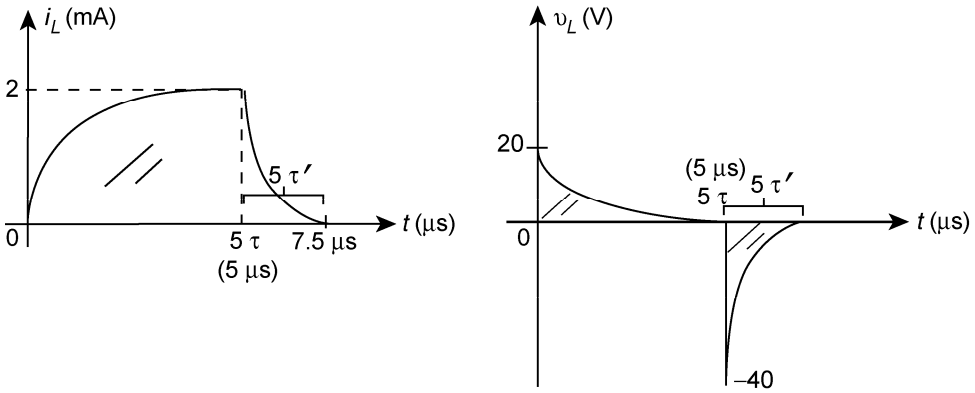
b. $5\tau \Rightarrow$ steady state

$$\tau' = \frac{L}{R} = \frac{10\text{ mH}}{10\text{ k}\Omega} = 1\ \mu\text{s}$$

$$i_L = I_m e^{-t/\tau'} = \mathbf{2\ mA}e^{\mathbf{-t/1\mu s}}$$

$$\upsilon_L = -(2\text{ mA})(20\text{ k}\Omega)e^{-t/\tau} = \mathbf{-40\ V}e^{\mathbf{-t/1\mu s}}$$



20. a. $\tau = \dfrac{L}{R} = \dfrac{1\text{ mH}}{2\text{ k}\Omega} = 0.5\ \mu\text{s}$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{12\text{ V}}{2\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{6\ mA(1 - }e^{\mathbf{-t/0.5\mu s}}\mathbf{)}$$

$$\upsilon_L = Ee^{-t/\tau} = \mathbf{12\ V}\ e^{\mathbf{-t/0.5\mu s}}$$

b. $i_L = 6\text{ mA}(1 - e^{-t/0.5\mu s}) = 6\text{ mA}(1 - e^{-1\mu s/0.5\mu s})$

$= 6\text{ mA}(1 - e^{-2}) = 5.19\text{ mA}$

$$i_L = I'_m e^{-t/\tau'} \qquad \tau' = \frac{L}{R} = \frac{1\text{ mH}}{12\text{ k}\Omega} = 83.3\text{ ns}$$

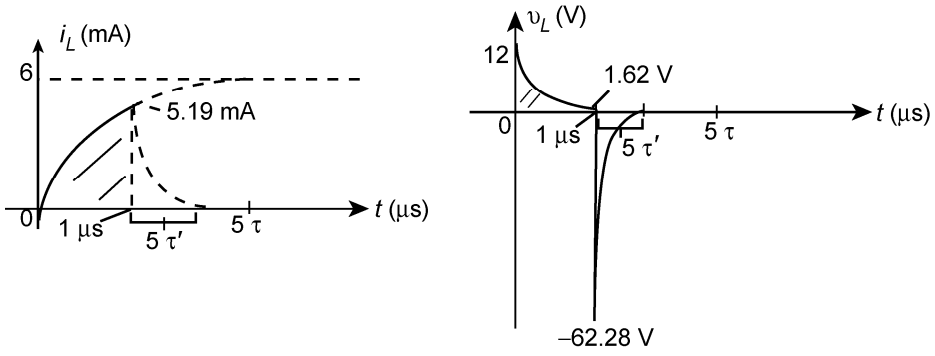
$$i_L = \mathbf{5.19\ mA}e^{\mathbf{-t/83.3ns}}$$

$t = 1\ \mu\text{s}$: $\upsilon_L = 12\text{ V}e^{-t/0.5\mu s} = 12\text{ V}e^{-2} = 12\text{ V}(0.1353) = 1.62\text{ V}$

$V'_L = (5.19\text{ mA})(12\text{ k}\Omega) = 62.28\text{ V}$

$$\upsilon_L = \mathbf{-62.28\ V}e^{\mathbf{-t/83.3ns}}$$

c.



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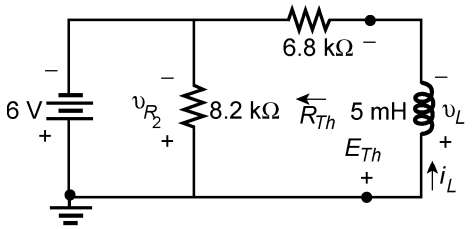
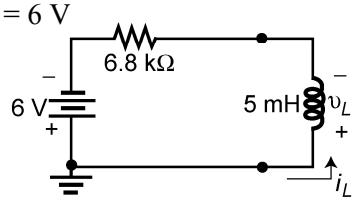
21. a.



$R_{Th} = 6.8\ \text{k}\Omega$

$E_{Th} = 6\ \text{V}$

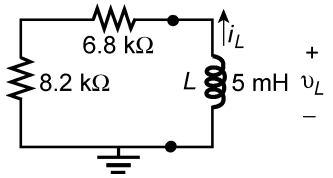


$$\tau = \frac{L}{R} = \frac{5\ \text{mH}}{6.8\ \text{k}\Omega} = 0.74\ \mu\text{s}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{6\ \text{V}}{6.8\ \text{k}\Omega}(1 - e^{-t/\tau}) = \mathbf{0.88\ mA(1 - e^{-t/0.74\mu s})}$$

$$\upsilon_L = Ee^{-t/\tau} = \mathbf{6\ V}e^{-t/0.74\mu s}$$

b. Assume steady state and $I_L = 0.88\ \text{mA}$



$$\tau' = \frac{L}{R} = \frac{5\ \text{mH}}{15\ \text{k}\Omega} = 0.33\ \mu\text{s}$$

$$i_L = I_m e^{-t/\tau'} = \mathbf{0.88\ mA}\ e^{-t/0.33\mu s}$$

$$\upsilon_L = -V_m e^{-t/\tau'}$$

$$V_m = I_m R = (0.88\ \text{mA})(15\ \text{k}\Omega) = 13.23\ \text{V}$$

$$\upsilon_L = \mathbf{-13.23\ V}e^{-t/0.33\mu s}$$

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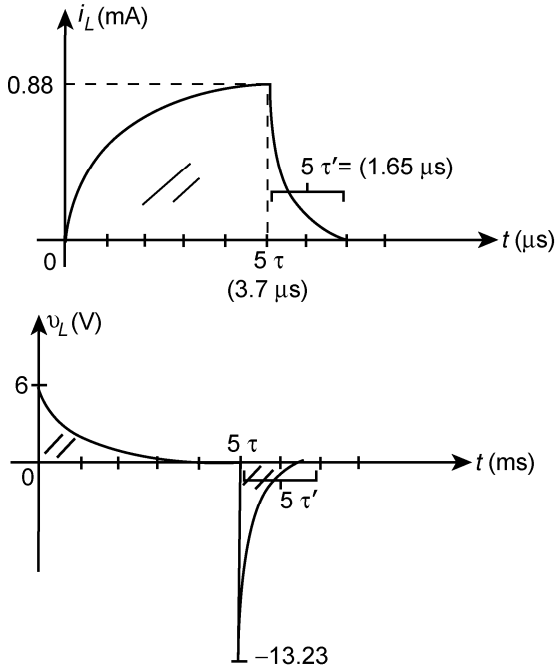
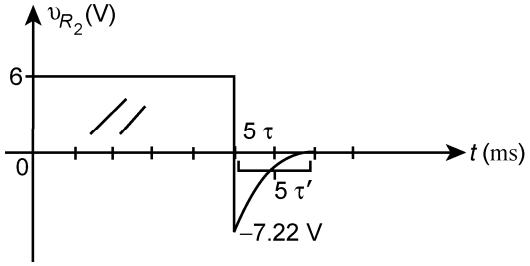
c.



d. $V_{R_{2\max}} = I_m R_2 = (0.88 \text{ mA})(8.2 \text{ k}\Omega) = 7.22 \text{ V}$



22. a. $R_{Th} = 2 \text{ k}\Omega + 3 \text{ k}\Omega \,||\, 6 \text{ k}\Omega = 2 \text{ k}\Omega + 2 \text{ k}\Omega = 4 \text{ k}\Omega$

$$E_{Th} = \frac{6 \text{ k}\Omega(12 \text{ V})}{6 \text{ k}\Omega + 3 \text{ k}\Omega} = 8 \text{ V}, \quad \tau = \frac{L}{R} = \frac{100 \text{ mH}}{4 \text{ k}\Omega} = 25 \ \mu\text{s}$$

$$I_f = \frac{E_{Th}}{R_{Th}} = \frac{8 \text{ V}}{4 \text{ k}\Omega} = 2 \text{ mA}$$

$i_L = \mathbf{2 \text{ mA}(1 - e^{-t/25\mu s})}$

$\boldsymbol{\upsilon_L = 8 \text{ V} e^{-t/25\mu s}}$

b. $i_L = 2 \text{ mA}(1 - e^{-1}) = \mathbf{1.26 \text{ mA}}$

$\upsilon_L = 8 \text{ V} e^{-1} = \mathbf{2.94 \text{ V}}$

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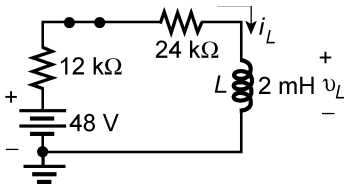
23. a. Source conversion: $E = IR = (4\text{ mA})(12\text{ k}\Omega) = 48\text{ V}$



$$\tau = \frac{L}{R} = \frac{2\text{ mH}}{36\text{ k}\Omega} = 55.56\text{ ns}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{48\text{ V}}{36\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{1.33\text{ mA}(1 - e^{-t/55.56\text{ns}})}$$

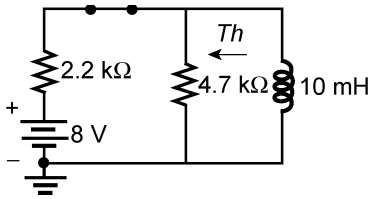
$$\upsilon_L = Ee^{-t/\tau} = \mathbf{48\text{ V}e^{-t/55.56\text{ns}}}$$

b. $t = 100$ ns:

$$i_L = 1.33\text{ mA}(1 - e^{-100\text{ns}/55.56\text{ns}}) = 1.33\text{ mA}(1 - \underbrace{e^{-1.8}}_{0.165}) = \mathbf{1.11\text{ mA}}$$

$$\upsilon_L = \mathbf{48\text{ V}e^{-1.8} = 7.93\text{ V}}$$

24. a.



$$R_{Th} = 2.2\text{ k}\Omega \parallel 4.7\text{ k}\Omega = 1.50\text{ k}\Omega$$

$$E_{Th} = \frac{4.7\text{ k}\Omega(8\text{ V})}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega} = 5.45\text{ V}$$

$$\tau = \frac{L}{R} = \frac{10\text{ mH}}{1.50\text{ k}\Omega} = 6.67\ \mu\text{s}$$

$$i_L = \frac{E}{R}(1 - e^{-t/\tau}) = \frac{5.45\text{ V}}{1.5\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{3.63\text{ mA}(1 - e^{-t/6.67\mu\text{s}})}$$

$$\upsilon_L = Ee^{-t/\tau} = \mathbf{5.45\text{ V}e^{-t/6.67\mu\text{s}}}$$

b. $t = 10\ \mu$s:

$$i_L = 3.63\text{ mA}(1 - e^{-10\mu\text{s}/6.67\mu\text{s}}) = 3.63\text{ mA}(1 - \underbrace{e^{-1.4}}_{0.246})$$

$= \mathbf{2.74\text{ mA}}$

$\upsilon_L = 5.45\text{ V}(0.246) = \mathbf{1.34\text{ V}}$

c. $\tau' = \frac{L}{R} = \frac{10\text{ mH}}{4.7\text{ k}\Omega} = 2.13\ \mu$s

$i_L = \mathbf{2.74\text{ mA}e^{-t/2.13\mu\text{s}}}$

At $t = 10\ \mu$s

$V_L = (2.74\text{ mA})(4.7\text{ k}\Omega) = 12.88\text{ V}$

$\upsilon_L = \mathbf{-12.88\text{ V}e^{-t/2.13\mu\text{s}}}$

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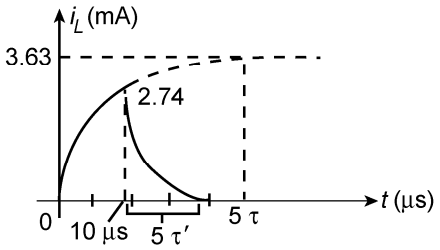

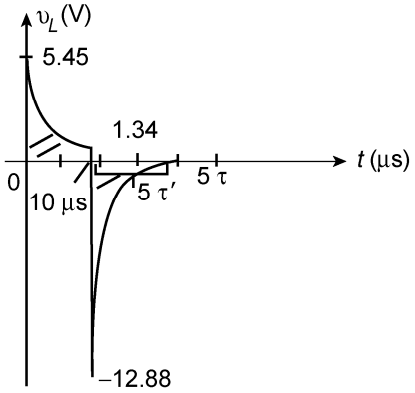

25. a. $\upsilon_L = Ee^{-t/\tau}$ $\tau = \dfrac{L}{R_1 + R_3} = \dfrac{0.6\text{ H}}{100\,\Omega + 20\,\Omega} = \dfrac{0.6\text{ H}}{120\,\Omega} = 5\text{ ms}$

$\upsilon_L = 36\text{ V}e^{-t/5\text{ ms}}$

$\upsilon_L = 36\text{ V}e^{-25\text{ ms}/5\text{ ms}} = 36\text{ V}e^{-5} = 36\text{ V}(0.00674) = \mathbf{0.24\text{ V}}$

b. $\upsilon_L = 36\text{ V}e^{-1\text{ ms}/5\text{ ms}} = 36\text{ V}e^{-0.2} = 36\text{ V}(0.819) = \mathbf{29.47\text{ V}}$

c. $\upsilon_{R_1} = i_{R_1}R_1 = i_L R_1 = \left(\dfrac{E}{R_1 + R_3}(1 - e^{-t/\tau})\right)R_1$

$= \left(\dfrac{36\text{ V}}{120\,\Omega}(1 - e^{-t/5\text{ms}})\right)100\,\Omega$

$= (300\text{ mA}(1 - e^{-t/5\text{ ms}}))100\,\Omega$

$= 30\text{ V}(1 - e^{-5\text{ ms}/5\text{ ms}}) = 30\text{ V}(1 - e^{-1})$

$= 30\text{ V}(1 - 0.368) = \mathbf{18.96\text{ V}}$

d. $i_L = 300\text{ mA}(1 - e^{-t/5\text{ ms}})$

$100\text{ mA} = 300\text{ mA}(1 - e^{-t/5\text{ ms}})$

$0.333 = 1 - e^{-t/5\text{ ms}}$

$0.667 = e^{-t/5\text{ ms}}$

$\log_e 0.667 = -t/5\text{ ms}$

$0.405 = t/5\text{ ms}$

$t = 0.405(5\text{ ms}) = \mathbf{2.03\text{ ms}}$

26. a. $I_i = \dfrac{16\text{ V}}{4.7\text{ k}\Omega + 3.3\text{ k}\Omega} = 2\text{ mA}$

$t = 0$ s: Thevenin:

$R_{Th} = 3.3\text{ k}\Omega + 1\text{ k}\Omega \,||\, 4.7\text{ k}\Omega = 3.3\text{ k}\Omega + 0.82\text{ k}\Omega = 4.12\text{ k}\Omega$

$E_{Th} = \dfrac{1\text{ k}\Omega(16\text{ V})}{1\text{ k}\Omega + 4.7\text{ k}\Omega} = 2.81\text{ V}$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

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$$I_f = \frac{2.81\text{ V}}{4.12\text{ k}\Omega} = 0.68\text{ mA},\ \tau = \frac{L}{R} = \frac{2\text{ H}}{4.12\text{ k}\Omega} = 0.49\text{ ms}$$

$$i_L = 0.68\text{ mA} + (2\text{ mA} - 0.68\text{ mA})e^{-t/0.49\text{ ms}}$$

$$i_L = \mathbf{0.68\text{ mA} + 1.32\text{ mA}}e^{\mathbf{-t/0.49\text{ ms}}}$$

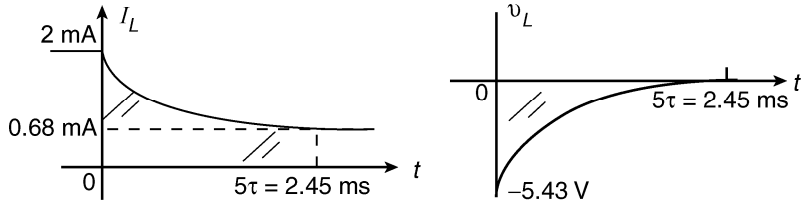
$$\upsilon_R(0+) = 2\text{ mA}(4.12\text{ k}\Omega) = 8.24\text{ V}$$

KVL(0+): $2.81\text{ V} - 8.24\text{ V} - \upsilon_L = 0$

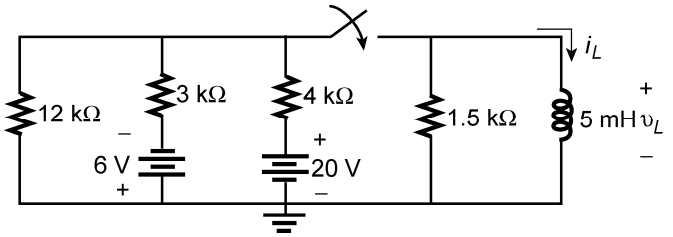
$$\upsilon_L = -5.43\text{ V}$$

$$\upsilon_L = \mathbf{-5.43\text{ V}}e^{\mathbf{-t/0.49\text{ ms}}}$$

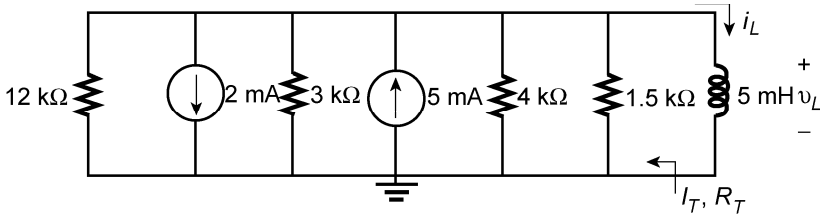
b.



27. a. Redrawn:



Source conversions:



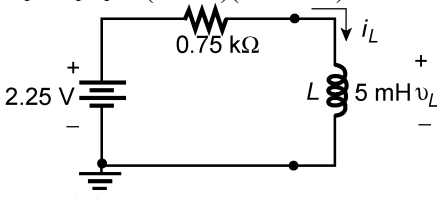
$$I_T = 5\text{ mA} - 2\text{ mA} = 3\text{ mA}\uparrow$$

$$\frac{1}{R_T} = \frac{1}{12\text{ k}\Omega} + \frac{1}{3\text{ k}\Omega} + \frac{1}{4\text{ k}\Omega} + \frac{1}{1.5\text{ k}\Omega}$$

and $R_T = 0.75\text{ k}\Omega$

Source conversion:

$$E_T = I_T R_T = (3\text{ mA})(0.75\text{ k}\Omega) = 2.25\text{ V}$$



$$\tau = \frac{L}{R} = \frac{5\text{ mH}}{0.75\text{ k}\Omega} = 6.67\ \mu\text{s}$$

$$i_L = \frac{2.25\text{ V}}{0.75\text{ k}\Omega}(1 - e^{-t/\tau}) = \mathbf{3\text{ mA}(1 - }e^{\mathbf{-t/6.67\ \mu s}}\mathbf{)}$$

$$\upsilon_L = \mathbf{2.25\text{ V}}e^{\mathbf{-t/6.67\ \mu s}}$$

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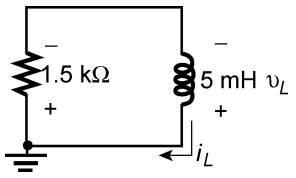
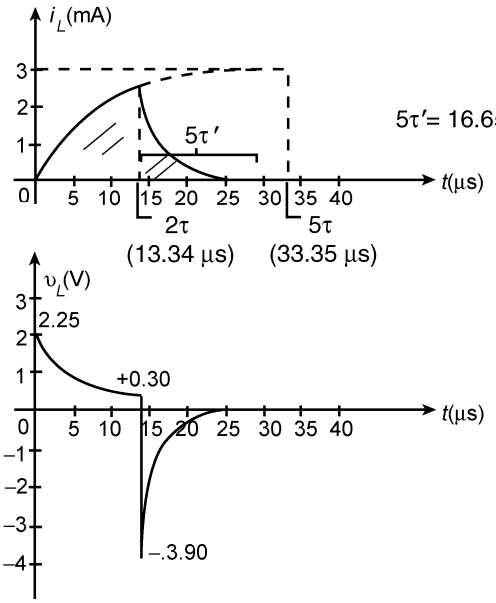
b. 2τ: 0.865 I_m, 0.135 V_m
i_L: 0.865(3 mA) = **2.60 mA**
υ_L: 0.135(2.25 V) = **0.30 V**

c.

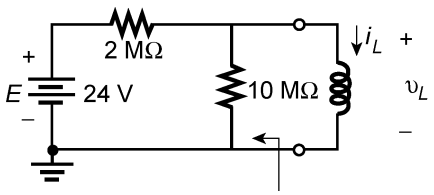


$$\tau' = \frac{L}{R} = \frac{5\text{ mH}}{1.5\,\text{k}\Omega} = 3.33\ \mu\text{s}$$
i_L = **2.60 mA** $e^{-t/3.33\ \mu s}$
$i_L(0+)$ = 2.60 mA
$\upsilon_R(0+)$ = (2.60 mA)(1.5 kΩ) = 3.90 V
υ_L = **–3.90 V** $e^{-t/3.33\ \mu s}$

d.



28. a.



$$R_{\text{Th}} = 2\ \text{M}\Omega \parallel 10\ \text{M}\Omega = 1.67\ \text{M}\Omega$$
$$E_{Th} = \frac{10\ \text{M}\Omega(24\ \text{V})}{10\ \text{M}\Omega + 2\ \text{M}\Omega} = 20\ \text{V}$$

$$I_L(0^-) = \frac{E_{Th}}{R_{Th}} = \frac{20\ \text{V}}{1.67\ \text{M}\Omega} = \textbf{12 μA}$$
$$\tau' = \frac{L}{R_{\text{meter}}} = \frac{5\ \text{H}}{10\ \text{M}\Omega} = 5\mu\text{s}$$
$$i_L = 12\ \mu\text{A}e^{-t/5\ \mu s}$$
$$10\ \mu\text{A} = 12\ \mu\text{A}e^{-t/5\ \mu s}$$
$$0.833 = e^{-t/5\ \mu s}$$
$$\log_e 0.833 = -t/5\ \mu s$$

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$0.183 = t/5\ \mu s$

$t = 0.183(5\ \mu s) = \mathbf{0.92\ \mu s}$

b. $\upsilon_L(0^+) = i_L(0^+)R_m = (12\ \mu A)(10\ M\Omega) = 120\ V$

$\upsilon_L = 120\ V e^{-t/5\mu s} = 120\ V e^{-10\mu s/5\mu s} = 120\ V e^{-2} = 120\ V(0.135) = \mathbf{16.2\ V}$

c. $\upsilon_L = 120\ V e^{-5t/\tau} = 120\ V e^{-5} = 120\ V(6.74 \times 10^{-3}) = \mathbf{0.81\ V}$

29. a. $I_i = -\dfrac{24\ V}{2.2\ k\Omega} = -10.91\ mA$

Switch open: $I_f = -\dfrac{24\ V}{2.2\ k\Omega + 4.7\ k\Omega} = -\dfrac{24\ V}{6.9\ k\Omega} = -3.48\ mA$

$i_L = I_f + (I_i - I_f)e^{-t/\tau}$

$\tau = \dfrac{L}{R} = \dfrac{1.2\ H}{6.9\ k\Omega} = 173.9\ \mu s$

$i_L = -3.48\ mA + (-10.91\ mA - (-3.48\ mA))e^{-t/173.9\ \mu s}$

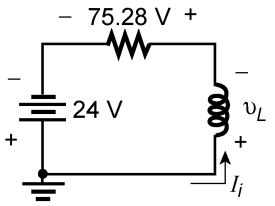
$i_L = \mathbf{-3.48\ mA - 7.43\ mA}e^{\mathbf{-t/173.9\ \mu s}}$

$t = 0+$:

$\upsilon_R(0+) = (10.91\ mA)(6.9\ k\Omega) = 75.28\ V$

KVL: $-24\ V + 75.28\ V - \upsilon_L = 0$

$\upsilon_L = 51.28\ V$



$\upsilon_L = \mathbf{51.28\ V}e^{\mathbf{-t/173.9\ \mu s}}$

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. $50\ mA = 100\ mA(1 - e^{-t/\tau})$

$0.5 = 1 - e^{-t/\tau}$

$-0.5 = -e^{-t/\tau}$

$0.5 = e^{-t/\tau}$

$\log_e 0.5 = -t/\tau$

$t = -(\tau)(\log_e 0.5) = -(20\ ms)(\log_e 0.5) = -(20\ ms)(-693.15 \times 10^{-3})$

$= \mathbf{13.86\ ms}$

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d. $99\text{ mA} = 100\text{ mA}(1 - e^{-t/20\text{ ms}})$

$0.99 = 1 - e^{-t/20\text{ms}}$

$-0.01 = -e^{-t/20\text{ms}}$

$0.01 = e^{-t/20\text{ms}}$

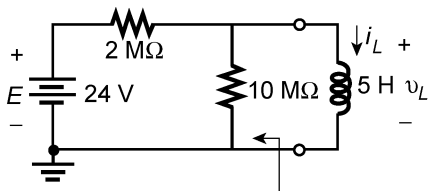
$\log_e 0.01 = -t/20\text{ ms}$

$t = -(20\text{ ms})(\log_e 0.01) = -(20\text{ ms})(-4.605) = \mathbf{92.1ms}$

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. $i_L = 12\ \mu\text{A}(1 - e^{-t/3\ \mu\text{s}})$ $\qquad \tau = \dfrac{L}{R} = \dfrac{5\text{ H}}{1.67\text{ M}\Omega} = 3\ \mu\text{s}$

$10\ \mu\text{A} = 12\ \mu\text{A}(1 - e^{-t/3\ \mu\text{s}})$

$0.8333 = 1 - e^{-t/3\ \mu\text{s}}$

$0.1667 = e^{-t/3\ \mu\text{s}}$

$\log_e(0.1667) = -t/3\ \mu\text{s}$

$1.792 = t/3\ \mu\text{s}$

$t = 1.792(3\ \mu\text{s}) = \mathbf{5.38\ \mu s}$

d. $v_L = 20\text{ V}\ e^{-t/3\ \mu\text{s}} = 20\text{ V}\ e^{-12\ \mu\text{s}/3\ \mu\text{s}} = 20\text{ V}\ e^{-4}$

$= 20\text{ V}(0.0183) = \mathbf{0.37\text{ V}}$

32. $e_L = L\dfrac{\Delta i}{\Delta t}$: $\quad 0 - 3\text{ ms}, e_L = \mathbf{0\text{ V}}$

$$3 - 8\text{ ms}, e_L = (200\text{ mH})\left(\frac{40\times10^{-3}\text{ A}}{5\times10^{-3}\text{ s}}\right) = \mathbf{1.6\text{ V}}$$

$$8 - 13\text{ ms}, e_L = -(200\text{ mH})\left(\frac{40\times10^{-3}\text{ A}}{5\times10^{-3}\text{ s}}\right) = \mathbf{-1.6\text{ V}}$$

$13 - 14\text{ ms}, e_L = \mathbf{0\text{ V}}$

$$14 - 15\text{ ms}, e_L = (200\text{ mH})\left(\frac{40\times10^{-3}\text{ A}}{5\times10^{-3}\text{ s}}\right) = \mathbf{8\text{ V}}$$

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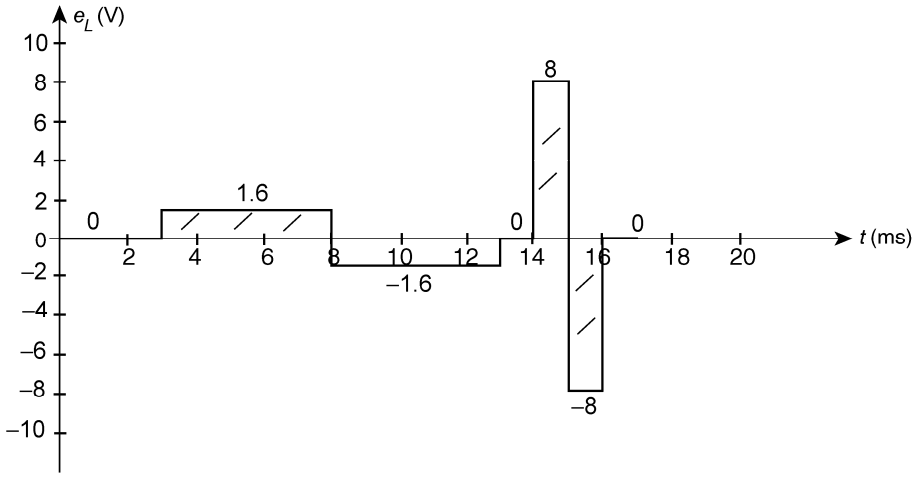
15 – 16 ms, e_L = **–8 V**

16 – 17 ms, e_L = **0 V**



33. $\upsilon_L = L\dfrac{\Delta i_L}{\Delta t}$

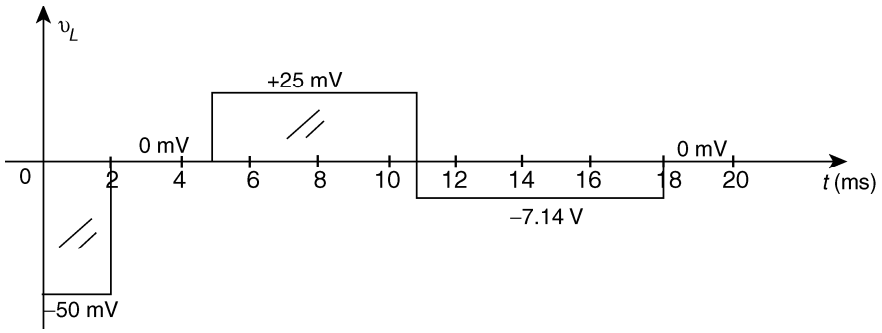
$0 \rightarrow 2$ ms: $\upsilon_L = (5\text{ mH})\left(-\dfrac{20\text{ mA}}{2\text{ ms}}\right)$ = **–50 mV**

$2 \rightarrow 5$ ms: $\Delta i_L = 0$ mA, $\upsilon_L = 0$ V

$5 \rightarrow 11$ ms: $\upsilon_L = (5\text{ mH})\left(\dfrac{+30\text{ mA}}{6\text{ ms}}\right)$ = **+25 mV**

$11 \rightarrow 18$ ms: $\upsilon_L = (5\text{ mH})\left(\dfrac{-10\text{ mA}}{7\text{ ms}}\right)$ = **–7.14 V**

$18 \rightarrow$: $\Delta\, i_L = 0$ mA, υ_L = **0 V**



34. L = 10 mH, 4 mA at t = 0 s

$$\upsilon_L = L\frac{\Delta i}{\Delta t} \Rightarrow \Delta i = \frac{\Delta t}{L}\upsilon_L$$

0 – 5 μs: $\upsilon_L = 0$ V, $\Delta i_L = 0$ mA and i_L = **4 mA**

5 – 10 μs: $\Delta i_L = \dfrac{5\ \mu\text{s}}{10\text{ mH}}(-24\text{ V})$ = **–12 mA**

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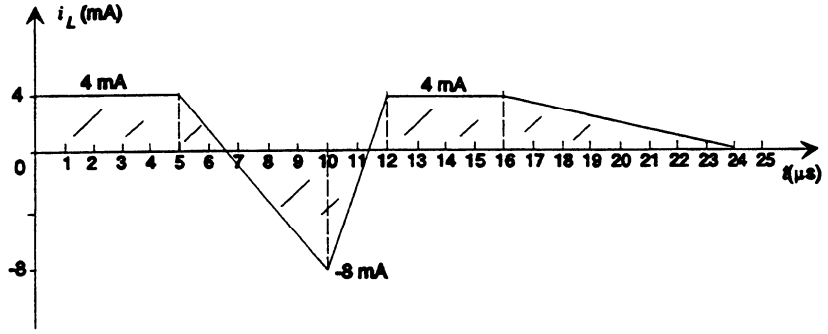
$10 - 12\ \mu s$: $\Delta i_L = \dfrac{2\ \mu s}{10\ \text{mH}}(+60\ \text{V}) = \mathbf{+12\ mA}$

$12 - 16\ \mu s$: $\upsilon_L = 0$ V, $\Delta i_L = 0$ mA and $i_L = \mathbf{4\ mA}$

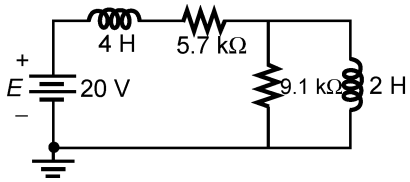
$16 - 24\ \mu s$: $\Delta i_L = \dfrac{8\ \mu s}{10\ \text{mH}}(-5\ \text{V}) = \mathbf{-4\ mA}$



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. $R'_T = 2\ \text{k}\Omega \parallel 8\ \text{k}\Omega = 1.6\ \text{k}\Omega$, $L'_T = 4\ \text{H} \parallel 6\ \text{H} = 2.4\ \text{H}$

$$\tau = \frac{L'_T}{R'_T} = \frac{2.4\ \text{H}}{1.6\ \text{k}\Omega} = 1.5\ \text{ms}$$

$$i_L = \frac{E}{R'_T}(1 - e^{-t/\tau})$$

$$= \frac{36\ \text{V}}{1.6\ \text{k}\Omega}(1 - e^{-t/1.5\text{ms}}) = \mathbf{22.5\ mA(1 - e^{-t/1.5ms})}$$

$$\upsilon_L = Ee^{-t/\tau} = \mathbf{36\ V}e^{-t/1.5\text{ms}}$$

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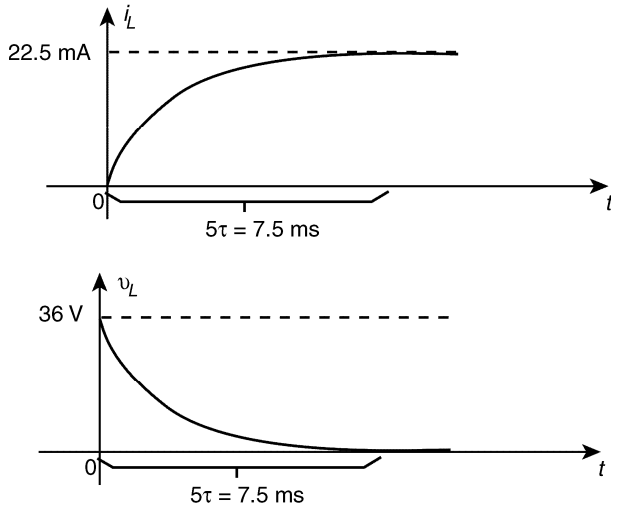
b.



39. a. Source conversion: $E = 16$ V, $R_s = 2\ \text{k}\Omega$

$R_{Th} = 2\ \text{k}\Omega + 2\ \text{k}\Omega \,||\, 8\ \text{k}\Omega = 2\ \text{k}\Omega + 16\ \text{k}\Omega = 3.6\ \text{k}\Omega$

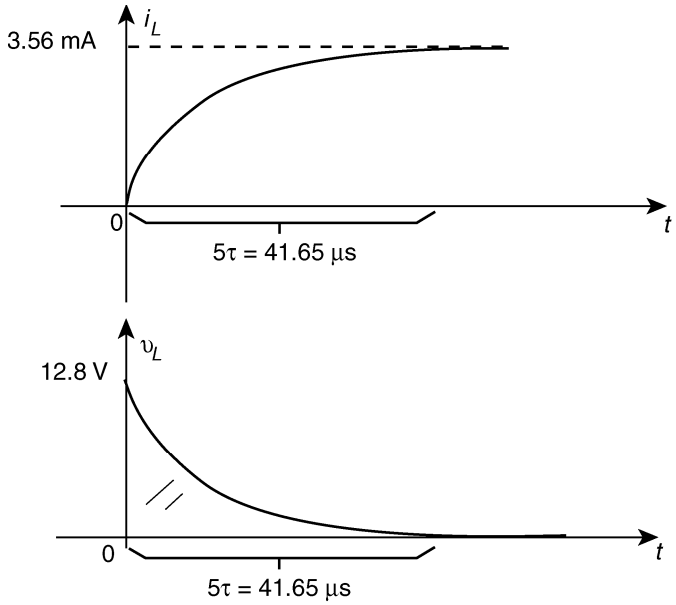
$$E_{Th} = \frac{8\ \text{k}\Omega(16\ \text{V})}{8\ \text{k}\Omega + 2\ \text{k}\Omega} = 12.8\ \text{V}$$

$$I_m = \frac{E_{Th}}{R_{Th}} = \frac{12.8\ \text{V}}{3.6\ \text{k}\Omega} = 3.56\ \text{mA}, \quad \tau = \frac{L}{R} = \frac{30\ \text{mH}}{3.6\ \text{k}\Omega} = 8.33\ \mu\text{s}$$

$i_L = \mathbf{3.56\ mA(1 - e^{-t/8.33\mu s})}$

$\upsilon_L = E_{Th}e^{-t/\tau} = \mathbf{12.8\ V}e^{-t/8.33\mu s}$

b.



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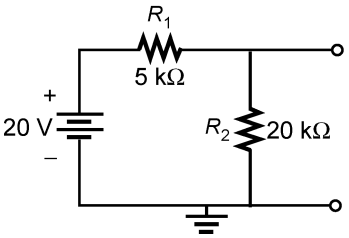
40. a.



$\leftarrow R_{Th} = 5\ \text{k}\Omega \parallel 20\ \text{k}\Omega = 4\ \text{k}\Omega$

$$E_{Th} = \frac{20\ \text{k}\Omega(20\ \text{V})}{20\ \text{k}\Omega + 5\ \text{k}\Omega} = 16\ \text{V}$$

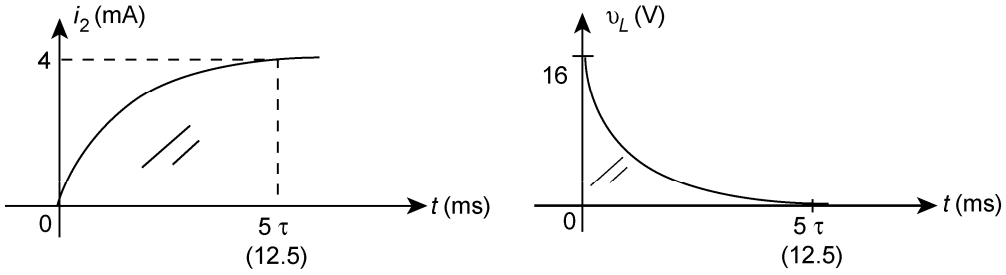
$L_T = 5\ \text{H} + 6\ \text{H} \parallel 30\ \text{H} = 5\ \text{H} + 5\ \text{H} = \mathbf{10\ H}$

$$\tau = \frac{L_T}{R} = \frac{10\ \text{H}}{4\ \text{k}\Omega} = 2.5\ \text{ms}$$

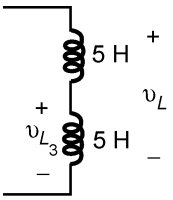
$\upsilon_L = \mathbf{16V}e^{-t/2.5\ \text{ms}}$

$$i_L = \frac{16\ \text{V}}{4\ \text{k}\Omega}(1 - e^{-t/\tau}) = \mathbf{4\ mA(1 - e^{-t/2.5\ ms})}$$

b.



c.



$$\upsilon_{L_3} = \frac{\upsilon_L}{2} = \mathbf{8\ V}\ e^{-t/2.5\ \text{ms}}$$

41. $$I_{R_1} = \frac{E}{R_1} = \frac{20\ \text{V}}{4\ \Omega} = 5\ \text{A}$$

$$I_2 = I_{R_2} = \frac{E}{R_2 + R_3} = \frac{20\ \text{V}}{6\ \Omega + 4\ \Omega} = \frac{20\ \text{V}}{10\ \Omega} = \mathbf{2\ A}$$

$$I_1 = I_{R_1} + I_2 = 5\ \text{A} + 2\ \text{A} = \mathbf{7\ A}$$

42. $I_1 = I_2 = \mathbf{0\ A}$
$V_1 = V_2 = E = \mathbf{60\ V}$

43. $$I_1 = \frac{12\ \text{V}}{4\ \Omega} = \mathbf{3\ A},\ I_2 = \mathbf{0\ A}$$
$V_1 = \mathbf{12\ V},\ V_2 = \mathbf{0\ V}$

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44. $$V_1 = \frac{(3\ \Omega + 3\ \Omega \parallel 6\ \Omega)(50\ \text{V})}{(3\ \Omega + 3\ \Omega \parallel 6\ \Omega) + 20\ \Omega} = \frac{(3\ \Omega + 2\ \Omega)(50\ \text{V})}{(3\ \Omega + 2\ \Omega) + 20\ \Omega} = \mathbf{10\ V}$$

$$R_T = 20\ \Omega + 3\ \Omega + 3\ \Omega \parallel 6\ \Omega = 23\ \Omega + 2\ \Omega = 25\ \Omega$$

$$I_s = I_1 = \frac{50\ \text{V}}{25\ \Omega} = \mathbf{2\ A}$$

$$I_{5\Omega} = 0\ \text{A},\ \therefore I_2 = \frac{6\ \Omega(I_s)}{6\ \Omega + 3\ \Omega} = \frac{6\ \Omega(2\ \text{A})}{6\ \Omega + 3\ \Omega} = \mathbf{1.33\ A}$$

$$V_2 = \frac{(3\ \Omega \parallel 6\ \Omega)(50\ \text{V})}{(3\ \Omega \parallel 6\ \Omega) + 20\ \Omega + 3\ \Omega} = \frac{2\ \Omega(50\ \text{V})}{2\ \Omega + 23\ \Omega}$$

$$= \mathbf{4\ V}$$

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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. $B = \dfrac{\Phi}{A} = \dfrac{4 \times 10^{-4}\ \text{Wb}}{0.01\ \text{m}^2} =$ **0.04 T**

4. a. $\mathcal{R} = \dfrac{l}{\mu A} = \dfrac{0.06\ \text{m}}{\mu 2 \times 10^{-4}\ \text{m}^2} = \dfrac{300}{\mu\ \text{m}}$

   b. $\mathcal{R} = \dfrac{l}{\mu A} = \dfrac{0.0762\ \text{m}}{\mu 5 \times 10^{-4}\ \text{m}^2} = \dfrac{152.4}{\mu\ \text{m}}$

   c. $\mathcal{R} = \dfrac{l}{\mu \text{A}} = \dfrac{0.1\ \text{m}}{\mu 1 \times 10^{-4}\ \text{m}^2} = \dfrac{1000}{\mu\ \text{m}}$

   from the above $\mathcal{R}_{(c)} > \mathcal{R}_{(a)} > \mathcal{R}_{(b)}$

5. $\mathcal{R} = \dfrac{\mathcal{F}}{\Phi} = \dfrac{400\ \text{At}}{4.2 \times 10^{-4}\ \text{Wb}} =$ **952.4×10^3 At/Wb**

6. $\mathcal{R} = \dfrac{\mathcal{F}}{\Phi} = \dfrac{120\ \text{gilberts}}{72{,}000\ \text{maxwells}} =$ **1.67×10^{-3} rels (CGS)**

7. $6\ \cancel{\text{in.}} \left[\dfrac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right] = 0.1524\ \text{m}$

   $H = \dfrac{\mathcal{F}}{l} = \dfrac{400\ \text{At}}{0.1524\ \text{m}} =$ **2624.67 At/m**

8. $\mu = \dfrac{2B}{H} = \dfrac{2(1200 \times 10^{-4}\ \text{T})}{600\ \text{At/m}} =$ **4×10^{-4} Wb/Am**

9. $B = \dfrac{\Phi}{A} = \dfrac{10 \times 10^{-4}\ \text{Wb}}{3 \times 10^{-3}\ \text{m}^2} = 0.33\ \text{T}$

   Fig. 12.7: $H \cong 800$ At/m

   $NI = Hl \Rightarrow I = Hl/N = (800\ \text{At/m})(0.2\ \text{m})/75\ \text{t} =$ **2.13 A**

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10. $B = \dfrac{\Phi}{A} = \dfrac{3\times10^{-4}\ \text{Wb}}{5\times10^{-4}\ \text{m}^2} = 0.6\ \text{T}$

Fig. 12.7, $H_{\text{iron}} = 2500$ At/m

Fig. 12.8, $H_{\text{steel}} = 70$ At/m

$NI = Hl_{(\text{iron})} + Hl_{(\text{steel})}$

$(100\ \text{t})I = (H_{\text{iron}} + H_{\text{steel}})l$

$(100\ \text{t})I = (2500\ \text{At/m} + 70\ \text{At/m})0.3\ \text{m}$

$$I = \frac{771\ \text{A}}{100} = \mathbf{7.71\ A}$$

11. a. $N_1I_1 + N_2I_2 = Hl$

$$B = \frac{\Phi}{A} = \frac{12\times10^{-4}\ \text{Wb}}{12\times10^{-4}\ \text{m}^2} = 1\ \text{T}$$

Fig. 12.7: $H \cong 750$ At/m

$N_1(2\ \text{A}) + 30\ \text{At} = (750\ \text{At/m})(0.2\ \text{m})$

$N_1 = \mathbf{60\ t}$

b. $$\mu = \frac{B}{H} = \frac{1\ \text{T}}{750\ \text{At/m}} = \mathbf{13.34 \times 10^{-4}\ Wb/Am}$$

12. a. $$80{,}000\ \cancel{\text{lines}}\left[\frac{1\ \text{Wb}}{10^8\ \cancel{\text{lines}}}\right] = 8 \times 10^4 \times 10^{-8}\ \text{Wb} = 8 \times 10^{-4}\ \text{Wb}$$

$$l_{(\text{cast steel})} = 5.5\ \cancel{\text{in.}}\left[\frac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right] = 0.14\ \text{m}$$

$$l_{(\text{sheet steel})} = 0.5\ \cancel{\text{in.}}\left[\frac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right] = 0.013\ \text{m}$$

$$\text{Area} = 1\ \cancel{\text{in.}}^2\left[\frac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right]\left[\frac{1\ \text{m}}{39.37\ \cancel{\text{in.}}}\right] = 6.45 \times 10^{-4}\ \text{m}^2$$

$$B = \frac{\Phi}{A} = \frac{8\times10^{-4}\ \text{Wb}}{6.45\times10^{-4}\ \text{m}^2} = 1.24\ \text{T}$$

Fig 12.8: $H_{\text{sheet steel}} \cong 460$ At/m, Fig. 12.7: $H_{\text{cast steel}} \cong 1275$ At/m

$NI = Hl_{(\text{sheet steel})} + Hl_{(\text{cast iron})}$

$= (460\ \text{At/m})(0.013\ \text{m}) + (1275\ \text{At/m})(0.14\ \text{m})$

$= 5.98\ \text{At} + 178.50\ \text{At}$

$NI = \mathbf{184.48\ At}$

b. Cast steel: $$\mu = \frac{B}{H} = \frac{1.24\ \text{T}}{1275\ \text{At/m}} = \mathbf{9.73 \times 10^{-4}\ Wb/Am}$$

Sheet steel: $$\mu = \frac{B}{H} = \frac{1.24\ \text{T}}{460\ \text{At/m}} = \mathbf{26.96 \times 10^{-4}\ Wb/Am}$$

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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 = $ "

$$B = \frac{\Phi}{A} \text{ with } 0.25\ \cancel{\text{in.}}^2 \left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right]\left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 1.6 \times 10^{-4}\text{ m}^2$$

$$B = \frac{0.8\times10^{-4}\text{ Wb}}{1.6\times10^{-4}\text{ m}^2} = 0.5\text{ T}$$

Fig. 12.8: $H_{\text{cast steel}} \cong 280$ At/m

Fig. 12.7: $H_{\text{cast iron}} \cong 1500$ At/m

$$l_{\text{cast steel}} = 5.5\ \cancel{\text{in.}}\left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.14\text{ m}$$

$$l_{\text{cast iron}} = 2.5\ \cancel{\text{in.}}\left[\frac{1\text{ m}}{39.37\ \cancel{\text{in.}}}\right] = 0.064\text{ m}$$

$(50\text{ t})I = (280\text{ At/m})(0.14\text{ m}) + (1500\text{ At/m})(0.064\text{ m})$

$50I = 39.20 + 96.00 = 135.20$

$I =$ **2.70 A**

14. a. $l_{ab} = l_{ef} = 0.05$ m, $l_{af} = 0.02$ m, $l_{bc} = l_{de} = 0.0085$ m

$NI = 2H_{ab}l_{ab} + 2H_{bc}l_{bc} + H_{fa}l_{fa} + H_gl_g$

$$B = \frac{\Phi}{A} = \frac{2.4\times10^{-4}\text{ Wb}}{2\times10^{-4}\text{ m}^2} = 1.2\text{ T} \Rightarrow H \cong 360\text{ At/m (Fig. 12.8)}$$

$100I = 2(360\text{ At/m})(0.05\text{ m}) + 2(360\text{ At/m})(0.0085\text{ m})$
$+ (360\text{ At/m})(0.02\text{ m}) + 7.97\times10^5(1.2\text{ T})(0.003\text{ m})$
$= 36\text{ At} + 6.12\text{ At} + 7.2\text{ At} + 2869\text{ At}$

$100I = 2918.32$ At

$I \cong$ **29.18 A**

b. air gap: metal = 2869 At**:**49.72 At = **58.17:1**

$$\mu_{\text{sheet steel}} = \frac{B}{H} = \frac{1.2\text{ T}}{360\text{ At/m}} = \mathbf{3.33\times10^{-3}\ Wb/Am}$$

$\mu_{\text{air}} = \mathbf{4\pi\times10^{-7}\ Wb/Am}$

$\mu_{\text{sheet steel}}$**:** $\mu_{\text{air}} = 3.33\times10^{-3}$ Wb/Am**:**$4\pi\times10^{-7} \cong$ **2627:1**

15. $4\ \cancel{\text{cm}}\left[\frac{1\text{ m}}{100\ \cancel{\text{cm}}}\right] = 0.04\text{ m}$

$$f = \frac{1}{2}NI\frac{d\phi}{dx} = \frac{1}{2}(80\text{ t})(0.9\text{ A})\frac{(8\times10^{-4}\text{ Wb} - 0.5\times10^{-4}\text{ Wb})}{\frac{1}{2}(0.04\text{ m})} = \frac{36(7.5\times10^{-4})}{0.02}$$

$=$ **1.35 N**

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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: $H_{\text{sheet steel}} \cong 2100$ At/m

$H_g = 7.97 \times 10^5 B_g = (7.97 \times 10^5)(1.54\text{ T}) = 1.23 \times 10^6$ At/m

$N_1I_1 + N_2I_2 = H_gl_g + Hl_{(\text{sheet steel})}$

(200 t)I_1 + (40 t)(0.3 A) = (1.23 × 10^6 At/m)(2 mm) + (2100 At/m)(1.88 m)

$I_1 =$ **31.98 A**

17. a. $0.2\text{ cm}\left[\frac{1\text{ m}}{100\text{ cm}}\right] = 2 \times 10^{-3}\text{ m}$

$$A = \frac{\pi d^2}{4} = \frac{(3.14)(0.01\text{ m})^2}{4} = 0.79 \times 10^{-4}\text{ m}^2$$

$NI = H_gl_g$, $H_g = 7.96 \times 10^5\, B_g$

$$(200\text{ t})I = \left[(7.96\times10^5)\left(\frac{0.2\times10^{-4}\text{ Wb}}{0.79\times10^{-4}\text{ m}^2}\right)\right]2 \times 10^{-3}\text{ m}$$

$I =$ **2.02 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(m^2)	*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	

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$$B_{bc} = B_{cd} = B_g = B_{ef} = B_{fg} = \frac{\Phi}{A} = \frac{2\times10^{-4}\text{ Wb}}{5\times10^{-4}\text{ m}^2} = 0.4\text{ T}$$

Air gap: $H_g = 7.97 \times 10^5(0.4\text{ T}) = 3.19 \times 10^5$ At/m

$H_g l_g = (3.19 \times 10^5\text{ At/m})(2\text{ mm}) = 638$ At

Fig 12.8: $H_{bc} = H_{cd} = H_{ef} = H_{fg} = 55$ At/m

$H_{bc}l_{bc} = H_{fg}l_{fg} = (55\text{ At/m})(0.1\text{ m}) = 5.5$ At

$H_{cd}l_{cd} = H_{ef}l_{ef} = (55\text{ At/m})(0.099\text{ m}) = 5.45$ At

For loop 2: $\sum \mathscr{F} = 0$

$H_{bc}l_{bc} + H_{cd}l_{cd} + H_g l_g + H_{ef}l_{ef} + H_{fg}l_{fg} - H_{gb}l_{gb} = 0$

$5.5\text{ At} + 5.45\text{ At} + 638\text{ At} + 5.45\text{ At} + 5.50\text{ At} - H_{gb}l_{gb} = 0$

$H_{gb}l_{gb} = 659.90$ At

and $H_{gb} = \dfrac{659.90\text{ At}}{0.2\text{ m}} = 3300$ At/m

Fig 12.7: $B_{gb} \cong 1.55$ T

with $\Phi_2 = B_{gb}A = (1.55\text{ T})(2 \times 10^{-4}\text{ m}^2) = 3.1 \times 10^{-4}$ Wb

$\Phi_T = \Phi_1 + \Phi_2$

$= 2 \times 10^{-4}\text{ Wb} + 3.1 \times 10^{-4}\text{ Wb}$

$= 5.1 \times 10^{-4}\text{ Wb} = \Phi_{ab} = \Phi_{ha} = \Phi_{gh}$

$$B_{ab} = B_{ha} = B_{gh} = \frac{\Phi_T}{A} = \frac{5.1\times10^{-4}\text{ Wb}}{5\times10^{-4}\text{ m}^2} = 1.02\text{ T}$$

B–H curve: (Fig 12.8):

$H_{ab} = H_{ha} = H_{gh} \cong 180$ At/m

$H_{ab}l_{ab} = (180\text{ At/m})(0.2\text{ m}) = 36$ At

$H_{ha}l_{ha} = (180\text{ At/m})(0.2\text{ m}) = 36$ At

$H_{gh}l_{gh} = (180\text{ At/m})(0.2\text{ m}) = 36$ At

which **completes** the table!

Loop #1: $\sum \mathscr{F} = 0$

$NI = H_{ab}l_{ab} + H_{bg}l_{bg} + H_{gh}l_{gh} + H_{ah}l_{ah}$

$(200\text{ t})I = 36\text{ At} + 659.49\text{ At} + 36\text{ At} + 36\text{ At}$

$(200\text{ t})I = 767.49$ At

$I \cong \mathbf{3.84\ A}$

19. $NI = Hl$

$l = 2\pi r = (6.28)(0.08\text{ m}) = 0.50$ m

$(100\text{ t})(2\text{ A}) = H(0.50\text{ m})$

$H = 400$ At/m

Fig. 12.8: $B \cong 0.68$ T

$\Phi = BA = (0.68\text{ T})(0.009\text{ m}^2)$

$\Phi = \mathbf{6.12\ mWb}$

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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!

$$\frac{300 \text{ At}}{515.67 \text{ At}} \times 100\% \cong 58\%$$

Reduce Φ to 58%

$0.58(0.94 \times 10^{-4} \text{ Wb}) = 0.55 \times 10^{-4} \text{ Wb}$

$$B = \frac{\Phi}{A} = \frac{0.55 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{ m}^2} = 0.28 \text{ T} \Rightarrow H \cong 190 \text{ At/m}$$ (Fig. 12.8)

$300 \text{ At} = (190 \text{ At/m})(0.8 \text{ m}) + 637.6(0.28 \text{ T})$

$300 \text{ At} \neq 330.53 \text{ At}$

Reduce Φ another 10% $= 0.55 \times 10^{-4} \text{ Wb} - 0.1(0.55 \times 10^{-4} \text{ Wb})$

$= 0.495 \times 10^{-4} \text{ Wb}$

$$B = \frac{\Phi}{A} = \frac{0.495 \times 10^{-4} \text{ Wb}}{2 \times 10^{-4} \text{ m}^2} = 0.25 \text{ T} \Rightarrow H \cong 175 \text{ At/m}$$ (Fig. 12.7)

$300 \text{ At} = (175 \text{ At/m})(0.8) + 637.6(0.28 \text{ T})$

$300 \text{ At} \neq 318.53 \text{ At}$ but within 5% $\therefore$ OK

$\Phi \cong \mathbf{0.55 \times 10^{-4} \text{ Wb}}$

21. a. $1\tau = 0.632 \, T_{max}$

$T_{max} \cong 1.5 \text{ T}$ for cast steel

$0.632(1.5 \text{ T}) = 0.945 \text{ T}$

At 0.945 T, $H \cong 700 \text{ At/m}$ (Fig. 12.7)

$\therefore \boldsymbol{B = 1.5 \text{ T}(1 - e^{-H/700 \text{ At/m}})}$

b. $H = 900 \text{ At/m}$:

$$B = 1.5 \text{ T}\left(1 - e^{-\frac{900 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.09 \text{ T}}$$

Graph: $\cong$ **1.1 T**

$H = 1800 \text{ At/m}$:

$$B = 1.5 \text{ T}\left(1 - e^{-\frac{1800 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.39 \text{ T}}$$

Graph: $\cong$ **1.38 T**

$H = 2700 \text{ At/m}$:

$$B = 1.5\left(1 - e^{-\frac{2700 \text{ At/m}}{700 \text{ At/m}}}\right) = \mathbf{1.47 \text{ T}}$$

Graph: $\cong$ **1.47 T**

Excellent comparison!

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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 $$H = -700\log_e\left(1 - \frac{B}{1.5\text{ T}}\right)$$

d. $B = 1$ T:

$$H = -700\log_e\left(1 - \frac{1\text{ T}}{1.5\text{ T}}\right) = \mathbf{769.03\text{ At/m}}$$

Graph: $\cong$ **750 At/m**

$B = 1.4$ T:

$$H = -700\log_e\left(1 - \frac{1.4\text{ T}}{1.5\text{ T}}\right) = \mathbf{1895.64\text{ At/m}}$$

Graph: $\cong$ **1920 At/m**

e. $$H = -700\log_e\left(1 - \frac{B}{1.5\text{ T}}\right)$$

$$= -700\log_e\left(1 - \frac{0.2\text{ T}}{1.5\text{ T}}\right)$$

$$= 100.2\text{ At/m}$$

$$I = \frac{Hl}{N} = \frac{(100.2\text{ At/m})(0.16\text{ m})}{400\text{ t}} = \mathbf{40.1\text{ mA}}$$

vs 44 mA for Ex. 12.1

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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. $T = \dfrac{1}{20\ \text{Hz}} = 0.05\ \text{s}, 5(0.05\ \text{s}) = \mathbf{0.25\ s}$

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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. $\text{Radians} = \left(\dfrac{\pi}{180°}\right)45° = \mathbf{\dfrac{\pi}{4}\ rad}$

    b. $\text{Radians} = \left(\dfrac{\pi}{180°}\right)60° = \mathbf{\dfrac{\pi}{3}\ rad}$

    c. $\text{Radians} = \left(\dfrac{\pi}{180°}\right)270° = \mathbf{1.5\pi\ rad}$

    d. $\text{Radians} = \left(\dfrac{\pi}{180°}\right)170° = \mathbf{0.94\pi\ rad}$

11. a. $\text{Degrees} = \left(\dfrac{180°}{\pi}\right)\dfrac{\pi}{4} = \mathbf{45°}$

    b. $\text{Degrees} = \left(\dfrac{180°}{\pi}\right)\dfrac{\pi}{6} = \mathbf{30°}$

    c. $\text{Degrees} = \left(\dfrac{180°}{\pi}\right)\dfrac{1}{10}\pi = \mathbf{18°}$

    d. $\text{Degrees} = \left(\dfrac{180°}{\pi}\right)0.6\ \pi = \mathbf{108°}$

12. a. $\omega = \dfrac{2\pi}{T} = \dfrac{2\pi}{2\ \text{s}} = \mathbf{3.14\ rad/s}$

    b. $\omega = \dfrac{2\pi}{0.3 \times 10^{-3}\ \text{s}} = \mathbf{20.94 \times 10^3\ rad/s}$

    c. $\omega = \dfrac{2\pi}{4 \times 10^{-6}\ \text{s}} = \mathbf{1.57 \times 10^6\ rad/s}$

    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. $\omega = 2\pi f = 2\pi(0.004\ \text{MHz}) = \mathbf{25.13 \times 10^3\ rad/s}$

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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 = $\mathbf{10^6}$, $f = \dfrac{\omega}{2\pi} = \dfrac{10{,}000 \text{ rad/s}}{2\pi}$ = **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**

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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 $\upsilon = \mathbf{80 \sin 523.58}t$

25. –

26. –

27. a. $\omega = 2\pi f = 377$ rad/s

$\upsilon = \mathbf{25 \sin (\omega t + 30°)}$

b. $\pi - \frac{2}{3}\pi = \frac{\pi}{3} = 60°$, $\omega = 2\pi f = 6.28 \times 10^3$ rad/s

$i = \mathbf{3 \times 10^{-3} \sin(6.28 \times 10^3 t - 60°)}$

28. a. $\omega = 2\pi f = 2\pi(40\ \text{Hz}) = 251.33$ rad/s

$\upsilon = \mathbf{0.01 \sin (251.33t - 110°)}$

b. $\omega = 2\pi f = 2\pi(10\ \text{kHz}) = 62.83 \times 10^3$ rad/s, $\frac{3}{4}\pi\left(\frac{180°}{\pi}\right) = 135°$

$i = \mathbf{2 \times 10^{-3} \sin (62.83 \times 10^3 t + 135°)}$

29. υ **leads** i **by 10°**

30. i **leads** υ **by 70°**

31. i **leads** υ **by 80°**

32. $\upsilon = 2 \sin (\omega t - \underbrace{30° + 90°}_{+60°})$

$i = 5 \sin(\omega t + 60°)$

} **in phase**

33. $\upsilon = 4 \sin(\omega t + 90° + 90° + 180° = 4 \sin \omega t$

$i = \sin(\omega t + 10° + 180°) = \sin(\omega t + 190°)$

} i **leads** υ **by 190°**

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34. $T = \frac{1}{f} = \frac{1}{1000\ \text{Hz}} = 1\ \text{ms}$

$$t_1 = \frac{120°}{180°}\left(\frac{T}{2}\right) = \frac{2}{3}\left(\frac{1\ \text{ms}}{2}\right) = \mathbf{\frac{1}{3}\ ms}$$

35. $\omega = 2\pi f = 50{,}000\ \text{rad/s}$

$$f = \frac{50{,}000}{2\pi} = 7957.75\ \text{Hz}$$

$$T = \frac{1}{f} = 125.66\ \mu\text{s}$$

$$t_1 = \frac{40°}{180°}\left(\frac{T}{2}\right) = 0.222(62.83\ \mu\text{s}) = \mathbf{13.95\ \mu s}$$

36. a. $T = (8\ \text{div.})(1\ \text{ms/div.}) = \mathbf{8\ ms}$ (both waveforms)

b. $f = \frac{1}{T} = \frac{1}{8\ \text{ms}} = \mathbf{125\ Hz\ (both)}$

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.

$\theta = \frac{4.6\ \text{div.}}{8\ \text{div.}} \times 360° = \mathbf{207°}$ ***i* leads *e***

or ***e* leads *i* by 153°**

37. $$G = \frac{(6\ \text{V})(1\ \text{s}) + (3\ \text{V})(1\ \text{s}) - (3\ \text{V})(1\ \text{s})}{3\ \text{s}} = \frac{6\ \text{V}}{3} = \mathbf{2\ V}$$

38. $$G = \frac{\left[\frac{1}{2}(4\ \text{ms})(20\ \text{mA})\right] - (2\ \text{ms})(5\ \text{mA})}{8\ \text{ms}} = \frac{40\ \text{mA} - 10\ \text{mA}}{8} = \frac{30\ \text{mA}}{8} = \mathbf{3.87\ mA}$$

39. $$G = \frac{2A_m - (5\ \text{mA})(\pi)}{2\pi} = \frac{2(20\ \text{mA}) - (5\ \text{mA})(\pi)}{2\pi} = \frac{40\ \text{mA} - 15.708\ \text{mA}}{2\pi} = \mathbf{3.87\ mA}$$

40. a. $T = (2\ \text{div.})(50\ \mu\text{s}) = \mathbf{100\ \mu s}$

b. $f = \frac{1}{T} = \frac{1}{100\ \mu\text{s}} = \mathbf{10\ kHz}$

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. $f = \frac{1}{T} = \frac{1}{40\ \mu\text{s}} = \mathbf{25\ kHz}$

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c. $G = \dfrac{(2.5\text{ div.})(1.5\cancel{\text{div.}}) + (1\text{ div.})(0.5\cancel{\text{div.}}) + (1\text{ div.})(0.6\cancel{\text{ div.}}) + (2.5\text{ div.})(0.4\cancel{\text{ div.}}) + (1\text{ div.})(1\cancel{\text{div.}})}{4\cancel{\text{ div.}}}$

$= \dfrac{3.75\text{ div.} + 0.5\text{ div.} + 0.6\text{ div.} + 1\text{ div.} + 1\text{ div.}}{4}$

$= \dfrac{6.85\text{ div.}}{4} = 1.713\text{ div.}$

$1.713\ \cancel{\text{div.}}(10\text{ mV}/\cancel{\text{div.}}) = \mathbf{17.13\ mV}$

42. a. $V_{rms} = 0.7071(140\text{ V}) = \mathbf{98.99\ V}$
b. $I_{rms} = 0.7071(6\text{ mA}) = \mathbf{4.24\ mA}$
c. $V_{rms} = 0.7071(40\ \mu\text{V}) = \mathbf{28.28\ \mu V}$

43. a. $\upsilon = \mathbf{14.14\ \sin 377}t$
b. $i = \mathbf{70.7 \times 10^{-3}\ \sin 377}t$
c. $\upsilon = \mathbf{2.83 \times 10^{3}\ \sin 377}t$

44. $V_{rms} = \dfrac{\sqrt{(2\text{ V})^2(4\text{ s}) + (-2\text{ V})^2(1\text{ s}) + (3\text{ V})^2\left(\frac{1}{2}\text{s}\right)}}{12\text{ s}} = \mathbf{1.43\ V}$

45. $V_{rms} = \sqrt{\dfrac{(3\text{ V})^2(2\text{ s}) + (2\text{ V})^2(2\text{ s}) + (1\text{ V})^2(2\text{ s}) + (-1\text{ V})^2(2\text{ s}) + (-3\text{ V})^2(2\text{ s}) + (-2\text{ V})^2(2\text{ s})}{12\text{ s}}}$

$= \mathbf{+2.16\ V}$

46. $G = \dfrac{(10\text{ V})(4\text{ ms}) - (10\text{ V})(4\text{ ms})}{8\text{ ms}} = \dfrac{0}{8\text{ ms}} = \mathbf{0\ V}$

$V_{rms} = \sqrt{\dfrac{(10\text{ V})^2(4\text{ ms}) + (-10\text{ V})^2(4\text{ ms})}{8\text{ ms}}} = \mathbf{10\ V}$

47. a. $T = (4\text{ div.})(10\ \mu\text{s/div.}) = \mathbf{40\ \mu s}$

$f = \dfrac{1}{T} = \dfrac{1}{40\ \mu\text{s}} = \mathbf{25\ kHz}$

Av. = (1 div.)(20 mV/div.) = **20 mV**

Peak = (2 div.)(20 mV/div.) = **40 mV**

$\text{rms} = \sqrt{V_0^2 + \dfrac{V_{max}^2}{2}} = \sqrt{(20\text{ mV})^2 + \dfrac{(40\text{ mV})^2}{2}} = \mathbf{34.64\ mV}$

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b. $T = (2 \text{ div.})(50\ \mu\text{s}) = \mathbf{100\ \mu s}$

$$f = \frac{1}{T} = \frac{1}{100\ \mu\text{s}} = \mathbf{10\ kHz}$$

Av. = (–1.5 div.)(0.2 V/div.) = **–0.3 V**

Peak = (1.5 div.)(0.2 V/div.) = **0.3 mV**

$$\text{rms} = \sqrt{V_0^2 + \frac{V_{\text{max}}^2}{2}} = \sqrt{(.3\text{ V})^2 + \frac{(.3\text{ V})^2}{2}} = \mathbf{367.42\ mV}$$

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. $V_{\text{rms}} = 0.707(16 \text{ V}) = \mathbf{11.31\ V}$

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Chapter 14

1. –

2. –

3. a. (377)(10) cos 377t = **3770 cos 377*t***

   b. (754)(0.6) cos(754t + 20°) = **452.4 cos(754*t* + 20°)**

   c. ($\sqrt{2}$ 20)(157) cos(157t – 20°) = **4440.63 cos(157*t* – 20°)**

   d. (–200)(1) cos(t + 180°) = –200 cos(t + 180°) = **200 cos *t***

4. a. $I_m = V_m/R$ = 150 V/5 Ω = 30 A, i = **30 sin 200*t***

   b. $I_m = V_m/R$ = 30 V/5 Ω = 6 A, i = **6 sin(377*t* + 20°)**

   c. $I_m = V_m/R$ = 40 V/5 Ω = 8 A, i = **8 sin(ω*t* + 100°)**

   d. $I_m = V_m/R$ = 80 V/5 Ω = 16 A, i = **16 sin(ω*t* + 220°)**

5. a. $V_m = I_mR = (0.1 \text{ A})(7 \times 10^3\ \Omega) = 700$ V
   υ = **700 sin 1000*t***

   b. $V_m = I_mR = (2 \times 10^{-3} \text{ A})((7 \times 10^3\ \Omega) = 14.8$ V
   υ = **14.8 sin(400*t* – 120°)**

   c. $i = 6 \times 10^{-6} \sin(\omega t - 2° + 90°) = 6 \times 10^{-6} \sin(\omega t + 88°)$
   $V_m = I_mR = (6 \times 10^{-6} \text{ A})((7 \times 10^3\ \Omega) = 42 \times 10^{-3}$ V
   υ = **42×10^{-3} sin(ω*t* + 88°)**

   d. $i = 0.004 \sin(\omega t + 90° + 90° + 180°) = 0.004 \sin(\omega t + 360°) = 0.0004 \sin \omega t$
   $V_m = I_mR = (4 \times 10^{-3} \text{ A})((7 \times 10^3\ \Omega) = 28$ V
   υ = **28 sin ω*t***

6. a. **0 Ω**

   b. $X_L = 2\pi fL = 2\pi Lf = (6.28)(2 \text{ H})f = 12.56f = 12.56(10 \text{ Hz})$ = **125.6 Ω**

   c. $X_L = 12.56f = 12.56(60 \text{ Hz})$ = **753.6 Ω**

   d. $X_L = 12.56f = 12.56(2000 \text{ Hz})$ = **25.13 kΩ**

   e. $X_L = 12.56f = 12.56(10^5 \text{ Hz})$ = **1.256 MΩ**

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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. $V_m = I_m X_L = (5\text{ A})(20\ \Omega) = 100\text{ V}$
$\upsilon = \mathbf{100\ \sin(\omega t + 90°)}$

b. $V_m = I_m X_L = (40 \times 10^{-3}\text{ A})(20\ \Omega) = 0.8\text{ V}$
$\upsilon = \mathbf{0.8\ \sin(\omega t + 150°)}$

c. $i = 6\ \sin(\omega t + 150°)$, $V_m = I_m X_L = (6\text{ A})(20\ \Omega) = 120\text{ V}$
$\upsilon = 120\ \sin(\omega t + 240°) = \mathbf{120\ \sin(\omega t - 120°)}$

d. $i = 3\ \sin(\omega t + 100°)$, $V_m = I_m X_L = (3\text{ A})(20\ \Omega) = 60\text{ V}$
$\upsilon = \mathbf{60\ \sin(\omega t + 190°)}$

10. a. $X_L = \omega L = (100\text{ rad/s})(0.1\text{ H}) = 10\ \Omega$
$V_m = I_m X_L = (10\text{ A})(10\ \Omega) = 100\text{ V}$
$\upsilon = \mathbf{100\ \sin(100t + 90°)}$

b. $X_L = \omega L = (377\text{ rad/s})(0.1\text{ H}) = 37.7\ \Omega$
$V_m = I_m X_L = (6 \times 10^{-3}\text{ A})(37.7\ \Omega) = 226.2\text{ mV}$
$\upsilon = \mathbf{226.2 \times 10^{-3}\ \sin(377t + 90°)}$

c. $X_L = \omega L = (400\text{ rad/s})(0.1\text{ H}) = 40\ \Omega$
$V_m = I_m X_L = (5 \times 10^{-6}\text{ A})(40\ \Omega) = 200\ \mu\text{V}$
$\upsilon = \mathbf{200 \times 10^{-6}\ \sin(400t + 110°)}$

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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. $I_m = \dfrac{V_m}{X_L} = \dfrac{120 \text{ V}}{50 \Omega} = 2.4 \text{ A}$, $i = \mathbf{2.4 \sin(\omega}\boldsymbol{t} \mathbf{- 90°)}$

b. $I_m = \dfrac{V_m}{X_L} = \dfrac{30 \text{ V}}{50 \Omega} = 0.6 \text{ A}$, $i = \mathbf{0.6 \sin(\omega}\boldsymbol{t} \mathbf{- 70°)}$

c. $\upsilon = 40 \sin(\omega t + 100°)$
$I_m = \dfrac{V_m}{X_L} = \dfrac{40 \text{ V}}{50 \Omega} = 0.8 \text{ A}$, $i = \mathbf{0.8 \sin(\omega}\boldsymbol{t} \mathbf{+ 10°)}$

d. $\upsilon = 80 \sin(377t + 220°)$
$I_m = \dfrac{V_m}{X_L} = \dfrac{80 \text{ V}}{50 \Omega} = 1.6 \text{ A}$, $i = \mathbf{1.6 \sin(377}\boldsymbol{t} \mathbf{+ 130°)}$

12. a. $X_L = \omega L = (60 \text{ rad/s})(0.2 \text{ H}) = 12 \Omega$
$I_m = V_m / X_L = 1.5 \text{ V}/12 \Omega = 0.125 \text{ A}$
$i = \mathbf{0.125 \sin(60}\boldsymbol{t} \mathbf{- 90°)}$

b. $X_L = \omega L = (10 \text{ rad/s})(0.2 \text{ H}) = 2 \Omega$
$I_m = V_m / X_L = 16 \text{ mV}/2 \Omega = 8 \text{ mA}$
$i = 8 \times 10^{-3} \sin(t + 2° - 90°) = \mathbf{8 \times 10^{-3} \sin(}\boldsymbol{t} \mathbf{- 88°)}$

c. $\upsilon = 4.8 \sin(0.05t + 230°)$
$X_L = \omega L = (0.05 \text{ rad/s})(0.2 \text{ H}) = 0.01 \Omega$
$I_m = V_m / X_L = 4.8 \text{ V}/0.01 \Omega = 480 \text{ A}$
$i = 480 \sin(0.05t + 230° - 90°) = \mathbf{480 \sin(0.05}\boldsymbol{t} \mathbf{+ 140°)}$

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. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(120 \text{ Hz})(5 \times 10^{-6} \text{ F})} = \mathbf{265.39 \Omega}$

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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. $I_m = V_m/X_C = 120\text{ V}/2.5\ \Omega = 48\text{ A}$
$i = \mathbf{48\sin(\omega t + 90°)}$

b. $I_m = V_m/X_C = 0.4\text{ V}/2.5\ \Omega = 0.16\text{ A}$
$i = \mathbf{0.16\sin(\omega t + 110°)}$

c. $\upsilon = 8\sin(\omega t + 100°)$
$I_m = V_m/X_C = 8\text{ V}/2.5\ \Omega = 3.2\text{ A}$
$i = \mathbf{3.2\sin(\omega t + 190°)}$

d. $\upsilon = -70\sin(\omega t + 40°) = 70\sin(\omega t + 220°)$
$I_m = V_m/X_C = 70\text{ V}/2.5\ \Omega = 28\text{ A}$
$i = 28\sin(\omega t + 310°) = \mathbf{28\sin(\omega t - 50°)}$

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17. a. $\upsilon = 30 \sin 200t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(200)(1\times10^{-6})} = 5\ \text{k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{30\ \text{V}}{5\ \text{k}\Omega} = 6\ \text{mA}$, $i = \mathbf{6 \times 10^{-3}\ \sin(200t + 90°)}$

b. $\upsilon = 60 \times 10^{-3} \sin 377t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(377)(1\times10^{-6})} = 2.65\ \text{k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{60\times10^{-3}\ \text{V}}{2{,}650\ \Omega} = 22.64\ \mu\text{A}$, $i = \mathbf{22.64 \times 10^{-6}\ \sin(377t + 90°)}$

c. $\upsilon = 120 \sin(374t + 210°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(374)(1\times10^{-6})} = 2.67\ \text{k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{120\ \text{V}}{2{,}670\ \Omega} = 44.94\ \text{mA}$, $i = \mathbf{44.94 \times 10^{-3}\ \sin(374t + 300°)}$

d. $\upsilon = 70 \sin(800t + 70°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(800)(1\times10^{-6})} = 1.25\ \text{k}\Omega$

$I_m = \dfrac{V_m}{X_C} = \dfrac{70\ \text{V}}{1250\ \Omega} = 56\ \text{mA}$, $i = \mathbf{56 \times 10^{-3}\ \sin(\omega t + 160°)}$

18. a. $V_m = I_m X_C = (50 \times 10^{-3}\ \text{A})(10\ \Omega) = 0.5\ \text{V}$
$\upsilon = \mathbf{0.5\ \sin(\omega t - 90°)}$

b. $V_m = I_m X_C = (2 \times 10^{-6})(10\ \Omega) = 20\ \mu\text{V}$
$\upsilon = \mathbf{20 \times 10^{-6}\ \sin(\omega t - 30°)}$

c. $i = -6 \sin(\omega t - 30°) = 6 \sin(\omega t + 150°)$
$V_m = I_m X_C = (6\ \text{A})(10\ \Omega) = 60\ \text{V}$
$\upsilon = \mathbf{60\ \sin(\omega t + 60°)}$

d. $i = 3 \sin(\omega t + 100°)$
$V_m = I_m X_C = (3\ \text{A})(10\ \Omega) = 30\ \text{V}$
$\upsilon = \mathbf{30\ \sin(\omega t + 10°)}$

19. a. $i = 0.2 \sin 300t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(300)(0.5\times10^{-6})} = 6.67\ \text{k}\Omega$

$V_m = I_m X_C = (0.2\ \text{A})(6{,}670\ \Omega) = 1334\ \text{V}$, $\upsilon = \mathbf{1334\ \sin(300t - 90°)}$

b. $i = 8 \times 10^{-3} \sin 377t$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(377)(0.5\times10^{-6})} = 5.31\ \text{k}\Omega$

$V_m = I_m X_C = (8 \times 10^{-3}\ \text{A})(5.31 \times 10^{3}\ \Omega) = 42.48\ \text{V}$
$\upsilon = \mathbf{42.48\ \sin(377t - 90°)}$

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c. $i = 60 \times 10^{-3} \sin(754t + 90°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(754)(0.5 \times 10^{-6})} = 2.65\ \text{k}\Omega$

$V_m = I_m X_C = (60 \times 10^{-3}\ \text{A})(2.65 \times 10^{3}\ \Omega) = 159\ \text{V}$

$\upsilon =$ **159 sin 754*t***

d. $i = 80 \times 10^{-3} \sin(1600t - 80°)$, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(1600)(0.5 \times 10^{-6})} = 1.25\ \text{k}\Omega$

$V_m = I_m X_C = (80 \times 10^{-3}\ \text{A})(1.25 \times 10^{3}\ \Omega) = 100\ \text{V}$

$\upsilon =$ **100 sin(1600*t* – 170°)**

20. a. υ leads i by 90° $\Rightarrow L$, $X_L = V_m/I_m = 550\ \text{V}/11\ \text{A} = 50\ \Omega$

$$L = \frac{X_L}{\omega} = \frac{50\ \Omega}{377\ \text{rad/s}} = \textbf{132.63 mH}$$

b. υ leads i by 90° $\Rightarrow L$, $X_L = V_m/I_m = 36\ \text{V}/4\ \text{A} = 9\ \Omega$

$$L = \frac{1}{\omega X_L} = \frac{1}{(754\ \text{rad/s})(9\ \Omega)} = \textbf{147.36 µH}$$

c. υ and i are in phase $\Rightarrow R$

$$R = \frac{V_m}{I_m} = \frac{10.5\ \text{V}}{1.5\ \text{A}} = \textbf{7 Ω}$$

21. a. $\left.\begin{array}{l} i = 5\sin(\omega t + 90°) \\ \upsilon = 2000 \sin \omega t \end{array}\right\}$ i leads υ by 90° $\Rightarrow$ ***C***

$$X_C = \frac{V_m}{I_m} = \frac{2000\ \text{V}}{5\ \text{A}} = 400\ \Omega$$

b. $\left.\begin{array}{l} i = 2\sin(157t + 60°) \\ \upsilon = 80\sin(157t + 150°) \end{array}\right\}$ υ leads i by 90° $\Rightarrow$ ***L***

$$X_L = \frac{V_m}{I_m} = \frac{80\ \text{V}}{2\ \text{A}} = 40\ \Omega,\ L = \frac{X_L}{\omega} = \frac{40\ \Omega}{157\ \text{rad/s}} = \textbf{254.78 mH}$$

c. $\left.\begin{array}{l} \upsilon = 35\sin(\omega t - 20°) \\ i = 7\sin(\omega t - 20°) \end{array}\right\}$ in phase $\Rightarrow$ ***R***

$$R = \frac{V_m}{I_m} = \frac{35\ \text{V}}{7\ \text{A}} = \textbf{5 Ω}$$

22. –

23. –

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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. $X_L = 2\pi fL = R$

$$L = \frac{R}{2\pi f} = \frac{10{,}000\,\Omega}{2\pi(5\times10^3\ \text{Hz})} = \textbf{318.47 mH}$$

26. $X_C = X_L$

$$\frac{1}{2\pi fC} = 2\pi fL$$

$$f^2 = \frac{1}{4\pi^2 LC}$$

and $f = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(10\times10^{-3}\ \text{H})(1\times10^{-6}\,\text{F})}} = \textbf{1.59 kHz}$

27. $X_C = X_L$

$$\frac{1}{2\pi fC} = 2\pi fL \Rightarrow C = \frac{1}{4\pi^2 f^2 L} = \frac{1}{4(9.86)(2500\times10^6)(2\times10^{-3})} = \textbf{5.07 nF}$$

28. a. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(550\ \text{V})(11\ \text{A})}{2}\cos 90° = (\ )(0) = \textbf{0 W}$

b. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(36\ \text{V})(4\ \text{A})}{2}\cos 90° = (\ )(0) = \textbf{0 W}$

c. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(10.5\ \text{V})(1.5\ \text{A})}{2}\cos 0° = \textbf{7.88 W}$

29. a. $P = \dfrac{V_m I_m}{2}\cos\theta = \dfrac{(5\ \text{A})(2000\ \text{V})}{2}\cos 90° = \textbf{0 W}$

b. $\cos\theta = 0 \Rightarrow \textbf{0 W}$

c. $P = \dfrac{(35\ \text{V})(7\ \text{A})}{2}\cos 0° = \textbf{122.5 W}$

30. a. $P = \dfrac{(60\ \text{V})(15\ \text{A})}{2}\cos 30° = \textbf{389.7 W}$, $F_p = \textbf{0.866}$

b. $P = \dfrac{(50\ \text{V})(2\ \text{A})}{2}\cos 0° = \textbf{50 W}$, $F_p = \textbf{1.0}$

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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. $L \Rightarrow \mathbf{0\ W}$

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36. a. $E_m = I_m X_C = (30 \times 10^{-3}\ \text{A})(2.4\ \text{k}\Omega) = 72\ \text{V}$
$e = 72 \sin(377t - 20° - 90°) = \mathbf{72\ \sin(377t - 110°)}$

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. $X_{C_1} = \dfrac{1}{2\pi f C_1} = \dfrac{1}{\omega C_1} = \dfrac{1}{(10^4\ \text{rad/s})(2\ \mu\text{F})} = 50\ \Omega$

$X_{C_2} = \dfrac{1}{\omega \text{C}_2} = \dfrac{1}{(10^4)(10\ \mu F)} = 10\ \Omega$

$\mathbf{E} = 100\ \text{V} \angle 60°$ $\qquad \mathbf{I}_1 = \dfrac{\mathbf{E}}{\mathbf{Z}_{C_1}} = \dfrac{120\ \text{V} \angle 60°}{50\ \Omega \angle -90°} = 2.4\ \text{A} \angle 150°$

$\mathbf{I}_2 = \dfrac{\mathbf{E}}{\mathbf{Z}_{C_2}} = \dfrac{120\ \text{V} \angle 60°}{10\ \Omega \angle -90°} = 12\ \text{A} \angle 150°$

$i_1 = \sqrt{2}\ 2.4 \sin(10^4 t + 150°) = \mathbf{3.39\ \sin(10^4 t + 150°)}$
$i_2 = \sqrt{2}\ 12 \sin(10^4 t + 150°) = \mathbf{16.97\ \sin(10^4 t + 150°)}$

b. $\mathbf{I}_s = \mathbf{I}_1 + \mathbf{I}_2 = 2.4\ \text{A} \angle 150° + 12\ \text{A} \angle 150° = 14.4\ \text{A} \angle 150°$
$i_s = \sqrt{2}\ 14.4 \sin(10^4 t + 150°) = \mathbf{20.36\ \sin(10^4 t + 150°)}$

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 $\upsilon_s = \mathbf{8..53 \times 10^3\ \sin(10^3 t + 120°)}$

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 $i_1 = \mathbf{22.63\ \sin(10^3 t + 30°)}$
$X_{L_2} = 2\pi f L_2 = 2\pi(10^3\ \text{Hz})(120\ \text{mH}) = 753.98\ \Omega$

$I_{m_2} = \dfrac{8.53 \times 10^3}{753.98\ \Omega} = 11.31\ \text{A}$

and $i_2 = \mathbf{11.31\ \sin(10^3 t + 30°)}$

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39. a. **5.0 ∠36.87°** b. **2.83 ∠45°**
c. **17.09 ∠69.44°** d. **1.0×10^{3} ∠84.29°**
e. **1077.03 ∠21.80°** f. **6.58×10^{-3} ∠81.25°**
g. **11.78 ∠–49.82°** h. **8.94 ∠–153.43°**
i. **61.85 ∠–104.04°** j. **101.73 ∠–39.94°**
k. **4,326.66 ∠123.69°** l. **25.5×10^{-3} ∠–78.69°**

40. a. **5.196 + *j*3.0** b. **6.946 + *j*39.39**
c. **2530.95 + *j*6953.73** d. **$3.96 \times 10^{-4} + j5.57 \times 10^{-5}$**
e. ***j*0.04** f. **$6.91 \times 10^{-3} + j6.22 \times 10^{-3}$**
g. **–56.29 + *j*32.50** h. **–0.85 + *j*0.85**
i. **–469.85 – *j*171.01** j. **5177.04 – *j*3625.0**
k. **–4.31 – *j*6.16** l. **$-6.93 \times 10^{-3} - j4.00 \times 10^{-3}$**

41. a. **15.03 ∠86.19** b. **60.21 ∠4.76°**
c. **0.30 ∠88.09°** d. **223.61 ∠–63.43°**
e. **86.18 ∠93.73°** f. **38.69 ∠–94.0°**

42. a. **12.95 + *j*1.13** b. **8.37 + *j*159.78**
c. **$7.00 \times 10^{-6} + j2.44 \times 10^{-7}$** d. **–8.69 + *j*0.46**
e. **75.82 – *j*5.30** f. **–34.51 – *j*394.49**

43. a. **11.8 + *j*7.0** b. **151.90 + *j*49.90**
c. **$4.72 \times 10^{-6} + j71$** d. **5.20 + *j*1.60**
e. **209.30 + *j*311.0** f. **–21.20 + *j*12.0**
g. $6 \angle 20° + 8 \angle 80° = (5.64 + j2.05) + (1.39 + j7.88) =$ **7.03 + *j*9.93**
h. $(29.698 + j29.698) + (31.0 + j53.69) - (-35 + j60.62) =$ **95.7 + *j*22.77**

44. a. **–12.0 + *j*34.0** b. **86.80 + *j*312.40**
c. **$56. \times 10^{-3} - j\ 8 \times 10^{-3}$** d. **698.00 ∠–114°**
e. **8.00 ∠20°** f. **49.68 ∠–64.0°**
g. **40×10^{-3} ∠40°** h. **–16,740 ∠160°**

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45. a. **$6.0 \angle -50°$**

b. **$200 \times 10^{-6} \angle 60°$**

c. **$109 \angle -170.0°$**

d. **$76.47 \angle -80$**

e. **$4 \angle 0°$**

f. **$5.93 \angle -134.47°$**

g. $(0.05 + j0.25)/(8 - j60) = 0.255 \angle 78.69°/60.53 \angle -82.41° =$ **$4.21 \times 10^{-3} \angle 161.10°$**

h. **$9.30 \angle -43.99°$**

46. a. $\dfrac{10 - j5}{1 + j0} =$ **$10.0 - j5.0$**

b. $\dfrac{8 \angle 60°}{102 + j400} = \dfrac{8 \angle 60°}{412.80 \angle 75.69°} =$ **$19.38 \times 10^{-3} \angle -15.69°$**

c. $\dfrac{(6 \angle 20°)(120 \angle -40°)(8.54 \angle 69.44°)}{2 \angle -30°} = \dfrac{6.15 \times 10^{3} \angle 49.44°}{2 \angle -30°} =$ **$3.07 \times 10^{3} \angle 79.44°$**

d. $\dfrac{(0.16 \angle 120°)(300 \angle 40°)}{9.487 \angle 71.565°} = \dfrac{48 \angle 160°}{9.487 \angle 71.565°} =$ **$5.06 \angle 88.44°$**

e. $\left(\dfrac{1}{4 \times 10^{-4} \angle 20°}\right)\left(\dfrac{8}{j(j^2)}\right)\left(\dfrac{1}{36 - j30}\right)$

$\left(2500 \angle -20°\right)\left(\dfrac{8}{-j}\right)\left(\dfrac{1}{46.861 \angle -39.81°}\right)$

$(2500 \angle -20°)(8j)(0.0213 \angle 39.81°) =$ **$426 \angle 109.81°$**

47. a. $x + j4 + 3x + jy - j7 = 16$

$(x + 3x) + j(4 + y - 7) = 16 + j0$

$x + 3x = 16$ $\qquad$ $4 + y - 7 = 0$

$4x = 16$ $\qquad$ $y = +7 - 4$

$x =$ **4** $\qquad$ $y =$ **3**

b. $(10 \angle 20°)(x \angle -60°) = 30.64 - j25.72$

$10x \angle -40° = 40 \angle -40°$

$10\,x = 40$

$x =$ **4**

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c. $5x + j10$
$2 - jy$
$10x + j20 - j5xy - j^2 10y = 90 - j70$
$(10x + 10y) + j(20 - 5xy) = 90 - j70$
$10x + 10y = 90$
$x + y = 9$
$x = 9 - y \Rightarrow$

$20 - 5xy = -70$
$20 - 5(9 - y)y = -70$
$5y(9 - y) = 90$
$y^2 - 9y + 18 = 0$
$y = \dfrac{-(-9) \pm \sqrt{(-9)^2 - 4(1)(18)}}{2}$
$y = \dfrac{9 \pm 3}{2} = 6, 3$

For $y = 6$, $x = 3$
$y = 3$, $x = 6$
($x = 3$, $y = 6$) or ($x = 6$, $y = 3$)

d. $\dfrac{80 \angle 0°}{40 \angle \theta} = 4 \angle -\theta = 3.464 - j2 = 4 \angle -30°$
$\theta = 30°$

48. a. **$160.0 \angle 30°$** b. **$25 \times 10^{-3} \angle -40°$**

c. **$70.71 \angle -90°$** d. **$14.14 \angle 0°$**

e. **$4.24 \times 10^{-6} \angle 90°$** f. **$2.55 \times 10^{-6} \angle 70°$**

49. a. **$56.57 \sin(377t + 20°)$** b. **$169.68 \sin(377t + 10°)$**

c. **$11.31 \times 10^{-3} \sin(377t + 120°)$** d. **$7.07 \sin(377t + 90°)$**

e. **$1696.8 \sin(377t - 50°)$** f. **$6000 \sin(377t - 180°)$**

50. (Using peak values)
$e_{in} = \upsilon_a + \upsilon_b \Rightarrow \upsilon_a = e_{in} - \upsilon_b$
$= 60 \text{ V} \angle 20° - 20 \text{ V} \angle -20°$
$= 46.49 \text{ V} \angle 36.05°$
and $e_{in} = 46.49 \sin(377t + 36.05°)$

51. $i_s = i_1 + i_2 \Rightarrow i_1 = i_s - i_2$
(Using peak values) $= (20 \times 10^{-6} \text{ A} \angle 60°) - (6 \times 10^{-6} \text{ A} \angle -30°) = 20.88 \times 10^{-6} \text{ A} \angle 76.70°$
$i_1 = \mathbf{20.88 \times 10^{-6}} \sin(\omega t + 76.70°)$

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 $e =$ **$102.07 \sin(\omega t + 62.61°)$**

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53. (Using effective values)

$$\mathbf{I}_s = \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3 = 4.24 \text{ mA} \angle 180° + 5.66 \text{ mA} \angle -180° + 11.31 \text{ mA} \angle -180°$$
$$= -4.24 \text{ mA} - 5.66 \text{ mA} - 11.31 \text{ mA}$$
$$= 21.21 \times 10^{-3} \sin (377t + 180°)$$
$$i_s = \mathbf{-21.21 \times 10^{-3} \sin 377}\boldsymbol{t}$$

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Chapter 15

1. a. $R \angle 0° = \mathbf{6.8\ \Omega \angle 0° = 6.8\ \Omega}$

b. $X_L = \omega L = (377 \text{ rads/s})(1.2 \text{ H}) = 452.4\ \Omega$
$X_L \angle 90° = \mathbf{452.4\ \Omega \angle 90° = +}\boldsymbol{j}\mathbf{452.4\ \Omega}$

c. $X_L = 2\pi fL = (6.28)(50 \text{ Hz})(0.05 \text{ H}) = 15.7\ \Omega$
$X_L \angle 90° = \mathbf{15.7\ \Omega \angle 90° = +}\boldsymbol{j}\mathbf{15.7\ \Omega}$

d. $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(100 \text{ rad/s})(10 \times 10^{-6} \text{ F})} = 1 \text{ k}\Omega$
$X_C \angle -90° = \mathbf{1\ k\Omega \angle -90° = -}\boldsymbol{j}\mathbf{1\ k\Omega}$

e. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10 \times 10^3 \text{ Hz})(0.05 \times 10^{-6} \text{ F})} = 318.47\ \Omega$
$X_C \angle -90° = \mathbf{318.47\ \Omega \angle -90° = -}\boldsymbol{j}\mathbf{318.47\ \Omega}$

f. $R \angle 0° = \mathbf{220\ \Omega \angle 0° = 220\ \Omega}$

2. a. $\mathbf{V} = 10.61 \text{ V} \angle 10°$, $\mathbf{I} = \dfrac{V \angle \theta}{R \angle 0°} = \dfrac{10.61 \text{ V} \angle 10°}{3\ \Omega \angle 0°} = 3.54 \text{ A} \angle 10°$
$\boldsymbol{i} = \mathbf{5 \sin(}\boldsymbol{\omega t}\mathbf{ + 10°)}$

b. $\mathbf{V} = 39.60 \text{ V} \angle 10°$, $\mathbf{I} = \dfrac{V \angle \theta}{X_L \angle 90°} = \dfrac{39.60 \text{ V} \angle 10°}{7\ \Omega \angle 90°} = 5.66 \text{ A} \angle -80°$
$\boldsymbol{i} = \mathbf{8 \sin(}\boldsymbol{\omega t}\mathbf{ - 80°)}$

c. $\mathbf{V} = 17.68 \text{ V} \angle -20°$, $\mathbf{I} = \dfrac{V \angle \theta}{X_C \angle -90°} = \dfrac{17.68 \text{ V} \angle -20°}{100\ \Omega \angle -90°} = 0.1768 \text{ A} \angle 70°$
$\boldsymbol{i} = \mathbf{0.25 \sin(}\boldsymbol{\omega t}\mathbf{ + 70°)}$

d. $\mathbf{V} = 2.828 \text{ mV} \angle -120°$, $\mathbf{I} = \dfrac{V \angle \theta}{R \angle 0°} = \dfrac{2.828 \text{ mV} \angle -120°}{5.1 \text{ k}\Omega \angle 0°} = 0.555\ \mu\text{A} \angle -120°$
$\boldsymbol{i} = \mathbf{0.785 \times 10^{-6} \sin(}\boldsymbol{\omega t}\mathbf{ - 120°)}$

e. $\mathbf{V} = 11.312 \text{ V} \angle 60°$, $\mathbf{I} = \dfrac{V \angle \theta}{X_L \angle 90°} = \dfrac{11.312 \text{ V} \angle 60°}{(377 \text{ rad/s})(0.2 \text{ H} \angle 90°)} = 150.03 \text{ mA} \angle -30°$
$\boldsymbol{i} = \mathbf{106.09 \times 10^{-3} \sin(377}\boldsymbol{t}\mathbf{ - 30°)}$

f. $\mathbf{V} = 84.84 \text{ V} \angle 0°$, $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(5 \text{ kHz})(2\ \mu\text{F})} = 15.924\ \Omega$
$\mathbf{I} = \dfrac{V \angle \theta}{X_C \angle -90°} = \dfrac{84.84 \text{ V} \angle 0°}{15.924\ \Omega \angle -90°} = 5.328 \text{ A} \angle 90°$
$\boldsymbol{i} = \mathbf{7.534 \sin(}\boldsymbol{\omega t}\mathbf{ + 90°)}$

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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. $\mathbf{Z}_T = \mathbf{6.8\ \Omega + j8.2\ \Omega = 10.65\ \Omega \angle 50.33°}$

b. $\mathbf{Z}_T = 2\ \Omega - j6\ \Omega + 10\ \Omega = \mathbf{12\ \Omega - j6\ \Omega = 13.42\ \Omega \angle -26.57°}$

c. $\mathbf{Z}_T = 1\text{ k}\Omega + j3\text{ k}\Omega + 4\text{ k}\Omega + j7\text{ k}\Omega = \mathbf{5\text{ k}\Omega + j10\text{ k}\Omega = 11.18\text{ k}\Omega \angle 63.44°}$

5. a. $\mathbf{Z}_T = \mathbf{3\ \Omega + j4\ \Omega - j5\ \Omega = 3\ \Omega - j1\ \Omega = 3.16\ \Omega \angle -18.43°}$

b. $\mathbf{Z}_T = 1\text{ k}\Omega + j8\text{ k}\Omega - j4\text{ k}\Omega = \mathbf{1\text{ k}\Omega + j4\text{ k}\Omega = 4.12\text{ k}\Omega \angle 75.96°}$

c. $L_T = 240\text{ mH}$
$X_L = \omega L = 2\pi fL = 2\pi(10^3\text{ Hz})(240 \times 10^{-3}\text{ H}) = 1.51\text{ k}\Omega$
$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10^3\text{ Hz})(0.1 \times 10^{-6}\text{ F})} = 1.59\text{ k}\Omega$$
$= 470\ \Omega + j1.51\text{ k}\Omega - j1.59\text{ k}\Omega$
$= \mathbf{470\ \Omega - j80\ \Omega = 476.76\ \Omega \angle -9.66°}$

6. a. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120\text{ V} \angle 0°}{60\text{ A} \angle 70°} = 2\ \Omega \angle -70° = \mathbf{0.684\ \Omega - j1.879\ \Omega = R - jX_C}$$

b. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{80\text{ V} \angle 320°}{20\text{ mA} \angle 40°} = 4\text{ k}\Omega \angle 280° = \mathbf{4\text{ k}\Omega \angle -80° = 0.695\text{ k}\Omega - j3.939\ \Omega}$$
$$= \boldsymbol{R - jX_C}$$

c. $$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}} = \frac{8\text{ kV} \angle 0°}{0.2\text{ A} \angle -60°} = 40\text{ k}\Omega \angle 60° = \mathbf{20\text{ k}\Omega + j34.64\text{ k}\Omega = R + jX_L}$$

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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. $\upsilon_R = \mathbf{113.12\ \sin(\omega t - 36.87°)}$
$\upsilon_L = \mathbf{84.84\ \sin(\omega t + 53.13°)}$
$i = \mathbf{14.14\ \sin(\omega t - 36.87°)}$

8. a. $\mathbf{Z}_T = 6\ \Omega - j30\ \Omega = \mathbf{30.59\ \Omega \angle -78.69°}$

c. $\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{120\ \text{V} \angle 20°}{30.59\ \Omega \angle -78.69°} = \mathbf{3.92\ A \angle 98.69°}$

$\mathbf{V}_R = (I \angle \theta)(R \angle 0°) = (3.92\ \text{A} \angle 98.69°)(6\ \Omega \angle 0°) = \mathbf{23.52\ V \angle 98.69°}$
$\mathbf{V}_C = (I \angle \theta)(X_C \angle -90°) = (3.92\ \text{A} \angle 98.69°)(30\ \Omega \angle -90°) = \mathbf{117.60\ V \angle 8.69°}$

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. $i = \mathbf{5.54\ \sin(377t + 98.69°)}$
$\upsilon_R = \mathbf{33.26\ \sin(377t + 98.69°)}$
$\upsilon_C = \mathbf{166.29\ \sin(377t + 8.69°)}$

9. a. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10^3\ \text{Hz})(0.2 \times 10^{-6}\ \text{F})} = 795.77\ \Omega$

$\mathbf{Z}_T = 2.2\ \text{k}\Omega - j795.77\ \Omega = \mathbf{2.34\ k\Omega \angle -19.89°}$

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. $P = I^2R = (6.04\ \text{mA})^2\ 2.2\ \text{k}\Omega = \mathbf{80.26\ mW}$
$F_p = \cos\theta_T = \cos 19.89° = \mathbf{0.94\ leading}$

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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. $F_p = \cos\theta_T = \dfrac{R}{Z_T} = 4\ \Omega/5.66\ \Omega = \mathbf{0.707\ leading}$

i. $i = \mathbf{12.49\ \sin(377t + 45°)}$
$e = \mathbf{70.7\ \sin 377t}$
$\upsilon_R = \mathbf{49.94\ \sin(377t + 45°)}$
$\upsilon_L = \mathbf{74.91\ \sin(377t + 135°)}$
$\upsilon_C = \mathbf{124.86\ \sin(377t - 45°)}$

11. a. $\mathbf{Z}_T = 1.8\ \text{k}\Omega + j2\ \text{k}\Omega - j0.6\ \text{k}\Omega = \mathbf{1.8\ k\Omega + j1.2\ k\Omega = 2.16\ k\Omega\ \angle 33.69°}$

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. $F_p = \cos\theta_T = \cos 33.69° = \mathbf{0.832\ lagging}$

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i. $i = \mathbf{2.77 \times 10^{-3} \sin(\omega t + 26.31°)}$
$\upsilon_R = \mathbf{4.99 \sin(\omega t + 26.31°)}$
$\upsilon_L = \mathbf{3.79 \sin(\omega t + 116.31°)}$
$\upsilon_C = \mathbf{1.67 \sin(\omega t - 63.69°)}$

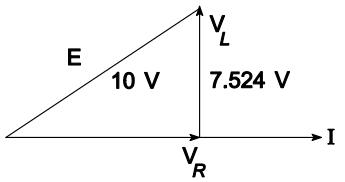
12. $V_{80\Omega}(\text{rms}) = 0.7071\left(\frac{45.27\text{ V}}{2}\right) = 16\text{ V}$

$$V_{\text{scope}} = \frac{80\,\Omega\ (20\text{ V})}{80\,\Omega + R} = 16\text{ V}$$
$$1600 = 1280 + 16R$$
$$R = \frac{320}{16} = \mathbf{20\ \Omega}$$

13. a. $V_L(\text{rms}) = 0.7071\left(\frac{21.28\text{ V}}{2}\right) = 7.524\text{ V}$

$$X_L = \frac{V_L}{I_L} = \frac{7.524\text{ V}}{29.94\text{ mA}} = 251.303\ \Omega$$
$$X_L = 2\pi fL \Rightarrow L = \frac{X_L}{2\pi f} = \frac{251.303\,\Omega}{2\pi(1\text{ kHz})} = 39.996\text{ mH} \cong \mathbf{40\ mH}$$

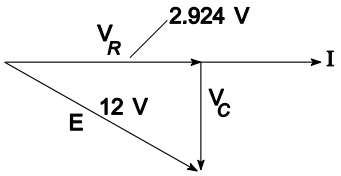
b.



$$E^2 = V_R^2 + V_L^2$$
$$V_R = \sqrt{E^2 - V_L^2}$$
$$= \sqrt{(100\text{ V}) - (56.611)} = \sqrt{43.389} = 6.587\text{ V}$$

$$R = \frac{V_R}{I_R} = \frac{6.587\text{ V}}{29.94\text{ mA}} = \mathbf{220\ \Omega}$$

14. $V_R(\text{rms}) = 0.7071\left(\frac{8.27\text{ V}}{2}\right) = 2.924\text{ V}$



$$V_C = \sqrt{E^2 - V_R^2}$$
$$= \sqrt{144 - 8.55} = \sqrt{135.45} = 11.638\text{ V}$$

$$I_C = I_R = \frac{2.924\text{ V}}{10\text{ k}\Omega} = 292.4\ \mu\text{A}$$
$$X_C = \frac{V_C}{I_C} = \frac{11.638\text{ V}}{292.4\ \mu\text{A}} = 39.802\text{ k}\Omega$$
$$X_C = \frac{1}{2\pi fC} \Rightarrow C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(40\text{ kHz})(39.802\text{ k}\Omega)} = 99.967\text{ pF} \cong \mathbf{100\ pF}$$

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15. a. $$\mathbf{V}_1 = \frac{(2\,\text{k}\Omega\angle 0°)(120\,\text{V}\angle 60°)}{2\,\text{k}\Omega + j8\,\text{k}\Omega} = \frac{240\,\text{V}\angle 60°}{8.25\angle 75.96°} = \mathbf{29.09\ V\angle -15.96°}$$

$$\mathbf{V}_2 = \frac{(8\,\text{k}\Omega\angle 90°)(120\,\text{V}\angle 60°)}{8.25\,\text{k}\Omega\angle 75.96°} = \mathbf{116.36\ V\angle 74.04°}$$

b. $$\mathbf{V}_1 = \frac{(40\,\Omega\angle 90°)(60\,\text{V}\angle 5°)}{6.8\,\Omega + j40\,\Omega + 22\,\Omega} = \frac{2400\,\text{V}\angle 95°}{28.8 + j40} = \mathbf{48.69\ V\angle 40.75°}$$

$$\mathbf{V}_2 = \frac{(22\,\Omega\angle 0°)(60\,\text{V}\angle 5°)}{49.29\,\Omega\angle 54.25°} = \frac{1.32\,\text{kV}\angle 5°}{49.29\,\Omega\angle 54.25°} = \mathbf{26.78\ V\angle -49.25°}$$

16. a. $$\mathbf{V}_1 = \frac{(20\,\Omega\angle 90°)(20\,\text{V}\angle 70°)}{20\,\Omega + j20\,\Omega - j40\,\Omega} = \mathbf{14.14\ V\angle -155°}$$

$$\mathbf{V}_2 = \frac{(40\,\Omega\angle -90°)(20\,\text{V}\angle 70°)}{28.28\,\Omega\angle -45°} = \mathbf{28.29\ V\angle 25°}$$

b. $\mathbf{Z}_T = 4.7\ \text{k}\Omega + j30\ \text{k}\Omega + 3.3\ \text{k}\Omega - j10\ \text{k}\Omega = 8\ \text{k}\Omega + j20\ \text{k}\Omega = 21.541\ \text{k}\Omega\angle 68.199°$

$\mathbf{Z}'_T = 3.3\ \text{k}\Omega + j30\ \text{k}\Omega - j10\ \text{k}\Omega = 3.3\ \text{k}\Omega + j20\ \text{k}\Omega = 20.27\ \text{k}\Omega\angle 80.631°$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'_T\mathbf{E}}{\mathbf{Z}_T} = \frac{(20.27\,\text{k}\Omega\angle 80.631°)(120\,\text{V}\angle 0°)}{21.541\,\text{k}\Omega\angle 68.199°} = \mathbf{112.92\ V\angle 12.432°}$$

$$\mathbf{V}_2 = \frac{\mathbf{Z}''_T\mathbf{E}}{\mathbf{Z}_T} \qquad \mathbf{Z}''_T = 3.3\ \text{k}\Omega - j10\ \text{k}\Omega = 10.53\ \text{k}\Omega\angle -71.737°$$

$$= \frac{(10.53\,\text{k}\Omega\angle -71.737°)(120\,\text{V}\angle 0°)}{21.541\,\text{k}\Omega\angle 68.199°} = \mathbf{58.66\ V\angle -139.94°}$$

17. a. $X_L = \omega L = (377\ \text{rad/s})(0.4\ \text{H}) = 150.8\ \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(377\ \text{rad/s})(4\ \mu\text{F})} = 663\ \Omega$$

$\mathbf{Z}_T = 30\ \Omega + j150.8\ \Omega - j663\ \Omega = 30\ \Omega - j512.2\ \Omega = \mathbf{513.08\ \Omega\angle -86.65°}$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{20\,\text{V}\angle 40°}{513.08\,\Omega\angle -86.65°} = \mathbf{39\ mA\angle 126.65°}$$

$\mathbf{V}_R = (I\angle\theta)(R\angle 0°) = (39\ \text{mA}\angle 126.65°)(30\ \Omega\angle 0°) = \mathbf{1.17\ V\angle 126.65°}$

$\mathbf{V}_C = (39\ \text{mA}\angle 126.65°)(0.663\ \text{k}\Omega\angle -90°) = \mathbf{25.86\ V\angle 36.65°}$

b. $$\cos\theta_T = \frac{R}{Z_T} = \frac{30\,\Omega}{513.08\,\Omega} = \mathbf{0.058\ leading}$$

c. $P = I^2R = (39\ \text{mA})^2\ 30\ \Omega = \mathbf{45.63\ mW}$

f. $$\mathbf{V}_R = \frac{(30\,\Omega\angle 0°)(20\,\text{V}\angle 40°)}{\mathbf{Z}_T} = \frac{600\,\text{V}\angle 40°}{513.08\ \Omega\angle -86.65°} = \mathbf{1.17\ V\angle 126.65°}$$

$$\mathbf{V}_C = \frac{(0.663\,\text{k}\Omega\angle -90°)(20\,\text{V}\angle 40°)}{513.08\,\Omega\angle -86.65°} = \mathbf{25.84\ V\angle 36.65°}$$

g. $\mathbf{Z}_T = \mathbf{30\ \Omega - j512.2\ \Omega} = R - jX_C$

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18. a. $X_L = \omega L = (377 \text{ rad/s})(0.4 \text{ H}) = 150.8\ \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(220 \times 10^{-6} \text{ F})} = 12.06\ \Omega$$

$\mathbf{Z}_T = 30\ \Omega + j150.8\ \Omega - j12.06\ \Omega$

$= 30\ \Omega + j138.74\ \Omega = 141.95\ \Omega \angle 77.80°$

$\mathbf{I} = \mathbf{E}/\mathbf{Z}_T = 20\text{ V} \angle 40°/141.95\ \Omega \angle 77.80° =$ **140.89 mA ∠–37.80°**

$\mathbf{V}_R = (I \angle \theta)(R \angle 0°) = (140.89\text{ mA} \angle -37.80°)(30\ \Omega \angle 0°) =$ **4.23 V ∠–37.80°**

$\mathbf{V}_C = (I \angle \theta)(X_C \angle -90°) = (140.89\text{ mA} \angle -37.80°)(12.06\ \Omega \angle -90°)$

$=$ **1.70 V ∠–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. $$\mathbf{V}_R = \frac{(30\ \Omega \angle 0°)(20\text{ V} \angle 40°)}{141.95\ \Omega \angle 77.80°} =$$ **4.23 V ∠–37.80°**

$$\mathbf{V}_C = \frac{(12.06\ \Omega \angle -90°)(20\text{ V} \angle 40°)}{141.95\ \Omega \angle 77.80°} =$$ **1.70 V ∠–127.80°**

g. $\mathbf{Z}_T = 30\ \Omega + j138.74\ \Omega = R + jX_L$

19. $P = VI \cos \theta \Rightarrow 8000\text{ W} = (200\text{ V})(I)(0.8)$

$$I = \frac{8000\text{ A}}{160} = 50\text{ A}$$

$0.8 = \cos \theta$

$\theta = 36.87°$

$\mathbf{V} = 200\text{ V} \angle 0°,\ I = 50\text{ A} \angle -36.87°$

$$\mathbf{Z}_T = \frac{\mathbf{V}}{\mathbf{I}} = \frac{200\text{ V} \angle 0°}{50\text{ A} \angle -36.87°} = 4\ \Omega \angle 36.87° =$$ **3.2 Ω + *j*2.4 Ω**

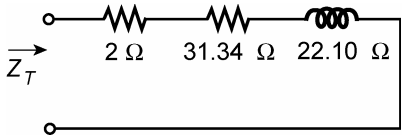
20. $P = VI \cos \theta \Rightarrow 300\text{ W} = (120\text{ V})(3\text{ A}) \cos \theta$

$\cos \theta = 0.833 \Rightarrow \theta =$ **33.59°**

$\mathbf{V} = 120\text{ V} \angle 0°,\ \mathbf{I} = 3\text{ A} \angle -33.59°$

$$\mathbf{Z}_T = \frac{\mathbf{V}}{\mathbf{I}} = \frac{120\text{ V} \angle 0°}{3\text{ A} \angle -33.59°} = 40\ \Omega \angle 33.59° =$$ **33.34 Ω + *j*22.10 Ω**

$R_T = 33.34\ \Omega = 2\ \Omega + R \Rightarrow R = 31.34\ \Omega$



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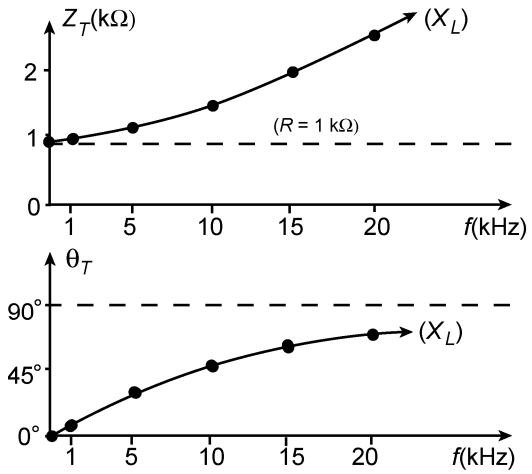
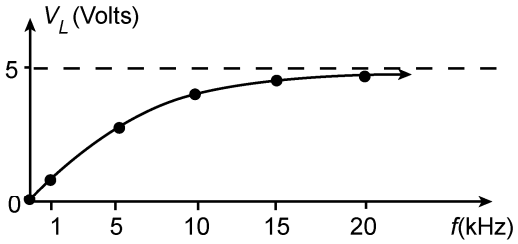
21. a. $\mathbf{Z}_T = \sqrt{R^2 + X_L^2}\ \angle \tan^{-1} X_L/R$

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°



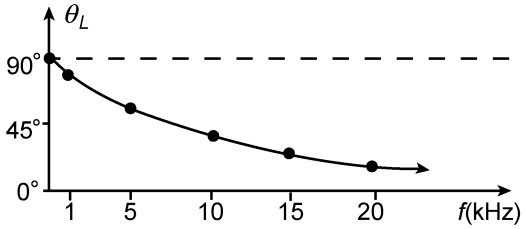
b. $V_L = \dfrac{X_L E}{Z_T}$

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°



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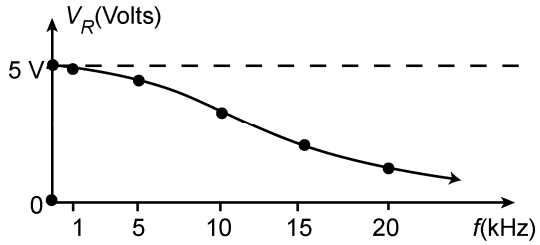
d.

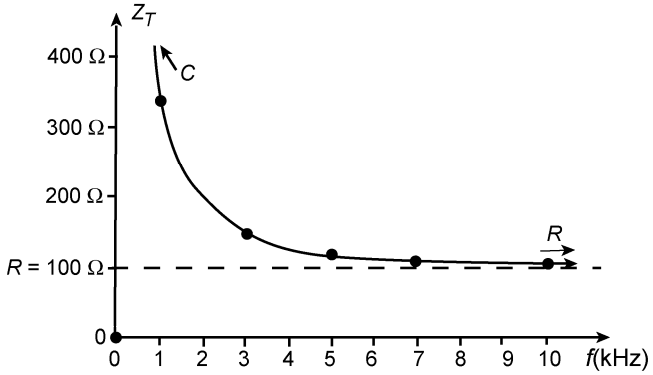
f	$V_R = RE/Z_T$
0 Hz	5.0 V
1 kHz	4.96 V
5 kHz	4.23 V
10 kHz	3.11 V
15 kHz	2.34 V
20 kHz	1.848 V

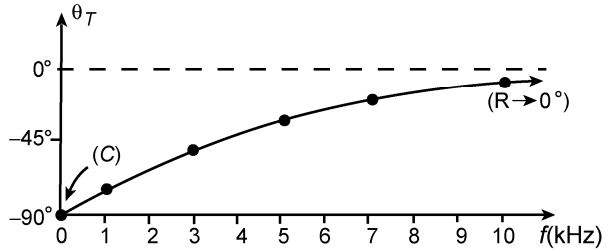


22. a. $\mathbf{Z}_T = \sqrt{R^2 + X_C^2}\ \angle -\tan^{-1} X_C/R$

$|Z_T| = \sqrt{R^2 + X_C^2}$, $\theta_T = -\tan^{-1} X_C/R$

f	$\lvert\mathbf{Z}_T\rvert$	θ_T
0 kHz	$\infty\ \Omega$	–90.0°
1 kHz	333.64 Ω	–72.56°
3 kHz	145.8 Ω	–46.7°
5 kHz	118.54 Ω	–32.48°
7 kHz	109.85 Ω	–24.45°
10 kHz	104.94 Ω	–17.66°





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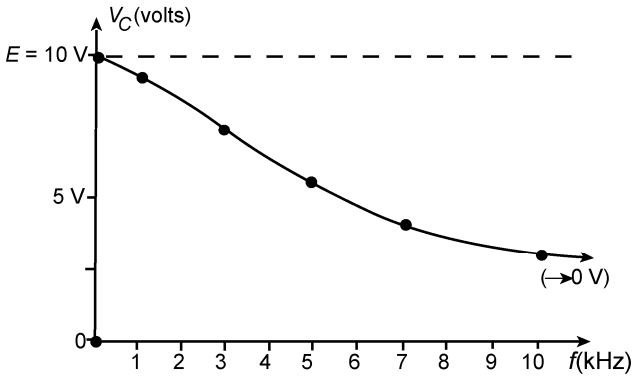
b. $$\mathbf{V}_C = \frac{(X_C \angle -90°)(E \angle 0°)}{R - jX_C} = \frac{X_C E}{\sqrt{R^2 + X_C^2}} \angle -90° + \tan^{-1} X_C/R$$

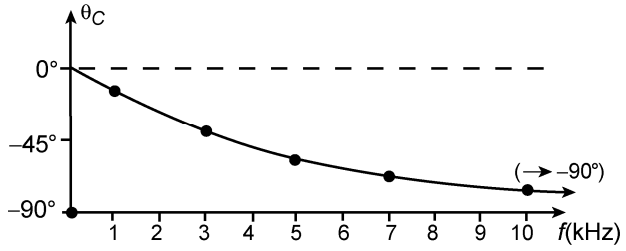
$$|V_C| = \frac{X_C E}{\sqrt{R^2 + X_C^2}}$$

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



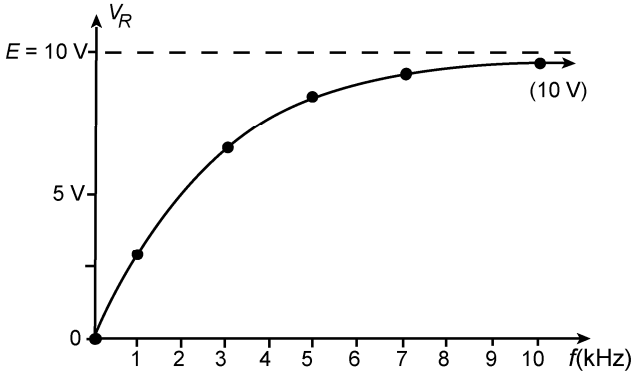
c. $$\theta_C = -90° + \tan^{-1} X_C/R$$

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. $$|V_R| = \frac{RE}{\sqrt{R^2 + X_C^2}}$$

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



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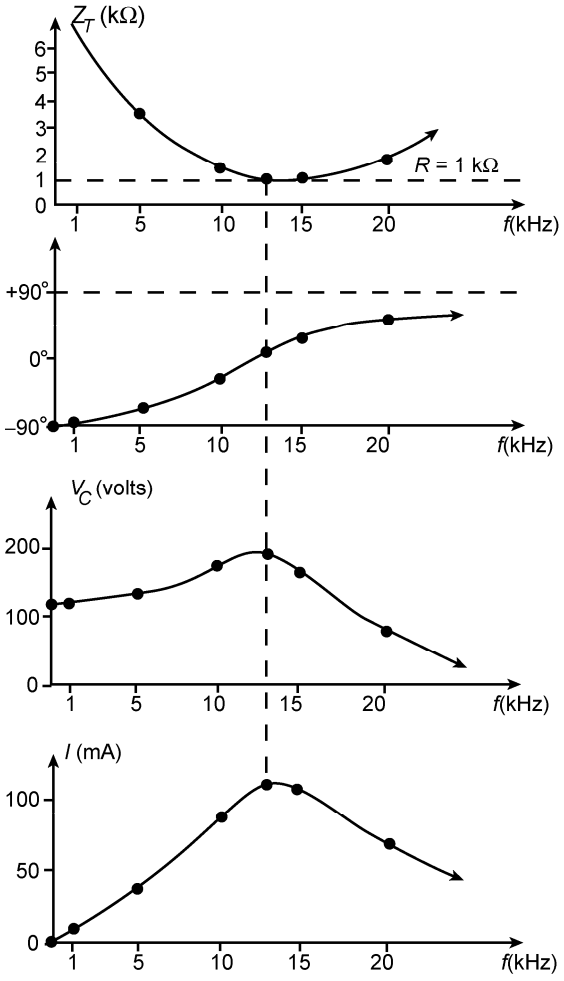
23. a. $\mathbf{Z}_T = \sqrt{R^2 + (X_L - X_C)^2} \angle \tan^{-1}(X_L - X_C)/R$

f	Z_T	θ_T
0 Hz	$\infty\ \Omega$	–90.0°
1 kHz	19,793.97 Ω	–87.1°
5 kHz	3,496.6 Ω	–73.38°
10 kHz	1,239.76 Ω	–36.23°
15 kHz	1,145.47 Ω	+29.19°
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

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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. $\mathbf{Z}_T = \dfrac{(10\ \Omega\angle 0°)(60\ \Omega\ \angle 90°)}{10\ \Omega + j60\ \Omega} = \mathbf{9.86\ \Omega\ \angle 9.46° = 9.73\ \Omega + j1.62\ \Omega} = R + jX_L$

$\mathbf{Y}_T = \mathbf{0.10\ S\ \angle -9.46° = 0.1\ S - j0.02\ S} = G - jB_L$

e. $22\ \Omega \parallel 2.2\ \Omega = 2\ \Omega$

$\mathbf{Z}_T = \dfrac{(2\ \Omega\angle 0°)(6\ \Omega\ \angle -90°)}{2\ \Omega - j6\ \Omega} = \dfrac{12\ \Omega\ \angle -90°}{6.32\ \Omega\ \angle -71.57°} = \mathbf{1.90\ \Omega\ \angle -18.43°}$

$= \mathbf{1.80\ \Omega - j0.6\ \Omega} = R - jX_C$

$\mathbf{Y}_T = \mathbf{0.53\ S\ \angle 18.43°} = \mathbf{0.5\ S + j0.17\ S} = G + jB_C$

f. $\mathbf{Y}_T = \dfrac{1}{3\ \text{k}\Omega\ \angle 0°} + \dfrac{1}{6\ \text{k}\Omega\ \angle 90°} + \dfrac{1}{9\ \text{k}\Omega\ \angle -90°}$

$= 0.333 \times 10^{-3}\ \angle 0° + 0.167 \times 10^{-3}\ \angle -90° + 0.111 \times 10^{-3}\ \angle 90°$

$= \mathbf{0.333 \times 10^{-3}\ S - j0.056 \times 10^{-3}\ S = 0.34\ mS\ \angle -9.55°}$

$= G - jB_L$

$\mathbf{Z}_T = \dfrac{1}{\mathbf{Y}_T} = \mathbf{2.94\ k\Omega\ \angle 9.55° = 2.90\ k\Omega + j0.49\ k\Omega}$

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26. a. $\mathbf{Z}_T = 4.7\ \Omega + j8\ \Omega = \mathbf{9.28\ \Omega \angle 59.57°}$, $\mathbf{Y}_T = \mathbf{0.108\ S \angle -59.57°}$

$\mathbf{Y}_T = \mathbf{54.7\ mS - j93.12\ mS} = G - jB_L$

b. $\mathbf{Z}_T = 33\ \Omega + 20\ \Omega - j70\ \Omega = \mathbf{53\ \Omega - j70\ \Omega} = \mathbf{87.80\ \Omega \angle -52.87°}$

$\mathbf{Y}_T = \mathbf{11.39\ mS \angle 52.87°} = \mathbf{6.88\ mS + j9.08\ mS} = G + jB_C$

c. $\mathbf{Z}_T = 200\ \Omega + j500\ \Omega - j600\ \Omega = \mathbf{200\ \Omega - j100\ \Omega} = \mathbf{223.61\ \Omega \angle -26.57°}$

$\mathbf{Y}_T = \mathbf{4.47\ mS \angle 26.57°} = \mathbf{4\ mS + j2\ mS} = G + jB_C$

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. $P = I^2 R = (1.79\ \text{A})^2\ 10\ \Omega = \mathbf{32.04\ W}$

g. $F_p = \dfrac{G}{Y_T} = \dfrac{0.1\ \text{S}}{111.8\ \text{mS}} = \mathbf{0.894\ lagging}$

h. $e = \mathbf{25.30\ \sin(377t + 26.57°)}$
$i_R = \mathbf{2.53\ \sin(377t + 26.57°)}$
$i_L = \mathbf{1.26\ \sin(377t - 63.43°)}$
$i_s = \mathbf{2.83\ \sin 377t}$

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29. a. $\mathbf{Y}_T = \dfrac{1}{10\,\text{k}\Omega\angle 0^\circ} + \dfrac{1}{20\,\text{k}\Omega\angle -90^\circ} = 0.1\text{ mS}\angle 0^\circ + 0.05\text{ mS}\angle -90^\circ$

$= \mathbf{0.112\text{ mS}\angle 26.57^\circ}$

c. $\mathbf{E} = \dfrac{\mathbf{I}_s}{\mathbf{Y}_\text{T}} = \dfrac{2\text{ mA}\angle 20^\circ}{0.1118\text{ mS}\angle 26.565^\circ} = \mathbf{17.89\text{ V}\angle -6.57^\circ}$

$\mathbf{I}_R = \dfrac{\mathbf{E}}{\mathbf{Z}_R} = \dfrac{17.89\text{ V}\angle -6.57^\circ}{10\,\text{k}\Omega\angle 0^\circ} = \mathbf{1.79\text{ mA}\angle -6.57^\circ}$

$\mathbf{I}_C = \dfrac{\mathbf{E}}{\mathbf{Z}_C} = \dfrac{17.89\text{ V}\angle -6.57^\circ}{20\,\text{k}\Omega\angle -90^\circ} = \mathbf{0.90\text{ mA}\angle 83.44^\circ}$

e. $\mathbf{I}_s = \mathbf{I}_R + \mathbf{I}_C$

$2\text{ mA}\angle 20^\circ = 1.79\text{ mA}\angle -6.57^\circ + 0.90\text{ mA}\angle 83.44^\circ$

$= 1.88\text{ mA} + j0.69\text{ mA}$

$2\text{ mA}\angle 20^\circ \overset{\checkmark}{=} 2\text{ mA}\angle 20.15^\circ$

f. $P = I^2R = (1.79\text{ mA})^2\ 10\text{ k}\Omega = \mathbf{32.04\text{ mW}}$

g. $F_p = \dfrac{G}{Y_T} = \dfrac{0.1\,\text{mS}}{0.1118\,\text{mS}} = \mathbf{0.894\text{ leading}}$

h. $\omega = 2\pi f = 377$ rad/s

$\boldsymbol{i_s = 2.83 \times 10^{-3}\sin(\omega t + 20^\circ)}$

$\boldsymbol{i_R = 2.53 \times 10^{-3}\sin(\omega t - 6.57^\circ)}$

$\boldsymbol{i_C = 1.27 \times 10^{-3}\sin(\omega t + 83.44^\circ)}$

$\boldsymbol{e = 25.3\sin(\omega t - 6.57^\circ)}$

30. a. $\mathbf{Y}_T = \dfrac{1}{12\,\Omega\angle 0^\circ} + \dfrac{1}{10\,\Omega\angle 90^\circ} = 0.083\text{ S} - j0.1\text{ S} = \mathbf{129.96\text{ mS}\angle -50.31^\circ}$

c. $\mathbf{I}_s = \mathbf{E}\mathbf{Y}_T = (60\text{ V}\angle 0^\circ)(0.13\text{ S}\angle -50.31^\circ) = \mathbf{7.8\text{ A}\angle -50.31^\circ}$

$\mathbf{I}_R = \dfrac{E\angle\theta}{R\angle 0^\circ} = 60\text{ V}\angle 0^\circ/12\ \Omega\angle 0^\circ = \mathbf{5\text{ A}\angle 0^\circ}$

$\mathbf{I}_L = \dfrac{E\angle\theta}{X_L\angle 90^\circ} = 60\text{ V}\angle 0^\circ/10\ \Omega\angle 90^\circ = \mathbf{6\text{ A}\angle -90^\circ}$

f. $P = I^2R = (5\text{ A})^2\ 12\ \Omega = \mathbf{300\text{ W}}$

g. $F_p = G/Y_T = 0.083\text{ S}/0.13\text{ S} = \mathbf{0.638\text{ lagging}}$

h. $\boldsymbol{e = 84.84\sin 377t}$

$\boldsymbol{i_R = 7.07\sin 377t}$

$\boldsymbol{i_L = 8.484\sin(377t - 90^\circ)}$

$\boldsymbol{i_s = 11.03\sin(377t - 50.31^\circ)}$

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31. a. $\mathbf{Y}_T = \dfrac{1}{1.2\,\Omega\angle 0°} + \dfrac{1}{2\,\Omega\angle 90°} + \dfrac{1}{5\,\Omega\angle -90°}$

$= 0.833\text{ S}\angle 0° + 0.5\text{ S}\angle -90° + 0.2\text{ S}\angle 90°$

$= 0.833\text{ S} - j0.3\text{ S} = \mathbf{0.89\text{ S}\angle -19.81°}$

$\mathbf{Z}_T = 1.12\,\Omega\angle 19.81°$

c. $X_C = \dfrac{1}{\omega C} \Rightarrow C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377\text{ rad/s})(5\,\Omega)} = \mathbf{531\ \mu F}$

$X_L = \omega L \Rightarrow L = \dfrac{X_L}{\omega} = \dfrac{2\,\Omega}{377\text{ rad/s}} = \mathbf{5.31\text{ mH}}$

d. $\mathbf{E} = \dfrac{\mathbf{I}_s}{\mathbf{Y}_T} = \dfrac{(0.707)(3\text{ A})\angle 60°}{0.885\,\text{S}\angle -19.81°} = \dfrac{2.121\,\text{A}\angle 60°}{0.885\,\text{S}\angle -19.81°} = \mathbf{2.40\text{ V}\angle 79.81°}$

$\mathbf{I}_R = \dfrac{E\angle\theta}{R\angle 0°} = \dfrac{2.397\text{ V}\angle 79.81°}{1.2\,\Omega\angle 0°} = \mathbf{2.00\text{ A}\angle 79.81°}$

$\mathbf{I}_L = \dfrac{E\angle\theta}{X_L\angle 90°} = \dfrac{2.397\text{ V}\angle 79.81°}{2\,\Omega\angle 90°} = \mathbf{1.20\text{ A}\angle -10.19°}$

$\mathbf{I}_C = \dfrac{E\angle\theta}{X_C\angle -90°} = \dfrac{2.397\text{ V}\angle 79.81°}{5\,\Omega\angle -90°} = \mathbf{0.48\text{ A}\angle 169.81°}$

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. $P = I^2R = (2.00\text{ A})^2\ 1.2\,\Omega = \mathbf{4.8\text{ W}}$

h. $F_p = \dfrac{G}{Y_T} = \dfrac{0.833\,\text{S}}{0.885\,\text{S}} = \mathbf{0.941\text{ lagging}}$

i. $e = \mathbf{3.39\sin(377t + 79.81°)}$

$i_R = \mathbf{2.83\sin(377t + 79.81°)}$

$i_L = \mathbf{1.70\sin(377t - 10.19°)}$

$i_C = \mathbf{0.68\sin(377t + 169.81°)}$

32. a. $\mathbf{Y}_T = \dfrac{1}{3\,\text{k}\Omega\angle 0°} + \dfrac{1}{4\,\text{k}\Omega\angle 90°} + \dfrac{1}{8\,\text{k}\Omega\angle -90°}$

$= 0.333\text{ mS}\angle 0° + 0.25\text{ mS}\angle -90° + 0.125\text{ mS}\angle 90°$

$= \mathbf{0.333\text{ mS} + j0.125\text{ mS} = 0.356\text{ mS}\angle 20.57°}$

c. $X_L = \omega L \Rightarrow L = X_L/\omega = 4000\ \Omega/377\text{ rad/s} = \mathbf{10.61\text{ H}}$

$X_C = \dfrac{1}{\omega C} \Rightarrow C = \dfrac{1}{\omega X_C} = \dfrac{1}{(377\text{ rad/s})(8\,\text{k}\Omega)} = \mathbf{0.332\ \mu F}$

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d. $\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 3.535\text{ mA} \angle -20° / 0.356\text{ mS} \angle 20.57° = \mathbf{9.93\text{ V} \angle -40.57°}$

$$\mathbf{I}_R = \frac{E \angle \theta}{R \angle 0°} = 9.93\text{ V} \angle -40.57° / 3\text{ k}\Omega \angle 0° = \mathbf{3.31\text{ mA} \angle -40.57°}$$

$$\mathbf{I}_L = \frac{E \angle \theta}{X_L \angle 90°} = 9.93\text{ V} \angle -40.57° / 4\text{ k}\Omega \angle 90° = \mathbf{2.48\text{ mA} \angle -130.57°}$$

$$\mathbf{I}_C = \frac{E \angle \theta}{X_C \angle -90°} = 9.93\text{ V} \angle -40.57° / 8\text{ k}\Omega \angle -90° = \mathbf{1.24\text{ mA} \angle 49.43°}$$

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. $$\mathbf{Y}_T = \frac{1}{5\ \Omega \angle -90°} + \frac{1}{22\ \Omega \angle 0°} + \frac{1}{10\ \Omega \angle 90°}$$

$= 0.2\text{ S} \angle 90° + 0.045\text{ S} \angle 0° + 0.1\text{ S} \angle -90°$

$= 0.045\text{ S} + j0.1\text{ S} = \mathbf{0.110\text{ S} \angle 65.77°}$

$\mathbf{Z}_T = \mathbf{9.09\ \Omega \angle -65.77°}$

c. $$C = \frac{1}{\omega X_C} = \frac{1}{(377\text{ rad/s})(5\ \Omega)} = \mathbf{636.9\ \mu F}$$

$$L = \frac{X_L}{\omega} = \frac{10\ \Omega}{314\text{ rad/s}} = \mathbf{31.8\text{ mH}}$$

d. $\mathbf{E} = (0.707)(35.4\text{ V}) \angle 60° = \mathbf{25.03\text{ V} \angle 60°}$

$\mathbf{I}_s = \mathbf{E}\mathbf{Y}_T = (25.03\text{ V} \angle 60°)(0.11\text{ S} \angle 65.77°) = \mathbf{2.75\text{ A} \angle 125.77°}$

$$\mathbf{I}_C = \frac{E \angle \theta}{X_C \angle -90°} = \frac{25.03\text{ V} \angle 60°}{5 \angle -90°} = \mathbf{5\text{ A} \angle 150°}$$

$$\mathbf{I}_R = \frac{E \angle \theta}{R \angle 0°} = \frac{25.03\text{ V} \angle 60°}{22\ \Omega \angle 0°} = \mathbf{1.14\text{ A} \angle 60°}$$

$$\mathbf{I}_L = \frac{E \angle \theta}{X_L \angle 90°} = \frac{25.03\text{ V} \angle 60°}{10\ \Omega \angle 90°} = \mathbf{2.50\text{ A} \angle -30°}$$

f. $\mathbf{I}_s = \mathbf{I}_C + \mathbf{I}_R + \mathbf{I}_L$

$2.75\text{ A} \angle 125.77° = 5\text{ A} \angle 150° + 1.14\text{ A} \angle 60° + 2.50\text{ A} \angle -30°$

$= (-4.33 + j2.5) + (0.57 + j0.9) + (2.17 - j1.25)$

$= -1.59 + j2.24$

✓ $= 2.75 \angle 125.4°$

g. $P = I^2R = (1.14\text{ A})^2\ 22\ \Omega = \mathbf{28.59\text{ W}}$

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h. $F_p = \dfrac{G}{Y_T} = \dfrac{0.045\,\text{S}}{0.110\,\text{S}} = \mathbf{0.409\ leading}$

i. $e = \mathbf{35.4\ \sin(314t + 60°)}$
$i_s = \mathbf{3.89\ \sin(314t + 125.77°)}$
$i_C = \mathbf{7.07\ \sin(314t + 150°)}$
$i_R = \mathbf{1.61\ \sin(314t + 60°)}$
$i_L = \mathbf{3.54\ \sin(314t - 30°)}$

34. a. $\mathbf{I}_1 = \dfrac{(80\,\Omega\angle 90°)(20\text{ A}\angle 40°)}{22\,\Omega + j80\,\Omega} = \dfrac{1600\text{ A}\angle 130°}{82.97\angle 74.62°} = \mathbf{19.28\text{ A}\angle 55.38°}$

$\mathbf{I}_2 = \dfrac{(22\,\Omega\angle 0°)(20\text{ A}\angle 40°)}{82.97\,\Omega\angle 74.62°} = \dfrac{440\text{ A}\angle 40°}{82.97\angle 74.62°} = \mathbf{5.30\text{ A}\angle -34.62°}$

b. $\mathbf{I}_1 = \dfrac{(12\,\Omega - j6\,\Omega)(6\text{ A}\angle 30°)}{12\,\Omega - j6\,\Omega + j4\,\Omega} = \dfrac{(13.42\angle -26.57°)(6\text{ A}\angle 30°)}{12 - j2}$

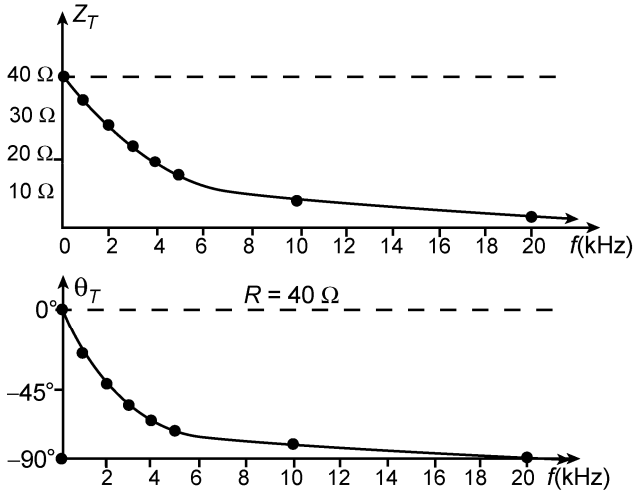
$= \dfrac{80.52\text{ A}\angle 3.43°}{12.17\angle -9.46°} = \mathbf{6.62\text{ A}\angle 12.89°}$

$\mathbf{I}_2 = \dfrac{(4\,\Omega\angle 90°)(6\text{ A}\angle 30°)}{12.17\,\Omega\angle -9.46°} = \dfrac{24\text{ A}\angle 120°}{12.17\angle -9.46°} = \mathbf{1.97\text{ A}\angle 129.46°}$

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°



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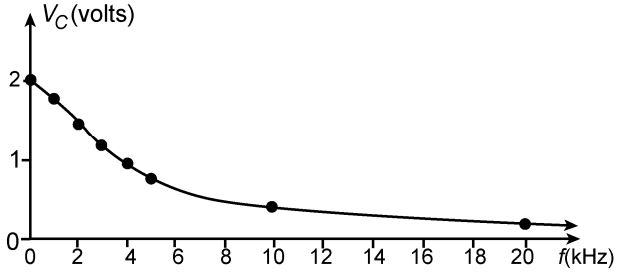
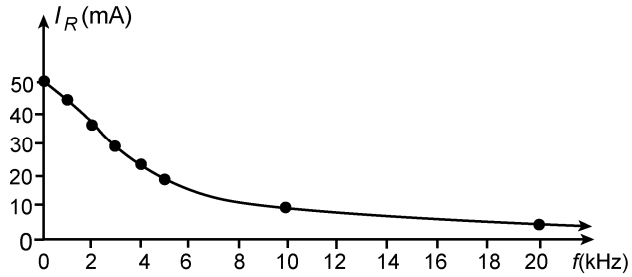
b. $|V_C| = \dfrac{IRX_C}{\sqrt{R^2 + X_C^2}} = I[Z_T(f)]$

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. $|I_R| = \left|\dfrac{V_C}{R}\right|$

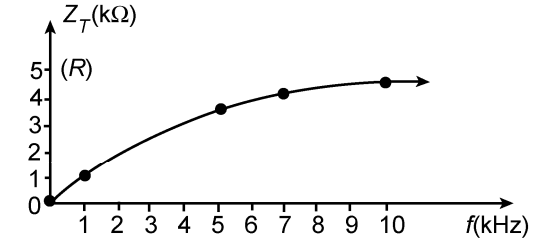
f	$\lvert I_R\rvert$
0 kHz	50.0 mA
1 kHz	44.7 mA
2 kHz	35.3 mA
3 kHz	27.64 mA
4 kHz	22.28 mA
5 kHz	18.50 mA
10 kHz	9.78 mA
20 kHz	4.95 mA

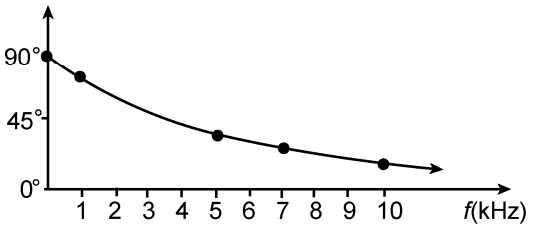


36. a. $\mathbf{Z}_T = \dfrac{\mathbf{Z}_R\mathbf{Z}_L}{\mathbf{Z}_R + \mathbf{Z}_L} = \dfrac{(R\angle 0°)(X_L\angle 90°)}{R + jX_L} = \dfrac{RX_L}{\sqrt{R^2 + X_L^2}}\angle 90° - \tan^{-1}X_L/R$

$|\mathbf{Z}_T| = \dfrac{RX_L}{\sqrt{R^2 + X_L^2}}\ \theta_T = 90° - \tan^{-1}X_L/R$

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°





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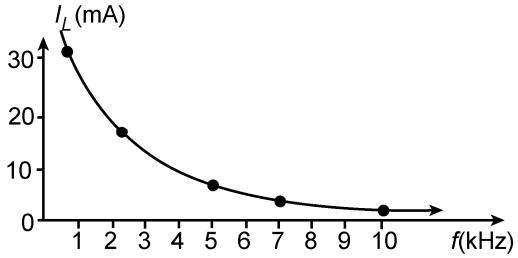
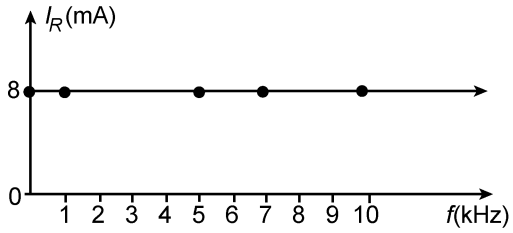
b. $|I_L| = \dfrac{E}{X_L}$

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

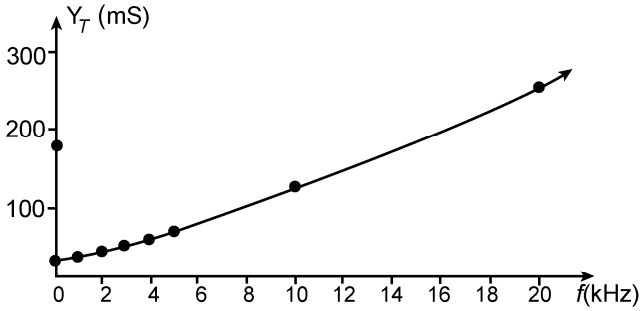


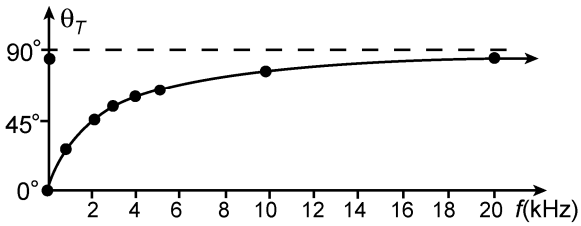
c. $I_R = \dfrac{E}{R} = \dfrac{40\text{ V}}{5\text{ k}\Omega} = 8\text{ mA (constant)}$



37. $\mathbf{Y}_T = \dfrac{\sqrt{R^2 + X_C^2}}{RX_C} \angle 90° - \tan^{-1} X_C/R$

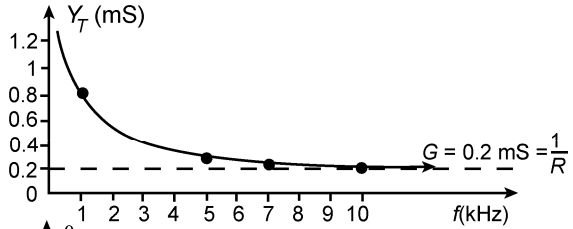
f	$\lvert Y_T \rvert$	θ_T
0 Hz	25.0 mS	0.0°
1 kHz	27.98 mS	26.67°
2 kHz	35.44 mS	45.14°
3 kHz	45.23 mS	56.44°
4 kHz	56.12 mS	63.55°
5 kHz	67.61 mS	68.30°
10 kHz	128.04 mS	78.75°
20 kHz	252.59 mS	89.86°

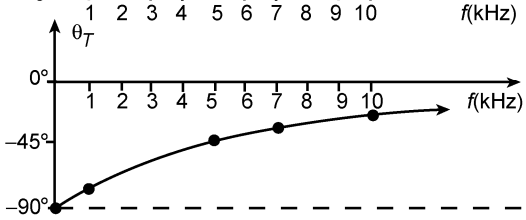




38. $Y_T = \dfrac{1}{Z_T}$ (use data of Prob. 36), $\theta_{T_Y} = -\theta_{T_Z}$

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°





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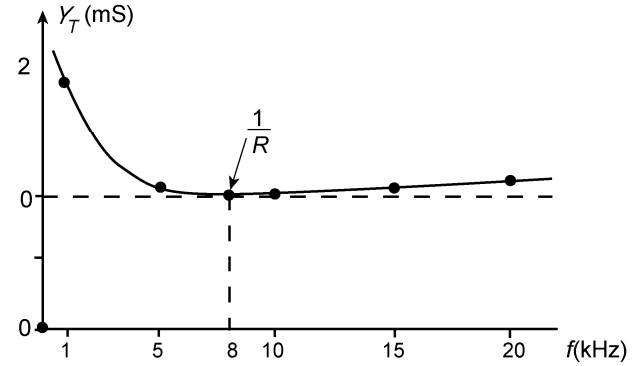
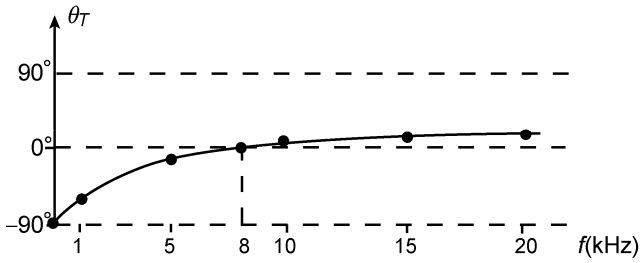
39. a. $\mathbf{Y}_T = G\angle 0° + B_L\angle -90° + B_C\angle 90°$

$$= \sqrt{G^2 + (B_C - B_L)^2}\ \angle \tan^{-1}\frac{B_C - B_L}{G}$$

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

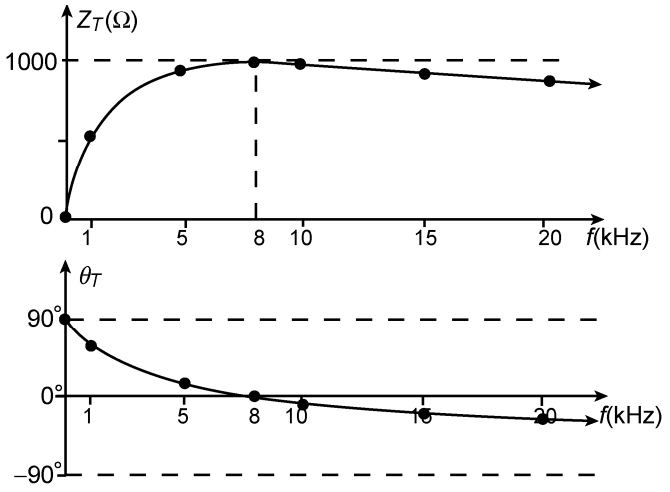


f	$\lvert\theta_T\rvert$
0 Hz	–90.0°
1 kHz	–57.42°
5 kHz	–10.87°
10 kHz	+5.26°
15 kHz	+15.16°
20 kHz	+22.95°



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°



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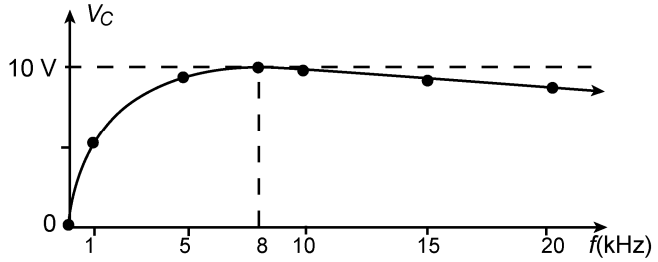
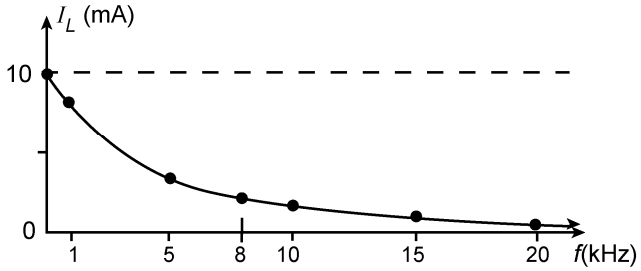
c. $V_C(f) = I[Z_T(f)]$

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. $R_p = \dfrac{R_s^2 + X_s^2}{R_s} = \dfrac{(20\,\Omega)^2 + (40\,\Omega)^2}{20\,\Omega} = \mathbf{100\ \Omega}\ (R)$

$X_p = \dfrac{R_s^2 + X_s^2}{X_s} = \dfrac{2000\,\Omega}{40} = \mathbf{50\ \Omega}\ (C)$

b. $R_p = \dfrac{R_s^2 + X_s^2}{R_s} = \dfrac{(2\,\text{k}\Omega)^2 + (3\,\text{k}\Omega)^2}{2\,\text{k}\Omega} = \mathbf{6.5\ k\Omega}\ (R)$

$X_p = \dfrac{R_s^2 + X_s^2}{X_s} = \dfrac{(2\,\text{k}\Omega)^2 + (3\,\text{k}\Omega)^2}{3\,\text{k}\Omega} = \mathbf{4.33\ k\Omega}\ (C)$

41. a. $R_s = \dfrac{R_p X_p^2}{X_p^2 + R_p^2} = \dfrac{(8.2\,\text{k}\Omega)(20\,\text{k}\Omega)^2}{(20\,\text{k}\Omega)^2 + (8.2\,\text{k}\Omega)^2} = \mathbf{7.02\ k\Omega}$

$X_s = \dfrac{R_p^2 X_p}{X_p^2 + R_p^2} = \dfrac{(8.2\,\text{k}\Omega)^2(20\,\text{k}\Omega)}{467.24\,\text{k}\Omega} = \mathbf{2.88\ k\Omega}$

$\mathbf{Z}_T = \mathbf{7.02\ k\Omega - }\boldsymbol{j}\mathbf{2.88\ k\Omega}$

b. $R_s = \dfrac{R_p X_p^2}{X_p^2 + R_p^2} = \dfrac{(68\,\Omega)(40\,\Omega)^2}{(40\,\Omega)^2 + (68\,\Omega)^2} = \mathbf{17.48\ \Omega}$

$X_s = \dfrac{R_p^2 X_p}{X_p^2 + R_p^2} = \dfrac{(68\,\Omega)^2(40\,\Omega)}{6224\,\Omega^2} = \mathbf{29.72\ \Omega}$

$\mathbf{Z}_T = \mathbf{17.48\ \Omega + }\boldsymbol{j}\mathbf{29.72\ \Omega}$

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42. a. $C_T = 2\ \mu\text{F}$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3\ \text{Hz})(2\ \mu\text{F})} = 79.62\ \Omega$$

$$X_L = \omega L = 2\pi(10^3\ \text{Hz})(10\ \text{mH}) = 62.80\ \Omega$$

$$\mathbf{Y}_T = \frac{1}{220\ \Omega\ \angle 0°} + \frac{1}{79.62\ \Omega\ \angle -90°} + \frac{1}{62.8\ \Omega\ \angle 90°}$$

$$= 4.55\ \text{mS}\ \angle 0° + 12.56\ \text{mS}\ \angle 90° + 15.92\ \text{mS}\ \angle -90°$$
$$= \mathbf{4.55\ mS - \textit{j}3.36\ mS = 5.66\ mS\ \angle -36.44°}$$

$$\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 1\ \text{A}\ \angle 0°/5.66\ \text{mS}\ \angle -36.44° = \mathbf{176.68\ V\ \angle 36.44°}$$

$$\mathbf{I}_R = \frac{E\ \angle \theta}{R\ \angle 0°} = 176.68\ \text{V}\ \angle 36.44°/220\ \Omega\ \angle 0° = \mathbf{0.803\ A\ \angle 36.44°}$$

$$\mathbf{I}_L = \frac{E\ \angle \theta}{X_L\ \angle 90°} = 176.68\ \text{V}\ \angle 36.44°/62.80\ \angle 90° = \mathbf{2.813\ A\ \angle -53.56°}$$

b. $F_p = G/Y_T = 4.55\ \text{mS}/5.66\ \text{mS} = \mathbf{0.804\ lagging}$

e. $P = I^2R = (0.803\ \text{A})^2\ 220\ \Omega = \mathbf{141.86\ W}$

f. $\mathbf{I}_s = \mathbf{I}_R + 2\mathbf{I}_C + \mathbf{I}_L$

$$\text{and } \mathbf{I}_C = \frac{\mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L}{2}$$

$$= \frac{1\ \text{A}\ \angle 0° - 0.803\ \text{A}\ \angle 36.44° - 2.813\ \text{A}\ \angle -53.56°}{2}$$

$$= \frac{1 - (0.646 + j0.477) - (1.671 - j2.263)}{2} = \frac{-1.317 + j1.786}{2}$$

$$\mathbf{I}_C = -0.657 + j0.893 = \mathbf{1.11\ A\ \angle 126.43°}$$

g. $$\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{5.66\ \text{mS}\ \angle -36.44°} = 176.7\ \Omega\ \angle 36.44°$$
$$= \mathbf{142.15\ \Omega + \textit{j}104.96\ \Omega} = R + jX_L$$

43. a. $(R = 220\ \Omega) \parallel (L = 1\ \text{H}) \parallel (C = 2\ \mu\text{F})$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3\ \text{Hz})(2\ \mu\text{F})} = 79.62\ \Omega$$

$$X_L = \omega L = 2\pi(10^3\ \text{Hz})(1\ \text{H}) = 6.28\ \text{k}\Omega$$

$$\mathbf{Y}_T = \frac{1}{220\ \Omega\ \angle 0°} + \frac{1}{6.28 \times 10^3\ \Omega\ \angle 90°} + \frac{1}{79.62\ \Omega\ \angle -90°}$$
$$= 0.0045 - j0.1592 \times 10^{-3} + j0.0126$$
$$= 4.5 \times 10^{-3} - j0.1592 \times 10^{-3} + j12.6 \times 10^{-3}$$
$$= \mathbf{4.5\ mS + \textit{j}12.44\ mS = 13.23\ mS\ \angle 70.11°}$$

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$\mathbf{E} = \mathbf{I}/\mathbf{Y}_T = 1\text{ A}\angle 0°/13.23\text{ mS}\angle 70.11° = \mathbf{75.6\text{ V}\angle -70.11°}$

$\mathbf{I}_R = \dfrac{E\angle\theta}{R\angle 0°} = 75.6\text{ V}\angle -70.11°/220\ \Omega\angle 0° = \mathbf{0.34\text{ A}\angle -70.11°}$

$\mathbf{I}_L = \dfrac{E\angle\theta}{X_L\angle 90°} = 75.6\text{ V}\angle -70.11°/6.28\text{ k}\Omega\angle 90° = \mathbf{12.04\text{ mA}\angle -160.11°}$

b. $F_p = \dfrac{G}{Y_T} = \dfrac{4.5\text{ mS}}{13.23\text{ mS}} = \mathbf{0.340\text{ leading}}$

c. $P = I^2R = (0.34\text{A})^2\ 220\ \Omega = \mathbf{25.43\text{ W}}$

f. $2\mathbf{I}_C = \mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L$

$$\mathbf{I}_C = \frac{\mathbf{I}_s - \mathbf{I}_R - \mathbf{I}_L}{2} = \frac{1\text{ A}\angle 0° - 0.34\text{ A}\angle -70.11° - 12.04\text{ mA}\angle -160.11°}{2}$$

$$= \frac{1-(0.12-j0.32)-(-11.32\times 10^{-3} - j4.1\times 10^{-3})}{2}$$

$$= \frac{0.89 + j0.32}{2}$$

$\mathbf{I}_C = 0.45 + j0.16 = \mathbf{0.47\text{ A}\angle 19.63°}$

g. $\mathbf{Z}_T = \dfrac{1}{\mathbf{Y}_T} = \dfrac{1}{13.23\text{ mS}\angle 70.11°} = 75.59\ \Omega\angle -70.11° = \mathbf{25.72\ \Omega - j71.08\ \Omega}$

$R = \mathbf{25.72\ \Omega}$, $X_C = \mathbf{71.08\ \Omega}$

44. $P = VI\cos\theta = 3000\text{ W}$

$$\cos\theta = \frac{3000\text{ W}}{VI} = \frac{3000\text{ W}}{(100\text{ V})(40\text{ A})} = \frac{3000}{4000} = 0.75\text{ (lagging)}$$

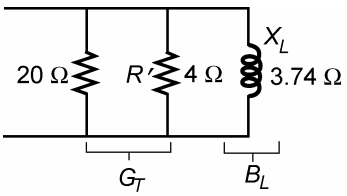
$$\theta = \cos^{-1} 0.75 = 41.41°$$

$$\mathbf{Y}_T = \frac{\mathbf{I}}{\mathbf{E}} = \frac{40\text{ A}\angle -41.41°}{100\text{ V}\angle 0°} = 0.4\text{ S}\angle -41.41° = 0.3\text{ S} - j0.265\text{ S} = G_T - jB_L$$

$$G_T = 0.3\text{ S} = \frac{1}{20\ \Omega} + \frac{1}{R'} = 0.05\text{ S} + \frac{1}{R'}$$

$$\text{and } R' = \frac{1}{0.25\text{ S}} = 4\ \Omega$$

$$X_L = \frac{1}{B_L} = \frac{1}{0.265\text{ S}} = \mathbf{3.74\ \Omega}$$



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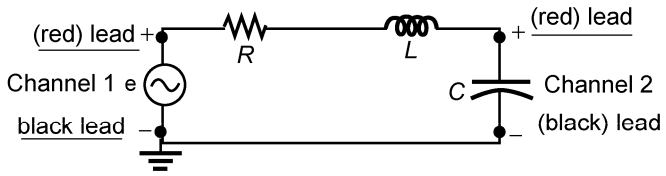
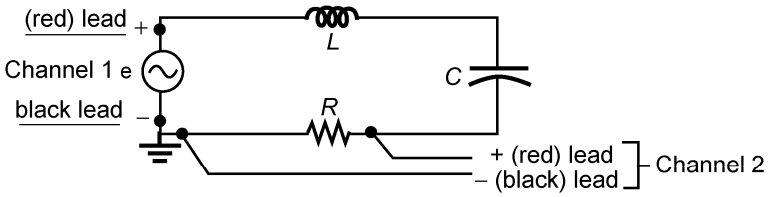
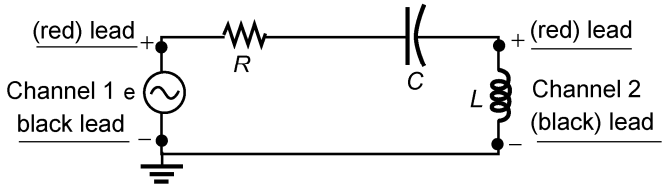
45. a.



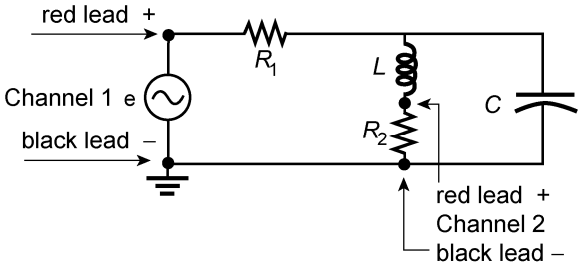
b.



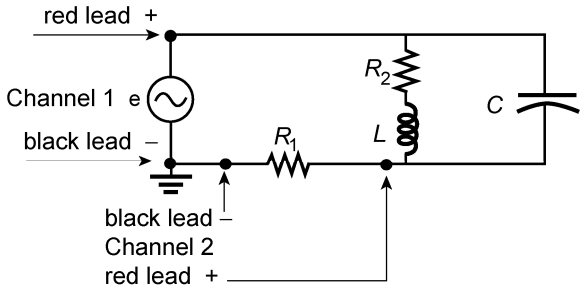
c.



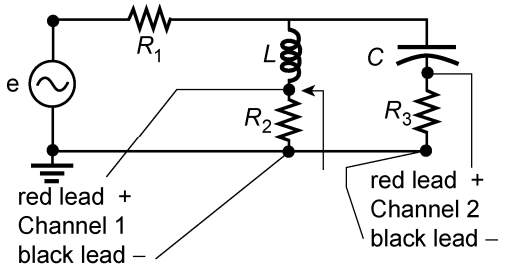
46. a. e and υ_{R_2}



b. e and i_s



c. i_L and i_C



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47. (I): (a) $\theta_{\text{div.}} = 0.8$ div., $\theta_T = 4$ div.

$$\theta = \frac{0.8\,\text{div.}}{4\,\text{div.}} \times 360° = 72°$$

υ_1 leads υ_2 by 72°

(b) υ_1: peak-to-peak = (5 div.)(0.5 V/div.) = **2.5 V**

$$V_1(\text{rms}) = 0.7071\left(\frac{2.5\,\text{V}}{2}\right) = \mathbf{0.88\ V}$$

υ_2: peak-to-peak = (2.4 div.)(0.5 V/div.) = **1.2 V**

$$V_2(\text{rms}) = 0.7071\left(\frac{1.2\,\text{V}}{2}\right) = \mathbf{0.42\ V}$$

(c) T = (4 div.)(0.2 ms/div.) = 0.8 ms

$$f = \frac{1}{T} = \frac{1}{0.8\,\text{ms}} = \mathbf{1.25\ kHz}\ \text{(both)}$$

(II): (a) $\theta_{\text{div.}} = 2.2$ div., $\theta_T = 6$ div.

$$\theta = \frac{2.2\,\text{div.}}{6\,\text{div.}} \times 360° = 132°$$

υ_1 leads υ_2 by 132°

(b) υ_1: peak-to-peak = (2.8 div.)(2 V/div.) = **5.6 V**

$$V_1(\text{rms}) = 0.7071\left(\frac{5.6\,\text{V}}{2}\right) = \mathbf{1.98\ V}$$

υ_2: peak-to-peak = (4 div.)(2 V/div.) = **8 V**

$$V_2(\text{rms}) = 0.7071\left(\frac{8\,\text{V}}{2}\right) = \mathbf{2.83\ V}$$

(c) T = (6 div.)(10 μs/div.) = 60 μs

$$f = \frac{1}{T} = \frac{1}{60\,\mu\text{s}} = \mathbf{16.67\ kHz}$$

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Chapter 16

1. a. $\mathbf{Z}_T = 2\ \Omega + j6\ \Omega + 8\ \Omega \angle{-90°} \parallel 12\ \Omega \angle{-90°}$

$$= 2\ \Omega + j6\ \Omega + \frac{(8\ \Omega \angle -90°)(12\ \Omega \angle -90°)}{-j8\Omega - j12\Omega} = 2\ \Omega + j6\ \Omega + \frac{96\ \Omega \angle -180°}{20 \angle -90°}$$

$$= 2\ \Omega + j6\ \Omega + 4.8\ \Omega \angle{-90°} = 2\ \Omega + j6\ \Omega - j4.8\ \Omega = 2\ \Omega + j\ 1.2\ \Omega$$

$\mathbf{Z}_T = \mathbf{2.33\ \Omega \angle 30.96°}$

b. $\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{12\ \text{V} \angle 0°}{2.33\ \Omega \angle 30.96°} = \mathbf{5.15\ A \angle -30.96°}$

c. $\mathbf{I}_1 = \mathbf{I} = \mathbf{5.15\ A \angle -30.96°}$

d. $(\text{CDR})\mathbf{I}_2 = \dfrac{(12\ \Omega \angle -90°)(5.15\ \text{A} \angle -30.96°)}{-j12\ \Omega - j8\ \Omega} = \dfrac{61.80\ \text{A} \angle -120.96°}{20 \angle -90°} = \mathbf{3.09\ A \angle -30.96°}$

$$\mathbf{I}_3 = \frac{(8\ \Omega \angle -90°)(5.15\ \text{A} \angle -30.96°)}{20\ \Omega \angle -90°} = \frac{41.2\ \text{A} \angle -120.96°}{20 \angle -90°} = \mathbf{2.06\ A \angle -30.96°}$$

e. $\mathbf{V}_L = (I \angle \theta)(X_L \angle 90°) = (5.15\ \text{A} \angle -30.96°)(6\ \Omega \angle 90°) = \mathbf{30.9\ V \angle 59.04°}$

2. a. $\mathbf{Z}_T = 3\ \Omega + j6\ \Omega + 2\ \Omega \angle 0° \parallel 8\ \Omega \angle -90°$

$= 3\ \Omega + j6\ \Omega + 1.94\ \Omega \angle -14.04°$

$= 3\ \Omega + j6\ \Omega + 1.88\ \Omega - j0.47\ \Omega$

$= 4.88\ \Omega + j5.53\ \Omega = \mathbf{7.38\ \Omega \angle 48.57°}$

b. $\mathbf{I}_s = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{30\ \text{V} \angle 0°}{7.38\ \Omega \angle 48.57°} = \mathbf{4.07\ A \angle -48.57°}$

c. $\mathbf{I}_C = \dfrac{\mathbf{Z}_{R_2}\mathbf{I}_s}{\mathbf{Z}_{R_2} + \mathbf{Z}_C} = \dfrac{(2\ \Omega \angle 0°)(4.07\ \text{A} \angle -48.57°)}{2\ \Omega - j8\ \Omega}$

$$= \frac{8.14\ \text{A} \angle -48.57°}{8.25 \angle -75.96°} = \mathbf{0.987\ A \angle 27.39°}$$

d. $\mathbf{V}_L = \dfrac{\mathbf{Z}_L\mathbf{E}}{\mathbf{Z}_T} = \dfrac{(6\ \Omega \angle 90°)(30\ \text{V} \angle 0°)}{7.38\ \Omega \angle 48.57°} = \dfrac{180\ \text{V} \angle 90°}{7.38\ \Omega \angle 48.57°}$

$= \mathbf{24.39\ V \angle 41.43°}$

3. a. $\mathbf{Z}_T = 12\ \Omega \angle 90° \parallel (9.1\ \Omega - j12\ \Omega) = 12\ \Omega \angle 90° \parallel 15.06\ \Omega \angle -52.826°$

$$= \frac{180.72\ \Omega \angle 37.17°}{9.10 \angle 0°}$$

$= \mathbf{19.86\ \Omega \angle 37.17°}$

$\mathbf{Y}_T = \dfrac{1}{\mathbf{Z}_T} = \dfrac{1}{19.86\ \Omega \angle 37.17°} = \mathbf{50.35\ mS \angle -37.17°}$

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b. $\mathbf{I}_s = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{60\text{ V}\angle 30^\circ}{19.86\,\Omega\angle 37.17^\circ} = \mathbf{3.02\text{ A}\ \angle -7.17^\circ}$

c. (CDR) $\mathbf{I}_2 = \dfrac{(12\,\Omega\angle 90^\circ)(3.02\text{ A}\angle -7.17^\circ)}{j12\,\Omega + 9.1\,\Omega - j12\,\Omega} = \dfrac{36.24\text{ A}\angle 82.83^\circ}{9.1\angle 0^\circ}$

$= \mathbf{3.98\text{ A}\angle 82.83^\circ}$

d. (VDR) $\mathbf{V}_C = \dfrac{(12\,\Omega\angle -90^\circ)(60\text{ V}\angle 30^\circ)}{9.1\,\Omega - j12\,\Omega} = \dfrac{720\text{ V}\angle -60^\circ}{15.06\angle -52.826^\circ}$

$= \mathbf{47.81\text{ V}\angle -7.17^\circ}$

e. $P = EI\cos\theta = (60\text{ V})(3.02\text{ A})\cos(30^\circ - 7.17^\circ)$
$= 181.20(0.922) = \mathbf{167.07\text{ W}}$

4. a. $\mathbf{Z}_T = 2\,\Omega + \dfrac{(4\,\Omega\angle -90^\circ)(6\Omega\angle 90^\circ)}{-j4\,\Omega + j6\,\Omega} + \dfrac{(4\,\Omega\angle 0^\circ)(3\,\Omega\angle 90^\circ)}{4\,\Omega + j3\,\Omega}$

$= 2\,\Omega + \dfrac{24\,\Omega\angle 0^\circ}{2\angle 90^\circ} + \dfrac{12\,\Omega\angle 90^\circ}{5\angle 36.87^\circ}$
$= 2\,\Omega + 12\,\Omega\angle -90^\circ + 2.4\angle 53.13^\circ$
$= 2\,\Omega - j12\,\Omega + 1.44\,\Omega + j1.92\,\Omega$
$= \mathbf{3.44\,\Omega - j10.08\,\Omega = 10.65\,\Omega\angle -71.16^\circ}$

b. $\mathbf{V}_2 = \mathbf{I}(2.4\,\Omega\angle 53.13^\circ) = (5\text{ A}\angle 0^\circ)(2.4\,\Omega\angle 53.13^\circ) = \mathbf{12\text{ V}\angle 53.13^\circ}$
$\mathbf{I}_L = \dfrac{(4\,\Omega\angle 0^\circ)(\mathbf{I})}{4\,\Omega + j3\,\Omega} = \dfrac{(4\,\Omega\angle 0^\circ)(5\text{ A}\angle 0^\circ)}{5\,\Omega\angle 36.87^\circ} = \dfrac{20\text{ A}\angle 0^\circ}{5\angle 36.87^\circ} = \mathbf{4\text{ A}\angle -36.87^\circ}$

c. $F_p = \dfrac{R}{\mathbf{Z}_T} = \dfrac{3.44\,\Omega}{10.65\,\Omega} = \mathbf{0.323\text{ (leading)}}$

5. a. $400\,\Omega\angle -90^\circ \parallel 400\,\Omega\angle -90^\circ = \dfrac{400\,\Omega\angle -90^\circ}{2} = 200\,\Omega\angle -90^\circ$

$\mathbf{Z}' = 200\,\Omega - j200\,\Omega = 282.843\,\Omega\angle -45^\circ$
$\mathbf{Z}'' = -j200\,\Omega + j560\,\Omega = +j360\,\Omega = 360\,\Omega\angle 90^\circ$
$\mathbf{Z}_T = \mathbf{Z}' \parallel \mathbf{Z}'' = \dfrac{(282.843\,\Omega\angle -45^\circ)(360\,\Omega\angle 90^\circ)}{(200\,\Omega - j200\,\Omega) + j360\,\Omega} = \dfrac{101.83\text{ k}\Omega\angle 45^\circ}{256.12\angle 38.66^\circ}$

$= 397.59\,\Omega\angle 6.34^\circ$

$\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}_T} = \dfrac{100\text{ V}\angle 0^\circ}{397.59\,\Omega\angle 6.34^\circ} = \mathbf{0.25\text{ A}\angle -6.34^\circ}$

b. $\mathbf{V}_C = \dfrac{(200\,\Omega\angle -90^\circ)(100\text{ V}\angle 0^\circ)}{200\,\Omega - j200\,\Omega} = \dfrac{20{,}000\text{ V}\angle -90^\circ}{282.843\angle -45^\circ} = \mathbf{70.71\text{ V}\angle -45^\circ}$

c. $P = EI\cos\theta = (100\text{ V})(0.25\text{ A})\cos 6.34^\circ$
$= (25)(0.994) = \mathbf{24.85\text{ W}}$

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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. $V_{R_1} = (I_1 \angle \theta)R \angle 0° = (24\ \text{A} \angle 6.87°)(3\ \Omega \angle 0°) = 72\ \text{V} \angle 6.87°$

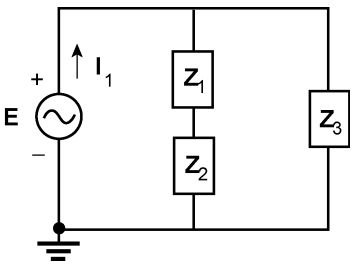
$$\mathbf{V}_{ab} + V_{R_1} - \mathbf{V}_C = 0$$

$$\mathbf{V}_{ab} = \mathbf{V}_C - V_{R_1} = 260\ \text{V} \angle 60° - 72\ \text{V} \angle 6.87°$$

$$= (130\ \text{V} + j225.167\ \text{V}) - (71.483\ \text{V} + j8.612\ \text{V})$$

$$= \mathbf{58.52\ V + j216.56\ V = 224.33\ V \angle 74.88°}$$

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. $P = EI \cos\theta = (40\ \text{V})(1.423\ \text{A})\cos 18.259°$

$= \mathbf{54.07\ W}$

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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. $$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60\ \text{V} \angle 0°}{1.227\,\Omega \angle 16.032°} = \mathbf{48.9\ A \angle -16.03°}$$

$\mathbf{I}_s \stackrel{?}{=} \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3$

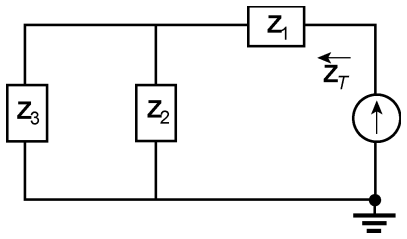
$48.9\ \text{A} \angle -16.03° \stackrel{?}{=} 26.83\ \text{A} \angle -26.57° + 20\ \text{A} \angle 0° + 3.35\ \text{A} \angle -26.57°$

$= (24\ \text{A} - j12\ \text{A}) + (20\ \text{A}) + (3\ \text{A} - j1.5\ \text{A})$

$\stackrel{\checkmark}{=} 47\ \text{A} + j13.5\ \text{A} = \mathbf{48.9\ A \angle -16.03°}$ (checks)

d. $$F_p = \frac{G}{Y_T} = \frac{0.783\ \text{S}}{0.820\ \text{S}} = \mathbf{0.955\ (lagging)}$$

9. a.



$$\mathbf{Z}' = 3\ \Omega \angle 0° \parallel 4\ \Omega \angle -90° = \frac{12\,\Omega \angle -90°}{3 - j4}$$

$$= \frac{12\,\Omega \angle -90°}{5 \angle -53.13°} = 2.4\ \Omega \angle -36.87°$$

$\mathbf{Z}_3 = 2\ \mathbf{Z}' + j7\ \Omega$

$= 4.8\ \Omega \angle -36.87° + j7\ \Omega$

$= 3.84\ \Omega - j2.88\ \Omega + j7\ \Omega$

$= 3.84\ \Omega + j4.12\ \Omega$

$= 5.63\ \Omega \angle 47.02°$

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$$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \,||\, \mathbf{Z}_3 = 8.8\ \Omega + 8.2\ \Omega \angle 0° \,||\, 5.63\ \Omega \angle 47.02°$$
$$= 8.8\ \Omega + \frac{46.18\,\Omega \angle 47.02°}{8.2 + 3.84 + j4.12} = 8.8\,\Omega + \frac{46.18\,\Omega \angle 47.02°}{12.73 \angle 18.89°}$$
$$= 8.8\ \Omega + 3.63\ \Omega \angle 28.13° = 8.8\ \Omega + 3.20\ \Omega + j1.71\ \Omega$$
$$= 12\ \Omega + j1.71\ \Omega = \mathbf{12.12\ \Omega \angle 8.11°}$$
$$\mathbf{Y}_T = \frac{1}{\mathbf{Z}_T} = \mathbf{82.51\ mS \angle -8.11°}$$

b. $\mathbf{V}_1 = \mathbf{I}\mathbf{Z}_1 = (3\ \text{A} \angle 30°)(6.8\ \Omega \angle 0°) = \mathbf{20.4\ V \angle 30°}$
$\mathbf{V}_2 = \mathbf{I}(\mathbf{Z}_2 \,||\, \mathbf{Z}_3) = (3\ \text{A} \angle 30°)(3.63\ \Omega \angle 28.13°)$
$= \mathbf{10.89\ V \angle 58.13°}$

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. $X_{L_1} = \omega L_1 = 2\pi(10^3\ \text{Hz})(0.1\ \text{H}) = 628\ \Omega$
$X_{L_2} = \omega L_2 = 2\pi(10^3\ \text{Hz})(0.2\ \text{H}) = 1.256\ \text{k}\Omega$
$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10^3\ \text{Hz})(1\,\mu\text{F})} = 0.159\ \text{k}\Omega$$
$$\mathbf{Z}_T = R \angle 0° + X_{L_1} \angle 90° + X_C \angle -90° \,||\, X_{L_2} \angle 90°$$
$$= 300\ \Omega + j628\ \Omega + 0.159\ \text{k}\Omega \angle -90° \,||\, 1.256\ \text{k}\Omega \angle 90°$$
$$= 300\ \Omega + j628\ \Omega - j182\ \Omega$$
$$= \mathbf{300\ \Omega + j446\ \Omega = 537.51\ \Omega \angle 56.07°}$$
$$\mathbf{Y}_T = \frac{1}{\mathbf{Z}_T} = \frac{1}{537.51\ \Omega \angle 56.07°} = \mathbf{1.86\ mS \angle -56.07°}$$

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): $$\mathbf{I}_1 = \frac{\mathbf{Z}_{L_2}\mathbf{I}_s}{\mathbf{Z}_{L_2} + \mathbf{Z}_C} = \frac{(1.256\,\text{k}\Omega \angle 90°)(93\,\text{mA} \angle -56.07°)}{+j1.256\,\text{k}\Omega - j0.159\,\text{k}\Omega}$$
$$= \frac{116.81\,\text{mA} \angle 33.93°}{1.097 \angle 90°} = \mathbf{106.48\ mA \angle -56.07°}$$
$$\mathbf{I}_2 = \frac{\mathbf{Z}_C\mathbf{I}_s}{\mathbf{Z}_{L_2} + \mathbf{Z}_C} = \frac{(0.159\,\text{k}\Omega \angle -90°)(93\,\text{mA} \angle -56.07°)}{1.097\,\text{k}\Omega \angle 90°}$$
$$= \frac{14.79\,\text{mA} \angle -146.07°}{1.097 \angle 90°} = 13.48\ \text{mA} \angle -236.07°$$
$$= \mathbf{13.48\ mA \angle 123.93°}$$

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d. $\mathbf{V}_1 = (I_2 \angle\theta)(X_{L_2} \angle 90°) = (13.48 \text{ mA} \angle 123.92°)(1.256 \text{ k}\Omega \angle 90°)$

$= \mathbf{16.93 \text{ V} \angle 213.93°}$

$\mathbf{V}_{ab} = \mathbf{E} - (I_s \angle\theta)(R \angle 0°) = 50 \text{ V} \angle 0° - (93 \text{ mA} \angle -56.07°)(300 \ \Omega \angle 0°)$

$= 50 \text{ V} - 27.9 \text{ V} \angle -56.07°$

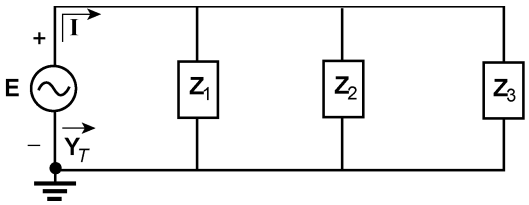
$= 50 \text{ V} - (15.573 \text{ V} - j23.149 \text{ V})$

$= 34.43 \text{ V} + j23.149 \text{ V} = \mathbf{41.49 \text{ V} \angle 33.92°}$

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.



$\mathbf{Z}_1 = 2 \ \Omega - j2 \ \Omega = 2.828 \ \Omega \angle -45°$

$\mathbf{Z}_2 = 3 \ \Omega - j9 \ \Omega + j6 \ \Omega$

$= 3 \ \Omega - j3 \ \Omega = 4.243 \ \Omega \angle -45°$

$\mathbf{Z}_3 = 10 \ \Omega \angle 0°$

$$\mathbf{Y}_T = \frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} = \frac{1}{2.828 \ \Omega \angle -45°} + \frac{1}{4.243 \ \Omega \angle -45°} + \frac{1}{10 \ \Omega \angle 0°}$$

$= 0.354 \text{ S} \angle 45° + 0.236 \text{ S} \angle 45° + 0.1 \text{ S} \angle 0° = 0.59 \text{ S} \angle 45° + 0.1 \text{ S} \angle 0°$

$= 0.417 \text{ S} + j0.417 \text{ S} + 0.1 \text{ S}$

$\mathbf{Y}_T = 0.517 \text{ S} + j \ 0.417 \text{ S} = \mathbf{0.66 \text{ S} \angle 38.89°}$

$$\mathbf{Z}_T = \frac{1}{\mathbf{Y}_T} = \frac{1}{0.66 \text{ S} \angle 38.89°} = \mathbf{1.52 \ \Omega \angle -38.89°}$$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50 \text{ V} \angle 0°}{1.52 \ \Omega \angle -38.89°} = \mathbf{32.89 \text{ A} \angle 38.89°}$$

12. $\mathbf{Z}' = 12 \ \Omega - j20 \ \Omega = 23.32 \ \Omega \angle -59.04°$

$X_L \angle 90° \parallel \mathbf{Z}' = 20 \ \Omega \angle 90° \parallel 23.32 \ \Omega \angle -59.04° = 33.34 \ \Omega \angle 19.99°$

$\mathbf{Z}'' = R_3 \angle 0° + X_L \angle 90° \parallel \mathbf{Z}' = 12 \ \Omega + 33.34 \ \Omega \angle 19.99°$

$= 12 \ \Omega + (31.33 \ \Omega - j11.40 \ \Omega)$

$= 43.33 \ \Omega - j11.40 \ \Omega = 44.80 \ \Omega \angle 14.74°$

$R_2 \angle 0° \parallel \mathbf{Z}'' = 20 \ \Omega \angle 0° \parallel 44.80 \ \Omega \angle 14.74° = 13.93 \ \Omega \angle 4.54°$

$\mathbf{Z}_T = R_1 \angle 0° + R_2 \angle 0° \parallel \mathbf{Z}'' = 12 \ \Omega + 13.93 \angle 4.54°$

$= 12 \ \Omega + (13.89 \ \Omega + j1.10 \ \Omega)$

$= 25.89 \ \Omega + j1.10 \ \Omega = \mathbf{25.91 \ \Omega \angle 2.43°}$

$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100 \text{ V} \angle 0°}{25.91 \ \Omega \angle 2.43°} = \mathbf{3.86 \text{ A} \angle -2.43°}$$

$\mathbf{I}_{R_1} = \mathbf{I}$

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$$\mathbf{I}_{R_3} = \frac{R_2 \angle 0^\circ \ \mathbf{I}_s}{R_2 \angle 0^\circ + \mathbf{Z}''} = \frac{(20\,\Omega \angle 0^\circ)(3.86\text{ A} \angle -2.43^\circ)}{\underbrace{20\,\Omega + 43.33\,\Omega}_{63.33\ \Omega} + j11.40\,\Omega} = \frac{77.20\text{ A} \angle -2.43^\circ}{64.35 \angle 10.20^\circ}$$

$$= 1.20\text{ A} \angle -12.63^\circ$$

$$\mathbf{I}_4 = \frac{X_L \angle 90^\circ \mathbf{I}_{R_3}}{X_L \angle 90^\circ + \mathbf{Z}'} = \frac{(20\,\Omega \angle 90^\circ)(1.20\text{ A} \angle -12.63^\circ)}{j20\,\Omega + 12\,\Omega - j20\,\Omega} = \frac{24.00\text{ A} \angle 77.37^\circ}{12 \angle 0^\circ}$$

$$= \mathbf{2.00\text{ A} \angle 77.37^\circ}$$

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. $\mathbf{Z}' = X_{C_2} \angle -90^\circ \parallel R_1 \angle 0^\circ = 2\ \Omega \angle -90^\circ \parallel 1\ \Omega \angle 0^\circ$

$$= \frac{2\,\Omega \angle -90^\circ}{1 - j2} = \frac{2\,\Omega \angle -90^\circ}{2.236 \angle -63.435^\circ}$$

$$= 0.894\ \Omega \angle -26.565^\circ$$

$\mathbf{Z}'' = X_{L_2} \angle 90^\circ + \mathbf{Z}' = +j8\ \Omega + 0.894\ \Omega \angle -26.565^\circ$

$= +j8\ \Omega + (0.8\ \Omega - j4\ \Omega)$

$= 0.8\ \Omega + j4 = 4.079\ \Omega \angle 78.69^\circ$

$$\mathbf{I}_{X_{L_2}} = \frac{X_{C_1} \angle -90^\circ \mathbf{I}}{X_{C_1} \angle -90^\circ + \mathbf{Z}''} = \frac{(2\ \Omega \angle -90^\circ)(0.5\text{ A} \angle 0^\circ)}{-j2\ \Omega + (0.8\ \Omega + j4\ \Omega)} = \frac{1\text{ A} \angle -90^\circ}{0.8 + j2}$$

$$= \frac{1\text{ A} \angle -90^\circ}{2.154 \angle 68.199^\circ} = 0.464\text{ A} \angle -158.99^\circ$$

$$\mathbf{I}_1 = \frac{X_{C_2} \angle -90^\circ \mathbf{I}_{X_{C_2}}}{X_{C_2} \angle -90^\circ + R_1} = \frac{(2\ \Omega \angle -90^\circ)(0.464\ \text{A} \angle -158.99^\circ)}{-j2\,\Omega + 1\,\Omega} = \frac{0.928\text{ A} \angle -248.99^\circ}{2.236 \angle -63.435^\circ}$$

$$= \mathbf{0.42\text{ A} \angle 174.45^\circ}$$

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Chapter 17

1. –

2. a. $\mathbf{Z} = 2.2\ \Omega + 5.6\ \Omega + j8.2\ \Omega = 7.8\ \Omega + j8.2\ \Omega = \mathbf{11.32\ \Omega\ \angle 46.43°}$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{20\ \text{V}\ \angle 20°}{11.32\ \Omega\ \angle 46.43°} = \mathbf{1.77\ A\ \angle -26.43°}$$

b. $\mathbf{Z} = -j5\ \Omega + 2\ \Omega\ \angle 0° \parallel 5\ \Omega\ \angle 90° = -j5\ \Omega + 1.72\ \Omega + j0.69\ \Omega = \mathbf{4.64\ \Omega\ \angle -68.24°}$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{60\ \text{V}\ \angle 30°}{4.64\ \Omega\ \angle -68.24°} = \mathbf{12.93\ A\ \angle 98.24°}$$

3. a. $\mathbf{Z} = 15\ \Omega - j16\ \Omega = \mathbf{21.93\ \Omega\ \angle -46.85°}$

$\mathbf{E} = \mathbf{IZ} = (0.5\ \text{A}\ \angle 60°)(21.93\ \Omega\ \angle -46.85°)$

$= \mathbf{10.97\ V\ \angle 13.15°}$

b. $\mathbf{Z} = 10\ \Omega\ \angle 0° \parallel 6\ \Omega\ \angle 90° = \mathbf{5.15\ \Omega\ \angle 59.04°}$

$\mathbf{E} = \mathbf{IZ} = (2\ \text{A}\ \angle 120°)(5.15\ \Omega\ \angle 59.04°)$

$= \mathbf{10.30\ V\ \angle 179.04°}$

4. a. $\mathbf{I} = \dfrac{\mu\mathbf{V}}{R} = \dfrac{16\ \text{V}}{4 \times 10^3} = \mathbf{4 \times 10^{-3}\ V}$

$\mathbf{Z} = \mathbf{4\ k\Omega\ \angle 0°}$

b. $\mathbf{V} = (h\mathbf{I})(R) = (50\ \mathbf{I})(50\ \text{k}\Omega) = \mathbf{2.5 \times 10^6\ I}$

$\mathbf{Z} = \mathbf{50\ k\Omega\ \angle 0°}$

5. a. Clockwise mesh currents:

$\mathbf{E} - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_1\mathbf{Z}_2 + \mathbf{I}_2\mathbf{Z}_2 = 0$

$-\mathbf{I}_2\mathbf{Z}_2 + \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_2\mathbf{Z}_3 - \mathbf{E}_2 = 0$

$[\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1$

$-\mathbf{Z}_2\mathbf{I}_1 + [\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{I}_2 = -\mathbf{E}_2$

$\mathbf{Z}_1 = R_1\ \angle 0° = 4\ \Omega\ \angle 0°$

$\mathbf{Z}_2 = X_L\ \angle 90° = 6\ \Omega\ \angle 90°$

$\mathbf{Z}_3 = X_C\ \angle -90° = 8\ \Omega\ \angle -90°$

$\mathbf{E}_1 = 10\ \text{V}\ \angle 0°,\ \mathbf{E}_2 = 40\ \text{V}\ \angle 60°$

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\begin{vmatrix} \mathbf{E}_1 & -\mathbf{Z}_2 \\ -\mathbf{E}_2 & [\mathbf{Z}_2 + \mathbf{Z}_3] \end{vmatrix}}{\begin{vmatrix} [\mathbf{Z}_1 + \mathbf{Z}_2] & -\mathbf{Z}_2 \\ -\mathbf{Z}_2 & [\mathbf{Z}_2 + \mathbf{Z}_3] \end{vmatrix}} = \frac{[\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{E}_1 - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{5.15\ A\ \angle -24.5°}$$

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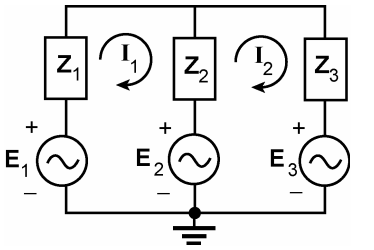
b. By interchanging the right two branches, the general configuration of part (a) will result and

$$\mathbf{I}_{50\Omega} = \mathbf{I}_1 = \frac{[\mathbf{Z}_2 + \mathbf{Z}_3]\mathbf{E}_1 - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3}$$
$$= \mathbf{0.44\ A\ \angle 143.48°}$$

$\mathbf{Z}_1 = R_1 = 50\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = X_C\ \angle -90° = 60\ \Omega\ \angle -90°$
$\mathbf{Z}_3 = X_L\ \angle 90° = 20\ \Omega\ \angle 90°$
$\mathbf{E}_1 = 5\ \text{V}\ \angle 30°$, $\mathbf{E}_2 = 20\ \text{V}\ \angle 0°$

6. a.



$\mathbf{Z}_1 = 12\ \Omega + j12\ \Omega = 16.971\ \Omega\ \angle 45°$
$\mathbf{Z}_2 = 3\ \Omega\ \angle 0°$
$\mathbf{Z}_3 = -j1\ \Omega$
$\mathbf{E}_1 = 20\ \text{V}\ \angle 50°$
$\mathbf{E}_2 = 60\ \text{V}\ \angle 70°$
$\mathbf{E}_3 = 40\ \text{V}\ \angle 0°$

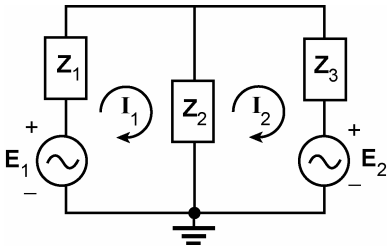
$$\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_2] - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1 - \mathbf{E}_2$$
$$\mathbf{I}_2[\mathbf{Z}_2 + \mathbf{Z}_3] - \mathbf{Z}_2\mathbf{I}_1 = \mathbf{E}_2 - \mathbf{E}_3$$

$$(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1 - \mathbf{E}_2$$
$$-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 = \mathbf{E}_2 - \mathbf{E}_3$$

Using determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{(\mathbf{E}_1 - \mathbf{E}_2)(\mathbf{Z}_2 + \mathbf{Z}_3) + \mathbf{Z}_2(\mathbf{E}_2 - \mathbf{E}_3)}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{2.55\ A\ \angle 132.72°}$$

b.



Source conversion:

$\mathbf{E}_1 = \mathbf{IZ} = (6\ \text{A}\ \angle 0°)(2\ \Omega\ \angle 0°)$
$= 12\ \text{V}\ \angle 0°$
$\mathbf{Z}_1 = 2\ \Omega + 20\ \Omega + j20\ \Omega = 22\ \Omega + j20\ \Omega$
$= 29.732\ \Omega\ \angle 42.274°$
$\mathbf{Z}_2 = -j10\ \Omega = 10\ \Omega\ \angle -90°$
$\mathbf{Z}_3 = 10\ \Omega\ \angle 0°$

$$\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_2] - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1$$
$$\mathbf{I}_2[\mathbf{Z}_2 + \mathbf{Z}_3] - \mathbf{Z}_2\mathbf{I}_1 = -\mathbf{E}_2$$

$$(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = \mathbf{E}_1$$
$$-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 = -\mathbf{E}_2$$

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\mathbf{E}_1(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{Z}_2\mathbf{E}_2}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{0.495\ A\ \angle 72.26°}$$

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7. a. Clockwise mesh currents:

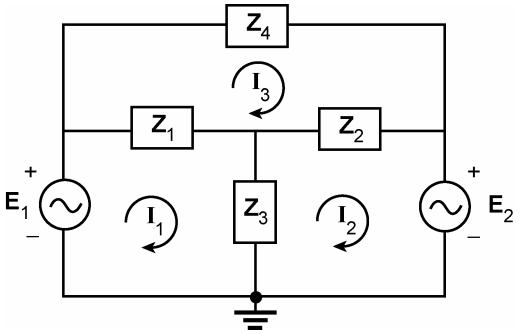
$\mathbf{E}_1 - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{I}_1\mathbf{Z}_2 + \mathbf{I}_2\mathbf{Z}_2 = 0$
$-\mathbf{I}_2\mathbf{Z}_2 + \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_2\mathbf{Z}_3 - \mathbf{I}_2\mathbf{Z}_4 + \mathbf{I}_3\mathbf{Z}_4 = 0$
$-\mathbf{I}_3\mathbf{Z}_4 + \mathbf{I}_2\mathbf{Z}_4 - \mathbf{I}_3\mathbf{Z}_5 - \mathbf{E}_2 = 0$

$\mathbf{Z}_1 = 4\ \Omega + j3\ \Omega$, $\mathbf{Z}_2 = -j1\ \Omega$
$\mathbf{Z}_3 = +j6\ \Omega$, $\mathbf{Z}_4 = !j2\ \Omega$
$\mathbf{Z}_5 = 8\ \Omega$
$\mathbf{E}_1 = 60\ \text{V} \angle 0°$, $\mathbf{E}_2 = 120\ \text{V} \angle 120°$

$$\begin{array}{llll} [\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{I}_1 & -\mathbf{Z}_2\ \mathbf{I}_2 & +0 & = \mathbf{E}_1 \\ -\mathbf{Z}_2\ \mathbf{I}_1 & +[\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4]\mathbf{I}_2 & -\mathbf{Z}_4\ \mathbf{I}_3 & = 0 \\ 0 & -\mathbf{Z}_4\ \mathbf{I}_2 & +[\mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{I}_3 & = -\mathbf{E}_2 \end{array}$$

$$\mathbf{I}_{R_1} = \mathbf{I}_3 = \frac{[\mathbf{Z}_2\mathbf{Z}_4]\mathbf{E}_1 + [\mathbf{Z}_2^2 - [\mathbf{Z}_1 + \mathbf{Z}_2]\ [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4]]\mathbf{E}_2}{[\mathbf{Z}_1 + \mathbf{Z}_2][\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4][\mathbf{Z}_4 + \mathbf{Z}_5] - [\mathbf{Z}_1 + \mathbf{Z}_2]\mathbf{Z}_4^2 - [\mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{Z}_2^2}$$
$$= \mathbf{13.07\ A} \angle \mathbf{-33.71°}$$

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:

$$\mathbf{I}_3 = \frac{-(\mathbf{Z}_1 + \mathbf{Z}_3)(\mathbf{Z}_2)\mathbf{E}_2 - \mathbf{Z}_1\mathbf{Z}_3\mathbf{E}_2 + \mathbf{E}_1[\mathbf{Z}_2\mathbf{Z}_3 + \mathbf{Z}_1(\mathbf{Z}_2 + \mathbf{Z}_3)]}{(\mathbf{Z}_1 + \mathbf{Z}_3)[(\mathbf{Z}_2 + \mathbf{Z}_3)(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{Z}_2^2] + \mathbf{Z}_3[\mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{Z}_1\mathbf{Z}_2] - \mathbf{Z}_1[-\mathbf{Z}_2\mathbf{Z}_3 - \mathbf{Z}_1(\mathbf{Z}_2 + \mathbf{Z}_3)]}$$
$$= \mathbf{48.33\ A} \angle \mathbf{-77.57°}$$

or $\mathbf{I}_3 = \dfrac{\mathbf{E}_1 - \mathbf{E}_2}{\mathbf{Z}_4}$ if one carefully examines the network!

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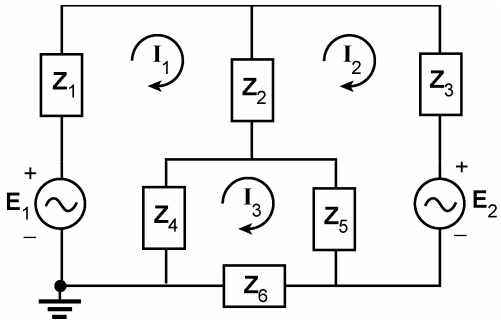
8. a.



$\mathbf{Z}_1 = 5\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 5\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 4\ \Omega\ \angle 0°$, $\mathbf{Z}_4 = 6\ \Omega\ \angle -90°$
$\mathbf{Z}_5 = 4\ \Omega\ \angle 0°$, $\mathbf{Z}_6 = 6\ \Omega + j8\ \Omega$
$\mathbf{E}_1 = 20\ \text{V}\ \angle 0°$, $\mathbf{E}_2 = 40\ \text{V}\ \angle 60°$

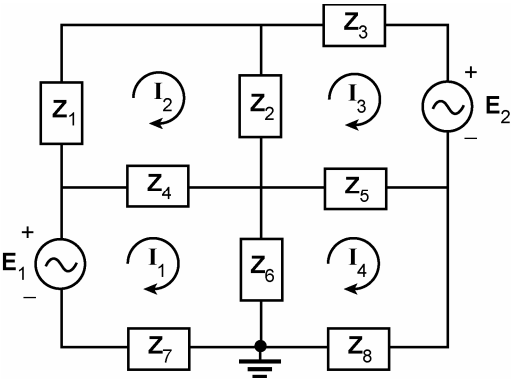
$$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_3\mathbf{Z}_4 = \mathbf{E}_1$$
$$\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5) - \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_3\mathbf{Z}_5 = -\mathbf{E}_2$$
$$\mathbf{I}_3(\mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6) - \mathbf{I}_1\mathbf{Z}_4 - \mathbf{I}_2\mathbf{Z}_5 = 0$$

$$\begin{array}{llll} (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4)\,\mathbf{I}_1 & -\mathbf{Z}_2\mathbf{I}_2 & -\mathbf{Z}_4\mathbf{I}_3 = \mathbf{E}_1 \\ -\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5)\mathbf{I}_2 & -\mathbf{Z}_5\mathbf{I}_3 = -\mathbf{E}_2 \\ -\mathbf{Z}_4\mathbf{I}_1 & -\mathbf{Z}_5\mathbf{I}_2 + (\mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6)\mathbf{I}_3 = 0 \end{array}$$

Using $\mathbf{Z}' = \mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4$, $\mathbf{Z}'' = \mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5$, $\mathbf{Z}''' = \mathbf{Z}_4 + \mathbf{Z}_5 + \mathbf{Z}_6$ and determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_1 = \frac{\mathbf{E}_1(\mathbf{Z}''\mathbf{Z}''' - \mathbf{Z}_5^2) - \mathbf{E}_2(\mathbf{Z}_2\mathbf{Z}''' + \mathbf{Z}_4\mathbf{Z}_5)}{\mathbf{Z}'(\mathbf{Z}''\mathbf{Z}''' - \mathbf{Z}_5^2) - \mathbf{Z}_2(\mathbf{Z}_2\mathbf{Z}''' + \mathbf{Z}_4\mathbf{Z}_5) - \mathbf{Z}_4(\mathbf{Z}_2\mathbf{Z}_5 + \mathbf{Z}_4\mathbf{Z}'')}$$
$$= \mathbf{3.04\ A\ \angle 169.12°}$$

b.



$\mathbf{Z}_1 = 10\ \Omega + j20\ \Omega$ $\quad \mathbf{Z}_2 = -j20\ \Omega$
$\mathbf{Z}_3 = 80\ \Omega\ \angle 0°$ $\quad \mathbf{Z}_4 = 6\ \Omega\ \angle 0°$
$\mathbf{Z}_5 = 15\ \Omega\ \angle 90°$ $\quad \mathbf{Z}_6 = 10\ \Omega\ \angle 0°$
$\mathbf{Z}_7 = 5\ \Omega\ \angle 0°$ $\quad \mathbf{Z}_8 = 5\ \Omega - j20\ \Omega$
$\mathbf{E}_1 = 25\ \text{V}\ \angle 0°$ $\quad \mathbf{E}_2 = 75\ \text{V}\ \angle 20°$

$$\mathbf{I}_1(\mathbf{Z}_4 + \mathbf{Z}_6 + \mathbf{Z}_7) - \mathbf{I}_2\mathbf{Z}_4 - \mathbf{I}_4\mathbf{Z}_6 = \mathbf{E}_1$$
$$\mathbf{I}_2(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4) - \mathbf{I}_1\mathbf{Z}_4 - \mathbf{I}_3\mathbf{Z}_2 = 0$$
$$\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5) - \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_4\mathbf{Z}_5 = -\mathbf{E}_2$$
$$\mathbf{I}_4(\mathbf{Z}_5 + \mathbf{Z}_6 + \mathbf{Z}_8) - \mathbf{I}_1\mathbf{Z}_6 - \mathbf{I}_3\mathbf{Z}_5 = 0$$

$$\begin{array}{llll} (\mathbf{Z}_4 + \mathbf{Z}_6 + \mathbf{Z}_7)\,\mathbf{I}_1 & -\mathbf{Z}_4\mathbf{I}_2 & +0 & -\mathbf{Z}_6\mathbf{I}_4 = \mathbf{E}_1 \\ -\mathbf{Z}_4\mathbf{I}_1 + (\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_4)\mathbf{I}_2 & -\mathbf{Z}_2\mathbf{I}_3 & +0 = 0 \\ 0 & -\mathbf{Z}_2\,\mathbf{I}_2 + (\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_5)\mathbf{I}_3 & -\mathbf{Z}_5\mathbf{I}_4 = -\mathbf{E}_2 \\ -\mathbf{Z}_6\mathbf{I}_1 & +0 & -\mathbf{Z}_5\mathbf{I}_3 + (\mathbf{Z}_5 + \mathbf{Z}_6 + \mathbf{Z}_7)\mathbf{I}_4 = 0 \end{array}$$

Applying determinants:

$$\mathbf{I}_{R_1} = \mathbf{I}_{80\Omega} = \mathbf{0.68\ A\ \angle -162.9°}$$

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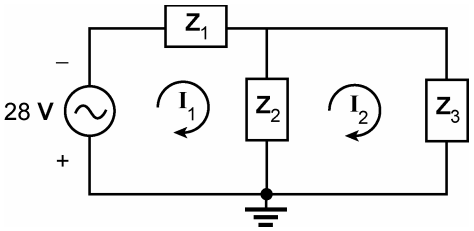
9.



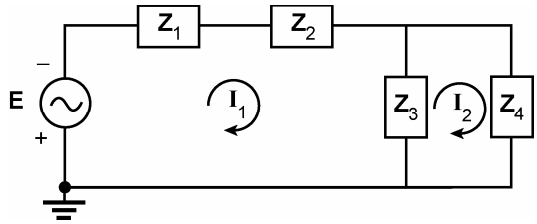
$\mathbf{Z}_1 = 5\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 10\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_3 = 1\ \text{k}\Omega + j4\ \text{k}\Omega = 4.123\ \text{k}\Omega\ \angle 75.96°$

$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2) - \mathbf{Z}_2\mathbf{I}_2 = -28\ \mathbf{V}$
$\mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) - \mathbf{Z}_2\mathbf{I}_1 = 0$

$(\mathbf{Z}_1 + \mathbf{Z}_2)\mathbf{I}_1 - \mathbf{Z}_2\mathbf{I}_2 = -28\ \mathbf{V}$
$-\mathbf{Z}_2\mathbf{I}_1 + (\mathbf{Z}_2 + \mathbf{Z}_3)\mathbf{I}_2 = 0$

$$\mathbf{I}_L = \mathbf{I}_2 = \frac{-\mathbf{Z}_2\,28\ \mathbf{V}}{\mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3} = \mathbf{-3.17 \times 10^{-3}\ V\ \angle 137.29°}$$

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. $6\mathbf{V}_x - \mathbf{I}_1\ 1\ \text{k}\Omega - 10\ \text{V}\ \angle 0° = 0$
$10\ \text{V}\angle 0° - \mathbf{I}_2\ 4\ \text{k}\Omega - \mathbf{I}_2\ 2\ \text{k}\Omega = 0$

$\mathbf{V}_x = \mathbf{I}_2\ 2\ \text{k}\Omega$

$-\mathbf{I}_1\ 1\ \text{k}\Omega + \mathbf{I}_2\ 12\ \text{k}\Omega = 10\ \text{V}\ \angle 0°$
$-\mathbf{I}_2\ 6\ \text{k}\Omega = -10\ \text{V}\ \angle 0°$

$$\mathbf{I}_2 = \mathbf{I}_{2\text{k}\Omega} = \frac{10\ \text{V}\ \angle 0°}{6\ \text{k}\Omega} = \mathbf{1.67\ mA\ \angle 0°} = \mathbf{I}_{2\text{k}\Omega}$$

$-\mathbf{I}_1\ 1\ \text{k}\Omega + (1.667\ \text{mA}\ \angle 0°)(12\ \text{k}\Omega) = 10\ \text{V}\ \angle 0°$
$-\mathbf{I}_1\ 1\ \text{k}\Omega + 20\ \text{V}\ \angle 0° = 10\ \text{V}\ \angle 0°$
$-\mathbf{I}_1\ 1\ \text{k}\Omega = -10\ \text{V}\ \angle 0°$

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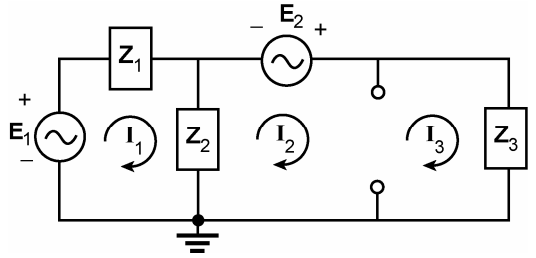
$$\mathbf{I}_1 = \mathbf{I}_{1k\Omega} = \frac{10\text{ V}\angle 0°}{1\text{ k}\Omega} = \mathbf{10\text{ mA}\angle 0°}$$

12.



$\mathbf{E}_1 = 5\text{ V}\angle 0°$
$\mathbf{E}_2 = 20\text{ V}\angle 0°$
$\mathbf{Z}_1 = 2.2\text{ k}\Omega\angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega\angle 90°$
$\mathbf{Z}_3 = 10\text{ k}\Omega\angle 0°$
$\mathbf{I} = 4\text{ mA}\angle 0°$

$$\mathbf{E}_1 - \mathbf{I}_1\mathbf{Z}_1 - \mathbf{Z}_2(\mathbf{I}_1 - \mathbf{I}_2) = 0$$
$$-\mathbf{Z}_2(\mathbf{I}_2 - \mathbf{I}_1) + \mathbf{E}_2 - \mathbf{I}_3\mathbf{Z}_3 = 0$$

$$\mathbf{I}_3 - \mathbf{I}_2 = \mathbf{I}$$

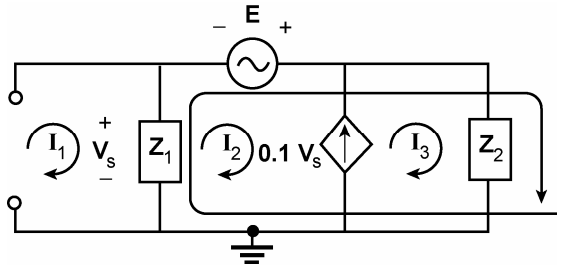
Substituting, we obtain:

$$\mathbf{I}_1(\mathbf{Z}_1 + \mathbf{Z}_2) - \mathbf{I}_2\mathbf{Z}_2 = \mathbf{E}_1$$
$$\mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}_2(\mathbf{Z}_2 + \mathbf{Z}_3) = \mathbf{I}\mathbf{Z}_3 - \mathbf{E}_2$$

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:

$$(1\text{ k}\Omega)\mathbf{I}_2 + (4\text{ k}\Omega + j6\text{ k}\Omega)\mathbf{I}_3 = 16\text{ V}\angle 0°$$
$$(99\ \Omega)\mathbf{I}_2 + \mathbf{I}_3 = 0.6\text{ V}\angle 0°$$

Determinants:

$\mathbf{I}_3 = \mathbf{I}_{6\text{ k}\Omega} = \mathbf{1.38\text{ mA}\angle -56.31°}$

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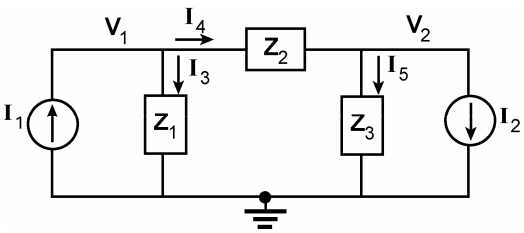
14. a.



$\mathbf{Z}_1 = 4\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 2\ \Omega\ \angle -90°$
$\mathbf{I}_1 = 3\ \text{A}\ \angle 0°$
$\mathbf{I}_2 = 5\ \text{A}\ \angle 30°$

$\mathbf{I}_1 = \mathbf{I}_3 + \mathbf{I}_4$

$$\mathbf{I}_1 = \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} \Rightarrow \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2}\right] - \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}\right] = \mathbf{I}_1$$

or $\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{V}_2[\mathbf{Y}_2] = \mathbf{I}_1$

$\mathbf{I}_4 = \mathbf{I}_5 + \mathbf{I}_2$

$$\frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} = \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \mathbf{I}_2 \Rightarrow \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3}\right] - \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_2}\right] = -\mathbf{I}_2$$

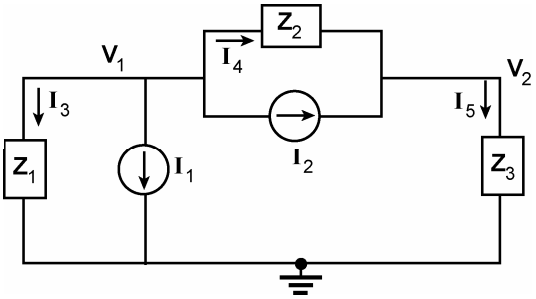
or $\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{V}_1[\mathbf{Y}_2] = -\mathbf{I}_2$

$$[\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 - \mathbf{Y}_2\mathbf{V}_2 = \mathbf{I}_1$$
$$-\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{V}_2 = -\mathbf{I}_2$$

$$\mathbf{V}_1 = \frac{[\mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{I}_1 - \mathbf{Y}_2\,\mathbf{I}_2}{\mathbf{Y}_1\,\mathbf{Y}_2 + \mathbf{Y}_1\,\mathbf{Y}_3 + \mathbf{Y}_2\,\mathbf{Y}_3} = \mathbf{14.68\ V\ \angle 68.89°}$$

$$\mathbf{V}_2 = \frac{-[\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{I}_2 + \mathbf{Y}_2\,\mathbf{I}_1}{\mathbf{Y}_1\,\mathbf{Y}_2 + \mathbf{Y}_1\,\mathbf{Y}_3 + \mathbf{Y}_2\,\mathbf{Y}_3} = \mathbf{12.97\ V\ \angle 155.88°}$$

b.



$\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega = 5\ \angle 53.13°$
$\mathbf{Z}_2 = 2\ \Omega\ \angle 0°$
$\mathbf{Z}_3 = 6\ \Omega\ \angle 0° \parallel 8\ \Omega\ \angle -90°$
$= 4.8\ \Omega\ \angle -36.87°$
$\mathbf{I}_1 = 0.6\ \text{A}\ \angle 20°$
$\mathbf{I}_2 = 4\ \text{A}\ \angle 80°$

$0 = \mathbf{I}_1 + \mathbf{I}_3 + \mathbf{I}_4 + \mathbf{I}_2$

$$0 = \mathbf{I}_1 + \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} + \mathbf{I}_2$$

$$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2}\right] - \mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}\right] = -\mathbf{I}_1 - \mathbf{I}_2$$

or $\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{V}_2[\mathbf{Y}_2] = -\mathbf{I}_1 - \mathbf{I}_2$

$\mathbf{I}_2 + \mathbf{I}_4 = \mathbf{I}_5$

$$\mathbf{I}_2 + \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_2} = \frac{\mathbf{V}_2}{\mathbf{Z}_3}$$

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$$\mathbf{V}_2\left[\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}\right]-\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_2}\right]=+\mathbf{I}_2$$

or $\mathbf{V}_2[\mathbf{Y}_2+\mathbf{Y}_3]-\mathbf{V}_1[\mathbf{Y}_2]=\mathbf{I}_2$

and $[\mathbf{Y}_1+\mathbf{Y}_2]\mathbf{V}_1-\mathbf{Y}_2\mathbf{V}_2=-\mathbf{I}_1-\mathbf{I}_2$

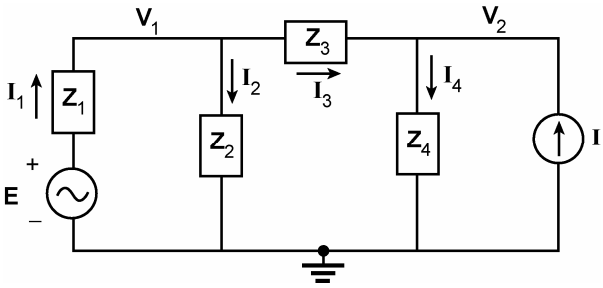
$-\mathbf{Y}_2\mathbf{V}_1+[\mathbf{Y}_2+\mathbf{Y}_3]\mathbf{V}_2=\mathbf{I}_2$

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 $\mathbf{V}_2 = \mathbf{8.94\ V\ \angle 106.9°}$

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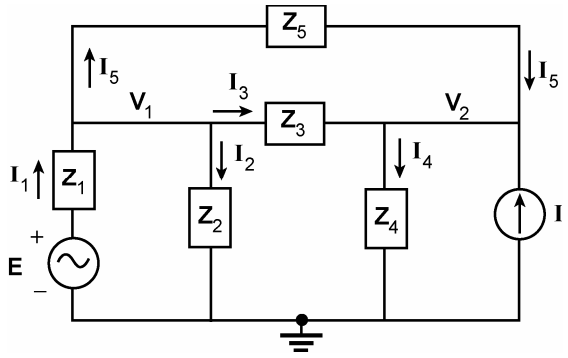
b.



$\mathbf{Z}_1 = 10\ \Omega\ \angle 0°$
$\mathbf{Z}_2 = 10\ \Omega\ \angle 0°$
$\mathbf{Z}_3 = 4\ \Omega\ \angle 90°$
$\mathbf{Z}_4 = 2\ \Omega\ \angle 0°$
$\mathbf{Z}_5 = 8\ \Omega\ \angle -90°$
$\mathbf{E} = 50\ \text{V}\ \angle 120°$
$\mathbf{I} = 0.8\ \text{A}\ \angle 70°$

$\mathbf{I}_1 = \mathbf{I}_2 + \mathbf{I}_5$

$$\frac{\mathbf{E}-\mathbf{V}_1}{\mathbf{Z}_1} = \frac{\mathbf{V}_1}{\mathbf{Z}_2} + \frac{(\mathbf{V}_1-\mathbf{V}_2)}{\mathbf{Z}_5} + \frac{\mathbf{V}_1-\mathbf{V}_2}{\mathbf{Z}_3} \Rightarrow \mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1}+\frac{1}{\mathbf{Z}_2}+\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_5}\right]-\mathbf{V}_2\left[\frac{1}{\mathbf{Z}_3}+\frac{1}{\mathbf{Z}_5}\right]=\frac{\mathbf{E}}{\mathbf{Z}_1}$$

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:

$\mathbf{V}_1 = \mathbf{11.74\ V\ \angle -4.61°}$, $\mathbf{V}_2 = \mathbf{22.53\ V\ \angle -36.48°}$

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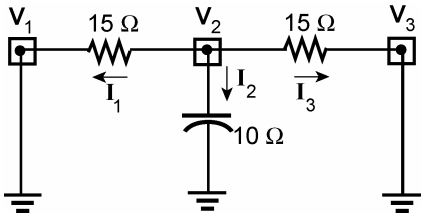
17.



(Note that 3 + *j*4 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:

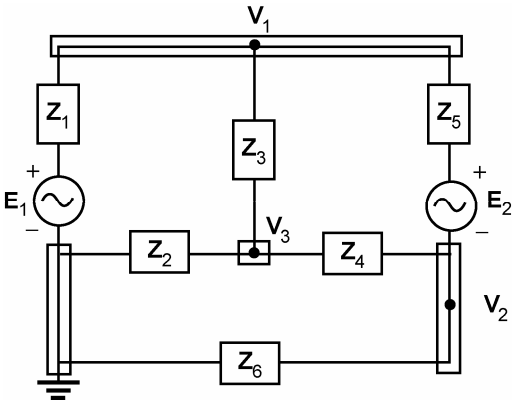
$$\mathbf{V}_2[2 + j1.5] - \mathbf{V}_1 - \mathbf{V}_3 = 0$$

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: $\mathbf{V}_1 = \mathbf{5.84\ V\ \angle 29.4°}$, $\mathbf{V}_2 = \mathbf{28.06\ V\ \angle -89.15°}$, $\mathbf{V}_3 = \mathbf{31.96\ V\ \angle -77.6°}$

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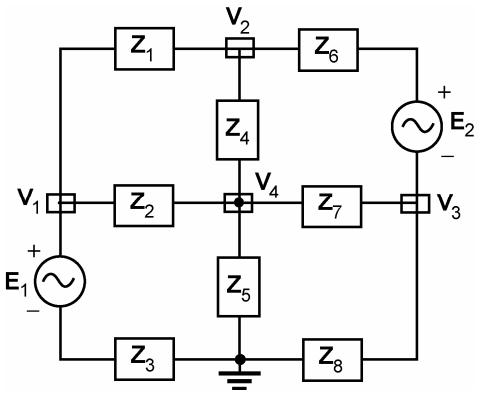
19.



$\mathbf{E}_1 = 25\text{ V} \angle 0°$
$\mathbf{E}_2 = 75\text{ V} \angle 20°$

$\mathbf{Z}_1 = 10\ \Omega + j20\ \Omega$
$\mathbf{Z}_2 = 6\ \Omega \angle 0°$
$\mathbf{Z}_3 = 5\ \Omega \angle 0°$
$\mathbf{Z}_4 = 20\ \Omega \angle -90°$
$\mathbf{Z}_5 = 10\ \Omega \angle 0°$
$\mathbf{Z}_6 = 80\ \Omega \angle 0°$
$\mathbf{Z}_7 = 15\ \Omega \angle 90°$
$\mathbf{Z}_8 = 5\ \Omega - j20\ \Omega$

$$\mathbf{V}_1: \quad \frac{\mathbf{V}_1 - \mathbf{V}_2}{\mathbf{Z}_1} + \frac{\mathbf{V}_1 - \mathbf{V}_4}{\mathbf{Z}_2} + \frac{\mathbf{V}_1 - \mathbf{E}_1}{\mathbf{Z}_3} = 0$$

$$\mathbf{V}_2: \quad \frac{\mathbf{V}_2 - \mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2 - \mathbf{V}_4}{\mathbf{Z}_4} + \frac{\mathbf{V}_2 - \mathbf{E}_2 - \mathbf{V}_3}{\mathbf{Z}_6} = 0$$

$$\mathbf{V}_3: \quad \frac{\mathbf{V}_3 + \mathbf{E}_2 - \mathbf{V}_2}{\mathbf{Z}_6} + \frac{\mathbf{V}_3 - \mathbf{V}_4}{\mathbf{Z}_7} + \frac{\mathbf{V}_3}{\mathbf{Z}_8} = 0$$

$$\mathbf{V}_4: \quad \frac{\mathbf{V}_4 - \mathbf{V}_1}{\mathbf{Z}_2} + \frac{\mathbf{V}_4 - \mathbf{V}_2}{\mathbf{Z}_4} + \frac{\mathbf{V}_4 - \mathbf{V}_3}{\mathbf{Z}_7} + \frac{\mathbf{V}_4}{\mathbf{Z}_5} = 0$$

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:

$\mathbf{V}_1 =$ **14.62 V ∠–5.86°**, $\mathbf{V}_2 =$ **35.03 V ∠–37.69°**
$\mathbf{V}_3 =$ **32.4 V ∠–73.34°**, $\mathbf{V}_4 =$ **5.67 V ∠23.53°**

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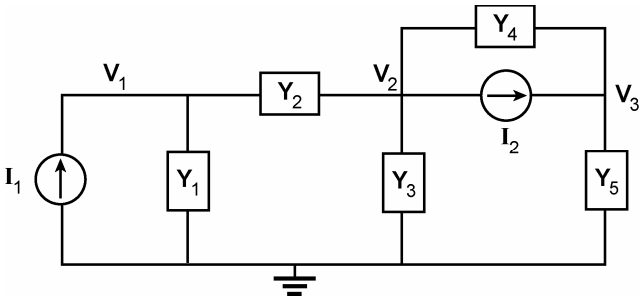
20. a.



$$\mathbf{Y}_1 = \frac{1}{4\,\Omega\angle 0^\circ} = 0.25\text{ S}\angle 0^\circ$$

$$\mathbf{Y}_2 = \frac{1}{1\,\Omega\angle 90^\circ} = 1\text{ S}\angle -90^\circ$$

$$\mathbf{Y}_3 = \frac{1}{5\,\Omega\angle 0^\circ} = 0.2\text{ S}\angle 0^\circ$$

$$\mathbf{Y}_4 = \frac{1}{4\,\Omega\angle -90^\circ} = 0.25\text{ S}\angle 90^\circ$$

$$\mathbf{Y}_5 = \frac{1}{8\,\Omega\angle 90^\circ} = 0.125\text{ S}\angle -90^\circ$$

$\mathbf{I}_1 = 2\text{ A}\angle 30^\circ$

$\mathbf{I}_2 = 3\text{ A}\angle 150^\circ$

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2] - \mathbf{Y}_2\mathbf{V}_2 = \mathbf{I}_1$$
$$\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_3 = -\mathbf{I}_2$$
$$\mathbf{V}_3[\mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_4\mathbf{V}_2 = \mathbf{I}_2$$

$$\begin{array}{ccc} [\mathbf{Y}_1 + \mathbf{Y}_2]\mathbf{V}_1 & -\mathbf{Y}_2\,\mathbf{V}_2 & +0 = \mathbf{I}_1 \\ -\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4]\mathbf{V}_2 & -\mathbf{Y}_4\,\mathbf{V}_3 & = -\mathbf{I}_2 \\ 0 & -\mathbf{Y}_4\mathbf{V}_2 + [\mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_3 & = \mathbf{I}_2 \end{array}$$

$$\mathbf{V}_1 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4)(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_4^2\right] - \mathbf{I}_2[\mathbf{Y}_2\mathbf{Y}_5]}{\left[\mathbf{Y}_1 + \mathbf{Y}_2\right]\left[(\mathbf{Y}_2 + \mathbf{Y}_3 + \mathbf{Y}_4)(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_4^2\right] - \mathbf{Y}_2^2(\mathbf{Y}_4 + \mathbf{Y}_5) = \mathbf{Y}_\Delta}$$

$$= \mathbf{5.74\text{ V}\angle 122.76^\circ}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}_1\mathbf{Y}_2(\mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{I}_2\mathbf{Y}_5(\mathbf{Y}_1 + \mathbf{Y}_2)}{\mathbf{Y}_\Delta} = \mathbf{4.04\text{ V}\angle 145.03^\circ}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}_2\left[(\mathbf{Y}_1 + \mathbf{Y}_2)(\mathbf{Y}_3 + \mathbf{Y}_4) - \mathbf{Y}_2^2\right] - \mathbf{Y}_2\mathbf{Y}_4\mathbf{I}_1}{\mathbf{Y}_\Delta} = \mathbf{25.94\text{ V}\angle 78.07^\circ}$$

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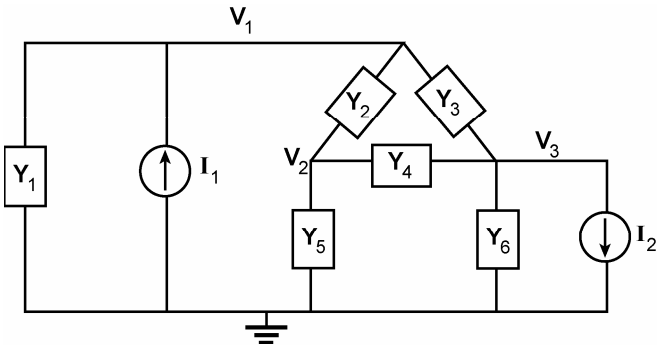
b.



$$\mathbf{Y}_1 = \frac{1}{4\ \Omega\ \angle 0°} = 0.25\ \text{S}\ \angle 0°$$
$$\mathbf{Y}_2 = \frac{1}{6\ \Omega\ \angle 0°} = 0.167\ \text{S}\ \angle 0°$$
$$\mathbf{Y}_3 = \frac{1}{8\ \Omega\ \angle 0°} = 0.125\ \text{S}\ \angle 0°$$
$$\mathbf{Y}_4 = \frac{1}{2\ \Omega\ \angle -90°} = 0.5\ \text{S}\ \angle 90°$$
$$\mathbf{Y}_5 = \frac{1}{5\ \Omega\ \angle 90°} = 0.2\ \text{S}\ \angle -90°$$
$$\mathbf{Y}_6 = \frac{1}{4\ \Omega\ \angle 90°} = 0.25\ \text{S}\ \angle -90°$$
$$\mathbf{I}_1 = 4\ \text{A}\ \angle 0°$$
$$\mathbf{I}_2 = 6\ \text{A}\ \angle 90°$$

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3] - \mathbf{Y}_2\mathbf{V}_2 - \mathbf{Y}_3\mathbf{V}_3 = \mathbf{I}_1$$
$$\mathbf{V}_2[\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_3 = 0$$
$$\mathbf{V}_3[\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6] - \mathbf{Y}_3\mathbf{V}_1 - \mathbf{Y}_4\mathbf{V}_2 = -\mathbf{I}_2$$

$$\begin{aligned}
[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_3]\mathbf{V}_1 &- \mathbf{Y}_2\mathbf{V}_2 &- \mathbf{Y}_3\mathbf{V}_3 &= \mathbf{I}_1 \\
-\mathbf{Y}_2\mathbf{V}_1 + [\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_2 &&- \mathbf{Y}_4\mathbf{V}_3 &= 0 \\
-\mathbf{Y}_3\mathbf{V}_1 &- \mathbf{Y}_4\mathbf{V}_2 + [\mathbf{Y}_3 + \mathbf{Y}_4 + \mathbf{Y}_6]\mathbf{V}_3 &&= -\mathbf{I}_2
\end{aligned}$$

$$\mathbf{V}_1 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6) - \mathbf{Y}_4^2\right] - \mathbf{I}_2\left[\mathbf{Y}_2\mathbf{Y}_4 + \mathbf{Y}_3(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_5)\right]}{\mathbf{Y}_\Delta = (\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3)\left[(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6) - \mathbf{Y}_4^2\right] - \mathbf{Y}_2\left[\mathbf{Y}_2(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6) + \mathbf{Y}_3\mathbf{Y}_4\right] - \mathbf{Y}_3\left[\mathbf{Y}_2\mathbf{Y}_4 + \mathbf{Y}_3(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)\right]}$$

$$= \mathbf{15.13\ V\ \angle 1.29°}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_2)(\mathbf{Y}_3+\mathbf{Y}_4+\mathbf{Y}_6) + \mathbf{Y}_3\mathbf{Y}_4\right] + \mathbf{I}_2\left[\mathbf{Y}_4(\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3) - \mathbf{Y}_2\mathbf{Y}_3\right]}{\mathbf{Y}_\Delta} = \mathbf{17.24\ V\ \angle 3.73°}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}_1\left[(\mathbf{Y}_3)(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_4\right] + \mathbf{I}_2\left[\mathbf{Y}_2^2 - (\mathbf{Y}_1+\mathbf{Y}_2+\mathbf{Y}_3)(\mathbf{Y}_2+\mathbf{Y}_4+\mathbf{Y}_5)\right]}{\mathbf{Y}_\Delta}$$

$$= \mathbf{10.59\ V\ \angle -0.11°}$$

21. Left node: $\mathbf{V}_1$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$
$$4\mathbf{I}_x = \mathbf{I}_x + 5\ \text{mA}\ \angle 0° + \frac{\mathbf{V}_1 - \mathbf{V}_2}{2\ \text{k}\Omega}$$

Right node: $\mathbf{V}_2$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$
$$8\ \text{mA}\ \angle 0° = \frac{\mathbf{V}_2}{1\ \text{k}\Omega} + \frac{\mathbf{V}_2 - \mathbf{V}_1}{2\ \text{k}\Omega} + 4\mathbf{I}_x$$

Insert $\mathbf{I}_x = \dfrac{\mathbf{V}_1}{4\ \text{k}\Omega\ \angle -90°}$

Rearrange, reduce and 2 equations with 2 unknowns result:

$$\mathbf{V}_1[1.803\ \angle 123.69°] + \mathbf{V}_2 = 10$$
$$\mathbf{V}_1[2.236\ \angle 116.57°] + 3\ \mathbf{V}_2 = 16$$

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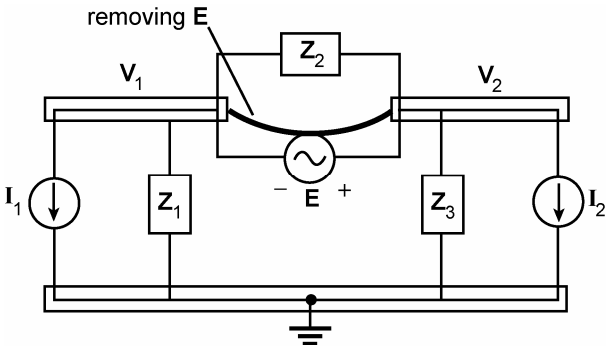
Determinants: $\mathbf{V}_1 = \mathbf{4.37\ V\ \angle -128.66°}$
$\mathbf{V}_2 = \mathbf{V}_{1k\Omega} = \mathbf{2.25\ V\ \angle 17.63°}$

22.



$\mathbf{Z}_1 = 1\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 2\ \text{k}\Omega\ \angle 90°$
$\mathbf{Z}_3 = 3\ \text{k}\Omega\ \angle -90°$
$\mathbf{I}_1 = 12\ \text{mA}\ \angle 0°$
$\mathbf{I}_2 = 4\ \text{mA}\ \angle 0°$
$\mathbf{E} = 10\ \text{V}\ \angle 0°$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$0 = \mathbf{I}_1 + \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2}{\mathbf{Z}_3} + \mathbf{I}_2$$

$$\text{and } \frac{\mathbf{V}_1}{\mathbf{Z}_1} + \frac{\mathbf{V}_2}{\mathbf{Z}_3} = -\mathbf{I}_1 - \mathbf{I}_2$$

with $\mathbf{V}_2 - \mathbf{V}_1 = \mathbf{E}$

Substituting and rearranging:

$$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_3}\right] = -\mathbf{I}_1 - \mathbf{I}_2 - \frac{\mathbf{E}}{\mathbf{Z}_3}$$

and solving for $\mathbf{V}_1$:

$\mathbf{V}_1 = \mathbf{15.4\ V\ \angle\ 178.2°}$
with $\mathbf{V}_2 = \mathbf{V}_C = \mathbf{5.41\ V\ \angle\ 174.87°}$

23. Left node: $\mathbf{V}_1$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$2\ \text{mA}\ \angle 0° = 12\ \text{mA}\ \angle 0° + \frac{\mathbf{V}_1}{2\,\text{k}\Omega} + \frac{\mathbf{V}_1 - \mathbf{V}_2}{1\,\text{k}\Omega}$$

$$\text{and } 1.5\,\mathbf{V}_1 - \mathbf{V}_2 = -10$$

Right node: $\mathbf{V}_2$

$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$0 = 2\ \text{mA}\ \angle 0° + \frac{\mathbf{V}_2 - \mathbf{V}_1}{1\,\text{k}\Omega} - \frac{\mathbf{V}_2 - 6\,\mathbf{V}_x}{3.3\,\text{k}\Omega}$$

$$\text{and } 2.7\,\mathbf{V}_1 - 3.7\,\mathbf{V}_2 = -6.6$$

Using determinants: $\mathbf{V}_1 = \mathbf{V}_{2k\Omega} = \mathbf{-10.67\ V\ \angle 0° = 10.67\ V\ \angle 180°}$
$\mathbf{V}_2 = \mathbf{-6\ V\ \angle 0° = 6\ V\ \angle 180°}$

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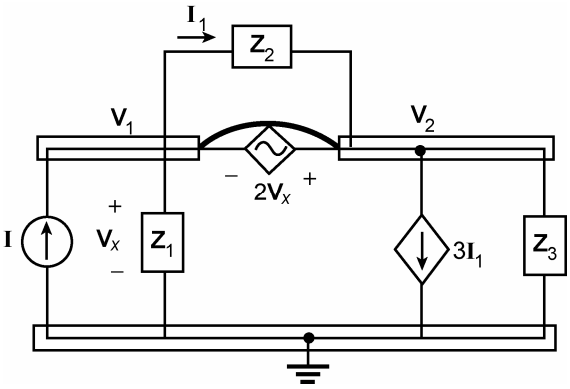
24.



$\mathbf{Z}_1 = 2\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 1\ \text{k}\Omega\angle 0°$
$\mathbf{Z}_3 = 1\ \text{k}\Omega\ \angle 0°$
$\mathbf{I} = 5\ \text{mA}\ \angle 0°$

$\mathbf{V}_1$: $\mathbf{I} = \dfrac{\mathbf{V}_1}{\mathbf{Z}_1} + 3\mathbf{I}_1 + \dfrac{\mathbf{V}_2}{\mathbf{Z}_3}$

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 $\mathbf{V}_2 = 3\mathbf{V}_1$

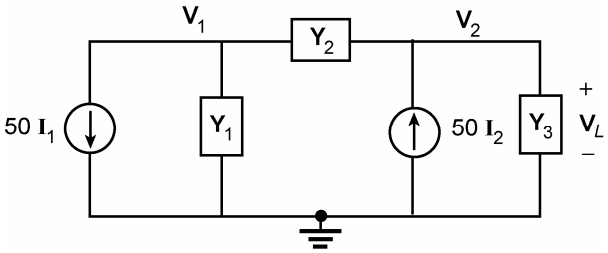
Substituting will result in:

$$\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_1} + \frac{3}{\mathbf{Z}_2}\right] + 3\,\mathbf{V}_1\left[\frac{1}{\mathbf{Z}_3} - \frac{3}{\mathbf{Z}_2}\right] = \mathbf{I}$$

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.



$$\mathbf{I}_1 = \frac{E_i\angle\theta}{R_1\ \angle 0°} = 1 \times 10^{-3}\ \mathbf{E}_i$$

$$\mathbf{Y}_1 = \frac{1}{50\ \text{k}\Omega} = 0.02\ \text{mS}\ \angle 0°$$

$$\mathbf{Y}_2 = \frac{1}{1\ \text{k}\Omega} = 1\ \text{mS}\ \angle 0°$$

$\mathbf{Y}_3 = 0.02\ \text{mS}\ \angle 0°$
$\mathbf{I}_2 = (\mathbf{V}_1 - \mathbf{V}_2)\mathbf{Y}_2$

$\mathbf{V}_1(\mathbf{Y}_1 + \mathbf{Y}_2) - \mathbf{Y}_2\mathbf{V}_2 = -50\mathbf{I}_1$
$\mathbf{V}_2(\mathbf{Y}_2 + \mathbf{Y}_3) - \mathbf{Y}_2\mathbf{V}_1 = 50\mathbf{I}_2 = 50(\mathbf{V}_1 - \mathbf{V}_2)\mathbf{Y}_2 = 50\mathbf{Y}_2\mathbf{V}_1 - 50\mathbf{Y}_2\mathbf{V}_2$

$(\mathbf{Y}_1 + \mathbf{Y}_2)\mathbf{V}_1 - \mathbf{Y}_2\mathbf{V}_2 = -50\mathbf{I}_1$
$-51\mathbf{Y}_2\mathbf{V}_1 + (51\mathbf{Y}_2 + \mathbf{Y}_3)\mathbf{V}_2 = 0$

$$\mathbf{V}_L = \mathbf{V}_2 = \frac{-(50)(51)\mathbf{Y}_2\mathbf{I}_1}{(\mathbf{Y}_1 + \mathbf{Y}_2)(51\mathbf{Y}_2 + \mathbf{Y}_3) - 51\mathbf{Y}_2^2} = \mathbf{-2451.92\ E}_i$$

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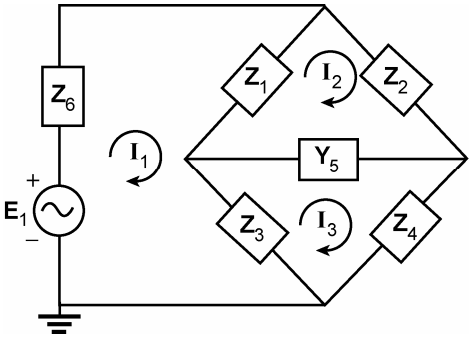
26. a. yes

$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$

$$\frac{5\times10^3\angle0°}{2.5\times10^3\angle90°} = \frac{8\times10^3\angle0°}{4\times10^3\angle90°}$$

$$2\angle-90° = 2\angle-90° \text{ (balanced)}\checkmark$$

b. $\mathbf{Z}_1 = 5\ \text{k}\Omega\angle0°$, $\mathbf{Z}_2 = 8\ \text{k}\Omega\angle0°$
$\mathbf{Z}_3 = 2.5\ \text{k}\Omega\angle90°$, $\mathbf{Z}_4 = 4\ \text{k}\Omega\angle90°$
$\mathbf{Z}_5 = 5\ \text{k}\Omega\angle-90°$, $\mathbf{Z}_6 = 1\ \text{k}\Omega\angle0°$



$$\mathbf{I}_1[\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6] - \mathbf{Z}_1\mathbf{I}_2 - \mathbf{Z}_3\mathbf{I}_3 = \mathbf{E}$$
$$\mathbf{I}_2[\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5] - \mathbf{Z}_1\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_3 = 0$$
$$\mathbf{I}_3[\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5] - \mathbf{Z}_3\mathbf{I}_1 - \mathbf{Z}_5\mathbf{I}_2 = 0$$

$$\begin{aligned}
[\mathbf{Z}_1 + \mathbf{Z}_3 + \mathbf{Z}_6]\mathbf{I}_1 &- \mathbf{Z}_1\mathbf{I}_2 &- \mathbf{Z}_3\mathbf{I}_3 &= \mathbf{E}\\
-\mathbf{Z}_1\mathbf{I}_1 &+ [\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5]\mathbf{I}_2 &- \mathbf{Z}_5\mathbf{I}_3 &= 0\\
-\mathbf{Z}_3\mathbf{I}_1 &- \mathbf{Z}_5\mathbf{I}_2 &+ [\mathbf{Z}_3 + \mathbf{Z}_4 + \mathbf{Z}_5]\mathbf{I}_3 &= 0
\end{aligned}$$

$$\mathbf{I}_2 = \frac{\mathbf{E}[\mathbf{Z}_1(\mathbf{Z}_3+\mathbf{Z}_4+\mathbf{Z}_5) + \mathbf{Z}_3\mathbf{Z}_5]}{\mathbf{Z}_\Delta = (\mathbf{Z}_1+\mathbf{Z}_3+\mathbf{Z}_6)[(\mathbf{Z}_1+\mathbf{Z}_2+\mathbf{Z}_5)(\mathbf{Z}_3+\mathbf{Z}_4+\mathbf{Z}_5) - \mathbf{Z}_5^2] - \mathbf{Z}_1[\mathbf{Z}_1(\mathbf{Z}_3+\mathbf{Z}_4+\mathbf{Z}_5) - \mathbf{Z}_3\mathbf{Z}_5] - \mathbf{Z}_3[\mathbf{Z}_1\mathbf{Z}_5 + \mathbf{Z}_3(\mathbf{Z}_1+\mathbf{Z}_2+\mathbf{Z}_5)]}$$

$$\mathbf{I}_3 = \frac{\mathbf{E}[\mathbf{Z}_1\mathbf{Z}_5 + \mathbf{Z}_3(\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5)]}{\mathbf{Z}_\Delta}$$

$$\mathbf{I}_{Z_5} = \mathbf{I}_2 - \mathbf{I}_3 = \frac{\mathbf{E}[\mathbf{Z}_1\mathbf{Z}_4 - \mathbf{Z}_3\mathbf{Z}_2]}{\mathbf{Z}_\Delta} = \frac{E\left[20\times10^6\angle90° - 20\times10^6\angle90°\right]}{\mathbf{Z}_\Delta} = \mathbf{0}\ \mathbf{A}$$

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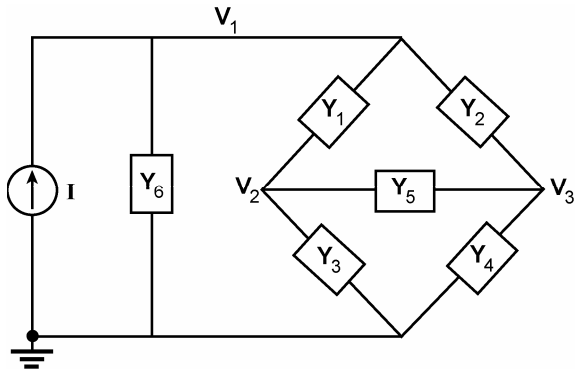
c.



$$\mathbf{I} = \frac{\mathbf{E}_s}{\mathbf{R}_s} = \frac{10\,\text{V}\angle 0°}{1\,\text{k}\Omega\angle 0°} = 10\,\text{mA}\angle 0°$$

$$\mathbf{Y}_1 = \frac{1}{5\,\text{k}\Omega\angle 0°} = 0.2\,\text{mS}\angle 0°$$

$$\mathbf{Y}_2 = \frac{1}{8\,\text{k}\Omega\angle 0°} = 0.125\,\text{mS}\angle 0°$$

$$\mathbf{Y}_3 = \frac{1}{2.5\,\text{k}\Omega\angle 90°} = 0.4\,\text{mS}\angle -90°$$

$$\mathbf{Y}_4 = \frac{1}{4\,\text{k}\Omega\angle 90°} = 0.25\,\text{mS}\angle -90°$$

$$\mathbf{Y}_5 = \frac{1}{5\,\text{k}\Omega\angle -90°} = 0.2\,\text{mS}\angle 90°$$

$$\mathbf{Y}_6 = \frac{1}{1\,\text{k}\Omega\angle 0°} = 1\,\text{mS}\angle 0°$$

$$\mathbf{V}_1[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6] - \mathbf{Y}_1\mathbf{V}_2 - \mathbf{Y}_2\mathbf{V}_3 = \mathbf{I}$$
$$\mathbf{V}_2[\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5] - \mathbf{Y}_1\mathbf{V}_1 - \mathbf{Y}_5\mathbf{V}_3 = 0$$
$$\mathbf{V}_3[\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5] - \mathbf{Y}_2\mathbf{V}_1 - \mathbf{Y}_5\mathbf{V}_2 = 0$$

$$\begin{aligned}
[\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6]\mathbf{V}_1 &- \mathbf{Y}_1\mathbf{V}_2 &- \mathbf{Y}_2\mathbf{V}_3 &= \mathbf{I}\\
-\mathbf{Y}_1\mathbf{V}_1 &+ [\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5]\mathbf{V}_2 &- \mathbf{Y}_5\mathbf{V}_3 &= 0\\
-\mathbf{Y}_2\mathbf{V}_1 &- \mathbf{Y}_5\mathbf{V}_2 &+ [\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5]\mathbf{V}_3 &= 0
\end{aligned}$$

$$\mathbf{V}_2 = \frac{\mathbf{I}[\mathbf{Y}_1(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_5]}{\mathbf{Y}_\Delta = (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6)[(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_5^2] - \mathbf{Y}_1[\mathbf{Y}_1(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_5] - \mathbf{Y}_2[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)]}$$

$$\mathbf{V}_3 = \frac{\mathbf{I}[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)]}{\mathbf{Y}_\Delta}$$

$$\mathbf{V}_{Z_5} = \mathbf{V}_2 - \mathbf{V}_3 = \frac{\mathbf{I}[\mathbf{Y}_1\mathbf{Y}_4 - \mathbf{Y}_4\mathbf{Y}_3]}{\mathbf{Y}_\Delta} = \frac{\mathbf{I}[0.05\times 10^{-3}\angle -90° - 0.05\times 10^{-3}\angle -90°]}{\mathbf{Y}_\Delta}$$

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

27. a.
$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$
$$\frac{4\times 10^3\angle 0°}{4\times 10^3\angle 90°} \stackrel{?}{=} \frac{4\times 10^3\angle 0°}{4\times 10^3\angle -90°}$$
$$1\angle -90° \neq 1\angle 90° \textbf{ (not balanced)}$$

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
$$\mathbf{Z}_1 = 5\,\text{k}\Omega\angle 0°,\ \mathbf{Z}_2 = 8\,\text{k}\Omega\angle 0°,\ \mathbf{Z}_3 = 2.5\,\text{k}\Omega\angle 90°$$
$$\mathbf{Z}_4 = 4\,\text{k}\Omega\angle 90°,\ \mathbf{Z}_5 = 5\,\text{k}\Omega\angle -90°,\ \mathbf{Z}_6 = 1\,\text{k}\Omega\angle 0°$$
and
$$\mathbf{I}_{X_C} = \textbf{1.76 mA}\angle\textbf{–71.54°}$$

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c. The solution to 26(c) resulted in

$$\mathbf{V}_3 = \mathbf{V}_{X_C} = \frac{\mathbf{I}[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1+\mathbf{Y}_3+\mathbf{Y}_5)]}{\mathbf{Y}_\Delta}$$

where $\mathbf{Y}_\Delta = (\mathbf{Y}_1 + \mathbf{Y}_2 + \mathbf{Y}_6)[(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) - \mathbf{Y}_5^2]$
$- \mathbf{Y}_1[\mathbf{Y}_1(\mathbf{Y}_2 + \mathbf{Y}_4 + \mathbf{Y}_5) + \mathbf{Y}_2\mathbf{Y}_5]$
$- \mathbf{Y}_2[\mathbf{Y}_1\mathbf{Y}_5 + \mathbf{Y}_2(\mathbf{Y}_1 + \mathbf{Y}_3 + \mathbf{Y}_5)]$

with $\mathbf{Y}_1 = 0.2$ mS $\angle 0°$, $\mathbf{Y}_2 = 0.125$ mS $\angle 0°$, $\mathbf{Y}_3 = 0.4$ mS $\angle -90°$
$\mathbf{Y}_4 = 0.25$ mS $\angle -90°$, $\mathbf{Y}_5 = 0.2$ mS $\angle 90°$

Source conversion: $\mathbf{Y}_6 = 1$ mS $\angle 0°$, $\mathbf{I} = 10$ 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. $X_{C_1} = \dfrac{1}{\omega C} = \dfrac{1}{(1000\ \text{rad/s})(3\,\mu\text{F})} = \dfrac{1}{3}\text{k}\Omega$

$\mathbf{Z}_1 = R_1 \parallel X_{C_1}\ \angle -90° = (2\ \text{k}\Omega\ \angle 0°) \parallel 2\dfrac{1}{3}\ \text{k}\Omega\ \angle -90° = 328.8\ \Omega\ \angle -80.54°$

$\mathbf{Z}_2 = R_2\ \angle 0° = 0.5\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_3 = R_3\ \angle 0° = 4\ \text{k}\Omega\ \angle 0°$

$\mathbf{Z}_4 = R_x + j\,X_{L_x} = 1\ \text{k}\Omega + j6\ \text{k}\Omega$

$$\frac{\mathbf{Z}_1}{\mathbf{Z}_3} = \frac{\mathbf{Z}_2}{\mathbf{Z}_4}$$

$$\frac{328.8\,\Omega\ \angle -80.54°}{4\ \text{k}\Omega\ \angle 0°} \stackrel{?}{=} \frac{0.5\ \text{k}\Omega\ \angle 0°}{6.083\,\Omega\ \angle 80.54°}$$

$82.2\ \angle -80.54° \checkmark 82.2\ \angle -80.54°$ **(balanced)**

30. Apply Eq. **17.6.**

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31. For balance:

$$R_1(R_x + j\,X_{L_x}) = R_2(R_3 + j\,X_{L_3})$$

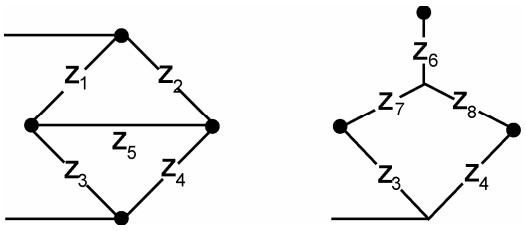
$$R_1R_x + jR_1\,X_{L_x} = R_2R_3 + jR_2\,X_{L_3}$$

$$\therefore R_1R_x = R_2R_3 \text{ and } R_x = \frac{R_2R_3}{R_1}$$

$$R_1\,X_{L_x} = R_2\,X_{L_3} \text{ and } R_1\omega L_x = R_2\omega L_3$$

$$\text{so that } L_x = \frac{\boldsymbol{R_2L_3}}{\boldsymbol{R_1}}$$

32. a.



$\mathbf{Z}_1 = 8\ \Omega\ \angle{-90°} = -j8\ \Omega$
$\mathbf{Z}_2 = 4\ \Omega\ \angle 90° = +j4\ \Omega$
$\mathbf{Z}_3 = 8\ \Omega\ \angle 90° = +j8\ \Omega$
$\mathbf{Z}_4 = 6\ \Omega\ \angle{-90°} = -j6\ \Omega$
$\mathbf{Z}_5 = 5\ \Omega\ \angle 0°$

$$\mathbf{Z}_6 = \frac{\mathbf{Z}_1\mathbf{Z}_2}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 5\ \Omega\ \angle 38.66°$$

$$\mathbf{Z}_7 = \frac{\mathbf{Z}_1\mathbf{Z}_5}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 6.25\ \Omega\ \angle{-51.34°}$$

$$\mathbf{Z}_8 = \frac{\mathbf{Z}_2\mathbf{Z}_5}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_5} = 3.125\ \Omega\ \angle 128.66°$$

$\mathbf{Z}' = \mathbf{Z}_7 + \mathbf{Z}_3 = 3.9\ \Omega + j3.12\ \Omega = 4.99\ \Omega\ \angle 38.66°$

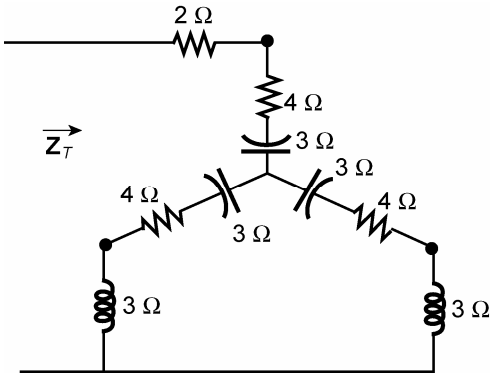
$\mathbf{Z}'' = \mathbf{Z}_8 + \mathbf{Z}_4 = -1.95\ \Omega - j3.56\ \Omega = 4.06\ \Omega\ \angle{-118.71°}$

$\mathbf{Z}' \parallel \mathbf{Z}'' = 10.13\ \Omega\ \angle{-67.33°} = 3.90\ \Omega - j9.35\ \Omega$

$\mathbf{Z}_T = \mathbf{Z}_6 + \mathbf{Z}' \parallel \mathbf{Z}'' = 7.80\ \Omega - j6.23\ \Omega = 9.98\ \Omega\ \angle{-38.61°}$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{120\ \text{V}\ \angle 0°}{9.98\,\Omega\ \angle{-38.61°}} = \mathbf{12.02\ A\ \angle 38.61°}$$

b. $\mathbf{Z}_Y = \dfrac{\mathbf{Z}_\Delta}{3} = \dfrac{12\,\Omega - j9\,\Omega}{3} = 4\ \Omega - j3\ \Omega$



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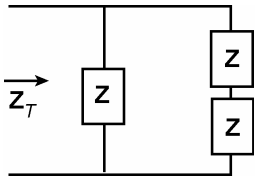
$$\mathbf{Z}_T = 2\ \Omega + 4\ \Omega + j3\ \Omega + [4\ \Omega - j3\ \Omega + j3\ \Omega] \parallel [4\ \Omega - j3\ \Omega + j3\ \Omega]$$
$$= 6\ \Omega - j3\ \Omega + 2\ \Omega$$
$$= 8\ \Omega - j3\ \Omega = 8.544\ \Omega \angle -20.56°$$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{60\ \text{V} \angle 0°}{8.544\ \Omega \angle -20.56°} = \mathbf{7.02\ A \angle 20.56°}$$

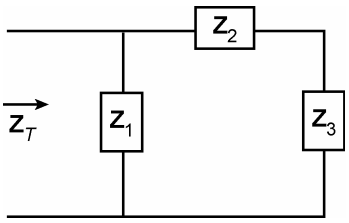
33. a.



$$\mathbf{Z}_\Delta = 3\mathbf{Z}_Y = 3(3\ \Omega \angle 90°) = 9\ \Omega \angle 90°$$
$$\mathbf{Z} = 9\ \Omega \angle 90° \parallel (12\ \Omega - j16\ \Omega)$$
$$= 9\ \Omega \angle 90° \parallel 20\ \Omega \angle 53.13°$$
$$= 12.96\ \Omega \angle 67.13°$$

$$\mathbf{Z}_T = \mathbf{Z} \parallel \mathbf{2Z} = \frac{2\mathbf{Z}^2}{\mathbf{Z} + 2\mathbf{Z}} = \frac{2}{3}\mathbf{Z} = \frac{2}{3}\ [12.96\ \Omega \angle 67.13°] = 8.64\ \Omega \angle 67.13°$$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100\ \text{V} \angle 0°}{8.64\ \Omega \angle 67.13°} = \mathbf{11.57\ A \angle -67.13°}$$

b. $\mathbf{Z}_\Delta = 3\mathbf{Z}_Y = 3(5\ \Omega) = 15\ \Omega$



$$\mathbf{Z}_1 = 15\ \Omega \angle 0° \parallel 5\ \Omega \angle -90°$$
$$= 4.74\ \Omega \angle -71.57°$$
$$\mathbf{Z}_2 = 15\ \Omega \angle 0° \parallel 6\ \Omega \angle 90°$$
$$= 5.57\ \Omega \angle 68.2° = 2.07\ \Omega + j5.17\ \Omega$$
$$\mathbf{Z}_3 = \mathbf{Z}_1 = 4.74\ \Omega \angle -71.57°$$
$$= 1.5\ \Omega - j4.5\ \Omega$$

$$\mathbf{Z}_T = \mathbf{Z}_1 \parallel (\mathbf{Z}_2 + \mathbf{Z}_3) = (4.74\ \Omega \angle -71.57°) \parallel (2.07\ \Omega + j5.17\ \Omega + 1.5\ \Omega - j4.5\ \Omega)$$
$$= (4.74\ \Omega \angle -7.57°) \parallel (3.63\ \Omega \angle 10.63°)$$
$$= 2.71\ \Omega \angle -23.87°$$
$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{100\ \text{V} \angle 0°}{2.71\ \Omega \angle -23.87°} = \mathbf{36.9\ A \angle 23.87°}$$

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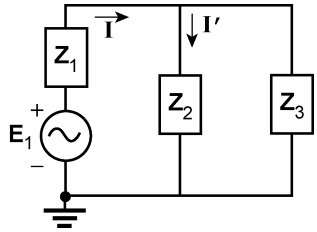
Chapter 18

1. a.

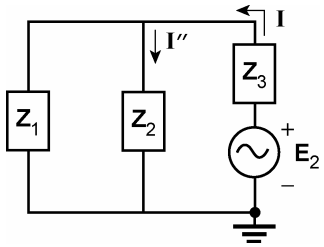


$\mathbf{Z}_1 = 3\ \Omega\ \angle 0°,\ \mathbf{Z}_2 = 8\ \Omega\ \angle 90°,\ \mathbf{Z}_3 = 6\ \Omega\ \angle -90°$

$\mathbf{Z}_2 \| \mathbf{Z}_3 = 8\ \Omega\ \angle 90° \| 6\ \Omega\ \angle -90° = 24\ \Omega\ \angle -90°$

$$\mathbf{I} = \frac{\mathbf{E}_1}{\mathbf{Z}_1 + \mathbf{Z}_2 \| \mathbf{Z}_3} = \frac{30\ \text{V}\ \angle 30°}{3\ \Omega - j24\ \Omega} = 1.24\ \text{A}\ \angle 112.875°$$

$$\mathbf{I}' = \frac{\mathbf{Z}_3\mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(6\ \Omega\ \angle -90°)(1.24\ \text{A}\ \angle 112.875°)}{2\ \Omega\ \angle 90°} = 3.72\ \text{A}\ \angle -67.125°$$



$\mathbf{Z}_1 \| \mathbf{Z}_2 = 3\ \Omega\ \angle 0° \| 8\ \Omega\ \angle 90° = 2.809\ \Omega\ \angle 20.556°$

$$\mathbf{I} = \frac{\mathbf{E}_2}{\mathbf{Z}_3 + \mathbf{Z}_1 \| \mathbf{Z}_2} = \frac{60\ \text{V}\ \angle 10°}{-j6\ \Omega + 2.630\ \Omega + j0.986\ \Omega}$$

$= 10.597\ \text{A}\ \angle 72.322°$

$$\mathbf{I}'' = \frac{\mathbf{Z}_1\mathbf{I}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(3\ \Omega\ \angle 0°)(10.597\ \text{A}\ \angle 72.322°)}{3\ \Omega + j8\ \Omega} = 3.721\ \text{A}\ \angle 2.878°$$

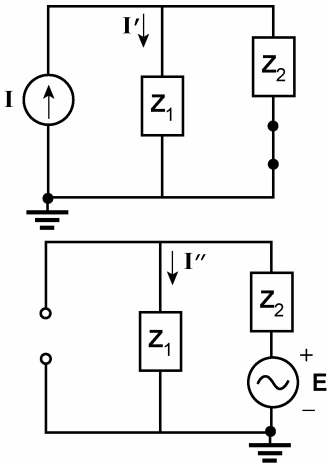
$\mathbf{I}_{L_1} = \mathbf{I}' + \mathbf{I}'' = 3.72\ \text{A}\ \angle -67.125° + 3.721\ \text{A}\ \angle 2.878°$

$= 1.446\ \text{A} - j3.427\ \text{A} + 3.716\ \text{A} + j0.187\ \text{A}$

$= 5.162\ \text{A} - j3.24\ \text{A}$

$= \mathbf{6.09\ A\ \angle -32.12°}$

b.



$\mathbf{Z}_1 = 8\ \Omega\ \angle 90°,\ \mathbf{Z}_2 = 5\ \Omega\ \angle -90°$

$\mathbf{I} = 0.3\ \text{A}\ \angle 60°,\ \mathbf{E} = 10\ \text{V}\ \angle 0°$

$$\mathbf{I}' = \frac{\mathbf{Z}_2\mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(5\ \Omega\ \angle -90°)(0.3\ \text{A}\ \angle 60°)}{+j8\ \Omega - j5\ \Omega}$$

$= 0.5\text{A}\ \angle -120°$

$$\mathbf{I}'' = \frac{\mathbf{E}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{10\ \text{V}\ \angle 0°}{3\ \Omega\ \angle 90°} = 3.33\ \text{A}\ \angle -90°$$

$\mathbf{I}_{Z_1} = \mathbf{I}_{L_1} = \mathbf{I}' + \mathbf{I}''$

$= 0.5\ \text{A}\ \angle -120° + 3.33\ \text{A}\ \angle -90°$

$= -0.25\ \text{A} - j0.433\ \text{A} - j3.33\ \text{A}$

$= -0.25\ \text{A} - j3.763\ \text{A}$

$= \mathbf{3.77\ A\ \angle -93.8°}$

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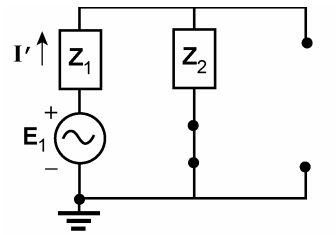
2. a. $\mathbf{E}_1$:



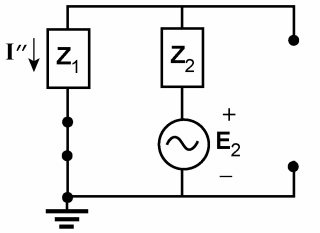
$\mathbf{E}_1 = 20\text{ V}\angle 0°, \quad \mathbf{Z}_1 = 4\ \Omega + j3\ \Omega = 5\ \Omega\angle 36.87°$

$\mathbf{Z}_2 = 1\ \Omega\angle 0°$

$$\mathbf{I}' = \frac{\mathbf{E}_1}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{20\text{ V}\angle 0°}{4\,\Omega + j3\,\Omega + 1\,\Omega}$$

$$= 3.43\text{ A}\angle -30.96°$$

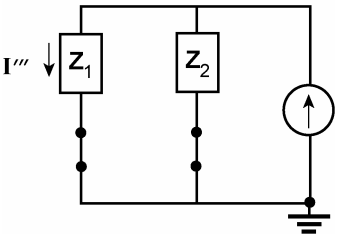
$\mathbf{E}_2$:



$$\mathbf{I}'' = \frac{\mathbf{E}_2}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{120\text{ V}\angle 0°}{5.83\,\Omega\angle 30.96°}$$

$$= 20.58\text{ A}\angle -30.96°$$

$\mathbf{I}$:



$$\mathbf{I}''' = \frac{\mathbf{Z}_2\mathbf{I}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(1\,\Omega\angle 0°)(0.5\text{ A}\angle 60°)}{5.83\,\Omega\angle 30.96°}$$

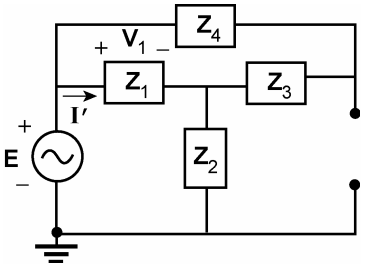
$$= 0.0858\text{ A}\angle 29.04°$$

$\uparrow \mathbf{I}_L = \mathbf{I}' - \mathbf{I}'' - \mathbf{I}'''$

$= (3.43\text{ A}\angle -30.96°) - (20.58\text{ A}\angle -30.96°) - (0.0858\text{ A}\angle 29.04°)$

$= \mathbf{17.20\text{ A}\angle 149.30°}$ or $\mathbf{17.20\text{ A}\angle -30.70°\downarrow}$

b. $\mathbf{E}$:



$\mathbf{Z}_1 = 3\ \Omega\angle 90°, \mathbf{Z}_2 = 7\ \Omega\angle -90°$

$\mathbf{E} = 10\text{ V}\angle 90°$

$\mathbf{Z}_3 = 6\ \Omega\angle -90°, \mathbf{Z}_4 = 4\ \Omega\angle 0°$

$\mathbf{Z}' = \mathbf{Z}_1 \| (\mathbf{Z}_3 + \mathbf{Z}_4)$

$= 3\ \Omega\angle 90° \| (4\ \Omega - j6\ \Omega)$

$= 3\ \Omega\angle 90° \| 7.21\ \Omega\angle -56.31°$

$= 4.33\ \Omega\angle 70.56°$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'\mathbf{E}}{\mathbf{Z}' + \mathbf{Z}_2}$$

$$= \frac{(4.33\,\Omega\angle 70.56°)(10\text{ V}\angle 90°)}{(1.44\,\Omega + j4.08\,\Omega) - j7\Omega}$$

$$= \frac{43.3\text{ V}\angle 160.56°}{3.26\angle -63.75°} = 13.28\text{ V}\angle 224.31°$$

$$\mathbf{I}' = \frac{\mathbf{V}_1}{\mathbf{Z}_1} = \frac{13.28\text{ V}\angle 224.31°}{3\,\Omega\angle 90°}$$

$= 4.43\text{ A}\angle 134.31°$

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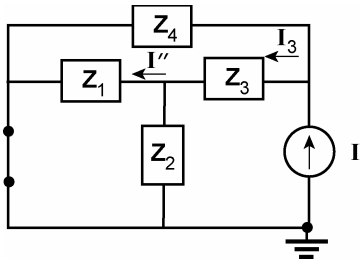
I:

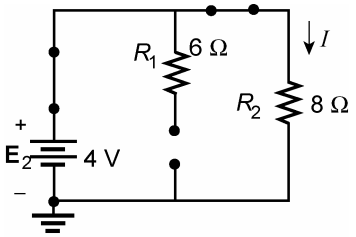


$$\mathbf{Z}'' = \mathbf{Z}_3 + \mathbf{Z}_1 \| \mathbf{Z}_2$$
$$= -j6\ \Omega + 3\ \Omega\ \angle 90° \| 7\ \Omega\ \angle -90°$$
$$= -j6\ \Omega + 5.25\ \Omega\ \angle 90°$$
$$= -j6\ \Omega + j5.25\ \Omega$$
$$= -j0.75\ \Omega = 0.75\ \Omega \angle -90°$$

CDR: $$\mathbf{I}_3 = \frac{\mathbf{Z}_4\mathbf{I}}{\mathbf{Z}_4 + \mathbf{Z}''} = \frac{(4\ \Omega\ \angle 0°)(0.6\ \text{A}\ \angle 120°)}{4\ \Omega - j0.75\ \Omega} = \frac{2.4\ \text{A}\ \angle 120°}{4.07\ \angle -10.62°}$$
$$= 0.59\ \text{A}\ \angle 130.62°$$
$$\mathbf{I}'' = \frac{\mathbf{Z}_2\mathbf{I}_3}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(7\ \Omega\ \angle -90°)(0.59\ \text{A}\ \angle 130.62°)}{-j7\ \Omega + j3\ \Omega} = \frac{4.13\ \text{A}\ \angle 40.62°}{4\ \angle -90°}$$
$$= 1.03\ \text{A}\ \angle 130.62°$$

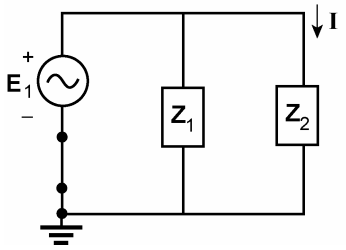
$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}''$ (direction of $\mathbf{I}'$)
$= 4.43\ \text{A}\ \angle 134.31° - 1.03\ \text{A}\ \angle 130.62°$
$= (-3.09\ \text{A} + j3.17\ \text{A}) - (-0.67\ \text{A} + j0.78\ \text{A}) = -2.42\ \text{A} + j2.39\ \text{A}$
$= \mathbf{3.40\ A\ \angle 135.36°}$

3. DC:



$$I_{DC} = \frac{4\ \text{V}}{8\ \Omega} = 0.5\ \text{A}$$

AC:



$$\mathbf{Z}_2 = R_2 + jX_L = 8\ \Omega + j4\ \Omega$$
$$= 8.944\ \Omega\ \angle 26.565°$$
$$\mathbf{I} = \frac{\mathbf{E}_1}{\mathbf{Z}_2} = \frac{10\ \text{V}\ \angle 0°}{8.944\ \Omega\ \angle 26.565°}$$
$$= 1.118\ \text{A}\ \angle -26.565°$$

$\mathbf{I} = \mathbf{0.5\ A + 1.118\ A\ \angle -26.57°}$
$i = \mathbf{0.5\ A + 1.58\ \sin(\omega t - 26.57°)}$

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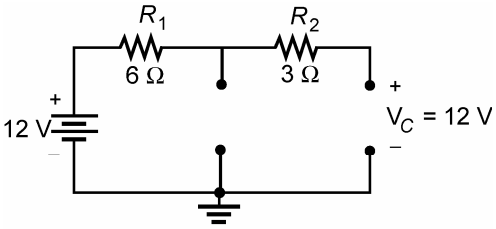
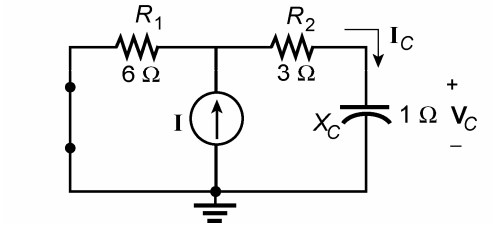
4. DC:



AC:



$$\mathbf{I}_C = \frac{(6\,\Omega\angle 0°)(\mathbf{I})}{6\,\Omega + 3\,\Omega - j1\,\Omega}$$

$$= \frac{(6\,\Omega\angle 0°)(4\text{ A}\angle 0°)}{9\,\Omega - j1\,\Omega}$$

$$= \frac{24\text{ A}\angle 0°}{9.055\angle -6.34°}$$

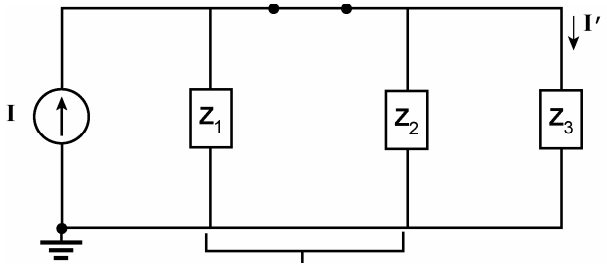
$$= 2.65\text{ A}\angle 6.34°$$

$\mathbf{V}_C = \mathbf{I}_C\mathbf{X}_C = (2.65\text{ A}\angle 6.34°)(1\,\Omega\angle -90°) = 2.65\text{ V}\angle -83.66°$

$= \mathbf{12\text{ V} + 2.65\text{ V}\angle -83.66°}$

$\upsilon_C = \mathbf{12\text{ V} + 3.75\sin(\omega t - 83.66°)}$

5.



$\mathbf{E} = 20\text{ V}\angle 0°$

$\mathbf{Z}_1 = 10\text{ k}\Omega\angle 0°$

$\mathbf{Z}_2 = 5\text{ k}\Omega - j5\text{ k}\Omega$

$= 7.071\text{ k}\Omega\angle -45°$

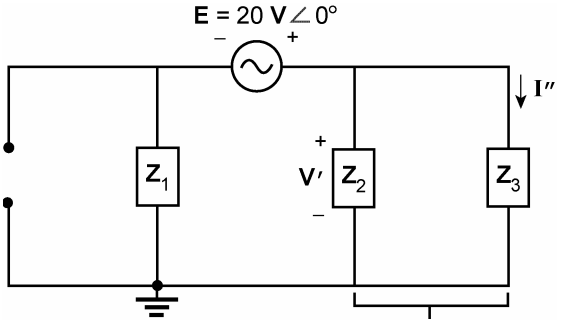
$\mathbf{Z}_3 = 5\text{ k}\Omega\angle 90°$

$\mathbf{I} = 5\text{ mA}\angle 0°$

$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 10\text{ k}\Omega\angle 0° \parallel 7.071\text{ k}\Omega\angle -45° = 4.472\text{ k}\Omega\angle -26.57°$

(CDR) $$\mathbf{I}' = \frac{\mathbf{Z}'\mathbf{I}}{\mathbf{Z}' + \mathbf{Z}_3} = \frac{(4.472\text{ k}\Omega\angle -26.57°)(5\text{ mA}\angle 0°)}{4\text{ k}\Omega - j2\text{ k}\Omega + j5\text{ k}\Omega} = \frac{22.36\text{ mA}\angle -26.57°}{5\angle 36.87°}$$

$= 4.472\text{ mA}\angle -63.44°$



$\mathbf{Z}'' = \mathbf{Z}_2 \parallel \mathbf{Z}_3$

$= 7.071\text{ k}\Omega\angle -45° \parallel 5\text{ k}\Omega\angle 90°$

$= 7.071\text{ k}\Omega\angle 45°$

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(VDR) $$\mathbf{V}' = \frac{\mathbf{Z}''\mathbf{E}}{\mathbf{Z}'' + \mathbf{Z}_1} = \frac{(7.071\,\text{k}\Omega\angle 45°)(20\,\text{V}\angle 0°)}{(5\,\text{k}\Omega + j5\,\text{k}\Omega) + (10\,\text{k}\Omega)} = \frac{141.42\,\text{V}\angle 45°}{15.81\angle 18.435°}$$

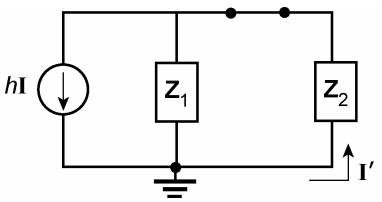
$$= 8.945\,\text{V}\angle 26.565°$$

$$\mathbf{I}'' = \frac{\mathbf{V}'}{\mathbf{Z}_3} = \frac{8.945\,\text{V}\angle 26.565°}{5\,\text{k}\Omega\angle 90°} = 1.789\,\text{mA}\angle -63.435° = 0.8\,\text{mA} - j1.6\,\text{mA}$$

$$\mathbf{I} = \mathbf{I}' + \mathbf{I}'' = (2\,\text{mA} - j4\,\text{mA}) + (0.8\,\text{mA} - j1.6\,\text{mA}) = 2.8\,\text{mA} - j5.6\,\text{mA}$$

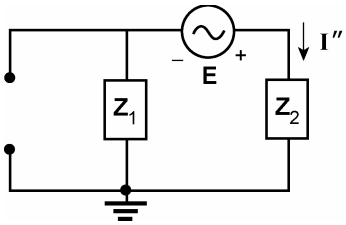
$$= \mathbf{6.26\,mA\angle -63.43°}$$

6.



$\mathbf{Z}_1 = 20\,\text{k}\Omega\angle 0°$
$\mathbf{Z}_2 = 10\,\text{k}\Omega\angle 90°$
$\mathbf{I} = 2\,\text{mA}\angle 0°$
$\mathbf{E} = 10\,\text{V}\angle 0°$

$$\mathbf{I}' = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20\,\text{k}\Omega\angle 0°)(100)(2\,\text{mA}\angle 0°)}{20\,\text{k}\Omega + j10\,\text{k}\Omega} = 0.179\,\text{A}\angle -26.57°$$



$$\mathbf{I}'' = \frac{\mathbf{E}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{10\,\text{V}\angle 0°}{22.36\,\text{k}\Omega\angle 26.57°}$$

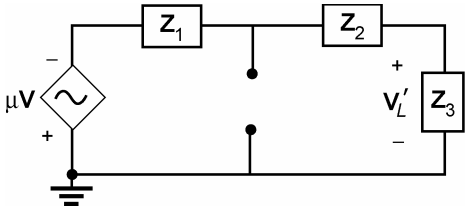
$$= 0.447\,\text{mA}\angle -26.57°$$

$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}''$ (direction of $\mathbf{I}'$)

$= 179\,\text{mA}\angle -26.57° - 0.447\,\text{mA}\angle -26.57°$

$= \mathbf{178.55\,mA\angle -26.57°}$

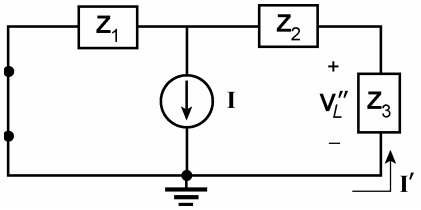
7. $\mu\mathbf{V}$:



$\mathbf{Z}_1 = 5\,\text{k}\Omega\angle 0°$, $\mathbf{Z}_2 = 1\,\text{k}\Omega\angle -90°$
$\mathbf{Z}_3 = 4\,\text{k}\Omega\angle 0°$
$\mathbf{V} = 2\,\text{V}\angle 0°$, $\mu = 20$

$$\mathbf{V}'_L = \frac{-\mathbf{Z}_3(\mu\mathbf{V})}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3} = \frac{-(4\,\text{k}\Omega\angle 0°)(20)(2\,\text{V}\angle 0°)}{5\,\text{k}\Omega - j1\,\text{k}\Omega + 4\,\text{k}\Omega} = -17.67\,\text{V}\angle 6.34°$$

I:



CDR: $$\mathbf{I}' = \frac{\mathbf{Z}_1\mathbf{I}}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3}$$

$$= \frac{(5\,\text{k}\Omega\angle 0°)(2\,\text{mA}\angle 0°)}{9.056\,\text{k}\Omega\angle -6.34°}$$

$$= 1.104\,\text{mA}\angle 6.34°$$

$\mathbf{V}''_L = -\mathbf{I}'\mathbf{Z}_3 = -(1.104\,\text{mA}\angle 6.34°)(4\,\text{k}\Omega\angle 0°) = -4.416\,\text{V}\angle 6.34°$

$\mathbf{V}_L = \mathbf{V}'_L + \mathbf{V}''_L = -17.67\,\text{V}\angle 6.34° - 4.416\,\text{V}\angle 6.34° = \mathbf{-22.09\,V\angle 6.34°}$

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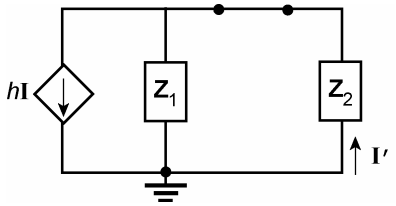
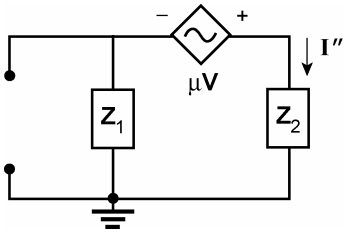
8.



$\mathbf{Z}_1 = 20\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\ \text{k}\Omega + j5\ \text{k}\Omega$

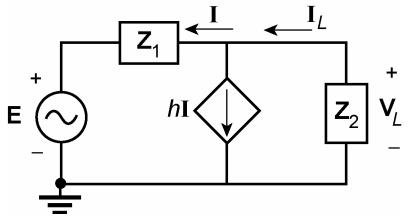
$$\mathbf{I}' = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20\,\text{k}\Omega\ \angle 0°)(100)(1\,\text{mA}\ \angle 0°)}{20\,\text{k}\Omega + 5\,\text{k}\Omega + j5\,\text{k}\Omega} = 78.45\ \text{mA}\ \angle -11.31°$$



$$\mathbf{I}'' = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(10\ \text{V}\ \angle 0°)}{25.495\,\text{k}\Omega\ \angle 11.31°}$$
$$= 7.845\ \text{mA}\ \angle -11.31°$$

$\mathbf{I}_L = \mathbf{I}' - \mathbf{I}''$ (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.



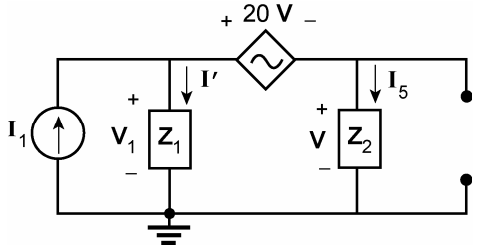
$\mathbf{Z}_1 = 2\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 2\ \text{k}\Omega\ \angle 0°$
$\mathbf{V}_L = -\mathbf{I}_L\mathbf{Z}_2$
$\mathbf{I}_L = h\mathbf{I} + \mathbf{I} = (h + 1)\mathbf{I}$
$\mathbf{V}_L = -(h + 1)\mathbf{I}\mathbf{Z}_2$
and by KVL: $\mathbf{V}_L = \mathbf{I}\mathbf{Z}_1 + \mathbf{E}$
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: $\mathbf{V}_1 - 20\ \mathbf{V} - \mathbf{V} = 0$ $\qquad \mathbf{I}' = \dfrac{\mathbf{V}_1}{\mathbf{Z}_1}\ \therefore\ \mathbf{I}' = \dfrac{21\,\mathbf{V}}{\mathbf{Z}_1}$ or $\mathbf{V} = \dfrac{\mathbf{Z}_1}{21}\mathbf{I}'$

$\mathbf{V}_1 = 21\ \mathbf{V}$

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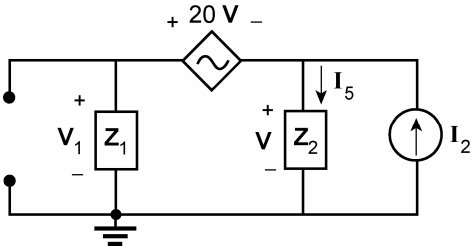
$$\mathbf{V} = \mathbf{I}_5\mathbf{Z}_2 = [\mathbf{I}_1 - \mathbf{I}']\mathbf{Z}_2$$

$$\frac{\mathbf{Z}_1}{21}\mathbf{I}' = \mathbf{I}_1\mathbf{Z}_2 - \mathbf{I}'\mathbf{Z}_2$$

$$\mathbf{I}'\left[\frac{\mathbf{Z}_1}{21} + \mathbf{Z}_2\right] = \mathbf{I}_1\mathbf{Z}_2$$

$$\text{and } \mathbf{I}' = \frac{\mathbf{Z}_2}{\dfrac{\mathbf{Z}_1}{21} + \mathbf{Z}_2}\,[\mathbf{I}_1] = \frac{(5\,\text{k}\Omega\angle 0°)(1\,\text{mA}\angle 0°)}{\left(\dfrac{2\,\text{k}\Omega\angle 0°}{21}\right) + 5\,\text{k}\Omega\angle 0°} = 0.981\ \text{mA}\angle 0°$$

$\mathbf{I}_2$:



$$\mathbf{V}_1 = 20\ \text{V} + \text{V} = 21\ \text{V}$$

$$\mathbf{I}'' = \frac{\mathbf{V}_1}{\mathbf{Z}_1} = \frac{21\,\text{V}}{\mathbf{Z}_1} \Rightarrow \mathbf{V} = \frac{\mathbf{Z}_1}{21}\mathbf{I}''$$

$$\mathbf{I}_5 = \frac{\mathbf{V}}{\mathbf{Z}_2} = \frac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}\mathbf{I}''$$

$$\mathbf{I}'' = \mathbf{I}_2 - \mathbf{I}_5 = \mathbf{I}_2 - \frac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}\mathbf{I}''$$

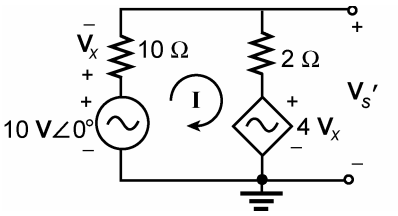
$$\mathbf{I}''\left[1 + \frac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}\right] = \mathbf{I}_2$$

$$\mathbf{I}'' = \frac{\mathbf{I}_2}{1 + \dfrac{\mathbf{Z}_1}{21\,\mathbf{Z}_2}} = \frac{2\,\text{mA}\angle 0°}{1 + \dfrac{2\,\text{k}\Omega}{21(5\,\text{k}\Omega)}} = 1.963\ \text{mA}\angle 0°$$

$$\mathbf{I} = \mathbf{I}' + \mathbf{I}'' = 0.981\ \text{mA}\angle 0° + 1.963\ \text{mA}\angle 0°$$

$$= \mathbf{2.94\ mA\angle 0°}$$

11. $\mathbf{E}_1$:



$$10\ \text{V}\angle 0° - \mathbf{I}\ 10\ \Omega - \mathbf{I}\ 2\ \Omega - 4\ \mathbf{V}_x = 0$$

with $\mathbf{V}_x = \mathbf{I}\ 10\ \Omega$

Solving for $\mathbf{I}$:

$$\mathbf{I} = \frac{10\,\text{V}\angle 0°}{52\,\Omega} = 192.31\ \text{mA}\angle 0°$$

$$\mathbf{V}_s' = 10\ \text{V}\angle 0° - \mathbf{I}(10\ \Omega) = 10\ \text{V} - (192.31\ \text{mA}\angle 0°)(10\ \Omega\angle 0°) = 8.08\ \text{V}\angle 0°$$

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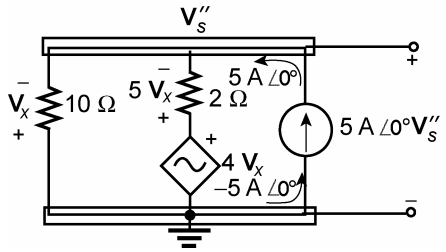
I:



$$\sum \mathbf{I}_i = \sum \mathbf{I}_o$$

$$5\text{ A}\angle 0° + \frac{\mathbf{V}_x}{10\,\Omega} + \frac{5\,\mathbf{V}_x}{2\,\Omega} = 0$$

$$5\text{ A} + 0.1\,\mathbf{V}_x + 2.5\,\mathbf{V}_x = 0$$

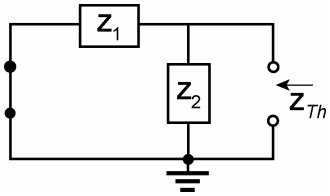
$$2.6\,\mathbf{V}_x = -5\text{ A}$$

$$\mathbf{V}_x = -\frac{5}{2.6}\mathbf{V} = -1.923\text{ V}$$

$$\mathbf{V}_s'' = -\mathbf{V}_x = -(-1.923\text{ V}) = 1.923\text{ V}\angle 0°$$

$$\mathbf{V}_s = \mathbf{V}_s' + \mathbf{V}_s'' = 8.08\text{ V}\angle 0° + 1.923\text{ V}\angle 0° = \mathbf{10\text{ V}\angle 0°}$$

12. a. $\mathbf{Z}_{Th}$:



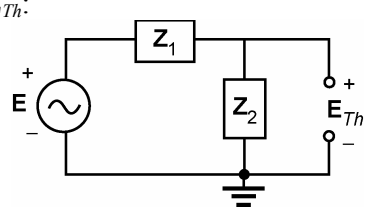
$\mathbf{Z}_1 = 3\ \Omega\angle 0°$, $\mathbf{Z}_2 = 4\ \Omega\angle 90°$

$\mathbf{E} = 100\text{ V}\angle 0°$

$\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (3\ \Omega\angle 0° \parallel 4\ \Omega\angle 90°)$

$= \mathbf{2.4\ \Omega\angle 36.87° = 1.92\ \Omega + j1.44\ \Omega}$

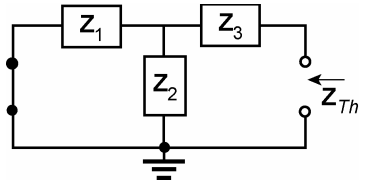
$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(4\,\Omega\angle 90°)(100\text{ V}\angle 0°)}{5\,\Omega\angle 53.13°}$$

$$= \mathbf{80\text{ V}\angle 36.87°}$$

b. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_{Th} = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2$

$= +j6\text{ k}\Omega + (2\text{ k}\Omega\angle 0° \parallel 3\text{ k}\Omega\angle -90°)$

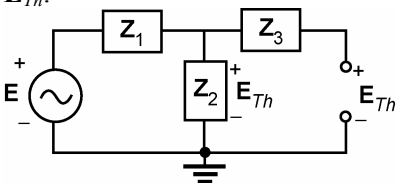
$= +j6\text{ k}\Omega + 1.664\text{ k}\Omega\angle -33.69°$

$= +j6\text{ k}\Omega + 1.385\text{ k}\Omega - j0.923\text{ k}\Omega$

$= 1.385\text{ k}\Omega + j5.077\text{ k}\Omega$

$= \mathbf{5.26\text{ k}\Omega\angle 74.74°}$

$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(3\text{ k}\Omega\angle -90°)(20\text{ V}\angle 0°)}{2\text{ k}\Omega - j3\text{ k}\Omega}$$

$$= \frac{60\text{ V}\angle -90°}{3.606\angle -56.31°} = \mathbf{16.64\text{ V}\angle -33.69°}$$

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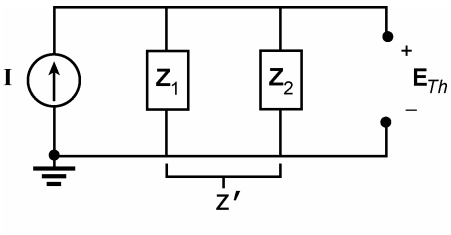
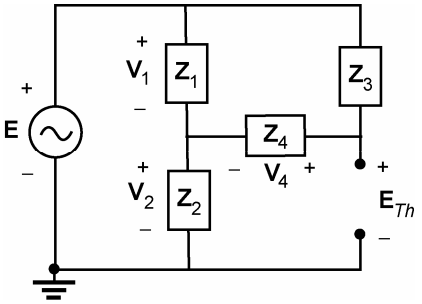
13. a. From #27. $\mathbf{Z}_{Th} = \mathbf{Z}_1 \,||\, \mathbf{Z}_2$

$\mathbf{Z}_{Th} = \mathbf{Z}_N = \mathbf{21.31\ \Omega\ \angle 32.2°}$



$\mathbf{E}_{Th} = \mathbf{IZ'} = \mathbf{IZ}_{Th}$
$= (0.1\ \text{A}\ \angle 0°)(21.31\ \Omega\ \angle 32.12°)$
$= \mathbf{2.13\ V\ \angle 32.2°}$

b. From #27. $\mathbf{Z}_{Th} = \mathbf{Z}_N = \mathbf{6.81\ \Omega\ \angle -54.23°} = \mathbf{3.98\ \Omega - j5.53\ \Omega}$



$\mathbf{Z}_1 = 2\ \Omega\ \angle 0°$, $\mathbf{Z}_3 = 8\ \Omega\ \angle -90°$
$\mathbf{Z}_2 = 4\ \Omega\ \angle 90°$, $\mathbf{Z}_4 = 10\ \Omega\ \angle 0°$
$\mathbf{E} = 50\ \text{V}\ \angle 0°$
$\mathbf{E}_{Th} = \mathbf{V}_2 + \mathbf{V}_4$

$$\mathbf{V}_2 = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1 \,||\, (\mathbf{Z}_3 + \mathbf{Z}_4)}$$

$$= \frac{(4\ \Omega\ \angle 90°)(50\ \text{V}\ \angle 0°)}{+j4\ \Omega + 2\ \Omega\ \angle 0° \,||\, (10\ \Omega - j8\ \Omega)}$$

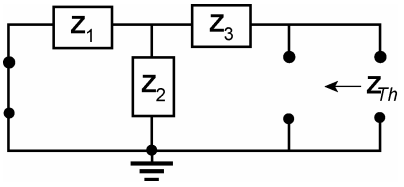
$= 47.248\ \text{V}\ \angle 24.7°$

$\mathbf{V}_1 = \mathbf{E} - \mathbf{V}_2 = 50\ \text{V}\ \angle 0° - 47.248\ \text{V}\ \angle 24.7° = 20.972\ \text{V}\ \angle -70.285°$

$$\mathbf{V}_4 = \frac{\mathbf{Z}_4\mathbf{V}_1}{\mathbf{Z}_4 + \mathbf{Z}_3} = \frac{(10\ \Omega\ \angle 0°)(20.972\ \text{V}\ \angle -70.285°)}{10\ \Omega - j8\ \Omega} = 16.377\ \text{V}\ \angle -31.625°$$

$\mathbf{E}_{Th} = \mathbf{V}_2 + \mathbf{V}_4 = 47.248\ \text{V}\ \angle 24.7° + 16.377\ \text{V}\ \angle -31.625°$
$= (42.925\ \text{V} + j19.743\ \text{V}) + (13.945\ \text{V} - j8.587\ \text{V})$
$= 56.870\ \text{V} + j11.156\ \text{V} = \mathbf{57.95\ V\ \angle 11.10°}$

14. a. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 10\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 8\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 8\ \Omega\ \angle -90°$

$\mathbf{Z}_{Th} = \mathbf{Z}_3 + \mathbf{Z}_1 \,||\, \mathbf{Z}_2$
$= -j8\ \Omega + 10\ \Omega\ \angle 0° \angle\ ||\ 8\ \Omega\ \angle 90°$
$= -j8\ \Omega + 6.247\ \Omega\ \angle 51.34°$
$= -j8\ \Omega + 3.902\ \Omega + j4.878\ \Omega$
$= 3.902\ \Omega - j3.122\ \Omega$
$= \mathbf{5.00\ \Omega\ \angle -38.66°}$

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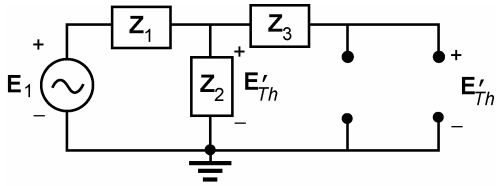
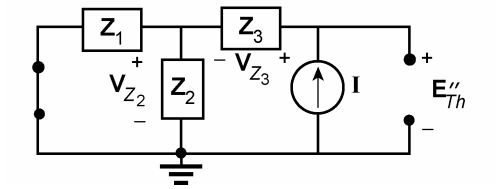
$\mathbf{E}_{Th}$: Superposition:

($\mathbf{E}_1$)



$$\mathbf{E}'_{Th} = \frac{(8\,\Omega\angle 90°)(120\text{ V}\angle 0°)}{10\,\Omega + j8\,\Omega}$$
$$= \frac{960\text{ V}\angle 90°}{12.806\angle 38.66°}$$
$$= 74.965\text{ V}\angle 51.34°$$

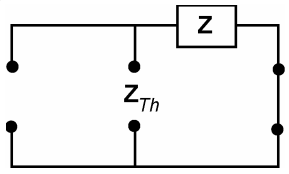
(**I**)



$$\mathbf{E}''_{Th} = \mathbf{V}_{Z_2} + \mathbf{V}_{Z_3}$$
$$= \mathbf{I}\mathbf{Z}_3 + \mathbf{I}(\mathbf{Z}_1 \parallel \mathbf{Z}_2)$$
$$= \mathbf{I}(\mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2)$$
$$= (0.5\text{ A}\angle 60°)(-j8\,\Omega + 10\,\Omega\angle 0° \parallel 8\,\Omega\angle 90°)$$
$$= (0.5\text{ A}\angle 60°)(-j8\,\Omega + 3.902\,\Omega + j4.878\,\Omega)$$
$$= (0.5\text{ A}\angle 60°)(3.902\,\Omega - j3.122\,\Omega)$$
$$= (0.5\text{ A}\angle 60°)(4.997\,\Omega\angle -38.663°)$$
$$= 2.499\text{ V}\angle 21.337°$$

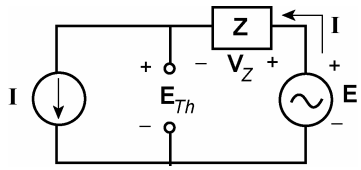
$$\mathbf{E}_{Th} = \mathbf{E}'_{Th} + \mathbf{E}''_{Th}$$
$$= 74.965\text{ V}\angle 51.34° + 2.449\text{ V}\angle 21.337°$$
$$= (46.83\text{ V} + j58.538\text{ V}) + (2.328\text{ V} + j0.909\text{ V})$$
$$= 49.158\text{ V} + j59.447\text{ V} = \mathbf{77.14\text{ V}\angle 50.41°}$$

b. $\mathbf{Z}_{Th}$:



$$\mathbf{Z}_{Th} = \mathbf{Z} = 10\,\Omega - j10\,\Omega = \mathbf{14.14\,\Omega\angle -45°}$$

$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = \mathbf{E} - \mathbf{V}_Z$$
$$= 20\text{ V}\angle 40° - \mathbf{IZ}$$
$$= 20\text{ V}\angle 40° - (0.6\text{ A}\angle 90°)(14.14\,\Omega\angle -45°)$$
$$= 20\text{ V}\angle 40° - 8.484\text{ V}\angle 45°$$
$$= (15.321\text{ V} + j12.856\text{ V}) - (6\text{ V} + j6\text{ V})$$
$$= 9.321\text{ V} + j6.856\text{ V}$$
$$= \mathbf{11.57\text{ V}\angle 36.34°}$$

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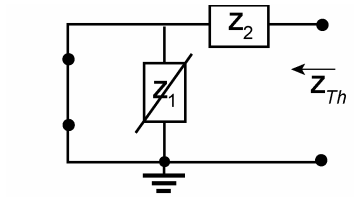
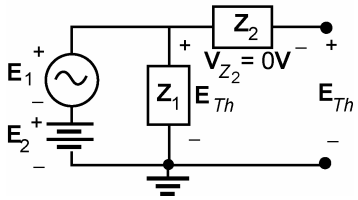
15. a.



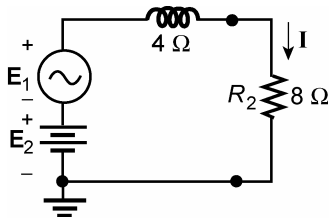
$\mathbf{Z}_1 = 6\ \Omega - j2\ \Omega = 6.325\ \Omega \angle -18.435°$
$\mathbf{Z}_2 = 4\ \Omega \angle 90°$
$\mathbf{Z}_{Th} = \mathbf{Z}_2 = \mathbf{4\ \Omega \angle 90°}$



By inspection:

$\mathbf{E}_{Th} = \mathbf{E}_2 + \mathbf{E}_1$
$= \mathbf{4\ V + 10\ V \angle 0°}$
DC AC

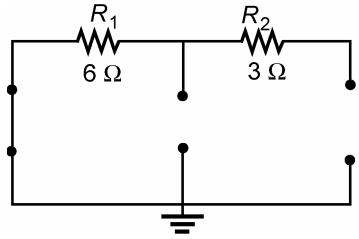
b.



$$\mathbf{I} = \frac{E_2}{R_2} + \frac{\mathbf{E}_1}{R_2 + jX_L}$$
$$= \frac{4\ \text{V}}{8\ \Omega} + \frac{10\ \text{V} \angle 0°}{8\ \Omega + j4\ \Omega}$$
$$= 0.5\ \text{A} + \frac{10\ \text{V} \angle 0°}{8.944\ \Omega \angle 26.565°}$$
$$= 0.5\ \text{A} + 1.118\ \text{A} \angle -26.565°$$
(dc) (ac)

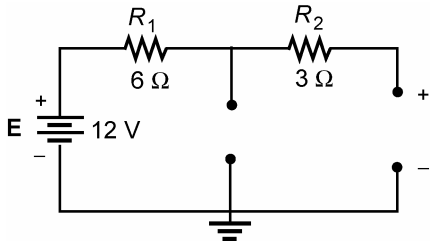
$i = \mathbf{0.5 + 1.58\ \sin(\omega t - 26.57°)}$

16. a. $\mathbf{Z}_{Th}$:



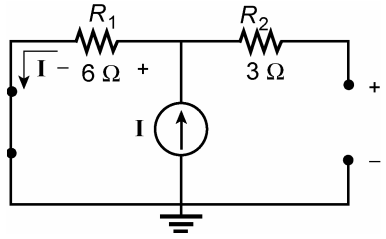
$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_{R_1} + \mathbf{Z}_{R_2} = 6\ \Omega + 3\ \Omega = \mathbf{9\ \Omega}$

DC:



$\mathbf{E'}_{Th} = 12\ \text{V}$

AC:



$\leftarrow \mathbf{E''}_{Th} = \mathbf{IZ}_{R_1} = (4\ \text{A} \angle 0°)(6\ \Omega \angle 0°) = 24\ \text{V} \angle 0°$

$\mathbf{E}_{Th} = 12\ \text{V} + 24\ \text{V} \angle 0°$
(DC) (AC)

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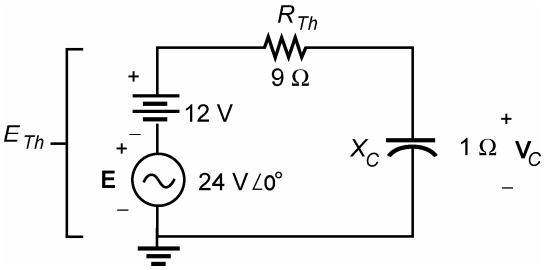
b.



DC: $\mathbf{V}_C = 12\text{ V}$

AC: $$\mathbf{V}_C = \frac{\mathbf{Z}_C\mathbf{E}}{\mathbf{Z}_C + \mathbf{Z}_{R_{Th}}}$$

$$= \frac{(1\,\Omega \angle -90°)(24\text{ V} \angle 0°)}{-j1\,\Omega + 9\,\Omega}$$

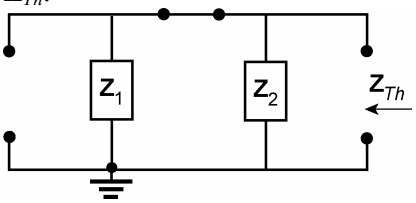
$$= \frac{24\text{ V} \angle -90°}{9.055 \angle -6.34°}$$

$$\mathbf{V}_C = 2.65\text{ V} \angle -83.66°$$

$$v_C = 12\text{ V} + 2.65\text{ V} \angle -83.66°$$

$$= \mathbf{12\text{ V} + 3.75\sin(\omega t - 83.66°)}$$

17. a. $\mathbf{Z}_{Th}$:



$$\mathbf{Z}_1 = 10\text{ k}\Omega \angle 0°$$

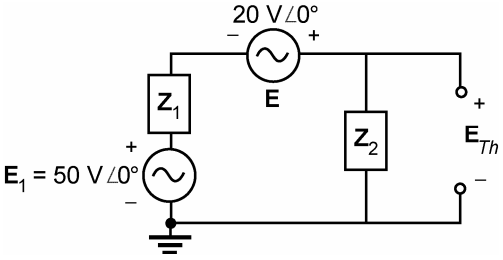
$$\mathbf{Z}_2 = 5\text{ k}\Omega - j5\text{ k}\Omega$$

$$= 7.071\text{ k}\Omega \angle -45°$$

$$\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (10\text{ k}\Omega \angle 0°) \parallel (7.071\text{ k}\Omega \angle -45°) = \mathbf{4.47\text{ k}\Omega \angle -26.57°}$$

Source conversion:

$$\mathbf{E}_1 = (I\angle\theta)(R_1\angle 0°) = (5\text{ mA} \angle 0°)(10\text{ k}\Omega \angle 0°) = 50\text{ V} \angle 0°$$



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2(\mathbf{E} + \mathbf{E}_1)}{\mathbf{Z}_2 + \mathbf{Z}_1}$$

$$= \frac{(7.071\text{ k}\Omega \angle -45°)(20\text{ V} \angle 0° + 50\text{ V} \angle 0°)}{(5\text{ k}\Omega - j5\text{ k}\Omega) + (10\text{ k}\Omega)}$$

$$= \frac{(7.071\text{ k}\Omega \angle -45°)(70\text{ V} \angle 0°)}{(15\text{ k}\Omega - j5\text{ k}\Omega)}$$

$$= \frac{494.97\text{ V} \angle -45°}{15.811 \angle -18.435°}$$

$$= \mathbf{31.31\text{ V} \angle -26.57°}$$

b. $$\mathbf{I} = \frac{\mathbf{E}_{Th}}{\mathbf{Z}_{Th} + \mathbf{Z}_L} = \frac{31.31\text{ V} \angle -26.565°}{4.472\text{ k}\Omega \angle -26.565° + 5\text{ k}\Omega \angle 90°}$$

$$= \frac{31.31\text{ V} \angle -26.565°}{4\text{ k}\Omega - j2\text{ k}\Omega + j5\text{ k}\Omega} = \frac{31.31\text{ V} \angle -26.565°}{4\text{ k}\Omega + j3\text{ k}\Omega}$$

$$= \frac{31.31\text{ V} \angle -26.565°}{5\text{ k}\Omega \angle 36.87°} = \mathbf{6.26\text{ mA} \angle 63.44°}$$

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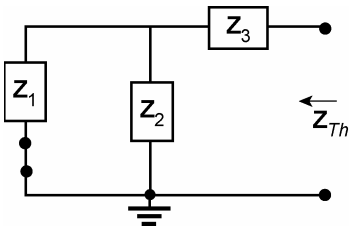
18.

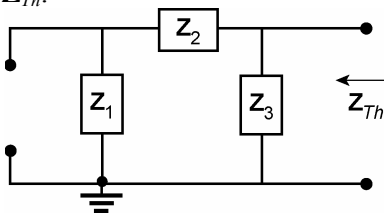


$\mathbf{Z}_1 = 10\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_2 = 10\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_3 = 1\ \text{k}\Omega \angle -90°$

$$\mathbf{Z}_{Th} = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 5\ \text{k}\Omega - j1\ \text{k}\Omega \cong \mathbf{5.1\ k\Omega \angle -11.31°}$$

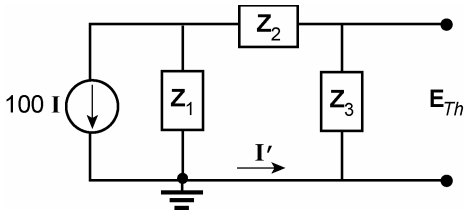
$\mathbf{E}_{Th}$: (VDR) $$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2(20\,\mathbf{V})}{\mathbf{Z}_2 + \mathbf{Z}_1} = \frac{(10\,\text{k}\Omega \angle 0°)(20\,\mathbf{V})}{10\ \text{k}\Omega + 10\,\text{k}\Omega} = \mathbf{10\ V}$$

19. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 40\ \text{k}\Omega \angle 0°$
$\mathbf{Z}_2 = 0.2\ \text{k}\Omega \angle -90°$
$\mathbf{Z}_3 = 5\ \text{k}\Omega \angle 0°$

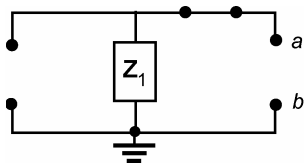
$$\mathbf{Z}_{Th} = \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2) = 5\ \text{k}\Omega \angle 0° \parallel (40\ \text{k}\Omega - j0.2\ \text{k}\Omega) = \mathbf{4.44\ k\Omega \angle -0.03°}$$



$$\mathbf{I}' = \frac{\mathbf{Z}_1(100\,\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(40\,\text{k}\Omega \angle 0°)(100\,\mathbf{I})}{45\,\text{k}\Omega \angle -0.255°} = 88.89\,\mathbf{I} \angle 0.255°$$

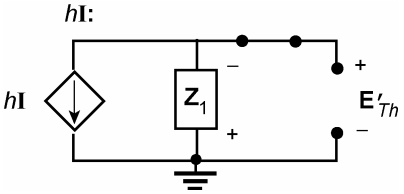
$$\mathbf{E}_{Th} = -\mathbf{I}'\mathbf{Z}_3 = -(88.89\,\mathbf{I} \angle 0.255°)(5\ \text{k}\Omega \angle 0°) = \mathbf{-444.45 \times 10^3\ I \angle 0.26°}$$

20. $\mathbf{Z}_{Th}$:



$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 = \mathbf{20\ k\Omega \angle 0°}$

$\mathbf{E}_{Th}$:



$\mathbf{E}'_{Th} = -(h\mathbf{I})(\mathbf{Z}_1)$
$= -(100)(2\ \text{mA} \angle 0°)(20\ \text{k}\Omega \angle 0°)$
$= -4\ \text{kV} \angle 0°$

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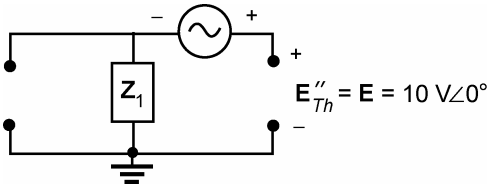
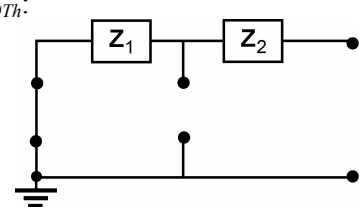
E:



$$\mathbf{E}_{Th} = \mathbf{E}'_{Th} + \mathbf{E}''_{Th}$$
$$= -4\text{ kV}\angle 0° + 10\text{ V}\angle 0°$$
$$= \mathbf{-3990\text{ V}\angle 0°}$$

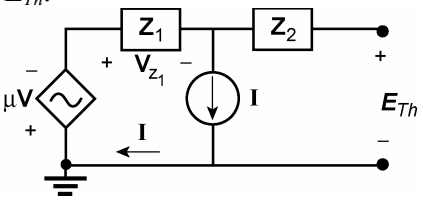
21. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 5\text{k}\Omega\angle 0°$ $\mathbf{Z}_2 = -j1$

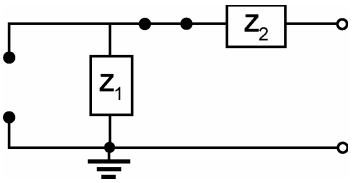
$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 + \mathbf{Z}_2 = 5\text{ k}\Omega - j1\text{ k}\Omega$$
$$= \mathbf{5.10\text{ k}\Omega\ \angle -11.31°}$$

$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = -\left[\mu\mathbf{V} + \mathbf{V}_{Z_1}\right]$$
$$= -\mu\mathbf{V} - \mathbf{I}\mathbf{Z}_1$$
$$= -(20)(2\text{ V}\angle 0°) - (2\text{ mA}\angle 0°)(5\text{ k}\Omega\angle 0°)$$
$$= \mathbf{-50\text{ V}\angle 0°}$$

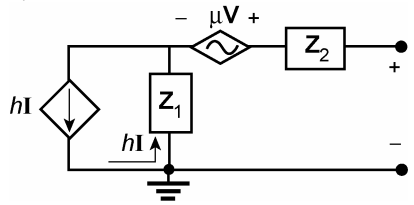
22. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 20\text{ k}\Omega\angle 0°$
$\mathbf{Z}_2 = 5\text{ k}\Omega\angle 0°$

$$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 + \mathbf{Z}_2 = \mathbf{25\text{ k}\Omega\angle 0°}$$

$\mathbf{E}_{Th}$:



$$E_{Th} = \mu\mathbf{V} - (h\mathbf{I})(\mathbf{Z}_1)$$
$$= (20)(10\text{ V}\angle 0°) - (100)(1\text{ mA}\angle 0°)(20\text{ k}\Omega\angle 0°)$$
$$= \mathbf{-1800\text{ V}\angle 0°}$$

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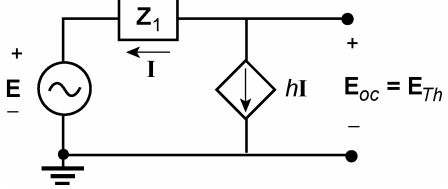
23. $\mathbf{E}_{Th}$: $(\mathbf{E}_{oc})$



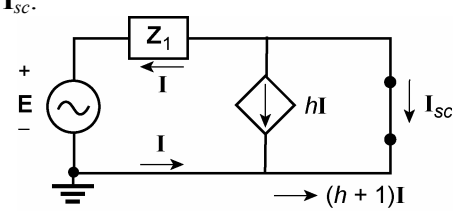
$h\mathbf{I} = -\mathbf{I}$ $\quad \mathbf{Z}_1 = 2\ \text{k}\Omega\ \angle 0°$

$\therefore \mathbf{I} = 0$

and $h\mathbf{I} = 0$

with $\mathbf{E}_{oc} = \mathbf{E}_{Th} = \mathbf{E} = \mathbf{20\ V\ \angle 53°}$

$\mathbf{I}_{sc}$:



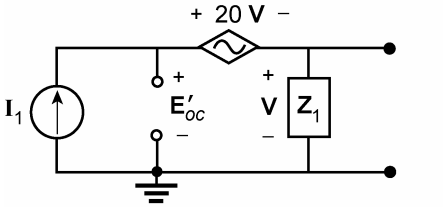
$\mathbf{I}_{sc} = -(h + 1)\mathbf{I}$

$= -(h + 1)(10\ \text{mA}\ \angle 53°)$

$= -510\ \text{mA}\ \angle 53°$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{20\ \text{V}\ \angle 53°}{-510\ \text{mA}\ \angle 53°} = \mathbf{-39.22\ \Omega\ \angle 0°}$$

24. $\mathbf{E}_{Th}$:



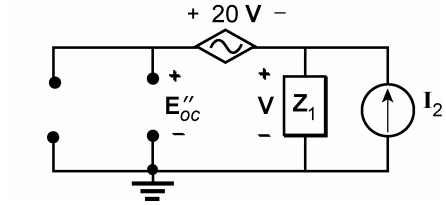
$\mathbf{E}'_{oc} = 21\ \text{V}$ $\quad \mathbf{Z}_1 = 5\ \text{k}\Omega\ \angle 0°$

$\mathbf{V} = \mathbf{I}_1\mathbf{Z}_1 = (1\ \text{mA}\ \angle 0°)(5\ \text{k}\Omega\ \angle 0°)$

$= 5\ \text{V}\ \angle 0°$

$\mathbf{E}'_{oc} = \mathbf{E}'_{Th} = 21(5\ \text{V}\ \angle 0°)$

$= 105\ \text{V}\ \angle 0°$



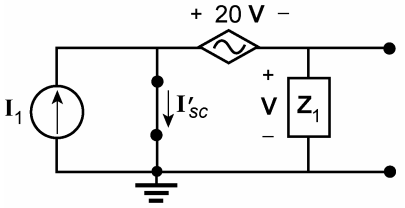
$\mathbf{V} = \mathbf{I}_2\mathbf{Z}_1$

$= (2\ \text{mA}\ \angle 0°)(5\ \text{k}\Omega\ \angle 0°)$

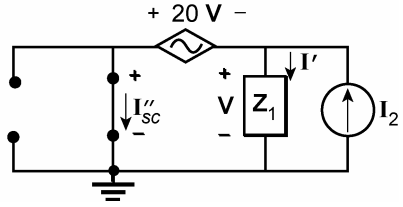
$= 10\ \text{V}\ \angle 0°$

$\mathbf{E}''_{oc} = \mathbf{E}''_{Th} = \mathbf{V} + 20\ \mathbf{V} = 21\ \text{V} = 210\ \text{V}\ \angle 0°$

$\mathbf{I}_{sc}$:



$\mathbf{I}'_{sc} = \mathbf{I}_1$



$20\ \text{V} = \mathbf{V}\ \therefore\ \mathbf{V} = 0\ \text{V}$

and $\mathbf{I}' = 0\ \text{A}$

$\therefore\ \mathbf{I}''_{sc} = \mathbf{I}_2$

$\mathbf{I}_{sc} = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 3\ \text{mA}\ \angle 0°$

$\mathbf{E}_{oc} = \mathbf{E}'_{oc} + \mathbf{E}''_{oc} = 315\ \text{V}\ \angle 0° = \mathbf{E}_{Th}$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{315\ \text{V}\ \angle 0°}{3\ \text{mA}\ \angle 0°} = \mathbf{105\ k\Omega\ \angle 0°}$$

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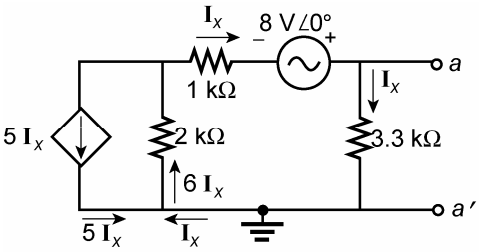
25. $\mathbf{E}_{oc}$:
($\mathbf{E}_{Th}$)

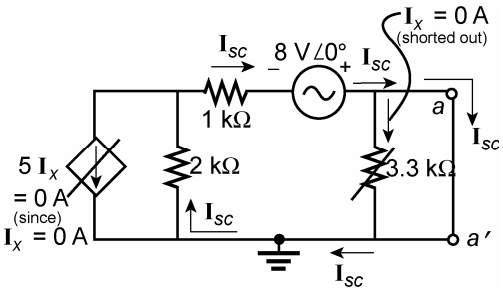


KVL: $-6\ \mathbf{I}_x(2\ \text{k}\Omega) - \mathbf{I}_x(1\ \text{k}\Omega) + 8\ \text{V}\ \angle 0° - \mathbf{I}_x(3.3\ \text{k}\Omega) = 0$

$$\mathbf{I}_x = \frac{8\ \text{V}\ \angle 0°}{16.3\ \text{k}\Omega} = 0.491\ \text{mA}\ \angle 0°$$

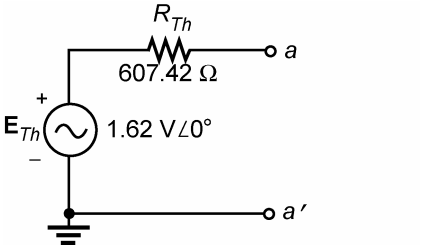
$$\mathbf{E}_{oc} = \mathbf{E}_{Th} = \mathbf{I}_x(3.3\ \text{k}\Omega) = \mathbf{1.62\ V\ \angle 0°}$$

$\mathbf{I}_{sc}$:



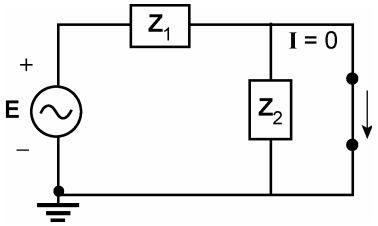
$$\mathbf{I}_{sc} = \frac{8\ \text{V}}{3\ \text{k}\Omega} = 2.667\ \text{mA}\ \angle 0°$$

$$\mathbf{Z}_{Th} = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{1.62\ \text{V}\ \angle 0°}{2.667\ \text{mA}\ \angle 0°} = \mathbf{607.42\ \Omega\ \angle 0°}$$



26. a. From Problem 12(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 1.92\ \Omega + j1.44\ \Omega = \mathbf{2.4\ \Omega\ \angle 36.87°}$

$\mathbf{I}_N$:



$\mathbf{Z}_1 = 3\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 4\ \Omega\ \angle 90°$

$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{100\ \text{V}\ \angle 0°}{3\ \Omega\ \angle 0°}$$

$$= \mathbf{33.33\ A\ \angle 0°}$$

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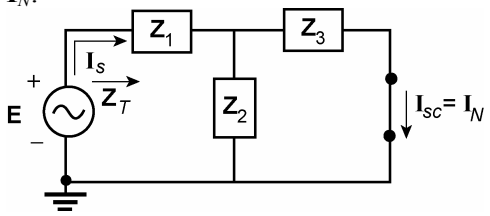
b. From Problem 12(b): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 5.263\ \text{k}\Omega\ \angle 74.74° = \mathbf{1.39\ k\Omega + \textit{j}5.08\ k\Omega}$

$\mathbf{I}_N$:

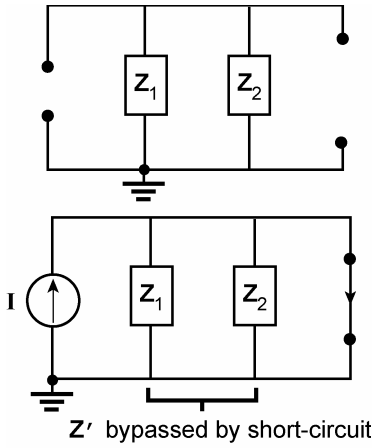


$\mathbf{Z}_1 = 2\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 3\ \text{k}\Omega\ \angle -90°$
$\mathbf{Z}_3 = 6\ \text{k}\Omega\angle 90°$

$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3$
$= 2\ \text{k}\Omega + 3\ \text{k}\Omega\ \angle -90° \parallel 6\ \text{k}\Omega\ \angle 90°$
$= 2\ \text{k}\Omega + 6\ \text{k}\Omega\ \angle -90°$
$= 2\ \text{k}\Omega - \textit{j}6\ \text{k}\Omega$
$= 6.325\ \text{k}\Omega\ \angle -71.565°$

$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{20\ \text{V}\ \angle 0°}{6.325\,\text{k}\Omega\ \angle -71.565°}$$
$$= 3.162\ \text{mA}\ \angle 71.565°$$
$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{Z}_2\mathbf{I}_s}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(3\,\text{k}\Omega\ \angle -90°)(3.162\,\text{mA}\ \angle 71.565°)}{-\textit{j}3\,\text{k}\Omega + \textit{j}6\,\text{k}\Omega}$$
$$= \frac{9.486\,\text{mA}\ \angle -18.435°}{3\ \angle 90°} = \mathbf{3.16\ mA\ \angle -108.44°}$$

27. a.

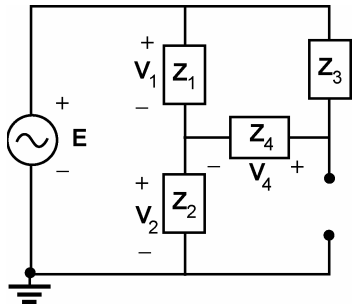


$\mathbf{Z}_1 = 20\ \Omega + \textit{j}20\ \Omega = 28.284\ \Omega\ \angle 45°$
$\mathbf{Z}_2 = 68\ \Omega\ \angle 0°$

$\leftarrow \mathbf{Z}_N = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= (28.284\ \Omega\ \angle 45°) \parallel (68\ \Omega\ \angle 0°)$
$= \mathbf{21.31\ \Omega\ \angle 32.2°}$

$\leftarrow \mathbf{I}_{sc} = \mathbf{I} = \mathbf{I}_N = 0.1\ \text{A}\ \angle 0°$

b.



$\mathbf{Z}_1 = 2\ \Omega\ \angle 0°$, $\mathbf{Z}_2 = 4\ \Omega\ \angle 90°$
$\mathbf{Z}_3 = 8\ \Omega\ \angle -90°$, $\mathbf{Z}_4 = 10\ \Omega\ \angle 0°$
$\mathbf{E} = 50\ \text{V}\ \angle 0°$

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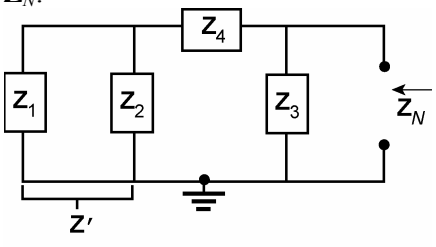
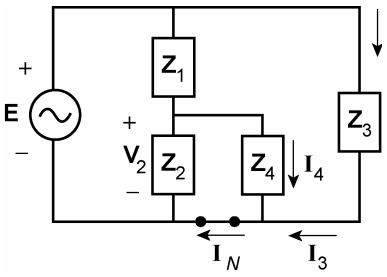
$\mathbf{Z}_N$:



$\mathbf{Z}' = \mathbf{Z}_1 \,||\, \mathbf{Z}_2 = 2\ \Omega\ \angle 0° \,||\, 4\ \Omega\ \angle 90°$
$= 1.789\ \Omega\ \angle 26.565° = 1.6\ \Omega + j0.8\ \Omega$
$\mathbf{Z}' + \mathbf{Z}_4 = 1.6\ \Omega + j0.8\ \Omega + 10\ \Omega = 11.6\ \Omega + j0.8\ \Omega = 11.628\ \Omega\ \angle 3.945°$
$\mathbf{Z}_N = \mathbf{Z}_3 \,||\, (\mathbf{Z}' + \mathbf{Z}_4) = (8\ \Omega\ \angle -90°) \,||\, (11.628\ \Omega\ \angle 3.945°) = \mathbf{6.81\ \Omega\ \angle -54.23°}$
$= \mathbf{3.98\ \Omega - j5.53\ \Omega}$

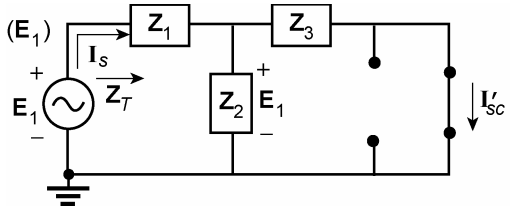


$$\mathbf{I}_3 = \frac{\mathbf{E}}{\mathbf{Z}_3} = \frac{50\ \text{V}\ \angle 0°}{8\ \Omega\ \angle -90°} = 6.250\ \text{A}\ \angle 90°$$
$\mathbf{Z}' = \mathbf{Z}_2 \,||\, \mathbf{Z}_4 = 4\ \Omega\ \angle 90° \,||\, 10\ \Omega\ \angle 0°$
$= 3.714\ \Omega\ \angle 68.2°$
$$\mathbf{V}_2 = \frac{\mathbf{Z}'\mathbf{E}}{\mathbf{Z}' + \mathbf{Z}_1} = \frac{(3.714\ \Omega\ \angle 68.2°)(50\ \text{V}\ \angle 0°)}{1.378\ \Omega + j3.448\ \Omega + 2\ \Omega}$$
$$= \frac{185.7\ \text{V}\ \angle 68.2°}{4.827\ \angle 45.588°} = 38.471\ \text{V}\ \angle 22.612°$$

$$\mathbf{I}_4 = \frac{\mathbf{V}_2}{\mathbf{Z}_4} = \frac{38.471\ \text{V}\ \angle 22.612°}{10\ \Omega\ \angle 0°} = 3.847\ \text{A}\ \angle 22.612°$$
$\mathbf{I}_N = \mathbf{I}_3 + \mathbf{I}_4 = 6.250\ \text{A}\ \angle 90° + 3.847\ \text{A}\ \angle 22.612°$
$= +j6.25\ \text{A} + 3.551\ \text{A} + j1.479\ \text{A} = 3.551\ \text{A} + j7.729\ \text{A}$
$= \mathbf{8.51\ A\ \angle 65.32°}$

28. a. From Problem 14(a): $\mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{5.00\ \Omega\ \angle -38.66°}$

$\mathbf{I}_N$: Superposition:



$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \,||\, \mathbf{Z}_3$
$= 10\ \Omega + 8\ \Omega\ \angle 90° \,||\, 8\ \Omega\ \angle -90°$
$$= 10\ \Omega + \frac{64\ \Omega\ \angle 0°}{0}$$
= very large impedance
$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = 0\ \text{A}$$
and $\mathbf{V}_{Z_1} = 0\ \text{V}$
with $\mathbf{V}_{Z_2} = \mathbf{V}_{Z_3} = \mathbf{E}_1 = 120\ \text{V}\ \angle 0°$
so that $$\mathbf{I}'_{sc} = \frac{\mathbf{E}_1}{\mathbf{Z}_3} = \frac{120\ \text{V}\ \angle 0°}{8\ \Omega\ \angle -90°}$$
$= 15\ \text{A}\ \angle 90°$

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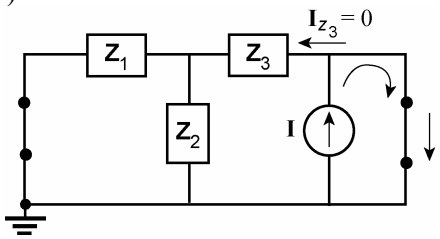
(I)

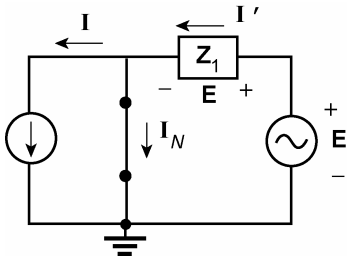


$\mathbf{I''}_{sc} = \mathbf{I} = 0.5\text{ A} \angle 60°$

$$\mathbf{I}_N = \mathbf{I'}_{sc} + \mathbf{I''}_{sc} = +j15\text{ A} + 0.5\text{ A} \angle 60° = +j15\text{ A} + 0.25\text{ A} + j0.433\text{ A}$$
$$= 0.25\text{ A} + j15.433\text{ A} = \mathbf{15.44\text{ A} \angle 89.07°}$$

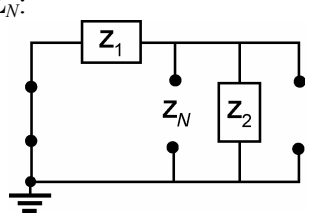
b. From Problem 14(b): $\mathbf{Z}_N = \mathbf{Z}_{Th} = 10\ \Omega - j10\ \Omega = \mathbf{14.14\ \Omega \angle -45°}$

$\mathbf{I}_N$:



$$\mathbf{I}_N = \mathbf{I}' - \mathbf{I}$$
$$= \frac{\mathbf{E}}{\mathbf{Z}} - \mathbf{I}$$
$$= \frac{20\text{ V} \angle 40°}{14.142\ \Omega \angle -45°} - 0.6\text{ A} \angle 90°$$
$$= 1.414\text{ A} \angle 85° - j0.6\text{ A}$$
$$= 0.123\text{ A} + j1.409\text{ A} - j0.6\text{ A}$$
$$= 0.123\text{ A} + j0.809\text{ A}$$
$$= \mathbf{0.82\text{ A} \angle 81.35°}$$

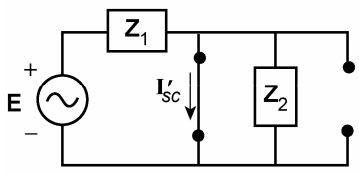
29. a. $\mathbf{Z}_N$:



$\mathbf{E} = 20\text{ V} \angle 0°$, $\mathbf{I}_2 = 0.4\text{ A} \angle 20°$
$\mathbf{Z}_1 = 6\ \Omega + j8\ \Omega = 10\ \Omega \angle 53.13°$
$\mathbf{Z}_2 = \Omega - j12\ \Omega = 15\ \Omega \angle -53.13°$
$\mathbf{Z}_N = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (10\ \Omega \angle 53.13°) \parallel (15\ \Omega \angle -53.13°)$
$= \mathbf{9.66\ \Omega \angle 14.93°}$

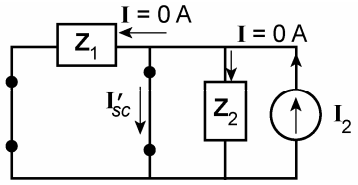
$\mathbf{I}_N$:

(E)



$\mathbf{I'}_{sc} = \mathbf{E}/\mathbf{Z}_1 = 20\text{ V} \angle 0°/10\ \Omega \angle 53.13°$
$= 2\text{ A} \angle -53.13°$

(I_2)



$\mathbf{I''}_{sc} = \mathbf{I}_2 = 0.4\text{ A} \angle 20°$

$\mathbf{I}_N = \mathbf{I'}_{sc} + \mathbf{I''}_{sc} = 2\text{ A} \angle -53.13° + 0.4\text{ A} \angle 20°$
$= \mathbf{2.15\text{ A} \angle -42.87°}$

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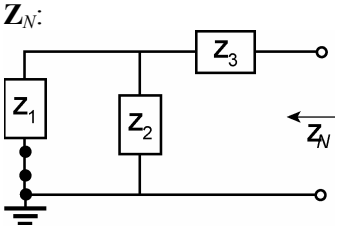
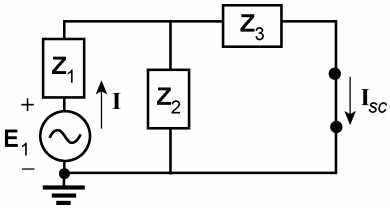
b. $\mathbf{Z}_N$:



$\mathbf{E}_1 = 120\ \text{V} \angle 30°$, $\mathbf{Z}_1 = 3\ \Omega \angle 0°$
$\mathbf{Z}_2 = 8\ \Omega - j8\ \Omega$, $\mathbf{Z}_3 = 4\ \Omega \angle 90°$

$$\mathbf{Z}_N = \mathbf{Z}_3 + \mathbf{Z}_1 \,||\, \mathbf{Z}_2$$
$$= 4\ \Omega \angle 90° + (3\ \Omega \angle 0°) \,||\, (8\ \Omega - j8\ \Omega)$$
$$= \mathbf{4.37\ \Omega \angle 55.67° = 2.47\ \Omega + j3.61\ \Omega}$$

$\mathbf{I}_N$:



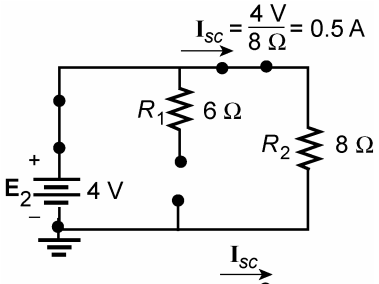
$$\mathbf{I} = \frac{\mathbf{E}_1}{\mathbf{Z}_T} = \frac{120\ \text{V} \angle 30°}{\mathbf{Z}_1 + \mathbf{Z}_2 \,||\, \mathbf{Z}_3}$$
$$= \frac{120\ \text{V} \angle 30°}{3\ \Omega + (8\ \Omega - j8\ \Omega) \,||\, 4\ \Omega \angle 90°}$$
$$= \frac{120\ \text{V} \angle 30°}{6.65\ \Omega \angle 46.22°}$$
$$= 18.05\ \text{A} \angle -16.22°$$

$$\mathbf{I}_{sc} = \mathbf{I}_N = \frac{\mathbf{Z}_2(\mathbf{I})}{\mathbf{Z}_2 + \mathbf{Z}_3} = \frac{(8\ \Omega - j8\ \Omega)(18.05\ \text{A} \angle -16.22°)}{8\ \Omega - j8\ \Omega + j4\ \Omega} = \mathbf{22.83\ A \angle -34.65°}$$

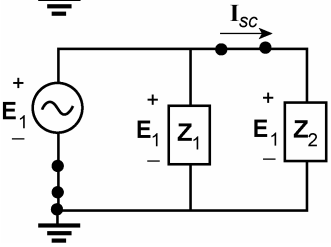
30. a. $\mathbf{Z}_N = 8\ \Omega \angle \mathbf{0°}$

$\mathbf{I}_N$:

DC



AC



$\mathbf{Z}_1 = 6\ \Omega - j2\ \Omega$
$\mathbf{Z}_2 = 8\ \Omega \angle 0°$

$$\mathbf{I}_{sc} = \frac{\mathbf{E}_1}{\mathbf{Z}_2} = \frac{10\ \text{V} \angle 0°}{8\ \Omega \angle 0°} = 1.25\ \text{A} \angle 0°$$
$$\mathbf{I}_N = 0.5\ \text{A} + 1.25\ \text{A} \angle 0°$$

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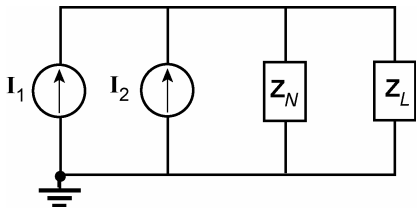
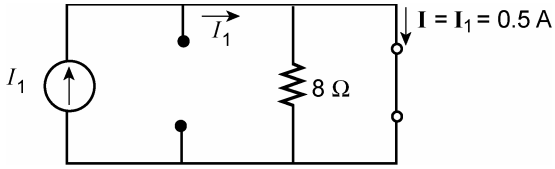
b.



$\mathbf{Z}_N = 8\ \Omega\ \angle 0°$
$\mathbf{Z}_L = 4\ \Omega\ \angle 90°$

DC:



AC:

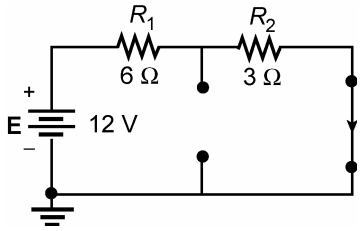
$$\mathbf{I} = \frac{\mathbf{Z}_N(\mathbf{I}_2)}{\mathbf{Z}_N + \mathbf{Z}_L} = \frac{(8\,\Omega\angle 0°)(1.25\text{ A}\angle 0°)}{8\,\Omega + j4\,\Omega} = \mathbf{1.118\ A\ \angle -26.57°}$$

$I_{8\Omega} = 0.5\text{ A} + 1.118\text{ A}\angle -26.57°$
(dc) (ac)

$i = \mathbf{0.5 + 1.58\sin(\omega t - 26.57°)}$

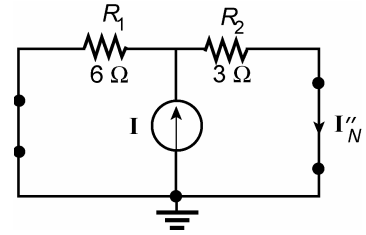
31. a. From #16 $\mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{9\ \Omega\ \angle 0°}$

DC:



$$\mathbf{I'}_N = \frac{E}{R_T} = \frac{12\text{ V}}{9\,\Omega} = 1.33\text{ A}$$

AC:



$$\mathbf{I''}_N = \frac{R_1\mathbf{I}}{R_1 + R_2} = \frac{(6\,\Omega\angle 0°)(4\text{ A}\angle 0°)}{9\,\Omega\angle 0°}$$

$$= \frac{24\text{ V}\angle 0°}{9\,\Omega\angle 0°} = 2.67\text{ A}\angle 0°$$

$\mathbf{I}_N = \mathbf{1.33\ A + 2.67\ A\ \angle 0°}$

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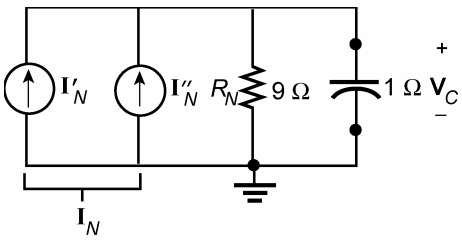
b.



DC: $V_C = IR$
$= (1.33\text{ A})(9\ \Omega)$
$= 12\text{ V}$

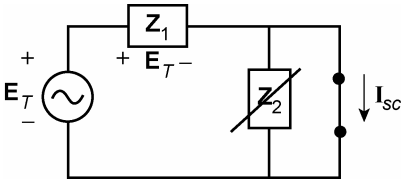
AC: $\mathbf{Z}' = 9\ \Omega\ \angle 0° \parallel 1\ \Omega\ \angle -90°$
$= 0.994\ \Omega\ \angle -83.66°$

$\mathbf{V}_C = \mathbf{I}\mathbf{Z}' = (2.667\text{ A}\ \angle 0°)(0.994\ \Omega\ \angle -83.66°)$
$= 2.65\text{ V}\ \angle -83.66°$
$V_C = \mathbf{12\text{ V} + 2.65\text{ V}\ \angle -83.66°}$

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 $\mathbf{E}_T = \mathbf{E}_1 + \mathbf{E} = 50\text{ V}\ \angle 0° + 20\text{ V}\ \angle 0° = 70\text{ V}\ \angle 0°$



$\mathbf{Z}_1 = 10\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\ \text{k}\Omega - j5\ \text{k}\Omega = 7.071\ \text{k}\Omega\ \angle -45°$

$$\mathbf{I}_{sc} = \frac{\mathbf{E}_T}{\mathbf{Z}_1} = \frac{70\text{ V}\ \angle 0°}{10\text{ k}\Omega\ \angle 0°} = 7\text{ mA}\ \angle 0°$$

$\mathbf{I}_N = \mathbf{I}_{sc} = \mathbf{7\text{ mA}\ \angle 0°}$

b. $$\mathbf{I} = \frac{\mathbf{Z}_N(\mathbf{I}_N)}{\mathbf{Z}_N + \mathbf{Z}_L} = \frac{(4.472\text{ k}\Omega\ \angle -26.565°)(7\text{ mA}\ \angle 0°)}{4.472\text{ k}\Omega\ \angle -26.565° + 5\text{ k}\Omega\ \angle 90°}$$
$$= \frac{31.30\text{ mA}\ \angle -26.565°}{4 - j2 + j5} = \frac{31.30\text{ mA}\ \angle -26.565°}{4 + j3}$$
$$= \frac{31.30\text{ mA}\ \angle -26.565°}{5\ \angle 36.87°} = \mathbf{6.26\text{ mA}\ \angle 63.44°}$$ as obtained in Problem 17.

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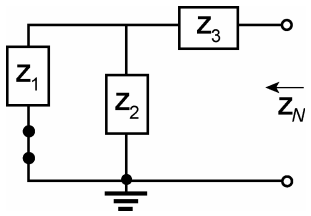
33.

$\mathbf{Z}_N$:



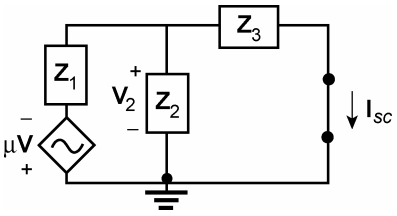
$\mathbf{Z}_1 = 10\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 10\ \text{k}\Omega\ \angle 0$

$\mathbf{Z}_3 = -j1\ \text{k}\Omega$

$\mathbf{Z}_N = \mathbf{Z}_3 + \mathbf{Z}_1 \parallel \mathbf{Z}_2 = 5\ \text{k}\Omega - j1\ \text{k}\Omega$

$= \mathbf{5.1\ k\Omega\ \angle -11.31°}$

$\mathbf{I}_N$:



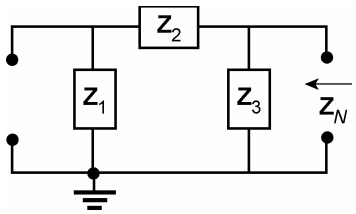
$$\mathbf{V}_2 = \frac{-(\mathbf{Z}_2 \parallel \mathbf{Z}_3)20\ \text{V}}{(\mathbf{Z}_2 \parallel \mathbf{Z}_3) + \mathbf{Z}_1}$$

$$= \frac{-(0.995\ \text{k}\Omega\ \angle -84.29°)(20\ \text{V})}{0.1\ \text{k}\Omega - j0.99\ \text{k}\Omega + 10\ \text{k}\Omega}$$

$$\text{V}_2 = -1.961\ \text{V}\ \angle -78.69°$$

$$\mathbf{I}_N = \mathbf{I}_{sc} = \frac{\mathbf{V}_2}{\mathbf{Z}_3} = \frac{-1.961\ \text{V}\ \angle -78.69°}{1\ \text{k}\Omega\ \angle -90°} = \mathbf{-1.96 \times 10^{-3}\ V\ \angle 11.31°}$$

34. $\mathbf{Z}_N$:



$\mathbf{Z}_1 = 40\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 0.2\ \text{k}\Omega\ \angle -90°$

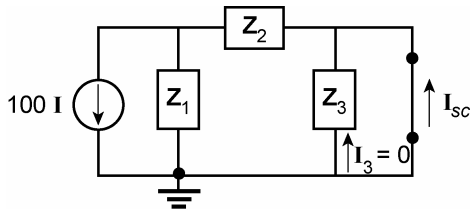
$\mathbf{Z}_3 = 5\ \text{k}\Omega\ \angle 0°$

$\mathbf{Z}_N = \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2)$

$= 5\ \text{k}\Omega\ \angle 0° \parallel (40\ \text{k}\Omega - j0.2\ \text{k}\Omega)$

$= \mathbf{4.44\ k\Omega\ \angle -0.03°}$

$\mathbf{I}_N$:



$$\mathbf{I}_N = \mathbf{I}_{sc} = \frac{\mathbf{Z}_1(100\,\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2}$$

$$= \frac{(40\ \text{k}\Omega\ \angle 0°)(100\,\mathbf{I})}{40\ \text{k}\Omega\ \angle -0.286°}$$

$= \mathbf{100\ I\ \angle 0.29°}$

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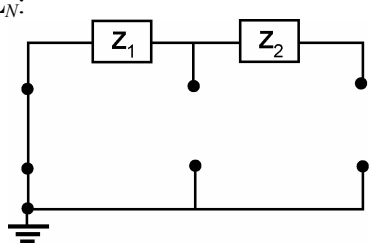
35. $\mathbf{Z}_N$:



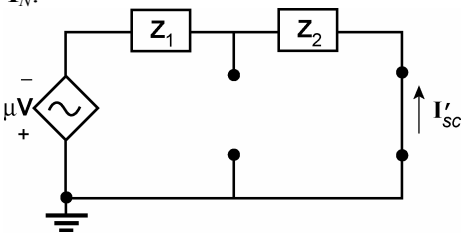
$\mathbf{Z}_1 = 5\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 1\ \text{k}\Omega\ \angle -90°$

$\leftarrow \mathbf{Z}_N = \mathbf{Z}_1 + \mathbf{Z}_2 = 5\ \text{k}\Omega - j1\ \text{k}\Omega$

$= \mathbf{5.1\ k\Omega\ \angle -11.31°}$

.

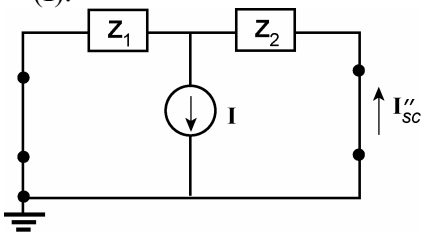
$\mathbf{I}_N$:



$$\mathbf{I}'_{sc} = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(2\ \text{V}\ \angle 0°)}{5.1\,\text{k}\Omega\ \angle -11.31°}$$

$= 7.843\ \text{mA}\ \angle 11.31°$

(**I**):



$$\mathbf{I}''_{sc} = \frac{\mathbf{Z}_1(\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2}$$

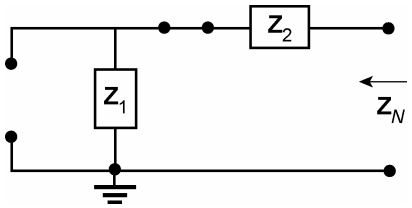
$$= \frac{(5\ \text{k}\Omega\ \angle 0°)(2\ \text{mA}\ \angle 0°)}{5.1\,\text{k}\Omega\ \angle -11.31°}$$

$= 1.96\ \text{mA}\ \angle 11.31°$

$\mathbf{I}_N = \mathbf{I}'_{sc} + \mathbf{I}''_{sc} = 7.843\ \text{mA}\ \angle 11.31° + 1.96\ \text{mA}\ \angle 11.31°$

$= \mathbf{9.81\ mA\ \angle 11.31°}$

36. $\mathbf{Z}_N$:



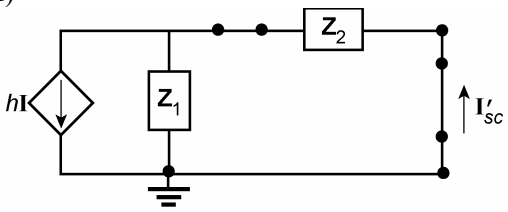
$\mathbf{Z}_1 = 20\ \text{k}\Omega\ \angle 0°$, $\mathbf{Z}_2 = 5\ \text{k}\Omega\ \angle 0°$

$\mathbf{V} = 10\ \text{V}\ \angle 0°$, $\mu = 20$, $h = 100$

$\mathbf{I} = 1\ \text{mA}\ \angle 0°$

$\mathbf{Z}_N = \mathbf{Z}_1 + \mathbf{Z}_2 = \mathbf{25\ k\Omega\ \angle 0°}$

$\mathbf{I}_N$: ($h\mathbf{I}$)

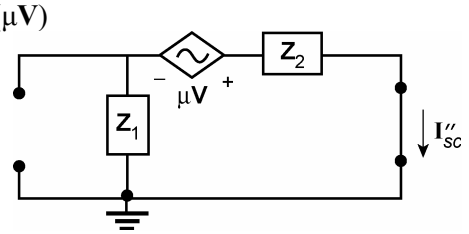


$$\mathbf{I}'_{sc} = \frac{\mathbf{Z}_1(h\mathbf{I})}{\mathbf{Z}_1 + \mathbf{Z}_2}$$

$$= \frac{(20\,\text{k}\Omega\ \angle 0°)(h\mathbf{I})}{20\,\text{k}\Omega\ \angle 0° + 5\,\text{k}\Omega\angle 0°}$$

$= 80\ \text{mA}\ \angle 0°$

($\mu\mathbf{V}$)



$$\mathbf{I}''_{sc} = \frac{\mu\mathbf{V}}{\mathbf{Z}_1 + \mathbf{Z}_2} = \frac{(20)(10\ \text{V}\ \angle 0°)}{25\,\text{k}\Omega}$$

$= 8\ \text{mA}\ \angle 0°$

$\mathbf{I}_N$ (direction of $\mathbf{I}'_{sc}$) = $\mathbf{I}'_{sc} - \mathbf{I}''_{sc} = 80\ \text{mA}\ \angle 0° - 8\ \text{mA}\ \angle 0° = \mathbf{72\ mA\ \angle 0°}$

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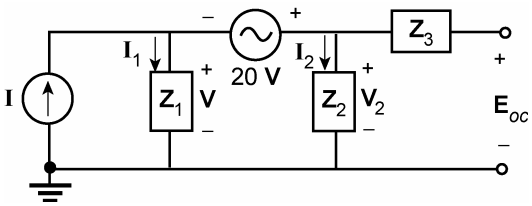
37.



$\mathbf{Z}_1 = 1\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 3\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_3 = 4\ \text{k}\Omega\ \angle 0°$

$$\mathbf{V}_2 = 21\ \mathbf{V} = \mathbf{E}_{oc} \Rightarrow \mathbf{V} = \frac{\mathbf{E}_{oc}}{21}$$

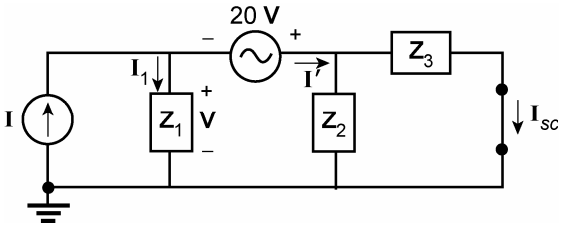
$$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2,\ \mathbf{I}_1 = \frac{\mathbf{V}}{\mathbf{Z}_1} = \frac{\mathbf{E}_{oc}}{21\,\mathbf{Z}_1}$$

$$\mathbf{I}_2 = \frac{\mathbf{E}_{oc}}{\mathbf{Z}_2},\ \mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2 = \frac{\mathbf{E}_{oc}}{21\,\mathbf{Z}_1} + \frac{\mathbf{E}_{oc}}{\mathbf{Z}_2} = \mathbf{E}_{oc}\left[\frac{1}{21\,\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2}\right]$$

$$\mathbf{I} = \mathbf{E}_{oc}\left[\frac{\mathbf{Z}_2 + 21\,\mathbf{Z}_1}{21\,\mathbf{Z}_1\mathbf{Z}_2}\right]$$

and $$\mathbf{E}_{oc} = \frac{21\,\mathbf{Z}_1\mathbf{Z}_2\mathbf{I}}{\mathbf{Z}_2 + 21\mathbf{Z}_1} = \frac{(21)(1\,\text{k}\Omega\ \angle 0°)(3\,\text{k}\Omega\ \angle 0°)(2\ \text{mA}\ \angle 0°)}{3\,\text{k}\Omega + 21(1\,\text{k}\Omega\ \angle 0°)}$$

$$\mathbf{E}_{Th} = \mathbf{E}_{oc} = 5.25\ \text{V}\ \angle \mathbf{0°}$$



$$\mathbf{I}_{sc} = \frac{\mathbf{V}_3}{\mathbf{Z}_3} = \frac{21\,\mathbf{V}}{\mathbf{Z}_3} \Rightarrow \mathbf{V} = \frac{\mathbf{Z}_3}{21}\,\mathbf{I}_{sc}$$

$\mathbf{V} = \mathbf{I}_1\mathbf{Z}_1$
$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}'$

$$\mathbf{I}_{sc} = \frac{\mathbf{Z}_2\mathbf{I}'}{\mathbf{Z}_2 + \mathbf{Z}_3} \Rightarrow \mathbf{I}' = \left(\frac{\mathbf{Z}_2 + \mathbf{Z}_3}{\mathbf{Z}_2}\right)\mathbf{I}_{sc}$$

$$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}' = \frac{\mathbf{V}}{\mathbf{Z}_1} + \left(\frac{\mathbf{Z}_2 + \mathbf{Z}_3}{\mathbf{Z}_2}\right)\mathbf{I}_{sc} = \left[\frac{\mathbf{Z}_3}{21\,\mathbf{Z}_1} + \frac{\mathbf{Z}_2 + \mathbf{Z}_3}{\mathbf{Z}_2}\right]\mathbf{I}_{sc}$$

$$\mathbf{I}_{sc} = \frac{\mathbf{I}}{\dfrac{\mathbf{Z}_3}{21\,\mathbf{Z}_1} + \dfrac{\mathbf{Z}_3 + \mathbf{Z}_2}{\mathbf{Z}_2}} = \frac{2\ \text{mA}\ \angle 0°}{\dfrac{4\,\text{k}\Omega}{21\,\text{k}\Omega} + \dfrac{7\,\text{k}\Omega}{3\,\text{k}\Omega}} = 0.79\ \text{mA}\ \angle 0°$$

$\therefore$ $\mathbf{I}_N = \mathbf{0.79\ mA\ \angle 0°}$

$$\mathbf{Z}_N = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{5.25\ \text{V}\ \angle 0°}{0.79\ \text{mA}\ \angle 0°} = \mathbf{6.65\ k\Omega\ \angle 0°}$$

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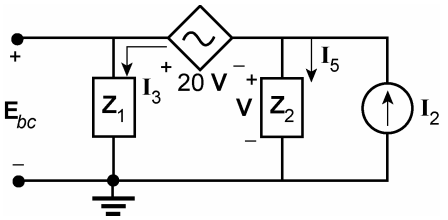
38.



$\mathbf{Z}_1 = 2\ \text{k}\Omega\ \angle 0°$
$\mathbf{Z}_2 = 5\ \text{k}\Omega\ \angle 0°$

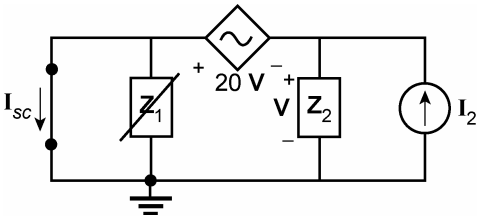
$\mathbf{I}_2 = \mathbf{I}_3 + \mathbf{I}_5$
$\mathbf{V} = \mathbf{I}_5\mathbf{Z}_2 = (\mathbf{I}_2 - \mathbf{I}_3)\mathbf{Z}_2$
$\mathbf{E}_{oc} = \mathbf{E}_{Th} = 21\ \mathbf{V} = 21(\mathbf{I}_2 - \mathbf{I}_3)\mathbf{Z}_2$

$$= 21\left(\mathbf{I}_2 - \frac{\mathbf{E}_{oc}}{\mathbf{Z}_1}\right)\mathbf{Z}_2$$

$$\mathbf{E}_{oc}\left[1 + 21\frac{\mathbf{Z}_2}{\mathbf{Z}_1}\right] = 21\ \mathbf{Z}_2\mathbf{I}_2$$

$$\mathbf{E}_{oc} = \frac{21\,\mathbf{Z}_2\mathbf{I}_2}{1 + 21\dfrac{\mathbf{Z}_2}{\mathbf{Z}_1}} = \frac{21(5\,\text{k}\Omega\ \angle 0°)(2\,\text{mA}\ \angle 0°)}{1 + 21\left(\dfrac{5\,\text{k}\Omega\ \angle 0°}{2\,\text{k}\Omega\ \angle 0°}\right)}$$

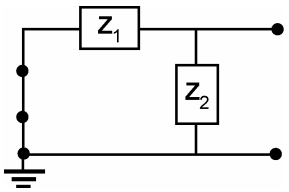
$\mathbf{E}_{Th} = \mathbf{E}_{oc} = 3.925\ \text{V}\ \angle 0°$



$20\ \mathbf{V} \neq -\mathbf{V}\ \therefore\ \mathbf{V} = 0$
and $\mathbf{I}_N = \mathbf{I}_{sc} = \mathbf{I}_2 = \mathbf{2\ mA\ \angle 0°}$

$$\mathbf{Z}_N = \frac{\mathbf{E}_{oc}}{\mathbf{I}_{sc}} = \frac{3.925\,\text{V}\ \angle 0°}{2\,\text{mA}\ \angle 0°} = \mathbf{1.96\ k\Omega}$$

39. a.



$\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega$, $\mathbf{Z}_2 = -j6\ \Omega$
$\leftarrow \mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= 5\ \Omega\ \angle 53.13° \parallel 6\ \Omega\ \angle -90°$
$= 8.32\ \Omega\ \angle -3.18°$
$\mathbf{Z}_L = \mathbf{8.32\ \Omega\ \angle 3.18°} = \mathbf{8.31\ \Omega - j0.46\ \Omega}$

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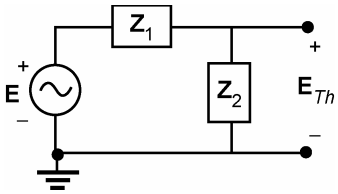
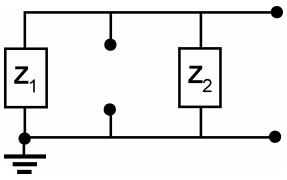
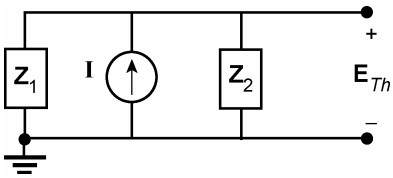


$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_2\mathbf{E}}{\mathbf{Z}_2 + \mathbf{Z}_1}$$
$$= \frac{(6\,\Omega \angle -90°)(120\text{ V} \angle 0°)}{3.61\,\Omega \angle -33.69°}$$
$$= \mathbf{199.45\text{ V} \angle -56.31°}$$
$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(3.124\text{ V})^2}{4(8.31\,\Omega)} = \mathbf{1198.2\text{ W}}$$

b.

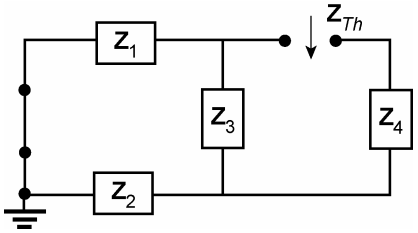


$\mathbf{Z}_1 = 3\ \Omega + j4\ \Omega = 5\ \Omega \angle 53.13°$
$\mathbf{Z}_2 = 2\ \Omega \angle 0°$
$\leftarrow \mathbf{Z}_N = \mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2$
$= 5\ \Omega \angle 53.13° \parallel 2\ \Omega \angle 0°$
$$= \frac{10\,\Omega \angle 53.13°}{2 + 3 + j4}$$
$$= \frac{10\ \Omega \angle 53.13°}{5 + j4}$$
$$= \frac{10\ \Omega \angle 53.13°}{6.403 \angle 38.66°}$$
$= \mathbf{1.56\ \Omega \angle 14.47°}$
$\mathbf{Z}_{Th} = 1.56\ \Omega \angle 14.47°$
$= 1.51\ \Omega + j0.39\ \Omega$
$\mathbf{Z}_L = \mathbf{1.51\ \Omega - j0.39\ \Omega}$



$\mathbf{E}_{Th} = \mathbf{I}(\mathbf{Z}_1 \parallel \mathbf{Z}_2)$
$= (2\text{ A} \angle 30°)(1.562\ \Omega \angle 14.47°)$
$= \mathbf{3.12\text{ V} \angle 44.47°}$
$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(3.12\text{ V})^2}{4(1.51\,\Omega)} = \mathbf{1.61\text{ W}}$$

40. a. $\mathbf{Z}_{Th}$:



$\mathbf{Z}_1 = 4\ \Omega \angle 90°$, $\mathbf{Z}_2 = 10\ \Omega \angle 0°$
$\mathbf{Z}_3 = 5\ \Omega \angle -90°$, $\mathbf{Z}_4 = 6\ \Omega \angle -90°$
$\mathbf{E} = 60\text{ V} \angle 60°$

$\mathbf{Z}_{Th} = \mathbf{Z}_4 + \mathbf{Z}_3 \parallel (\mathbf{Z}_1 + \mathbf{Z}_2) = -j6\ \Omega + (5\ \Omega \angle -90°) \parallel (10\ \Omega + j4\ \Omega)$
$= 2.475\ \Omega - j4.754\ \Omega$
$= 11.04\ \Omega \angle -77.03°$
$\mathbf{Z}_L = \mathbf{11.04\ \Omega \angle 77.03°}$

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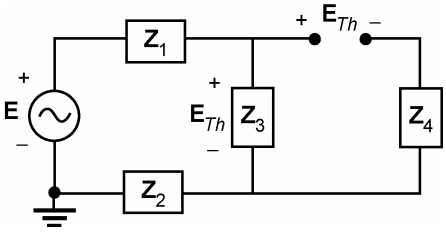
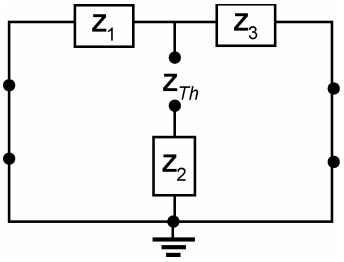
$\mathbf{E}_{Th}$:



$$\mathbf{E}_{Th} = \frac{\mathbf{Z}_3(\mathbf{E})}{\mathbf{Z}_3 + \mathbf{Z}_1 + \mathbf{Z}_2}$$
$$= \frac{(5\,\Omega \angle -90°)(60\text{ V} \angle 60°)}{-j5\,\Omega + j4\,\Omega + 10\,\Omega}$$
$$= \mathbf{29.85\text{ V} \angle -24.29°}$$

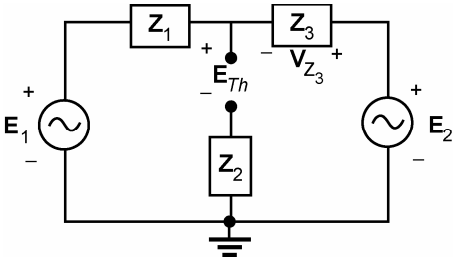
$$P_{\max} = E_{Th}^2/4R_{Th} = (29.85\text{ V})^2/4(2.475\,\Omega) = \mathbf{90\text{ W}}$$

b.



$\mathbf{Z}_1 = 3\,\Omega + j4\,\Omega = 5\,\Omega \angle 53.13°$
$\mathbf{Z}_2 = -j8\,\Omega$
$\mathbf{Z}_3 = 12\,\Omega + j9\,\Omega$

$\mathbf{Z}_{Th} = \mathbf{Z}_2 + \mathbf{Z}_1 \parallel \mathbf{Z}_3 = -j8\,\Omega + (5\,\Omega \angle 53.13°) \parallel (15\,\Omega \angle 36.87°)$
$= 5.71\,\Omega \angle -64.30° = 2.475\,\Omega - j5.143\,\Omega$
$\mathbf{Z}_L = \mathbf{5.71\,\Omega \angle 64.30° = 2.48\,\Omega + j5.15\,\Omega}$



$$\mathbf{E}_{Th} + \mathbf{V}_{Z_3} - \mathbf{E}_2 = 0$$
$$\mathbf{E}_{Th} = \mathbf{E}_2 - \mathbf{V}_{Z_3}$$
$$\mathbf{V}_{Z_3} = \frac{\mathbf{Z}_3(\mathbf{E}_2 - \mathbf{E}_1)}{\mathbf{Z}_3 + \mathbf{Z}_1}$$
$$= 168.97\text{ V} \angle 112.53°$$

$\mathbf{E}_{Th} = \mathbf{E}_2 - \mathbf{V}_{Z_3} = 200\text{ V} \angle 90° - 168.97\text{ V} \angle 112.53° = \mathbf{78.24\text{ V} \angle 34.16°}$
$P_{\max} = E_{Th}^2/4R_{Th} = (78.24\text{ V})^2/4(2.475\,\Omega) = \mathbf{618.33\text{ W}}$

41. $\mathbf{I} = \dfrac{E\angle 0°}{R_1\angle 0°} = \dfrac{1\text{ V} \angle 0°}{1\,\text{k}\Omega \angle 0°} = 1\text{ mA} \angle 0°$

$\mathbf{Z}_{Th} = 40\,\text{k}\Omega \angle 0°$
$\mathbf{E}_{Th} = (50\,\mathbf{I})(40\,\text{k}\Omega \angle 0°) = (50)(1\text{ mA} \angle 0°)(40\,\text{k}\Omega \angle 0°) = 2000\text{ V} \angle 0°$

$$P_{\max} = \frac{E_{Th}^2}{4R_{Th}} = \frac{(2\,\text{kV})^2}{4(40\,\text{k}\Omega)} = \mathbf{25\text{ W}}$$

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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):

$\mathbf{Z}_{Th} = 4.47\text{ k}\Omega\ \angle -26.57° = 4\text{ k}\Omega - j2\text{ k}\Omega$

$\mathbf{Z}_L = \mathbf{4\ k\Omega + j2\ k\Omega}$

$\mathbf{E}_{Th} = \mathbf{31.31\ V\ \angle -26.57°}$

b. $P_{\max} = E_{Th}^2/4R_{Th} = (31.31\text{ V})^2/4(4\text{ k}\Omega) = \mathbf{61.27\ mW}$

45. a. $\mathbf{Z}_{Th} = 2\text{ k}\Omega\ \angle 0° \parallel 2\text{ k}\Omega\ \angle -90° = 1\text{ k}\Omega - j1\text{ k}\Omega$

$$R_L = \sqrt{R_{Th}^2 + \left(X_{Th} + X_{\text{Load}}\right)^2}$$
$$= \sqrt{(1\text{ k}\Omega)^2 + (-1\text{ k}\Omega + 2\text{ k}\Omega)^2}$$
$$= \sqrt{(1\text{ k}\Omega)^2 + (1\text{ k}\Omega)^2}$$
$$= \mathbf{1.41\ k\Omega}$$

b. $R_{\text{av}} = (R_{Th} + R_{\text{Load}})/2 = (1\text{ k}\Omega + 1.41\text{ k}\Omega)/2 = 1.21\text{ k}\Omega$

$P_{\max} = \dfrac{E_{Th}^2}{4R_{\text{av}}} = \dfrac{(50\text{ V})^2}{4(1.21\text{ k}\Omega)} = \mathbf{516.53\ mW}$

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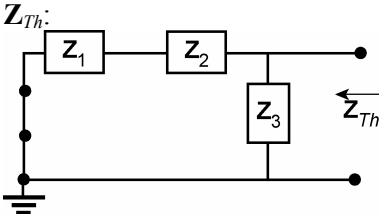
46. **a.** $\mathbf{Z}_{Th}$:



$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10\text{ kHz})(4\text{ nF})}$$
$$\cong 3978.87\ \Omega$$
$$X_L = 2\pi fL = 2\pi(10\text{ kHz})(30\text{ mH})$$
$$\cong 1884.96\ \Omega$$
$$\mathbf{Z}_1 = 1\text{ k}\Omega\ \angle 0°,\ \mathbf{Z}_2 = 1884.96\ \Omega\ \angle 90°$$
$$\mathbf{Z}_3 = 3978.87\ \Omega\ \angle -90°$$

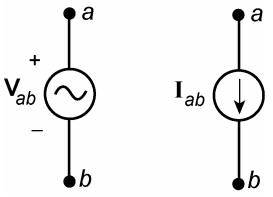
$$\mathbf{Z}_{Th} = (\mathbf{Z}_1 + \mathbf{Z}_2) \parallel \mathbf{Z}_3 = (1\text{ k}\Omega + j1884.96\ \Omega) \parallel 3978.87\ \Omega\ \angle -90°)$$
$$= 2133.79\ \Omega\ \angle 62.05° \parallel 3978.87\ \Omega\ \angle -90°)$$
$$= 3658.65\ \Omega\ \angle 36.52°$$

$$\therefore\quad \mathbf{Z}_L = \mathbf{3658.65\ \Omega\ \angle -36.52° = 2940.27\ \Omega - j2177.27\ \Omega}$$
$$C = \frac{1}{2\pi fX_C} = \frac{1}{2\pi(10\text{ kHz})(2177.27\ \Omega)} = \mathbf{7.31\ nF}$$

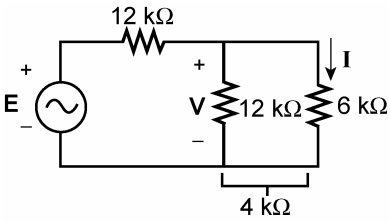
b. $R_L = R_{Th} = \mathbf{2940.27\ \Omega}$

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. $$\mathbf{I}_{ab} = \frac{(4\text{ k}\Omega\ \angle 0°)(4\text{ mA}\ \angle 0°)}{4\text{ k}\Omega + 8\text{ k}\Omega} = \mathbf{1.33\ mA\ \angle 0°}$$
$$\mathbf{V}_{ab} = (\mathbf{I}_{ab})(8\text{ k}\Omega\ \angle 0°) = \mathbf{10.67\ V\ \angle 0°}$$

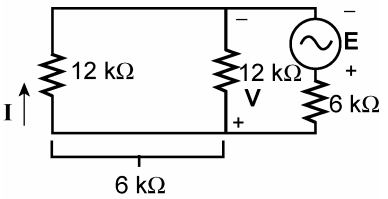


48. a.



$$\mathbf{V} = \frac{4\text{ k}\Omega(\mathbf{E})}{4\text{ k}\Omega + 12\text{ k}\Omega} = \frac{1}{4}(20\text{ V}\ \angle 0°)$$
$$= 5\text{ V}\ \angle 0°$$
$$\mathbf{I} = \frac{5\text{ V}\ \angle 0°}{6\text{ k}\Omega} = \mathbf{0.83\ mA\ \angle 0°}$$

b.



$$\mathbf{V} = \frac{6\text{ k}\Omega(\mathbf{E})}{6\text{ k}\Omega + 6\text{ k}\Omega} = \frac{1}{2}(20\text{ V}\ \angle 0°)$$
$$= 10\text{ V}\ \angle 0°$$
$$\mathbf{I} = \frac{10\text{ V}\ \angle 0°}{12\text{ k}\Omega} = \mathbf{0.83\ mA\ \angle 0°}$$

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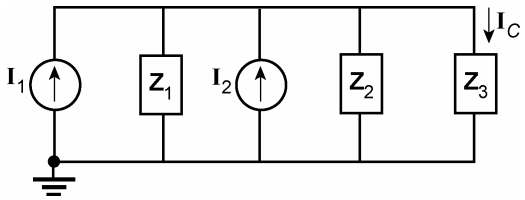
49.



$$\mathbf{I}_1 = \frac{100\text{ V}\angle 0°}{2\text{ k}\Omega\angle 0°} = 50\text{ mA}\angle 0°$$

$$\mathbf{I}_2 = \frac{50\text{ V}\angle 0°}{4\text{ k}\Omega\angle 90°}$$

$$= 12.5\text{ mA}\angle -90°$$

$\mathbf{Z}_1 = 2\text{ k}\Omega\angle 0°$

$\mathbf{Z}_2 = 4\text{ k}\Omega\angle 90°$

$\mathbf{Z}_3 = 4\text{ k}\Omega\angle -90°$

$\mathbf{I}_T = \mathbf{I}_1 - \mathbf{I}_2 = (50\text{ mA}\angle 0° - 12.5\text{ mA}\angle -90°) = 50\text{ mA} + j12.5\text{ mA}$

$= 51.54\text{ mA}\angle 14.04°$

$\mathbf{Z}' = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = (2\text{ k}\Omega\angle 0°) \parallel (4\text{ k}\Omega\angle 90°) = 1.79\text{ k}\Omega\angle 26.57°$

$$\mathbf{I}_C = \frac{\mathbf{Z}'\mathbf{I}_T}{\mathbf{Z}' + \mathbf{Z}_3} = \frac{(1.79\text{ k}\Omega\angle 26.57°)(51.54\text{ mA}\angle 14.04°)}{1.6\text{ k}\Omega + j0.8\text{ k}\Omega - j4\text{ k}\Omega}$$

$$= \mathbf{25.77\text{ mA}\angle 104.04°}$$

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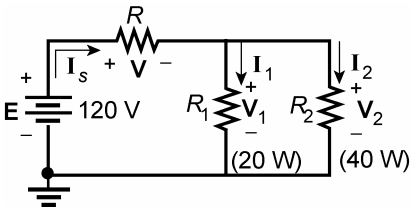
Chapter 19

1. a. $P_T = 60\text{ W} + 20\text{ W} + 40\text{ W} = \mathbf{120\ W}$

   b. $Q_T = \mathbf{0\ VARS}$, $S_T = P_T = \mathbf{120\ VA}$

   c. $S_T = EI_s, \quad I_s = \dfrac{S_T}{E} = \dfrac{120\text{ VA}}{240\text{ V}} = \mathbf{0.5\ A}$

   d. 

$$P = I_s^2 R,\ R = \frac{P}{I_s^2} = \frac{60\text{ W}}{(0.5\text{ A})^2} = 240\ \Omega$$

$$V = I_s R = (0.5\text{ A})(240\ \Omega) = 120\text{ V}$$

$$V_1 = V_2 = E - V = 240\text{ V} - 120\text{ V} = 120\text{ V}$$

$$P_1 = \frac{V_1^2}{R_1},\ R_1 = \frac{V_1^2}{P_1} = \frac{(120\text{ V})^2}{20\text{ W}} = \mathbf{720\ \Omega}$$

$$P_2 = \frac{V_2^2}{R_2},\ R_2 = \frac{V_2^2}{P_2} = \frac{(120\text{ V})^2}{40\text{ W}} = \mathbf{360\ \Omega}$$

   e. $I_1 = \dfrac{V_1}{R_1} = \dfrac{120\text{ V}}{720\ \Omega} = \mathbf{0.17\ A}$, $I_2 = \dfrac{V_2}{R_2} = \dfrac{120\text{ V}}{360\ \Omega} = \mathbf{0.33\ A}$

2. a. $\mathbf{Z}_T = 3\ \Omega - j5\ \Omega + j9\ \Omega = 3\ \Omega + j4\ \Omega = 5\ \Omega\ \angle 53.13°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50\text{ V}\ \angle 0°}{5\ \Omega\ \angle 53.13°} = 10\text{ A}\ \angle -53.13°$$

   R: $P = I^2R = (10\text{ A})^2\ 3\ \Omega = \mathbf{300\ W}$
   L: $P = \mathbf{0\ W}$
   C: $P = \mathbf{0\ W}$

   b. *R*: $Q = \mathbf{0\ VAR}$
   C: $Q_C = I^2X_C = (10\text{ A})^2\ 5\ \Omega = \mathbf{500\ VAR}$
   L: $Q_L = I^2X_L = (10\text{ A})^2\ 9\ \Omega = \mathbf{900\ VAR}$

   c. *R*: $S = \mathbf{300\ VA}$
   C: $S = \mathbf{500\ VA}$
   L: $S = \mathbf{900\ VA}$

   d. $P_T = 300\text{ W}$
   $Q_T = Q_L - Q_C = \mathbf{400\ VAR(}\boldsymbol{L}\mathbf{)}$
   $S_T = \sqrt{P_T^2 + Q_T^2} = EI = (50\text{ V})(10\text{ A}) = \mathbf{500\ VA}$
   $F_p = \dfrac{P_T}{S_T} = \dfrac{300\text{ W}}{500\text{ VA}} = \mathbf{0.6\ lagging}$

   e. –

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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. $P_T = 0 + 100\text{ W} + 300\text{ W} = \mathbf{400\ W}$

$Q_T = 200\text{ VAR}(L) - 600\text{ VAR}(C) + 0 = \mathbf{-400\ VAR(}\boldsymbol{C}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{565.69\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{400\text{ W}}{565.69\text{ VA}} = \mathbf{0.707\ (leading)}$

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. $P_T = 600\text{ W} + 500\text{ W} + 100\text{ W} = \mathbf{1200\ W}$

$Q_T = 1200\text{ VAR}(L) + 600\text{ VAR}(L) - 600\text{ VAR}(C) = \mathbf{1200\ VAR(}\boldsymbol{L}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \sqrt{(1200\text{ W})^2 + (1200\text{ VAR})^2} = \mathbf{1697\ VA}$

b. $F_p = \dfrac{P_T}{S_T} = \dfrac{1200\text{ W}}{1697\text{ VA}} = \mathbf{0.7071\ (lagging)}$

c. –

d. $I_s = \dfrac{S_T}{E} = \dfrac{1697\text{ VA}}{200\text{ V}} = 8.485\text{ A}, 0.7071 \Rightarrow 45°\text{ (lagging)}$

$\mathbf{I}_s = \mathbf{8.49\ A} \angle \mathbf{-45°}$

5. a. $P_T = 200\text{ W} + 200\text{ W} + 0 + 100\text{ W} = \mathbf{500\ W}$

$Q_T = 100\text{ VAR}(L) + 100\text{ VAR}(L) - 200\text{ VAR}(C) - 200\text{ VAR}(C) = \mathbf{-200\ VAR(}\boldsymbol{C}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{538.52\ VA}$

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b. $F_p = \dfrac{P_T}{S_T} = \dfrac{500\text{ W}}{538.52\text{ VA}} = \mathbf{0.928\ (leading)}$

c. –

d. $P_T = EI_s \cos\theta_T$

$500\text{ W} = (50\text{ V})I_s(0.928)$

$I_s = \dfrac{500\text{ W}}{46.4\text{ V}} = 10.776\text{ A}$

$\mathbf{I}_s = \mathbf{10.78\ A\ \angle 21.88°}$

6. a. $\mathbf{I}_R = \dfrac{60\text{ V}\angle 30°}{20\,\Omega\angle 0°} = 3\text{ A}\angle 30°$

$P = I^2R = (3\text{ A})^2\ 20\ \Omega = \mathbf{180\ W}$

$Q_R = \mathbf{0\ VAR}$

$S = P = \mathbf{180\ VA}$

b. $\mathbf{I}_L = \dfrac{60\text{ V}\angle 30°}{10\,\Omega\angle 90°} = 6\text{ A}\angle -60°$

$P_L = \mathbf{0\ W}$

$Q_L = I^2X_L = (6\text{ A})^2\ 10\ \Omega = \mathbf{360\ VAR(}\boldsymbol{L}\mathbf{)}$

$S = Q = \mathbf{360\ VA}$

c. $P_T = 180\text{ W} + 400\text{ W} = \mathbf{580\ W}$

$Q_T = 600\text{ VAR}(L) + 360\text{ VAR}(L) = \mathbf{960\ VAR(}\boldsymbol{L}\mathbf{)}$

$S_T = \sqrt{(580\text{ W})^2 + (960\text{ VAR})^2} = \mathbf{1121.61\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{580\text{ W}}{1121.61\text{ VA}} = \mathbf{0.517\ (lagging)}\ \ \theta = 58.87°$

d. $S_T = EI_s$

$I_s = \dfrac{S_T}{E} = \dfrac{1121.61\text{ VA}}{60\text{ V}} = 18.69\text{ A}$

$\theta_{I_s} = 30° - 58.87° = -28.87°$

$\mathbf{I}_s = \mathbf{18.69\ A\ \angle -28.87°}$

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: $Q_C = \dfrac{E^2}{X_C} = \dfrac{(20\text{ V})^2}{5\,\Omega} = \mathbf{80\ VAR(}\boldsymbol{C}\mathbf{)}$

L: $Q_L = \dfrac{E^2}{X_L} = \dfrac{(20\text{ V})^2}{4\,\Omega} = \mathbf{100\ VAR(}\boldsymbol{L}\mathbf{)}$

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c. R: $S = \mathbf{200\ VA}$
C: $S = \mathbf{80\ VA}$
L: $S = \mathbf{100\ VA}$

d. $P_T = 200\ \text{W} + 0 + 0 = \mathbf{200\ W}$
$Q_T = 0 + 80\ \text{VAR}(C) + 100\ \text{VAR}(L) = \mathbf{20\ VAR(}\boldsymbol{L}\mathbf{)}$
$S_T = \sqrt{(200\ \text{W})^2 + (20\ \text{VAR})^2} = \mathbf{200\ VA}$
$F_p = \dfrac{P_T}{S_T} = \dfrac{200\ \text{W}}{200.998\ \text{VA}} = \mathbf{0.995\ (lagging)} \Rightarrow 5.73°$

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. $P_T = P_R = \mathbf{300\ W}$
$Q_T = 400\ \text{VAR}(L) - 250\ \text{VAR}(C) = \mathbf{150\ VAR(}\boldsymbol{L}\mathbf{)}$
$S_T = \sqrt{(300\ \text{W})^2 + (150\ \text{VAR})^2} = \mathbf{335.41\ VA}$
$F_p = \dfrac{P_T}{S_T} = \dfrac{300\ \text{W}}{335.41\ \text{VA}} = \mathbf{0.894\ (lagging)}$

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
$\theta = 60° - 26.62° = 33.38°$
$\mathbf{I}_s = \mathbf{6.71\ A\ \angle 33.38°}$

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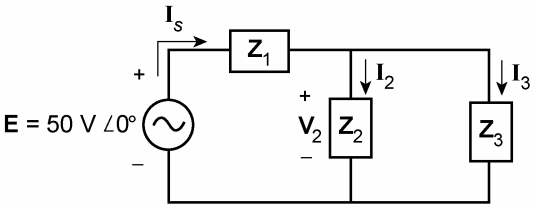
9. a–c.



$X_L = \omega L = (400 \text{ rad/s})(0.1 \text{ H}) = 40\ \Omega$

$X_C = \dfrac{1}{\omega C} = \dfrac{1}{(400 \text{ rad/s})(100\ \mu\text{F})}$

$= 25\ \Omega$

$\mathbf{Z}_1 = 40\ \Omega \angle 90°$, $\mathbf{Z}_2 = 25\ \Omega \angle -90°$

$\mathbf{Z}_3 = 30\ \Omega \angle 0°$

$$\mathbf{Z}_T = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3 = +j40\ \Omega + (25\ \Omega \angle -90°) \parallel (30\ \Omega \angle 0°)$$
$$= +j40\ \Omega + 19.21\ \Omega \angle -50.19°$$
$$= +j40\ \Omega + 12.3\ \Omega - j14.76\ \Omega$$
$$= 12.3\ \Omega + j25.24\ \Omega$$
$$= 28.08\ \Omega \angle 64.02°$$

$$\mathbf{I}_s = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50\ \text{V} \angle 0°}{28.08\ \Omega \angle 64.02°} = 1.78\ \text{A} \angle -64.02°$$

$$\mathbf{V}_2 = \mathbf{I}_s(\mathbf{Z}_2 \parallel \mathbf{Z}_3) = (1.78\ \text{A} \angle -64.02°)(19.21\ \Omega \angle -50.19°)$$
$$= 34.19\ \text{V} \angle -114.21°$$

$$\mathbf{I}_2 = \frac{\mathbf{V}_2}{\mathbf{Z}_2} = \frac{34.19\ \text{V} \angle -114.21°}{25\ \Omega \angle -90°} = 1.37\ \text{A} \angle -24.21°$$

$$\mathbf{I}_3 = \frac{\mathbf{V}_2}{\mathbf{Z}_3} = \frac{34.19\ \text{V} \angle -114.21°}{30\ \Omega \angle 0°} = 1.14\ \text{A} \angle -114.21°$$

$\mathbf{Z}_1$: $P = \mathbf{0\ W}$, $Q_L = I_s^2 X_L = (1.78\ \text{A})^2\ 40\ \Omega = \mathbf{126.74\ VAR(}\boldsymbol{L}\mathbf{),}\ S = \mathbf{126.74\ VA}$

$\mathbf{Z}_2$: $P = \mathbf{0\ W}$, $Q_C = I_2^2 X_C = (1.37\ \text{A})^2\ 25\ \Omega = \mathbf{46.92\ VAR(}\boldsymbol{C}\mathbf{),}\ S = \mathbf{46.92\ VA}$

$\mathbf{Z}_3$: $P = I_3^2 R = (1.14\ \text{A})^2\ 30\ \Omega = \mathbf{38.99\ W}$, $Q_R = \mathbf{0\ VAR,}\ S = \mathbf{38.99\ VA}$

d. $P_T = 0 + 0 + 38.99\ \text{W} = \mathbf{38.99\ W}$

$Q_T = +126.74\ \text{VAR}(L) - 46.92\ \text{VAR}(C) + 0 = \mathbf{79.82\ VAR(}\boldsymbol{L}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{88.83\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{38.99\ \text{W}}{88.83\ \text{VA}} = \mathbf{0.439\ (lagging)}$

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. $W_L = \dfrac{V_L I_L}{\omega_1} = \dfrac{(I_s X_L) I_s}{\omega_1} = \dfrac{I_s^2 X_L}{\omega_1} = \dfrac{(1.78\ \text{A})^2\ 40\ \Omega}{400 \text{ rad/s}} = \mathbf{0.32\ J}$

$W_C = \dfrac{V_C I_C}{\omega_1} = \dfrac{V_2 I_2}{\omega_1} = \dfrac{(34.19\ \text{V})(1.37\ \text{A})}{400 \text{ rad/s}} = \mathbf{0.12\ J}$

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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°

$$\mathbf{Z}_T = \frac{\mathbf{E}}{\mathbf{I}_s} = \frac{200\ \text{V}\angle 0°}{50\ \text{A}\angle 60°} = 4\ \Omega\angle -60° = 2\ \Omega - j3.464\ \Omega = R - jX_C$$

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)

$\mathbf{E} = 120\ \text{V}\angle 0°$, $\mathbf{I} = 41.67\ \text{A}\angle -36.87°$

$$\mathbf{Z} = \frac{\mathbf{E}}{\mathbf{I}} = \frac{120\ \text{V}\angle 0°}{41.67\ \text{A}\angle -36.87°} = 2.88\ \Omega\angle 36.87° = \mathbf{2.30\ \Omega + j1.73\ \Omega} = R + jX_L$$

b. $P = S\cos\theta = (5000\ \text{VA})(0.8) = \mathbf{4000\ W}$

12. a. $P_T = 0 + 300\ \text{W} = \mathbf{300\ W}$

$Q_T = 600\ \text{VAR}(C) + 200(L) = \mathbf{400\ VAR}(\boldsymbol{C})$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{500\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{300\ \text{W}}{500\ \text{VA}} = \mathbf{0.6\ (leading)}$

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

$$R = 0,\ L = 0,\ Q_C = I^2X_C \Rightarrow X_C = \frac{Q_C}{I^2} = \frac{600\ \text{VAR}}{(16.67\ \text{A})^2} = \mathbf{2.159\ \Omega}$$

Load: 200 VAR(L), 300 W

$C = 0$, $R = P/I^2 = 300\ \text{W}/(16.67\ \text{A})^2 = \mathbf{1.079\ \Omega}$

$$X_L = \frac{Q_L}{I^2} = \frac{200\ \text{VAR}}{(16.67\ \text{A})^2} = \mathbf{0.7197\ \Omega}$$

$\mathbf{Z}_T = !j2.159\ \Omega + 1.0796\ \Omega + j0.7197\ \Omega$

$= \mathbf{1.08\ \Omega - j1.44\ \Omega}$

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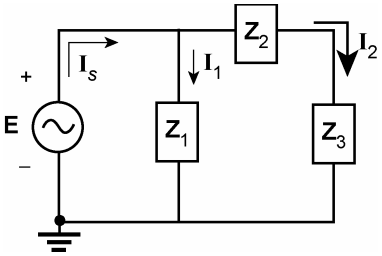
13. a. $P_T = 0 + 300\text{ W} + 600\text{ W} = \mathbf{900\ W}$
$Q_T = 500\text{ VAR}(C) + 0 + 500\text{ VAR}(L) = \mathbf{0\ VAR}$
$S_T = P_T = \mathbf{900\ VA}$
$$F_p = \frac{P_T}{S_T} = \mathbf{1}$$

b. $$I_s = \frac{S_T}{E} = \frac{900\text{ VA}}{100\text{ V}} = 9\text{ A},\ \mathbf{I}_s = \mathbf{9\ A\ \angle 0°}$$

c. –

d.



$\mathbf{Z}_1$: $$Q_C = \frac{V^2}{X_C} \Rightarrow X_C = \frac{V^2}{Q_C} = \frac{10^4}{500} = \mathbf{20\ \Omega}$$
$$\mathbf{I}_1 = \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{100\text{ V}\angle 0°}{20\,\Omega\angle -90°} = 5\text{A}\ \angle 90°$$
$$\mathbf{I}_2 = \mathbf{I}_s - \mathbf{I}_1 = 9\text{ A} - j5\text{ A} = 10.296\text{ A}\ \angle -29.05°$$

$\mathbf{Z}_2$: $$R = \frac{P}{I^2} = \frac{300\text{ W}}{(10.296\text{ A})^2} = \frac{300}{106} = \mathbf{2.83\ \Omega}$$
$$X_{L,C} = \mathbf{0\ \Omega}$$

$\mathbf{Z}_3$: $$R = \frac{P}{I_2^2} = \frac{600\text{ W}}{(10.296\text{ A})^2} = \mathbf{5.66\ \Omega}$$
$$X_L = \frac{Q}{I_2^2} = \frac{500}{(10.296\text{ A})^2} = \mathbf{4.72\ \Omega},\ X_C = \mathbf{0\ \Omega}$$

14. a. $P_T = 200\text{ W} + 30\text{ W} + 0 = \mathbf{230\ W}$
$Q_T = 0 + 40\text{ VAR}(L) + 100\text{ VAR}(L) = \mathbf{140\ VAR}(\boldsymbol{L})$
$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{269.26\ VA}$$
$$F_p = \frac{P_T}{S_T} = \frac{230\text{ W}}{269.26\text{ VA}} = \mathbf{0.854\ (lagging)} \Rightarrow 31.35°$$

b. $$I_s = \frac{S_T}{E} = \frac{269.26\text{ VA}}{100\text{ V}} = 2.6926\text{ A}$$
$\mathbf{I}_s = \mathbf{2.69\ A\ \angle -31.35°}$

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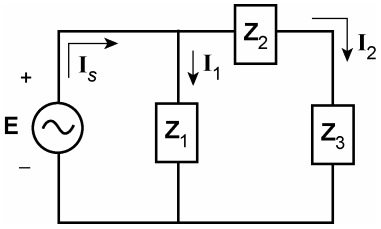
c.



$\mathbf{Z}_1$: $R = \dfrac{V^2}{P} = \dfrac{10^4}{200} = 50\ \Omega$

$X_L, X_C = 0\ \Omega$

$\mathbf{I}_1 = \dfrac{100\ \text{V}\angle 0°}{50\ \Omega\angle 0°} = 2\ \text{A}\angle 0°$

$\mathbf{I}_2 = \mathbf{I}_s - \mathbf{I}_1$

$= 2.6926\ \text{A}\angle -31.35° - 2\ \text{A}\angle 0°$

$= 2.299\ \text{A} - j1.40\ \text{A} - 2.0\ \text{A}$

$= 0.299\ \text{A} - j1.40\ \text{A}$

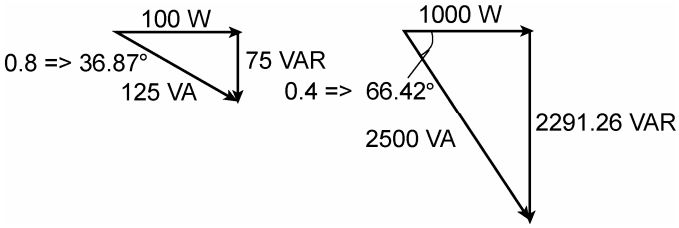
$= 1.432\ \text{A}\angle -77.94°$

$\mathbf{Z}_2$: $R = \dfrac{P}{I_2^2} = \dfrac{30\ \text{W}}{(1.432\ \text{A})^2} = \mathbf{14.63\ \Omega}$, $X_L = \dfrac{Q}{I_2^2} = \dfrac{40\ \text{VAR}}{(1.432\ \text{A})^2} = \mathbf{19.50\ \Omega}$

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

$\mathbf{Z}_3$: $X_L = \dfrac{Q}{I_2^2} = \dfrac{100\ \text{VAR}}{(1.432\ \text{A})^2} = \mathbf{48.76\ \Omega}$, $R = \mathbf{0\ \Omega}$, $X_C = \mathbf{0\ \Omega}$

15. a. $P_T = 100\ \text{W} + 1000\ \text{W} = \mathbf{1100\ W}$



$Q_T = 75\ \text{VAR}(C) + 2291.26\ \text{VAR}(C) = \mathbf{2366.26\ VAR(}\boldsymbol{C}\mathbf{)}$

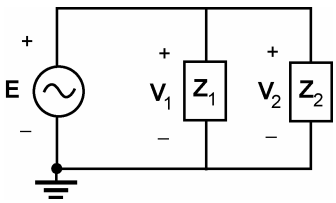
$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{2609.44\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{1100\ \text{W}}{2609.44\ \text{VA}} = \mathbf{0.422\ (leading)} \Rightarrow 65.04°$

b. $S_T = EI \Rightarrow E = \dfrac{S_T}{I} = \dfrac{2609.44\ \text{VA}}{5\ \text{A}} = 521.89\ \text{V}$

$\mathbf{E = 521.89\ V\angle -65.07°}$

c.



$I_{Z_1} = \dfrac{S}{V_1} = \dfrac{S}{E} = \dfrac{125\ \text{VA}}{521.89\ \text{V}} = 0.2395\ \text{A}$

$I_{Z_2} = \dfrac{S}{V_2} = \dfrac{S}{E} = \dfrac{2500\ \text{VA}}{521.89\ \text{V}} = 4.79\ \text{A}$

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$\mathbf{Z}_1$: $R = \dfrac{P}{I_{Z_1}^2} = \dfrac{100\text{ W}}{(0.2395)^2} = \mathbf{1743.38\ \Omega}$

$Q = I_{Z_1}^2 X_C \Rightarrow\ X_C = \dfrac{Q}{I_{Z_1}^2} = \dfrac{75\text{ VAR}}{(0.2395\text{ A})^2} = \mathbf{1307.53\ \Omega}$

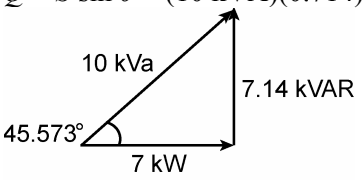
$\mathbf{Z}_2$: $R = \dfrac{P}{I_{Z_1}^2 X_C} = \dfrac{1000\text{ W}}{(4.790\text{ A})^2} = \mathbf{43.59\ \Omega}$

$X_C = \dfrac{Q}{I_{Z_1}^2 X_C} = \dfrac{2291.26\text{ VAR}}{(4.790\text{ A})^2} = \mathbf{99.88\ \Omega}$

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. $Q_C = 7.14\text{ kVAR} = \dfrac{V^2}{X_C}$

$X_C = \dfrac{V^2}{Q_C} = \dfrac{(208\text{ V})^2}{7.14\text{ kVAR}} = 6.059\ \Omega$

$X_C = \dfrac{1}{2\pi fC} \Rightarrow\ C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{(2\pi)(60\text{ Hz})(6.059\ \Omega)} = \mathbf{438\ \mu F}$

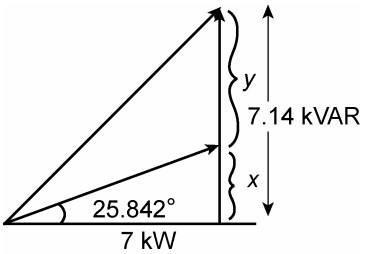
c. Uncompensated:

$I_s = \dfrac{S_T}{E} = \dfrac{10{,}000\text{ VA}}{208\text{ V}} = \mathbf{48.08\ A}$

Compensated:

$I_s = \dfrac{S_T}{E} = \dfrac{P_T}{E} = \dfrac{7{,}000\text{ W}}{208\text{ V}} = \mathbf{33.65\ A}$

d.



$\cos\theta = 0.9$

$\theta = \cos^{-1}0.9 = 25.842°$

$\tan\theta = \dfrac{x}{7\text{ kW}}$

$x = (7\text{ kW})(\tan 25.842°)$

$= (7\text{ kW})(0.484)$

$= 3.39\text{ kVAR}$

$y = (7.14 - 3.39)\text{ kVAR}$

$= 3.75\text{ kVAR}$

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$$Q_C = 3.75 \text{ kVAR} = \frac{V^2}{X_C}$$

$$X_C = \frac{V^2}{Q_C} = \frac{(208 \text{ V})^2}{3.75 \text{ kVAR}} = 11.537 \ \Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{(2\pi)(60 \text{ Hz})(11.537 \ \Omega)} = \mathbf{230\ \mu F}$$

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. $P_T = 5$ kW, $Q_T = 6$ 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. $S_T = EI_s = P_T$

$$\therefore \ I_s = \frac{P_T}{E} = \frac{5000 \text{ W}}{120 \text{ V}} = \mathbf{41.67\ A}$$

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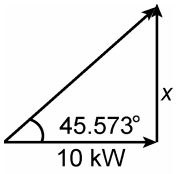
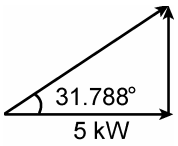
18. a. Load 1: $P = 20{,}000$ W, $Q = 0$ VAR
Load 2: $\theta = \cos^{-1}0.7 = 45.573°$



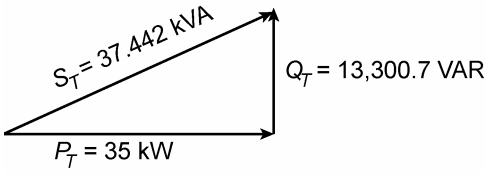
$$\tan\theta = \frac{x}{10\text{ kW}}$$
$$x = (10\text{ kW})\tan 45.573°$$
$$= (10\text{ kW})(1.02)$$
$$= \mathbf{10{,}202\text{ VAR}(}\boldsymbol{L}\mathbf{)}$$

Load 3: $\theta = \cos^{-1}0.85 = 31.788°$



$$\tan\theta = \frac{x}{5\text{ kW}}$$
$$x = (5\text{ kW})\tan 31.788°$$
$$= (5\text{ kW})(0.62)$$
$$= 3098.7\text{ VAR}(L)$$

$P_T = 20{,}000$ W + 10,000 W + 5,000 W = **35 kW**
$Q_T = 0 + 10{,}202$ VAR + 3098.7 VAR = **13,300.7 VAR(*L*)**
$S_T = \sqrt{P_T^2 + Q_T^2} =$ **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:

$$I_s = \frac{S_T}{E} = \frac{37.442\text{ kVA}}{1\text{ kV}} = \mathbf{37.44\text{ A}}$$

Compensated:

$$S_T = P_T = 35\text{ kW}$$
$$I_s = \frac{S_T}{E} = \frac{35\text{ kW}}{1\text{ kV}} = \mathbf{35\text{ A}}$$

19. a. $\mathbf{Z}_T = R_1 + R_2 + R_3 + jX_L - jX_C$
$= 2\ \Omega + 3\ \Omega + 1\ \Omega + j3\ \Omega - j12\ \Omega = 6\ \Omega - j9\ \Omega = 10.82\ \Omega\ \angle -56.31°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}_T} = \frac{50\text{ V}\ \angle 0°}{10.82\,\Omega\ \angle -56.31°} = 4.62\text{ A}\ \angle 56.31°$$

$P = VI\cos\theta = (50\text{ V})(4.62\text{ A})\cos 56.31° =$ **128.14 W**

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b. a-b: $P = I^2R = (4.62\text{ A})^2\ 2\ \Omega =$ **42.69 W**
b-c: $P = I^2R = (4.62\text{ A})^2\ 3\ \Omega =$ **64.03 W**
a-c: 42.69 W + 64.03 W = **106.72 W**
a-d: **106.72 W**
c-d: **0 W**
d-e: **0 W**
f-e: $P = I^2R = (4.62\text{ A})^2\ 1\ \Omega =$ **21.34 W**

20. a. $S_T = 660\text{ VA} = EI_s$

$$I_s = \frac{660\text{ VA}}{120\text{ V}} = 5.5\text{ A}$$

$\theta = \cos^{-1}0.6 = 53.13°$
$\therefore \mathbf{E} = 120\text{ V}\angle 0°$, $\mathbf{I}_s = 5.5\text{ A}\angle -53.13°$
$P = EI\cos\theta = (120\text{ V})(5.5\text{ A})(0.6) =$ **396 W**
Wattmeter = **396 W**, Ammeter = **5.5 A**, Voltmeter = **120 V**

b. $\mathbf{Z}_T = \dfrac{\mathbf{E}}{\mathbf{I}} = \dfrac{120\text{ V}\angle 0°}{5.5\text{ A}\angle -53.13°} =$ **21.82 Ω ∠53.13° = 13.09 Ω + *j*17.46 Ω** $= R + jX_L$

21. a. $R = \dfrac{P}{I^2} = \dfrac{80\text{ W}}{(4\text{ A})^2} =$ **5 Ω**, $\mathbf{Z}_T = \dfrac{E}{I} = \dfrac{200\text{ V}}{4\text{ A}} = 50\ \Omega$

$$X_L = \sqrt{Z_T^2 - R^2} = \sqrt{(50\ \Omega)^2 - (5\ \Omega)^2} = 49.75\ \Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{49.75\ \Omega}{(2\pi)(60\text{ Hz})} =$$ **132.03 mH**

b. $R = \dfrac{P}{I^2} = \dfrac{90\text{ W}}{(3\text{ A})^2} =$ **10 Ω**

c. $R = \dfrac{P}{I^2} = \dfrac{60\text{ W}}{(2\text{ A})^2} =$ **15 Ω**, $Z_T = \dfrac{E}{I} = \dfrac{200\text{ V}}{2\text{ A}} = 100\ \Omega$

$$X_L = \sqrt{Z_T^2 - R^2} = \sqrt{(100\ \Omega)^2 - (15\ \Omega)^2} = 98.87\ \Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{98.87\ \Omega}{376.8} =$$ **262.39 mH**

22. a. $X_L = 2\pi fL = (6.28)(50\text{ Hz})(0.08\text{ H}) = 25.12\ \Omega$

$$Z_T = \sqrt{R^2 + X_L^2} = \sqrt{(4\ \Omega)^2 + (25.12\ \Omega)^2} = 25.44\ \Omega$$

$$I = \frac{E}{Z_T} = \frac{60\text{ V}}{25.44\ \Omega} = 2.358\text{ A}$$

$P = I^2R = (2.358\text{ A})^2\ 4\ \Omega =$ **22.24 W**

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b. $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{30\text{ W}}{7\ \Omega}} = \mathbf{2.07\ A}$

$Z_T = \frac{E}{I} = \frac{60\text{ V}}{2.07\text{ A}} = 28.99\ \Omega$

$X_L = \sqrt{(28.99\ \Omega)^2 - (7\ \Omega)^2} = 28.13\ \Omega$

$L = \frac{X_L}{2\pi f} = \frac{28.13\ \Omega}{(2\pi)(50\text{ Hz})} = \mathbf{89.54\ mH}$

c. $P = I^2R = (1.7\text{ A})^2\ 10\ \Omega = \mathbf{28.9\ W}$

$Z_T = \frac{E}{I} = \frac{60\text{ V}}{1.7\text{ A}} = 35.29\ \Omega$

$X_L = \sqrt{(35.29\ \Omega)^2 - (10\ \Omega)^2} = 33.84\ \Omega$

$L = \frac{X_L}{2\pi f} = \frac{38.84\ \Omega}{314} = \mathbf{107.77\ mH}$

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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. $X_L = 2\pi fL,\ L = \dfrac{X_L}{2\pi f} = \dfrac{40\,\Omega}{2\pi(5\,\text{kHz})} = \mathbf{1.27\ mH}$

$X_C = \dfrac{1}{2\pi fC},\ C = \dfrac{1}{2\pi fX_C} = \dfrac{1}{2\pi(5\,\text{kHz})(40\,\Omega)} = \mathbf{795.77\ nF}$

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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. $f_2 = \dfrac{1}{2\pi}\left[\dfrac{R}{2L} + \dfrac{1}{2}\sqrt{\left(\dfrac{R}{L}\right)^2 + \dfrac{4}{LC}}\right]$

$= \dfrac{1}{2\pi}\left[\dfrac{4.7\ \Omega}{2(3.91\text{ mH})} + \dfrac{1}{2}\sqrt{\left(\dfrac{4.7\ \Omega}{3.91\text{ mH}}\right)^2 + \dfrac{4}{(3.91\text{ mH})(2\ \mu\text{F})}}\right]$

$= \dfrac{1}{2\pi}\left[601.02 + 11.324\times10^3\right]$

$= \mathbf{1897.93\ Hz}$

$f_1 = \dfrac{1}{2\pi}\left[-\dfrac{R}{2L} + \dfrac{1}{2}\sqrt{\left(\dfrac{R}{L}\right)^2 + \dfrac{4}{LC}}\right]$

$= \dfrac{1}{2\pi}\left[-601.02 + 11.324\times10^3\right]$

$= \mathbf{1.71\ kHz}$

$P_{\text{HPF}} = \dfrac{1}{2}P_{\max} = \dfrac{1}{2}(42.58\ \mu\text{W}) = \mathbf{21.29\ \mu W}$

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5. a. $BW = f_s/Q_s = 6000 \text{ Hz}/15 = \mathbf{400 \text{ Hz}}$

b. $f_2 = f_s + \dfrac{BW}{2} = 6000 \text{ Hz} + 200 \text{ Hz} = \mathbf{6200 \text{ Hz}}$

$f_1 = f_s - \dfrac{BW}{2} = 6000 \text{ Hz} - 200 \text{ Hz} = \mathbf{5800 \text{ Hz}}$

c. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_s R = (15)(3\ \Omega) = \mathbf{45\ \Omega} = X_C$

d. $P_{\text{HPF}} = \dfrac{1}{2} P_{\max} = \dfrac{1}{2}(I^2 R) = \dfrac{1}{2}(0.5 \text{ A})^2\, 3\Omega = \mathbf{375 \text{ mW}}$

6. a. $L = \dfrac{X_L}{2\pi f} = \dfrac{200\,\Omega}{2\pi(10^4 \text{ Hz})} = 3.185 \text{ mH}$

$BW = \dfrac{R}{2\pi L} = \dfrac{5\,\Omega}{2\pi(3.185 \text{ mH})} \cong \mathbf{250 \text{ Hz}}$

or $Q_s = \dfrac{X_L}{R} = \dfrac{X_C}{R} = \dfrac{200\,\Omega}{5\,\Omega} = 40$, $BW = \dfrac{f_s}{Q_s} = \dfrac{10{,}000 \text{ Hz}}{40} = \mathbf{250 \text{ Hz}}$

b. $f_2 = f_s + BW/2 = 10{,}000 \text{ Hz} + 250 \text{ Hz}/2 = \mathbf{10{,}125 \text{ Hz}}$
$f_1 = f_s - BW/2 = 10{,}000 \text{ Hz} - 125 \text{ Hz} = \mathbf{9{,}875 \text{ Hz}}$

c. $Q_s = \dfrac{X_L}{R} = \dfrac{200\,\Omega}{5\,\Omega} = \mathbf{40}$

d. $\mathbf{I} = \dfrac{E\angle 0°}{R\angle 0°} = \dfrac{30 \text{ V}\angle 0°}{5\,\Omega\angle 0°} = 6 \text{ A}\angle 0°$, $\mathbf{V}_L = (I\angle 0°)(X_L\angle 90°)$

$= (6 \text{ A}\angle 0°)(200\ \Omega\angle 90°)$

$= \mathbf{1200 \text{ V}\angle 90°}$

$\mathbf{V}_C = (I\angle 0°)(X_C\angle -90°) = \mathbf{1200 \text{ V}\angle -90°}$

e. $P = I^2 R = (6 \text{ A})^2\, 5\ \Omega = \mathbf{180 \text{ W}}$

7. a. $BW = \dfrac{f_s}{Q_s} \Rightarrow Q_s = f_s/BW = 2000 \text{ Hz}/200 \text{ Hz} = \mathbf{10}$

b. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_s R = (10)(2\ \Omega) = \mathbf{20\ \Omega}$

c. $L = \dfrac{X_L}{2\pi f} = \dfrac{20\,\Omega}{(6.28)(2 \text{ kHz})} = \mathbf{1.59 \text{ mH}}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{(6.28)(2 \text{ kHz})(20\,\Omega)} = \mathbf{3.98\ \mu\text{F}}$

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d. $f_2 = f_s + BW/2 = 2000 \text{ Hz} + 100 \text{ Hz} = \mathbf{2100 \text{ Hz}}$
$f_1 = f_s - BW/2 = 2000 \text{ Hz} - 100 \text{ Hz} = \mathbf{1900 \text{ Hz}}$

8. a. $BW = 6000 \text{ Hz} - 5400 \text{ Hz} = \mathbf{600 \text{ Hz}}$

b. $BW = f_s/Q_s \Rightarrow f_s = Q_s BW = (9.5)(600 \text{ Hz}) = \mathbf{5700 \text{ Hz}}$

c. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = X_C = Q_s R = (9.5)(2\ \Omega) = \mathbf{19\ \Omega}$

d. $L = \dfrac{X_L}{2\pi f} = \dfrac{19\ \Omega}{2\pi(5700 \text{ Hz})} = \mathbf{0.53 \text{ mH}}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{2\pi(5.7 \text{ kHz})(19\ \Omega)} = \mathbf{1.47\ \mu F}$

9. $I_M = \dfrac{E}{R} \Rightarrow R = \dfrac{E}{I_M} = \dfrac{5 \text{ V}}{500 \text{ mA}} = \mathbf{10\ \Omega}$

$BW = f_s/Q_s \Rightarrow Q_s = f_s/BW = 8400 \text{ Hz}/120 \text{ Hz} = 70$

$Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_s R = (70)(10\ \Omega) = \mathbf{700\ \Omega}$

$X_C = X_L = \mathbf{700\ \Omega}$

$L = \dfrac{X_L}{2\pi f} = \dfrac{700\ \Omega}{(2\pi)(8.4 \text{ kHz})} = \mathbf{13.26 \text{ mH}}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{(2\pi)(8.4 \text{ kHz})(0.7 \text{ k}\Omega)} = \mathbf{27.07 \text{ nF}}$

$f_2 = f_s + BW/2 = 8400 \text{ Hz} + 120 \text{ Hz}/2 = \mathbf{8460 \text{ Hz}}$
$f_1 = f_s - BW/2 = 8400 \text{ Hz} - 60 \text{ Hz} = \mathbf{8340 \text{ Hz}}$

10. $Q_s = \dfrac{X_L}{R} \Rightarrow X_L = Q_s R = 20(2\ \Omega) = \mathbf{40\ \Omega} = X_C$

$BW = \dfrac{f_s}{Q_s} \Rightarrow f_s = Q_s BW = (20)(400 \text{ Hz}) = \mathbf{8 \text{ kHz}}$

$L = \dfrac{X_L}{2\pi f} = \dfrac{40\ \Omega}{2\pi(8 \text{ kHz})} = \mathbf{795.77\ \mu H}$

$C = \dfrac{1}{2\pi f X_C} = \dfrac{1}{2\pi(8 \text{ kHz})(40\ \Omega)} = \mathbf{497.36 \text{ nF}}$

$f_2 = f_s + BW/2 = 8000 \text{ Hz} + 400 \text{ Hz}/2 = \mathbf{8200 \text{ Hz}}$
$f_1 = f_s - BW/2 = 8000 \text{ Hz} - 200 \text{ Hz} = \mathbf{7800 \text{ Hz}}$

11. a. $f_s = \dfrac{\omega_s}{2\pi} = \dfrac{2\pi \times 10^6 \text{ rad/s}}{2\pi} = \mathbf{1 \text{ MHz}}$

b. $\dfrac{f_2 - f_1}{f_s} = 0.16 \Rightarrow BW = f_2 - f_1 = 0.16 f_s = 0.16(1 \text{ MHz}) = \mathbf{160 \text{ kHz}}$

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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. $Q_\ell = \dfrac{X_L}{R_\ell} = 80 \Rightarrow R_P = \dfrac{X_L}{80} = \dfrac{2\pi f_s L}{80} = \dfrac{2\pi(10^6\text{ Hz})(0.716\text{ mH})}{80} = \mathbf{56.23\ \Omega}$

12. a. $Q_\ell = \dfrac{X_L}{R_\ell}$

$R_\ell = \dfrac{X_L}{Q_\ell} = \dfrac{2\pi fL}{Q_\ell} = \dfrac{2\pi(1\text{MHz})(100\ \mu\text{H})}{12.5} = 50.27\ \Omega$

$\dfrac{f_2 - f_1}{f_s} = \dfrac{1}{Q_s} = 0.2$

$Q_s = \dfrac{1}{0.2} = 5 = \dfrac{X_L}{R} = \dfrac{2\pi fL}{R} = \dfrac{2\pi(1\text{ MHz})(100\ \mu\text{H})}{R} = \dfrac{628.32\,\Omega}{R}$

$R = \dfrac{628.32\,\Omega}{5} = 125.66$

$R = R_d + R_\ell$

$125.66\ \Omega = R_d + 50.27\ \Omega$

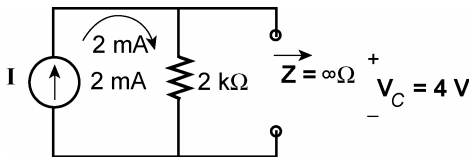
and $R_d = 125.66\ \Omega - 50.27\ \Omega = \mathbf{75.39\ \Omega}$

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. $I_L = \dfrac{V_L}{X_L} = \dfrac{4\text{ V}}{2\pi f_p L} = \dfrac{4\text{ V}}{100\,\Omega} = \mathbf{40\ mA}$

$I_C = \dfrac{V_L}{X_C} = \dfrac{4\text{ V}}{1/2\pi f_p C} = \dfrac{4\text{ V}}{100\,\Omega} = \mathbf{40\ mA}$

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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. $f_p = f_s\sqrt{1 - \dfrac{R_\ell^2 C}{L}} = 11{,}253.95\ \text{Hz}\ \sqrt{1 - \dfrac{(4\,\Omega)^2\ 2\ \mu\text{F}}{0.1\,\text{mH}}} = 11{,}253.95\ \text{Hz}(0.825)$

$= \mathbf{9{,}280.24\ Hz}$

$f_m = f_s\sqrt{1 - \dfrac{1}{4}\left[\dfrac{R_\ell^2 C}{L}\right]} = 11{,}253.95\ \text{Hz}\ \sqrt{1 - \dfrac{1}{4}\left[\dfrac{(4\,\Omega)^2\ 2\,\mu\text{F}}{0.1\,\text{mH}}\right]}$

$= 11{,}253.95\ \text{Hz}(0.996) = \mathbf{10{,}794.41\ Hz}$

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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. $$Z_{T_p} = R_s \,||\, R_p = R_s \,||\, \left(\frac{R_\ell^2 + X_L^2}{R_\ell}\right) = \frac{R_\ell^2 + X_L^2}{R_\ell} = \frac{(4\,\Omega)^2 + (5.83\,\Omega)^2}{4\,\Omega} = \mathbf{12.5\ \Omega}$$

f. $V_C = IZ_{T_p} = (2\text{ mA})(12.5\ \Omega) = \mathbf{25\text{ mV}}$

g. Since $R_s = \infty\ \Omega$ $$Q_p = Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_p L}{R_\ell} = \frac{2\pi(9{,}280.24\,\text{Hz})(0.1\,\text{mH})}{4\,\Omega} = \mathbf{1.46}$$

$$BW = \frac{f_p}{Q_p} = \frac{9{,}280.24\,\text{Hz}}{1.46} = \mathbf{6.36\text{ kHz}}$$

h. $$I_C = \frac{V_C}{X_C} = \frac{25\,\text{mV}}{8.57\,\Omega} = \mathbf{2.92\text{ mA}}$$

$$I_L = \frac{V_L}{Z_{R-L}} = \frac{V_C}{R_\ell + jX_L} = \frac{25\,\text{mV}}{4\,\Omega + j5.83\,\Omega} = \frac{25\,\text{mV}}{7.07\,\Omega} = \mathbf{3.54\text{ mA}}$$

16. a. $$Q_\ell = \frac{X_L}{R_L} = \frac{100\,\Omega}{20\,\Omega} = 5 \leq 10$$

$$\therefore \frac{X_L}{R_\ell^2 + X_L^2} = \frac{1}{X_C} \Rightarrow X_C = \frac{R_\ell^2 + X_\ell^2}{X_L} = \frac{(20\,\Omega)^2 + (100\,\Omega)^2}{100\,\Omega} = \mathbf{104\ \Omega}$$

b. $$Z_T = R_s \,||\, R_p = R_s \,||\, \frac{R_\ell^2 + X_L^2}{R_\ell} = 1000\,\Omega \,||\, \frac{10{,}400\,\Omega}{20} = \mathbf{342.11\ \Omega}$$

c. $\mathbf{E} = \mathbf{IZ}_{T_p} = (5\text{ mA}\ \angle 0°)(342.11\ \Omega\ \angle 0°) = 1.711\text{ V}\ \angle 0°$

$$\mathbf{I}_C = \frac{\mathbf{E}}{X_C\ \angle -90°} = \frac{1.711\text{ V}\ \angle 0°}{104\,\Omega\ \angle -90°} = \mathbf{16.45\text{ mA}\ \angle 90°}$$

$\mathbf{Z}_L = 20\ \Omega + j100\ \Omega = 101.98\ \Omega\ \angle 78.69°$

$$\mathbf{I}_L = \frac{\mathbf{E}}{\mathbf{Z}_L} = \frac{1.711\,\text{V}\ \angle 0°}{101.98\,\Omega\ \angle 78.69°} = \mathbf{16.78\text{ mA}\ \angle -78.69°}$$

d. $$L = \frac{X_L}{2\pi f} = \frac{100\,\Omega}{2\pi(20\,\text{kHz})} = \mathbf{795.77\ \mu H}$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(20\,\text{kHz})(104\,\Omega)} = \mathbf{76.52\text{ nF}}$$

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e. $Q_p = \dfrac{R}{X_C} = \dfrac{342.11\,\Omega}{104\,\Omega} = \mathbf{3.29}$

$BW = f_p/Q_p = 20{,}000$ Hz$/3.29 =$ **6079.03 Hz**

17. a. $Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{30\,\Omega}{2\,\Omega} = 15$ (use approximate approach): $X_C = X_L =$ **30 Ω**

b. $Z_{T_p} = R_s \,||\, Q_\ell^2 R_\ell = 450\ \Omega \,||\, (15)^2\ 2\ \Omega = 450\ \Omega \,||\, 450\ \Omega =$ **225 Ω**

c. $\mathbf{E} = \mathbf{I}\,\mathbf{Z}_{T_p} = (80\text{ mA}\ \angle 0°)(225\ \Omega\ \angle 0°) =$ **18 V ∠0°**

$\mathbf{I}_C = \dfrac{\mathbf{E}}{X_C \angle -90°} = \dfrac{18\text{ V}\ \angle 0°}{30\,\Omega \angle -90°} =$ **0.6 A ∠90°**

$\mathbf{I}_L = \dfrac{\mathbf{E}}{\mathbf{Z}_{R\text{-}L}} = \dfrac{18\text{ V}\ \angle 0°}{2\,\Omega + j30\,\Omega} = \dfrac{18\text{ V}\ \angle 0°}{30.07\,\Omega \angle 86.19°} \cong$ **0.6 A ∠–86.19°**

d. $X_L = 2\pi f_p L,\ L = \dfrac{X_L}{2\pi f_p} = \dfrac{30\,\Omega}{2\pi(20\times 10^3\text{ Hz})} =$ **0.239 mH**

$X_C = \dfrac{1}{2\pi f_p C},\ C = \dfrac{1}{2\pi f_p X_C} = \dfrac{1}{2\pi(20\times 10^3\text{ Hz})(30\,\Omega)} =$ **265.26 nF**

e. $Q_p = \dfrac{Z_{T_p}}{X_L} = \dfrac{225\,\Omega}{30\ \Omega} =$ **7.5**, $BW = \dfrac{f_p}{Q_p} = \dfrac{20{,}000\text{ Hz}}{7.5} =$ **2.67 kHz**

18. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(80\,\mu\text{H})(0.03\,\mu\text{F})}} =$ **102.73 kHz**

$f_p = f_s\sqrt{1 - \dfrac{R_\ell^2 C}{L}} = 102.73\text{ kHz}\ \sqrt{1 - \dfrac{(1.5\,\Omega)^2\ 0.03\,\mu\text{F}}{80\,\mu\text{H}}} = 102.73\text{ kHz}(.99958)$

$=$ **102.69 kHz**

$f_m = f_s\sqrt{1 - \dfrac{1}{4}\left[\dfrac{R_\ell^2 C}{L}\right]} = 102.73\text{ kHz}(0.99989) =$ **102.72 kHz**

Since $f_s \cong f_p \cong f_m \Rightarrow$ high Q_p

b. $X_L = 2\pi f_p L = 2\pi(102.69\text{ kHz})(80\ \mu\text{H}) =$ **51.62 Ω**

$X_C = \dfrac{1}{2\pi f_p C} = \dfrac{1}{2\pi(102.69\text{ kHz})(0.03\,\mu\text{F})} =$ **51.66 Ω**

$X_L \cong X_C$

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c. $Z_{T_p} = R_s \,||\, Q_\ell^2 R_\ell$

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{51.62\,\Omega}{1.5\,\Omega} = 34.41$$

$$Z_{T_p} = 10\,\text{k}\Omega \,||\, (34.41)^2 1.5\,\Omega = 10\,\text{k}\Omega \,||\, 1.776\,\text{k}\Omega = \mathbf{1.51\ k\Omega}$$

d. $$Q_p = \frac{R_s \,||\, Q_\ell^2 R_\ell}{X_L} = \frac{Z_{T_p}}{X_L} = \frac{1.51\,\text{k}\Omega}{51.62\,\Omega} = \mathbf{29.25}$$

$$BW = \frac{f_p}{Q_p} = \frac{102.69\,\text{kHz}}{29.25} = \mathbf{3.51\ kHz}$$

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. $X_L = 2\pi f_p L = 2\pi(6.647\ \text{kHz})(0.5\ \text{mH}) = 20.88\ \Omega$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(6.647\ \text{kHz})(1\,\mu\text{F})} = 23.94\ \Omega$$

$X_C > X_L$ (low Q)

c. $$Z_{T_p} = R_s \,||\, R_p = R_s \,||\, \frac{R_\ell^2 + X_L^2}{R_\ell} = 500\ \Omega \,||\, \frac{(8\,\Omega)^2 + (20.88\,\Omega)^2}{8\,\Omega} = 500\ \Omega \,||\, 62.5\ \Omega$$

$$= \mathbf{55.56\ \Omega}$$

d. $$Q_p = \frac{Z_{T_p}}{X_{L_p}} = \frac{55.56\,\Omega}{23.94\,\Omega} = \mathbf{2.32}$$

$$BW = \frac{f_p}{Q_p} = \frac{6.647\ \text{kHz}}{2.32} = \mathbf{2.87\ kHz}$$

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e. One method: $V_C = IZ_{T_p} = (40\text{ mA})(55.56\ \Omega) = 2.22\text{ V}$

$$I_C = \frac{V_C}{X_C} = \frac{2.22\text{ V}}{23.94\,\Omega} = \mathbf{92.73\ mA}$$

$$I_L = \frac{|V_C|}{|R_\ell + jX_L|} = \frac{2.22\text{ V}}{|8 + j20.88|} = \frac{2.22\text{ V}}{22.36\,\Omega} = \mathbf{99.28\ mA}$$

f. $V_C = \mathbf{2.22\ V}$

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. $$X_L = 2\pi f_p L \Rightarrow f_p = \frac{X_L}{2\pi L} = \frac{1580.3\ \Omega}{2\pi(16\text{ mH})} = \mathbf{15.72\ kHz}$$

d. $$X_C = \frac{1}{2\pi f_p C} \Rightarrow C = \frac{1}{2\pi f_s X_C} = \frac{1}{2\pi(15.72\text{ kHz})(1580.3\,\Omega)} = \mathbf{6.4\ nF}$$

21. a. $$Q_\ell = 20 > 10\ \therefore f_p = f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(200\text{ mH})(10\text{ nF})}} = \mathbf{3558.81\ Hz}$$

b. $$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi fL}{R_\ell} \Rightarrow R_\ell = \frac{2\pi fL}{Q_\ell} = \frac{2\pi(3558.81\text{ Hz})(0.2\text{ H})}{20} = 223.61\ \Omega$$

$$Z_{T_p} = R_s \,||\, R_p = R_s \,||\, Q_\ell^2 R_\ell = 40\text{ k}\Omega \,||\, (20)^2\ 223.61\ \Omega$$

$$Z_{T_p} = 27.64\text{ k}\Omega$$

$$V_C = IZ_{T_p} = (5\text{ mA})(27.64\text{ k}\Omega) = \mathbf{138.2\ V}$$

c. $P = I^2R = (5\text{ mA})^2 27.64\text{ k}\Omega = \mathbf{691\ mW}$

d. $$Q_p = \frac{R}{X_L} = \frac{R_s \,||\, R_p}{X_L} = \frac{27.64\text{ k}\Omega}{2\pi(3558.81\text{ Hz})(0.2\text{ H})} = \mathbf{6.18}$$

$$BW = \frac{f_p}{Q_p} = \frac{3558.81\text{ Hz}}{6.18} = \mathbf{575.86\ Hz}$$

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22. a. Ratio of X_C to R_ℓ suggests high Q system.

$\therefore X_L = \mathbf{400\ \Omega} = X_C$

b. $$Q_\ell = \frac{X_L}{R_\ell} = \frac{400\,\Omega}{8\,\Omega} = \mathbf{50}$$

c. $$Q_p = \frac{R}{X_L} = \frac{R_s \,||\, R_p}{X_L} = \frac{R_s \,||\, Q_\ell^2 R_\ell}{X_L} = \frac{20\,\text{k}\Omega \,||\, (50)^2\, 8\,\Omega}{400\,\Omega} = \frac{10\,\text{k}\Omega}{400\,\Omega} = \mathbf{25}$$

$$BW = \frac{f_p}{Q_p} \Rightarrow f_p = Q_p BW = (25)(1000\text{ Hz}) = \mathbf{25\ kHz}$$

d. $$V_{C_{\max}} = IZ_{T_p} = (0.1\text{ mA})(10\text{ k}\Omega) = \mathbf{1\ V}$$

e. $$f_2 = f_p + BW/2 = 25\text{ kHz} + \frac{1\,\text{kHz}}{2} = \mathbf{25.5\ kHz}$$

$$f_1 = f_p - BW/2 = 25\text{ kHz} - \frac{1\,\text{kHz}}{2} = \mathbf{24.5\ kHz}$$

23. a. $$X_C = \frac{R_\ell^2 + X_L^2}{X_L} \Rightarrow X_L^2 - X_L X_C + R_\ell^2 = 0$$

$$X_L^2 - 100\,X_L + 144 = 0$$

$$X_L = \frac{-(-100) \pm \sqrt{(100)^2 - 4(1)(144)}}{2}$$

$$= 50\ \Omega \pm \frac{\sqrt{10^4 - 576}}{2} = 50\ \Omega \pm 48.54\ \Omega$$

$X_L = \mathbf{98.54\ \Omega}$ or 1.46 Ω

b. $$Q_\ell = \frac{X_L}{R_\ell} = \frac{98.54\,\Omega}{12\,\Omega} = \mathbf{8.21}$$

c. $$Q_p = \frac{R_s \,||\, R_p}{X_{L_p}} = \frac{40\,\text{k}\Omega \,||\, \dfrac{R_\ell^2 + X_L^2}{R_\ell}}{X_C} = \frac{40\,\text{k}\Omega \,||\, \dfrac{(12\,\Omega)^2 + (98.54\,\Omega)^2}{12\,\Omega}}{100\,\Omega}$$

$$= \frac{40\,\text{k}\Omega \,||\, 821.18\,\Omega}{100\,\Omega} = \frac{804.66\,\Omega}{100\,\Omega} = \mathbf{8.05}$$

$$BW = f_p/Q_p \Rightarrow f_p = Q_p BW = (8.05)(1\text{ kHz}) = \mathbf{8.05\ kHz}$$

d. $$V_{C_{\max}} = IZ_{T_p} = (6\text{ mA})(804.66\ \Omega) = \mathbf{4.83\ V}$$

e. $$f_2 = f_p + BW/2 = 8.05\text{ kHz} + \frac{1\,\text{kHz}}{2} = \mathbf{8.55\ kHz}$$

$$f_1 = f_p - BW/2 = 8.05\text{ kHz} - \frac{1\,\text{kHz}}{2} = \mathbf{7.55\ kHz}$$

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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 $Q \therefore$ $f_p \cong f_s = \dfrac{1}{2\pi\sqrt{LC}} \Rightarrow C = \dfrac{1}{4\pi^2 f_p^2 L} = \dfrac{1}{4\pi^2(20\text{ kHz})^2\ 2\text{ mH}} = \mathbf{31.66\ nF}$

$$Q_p = \frac{R}{X_C} \Rightarrow R = Q_p X_C = \frac{Q_p}{2\pi f_p C} = \frac{11.11}{2\pi(20\text{ kHz})(31.66\text{ nF})} = \mathbf{2.79\ k\Omega}$$

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$$R_p = Q_\ell^2 R_\ell = (80)^2\ 3.14\ \Omega = 20.1\ \text{k}\Omega$$

$$R = R_s \parallel R_p = \frac{R_s R_p}{R_s + R_p} \Rightarrow R_s = \frac{R_p R}{R_p - R} = \frac{(20.1\,\text{k}\Omega)(2.793\,\text{k}\Omega)}{20.1\,\text{k}\Omega - 2.793\,\text{k}\Omega} = \mathbf{3.24\ k\Omega}$$

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:

$$f_p = f_s\sqrt{1 - \frac{R_\ell^2 C}{L}} = (251.65\,\text{kHz})\sqrt{1 - \frac{(20\,\Omega)^2(20\,\text{nF})}{20\ \mu\text{H}}}$$

$$= (251.65\ \text{kHz})(0.775) = \mathbf{194.93\ kHz}$$

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$$X_L = 2\pi f_p L = 2\pi(194.93\text{ kHz})(20\ \mu\text{H}) = 24.496\ \Omega$$

$$R_p = \frac{R_\ell^2 + X_L^2}{R_\ell} = \frac{(20\,\Omega)^2 + (24.496\,\Omega)^2}{20\,\Omega} = 50\ \Omega$$

$$Z_{T_p} = R_s \,||\, R_p = 40\text{ k}\Omega\ \,||\, 50\ \Omega = \mathbf{49.94\ \Omega}$$

$$Q_p = \frac{R}{X_L} = \frac{49.94\,\Omega}{24.496\,\Omega} = \mathbf{2.04}$$

$$BW = \frac{f_p}{Q_p} = \frac{194.93\text{ kHz}}{2.04} = \mathbf{95.55\text{ kHz}}$$

f. **0.4 mH, 1 nF**

$f_s = 251.65$ kHz since LC product the same

$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi(251.65\text{ kHz})(0.4\text{ mH})}{20\,\Omega} = 31.62 \geq 10$$

$\therefore f_p = f_s = \mathbf{251.65\text{ kHz}}$

$Z_{T_p} = R_s \,||\, Q_\ell^2 R_\ell = 40\text{ k}\Omega\ \,||\, (31.62)^2\ 20\ \Omega = 40\text{ k}\Omega\ \,||\, (\cong 20\text{ k}\Omega) \cong \mathbf{13.33\ k\Omega}$

$$Q_p = \frac{R_s \,||\, Q_\ell^2 R_\ell}{X_L} = \frac{13.33\,\text{k}\Omega}{632.47\,\Omega} = \mathbf{21.08}$$

$$BW = \frac{f_p}{Q_p} = \frac{251.65\text{ kHz}}{21.08} = \mathbf{11.94\text{ kHz}}$$

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.

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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. $\log_{10} 27 = \mathbf{1.43}$
$3 \log_{10} 3 = 3(0.4771) = \mathbf{1.43}$

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9. a. $\text{bels} = \log_{10} \frac{P_2}{P_1} = \log_{10} \frac{280\,\text{mW}}{4\,\text{mW}} = \log_{10} 70 = \mathbf{1.85}$

b. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = 10(\log_{10} 70) = 10(1.845) = \mathbf{18.45}$

10. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1}$

$6\ \text{dB} = 10 \log_{10} \frac{100\ \text{W}}{P_1}$

$0.6 = \log_{10} x$

$x = 3.981 = \frac{100\ \text{W}}{P_1}$

$P_1 = \frac{100\ \text{W}}{3.981} = \mathbf{25.12\ W}$

11. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{40\ \text{W}}{2\ \text{W}} = 10 \log_{10} 20 = \mathbf{13.01}$

12. $\text{dB}_m = 10 \log_{10} \frac{P}{1\,\text{mW}}$

$\text{dB}_m = 10 \log_{10} \frac{120\,\text{mW}}{1\,\text{mW}} = 10 \log_{10} 120 = \mathbf{20.79}$

13. $\text{dB}_v = 20 \log_{10} \frac{V_2}{V_1} = 20 \log_{10} \frac{8.4\ \text{V}}{0.1\ \text{V}} = 20 \log_{10} 84 = \mathbf{38.49}$

14. $\text{dB}_\upsilon = 20 \log_{10} \frac{V_2}{V_1}$

$22 = 20 \log_{10} \frac{V_o}{20\,\text{mV}}$

$1.1 = \log_{10} x$

$x = 12.589 = \frac{V_o}{20\,\text{mV}}$

$V_o = \mathbf{251.79\ mV}$

15. $\text{dB}_s = 20 \log_{10} \frac{P}{0.0002\ \mu\text{bar}}$

$\text{dB}_s = 20 \log_{10} \frac{0.001\ \mu\text{bar}}{0.0002\ \mu\text{bar}} = \mathbf{13.98}$

$\text{dB}_s = 20 \log_{10} \frac{0.016\ \mu\text{bar}}{0.0002\ \mu\text{bar}} = \mathbf{38.06}$

Increase = **24.08 dB$_s$**

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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 $P_2 = \mathbf{31.62}\ \boldsymbol{P}_1$

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. $$A_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}}\angle -90° + \tan^{-1} X_C/R = \frac{1}{\sqrt{\left(\dfrac{R}{X_C}\right)^2 + 1}}\angle -\tan^{-1} R/X_C$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2\ \text{k}\Omega)(0.02\ \mu\text{F})} = \mathbf{3617.16\ Hz}$$

$f = f_c$: $A_v = \dfrac{V_o}{V_i} = \mathbf{0.707}$

$f = 0.1f_c$: At f_c, $X_C = R = 2.2\ \text{k}\Omega$

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$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi 0.1 f_c C} = \frac{1}{0.1}\left[\frac{1}{2\pi f_c C}\right] = 10\left[2.2\,\text{k}\Omega\right] = 22\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{R}{X_C}\right)^2 + 1}} = \frac{1}{\sqrt{\left(\frac{2.2\,\text{k}\Omega}{22\,\text{k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(.1)^2 + 1}} = \mathbf{0.995}$$

$f = 0.5f_c = \frac{1}{2} f_c$:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi\left(\frac{f_c}{2}\right)C} = 2\left[\frac{1}{2\pi f_c C}\right] = 2\left[2.2\,\text{k}\Omega\right] = 4.4\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{2.2\,\text{k}\Omega}{4.4\,\text{k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(0.5)^2 + 1}} = \mathbf{0.894}$$

$f = 2f_c$:

$$X_C = \frac{1}{2\pi(2f_c)C} = \frac{1}{2}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{2}\left[2.2\,\text{k}\Omega\right] = 1.1\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{2.2\,\text{k}\Omega}{1.1\,\text{k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(2)^2 + 1}} = \mathbf{0.447}$$

$f = 10f_c$:

$$X_C = \frac{1}{2\pi(10 f_c)C} = \frac{1}{10}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{10}\left[2.2\,\text{k}\Omega\right] = 0.22\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left(\frac{2.2\,\text{k}\Omega}{0.22\,\text{k}\Omega}\right)^2 + 1}} = \frac{1}{\sqrt{(10)^2 + 1}} = \mathbf{0.0995}$$

b. $\theta = -\tan^{-1} R/X_C$

$f = f_c$: $\theta = -\tan^{-1} = \mathbf{-45°}$

$f = 0.1f_c$: $\theta = -\tan^{-1} 2.2\ \text{k}\Omega/22\ \text{k}\Omega = -\tan^{-1} \frac{1}{10} = \mathbf{-5.71°}$

$f = 0.5f_c$: $\theta = -\tan^{-1} 2.2\ \text{k}\Omega/4.4\ \text{k}\Omega = -\tan^{-1} \frac{1}{2} = \mathbf{-26.57°}$

$f = 2f_c$: $\theta = -\tan^{-1} 2.2\ \text{k}\Omega/1.1\ \text{k}\Omega = -\tan^{-1} 2 = \mathbf{-63.43°}$

$f = 10f_c$: $\theta = -\tan^{-1} 2.2\ \text{k}\Omega/0.22\ \text{k}\Omega = -\tan^{-1} 10 = \mathbf{-84.29°}$

20. a. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(1\,\text{k}\Omega)(0.01\,\mu\text{F})} = 15.915\ \text{kHz}$

$f = 2f_c = 31.83\ \text{kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(31.83\,\text{kHz})(0.01\,\mu\text{F})} = 500\ \Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{500\,\Omega}{\sqrt{(1\,\text{k}\Omega)^2 + (0.5\,\text{k}\Omega)^2}} = 0.4472$$

$V_o = 0.4472 V_i = 0.4472(10\ \text{mV}) = \mathbf{4.47\ mV}$

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b. $f = \frac{1}{10} f_c = \frac{1}{10}(15{,}915 \text{ kHz}) = 1.5915 \text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.5915 \text{ kHz})(0.01\,\mu\text{F})} = 10 \text{ k}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{10 \text{ k}\Omega}{\sqrt{(1 \text{ k}\Omega)^2 + (10 \text{ k}\Omega)^2}} = 0.995$$

$V_o = 0.995 V_i = 0.995(10 \text{ mV}) = \mathbf{9.95 \text{ mV}}$

c. Yes, at $f = f_c$, $V_o = 7.07$ mV

at $f = \frac{1}{10} f_c$, $V_o = 9.95$ mV (much higher)

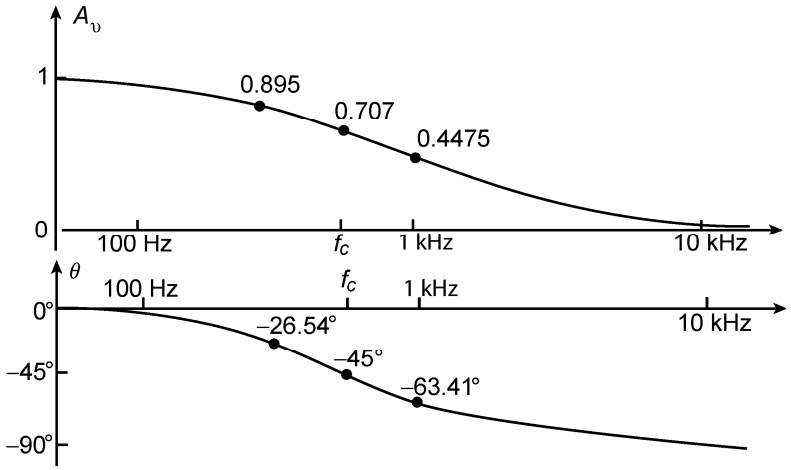
at $f = 2f_c$, $V_o = 4.47$ mV (much lower)

21. $f_c = 500 \text{ Hz} = \frac{1}{2\pi RC} = \frac{1}{2\pi(1.2 \text{ k}\Omega)C}$

$$C = \frac{1}{2\pi Rf_c} = \frac{1}{2\pi(1.2 \text{ k}\Omega)(500 \text{ Hz})} = \mathbf{0.265\ \mu F}$$

$$A_v = \frac{V_o}{V_i} = \frac{1}{\sqrt{\left(\frac{R}{X_C}\right)^2 + 1}}$$

At $f = 250$ Hz, $X_C = 2402.33\ \Omega$ and $A_v = 0.895$
At $f = 1000$ Hz, $X_C = 600.58\ \Omega$ and $A_v = 0.4475$
$\theta = -\tan^{-1} R/X_C$
At $f = 250 \text{ Hz} = \frac{1}{2} f_c$, $\theta = -26.54°$
At $f = 1 \text{ kHz} = 2f_c$, $\theta = -63.41°$



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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. $$A_v = \frac{V_o}{V_i} = 0.01 = \frac{X_C}{\sqrt{R^2 + X_C^2}}$$

$$\sqrt{R^2 + X_C^2} = \frac{X_C}{0.01} = 100\,X_C$$

$$R^2 + X_C^2 = 10^4\,X_C^2$$

$$R^2 = 10^4\,X_C^2 - X_C^2 = 9{,}999\,X_C^2$$

$$X_C = \frac{R}{\sqrt{9{,}999}} = \frac{4.7\,\text{k}\Omega}{99.995} \cong 47\ \Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(47\,\Omega)(500\,\text{pF})} = \mathbf{6.77\ MHz}$$

23. a. $$A_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{R}{\sqrt{R^2 + X_C^2}} \angle \tan^{-1} X_C/R = \frac{1}{\sqrt{1 + \left(\dfrac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2\,\text{k}\Omega)(20\,\text{nF})} = \mathbf{3.62\ kHz}$$

$f = f_c$: $A_v = \dfrac{V_o}{V_i} = \mathbf{0.707}$

$f = 2f_c$: At f_c, $X_C = R = 2.2\ \text{k}\Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(2f_c)C} = \frac{1}{2}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{2}\left[2.2\,\text{k}\Omega\right] = 1.1\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left(\dfrac{1.1\,\text{k}\Omega}{2.2\,\text{k}\Omega}\right)^2}} = \mathbf{0.894}$$

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$f = \frac{1}{2}f_c$: $X_C = \frac{1}{2\pi\left(\frac{f_c}{2}\right)C} = 2\left[\frac{1}{2\pi f_c C}\right] = 2[2.2\,\text{k}\Omega] = 4.4\,\text{k}\Omega$

$$A_v = \frac{1}{\sqrt{1+\left(\frac{4.4\,\text{k}\Omega}{2.2\,\text{k}\Omega}\right)^2}} = \mathbf{0.447}$$

$f = 10f_c$: $X_C = \frac{1}{2\pi(10f_c)C} = \frac{1}{10}\left[\frac{1}{2\pi f_c C}\right] = \frac{2.2\,\text{k}\Omega}{10} = 0.22\,\text{k}\Omega$

$$A_v = \frac{1}{\sqrt{1+\left(\frac{0.22\,\text{k}\Omega}{2.2\,\text{k}\Omega}\right)^2}} = \mathbf{0.995}$$

$f = \frac{1}{10}f_c$: $X_C = \frac{1}{2\pi\left(\frac{f_c}{10}\right)C} = 10\left[\frac{1}{2\pi f_c C}\right] = 10[2.2\,\text{k}\Omega] = 22\,\text{k}\Omega$

$$A_v = \frac{1}{\sqrt{1+\left(\frac{22\,\text{k}\Omega}{2.2\,\text{k}\Omega}\right)^2}} = \mathbf{0.0995}$$

b. $f = f_c$, $\theta = \mathbf{45°}$

$f = 2f_c$, $\theta = \tan^{-1}(X_C/R) = \tan^{-1} 1.1\,\text{k}\Omega/2.2\,\text{k}\Omega = \tan^{-1}\frac{1}{2} = \mathbf{26.57°}$

$f = \frac{1}{2}f_c$, $\theta = \tan^{-1}\frac{4.4\,\text{k}\Omega}{2.2\,\text{k}\Omega} = \tan^{-1} 2 = \mathbf{63.43°}$

$f = 10f_c$, $\theta = \tan^{-1}\frac{0.22\,\text{k}\Omega}{2.2\,\text{k}\Omega} = \mathbf{5.71°}$

$f = \frac{1}{10}f_c$, $\theta = \tan^{-1}\frac{22\,\text{k}\Omega}{2.2\,\text{k}\Omega} = \mathbf{84.29°}$

24. a. $f = f_c$: $A_v = \frac{V_o}{V_i} = \mathbf{0.707}$

b. $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(10\,\text{k}\Omega)(1000\,\text{pF})} = 15.915\,\text{kHz}$

$f = 4f_c = 4(15.915\,\text{kHz}) = 63.66\,\text{kHz}$

$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(63.66\,\text{kHz})(1000\,\text{pF})} = 2.5\,\text{k}\Omega$

$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10\,\text{k}\Omega}{\sqrt{(10\,\text{k}\Omega)^2 + (2.5\,\text{k}\Omega)^2}} = \mathbf{0.970}$ (significant rise)

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c. $f = 100f_c = 100(15.915\text{ kHz}) = 1591.5\text{ kHz} \cong 1.592\text{ MHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.592\text{ MHz})(1000\text{ pF})} = 99.972\ \Omega$$

$$A_v = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10\text{ k}\Omega}{\sqrt{(10\text{ k}\Omega)^2 + (99.972\ \Omega)^2}} = 0.99995 \cong 1$$

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. $$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1}{\sqrt{1 + \left(\frac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$$

$$f_c = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi(2\text{ kHz})(0.1\ \mu\text{F})} = 795.77\ \Omega$$

$$R = 795.77\ \Omega \Rightarrow \underbrace{750\ \Omega + 47\ \Omega}_{\text{nominal values}} = 797\ \Omega$$

$$\therefore f_c = \frac{1}{2\pi(797\ \Omega)(0.1\ \mu\text{F})} = \mathbf{1996.93\ Hz} \text{ using nominal values}$$

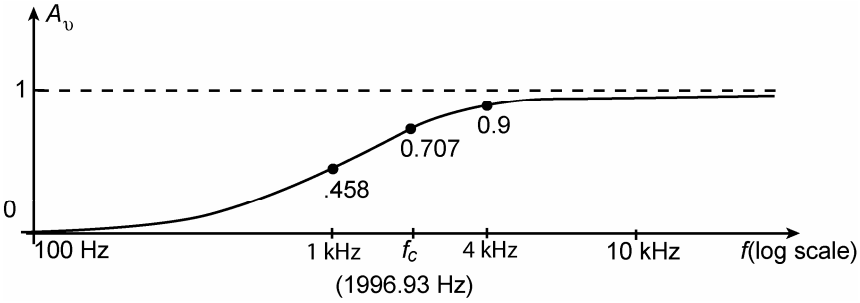
At $f = 1\text{ kHz}$, $A_v = 0.458$

$f = 4\text{ kHz}$, $A_v \cong 0.9$

$$\theta = \tan^{-1}\frac{X_C}{R}$$

$f = 1\text{ kHz}$, $\theta = 63.4°$

$f = 4\text{ kHz}$, $\theta = 26.53°$



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26. a. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(100\,\text{k}\Omega)(20\,\text{pF})} = \mathbf{79.58\ kHz}$

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. $$A_v = \frac{V_o}{V_i} = 0.5 = \frac{R}{\sqrt{R^2 + X_C^2}}$$

$$\sqrt{R^2 + X_C^2} = 2R$$

$$R^2 + X_C^2 = 4R^2$$

$$X_C^2 = 4R^2 - R^2 = 3R^2$$

$$X_C = \sqrt{3R^2} = \sqrt{3}R = \sqrt{3}\ (100\ \text{k}\Omega) = 173.2\ \text{k}\Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(173.2\,\text{k}\Omega)(20\,\text{pF})}$$

$$f = \mathbf{45.95\ kHz}$$

27. a. low-pass section: $f_{c_1} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(0.1\,\text{k}\Omega)(2\,\mu\text{F})} = \mathbf{795.77\ Hz}$

high-pass section: $f_{c_2} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(10\,\text{k}\Omega)(8\,\text{nF})} = \mathbf{1989.44\ Hz}$

For the analysis to follow, it is assumed $(R_2 + jX_{C_2}) \,||\, R_1 \cong R_1$ for all frequencies of interest.

At $f_{c_1} = 795.77$ Hz:

$$V_{R_1} = 0.707\ V_i$$

$$X_{C_2} = \frac{1}{2\pi fC_2} = 25\ \text{k}\Omega$$

$$|V_o| = \frac{25\,\text{k}\Omega(V_{R_1})}{\sqrt{(10\,\text{k}\Omega)^2 + (25\,\text{k}\Omega)^2}} = 0.9285\ V_{R_1}$$

$$V_o = (0.9285)(0.707\ V_i) = \mathbf{0.66\ V_i}$$

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At f_{c_2} = 1989.44 Hz:

$$V_o = 0.707\ V_{R_1}$$

$$X_{C_1} = \frac{1}{2\pi f C_1} = 40\ \Omega$$

$$\left|V_{R_1}\right| = \frac{R_1 V_i}{\sqrt{R_1^2 + X_{C_1}^2}} = \frac{100\,\Omega(V_i)}{\sqrt{(100\,\Omega)^2 + (40\,\Omega)^2}} = 0.928\ V_i$$

$$|V_o| = (0.707)(0.928\ V_i) = \mathbf{0.66\ V_i}$$

$$\text{At } f = 795.77 \text{ Hz} + \frac{(1989.44 \text{ Hz} - 795.77 \text{ Hz})}{2} = 1392.60 \text{ Hz}$$

X_{C_1} = 57.14 Ω, X_{C_2} = 14.29 kΩ

$$\left|V_{R_1}\right| = \frac{100\,\Omega(V_i)}{\sqrt{(100\,\Omega)^2 + (57.14\,\Omega)^2}} = 0.868\ V_i$$

$$\left|V_o\right| = \frac{14.29\,\text{k}\Omega\left(V_{R_1}\right)}{\sqrt{(10\,\text{k}\Omega)^2 + (14.29\,\text{k}\Omega)^2}} = 0.8193\ V_{R_1}$$

V_o = 0.8193(0.868 V_i) = **0.71V_i**

and $A_v = \frac{V_o}{V_i}$ = **0.71** (≅ 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 Ω, X_{C_2} = 39.8 kΩ,
$V_{R_1} = 0.532\ V_i$, $V_o = 0.97\ V_{R_1}$
V_o = **0.52 V_i**

f = 4 kHz: X_{C_1} = 19.89 Ω, X_{C_2} = 4.97 kΩ,
$V_{R_1} = 0.981\ V_i$, $V_o = 0.445\ V_{R_1}$
V_o = **0.44 V_i**

b. Using 0.707(.711) = 0.5026 ≅ 0.5 to define the bandwidth

BW = 3.4 kHz – 0.49 kHz = 2.91 kHz

and BW ≅ **2.9 kHz**

with $f_{\text{center}} = 490 \text{ Hz} + \left(\frac{2.9 \text{ kHz}}{2}\right)$ = **1940 Hz**

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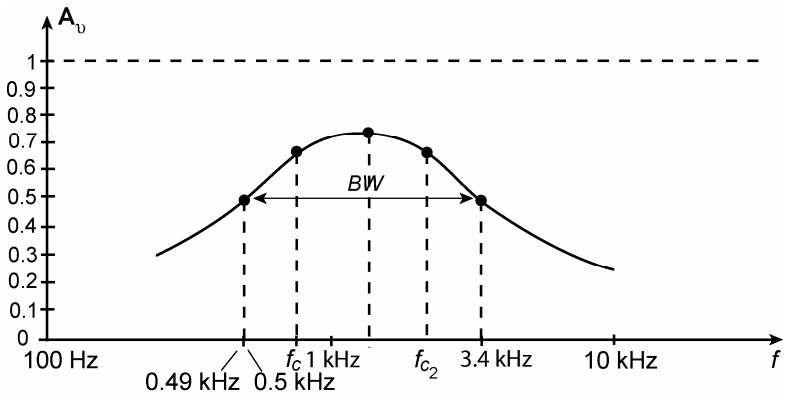


28. $f_1 = \dfrac{1}{2\pi R_1 C_1} = 4 \text{ kHz}$

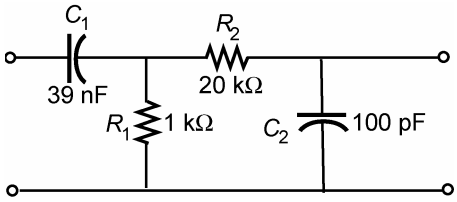
Choose $R_1 = 1 \text{ k}\Omega$

$$C_1 = \frac{1}{2\pi f_1 R_1} = \frac{1}{2\pi(4 \text{ kHz})(1 \text{ k}\Omega)} = 39.8 \text{ nF} \quad \therefore \text{ Use } \mathbf{39\ nF}$$

$f_2 = \dfrac{1}{2\pi R_2 C_2} = 80 \text{ kHz}$

Choose $R_2 = 20 \text{ k}\Omega$

$$C_2 = \frac{1}{2\pi f_2 R_2} = \frac{1}{2\pi(80 \text{ kHz})(20 \text{ k}\Omega)} = 99.47 \text{ pF} \quad \therefore \text{ Use } 100 \text{ pF}$$



Center frequency = $4 \text{ kHz} + \dfrac{80 \text{ kHz} - 4 \text{ kHz}}{2} = 42 \text{ kHz}$

At $f = 42$ kHz, $X_{C_1} = 97.16\ \Omega$, $X_{C_2} = 37.89\ \text{k}\Omega$

Assuming $\boldsymbol{Z}_2 \gg \boldsymbol{Z}_1$

$$|V_{R_1}| = \frac{R_1(V_i)}{\sqrt{R_1^2 + X_{C_1}^2}} = 0.995 V_i$$

$$|V_o| = \frac{X_{C_2}(V_{R_1})}{\sqrt{R_2^2 + X_{C_1}^2}} = 0.884 V_i$$

$V_o = 0.884 V_{R_1} = 0.884(0.995 V_i) = \mathbf{0.88\ V_i}$

as $f = f_1$: $V_{R_1} = 0.707 V_i$, $X_{C_2} = 221.05\ \text{k}\Omega$

and $V_o = 0.996 V_{R_1}$

so that $V_o = 0.996 V_{R_1} = 0.996(0.707 V_i) = 0.704 V_i$

Although $A_v = 0.88$ is less than the desired level of 1, f_1 and f_2 do define a band of frequencies for which $A_v \geq 0.7$ and the power to the load is significant.

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29. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(5\text{ mH})(500\text{ pF})}} = \mathbf{100.66\ kHz}$

b. $Q_s = \dfrac{X_L}{R + R_\ell} = \dfrac{2\pi(100.658\text{ kHz})(5\text{ mH})}{160\,\Omega + 12\,\Omega} = \mathbf{18.39}$

$BW = \dfrac{f_s}{Q_s} = \dfrac{100.658\text{ kHz}}{18.39} = \mathbf{5{,}473.52\ Hz}$

c. At $f = f_s$: $V_{o_{\max}} = \dfrac{R}{R + R_\ell} V_i = \dfrac{160\,\Omega(1\text{ V})}{172\,\Omega} = 0.93\text{ V}$ and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.93}$

Since $Q_s \geq 10$, $f_1 = f_s - \dfrac{BW}{2} = 100.658\text{ kHz} - \dfrac{5{,}473.52\text{ Hz}}{2} = 97{,}921.24\text{ Hz}$

$f_2 = f_s + \dfrac{BW}{2} = 103{,}394.76\text{ Hz}$

At $f = 95$ kHz: $X_L = 2\pi fL = 2\pi(95 \times 10^3\text{ Hz})(5\text{ mH}) = 2.98\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(95\times10^3\text{ Hz})(500\text{ pF})} = 3.35\text{ k}\Omega$

$\mathbf{V}_o = \dfrac{160\,\Omega(1\text{ V}\angle0°)}{172 + j2.98\text{ k}\Omega - j3.35\text{ k}\Omega} = \dfrac{160\text{ V}\angle0°}{172 - j370}$

$= \dfrac{160\text{ V}\angle0°}{480\angle -65.07°} = \mathbf{0.39\ V\angle 65.07°}$

At $f = 105$ kHz: $X_L = 2\pi fL = 2\pi(105\text{ kHz})(5\text{ mH}) = 3.3\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(105\text{ kHz})(500\text{ pF})} = 3.03\text{ k}\Omega$

$\mathbf{V}_o = \dfrac{160\,(1\text{ V}\angle0°)}{172 + j3.3\text{ k}\Omega - j3.03\text{ k}\Omega} = \dfrac{160\text{ V}\angle0°}{172 + j270}$

$= \dfrac{160\text{ V}\angle0°}{320\angle57.50°} = \mathbf{0.5\angle -57.50°}$

d. $f = f_s$: $V_{o_{\max}} = \mathbf{0.93\ V}$

$f = f_1 = 97{,}921.24$ Hz, $V_o = 0.707(0.93\text{ V}) = \mathbf{0.66\ V}$

$f = f_2 = 103{,}394.76$ Hz, $V_o = 0.707(0.93\text{ V}) = \mathbf{0.66\ V}$

30. a. $f_p = \dfrac{1}{2\pi\sqrt{LC}}\sqrt{1 - \dfrac{R_\ell^2 C}{L}} \cong \mathbf{159.15\ kHz}$

$Q_\ell = \dfrac{X_L}{R_\ell} = \dfrac{2\pi f_p L}{R_\ell} = \dfrac{2\pi(159.15\text{ kHz})(1\text{ mH})}{16\,\Omega} = 62.5 \gg 10$

$Z_{T_p} = Q_\ell^2 R_\ell = (62.5)^2\ 16\,\Omega = 62.5\text{ k}\Omega \gg 4\text{ k}\Omega$

and $V_o \cong V_i$ at resonance.

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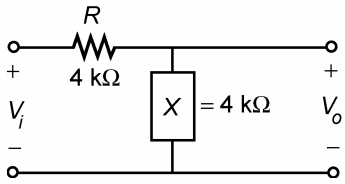
However, $R = 4\ \text{k}\Omega$ affects the shape of the resonance curve and $BW = f_p/Q_\ell$ cannot be applied.

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 $\boldsymbol{Z}_L = R_\ell + jX_L \cong X_L$
and $X = X_L \,||\, X_C$.

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 $BW = 2(18.75\ \text{kHz}) =$ **37.5 kHz**

b. $$Q_p = \frac{f_p}{BW} = \frac{159.15\,\text{kHz}}{37.5\,\text{kHz}} = \mathbf{4.24}$$

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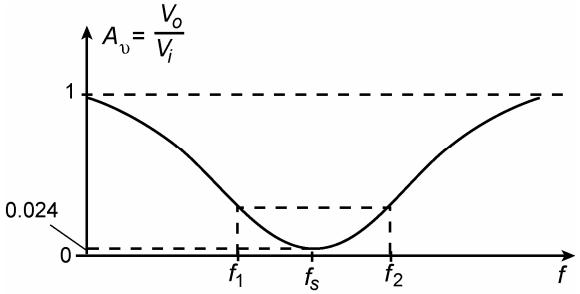
31. a. $$Q_s = \frac{X_L}{R + R_\ell} = \frac{5000\,\Omega}{400\,\Omega + 10\,\Omega} = \frac{5000\,\Omega}{410\,\Omega} = \mathbf{12.2}$$

b. $$BW = \frac{f_s}{Q_s} = \frac{5000\text{ Hz}}{12.2} = \mathbf{409.84\text{ Hz}}$$

$$f_1 = 5000\text{ Hz} - \frac{409.84\text{ Hz}}{2} = \mathbf{4.80\text{ kHz}}$$

$$f_2 = 5000\text{ Hz} + \frac{410\text{ Hz}}{2} = \mathbf{5.20\text{ kHz}}$$

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, $$V_o = \frac{32\,\text{k}\Omega\,V_i}{32\,\text{k}\Omega + 1\,\text{k}\Omega} = 0.97V_i$$

and $$A_v = \frac{V_o}{V_i} = 0.97$$

For the low cutoff frequency note solution to Problem 30:

$$f_1^2 + \frac{1}{2\pi RC} f_1 - \frac{1}{4\pi^2 LC} = 0$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(20\text{ kHz})(400\,\Omega)} = 19.9\text{ nF}$$

$$L = \frac{X_L}{2\pi f} = \frac{400\,\Omega}{2\pi(20\text{ kHz})} = 3.18\text{ mH}$$

Substituting into the above equation and solving

$f_1 = 16.4$ kHz

with $\frac{BW}{2} = 20\text{ kHz} - 16.4\text{ kHz} = 3.6\text{ kHz}$

and $BW = 2(3.6\text{ kHz}) = \mathbf{7.2\text{ kHz}}$

$$Q_p = \frac{f_p}{BW} = \frac{20\text{ kHz}}{7.2\text{ kHz}} = \mathbf{2.78}$$

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b. –

c. At resonance

$$Z_{T_p} = 32\ \text{k}\Omega \,||\, 100\ \text{k}\Omega = 24.24\ \text{k}\Omega$$

$$\text{with } V_o = \frac{24.24\,\text{k}\Omega\, V_i}{24.24\,\text{k}\Omega + 1\,\text{k}\Omega} = 0.96V_i$$

$$\text{and } A_v = \frac{V_o}{V_i} = 0.96 \text{ vs } 0.97 \text{ above}$$

At frequencies to the right and left of f_p, the impedance Z_{T_p} will decrease and be affected less and less by the parallel 100 kΩ load. The characteristics, therefore, are only slightly affected by the 100 kΩ load.

d. At resonance

$$Z_{T_p} = 32\ \text{k}\Omega \,||\, 20\ \text{k}\Omega = 12.31\ \text{k}\Omega$$

$$\text{with } V_o = \frac{12.31\,\text{k}\Omega\, V_i}{12.31\,\text{k}\Omega + 1\,\text{k}\Omega} = 0.925V_i \text{ vs } 0.97\ V_i \text{ above}$$

At frequencies to the right and left of f_p, the impedance of each frequency will actually be less due to the parallel 20 kΩ load. The effect will be to narrow the resonance curve and decrease the bandwidth with an increase in Q_p.

33. a. $f_p = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(400\ \mu\text{H})(120\ \text{pF})}} =$ **726.44 kHz** (band-stop)

$$X_{L_s}\angle 90° + \left(X_{L_p}\angle 90° \,||\, X_C \angle -90°\right) = 0$$

$$jX_{L_s} + \frac{\left(X_{L_p}\angle 90°\right)\left(X_C \angle -90°\right)}{jX_{L_p} - jX_C} = 0$$

$$jX_{L_s} + \frac{X_{L_p}X_C}{j\left(X_{L_p} - X_C\right)} = 0$$

$$jX_{L_s} - j\frac{X_{L_p}X_C}{\left(X_{L_p} - X_C\right)} = 0$$

$$X_{L_s} - \frac{X_{L_p}X_C}{X_{L_p} - X_C} = 0$$

$$X_{L_s}X_C - X_{L_s}X_{L_p} + X_{L_p}X_C = 0$$

$$\frac{\omega L_s}{\omega C} - \omega L_s + \frac{\omega L_p}{\omega C} = 0$$

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$$L_sL_p\omega^2 - \frac{1}{C}\left[L_s + L_p\right] = 0$$

$$\omega = \sqrt{\frac{L_s + L_p}{CL_sL_p}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{L_s + L_p}{CL_sL_p}} = \frac{1}{2\pi}\sqrt{\frac{460\times10^{-6}}{28.8\times10^{-19}}} = \mathbf{2.01\ MHz}\ \text{(pass-band)}$$

34. a. $$f_s = \frac{1}{2\pi\sqrt{LC}} \Rightarrow L_s = \frac{1}{4\pi^2 f_s^2 C} = \frac{1}{4\pi^2(100\ \text{kHz})^2(200\ \text{pF})} = 12.68\ \text{mH}$$

$X_L = 2\pi fL = 2\pi(30\ \text{kHz})(12.68\ \text{mH}) = 2388.91\ \Omega$

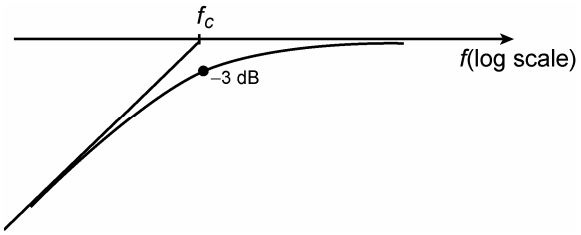
$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(30\ \text{kHz})(200\ \text{pF})} = 26.54\ \text{k}\Omega$$

$X_C - X_L = 26.54\ \text{k}\Omega - 2388.91\ \Omega = 24.15\ \text{k}\Omega(C)$

$$X_{L_p} = X_{C_{(\text{net})}} = 24.15\ \text{k}\Omega$$

$$L_p = \frac{X_L}{2\pi f} = \frac{24.15\ \text{k}\Omega}{2\pi(30\ \text{kHz})} = \mathbf{128.19\ mH}$$

35. a, b. $$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(0.47\ \text{k}\Omega)(0.05\ \mu\text{F})} = \mathbf{772.55\ Hz}$$



c. $f = \frac{1}{2}f_c$: $$A_{v_{\text{dB}}} = 20\log_{10}\frac{1}{\sqrt{1+\left(f_c/f\right)^2}} = 20\log_{10}\frac{1}{\sqrt{1+(2)^2}} = \mathbf{-7\ dB}$$

$f = 2f_c$: $$A_{v_{\text{dB}}} = 20\log_{10}\frac{1}{\sqrt{1+(0.5)^2}} = \mathbf{-0.969\ dB}$$

$f = \frac{1}{10}f_c$: $$A_{v_{\text{dB}}} = 20\log_{10}\frac{1}{\sqrt{1+(10)^2}} = \mathbf{-20.04\ dB}$$

$f = 10f_c$: $$A_{v_{\text{dB}}} = 20\log_{10}\frac{1}{\sqrt{1+(0.1)^2}} = \mathbf{-0.043\ dB}$$

d. $f = \frac{1}{2}f_c$: $$A_v = \frac{1}{\sqrt{1+\left(f_c/f\right)^2}} = \frac{1}{\sqrt{1+(2)^2}} = \mathbf{0.447}$$

$f = 2f_c$: $$A_v = \frac{1}{\sqrt{1+(0.5)^2}} = \mathbf{0.894}$$

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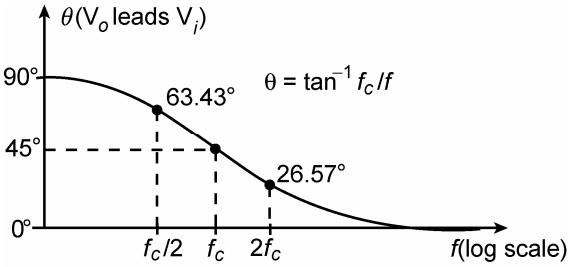
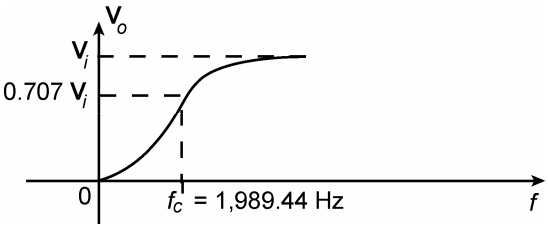
e.



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 $$V_o = \left(\frac{1}{\sqrt{1+(f_c/f)^2}}\right)V_i$$



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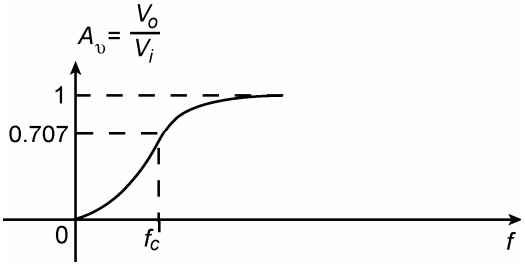
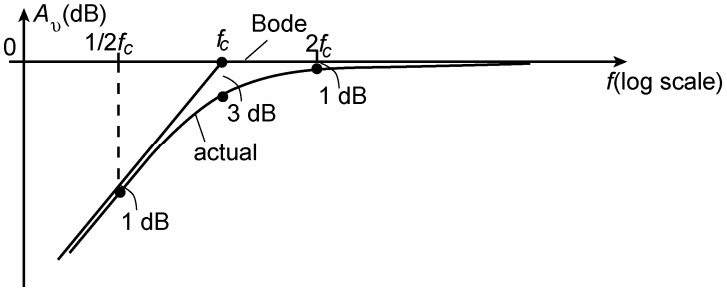


c. & d.



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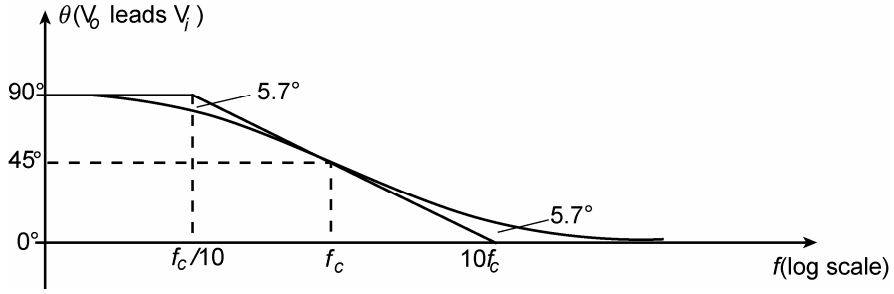
e. Remember the log scale! $1.5f_c$ is not midway between f_c and $2f_c$

$$A_{v_{dB}} = 20 \log_{10} A_v$$
$$-1.5 = 20 \log_{10} A_v$$
$$-0.075 = \log_{10} A_v$$
$$A_v = \frac{V_o}{V_i} = \mathbf{0.84}$$

f. $\theta = \tan^{-1} f_c/f$



37. a, b. $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = A_v \angle\theta = \dfrac{1}{\sqrt{1 + (f/f_c)^2}} \angle -\tan^{-1} f/f_c$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(12\,\text{k}\Omega)(1\,\text{nF})} = \mathbf{13.26\ kHz}$$

c. $f = f_c/2 = 6.63$ kHz

$$A_{v_{dB}} = 20 \log_{10} \frac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{-0.97\ dB}$$

$f = 2f_c = 26.52$ kHz

$$A_{v_{dB}} = 20 \log_{10} \frac{1}{\sqrt{1 + (2)^2}} = \mathbf{-6.99\ dB}$$

$f = f_c/10 = 1.326$ kHz

$$A_{v_{dB}} = 20 \log_{10} \frac{1}{\sqrt{1 + (0.1)^2}} = \mathbf{-0.04\ dB}$$

$f = 10f_c = 132.6$ kHz

$$A_{v_{dB}} = 20 \log_{10} \frac{1}{\sqrt{1 + (10)^2}} = \mathbf{-20.04\ dB}$$

d. $f = f_c/2$: $\quad A_v = \dfrac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{0.894}$

$f = 2f_c$: $\quad A_v = \dfrac{1}{\sqrt{1 + (2)^2}} = \mathbf{0.447}$

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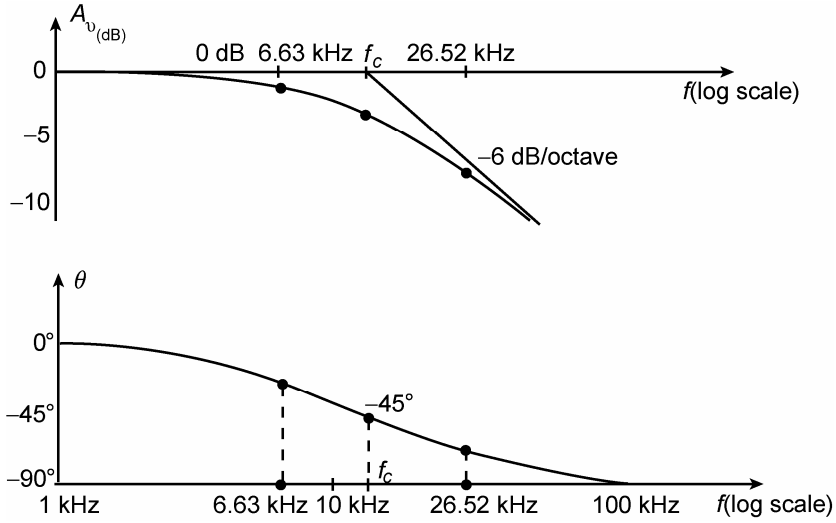
e. $\theta = \tan^{-1} f/f_c$

$f = f_c/2$: $\theta = -\tan^{-1} 0.5 = -26.57°$

$f = f_c$: $\theta = -\tan^{-1} 1 = -45°$

$f = 2f_c$: $\theta = -\tan^{-1} 2 = -63.43°$



38. a. $$R_2 \,||\, X_C = \frac{(R_2)(-jX_C)}{R_2 - jX_C} = -j\frac{R_2X_C}{R_2 - jX_C}$$

$$\mathbf{V}_o = \frac{\left(\frac{-jR_2X_C}{R_2 - jX_C}\right)\mathbf{V}_i}{R_1 - j\frac{R_2X_C}{R_2 - jX_C}} = -j\frac{R_2X_C\mathbf{V}_i}{R_1(R_2 - jX_C) - jR_2X_C}$$

$$= \frac{-jR_2X_C\mathbf{V}_i}{R_1R_2 - jR_1X_C - jR_2X_C} = \frac{-jR_2X_C\mathbf{V}_i}{R_1R_2 - j(R_1 + R_2)X_C}$$

$$= \frac{R_2X_C\mathbf{V}_i}{jR_1R_2 + (R_1 + R_2)X_C} = \frac{R_2\mathbf{V}_i}{j\frac{R_1R_2}{X_C} + (R_1 + R_2)}$$

$$= \frac{R_2\mathbf{V}_i}{R_1 + R_2 + j\frac{R_1R_2}{X_C}} = \frac{\left(\frac{R_2}{R_1 + R_2}\right)\mathbf{V}_i}{1 + j\left(\frac{R_1R_2}{R_1 + R_2}\right)\frac{1}{X_C}}$$

and $$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{\frac{R_2}{R_1 + R_2}}{1 + j\omega\left(\frac{R_1R_2}{R_1 + R_2}\right)C}$$

or $$\mathbf{A}_v = \frac{R_2}{R_1 + R_2}\left[\frac{1}{1 + j2\pi f(R_1 \,||\, R_2)C}\right]$$

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defining $f_c = \dfrac{1}{2\pi(R_1 \,||\, R_2)C}$

$$\mathbf{A}_v = \frac{R_2}{R_1 + R_2}\left[\frac{1}{1 + j\, f/f_c}\right]$$

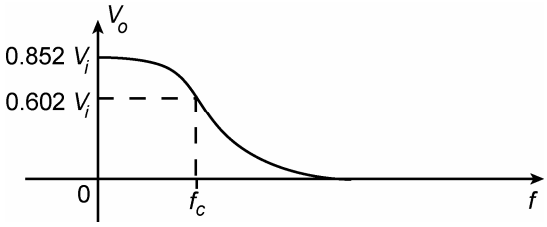
$$\text{and } \mathbf{A}_v = \frac{R_2}{R_1 + R_2}\left[\frac{1}{\sqrt{1 + (f/f_c)^2}} \angle -\tan^{-1} f/f_c\right]$$

$$\text{with } |V_o| = \frac{R_2}{R_1 + R_2}\left[\frac{1}{\sqrt{1 + (f/f_c)^2}}\right]|V_i|$$

$$\text{for } f \ll f_c,\ V_o = \frac{R_2}{R_1 + R_2}V_i = \frac{27\,\text{k}\Omega}{4.7\,\text{k}\Omega + 27\,\text{k}\Omega}V_i = 0.852V_i$$

$$\text{at } f = f_c\text{:}\quad V_o = 0.852[0.707]V_i = 0.602V_i$$

$$f_c = \frac{1}{2\pi(R_1 \,||\, R_2)C} = \mathbf{994.72\ Hz}$$



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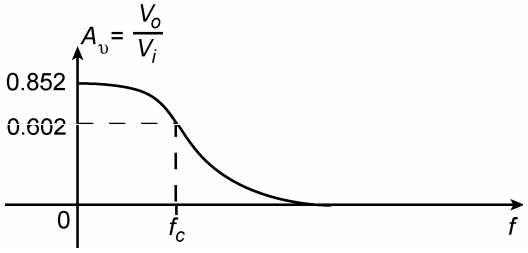
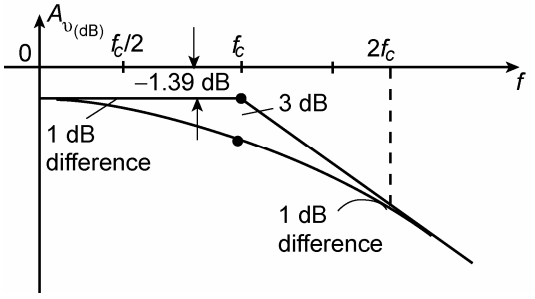


c. & d.



$$-20 \log_{10} \frac{R_1 + R_2}{R_2} = -20 \log_{10} \frac{4.7\,\text{k}\Omega + 27\,\text{k}\Omega}{27\,\text{k}\Omega}$$

$$= -20 \log_{10} 1.174 = -1.39\ \text{dB}$$

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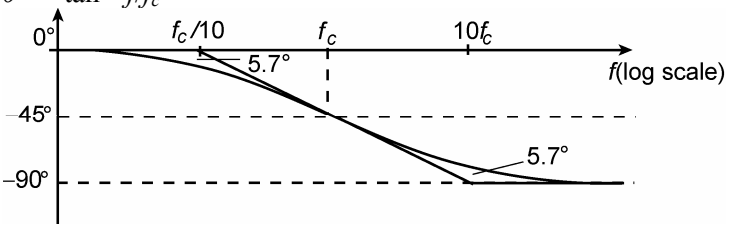
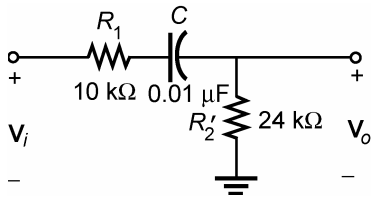
e. $A_{v_{dB}} \cong -1.39 \text{ dB} - 0.5 \text{ dB} = -1.89 \text{ dB}$

$$A_{v_{dB}} = 20 \log_{10} A_v$$
$$-1.89 = 20 \log_{10} A_v$$
$$0.0945 = \log_{10} A_v$$
$$A_v = \frac{V_o}{V_i} = \mathbf{0.80}$$

f. $\theta = -\tan^{-1} f/f_c$



39.

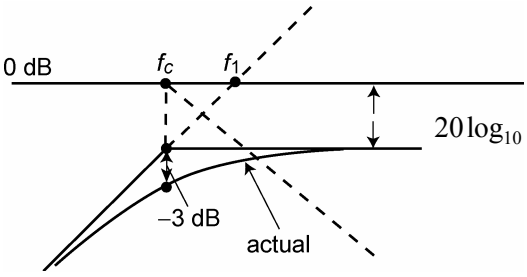


a. From Section 21.11,

$$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{j\, f/f_1}{1 + jf/f_c}$$

$$f_1 = \frac{1}{2\pi R_2' C} = \frac{1}{2\pi(24\ \text{k}\Omega)(0.01\,\mu\text{F})} = 663.15 \text{ Hz}$$

$$f_c = \frac{1}{2\pi\left(R_1 + R_2'\right)C} = \frac{1}{2\pi(10\ \text{k}\Omega + 24\,\text{k}\Omega)(0.01\,\mu\text{F})} = 468.1 \text{ Hz}$$



$$20\log_{10}\frac{f}{f_1} = 20\log_{10}\frac{f_c}{f_1}$$
$$= 20\ \log_{10}\frac{468.1 \text{ Hz}}{663.15 \text{ Hz}}$$
$$= \mathbf{-3.03\ dB}$$

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b. $\theta = 90° - \tan^{-1}\dfrac{f}{f_1} = +\tan^{-1}\dfrac{f_1}{f}$

$f = f_1$: $\theta = 45°$

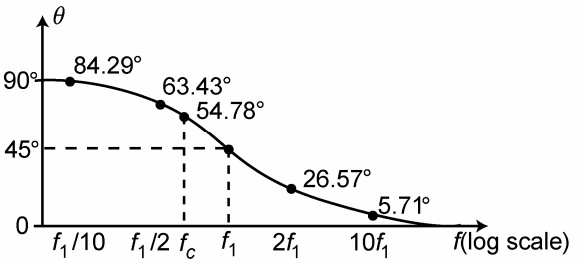
$f = f_c$: $\theta = 54.78°$

$f = \dfrac{1}{2}f_1 = 331.58$ Hz, $\theta = 63.43°$

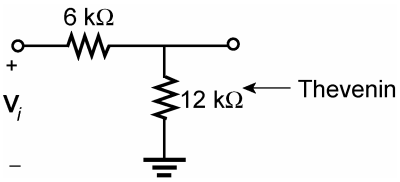
$f = \dfrac{1}{10}f_1 = 66.31$ Hz, $\theta = 84.29°$

$f = 2f_1 = 1{,}326.3$ Hz, $\theta = 26.57°$

$f = 10f_1 = 6{,}631.5$ Hz, $\theta = 5.71°$

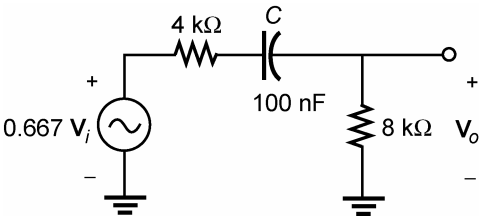


40. a.



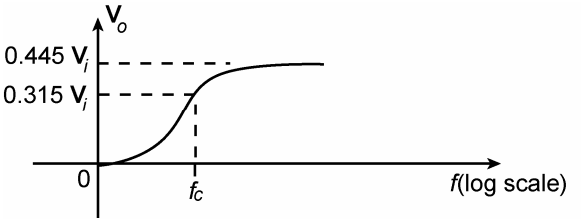
$$\mathbf{V}_{Th} = \frac{12\,\text{k}\Omega\,\mathbf{V}_i}{12\,\text{k}\Omega + 6\,\text{k}\Omega} = 0.667\,\mathbf{V}_i$$

$R_{Th} = 6\ \text{k}\Omega \parallel 12\ \text{k}\Omega = 4\ \text{k}\Omega$



$f = \infty$ Hz: ($C \Rightarrow$ short circuit)

$$\mathbf{V}_o = \frac{8\,\text{k}\Omega\,(0.667\,\mathbf{V}_i)}{8\,\text{k}\Omega + 4\,\text{k}\Omega} = 0.445\,\mathbf{V}_i$$



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voltage-divider rule: $\mathbf{V}_o = \dfrac{R_2(0.667\,\mathbf{V}_i)}{R_1 + R_2 - jX_C} = \dfrac{0.667\,R_2\mathbf{V}_i}{R_1 + R_2 - jX_C}$

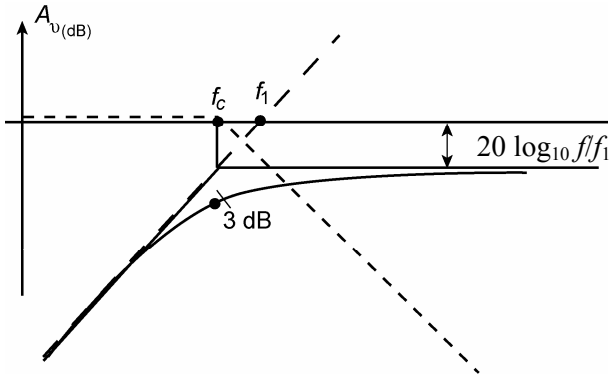
and $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{0.667R_2}{R_1 + R_2 - jX_C} = \dfrac{j2\pi f(0.667R_2)C}{1 + j2\pi f(R_1 + R_2)C}$

so that $\mathbf{A}_v = \dfrac{j\ f/f_1}{1 + j\ f/f_c}$ with $f_1 = \dfrac{1}{2\pi 0.667R_2C} = \dfrac{1}{2\pi 0.667(8\,\text{k}\Omega)(100\,\text{nF})}$

$= 298.27$ Hz

and $f_c = \dfrac{1}{2\pi(R_1 + R_2)C} = \dfrac{1}{2\pi(4\,\text{k}\Omega + 8\,\text{k}\Omega)(100\,\text{nF})}$

$= 132.63$ Hz

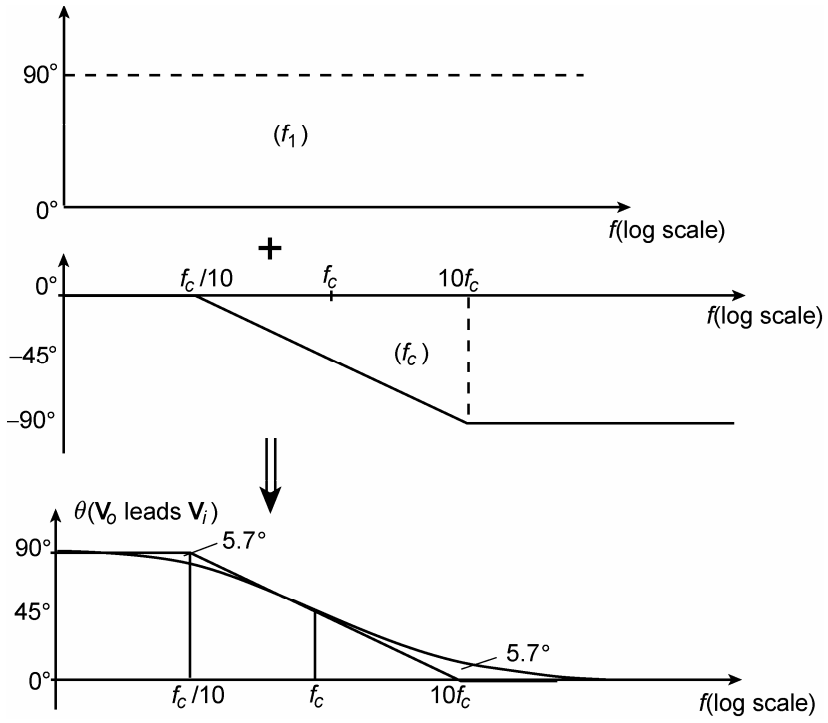


$20 \log_{10} f/f_1 = 20 \log_{10} \dfrac{132.63\,\text{Hz}}{298.27\,\text{Hz}}$

$= 20 \log_{10} 0.445 = -7.04$ dB

b. $\theta = 90° - \tan^{-1} f/f_c = +\tan^{-1} f_c/f = \tan^{-1} 132.6\ \text{Hz}/f$

or



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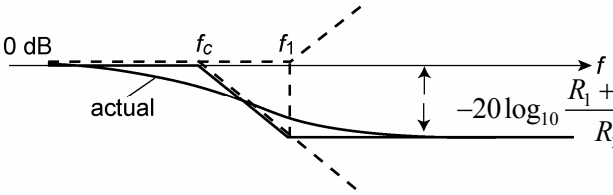
41. a. $\mathbf{A}_v = \dfrac{1 + j\dfrac{f}{f_1}}{1 + j\dfrac{f}{f_c}}$

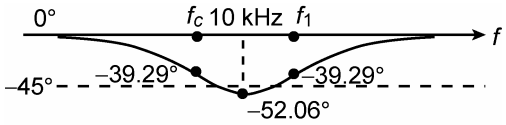
$$f_1 = \frac{1}{2\pi R_2 C} = \frac{1}{2\pi(10\,\text{k}\Omega)(800\,\text{pF})} = 19{,}894.37\ \text{Hz}$$

$$f_c = \frac{1}{2\pi(R_1 + R_2)C} = \frac{1}{2\pi(10\,\text{k}\Omega + 90\,\text{k}\Omega)(800\,\text{pF})} = 1{,}989.44\ \text{Hz}$$



$$-20\log_{10}\frac{R_1 + R_2}{R_2} = -20\log_{10}10 = \mathbf{20\,dB}$$

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 $\left(-20\log\dfrac{12\,\text{k}\Omega + 6\,\text{k}\Omega}{6\,\text{k}\Omega} = -9.54\,\text{dB}\right)$

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(b) Note Fig. 21.67.

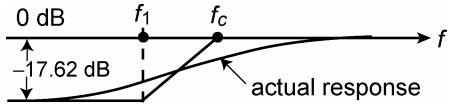
From 0° to –26.50° at f_c and f_1
$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$
At f = 1500 Hz (between f_c and f_1)
$\theta = \tan^{-1}$ 1500 Hz/2652.58 Hz – $\tan^{-1}$ 1500 Hz/884.19 Hz
$= 29.49° - 59.48° = -30°$

43. a. $$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1 - jf_1/f}{1 - jf_c/f}$$

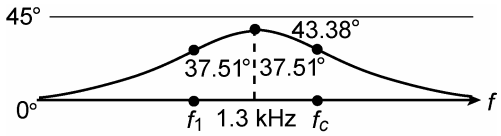
$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3\,\text{k}\Omega)(0.05\,\mu\text{F})} = 964.58\ \text{Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \,||\, R_2)C} = \frac{1}{2\pi\underbrace{(3.3\,\text{k}\Omega \,||\, 0.5\,\text{k}\Omega)}_{0.434\ \text{k}\Omega}(0.05\,\mu\text{F})} = \mathbf{7{,}334.33\ Hz}$$

$$-20\log_{10}\frac{R_1 + R_2}{R_2} = -20\log_{10}\frac{3.3\,\text{k}\Omega + 0.5\,\text{k}\Omega}{0.5\,\text{k}\Omega} = -20\log_{10} 7.6 = -17.62\ \text{dB}$$



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.

$$\mathbf{A}_v = \frac{1 - j(f_1/f)}{1 - j(f_c/f)}$$

$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3\,\text{k}\Omega)(0.05\,\mu\text{F})} = \mathbf{964.58\ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \,||\, R_2)C} = \frac{1}{2\pi\underbrace{(3.3\,\text{k}\Omega \,||\, 0.5\,\text{k}\Omega)}_{0.434\ \text{k}\Omega}0.05\,\mu\text{F}} = \mathbf{7334.33\ Hz}$$

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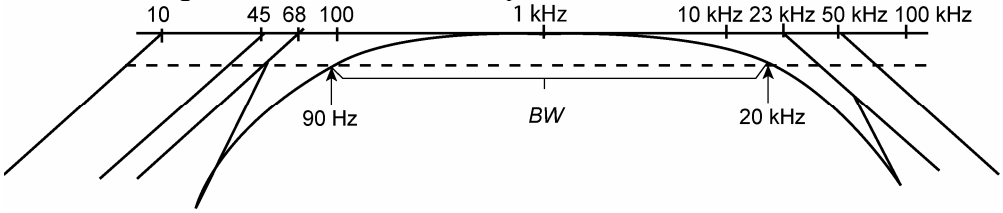
Note Fig. 21.72.

$$-20 \log_{10} \frac{R_1 + R_2}{R_2} = -20 \log_{10} \frac{3.3\,\text{k}\Omega + 0.5\,\text{k}\Omega}{0.5\,\text{k}\Omega} = -17.62 \text{ dB}$$

Asymptote at −17.62 dB from $0 \rightarrow f_1$
+6 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 Hz/3.0 kHz + $\tan^{-1}$ 7334.33 Hz/3.0 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

$\therefore BW = 20 \text{ kHz} - 90 \text{ Hz} = \mathbf{19{,}910\ Hz} \cong 20 \text{ kHz}$
$f_1 = \mathbf{90\ Hz}, f_2 = \mathbf{20\ kHz}$

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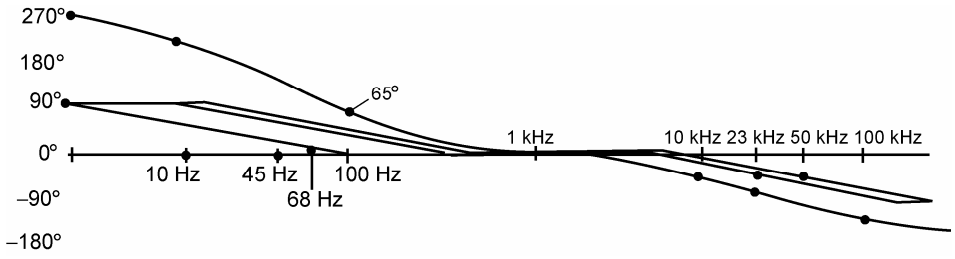


Testing: $f = 100$ Hz

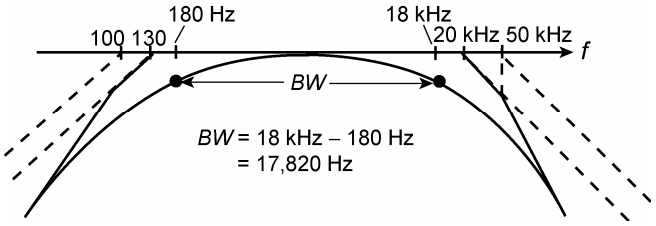
$$\theta = \tan^{-1}\frac{10\text{ Hz}}{f} + \tan^{-1}\frac{45\text{ Hz}}{f} + \tan^{-1}\frac{68\text{ Hz}}{f} - \tan^{-1}\frac{f}{23\text{ kHz}} - \tan^{-1}\frac{f}{50\text{ kHz}}$$

$= \tan^{-1} 0.1 + \tan^{-1} 0.45 + \tan^{-1} 0.68 - \tan^{-1} 0.00435 - \tan^{-1} .002$

$= 5.71° + 24.23° + 34.22° - 0.249° - 0.115°$

$=$ **63.8°** vs about 65° on the plot

45. a. $$\frac{A_v}{A_{v_{\max}}} = \frac{1}{\left(1 - j\frac{100\text{ Hz}}{f}\right)\left(1 - j\frac{130\text{ Hz}}{f}\right)\left(1 + j\frac{f}{20\text{ kHz}}\right)\left(1 + j\frac{f}{50\text{ kHz}}\right)}$$



Proximity of 100 Hz to 130 Hz will raise lower cutoff frequency above 130 Hz:

Testing: $f = 180$ Hz: (with lower terms only)

$$A_{v_{\text{dB}}} = -20\log_{10}\sqrt{1 + \left(\frac{100}{f}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{130}{f}\right)^2}$$

$$= -20\log_{10}\sqrt{1 + \left(\frac{100}{180}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{130}{180}\right)^2}$$

$= 1.17$ dB $- 1.82$ 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)

$$A_{v_{\text{dB}}} = -20\log_{10}\sqrt{1 + \left(\frac{f}{20\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{f}{50\text{ kHz}}\right)^2}$$

$$= -20\log_{10}\sqrt{1 + \left(\frac{18\text{ kHz}}{20\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{13\text{ kHz}}{20\text{ kHz}}\right)^2}$$

$= -2.576$ dB $- 0.529$ dB $=$ **–3.105 dB**

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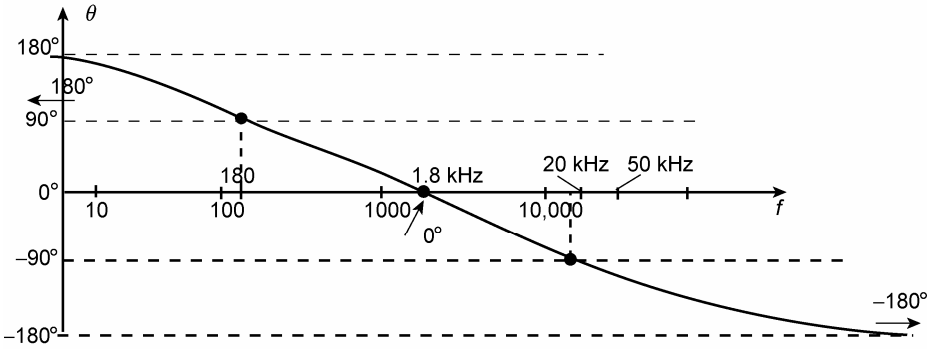
b.

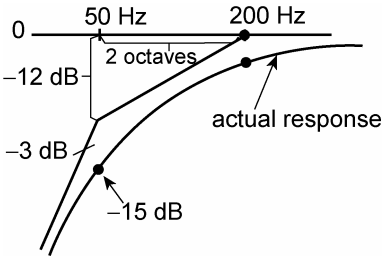


Testing: $f = 1.8$ kHz:

$$\theta = \tan^{-1}\frac{100}{1.8\text{ kHz}} + \tan^{-1}\frac{130}{1.8\text{ kHz}} - \tan^{-1}\frac{1.8\text{ kHz}}{20\text{ kHz}} - \tan^{-1}\frac{1.8\text{ kHz}}{50\text{ kHz}}$$
$$= 3.18° + 4.14° - 5.14° - 2.06°$$
$$= \mathbf{0.12°} \cong \mathbf{0°}$$

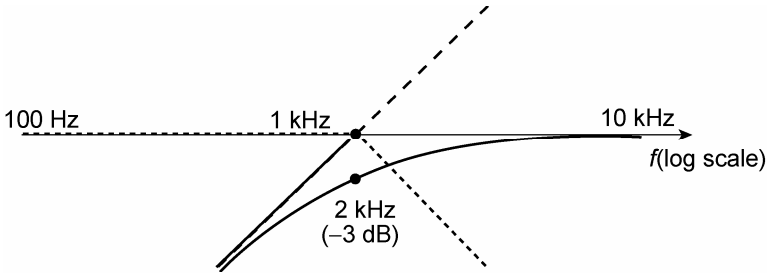
47. $f_{low} = f_{high} - BW = 36\text{ kHz} - 35.8\text{ kHz} = 0.2\text{ kHz} = 200\text{ Hz}$

$$A_v = \frac{-120}{\left(1 - j\frac{50}{f}\right)\left(1 - j\frac{200}{f}\right)\left(1 + j\frac{f}{36\text{ kHz}}\right)}$$



48. $$\mathbf{A}_v = \frac{0.05}{0.05 - j\frac{100}{f}} = \frac{1}{1 - j\frac{100}{0.05\,f}} = \frac{1}{1 - j\frac{2000}{f}} = \frac{+jf}{+jf + 2000}$$

$$= \frac{+j\frac{f}{2000}}{1 + j\frac{f}{2000}} \text{ and } f_1 = 2000\text{ Hz}$$



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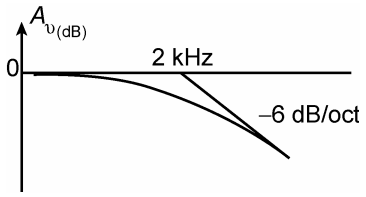
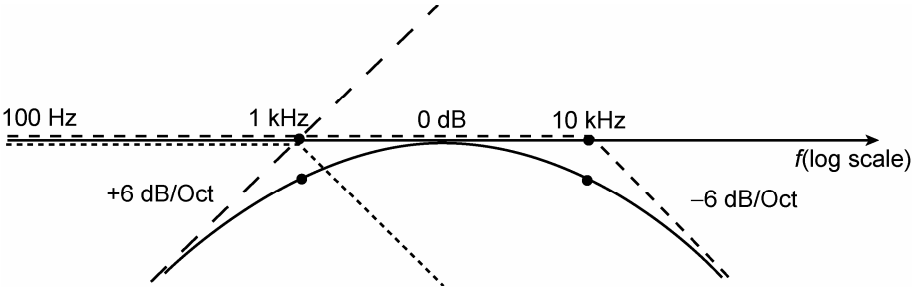
49. $\mathbf{A}_v = \dfrac{200}{200 + j0.1f} = \dfrac{1}{1 + j\dfrac{0.1f}{200}} = \dfrac{1}{1 + j\dfrac{f}{2000}}$

$A_{v_{\text{dB}}} = 20\log_{20}\dfrac{1}{\sqrt{1+\left(\dfrac{f}{2000}\right)^2}}$, $\dfrac{f}{2000} = 1$ and $f =$ **2 kHz**

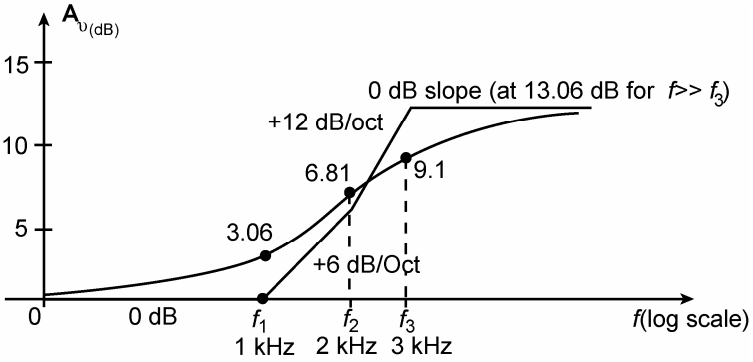


50. $\mathbf{A}_v = \dfrac{jf/1000}{(1 + jf/1000)(1 + jf/10{,}000)}$



51. $\mathbf{A}_v = \dfrac{\left(1 + j\dfrac{f}{1000}\right)\left(1 + j\dfrac{f}{2000}\right)}{\left(1 + j\dfrac{f}{3000}\right)^2}$

$\mathbf{A}_{v_{\text{dB}}} = 20\log_{10}\sqrt{1+\left(\dfrac{f_1}{1000}\right)^2} + 20\log_{10}\sqrt{1+\left(\dfrac{f_2}{2000}\right)^2} + 40\log_{10}\dfrac{1}{\sqrt{1+\left(\dfrac{f_3}{3000}\right)^2}}$



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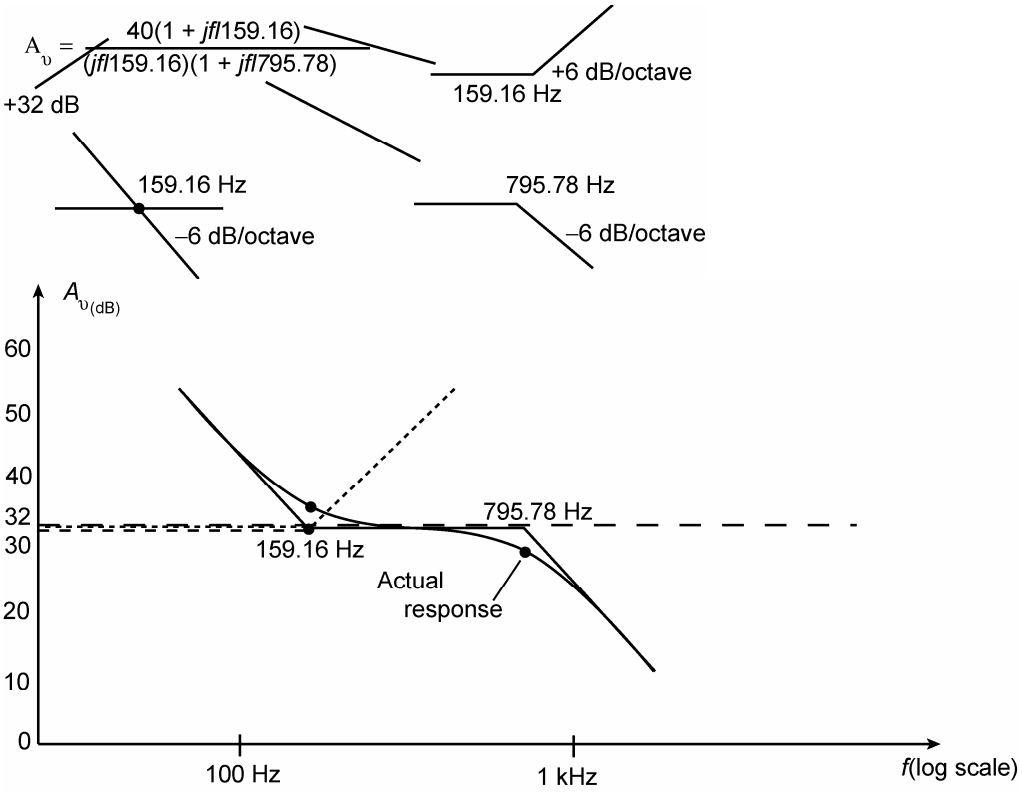
52. $\frac{j\omega}{1000} = j\frac{2\pi f}{1000} = j\frac{f}{\frac{1000}{2\pi}} = j\frac{f}{159.16\text{ Hz}}$, $\frac{j\omega}{5000} = j\frac{f}{795.78\text{ Hz}}$



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 $A_v = \frac{V_o}{V_i} =$ **0.673** vs desired 0.707 (off by less than 5%)

Tweeter − 5 kHz:

$$X_L = 2\pi fL = 2\pi(5\text{ kHz})(0.39\text{ mH}) = 12.25\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(5\text{ kHz})(2.7\ \mu\text{F})} = 11.79\ \Omega$$

$$R \parallel X_L = 8\ \Omega\angle 0° \parallel 12.25\ \Omega\angle 90° = 6.7\ \Omega\angle 33.15°$$

$$\mathbf{V}_o = \frac{(6.7\,\Omega\angle 33.15°)(\mathbf{V}_i)}{(6.7\,\Omega\angle 33.15°) - j\,11.79\,\Omega}$$

$$\mathbf{V}_o = 0.678\ \angle 88.54°\ \mathbf{V}_i$$

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and $A_v = \dfrac{V_o}{V_i} =$ **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 $A_v = \dfrac{V_o}{V_i} =$ **0.015** vs desired 0 (excellent)

Tweeter − 3 kHz:

$$X_L = 2\pi fL = 2\pi(3\text{ kHz})(0.39\text{ mH}) = 7.35\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3\text{ kHz})(2.7\ \mu\text{F})} = 19.65\ \Omega$$

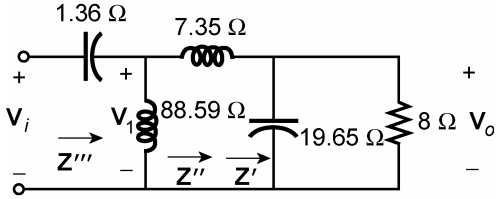
$$R \parallel X_L = 8\ \Omega\angle 0° \parallel 7.35\ \Omega\angle 90° = 5.42\ \Omega\angle 47.42°$$

$$\mathbf{V}_o = \frac{(R \parallel X_L)(\mathbf{V}_i)}{(R \parallel X_L) + jX_C} = \frac{(5.42\,\Omega\angle 47.42°)(\mathbf{V}_i)}{(5.42\,\Omega\angle 47.42°) - j\,19.65\,\Omega}$$

$$\mathbf{V}_o = 0.337\ \angle 124.24°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} =$ **0.337** (acceptable since relatively close to cut frequency for tweeter)

c. Mid-range speaker − 3 kHz:



$$\mathbf{Z}' = \overbrace{7.41\ \Omega\angle -22.15°}$$

$$\overbrace{\mathbf{Z}'' = 8.24\ \Omega\angle 33.58°}$$

$$\overbrace{\mathbf{Z}''' = 7.816\ \Omega\angle 37.79°}$$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'''\mathbf{V}_i}{\mathbf{Z}''' - jX_C} = \frac{(7.816\,\Omega\angle 37.79°)\mathbf{V}_i}{7.816\,\Omega\angle 37.79° - j1.36\,\Omega} = 1.11\ \angle 8.83°\ \mathbf{V}_i$$

$$\mathbf{V}_o = \frac{\mathbf{Z}'\mathbf{V}_1}{\mathbf{Z}' + jX_L} = \frac{(7.41\,\Omega\angle -22.15°)\mathbf{V}_i}{7.41\,\Omega\angle -22.15° + j7.35\,\Omega} = 0.998\ \angle -46.9°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} =$ **0.998** (excellent)

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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: $e_p = \mathbf{15\ V}$, $e_s = \mathbf{24\ V}$

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4. a. $E_s = \frac{N_s}{N_p} E_p = \frac{64\text{ t}}{8\text{ t}}(25\text{ V}) = \mathbf{200\ V}$

b. $\Phi_{\max} = \frac{E_p}{4.4 f N_p} = \frac{25\text{ V}}{4.44(60\text{ Hz})(8\text{ t})} = \mathbf{11.73\ mWb}$

5. a. $E_s = \frac{N_s}{N_p} E_p = \frac{30\text{ t}}{240\text{ t}}(25\text{ V}) = \mathbf{3.13\ V}$

b. $\Phi_{m(\max)} = \frac{E_p}{4.44\ f N_p} = \frac{25\text{ V}}{(4.44)(60\text{ Hz})(240\text{ t})} = \mathbf{391.02\ \mu Wb}$

6. $E_p = \frac{N_p}{N_s} E_s = \frac{60\text{ t}}{720\text{ t}}\ (240\text{ V}) = \mathbf{20\ V}$

7. $f = \frac{E_p}{(4.44) N_p \Phi_{m(\max)}} = \frac{25\text{ V}}{(4.44)(8\text{ t})(12.5\text{ mWb})} = \mathbf{56.31\ Hz}$

8. a. $I_L = aI_p = \left(\frac{1}{5}\right)(2\text{ A}) = \mathbf{0.4\ A}$

$V_L = I_L Z_L = \left(\frac{2}{5}\text{ A}\right)(2\ \Omega) = \mathbf{0.8\ V}$

b. $Z_{\text{in}} = a^2 Z_L = \left(\frac{1}{5}\right)^2 2\ \Omega = \mathbf{0.08\ \Omega}$

9. $Z_p = \frac{V_g}{I_p} = \frac{1600\text{ V}}{4\text{ A}} = \mathbf{400\ \Omega}$

10. $V_g = aV_L = \left(\frac{1}{4}\right)(1200\text{ V}) = \mathbf{300\ V}$

$I_p = \frac{V_g}{Z_i} = \frac{300\text{ V}}{4\ \Omega} = \mathbf{75\ A}$

11. $I_L = I_s = \frac{V_L}{Z_L} = \frac{240\text{ V}}{20\ \Omega} = 12\text{ A}$

$\frac{I_s}{I_p} = a = \frac{N_p}{N_s} \Rightarrow \frac{12\text{ A}}{0.05\text{ A}} = \frac{N_p}{50}$

$N_p = \frac{50(12)}{0.05} = \mathbf{12{,}000\ turns}$

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12. a. $a = \dfrac{N_p}{N_s} = \dfrac{400\text{ t}}{1200\text{ t}} = \dfrac{1}{3}$

$Z_i = a^2 Z_L = \left(\dfrac{1}{3}\right)^2 [9\ \Omega + j12\ \Omega] = 1\ \Omega + j1.333\ \Omega = 1.667\ \Omega\ \angle 53.13°$

$I_p = V_g / Z_i = 100\text{ V}/1.667\ \Omega = \mathbf{60\text{ A}}$

b. $I_L = aI_p = \dfrac{1}{3}\ (60\text{ A}) = \mathbf{20\text{ A}}$, $V_L = I_L Z_L = (20\text{ A})(15\ \Omega) = \mathbf{300\text{ V}}$

13. a. $Z_p = a^2 Z_L \Rightarrow a = \sqrt{\dfrac{Z_p}{Z_L}}$

$Z_p = \dfrac{V_p}{I_p} = \dfrac{10\text{ V}}{20\text{ V}/72\ \Omega} = 36\ \Omega$

$a = \sqrt{\dfrac{36\ \Omega}{4\ \Omega}} = \mathbf{3}$

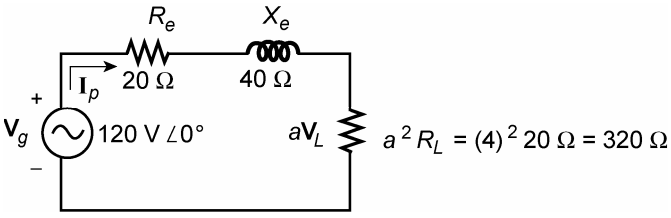
b. $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p} = \dfrac{1}{3} \Rightarrow V_s = \dfrac{1}{3}V_p = \dfrac{1}{3}(10\text{ V}) = \mathbf{3\frac{1}{3}\text{ V}}$

$P = \dfrac{V_s^2}{Z_s} = \dfrac{(3.33\text{ V})^2}{4\ \Omega} = \mathbf{2.78\text{ W}}$

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. $\mathbf{I}_p = \dfrac{\mathbf{V}_g}{\mathbf{Z}_p} = \dfrac{120\text{ V}\ \angle 0°}{20\ \Omega + 320\ \Omega + j40\ \Omega} = \dfrac{120\text{ V}\ \angle 0°}{340\ \Omega + j40\ \Omega} = \mathbf{0.351\text{ A}\ \angle -6.71°}$

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 $\mathbf{V}_L = a\mathbf{I}_p R_L \angle 0° = (4)(0.351\text{ A}\ \angle -6.71°)(20\ \Omega\ \angle 0°) = \mathbf{28.1\text{ V}\ \angle -6.71°}$

f. –

g. $V_L = \dfrac{N_s}{N_p} V_g = \dfrac{1}{4}(120\text{ V}) = \mathbf{30\text{ V}}$

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15. a. $a = \dfrac{N_p}{N_s} = \dfrac{4\text{ t}}{1\text{ t}} = 4$

$R_e = R_p + a^2R_s = 4\ \Omega + (4)^2\ 1\ \Omega = 20\ \Omega$

$X_e = X_p + a^2X_s = 8\ \Omega + (4)^2\ 2\ \Omega = 40\ \Omega$

$\mathbf{Z}_p = \mathbf{Z}_{R_e} + \mathbf{Z}_{X_e} + a^2\mathbf{Z}_{X_L} = 20\ \Omega + j40\ \Omega + j(4)^2\ 20\ \Omega$

$= 20\ \Omega + j40\ \Omega + j320\ \Omega = 20\ \Omega + j360\ \Omega = \mathbf{360.56\ \Omega\ \angle 86.82°}$

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. $\mathbf{V}_{R_e} = (I\angle\theta)(R_e\angle 0°) = (332.82\text{ mA}\ \angle -86.82°)(20\ \Omega\ \angle 0°)$

$= \mathbf{6.66\ V\ \angle -86.82°}$

$\mathbf{V}_{X_e} = (I\angle\theta)(X_e\angle 90°) = (332.82\text{ mA}\ \angle -86.32°)(40\ \Omega\ \angle 90°)$

$= \mathbf{13.31\ V\ \angle 3.18°}$

$\mathbf{V}_{X_L} = \mathbf{I}(a^2\ Z_{X_L}) = (332.82\text{ mA}\ \angle -86.82°)(320\ \Omega\ \angle 90°)$

$= \mathbf{106.50\ V\ \angle 3.18°}$

16. a. $a = N_p/N_s = 4\text{ t}/1\text{ t} = 4$, $R_e = R_p + a^2R_s = 4\ \Omega + (4)^2\ 1\ \Omega = 20\ \Omega$

$X_e = X_p + a^2X_s = 8\ \Omega + (4)^2\ 2\ \Omega = 40\ \Omega$

$\mathbf{Z}_p = R_e + jX_e - ja^2X_C = 20\ \Omega + j40\ \Omega - j(4)^2\ 20\ \Omega$

$= 20\ \Omega - j280\ \Omega = \mathbf{280.71\ \Omega\ \angle -85.91°}$

b. $\mathbf{I}_p = \dfrac{\mathbf{V}_g}{\mathbf{Z}_p} = \dfrac{120\text{ V}\ \angle 0°}{280.71\ \Omega\ \angle -85.91°} = \mathbf{0.43\ A\ \angle 85.91°}$

c. $\mathbf{V}_{R_e} = (I_p\angle\theta)(R_e\angle 0°) = (0.427\text{ A}\ \angle 85.91°)(20\ \Omega\ \angle 0°) = \mathbf{8.54\ V\ \angle 85.91°}$

$\mathbf{V}_{X_e} = (I_p\angle\theta)(X_e\angle 90°) = (0.427\text{ A}\ \angle 85.91°)(40\ \Omega\ \angle 90°) = \mathbf{17.08\ V\ \angle 175.91°}$

$\mathbf{V}_{X_C} = (I_p\angle\theta)(a^2X_C\angle -90°) = (0.427\text{ A}\ \angle 85.91°)(320\ \Omega\ \angle -90°) = \mathbf{136.64\ V\ \angle -4.09°}$

17. –

18. Coil 1: $L_1 - M_{12}$

Coil 2: $L_2 - M_{12}$

$L_T = L_1 + L_2 - 2M_{12} = 4\text{ H} + 7\text{ H} - 2(1\text{ H}) = \mathbf{9\ H}$

19. $L_{T_{(+)}} = L_1 + L_2 + 2M_{12}$

$M_{12} = k\sqrt{L_1L_2} = (0.8)\sqrt{(200\text{ mH})(600\text{ mH})} = \mathbf{277\ mH}$

$L_{T_{(+)}} = 200\text{ mH} + 600\text{ mH} + 2(277\text{ mH}) = \mathbf{1.35\ H}$

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20. $M_{23} = k\sqrt{L_2 L_3} = 1\sqrt{(1\text{ H})(4\text{ H})} = 2\text{ H}$

Coil 1: $L_1 + M_{12} - M_{13} = 2\text{ H} + 0.2\text{ H} - 0.1\text{ H} = 2.1\text{ H}$

Coil 2: $L_2 + M_{12} - M_{23} = 1\text{ H} + 0.2\text{ H} - 2\text{ H} = -0.8\text{ H}$

Coil 3: $L_3 - M_{23} - M_{13} = 4\text{ H} - 2\text{ H} - 0.1\text{ H} = 1.9\text{ H}$

$L_T = 2.1\text{ H} - 0.8\text{ H} + 1.9\text{ H} = \mathbf{3.2\text{ H}}$

21. $\mathbf{E}_1 - \mathbf{I}_1[\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}] - \mathbf{I}_2[\mathbf{Z}_m] = 0$

$\mathbf{I}_2[\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}] + \mathbf{I}_1[\mathbf{Z}_m] = 0$

$\mathbf{I}_1(\mathbf{Z}_{R_1} + \mathbf{Z}_{L_1}) + \mathbf{I}_2(\mathbf{Z}_m) = \mathbf{E}_1$

$\mathbf{I}_1(\mathbf{Z}_m) + \mathbf{I}_2(\mathbf{Z}_{L_2} + \mathbf{Z}_{R_L}) = 0 \qquad X_m = -\omega M \angle 90°$

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22. $\mathbf{Z}_i = \mathbf{Z}_p + \dfrac{(\omega M)^2}{\mathbf{Z}_s + \mathbf{Z}_L} = R_p + j\,X_{L_p} + \dfrac{(\omega M)^2}{R_s + jX_{L_s} + R_L}$

$R_p = 2\ \Omega,\ X_{L_p} = \omega L_p = (10^3\text{ rad/s})(8\text{ H}) = 8\text{ k}\Omega$

$R_s = 1\ \Omega,\ X_{L_s} = \omega L_s = (10^3\text{ rad/s})(2\text{ H}) = 2\text{ k}\Omega$

$M = k\sqrt{L_p L_s} = 0.05\sqrt{(8\text{ H})(2\text{ H})} = 0.2\text{ H}$

$$\mathbf{Z}_i = 2\ \Omega + j8\text{ k}\Omega + \frac{(10^3\text{ rad/s}\cdot 0.2\text{ H})^2}{1\,\Omega + j2\,\text{k}\,\Omega + 20\,\Omega}$$

$$= 2\ \Omega + j8\text{ k}\Omega + \frac{4\times 10^4\ \Omega}{21 + j2\times 10^3}$$

$= 2\ \Omega + j8\text{ k}\Omega + 0.21\ \Omega - j19.99\ \Omega = 2.21\ \Omega + j7980\ \Omega$

$\mathbf{Z}_i = \mathbf{7980\ \Omega\ \angle 89.98°}$

23. a. $a = \dfrac{N_p}{N_s} = \dfrac{V_p}{V_s} = \dfrac{2400\text{ V}}{120\text{ V}} = \mathbf{20}$

b. $10{,}000\text{ VA} = V_s I_s \Rightarrow I_s = \dfrac{10{,}000\text{ VA}}{V_s} = \dfrac{10{,}000\text{ VA}}{120\text{ V}} = \mathbf{83.33\text{ A}}$

c. $I_p = \dfrac{10{,}000\text{ VA}}{V_p} = \dfrac{10{,}000\text{ VA}}{2400\text{ V}} = \mathbf{4.17\text{ A}}$

d. $a = \dfrac{V_p}{V_s} = \dfrac{120\text{ V}}{2400\text{ V}} = 0.05 = \dfrac{1}{20}$

$I_s = \dfrac{10{,}000\text{ VA}}{2400\text{ V}} = \mathbf{4.17\text{ A}}$, $I_p = \mathbf{83.33\text{ A}}$

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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. $\mathbf{E}_2 = \dfrac{N_2}{N_1}\mathbf{E}_1 = \left(\dfrac{40\ \text{t}}{120\ \text{t}}\right)(120\ \text{V}\angle 60°) = \mathbf{40\ V\ \angle 60°}$

$\mathbf{I}_2 = \dfrac{\mathbf{E}_2}{\mathbf{Z}_2} = \dfrac{40\ \text{V}\angle 60°}{12\ \Omega\angle 0°} = \mathbf{3.33\ A\ \angle 60°}$

$\mathbf{E}_3 = \dfrac{N_3}{N_1}\mathbf{E}_1 = \left(\dfrac{30\ \text{t}}{120\ \text{t}}\right)(120\ \text{V}\angle 60°) = \mathbf{30\ V\ \angle 60°}$

$\mathbf{I}_3 = \dfrac{\mathbf{E}_3}{\mathbf{Z}_3} = \dfrac{30\ \text{V}\angle 60°}{10\ \Omega\angle 0°} = \mathbf{3\ A\ \angle 60°}$

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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 $$-\mathbf{I}_3(\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}) + \mathbf{I}_2\mathbf{Z}_2 - \mathbf{I}_1\mathbf{Z}_{M_{13}} = 0$$

$\therefore$ $$[\mathbf{Z}_1 + \mathbf{Z}_{L_1}]\mathbf{I}_1 - \mathbf{Z}_{M_{12}}\mathbf{I}_2 + \mathbf{Z}_{M_{13}}\mathbf{I}_3 = \mathbf{E}_1$$

$$\mathbf{Z}_{M_{12}}\mathbf{I}_1 - [\mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_{L_2}]\mathbf{I}_2 + \mathbf{Z}_2\mathbf{I}_3 = 0$$

$$\mathbf{Z}_{M_{13}}\mathbf{I}_1 \quad \mathbf{Z}_2\mathbf{I}_2 + [\mathbf{Z}_2 + \mathbf{Z}_4 + \mathbf{Z}_{L_3}]\mathbf{I}_3 = 0$$

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Chapter 23

1. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\text{ V}}$

   b. $V_\phi = E_\phi = \mathbf{120.1\text{ V}}$

   c. $I_\phi = \dfrac{V_\phi}{R_\phi} = \dfrac{120.1\text{ V}}{10\,\Omega} = \mathbf{12.01\text{ A}}$

   d. $I_L = I_\phi = \mathbf{12.01\text{ A}}$

2. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\text{ V}}$

   b. $V_\phi = E_\phi = \mathbf{120.1\text{ V}}$

   c. $\mathbf{Z}_\phi = 12\,\Omega - j16\,\Omega = 20\,\Omega\angle{-53.13°}$

   $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.1\text{ V}}{20\,\Omega} \cong \mathbf{6\text{ A}}$

   d. $I_L = I_\phi = \mathbf{6\text{ A}}$

3. a. $E_\phi = \mathbf{120.1\text{ V}}$

   b. $V_\phi = \mathbf{120.1\text{ V}}$

   c. $\mathbf{Z}_\phi = (10\,\Omega\angle 0° \parallel (10\,\Omega\angle{-90°}) = 7.071\,\Omega\angle{-45°}$

   $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.1\text{ V}}{7.071\,\Omega} = \mathbf{16.98\text{ A}}$

   d. $I_L = \mathbf{16.98\text{ A}}$

4. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{120°}$

   b. $\mathbf{V}_{an} = \mathbf{120\text{ V}\angle 0°}$, $\mathbf{V}_{bn} = \mathbf{120\text{ V}\angle{-120°}}$, $\mathbf{V}_{cn} = \mathbf{120\text{ V}\angle 120°}$

   c. $\mathbf{I}_{an} = \dfrac{\mathbf{V}_{an}}{\mathbf{Z}_{an}} = \dfrac{120\text{ V}\angle 0°}{20\,\Omega\angle 0°} = \mathbf{6\text{ A}\angle 0°}$

   $\mathbf{I}_{bn} = \dfrac{\mathbf{V}_{bn}}{\mathbf{Z}_{bn}} = \dfrac{120\text{ V}\angle{-120°}}{20\,\Omega\angle 0°} = \mathbf{6\text{ A}\angle{-120°}}$

   $\mathbf{I}_{cn} = \dfrac{\mathbf{V}_{cn}}{\mathbf{Z}_{cn}} = \dfrac{120\text{ V}\angle 120°}{20\,\Omega\angle 0°} = \mathbf{6\text{ A}\angle 120°}$

   d. $I_L = I_\phi = \mathbf{6A}$

   e. $V_L = \sqrt{3}\,V_\phi = \sqrt{3}\,(120\text{ V}) = \mathbf{207.8\text{ V}}$

5. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

   b. $\mathbf{V}_{an} = \mathbf{120\text{ V}\angle 0°}$, $\mathbf{V}_{bn} = \mathbf{120\text{ V}\angle{-120°}}$, $\mathbf{V}_{cn} = \mathbf{120\text{ V}\angle 120°}$

   c. $\mathbf{Z}_\phi = 9\,\Omega + j12\,\Omega = 15\,\Omega\angle 53.13°$

   $\mathbf{I}_{an} = \dfrac{120\text{ V}\angle 0°}{15\,\Omega\angle 53.13°} = \mathbf{8\text{ A}\angle{-53.13°}}$, $\mathbf{I}_{bn} = \dfrac{120\text{ V}\angle{-120°}}{15\,\Omega\angle 53.13°} = \mathbf{8\text{ A}\angle{-173.13°}}$

   $\mathbf{I}_{cn} = \dfrac{120\text{ V}\angle 120°}{15\,\Omega\angle 53.13°} = \mathbf{8\text{ A}\angle 66.87°}$

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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. $$\mathbf{E}_{AN} = \frac{22\text{ kV}}{\sqrt{3}}\ \angle -30° = \mathbf{12.7\ kV\ \angle -30°}$$

$$\mathbf{E}_{BN} = \frac{22\text{ kV}}{\sqrt{3}}\ \angle -150° = \mathbf{12.7\ kV\ \angle -150°}$$

$$\mathbf{E}_{CN} = \frac{22\text{ kV}}{\sqrt{3}}\ \angle 90° = \mathbf{12.7\ kV\ \angle 90°}$$

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b, c. $\mathbf{I}_{Aa} = \mathbf{I}_{an} = \dfrac{\mathbf{E}_{AN}}{\mathbf{Z}_{AN}} = \dfrac{12.7\text{ kV} \angle -30°}{(30\,\Omega + j40\,\Omega) + (0.4\text{ k}\Omega + j1\text{ k}\Omega)}$

$= \dfrac{12.7\text{ kV} \angle -30°}{430\,\Omega + j1040\,\Omega} = \dfrac{12.7\text{ kV} \angle -30°}{1125.39\,\Omega \angle 67.54°}$

$= \mathbf{11.29\text{ A} \angle -97.54°}$

$\mathbf{I}_{Bb} = \mathbf{I}_{bn} = \dfrac{\mathbf{E}_{BN}}{\mathbf{Z}_{BN}} = \dfrac{12.7\text{ kV} \angle -150°}{1125.39\,\Omega \angle 67.54°} = \mathbf{11.29\text{ A} \angle -217.54°}$

$\mathbf{I}_{Cc} = \mathbf{I}_{cn} = \dfrac{\mathbf{E}_{CN}}{\mathbf{Z}_{CN}} = \dfrac{12.7\text{ kV} \angle 90°}{1125.39\,\Omega \angle 67.54°} = \mathbf{11.29\text{ A} \angle 22.46°}$

d. $\mathbf{V}_{an} = \mathbf{I}_{an}\mathbf{Z}_{an} = (11.29\text{ A} \angle -97.54°)(400 + j1000)$

$= (11.29\text{ A} \angle -97.54°)(1077.03\,\Omega \angle 68.2°)$

$= \mathbf{12.16\text{ kV} \angle -29.34°}$

$\mathbf{V}_{bn} = \mathbf{I}_{bn}\mathbf{Z}_{bn} = (11.29\text{ A} \angle -217.54°)(1077.03 \angle 68.2°)$

$= \mathbf{12.16\text{ kV} \angle -149.34°}$

$\mathbf{V}_{cn} = \mathbf{I}_{cn}\mathbf{Z}_{cn} = (11.29\text{ A} \angle 22.46°)(1077.03 \angle 68.2°)$

$= \mathbf{12.16\text{ kV} \angle 90.66°}$

10. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\text{ V}}$ b. $V_\phi = E_L = \mathbf{208\text{ V}}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{208\text{ V}}{20\,\Omega} = \mathbf{10.4\text{ A}}$ d. $I_L = \sqrt{3}\ I_\phi = (1.732)(10.4\text{ A}) = \mathbf{18\text{ A}}$

11. a. $E_\phi = E_L/\sqrt{3} = 208\text{ V}/1.732 = \mathbf{120.1\text{ V}}$ b. $V_\phi = E_L = \mathbf{208\text{ V}}$

c. $\mathbf{Z}_\phi = 6.8\,\Omega + j14\,\Omega = 15.564\,\Omega \angle 64.09°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{208\text{ V}}{15.564\,\Omega} = \mathbf{13.36\text{ A}}$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(13.36\text{ A}) = \mathbf{23.14\text{ A}}$

12. $\mathbf{Z}_\phi = 18\,\Omega \angle 0° \parallel 18\,\Omega \angle -90° = 12.728\,\Omega \angle -45°$

a. $E_\phi = V_L/\sqrt{3} = 208\text{ V}/\sqrt{3} = \mathbf{120.09\text{ V}}$ b. $V_\phi = \mathbf{208\text{ V}}$

c. $I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{208\text{ V}}{12.728\,\Omega} = \mathbf{16.34\text{ A}}$

d. $I_L = \sqrt{3}\ I_\phi = (1.732)(16.34\text{ A}) = \mathbf{28.30\text{ A}}$

13. a. $\theta_2 = \mathbf{-120°}$, $\theta_3 = \mathbf{+120°}$

b. $\mathbf{V}_{ab} = \mathbf{208\text{ V} \angle 0°}$, $\mathbf{V}_{bc} = \mathbf{208\text{ V} \angle -120°}$, $\mathbf{V}_{ca} = \mathbf{208\text{ V} \angle 120°}$

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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. $\mathbf{Z}_\phi = 3\,\Omega\angle 0° \parallel 4\,\Omega\angle 90° = 2.4\,\Omega\angle 36.87°$

$\mathbf{I}_{ab} = \dfrac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \dfrac{208\text{ V}\angle 0°}{2.4\,\Omega\angle 36.87°} = \mathbf{86.67\text{ A}\angle -36.87°}$

$\mathbf{I}_{bc} = \dfrac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \dfrac{208\text{ V}\angle -120°}{2.4\,\Omega\angle 36.87°} = \mathbf{86.67\text{ A}\angle -156.87°}$

$\mathbf{I}_{ca} = \dfrac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \dfrac{208\text{ V}\angle 120°}{2.4\,\Omega\angle 36.87°} = \mathbf{86.67\text{ A}\angle 83.13°}$

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e. $I_L = \sqrt{3}\ I_\phi = (1.732)(86.67\text{ A}) = \mathbf{150.11\ A}$

f. $E_\phi = \mathbf{120.1\ V}$

16. $V_{ab} = V_{bc} = V_{ca} = \mathbf{220\ V}$

$\mathbf{Z}_\phi = 10\ \Omega + j10\ \Omega = 14.142\ \Omega\angle 45°$

$$I_{ab} = I_{bc} = I_{ca} = \frac{V_\phi}{Z_\phi} = \frac{220\text{ V}}{14.142\ \Omega} = \mathbf{15.56\ A}$$

17. a. $$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\boldsymbol{Z}_{ab}} = \frac{16\text{ kV}\angle 0°}{300\ \Omega + j1000\ \Omega} = \frac{16\text{ kV}\angle 0°}{1044.03\ \Omega\angle 73.30°}$$

$\mathbf{I}_{ab} = \mathbf{15.33\ A\ \angle -73.30°}$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{16\text{ kV}\angle -120°}{1044.03\ \Omega\angle 73.30°} = \mathbf{15.33\ A\ \angle -193.30°}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{16\text{ kV}\angle 120°}{1044.03\ \Omega\angle 73.30°} = \mathbf{15.33\ A\ \angle 46.7°}$$

b. $\mathbf{I}_{Aa} - \mathbf{I}_{ab} + \mathbf{I}_{ca} = 0$

$\mathbf{I}_{Aa} = \mathbf{I}_{ab} - \mathbf{I}_{ca} = 15.33\text{ A}\angle -73.30° - 15.33\text{ A}\angle 46.7°$

$= (4.41\text{ A} - j14.68\text{ A}) - (10.51\text{ A} + j11.16\text{ A})$

$= 4.41\text{ A} - 10.51\text{ A} - j(14.68\text{ A} + 11.16\text{ A})$

$= -6.11\text{ A} - j25.84\text{ A} = \mathbf{26.55\ A\ \angle -103.30°}$

$\mathbf{I}_{Bb} + \mathbf{I}_{ab} = \mathbf{I}_{bc}$

$\mathbf{I}_{Bb} = \mathbf{I}_{bc} - \mathbf{I}_{ab} = 15.33\text{ A}\angle -193.30° - 15.33\text{ A}\angle -73.30°$

$= \mathbf{26.55\ A\ \angle 136.70°}$

$\mathbf{I}_{Cc} + \mathbf{I}_{bc} = \mathbf{I}_{ca}$

$\mathbf{I}_{Cc} = \mathbf{I}_{ca} - \mathbf{I}_{bc} = 15.33\text{ A}\angle 46.7° - 15.33\text{ A}\angle -193.30°$

$= \mathbf{26.55\ A\ \angle 16.70°}$

c. $\mathbf{E}_{AB} = \mathbf{I}_{Aa}(10\ \Omega + j20\ \Omega) + \mathbf{V}_{ab} - \mathbf{I}_{Bb}(22.361\ \Omega\angle 63.43°)$

$= (26.55\text{ A}\angle -103.30°)(22.361\ \Omega\angle 63.43°) + 16\text{ kV}\angle 0°$

$\quad - (26.55\text{ A}\angle 136.70°)(22.361\ \Omega\angle 63.43°)$

$= (455.65\text{ V} - j380.58\text{ V}) + 16{,}000\text{ V} - (-557.42\text{ V} - j204.32\text{ V})$

$= 17.01\text{ kV} - j176.26\text{ V}$

$= \mathbf{17.01\ kV\ \angle -0.59°}$

$\mathbf{E}_{BC} = \mathbf{I}_{Bb}(22.361\ \Omega\angle 63.43°) + \mathbf{V}_{bc} - \mathbf{I}_{Cc}(22.361\ \Omega\angle 63.53°)$

$= (26.55\text{ A}\angle 136.70°)(22.361\ \Omega\angle 63.53°) + 16\text{ kV}\angle -120°$

$\quad - (26.55\text{ A}\angle 16.70°)(22.361\ \Omega\angle 63.53°)$

$= \mathbf{17.01\ kV\ \angle -120.59°}$

$\mathbf{E}_{CA} = \mathbf{I}_{Cc}(22.361\ \Omega\angle 63.43°) + \mathbf{V}_{ca} - \mathbf{I}_{Aa}(22.361\ \Omega\angle 63.43°)$

$= \mathbf{17.01\ kV\ \angle 119.41°}$

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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. $\mathbf{Z}_\phi = 15\ \Omega\ \angle 0° \parallel 20\ \Omega\ \angle -90° = 12\ \Omega\ \angle -36.87°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{120.1\ \text{V}}{12\ \Omega} \cong \mathbf{10\ A}$

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. $I_L = \sqrt{3}\ I_\phi = (1.732)(2\ \text{A}) = \mathbf{3.46\ A}$

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25. a. $E_\phi = E_L = \mathbf{440\ V}$ b. $V_\phi = E_L = \mathbf{440\ V}$

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. $I_L = \sqrt{3}\ I_\phi = (1.732)(29.33\ \text{A}) = \mathbf{50.8\ A}$

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. $I_L = \sqrt{3}\ I_\phi = (1.732)(28.28\ \text{A}) = \mathbf{48.98\ A}$

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. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3}\ (5\ \text{A}) = \mathbf{8.66\ A}$

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. $\mathbf{Z}_\phi = 12\ \Omega + j16\ \Omega = 20\ \Omega \angle 53.13°$

$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{100\ \text{V} \angle 0°}{20\ \Omega \angle 53.13°} = \mathbf{5\ A \angle -53.13°}$$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{100\ \text{V} \angle -120°}{20\ \Omega \angle 53.13°} = \mathbf{5\ A \angle -173.13°}$$

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$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{100\text{ V}\angle 120°}{20\,\Omega\angle 53.13°} = \mathbf{5\text{ A}\angle 66.87°}$$

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. $P_T = 3I_{\phi}^2 R_{\phi} = 3(6\text{ A})^2\ 12\,\Omega = \mathbf{1296\text{ W}}$

$Q_T = 3I_{\phi}^2 X_{\phi} = 3(6\text{ A})^2\ 16\,\Omega = \mathbf{1728\text{ VAR}(}\boldsymbol{C}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{2160\text{ VA}}$

$$F_p = \frac{P_T}{S_T} = \frac{1296\text{ W}}{2160\text{ VA}} = \mathbf{0.6\text{ (leading)}}$$

31. $V_{\phi} = 120\text{ V},\ I_{\phi} = 120\text{ V}/20\,\Omega = 6\text{ A}$

$P_T = 3I_{\phi}^2 R_{\phi} = 3(6\text{ A})^2\ 20\,\Omega = \mathbf{2160\text{ W}}$

$Q_T = \mathbf{0\text{ VAR}}$

$S_T = P_T = \mathbf{2160\text{ VA}}$

$$F_p = \frac{P_T}{S_T} = \frac{2160\text{ W}}{2160\text{ VA}} = \mathbf{1}$$

32. $P_T = 3I_{\phi}^2 R_{\phi} = 3(8.98\text{ A})^2\ 10\,\Omega = \mathbf{2419.21\text{ W}}$

$Q_T = 3I_{\phi}^2 X_{\phi} = 3(8.98\text{ A})^2\ 10\,\Omega = \mathbf{2419.21\text{ VAR}(}\boldsymbol{C}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3421.28\text{ VA}}$

$$F_p = \frac{P_T}{S_T} = \frac{2419.21\text{ W}}{3421.28\text{ VA}} = \mathbf{0.7071\text{ (leading)}}$$

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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. $$P_T = 3\frac{V_\phi^2}{R_\phi} = \frac{3(120.1\text{ V})^2}{15\,\Omega} = \mathbf{2884.80\ W}$$

$$Q_T = 3\frac{V_\phi^2}{X_\phi} = \frac{3(120.1\text{ V})^2}{20\,\Omega} = \mathbf{2163.60\ VAR(}\boldsymbol{C}\mathbf{)}$$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3605.97\ VA}$

$$F_p = \frac{P_T}{S_T} = \frac{2884.80\text{ W}}{3605.97\text{ VA}} = \mathbf{0.8\ (leading)}$$

37. $\mathbf{Z}_\phi = 10\ \Omega + j20\ \Omega = 22.36\ \Omega\ \angle 63.43°$

$$V_\phi = \frac{V_L}{\sqrt{3}} = \frac{120\text{ V}}{1.732} = 69.28\text{ V}$$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{69.28\text{ V}}{22.36\,\Omega} = 3.098\text{ A}$$

$P_T = 3I_\phi^2 R_\phi = 3(3.098\text{ A})^2\ 10\ \Omega = \mathbf{287.93\ W}$

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$Q_T = 3I_\phi^2 X_\phi = 3(3.098\text{ A})^2\ 20\ \Omega = \mathbf{575.86\ VAR}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{643.83\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{287.93\text{ W}}{643.83\text{ VA}} = \mathbf{0.447\ (lagging)}$

38. $P_T = 3\dfrac{V_\phi^2}{R_\phi} = \dfrac{3(440\text{ V})^2}{22\ \Omega} = \mathbf{26.4\ kW}$

$Q_T = P_T = \mathbf{26.4\ kVAR(}\boldsymbol{L}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{37.34\ kVA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{26.4\text{ kW}}{37.34\text{ kVA}} = \mathbf{0.707\ (lagging)}$

39. $\mathbf{Z}_\phi = 12\ \Omega + j16\ \Omega = 20\ \Omega\ \angle 53.13°$

$I_\phi = \dfrac{V_\phi}{Z_\phi} = \dfrac{100\text{ V}}{20\ \Omega} = 5\text{ A}$

$P_T = 3I_\phi^2 R_\phi = 3(5\text{ A})^2\ 12\ \Omega = \mathbf{900\ W}$

$Q_T = 3I_\phi^2 X_\phi = 3(5\text{ A})^2\ 16\ \Omega = \mathbf{1200\ VAR(}\boldsymbol{L}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{1500\ VA}$

$F_p = \dfrac{P_T}{S_T} = \dfrac{900\text{ W}}{1500\text{ VA}} = \mathbf{0.6\ (lagging)}$

40. $P_T = \sqrt{3}\ E_L I_L \cos\theta$

$4800\text{ W} = (1.732)(200\text{ V})I_L\ (0.8)$

$I_L = 17.32\text{ A}$

$I_\phi = \dfrac{I_L}{\sqrt{3}} = \dfrac{17.32\text{ A}}{1.732} = 10\text{ A}$

$\theta = \cos^{-1} 0.8 = 36.87°$

$\mathbf{Z}_\phi = \dfrac{\mathbf{V}_\phi}{\mathbf{I}_\phi} = \dfrac{200\text{ V}\ \angle 0°}{10\text{ A}\ \angle -36.87°} = 20\ \Omega\ \angle 36.87° = \mathbf{16\ \Omega + }\boldsymbol{j}\mathbf{12\ \Omega}$

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)

$\mathbf{Z}_\phi = \dfrac{\mathbf{V}_\phi}{\mathbf{I}_\phi} = \dfrac{120.1\text{ V}\ \angle 0°}{5.55\text{ A}\ \angle 53.13°} = 21.64\ \Omega\ \angle -53.13° = \underbrace{12.98\ \Omega}_{R} - j\underbrace{17.31\ \Omega}_{X_C}$

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42. Δ: $\mathbf{Z}_\phi = 15\ \Omega + j20\ \Omega = 25\ \Omega\angle 53.13°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{125\text{ V}}{25\ \Omega} = 5\text{ A}$$

$P_T = 3I_\phi^2 R_\phi = 3(5\text{ A})^2\ 15\ \Omega =$ **1125 W**

$Q_T = 3I_\phi^2 X_\phi = 3(5\text{ A})^2\ 20\ \Omega =$ **1500 VAR(*L*)**

Y: $V_\phi = V_L/\sqrt{3} = 125\text{ V}/1.732 =$ **72.17 V**

$\mathbf{Z}_\phi = 3\ \Omega - j4\ \Omega = 5\ \Omega\angle -53.13°$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{72.17\text{ V}}{5\ \Omega} =$$ **14.43 A**

$P_T = 3I_\phi^2 R_\phi = 3(14.43\text{ A})^2\ 3\ \Omega =$ **1874.02 W**

$Q_T = 3I_\phi^2 X_\phi = 3(14.43\text{ A})^2\ 4\ \Omega =$ **2498.7 VAR**

$P_T = 1125\text{ W} + 1874.02\text{ W} =$ **2999.02 W**

$Q_T = 1500\text{ VAR}(L) - 2498.7\text{ VAR}(C) =$ **998.7 VAR(*C*)**

$S_T = \sqrt{P_T^2 + Q_T^2} =$ **3161 VA**

$$F_p = \frac{P_T}{S_T} = \frac{2999.02\text{ W}}{3161\text{ VA}} =$$ **0.949 (leading)**

43. a. $$E_\phi = \frac{16\text{ kV}}{\sqrt{3}} =$$ **9,237.6 V**

b. $I_L = I_\phi =$ **80 A**

c. $$P_{\phi_L} = \frac{1200\text{ kW}}{3} = 400\text{ kW}$$

$P_{4\Omega} = (80\text{ A})^2 4\ \Omega = 25.6\text{ kW}$

$P_T = 3P_\phi = 3(25.6\text{ kW} + 400\text{ kW}) =$ **1276.8 kW**

d. $F_p = \dfrac{P_T}{S_T}$, $S_T = \sqrt{3}\ V_L I_L = \sqrt{3}\ (16\text{ kV})(80\text{ A}) = 2{,}217.025\text{ kVA}$

$$F_p = \frac{1{,}276.8\text{ kW}}{2{,}217.025\text{ kVA}} =$$ **0.576 lagging**

e. $\theta_L = \cos^{-1} 0.576 = 54.83°$ (lagging)

$$\mathbf{I}_{Aa} = \underbrace{\frac{\mathbf{E}_{AN}\angle 0°}{Z_T\angle 54.83°}}_{\text{for entire load}} \Rightarrow \underbrace{\mathbf{80A}}_{\text{given}}\ \angle -\mathbf{54.83°}$$

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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. $$\eta = \frac{P_o}{P_i} = \frac{P_i - P_{\text{lost}}}{P_i} = \frac{1276.8\ \text{kW} - 3(25.6\ \text{kW})}{1276.8\ \text{kW}} = 0.9398 \Rightarrow \mathbf{93.98\%}$$

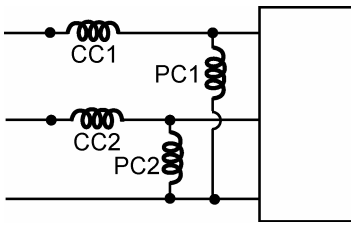
44. a. –

b. $$V_\phi = \frac{220\ \text{V}}{\sqrt{3}} = 127.02\ \text{V},\quad \mathbf{Z}_\phi = 10\ \Omega - j10\ \Omega = 14.14\ \Omega\angle -45°$$
$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{127.02\ \text{V}}{14.14\ \Omega} = 8.98\ \text{A}$$
$$P_T = 3I_\phi^2 R_\phi = 3(8.98\ \text{A})^2\ 10\ \Omega = \mathbf{2419.2\ W}$$
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. $$0.2 \Rightarrow \frac{P_\ell}{P_h} = 0.5$$
$$P_h = \frac{P_\ell}{0.5} = \frac{100\ \text{W}}{0.5} = \mathbf{200\ W}$$
$$P_T = P_h - P_\ell = 200\ \text{W} - 100\ \text{W} = \mathbf{100\ W}$$

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48. a. $\mathbf{I}_{ab} = \dfrac{\mathbf{E}_{AB}}{R\angle 0°} = \dfrac{208\text{ V}\angle 0°}{10\,\Omega\angle 0°} = \mathbf{20.8\text{ A}\angle 0°}$

$\mathbf{I}_{bc} = \dfrac{\mathbf{E}_{BC}}{R\angle 0°} = \dfrac{208\text{ V}\angle -120°}{10\,\Omega\angle 0°} = \mathbf{20.8\text{ A}\angle -120°}$

$\mathbf{I}_{ca} = \dfrac{\mathbf{E}_{CA}}{R\angle 0°} = \dfrac{208\text{ V}\angle 120°}{10\,\Omega\angle 0°} = \mathbf{20.8\text{ A}\angle 120°}$

b. $\mathbf{I}_{Aa} + \mathbf{I}_{ca} - \mathbf{I}_{ab} = 0$

$\mathbf{I}_{Aa} = \mathbf{I}_{ab} - \mathbf{I}_{ca}$

$= 20.8\text{ A}\angle 0° - 20.8\text{ A}\angle 120°$

$= 20.8\text{ A} - (-10.4\text{ A} + j18.01\text{ A})$

$= 31.2\text{ A} - j18.01\text{ A}$

$= \mathbf{36.02\text{ A}\angle -30°}$

$\mathbf{I}_{Bb} + \mathbf{I}_{ab} - \mathbf{I}_{bc} = 0$

$\mathbf{I}_{Bb} = \mathbf{I}_{bc} - \mathbf{I}_{ab}$

$= 20.8\text{ A}\angle -120° - 20.8\text{ A}\angle 0°$

$= (-10.4\text{ A} - j18.01\text{ A}) - 20.8\text{ A}$

$= -31.2\text{ A} - j18.01\text{ A}$

$= \mathbf{36.02\text{ A}\angle -150°}$

$\mathbf{I}_{Cc} + \mathbf{I}_{bc} - \mathbf{I}_{ca} = 0$

$\mathbf{I}_{Cc} = \mathbf{I}_{ca} - \mathbf{I}_{bc}$

$= 20.8\text{ A}\angle 120° - 20.8\text{ A}\angle -120°$

$= (-10.4\text{ A} + j18.01\text{ A}) - (-10.4\text{ A} - j18.01\text{ A})$

$= -10.4\text{ A} + 10.4\text{ A} + j18.01\text{ A} + j18.01\text{ A}$

$= \mathbf{32.02\text{ A}\angle 90°}$

c. $P_1 = V_{ac}I_{Aa}\cos\theta_{\mathbf{V}_{ca}}^{\mathbf{I}_{Aa}}$, $\mathbf{V}_{ac} = V_{ca}\angle\theta - 180° = 208\text{ V}\angle 120° - 180°$

$= 208\text{ V}\angle -60°$

$\mathbf{I}_{Aa} = 36.02\text{ A}\angle -30°$

$= (208\text{ V})(36.02\text{ A})\cos 30°$

$= \mathbf{6488.4\text{ W}}$

$P_2 = V_{bc}I_{Bb}\cos\theta_{\mathbf{I}_{Bb}}^{\mathbf{V}_{bc}}$, $\mathbf{V}_{bc} = 208\text{ V}\angle -120°$, $\mathbf{I}_{Bb} = 36.02\text{ A}\angle -150°$

$= (208\text{ V})(36.02\text{ A})\cos 30°$

$= \mathbf{6488.4\text{ W}}$

d. $P_T = P_1 + P_2 = 6488.4\text{ W} + 6488.4\text{ W}$

$= \mathbf{12{,}976.8\text{ W}}$

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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. $P_T = I_{an}^2\ 10\ \Omega + I_{bn}^2\ 12\ \Omega + I_{cn}^2\ 2\ \Omega$

$= (8.49\ \text{A})^2\ 10\ \Omega + (7.08\ \text{A})^2\ 12\ \Omega + (42.47\ \text{A})^2\ 2\ \Omega$

$= 720.80\ \text{W} + 601.52\ \text{W} + 3.61\ \text{kW}$

$= \mathbf{4.93\ kW}$

$Q_T = P_T = \mathbf{4.93\ kVAR(}\boldsymbol{L}\mathbf{)}$

$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{6.97\ kVA}$

$F_p = \dfrac{P_T}{S_T} = \mathbf{0.707\ (lagging)}$

d. $\mathbf{E}_{an} = 120.09\ \text{V}\angle -30°$, $\mathbf{E}_{bn} = 120.09\ \text{V}\angle -150°$, $\mathbf{E}_{cn} = 120.09\ \text{V}\angle 90°$

$\mathbf{I}_{an} = \dfrac{\mathbf{E}_{an}}{\mathbf{Z}_{an}} = \dfrac{120.09\ \text{V}\angle -30°}{10\ \Omega + j10\ \Omega} = \dfrac{120.09\ \text{V}\angle -30°}{14.142\ \Omega\angle 45°} = \mathbf{8.49\ A\angle -75°}$

$\mathbf{I}_{bn} = \dfrac{\mathbf{E}_{bn}}{\mathbf{Z}_{bn}} = \dfrac{120.09\ \text{V}\angle -150°}{12\ \Omega + j12\ \Omega} = \dfrac{120.09\ \text{V}\angle -150°}{16.971\ \Omega\angle 45°} = \mathbf{7.08\ A\angle -195°}$

$\mathbf{I}_{cn} = \dfrac{\mathbf{E}_{cn}}{\mathbf{Z}_{cn}} = \dfrac{120.09\ \text{V}\angle 90°}{2\ \Omega + j2\ \Omega} = \dfrac{120.09\ \text{V}\angle 90°}{2.828\ \Omega\angle 45°} = \mathbf{42.47\ A\angle 45°}$

e. $\mathbf{I}_N = \mathbf{I}_{an} + \mathbf{I}_{bn} + \mathbf{I}_{cn}$

$= 8.49\ \text{A}\angle -75° + 7.08\ \text{A}\angle -195° + 42.47\ \text{A}\angle 45°$

$= (2.02\ \text{A} - j8.20\ \text{A}) + (-6.84\ \text{A} + j1.83\ \text{A}) + (30.30\ \text{A} + j30.30\ \text{A})$

$= 25.66\ \text{A} - j23.93\ \text{A}$

$= \mathbf{35.09\ A\angle -43.00°}$

50. $\mathbf{Z}_1 = 12\ \Omega - j16\ \Omega = 20\ \Omega\angle -53.13°$, $\mathbf{Z}_2 = 3\ \Omega + j4\ \Omega = 5\ \Omega\angle 53.13°$

$\mathbf{Z}_3 = 20\ \Omega\angle 0°$

$\mathbf{E}_{AB} = 200\ \text{V}\angle 0°$, $\mathbf{E}_{BC} = 200\ \text{V}\angle -120°$, $\mathbf{E}_{CA} = 200\ \text{V}\angle 120°$

$\mathbf{Z}_\Delta = \mathbf{Z}_1\mathbf{Z}_2 + \mathbf{Z}_1\mathbf{Z}_3 + \mathbf{Z}_2\mathbf{Z}_3$

$= (20\ \Omega\angle -53.13°)(5\ \Omega\angle 53.13°) + (20\ \Omega\angle -53.13°)(20\ \Omega\angle 0°)$

$+ (5\ \Omega\angle 53.13°)(20\ \Omega\angle 0°)$

$= 100\ \Omega\angle 0° + 400\ \Omega\angle -53.13° + 100\ \Omega\angle 53.13°$

$= 100\ \Omega + (240\ \Omega - j320\ \Omega) + (60\ \Omega + j80\ \Omega)$

$= 400\ \Omega - j240\ \Omega$

$= 466.48\ \Omega\angle -30.96°$

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$$\mathbf{I}_{an} = \frac{\mathbf{E}_{AB}\mathbf{Z}_3 - \mathbf{E}_{CA}\mathbf{Z}_2}{\mathbf{Z}_\Delta} = \frac{(200\text{ V}\angle 0°)(20\,\Omega\angle 0°) - (200\text{ V}\angle 120°)(5\,\Omega\angle 53.13°)}{\mathbf{Z}_\Delta}$$

$$= \frac{4000\text{ A}\angle 0° - 1000\text{ A}\angle 173.13°}{466.48\angle -30.96°} = \mathbf{10.71\text{ A}\angle 29.59°}$$

$$\mathbf{I}_{bn} = \frac{\mathbf{E}_{BC}\mathbf{Z}_1 - \mathbf{E}_{AB}\mathbf{Z}_3}{\mathbf{Z}_\Delta} = \frac{(200\text{ V}\angle -120°)(20\,\Omega\angle -53.13°) - (200\text{ V}\angle 0°)(20\,\Omega\angle 0°)}{\mathbf{Z}_\Delta}$$

$$= \frac{4000\text{ A}\angle -173.13° - 4000\text{ A}\angle 0°}{466.48\angle -30.96°} = \mathbf{17.12\text{ A}\angle -145.61°}$$

$$\mathbf{I}_{cn} = \frac{\mathbf{E}_{CA}\mathbf{Z}_2 - \mathbf{E}_{BC}\mathbf{Z}_1}{\mathbf{Z}_\Delta} = \frac{(200\text{ V}\angle 120°)(5\,\Omega\angle 53.13°) - (200\text{ V}\angle -120°)(20\,\Omega\angle -53.13°)}{\mathbf{Z}_\Delta}$$

$$= \frac{1000\text{ A}\angle 173.13° - 4000\text{ A}\angle -173.13°}{466.48\angle -30.96°} = \mathbf{6.51\text{ A}\angle 42.32°}$$

$$P_T = I_{an}^2\,12\,\Omega + I_{bn}^2\,4\,\Omega + I_{cn}^2\,20\,\Omega$$

$$= 1376.45\text{ W} + 1172.38\text{ W} + 847.60\text{ W} = \mathbf{3396.43\text{ W}}$$

$$Q_T = I_{an}^2\,16\,\Omega + I_{bn}^2\,3\,\Omega = 1835.27\text{ VAR}(C) + 879.28\text{ VAR}(L) = \mathbf{955.99\text{ VAR}(}\boldsymbol{C}\mathbf{)}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3508.40\text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{3396.43\text{ W}}{3508.40\text{ VA}} = \mathbf{0.968\text{ (leading)}}$$

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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. $$\% \text{ tilt} = \frac{V_1 - V_2}{V} \times 100\%$$
   $$V = \frac{8\text{ V} + 7.5\text{ V}}{2} = 7.75\text{ V}$$
   $$\% \text{ tilt} = \frac{8\text{ V} - 7.5\text{ V}}{7.75\text{ V}} \times 100\% = \textbf{6.5\%}$$

2. a. **negative-going** b. **+7 mV** c. **3 μs**

   d. **–8 mV** (from base line level)

   e. $$V = \frac{-8\text{ mV} - 7\text{ mV}}{2} = \frac{-15\text{ mV}}{2} = -7.5\text{ mV}$$
   $$\% \text{ Tilt} = \frac{V_1 - V_2}{V} \times 100\% = \frac{-8\text{ mV} - (-7\text{ mV})}{-7.5\text{ mV}} \times 100\%$$
   $$= \frac{-1\text{ mV}}{-7.5\text{ mV}} \times 100\% = \textbf{13.3\%}$$

   f. $T = 15\ \mu\text{s} - 7\ \mu\text{s} = 8\ \mu\text{s}$
   $$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu\text{s}} = \textbf{125 kHz}$$

   g. $$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{3\ \mu\text{s}}{8\ \mu\text{s}} \times 100\% = \textbf{37.5\%}$$

3. a. **positive-going** b. V_b = **10 mV** c. $t_p = \left(\frac{8}{10}\right) 4\text{ ms} = \textbf{3.2 ms}$

   d. Amplitude = (30 – 10)mV = **20 mV**

   e. $$\% \text{ tilt} = \frac{V_1 - V_2}{V} \times 100\%$$
   $$V = \frac{30\text{ mV} + 28\text{ mV}}{2} = 29\text{ mV}$$
   $$\% \text{ tilt} = \frac{30\text{ mV} - 28\text{ mV}}{29\text{ mV}} \times 100\% \cong \textbf{6.9\%}$$

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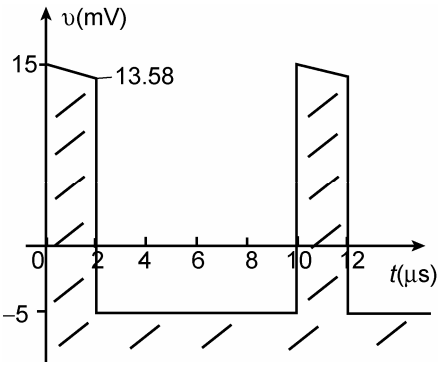
4. $t_r \cong$ (0.2 div.)(2 ms/div.) = **0.4 ms**
$t_f \cong$ (0.4 div.)(2 ms/div.) = **0.8 ms**

5. $\text{tilt} = \dfrac{V_1 - V_2}{V} = 0.1$ 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)
$t_p = (8 - 1)\mu\text{s}$ = **7 μs**

d. $\text{prf} = \dfrac{1}{T} = \dfrac{1}{20\ \mu\text{s}}$ = **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. $T = (3.6 - 2.0)\text{ms} = 1.6$ ms

$\text{prf} = \dfrac{1}{T} = \dfrac{1}{1.6\ \text{ms}}$ = **625 Hz**

$\text{Duty cycle} = \dfrac{t_p}{T} \times 100\% = \dfrac{0.2\ \text{ms}}{1.6\ \text{ms}} \times 100\%$ = **12.5%**

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9. $T = (15 - 7)\mu s = 8\ \mu s$

$$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu s} = \mathbf{125\ kHz}$$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{(20-15)\mu s}{8\ \mu s} \times 100\% = \frac{5}{8} \times 100\% = \mathbf{62.5\%}$$

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. $T = (9 - 1)\mu s = \mathbf{8\ \mu s}$ b. $t_p = (3 - 1)\mu s = \mathbf{2\ \mu s}$

c. $$\text{prf} = \frac{1}{T} = \frac{1}{8\ \mu s} = \mathbf{125\ kHz}$$

d. $V_{av} = (\text{Duty cycle})(\text{Peak value}) + (1 - \text{Duty cycle})(V_b)$

$$\text{Duty cycle} = \frac{t_p}{T} \times 100\% = \frac{2\ \mu s}{8\ \mu s} \times 100\% = 25\%$$

$V_{av} = (0.25)(6\ \text{mV}) + (1 - 0.25)(-2\ \text{mV})$
$= 1.5\ \text{mV} - 1.5\ \text{mV} = \mathbf{0\ V}$

or

$$V_{av} = \frac{(2\ \mu s)(6\ \text{mV}) - (2\ \mu s)(6\ \text{mV})}{8\ \mu s} = \mathbf{0\ V}$$

e. $$V_{eff} = \sqrt{\frac{(36 \times 10^{-6})(2\ \mu s) + (4 \times 10^{-6})(6\ \mu s)}{8\ \mu s}} = \mathbf{3.46\ mV}$$

12. Eq. 24.5 cannot be applied due to tilt in the waveform.
(Method of Section 13.6)
Between 2 and 3.6 ms

$$V_{av} = \frac{(3.4\ \text{ms} - 2\ \text{ms})(2\ \text{V}) + (3.6\ \text{ms} - 3.4\ \text{ms})(7.5\ \text{V}) + \frac{1}{2}(3.6\ \text{ms} - 3.4\ \text{ms})(0.5\ \text{V})}{3.6\ \text{ms} - 2\ \text{ms}}$$

$$= \frac{(1.4\ \text{ms})(2\ \text{V}) + (0.2\ \text{ms})(7.5\ \text{V}) + \frac{1}{2}(0.2\ \text{ms})(0.5\ \text{V})}{1.6\ \text{ms}}$$

$$= \frac{2.8\ \text{V} + 1.5\ \text{V} + 0.05\ \text{V}}{1.6} = \mathbf{2.719\ V}$$

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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. $\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$
$= -5 + (20 - (-5))(1 - e^{-t/0.2\text{ ms}})$
$= -5 + 25(1 - e^{-t/0.2\text{ ms}})$
$= -5 + 25 - 25e^{-t/0.2\text{ ms}}$
$\upsilon_C = \mathbf{20\ V - 25\ V}e^{-t/0.2\text{ ms}}$

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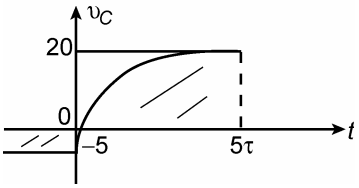
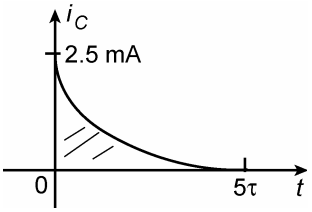
b.



c. $I_i = 0$

$$i_C = \frac{E - \upsilon_C}{R} = \frac{20\text{ V} - \left[20\text{ V} - 25\text{ V}\,e^{-t/0.2\text{ ms}}\right]}{10\text{ k}\Omega} = \mathbf{2.5\ mA}e^{-t/0.2\text{ ms}}$$

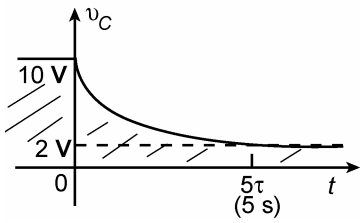
d.



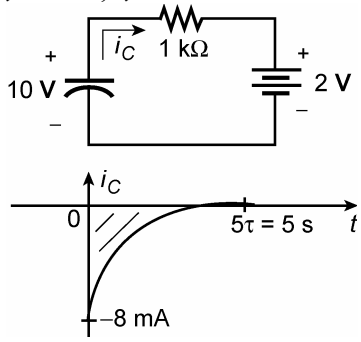
17. $\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$
$= 8 + (4 - 8)(1 - e^{-t/20\text{ ms}})$
$= 8 - 4(1 - e^{-t/20\text{ ms}})$
$= 8 - 4 + 4e^{-t/20\text{ ms}}$
$= 4 + 4e^{-t/20\text{ ms}}$
$\upsilon_C = \mathbf{4\ V(1 + e^{-t/20\ ms})}$

$\tau = RC = (2\text{ k}\Omega)(10\ \mu\text{F})$
$= 20\text{ ms}$

18. $V_i = 10\text{ V}$, $V_f = 2\text{ V}$, $\tau = RC = (1\text{ k}\Omega)(1000\ \mu\text{F}) = 1\text{ s}$
$\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$
$= 10\text{ V} + (2\text{ V} - 10\text{ V})(1 - e^{-t})$
$= 10 - 8(1 - e^{-t})$
$= 10 - 8 + 8e^{-t}$
$\upsilon_C = \mathbf{2\ V + 8\ V}e^{-t}$



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 $i_C = \mathbf{-8mA}e^{-t}$

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20. $\tau = RC = (5\ \text{k}\Omega)(0.04\ \mu\text{F}) = 0.2\ \text{ms}$ (throughout)

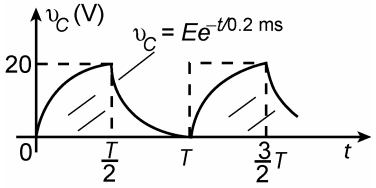
$\upsilon_C = E(1 - e^{-t/\tau}) = \mathbf{20\ V(1 - e^{-t/0.2\ ms})}$

(Starting at $t = 0$ for each plot)

a. $T = \dfrac{1}{f} = \dfrac{1}{500\ \text{Hz}} = 2\ \text{ms}$

$\dfrac{T}{2} = 1\ \text{ms}$

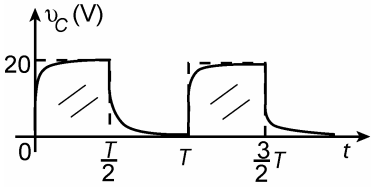
$5\tau = 1\ \text{ms} = \dfrac{T}{2}$



b. $T = \dfrac{1}{f} = \dfrac{1}{100\ \text{Hz}} = 10\ \text{ms}$

$\dfrac{T}{2} = 5\ \text{ms}$

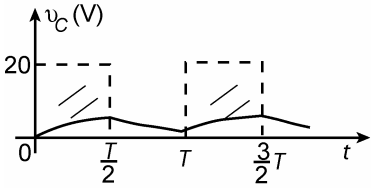
$5\tau = 1\ \text{ms} = \dfrac{1}{5}\left(\dfrac{T}{2}\right)$



c. $T = \dfrac{1}{f} = \dfrac{1}{5\ \text{Hz}} = 0.2\ \text{ms}$

$\dfrac{T}{2} = 0.1\ \text{ms}$

$5\tau = 1\ \text{ms} = 10\left(\dfrac{T}{2}\right)$



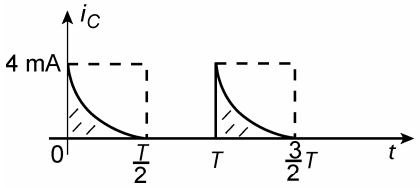
21. The mathematical expression for i_C is the same for each frequency!

$\tau = RC = (5\ \text{k}\Omega)(0.04\ \mu\text{F}) = 0.2\ \text{ms}$

and $i_C = \dfrac{20\ \text{V}}{5\ \text{k}\Omega} e^{-t/0.2\ \text{ms}} = \mathbf{4\ mA}e^{\mathbf{-t/0.2\ ms}}$

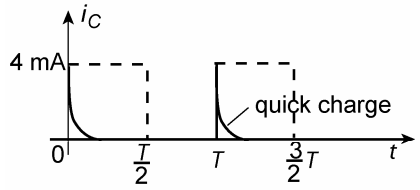
a. $T = \dfrac{1}{500\ \text{Hz}} = 2\ \text{ms}, \dfrac{T}{2} = 1\ \text{ms}$

$5\tau = 5(0.2\ \text{ms}) = 1\ \text{ms} = \dfrac{T}{2}$



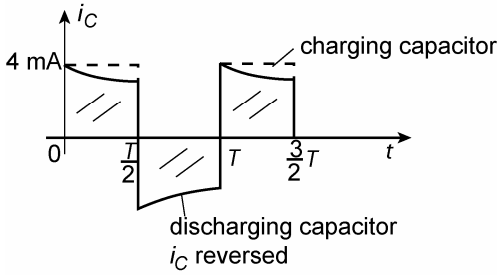
b. $T = \dfrac{1}{100\ \text{Hz}} = 10\ \text{ms}, \dfrac{T}{2} = 5\ \text{ms}$

$5\tau = 1\ \text{ms} = \dfrac{1}{5}\left(\dfrac{T}{2}\right)$



c. $T = \dfrac{1}{5000\ \text{Hz}} = 0.2\ \text{ms}, \dfrac{T}{2} = 0.1\ \text{ms}$

$5\tau = 1\ \text{ms} = 10\left(\dfrac{T}{2}\right)$



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22. $\tau = 0.2$ ms as above

$$T = \frac{1}{500\text{ Hz}} = 2\text{ ms}$$

$$5\tau = 1\text{ ms} = \frac{T}{2}$$

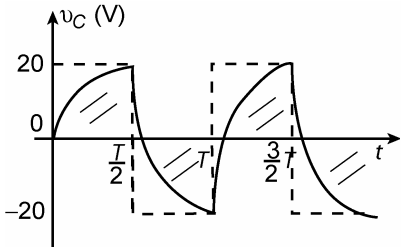
$0 \rightarrow \frac{T}{2}$: $\upsilon_C = 20\text{ V}(1 - e^{-t/0.2\text{ ms}})$

$\frac{T}{2} \rightarrow T$: $V_i = 20$ V, $V_f = -20$ V

$$\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$$
$$= 20 + (-20 - 20)(1 - e^{-t/0.2\text{ ms}})$$
$$= 20 - 40(1 - e^{-t/0.2\text{ ms}})$$
$$= 20 - 40 + 40e^{-t/0.2\text{ ms}}$$
$$\upsilon_C = \mathbf{-20\text{ V} + 40\text{ V}}e^{\mathbf{-t/0.2\text{ ms}}}$$

$T \rightarrow \frac{3}{2}T$: $V_i = -20$ V, $V_f = +20$ V

$$\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$$
$$= -20 + (20 - (-20))(1 - e^{-t/\tau})$$
$$= -20 + 40(1 - e^{-t/\tau})$$
$$= -20 + 40 - 40e^{-t/\tau}$$
$$\upsilon_C = \mathbf{20\text{ V} - 40\text{ V}}e^{\mathbf{-t/0.2\text{ ms}}}$$



23. $\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$

$V_i = 20$ V, $V_f = 20$ V

$\upsilon_C = 20 + (20 - 20)(1 - e^{-t/RC})$

$= \mathbf{20\text{ V}}$ (for $0 \rightarrow \frac{T}{2}$)

For $\frac{T}{2} \rightarrow T$, $\upsilon_i = 0$ V and $\upsilon_C = \mathbf{20\text{ V}}e^{\mathbf{-t/\tau}}$

$\tau = RC = 0.2$ ms

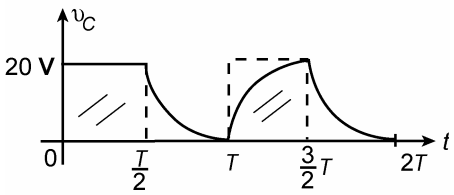
with $\frac{T}{2} = 1$ ms and $5\tau = \frac{T}{2}$

For $T \rightarrow \frac{3}{2}T$, $\upsilon_i = 20$ V

$\upsilon_C = \mathbf{20\text{ V}(1 - e^{-t/\tau})}$

For $\frac{3}{2}T \rightarrow 2T$, $\upsilon_i = 0$ V

$\upsilon_C = \mathbf{20\text{ V}}e^{\mathbf{-t/\tau}}$



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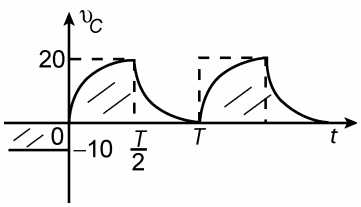
24. $\tau = RC = 0.2$ ms

$5\tau = 1$ ms $= \dfrac{T}{2}$

$V_i = -10$ V, $V_f = +20$ V

$0 \rightarrow \dfrac{T}{2}$:

$$\upsilon_C = V_i + (V_f - V_i)(1 - e^{-t/\tau})$$
$$= -10 + (20 - (-10))(1 - e^{-t/\tau})$$
$$= -10 + 30(1 - e^{-t/\tau})$$
$$= -10 + 30 - 30e^{-t/\tau}$$
$$\upsilon_C = \mathbf{+20\ V - 30\ V}e^{\mathbf{-t/0.2\ ms}}$$



$\dfrac{T}{2} \rightarrow T$: $V_i = 20$ V, $V_f = 0$ V

$\upsilon_C = \mathbf{20\ V}e^{\mathbf{-t/0.2\ ms}}$

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. $\mathbf{Z}_p$: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^5\ \text{rad/s})(3\,\text{pF})} = 3.333\ \text{M}\Omega$

$$\mathbf{Z}_p = \frac{(9\,\text{M}\Omega\angle 0°)(3.333\,\text{M}\Omega)}{9\,\text{M}\Omega - j3.333\,\text{M}\Omega} = 3.126\ \text{M}\Omega\angle -69.68°$$

$\mathbf{Z}_s$: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(10^5\ \text{rad/s})(27\,\text{pF})} = 0.370\ \text{M}\Omega$

$$\mathbf{Z}_s = \frac{(1\,\text{M}\Omega\angle 0°)(0.370\,\text{M}\Omega\angle -90°)}{1\,\text{M}\Omega - j0.370\,\text{M}\Omega} = 0.347\ \text{M}\Omega\angle -69.68°$$

✓ $\theta_{\mathbf{Z}_p} = \theta_{\mathbf{Z}_s}$

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$$\mathbf{V}_{\text{scope}} = \frac{\mathbf{Z}_s \mathbf{V}_i}{\mathbf{Z}_s + \mathbf{Z}_p} = \frac{(0.347\,\text{M}\Omega \angle -69.68°)(100\,\text{V} \angle 0°)}{(0.121\,\text{M}\Omega - j0.325\,\text{M}\Omega) + (1.086\,\text{M}\Omega - j2.931\,\text{M}\Omega)}$$

$$= \frac{34.70 \times 10^6\,\text{V} \angle -69.68°}{3.470 \times 10^6 \angle -69.68°}$$

$$\cong \mathbf{10\ V\ \angle 0°} = \frac{1}{10}(100\,\text{V} \angle 0°)$$

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Chapter 25

1.

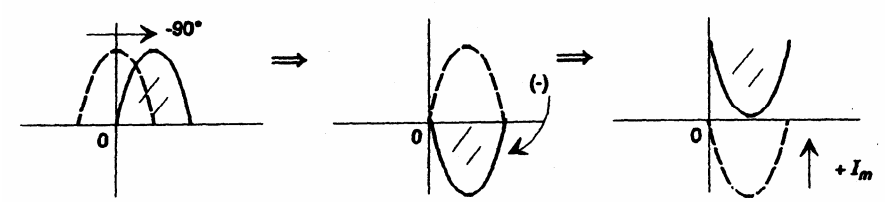
I:	a.	no	b.	no	c.	yes	d.	no	e.	yes
II:	a.	yes	b.	yes	c.	yes	d.	yes	e.	no
III:	a.	yes	b.	yes	c.	no	d.	yes	e.	yes
IV:	a.	no	b.	no	c.	yes	d.	yes	e.	yes

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. $$\frac{2I_m}{\pi}-\frac{I_m}{2}=\frac{2I_m}{\pi}\left[1-\frac{\pi}{4}\right]$$

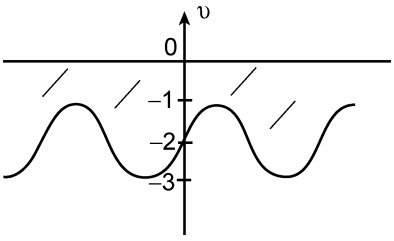
$$i = \frac{2I_m}{\pi}\left[1-\frac{\pi}{4}+\frac{2}{3}\cos(2\omega t-90°)-\frac{2}{15}\cos(4\omega t-90°)+\frac{2}{35}\cos(6\omega t-90°)+\ldots\right]$$

d.

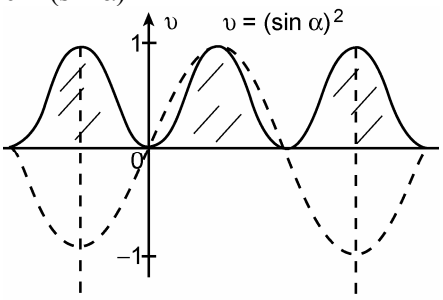


$$i = \frac{-2I_m}{\pi}\left[1-\frac{\pi}{4}+\frac{2}{3}\cos(2\omega t-90°)-\frac{2}{15}\cos(4\omega t-90°)+\frac{2}{35}\cos(6\omega t-90°)+\ldots\right]$$

3. a. $\upsilon = -4 + 2\sin\alpha$



b. $\upsilon = (\sin\alpha)^2$



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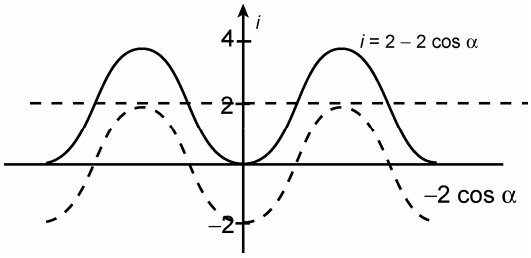
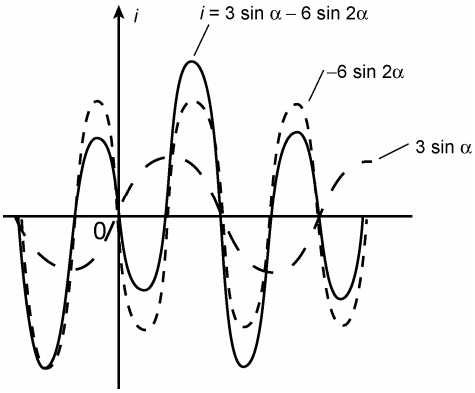
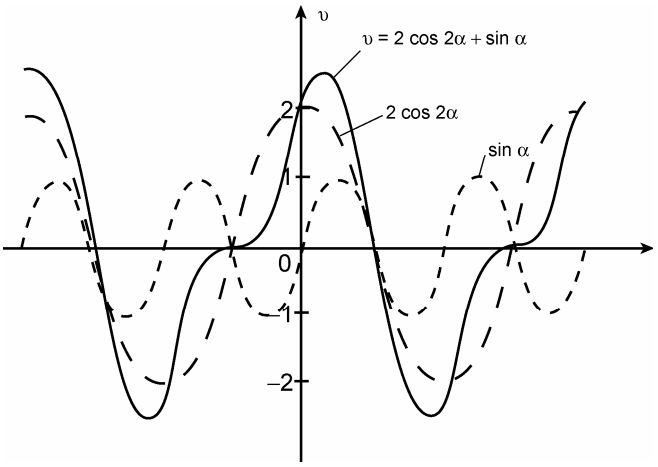
c. $i = 2 - 2\cos\alpha$



4. a.



b.



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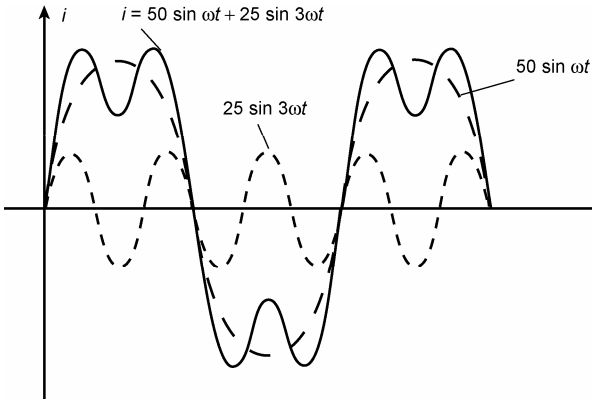
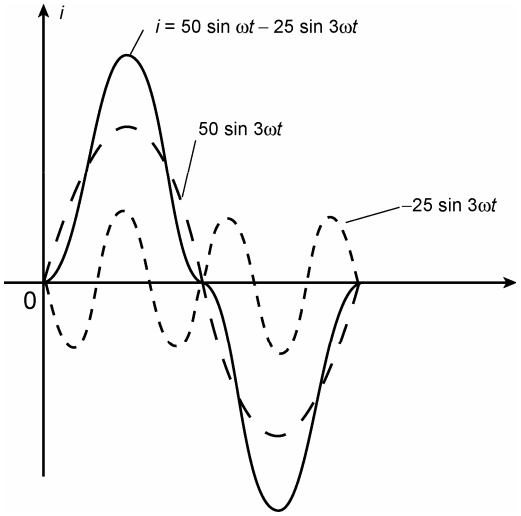
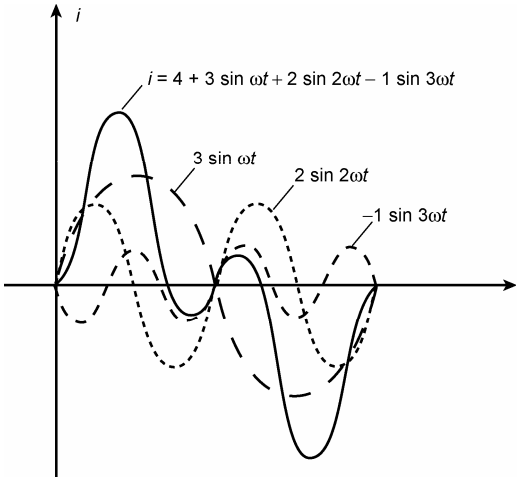
5. a.



b.



c.



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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: $E = 18\text{ V}$, $I_o = \frac{E}{R} = \frac{18\text{ V}}{12\ \Omega} = 1.5\text{ A}$

$\omega = 400$ rad/s: $X_L = \omega L = (400\text{ rad/s})(0.02\text{ H}) = 8\ \Omega$

$$\mathbf{Z} = 12\ \Omega + j8\ \Omega = 14.42\ \Omega\ \angle 33.69°$$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = \frac{30\text{ V}/\sqrt{2}\ \angle 0°}{14.42\ \Omega\ \angle 33.69°} = \frac{2.08\text{ A}}{\sqrt{2}}\ \angle -33.69°$$

$$i = 1.5 + \sqrt{2}\left(\frac{2.08}{\sqrt{2}}\right)\sin(400t - 33.69°)$$

$$i = \mathbf{1.5 + 2.08\ \sin(400t - 33.69°)}$$

b. $$I_{eff} = \sqrt{(1.5\text{ A})^2 + \frac{(2.08\text{ A})^2}{2}} = \mathbf{2.10\ A}$$

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c. DC: $\upsilon_R = E = 18\text{ V},\ \mathbf{V}_R = \left(\frac{2.08\text{ A}}{\sqrt{2}}\angle -33.69°\right)(12\,\Omega\angle 0°)$

$$= \frac{24.96\text{ V}}{\sqrt{2}}\angle -33.69°$$

$$\upsilon_R = 18 + \sqrt{2}\left(\frac{24.96}{\sqrt{2}}\right)\sin(400t - 33.69°)$$

$$\upsilon_R = \mathbf{18 + 24.96\ \sin(400}\boldsymbol{t}\mathbf{ - 33.69°)}$$

d. $$V_{R_{\text{eff}}} = \sqrt{(18\text{ V})^2 + \frac{(24.96\text{ V})^2}{2}} = \mathbf{25.21\ V}$$

e. DC: $V_L = 0$ V

$\omega = 400$ rad/s: $\mathbf{V}_L = \left(\frac{2.08\text{ A}}{\sqrt{2}}\angle -33.69°\right)(8\,\Omega\angle 90°)$

$$= \frac{16.64\text{ A}}{\sqrt{2}}\angle 56.31°$$

$$\upsilon_L = \mathbf{0 + 16.64\ \sin(400}\boldsymbol{t}\mathbf{ + 56.31°)}$$

f. $$V_{L_{\text{eff}}} = \sqrt{0^2 + \frac{(16.64\text{ V})^2}{2}} = \mathbf{11.77\ V}$$

g. $P = I_{\text{eff}}^2 R = (2.101\text{ A})^2\ 12\,\Omega = \mathbf{52.97\ W}$

11. a. DC: $I_{\text{DC}} = \frac{24\text{ V}}{12\,\Omega} = 2$ A

$\omega = 400$ rad/s:

$\mathbf{Z} = 12\,\Omega + j(400\text{ rad/s})(0.02\text{ H}) = 12\,\Omega + j8\,\Omega = 14.422\,\Omega\angle 33.69°$

$\mathbf{I} = \frac{30\text{ V}\angle 0°}{14.422\,\Omega\angle 33.69°} = 2.08\text{ A}\angle -33.69°$ (peak values)

$\omega = 800$ rad/s:

$\mathbf{Z} = 12\,\Omega + j(800\text{ rad/s})(0.02\text{ H}) = 12\,\Omega + j16\,\Omega = 20\,\Omega\angle 53.13°$

$\mathbf{I} = \frac{10\text{ V}\angle 0°}{20\,\Omega\angle 53.13°} = 0.5\text{ A}\angle -53.13°$ (peak values)

$i = \mathbf{2 + 2.08\ \sin(400}\boldsymbol{t}\mathbf{ - 33.69°) + 0.5\ \sin(800}\boldsymbol{t}\mathbf{ - 53.13°)}$

b. $$I_{\text{eff}} = \sqrt{(2\text{ A})^2 + \frac{(2.08\text{ A})^2 + (0.5\text{ A}^2)}{2}} = \mathbf{2.51\ A}$$

c. $\upsilon_R = iR = i(12\,\Omega)$

$= \mathbf{24 + 24.96\ \sin(400}\boldsymbol{t}\mathbf{ - 33.69°) + 6\ \sin(800}\boldsymbol{t}\mathbf{ - 53.13°)}$

d. $$V_{\text{eff}} = \sqrt{(24\text{ V})^2 + \frac{(24.96\text{ V})^2 + (6\text{ V})^2}{2}} = \mathbf{30.09\ V}$$

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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: $\mathbf{V}_L = (0.5\text{ A} \angle -53.13°)(16\ \Omega \angle 90°)$

$= 8\text{ V} \angle 36.87°$

$\upsilon_L = \mathbf{0 + 16.64 \sin(400}t\mathbf{ + 56.31°) + 8 \sin(800}t\mathbf{ + 36.87°)}$

f. $$V_{\text{eff}} = \sqrt{(0)^2 + \frac{(16.64\text{ V})^2 + (8\text{ V})^2}{2}} = \mathbf{13.06\ V}$$

g. $P_T = I_{\text{eff}}^2 R = (2.508\text{ A})^2\ 12\ \Omega = \mathbf{75.48\ W}$

12. a. DC: $$I = -\frac{60\text{ V}}{12\ \Omega} = -5\text{ A}$$

$\omega = 300$ 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: $X_L = \omega L = (600\text{ rad/s})(0.02\text{ H}) = 12\ \Omega$

$\mathbf{Z} = 12\ \Omega + j12\ \Omega = 16.97\ \Omega \angle 45°$

$\mathbf{E} = -(0.707)(10\text{ V}) \angle 0° = -7.07\text{ V} \angle 0°$

$$\mathbf{I} = \frac{\mathbf{E}}{\mathbf{Z}} = -\frac{7.07\text{ V} \angle 0°}{16.97\ \Omega \angle 45°} = -0.417\text{ A} \angle -45°$$

$i = -5 + (1.414)(1.054)\sin(300t - 26.57°) - (1.414)(0.417)\sin(600t - 45°)$

$i = \mathbf{-5 + 1.49 \sin(300}t\mathbf{ - 26.57°) - 0.59 \sin(600}t\mathbf{ - 45°)}$

b. $$I_{\text{eff}} = \sqrt{(10\text{ A})^2 + \frac{(1.49\text{ A})^2 + (0.59\text{ A})^2}{2}} = \mathbf{10.06\ A}$$

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: $\mathbf{V}_R = (-0.417\text{ A} \angle -45°)(12\ \Omega \angle 0°)$

$= -5\text{ V} \angle -45°$

$\upsilon_R = -60 + (1.414)(12.648)\sin(300t - 26.57°) - (1.414)(5)\sin(600t - 45°)$

$\upsilon_R = \mathbf{-60 + 17.88 \sin(300}t\mathbf{ - 26.57°) - 7.07 \sin(600}t\mathbf{ - 45°)}$

d. $$V_{R_{\text{eff}}} = \sqrt{(60\text{ V})^2 + \frac{(17.88\text{ V})^2 + (7.07\text{ V})^2}{2}} = \mathbf{61.52\ V}$$

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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(300*t* + 63.43°) – 3.54 sin(600*t* + 45°)**

f. $V_{L_{\text{eff}}} = \sqrt{\dfrac{(8.94\text{ V})^2 + (3.54\text{ V})^2}{2}} =$ **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: $X_C = \dfrac{1}{\omega C} = \dfrac{1}{(400\text{ rad/s})(125\ \mu\text{F})} = 20\ \Omega$

$\mathbf{Z} = 15\ \Omega - j20\ \Omega = 25\ \Omega \angle -53.13°$

$\mathbf{E} = (0.707)(30\text{ V}) \angle 0° = 21.21\text{ V} \angle 0°$

$\mathbf{I} = \dfrac{\mathbf{E}}{\mathbf{Z}} = \dfrac{21.21\text{ V} \angle 0°}{25\ \Omega \angle -53.13°} = 0.848\text{ A} \angle 53.13°$

$i = 0 + (1.414)(0.848)\sin(400t + 53.13°)$

$i =$ **1.2 sin(400*t* + 53.13°)**

b. $I_{\text{eff}} = \sqrt{\dfrac{(1.2\text{ A})^2}{2}} =$ **0.85 A** 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(400*t* + 53.13°)**

d. $V_{R_{\text{eff}}} = \sqrt{\dfrac{(18\text{ V})^2}{2}} =$ **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(400*t* – 36.87°)**

f. $V_{C_{\text{eff}}} = \sqrt{(18\text{ V})^2 + \dfrac{(23.98\text{ V})^2}{2}} =$ **24.73 V**

g. $P = I_{\text{eff}}^2 R = (0.848\text{ A})^2\ 15\ \Omega =$ **10.79 W**

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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: $X_C = \frac{1}{\omega C} = \frac{1}{(1508 \text{ rad/s})(1\,\mu\text{F})} = 6631.13\ \Omega$

$X_L = \omega L = (1508 \text{ rad/s})(0.1 \text{ H}) = 150.8\ \Omega$

$\mathbf{Z}' = (1\text{ k}\Omega\ \angle 0°) \parallel 150.8\ \Omega\ \angle 90° = 149.12\ \Omega\ \angle 81.42°$

$\mathbf{E} = (0.707)(8.49 \text{ V})\ \angle 90° = 6 \text{ V}\ \angle 90°$

$\mathbf{V}_o = \frac{\mathbf{Z}'(\mathbf{E})}{\mathbf{Z}' + \mathbf{Z}_C} = \frac{(149.12\,\Omega\ \angle 81.42°)(6 \text{ V}\ \angle 90°)}{149.12\,\Omega\ \angle 81.42° + 6631.13\,\Omega\ \angle -90°}$

$= 1.73 \text{ V}\ \angle -101.1°$

$\upsilon_o = 0 + 1.414(1.799)\sin(754t - 94.57°) - 1.414(1.73)\sin(1508t - 101.1°)$

$\upsilon_o =$ **$2.54 \sin(754t - 94.57°) - 2.45 \sin(1508t - 101.1°)$**

b. $V_{o_{\text{eff}}} = \sqrt{\frac{(2.54 \text{ V})^2 + (2.45 \text{ V})^2}{2}} =$ **2.50 V**

c. $P = \frac{(V_{\text{eff}})^2}{\text{R}} = \frac{(2.50 \text{ V})^2}{1\,\text{k}\Omega} =$ **6.25 mW**

15. $i = 0.318I_m + 0.500\, I_m \sin \omega t - 0.212I_m \cos 2\omega t - 0.0424I_m \cos 4\omega t + \ \ldots$ ($I_m = 10$ 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; $X_L = \omega L = (377 \text{ rad/s})(1.2 \text{ mH}) = 0.452\ \Omega$

$X_C = \frac{1}{\omega C} = \frac{1}{(377 \text{ rad/s})(200\,\mu\text{F})} = 13.26\ \Omega$

$\mathbf{Z}' = 200\ \Omega - j13.26\ \Omega = 200.44\ \Omega\ \angle -3.79°$

$\mathbf{I} = (0.707)(5 \times 10^{-3})\text{A}\ \angle 0° = 3.54 \text{ mA}\ \angle 0°$

$\mathbf{I}_o = \frac{\mathbf{Z}_L\mathbf{I}}{\mathbf{Z}_L + \mathbf{Z}'} = \frac{(0.452\,\Omega\ \angle 90°)(3.54 \text{ mA}\ \angle 0°)}{j0.452\,\Omega + 200\,\Omega - j13.26\,\Omega} = 7.98\ \mu\text{A}\ \angle 93.66°$

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$\mathbf{V}_o = (7.98\ \mu\text{A}\ \angle 93.66°)(200\ \Omega\ \angle 0°) = 1.596\ \text{mV}\ \angle 93.66°$

$\omega = 754$ rad/s: $X_L = \omega L = (754\ \text{rad/s})(1.2\ \text{mH}) = 0.905\ \Omega$

$$X_C = \frac{1}{\omega C} = \frac{1}{(754\ \text{rad/s})(200\ \mu\text{F})} = 6.63\ \Omega$$

$$\mathbf{Z}' = 200\ \Omega - j6.63\ \Omega = 200.11\ \Omega\ \angle -1.9°$$

$$\mathbf{I} = (0.707)(2.12\ \text{mA})\ \angle 90° = 1.5\ \text{mA}\ \angle 90°$$

$$\mathbf{I}_o = \frac{\mathbf{Z}_L\mathbf{I}}{\mathbf{Z}_L + \mathbf{Z}'} = \frac{(0.905\ \Omega\ \angle 90°)(1.5\ \text{mA}\ \angle 90°)}{j0.905\ \Omega + 200\ \Omega - j6.63\ \Omega} = 6.8\ \mu\text{A}\ \angle 181.64°$$

$\mathbf{V}_o = (6.8\ \mu\text{A}\ \angle 181.64°)(200\ \Omega\ \angle 0°) = 1.36\ \text{mA}\ \angle 181.64°$

$\upsilon_o = 0 + (1.414)(1.596 \times 10^{-3})\sin(377t + 93.66°)$

$\quad - (1.414)(1.360 \times 10^{-3})\sin(754t + 181.64°)$

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

16. a. $60 + 70 \sin \omega t + 20 \sin(2\omega t + 90°) + 10 \sin(3\omega t + 60°)$
$+20 + 30 \sin \omega t - 20 \sin(2\omega t + 90°) + 5 \sin(3\omega t + 90°)$

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 = $\mathbf{80 + 100 \sin \omega}t\mathbf{ + 14.55 \sin(3\omega}t\mathbf{ + 69.9°)}$

b. $20 + 60 \sin \alpha + 10 \sin(2\alpha - 180°) + 5 \sin(3\alpha + 180°)$
$-5 + 10 \sin \alpha + \quad 0 \quad - 4 \sin(3\alpha - 30°)$

DC: $20 - 5 = 15$

α: $60 + 10 = 70 \Rightarrow 70 \sin \alpha$

2α: $10 \sin(2\alpha - 180°)$

3α: $5\ \angle 180° - 4\ \angle -30° = -5 - [3.46 - j2] = -8.46 + j2$

$= 8.69\ \angle 166.7°$

Sum = $\mathbf{15 + 70 \sin \alpha + 10 \sin(2\alpha - 180°) + 8.69 \sin(3\alpha + 166.7°)}$

17. $i_T = i_1 + i_2$

$= 10 + 30 \sin 20t \quad - 0.5 \sin(40t + 90°)$

$+20 + 4 \sin(20t + 90°) + 0.5 \sin(40t + 30°)$

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: $-0.5\ \text{A}\ \angle 90° + 0.5\ \text{A}\ \angle 30°$

$= -j0.5\ \text{A} + 0.433\ \text{A} + j0.25\ \text{A}$

$= 0.433\ \text{A} - j0.25\ \text{A} = 0.5\ \text{A}\ \angle -30°$

$i_T = \mathbf{30 + 30.27 \sin(20}t\mathbf{ + 7.59°) + 0.5 \sin(40}t\mathbf{ - 30°)}$

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18. $e = \upsilon_1 + \upsilon_2$

$= 20 - 200 \sin 600t + 100 \sin(1200t + 90°) + 75 \sin 1800t$

$-10 + 150 \sin(600t + 30°) \quad + 0 \quad + 50 \sin(1800t + 60°)$

DC: $20 \text{ V} - 10 \text{ V} = 10 \text{ V}$

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: $75 \text{ V} \angle 0° + 50 \text{ V} \angle 60° = 108.97 \text{ V} \angle 23.41°$

$e = \mathbf{10 + 102.66 \sin(600t + 133.07°) + 100 \sin(1200t + 90°) + 108.97 \sin(1800t + 23.41°)}$

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