PART ONE

Solutions to End-of-Chapter Problems

CHAPTER 1
QUANTITIES AND UNITS

SECTION 1-1 Scientific and Engineering Notation

1. (a) $3000 = \mathbf{3 \times 10^3}$ (b) $75{,}000 = \mathbf{7.5 \times 10^4}$ (c) $2{,}000{,}000 = \mathbf{2 \times 10^6}$

2. (a) $\frac{1}{500} = 0.002 = \mathbf{2 \times 10^{-3}}$

   (b) $\frac{1}{2000} = 0.0005 = \mathbf{5 \times 10^{-4}}$

   (c) $\frac{1}{5{,}000{,}000} = 0.0000002 = \mathbf{2 \times 10^{-7}}$

3. (a) $8400 = \mathbf{8.4 \times 10^3}$ (b) $99{,}000 = \mathbf{9.9 \times 10^4}$ (c) $0.2 \times 10^6 = \mathbf{2 \times 10^5}$

4. (a) $0.0002 = \mathbf{2 \times 10^{-4}}$ (b) $0.6 = \mathbf{6 \times 10^{-1}}$

   (c) $\mathbf{7.8 \times 10^{-2}}$ (already in scientific notation)

5. (a) $2.5 \times 10^{-6} = \mathbf{0.0000025}$ (b) $5.0 \times 10^2 = \mathbf{500}$ (c) $3.9 \times 10^{-1} = \mathbf{0.39}$

6. (a) $4.5 \times 10^{-6} = \mathbf{0.0000045}$

   (b) $8 \times 10^{-9} = \mathbf{0.000000008}$

   (c) $4.0 \times 10^{-12} = \mathbf{0.0000000000040}$

7. (a) $9.2 \times 10^6 + 3.4 \times 10^7 = 9.2 \times 10^6 + 34 \times 10^6 = \mathbf{4.32 \times 10^7}$

   (b) $5 \times 10^3 + 8.5 \times 10^{-1} = 5 \times 10^3 + 0.00085 \times 10^3 = \mathbf{5.00085 \times 10^3}$

   (c) $5.6 \times 10^{-8} + 4.6 \times 10^{-9} = 56 \times 10^{-9} + 4.6 \times 10^{-9} = \mathbf{6.06 \times 10^{-8}}$

8. (a) $3.2 \times 10^{12} - 1.1 \times 10^{12} = \mathbf{2.1 \times 10^{12}}$

   (b) $2.6 \times 10^8 - 1.3 \times 10^7 = 26 \times 10^7 - 1.3 \times 10^7 = \mathbf{24.7 \times 10^7}$

   (c) $1.5 \times 10^{-12} - 8 \times 10^{-13} = 15 \times 10^{-13} - 8 \times 10^{-13} = \mathbf{7 \times 10^{-13}}$

9. (a) $(5 \times 10^3)(4 \times 10^5) = 5 \times 4 \times 10^{3+5} = 20 \times 10^8 = \mathbf{2 \times 10^9}$

(b) $(1.2 \times 10^{12})(3 \times 10^2) = 1.2 \times 3 \times 10^{12+2} = \mathbf{3.6 \times 10^{14}}$

(c) $(2.2 \times 10^{-9})(7 \times 10^{-6}) = 2.2 \times 7 \times 10^{-9-6} = 15.4 \times 10^{-15} = \mathbf{1.54 \times 10^{-14}}$

10. (a) $\dfrac{1.0\times10^3}{2.5\times10^2} = 0.4 \times 10^{3-2} = 0.4 \times 10^1 = \mathbf{4}$

(b) $\dfrac{2.5\times10^{-6}}{5.0\times10^{-8}} = 0.5 \times 10^{-6-(-8)} = 0.5 \times 10^2 = \mathbf{50}$

(c) $\dfrac{4.2\times10^8}{2\times10^{-5}} = 2.1 \times 10^{8-(-5)} = \mathbf{2.1 \times 10^{13}}$

11. (a) $89{,}000 = \mathbf{89 \times 10^3}$

(b) $450{,}000 = \mathbf{450 \times 10^3}$

(c) $12{,}040{,}000{,}000{,}000 = \mathbf{12.04 \times 10^{12}}$

12. (a) $2.35 \times 10^5 = \mathbf{235 \times 10^3}$

(b) $7.32 \times 10^7 = \mathbf{73.2 \times 10^6}$

(c) $\mathbf{1.333 \times 10^9}$ (already in engineering notation)

13. (a) $0.000345 = \mathbf{345 \times 10^{-6}}$

(b) $0.025 = \mathbf{25 \times 10^{-3}}$

(c) $0.00000000129 = \mathbf{1.29 \times 10^{-9}}$

14. (a) $9.81 \times 10^{-3} = \mathbf{9.81 \times 10^{-3}}$

(b) $4.82 \times 10^{-4} = \mathbf{482 \times 10^{-6}}$

(c) $4.38 \times 10^{-7} = \mathbf{438 \times 10^{-9}}$

15. (a) $2.5 \times 10^{-3} + 4.6 \times 10^{-3} = (2.5 + 4.6) \times 10^{-3} = \mathbf{7.1 \times 10^{-3}}$

(b) $68 \times 10^6 + 33 \times 10^6 = (68 + 33) \times 10^6 = \mathbf{101 \times 10^6}$

(c) $1.25 \times 10^6 + 250 \times 10^3 = 1.25 \times 10^6 + 0.25 \times 10^6 = (1.25 + 0.25) \times 10^6 = \mathbf{1.50 \times 10^6}$

16. (a) $(32 \times 10^{-3})(56 \times 10^3) = 1792 \times 10^{(-3+3)} = 1792 \times 10^0 = \mathbf{1.792 \times 10^3}$

(b) $(1.2 \times 10^{-6})(1.2 \times 10^{-6}) = 1.44 \times 10^{(-6-6)} = \mathbf{1.44 \times 10^{-12}}$

(c) $(100)(55 \times 10^{-3}) = 5500 \times 10^{-3} = \mathbf{5.5}$

17. (a) $\dfrac{50}{2.2\times10^{3}} = \mathbf{22.7 \times 10^{-3}}$

(b) $\dfrac{5\times10^{3}}{25\times10^{-6}} = 0.2 \times 10^{(3-(-6))} = 0.2 \times 10^{9} = \mathbf{200 \times 10^{6}}$

(c) $\dfrac{560\times10^{3}}{660\times10^{3}} = 0.848 \times 10^{(3-3)} = 0.848 \times 10^{0} = \mathbf{848 \times 10^{-3}}$

SECTION 1-2 Units and Metric Prefixes

18. (a) $89{,}000\ \Omega = 89 \times 10^{3} =$ **89 kΩ**

(b) $450{,}000\ \Omega = 450 \times 10^{3} =$ **450 kΩ**

(c) $12{,}040{,}000{,}000{,}000\ \Omega = 12.04 \times 10^{12} =$ **12.04 TΩ**

19. (a) 0.000345 A $= 345 \times 10^{-6}$ A = **345 μA**

(b) 0.025 A $= 25 \times 10^{-3}$ A = **25 mA**

(c) 0.00000000129 A $= 1.29 \times 10^{-9}$ A = **1.29 nA**

20. (a) 31×10^{-3} A = **31 mA** (b) 5.5×10^{3} V = **5.5 kV** (c) 20×10^{-12} F = **20 pF**

21. (a) 3×10^{-6} F = **3 μF** (b) $3.3 \times 10^{6}\ \Omega$ = **3.3 MΩ** (c) 350×10^{-9} A = **350 nA**

22. (a) 5 μA = $\mathbf{5 \times 10^{-6}}$ **A** (b) 43 mV = $\mathbf{43 \times 10^{-3}}$ **V**

(c) 275 kΩ = $\mathbf{275 \times 10^{3}\ \Omega}$ (d) 10 MW = $\mathbf{10 \times 10^{6}}$ **W**

SECTION 1-3 Metric Unit Conversions

23. (a) (5 mA) $(1 \times 10^{3}$ μA/mA$) = 5 \times 10^{3}$ μA = **5000 μA**

(b) (3200 μW)$(1 \times 10^{-3}$ W/μW) = **3.2 mW**

(c) (5000 kV)(1×10^{-3}) MV/kV = **5 MV**

(d) (10 MW)$(1 \times 10^{3}$ kW/MW$) = 10 \times 10^{3}$ kW = **10,000 kW**

24. (a) $\dfrac{1\text{ mA}}{1\ \mu\text{A}} = \dfrac{1\times10^{-3}\text{A}}{1\times10^{-6}\text{A}} = 1 \times 10^3 = \mathbf{1000}$

(b) $\dfrac{0.05\text{ kV}}{1\text{ mV}} = \dfrac{0.05\times10^{3}\text{ V}}{1\times10^{-3}\text{ V}} = 0.05 \times 10^6 = \mathbf{50{,}000}$

(c) $\dfrac{0.02\text{ k}\Omega}{1\text{M}\Omega} = \dfrac{0.02\times10^{3}\ \Omega}{1\times10^{6}\ \Omega} = 0.02 \times 10^{-3} = \mathbf{2 \times 10^{-5}}$

(d) $\dfrac{155\text{ mW}}{1\text{ kW}} = \dfrac{155\times10^{-3}\text{ W}}{1\times10^{3}\text{ W}} = 155 \times 10^{-6} = \mathbf{1.55 \times 10^{-4}}$

25. (a) 50 mA + 680 μA = 50 mA + 0.68 mA = **50.68 mA**

(b) 120 kΩ + 2.2 MΩ = 0.12 MΩ + 2.2 MΩ = **2.32 MΩ**

(c) 0.02 μF + 3300 pF = 0.02 μF + 0.0033 μF = **0.0233 μF**

26. (a) $\dfrac{10\text{ k}\Omega}{2.2\text{ k}\Omega + 10\text{ k}\Omega} = \dfrac{10\text{ k}\Omega}{12.2\text{ k}\Omega} = \mathbf{0.8197}$

(b) $\dfrac{250\text{ mV}}{50\ \mu\text{V}} = \dfrac{250\times10^{-3}}{50\times10^{-6}} = \mathbf{5000}$

(c) $\dfrac{1\text{MW}}{2\text{ kW}} = \dfrac{1\times10^{6}}{2\times10^{3}} = \mathbf{500}$

SECTION 1-4 Measured Numbers

27. (a) 1.00×10^3 has 3 significant digits.

(b) 0.0057 has 2 significant digits.

(c) 1502.0 has 5 significant digits.

(d) 0.000036 has 2 significant digits.

(e) 0.105 has 3 significant digits.

(f) 2.6×10^2 has 2 significant digits.

28. (a) 50,505 ≅ $\mathbf{50.5 \times 10^3}$

(b) 220.45 ≅ **220**

(c) 4646 ≅ $\mathbf{4.65 \times 10^3}$

(d) 10.99 ≅ **11.0**

(e) 1.005 ≅ **1.00**

CHAPTER 2
VOLTAGE, CURRENT, AND RESISTANCE

BASIC PROBLEMS

SECTION 2-2 Electrical Charge

1. Q = (charge per electron)(number of electrons) = $(1.6 \times 10^{-19}$ C/e$)(50 \times 10^{31}$e$)$ = $\mathbf{80 \times 10^{12}}$ **C**

2. $(6.25 \times 10^{18}$ e/C$)(80 \times 10^{-6}$ C$)$ = $\mathbf{5 \times 10^{14}}$ **e**

3. The magnitude of the charge on a proton (p) is equal to the magnitude of the charge on the electron (e). Therefore, $(1.6 \times 10^{-19}$ C/p$)(29$ p$)$ = $\mathbf{4.64 \times 10^{-18}}$ **C**

4. $(1.6 \times 10^{-19}$ C/p$)(17$ p$)$ = $\mathbf{2.72 \times 10^{-18}}$ **C**

SECTION 2-3 Voltage

5. (a) $V = \dfrac{W}{Q} = \dfrac{10\text{ J}}{1\text{ C}} = \mathbf{10\text{ V}}$ (b) $V = \dfrac{W}{Q} = \dfrac{5\text{ J}}{2\text{ C}} = \mathbf{2.5\text{ V}}$ (c) $V = \dfrac{W}{Q} = \dfrac{100\text{ J}}{25\text{ C}} = \mathbf{4\text{ V}}$

6. $V = \dfrac{W}{Q} = \dfrac{500\text{ J}}{100\text{ C}} = \mathbf{5\text{ V}}$

7. $V = \dfrac{W}{Q} = \dfrac{800\text{ J}}{40\text{ C}} = \mathbf{20\text{ V}}$

8. $W = VQ = (12\text{ V})(2.5\text{ C}) = \mathbf{30\text{ J}}$

9. $V = \dfrac{W}{Q} = \dfrac{2.5\text{ J}}{0.2\text{ C}} = \mathbf{12.5\text{ V}}$

SECTION 2-4 Current

10. $I = \dfrac{Q}{t} = \dfrac{0.2\text{ C}}{10\text{ s}} = \mathbf{20\text{ mA}}$

11. (a) $I = \frac{Q}{t} = \frac{75\text{ C}}{1\text{ s}} = \mathbf{75\ A}$ (b) $I = \frac{Q}{t} = \frac{10\text{ C}}{0.5\text{ s}} = \mathbf{20\ A}$ (c) $I = \frac{Q}{t} = \frac{5\text{ C}}{2\text{ s}} = \mathbf{2.5\ A}$

12. $I = \frac{Q}{t} = \frac{0.6\text{ C}}{3\text{ s}} = \mathbf{0.2\ A}$

13. $I = \frac{Q}{t}$; $t = \frac{Q}{I} = \frac{10\text{ C}}{5\text{ A}} = \mathbf{2\ s}$

14. $Q = I \times t = (1.5\text{ A})(0.1\text{ s}) = \mathbf{0.15\ C}$

SECTION 2-5 Resistance

15. A: Blue, gray, red, silver: **6800 Ω ± 10%**
    B: Orange, orange, black, silver: **33 Ω ± 10%**
    C: Yellow, violet, orange, gold: **47,000 Ω ± 5%**

16. A: R_{min} = 6800 Ω − 0.1(6800 Ω) = 6800 Ω − 680 Ω = **6120 Ω**
    R_{max} = 6800 Ω + 680 Ω = **7480 Ω**
    B: R_{min} = 33 Ω − 0.1(33 Ω) = 33 Ω − 3.3 Ω = **29.7 Ω**
    R_{max} = 33 Ω + 3.3 Ω = **36.3 Ω**
    C: R_{min} = 47,000 Ω − (0.05)(47,000 Ω) = 47,000 Ω − 2350 Ω = **44,650 Ω**
    R_{max} = 47,000 Ω + 2350 Ω = **49,350 Ω**

17. (a) 1st band = **red**, 2nd band = **violet**, 3rd band = **brown**, 4th band = **gold**

    (b) 330 Ω; **orange, orange, brown, (B)**
    2.2 kΩ: **red, red, red (D)**
    39 kΩ: **orange, white, orange (A)**
    56 kΩ: **green, blue, orange (L)**
    100 kΩ: **brown, black, yellow (F)**

18. (a) **36.5 Ω ± 2%**

    (b) **2.74 kΩ ± 0.25%**

    (c) **82.5 kΩ ± 1%**

19. (a) Brown, black, black, gold: **10 Ω ± 5%**

    (b) Green, brown, green, silver: 5,100,000 Ω ± 10% **= 5.1 MΩ ± 10%**

    (c) Blue, gray, black, gold: **68 Ω ± 5%**

20. (a) 0.47 Ω ± 5%: **yellow, violet, silver, gold**

    (b) 270 kΩ ± 5%: **red, violet, yellow, gold**

(c) 5.1 MΩ ± 5%: **green, brown, green, gold**

21. (a) Red, gray, violet, red, brown: 28,700 Ω ± 1% = **28.7 kΩ ± 1%**
    (b) Blue, black, yellow, gold, brown: **60.4 Ω ± 1%**
    (c) White, orange, brown, brown, brown: 9310 ± 1% = **9.31 kΩ ± 1%**

22. (a) 14.7 kΩ ± 1%: **brown, yellow, violet, red, brown**
    (b) 39.2 Ω ± 1%: **orange, white, red, gold, brown**
    (c) 9.76 kΩ ± 1%: **white, violet, blue, brown, brown**

23. (a) 220 = **22 Ω** (b) 472 = **4.7 kΩ**
    (c) 823 = **82 kΩ** (d) 3K3 = **3.3 kΩ**
    (e) 560 = **56 Ω** (f) 10M = **10 MΩ**

24. **500 Ω**, equal resistance on each side of the contact.

SECTION 2-6 The Electric Circuit

25. There is current through **Lamp 2.**

26. See Figure 2-1.

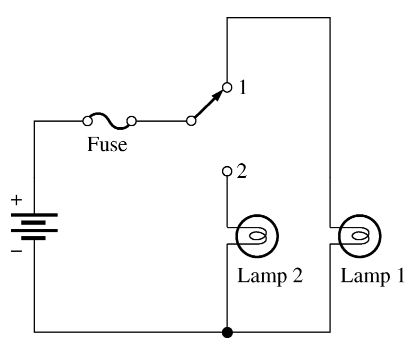


Figure 2-1

SECTION 2-7 Basic Circuit Measurements

27. See Figure 2-2(a).

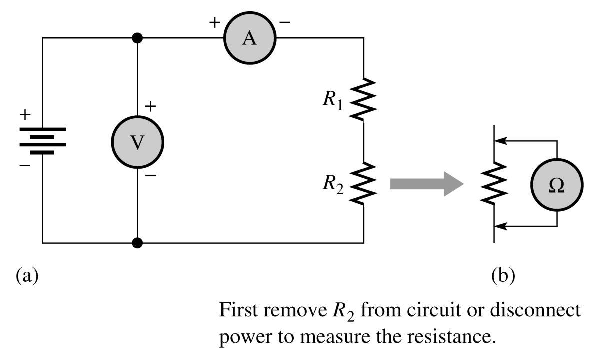


Figure 2-2

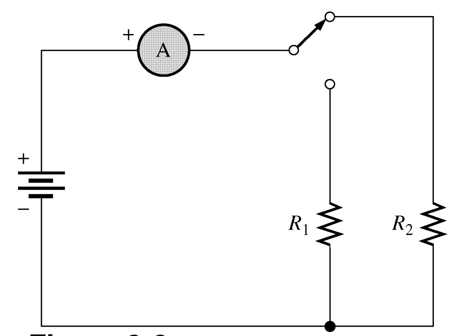


Figure 2-3

28. See Figure 2-2(b).

29. Position 1: V1 = **0 V**, V2 = $\boldsymbol{V_S}$
    Position 2: V1 = $\boldsymbol{V_S}$, V2 = **0 V**

30. See Figure 2-3.

31. On the 600 V DC scale: **250 V**

32. $R = (10)(10\ \Omega) = \mathbf{100\ \Omega}$

33. (a) $2(100\ \Omega) = \mathbf{200\ \Omega}$ (b) $15(10\ \text{M}\Omega) = \mathbf{150\ M\Omega}$

    (c) $45(100\ \Omega) = \mathbf{4500\ \Omega}$

34. See Figure 2-4.

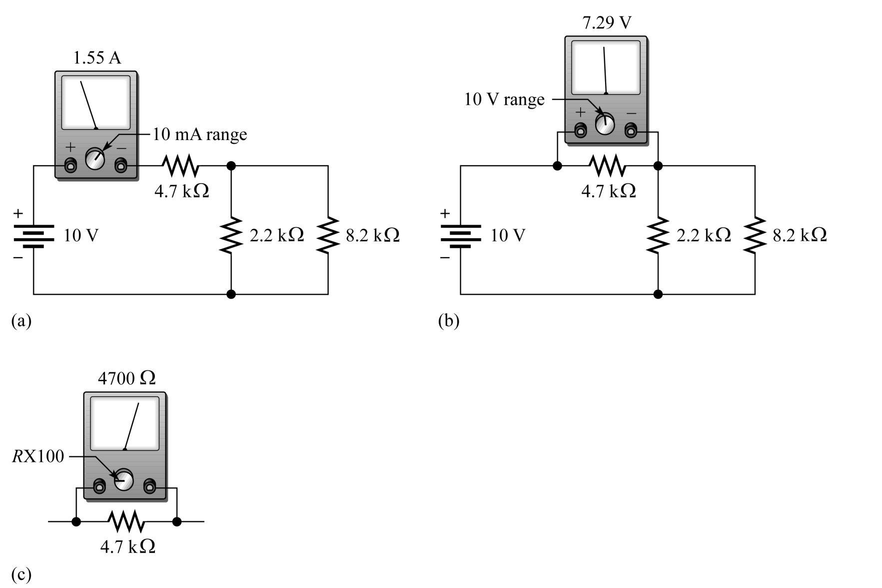


Figure 2-4

ADVANCED PROBLEMS

35. $I = \dfrac{Q}{t}$

$Q = I \times t = (2\text{ A})(15\text{ s}) = 30\text{ C}$

$V = \dfrac{W}{Q} = \dfrac{1000\text{ J}}{30\text{ C}} = \mathbf{33.3\ V}$

36. $I = \dfrac{Q}{t}$

Q = (number of electrons) / (number of electrons/coulomb)

$Q = \dfrac{574\times10^{15}\text{ e}}{6.25\times10^{18}\text{ e/C}} = 9.184 \times 10^{-2}\text{ C}$

$I = \dfrac{Q}{t} = \dfrac{9.184\times10^{-2}\text{ C}}{250\times10^{-3}\text{ s}} = \mathbf{0.367\ A}$

37. Total wire length = 100 ft
Resistance per 1000 ft = (1000 ft)(6 Ω/100 ft) = 60 Ω
Smallest wire size is **AWG 27** which has 51.47 Ω/1000 ft

38. (a) 4R7J = **4.7 Ω ± 5%**

(b) 560KF = **560 kΩ ± 1%**

(c) 1M5G = **1.5 MΩ ± 2%**

39. The circuit in (b) can have both lamps on at the same time.

40. There is always current through R_5.

41. See Figure 2-5.

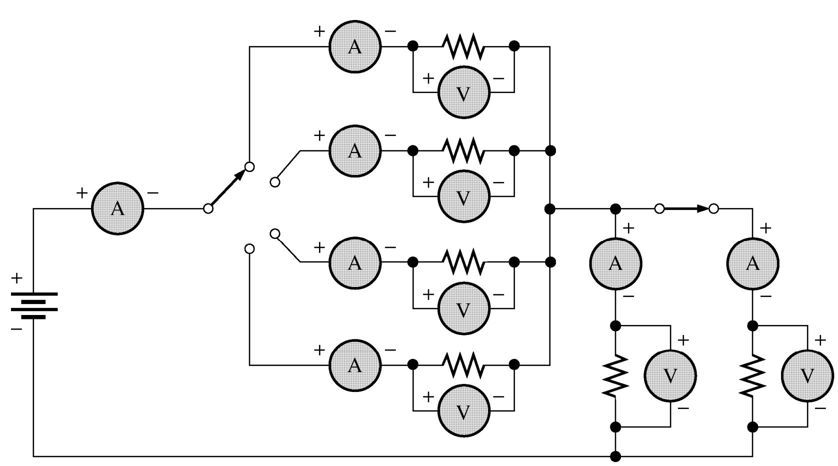


Figure 2-5

42. See Figure 2-5.

43. See Figure 2-6.

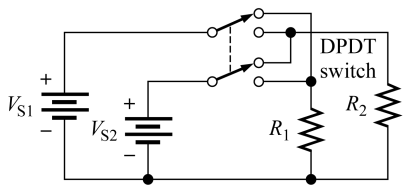


Figure 2-6

CHAPTER 3
OHM'S LAW, ENERGY, AND POWER

BASIC PROBLEMS

SECTION 3-1 Ohm's Law

1. I is directly proportional to V and will change the same percentage as V.
   (a) $I = 3(1\text{ A}) = \mathbf{3\text{ A}}$
   (b) $I = 1\text{ A} - (0.8)(1\text{ A}) = 1\text{ A} - 0.8\text{ A} = \mathbf{0.2\text{ A}}$
   (c) $I = 1\text{ A} + (0.5)(1\text{ A}) = 1\text{ A} + 0.5\text{ A} = \mathbf{1.5\text{ A}}$

2. (a) When the resistance doubles, the current is halved from 100 mA to **50 mA.**
   (b) When the resistance is reduced by 30%, the current increases from 100 mA to $I = V/0.7R = 1.429(V/R) = (1.429)(100\text{ mA}) \cong \mathbf{143\text{ mA}}$
   (c) When the resistance is quadrupled, the current decreases from 100 mA to **25 mA**.

3. Tripling the voltage triples the current from 10 mA to 30 mA, but doubling the resistance halves the current to **15 mA.**

SECTION 3-2 Application of Ohm's Law

4. (a) $I = \dfrac{V}{R} = \dfrac{5\text{ V}}{1\ \Omega} = \mathbf{5\text{ A}}$
   (b) $I = \dfrac{V}{R} = \dfrac{15\text{ V}}{10\ \Omega} = \mathbf{1.5\text{ A}}$
   (c) $I = \dfrac{V}{R} = \dfrac{50\text{ V}}{100\ \Omega} = \mathbf{0.5\text{ A}}$
   (d) $I = \dfrac{V}{R} = \dfrac{30\text{ V}}{15\text{ k}\Omega} = 2\ \mathbf{mA}$
   (e) $I = \dfrac{V}{R} = \dfrac{250\text{ V}}{4.7\text{ M}\Omega} = \mathbf{53.2\ \mu A}$

5. (a) $I = \dfrac{V}{R} = \dfrac{9\text{ V}}{2.7\text{ k}\Omega} = \mathbf{3.33\text{ mA}}$
   (b) $I = \dfrac{V}{R} = \dfrac{5.5\text{ V}}{10\text{ k}\Omega} = \mathbf{550\ \mu A}$
   (c) $I = \dfrac{V}{R} = \dfrac{40\text{ V}}{68\text{ k}\Omega} = \mathbf{588\ \mu A}$
   (d) $I = \dfrac{V}{R} = \dfrac{1\text{ kV}}{2\text{ k}\Omega} = \mathbf{500\text{ mA}}$
   (e) $I = \dfrac{V}{R} = \dfrac{66\text{ kV}}{10\text{ M}\Omega} = \mathbf{6.60\text{ mA}}$

6. $I = \frac{V}{R} = \frac{12\text{ V}}{10\ \Omega}$ **= 1.2 A**

7. (a) $I = \frac{V}{R} = \frac{25\text{ V}}{10\text{ k}\Omega}$ **= 2.50 mA**

(b) $I = \frac{V}{R} = \frac{5\text{ V}}{2.2\text{ M}\Omega}$ **= 2.27 μA**

(c) $I = \frac{V}{R} = \frac{15\text{ V}}{1.8\text{ k}\Omega}$ **= 8.33 mA**

8. Orange, violet, yellow, gold, brown ≡ 37.4 Ω ± 1%

$I = \frac{V_S}{R} = \frac{12\text{ V}}{37.4\ \Omega}$ **= 0.321 A**

9. $I = \frac{24\text{ V}}{37.4\ \Omega} = 0.642\text{ A}$

0.642 A is greater than 0.5 A, so **the fuse will blow.**

10. (a) $V = IR$ = (2 A)(18 Ω) = **36 V**
(b) $V = IR$ = (5 A)(47 Ω) = **235 V**
(c) $V = IR$ = (2.5 A)(620 Ω) = **1550 V**
(d) $V = IR$ = (0.6 A)(47 Ω) = **28.2 V**
(e) $V = IR$ = (0.1 A)(470 Ω) = **47 V**

11. (a) $V = IR$ = (1 mA)(10 Ω) = **10 mV**
(b) $V = IR$ = (50 mA)(33 Ω) = **1.65 V**
(c) $V = IR$ = (3 A)(4.7 kΩ) = **14.1 kV**
(d) $V = IR$ = (1.6 mA)(2.2 kΩ) = **3.52 V**
(e) $V = IR$ = (250 μA)(1 kΩ) = **250 mV**
(f) $V = IR$ = (500 mA)(1.5 MΩ) = **750 kV**
(g) $V = IR$ = (850 μA)(10 MΩ) = **8.5 kV**
(h) $V = IR$ = (75 μA)(47 Ω) = **3.53 mV**

12. $V_S = IR$ = (3 A)(27 Ω) = **81 V**

13. (a) $V = IR$ = (3 mA)(27 kΩ) = **81 V**
(b) $V = IR$ = (5 μA)(100 MΩ) = **500 V**
(c) $V = IR$ = (2.5 A)(47 Ω) = **117.5 V**

14. (a) $R = \frac{V}{I} = \frac{10\text{ V}}{2\text{ A}}$ **= 5 Ω**

(b) $R = \frac{V}{I} = \frac{90\text{ V}}{45\text{ A}}$ **= 2 Ω**

(c) $R = \frac{V}{I} = \frac{50\text{ V}}{5\text{ A}}$ **= 10 Ω**

(d) $R = \frac{V}{I} = \frac{5.5\text{ V}}{10\text{ A}}$ **= 0.55 Ω**

(e) $R = \frac{V}{I} = \frac{150\text{ V}}{0.5\text{ A}}$ **= 300 Ω**

15. (a) $R = \frac{V}{I} = \frac{10\text{ kV}}{5\text{ A}}$ **= 2 kΩ**

(b) $R = \frac{V}{I} = \frac{7\text{ V}}{2\text{ mA}}$ **= 3.5 kΩ**

(c) $R = \frac{V}{I} = \frac{500\text{ V}}{250\text{ mA}}$ **= 2 kΩ**

(d) $R = \frac{V}{I} = \frac{50\text{ V}}{500\ \mu\text{A}}$ **= 100 kΩ**

(e) $R = \dfrac{V}{I} = \dfrac{1\text{ kV}}{1\text{ mA}} = 1\ \mathbf{M\Omega}$

16. $R = \dfrac{V}{I} = \dfrac{6\text{ V}}{2\text{ mA}} = \mathbf{3\ k\Omega}$

17. (a) $R = \dfrac{V}{I} = \dfrac{8\text{ V}}{2\text{ A}} = \mathbf{4\ \Omega}$ (b) $R = \dfrac{V}{I} = \dfrac{12\text{ V}}{4\text{ mA}} = \mathbf{3\ k\Omega}$

(c) $R = \dfrac{V}{I} = \dfrac{30\text{ V}}{150\ \mu\text{A}} = 0.2\text{ M}\Omega = \mathbf{200\ k\Omega}$

18. $I = \dfrac{V}{R} = \dfrac{3.2\text{ V}}{3.9\ \Omega} = \mathbf{0.82\ A}$

SECTION 3-3 Energy and Power

19. $P = \dfrac{W}{t} = \dfrac{26\text{ J}}{10\text{ s}} = \mathbf{2.6\ W}$

20. Since 1 watt = 1 joule, P = 350 J/s = **350 W**

21. $P = \dfrac{W}{t} = \dfrac{7500\text{ J}}{5\text{ h}}$

$\left(\dfrac{7500\text{ J}}{5\text{ h}}\right)\left(\dfrac{1\text{ h}}{3600\text{ s}}\right) = \dfrac{7500\text{ J}}{18{,}000\text{ s}} = 0.417\text{ J/s} = \mathbf{417\ mW}$

22. (a) $1000\text{ W} = 1 \times 10^3\text{ W} = \mathbf{1\ kW}$ (b) $3750\text{ W} = 3.750 \times 10^3\text{ W} = \mathbf{3.75\ kW}$

(c) $160\text{ W} = 0.160 \times 10^3\text{ W} = \mathbf{0.160\ kW}$ (d) $50{,}000\text{ W} = 50 \times 10^3\text{ W} = \mathbf{50\ kW}$

23. (a) $1{,}000{,}000\text{ W} = 1 \times 10^6\text{ W} = \mathbf{1\ MW}$ (b) $3 \times 10^6\text{ W} = \mathbf{3\ MW}$

(c) $15 \times 10^7\text{ W} = 150 \times 10^6\text{ W} = \mathbf{150\ MW}$ (d) $8700\text{ kW} = 8.7 \times 10^6\text{ W} = \mathbf{8.7\ MW}$

24. (a) $1\text{ W} = 1000 \times 10^{-3}\text{ W} = \mathbf{1000\ mW}$ (b) $0.4\text{ W} = 400 \times 10^{-3}\text{ W} = \mathbf{400\ mW}$

(c) $0.002\text{ W} = 2 \times 10^{-3}\text{ W} = \mathbf{2\ mW}$ (d) $0.0125\text{ W} = 12.5 \times 10^{-3}\text{ W} = \mathbf{12.5\ mW}$

25. (a) 2 W = **2,000,000 μW** (b) 0.0005 W = **500 μW**

(c) 0.25 mW = **250 μW** (d) 0.00667 mW = **6.67 μW**

26. (a) $1.5 \text{ kW} = 1.5 \times 10^3 \text{ W} = \mathbf{1500 \text{ W}}$ (b) $0.5 \text{ MW} = 0.5 \times 10^6 \text{ W} = \mathbf{500{,}000 \text{ W}}$

(c) $350 \text{ mW} = 350 \times 10^{-3} \text{ W} = \mathbf{0.350 \text{ W}}$ (d) $9000\ \mu\text{W} = 9000 \times 10^{-6} \text{ W} = \mathbf{0.009 \text{ W}}$

27. $P = \dfrac{W}{t}$ in watts

$$V = \frac{W}{Q}$$

$$I = \frac{Q}{t}$$

$$P = VI = \frac{W}{t}$$

So, (1 V)(1 A) = 1 W

28. $P = \dfrac{W}{t} = \dfrac{1 \text{ J}}{1 \text{ s}} = 1 \text{ W}$

$$1 \text{ kW} = 1000 \text{ W} = \frac{1000 \text{ J}}{1 \text{ s}}$$

1 kW-second = 1000 J

$1 \text{ kWh} = 3600 \times 1000 \text{ J}$

$\mathbf{1 \text{ kWh} = 3.6 \times 10^6 \text{ J}}$

SECTION 3-4 Power in an Electric Circuit

29. $P = VI = (5.5 \text{ V})(3 \text{ mA}) = \mathbf{16.5 \text{ mW}}$

30. $P = VI = (115 \text{ V})(3 \text{ A}) = \mathbf{345 \text{ W}}$

31. $P = I^2R = (500 \text{ mA})^2(4.7 \text{ k}\Omega) = \mathbf{1.18 \text{ kW}}$

32. $P = I^2R = (100 \times 10^{-6} \text{ A})^2(10 \times 10^3\ \Omega) = 1 \times 10^{-4} \text{ W} = \mathbf{100\ \mu W}$

33. $P = \dfrac{V^2}{R} = \dfrac{(60 \text{ V})^2}{620\ \Omega} = \mathbf{5.81 \text{ W}}$

34. $P = \dfrac{V^2}{R} = \dfrac{(1.5 \text{ V})^2}{56\ \Omega} = 0.0402 \text{ W} = \mathbf{40.2 \text{ mW}}$

35. $P = I^2R$

$$R = \frac{P}{I^2} = \frac{100 \text{ W}}{(2 \text{ A})^2} = \mathbf{25\ \Omega}$$

36. 5×10^6 watts for 1 minute = 5×10^3 kWmin

$$\frac{5\times10^3 \text{ kWmin}}{60 \text{ min/1 hr}} = \mathbf{83.3\ kWh}$$

37. $$\frac{6700 \text{ W/s}}{(1000 \text{ W/kW})(3600 \text{ s/h})} = \mathbf{0.00186\ kWh}$$

38. (50 W)(12 h) = **600 Wh**
50 W = 0.05 kW
(0.05 kW)(12 h) = **0.6 kWh**

39. $$I = \frac{V}{R_L} = \frac{1.25 \text{ V}}{10\ \Omega} = 0.125 \text{ A}$$

$P = VI = (1.25 \text{ V})(0.125 \text{ A}) = 0.156 \text{ W} = \mathbf{156\ mW}$

40. $$P = \frac{W}{t}$$

$$156 \text{ mW} = \frac{156 \text{ mJ}}{1 \text{ s}}$$

$W_{\text{tot}} = (156 \text{ mJ/s})(90 \text{ h})(3600 \text{ s/h}) = \mathbf{50{,}544\ J}$

SECTION 3-5 The Power Rating of Resistors

41. $P = I^2R = (10 \text{ mA})^2(6.8 \text{ k}\Omega) = 0.68 \text{ W}$
Use the next highest standard power rating of **1 W**.

42. If the 8 W resistor is used, it will be operating in a marginal condition.
To allow for a **safety margin of 20%**, use a **12 W** resistor.

SECTION 3-6 Energy Conversion and Voltage Drop in a Resistance

43. (a) **+** at top, **–** at bottom of resistor (b) **+** at bottom, **–** at top of resistor

(c) **+** on right, **–** on left of resistor

SECTION 3-7 Power Supplies and Batteries

44. $V_{\text{OUT}} = \sqrt{P_L R_L} = \sqrt{(1 \text{ W})(50\ \Omega)} = \mathbf{7.07\ V}$

45. Ampere-hour rating = (1.5 A)(24 h) = **36 Ah**

46. $I = \dfrac{80 \text{ Ah}}{10 \text{ h}}$ = **8 A**

47. $I = \dfrac{650 \text{ mAh}}{48 \text{ h}}$ = **13.5 mA**

48. $P_{\text{LOST}} = P_{\text{IN}} - P_{\text{OUT}}$ = 500 mW − 400 mW = **100 mW**

$$\% \text{ efficiency } = \left(\frac{P_{\text{OUT}}}{P_{\text{IN}}}\right)100\% = \left(\frac{400 \text{ mW}}{500 \text{ mW}}\right)100\% = \mathbf{80\%}$$

49. $P_{\text{OUT}} = (\text{efficiency})P_{\text{IN}}$ = (0.85)(5 W) = **4.25 W**

SECTION 3-8 Introduction to Troubleshooting

50. The 4th bulb from the left is open.

51. If should take **five** (maximum) resistance measurements.

ADVANCED PROBLEMS

52. Assume that the total consumption of the power supply is the input power plus the power lost.
P_{OUT} = 2 W

$$\% \text{ efficiency} = \left(\frac{P_{\text{OUT}}}{P_{\text{IN}}}\right)100\%$$

$$P_{\text{IN}} = \left(\frac{P_{\text{OUT}}}{\% \text{ efficiency}}\right)100\% = \left(\frac{2 \text{ W}}{60\%}\right)100\% = 3.33 \text{ W}$$

The power supply itself uses
$P_{\text{IN}} - P_{\text{OUT}}$ = 3.33 W − 2 W = 1.33 W
Energy = $W = Pt$ = (1.33 W)(24 h) = 31.9 Wh ≅ **0.032 kWh**

53. $R_f = \dfrac{V}{I} = \dfrac{120 \text{ V}}{0.8 \text{ A}}$ = **150 Ω**

54. Measure the current with an ammeter connected as shown in Figure 3-1. Then calculate the unknown resistance with the formula, $\boldsymbol{R = 12\ \text{V}/I}$.

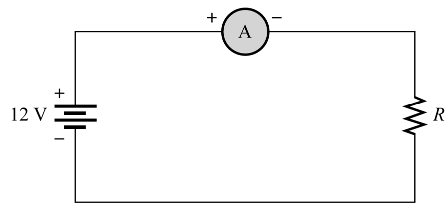


Figure 3-1

55. Calculate I for each value of V:

$$I_1 = \frac{0\ \text{V}}{100\ \Omega} = \mathbf{0\ A} \qquad I_2 = \frac{10\ \text{V}}{100\ \Omega} = \mathbf{100\ mA}$$

$$I_3 = \frac{20\ \text{V}}{100\ \Omega} = \mathbf{200\ mA} \qquad I_4 = \frac{30\ \text{V}}{100\ \Omega} = \mathbf{300\ mA}$$

$$I_5 = \frac{40\ \text{V}}{100\ \Omega} = \mathbf{400\ mA} \qquad I_6 = \frac{50\ \text{V}}{100\ \Omega} = \mathbf{500\ mA}$$

$$I_7 = \frac{60\ \text{V}}{100\ \Omega} = \mathbf{600\ mA} \qquad I_8 = \frac{70\ \text{V}}{100\ \Omega} = \mathbf{700\ mA}$$

$$I_9 = \frac{80\ \text{V}}{100\ \Omega} = \mathbf{800\ mA} \qquad I_{10} = \frac{90\ \text{V}}{100\ \Omega} = \mathbf{900\ mA}$$

$$I_{11} = \frac{100\ \text{V}}{100\ \Omega} = \mathbf{1\ A}$$

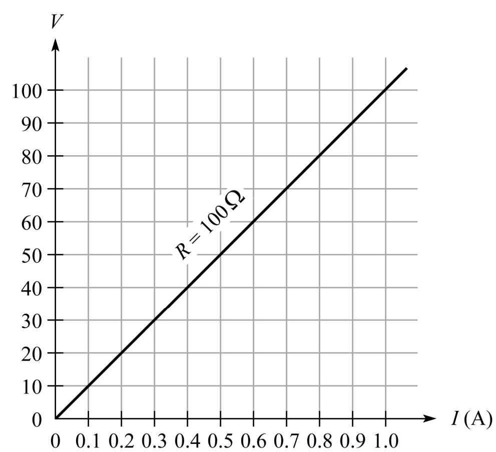


Figure 3-2

The graph is a straight line as shown in Figure 3-2. This indicates a *linear* relationship between I and V.

56. $R = \frac{V_S}{I} = \frac{1\text{ V}}{5\text{ mA}} = \mathbf{200\ \Omega}$

(a) $I = \frac{V_S}{R} = \frac{1.5\text{ V}}{200\ \Omega} = \mathbf{7.5\ mA}$

(b) $I = \frac{V_S}{R} = \frac{2\text{ V}}{200\ \Omega} = \mathbf{10\ mA}$

(c) $I = \frac{V_S}{R} = \frac{3\text{ V}}{200\ \Omega} = \mathbf{15\ mA}$

(d) $I = \frac{V_S}{R} = \frac{4\text{ V}}{200\ \Omega} = \mathbf{20\ mA}$

(e) $I = \frac{V_S}{R} = \frac{10\text{ V}}{200\ \Omega} = \mathbf{50\ mA}$

57. $R_1 = \frac{V}{I} = \frac{1\text{ V}}{2\text{ A}} = \mathbf{0.5\ \Omega}$ $R_2 = \frac{V}{I} = \frac{1\text{ V}}{1\text{ A}} = \mathbf{1\ \Omega}$ $R_3 = \frac{V}{I} = \frac{1\text{ V}}{0.5\text{ A}} = \mathbf{2\ \Omega}$

58. $\frac{V_2}{30\text{ mA}} = \frac{10\text{ V}}{50\text{ mA}}$

$V_2 = \frac{(10\text{ V})(30\text{ mA})}{50\text{ mA}} = 6\text{ V}$ **new value**

The voltage decreased by 4 V, from 10 V to 6 V.

59. The current increase is 50%, so the voltage increase must be the same; that is, the voltage must be increased by (0.5)(20 V) = **10 V**.

The new value of voltage is V_2 = 20 V + (0.5)(20 V) = 20 V + 10 V = **30 V**

60. Wire resistance: $R_W = \frac{(10.4\text{ CM}\cdot\Omega/\text{ft})(24\text{ ft})}{1624.3\text{ CM}} = 0.154\ \Omega$

(a) $I = \frac{V}{R + R_W} = \frac{6\text{ V}}{100.154\ \Omega} = \mathbf{59.9\ mA}$

(b) $V_R = (59.9\text{ mA})(100\ \Omega) = \mathbf{5.99\ V}$

(c) $V_{R_W} = 6\text{ V} - 5.99\text{ V} = 0.01\text{ V}$

For one length of wire, $V = \frac{0.01\text{ V}}{2} = \mathbf{0.005\ V}$

61. 300 W = 0.3 kW
30 days = (30 days)(24 h/day) = 720 h
Energy = (0.3 kW)(720 h) = **216 kWh**

62. $\frac{1500\text{ kWh}}{31\text{ days}} = 48.39\text{ kWh/day}$

$P = \frac{48.39\text{ kWh/day}}{24\text{ h/day}} = \mathbf{2.02\ kW}$

63. The minimum power rating you should use is **12 W** so that the power dissipation does not exceed the rating.

64. (a) $P = \frac{V^2}{R} = \frac{(12\text{ V})^2}{10\ \Omega}$ = **14.4 W**

(b) $W = Pt$ = (14.4 W)(2 min)(1/60 h/min) = **0.48 Wh**

(c) Neither, the power is the same because it is not time dependent.

65. $V_{R(\max)} = 120\text{ V} - 100\text{ V} = 20\text{ V}$

$I_{\max} = \frac{V_{R(\max)}}{R_{\min}} = \frac{20\text{ V}}{8\ \Omega} = 2.5\text{ A}$

A fuse with a rating of less than 2.5 A must be used. **A 2 A fuse is recommended.**

Multisim Troubleshooting Problems

66. R is open.

67. No fault

68. R_1 is shorted.

69. Lamp 4 is shorted.

70. Lamp 6 is open.

CHAPTER 4
SERIES CIRCUITS

BASIC PROBLEMS

SECTION 4-1 Resistors in Series

1. See Figure 4-1.

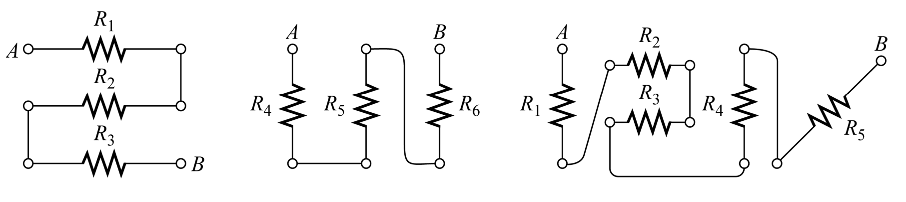


Figure 4-1

2. The groups of series resistors are

$R_1, R_2, R_3, R_9\ R_4$; $R_{13}, R_7, R_{14}, R_{16}$; R_6, R_8, R_{12}; $R_{10}, R_{11}, R_{15}, R_5$

See Figure 4-2.

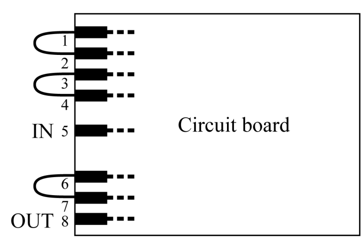


Figure 4-2

3. $R_{1-8} = R_{13} + R_7 + R_{14} + R_{16}$

$= 68\text{ k}\Omega + 33\text{ k}\Omega + 47\text{ k}\Omega + 22\text{ k}\Omega$

$= \mathbf{170\text{ k}\Omega}$

4. $R_{2-3} = R_{12} + R_8 + R_6 = 10\ \Omega + 18\ \Omega + 22\ \Omega = \mathbf{50\ \Omega}$

SECTION 4-2 Total Series Resistance

5. $R_T = 82\ \Omega + 56\ \Omega =$ **$138\ \Omega$**

6. (a) $R_T = 560\ \Omega + 1.0\ k\Omega =$ **$1560\ \Omega$**
   (b) $R_T = 47\ \Omega + 33\ \Omega =$ **$80\ \Omega$**
   (c) $R_T = 1.5\ k\Omega + 2.2\ k\Omega + 10\ k\Omega =$ **$13.7\ k\Omega$**
   (d) $R_T = 1.0\ k\Omega + 1.8\ k\Omega + 100\ k\Omega + 1.0\ M\Omega =$ **$1{,}102{,}800\ \Omega$ (round to $1.10\ M\Omega$)**

7. (a) $R_T = 1.0\ k\Omega + 4.7\ k\Omega + 2.2\ k\Omega =$ **$7.9\ k\Omega$**
   (b) $R_T = 10\ \Omega + 10\ \Omega + 12\ \Omega + 1.0\ \Omega =$ **$33\ \Omega$**
   (c) $R_T = 1.0\ M\Omega + 560\ k\Omega + 1.0\ M\Omega + 680\ k\Omega + 10\ M\Omega =$ **$13.24\ M\Omega$**

   See Figure 4-3.

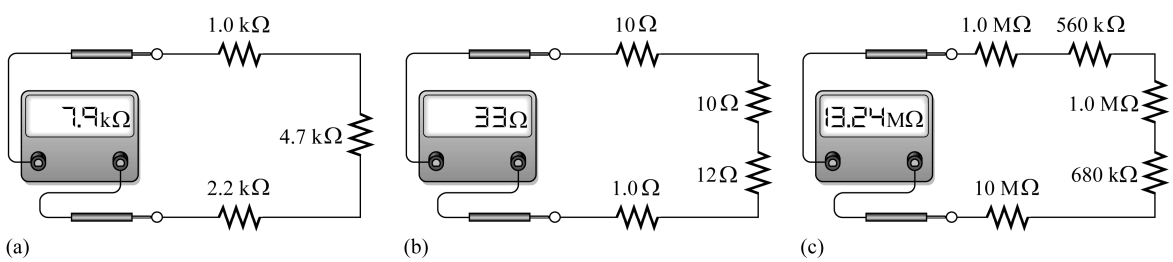


Figure 4-3

8. $R_T = 12(5.6\ k\Omega) =$ **$67.2\ k\Omega$**

9. $R_T = 6(47\ \Omega) + 8(100\ \Omega) + 2(22\ \Omega) = 282\ \Omega + 800\ \Omega + 44\ \Omega =$ **$1126\ \Omega$**

10. $R_T = R_1 + R_2 + R_3 + R_4 + R_5$
    $R_5 = R_T - (R_1 + R_2 + R_3 + R_4)$
    $= 20\ k\Omega - (4.7\ k\Omega + 1.0\ k\Omega + 2.2\ k\Omega + 3.9\ k\Omega)$
    $= 20\ k\Omega - 11.8\ k\Omega$
    $= 8.2\ k\Omega$

11. (a) $R_{1\text{–}8} = R_{13} + R_7 + R_{14} + R_{16}$
    $= 68\ k\Omega + 33\ k\Omega + 47\ k\Omega + 22\ k\Omega =$ **$170\ k\Omega$**

    (b) $R_{2\text{–}3} = R_{12} + R_8 + R_6$
    $= 10\ \Omega + 18\ \Omega + 22\ \Omega =$ **$50\ \Omega$**

    (c) $R_{4\text{–}7} = R_{10} + R_{11} + R_{15} + R_5$
    $= 2.2\ k\Omega + 8.2\ k\Omega + 1.0\ k\Omega + 1.0\ k\Omega =$ **$12.4\ k\Omega$**

    (d) $R_{5\text{–}6} = R_1 + R_2 + R_3 + R_9 + R_4$
    $= 220\ \Omega + 330\ \Omega + 390\ \Omega + 470\ \Omega + 560\ \Omega =$ **$1.97\ k\Omega$**

12. $R_T = R_{1-8} + R_{2-3} + R_{4-7} + R_{5-6}$
$= 170\text{ k}\Omega + 50\ \Omega + 12.4\text{ k}\Omega + 1.97\text{ k}\Omega = \mathbf{184.42\ k\Omega}$

SECTION 4-3 Current in a Series Circuit

13. $I = \dfrac{V_S}{R_T} = \dfrac{12\text{ V}}{120\ \Omega} = \mathbf{0.1\ A}$

14. $I = \mathbf{5\ mA}$ at all points in the circuit.

SECTION 4-4 Application of Ohm's Law

15. (a) $R_T = 2.2\text{ k}\Omega + 5.6\text{ k}\Omega + 1.0\text{ k}\Omega = 8.8\text{ k}\Omega$

$I = \dfrac{V}{R_T} = \dfrac{5.5\text{ V}}{8.8\text{ k}\Omega} = \mathbf{625\ \mu A}$

(b) $R_T = 1.0\text{ M}\Omega + 2.2\text{ M}\Omega + 560\text{ k}\Omega = 3.76\text{ M}\Omega$

$I = \dfrac{16\text{ V}}{3.76\text{ M}\Omega} = \mathbf{4.26\ \mu A}$

The ammeters are connected in series. See Figure 4-4.

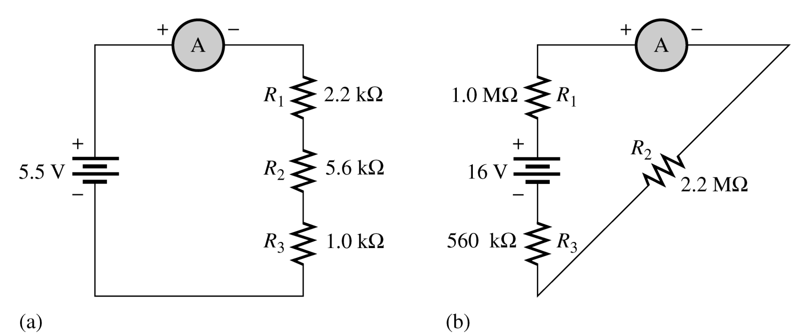


Figure 4-4

16. (a) $V_1 = \left(\dfrac{R_1}{R_T}\right)V_S = \left(\dfrac{2.2\text{ k}\Omega}{8.8\text{ k}\Omega}\right)5.5\text{ V} = \mathbf{1.375\ V}$

$V_2 = \left(\dfrac{R_2}{R_T}\right)V_S = \left(\dfrac{5.6\text{ k}\Omega}{8.8\text{ k}\Omega}\right)5.5\text{ V} = \mathbf{3.5\ V}$

$V_3 = \left(\dfrac{R_3}{R_T}\right)V_S = \left(\dfrac{1.0\text{ k}\Omega}{8.8\text{ k}\Omega}\right)5.5\text{ V} = \mathbf{625\ mV}$

(b) $V_1 = \left(\frac{R_1}{R_T}\right)V_S = \left(\frac{1.0\text{ M}\Omega}{3.76\text{ M}\Omega}\right)16\text{ V} = \mathbf{4.26\text{ V}}$

$V_2 = \left(\frac{R_2}{R_T}\right)V_S = \left(\frac{2.2\text{ M}\Omega}{3.76\text{ M}\Omega}\right)16\text{ V} = \mathbf{9.36\text{ V}}$

$V_3 = \left(\frac{R_3}{R_T}\right)V_S = \left(\frac{560\text{ k}\Omega}{3.76\text{ M}\Omega}\right)16\text{ V} = \mathbf{2.38\text{ V}}$

17. (a) $R_T = 3(470\ \Omega) = 1410\ \Omega$

$I = \frac{48\text{ V}}{1410\ \Omega} = \mathbf{34.0\text{ mA}}$

(b) $V_R = IR = (34.0\text{ mA})(470\ \Omega) = \mathbf{16\text{ V}}$

(c) $P_{min} = I^2R = (34.0\text{ mA})^2 470\ \Omega = \mathbf{0.543\text{ W}}$

18. $R_T = \frac{V_S}{I_T} = \frac{5\text{ V}}{1\text{ mA}} = 5\text{ k}\Omega$

$R_{each} = \frac{5\text{ k}\Omega}{4} = \mathbf{1.25\text{ k}\Omega}$

SECTION 4-5 Voltage Sources in Series

19. See Figure 4-5.

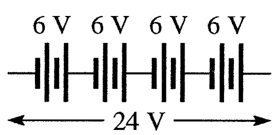


Figure 4-5

20. The total voltage is 6 V + 6 V + 6 V − 6 V = **12 V**

SECTION 4-6 Kirchhoff's Voltage Law

21. $V_S = 5.5\text{ V} + 8.2\text{ V} + 12.3\text{ V} = \mathbf{26\text{ V}}$

22. $V_S = V_1 + V_2 + V_3 + V_4 + V_5$

$V_5 = V_S - (V_1 + V_2 + V_3 + V_4) = 20\text{ V} - (1.5\text{ V} + 5.5\text{ V} + 3\text{ V} + 6\text{ V}) = 20\text{ V} - 16\text{ V} = \mathbf{4\text{ V}}$

23. (a) By Kirchhoff's voltage law:

$15\text{ V} = 2\text{ V} + V_2 + 3.2\text{ V} + 1\text{ V} + 1.5\text{ V} + 0.5\text{ V}$

$V_2 = 15\text{ V} - (2\text{ V} + 3.2\text{ V} + 1\text{ V} + 1.5\text{ V} + 0.5\text{ V}) = 15\text{ V} - 8.2\text{ V} = \mathbf{6.8\text{ V}}$

See Figure 4-6(a).

(b) $V_R = \mathbf{8\text{ V}}$; $V_{2R} = \mathbf{16\text{ V}}$; $V_{3R} = \mathbf{24\text{ V}}$; $V_{4R} = \mathbf{32\text{ V}}$

See Figure 4-6(b).

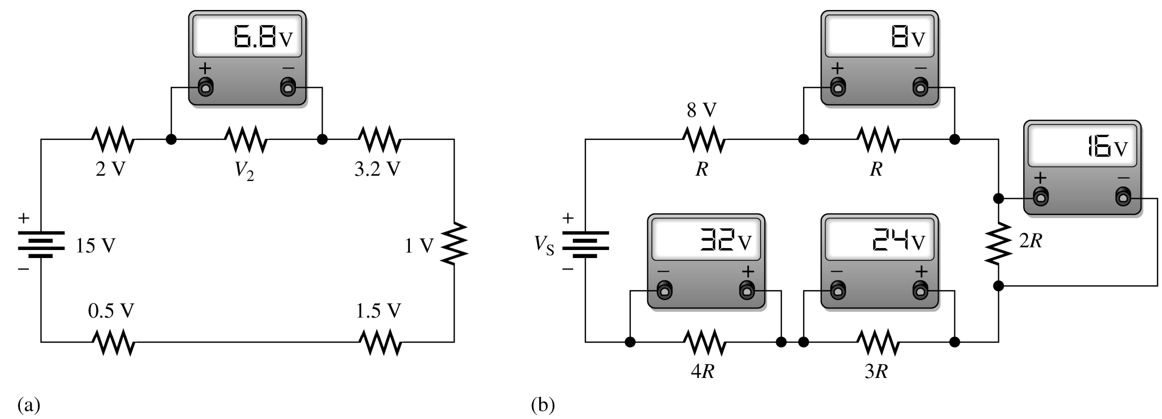


Figure 4-6

SECTION 4-7 Voltage Dividers

24. $\left(\frac{22\ \Omega}{500\ \Omega}\right)100 = \mathbf{4.4\%}$

25. (a) $V_{AB} = \left(\frac{47\ \Omega}{147\ \Omega}\right)12\text{ V} = \mathbf{3.84\text{ V}}$

(b) $V_{AB} = \left(\frac{2.2\text{ k}\Omega + 3.3\text{ k}\Omega}{1.0\text{ k}\Omega + 2.2\text{ k}\Omega + 3.3\text{ k}\Omega}\right)8\text{ V} = \left(\frac{5.5\text{ k}\Omega}{6.5\text{ k}\Omega}\right)8\text{ V} = \mathbf{6.77\text{ V}}$

26. $V_A = V_S = \mathbf{15\text{ V}}$

$$V_B = \left(\frac{R_2 + R_3}{R_1 + R_2 + R_3}\right)V_S = \left(\frac{13.3\text{ k}\Omega}{18.9\text{ k}\Omega}\right)15\text{ V} = \mathbf{10.6\text{ V}}$$

$$V_C = \left(\frac{R_3}{R_1 + R_2 + R_3}\right)V_S = \left(\frac{3.3\text{ k}\Omega}{18.9\text{ k}\Omega}\right)15\text{ V} = \mathbf{2.62\text{ V}}$$

27. $V_{min} = \left(\frac{R_3}{R_1 + R_2 + R_3}\right)V_S = \left(\frac{680\ \Omega}{2150\ \Omega}\right)12\text{ V} = \mathbf{3.80\ V}$

$V_{max} = \left(\frac{R_2 + R_3}{R_1 + R_2 + R_3}\right)V_S = \left(\frac{1680\ \Omega}{2150\ \Omega}\right)12\text{ V} = \mathbf{9.38\ V}$

28. $R_T = R + 2R + 3R + 4R + 5R = 15R$

$V_R = \left(\frac{R}{15R}\right)9\text{ V} = \mathbf{0.6\ V}$ $V_R = \left(\frac{2R}{15R}\right)9\text{ V} = \mathbf{1.2\ V}$ $V_R = \left(\frac{3R}{15R}\right)9\text{ V} = \mathbf{1.8\ V}$

$V_R = \left(\frac{4R}{15R}\right)9\text{ V} = \mathbf{2.4\ V}$ $V_R = \left(\frac{5R}{15R}\right)9\text{ V} = \mathbf{3.0\ V}$

29. $V_{5.6k}$ = **10 V** (by measurement); $I = \frac{10\text{ V}}{5.6\text{ k}\Omega} = 1.79\text{ mA}$;

V_{1k} = (1.79 mA)(1 kΩ) = **1.79 V**; V_{560} (1.79 mA)(560 Ω) = **1 V**;

V_{10k} = (1.79 mA)(10 kΩ) = **17.9 V**

SECTION 4-8 Power in Series Circuits

30. P_T = 5(50 mW) = **250 mW**

31. R_T = 5.6 kΩ + 1 kΩ + 560 Ω + 10 kΩ = 17.16 kΩ
$P = I^2R_T = (1.79\text{ mA})^2(17.16\text{ k}\Omega) = 0.055\text{ W}$ = **55 mW**

SECTION 4-9 Voltage Measurements

32. Voltage from point *A* to ground (*G*): V_{AG} = **10 V**

Resistance between *A* and *G*: R_{AG} = 5.6 kΩ + 5.6 kΩ + 1.0 kΩ + 1.0 kΩ = 13.2 kΩ

Resistance between *B* and *G*: R_{BG} = 5.6 kΩ + 1.0 kΩ + 1.0 kΩ = 7.6 kΩ

Resistance between *C* and *G*: R_{CG} = 1.0 kΩ + 1.0 kΩ = 2 kΩ

$$V_{BG} = \left(\frac{R_{BG}}{R_{AG}}\right)10\text{ V} = \left(\frac{7.6\text{ k}\Omega}{13.2\text{ k}\Omega}\right)10\text{ V} = \mathbf{5.76\ V}$$

$$V_{CG} = \left(\frac{R_{CG}}{R_{AG}}\right)10\text{ V} = \left(\frac{2\text{ k}\Omega}{13.2\text{ k}\Omega}\right)10\text{ V} = \mathbf{1.52\ V}$$

$$V_{DG} = \left(\frac{R_{DG}}{R_{AG}}\right)10\text{ V} = \left(\frac{1.0\text{ k}\Omega}{13.2\text{ k}\Omega}\right)10\text{ V} = \mathbf{0.758\ V}$$

33. Measure the voltage at point A with respect to ground and the voltage at point B with respect to ground. The difference of these two voltages is V_{R2}.

$$\boldsymbol{V_{R2} = V_A - V_B}$$

34. $R_T = R_1 + R_2 + R_3 + R_4 + R_5$
$= 560\text{ k}\Omega + 560\text{ k}\Omega + 100\text{ k}\Omega + 1.0\text{ M}\Omega + 100\text{ k}\Omega = 2.32\text{ M}\Omega$

$V_T = 15\text{ V}$

$$V_A = \left(\frac{R_{AG}}{R_T}\right)V_T = \left(\frac{1.76\text{ M}\Omega}{2.32\text{ M}\Omega}\right)15\text{ V} = \mathbf{11.4\text{ V}}$$

$$V_B = \left(\frac{R_{BG}}{R_T}\right)V_T = \left(\frac{1.2\text{ M}\Omega}{2.32\text{ M}\Omega}\right)15\text{ V} = \mathbf{7.76\text{ V}}$$

$$V_C = \left(\frac{R_{CG}}{R_T}\right)V_T = \left(\frac{1.1\text{ M}\Omega}{2.32\text{ M}\Omega}\right)15\text{ V} = \mathbf{7.11\text{ V}}$$

$$V_D = \left(\frac{R_{DG}}{R_T}\right)V_T = \left(\frac{100\text{ k}\Omega}{2.32\text{ M}\Omega}\right)15\text{ V} = \mathbf{647\text{ mV}}$$

35. $V_{AC} = V_A - V_C = 11.38\text{ V} - 7.11\text{ V} = \mathbf{4.27\text{ V}}$

36. $V_{CA} = V_C - V_A = 7.11\text{ V} - 11.38\text{ V} = \mathbf{-4.27\text{ V}}$

SECTION 4-10 Troubleshooting

37. (a) Zero current indicates an open. **R_4 is open** since all the voltage is dropped across it.

(b) $$\frac{V_S}{R_1 + R_2 + R_3} = \frac{10\text{ V}}{300\ \Omega} = 33.3\text{ mA}$$
R_4 and R_5 have no effect on the current. There is a **short from *A* to *B*.**

38. $R_T = 10\text{ k}\Omega + 8.2\text{ k}\Omega + 12\text{ k}\Omega + 2.2\text{ k}\Omega + 5.6\text{ k}\Omega = 38\text{ k}\Omega$
The meter reads about 28 kΩ. It should read 38 kΩ. **The 10 kΩ resistor is shorted.**

ADVANCED PROBLEMS

39. $V_1 = IR_1 = (10\text{ mA})(680\ \Omega) = 6.8\text{ V}$
$V_2 = IR_2 = (10\text{ mA})(1.0\text{ k}\Omega) = 10\text{ V}$
$V_4 = IR_4 = (10\text{ mA})(270\ \Omega) = 2.7\text{ V}$
$V_5 = IR_5 = (10\text{ mA})(270\ \Omega) = 2.7\text{ V}$
$V_3 = V_S - (V_1 + V_2 + V_4 + V_5)$
$V_3 = 30\text{ V} - (6.8\text{ V} + 10\text{ V} + 2.7\text{ V} + 2.7\text{ V}) = 30\text{ V} - 22.2\text{ V} = 7.8\text{ V}$

$$R_3 = \frac{V_3}{I} = \frac{7.8\text{ V}}{10\text{ mA}} = 0.78\text{ k}\Omega = \mathbf{780\ \Omega}$$

40. $R_T = 3(5.6\ \text{k}\Omega) + 1.0\ \text{k}\Omega + 2(100\ \Omega) = 18\ \text{k}\Omega$
Three 5.6 kΩ resistors, one 1 kΩ resistor, and two 100 Ω resistors

41. $V_A = \mathbf{10\ V}$, $R_T = 22\ \text{k}\Omega + 10\ \text{k}\Omega + 47\ \text{k}\Omega + 12\ \text{k}\Omega + 5.6\ \text{k}\Omega = 96.6\ \text{k}\Omega$

$$V_B = V_A - V_{22k} = 10\ \text{V} - \left(\frac{22\ \text{k}\Omega}{96.6\ \text{k}\Omega}\right)10\ \text{V} = 10\ \text{V} - 2.28\ \text{V} = \mathbf{7.72\ V}$$

$$V_C = V_B - V_{10k} = 7.72\ \text{V} - \left(\frac{10\ \text{k}\Omega}{96.6\ \text{k}\Omega}\right)10\ \text{V} = 7.72\ \text{V} - 1.04\ \text{V} = \mathbf{6.68\ V}$$

$$V_D = V_C - V_{47k} = 6.68\ \text{V} - \left(\frac{47\ \text{k}\Omega}{96.6\ \text{k}\Omega}\right)10\ \text{V} = 6.68\ \text{V} - 4.87\ \text{V} = \mathbf{1.81\ V}$$

$$V_E = V_D - V_{12k} = 1.81\ \text{V} - \left(\frac{12\ \text{k}\Omega}{96.6\ \text{k}\Omega}\right)10\ \text{V} = 1.81\ \text{V} - 1.24\ \text{V} = \mathbf{0.57\ V}$$

$V_F = \mathbf{0\ V}$

42. $V_2 = IR_2 = (20\ \text{mA})(100\ \Omega) = \mathbf{2\ V}$

$$R_5 = \frac{V_S}{I} = \frac{6.6\ \text{V}}{20\ \text{mA}} = \mathbf{330\ \Omega}$$

$$R_6 = \frac{P_6}{I^2} = \frac{112\ \text{mW}}{(20\ \text{mA})^2} = \mathbf{280\ \Omega}$$

$V_6 = IR_6 = (20\ \text{mA})(280\ \Omega) = \mathbf{5.6\ V}$
$V_1 = V_S - (20\ \text{V} + V_6) = 30\ \text{V} - (20\ \text{V} + 5.6\ \text{V}) = \mathbf{4.4\ V}$

$$R_1 = \frac{V_1}{I} = \frac{4.4\ \text{V}}{20\ \text{mA}} = \mathbf{220\ \Omega}$$

$V_3 + V_4 = 20\ \text{V} - V_2 - V_5 = 20\ \text{V} - 2\ \text{V} - 6.6\ \text{V} = 11.4\ \text{V}$

$$V_3 = V_4 = \frac{11.4\ \text{V}}{2} = \mathbf{5.7\ V} \qquad R_3 = R_4 = \frac{V_3}{I} = \frac{5.7\ \text{V}}{20\ \text{mA}} = \mathbf{285\ \Omega}$$

43. $V_S = IR_T = (250\ \text{mA})(1.5\ \text{k}\Omega) = 375\ \text{V}$
$I_{new} = 250\ \text{mA} - 0.25(250\ \text{mA}) = 250\ \text{mA} - 62.5\ \text{mA} = 188\ \text{mA}$

$$R_{new} = \frac{V_S}{I_{new}} = \frac{375\ \text{V}}{188\ \text{mA}} \cong 2000\ \Omega$$

500 Ω must be added to the existing 1500 Ω to reduce *I* by 25%.

44. $P = I^2R$

$$I_{max} = \sqrt{\frac{P}{R}} = \sqrt{\frac{0.5\ \text{W}}{120\ \Omega}} = 0.0645\ \text{A} = 64.5\ \text{mA}$$

Since all resistors in series have the same current, use the largest *R* to determine the maximum current allowable because the largest *R* has the greatest power.
Thus, the **120 Ω resistor burns out first.**

45. (a) $P_T = \frac{1}{8}\text{W} + \frac{1}{4}\text{W} + \frac{1}{2}\text{W} = 0.125\text{ W} + 0.25\text{ W} + 0.5\text{ W} = 0.875\text{ W}$

$$I = \sqrt{\frac{P_T}{R_T}} = \sqrt{\frac{0.875\text{ W}}{2400\ \Omega}} = \mathbf{19.1\ mA}$$

(b) $V_S = I_T R_T = (19.1\text{ mA})(2400\ \Omega) = \mathbf{45.8\ V}$

(c) $R = \frac{P}{I^2}$

$$R_{1/8} = \frac{P}{I^2} = \frac{0.125\text{ W}}{(19.1\text{ mA})^2} = \mathbf{343\ \Omega}$$

$$R_{1/4} = \frac{0.25\text{ W}}{(19.1\text{ mA})^2} = \mathbf{686\ \Omega}$$

$$R_{1/2} = \frac{0.5\text{ W}}{(19.1\text{ mA})^2} = \mathbf{1371\ \Omega}$$

46. See Figure 4-7.

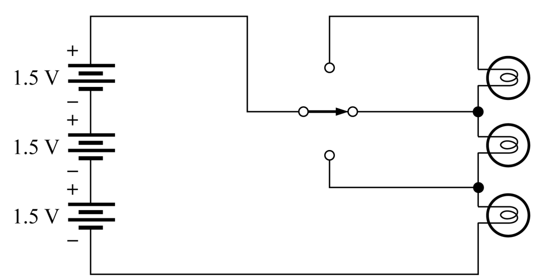


Figure 4-7

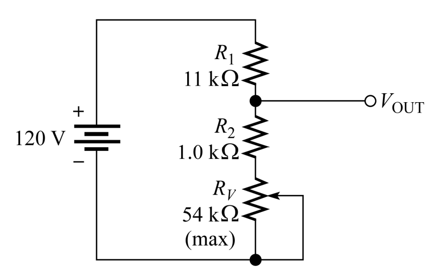


Figure 4-8

47. See Figure 4-8.

When the potentiometer is at minimum setting (0 Ω), $V_{OUT} = 10$ V:

$$R_1 + R_2 = \frac{120\text{ V}}{10\text{ mA}} = 12\text{ k}\Omega$$

$$\left(\frac{R_2}{R_1 + R_2}\right)120\text{ V} = 10\text{ V}$$

$$R_2 = \frac{10\text{ V}(12\text{ k}\Omega)}{120\text{ V}} = \mathbf{1.0\ k\Omega}$$

$R_1 = 12\text{ k}\Omega - 1.0\text{ k}\Omega = \mathbf{11\ k\Omega}$

When the potentiometer is at maximum setting, V_{OUT} = 100 V:

$$\left(\frac{R_2 + R_V}{R_1 + R_2 + R_V}\right)120\text{ V} = 100\text{ V}$$

$$\left(\frac{1.0\text{ k}\Omega + R_V}{12\text{ k}\Omega + R_V}\right)120\text{ V} = 100\text{ V}$$

$(1.0\text{ k}\Omega + R_V)120\text{ V} = (12\text{ k}\Omega + R_V)100\text{ V}$

$120\text{ k}\Omega + 120R_V = 1200\text{ k}\Omega + 100R_V$

$20R_V = 1080\text{ k}\Omega$

R_V = **54 kΩ**

48. See Figure 4-9.

$$R_1 = \frac{(30\text{ V} - 24.6\text{ V})}{1\text{ mA}} = 5.4\text{ k}\Omega$$

$$R_2 = \frac{(24.6\text{ V} - 14.7\text{ V})}{1\text{ mA}} = 9.9\text{ k}\Omega$$

$$R_3 = \frac{(14.7\text{ V} - 8.18\text{ V})}{1\text{ mA}} = 6.52\text{ k}\Omega$$

$$R_4 = \frac{8.18\text{ V}}{1\text{ mA}} = 8.18\text{ k}\Omega$$

A series of standard value resistors must be used to approximately achieve each resistance as follows:

R_1 = **4700 Ω + 680 Ω + 22 Ω = 5.4 kΩ**
R_2 = **8200 Ω + 1500 Ω + 220 Ω = 9.92 kΩ**
R_3 = **5600 Ω + 820 Ω + 100 Ω = 6.52 kΩ**
R_4 = **6800 Ω + 1000 Ω + 180 Ω + 100 Ω + 100 Ω = 8.18 kΩ**

The highest power dissipation is in the 8200 Ω resistor.
$P = (1\text{ mA})^2 8200\ \Omega = 8.2\text{ mW}$

All resistors must be at least 1/8 W.

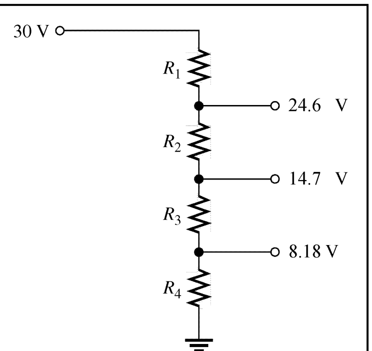


Figure 4-9

49. The groups are:

R_1, R_7, R_8, and R_{10}; R_2, R_4, R_6, and R_{11}; R_3, R_5, R_9, and R_{12}

See Figure 4-10.

$R_1 + R_7 + R_8 + R_{10} = 2.2\ \text{k}\Omega + 560\ \Omega + 470\ \Omega + 1.0\ \text{k}\Omega = \mathbf{4.23\ k\Omega}$
$R_2 + R_4 + R_6 + R_{11} = 4.7\ \text{k}\Omega + 5.6\ \text{k}\Omega + 3.3\ \text{k}\Omega + 10\ \text{k}\Omega = \mathbf{23.6\ k\Omega}$
$R_3 + R_5 + R_9 + R_{12} = 1.0\ \text{k}\Omega + 3.9\ \text{k}\Omega + 8.2\ \text{k}\Omega + 6.8\ \text{k}\Omega = \mathbf{19.9\ k\Omega}$

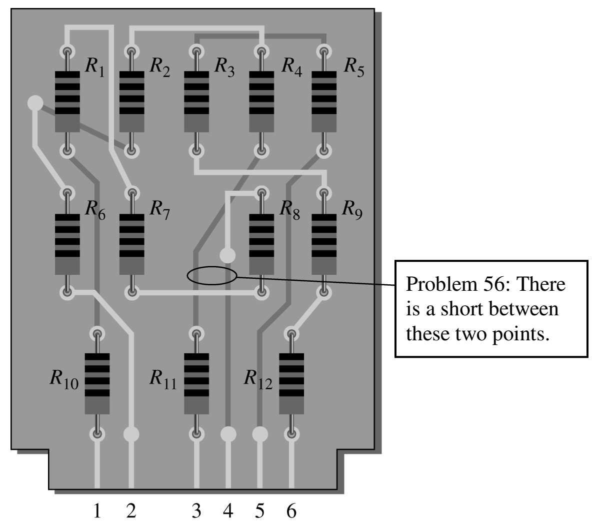


Figure 4-10

50. *Position 1:*
$R_T = R_1 + R_3 + R_5 = 510\ \Omega + 820\ \Omega + 680\ \Omega = \mathbf{2.01\ k\Omega}$
Position 2:
$R_T = R_1 + R_2 + R_3 + R_4 + R_5$
$= 510\ \Omega + 910\ \Omega + 820\ \Omega + 750\ \Omega + 680\ \Omega = \mathbf{3.67\ k\Omega}$

51. *Position A:*
$R_T = R_1 + R_2 + R_3 + R_4 = 220\ \Omega + 470\ \Omega + 510\ \Omega + 1.0\ \text{k}\Omega = 2.2\ \text{k}\Omega$
$$I = \frac{V}{R_T} = \frac{12\ \text{V}}{2.2\ \text{k}\Omega} = \mathbf{5.45\ mA}$$
Position B:
$R_T = R_2 + R_3 + R_4 = 470\ \Omega + 510\ \Omega + 1.0\ \text{k}\Omega = 1.98\ \text{k}\Omega$
$$I = \frac{V}{R_T} = \frac{12\ \text{V}}{1.98\ \text{k}\Omega} = \mathbf{6.06\ mA}$$
Position C:
$R_T = R_3 + R_4 = 510\ \Omega + 1.0\ \text{k}\Omega = 1.51\ \text{k}\Omega$
$$I = \frac{V}{R_T} = \frac{12\ \text{V}}{1.51\ \text{k}\Omega} = \mathbf{7.95\ mA}$$
Position D:
$R_T = R_4 = 1.0\ \text{k}\Omega$
$$I = \frac{V}{R_T} = \frac{12\ \text{V}}{1.0\ \text{k}\Omega} = \mathbf{12\ mA}$$

52. *Position A:*

$R_T = R_1 = 1.0\text{ k}\Omega$

$$I = \frac{V}{R_T} = \frac{9\text{ V}}{1.0\text{ k}\Omega} = \mathbf{9\text{ mA}}$$

Position B:

$R_T = R_1 + R_2 + R_5 = 1.0\text{ k}\Omega + 33\text{ k}\Omega + 22\text{ k}\Omega = 56\text{ k}\Omega$

$$I = \frac{V}{R_T} = \frac{9\text{ V}}{56\text{ k}\Omega} = \mathbf{161\ \mu A}$$

Position C:

$R_T = R_1 + R_2 + R_3 + R_4 + R_5 = 1.0\text{ k}\Omega + 33\text{ k}\Omega + 68\text{ k}\Omega + 27\text{ k}\Omega + 22\text{ k}\Omega = 151\text{ k}\Omega$

$$I = \frac{V}{R_T} = \frac{9\text{ V}}{151\text{ k}\Omega} = \mathbf{59.6\ \mu A}$$

53. First, find the value of R_5 with the switch in Position *D*.

$$6\text{ mA} = \frac{18\text{ V}}{R_5 + 1.8\text{ k}\Omega}$$

$$R_5 = \frac{18\text{ V}}{6\text{ mA}} - 1.8\text{ k}\Omega = 1.2\text{ k}\Omega$$

Position A:

$R_T = 5.38\text{ k}\Omega$ $\quad I = 18\text{ V}/5.38\text{ k}\Omega = 3.35\text{ mA}$

$V_1 = (3.35\text{ mA})(1.8\text{ k}\Omega) = \mathbf{6.03\ V}$

$V_2 = (3.35\text{ mA})(1.0\text{ k}\Omega) = \mathbf{3.35\ V}$

$V_3 = (3.35\text{ mA})(820\ \Omega) = \mathbf{2.75\ V}$

$V_4 = (3.35\text{ mA})(560\ \Omega) = \mathbf{1.88\ V}$

$V_5 = \mathbf{4\ V}$

Position B:

$R_T = 4.82\text{ k}\Omega$ $\quad I = 18\text{ V}/4.82\text{ k}\Omega = 3.73\text{ mA}$

$V_1 = (3.73\text{ mA})(1.8\text{ k}\Omega) = \mathbf{6.71\ V}$

$V_2 = (3.73\text{ mA})(1.0\text{ k}\Omega) = \mathbf{3.73\ V}$

$V_3 = (3.73\text{ mA})(820\ \Omega) = \mathbf{3.06\ V}$

$V_5 = \mathbf{4.5\ V}$

Position C:

$R_T = 4\text{ k}\Omega$ $\quad I = 18\text{ V}/4\text{ k}\Omega = 4.5\text{ mA}$

$V_1 = (4.5\text{ mA})(1.8\text{ k}\Omega) = \mathbf{8.1\ V}$

$V_2 = (4.5\text{ mA})(1.0\text{ k}\Omega) = \mathbf{4.5\ V}$

$V_5 = \mathbf{5.4\ V}$

Position D:

$R_T = 3\text{ k}\Omega$ $\quad I = 18\text{ V}/3\text{ k}\Omega = 6\text{ mA}$

$V_1 = (6\text{ mA})(1.8\text{ k}\Omega) = \mathbf{10.8\ V}$

$V_5 = \mathbf{7.2\ V}$

Note: The voltage approach can also be used.

54. See Figure 4-10. The results in the table are correct.

55. Yes, R_3 and R_5 are each shorted. Refer to Figure 4-10.

56. Yes, there is a short between the points indicated in Figure 4-10.

57. (a) R_{11} burned open due to excessive power because it had the largest value in ohms.
(b) Replace R_{11} (10 kΩ).
(c) $R_T = 47.7\text{ k}\Omega$

$$I_{max} = \sqrt{\frac{P_{11}}{R_{11}}} = \sqrt{\frac{0.5\text{ W}}{10\text{ k}\Omega}} = 7.07\text{ mA}$$

$$V_{TOTAL} = I_{max}R_T = (7.07\text{ mA})(47.7\text{ k}\Omega) = \mathbf{338\ V}$$

Multisim Troubleshooting Problems

58. R_1 is open.

59. R_6 is shorted.

60. R_2 is open.

61. Lamp 4 is open.

62. No fault

63. The 82 Ω resistor is shorted.

CHAPTER 5
PARALLEL CIRCUITS

BASIC PROBLEMS

SECTION 5-1 Resistors in Parallel

1. See Figure 5-1.

2. See Figure 5-2.

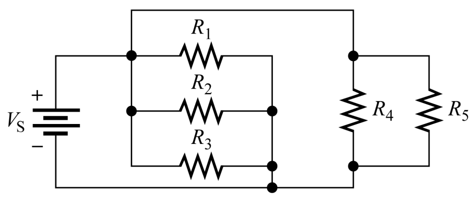


Figure 5-1

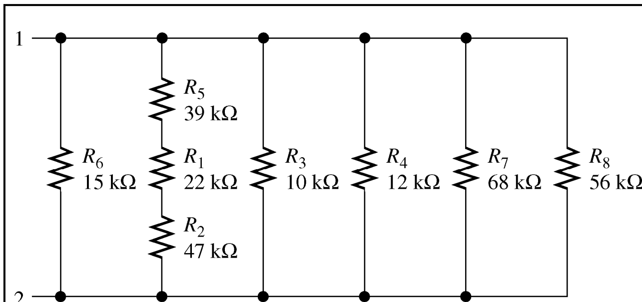


Figure 5-2

SECTION 5-2 Total Parallel Resistance

3. From Problem 2: $R_T = R_6 \parallel R_3 \parallel R_4 \parallel R_7 \parallel R_8 \parallel (R_1 + R_2 + R_5)$

$= 15 \text{ k}\Omega \parallel 10 \text{ k}\Omega \parallel 12 \text{ k}\Omega \parallel 68 \text{ k}\Omega \parallel 56 \text{ k}\Omega \parallel 108 \text{ k}\Omega = \mathbf{3.43 \text{ k}\Omega}$

4. $$R_T = \frac{1}{\frac{1}{1.0 \text{ M}\Omega} + \frac{1}{2.2 \text{ M}\Omega} + \frac{1}{4.7 \text{ M}\Omega} + \frac{1}{12 \text{ M}\Omega} + \frac{1}{22 \text{ M}\Omega}} = \mathbf{557 \text{ k}\Omega}$$

5. (a) $R = 47\ \Omega \parallel 6 \text{ k}\Omega = \mathbf{25.6\ \Omega}$
   (b) $R = 560\ \Omega \parallel 1.0 \text{ k}\Omega = \mathbf{359\ \Omega}$
   (c) $R = 1.5 \text{ k}\Omega \parallel 2.2 \text{ k}\Omega \parallel 10 \text{ k}\Omega = \mathbf{819\ \Omega}$
   (d) $R = 1.0 \text{ k}\Omega \parallel 2.2 \text{ M}\Omega \parallel 1.0 \text{ M}\Omega \parallel 470 \text{ k}\Omega = \mathbf{996\ \Omega}$

6. (a) $R_T = \dfrac{R_1R_2}{R_1 + R_2} = \dfrac{(4.7\text{ k}\Omega)(2.2\text{ k}\Omega)}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega}$ = **1.5 kΩ**

(b) $R_T = \dfrac{R_1R_2}{R_1 + R_2} = \dfrac{(27\ \Omega)(56\ \Omega)}{27\ \Omega + 56\ \Omega}$ = **18.2 Ω**

(c) $R_T = \dfrac{R_1R_2}{R_1 + R_2} = \dfrac{(1.5\text{ k}\Omega)(2.2\text{ k}\Omega)}{1.5\text{ k}\Omega + 2.2\text{ k}\Omega}$ = **892 Ω**

7. $R_T = \dfrac{22\text{ k}\Omega}{11}$ = **2 kΩ**

8. $R_{T1} = \dfrac{15\ \Omega}{5} = 3\ \Omega$

$R_{T2} = \dfrac{100\ \Omega}{10} = 10\ \Omega$

$R_{T3} = \dfrac{10\ \Omega}{2} = 5\ \Omega$

$R_T = \dfrac{1}{\dfrac{1}{3\ \Omega} + \dfrac{1}{10\ \Omega} + \dfrac{1}{5\ \Omega}}$ = **1.58 Ω**

SECTION 5-3 Voltage in a Parallel Circuit

9. $V_1 = V_2 = V_3 = V_4$ = **12 V**

$I_T = \dfrac{V_T}{R_T} = \dfrac{12\text{ V}}{600\ \Omega} = 20\text{ mA}$

The total current divides equally among the four equal resistors.

$I_1 = I_2 = I_3 = I_4 = \dfrac{20\text{ mA}}{4}$ = **5 mA**

10. The resistors are all in parallel across the source. The voltmeters are each measuring the voltage across a resistor, so each meter indicates **100 V**.

SECTION 5-4 Application of Ohm's Law

11. (a) $R_T = 33\text{ k}\Omega \parallel 33\text{ k}\Omega \parallel 33\text{ k}\Omega = 11\text{ k}\Omega$

$I_T = \dfrac{10\text{ V}}{11\text{ k}\Omega}$ = **909 μA**

(b) $R_T = 1.0\text{ k}\Omega \parallel 3.9\text{ k}\Omega \parallel 560\ \Omega = 329\ \Omega$

$$I_T = \frac{25\text{ V}}{329\ \Omega} = \mathbf{76\ mA}$$

12. $$I_T = I_1 + I_2 + I_3 = \frac{120\text{ V}}{240\ \Omega} + \frac{120\text{ V}}{240\ \Omega} + \frac{120\text{ V}}{240\ \Omega} = \mathbf{1.5\ A}$$

13. (a) $$I_1 = \frac{10\text{ V}}{56\text{ k}\Omega} = \mathbf{179\ \mu A}$$
$$I_2 = \frac{10\text{ V}}{22\text{ k}\Omega} = \mathbf{455\ \mu A}$$

(b) $$I_1 = \frac{8\text{ V}}{18\text{ k}\Omega} = \mathbf{444\ \mu A}$$
$$I_2 = \frac{8\text{ V}}{100\text{ k}\Omega} = \mathbf{80\ \mu A}$$

14. $$R_T = \frac{V_S}{I_T} = \frac{5\text{ V}}{2.5\text{ mA}} = 2\text{ k}\Omega$$
$R_{each} = 4(2\text{ k}\Omega) = \mathbf{8\ k\Omega}$

SECTION 5-5 Kirchhoff's Current Law

15. $I_T = 250\text{ mA} + 300\text{ mA} + 800\text{ mA} = \mathbf{1350\ mA}$

16. $I_T = I_1 + I_2 + I_3 + I_4 + I_5$
$I_5 = I_T - (I_1 + I_2 + I_3 + I_4)$
$I_5 = 500\text{ mA} - (50\text{ mA} + 150\text{ mA} + 25\text{ mA} + 100\text{ mA}) = 500\text{ mA} - 325\text{ mA} = \mathbf{175\ mA}$

17. $I_{2\text{–}3} = I_T - (I_1 + I_4) = 50\text{ mA} - 35\text{ mA} = 15\text{ mA}$
$I_2 = I_3 = \mathbf{7.5\ mA}$
See Figure 5-3.

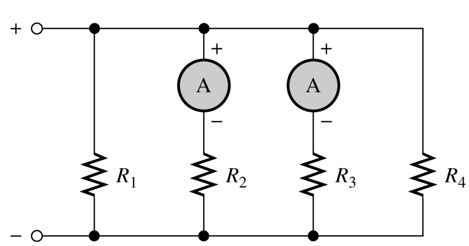


Figure 5-3

18. $I_T = I_1 + I_2 + I_3 + I_4 + I_5 + I_6 = 0.5\text{ A} + 0.5\text{ A} + 0.5\text{ A} + 0.5\text{ A} + 1.2\text{ A} + 1.2\text{ A} = \mathbf{4.4\text{ A}}$

19. (a) $I_T = I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8$
$= 0.5\text{ A} + 0.5\text{ A} + 0.5\text{ A} + 0.5\text{ A} + 1.2\text{ A} + 1.2\text{ A} + 1.0\text{ A} + 1.0\text{ A} = \mathbf{6.4\text{ A}}$

(b) $I_{ground} = \mathbf{6.4\text{ A}}$

SECTION 5-6 Current Dividers

20. The 10 kΩ resistor has the highest current.

21. $$I_1 = \left(\frac{R_2}{R_1 + R_2}\right)I_T = \left(\frac{2.7\text{ k}\Omega}{3.7\text{ k}\Omega}\right)3\text{ A} = \mathbf{2.19\text{ A}}$$
$$I_2 = \left(\frac{R_1}{R_1 + R_2}\right)I_T = \left(\frac{1.0\text{ k}\Omega}{3.7\text{ k}\Omega}\right)3\text{ A} = \mathbf{811\text{ mA}}$$

22. (a) $$I_1 = \left(\frac{R_2}{R_1 + R_2}\right)I_T = \left(\frac{2.2\text{ M}\Omega}{3.2\text{ M}\Omega}\right)10\ \mu\text{A} = \mathbf{6.88\ \mu A}$$
$$I_2 = \left(\frac{R_1}{R_1 + R_2}\right)I_T = \left(\frac{1.0\text{ M}\Omega}{3.2\text{ M}\Omega}\right)10\ \mu\text{A} = \mathbf{3.13\ \mu A}$$

(b) $$R_T = \frac{1}{\frac{1}{1.0\text{ k}\Omega} + \frac{1}{2.2\text{ k}\Omega} + \frac{1}{3.3\text{ k}\Omega} + \frac{1}{5.6\text{ k}\Omega}} = 516\ \Omega$$
$$I_1 = \left(\frac{R_T}{R_1}\right)I_T = \left(\frac{516\ \Omega}{1.0\text{ k}\Omega}\right)10\text{ mA} = \mathbf{5.16\text{ mA}}$$
$$I_2 = \left(\frac{R_T}{R_2}\right)I_T = \left(\frac{516\ \Omega}{2.2\text{ k}\Omega}\right)10\text{ mA} = \mathbf{2.35\text{ mA}}$$
$$I_3 = \left(\frac{R_T}{R_3}\right)I_T = \left(\frac{516\ \Omega}{3.3\text{ k}\Omega}\right)10\text{ mA} = \mathbf{1.56\text{ mA}}$$
$$I_4 = \left(\frac{R_T}{R_4}\right)I_T = \left(\frac{516\ \Omega}{5.6\text{ k}\Omega}\right)10\text{ mA} = \mathbf{921\ \mu A}$$

SECTION 5-7 Power in Parallel Circuits

23. $P_T = 5(40\text{ mW}) = \mathbf{200\text{ mW}}$

24. (a) $R_T = 1.0\text{ M}\Omega \parallel 2.2\text{ M}\Omega = 688\text{ k}\Omega$
$P_T = I_T^2 R_T = (10\ \mu\text{A})^2(688\text{ k}\Omega) = \mathbf{68.8\ \mu W}$

(b) $R_T = 1.0\text{ k}\Omega \parallel 2.2\text{ k}\Omega \parallel 3.3\text{ k}\Omega \parallel 5.6\text{ k}\Omega = 516\ \Omega$
$P_T = I_T^2 R_T = (10\text{ mA})^2(516\ \Omega) = \mathbf{51.6\text{ mW}}$

25. $P = VI$

$I_{each} = \dfrac{P}{V} = \dfrac{75\text{ W}}{120\text{ V}}$ = **0.625 A**

$I_T = 6(0.625\text{ A})$ = **3.75 A**

SECTION 5-8 Troubleshooting

26. $I_{each} = \dfrac{P}{V} = \dfrac{75\text{ W}}{120\text{ V}}$ = **0.625 A**

The current in each bulb is independent of the number of parallel bulbs.

$I_T = 3.75\text{ A} - 0.625\text{ A}$ = **3.125 A**

27. First determine what the total current should be:

$R_T = 220\ \Omega \parallel 100\ \Omega \parallel 1.0\text{ k}\Omega \parallel 560\ \Omega \parallel 270\ \Omega = 47.54\ \Omega$

$I_T = \dfrac{10\text{ V}}{47.54\ \Omega} = 210.4\text{ mA}$

The measured current is 200.4 mA which is 10 mA less than it should be.

Therefore, **one of the resistors must be open.**

$R_{open} = \dfrac{V}{I} = \dfrac{10\text{ V}}{10\text{ mA}} = 1.0\text{ k}\Omega$

The 1.0 kΩ resistor is open.

28. $R_T = \dfrac{1}{\dfrac{1}{4.7\text{ k}\Omega} + \dfrac{1}{10\text{ k}\Omega} + \dfrac{1}{8.2\text{ k}\Omega}} = 2.3\text{ k}\Omega$

$I_T = \dfrac{25\text{ V}}{R_T} = \dfrac{25\text{ V}}{2.3\text{ k}\Omega} = 10.87\text{ mA}$

The meter indicates 7.82 mA. Therefore, a resistor must be open.

$I_3 = \dfrac{25\text{ V}}{8.2\text{ k}\Omega} = 3.05\text{ mA}$

$I = I_T - I_M = 10.87\text{ mA} - 7.82\text{ mA} = 3.05\text{ mA}$

This shows that I_3 is missing from the total current as read on the meter.

Therefore, $\boldsymbol{R_3}$ **is open**.

29. $G_T = \dfrac{1}{560\ \Omega} + \dfrac{1}{270\ \Omega} + \dfrac{1}{330\ \Omega} = 8.52\text{ mS}$

$G_{meas} = \dfrac{1}{207.6\ \Omega} = 4.82\text{ mS}$

$G_{open} = G_T - G_{meas} = 8.52\text{ mS} - 4.82\text{ mS} = 3.70\text{ mS}$

So, $R_{open} = \dfrac{1}{G_{open}} = \dfrac{1}{3.70\text{ mS}} = 270\ \Omega$

$\boldsymbol{R_2}$ **is open**.

30. $G_T = \frac{1}{100\ \Omega} + \frac{1}{100\ \Omega} + \frac{1}{220\ \Omega} + \frac{1}{220\ \Omega} = 29.1\text{ mS}$

$G_{meas} = \frac{1}{40.7\ \Omega} = 24.6\text{ mS}$

There is a resistor open.

$G_{open} = G_T - G_{meas} = 29.1\text{ mS} - 24.6\text{ mS} = 4.5\text{ mS}$

So, $R_{open} = \frac{1}{4.5\text{ mS}} = 221\ \Omega$

One of the 220 Ω resistors is open, but identification requires more information.

ADVANCED PROBLEMS

31. $V_S = I_1R_1 = (1\text{ mA})(50\ \Omega) = 50\text{ mV}$

$R_2 = \frac{V_S}{I_2} = \frac{50\text{ mV}}{2\text{ mA}} = \mathbf{25\ \Omega}$

$R_3 = \frac{V_S}{I_3} = \frac{50\text{ mV}}{0.5\text{ mA}} = \mathbf{100\ \Omega}$

$I_4 = I_T - (I_1 + I_2 + I_3) = 7.5\text{ mA} - 3.5\text{ mA} = 4\text{ mA}$

$R_4 = \frac{V_S}{I_4} = \frac{50\text{ mV}}{4\text{ mA}} = \mathbf{12.5\ \Omega}$

32. $V_T = I_TR_T = (100\text{ mA})(25\ \Omega) = 2500\text{ mV} = 2.5\text{ V}$

$I_{220} = \frac{V_T}{R} = \frac{2.5\text{ V}}{220\ \Omega} = \mathbf{11.4\text{ mA}}$

33. $R_T = \frac{1}{\frac{1}{R} + \frac{1}{2R} + \frac{1}{3R} + \frac{1}{4R}} = \frac{R}{1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4}} = 0.48R$

$I_R = \left(\frac{R_T}{R}\right)10\text{ A} = \left(\frac{0.48R}{R}\right)10\text{ A} = \mathbf{4.8\text{ A}}$

$I_{2R} = \left(\frac{R_T}{2R}\right)10\text{ A} = \left(\frac{0.48R}{2R}\right)10\text{ A} = \mathbf{2.4\text{ A}}$

$I_{3R} = \left(\frac{R_T}{3R}\right)10\text{ A} = \left(\frac{0.48R}{3R}\right)10\text{ A} = \mathbf{1.6\text{ A}}$

$I_{4R} = \left(\frac{R_T}{4R}\right)10\text{ A} = \left(\frac{0.48R}{4R}\right)10\text{ A} = \mathbf{1.2\text{ A}}$

34. (a) $P_T = I_T^2 R_T = (50\text{ mA})^2(1.0\text{ k}\Omega) = 2.5\text{ W}$

Number of resistors $= n = \dfrac{P_T}{P_{each}} = \dfrac{2.5\text{ W}}{0.25\text{ W}} = \mathbf{10}$

All resistors are equal because each has the same power.

(b) $R_T = \dfrac{R}{n}$

$R = nR_T = 10(1.0\text{ k}\Omega) = \mathbf{10\text{ k}\Omega}$

(c) $I = \dfrac{I_T}{n} = \dfrac{50\text{ mA}}{10} = \mathbf{5\text{ mA}}$

(d) $V_S = I_T R_T = (50\text{ mA})(1.0\text{ k}\Omega) = \mathbf{50\text{ V}}$

35. (a) $I_2 = I_T - I_1 = 150\text{ mA} - 100\text{ mA} = \mathbf{50\text{ mA}}$

$R_1 = \dfrac{10\text{ V}}{100\text{ mA}} = \mathbf{100\ \Omega}$

$R_2 = \dfrac{10\text{ V}}{50\text{ mA}} = \mathbf{200\ \Omega}$

(b) $P_1 = P_T - P_2 = 2\text{ W} - 0.75\text{ W} = 1.25\text{ W}$

$V_S I_1 = 1.25\text{ W}$

$V_S = \dfrac{1.25\text{ W}}{I_1}$

$V_S I_2 = 0.75\text{ W}$

$V_S = \dfrac{0.75\text{ W}}{I_2}$

Thus,

$\dfrac{1.25\text{ W}}{I_1} = \dfrac{0.75\text{ W}}{I_2}$

$1.25 I_2 = 0.75 I_1$

$I_1 = \left(\dfrac{1.25}{0.75}\right) I_2 = 1.67 I_2$

$I_1 + I_2 = 200\text{ mA}$

$2.67 I_2 = 200\text{ mA}$

$I_2 = \dfrac{200\text{ mA}}{2.67} = \mathbf{74.9\text{ mA}}$

$I_1 = 1.67(74.9\text{ mA}) = \mathbf{125\text{ mA}}$

$V_S = \dfrac{0.75\text{ W}}{74.9\text{ mA}} = \mathbf{10\text{ V}}$

$R_1 = \dfrac{V_S}{I_1} = \dfrac{10\text{ V}}{125\text{ mA}} = \mathbf{80\ \Omega}$

$R_2 = \dfrac{V_S}{I_2} = \dfrac{10\text{ V}}{74.9\text{ mA}} = \mathbf{134\ \Omega}$

(c) $I_3 = \dfrac{100\text{ V}}{1.0\text{ k}\Omega} = \mathbf{100\ mA}$

$I_2 = \dfrac{100\text{ V}}{680\ \Omega} = \mathbf{147\ mA}$

$I_1 = I_T - I_1 - I_2 = 0.5\text{ A} - 147\text{ mA} - 100\text{ mA} = \mathbf{253\ mA}$

$R_1 = \dfrac{100\text{ V}}{253\text{ mA}} = \mathbf{395\ \Omega}$

36. (a) $R_T = R_1 = \mathbf{510\ k\Omega}$

(b) $R_T = R_1 \parallel R_2 = \dfrac{1}{\dfrac{1}{510\text{ k}\Omega} + \dfrac{1}{470\text{ k}\Omega}} = \mathbf{245\ k\Omega}$

(c) $R_T = R_1 = \mathbf{510\ k\Omega}$

(d) $R_T = R_1 \parallel R_2 \parallel R_3 = \dfrac{1}{\dfrac{1}{510\text{ k}\Omega} + \dfrac{1}{470\text{ k}\Omega} + \dfrac{1}{910\text{ k}\Omega}} = \mathbf{193\ k\Omega}$

37. $I_{max} = 0.5\text{ A}$

$R_{T(min)} = \dfrac{15\text{ V}}{I_{max}} = \dfrac{15\text{ V}}{0.5\text{ A}} = 30\ \Omega$

$\dfrac{(68\ \Omega)R_2}{68\ \Omega + R_2} = R_{T(min)}$

$(68\ \Omega)R_2 = (30\ \Omega)(68\ \Omega + R_2)$

$68R_2 = 2040 + 30R_2$

$68R_2 - 30R_2 = 2040$

$38R_2 = 2040$

$R_2 = \mathbf{53.7\ \Omega}$

38. *Position A:*

$R_T = R_1 \parallel R_2 \parallel R_3 = 560\text{ k}\Omega \parallel 220\text{ k}\Omega \parallel 270\text{ k}\Omega = 99.7\text{ k}\Omega$

$I_T = \dfrac{24\text{ V}}{R_T} = \dfrac{24\text{ V}}{99.7\text{ k}\Omega} = \mathbf{241\ \mu A}$

$I_1 = \dfrac{24\text{ V}}{560\text{ k}\Omega} = \mathbf{42.9\ \mu A}$

$I_2 = \dfrac{24\text{ V}}{220\text{ k}\Omega} = \mathbf{109\ \mu A}$

$I_3 = \dfrac{24\text{ V}}{270\text{ k}\Omega} = \mathbf{89.0\ \mu A}$

Position B:

$R_T = R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_5 \parallel R_6$

$= 560\text{ k}\Omega \parallel 220\text{ k}\Omega \parallel 270\text{ k}\Omega \parallel 1.0\text{ M}\Omega \parallel 820\text{ k}\Omega \parallel 2.2\text{ M}\Omega = 78.7\text{ k}\Omega$

$$I_T = \frac{24\text{ V}}{R_T} = \frac{24\text{ V}}{78.7\text{ k}\Omega} = \mathbf{305\ \mu A}$$

$I_1 = \mathbf{42.9\ \mu A}$

$I_2 = \mathbf{109\ \mu A}$

$I_3 = \mathbf{89.0\ \mu A}$

$$I_4 = \frac{24\text{ V}}{1.0\text{ M}\Omega} = \mathbf{24.0\ \mu A}$$

$$I_5 = \frac{24\text{ V}}{820\text{ k}\Omega} = \mathbf{29.3\ \mu A}$$

$$I_6 = \frac{24\text{ V}}{2.2\text{ M}\Omega} = \mathbf{10.9\ \mu A}$$

Position C:

$R_T = R_4 \parallel R_5 \parallel R_6 = 1.0\text{ M}\Omega \parallel 820\text{ k}\Omega \parallel 2.2\text{ M}\Omega = 374\text{ k}\Omega$

$$I_T = \frac{24\text{ V}}{R_T} = \frac{24\text{ V}}{374\text{ k}\Omega} = \mathbf{64.2\ \mu A}$$

$I_4 = \mathbf{24.0\ \mu A}$

$I_5 = \mathbf{29.3\ \mu A}$

$I_6 = \mathbf{10.9\ \mu A}$

39. From Kirchhoff's current law, the total current into the room is equal to the current in the appliances: $I_{HEATER} + I_{LAMPS} + I_{VACUUM} = 8.0\text{ A} + 2(0.833\text{ A}) + 5.0\text{ A} = 14.7\text{ A}$. The current into the room is less than the capacity of the breaker, so the vacuum cleaner can be plugged in without exceeding the capacity of the breaker.

40. $V_T = I_4R_4 = (100\text{ mA})(25\ \Omega) = 2500\text{ mV} = 2.5\text{ V}$

$$I_{220\ \Omega} = \frac{V_T}{R} = \frac{2.5\text{ V}}{220\ \Omega} = \mathbf{11.4\ mA}$$

41. $R_1 \parallel R_2 \parallel R_5 \parallel R_9 \parallel R_{10} \parallel R_{12}$

$= 100\text{ k}\Omega \parallel 220\text{ k}\Omega \parallel 560\text{ k}\Omega \parallel 390\text{ k}\Omega \parallel 1.2\text{ M}\Omega \parallel 100\text{ k}\Omega = \mathbf{33.6\ k\Omega}$

$R_4 \parallel R_6 \parallel R_7 \parallel R_8$

$= 270\text{ k}\Omega \parallel 1.0\text{ M}\Omega \parallel 820\text{ k}\Omega \parallel 680\text{ k}\Omega = \mathbf{135.2\ k\Omega}$

$R_3 \parallel R_{11} = 330\text{ k}\Omega \parallel 1.8\text{ M}\Omega = \mathbf{278.9\ k\Omega}$

42. $$R_T = \frac{R_1R_2}{R_1 + R_2}$$

$R_T(R_1 + R_2) = R_1R_2$

$R_TR_1 + R_TR_2 = R_1R_2$

$R_TR_1 = R_1R_2 - R_TR_2$

$R_TR_1 = R_2(R_1 - R_T)$

$$R_2 = \frac{R_TR_1}{(R_1 - R_T)}$$

$$R_2 = \frac{(680\ \Omega)(200\ \Omega)}{680\ \Omega - 200\ \Omega} = \mathbf{283\ \Omega}$$

43. $I_1 = 1.5\text{ mA} - 1.2\text{ mA} = 0.3\text{ mA}$
$V_S = V_1 = V_2 = V_3 = V_4 = I_1R_1 = (0.3\text{ mA})(1.0\text{ k}\Omega) = 0.3\text{ V}$
$I_2 = 1.2\text{ mA} - 0.8\text{ mA} = 0.4\text{ mA}$
$R_2 = \dfrac{V_2}{I_2} = \dfrac{0.3\text{ V}}{0.4\text{ mA}} = 0.75\text{ k}\Omega = \mathbf{750\ \Omega}$
$I_3 = \dfrac{V_3}{R_3} = \dfrac{0.3\text{ V}}{3.3\text{ k}\Omega} = 910\ \mu\text{A}$
$I_4 = 0.8\text{ mA} - 910\ \mu\text{A} = 709\ \mu\text{A}$
$R_4 = \dfrac{V_4}{I_4} = \dfrac{0.3\text{ V}}{709\ \mu\text{A}} = \mathbf{423\ \Omega}$

44. $V_S = I_TR_T = (250\text{ mA})(1.5\text{ k}\Omega) = 375\text{ V}$
$I_{new} = 250\text{ mA} + (0.25)(250\text{ mA}) = 250\text{ mA} + 62.5\text{ mA} = 313\text{ mA}$
$R_{T(new)} = \dfrac{V_S}{I_{new}} = \dfrac{375\text{ V}}{313\text{ mA}} = 1.20\text{ k}\Omega$
$R_{T(new)} = R_T \parallel R_{new}$
$$\frac{1}{R_{T(new)}} = \frac{1}{R_T} + \frac{1}{R_{new}}$$
$$\frac{1}{R_{new}} = \frac{1}{R_{T(new)}} - \frac{1}{R_T} = \frac{R_T - R_{T(new)}}{R_T R_{T(new)}}$$
$$R_{new} = \frac{R_T R_{T(new)}}{R_T - R_{T(new)}} = \frac{(1.20\text{ k}\Omega)(1.50\text{ k}\Omega)}{1.50\text{ k}\Omega - 1.20\text{ k}\Omega} = \mathbf{6\ k\Omega}$$

45. $R_T = 4.7\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel 10\text{ k}\Omega = 2.42\text{ k}\Omega$
$I_T = \dfrac{24\text{ V}}{2.42\text{ k}\Omega} = 10.3\text{ mA}$
With the 4.7 kΩ resistor open,
$I = \dfrac{25\text{ V}}{5\text{ k}\Omega} = 5\text{ mA}$
Therefore, the 4.7 kΩ resistor is open.

46. **Pins 1-2**
$R_T = 1.0\text{ k}\Omega \parallel 3.3\text{ k}\Omega = 767\ \Omega$ (correct reading)
When one resistor is open, the reading is either 1.0 kΩ or 3.3 kΩ.
Pins 3-4
$R_T = 270\ \Omega \parallel 390\ \Omega = 160\ \Omega$ (correct reading)
When one resistor is open, the reading is either 270 Ω or 390 Ω.
Pins 5-6
$R_T = 1.0\text{ M}\Omega \parallel 1.8\text{ M}\Omega \parallel 680\text{ k}\Omega \parallel 510\text{ k}\Omega = 201\text{ k}\Omega$ (correct reading)
R_5 open: $R_T = 1.8\text{ M}\Omega \parallel 680\text{ k}\Omega \parallel 510\text{ k}\Omega = 251\text{ k}\Omega$
R_6 open: $R_T = 1.0\text{ M}\Omega \parallel 680\text{ k}\Omega \parallel 510\text{ k}\Omega = 226\text{ k}\Omega$
R_7 open: $R_T = 1.0\text{ M}\Omega \parallel 1.8\text{ M}\Omega \parallel 510\text{ k}\Omega = 284\text{ k}\Omega$
R_8 open: $R_T = 1.0\text{ M}\Omega \parallel 1.8\text{ M}\Omega \parallel 680\text{ k}\Omega = 330\text{ k}\Omega$

47. (a) **One of the resistors has burned open** because the power exceeded 0.5 W. Since each resistor has the same voltage, the smallest value will reach the maximum power dissipation first, as per the formula $P = V^2/R$.

(b) $P = \dfrac{V^2}{R}$, $V = \sqrt{PR} = \sqrt{(0.5\text{ W})(1.8\text{ k}\Omega)} = \mathbf{30\ V}$

(c) **Replace the 1.8 kΩ resistor** and operate the circuit at less than 30 V or use a higher wattage resistor to replace the existing 1.8 kΩ.

48. (a) $R_{1\text{–}2} = R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_{11} \parallel R_{12}$
$= 10\text{ k}\Omega \parallel 2.2\text{ k}\Omega \parallel 2.2\text{ k}\Omega \parallel 3.3\text{ k}\Omega \parallel 18\text{ k}\Omega \parallel 1.0\text{ k}\Omega = \mathbf{422\ \Omega}$

(b) $R_{2\text{–}3} = R_5 \parallel R_6 \parallel R_7 \parallel R_8 \parallel R_9 \parallel R_{10}$
$= 4.7\text{ k}\Omega \parallel 4.7\text{ k}\Omega \parallel 6.8\text{ k}\Omega \parallel 5.6\text{ k}\Omega \parallel 5.6\text{ k}\Omega \parallel 1.0\text{ k}\Omega = \mathbf{518\ \Omega}$

(c) $R_{3\text{–}4} = R_5 \parallel R_6 \parallel R_7 \parallel R_8 \parallel R_9 \parallel R_{10} = \mathbf{518\ \Omega}$

(d) $R_{1\text{–}4} = R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_{11} \parallel R_{12} = \mathbf{422\ \Omega}$

49. (a) $R_{1\text{–}2} = (R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_{11} \parallel R_{12}) + (R_5 \parallel R_6 \parallel R_7 \parallel R_8 \parallel R_9 \parallel R_{10})$
$= 422\ \Omega + 518\ \Omega = \mathbf{940\ \Omega}$

(b) $R_{2\text{–}3} = R_5 \parallel R_6 \parallel R_7 \parallel R_8 \parallel R_9 \parallel R_{10} = \mathbf{518\ \Omega}$

(c) $R_{2\text{–}4} = R_5 \parallel R_6 \parallel R_7 \parallel R_8 \parallel R_9 \parallel R_{10} = \mathbf{518\ \Omega}$

(d) $R_{1\text{–}4} = R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_{11} \parallel R_{12} = \mathbf{422\ \Omega}$

Multisim Troubleshooting Problems

50. R_1 is open.

51. R_3 is open.

52. No fault

53. (a) The measured resistance between pin 1 and pin 4 agrees with the calculated value.

(b) The measured resistance between pin 2 and pin 3 agrees with the calculated value.

CHAPTER 6
SERIES-PARALLEL CIRCUITS

BASIC PROBLEMS

SECTION 6-1 Identifying Series-Parallel Relationships

1. R_2, R_3, and R_4 are in parallel and this parallel combination is in series with both R_1 and R_5.
$R_T = (R_2 \parallel R_3 \parallel R_4) + R_1 + R_5$

2. (a) R_1 in series with the parallel combination of R_2 and R_3. See Figure 6-1(a).
(b) R_1 in parallel with the series combination of R_2 and R_3. See Figure 6-1(b).
(c) R_1 in parallel with a branch containing R_2 in series with a parallel combination of four other resistors. See Figure 6-1(c).

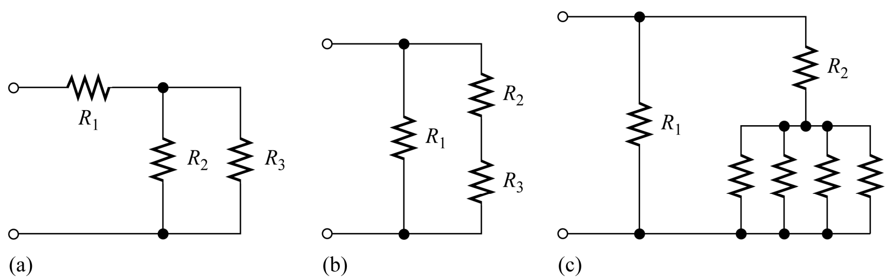


Figure 6-1

3. See Figure 6-2.

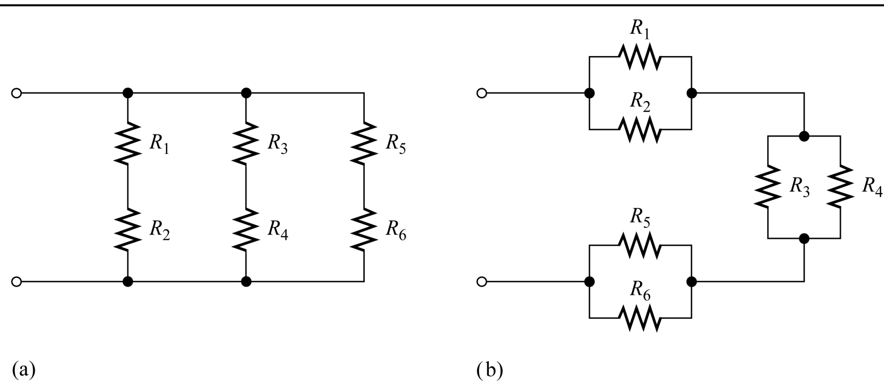


Figure 6-2

4. (a) R_1 and R_4 are in series with the parallel combination of R_2 and R_3.
$R_T = (R_2 \parallel R_3) + R_1 + R_4$
(b) R_1 is in series with the parallel combination of R_2, R_3, and R_4.
$R_T = R_1 + (R_2 \parallel R_3 \parallel R_4)$

SECTION 6-2 Analysis of Series-Parallel Resistive Circuits

5. $R_T = \dfrac{R_1 R_2}{R_1 + R_2}$

$R_2 = \dfrac{R_1 R_T}{R_1 - R_T} = \dfrac{(1.0\text{ k}\Omega)(667\ \Omega)}{1.0\text{ k}\Omega - 667\ \Omega} = \mathbf{2003\ \Omega}$

6. Brown, black, black, gold = 10 Ω ± 5%
Orange, orange, black, gold = 33 Ω ± 5%
Two 10 Ω resistors are in series with three 33 Ω resistors that are in parallel.

$R_{AB} = 10\ \Omega + 10\ \Omega + \dfrac{33\ \Omega}{3} = 20\ \Omega + 11\ \Omega = \mathbf{31\ \Omega}$

7. (a) $R_T = 56\ \Omega + 22\ \Omega + 100\ \Omega \parallel 100\ \Omega = 56\ \Omega + 22\ \Omega + 50\ \Omega = \mathbf{128\ \Omega}$
(b) $R_T = 680\ \Omega \parallel 330\ \Omega \parallel 220\ \Omega + 680\ \Omega = 111\ \Omega + 680\ \Omega = \mathbf{791\ \Omega}$

8. $R_T = R_1 + R_5 + R_2 \parallel R_3 \parallel R_4 = 10\ \Omega + 10\ \Omega + 11\ \Omega = 31\ \Omega$

$I_T = I_1 = I_5 = \dfrac{3\text{ V}}{31\,\Omega} = \mathbf{96.8\text{ mA}}$

$I_2 = I_3 = I_4 = \dfrac{96.8\text{ mA}}{3} = \mathbf{32.3\text{ mA}}$

$V_1 = V_5 = (96.8\text{ mA})(10\ \Omega) = \mathbf{968\text{ mV}}$
$V_2 = V_3 = V_4 = (32.3\text{ mA})(33\ \Omega) = \mathbf{1.07\text{ V}}$

9. (a) $R_T = 128\ \Omega$

$I_T = \dfrac{1.5\text{ V}}{128\ \Omega} = 11.7\text{ mA}$

$I_1 = I_4 = I_T = \mathbf{11.7\text{ mA}}$

$I_2 = I_3 = \dfrac{11.7\text{ mA}}{2} = \mathbf{5.85\text{ mA}}$

$V_1 = I_1 R_1 = (11.7\text{ mA})(56\ \Omega) = \mathbf{655\text{ mV}}$
$V_2 = V_3 = I_T(R_T \parallel R_3) = (11.7\text{ mA})(50\ \Omega) = \mathbf{585\text{ mV}}$
$V_4 = I_4 R_4 = (11.7\text{ mA})(22\ \Omega) = \mathbf{257\text{ mV}}$

(b) $R_{T(p)} = R_2 \parallel R_3 \parallel R_4 = 680\ \Omega \parallel 330\ \Omega \parallel 220\ \Omega = 111\ \Omega$
$R_T = R_{T(p)} + R_1 = 791\ \Omega$

$I_T = \dfrac{3\text{ V}}{791\,\Omega} = 3.8\text{ mA}$

$I_1 = I_T = \mathbf{3.8\text{ mA}}$

$$I_2 = \left(\frac{R_{T(p)}}{R_2}\right)I_T = \left(\frac{110.5\ \Omega}{680\ \Omega}\right)3.8\text{ mA} = \mathbf{618\ \mu A}$$

$$I_3 = \left(\frac{R_{T(p)}}{R_3}\right)I_T = \left(\frac{110.5\ \Omega}{330\ \Omega}\right)3.8\text{ mA} = \mathbf{1.27\ mA}$$

$$I_4 = \left(\frac{R_{T(p)}}{R_4}\right)I_T = \left(\frac{110.5\ \Omega}{220\ \Omega}\right)3.8\text{ mA} = \mathbf{1.91\ mA}$$

$V_1 = I_1R_1 = (3.8\text{ mA})(680\ \Omega) = \mathbf{2.58\ V}$
$V_2 = V_3 = V_4 = (3.8\text{ mA})(111\ \Omega) = \mathbf{420\ mV}$

10. (a) $R_4 \parallel R_5 = \dfrac{4.7\text{ k}\Omega}{2} = 2.35\text{ k}\Omega$

$R_4 \parallel R_5 + R_3 = 2.35\text{ k}\Omega + 3.3\text{ k}\Omega + 5.65\text{ k}\Omega$
$5.65\text{ k}\Omega \parallel R_2 = 5.65\text{ k}\Omega \parallel 2.7\text{ k}\Omega = 1.83\text{ k}\Omega$
$R_{AB} = 1.83\text{ k}\Omega \parallel 10\text{ k}\Omega = \mathbf{1.55\ k\Omega}$

(b) $I_T = \dfrac{V_S}{R_T} = \dfrac{6\text{ V}}{1.55\text{ k}\Omega} = \mathbf{3.87\ mA}$

(c) The resistance to the right of AB is 1.83 kΩ. The current through this part of the circuit is $I = 6\text{ V}/1.83\text{ k}\Omega = 3.28\text{ mA}$.

$$I_3 = \left(\frac{R_2}{R_2 + 5.65\text{ k}\Omega}\right)3.28\text{ mA} = \left(\frac{2.7\text{ k}\Omega}{8.35\text{ k}\Omega}\right)3.28\text{ mA} = 1.06\text{ mA}$$

$$I_5 = \frac{I_3}{2} = \frac{1.06\text{ mA}}{2} = \mathbf{530\ \mu A}$$

(d) $V_2 = V_S = \mathbf{6\ V}$

11. From Problem 10, $V_2 = 6$ V.

$$I_2 = \frac{V_2}{R_2} = \frac{6\text{ V}}{2.7\text{ k}\Omega} = \mathbf{2.22\ mA}$$

12. From Problem 10,

$I_3 = 1.06$ mA
$I_5 = 530\ \mu$A
$I_4 = I_3 - I_5 = 1.06\text{ mA} - 530\ \mu\text{A} = \mathbf{530\ \mu A}$

SECTION 6-3 Voltage Dividers with Resistive Loads

13. $V_{\text{OUT}} = \left(\dfrac{56\text{ k}\Omega}{112\text{ k}\Omega}\right)15\text{ V} = \mathbf{7.5\text{ V}}$ **unloaded**

$R_L = 1.0\text{ M}\Omega \parallel 56\text{ k}\Omega = 53\text{ k}\Omega$

$V_{\text{OUT}} = \left(\dfrac{56\text{ k}\Omega}{109\text{ k}\Omega}\right)15\text{ V} = \mathbf{7.29\text{ V}}$ **loaded**

14. *With no load:*

$V_A = \left(\dfrac{6.6\text{ k}\Omega}{9.9\text{ k}\Omega}\right)12\text{ V} = 8\text{ V}$

$V_B = \left(\dfrac{3.3\text{ k}\Omega}{9.9\text{ k}\Omega}\right)12\text{ V} = 4\text{ V}$

With a 10 kΩ resistor connected from output A to ground:

$R_{AG} = \dfrac{(6.6\text{ k}\Omega)(10\text{ k}\Omega)}{6.6\text{ k}\Omega + 10\text{ k}\Omega} = 3.98\text{ k}\Omega$

$V_{A(\text{loaded})} = \left(\dfrac{3.98\text{ k}\Omega}{7.28\text{ k}\Omega}\right)12\text{ V} = \mathbf{6.56\text{ V}}$

With a 10 kΩ resistor connected from output B to ground:

$R_{BG} = \dfrac{(3.3\text{ k}\Omega)(10\text{ k}\Omega)}{13.3\text{ k}\Omega} = 2.48\text{ k}\Omega$

$V_{B(\text{loaded})} = \left(\dfrac{2.48\text{ k}\Omega}{9.08\text{ k}\Omega}\right)12\text{ V} = \mathbf{3.28\text{ V}}$

Refer to Figure 6-3.

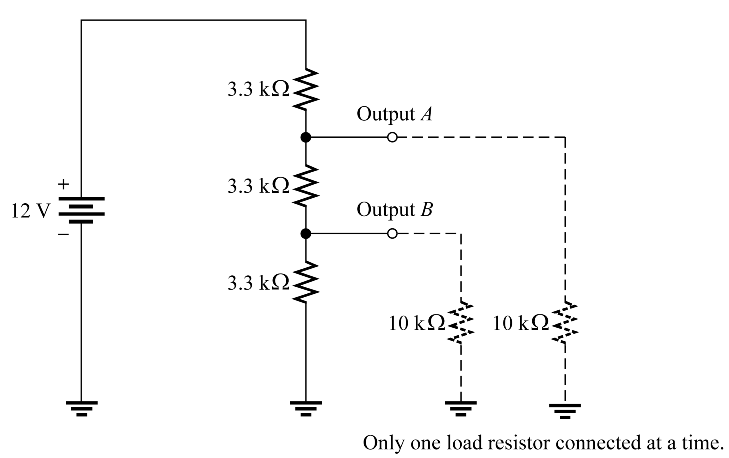


Figure 6-3

15. The **56 kΩ load** will cause a smaller decrease in output voltage for a given voltage divider because it has less effect on the circuit resistance than the 10 kΩ load does.

16. *With no load:*

$R_T = 10\text{ k}\Omega + 5.6\text{ k}\Omega + 2.7\text{ k}\Omega = 18.3\text{ k}\Omega$

$$I = \frac{22\text{ V}}{18.3\text{ k}\Omega} = \mathbf{1.2\text{ mA}}$$

With a 10 kΩ load:

$$R_T = 10\text{ k}\Omega + \frac{(8.3\text{ k}\Omega)(10\text{ k}\Omega)}{8.3\text{ k}\Omega + 10\text{ k}\Omega} = 14.54\text{ k}\Omega$$

$$I = \frac{22\text{ V}}{14.54\text{ k}\Omega} = \mathbf{1.51\text{ mA}}$$

SECTION 6-4 Loading Effect of a Voltmeter

17. The voltmeter presents the least loading across the 22 kΩ load.

18. 10 MΩ ‖ 1.0 MΩ = 909 kΩ

$$V_M = \left(\frac{909\text{ k}\Omega}{1.0\text{ M}\Omega + 909\text{ k}\Omega + 1.0\text{ M}\Omega}\right)100\text{ V} = \left(\frac{909\text{ k}\Omega}{2.909\text{ M}\Omega}\right)10\text{ V} = \mathbf{31.3\text{ V}}$$

19. $$V_{\text{ACT}} = \left(\frac{1\text{ M}\Omega}{3\text{ M}\Omega}\right)100\text{ V} = 33.3\text{ V}$$

$V_M = 31.3\text{ V}$

$\Delta V = V_{\text{ACT}} - V_M = 33.3\text{ V} - 31.3\text{ V} = \mathbf{2\text{ V}}$

20. $$\%\ V = \left(\frac{V_{\text{ACT}} - V_M}{V_M}\right)100\% = \left(\frac{33.3\text{ V} - 31.3\text{ V}}{33.3\text{ V}}\right)100\% = \mathbf{6\%}$$

21. The total resistance of the meter is $R_M = (10\text{ k}\Omega/\text{V})(10\text{ V}) = 100\text{ k}\Omega$.

$$\frac{R_M \parallel R_2}{R_M \parallel R_2 + R_1} = \frac{100\text{ k}\Omega \parallel 100\text{ k}\Omega}{100\text{ k}\Omega \parallel 100\text{ k}\Omega + 100\text{ k}\Omega} = \frac{50\text{ k}\Omega}{150\text{ k}\Omega} = \mathbf{33\%}$$

22. $$\frac{R_M \parallel R_2}{R_M \parallel R_2 + R_1} = \frac{10\text{ M}\Omega \parallel 100\text{ k}\Omega}{10\text{ M}\Omega \parallel 100\text{ k}\Omega + 100\text{ k}\Omega} = \frac{99\text{ k}\Omega}{199\text{ k}\Omega} = \mathbf{49.8\%}$$

SECTION 6-5 The Wheatstone Bridge

23. $R_{UNK} = R_V\left(\frac{R_2}{R_4}\right) = (18\text{ k}\Omega)(0.02) = \mathbf{360\ \Omega}$

24. $R_{UNK} = R_V\left(\frac{R_1}{R_2}\right)$; $\quad R_V = R_{UNK}\left(\frac{R_2}{R_1}\right) = 390\ \Omega\left(\frac{560\ \Omega}{1.0\text{ k}\Omega}\right) = \mathbf{218.4\ \Omega}$

25. $R_X = R_V\left(\frac{R_2}{R_4}\right) = 5\text{ k}\Omega\left(\frac{2.2\text{ k}\Omega}{1.5\text{ k}\Omega}\right) = \mathbf{7.33\ k\Omega}$

26. Change in thermistor resistance from 25°C to 65°C.

$$\Delta R_{therm} = 5\ \Omega(65°\text{C} - 25°\text{C}) = 5\ \Omega(40°\text{C}) = 200\ \Omega$$

At 65°C:

$$R_1 = R_{therm} = 1\text{ k}\Omega + 200\ \Omega = 1.2\text{ k}\Omega$$

$$V_A = \left(\frac{R_3}{R_1 + R_3}\right)V_S = \left(\frac{1.0\text{ k}\Omega}{2.2\text{ k}\Omega}\right)9\text{ V} = 4.09\text{ V}$$

$$V_B = \left(\frac{R_4}{R_3 + R_4}\right)V_S = \left(\frac{1.0\text{ k}\Omega}{2.0\text{ k}\Omega}\right)9\text{ V} = 4.5\text{ V}$$

$V_{OUT} = V_B - V_A = 4.5\text{ V} - 4.09\text{ V} = \mathbf{0.41\ V}$

SECTION 6-6 Thevenin's Theorem

27. $R_{TH} = 100\text{ k}\Omega \parallel 22\text{ k}\Omega = \mathbf{18\ k\Omega}$ $\quad V_{TH} = \left(\frac{22\text{ k}\Omega}{122\text{ k}\Omega}\right)15\text{ V} = \mathbf{2.7\ V}$

28. (a) $R_{TH} = 22\ \Omega + 78\ \Omega \parallel 147\ \Omega = 22\ \Omega + 51\ \Omega = \mathbf{73\ \Omega}$

$$V_{TH} = \left(\frac{78\ \Omega}{78\ \Omega + 100\ \Omega + 47\ \Omega}\right)2.5\text{ V} = \mathbf{867\ mV}$$

(b) $R_{TH} = 100\ \Omega \parallel 270\ \Omega = \mathbf{73\ \Omega}$

$$V_{TH} = \left(\frac{100\ \Omega}{370\ \Omega}\right)3\text{ V} = \mathbf{811\ mV}$$

(c) $R_{TH} = 100\text{ k}\Omega \parallel 56\text{ k}\Omega = \mathbf{35.9\ k\Omega}$

$$V_{TH} = \left(\frac{56\text{ k}\Omega}{156\text{ k}\Omega}\right)1.5\text{ V} = \mathbf{538\ mV}$$

29. $R_{TH} = R_1 \parallel R_3 + R_2 \parallel R_4 = 1.0\text{ k}\Omega \parallel 2.2\text{ k}\Omega + 2.2\text{ k}\Omega \parallel 1.5\text{ k}\Omega = 1.58\text{ k}\Omega$

$$V_{TH} = V_A - V_B = \left(\frac{R_3}{R_1 + R_3}\right)V_S - \left(\frac{R_4}{R_2 + R_4}\right)V_S = \left(\frac{2.2\text{ k}\Omega}{3.2\text{ k}\Omega}\right)5\text{ V} - \left(\frac{1.5\text{ k}\Omega}{3.7\text{ k}\Omega}\right)5\text{ V}$$

$$= 3.44\text{ V} - 2.03\text{ V} = 1.41\text{ V}$$

$$V_{R_L} = \left(\frac{R_L}{R_{TH} + R_L}\right)V_{TH} = \left(\frac{4.7\text{ k}\Omega}{6.28\text{ k}\Omega}\right)1.41\text{ V} = \mathbf{1.06\text{ V}}$$

$$I_{R_L} = \frac{V_{R_L}}{R_L} = \frac{1.06\text{ V}}{4.7\text{ k}\Omega} = \mathbf{226\ \mu A}$$

SECTION 6-7 The Maximum Power Transfer Theorem

30. $R_{TH} = R_1 \parallel R_2 = 100\text{ k}\Omega \parallel 22\text{ k}\Omega = 18\text{ k}\Omega$
$R_L = R_{TH} =$ **18 kΩ**

31. $R_L = R_{TH} =$ **75 Ω**

32. $R_{TH} = 73\ \Omega$
Therefore, $R_L = R_{TH} =$ **73 Ω** for maximum power transfer.

SECTION 6-8 The Superposition Theorem

33. *For the 1 V source:*
$R_T = R_1 + R_2 \parallel R_3 = 100\ \Omega + 56\ \Omega \parallel 27\ \Omega = 118.2\ \Omega$

$$I_T = \frac{1\text{ V}}{118.2\ \Omega} = 8.46\text{ mA}$$

$$I_3 = \left(\frac{R_2}{R_2 + R_3}\right)I_T = \left(\frac{56\ \Omega}{83\ \Omega}\right)8.46\text{ mA} = 5.71\text{ mA (up)}$$

For the 1.5 V source:
$R_T = R_2 + R_1 \parallel R_3 = 56\ \Omega + 100\ \Omega \parallel 27\ \Omega = 77.3\ \Omega$

$$I_T = \frac{1.5\text{ V}}{77.3\ \Omega} = 19.4\text{ mA}$$

$$I_3 = \left(\frac{R_1}{R_1 + R_3}\right)I_T = \left(\frac{100\ \Omega}{127\ \Omega}\right)19.4\text{ mA} = 15.3\text{ mA (up)}$$

$I_{3(total)} = 5.71\text{ mA} + 15.3\text{ mA} =$ **21.0 mA (up)**

34. *For the 1 V source:*

$$I_2 = \left(\frac{R_3}{R_2 + R_3}\right) I_{\text{T}} = \left(\frac{27\ \Omega}{83\ \Omega}\right) 8.46\text{ mA} = 2.75\text{ mA}\ \ \text{(up)}$$

For the 1.5 V source:

$I_2 = I_{\text{T}} = 19.4$ mA (down)

$I_{2(\text{total})} = 19.4$ mA – 2.75 mA = **16.7 mA (down)**

SECTION 6-9 Troubleshooting

35. $$R_{\text{eq}} = \frac{(680\ \Omega)(4.7\text{ k}\Omega)}{680\ \Omega + 4.7\text{ k}\Omega} = 594\ \Omega$$

$R_{\text{T}} = 560\ \Omega + 470\ \Omega + 594\ \Omega = 1624\ \Omega$

The voltmeter indicates 9.84 V.

The voltmeter should read: $V = \left(\frac{594\ \Omega}{1624\ \Omega}\right) 12\text{ V} = \mathbf{4.39\ V}$

The meter reading is incorrect, indicating that the 680 Ω resistor is open.

36. If R_2 opens: V_A = **15 V**, V_B = **0 V**, and V_C = **0 V**

37. $$V_{3.3\text{k}\Omega} = \left(\frac{R_4 \parallel (R_3 + R_2)}{R_4 \parallel (R_3 + R_2) + R_1}\right) 10\text{ V} = \left(\frac{1.62\text{ k}\Omega}{2.62\text{ k}\Omega}\right) 10\text{ V} = 6.18\text{ V}$$

The 7.62 V reading is incorrect.

$$V_{2.2\text{k}\Omega} = \left(\frac{2.2\text{ k}\Omega}{3.2\text{ k}\Omega}\right) 6.18\text{ V} = 4.25\text{ V}$$

The 5.24 V reading is incorrect.
The 3.3 kΩ resistor is open.

38. (a) R_1 *open:*

V_{R1} = **15 V**; $V_{R2} = V_{R3} = V_{R4} = V_{R5}$ = **0 V**

(b) R_3 *open:*

V_{R3} = **15 V**; $V_{R12} = V_{R2} = V_{R4} = V_{R5}$ = **0 V**

(c) R_4 *open:*

$R_{\text{T}} = R_1 + R_2 + R_3 + R_5 = 1.0\text{ k}\Omega + 560\ \Omega + 470\ \Omega + 2.2\text{ k}\Omega = 4.23\text{ k}\Omega$

$$V_{R1} = \left(\frac{R_1}{R_{\text{T}}}\right) 15\text{ V} = \left(\frac{1.0\text{ k}\Omega}{4.23\text{ k}\Omega}\right) 15\text{ V } 15\text{ V} = \mathbf{3.55\ V}$$

$$V_{R2} = \left(\frac{R_2}{R_{\text{T}}}\right) 15\text{ V} = \left(\frac{560\ \Omega}{4.23\text{ k}\Omega}\right) 15\text{ V} = \mathbf{1.99\ V}$$

$$V_{R3} = \left(\frac{R_3}{R_T}\right)15\text{ V} = \left(\frac{470\ \Omega}{4.23\text{ k}\Omega}\right)15\text{ V} = \mathbf{1.67\ V}$$

$$V_{R4} = V_{R5} = \left(\frac{R_5}{R_T}\right)15\text{ V} = \left(\frac{2.2\text{ k}\Omega}{4.23\text{ k}\Omega}\right)15\text{ V} = \mathbf{7.80\ V}$$

(d) *R_5 open:*

$R_T = R_1 + R_2 + R_3 + R_4 = 1.0\text{ k}\Omega + 560\ \Omega + 470\ \Omega + 3.3\text{ k}\Omega = 5.33\text{ k}\Omega$

$$V_{R1} = \left(\frac{R_1}{R_T}\right)15\text{ V} = \left(\frac{1.0\text{ k}\Omega}{5.33\text{ k}\Omega}\right)15\text{ V} = \mathbf{2.81\ V}$$

$$V_{R2} = \left(\frac{R_2}{R_T}\right)15\text{ V} = \left(\frac{560\ \Omega}{5.33\text{ k}\Omega}\right)15\text{ V} = \mathbf{1.58\ V}$$

$$V_{R3} = \left(\frac{R_3}{R_T}\right)15\text{ V} = \left(\frac{470\ \Omega}{5.33\text{ k}\Omega}\right)15\text{ V} = \mathbf{1.32\ V}$$

$$V_{R4} = V_{R5} = \left(\frac{R_5}{R_T}\right)15\text{ V} = \left(\frac{3.3\text{ k}\Omega}{5.33\text{ k}\Omega}\right)15\text{ V} = \mathbf{9.29\ V}$$

(e) *Point C shorted to ground:*

$R_T = R_1 + R_2 + R_3 = 1.0\text{ k}\Omega + 560\ \Omega + 470\ \Omega = 2.03\text{ k}\Omega$

$V_{R4} = V_{R5} = \mathbf{0\ V}$

$$V_{R1} = \left(\frac{R_1}{R_T}\right)15\text{ V} = \left(\frac{1.0\text{ k}\Omega}{2.03\text{ k}\Omega}\right)15\text{ V} = \mathbf{7.39\ V}$$

$$V_{R2} = \left(\frac{R_2}{R_T}\right)15\text{ V} = \left(\frac{560\ \Omega}{2.03\text{ k}\Omega}\right)15\text{ V} = \mathbf{4.14\ V}$$

$$V_{R3} = \left(\frac{R_3}{R_T}\right)15\text{ V} = \left(\frac{470\ \Omega}{2.03\text{ k}\Omega}\right)15\text{ V} = \mathbf{3.47\ V}$$

39. (a) *R_1 open:*

$V_{R1} = \mathbf{-10\ V}$, $V_{R2} = V_{R3} = V_{R4} = \mathbf{0\ V}$

(b) *R_2 open:*

$R_T = R_1 + R_4 = 1.0\text{ k}\Omega + 3.3\text{ k}\Omega = 4.3\text{ k}\Omega$

$$V_{R1} = -\left(\frac{R_1}{R_T}\right)10\text{ V} = -\left(\frac{1.0\text{ k}\Omega}{4.3\text{ k}\Omega}\right)10\text{ V} = \mathbf{-2.33\ V}$$

$V_{R2} = \mathbf{-7.67\ V}$

$V_{R3} = \mathbf{0\ V}$

$$V_{R4} = -\left(\frac{R_4}{R_T}\right)10\text{ V} = -\left(\frac{3.3\text{ k}\Omega}{4.3\text{ k}\Omega}\right)10\text{ V} = \mathbf{-7.67\ V}$$

(c) R_3 *open:*

$R_T = R_1 + R_4 = 1.0\text{ k}\Omega + 3.3\text{ k}\Omega = 4.3\text{ k}\Omega$

$$V_{R1} = -\left(\frac{R_1}{R_T}\right)10\text{ V} = -\left(\frac{1.0\text{ k}\Omega}{4.3\text{ k}\Omega}\right)10\text{ V} = \mathbf{-2.33\text{ V}}$$

$V_{R2} = \mathbf{0\text{ V}}$

$V_{R3} = \mathbf{-7.67\text{ V}}$

$$V_{R4} = -\left(\frac{R_4}{R_T}\right)10\text{ V} = -\left(\frac{3.3\text{ k}\Omega}{4.3\text{ k}\Omega}\right)10\text{ V} = \mathbf{-7.67\text{ V}}$$

(d) R_4 *shorted:*

$R_T = R_1 + R_2 + R_3 + R_4 = 1.0\text{ k}\Omega + 560\ \Omega + 470\ \Omega + 3.3\text{ k}\Omega = 5.33\text{ k}\Omega$

$V_{R1} = \mathbf{-10\text{ V}}$

$V_{R2} = V_{R3} = V_{R4} = \mathbf{0\text{ V}}$

ADVANCED PROBLEMS

40. (a) The parallel combination of R_2 and R_3 is in series with the parallel combination of R_4 and R_5. This is all in parallel with R_1.

(b) R_1 and R_2 are in series with the parallel combination of R_3 and R_4. Also, R_5 and R_8 are in series with the parallel combination of R_6 and R_7. These two series-parallel combinations are in parallel with each other.

41. Resistors R_8, R_9, and R_{11} can be removed with no effect on the circuit because they are shorted by the pc connection. See Figure 6-4.

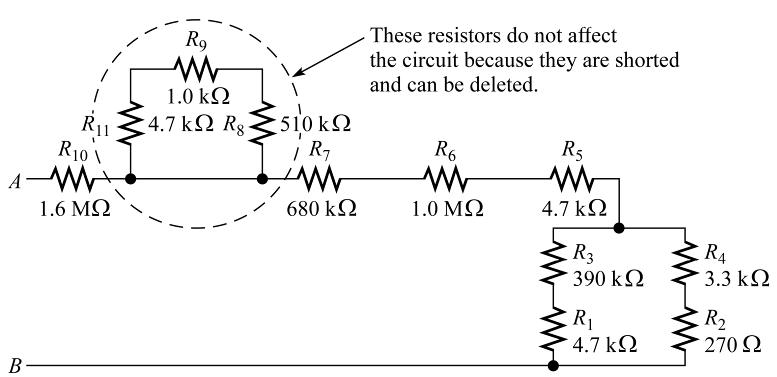


Figure 6-4

42. The circuit is redrawn and simplified as shown in Figure 6-5.

(a) $R_T = (((((560\ \Omega + 560\ \Omega) \parallel 1.0\ k\Omega) + (1.0\ k\Omega + 1.0\ k\Omega) \parallel 560\ \Omega) \parallel 910\ \Omega) \parallel 56\ \Omega) \parallel 560\ \Omega$
$= (((528.3\ \Omega + 437.5\ \Omega) \parallel 910\ \Omega) + 56\ \Omega) \parallel 560\ \Omega = \mathbf{271\ \Omega}$

(b) $I_T = \dfrac{60\ V}{271\ \Omega} = \mathbf{221\ mA}$

(c) $I_{56\ \Omega} = \left(\dfrac{560\ \Omega}{560\ \Omega + 525\ \Omega}\right) I_T = (0.516)221\ mA = 114\ mA$

$I_{910\ \Omega} = \left(\dfrac{966\ \Omega}{910\ \Omega + 966\ \Omega}\right) I_{56\ \Omega} = (0.515)114\ mA = \mathbf{58.7\ mA}$

(d) $V_{910\ \Omega} = I_{910\ \Omega}(910\ \Omega) = (58.7\ mA)\ 910\ \Omega = 53.4\ V$

The voltage from point *B* to the negative side of the battery is

$V_{B-} = \left(\dfrac{437.5\ \Omega}{437.5\ \Omega + 528.3\ \Omega}\right) V_{910\ \Omega} = \left(\dfrac{437.5\ \Omega}{966\ \Omega}\right) 53.4\ V = \mathbf{24.2\ V}$

$V_{AB} = \dfrac{24.2\ V}{2} = \mathbf{12.1\ V}$

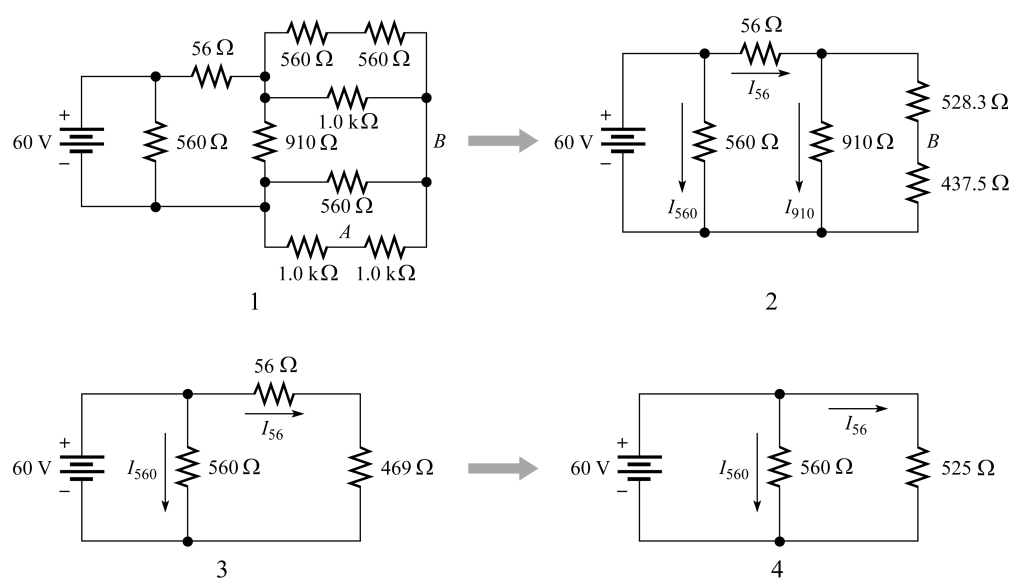


Figure 6-5

43. $R_B = 2.2\ k\Omega \parallel 2\ k\Omega = 1.05\ k\Omega$ $\qquad R_A = 2.2\ k\Omega \parallel 2.05\ k\Omega = 1.06\ k\Omega$

$R_T = 4.7\ k\Omega + 1.06\ k\Omega = \mathbf{5.76\ k\Omega}$

$V_A = \left(\dfrac{1.06\ k\Omega}{5.76\ k\Omega}\right) 18\ V = \mathbf{3.3\ V}$

$V_B = \left(\dfrac{1.05\ k\Omega}{2.05\ k\Omega}\right) V_A = \left(\dfrac{1.05\ k\Omega}{2.05\ k\Omega}\right) 3.3\ V = \mathbf{1.7\ V}$

$V_C = \left(\dfrac{1.0\ k\Omega}{2\ k\Omega}\right) V_B = (0.5)(1.7\ V) = \mathbf{850\ mV}$

44. The circuit is simplified in Figure 6-6 step-by-step to determine R_T.

R_T = **621 Ω**

$$I_T = I_1 = I_9 = \frac{10\text{ V}}{621\ \Omega} = \mathbf{16.1\ mA}$$

$$I_2 = \left(\frac{864\ \Omega}{1684\ \Omega}\right)16.1\text{ mA} = \mathbf{8.26\ mA}$$

$$I_3 = I_8 = \left(\frac{820\ \Omega}{1684\ \Omega}\right)16.1\text{ mA} = \mathbf{7.84\ mA}$$

$$I_4 = \left(\frac{880\ \Omega}{1700\ \Omega}\right)7.84\text{ mA} = \mathbf{4.06\ mA}$$

$$I_5 = \left(\frac{820\ \Omega}{1700\ \Omega}\right)7.84\text{ mA} = \mathbf{3.78\ mA}$$

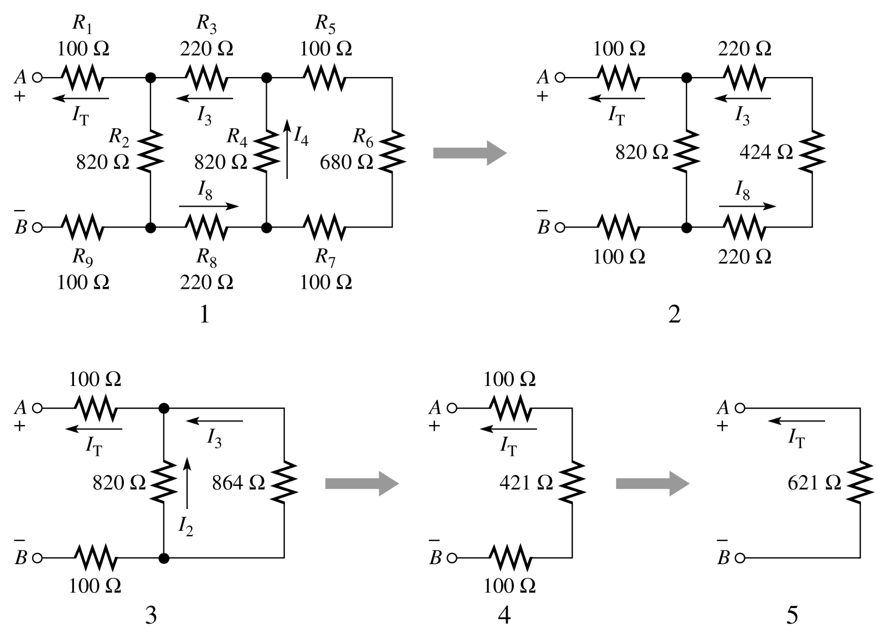


Figure 6-6

45. Using the currents found in Problem 44:

$V_1 = I_T R_1$ = (16.1 mA)(100 Ω) = **1.61 V**
$V_2 = I_2 R_2$ = (8.26 mA)(820 Ω) = **6.77 V**
$V_3 = I_3 R_3$ = (7.84 mA)(220 Ω) = **1.72 V**
$V_4 = I_4 R_4$ = (4.06 mA)(820 Ω) = **3.33 V**
$V_5 = I_5 R_5$ = (3.78 mA)(100 Ω) = **378 mV**
$V_6 = I_5 R_6$ = (3.78 mA)(680 Ω) = **2.57 V**
$V_7 = V_5$ = **378 mV**
$V_8 = I_8 R_8$ = (7.84 mA)(220 Ω) = **1.72 V**
$V_9 = I_T R_9$ = (16.1 mA)(100 Ω) = **1.61 V**

46. *Resistance of the right branch:*

$R_R = R_2 + R_5 \parallel R_6 + R_7 + R_8 = 330\ \Omega + 600\ \Omega + 680\ \Omega + 100\ \Omega = 1710\ \Omega$

Resistance of the left branch:

$R_L = R_3 + R_4 = 470\ \Omega + 560\ \Omega = 1030\ \Omega$

Total resistance:

$R_T = R_1 + R_L \parallel R_R = 1.0\ \text{k}\Omega + 642.8\ \Omega = 1643\ \Omega$

$$I_T = \frac{100\ \text{V}}{1643\ \Omega} = 60.9\ \text{mA}$$

Current in right branch:

$$I_R = \left(\frac{R_L}{R_L + R_R}\right)I_T = \left(\frac{1030\ \Omega}{2740\ \Omega}\right)60.9\ \text{mA} = 22.9\ \text{mA}$$

Current in left branch:

$$I_L = \left(\frac{R_R}{R_L + R_R}\right)I_T = \left(\frac{1710\ \Omega}{2740\ \Omega}\right)60.9\ \text{mA} = 38.0\ \text{mA}$$

Voltages with respect to the negative terminal of the source:

$V_A = I_1R_4 = (38.0\ \text{mA})(560\ \Omega) = 21.3\ \text{V}$

$V_B = I_R(R_7 + R_8) = (22.9\ \text{mA})(780\ \Omega) = 17.9\ \text{V}$

$V_{AB} = V_A - V_B = 21.3\ \text{V} - 17.9\ \text{V} = \mathbf{3.40\ V}$

47. Writing KVL around outside loop, and substituting $I_1 = (I_T - 1\ \text{mA})$:

$-220\ \text{V} + (I_T - 1\ \text{mA})\ 47\ \text{k}\Omega + I_T\ (33\ \text{k}\Omega) = 0$

$(47\ \text{k}\Omega + 33\ \text{k}\Omega)\ I_T = 220\ \text{V} + 47\ \text{V}$

$$I_T = \frac{267\ \text{V}}{80\ \text{k}\Omega} = 3.34\ \text{mA}$$

$V_3 = I_TR_3 = (3.34\ \text{mA})(33\ \text{k}\Omega) = 110\ \text{V}$

$I_1 = (I_T - 1\ \text{mA}) = 2.34\ \text{mA}$

$V_2 = V_S - V_3 = 220\ \text{V} - 110\ \text{V} = 110\ \text{V}$

$$R_2 = \frac{V_2}{I_2} = \frac{110\ \text{V}}{1.0\ \text{mA}} = \mathbf{110\ k\Omega}$$

48. $R_{C-GND} = R_6 = 1.0\ \text{k}\Omega$

$R_{B-GND} = (R_5 + R_6) \parallel R_4 = 2\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega = 1.05\ \text{k}\Omega$

$R_{A-GND} = (R_3 + R_{B-GND}) \parallel R_2 = 2.05\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega = 1.06\ \text{k}\Omega$

$R_T = R_1 + R_{A-GND} = 5.6\ \text{k}\Omega + 1.06\ \text{k}\Omega = 6.66\ \text{k}\Omega$

$$V_A = \left(\frac{1.06\ \text{k}\Omega}{6.66\ \text{k}\Omega}\right)18\ \text{V} = \mathbf{2.86\ V}$$

$$V_B = \left(\frac{1.05\ \text{k}\Omega}{2.05\ \text{k}\Omega}\right)2.86\ \text{V} = \mathbf{1.47\ V}$$

$$V_C = \left(\frac{1.0\ \text{k}\Omega}{2\ \text{k}\Omega}\right)1.47\ \text{V} = \mathbf{735\ mV}$$

49. $I_{max} = 100$ mA

$$R_T = \frac{24\text{ V}}{100\text{ mA}} = 240\ \Omega$$

$$\left(\frac{R_2}{R_T}\right)24\text{ V} = 6\text{ V}$$

$24R_2 = 6R_T$

$$R_2 = \frac{6(240\ \Omega)}{24} = \mathbf{60\ \Omega}$$

$R_1 = 140\ \Omega - 60\ \Omega = \mathbf{180\ \Omega}$

With load:

$R_2 \parallel R_L = 60\ \Omega \parallel 1000\ \Omega = 56.6\ \Omega$

$$V_{OUT} = \left(\frac{56.6\ \Omega}{180\ \Omega + 56.6\ \Omega}\right)24\text{ V} = 5.74\text{ V}$$

50. Refer to Figure 6-7.

$$R_T = \frac{10\text{ V}}{5\text{ mA}} = 2\text{ k}\Omega$$

$R_1 = R_2 + R_3$

$R_2 = R_3$

$R_1 = 2R_2$

$R_1 + 2R_2 = 2\text{ k}\Omega$

$2R_2 + 2R_2 = 2\text{ k}\Omega$

$4R_2 = 2\text{ k}\Omega$

$R_2 = R_3 = \mathbf{500\ \Omega}$

$R_1 = R_2 + R_3 = \mathbf{1000\ \Omega}$

With 1 kΩ loads across the 2.5 V and the 5 V outputs:

$$V_A = \left(\frac{(R_3 \parallel R_L + R_2) \parallel R_L}{(R_3 \parallel R_L + R_2) \parallel R_L + R_1}\right)V_S$$

$$= \left(\frac{(500\ \Omega \parallel 1\text{ k}\Omega + 500\ \Omega) \parallel 1\text{ k}\Omega}{(500\ \Omega \parallel 1\text{ k}\Omega + 500\ \Omega) \parallel 1\text{ k}\Omega + 1\text{ k}\Omega}\right)10\text{ V}$$

$$= \left(\frac{455\ \Omega}{455\ \Omega + 1\text{ k}\Omega}\right)10\text{ V} = \mathbf{3.13\ V}$$

$$V_B = \left(\frac{R_3 \| 1\text{ k}\Omega}{R_3 \| 1\text{ k}\Omega + R_2}\right)V_A = \left(\frac{333\ \Omega}{333\ \Omega + 500\ \Omega}\right)3.13\text{ V} = \mathbf{1.25\ V}$$

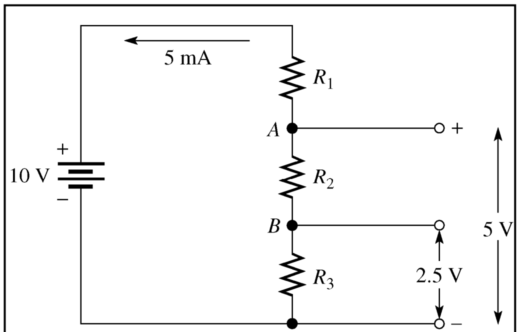


Figure 6-7

51. Refer to Figure 6-8(a).

With the 2 V source acting alone:

$R_T = 1.96\text{ k}\Omega$

$$I_T = \frac{2\text{ V}}{1.96\text{ k}\Omega} = 1.02\text{ mA}$$

$$I_1 = \left(\frac{2.2\text{ k}\Omega}{2.2\text{ k}\Omega + 1.69\text{ k}\Omega}\right)1.02\text{ mA} = 577\ \mu\text{A}$$

$$I_5 = \left(\frac{1.0\text{ k}\Omega}{1.0\text{ k}\Omega + 2.2\text{ k}\Omega}\right)577\ \mu\text{A} = 180\ \mu\text{A}\quad \text{up}$$

Refer to Figure 6-8(b).

With the 3 V source acting alone:

$R_T = 1.96\text{ k}\Omega$

$$I_T = \frac{3\text{ V}}{1.96\text{ k}\Omega} = 1.53\text{ mA}$$

$$I_5 = \left(\frac{1.69\text{ k}\Omega}{2.2\text{ k}\Omega + 1.69\text{ k}\Omega}\right)1.53\text{ mA} = 665\ \mu\text{A}\quad \text{up}$$

$I_{5(\text{total})} = 665\ \mu\text{A} + 180\ \mu\text{A} = \mathbf{845\ \mu A}$

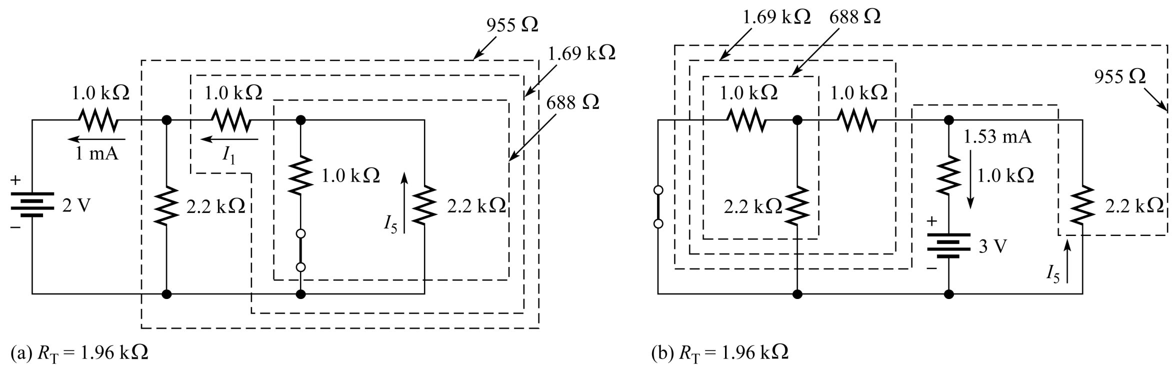


Figure 6-8

52. *Using Superposition:*

Current from the 12 V source:

$R_T = 220\ \Omega + 100\ \Omega \parallel 560\ \Omega \parallel 100\ \Omega \parallel 820\ \Omega = 220\ \Omega + 43.5\ \Omega = 264\ \Omega$

$$I_T = \frac{12\text{ V}}{264\ \Omega} = 45.5\text{ mA}$$

$$I_{R_L} = \left(\frac{43.5\ \Omega}{820\ \Omega}\right)45.5\text{ mA} = 2.41\text{ mA (up)}$$

Current from the 6 V source:

$R_T = 100\ \Omega + 220\ \Omega \parallel 560\ \Omega \parallel 100\ \Omega \parallel 820\ \Omega = 100\ \Omega + 57\ \Omega = 157\ \Omega$

$$I_T = \frac{6\text{ V}}{157\ \Omega} = 38.2\text{ mA}$$

$$I_{R_L} = \left(\frac{57\ \Omega}{820\ \Omega}\right)38.2\text{ mA} = 2.66\text{ mA (up)}$$

Current from the 10 V source:

$R_T = 560\ \Omega + 220\ \Omega \parallel 100\ \Omega \parallel 100\ \Omega \parallel 820\ \Omega = 560\ \Omega + 38.8\ \Omega = 599\ \Omega$

$$I_T = \frac{10\text{ V}}{599\ \Omega} = 16.7\text{ mA}$$

$$I_{R_L} = \left(\frac{38.8\ \Omega}{820\ \Omega}\right)16.7\text{ mA} = 0.79\text{ mA (down)}$$

Current from the 5 V source:

$R_T = 100\ \Omega + 220\ \Omega \parallel 100\ \Omega \parallel 560\ \Omega \parallel 820\ \Omega = 100\ \Omega + 57\ \Omega = 157\ \Omega$

$$I_T = \frac{5\text{ V}}{157\ \Omega} = 31.8\text{ mA}$$

$$I_{R_L} = \left(\frac{57\ \Omega}{820\ \Omega}\right)31.8\text{ mA} = 2.21\text{ mA (down)}$$

$$I_{R_{L(total)}} = 2.41\text{ mA} + 2.66\text{ mA} - 0.79\text{ mA} - 2.21\text{ mA} = \mathbf{2.08\text{ mA}}\text{ (up)}$$

53. Refer to Figure 6-9(a).

$R_{TH} = 2.65\text{ k}\Omega \parallel 2.35\text{ k}\Omega = 1.25\text{ k}\Omega$

Refer to Figure 6-9(b).

$$V_{TH} = \left(\frac{1.69\text{ k}\Omega}{6.39\text{ k}\Omega}\right)50\text{ V} = 13.2\text{ V}$$

Refer to Figure 6-9(c).

$$V_4 = \left(\frac{10\text{ k}\Omega}{11.3\text{ k}\Omega}\right)13.2\text{ V} = \mathbf{11.7\text{ V}}$$

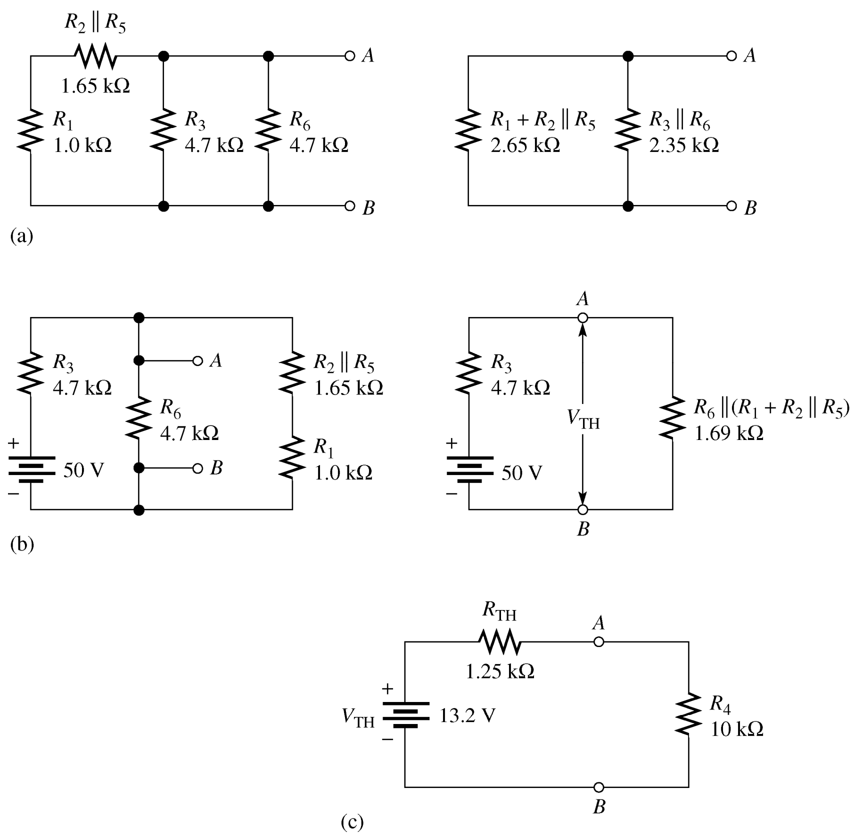


Figure 6-9

54. (a) When SW2 is connected to +12 V, the voltage at the junction of R_3, R_4, and R_5 is

$$V_2 = \left(\frac{24\text{ k}\Omega \parallel 26.4\text{ k}\Omega}{24\text{ k}\Omega + (24\text{ k}\Omega \parallel 26.4\text{ k}\Omega)}\right)12\text{ V} = \left(\frac{12.6\text{ k}\Omega}{36.6\text{ k}\Omega}\right)12\text{ V} = 4.13\text{ V}$$

The voltage at the junction of R_5, R_6, and R_7 is

$$V_3 = \left(\frac{24\text{ k}\Omega \parallel 36\text{ k}\Omega}{12\text{ k}\Omega + (24\text{ k}\Omega \parallel 36\text{ k}\Omega)}\right)V_2 = \left(\frac{14.4\text{ k}\Omega}{36.4\text{ k}\Omega}\right)4.13\text{ V} = 2.25\text{ V}$$

$$V_{OUT} = \left(\frac{24\text{ k}\Omega}{36\text{ k}\Omega}\right)V_3 = \left(\frac{24\text{ k}\Omega}{36\text{ k}\Omega}\right)2.25\text{ V} = \mathbf{1.5\text{ V}}$$

(b) When SW1 is connected to +12 V, the voltage at the junction of R_1, R_2, and R_3 is

$$V_1 = \left(\frac{24\text{ k}\Omega \parallel 24.6\text{ k}\Omega}{24\text{ k}\Omega + (24\text{ k}\Omega \parallel 24.6\text{ k}\Omega)}\right)12\text{ V} = \left(\frac{12.1\text{ k}\Omega}{36.1\text{ k}\Omega}\right)12\text{ V} = 4.02\text{ V}$$

The voltage at the junction of R_3, R_4, and R_5 is

$$V_2 = \left(\frac{24\text{ k}\Omega \parallel 24.4\text{ k}\Omega}{12\text{ k}\Omega + (24\text{ k}\Omega \parallel 24.4\text{ k}\Omega)}\right)V_1 = \left(\frac{12.6\text{ k}\Omega}{24.4\text{ k}\Omega}\right)4.02\text{ V} = 2.08\text{ V}$$

$$V_3 = \left(\frac{24\text{ k}\Omega \parallel 14.4\text{ k}\Omega}{12\text{ k}\Omega + (24\text{ k}\Omega \parallel 14.4\text{ k}\Omega)}\right)V_2 = \left(\frac{14.4\text{ k}\Omega}{26.4\text{ k}\Omega}\right)2.08\text{ V} = 1.13\text{ V}$$

$$V_{OUT} = \left(\frac{24\text{ k}\Omega}{36\text{ k}\Omega}\right)V_3 = \left(\frac{24\text{ k}\Omega}{36\text{ k}\Omega}\right)1.13\text{ V} = \mathbf{0.75\text{ V}}$$

55. See Figure 6-10.

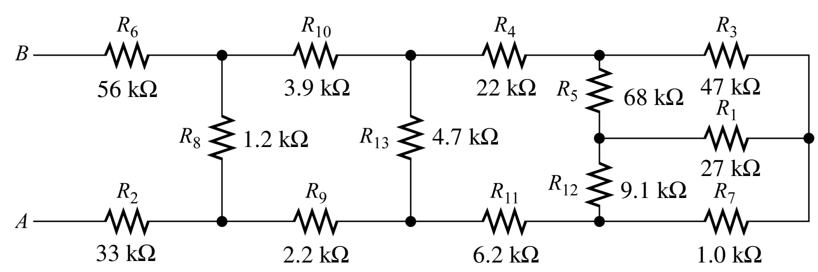


Figure 6-10

56. See Figure 6-11.

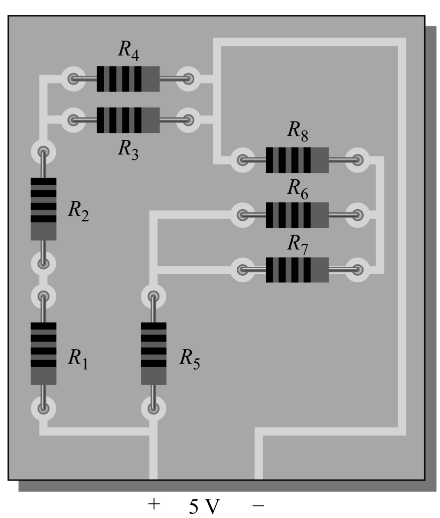


Figure 6-11

57. *Position 1:*

R_T = 10 kΩ + 30 kΩ ‖ 330 kΩ = 10 kΩ + 27.5 kΩ = 37.5 kΩ

$$V_1 = \left(\frac{27.5\text{ k}\Omega}{37.5\text{ k}\Omega}\right)120\text{ V} = \mathbf{88.0\text{ V}}$$

$$V_2 = \left(\frac{20\text{ k}\Omega}{30\text{ k}\Omega}\right)88.0\text{ V} = \mathbf{58.7\text{ V}}$$

$$V_3 = \left(\frac{10\text{ k}\Omega}{30\text{ k}\Omega}\right)88.0\text{ V} = \mathbf{29.3\text{ V}}$$

Position 2:

R_T = 20 kΩ + 20 kΩ ‖ 330 kΩ = 20 kΩ + 18.9 kΩ = 38.9 kΩ

$$V_1 = \left(\frac{10\text{ k}\Omega + 18.9\text{ k}\Omega}{35.5\text{ k}\Omega}\right)120\text{ V} = \mathbf{89.1\text{ V}}$$

$$V_2 = \left(\frac{18.9\text{ k}\Omega}{38.9\text{ k}\Omega}\right)120\text{ V} = \mathbf{58.2\text{ V}}$$

$$V_3 = \left(\frac{10\text{ k}\Omega}{20\text{ k}\Omega}\right)58.2\text{ V} = \mathbf{29.1\text{ V}}$$

Position 3:

R_T = 30 kΩ + 10 kΩ ‖ 330 kΩ = 30 kΩ + 9.71 kΩ = 39.7 kΩ

$$V_1 = \left(\frac{20\text{ k}\Omega + 9.71\text{ k}\Omega}{39.7\text{ k}\Omega}\right)120\text{ V} = \mathbf{89.8\text{ V}}$$

$$V_2 = \left(\frac{10\text{ k}\Omega + 9.71\text{ k}\Omega}{39.7\text{ k}\Omega}\right)120\text{ V} = \mathbf{59.6\text{ V}}$$

$$V_3 = \left(\frac{9.71\text{ k}\Omega}{39.7\text{ k}\Omega}\right)120\text{ V} = \mathbf{29.3\text{ V}}$$

58. (a) $$V_G = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD} = \left(\frac{560\text{ k}\Omega}{2.2\text{ M}\Omega + 560\text{ k}\Omega}\right)16\text{ V} = \mathbf{3.25\text{ V}}$$

V_S = 3.25 V − 1.5 V = **1.75 V**

(b) $$I_1 = \frac{V_{DD} - V_G}{R_1} = \frac{16\text{ V} - 3.25\text{ V}}{2.2\text{ M}\Omega} = \mathbf{5.80\ \mu A}$$

$I_2 = I_1$ = **5.80 μA**

$$I_S = \frac{V_S}{R_S} = \frac{1.75\text{ V}}{1.5\text{ k}\Omega} = \mathbf{1.17\text{ mA}}$$

$I_D = I_S$ = **1.17 mA**

(c) $V_D = V_{DD} - I_D R_D$ = 16 V − (167 μA)(4.7 kΩ) = 16 V − 0.783 V = 15.2 V

$V_{DS} - V_D - V_S$ = 15.2 V − 0.25 V = 14.97 V ≅ **15.0 V**

$V_{DG} - V_D - V_G$ = 15.2 V − 1.75 V = 13.47 V ≅ **13.5 V**

59. The circuit is redrawn in Figure 6-12.
The meter reading at point *A* should be:

$$V_A = \left(\frac{6\ \text{k}\Omega}{16\ \text{k}\Omega}\right)150\ \text{V} = 56.3\ \text{V}$$

The meter reading of 81.8 V is incorrect. The most likely failure is an open 12 kΩ resistor. This will cause the voltage at point *A* to be higher than it should be. To verify, let's calculate the voltage assuming that one of the 12 kΩ resistors is open.

$$V_A = \left(\frac{12\ \text{k}\Omega}{22\ \text{k}\Omega}\right)150\ \text{V} = 81.8\ \text{V}$$ This verifies an **open 12 kΩ**.

Now check V_B:

$$V_B = \left(\frac{2.2\ \text{k}\Omega}{7.8\ \text{k}\Omega}\right)150\ \text{V} = 42.3\ \text{V}$$

This meter reading is correct.

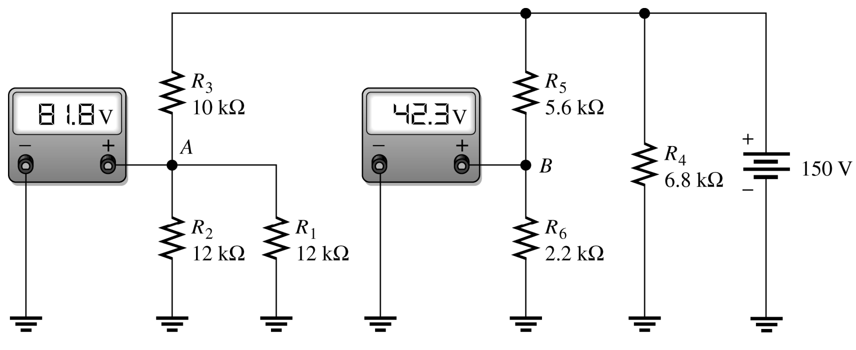


Figure 6-12

60. The circuit is redrawn in Figure 6-13.

$$R_{BG} = \frac{(10\ \text{k}\Omega + 47\ \text{k}\Omega)(100\ \text{k}\Omega)}{10\ \text{k}\Omega + 47\ \text{k}\Omega + 100\ \text{k}\Omega} = 36.3\ \text{k}\Omega$$

$R_{AG} = 33\ \text{k}\Omega + R_{BG} = 33\ \text{k}\Omega + 36.3\ \text{k}\Omega = 69.3\ \text{k}\Omega$

$R_\text{T} = R_{AG} = 27\ \text{k}\Omega = 69.3\ \text{k}\Omega + 27\ \text{k}\Omega = 96.3\ \text{k}\Omega$

$$V_{AG} = \left(\frac{R_{AG}}{R_\text{T}}\right)18\ \text{V} = \left(\frac{69.3\ \text{k}\Omega}{96.3\ \text{k}\Omega}\right)18\ \text{V} = 12.95\ \text{V}$$

$$V_{BG} = \left(\frac{R_{BG}}{R_\text{T}}\right)18\ \text{V} = \left(\frac{36.3\ \text{k}\Omega}{96.3\ \text{k}\Omega}\right)18\ \text{V} = 6.79\ \text{V}$$

$$V_{CG} = \left(\frac{47\ \text{k}\Omega}{57\ \text{k}\Omega}\right)V_{BG} = \left(\frac{47\ \text{k}\Omega}{57\ \text{k}\Omega}\right)6.79\ \text{V} = \mathbf{5.60\ V}$$ **correct**

$V_{AC} = V_{AG} - V_{CG} = 12.95\ \text{V} - 5.60\ \text{V} =$ **7.35 V** **correct**

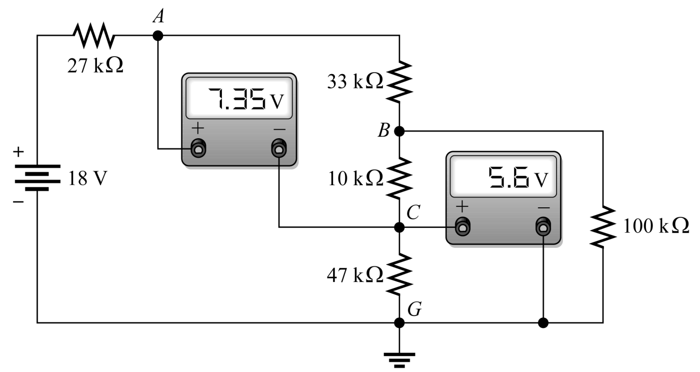


Figure 6-13

61. The 2.5 V reading indicated on one of the meters shows that the series-parallel branch containing the other meter is open. The 0 V reading on the other meter shows that there is no current in that branch. **Therefore, if only one resistor is open, it must be the 2.2 kΩ.**

62. The circuit is redrawn in Figure 6-14.
The resistance from point A to ground is
$R_A = 12\text{ k}\Omega \parallel 8.2\text{ k}\Omega = 4.87\text{ k}\Omega$

$$V_A = \left(\frac{4.87\text{ k}\Omega}{4.7\text{ k}\Omega + 4.87\text{ k}\Omega}\right)30\text{ V} = \left(\frac{4.87\text{ k}\Omega}{9.57\text{ k}\Omega}\right)30\text{ V} = 15.3\text{ V}$$

The meter reading of 15.3 V at point A is correct.

$$V_B = \left(\frac{3.3\text{ k}\Omega}{8.9\text{ k}\Omega}\right)30\text{ V} = 11.1\text{ V}$$

The meter reading of 30 V at point B is incorrect. Either the 5.6 kΩ resistor is shorted or the 3.3 kΩ resistor is open. Since resistors tend to fail open, **the 3.3 kΩ is most likely open.**

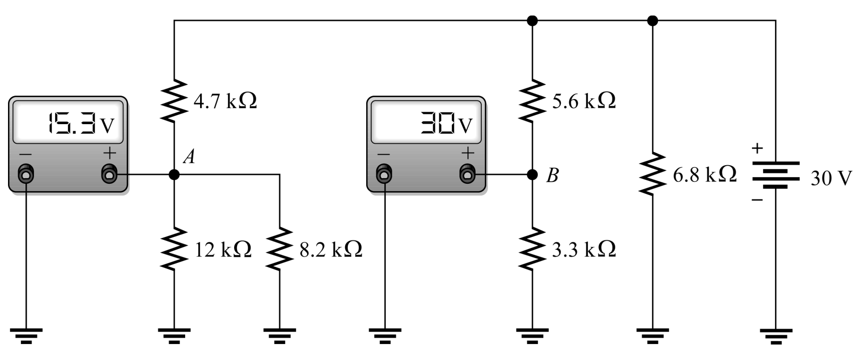


Figure 6-14

63. $V_A =$ **0 V**

$$V_B = \left(\frac{R_6}{R_5 + R_6}\right)30\text{ V} = \left(\frac{3.3\text{ k}\Omega}{8.9\text{ k}\Omega}\right)30\text{ V} = \mathbf{11.1\text{ V}}$$

Multisim Troubleshooting Problems

64. R_3 is open.

65. R_2 is shorted.

66. R_1 is open.

67. No fault

68. R_6 is open.

69. R_4 is shorted.

70. R_3 is open.

71. In fact, R_5 is shorted, but it must be removed from the bridge before that can be determined.

CHAPTER 7
MAGNETISM AND ELECTROMAGNETISM

BASIC PROBLEMS

SECTION 7-1 The Magnetic Field

1. Since $B = \dfrac{\phi}{A}$, when A increases, B (flux density) **decreases.**

2. $B = \dfrac{\phi}{A} = \dfrac{1500\ \mu\text{Wb}}{0.5\ \text{m}^2}$ = 3000 μWb/m^2 = **3000 μT**

3. $B = \dfrac{\phi}{A}$

   There are 100 centimeters per meter. (1 m/100 cm = 1 m^2/10,000 cm^2

   $A = 150\ \text{cm}^2\left(\dfrac{1\,\text{m}^2}{10{,}000\,\text{cm}^2}\right) = 0.015\ \text{m}^2$

   $\phi = BA = (2500 \times 10^{-6}\ \text{T})(0.015\ \text{m}^2) =$ **37.5 μWb**

4. 10^4 G = 1 T

   (0.6 G)(1 T/10^4 G) = **60 μT**

5. 1 T = 10^4 G

   (100,000 μT)(10^4 G/T) = **1000 G**

SECTION 7-2 Electromagnetism

6. The compass needle turns 180°.

7. $\mu_r = \dfrac{\mu}{\mu_0}$

   $\mu_0 = 4\pi \times 10^{-7}$ Wb/At·m

   $\mu_r = \dfrac{750\times10^{-6}\ \text{Wb/At·m}}{4\pi\times10^{-7}\ \text{Wb/At·m}} =$ **597**

8. $\mathscr{R} = \dfrac{l}{\mu A} = \dfrac{0.28\ \text{m}}{(150\times10^{-7}\ \text{Wb/At·m})(0.08\ \text{m}^2)}$ = **233 × 10^3 At/Wb**

9. $F_m = NI$ = (500 t)(3 A) = **1500 At**

SECTION 7-3 Electromagnetic Devices

10. When a solenoid is activated, its plunger is **retracted**.

11. (a) An **electromagnetic force** moves the plunger when the solenoid is activated.
    (b) A **spring force** returns the plunger to its at-rest position.

12. The relay connects +9 V to pin 2 turning *on* lamp 2 and turning *off* lamp 1.
13. The pointer in a d'Arsonval movement is deflected by the **electromagnetic force** when there is current through the coil.

SECTION 7-4 Magnetic Hysteresis

14. $F_m = 1500 \text{ At}$

$$H = \frac{F_m}{l} = \frac{1500 \text{ At}}{0.2 \text{ m}} = \mathbf{7500\ At/m}$$

15. The flux density can be changed by **changing the current**.

16. (a) $H = \frac{F_m}{l} = \frac{NI}{l} = \frac{500(0.25 \text{ A})}{0.3 \text{ m}} = \mathbf{417\ At/m}$

(b) $\phi = \frac{F_m}{R} = \frac{NI}{\left(\frac{l}{\mu A}\right)}$

$$\mu_r = \frac{\mu}{\mu_0}$$

$$\mu = \mu_r\mu_0 = (250)(4\pi \times 10^{-7}) = 3142 \times 10^{-7} \text{ Wb/At·m}$$

$$A = (2 \text{ cm})(2 \text{ cm}) = (0.02 \text{ m})(0.02 \text{ m}) = 0.0004 \text{ m}^2$$

$$\phi = \frac{(500 \text{ t})(0.25 \text{ A})}{\left(\frac{0.3 \text{ m}}{(3142\times10^{-7})(0.0004 \text{ m}^2)}\right)} = \frac{125 \text{ At}}{2.39\times10^6 \text{ At/Wb}} = \mathbf{52.3\ \mu Wb}$$

(c) $B = \frac{\phi}{A} = \frac{52.3\ \mu\text{Wb}}{0.0004 \text{ m}^2} = \mathbf{130{,}750\ \mu Wb/m^2}$

17. **Material A** has the most retentivity.

SECTION 7-5 Electromagnetic Induction

18. The **induced voltage doubles** when the rate of change of the magnetic flux doubles.
19. $I_{\text{induced}} = \frac{V_{\text{induced}}}{R} = \frac{100 \text{ mV}}{100\ \Omega} = \mathbf{1\ mA}$

20. T**he magnetic field is not changing**; therefore, there is no induced voltage.

21. $B = \frac{\phi}{A} = \frac{1.24 \times 10^{-3}\ \text{Wb}}{(0.085\ \text{m})^2} = 0.172\ \text{Wb/m}^2 = 0.172\ \text{T}$

$v = \frac{v_{ind}}{Bl\sin\theta} = \frac{44\ \text{mV}}{(0.172\ \text{T})(0.085\ \text{m})(\sin 90°)} = \mathbf{3.02\ m/s}$

22. (a) Positive (with respect to other end).

(b) The induced force will oppose the motion; it is downward.

SECTION 7-6 DC Generators

23. efficiency $= \frac{P_{\text{out}}}{P_{\text{in}}} = 0.80$

$P_{\text{in}} = \frac{P_{\text{out}}}{0.80} = \frac{45\ \text{W}}{0.80} = \mathbf{56.3\ W}$

24. $I_A = I_F + I_L = 1\ \text{A} + 12\ \text{A} = \mathbf{13\ A}$

25. (a) $P = IV = (12\ \text{A})(14\ \text{V}) = \mathbf{168\ W}$

(b) $P = IV = (1.0\ \text{A})(14\ \text{V}) = \mathbf{14\ W}$

SECTION 7-7 DC Motors

26. (a) $P = 0.015Ts = 0.105(3.0\ \text{N-m})(1200\ \text{rpm}) = \mathbf{378\ W}$

(b) $378\ \text{W}\left(\frac{1\ \text{hp}}{746\ \text{W}}\right) = \mathbf{0.51\ hp}$

27. $P_{\text{in}} = 62$ W; $P_{\text{out}} = 50$ W. efficiency $= \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{50\ \text{W}}{62\ \text{W}} = \mathbf{80.6\%}$

ADVANCED PROBLEMS

28. 60 rev/s $\times$ 2 peaks/rev = **120 peaks/s**

29. The output voltage has a 10 V dc peak with a 120 Hz ripple. See Figure 7-1.

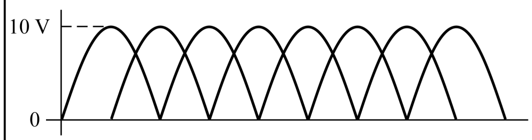


Figure 7-1

Multisim Troubleshooting Problems

30. Upper lamp is open.

31. The design is flawed. 12 V is too little voltage to operate two 12 V relays in series but 24 V is too much to operate a 12 V lamp. Install a separate 12 V power supply for the lamps and change the 12 V to 24 V for the relays.

CHAPTER 8
INTRODUCTION TO ALTERNATING CURRENT AND VOLTAGE

BASIC PROBLEMS

SECTION 8-1 The Sinusoidal Waveform

1. (a) $f = \dfrac{1}{T} = \dfrac{1}{1\,\text{s}} = \mathbf{1\ Hz}$

   (b) $f = \dfrac{1}{T} = \dfrac{1}{0.2\,\text{ms}} = \mathbf{5\ Hz}$

   (c) $f = \dfrac{1}{T} = \dfrac{1}{50\,\text{ms}} = \mathbf{20\ Hz}$

   (d) $f = \dfrac{1}{T} = \dfrac{1}{1\,\text{ms}} = \mathbf{1\ kHz}$

   (e) $f = \dfrac{1}{T} = \dfrac{1}{500\,\mu\text{s}} = \mathbf{2\ kHz}$

   (f) $f = \dfrac{1}{T} = \dfrac{1}{10\,\mu\text{s}} = \mathbf{100\ kHz}$

2. (a) $T = \dfrac{1}{f} = \dfrac{1}{1\,\text{Hz}} = \mathbf{1\ s}$

   (b) $T = \dfrac{1}{f} = \dfrac{1}{60\,\text{Hz}} = \mathbf{16.7\ ms}$

   (c)) $T = \dfrac{1}{f} = \dfrac{1}{500\,\text{Hz}} = \mathbf{2\ ms}$

   (d) $T = \dfrac{1}{f} = \dfrac{1}{1\,\text{kHz}} = \mathbf{1\ ms}$

   (e) $T = \dfrac{1}{f} = \dfrac{1}{200\,\text{kHz}} = \mathbf{5\ \mu s}$

   (f) $T = \dfrac{1}{f} = \dfrac{1}{5\,\text{MHz}} = \mathbf{200\ ns}$

3. $T = \dfrac{10\,\mu\text{s}}{5\,\text{cycles}} = \mathbf{2\ \mu s}$

4. $T = \frac{1}{f} = \frac{1}{50\text{ kHz}} = 20\ \mu\text{s} = 0.02\text{ ms}$

$\frac{10\text{ ms}}{0.02\text{ ms}}$ = **500 cycles in 10 ms**

5. $T = \frac{1}{f} = \frac{1}{10\text{ kHz}} = 100\ \mu\text{s}$

(100 μs/cycle)(100 cycles) = **10 ms**

SECTION 8-2 Voltage and Current Values of Sine Waves

6. (a) $V_{\text{rms}} = 0.707V_p = 0.707(12\text{ V}) = \mathbf{8.48\ V}$
   (b) $V_{pp} = 2V_p = 2(12\text{ V}) = \mathbf{24\ V}$
   (c) $V_{\text{AVG}} = \left(\frac{2}{\pi}\right)V_p = \left(\frac{2}{\pi}\right)12\text{ V} = \mathbf{7.64\ V}$

7. (a) $I_p = 1.414I_{\text{rms}} = 1.414(5\text{ mA}) = \mathbf{7.07\ mA}$
   (b) $I_{\text{AVG}} = 0.6371I_p = 0.637(7.07\text{ mA}) = \mathbf{4.5\ mA}$
   (c) $I_{pp} = 2I_p = 2(7.07\text{ mA}) = \mathbf{14.14\ mA}$

8. $V_p = \mathbf{25\ V}$
   $V_{pp} = 2V_p = \mathbf{50\ V}$
   $V_{\text{rms}} = 0.707V_p = \mathbf{17.7\ V}$
   $V_{\text{AVG}} = 0.637V_p = \mathbf{15.9\ V}$

9. (a) 17.7 V (b) 25 V (c) 0 V (d) −17.7 V

SECTION 8-3 Angular Measurement of a Sine Wave

10. (a) 17.5 V (b) 25 V (c) 0 V

11. $\theta = 45° - 30° =$ **15° waveform *A* leading**

12. With respect to 0°: Sine wave with peak at 75° is shifted **15° leading**. Sine wave with peak at 100° is shifted **10° lagging**.
    Phase difference: $\theta = 100° - 75° = \mathbf{25°}$

13. See Figure 8-1.

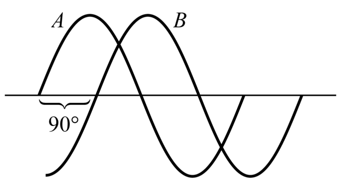


Figure 8-1

14. (a) $\frac{\pi \text{ rad}}{180°} \times 30° = \mathbf{0.524\ rad}$

(b) $\frac{\pi \text{ rad}}{180°} \times 45° = \mathbf{0.785\ rad}$

(c) $\frac{\pi \text{ rad}}{180°} \times 78° = \mathbf{1.36\ rad}$

(d) $\frac{\pi \text{ rad}}{180°} \times 135° = \mathbf{2.36\ rad}$

(e) $\frac{\pi \text{ rad}}{180°} \times 200° = \mathbf{3.49\ rad}$

(f) $\frac{\pi \text{ rad}}{180°} \times 300° = \mathbf{5.24\ rad}$

15. (a) $\frac{\pi}{8 \text{ rad}} \times 57.3°/\text{rad} = \mathbf{22.5°}$

(b) $\frac{\pi}{3 \text{ rad}} \times 57.3°/\text{rad} = \mathbf{60°}$

(c) $\frac{\pi}{2 \text{ rad}} \times 57.3°/\text{rad} = \mathbf{90°}$

(d) $\frac{3\pi}{5 \text{ rad}} \times 57.3°/\text{rad} = \mathbf{108°}$

(e) $\frac{6\pi}{5 \text{ rad}} \times 57.3°/\text{rad} = \mathbf{216°}$

(f) $\frac{1.8\pi}{\text{rad}} \times 57.3°/\text{rad} = \mathbf{324°}$

SECTION 8-4 The Sine Wave Formula

16. $V_p = 1.414(20\text{ V}) = 28.28\text{ V}$

(a) $v = V_p \sin\theta = (28.28\text{ V})\sin 15° = \mathbf{7.32\ V}$
(b) $v = (28.28\text{ V})\sin 33° = \mathbf{15.4\ V}$
(c) $v = (28.28\text{ V})\sin 50° = \mathbf{21.7\ V}$
(d) $v = (28.28\text{ V})\sin 110° = \mathbf{26.6\ V}$

(e) v = (28.28 V)sin 70° = **26.6 V**
(f) v = (28.28 V)sin 145° = **16.2 V**
(g) v = (28.28 V)sin 250° = **–26.6 V**
(h) v = (28.28 V)sin 325° = **–16.2 V**

17. (a) $i = I_p \sin\theta$ = (100 mA)sin 35° = **57.4 mA**
(b) i = (100 mA)sin 95° = **99.6 mA**
(c) i = (100 mA)sin 190° = **–17.4 mA**
(d) i = (100 mA)sin 215° = **–57.4 mA**
(e) i = (100 mA)sin 275° = **–99.6 mA**
(f) i = (100 mA)sin 360° = **0 mA**

18. $V_p = 1.414V_{\text{rms}} = 1.414(6.37\text{ V}) = 9\text{ V}$

(a) $\frac{\pi}{8} = 22.5°$
v = (9 V)sin 22.5° = **3.44 V**
(b) $\frac{\pi}{4} = 45°$
v = (9 V)sin 45° = **6.36 V**
(c) $\frac{\pi}{2} = 90°$
v = (9 V)sin 90° = **9 V**
(d) $\frac{3\pi}{4} = 135°$
v = (9 V)sin 135° = **6.36 V**
(e) $\pi = 180°$
v = (9 V)sin 180° = **0 V**
(f) $\frac{3\pi}{2} = 270°$
v = (9 V)sin 270° = **–9 V**
(g) $2\pi = 360°$
v = (9 V)sin 360° = **0 V**

19. v = (15 V)sin (30° + 30°) = **13.0 V**
v = (15 V)sin (30° + 45°) = **14.5 V**
v = (15 V)sin (30° + 90°) = **13.0 V**
v = (15 V)sin (30° + 180°) = **–7.5 V**
v = (15 V)sin (30° + 200°) = **–11.5 V**
v = (15 V)sin (30° + 300°) = **–7.5 V**

20. v = (15 V)sin (30° – 30°) = **0 V**
v = (15 V)sin (45° – 30°) = **3.88 V**
v = (15 V)sin (90° – 30°) = **13.0 V**
v = (15 V)sin (180° – 30°) = **7.5 V**
v = (15 V)sin (200° – 30°) = **2.60 V**
v = (15 V)sin (300° – 30°) = **–15 V**

SECTION 8-5 Analysis of AC Circuits

21. (a) $I_{\text{rms}} = 0.707\left(\frac{V_p}{R}\right) = 0.707\left(\frac{10\text{ V}}{1.0\text{ k}\Omega}\right)$ = **7.07 mA**

(b) I_{AVG} = **0 A** over a full cycle.

(c) $I_p = \frac{10\text{ V}}{1.0\text{ k}\Omega}$ = **10 mA**

(d) I_{pp} = 2(10 mA) = **20 mA**

(e) $i = I_p$ = **10 mA**

22. $V_{2(\text{rms})} = V_4 - V_3$ = 65 V − 30 V = 35 V
$V_{2(p)}$ = 1.414(35 V) = 49.5 V
$V_{2(\text{AVG})}$ = 0.637(49.5 V) = **31.5 V**
$V_{1(\text{rms})} = V_s - V_4$ = 120 V − 65 V = 55 V
$V_{1(p)}$ = 1.414(55 V) = 77.8 V
$V_{1(\text{AVG})}$ = 0.637(77.8 V) = **49.5 V**

23. $I_{pp} = \frac{16\text{ V}}{R_1} = \frac{16\text{ V}}{1.0\text{ k}\Omega}$ = 16 mA
$I_{\text{rms}} = 0.707\left(\frac{I_{pp}}{2}\right) = 0.707\left(\frac{16\text{ mA}}{2}\right)$ = 5.66 mA
$V_{R4} = I_{\text{rms}}R_4$ = (5.66 mA)(560 Ω) = 3.17 V rms
Applying Kirchhoff's voltage law:
$V_{R1} + V_{R2} + V_{R3} + V_{R4} = V_s$
0.707(8 V) + 5 V + V_{R3} + 3.17 V = 0.707(30 V)
V_{R3} = 21.21 V − 5.66 V − 5 V − 3.17 V = **7.38 V**

24. V_p = (1.414)(10.6 V) = 15 V
V_{max} = 24 V + V_p = **39 V**
V_{min} = 24 V − V_p = **9 V**

25. V_p = (1.414)(3 V) = 4.242 V
$V_{\text{DC}} = V_p$ = **4.24 V**

26. $V_{min} = V_{\text{DC}} - V_p$ = 5 V − 6 V = **−1 V**

SECTION 8-6 Alternators (AC Generators)

27. f = number of pole pairs × rev/s = 1 × 250 rev/s = **250 Hz**

28. f = number of pole pairs × rev/s
rev/s = $\frac{3600\text{ rev/min}}{60\text{ s/min}}$ = 60 rev/s
f = 2 pole pairs × 60 rev/s = **120 Hz**

29. $\text{rev/s} = \dfrac{f}{\text{pole pairs}} = \dfrac{400\text{ Hz}}{2} = \mathbf{200\ rps}$

30. $N = \dfrac{120f}{s} = \dfrac{120(400\text{ Hz})}{3000\text{ rpm}} = \mathbf{16\ poles}$

SECTION 8-7 AC Motors

31. A one-phase motor requires a starting winding or other means to produce torque for starting the motor, whereas a three-phase motor is self-starting.

32. The field is set up by current in the stator windings. As the current reaches a peak in one winding, the other windings have less current and hence less effect on the field. The result is a rotating field.

SECTION 8-8 Nonsinusoidal Waveforms

33. $t_r \cong 3.5\text{ ms} - 0.5\text{ ms} = \mathbf{3.0\ ms}$
$t_f \cong 16.0\text{ ms} - 13\text{ ms} = \mathbf{3.0\ ms}$
$t_W \cong 14.5\text{ ms} - 2.5\text{ ms} = \mathbf{12.0\ ms}$
Amplitude = **5 V**

34. (a) $\%\text{ duty cycle} = \left(\dfrac{t_W}{T}\right)100\% = \left(\dfrac{1\ \mu\text{s}}{4\ \mu\text{s}}\right)100\% = \mathbf{25\%}$

(b) $\%\text{ duty cycle} = \left(\dfrac{t_W}{T}\right)100\% = \left(\dfrac{20\text{ ms}}{30\text{ ms}}\right)100\% = \mathbf{66.7\%}$

35. (a) V_{AVG} = baseline + (duty cycle)(amplitude) = −1 V + (0.25)(2.5 V) = **−0.375 V**
(b) V_{AVG} = 1 V + (0.67)(3 V) = **3.01 V**

36. (a) $f = \dfrac{1}{4\ \mu\text{s}} = \mathbf{250\ kHz}$

(b) $f = \dfrac{1}{30\text{ ms}} = \mathbf{33.3\ Hz}$

37. (a) $f = \dfrac{1}{20\ \mu\text{s}} = \mathbf{50\ kHz}$

(b) $f = \dfrac{1}{100\ \mu\text{s}} = \mathbf{10\ Hz}$

38. $f = \dfrac{1}{T} = \dfrac{1}{40\,\mu\text{s}} = 25\text{ kHz}$

3rd harmonic = **75 kHz**
5th harmonic = **125 kHz**
7th harmonic = **175 kHz**
9th harmonic = **225 kHz**
11th harmonic = **275 kHz**
13th harmonic = **325 kHz**

39. fundamental frequency = **25 kHz**

SECTION 8-9 The Oscilloscope

40. Volts/div = 0.2 mV; Time/div = 50 ms
V_p = Volts/div × Number of divisions = 0.2 V/div × 3 divisions = **0.6 V**
T = Time/div × Number of divisions = 50 ms/div × 10 divisions = **500 ms**

41. $V_p = 0.6$ V
$V_{\text{rms}} = 0.707V_p = 0.707(0.6\text{ V}) =$ **0.424 V**
$T = 500$ ms
$f = \dfrac{1}{T} = \dfrac{1}{500\text{ ms}} = \mathbf{2\text{ Hz}}$

42. V_p = Volts/div × Number of divisions = 1 V/div 2.2 divisions = 2.2 V
$V_{\text{rms}} = 0.707V_p = 0.707(2.2\text{ V}) =$ **1.56 V**
T = Time/div × Number of divisions = 0.1 μs/div × 6.8 divisions = 0.68 μs
$f = \dfrac{1}{T} = \dfrac{1}{0.68\,\mu\text{s}} = \mathbf{1.47\text{ MHz}}$

43. Amplitude = Volts/div × Number of divisions = 0.5 V/div × 2.8 div = **1.4 V**
t_W = Time/div × Number of divisions = 0.1 s × 1.2 div = 0.12 s = **120 ms**
T = Time/div × Number of divisions = 0.1 s × 4 div = 0.4 s = 400 ms
% duty cycle = $\left(\dfrac{t_W}{T}\right)100\% = \left(\dfrac{120\text{ ms}}{400\text{ ms}}\right)100\% = (0.3)100\% = \mathbf{30\%}$

ADVANCED PROBLEMS

44. $t = \dfrac{1}{f} = \dfrac{1}{2.2\text{ kHz}} = 0.455\text{ ms}$
At $t = 0.12$ ms:
$\theta = \left(\dfrac{0.12\text{ ms}}{0.455\text{ ms}}\right)360° = 94.9°$
$v = \sqrt{2}\,(25\text{ V})\sin 94.9° = (35.36)\sin 94.9° = 35.2\text{ V}$

At $t = 0.2$ ms:

$$\theta = \left(\frac{0.2\text{ ms}}{0.455\text{ ms}}\right)360° = 158.2°$$

$$v = \sqrt{2}\,(25\text{ V})\sin 158.2° = (35.36)\sin 158.2° = 13.1\text{ V}$$

$$\Delta v = 35.2\text{ V} - 13.1\text{ V} = \mathbf{22.1\text{ V}}$$

45. $$I_{max} = \frac{V_{max}}{R_T} = \frac{200\text{ V} + 150\text{ V}}{100\ \Omega + 47\ \Omega} = \frac{350\text{ V}}{147\ \Omega} = \mathbf{2.38\text{ A}}$$

$$V_{AVG} = V_{DC} = \left(\frac{R_L}{R_T}\right)V_{DC} = \left(\frac{100\ \Omega}{147\ \Omega}\right)200\text{ V} = \mathbf{136\text{ V}}$$

See Figure 8-2.

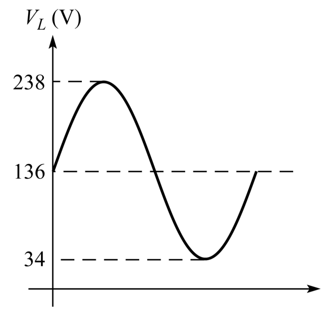


Figure 8-2

46. Average value = area under curve/period

$$V_{AVG} = \frac{(0\text{ V} + 1\text{ V} + 2\text{ V} + 3\text{ V} + 4\text{ V} + 5\text{ V} + 6\text{ V})(1\text{ ms})}{7\text{ ms}} = \frac{21\text{ V}\cdot\text{ms}}{7\text{ ms}} = \mathbf{3\text{ V}}$$

47. (a) **2.5 cycles** are displayed.
(b) $V_p = 2$ V/div × 2.8 div = 5.6 V, $V_{rms} = 0.707(5.6\text{ V}) = \mathbf{3.96\text{ V}}$
(c) $T = 4$ div × 20 μs/div = 80 μs, $f = \dfrac{1}{T} = \dfrac{1}{80\,\mu\text{s}} = \mathbf{12.5\text{ kHz}}$

48. See Figure 8-3.

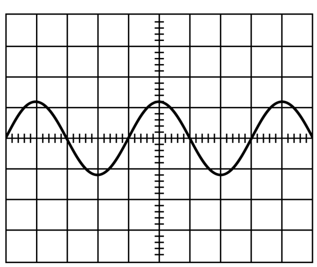


Figure 8-3

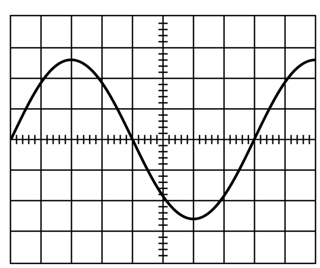


Figure 8-4

49. See Figure 8-4.

50. $V_{p(in)}$ = (1 div)(5 V/div) = **5 V**
T_{in} = (2 div)(0.1 ms/div) = 200 μs

$$f_{in} = \frac{1}{200\,\mu\text{s}} = \mathbf{5\ kHz}$$

R_{tot} = 560 Ω + (470 Ω ‖ (560 Ω + 470 Ω)) = 560 Ω + 323 Ω = 883 Ω

$$V_{p(out)} = \left(\frac{470\ \Omega}{470\ \Omega + 560\ \Omega}\right)\left(\frac{323\ \Omega}{883\ \Omega}\right)V_{p(in)} = \left(\frac{470\ \Omega}{1030\ \Omega}\right)\left(\frac{323\ \Omega}{883\ \Omega}\right)5\text{ V} = \mathbf{835\ mV}$$

$f_{out} = f_{in}$ = **5 kHz**
The scope display for channel 1 shows five cycles of the output waveform with the peak being 0.835 division high relative to the zero crossing of the sine wave.

51. $V_{p(out)}$ = (0.2 V/div)(3 div) = 0.6 V
T_{out} = (10 div)(50 ms/div) = 500 ms

$$f_{out} = \frac{1}{500\text{ ms}} = 2\text{ Hz}$$

$$V_{p(out)} = \left(\frac{1.0\text{ k}\Omega}{1.0\text{ k}\Omega + 2.2\text{ k}\Omega}\right)\left(\frac{1.0\text{ k}\Omega \parallel (2.2\text{ k}\Omega + 1.0\text{ k}\Omega)}{1.0\text{ k}\Omega + 1.0\text{ k}\Omega \parallel (2.2\text{ k}\Omega + 1.0\text{ k}\Omega)}\right)V_{p(in)}$$

$$= (0.313)\left(\frac{762\ \Omega}{1.762\text{ k}\Omega}\right)V_{p(in)} = 0.135V_{p(in)}$$

$$V_{p(in)} = \frac{V_{p(out)}}{0.135} = \frac{0.6\text{ V}}{0.135} = \mathbf{4.44\ V}$$

$f_{in} = f_{out}$ = **2 Hz**

Multisim Troubleshooting Problems

52. V_p = 35.3 V; T = 1 ms

53. R_3 is open.

54. R_1 is open.

55. Amplitude = 5 V; T = 1 ms

56. No fault

CHAPTER 9
CAPACITORS

BASIC PROBLEMS

SECTION 9-1 The Basic Capacitor

1. (a) $C = \dfrac{Q}{V} = \dfrac{50\,\mu\text{C}}{10\text{ V}} = \mathbf{5\ \mu F}$

   (b) $Q = CV = (0.001\ \mu\text{F})(1\text{ kV}) = \mathbf{1\ \mu C}$

   (c) $V = \dfrac{Q}{C} = \dfrac{2\text{ mC}}{200\,\mu\text{F}} = \mathbf{10\ V}$

2. (a) $(0.1\ \mu\text{F})(10^6\text{ pF}/\mu\text{F}) = \mathbf{100{,}000\ pF}$

   (b) $(0.0025\ \mu\text{F})(10^6\text{ pF}/\mu\text{F}) = \mathbf{2500\ pF}$

   (c) $(5\ \mu\text{F})(10^6\text{ pF}/\mu\text{F}) = \mathbf{5{,}000{,}000\ pF}$

3. (a) $(1000\text{ pF})(10^{-6}\ \mu\text{F/pF}) = \mathbf{0.001\ \mu F}$

   (b) $(3500\text{ pF})(10^{-6}\ \mu\text{F/pF}) = \mathbf{0.0035\ \mu F}$

   (c) $(250\text{ pF})(10^{-6}\ \mu\text{F/pF}) = \mathbf{0.00025\ \mu F}$

4. (a) $(0.0000001\text{ F})(10^6\ \mu\text{F/F}) = \mathbf{0.1\ \mu F}$

   (b) $(0.0022\text{ F})(10^6\ \mu\text{F/F}) = \mathbf{2200\ \mu F}$

   (c) $(0.0000000015\text{ F})(10^6\ \mu\text{F/F}) = \mathbf{0.0015\ \mu F}$

5. $W = \left(\dfrac{1}{2}\right)CV^2$

   $C = \dfrac{2W}{V^2} = \dfrac{2(10\text{ mJ})}{(100\text{ V})^2} = \mathbf{2\ \mu F}$

6. $C = \dfrac{A\varepsilon_r(8.85\times10^{-12}\text{ F/m})}{d} = \dfrac{(0.002\text{ m}^2)(5)(8.85\times10^{-12}\text{ F/m})}{63.5\ \mu\text{m}} = \mathbf{1.39\ nF}$

7. $C = \dfrac{A\varepsilon_r(8.85\times10^{-12}\text{ F/m})}{d}$

   $= \dfrac{(0.1\text{ m}^2)(1.006)(8.85\times10^{-12}\text{ F/m})}{0.01\text{ m}} = 8.85\times10^{-11}\text{ F} = \mathbf{88.5\ pF}$

8. $C = \dfrac{A\varepsilon_r(8.85\times10^{-12})}{d}$

$A = \dfrac{Cd}{\varepsilon_r\left(8.85\times10^{-12}\right)} = \dfrac{(1)\left(8\times10^{-5}\right)}{(2.5)\left(8.85\times10^{-12}\right)} = 3.6\times10^{6}\,\text{m}^2$

$l = \sqrt{A} = \sqrt{3.6\times10^{6}\,\text{m}^2} = 1.9\times10^{3}\text{ m}$ (almost 1.2 miles on a side)

The capacitor is too large to be practical and, of course, will not fit in the Astrodome.

9. $C = \dfrac{A\varepsilon_r(8.85\times10^{-12})}{d} = \dfrac{(0.09)(2.5)\left(8.85\times10^{-12}\right)}{8.0\times10^{-5}} = 24.9\text{ nF} = \mathbf{0.0249\ \mu F}$

10. $\Delta T = 50\ \text{C}°$
(−200 ppm/°C)50 C° = −10,000 ppm
$\Delta C = \left(\dfrac{1\times10^{3}}{1\times10^{6}}\right)(-10\times10^{3}\text{ ppm}) = -10\text{ pF}$
$C_{75°}$ = 1000 pF − 10 pF = **990 pF**

11. $\Delta T = 25\ \text{C}°$
(500 ppm/°C)25 C° = 12,500 ppm
$(1\times10^{6}$ pF/μF)(0.001 μF) = 1000 pF
$\Delta C = \left(\dfrac{1000}{1\times10^{6}}\right)12{,}500\text{ ppm} = \mathbf{12.5\ pF}$

SECTION 9-2 Types of Capacitors

12. The plate area is increased by increasing the number of layers of plate and dielectric materials.

13. Ceramic has a higher dielectric constant than mica.

14. See Figure 9-1.

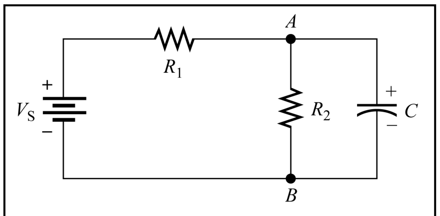


Figure 9-1

15. (a) 0.022 μF (b) 0.047 μF (c) 0.001 μF (d) 22 pF

16. Aluminum, tantalum; electrolytics are polarized, others are not.

17. (a) Encapsulation
(b) Dielectric (ceramic disk)
(c) Plate (metal disk)
(d) Conductive leads

SECTION 9-3 Series Capacitors

18. $C_T = \dfrac{1000\text{ pF}}{5} = \mathbf{200\ pF}$

19. (a) $C_T = \dfrac{1}{\dfrac{1}{1\,\mu\text{F}} + \dfrac{1}{2.2\,\mu\text{F}}} = \mathbf{0.69\ \mu F}$

(b) $C_T = \dfrac{1}{\dfrac{1}{100\text{ pF}} + \dfrac{1}{560\text{ pF}} + \dfrac{1}{390\text{ pF}}} = \mathbf{69.7\ pF}$

(c) $C_T = \dfrac{1}{\dfrac{1}{10\,\mu\text{F}} + \dfrac{1}{4.7\,\mu\text{F}} + \dfrac{1}{47\,\mu\text{F}} + \dfrac{1}{22\,\mu\text{F}}} = \mathbf{2.6\ \mu F}$

20. (a) $C_T = 0.69\ \mu\text{F}$

$V_{1\mu\text{F}} = \left(\dfrac{C_T}{1\,\mu\text{F}}\right)10\text{ V} = \left(\dfrac{0.69\,\mu\text{F}}{1\,\mu\text{F}}\right)10\text{ V} = \mathbf{6.9\ V}$

$V_{2.2\mu\text{F}} = \left(\dfrac{0.69\,\mu\text{F}}{2.2\,\mu\text{F}}\right)10\text{ V} = \mathbf{3.13\ V}$

(b) $C_T = 69.7\text{ pF}$

$V_{100\text{pF}} = \left(\dfrac{69.7\text{ pF}}{100\text{ pF}}\right)100\text{ V} = 69.7\text{ V}$

$V_{560\text{pF}} = \left(\dfrac{69.7\text{ pF}}{560\text{ pF}}\right)100\text{ V} = 12.4\text{ V}$

$V_{390\text{pF}} = \left(\dfrac{69.7\text{ pF}}{390\text{ pF}}\right)100\text{ V} = 17.9\text{ V}$

(c) $C_T = 2.6\ \mu\text{F}$

$V_{10\mu\text{F}} = \left(\dfrac{2.6\,\mu\text{F}}{10\,\mu\text{F}}\right)30\text{ V} = \mathbf{7.8\ V}$

$$V_{4.7\mu F} = \left(\frac{2.6\ \mu F}{4.7\ \mu F}\right)30\ V = \mathbf{16.8\ V}$$

$$V_{47\mu F} = \left(\frac{2.6\ \mu F}{47\ \mu F}\right)30\ V = \mathbf{1.68\ V}$$

$$V_{22\mu F} = \left(\frac{2.6\ \mu F}{22\ \mu F}\right)30\ V = \mathbf{3.59\ V}$$

21. $Q_T = Q_1 = Q_2 = Q_3 = Q_4 = 10\ \mu C$

$$V_1 = \frac{Q_1}{C_1} = \frac{10\ \mu C}{4.7\ \mu F} = \mathbf{2.13\ V}$$

$$V_2 = \frac{Q_2}{C_2} = \frac{10\ \mu C}{1\ \mu F} = \mathbf{10\ V}$$

$$V_3 = \frac{Q_3}{C_3} = \frac{10\ \mu C}{2.2\ \mu F} = \mathbf{4.55\ V}$$

$$V_4 = \frac{Q_4}{C_4} = \frac{10\ \mu C}{10\ \mu F} = \mathbf{1\ V}$$

SECTION 9-4 Parallel Capacitors

22. (a) $C_T = 47\ pF + 10\ pF + 1000\ pF = \mathbf{1057\ pF}$
    (b) $C_T = 0.1\ \mu F + 0.01\ \mu F + 0.001\ \mu F + 0.01\ \mu F = \mathbf{0.121\ \mu F}$

23. $C_T = C_1 + C_2 = 2.2\ \mu F + 3.3\ \mu F = \mathbf{5.5\ \mu F}$
    $Q_T = C_T V = (5\ 5\ \mu F)(5\ V) = \mathbf{27.5\ \mu C}$

24. Use four 0.47 μF capacitors and one 0.22 μF capacitor in parallel:
    $C_T = 4(0.47\ \mu F) + 0.22\ \mu F = \mathbf{2.1\ \mu F}$

SECTION 9-5 Capacitors in DC Circuits

25. (a) $\tau = RC = (100\ \Omega)(1\ \mu F) = \mathbf{100\ \mu s}$
    (b) $\tau = RC = (10\ M\Omega)(56\ pF) = \mathbf{560\ \mu s}$
    (c) $\tau = RC = (4.7\ k\Omega)(0.0047\ \mu F) = \mathbf{22.1\ \mu s}$
    (d) $\tau = RC = (1.5\ M\Omega)(0.01\ \mu F) = \mathbf{15\ ms}$

26. (a) $5\tau = 5RC = 5(47\ \Omega)(47\ \mu F) = \mathbf{11.04\ ms}$
    (b) $5\tau = 5RC = 5(3300\ \Omega)(0.015\ \mu F) = \mathbf{248\ \mu s}$
    (c) $5\tau = 5RC = 5(22\ k\Omega)(100\ pF) = \mathbf{11\ \mu s}$
    (d) $5\tau = 5RC = 5(4.7\ M\Omega)(10\ pF) = \mathbf{235\ \mu s}$

27. $\tau = RC = (100\ \Omega)(1\ \mu F) = 10\ \mu s$
    (a) $v_C = 15\ V(1 - e^{-t/RC}) = 15\ V(1 - e^{-10\mu s/10\mu s}) = 15\ V(1 - e^{-1}) = \mathbf{9.48\ V}$
    (b) $v_C = 15\ V(1 - e^{-2}) = \mathbf{13.0\ V}$
    (c) $v_C = 15\ V(1 - e^{-3}) = \mathbf{14.3\ V}$
    (d) $v_C = 15\ V(1 - e^{-4}) = \mathbf{14.7\ V}$
    (e) $v_C = 15\ V(1 - e^{-5}) = \mathbf{14.9\ V}$

28. $\tau = RC = (1.0\ k\Omega)(1.5\ \mu F) = 1.5\ ms$
    (a) $v_C = V_i e^{-t/RC} = 25e^{-1.5ms/1.5ms} = 25e^{-1} = \mathbf{9.2\ V}$
    (b) $v_C = V_i e^{-t/RC} = 25e^{-4.5ms/1.5ms} = 25e^{-3} = \mathbf{1.24\ V}$
    (c) $v_C = V_i e^{-t/RC} = 25e^{-6ms/1.5ms} = 25e^{-4} = \mathbf{458\ mV}$
    (d) $v_C = V_i e^{-t/RC} = 25e^{-7.5ms/1.5ms} = 25e^{-5} = \mathbf{168\ mV}$

29. (a) $v_C = 15\ V(1 - e^{-t/RC}) = 15\ V(1 - e^{-2\mu s/10\mu s}) = 15\ V(1 - e^{-0.2}) = \mathbf{2.72\ V}$
    (b) $v_C = 15\ V(1 - e^{-5\mu s/10\mu s}) = 15\ V(1 - e^{-0.5}) = \mathbf{5.90\ V}$
    (c) $v_C = 15\ V(1 - e^{-15\mu s/10\mu s}) = 15\ V(1 - e^{-1.5}) = \mathbf{11.7\ V}$

30. (a) $v_C = V_i e^{-t/RC} = 25e^{-0.5ms/1.5ms} = 25e^{-0.33} = \mathbf{18.0\ V}$
    (b) $v_C = V_i e^{-t/RC} = 25e^{-1ms/1.5ms} = 25e^{-0.67} = \mathbf{12.8\ V}$
    (c) $v_C = V_i e^{-t/RC} = 25e^{-2ms/1.5ms} = 25e^{-1.33} = \mathbf{6.61\ V}$

SECTION 9-6 Capacitors in AC Circuits

31. (a) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10\text{ Hz})(0.047\ \mu F)} = \mathbf{339\ k\Omega}$
    (b) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(250\text{ Hz})(0.047\ \mu F)} = \mathbf{13.5\ k\Omega}$
    (c) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(5\text{ kHz})(0.047\ \mu F)} = \mathbf{677\ \Omega}$
    (d) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(100\text{ kHz})(0.047\ \mu F)} = \mathbf{33.9\ \Omega}$

32. (a) $X_{CT} = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\,\text{kHz})(0.047\,\mu\text{F})}$ **= 3.39 kΩ**

(b) $C_T = 10\,\mu\text{F} + 15\,\mu\text{F} = 25\,\mu\text{F}$

$X_{CT} = \dfrac{1}{2\pi(1\,\text{Hz})(25\,\mu\text{F})}$ **= 6.37 kΩ**

(c) $C_T = \dfrac{1}{\dfrac{1}{1\,\mu\text{F}} + \dfrac{1}{1\,\mu\text{F}}} = 0.5\,\mu\text{F}$

$X_{CT} = \dfrac{1}{2\pi(60\,\text{Hz})(0.5\,\mu\text{F})}$ **= 5.31 kΩ**

33. $X_{C1} = \dfrac{1}{2\pi fC_1} = \dfrac{1}{2\pi(2\text{ kHz})(56\text{ nF})}$ **= 1.42 kΩ**

$X_{C2} = \dfrac{1}{2\pi fC_2} = \dfrac{1}{2\pi(2\text{ kHz})(82\text{ nF})}$ **= 970 Ω**

$X_{CT} = X_{C1} + X_{C2} = 1.42\text{ k}\Omega + 0.97\text{ k}\Omega$ **= 2.39 kΩ**

$C_T = \dfrac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2}} = \dfrac{1}{\dfrac{1}{56\text{ nF}} + \dfrac{1}{82\text{ nF}}} = 33.3\text{ nF}$

$V_{C1} = \left(\dfrac{C_T}{C_1}\right)V_S = \left(\dfrac{33.3\text{ nF}}{56\text{ nF}}\right)10\text{ V}$ **= 5.94 V**

$V_{C2} = \left(\dfrac{C_T}{C_2}\right)V_S = \left(\dfrac{33.3\text{ nF}}{82\text{ nF}}\right)10\text{ V}$ **= 4.06 V**

34. (a) For $X_{CT} = 100\ \Omega$:

$f = \dfrac{1}{2\pi X_{CT}C} = \dfrac{1}{2\pi(100\,\Omega)(0.047\,\mu\text{F})}$ **= 33.86 kHz**

For $X_{CT} = 1\text{ k}\Omega$:

$f = \dfrac{1}{2\pi X_{CT}C} = \dfrac{1}{2\pi(1\,\text{k}\Omega)(0.047\,\mu\text{F})}$ **= 3.386 kHz**

(b) For $X_{CT} = 100\ \Omega$:

$f = \dfrac{1}{2\pi X_{CT}C} = \dfrac{1}{2\pi(100\,\Omega)(25\,\mu\text{F})}$ **= 63.7 Hz**

For $X_{CT} = 1\text{ k}\Omega$:

$f = \dfrac{1}{2\pi X_{CT}C} = \dfrac{1}{2\pi(1\,\text{k}\Omega)(25\,\mu\text{F})}$ **= 6.37 kHz**

(c) For $X_{CT} = 100\ \Omega$:

$$f = \frac{1}{2\pi X_{CT} C} = \frac{1}{2\pi(100\ \Omega)(0.5\ \mu\text{F})} = \mathbf{3.18\ kHz}$$

For $X_{CT} = 1\ \text{k}\Omega$:

$$f = \frac{1}{2\pi X_{CT} C} = \frac{1}{2\pi(1\ \text{k}\Omega)(0.5\ \mu\text{F})} = \mathbf{318\ Hz}$$

35. $$X_C = \frac{V_{\text{rms}}}{I_{\text{rms}}} = \frac{20\ \text{V}}{100\ \text{mA}} = 0.2\ \text{k}\Omega = \mathbf{200\ \Omega}$$

36. $V_{\text{rms}} = I_{\text{rms}} X_C$

$$X_C = \frac{1}{2\pi(10\ \text{kHz})(0.0047\ \mu\text{F})} = 3.39\ \text{k}\Omega$$

$V_{\text{rms}} = (1\ \text{mA})(3.39\ \text{k}\Omega) = \mathbf{3.39\ V}$

37. $$X_C = \frac{1}{2\pi f C} = 3.39\ \text{k}\Omega$$

$P_{true} = \mathbf{0\ W}$

$P_r = I_{\text{rms}}^2 X_C = (1\ \text{mA})^2(3.39\ \text{k}\Omega) = \mathbf{3.39\ mVAR}$

SECTION 9-7 Capacitor Applications

38. The ripple voltage is reduced when the capacitance is increased.

39. $X_{C(bypass)}$ ideally should be **0 Ω** to provide a short to ground for ac.

ADVANCED PROBLEMS

40. $$V_X = \left(\frac{C_{\text{T}}}{C_X}\right)V_{\text{S}}$$

$$C_{\text{T}} = \frac{C_X V_X}{V_{\text{S}}} = \frac{(1\ \mu\text{F})(8\ \text{V})}{12\ \text{V}} = 0.667\ \mu\text{F}$$

$$C_X = \left(\frac{C_{\text{T}}}{V_X}\right)V_{\text{S}} = \left(\frac{0.667\ \mu\text{F}}{4\ \text{V}}\right)12\ \text{V} = \mathbf{2\ \mu F}$$

41. $v = v_i e^{-t/RC}$

$$e^{-t/RC} = \frac{v}{V_i}$$

$$\ln(e^{-t/RC}) = \ln\left(\frac{V}{V_i}\right)$$

$$-\left(\frac{t}{RC}\right) = \ln\left(\frac{v}{V_i}\right)$$

$$t = -RC\ \ln\left(\frac{V}{V_i}\right)$$

$$t = -(1.0\ \text{k}\Omega)(1.5\ \mu\text{F})\ln\left(\frac{3\ \text{V}}{25\ \text{V}}\right) = \mathbf{3.18\ ms}$$

42. $v = V_F(1 - e^{-t/RC})$

$v = V_F - V_F e^{-t/RC}$

$V_F e^{-t/RC} = V_F - v$

$$e^{-t/RC} = \frac{V_F - v}{V_F} = 1 - \frac{v}{V_F}$$

$$\ln(e^{-t/RC}) = \ln\left(1 - \frac{v}{V_F}\right)$$

$$-\left(\frac{t}{RC}\right) = \ln\left(1 - \frac{v}{V_F}\right)$$

$$t = -RC\ \ln\left(1 - \frac{v}{V_F}\right)$$

$$t = -(10\ \text{k}\Omega)(0.001\ \mu\text{F})\ln\left(1 - \frac{8\ \text{V}}{15\ \text{V}}\right) = \mathbf{7.62\ \mu s}$$

43. Looking from the capacitor, the Thevenin resistance is

$R_{TH} = R_4 + R_1 \parallel R_2 \parallel R_3 = 1471\ \Omega$

$\tau = R_{TH}C = (1471\ \Omega)(0.0022\ \mu\text{F}) = \mathbf{3.24\ \mu s}$

44. $t = RC\ \ln\left(1 - \frac{v_C}{V_F}\right)$

$$R = \frac{-t}{C\ln\left(1 - \frac{v_C}{V_F}\right)} = \frac{-10\ \mu\text{s}}{(1000\ \text{pF})\ln\left(1 - \frac{7.2}{10}\right)} = \mathbf{7.86\ k\Omega}$$

45. $\tau_1 = (R_1 + R_2)C = (55 \text{ k}\Omega)(1 \ \mu\text{F}) = 55 \text{ ms}$
$\tau_2 = (R_2 + R_3)C = (43 \text{ k}\Omega)(1 \ \mu\text{F})\ 43 \text{ ms}$
$5\tau_2 = 5(43 \text{ ms}) = 215 \text{ ms}$
$v_C = 20(1 - e^{-10\text{ms}/.55\text{ms}}) = 3.32 \text{ V}$
See Figure 9-2(a).
$v_C = 3.32e^{-5\text{ms}/43\text{ms}} = 2.96 \text{ V}$
See Figure 9-2(b).

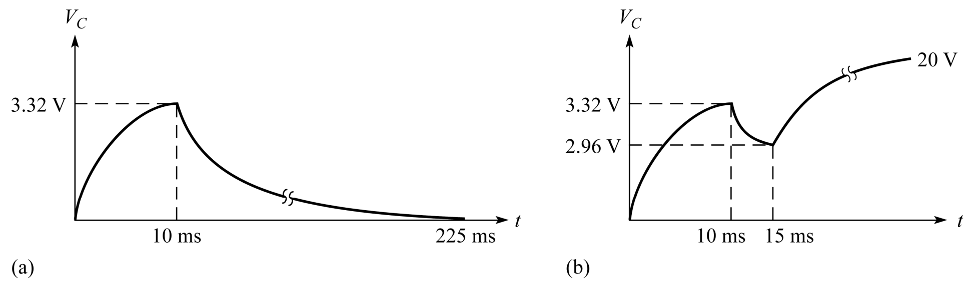


Figure 9-2

46. $C_{5\text{-}6} = 0.006 \ \mu\text{F}$, $C_{4\text{-}5\text{-}6} = 0.053 \ \mu\text{F}$, $C_{3\text{-}4\text{-}5\text{-}6} = 0.01169 \ \mu\text{F}$, $C_{2\text{-}3\text{-}4\text{-}5\text{-}6} = 0.03369 \ \mu\text{F}$
$C_\text{T} = 0.00771 \ \mu\text{F}$, $X_{C(tot)} = 68.8 \text{ k}\Omega$

$$I_{C1} = \frac{V_s}{X_{C(tot)}} = \frac{10\text{ V}}{68.8\text{ k}\Omega} = \mathbf{145\ \mu A}$$

$$V_{C1} = \left(\frac{C_\text{T}}{C_1}\right)V_s = \left(\frac{0.00771\,\mu\text{F}}{0.01\,\mu\text{F}}\right)10\text{ V} = \mathbf{7.71\ V}$$

$V_{C2} = V_s - V_{C1} = 10 \text{ V} - 7.71 \text{ V} = \mathbf{2.29\ V}$
$X_{C2} = 24.1 \text{ k}\Omega$

$$I_{C2} = \frac{V_{C2}}{X_{C2}} = \frac{2.29\text{ V}}{24.1\text{ k}\Omega} = \mathbf{95.0\ \mu A}$$

$$V_{C3} = \left(\frac{C_{3-4-5-6}}{C_3}\right)V_{C2} = \left(\frac{0.01183\,\mu\text{F}}{0.015\,\mu\text{F}}\right)2.29\text{ V} = \mathbf{1.78\ V}$$

$X_{C3} = 35.4 \text{ k}\Omega$

$$I_{C3} = \frac{V_{C3}}{X_{C3}} = \frac{1.78\text{ V}}{35.4\text{ k}\Omega} = \mathbf{50.4\ \mu A}$$

$V_{C4} = V_{C2} - V_{C3} = 2.29 \text{ V} - 1.78 \text{ V} = \mathbf{505\ mV}$
$X_{C4} = 11.3 \text{ k}\Omega$

$$I_{C4} = \frac{V_{C4}}{X_{C4}} = \frac{505\text{ mV}}{11.3\text{ k}\Omega} = \mathbf{44.7\ \mu A}$$

$$V_{C5} = \left(\frac{C_{5-6}}{C_5}\right)V_{C4} = \left(\frac{0.006\,\mu\text{F}}{0.01\,\mu\text{F}}\right)505\text{ mV} = \mathbf{303\ mV}$$

$X_{C5} = 53.1 \text{ k}\Omega$

$$I_{C5} = I_{C6} = \frac{V_{C5}}{X_{C5}} = \frac{303\text{ mV}}{53.1\text{ k}\Omega} = \mathbf{5.71\ \mu A}$$

$V_{C6} = V_{C4} - V_{C5} = 505 \text{ mV} - 303 \text{ mV} = \mathbf{202\ mV}$

47. $V_{C2} = V_{C3} = (4\text{ mA})X_{C3} = (4\text{ mA})(750\ \Omega) = 3\text{ V}$

$$f = \frac{1}{2\pi X_{C3}C_3} = \frac{1}{2\pi(750\ \Omega)(0.0015\ \mu\text{F})} = 141.5\text{ kHz}$$

$$X_{C2} = \frac{1}{2\pi f C_2} = \frac{1}{2\pi(141.5\text{ kHz})(0.0022\ \mu\text{F})} = 511\ \Omega$$

$$I_{C2} = \frac{V_{C2}}{X_{C2}} = \frac{3\text{ V}}{511\ \Omega} = 5.87\text{ mA}$$

$I_{C1} = I_{C(tot)} = I_{C2} + I_{C3} = 5.87\text{ mA} + 4\text{ mA} = 9.87\text{ mA}$

$V_{C1} = 5\text{ V} - 3\text{ V} = 2\text{ V}$

$$X_{C1} = \frac{V_{C1}}{I_{C1}} = \frac{2\text{ V}}{9.87\text{ mA}} = 203\ \Omega$$

$$C_1 = \frac{1}{2\pi f X_{C1}} = \frac{1}{2\pi(141.5\text{ kHz})(203\ \Omega)} = \mathbf{0.0056\ \mu F}$$

48. *Position 1*:

$$V_5 - \left(\frac{C_{T(1,5)}}{C_5}\right)12\text{ V}$$

$$\frac{1}{C_{T(1,5)}} = \frac{1}{C_1} + \frac{1}{C_5} = \frac{1}{0.01\ \mu\text{F}} + \frac{1}{0.068\ \mu\text{F}} \qquad C_T = 0.0087\ \mu\text{F}$$

$$V_5 = \left(\frac{0.0087\ \mu\text{F}}{0.068\ \mu\text{F}}\right)12\text{ V} = 1.54\text{ V}$$

$$\frac{1}{C_{T(3,6)}} = \frac{1}{C_3} + \frac{1}{C_6} = \frac{1}{0.047\ \mu\text{F}} + \frac{1}{0.056\ \mu\text{F}} \qquad C_{T(3,6)} = 0.0256\ \mu\text{F}$$

$$V_6 = \left(\frac{C_{T(3,6)}}{C_6}\right)12\text{ V} = \left(\frac{0.0256\ \mu\text{F}}{0.056\ \mu\text{F}}\right)12\text{ V} = 5.48\text{ V}$$

Position 2:

$$\frac{1}{C_{T(2,5)}} = \frac{1}{C_2} + \frac{1}{C_5} = \frac{1}{0.022\ \mu\text{F}} + \frac{1}{0.068\ \mu\text{F}} \qquad C_{T(2,5)} = 0.0166\ \mu\text{F}$$

$$V_5 = \left(\frac{C_{T(2,5)}}{C_5}\right)12\text{ V} = \left(\frac{0.0166\ \mu\text{F}}{0.068\ \mu\text{F}}\right)12\text{ V} = 2.93\text{ V}$$

$$\frac{1}{C_{T(4,6)}} = \frac{1}{C_4} + \frac{1}{C_6} = \frac{1}{0.015\ \mu\text{F}} + \frac{1}{0.056\ \mu\text{F}} \qquad C_{T(4,6)} = 0.0118\ \mu\text{F}$$

$$V_6 = \left(\frac{C_{T(4,6)}}{C_6}\right)12\text{ V} = \left(\frac{0.0118\ \mu\text{F}}{0.056\ \mu\text{F}}\right)12\text{ V} = 2.54\text{ V}$$

$\Delta V_5 = 2.93\text{ V} - 1.54\text{ V} =$ **1.39 V increase**, $\qquad \Delta V_6 = 5.48\text{ V} - 2.54\text{ V} =$ **2.94 V decrease**

49. $$\frac{1}{C_{tot(3,5,6)}} = \frac{1}{C_3} + \frac{1}{C_5} + \frac{1}{C_6} = \frac{1}{0.015\,\mu\text{F}} + \frac{1}{0.01\,\mu\text{F}} + \frac{1}{0.015\,\mu\text{F}} \qquad C_{tot(3,5,6)} = 0.0043\ \mu\text{F}$$

$C_{tot(2,3,5,6)} = 0.022\ \mu\text{F} + 0.0043\ \mu\text{F} = 0.0263\ \mu\text{F}$

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_{tot(2,3,5,6)}} = \frac{1}{0.01\,\mu\text{F}} + \frac{1}{0.0263\,\mu\text{F}} \qquad C_{tot} = 0.00725\ \mu\text{F}$$

$$V_{C1} = \left(\frac{C_{tot}}{C_1}\right)10\text{ V} = \left(\frac{0.00725\,\mu\text{F}}{0.01\,\mu\text{F}}\right)10\text{ V} = \mathbf{7.25\ V}$$

$$V_{C2} = \left(\frac{C_{tot}}{C_{tot(2,3,5,6)}}\right)10\text{ V} = \left(\frac{0.00725\,\mu\text{F}}{0.0263\,\mu\text{F}}\right)10\text{ V} = \mathbf{2.76\ V}$$

$$V_{C3} = \left(\frac{C_{tot(3,5,6)}}{C_3}\right)V_{C2} = \left(\frac{0.0043\,\mu\text{F}}{0.015\,\mu\text{F}}\right)2.76\text{ V} = \mathbf{0.79\ V}$$

$$V_{C5} = \left(\frac{C_{tot(3,5,6)}}{C_5}\right)V_{C2} = \left(\frac{0.0043\,\mu\text{F}}{0.01\,\mu\text{F}}\right)2.76\text{ V} = \mathbf{1.19\ V}$$

$$V_{C6} = \left(\frac{C_{tot(3,5,6)}}{C_6}\right)V_{C2} = \left(\frac{0.0043\,\mu\text{F}}{0.015\,\mu\text{F}}\right)2.76\text{ V} = \mathbf{0.79\ V}$$

$V_{C4} = V_{C5} + V_{C6} = 1.19\text{ V} + 0.79\text{ V} = \mathbf{1.98\ V}$

Multisim Troubleshooting Problems

50. C_2 is leaky.

51. C_2 is open.

52. C_1 is shorted.

53. No fault

54. C_1 is shorted.

CHAPTER 10
RC CIRCUITS

BASIC PROBLEMS

SECTION 10-1 Sinusoidal Response of *RC* Circuits

1. Both voltages are also sine waves with the same **8 kHz** frequency as the source voltage.

2. The current is sinusoidal.

SECTION 10-2 Impedance and Phase Angle of Series *RC* Circuits

3. (a) $Z = \sqrt{R^2 + X_C^2} = \sqrt{(270\ \Omega)^2 + (100\ \Omega)^2}$ = **288 Ω**

   (b) $Z = \sqrt{R^2 + X_C^2} = \sqrt{(680\ \Omega)^2 + (1000\ \Omega)^2}$ = **1209 Ω**

4. (a) $R_{tot} = 100\text{ k}\Omega + 47\text{ k}\Omega = 147\text{ k}\Omega$

   $C_{tot} = \dfrac{1}{\dfrac{1}{0.01\,\mu\text{F}} + \dfrac{1}{0.022\,\mu\text{F}}} = 0.00688\ \mu\text{F}$

   $X_{C(tot)} = \dfrac{1}{2\pi f C_{tot}} = \dfrac{1}{2\pi(100\text{ Hz})(0.00688\,\mu\text{F})} = 231\text{ k}\Omega$

   $Z = \sqrt{R_{tot}^2 + X_{C(tot)}^2} = \sqrt{(147\text{ k}\Omega)^2 + (231\text{ k}\Omega)^2}$ = **274 kΩ**

   $\theta = \tan^{-1}\left(\dfrac{X_{C(tot)}}{R_{tot}}\right) = \tan^{-1}\left(\dfrac{231\text{ k}\Omega}{147\text{ k}\Omega}\right)$ = **57.6°** (*I* leads *V*)

   (b) $C_{tot} = 560\text{ pF} + 560\text{ pF} = 1120\text{ pF}$

   $X_{C(tot)} = \dfrac{1}{2\pi f C_{tot}} = \dfrac{1}{2\pi(20\text{ kHz})(1120\text{ pF})} = 7.11\text{ k}\Omega$

   $Z = \sqrt{R_{tot}^2 + X_{C(tot)}^2} = \sqrt{(10\text{ k}\Omega)^2 + (7.11\text{ k}\Omega)^2}$ = **12.3 kΩ**

   $\theta = \tan^{-1}\left(\dfrac{X_{C(tot)}}{R}\right) = \tan^{-1}\left(\dfrac{7.11\text{ k}\Omega}{10\text{ k}\Omega}\right)$ = **35.4°** (*I* leads *V*)

5. (a) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(100\text{ Hz})(0.0022\ \mu\text{F})} = 723\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (723\text{ k}\Omega)^2} = \mathbf{726\ k\Omega}$

(b) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(500\text{ Hz})(0.0022\ \mu\text{F})} = 145\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (145\text{ k}\Omega)^2} = \mathbf{155\ k\Omega}$

(c) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1.0\text{ kHz})(0.0022\ \mu\text{F})} = 72.3\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (72.3\text{ k}\Omega)^2} = \mathbf{91.5\ k\Omega}$

(d) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(2.5\text{ kHz})(0.0022\ \mu\text{F})} = 28.9\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (31.8\text{ k}\Omega)^2} = \mathbf{63.0\ k\Omega}$

6. (a) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(100\text{ Hz})(0.0047\ \mu\text{F})} = 339\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (339\text{ k}\Omega)^2} = \mathbf{343\ k\Omega}$

(b) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(500\text{ Hz})(0.0047\ \mu\text{F})} = 67.7\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (67.7\text{ k}\Omega)^2} = \mathbf{87.9\ k\Omega}$

(c) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\text{ kHz})(0.0047\ \mu\text{F})} = 33.9\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (33.9\text{ k}\Omega)^2} = \mathbf{65.4\ k\Omega}$

(d) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(2.5\text{ kHz})(0.0047\ \mu\text{F})} = 13.5\text{ k}\Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\text{ k}\Omega)^2 + (13.5\text{ k}\Omega)^2} = \mathbf{57.6\ k\Omega}$

SECTION 10-3 Analysis of Series *RC* Circuits

7. (a) $I = \dfrac{V_s}{Z} = \dfrac{10\text{ V}}{288\ \Omega} = \mathbf{34.7\ mA}$

(b) $I = \dfrac{V_s}{Z} = \dfrac{5\text{ V}}{1209\ \Omega} = \mathbf{4.14\ mA}$

8. (a) $I = \frac{V_s}{Z} = \frac{50\text{ V}}{274\text{ k}\Omega} =$ **182 μA**

(b) $I = \frac{V_s}{Z} = \frac{8\text{ V}}{12.3\text{ k}\Omega} =$ **652 μA**

9. See Figure 10-1.

$$C_{tot} = \frac{1}{\frac{1}{0.1\,\mu\text{F}} + \frac{1}{0.22\,\mu\text{F}}} = 0.0688\ \mu\text{F}$$

$$X_C = \frac{1}{2\pi(15\text{ kHz})(0.0688\,\mu\text{F})} = 154\ \Omega$$

$$Z = \sqrt{R_{tot}^2 + X_C^2} = \sqrt{(50\ \Omega)^2 + (154\ \Omega)^2} = 162\ \Omega$$

$$I_{tot} = \frac{V_s}{Z} = \frac{2\text{ V}}{162\ \Omega} = \mathbf{12.3\ mA}$$

$$X_{C(0.1\mu\text{F})} = \frac{1}{2\pi(15\text{ kHz})(0.1\,\mu\text{F})} = 106\ \Omega$$

$$X_{C(0.22\,\mu\text{F})} = \frac{1}{2\pi(15\text{ kHz})(0.22\,\mu\text{F})} = 48.2\ \Omega$$

$V_{C1} = I_{tot}X_{C(0.1\mu\text{F})} = (12.3\text{ mA})(106\ \Omega) =$ **1.31 V**
$V_{C2} = I_{tot}X_{C(0.22\mu\text{F})} = (12.3\text{ mA})(48.2\ \Omega) =$ **0.595 V**
$V_R = I_{tot}R_{tot} = (12.3\text{ mA})(50\ \Omega) =$ **0.616 V**

$$\theta = \tan^{-1}\left(\frac{X_C}{R_{tot}}\right) = \tan^{-1}\left(\frac{154\ \Omega}{50\ \Omega}\right) = \mathbf{72.0°}\quad (I_{tot}\text{ leads }V_s)$$

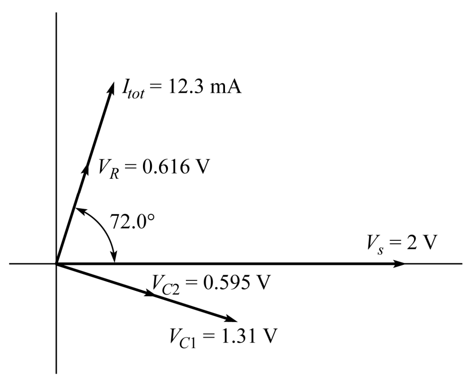


Figure 10-1

10. (a) $X_C = \dfrac{1}{2\pi(20\text{ Hz})(100\,\mu\text{F})} = 79.6\ \Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(56\ \Omega)^2 + (79.6\ \Omega)^2} = \mathbf{97.3\ \Omega}$

(b) $I = \dfrac{10\text{ V}}{97.3\ \Omega} = \mathbf{103\ mA}$

(c) $V_R = \left(\dfrac{R}{Z}\right)V_s = \left(\dfrac{56\ \Omega}{97.3\ \Omega}\right)10\text{ V} = \mathbf{5.76\ V}$

(d) $V_C = \left(\dfrac{X_C}{Z}\right)V_s = \left(\dfrac{79.6\ \Omega}{97.3\ \Omega}\right)10\text{ V} = \mathbf{8.18\ V}$

11. $Z = \dfrac{V_s}{I} = \dfrac{10\text{ V}}{10\text{ mA}} = 1\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi(10\text{ kHz})(0.027\,\mu\text{F})} = 589\ \Omega$

$\sqrt{R^2 + X_C^2} = 1\text{ k}\Omega$

$R^2 + (589\ \Omega)^2 = (1000\ \Omega)^2$

$R = \sqrt{(1000\ \Omega)^2 - (589\ \Omega)^2} = \mathbf{808\ \Omega}$

$\theta = -\tan^{-1}\left(\dfrac{589\ \Omega}{808\ \Omega}\right) = \mathbf{-36.1°}$

12. (a) $X_C = \dfrac{1}{2\pi(1\text{ Hz})(0.039\ \mu\text{F})} = 4.08\text{ M}\Omega$

$\phi = 90° - \tan^{-1}\left(\dfrac{X_C}{R}\right) = 90° - \tan^{-1}\left(\dfrac{4.08\text{ M}\Omega}{3.9\text{ k}\Omega}\right) = \mathbf{0.0548°}$

(b) $X_C = \dfrac{1}{2\pi(100\text{ Hz})(0.039\ \mu\text{F})} = 40.8\text{ k}\Omega$

$\phi = 90° - \tan^{-1}\left(\dfrac{X_C}{R}\right) = 90° - \tan^{-1}\left(\dfrac{40.8\text{ k}\Omega}{3.9\text{ k}\Omega}\right) = \mathbf{5.46°}$

(c) $X_C = \dfrac{1}{2\pi(1\text{ kHz})(0.039\ \mu\text{F})} = 4.08\text{ k}\Omega$

$\phi = 90° - \tan^{-1}\left(\dfrac{X_C}{R}\right) = 90° - \tan^{-1}\left(\dfrac{4.08\text{ k}\Omega}{3.9\text{ k}\Omega}\right) = \mathbf{43.7°}$

(d) $X_C = \dfrac{1}{2\pi(10\text{ kHz})(0.039\ \mu\text{F})} = 408\ \Omega$

$\phi = 90° - \tan^{-1}\left(\dfrac{X_C}{R}\right) = 90° - \tan^{-1}\left(\dfrac{408\ \Omega}{3.9\text{ k}\Omega}\right) = \mathbf{84.0°}$

13. (a) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\text{ Hz})(0.1\,\mu\text{F})} = 15.9\text{ M}\Omega$

$\phi = \tan^{-1}\left(\dfrac{X_C}{R}\right) = \tan^{-1}\left(\dfrac{1.59\text{ M}\Omega}{1.0\text{ k}\Omega}\right) = \mathbf{90.0°}$

(b) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(100\text{ Hz})(0.1\,\mu\text{F})} = 15.9\text{ k}\Omega$

$\phi = \tan^{-1}\left(\dfrac{X_C}{R}\right) = \tan^{-1}\left(\dfrac{15.9\text{ k}\Omega}{1.0\text{ k}\Omega}\right) = \mathbf{86.4°}$

(c) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(1\text{ kHz})(0.1\,\mu\text{F})} = 1.59\text{ k}\Omega$

$\phi = \tan^{-1}\left(\dfrac{X_C}{R}\right) = \tan^{-1}\left(\dfrac{1.59\text{ k}\Omega}{1.0\text{ k}\Omega}\right) = \mathbf{57.8°}$

(d) $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(10\text{ kHz})(0.1\,\mu\text{F})} = 159\ \Omega$

$\phi = \tan^{-1}\left(\dfrac{X_C}{R}\right) = \tan^{-1}\left(\dfrac{159\ \Omega}{1.0\text{ k}\Omega}\right) = \mathbf{9.04°}$

SECTION 10-4 Impedance and Phase Angle of Parallel *RC* Circuits

14. $Z = \dfrac{RX_C}{\sqrt{R^2 + X_C^2}} = \dfrac{(1.2\text{ k}\Omega)(2.2\text{ k}\Omega)}{\sqrt{(1.2\text{ k}\Omega)^2 + (2.2\text{ k}\Omega)^2}} = \mathbf{1.05\text{ k}\Omega}$

15. $B_C = 2\pi fC = 2.76\text{ mS}$

$G = \dfrac{1}{750\ \Omega} = 1.33\text{ mS}$

$Y = \sqrt{G^2 + B_C^2} = \sqrt{(1.33\text{ mS})^2 + (2.76\text{ mS})^2} = 3.07\text{ mS}$

$Z = \dfrac{1}{Y} = \dfrac{1}{3.07\text{ mS}} = \mathbf{326\ \Omega}$

$\theta = \tan^{-1}\left(\dfrac{2.76\text{ mS}}{1.33\text{ mS}}\right) = \mathbf{64.3°}$ (*I* leads *V*)

16. (a) $B_C = 2\pi(1.5\text{ kHz})(0.22\ \mu\text{F}) = 2.07\text{ mS}$

$Y = \sqrt{(1.33\text{ mS})^2 + (2.07\text{ mS})^2} = 2.47\text{ mS}$

$Z = \dfrac{1}{Y} = \dfrac{1}{2.47\text{ mS}} = \mathbf{405\ \Omega}$

$\theta = \tan^{-1}\left(\dfrac{2.07\text{ mS}}{1.33\text{ mS}}\right) = \mathbf{57.3°}$

(b) $B_C = 2\pi(3.0\text{ kHz})(0.22\ \mu\text{F}) = 4.15\text{ mS}$

$Y = \sqrt{(1.33\text{ mS})^2 + (4.15\text{ mS})^2} = 4.36\text{ mS}$

$Z = \dfrac{1}{Y} = \dfrac{1}{4.36\text{ mS}} = \mathbf{230\ \Omega}$

$\theta = \tan^{-1}\left(\dfrac{4.15\text{ mS}}{1.33\text{ mS}}\right) = \mathbf{72.2°}$

(c) $B_C = 2\pi(5.0\text{ kHz})(0.22\ \mu\text{F}) = 6.91\text{ mS}$

$Y = \sqrt{(1.33\text{ mS})^2 + (6.91\text{ mS})^2} = 7.04\text{ mS}$

$Z = \dfrac{1}{Y} = \dfrac{1}{7.04\text{ mS}} = \mathbf{142\ \Omega}$

$\theta = \tan^{-1}\left(\dfrac{6.91\text{ mS}}{1.33\text{ mS}}\right) = \mathbf{79.1°}$

(d) $B_C = 2\pi(10\text{ kHz})(0.22\ \mu\text{F}) = 13.8\text{ mS}$

$Y = \sqrt{(1.33\text{ mS})^2 + (13.8\text{ mS})^2} = 13.9\text{ mS}$

$Z = \dfrac{1}{Y} = \dfrac{1}{13.9\text{ mS}} = \mathbf{72.0\ \Omega}$

$\theta = \tan^{-1}\left(\dfrac{13.9\text{ mS}}{1.33\text{ mS}}\right) = \mathbf{84.5°}$

17. $B_C = 2\pi fC = 2\pi f(C_1 + C_2) = 2\pi(2\text{ kHz})(0.32\ \mu\text{F}) = 4.02\text{ mS}$

$G = \dfrac{1}{R_1 + R_2 + R_3} = \dfrac{1}{1480\ \Omega} = 0.676\text{ mS}$

$Y = \sqrt{G^2 + B_C^2} = \sqrt{(0.676\text{ mS})^2 + (4.02\text{ mS})^2} = 4.08\text{ mS}$

$Z = \dfrac{1}{Y} = \dfrac{1}{4.08\text{ mS}} = \mathbf{245\ \Omega}$

$\theta = \tan^{-1}\left(\dfrac{4.02\text{ mS}}{0.676\text{ mS}}\right) = \mathbf{80.5°}$

SECTION 10-5 Analysis of Parallel *RC* Circuits

18. $Z_{tot} = \dfrac{(68\ \Omega)(90\ \Omega)}{\sqrt{(68\ \Omega)^2 + (90\ \Omega)^2}} = 54.3\ \Omega$

$V_C = V_R = V_s = \mathbf{10\ V}$

$I_{tot} = \dfrac{10\text{ V}}{54.3\ \Omega} = \mathbf{184\ mA}$

$I_R = \dfrac{10\text{ V}}{68\ \Omega} = \mathbf{147\ mA}$

$I_C = \dfrac{10\ \Omega}{90\ \Omega} = \mathbf{111\ mA}$

19. $X_{C1} = \dfrac{1}{2\pi(50\text{ kHz})(0.47\ \mu\text{F})} = 67.7\ \Omega$

$X_{C2} = \dfrac{1}{2\pi(50\text{ kHz})(0.022\ \mu\text{F})} = 145\ \Omega$

$I_{C1} = \dfrac{V_s}{X_{C1}} = \dfrac{8\text{ V}}{67.7\ \Omega} = \mathbf{118\ mA}$

$I_{C2} = \dfrac{V_s}{X_{C2}} = \dfrac{8\text{ V}}{145\ \Omega} = \mathbf{55.3\ mA}$

$I_{R1} = \dfrac{V_s}{R_1} = \dfrac{8\text{ V}}{220\ \Omega} = \mathbf{36.4\ mA}$

$I_{R2} = \dfrac{V_s}{R_2} = \dfrac{8\text{ V}}{180\ \Omega} = \mathbf{44.4\ mA}$

$I_{tot} = \sqrt{I_{R(tot)}^2 + I_{C(tot}^2} = \sqrt{(80.8\text{ mA})^2 + (173.3\text{ mA})^2} = \mathbf{191\ mA}$

$\theta = \tan^{-1}\left(\dfrac{I_{C(tot)}}{I_{R(tot)}}\right) = \tan^{-1}\left(\dfrac{173.3\text{ mA}}{80.8\text{ mA}}\right) = \mathbf{65.0°}$

20. (a) $Z = \dfrac{RX_C}{\sqrt{R^2 + X_C^2}} = \dfrac{(1.0\text{ k}\Omega)(2.1\text{ k}\Omega)}{\sqrt{1.0\text{ k}\Omega^2 + 2.1\text{ k}\Omega^2}} = \mathbf{903\ \Omega}$

(b) $I_R = \dfrac{V_S}{R} = \dfrac{100\text{ mV}}{1.0\text{ k}\Omega} = \mathbf{100\ \mu V}$

(c) $I_C = \dfrac{V_S}{X_C} = \dfrac{100\text{ mV}}{2.1\text{ k}\Omega} = \mathbf{47.6\ \mu V}$

(d) $I_{tot} = \dfrac{V_S}{Z} = \dfrac{100\text{ mV}}{903\ \Omega} = \mathbf{111\ \mu V}$

(e) $\theta = \tan^{-1}\left(\dfrac{R}{X_C}\right) = \tan^{-1}\left(\dfrac{1.0\text{ k}\Omega}{2.1\text{ k}\Omega}\right) = \mathbf{25.5°}$ (I_{tot} leads V_s)

21. $X_C = \dfrac{1}{2\pi(500\text{ Hz})(0.047\ \mu\text{F})} = 6.77\text{ k}\Omega$

(a) $Z = \dfrac{(4.7\text{ k}\Omega)(6.77\text{ k}\Omega)}{\sqrt{(4.7\text{ k}\Omega)^2 + (6.77\text{ k}\Omega)^2}} = \mathbf{3.86\ k\Omega}$

(b) $I_R = \dfrac{V_s}{R} = \dfrac{100\text{ mV}}{4.7\text{ k}\Omega} = \mathbf{21.3\ \mu A}$

(c) $I_C = \dfrac{V_s}{X_C} = \dfrac{100\text{ mV}}{6.77\text{ k}\Omega} = \mathbf{14.8\ \mu A}$

(d) $I_{tot} = \dfrac{V_s}{Z} = \dfrac{100\text{ mV}}{3.86\text{ k}\Omega} = \mathbf{25.9\ \mu A}$

(e) $\theta = \tan^{-1}\left(\dfrac{4.7\text{ k}\Omega}{6.77\text{ k}\Omega}\right) = \mathbf{34.8°}$

22. $R_{tot} = 22\text{ k}\Omega$, $C_{tot} = 32.0\text{ pF}$

$$X_{C(tot)} = \frac{1}{2\pi(100\text{ kHz})(32.0\text{ pF})} = 49.8\text{ k}\Omega$$

$$Z = \frac{(22\text{ k}\Omega)(49.8\text{ k}\Omega)}{\sqrt{(22\text{ k}\Omega)^2 + (49.8\text{ k}\Omega)^2}} = 20.1\text{ k}\Omega$$

$$\theta = \tan^{-1}\left(\frac{R_{tot}}{X_{C(tot)}}\right) = \tan^{-1}\left(\frac{22\text{ k}\Omega}{49.8\text{ k}\Omega}\right) = 23.8°$$

$R_{eq} = Z\cos\theta = (20.1\text{ k}\Omega)\cos 23.8° = \mathbf{18.4\text{ k}\Omega}$

$X_{C(eq)} = Z\sin\theta = (20.1\text{ k}\Omega)\sin 23.8° = 8.13\text{ k}\Omega$

$$C_{eq} = \frac{1}{2\pi f X_{C(eq)}} = \mathbf{196\text{ pF}}$$

SECTION 10-6 Analysis of Series-Parallel *RC* Circuits

23. $$X_{C1} = \frac{1}{2\pi(15\text{ kHz})(0.1\text{ }\mu\text{F})} = 106\ \Omega$$

$$X_{C2} = \frac{1}{2\pi(15\text{ kHz})(0.047\text{ }\mu\text{F})} = 226\ \Omega$$

$$X_{C3} = \frac{1}{2\pi(15\text{ kHz})(0.22\text{ }\mu\text{F})} = 48.2\ \Omega$$

The total resistance in the resistive branch is

$R_{tot} = R_1 + R_2 = 330\ \Omega + 180\ \Omega = 510\ \Omega$

The combined parallel capacitance of C_2 and C_3 is

$C_{(tot)p} = C_1 + C_2 = 0.047\ \mu\text{F} + 0.22\ \mu\text{F} = 0.267\ \mu\text{F}$

$$X_{C(tot)p} = \frac{1}{2\pi(15\text{ kHz})(0.267\text{ }\mu\text{F})} = 39.7\ \Omega$$

The impedance of R_{tot} in parallel with $C_{(tot)p}$ is

$$Z_p = \frac{R_{tot}X_{C(tot)p}}{\sqrt{R_{tot}^2 + X_{C(tot)p}^2}} = \frac{(510\ \Omega)(39.7\ \Omega)}{\sqrt{(510\ \Omega)^2 + (39.7\ \Omega)^2}} = 39.6\ \Omega$$

The angle associated with R_{tot} and $C_{(tot)p}$ in parallel is

$$\theta = \tan^{-1}\left(\frac{R_{tot}}{X_{C(tot)p}}\right) = \tan^{-1}\left(\frac{510\ \Omega}{39.7\ \Omega}\right) = \mathbf{85.5°}$$

Converting from parallel to series:

$R_{eq} = Z_p\cos\theta = (39.6\ \Omega)\cos 85.5° = 3.08\ \Omega$

$X_{C(eq)} = Z_p\sin\theta = (39.6\ \Omega)\sin 85.5° = 39.5\ \Omega$

The total circuit impedance is

$$Z_{tot} = \sqrt{R_{eq}^2 + (X_{C1} + X_{C(eq)})^2} = \sqrt{(3.08\ \Omega)^2 + (145.6\ \Omega)^2} = 145.6\ \Omega$$

The voltage across the parallel branches is

$$V_{C2} = V_{C3} = V_{R1R2} = \left(\frac{Z_p}{Z_{tot}}\right)V_s = \left(\frac{39.6\ \Omega}{145.6\ \Omega}\right)12\text{ V} = \mathbf{3.26\ V}$$

$$V_{R1} = \left(\frac{330\ \Omega}{510\ \Omega}\right)3.26\text{ V} = \mathbf{2.11\ V}$$

$$V_{R2} = \left(\frac{180\ \Omega}{510\ \Omega}\right)3.26\text{ V} = \mathbf{1.15\ V}$$

$$V_{C1} = \left(\frac{X_{C1}}{Z_{tot}}\right)12\text{ V} = \left(\frac{106\ \Omega}{145.6\ \Omega}\right)12\text{ V} = \mathbf{8.74\ V}$$

24. From Problem 23, $R_{eq} = 3.08\ \Omega$ and $X_{C1} + X_{C(eq)} = 145.6\ \Omega$.
Since $145.6\ \Omega > 3.08\ \Omega$, the circuit is predominantly **capacitive.**

25. Using data from Problem 23:

$$I_{tot} = \frac{V_s}{Z_{tot}} = \frac{12\text{ V}}{145.6\ \Omega} = \mathbf{82.4\ mA}$$

$$I_{C2} = \frac{V_{C2}}{X_{C2}} = \frac{3.26\text{ V}}{226\ \Omega} = \mathbf{14.4\ mA}$$

$$I_{C3} = \frac{V_{C3}}{X_{C3}} = \frac{3.26\text{ V}}{48.2\ \Omega} = \mathbf{67.6\ mA}$$

$$I_{R1} = I_{R2} = \frac{3.26\text{ V}}{510\ \Omega} = \mathbf{6.39\ mA}$$

26. $R_{tot} = R_1 + R_2 \parallel R_3 = 89.9\ \Omega$

$$X_C = \frac{1}{2\pi(1\text{ kHz})(0.47\ \mu\text{F})} = 339\ \Omega$$

$$Z_{tot} = \sqrt{R_{tot}^2 + X_C^2} = \sqrt{(89.9\ \Omega)^2 + (339\ \Omega)^2} = 351\ \Omega$$

(a) $I_{tot} = \dfrac{V_s}{Z_{tot}} = \dfrac{15\text{ V}}{351\ \Omega} = \mathbf{42.7\ mA}$

(b) $\theta = \tan^{-1}\left(\dfrac{X_C}{R_{tot}}\right) = \tan^{-1}\left(\dfrac{339\ \Omega}{89.9\ \Omega}\right) = \mathbf{75.1^\circ}$ (I_{tot} leads V_s)

(c) $V_{R1} = \left(\dfrac{R_1}{Z_{tot}}\right)V_s = \left(\dfrac{47\ \Omega}{351\ \Omega}\right)15\text{ V} = \mathbf{2.01\ V}$

(d) $V_{R2} = \left(\dfrac{R_2 \parallel R_3}{Z_{tot}}\right)V_s = \left(\dfrac{42.9\ \Omega}{351\ \Omega}\right)15\text{ V} = \mathbf{1.83\ V}$

(e) $V_{R3} = V_{R2} = \mathbf{1.83\ V}$

(f) $V_C = \left(\dfrac{X_C}{Z_{tot}}\right)V_s = \left(\dfrac{339\ \Omega}{351\ \Omega}\right)15\text{ V} = \mathbf{14.5\ V}$

SECTION 10-7 Power in *RC* Circuits

27. $P_a = \sqrt{P_{\text{true}}^2 + P_r^2} = \sqrt{(2\text{ W})^2 + (3.5\text{ VAR})^2}$ = **4.03 VA**

28. From Problem 10: I_{tot} = 103 mA, X_C = 79.6 Ω

$P_{\text{rue}} = I_{tot}^2 R$ = (103 mA)^2(56 Ω) = **0.591 W**

$P_r = I_{tot}^2 X_C$ = (103 mA)^2(79.6 Ω) = **0.840 VAR**

29. Using the results from Problem 22:

R_{eq} = 18.4 kΩ

$$X_{C(\text{eq})} = \frac{1}{2\pi f C_{\text{eq}}} = \frac{1}{2\pi(100\text{ kHz})(196\text{ pF})} = 8.13\text{ k}\Omega$$

$$\theta = \tan^{-1}\left(\frac{X_{C(\text{eq})}}{R_{\text{eq}}}\right) = \tan^{-1}\left(\frac{8.13\text{ k}\Omega}{18.4\text{ k}\Omega}\right) = 23.8°$$

$PF = \cos\theta = \cos 23.8°$ = **0.915**

30. From Problem 26: I_{tot} = 42.7 mA, R_{tot} = 89.9 Ω, X_C = 339 Ω, Z_{tot} = 351 Ω

$P_{\text{true}} = I_{tot}^2 R_{tot}$ = (42.7 mA)^2(89.9 Ω) = **169 mW**

$P_r = I_{tot}^2 X_C$ = (42.7 mA)^2(339 Ω) = 6**18 mVAR**

$P_a = I_{tot}^2 Z_{tot}$ = (42.7 mA)^2(351 Ω) = **640 mVA**

$PF = \cos\theta = \cos(75.1°)$ = **0.257**

SECTION 10-8 Basic Applications

31. Use the formula, $V_{out} = \left(\frac{X_C}{Z_{tot}}\right)1\text{ V}$. See Figure 10-2.

Frequency (kHz)	X_C (kΩ)	Z_{tot} (kΩ)	V_{out} (V)
0			1.000
1	4.08	5.64	0.723
2	2.04	4.40	0.464
3	1.36	4.13	0.329
4	1.02	4.03	0.253
5	0.816	3.98	0.205
6	0.680	3.96	0.172
7	0.583	3.94	0.148
8	0.510	3.93	0.130
9	0.453	3.93	0.115
10	0.408	3.92	0.104

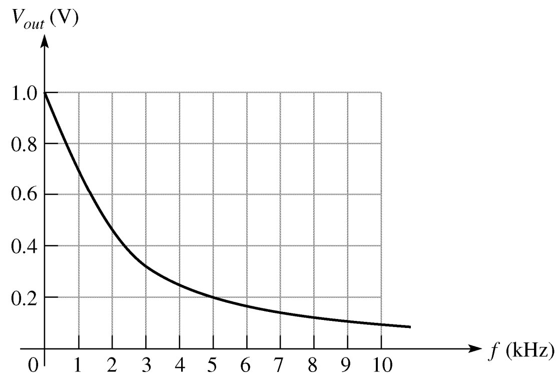


Figure 10-2

32. Use the formula, $V_{out} = \left(\frac{R}{Z_{tot}}\right)10\text{ V}$. See Figure 10-3.

Frequency (kHz)	X_C (Ω)	Z_{tot} (Ω)	V_{out} (V)
0			0
1	15.9	18.79	5.32
2	7.96	12.78	7.82
3	5.31	11.32	8.83
4	3.98	10.76	9.29
5	3.18	10.49	9.53
6	2.65	10.35	9.67
7	2.27	10.26	9.75
8	1.99	10.20	9.81
9	1.77	10.16	9.85
10	1.59	10.13	9.88

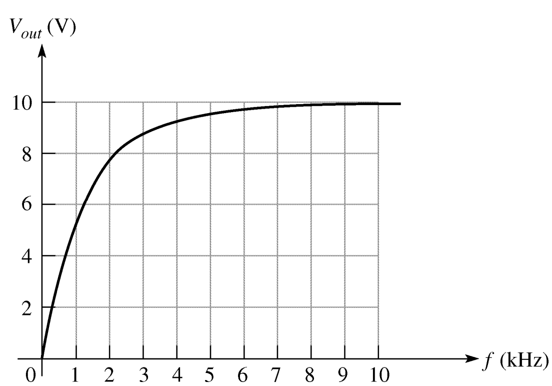


Figure 10-3

33. For Figure 10-73:

$$X_C = \frac{1}{2\pi(5\text{ kHz})(0.039\ \mu\text{F})} = 816\ \Omega$$

$$Z = \sqrt{(3.9\text{ k}\Omega)^2 + (816\ \Omega)^2} = 3.98\text{ k}\Omega$$

$$\theta = \tan^{-1}\left(\frac{X_C}{R}\right) = \tan^{-1}\left(\frac{816\ \Omega}{3.9\text{ k}\Omega}\right) = \mathbf{11.8°}$$

$$I = \frac{V_s}{Z} = \frac{1\text{ V}}{3980\ \Omega} = 251\ \mu\text{A}$$

$V_R = IR = (251\ \mu\text{A})(3.9\text{ k}\Omega) =$ **979 mV**
$V_C = IX_C = (251\ \mu\text{A})(816\ \Omega) =$ **205 mV**
The phasor diagram is shown is Figure 10-4(a).

For Figure 10-74:

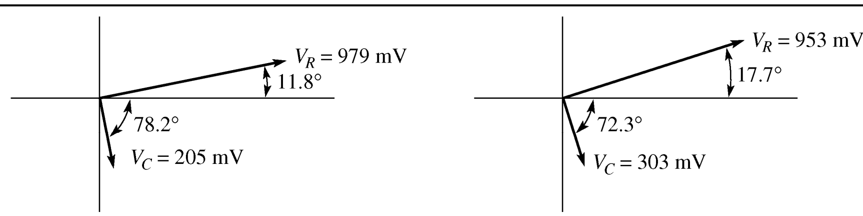
$$X_C = \frac{1}{2\pi(5\text{ kHz})(10\ \mu\text{F})} = 3.18\ \Omega$$

$$Z = \sqrt{(10\ \Omega)^2 + (3.18\ \Omega)^2} = 10.5\ \Omega$$

$$\theta = \tan^{-1}\left(\frac{X_C}{R}\right) = \tan^{-1}\left(\frac{3.18\ \Omega}{10\ \Omega}\right) = \mathbf{17.7°}$$

$$I = \frac{V_s}{Z} = \frac{1\text{ V}}{10.5\ \Omega} = 95.3\text{ mA}$$

$V_R = IR = (95.3\text{ mA})(10\ \Omega) =$ **953 mV**
$V_C = IX_C = (95.3\text{ mA})(3.18\ \Omega) =$ **303 mV**
The phasor diagram is shown in Figure 10-4(b).



(a) For Figure 10-73 (b) For Figure 10-74

Figure 10-4

34. $$X_C = \frac{1}{2\pi(3\text{ kHz})(0.047\ \mu\text{F})} = 1.13\text{ k}\Omega$$

The signal loss is the voltage drop across C.

$$V_C = \left(\frac{X_C}{\sqrt{R_{in(B)}^2 + X_C^2}}\right)V_{out(A)} = \left(\frac{1.13\text{ k}\Omega}{\sqrt{(10\text{ k}\Omega)^2 + (1.13\text{ k}\Omega)^2}}\right)50\text{ mV} = \mathbf{5.61\text{ mV}}$$

35. For Figure 10-73:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(3.9\text{ k}\Omega)(0.039\ \mu\text{F})} = \mathbf{1.05\ kHz}$$

For Figure 10-74:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(10\ \Omega)(10\ \mu\text{F})} = \mathbf{1.59\ kHz}$$

36. $$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(3.9\text{ k}\Omega)(0.039\ \mu\text{F})} = 1.05\text{ kHz}$$

Since this is a low-pass filter, $BW = f_c =$ **1.05 kHz**

SECTION 10-9 Troubleshooting

37. After removing C, the circuit is reduced to Thevenin's equivalent:

$$R_{th} = \frac{(4.7\text{ k}\Omega)(5\text{ k}\Omega)}{9.7\text{ k}\Omega} = 2.42\text{ k}\Omega$$

$$V_{th} = \left(\frac{5\text{ k}\Omega}{9.7\text{ k}\Omega}\right)10\text{ V} = 5.15\text{ V}$$

Assuming no leakage in the capacitor:

$$X_C = \frac{1}{2\pi(10\text{ Hz})(10\ \mu\text{F})} = 1592\ \Omega$$

$$V_{out} = \left(\frac{X_C}{\sqrt{R^2 + X_C^2}}\right)10\text{ V} = \left(\frac{1592\ \Omega}{\sqrt{(4.7\text{ k}\Omega)^2 + (1592\ \Omega)^2}}\right)10\text{ V} = \mathbf{3.21\ V}$$

$$\theta = \tan^{-1}\left(\frac{1592\ \Omega}{4.7\text{ k}\Omega}\right) = \mathbf{18.7°}$$

With the leakage resistance taken into account:

$$V_{out} = \left(\frac{X_C}{\sqrt{R_{th}^2 + X_C^2}}\right)V_{th} = \left(\frac{1592\ \Omega}{\sqrt{(2.42\text{ k}\Omega)^2 + (1592)^2}}\right)5.15\text{ V} = \mathbf{2.83\ V}$$

$$\theta = \tan^{-1}\left(\frac{1592\ \Omega}{2.42\text{ k}\Omega}\right) = \mathbf{33.3°}$$

The leaky capacitor reduces the output voltage by 0.38 V and increases the phase angle by 14.6°.

38. (a) The leakage resistance effectively appears in parallel with R_2.
Thevenizing from the capacitor:

$R_{th} = R_1 \parallel R_2 \parallel R_{leak} = 10\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel 2\text{ k}\Omega = 1.43\text{ k}\Omega$

$$V_{th} = \left(\frac{R_2 \parallel R_{leak}}{R_1 + R_2 \parallel R_{leak}}\right)V_{in} = \left(\frac{1.67\text{ k}\Omega}{11.67\text{ k}\Omega}\right)1\text{ V} = 143\text{ mV}$$

$$X_C = \frac{1}{2\pi(10\text{ Hz})(4.7\ \mu\text{F})} = 3386\ \Omega$$

$$V_{out} = \left(\frac{X_C}{\sqrt{R_{th}^2 + X_C^2}}\right)V_{th} = \left(\frac{3386\ \Omega}{\sqrt{(1.43\text{ k}\Omega)^2 + (3386\ \Omega)^2}}\right)143\text{ mV} = \mathbf{132\ mV}$$

(b) $$X_C = \frac{1}{2\pi(100\text{ kHz})(470\text{ pF})} = 3386\ \Omega$$

$R_{eq} = R_1 \parallel (R_2 + R_3) = 2.2\text{ k}\Omega \parallel 2\text{ k}\Omega = 1.05\text{ k}\Omega$

$$X_C \parallel R_{leak} = \frac{(R_{leak})(X_C)}{\sqrt{R_{leak}^2 + X_C^2}} = \frac{(2\text{ k}\Omega)(3386\ \Omega)}{\sqrt{(2\text{ k}\Omega)^2 + (3386\ \Omega)^2}} = 1722\ \Omega$$

$$V_{R1} = \left(\frac{R_{eq}}{X_C \parallel R_{leak} + R_{eq}}\right)V_{in} = 1.96\text{ V}$$

$X_C \parallel R_{leak}$ consists of a reactive and a resistive term and cannot be added directly to R_{eq}.

$$V_{out} = \left(\frac{R_3}{R_2 + R_3}\right)V_{R1} = \left(\frac{1.0\text{ k}\Omega}{2\text{ k}\Omega}\right)1.96\text{ V} = \mathbf{0.978\ V}$$

39. (a) V_{out} = **0 V (less than normal output)**

$$X_C = \frac{1}{2\pi(10\text{ Hz})(4.7\ \mu\text{F})} = 3386\ \Omega$$

(b) $$V_{out} = \left(\frac{X_C}{\sqrt{R^2 + X_C^2}}\right)V_{in} = \left(\frac{3386\ \Omega}{10{,}494\ \Omega}\right)1\text{ V} = \mathbf{0.321\ V}$$ **(greater than normal output)**

(c) $$V_{out} = \left(\frac{R_2}{R_1 + R_2}\right)V_{in} = \left(\frac{10\text{ k}\Omega}{20\text{ k}\Omega}\right)1\text{ V} = \mathbf{0.5\ V}$$ **(greater than normal output)**

(d) V_{out} = **0 V (less than normal output)**

40. (a) V_{out} = **0 V (less than normal)**

(b) $$V_{out} = \left(\frac{R_3}{R_2 + R_3}\right)V_{in} = \left(\frac{1.0\text{ k}\Omega}{2\text{ k}\Omega}\right)5\text{ V} = \mathbf{2.5\ V}$$ **(greater than normal output)**

$X_C = 3386$

(c) $$V_{out} = \left(\frac{R_3}{\sqrt{(R_2 + R_3)^2 + X_C^2}}\right)V_{in} = \left(\frac{1000\ \Omega}{3933\ \Omega}\right)5\text{ V} = \mathbf{1.27\ V}$$ **(greater than normal output)**

(d) V_{out} = **0 V (less than normal output)**

(e) $$V_{out} = \left(\frac{R_1}{\sqrt{R_1^2 + X_C^2}}\right)V_{in} = \left(\frac{2.2\text{ k}\Omega}{4038\ \Omega}\right)5\text{ V} = \mathbf{2.72\ V}$$ **(greater than normal output)**

ADVANCED PROBLEMS

41. (a) $I_{L(A)} = \dfrac{240\text{ V}}{50\ \Omega} = \mathbf{4.8\ A}$

$I_{L(B)} = \dfrac{240\text{ V}}{72\ \Omega} = \mathbf{3.33\ A}$

(b) $PF_A = \cos\theta = 0.85;\ \ \theta = 31.8°$
$PF_B = \cos\theta = 0.95;\ \ \theta = 18.19°$
$X_{C(A)} = (50\ \Omega)\sin 31.8° = 26.3\ \Omega$
$X_{C(B)} = (72\ \Omega)\sin 18.19° = 22.48\ \Omega$
$P_{r(A)} = I_{L(A)}X_{C(A)} = (4.8\text{ A})^2(26.3\ \Omega) = \mathbf{606\ VAR}$
$P_{r(B)} = I_{L(B)}X_{C(B)} = (3.33\text{ A})^2(22.48\ \Omega) = \mathbf{250\ VAR}$

(c) $R_A = (50\ \Omega)\cos 31.8° = 42.5\ \Omega$
$R_B = (72\ \Omega)\cos 18.19° = 68.4\ \Omega$
$P_{true(A)} = I_{L(A)}^2 R_A = (4.8\text{ A})^2(42.5\ \Omega) = \mathbf{979\ W}$
$P_{true(B)} = I_{L(B)}^2 R_B = (3.33\text{ A})^2(68.4\ \Omega) = \mathbf{758\ W}$

(d) $P_{a(A)} = \sqrt{\left(P_{true(A)}\right)^2 + \left(P_{r(A)}\right)^2} = \sqrt{(979\text{ W})^2 + (606\text{ VAR})^2} = \mathbf{1151\ VA}$

$P_{a(B)} = \sqrt{\left(P_{true(B)}\right)^2 + \left(P_{r(B)}\right)^2} = \sqrt{(758\text{ W})^2 + (250\text{ VAR})^2} = \mathbf{798\ VA}$

42. $\dfrac{V_{out1}}{V_{in1}} = \dfrac{R}{\sqrt{R^2 + X_C^2}} = 0.707$

$R = 0.707\sqrt{R^2 + X_C^2}$

$\sqrt{R^2 + X_C^2} = \dfrac{R}{0.707} = 1.414R$

$R^2 + X_C^2 = (1.414)^2R^2 = 2R^2$

$X_C^2 = 2R^2 - R^2 = R^2(2 - 1) = R^2$

$X_C = R$

$\dfrac{1}{2\pi fC} = R$

$C = \dfrac{1}{2\pi fR} = \dfrac{1}{2\pi(20\text{ Hz})(100\text{ k}\Omega)} = \mathbf{0.08\ \mu F}$

43. $X_C = \dfrac{1}{2\pi(1\text{ kHz})(0.01\ \mu\text{F})} = 15.9\text{ k}\Omega$

$\theta = \tan^{-1}\left(\dfrac{R_{tot}}{X_C}\right)$

$\left(\dfrac{R_{tot}}{X_C}\right) = \tan\theta$

$R_{tot} = X_C\tan\theta = (15.9\text{ k}\Omega)\tan 30° = 9.19\text{ k}\Omega$

$$R_{tot} = \frac{R_1R_2}{R_1 + R_2}$$
$R_{tot}(R_1 + R_2) = R_1R_2$
$R_1R_{tot} + R_2R_{tot} = R_1R_2$
$R_1(R_{tot} - R_2) = -R_2R_{tot}$
$$R_1 = \frac{R_2R_{tot}}{R_2 - R_{tot}} = \frac{(47\text{ k}\Omega)(9.19\text{ k}\Omega)}{37.9\text{ k}\Omega} = \mathbf{11.4\text{ k}\Omega}$$

44. $$X_{C1} = \frac{1}{2\pi(2.5\text{ kHz})(0.015\ \mu\text{F})} = 4244\ \Omega$$
$$X_{C2} = \frac{1}{2\pi(2.5\text{ kHz})(0.047\ \mu\text{F})} = 1355\ \Omega$$
$$R_4 \parallel X_{C2} = \frac{R_4X_{C2}}{\sqrt{R_4^2 + X_{C2}^2}} = \frac{(910\ \Omega)(1355\ \Omega)}{\sqrt{(910\ \Omega) + (1355\ \Omega)}} = 756\ \Omega$$
$$\theta_{R4C2} = \tan^{-1}\left(\frac{R_4}{X_{C2}}\right) = \tan^{-1}\left(\frac{910\ \Omega}{1355\ \Omega}\right) = 33.9°$$
The equivalent series R and X_C for $R_4 \parallel X_{C2}$:
$R_{eq} = (R_4 \parallel X_{C2})\cos\theta_{R4C2} = (756\ \Omega)\cos 33.9° = 627\ \Omega$
$X_{C(eq)} = (R_4 \parallel X_{C2})\sin\theta_{R4C2} = (756\ \Omega)\sin 33.9° = 422\ \Omega$
$$Z_{tot} = \sqrt{R_{tot}^2 + X_{C(tot)}^2} = \sqrt{(R_1 + R_2 + R_3 + R_{eq})^2 + (X_{C1} + X_{C(eq)})^2}$$
$$= \sqrt{(1.0\text{ k}\Omega + 680\ \Omega + 1.0\text{ k}\Omega + 627\ \Omega)^2 + (4244\ \Omega + 422\ \Omega)^2}$$
$$= \sqrt{(3307\ \Omega)^2 + (4666\ \Omega)^2} = 5719\ \Omega$$
$$\theta = \tan^{-1}\left(\frac{X_{C(tot)}}{R_{tot}}\right) = \tan^{-1}\left(\frac{4666\ \Omega}{3307\ \Omega}\right) = \mathbf{54.7°}$$
$$I_{tot} = \frac{V_s}{Z_{tot}} = \frac{10\text{ V}}{5719\ \Omega} = \mathbf{1.75\text{ mA}}$$
I_{tot} leads V_s by 54.7°
$I_{C1} = I_{R1} = I_{R2} = I_{R3} = I_{tot} = \mathbf{1.75\text{ mA}}$
$$I_{R4} = \left(\frac{X_{C2}}{\sqrt{R_4^2 + X_{C2}^2}}\right)I_{tot} = \left(\frac{1355\ \Omega}{\sqrt{(910\ \Omega)^2 + (1355\ \Omega)^2}}\right)1.75\text{ mA} = \mathbf{1.45\text{ mA}}$$
$$I_{C2} = \left(\frac{R_4}{\sqrt{R_4^2 + X_{C2}^2}}\right)I_{tot} = \left(\frac{910\ \Omega}{\sqrt{(910)^2 + (1355\ \Omega)^2}}\right)1.75\text{ mA} = \mathbf{0.976\text{ mA}}$$

$V_{C1} = I_{tot}X_{C1} = (1.75\text{ mA})(4244\ \Omega) = \mathbf{7.43\text{ V}}$
$V_{R1} = I_{tot}R_1 = (1.75\text{ mA})(1.0\ \Omega) = \mathbf{1.75\text{ V}}$
$V_{R2} = I_{tot}R_2 = (1.75\text{ mA})(680\ \Omega) = \mathbf{1.19\text{ V}}$
$V_{R3} = I_{tot}R_3 = (1.75\text{ mA})(1.0\ \Omega) = \mathbf{1.75\text{ V}}$
$V_{R4} = V_{C2} = I_{R4}R_4 = (1.45\text{ mA})(910\ \Omega) = \mathbf{1.32\text{ V}}$
V_{C1} lags I_{tot} by 90°.

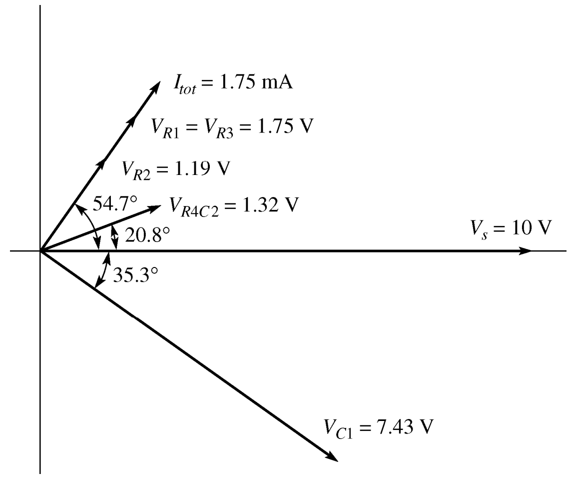


Figure 10-5

V_{R1}, V_{R2}, and V_{R3} are all in phase with I_{tot}.
V_{R4C2} lags I_{tot} by **33.9°**. See Figure 10-5.

45. $\theta = \cos^{-1}(0.75) = 41.4°$

$P_{\text{true}} = P_a \cos\theta$

$P_a = \dfrac{P_{\text{true}}}{PF} = \dfrac{1.5\text{ kW}}{0.75} = \mathbf{2\text{ kVA}}$

$P_r = P_a \sin\theta = (2\text{ kVA})\sin 41.4° = \mathbf{1.32\text{ kVAR}}$

46. $Z_{tot} = \dfrac{100\text{ V}}{5\text{ A}} = 20\ \Omega$

$P_{\text{true}} = I^2 R_{tot}$

$R_{tot} = \dfrac{P_{true}}{I^2} = \dfrac{400\text{ W}}{(5\text{ A})^2} = 16\ \Omega$

$R_x = R_{tot} - R_1 = 16\ \Omega - 4\ \Omega = \mathbf{12\ \Omega}$

$Z_{tot}^2 = R_{tot}^2 + X_C^2$

$X_C \sqrt{Z_{tot}^2 - R_{tot}^2} = \sqrt{(20\ \Omega)^2 - (16\ \Omega)^2} = \sqrt{144} = 12\ \Omega$

$C_x = \dfrac{1}{2\pi(1\text{ kHz})(12\ \Omega)} = \mathbf{13.3\ \mu F}$

47. For $I = 0$ A, $V_A = V_B$ and $V_{R1} = V_{R2}$

$X_{C1} = \dfrac{1}{2\pi(1\text{ kHz})(0.047\ \mu\text{F})} = 3.39\text{ k}\Omega$

$V_{R1} = V_{R2}$

$$\left(\frac{2.2\text{ k}\Omega}{\sqrt{(2.2\text{ k}\Omega)^2 + (3.39\text{ k}\Omega)^2}}\right)V_s = \left(\frac{1.0\text{ k}\Omega}{\sqrt{(1.0\text{ k}\Omega)^2 + X_{C2}^2}}\right)V_s$$

Cancelling the V_s terms and solving for X_{C2}:

$$\left(\frac{2.2\text{ k}\Omega}{\sqrt{(2.2\text{ k}\Omega)^2 + (3.39\text{ k}\Omega)^2}}\right) = \left(\frac{1.0\text{ k}\Omega}{\sqrt{(1.0\text{ k}\Omega)^2 + X_{C2}^2}}\right)$$

$$\sqrt{(1.0\text{ k}\Omega)^2 + X_{C2}^2} = \frac{1.0\text{ k}\Omega\sqrt{(2.2\text{ k}\Omega)^2 + (3.39\text{ k}\Omega)^2}}{2.2\text{ k}\Omega}$$

$$(1.0\text{ k}\Omega)^2 + X_{C2}^2 = \frac{(1.0\text{ k}\Omega)^2\left((2.2\text{ k}\Omega)^2 + (3.39\text{ k}\Omega)^2\right)}{(2.2\text{ k}\Omega)^2}$$

$$X_{C2} = \sqrt{\frac{(1.0\text{ k}\Omega)^2\left((2.2\text{ k}\Omega)^2 + (3.39\text{ k}\Omega)^2\right)}{(2.2\text{ k}\Omega)^2} - (1.0\text{ k}\Omega)^2} = 1.54\text{ k}\Omega$$

$$C_2 = \frac{1}{2\pi(1\text{ kHz})(1.54\text{ k}\Omega)} = \mathbf{0.103\ \mu F}$$

48. See Figure 10-6.

V_{in} = 10 V peak

$$f = \frac{1}{10\ \mu\text{s}} = 100\text{ kHz}$$

$$X_C = \frac{1}{2\pi(100\text{ kHz})(0.1\ \mu\text{F})} = 15.9\ \Omega$$

X_C can be neglected because it is very small compared to 22 kΩ.

$R_A = 22\text{ k}\Omega \parallel 18\text{ k}\Omega \parallel (8.2\text{ k}\Omega + 1.0\text{ k}\Omega) = 4.77\text{ k}\Omega$

$$V_{out} \cong V_A = \left(\frac{4.77\text{ k}\Omega}{14.77\text{ k}\Omega}\right)10\text{ V} = 3.23\text{ V peak}$$

The waveform on the scope is correct, so the circuit is OK.

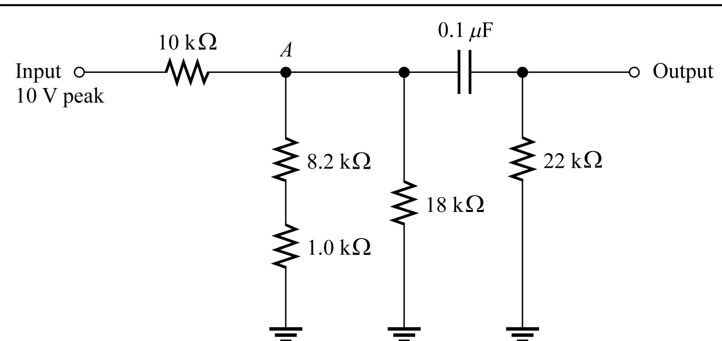


Figure 10-6

Multisim Troubleshooting Problems

49. C is leaky.

50. C_2 is shorted.

51. No fault

52. C is open.

53. R_2 is open.

54. C is shorted.

55. Phase shift with C_1 shorted = 13.7°.

CHAPTER 11
INDUCTORS

BASIC PROBLEMS

SECTION 11-1 The Basic Inductor

1. (a) 1 H × 1000 mH/H = **1000 mH**
   (b) 250 μH × 0.001 mH/μH = **0.25 mH**
   (c) 10 μH × 0.001 mH/μH = **0.01 mH**
   (d) 0.0005 H × 1000 mH/H = **0.5 mH**

2. (a) 300 mH × 10^3 μH/mH = **300,000 μH**
   (b) 0.08 H × 10^6 μH/H = **80,000 μH**
   (c) 5 mH × 10^3 μH/mH = **5000 μH**
   (d) 0.00045 mH × 10^3 μH/mH = **0.45 μH**

3. $$L = \frac{N^2 \mu A}{l}$$
   $$N = \sqrt{\frac{Ll}{\mu A}} = \sqrt{\frac{(30\text{ mH})(0.05\text{ m})}{(1.26\times10^{-6})(10\times10^{-5}\text{ m}^2)}} = \mathbf{3450\ turns}$$

4. $$I = \frac{V_{\text{dc}}}{R_W} = \frac{12\text{ V}}{120\ \Omega} = \mathbf{0.1\ A}$$

5. $$W = \left(\frac{1}{2}\right)LI^2 = \frac{(0.1\text{ H})(1\text{ A})^2}{2} = \mathbf{50\ mJ}$$

6. $v_{\text{induced}} = L \times$ (rate of change of I) = (100 mH)(200 mA/s) = **20 mV**

SECTION 11-3 Series and Parallel Inductors

7. L_T = 5 μH + 10 μH + 20 μH + 40 μH + 80 μH = **155 μH**

8. L_x = 50 mH − 10 mH − 22 mH = **18 mH**

9. $L_T = \dfrac{1}{\dfrac{1}{75\ \mu H}+\dfrac{1}{50\ \mu H}+\dfrac{1}{25\ \mu H}+\dfrac{1}{15\ \mu H}}$ = **7.14 μH**

10. $8\ mH = \dfrac{L_1(12\ mH)}{L_1 + 12\ mH}$

$(8\ mH)L_1 + (8\ mH)(12\ mH) = (12\ mH)L_1$

$(4\ mH)L_1 = 96\ mH^2$

$L_1 = \dfrac{96\ mH^2}{4\ mH}$ = **24 mH**

11. (a) $L_T = 1\ H + \dfrac{(10\ H)(5\ H)}{10\ H + 5\ H}$ = **4.33 H**

(b) $L_T = \dfrac{100\ mH}{2}$ = **50 mH**

(c) $L_T = \dfrac{1}{\dfrac{1}{100\ \mu H}+\dfrac{1}{200\ \mu H}+\dfrac{1}{400\ \mu H}}$ = **57 μH**

12. (a) $L_T = \dfrac{(100\ mH)(50\ mH)}{150\ mH} + \dfrac{(60\ mH)(40\ mH)}{100\ mH}$ = 33.33 mH + 24 mH = **57.3 mH**

(b) $L_T = \dfrac{(12\ mH)(6\ mH)}{18\ mH}$ = **4 mH**

(c) $L_T = 4\ mH + \dfrac{(2\ mH)(4\ mH)}{6\ mH}$ = **5.33 mH**

SECTION 11-4 Inductors in DC Circuits

13. (a) $\tau = \dfrac{L}{R} = \dfrac{100\ \mu H}{100\ \Omega}$ = **1 μs**

(b) $\tau = \dfrac{L}{R} = \dfrac{10\ mH}{4.7\ k\Omega}$ = **2.13 μs**

(c) $\tau = \dfrac{L}{R} = \dfrac{3\ H}{1.5\ M\Omega}$ = **2 μs**

14. (a) $5\tau = 5\left(\dfrac{L}{R}\right) = 5\left(\dfrac{50\ \mu H}{56\ \Omega}\right)$ = **4.46 μs**

(b) $5\tau = 5\left(\dfrac{L}{R}\right) = 5\left(\dfrac{15\ mH}{3300\ \Omega}\right)$ = **22.7 μs**

(c) $5\tau = 5\left(\dfrac{L}{R}\right) = 5\left(\dfrac{100\ mH}{22\ k\Omega}\right)$ = **22.7 μs**

15. $\tau = \dfrac{L}{R} = \dfrac{10\ mH}{1.0\ k\Omega}$ = 10 μs

(a) $v_L = V_i e^{-t/\tau} = 15e^{-10\mu s/10\mu s} = 15e^{-1}$ = **5.52 V**

(b) $v_L = V_i e^{-t/\tau} = 15e^{-20\mu s/10\mu s} = 15e^{-2}$ = **2.03 V**

(c) $v_L = V_i e^{-t/\tau} = 15e^{-30\mu s/10\mu s} = 15e^{-3} = \mathbf{0.747\ V}$
(d) $v_L = V_i e^{-t/\tau} = 15e^{-40\mu s/10\mu s} = 15e^{-4} = \mathbf{0.275\ V}$
(e) $v_L = V_i e^{-t/\tau} = 15e^{-50\mu s/10\mu s} = 15e^{-5} = \mathbf{0.101\ V}$

16. $\tau = \dfrac{L}{R} = \dfrac{75\text{ mH}}{8.2\text{ k}\Omega} = 9.15\ \mu\text{s}$

$I_F = \dfrac{V_s}{R} = \dfrac{10\text{ V}}{8.2\text{ k}\Omega} = 1.22\text{ mA}$

(a) $i = I_F\left(1 - e^{-10\mu s/9.15\mu s}\right) = \mathbf{0.811\ mA}$

(b) $i = I_F\left(1 - e^{-20\mu s/9.15\mu s}\right) = \mathbf{1.08\ mA}$

(c) $i = I_F\left(1 - e^{-30\mu s/9.15\mu s}\right) = \mathbf{1.17\ mA}$

SECTION 11-5 Inductors in AC Circuits

17. The total inductance for each circuit was found in Problem 11.
(a) $X_L = 2\pi f L_{tot} = 2\pi(5\text{ kHz})(4.33\text{ H}) = \mathbf{136\ k\Omega}$
(b) $X_L = 2\pi f L_{tot} = 2\pi(5\text{ kHz})(50\text{ mH}) = \mathbf{1.57\ k\Omega}$
(c) $X_L = 2\pi f L_{tot} = 2\pi(5\text{ kHz})(57\ \mu\text{H}) = \mathbf{1.79\ \Omega}$

18. The total inductance for each circuit was found in Problem 12.
(a) $X_L = 2\pi f L_{tot} = 2\pi(400\text{ Hz})(57.3\text{ mH}) = \mathbf{144\ \Omega}$
(b) $X_L = 2\pi f L_{tot} = 2\pi(400\text{ Hz})(4\text{ mH}) = \mathbf{10.1\ \Omega}$
(c) $X_L = 2\pi f L_{tot} = 2\pi(400\text{ Hz})(5.33\text{ mH}) = \mathbf{13.4\ \Omega}$

19. $L_{tot} = L_1 + \dfrac{L_2 L_3}{L_2 + L_3} = 50\text{ mH} + \dfrac{(20\text{ mH})(40\text{ mH})}{60\text{ mH}} = 63.3\text{ mH}$

$X_{L(tot)} = 2\pi f L_{tot} = 2\pi(2.5\text{ kHz})(63.3\text{ mH}) = 994\ \Omega$
$X_{L2} = 2\pi f L_{tot} = 2\pi(2.5\text{ kHz})(20\text{ mH}) = 314\ \Omega$
$X_{L3} = 2\pi f L_{tot} = 2\pi(2.5\text{ kHz})(40\text{ mH}) = 628\ \Omega$

$I_{tot} = \dfrac{V_{\text{rms}}}{X_{L(tot)}} = \dfrac{10\text{ V}}{994\ \Omega} = \mathbf{10.1\ mA}$

$I_{L2} = \left(\dfrac{X_{L3}}{X_{L2} + X_{L3}}\right) I_{tot} = \left(\dfrac{628\ \Omega}{314\ \Omega + 628\ \Omega}\right) 10.1\text{ mA} = \mathbf{6.7\ mA}$

$I_{L3} = \left(\dfrac{X_{L2}}{X_{L2} + X_{L3}}\right) I_{tot} = \left(\dfrac{314\ \Omega}{314\ \Omega + 628\ \Omega}\right) 10.1\text{ mA} = \mathbf{3.37\ mA}$

20. (a) L_{tot} = 57.33 mH

$X_L = \frac{V}{I} = \frac{10\text{ V}}{500\text{ mA}} = 20\ \Omega$

$X_L = 2\pi f L_{tot}$

$f = \frac{X_L}{2\pi L_{tot}} = \frac{20\ \Omega}{2\pi(57.3\text{ mH})}$ = **55.6 Hz**

(b) L_{tot} = 4 mH, X_L = 20 Ω

$f = \frac{X_L}{2\pi L_{tot}} = \frac{20\ \Omega}{2\pi(4\text{ mH})}$ = **796 Hz**

(c) L_{tot} = 5.33 mH, X_L = 20 Ω

$f = \frac{X_L}{2\pi L_{tot}} = \frac{20\ \Omega}{2\pi(5.33\text{ mH})}$ = **597 Hz**

21. $X_{L(tot)}$ = 994 Ω from Problem 19.

$P_r = I_{\text{rms}}^2 X_{L(tot)}$ = (10.1 mA)^2(994 Ω) = **101 mVAR**

ADVANCED PROBLEMS

22. $R_{\text{TH}} = R_1 \| R_2 + R_3 \| R_4$

$= 4.7\text{ k}\Omega \| 4.7\text{ k}\Omega + 3.3\text{ k}\Omega \| 6.8\text{ k}\Omega = 4.57\text{ k}\Omega$

$\tau = \frac{L}{R_{\text{TH}}} = \frac{3.3\text{ mH}}{4.57\text{ k}\Omega}$ = **0.722 μs**

23. (a) $v = V_F - (V_i - V_F)e^{-Rt/L}$ (for 60 μs, use 10 μs. The initial voltage is −10 V.)

$= 0\text{ V} + (-10\text{ V} - 0\text{ V})e^{-(8.2\text{ k}\Omega)(10\ \mu\text{s})/75\text{ mH}}$ = **−3.35 V**

(b) $v = V_F - (V_i - V_F)e^{-Rt/L}$ (for 70 μs, use 20 μs for calculation)

$= 0\text{ V} + (-10\text{ V} - 0\text{ V})e^{-(8.2\text{ k}\Omega)(20\ \mu\text{s})/75\text{ mH}}$ = **−1.12 V**

(c) $v = V_F - (V_i - V_F)e^{-Rt/L}$ (for 80 μs, use 30 μs for calculation)

$= 0\text{ V} + (-10\text{ V} - 0\text{ V})e^{-(8.2\text{ k}\Omega)(30\ \mu\text{s})/75\text{ mH}}$ = **−0.37 V**

24. By KVL, V_R is equal and opposite to V_L (because V_S = 0 V). Therefore, V_R = **3.35 V**.

25. $V_{\text{TH}} = \left(\frac{R_2}{R_1 + R_2}\right)V_{\text{S}} - \left(\frac{R_4}{R_3 + R_4}\right)V_{\text{S}} = \left(\frac{4.7\text{ k}\Omega}{9.4\text{ k}\Omega}\right)15\text{ V} - \left(\frac{6.8\text{ k}\Omega}{10.1\text{ k}\Omega}\right)15\text{ V} = -2.6\text{ V}$

$I_F = \frac{V_{\text{TH}}}{R_{\text{TH}}} = \frac{2.6\text{ V}}{4.57\text{ k}\Omega} = 569\ \mu\text{A}$

(a) $i = I_F\left(1 - e^{-t/\tau}\right) = 569\ \mu\text{A}\left(1 - e^{-1\mu\text{s}/0.722\mu\text{s}}\right)$ = **427 μA**

(b) $i = I_F$ = **569 μA**

26. $R_{\text{T}} = (R_1 + R_3) \,||\, (R_2 + R_4) = 8\text{ k}\Omega \,||\, 11.5\text{ k}\Omega = 4.72\text{ k}\Omega$

$$\tau = \frac{L}{R} = \frac{3.3\text{ mH}}{4.72\text{ k}\Omega} = 0.699\ \mu\text{s}$$

$$i = I_i e^{-t/\tau} = (569\ \mu\text{A})e^{-1\mu\text{s}/0.699\mu\text{s}} = \mathbf{136\ \mu A}$$

27. $X_{L1} = 2\pi(3\text{ kHz})(5\text{ mH}) = 94.2\ \Omega$
$X_{L3} = 2\pi(3\text{ kHz})(3\text{ mH}) = 56.5\ \Omega$
$V_{L3} = I_{L3}X_{L3} = (50\text{ mA})(56.5\ \Omega) = 2.83\text{ V}$
$V_{L1} = 10\text{ V} - 2.83\text{ V} = 7.17\text{ V}$

$$I_{L1} = \frac{V_{\text{L1}}}{X_{L1}} = \frac{7.17\text{ V}}{94.2\ \Omega} = 76.1\text{ mA}$$

$I_{L2} = I_{L1} - I_{L3} = 76.1\text{ mA} - 50\text{ mA} =$ **26.1 mA**

28. *Position 1:*
$L_{\text{T}} = 5\text{ mH} + 1\text{ mH} =$ **6 mH**
Position 2:
$L_{\text{T}} = 5\text{ mH} + 100\ \mu\text{H}\ \ 1\text{ mH} =$ **6.1 mH**
Position 3:
$L_{\text{T}} = 5\text{ mH} + 1000\ \mu\text{H} + 100\ \mu\text{H} + 1\text{ mH} =$ **7.1 mH**
Position 4:
$L_{\text{T}} = 5\text{ mH} + 10\text{ mH} + 1000\ \mu\text{H} + 100\ \mu\text{H} + 1\text{ mH} =$ **17.1 mH**

Multisim Troubleshooting Problems

29. L_3 is open.

30. L_1 is shorted.

31. No fault

32. L_2 is open.

33. L_3 is shorted.

CHAPTER 12
RL CIRCUITS

BASIC PROBLEMS

SECTION 12-1 Sinusoidal Response of *RL* Circuits

1. All the frequencies are **15 kHz**.

2. I, V_R, and V_L are all **sinusoidal.**

SECTION 12-2 Impedance and Phase Angle of Series *RL* Circuits

3. (a) $Z = \sqrt{R^2 + X_L^2} = \sqrt{(1.0\text{ k}\Omega)^2 + 500\ \Omega^2} = \mathbf{1.12\ \Omega}$

   (b) $Z = \sqrt{R^2 + X_L^2} = \sqrt{(1.5\text{ k}\Omega)^2 + (1.0\text{ k}\Omega)^2} = \mathbf{1.8\ k\Omega}$

4. (a) $R_{tot} = 47\ \Omega + 10\ \Omega = 57\ \Omega$

   $L_{tot} = 50\text{ mH} + 100\text{ mH} = 150\text{ mH}$

   $X_{L(tot)} = 2\pi f L_{tot} = 2\pi(100\text{ Hz})(150\text{ mH}) = 94.2\ \Omega$

   $Z = \sqrt{R_{tot}^2 + X_{L(tot)}^2} = \sqrt{(57\ \Omega)^2 + (94.2\ \Omega)^2} = \mathbf{110\ \Omega}$

   $$\theta = \tan^{-1}\left(\frac{X_{L(tot)}}{R_{tot}}\right) = \tan^{-1}\left(\frac{94.2\ \Omega}{57\ \Omega}\right) = \mathbf{58.8°}$$

   (b) $$L_{tot} = \frac{(5.0\text{ mH})(8.0\text{ mH})}{5.0\text{ mH} + 8.0\text{ mH}} = 3.08\text{ mH}$$

   $X_{L(tot)} = 2\pi f L_{tot} = 2\pi(20\text{ kHz})(3.08\text{ mH}) = 387\ \Omega$

   $Z = \sqrt{R_{tot}^2 + X_{L(tot)}^2} = \sqrt{(470\ \Omega)^2 + (387\ \Omega)^2} = \mathbf{609\ \Omega}$

   $$\theta = \tan^{-1}\left(\frac{X_{L(tot)}}{R_{tot}}\right) = \tan^{-1}\left(\frac{387\ \Omega}{470\ \Omega}\right) = \mathbf{39.5°}$$

5. (a) $X_L = 2\pi f L = 2\pi(100\text{ Hz})(0.02\text{ H}) = 12.6\ \Omega$

   $Z = \sqrt{R^2 + X_L^2} = \sqrt{(12\ \Omega)^2 + (12.6\ \Omega)^2} = \mathbf{17.4\ \Omega}$

   (b) $X_L = 2\pi f L = 2\pi(500\text{ Hz})(0.02\text{ H}) = 62.8\ \Omega$

   $Z = \sqrt{R^2 + X_L^2} = \sqrt{(12\ \Omega)^2 + (62.8\ \Omega)^2} = \mathbf{64.0\ \Omega}$

(c) $X_L = 2\pi fL = 2\pi(1 \text{ kHz})(0.02 \text{ H}) = 126\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(12\ \Omega)^2 + (126\ \Omega)^2} = \mathbf{127\ \Omega}$

(d) $X_L = 2\pi fL = 2\pi(2 \text{ kHz})(0.02 \text{ H}) = 251\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(12\ \Omega)^2 + (251\ \Omega)^2} = \mathbf{251\ \Omega}$

6. (a) $R = Z\cos\theta = (20\ \Omega)\cos 45° = \mathbf{14.1\ \Omega}$

$X_L = Z\sin\theta = (20\ \Omega)\sin 45° = \mathbf{14.1\ \Omega}$

(b) $R = Z\cos\theta = (500\ \Omega)\cos 35° = \mathbf{410\ \Omega}$

$X_L = Z\sin\theta = (500\ \Omega)\sin 35° = \mathbf{287\ \Omega}$

(c) $R = Z\cos\theta = (2.5\text{ k}\Omega)\cos 72.5° = \mathbf{752\ \Omega}$

$X_L = Z\sin\theta = (2.5\text{ k}\Omega)\sin 72.5° = \mathbf{2.38\ k\Omega}$

(d) $R = Z\cos\theta = (998\ \Omega)\cos 45° = \mathbf{706\ \Omega}$

$X_L = Z\sin\theta = (998\ \Omega)\sin 45° = \mathbf{706\ \Omega}$

SECTION 12-3 Analysis of Series *RL* Circuits

7. $R_{tot} = R_1 + R_2 = 47\ \Omega + 10\ \Omega = 57\ \Omega$

$L_{tot} = L_1 + L_2 = 50 \text{ mH} + 100 \text{ mH} = 150 \text{ mH}$

$X_{L(tot)} = 2\pi fL_{tot} = 2\pi(1 \text{ kHz})(150 \text{ mH}) = 942\ \Omega$

$$V_{R(tot)} = \left(\frac{R_{tot}}{\sqrt{R_{tot}^2 + X_{L(tot)}^2}}\right)V_s = \left(\frac{57\ \Omega}{944\ \Omega}\right)5 \text{ V} = \mathbf{0.302\ V}$$

8. $R_{tot} = 470\ \Omega$

$$L_{tot} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2}} = \frac{1}{\frac{1}{5.0 \text{ mH}} + \frac{1}{8.0 \text{ mH}}} = 3.08 \text{ mH}$$

$X_{L(tot)} = 2\pi fL_{tot} = 2\pi(20 \text{ kHz})(3.08 \text{ mH}) = 387\ \Omega$

$$V_{R(tot)} = \left(\frac{R_{tot}}{\sqrt{R_{tot}^2 + X_L^2}}\right)V_s = \left(\frac{470\ \Omega}{\sqrt{(470\ \Omega)^2 + (387\ \Omega)^2}}\right)8 \text{ V} = \mathbf{6.18\ V}$$

$$V_{L(tot)} = \left(\frac{X_{L(tot)}}{\sqrt{R_{tot}^2 + X_{L(tot)}^2}}\right)V_s = \left(\frac{387\ \Omega}{\sqrt{(470\ \Omega)^2 + (387\ \Omega)^2}}\right)8 \text{ V} = \mathbf{5.08\ V}$$

9. (a) $Z = 1.12\text{ k}\Omega$ from Problem 3.

$$I = \frac{V_s}{Z} = \frac{10 \text{ V}}{1.12\text{ k}\Omega} = \mathbf{8.94\ mA}$$

(b) $Z = 1.8\text{ k}\Omega$ from Problem 3.

$$I = \frac{V_s}{Z} = \frac{5 \text{ V}}{1.8\text{ k}\Omega} = \mathbf{2.77\ mA}$$

10. Using the results of Problem 4:

(a) $I = \dfrac{V_s}{Z} = \dfrac{5\text{ V}}{110\ \Omega}$ = **45.5 mA**

(b) $I = \dfrac{V_s}{Z} = \dfrac{8\text{ V}}{609\ \Omega}$ = **13.1 mA**

11. $X_L = 2\pi(60\text{ Hz})(0.1\text{ H}) = 37.7\ \Omega$

$\theta = \tan^{-1}\left(\dfrac{X_L}{R}\right) = \tan^{-1}\left(\dfrac{37.7\ \Omega}{47\ \Omega}\right)$ = **38.7°**

12. $\theta = \tan^{-1}\left(\dfrac{X_L}{R}\right)$

$X_L = 2\pi(60\text{ Hz})(0.1\text{ H}) = 37.7\ \Omega$

$\theta = \tan^{-1}\left(\dfrac{37.7\ \Omega}{47\ \Omega}\right) = 38.7°$

Double L:

$X_L = 2\pi(60\text{ Hz})(0.2\text{ H}) = 75.4\ \Omega$

$\theta = \tan^{-1}\left(\dfrac{75.4\ \Omega}{47\ \Omega}\right) = 58.1°$

θ increases by 19.4° from 38.7° to 58.1°.

13. The circuit phase angle was determined to be 38.7° in Problem 11. This is the phase angle by which the source voltage leads the current; it is the same as the angle between the resistor voltage and the source voltage. The inductor voltage leads the resistor voltage by 90°. See Figure 12-1.

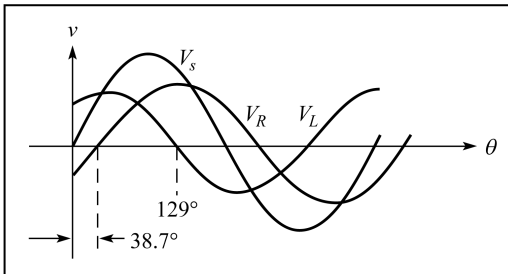


Figure 12-1

14. (a) $X_L = 2\pi(60\text{ Hz})(100\text{ mH}) = 37.7\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(150\ \Omega)^2 + (37.7\ \Omega)^2} = 155\ \Omega$

$V_R = \left(\dfrac{R}{Z}\right)V_s = \left(\dfrac{150\ \Omega}{155\ \Omega}\right)5\text{ V}$ = **4.84 V**

$V_L = \left(\dfrac{X_L}{Z}\right)V_s = \left(\dfrac{37.7\ \Omega}{155\ \Omega}\right)5\text{ V}$ = **1.22 V**

(b) $X_L = 2\pi(200 \text{ Hz})(100 \text{ mH}) = 126\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(150\ \Omega)^2 + (126\ \Omega)^2} = 196\ \Omega$

$V_R = \left(\frac{R}{Z}\right)V_s = \left(\frac{150\ \Omega}{196\ \Omega}\right)5 \text{ V} = \mathbf{3.83\ V}$

$V_L = \left(\frac{X_L}{Z}\right)V_s = \left(\frac{126\ \Omega}{196\ \Omega}\right)5 \text{ V} = \mathbf{3.21\ V}$

(c) $X_L = 2\pi(500 \text{ Hz})(100 \text{ mH}) = 314\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(150\ \Omega)^2 + (314\ \Omega)^2} = 348\ \Omega$

$V_R = \left(\frac{R}{Z}\right)V_s = \left(\frac{150\ \Omega}{348\ \Omega}\right)5 \text{ V} = \mathbf{2.15\ V}$

$V_L = \left(\frac{X_L}{Z}\right)V_s = \left(\frac{314\ \Omega}{348\ \Omega}\right)5 \text{ V} = \mathbf{4.5\ V}$

(d) $X_L = 2\pi(1 \text{ kHz})(100 \text{ mH}) = 628\ \Omega$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(150\ \Omega)^2 + (628\ \Omega)^2} = 646\ \Omega$

$V_R = \left(\frac{R}{Z}\right)V_s = \left(\frac{150\ \Omega}{646\ \Omega}\right)5 \text{ V} = \mathbf{1.16\ V}$

$V_L = \left(\frac{X_L}{Z}\right)V_s = \left(\frac{628\ \Omega}{646\ \Omega}\right)5 \text{ V} = \mathbf{4.86\ V}$

15. (a) $X_L = 2\pi(1 \text{ Hz})(10 \text{ H}) = 62.8\ \Omega$

$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{62.83\ \Omega}{39 \text{ k}\Omega}\right) = \mathbf{0.092°}$

(b) $X_L = 2\pi(100 \text{ Hz})(10 \text{ H}) = 6.28 \text{ k}\Omega$

$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{6.28 \text{ k}\Omega}{39 \text{ k}\Omega}\right) = \mathbf{9.15°}$

(c) $X_L = 2\pi(1 \text{ kHz})(10 \text{ H}) = 62.8 \text{ k}\Omega$

$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{62.8 \text{ k}\Omega}{39 \text{ k}\Omega}\right) = \mathbf{58.2°}$

(d) $X_L = 2\pi(10 \text{ kHz})(10 \text{ H}) = 628 \text{ k}\Omega$

$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{628 \text{ k}\Omega}{39 \text{ k}\Omega}\right) = \mathbf{86.4°}$

16. (a) $\phi = 90° - \tan^{-1}\left(\frac{X_L}{R}\right) = 90° - \tan^{-1}\left(\frac{62.8\ \Omega}{39 \text{ k}\Omega}\right) = \mathbf{89.9°}$

(b) $\phi = 90° - \tan^{-1}\left(\frac{X_L}{R}\right) = 90° - \tan^{-1}\left(\frac{6.28 \text{ k}\Omega}{39 \text{ k}\Omega}\right) = \mathbf{80.9°}$

(c) $\phi = 90° - \tan^{-1}\left(\frac{X_L}{R}\right) = 90° - \tan^{-1}\left(\frac{62.8\text{ k}\Omega}{39\text{ k}\Omega}\right) = \mathbf{31.8°}$

(d) $\phi = 90° - \tan^{-1}\left(\frac{X_L}{R}\right) = 90° - \tan^{-1}\left(\frac{628\text{ k}\Omega}{39\text{ k}\Omega}\right) = \mathbf{3.55°}$

SECTION 12-4 Impedance and Phase Angle of Parallel *RL* Circuits

17. $X_L = 2\pi(2\text{ kHz})(800\ \mu\text{H}) = 10\ \Omega$

$$Y_{tot} = \sqrt{\left(\frac{1}{12\ \Omega}\right)^2 + \left(\frac{1}{10\ \Omega}\right)^2} = 0.13\text{ S}$$

$$Z = \frac{1}{Y_{tot}} = \frac{1}{0.13\text{ S}} = \mathbf{7.69\ \Omega}$$

18. (a) $X_L = 2\pi(1.5\text{ kHz})(800\ \mu\text{H}) = 7.54\ \Omega$

$$Y = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L}\right)^2} = \sqrt{\left(\frac{1}{12\ \Omega}\right)^2 + \left(\frac{1}{7.54\ \Omega}\right)^2} = 0.157\text{ S}$$

$$Z = \frac{1}{Y} = \frac{1}{0.157\text{ S}} = \mathbf{6.37\ \Omega}$$

(b) $X_L = 2\pi(3\text{ kHz})(800\ \mu\text{H}) = 15.1\ \Omega$

$$Y = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L}\right)^2} = \sqrt{\left(\frac{1}{12\ \Omega}\right)^2 + \left(\frac{1}{15.1\ \Omega}\right)^2} = 0.106\text{ S}$$

$$Z = \frac{1}{Y} = \frac{1}{0.106\text{ S}} = \mathbf{9.43\ \Omega}$$

(c) $X_L = 2\pi(5\text{ kHz})(800\ \mu\text{H}) = 25.1\ \Omega$

$$Y = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L}\right)^2} = \sqrt{\left(\frac{1}{12\ \Omega}\right)^2 + \left(\frac{1}{25.1\ \Omega}\right)^2} = 0.092\text{ S}$$

$$Z = \frac{1}{Y} = \frac{1}{0.092\text{ S}} = \mathbf{10.9\ \Omega}$$

(d) $X_L = 2\pi(10\text{ kHz})(800\ \mu\text{H}) = 50.3\ \Omega$

$$Y = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L}\right)^2} = \sqrt{\left(\frac{1}{12\ \Omega}\right)^2 + \left(\frac{1}{50.3\ \Omega}\right)^2} = 0.086\text{ S}$$

$$Z = \frac{1}{Y} = \frac{1}{0.086\text{ S}} = \mathbf{11.6\ \Omega}$$

19. $X_L = 2\pi fL$

$$f = \frac{X_L}{2\pi L} = \frac{12\ \Omega}{2\pi(800\ \mu\text{H})} = \mathbf{2.39\ kHz}$$

SECTION 12-5 Analysis of Parallel *RL* Circuits

20. $$I_R = \frac{10\ \text{V}}{2.2\ \text{k}\Omega} = \mathbf{4.55\ mA}$$

$$I_L = \frac{10\ \text{V}}{3.5\ \text{k}\Omega} = \mathbf{2.86\ mA}$$

$$I_{tot} = \sqrt{(4.55\ \text{mA})^2 + (2.86\ \text{mA})^2} = \mathbf{5.37\ mA}$$

21. (a) $X_L = 2\pi(2\ \text{kHz})(25\ \text{mH}) = 314\ \Omega$

$$Z = \frac{RX_L}{\sqrt{R^2 + X_L^2}} = \frac{(560\ \Omega)(314\ \Omega)}{\sqrt{(560\ \Omega)^2 + (314\ \Omega)^2}} = \mathbf{274\ \Omega}$$

(b) $$I_R = \frac{V_s}{R} = \frac{50\ \text{V}}{560\ \Omega} = \mathbf{89.3\ mA}$$

(c) $$I_L = \frac{V_s}{X_L} = \frac{50\ \text{V}}{314\ \Omega} = \mathbf{159\ mA}$$

(d) $$I_{tot} = \frac{V_s}{Z} = \frac{50\ \text{V}}{274\ \Omega} = \mathbf{183\ mA}$$

(e) $$\theta = \tan^{-1}\left(\frac{R}{X_L}\right) = \tan^{-1}\left(\frac{560\ \Omega}{314\ \Omega}\right) = \mathbf{60.7^\circ}$$

22. $$Z_{tot} = \frac{(R_1 + R_2)X_L}{\sqrt{(R_1 + R_2)^2 + X_L^2}} = \frac{(11.5\ \text{k}\Omega)(5.0\ \text{k}\Omega)}{12.54\ \text{k}\Omega} = 4.59\ \text{k}\Omega$$

$$\theta = \tan^{-1}\left(\frac{11.5\ \text{k}\Omega}{5.0\ \text{k}\Omega}\right) = 66.5^\circ$$

$R_{eq} = Z_{tot}\cos\theta = (4.59\ \text{k}\Omega)\cos 66.5^\circ = \mathbf{1.83\ k\Omega}$

$X_{L(eq)} = Z_{tot}\sin\theta = (4.59\ \text{k}\Omega)\sin 66.5^\circ = \mathbf{4.21\ k\Omega}$

SECTION 12-6 Analysis of Series-Parallel *RL* Circuits

23. $X_L = 2\pi(100\ \text{kHz})(1.0\ \text{mH}) = 628\ \Omega$

$$Z_p = \frac{R_2X_L}{\sqrt{R_2^2 + X_L^2}} = \frac{(1500\ \Omega)(628\ \Omega)}{\sqrt{(1500\ \Omega)^2 + (628\ \Omega)^2}} = 579\ \Omega$$

$$\theta = \tan^{-1}\left(\frac{R_2}{X_L}\right) = \tan^{-1}\left(\frac{1500\ \Omega}{628\ \Omega}\right) = 67.3^\circ$$

$R_{eq} = Z_p\cos\,\theta = (579\ \Omega)\cos 67.3° = 224\ \Omega$
$X_{L(eq)} = Z_p\sin\,\theta = (579\ \Omega)\sin 67.3° = 534\ \Omega$
$Z_{tot} = \sqrt{(R_1 + R_{eq})^2 + X_{L(eq)}^2} = \sqrt{(444\ \Omega)^2 + (534\ \Omega)^2} = 694\ \Omega$

$I_{tot} = \dfrac{25\text{ V}}{694\ \Omega} = 36\text{ mA}$

$V_{R1} = I_{tot}R_1 = (36\text{ mA})(220\ \Omega) = \mathbf{7.92\ V}$
$V_{R2} = V_L = I_{tot}Z_p = (36\text{ mA})(579\ \Omega) = \mathbf{20.8\ V}$

24. The circuit is predominantly inductive because $X_{L(eq)} > R_{tot}$.

25. Using the results of Problem 23:
$I_{tot} = \mathbf{36\ mA}$

$I_L = \dfrac{V_L}{X_L} = \dfrac{20.8\text{ V}}{628\ \Omega} = \mathbf{33.2\ mA}$

$I_{R2} = \dfrac{V_{R2}}{R_2} = \dfrac{20.8\text{ V}}{1500\ \Omega} = \mathbf{13.9\ mA}$

SECTION 12-7 Power in *RL* Circuits

26. $P_a = \sqrt{P_{true}^2 + P_r^2} = \sqrt{(100\text{ mW})^2 + (340\text{ mVAR})^2} = \mathbf{354\ mVA}$

27. $X_L = 2\pi(60\text{ Hz})(0.1\text{ H}) = 37.7\ \Omega$
$Z = \sqrt{R^2 + X_L^2} = \sqrt{(47\ \Omega)^2 + (37.7\ \Omega)^2} = 60.3\ \Omega$

$I_{tot} = \dfrac{V_s}{Z} = \dfrac{1\text{ V}}{60.3\ \Omega} = 16.6\text{ mA}$

$P_{true} = I_{tot}^2R = (16.6\text{ mA})^2(47\ \Omega) = \mathbf{13.0\ mW}$
$P_r = I_{tot}^2X_L = (16.6\text{ mA})^2(37.7\ \Omega) = \mathbf{10.4\ mVAR}$

28. $\theta = \tan^{-1}\left(\dfrac{R}{X_L}\right) = \tan^{-1}\left(\dfrac{2.2\text{ k}\Omega}{3.5\text{ k}\Omega}\right) = 32.2°$
$PF = \cos\,\theta = \cos 32.2° = \mathbf{0.846}$

29. Using the results of Problems 23 and 25:
$PF = \cos\,\theta = \cos 67.3° = \mathbf{0.386}$
$P_{true} = V_sI\cos\,\theta = (25\text{ V})(36\text{ mA})(0.386) = \mathbf{347\ mW}$
$P_r = I_L^2X_L = (33.2\text{ mA})^2(628\ \Omega) = \mathbf{692\ mVAR}$
$P_a = V_sI_{tot} = (25\text{ V})(36\text{ mA}) = \mathbf{900\ mVA}$

SECTION 12-8 Basic Applications

30. Use the formula, $V_{out} = \left(\dfrac{R}{Z_{tot}}\right)V_{in}$. See Figure 12-2.

Frequency (kHz)	X_L (kΩ)	Z_{tot} (kΩ)	V_{out} (V)
0	0	39	1
1	62.8	73.9	0.53
2	126	132	0.30
3	189	193	0.20
4	251	254	0.15
5	314	316	0.12

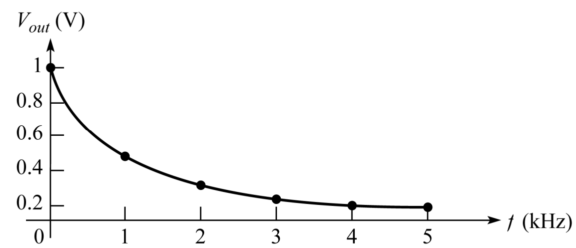


Figure 12-2

31. Use the formula, $V_{out} = \left(\dfrac{X_L}{Z_{tot}}\right)V_{in}$. See Figure 12-3.

Frequency (kHz)	X_L (kΩ)	Z_{tot} (kΩ)	V_{out} (mV)
0	0	39	0
1	62.8	73.9	42.5
2	126	132	47.7
3	189	193	49.0
4	251	254	49.4
5	314	316	49.7

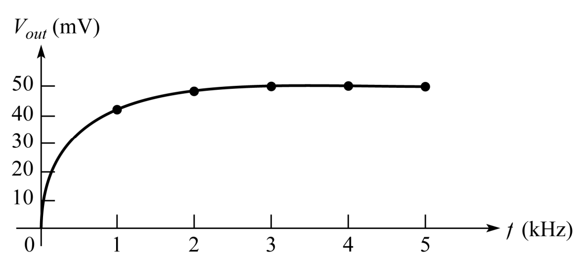


Figure 12-3

32. For Figure 12-55: See Figure 12-4(a).
$X_L = 2\pi(8\text{ kHz})(10\text{ H}) = 503\text{ k}\Omega$
$Z = \sqrt{R^2 + X_L^2} = \sqrt{(39\text{ k}\Omega)^2 + (503\text{ k}\Omega)^2} = 505\text{ k}\Omega$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{503\text{ k}\Omega}{39\text{ k}\Omega}\right) = \mathbf{85.6°}$$

$$V_R = \left(\frac{R}{Z}\right)V_{in} = \left(\frac{39\text{ k}\Omega}{505\text{ k}\Omega}\right)1\text{ V} = \mathbf{77.2\text{ mV}}$$

$$V_L = \left(\frac{X_L}{Z}\right)V_{in} = \left(\frac{503\text{ k}\Omega}{505\text{ k}\Omega}\right)1\text{ V} = \mathbf{996\text{ mV}}$$

For Figure 12-56: See Figure 12-4(b).

$X_L = 2\pi(8\text{ kHz})(10\text{ H}) = 503\text{ k}\Omega$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(39\text{ k}\Omega)^2 + (503\text{ k}\Omega)^2} = 505\text{ k}\Omega$$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{503\text{ k}\Omega}{39\text{ k}\Omega}\right) = \mathbf{85.6°}$$

$$V_R = \left(\frac{R}{Z}\right)V_{in} = \left(\frac{39\text{ k}\Omega}{505\text{ k}\Omega}\right)50\text{ mV} = \mathbf{3.86\text{ mV}}$$

$$V_L = \left(\frac{X_L}{Z}\right)V_{in} = \left(\frac{503\text{ k}\Omega}{505\text{ k}\Omega}\right)50\text{ mV} = \mathbf{49.8\text{ mV}}$$

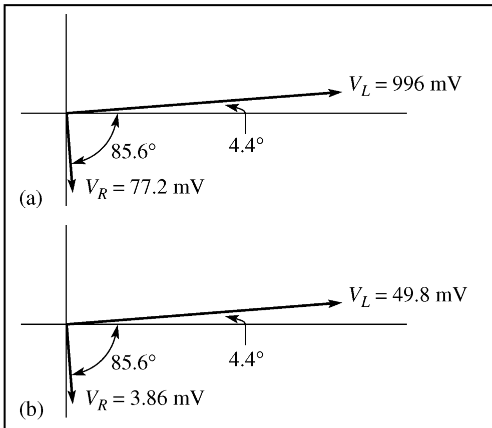


Figure 12-4

SECTION 12-9 Troubleshooting

33. $V_{R1} = V_{L1} = \mathbf{18\text{ V}}$
    $V_{R2} = V_{R3} = V_{L2} = \mathbf{0\text{ V}}$

34. (a) $V_{out} = \mathbf{0\text{ V}}$
    (b) $V_{out} = \mathbf{0\text{ V}}$
    (c) $V_{out} = \mathbf{0\text{ V}}$
    (d) $V_{out} = \mathbf{0\text{ V}}$

ADVANCED PROBLEMS

35. See Figure 12-5(a).

$R_{th} = R_3 + R_1 \parallel R_2 = 33\ \Omega + 56\ \Omega \parallel 22\ \Omega = 48.8\ \Omega$

$$V_{th} = \left(\frac{R_2}{R_1 + R_2}\right)25\text{ V} = \left(\frac{22\ \Omega}{78\ \Omega}\right)25\text{ V} = 7.05\text{ V}$$

See Figure 12-5(b):

$$L_{tot} = \frac{1}{\dfrac{1}{50\text{ mH}} + \dfrac{1}{50\text{ mH}}} = 25\text{ mH}$$

$X_{L(tot)} = 2\pi f L_{tot} = 2\pi(400\text{ Hz})(25\text{ mH}) = 62.8\ \Omega$

$$V_L = \left(\frac{X_{L(tot)}}{\sqrt{R_{th}^2 + X_{L(tot)}^2}}\right)V_{th} = \left(\frac{62.8\ \Omega}{\sqrt{(48.8\ \Omega)^2 + (62.8\ \Omega)^2}}\right)7.05\text{ V} = \mathbf{5.57\ V}$$

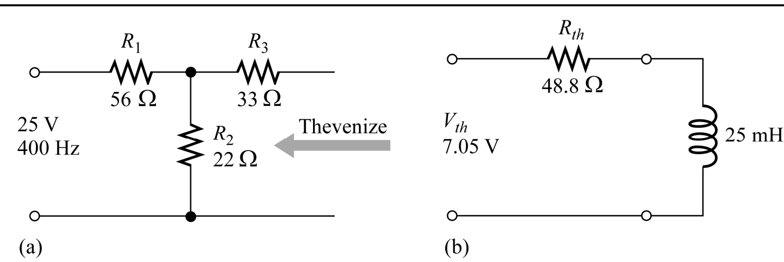


Figure 12-5

36. Since $X_{L(tot)} > R_{th}$, the circuit is predominantly **inductive**.

37. From Problem 35,

$X_{L(tot)} = 62.8\ \Omega$

$$Z_{tot} = R_1 + R_2 \parallel \sqrt{R_3^2 + X_{L(tot)}^2} = 56\ \Omega + 22\ \Omega \parallel \sqrt{(33\ \Omega)^2 + (62.8\ \Omega)^2} = 72.8\ \Omega$$

$$I_{tot} = \frac{V_s}{Z_{tot}} = \frac{25\text{ V}}{72.8\ \Omega} = \mathbf{343\ mA}$$

38. (a) $X_L = 2\pi f L = 2\pi(80\text{ kHz})(8.0\text{ mH}) = 4.02\text{ k}\Omega$

$$Z_{tot} = R_1 \parallel \left(R_2 + R_3 \parallel \sqrt{R_4^2 + X_L^2}\right)$$

$$= 1.2\text{ k}\Omega \parallel \left(1.0\text{ k}\Omega + 3.3\text{ k}\Omega \parallel \sqrt{(5.6\text{ k}\Omega)^2 + (4.02\text{ k}\Omega)^2}\right)$$

$$= \mathbf{875\ \Omega}$$

(b) $$I_{tot} = \frac{V_s}{Z_{tot}} = \frac{18\text{ V}}{875\ \Omega} = \mathbf{20.6\ mA}$$

(c) $R_{tot} = R_1 \parallel (R_2 + R_3) + R_4 = 1.2\text{ k}\Omega \parallel 4.3\text{ k}\Omega + 5.6\text{ k}\Omega = 6.54\text{ k}\Omega$

$$\theta = \tan^{-1}\left(\frac{X_L}{R_{tot}}\right) = \tan^{-1}\left(\frac{4.02\text{ k}\Omega}{6.54\text{ k}\Omega}\right) = \mathbf{31.6^\circ}$$

(d) See Figure 12-6(a).

$R_{th} = R_4 + R_2 \parallel R_3 = 5.6\ \text{k}\Omega + 1.0\ \text{k}\Omega \parallel 3.3\ \text{k}\Omega = 6.37\ \text{k}\Omega$

$$V_{th} = \left(\frac{R_3}{R_2 + R_3}\right)V_s = \left(\frac{3.3\ \text{k}\Omega}{4.3\ \text{k}\Omega}\right)18\ \text{V} = 13.8\ \text{V}$$

$$V_L = \left(\frac{X_L}{\sqrt{R_{th}^2 + X_L^2}}\right)V_{th} = \left(\frac{4.02\ \text{k}\Omega}{\sqrt{(6.37\ \text{k}\Omega)^2 + (4.02\ \text{k}\Omega)^2}}\right)13.8\ \text{V} = \mathbf{7.37\ V}$$

(e) See Figure 12-6(b) and (c):

$R_{th} = R_2 \parallel R_3 = 1.0\ \text{k}\Omega \parallel 3.3\ \text{k}\Omega = 767\ \Omega$

$$V_{th} = \left(\frac{R_3}{R_2 + R_3}\right)V_s = \left(\frac{3.3\ \text{k}\Omega}{4.4\ \text{k}\Omega}\right)18\ \text{V} = 13.8\ \text{V}$$

The voltage across the R_4-L combination is the same as the voltage across R_3.

$$V_{R3} = \left(\frac{\sqrt{R_4^2 + X_L^2}}{\sqrt{(R_{th} + R_4)^2 + X_L^2}}\right)V_{th}$$

$$= \left(\frac{\sqrt{(5.6\ \text{k}\Omega)^2 + (4.02\ \text{k}\Omega)^2}}{\sqrt{(6.37\ \text{k}\Omega)^2 + (4.02\ \text{k}\Omega)^2}}\right)13.8\ \text{V} = \left(\frac{6.89\ \text{k}\Omega}{7.53\ \text{k}\Omega}\right)13.8\ \text{V} = \mathbf{12.6\ V}$$

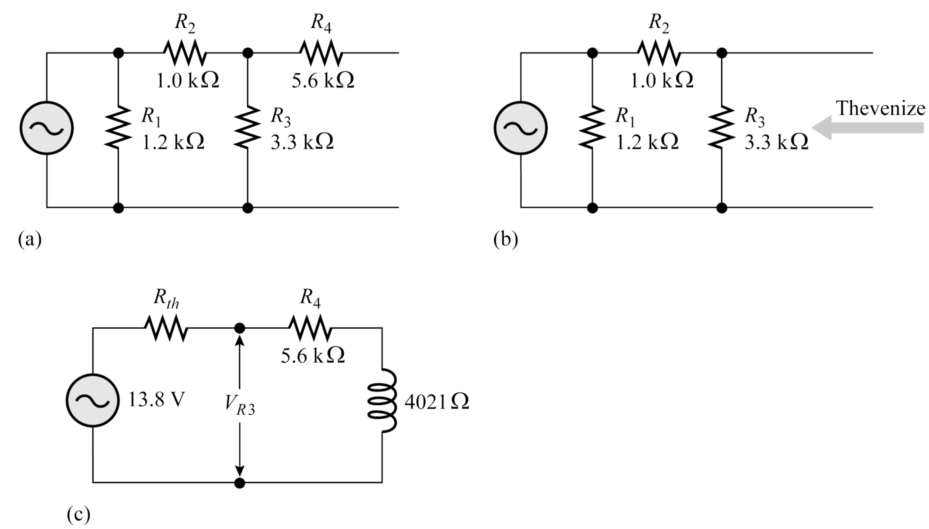


Figure 12-6

39. (a) $Z_{R_2-X_{L1}} = \frac{R_2 X_{L1}}{\sqrt{R_2^2 + X_{L1}^2}} = \frac{(68\ \Omega)(100\ \Omega)}{\sqrt{(68\ \Omega)^2 + (100\ \Omega)^2}} = 56.2\ \Omega$

$\theta_{R_2-X_{L1}} = \tan^{-1}\left(\frac{R_2}{X_{L1}}\right) = \tan^{-1}\left(\frac{68\ \Omega}{100\ \Omega}\right) = 34.2°$

Converting the parallel combination of R_2 and X_{L1} to an equivalent series form:

$R_{eq} = Z_{R_2-X_{L1}} \cos\theta_{R_2-X_{L1}} = (56.2\ \Omega)\cos 34.2° = 46.5\ \Omega$

$X_{L(eq)} = Z_{R_2-X_{L1}} \sin\theta_{R_2-X_{L1}} = (56.2\ \Omega)\sin 34.2° = 31.6\ \Omega$

$Z_B = \sqrt{(R_1 + R_{eq})^2 + X_{L(eq)}^2} = \sqrt{(47\ \Omega + 46.5\ \Omega)^2 + (31.6\ \Omega)^2} = 98.7\ \Omega$

$I_{R1} = \frac{V_s}{Z_B} = \frac{40\text{ V}}{98.7\ \Omega} = \mathbf{405\ mA}$

(b) $I_{L1} = \left(\frac{R_2}{\sqrt{R_2^2 + X_{L1}^2}}\right) I_{R1} = \left(\frac{68\ \Omega}{\sqrt{(68\ \Omega)^2 + (100\ \Omega)^2}}\right) 405\text{ mA} = \mathbf{228\ mA}$

(c) $X_{L2-L3} = X_{L2} + X_{L3} = 75\ \Omega + 45\ \Omega = 120\ \Omega$

$I_{L2} = \frac{V_s}{X_{L2-L3}} = \frac{40\text{ V}}{120\ \Omega} = \mathbf{333\ mA}$

(d) $I_{R2} = \left(\frac{X_{L1}}{\sqrt{R_2^2 + X_{L1}^2}}\right) I_{R1} = \left(\frac{100\ \Omega}{\sqrt{(68\ \Omega)^2 + (100\ \Omega)^2}}\right) 405\text{ mA} = \mathbf{335\ mA}$

40. $R_4 + R_5 = 3.9\text{ k}\Omega + 6.8\text{ k}\Omega = 10.7\text{ k}\Omega$

$R_3 \parallel (R_4 + R_5) = 4.7\text{ k}\Omega \parallel 10.7\text{ k}\Omega = 3.27\text{ k}\Omega$

$R_2 + R_3 \parallel (R_4 + R_5) = 5.6\text{ k}\Omega + 3.27\text{ k}\Omega = 8.87\text{ k}\Omega$

$R_{tot} = R_1 \parallel (R_2 + R_3 \parallel (R_4 + R_5)) = 3.3\text{ k}\Omega \parallel 8.87\text{ k}\Omega = 2.41\text{ k}\Omega$

$X_L = 2\pi(10\text{ k}\Omega)(50\text{ mH}) = 3.14\text{ k}\Omega$

$\theta = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{3.14\text{ k}\Omega}{2.41\text{ k}\Omega}\right) = \mathbf{52.5°}$ $\mathbf{V_{out}}$ **lags** $\mathbf{V_{in}}$

$V_{R1} = \left(\frac{R_{tot}}{\sqrt{R_{tot}^2 + X_L^2}}\right) V_{in} = \left(\frac{2.41\text{ k}\Omega}{\sqrt{(2.41\text{ k}\Omega)^2 + (3.14\text{ k}\Omega)^2}}\right) 1\text{ V} = 609\text{ mV}$

$V_{R3} = \left(\frac{R_3 \parallel (R_4 + R_5)}{R_3 \parallel (R_4 + R_5) + R_2}\right) V_{R1} = \left(\frac{3.27\text{ k}\Omega}{3.27\text{ k}\Omega + 5.6\text{ k}\Omega}\right) 609\text{ mV} = 225\text{ mV}$

$V_{out} = V_{R5} = \left(\frac{R_5}{R_4 + R_5}\right) V_{R3} = \left(\frac{6.8\text{ k}\Omega}{3.9\text{ k}\Omega + 6.8\text{ k}\Omega}\right) 225\text{ mV} = 143\text{ mV}$

Attenuation = $\frac{V_{out}}{V_{in}} = \frac{143\text{ mV}}{1\text{ V}} = \mathbf{0.143}$

41. $L_{tot} = \left((L_4 + L_5) \parallel L_3 + L_2\right) \parallel L_1$

$= \left((1.0\text{ mH} + 1.0\text{ mH}) \parallel 2.0\text{ mH} + 1.0\text{ mH}\right) \parallel 2.0\text{ mH}$

$= (1.0\text{ mH} + 1.0\text{ mH}) \parallel 2.0\text{ mH} = 2.0\text{ mH} \parallel 2.0\text{ mH} = 1.0\text{ mH}$

$X_{L(tot)} = 2\pi fL = 62.8\ \Omega$

$$V_{L(tot)} = \left(\frac{X_{L(tot)}}{\sqrt{R^2 + X_{L(tot)}^2}}\right)V_{in}$$

$$= \left(\frac{62.8\ \Omega}{\sqrt{(100\ \Omega)^2 + (62.8\ \Omega)^2}}\right)1\text{ V} = 0.532\text{ V}$$

$$V_{L3-4-5} = \left(\frac{62.8\ \Omega}{125.6\ \Omega}\right)0.532\text{ V} = 0.265\text{ V}$$

$$V_{out} = \left(\frac{62.8\ \Omega}{125.6\ \Omega}\right)0.265\text{ V} = 0.133\text{ V}$$

$$\text{Attenuation} = \frac{V_{out}}{V_{in}} = \frac{0.133\text{ V}}{1\text{ V}} = \mathbf{0.133}$$

42. $R_1 = \dfrac{12\text{ V}}{1\text{ A}} = 12\ \Omega$

$R_2 = \dfrac{2.5\text{ kV}}{1\text{ A}} = 2.5\text{ k}\Omega$

See Figure 12-7. When the switch is thrown from position 1 to position 2, the inductance will attempt to keep 1 A through R_2, thus a 2.5 kV spike is created across R_2 for a short time. This design neglects the arcing of the switch, assuming instantaneous closure from position 1 to position 2. The value of L is arbitrary since no time constant requirements are imposed.

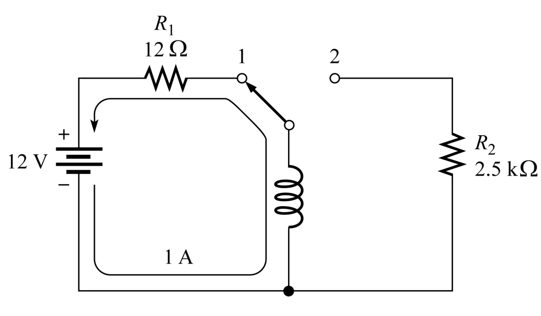


Figure 12-7

43. See Figure 12-8. The correct output voltage is calculated as follows:

$X_L = 2\pi fL = 2\pi(10\text{ kHz})(50\text{ mH}) = 3142\ \Omega$

$3.9\text{ k}\Omega + 6.8\text{ k}\Omega = 10.7\text{ k}\Omega$

$4.7\text{ k}\Omega \parallel 10.7\text{ k}\Omega = 3.27\text{ k}\Omega$

$5.6\text{ k}\Omega + 3.27\text{ k}\Omega = 8.87\text{ k}\Omega$

$3.3\text{ k}\Omega \parallel 8.87\text{ k}\Omega = 2.41\text{ k}\Omega$

$$V_A = \left(\frac{2.41\text{ k}\Omega}{\sqrt{(2.41\text{ k}\Omega)^2 + (3.142\text{ k}\Omega)^2}}\right)1\text{ V} = 0.609\text{ V}$$

$$V_B = \left(\frac{3.27\text{ k}\Omega}{3.27\text{ k}\Omega + 5.6\text{ k}\Omega}\right)0.609\text{ V} = 0.225\text{ V}$$

$$V_{out} = \left(\frac{6.8\text{ k}\Omega}{6.8\text{ k}\Omega + 3.9\text{ k}\Omega}\right)0.225\text{ V} = 0.143\text{ V}$$

The measured output is approximately 0.3 V peak, which is incorrect.
After trial and error, we find that if **the 4.7 kΩ is open** we get:
R_{tot} = 3.3 kΩ ‖ (5.6 kΩ + 3.9 kΩ + 6.8 kΩ) = 2.74 kΩ

$$V_A = \left(\frac{2.74\text{ k}\Omega}{\sqrt{(2.74\text{ k}\Omega)^2 + (3.142\text{ k}\Omega)^2}}\right)1\text{ V} = 0.657\text{ V}$$

$$V_{out} = \left(\frac{6.8\text{ k}\Omega}{5.6\text{ k}\Omega + 3.9\text{ k}\Omega + 6.8\text{ k}\Omega}\right)0.657\text{ V} = 0.274\text{ V}$$

This is relatively close to the measured value. Component tolerances could give us the scope reading.

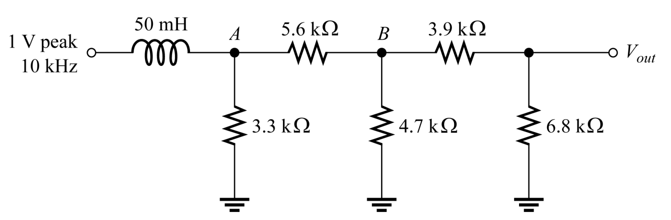


Figure 12-8

Multisim Troubleshooting Problems

44. R_2 is shorted.

45. L_2 is open.

46. L_1 is shorted.

47. R_2 is open.

48. No fault

49. L_1 is shorted.

CHAPTER 13
RLC CIRCUITS AND RESONANCE

BASIC PROBLEMS

SECTION 13-1 Impedance and Phase Angle of Series *RLC* Circuits

1. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(5\text{ kHz})(0.047\ \mu\text{F})} = 677\ \Omega$

   $X_L = 2\pi fL = 2\pi(5\text{ kHz})(5\text{ mH}) = 157\ \Omega$

   $Z = \sqrt{R^2 + (X_C - X_L)^2}$

   $= \sqrt{(10\ \Omega)^2 + (677\ \Omega - 157\ \Omega)^2} = \sqrt{(10\ \Omega)^2 + (520\ \Omega)^2} = \mathbf{520\ \Omega}$

   $\theta = \tan^{-1}\left(\dfrac{X_C - X_L}{R}\right) = \tan^{-1}\left(\dfrac{520\ \Omega}{10\ \Omega}\right) = \mathbf{88.9°}$ (V_s lagging I)

   $X_{tot} = X_C - X_L = \mathbf{520\ \Omega}$ **Capacitive**

2. $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(4.7\text{ k}\Omega)^2 + (8.0\text{ k}\Omega - 3.5\text{ k}\Omega)^2} = \mathbf{6.51\ k\Omega}$

3. Doubling f doubles X_L and halves X_C, thus increasing the net reactance and, therefore, the **impedance increases.**

SECTION 13-2 Analysis of Series *RLC* Circuits

4. $Z_{tot} = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(4.7\text{ k}\Omega)^2 + (4.5\text{ k}\Omega)^2} = 6.51\text{ k}\Omega$

   $I_{tot} = \dfrac{V_s}{Z_{tot}} = \dfrac{4\text{ V}}{6.51\text{ k}\Omega} = \mathbf{614\ \mu A}$

   $V_R = I_{tot}R = (614\ \mu\text{A})(4.7\text{ k}\Omega) = \mathbf{2.89\ V}$
   $V_L = I_{tot}X_L = (614\ \mu\text{A})(8.0\text{ k}\Omega) = \mathbf{4.91\ V}$
   $V_C = I_{tot}X_C = (614\ \mu\text{A})(3.5\text{ k}\Omega) = \mathbf{2.15\ V}$

5. $\theta = \tan^{-1}\left(\dfrac{X_{tot}}{R}\right) = \tan^{-1}\left(\dfrac{4.5\text{ k}\Omega}{4.7\text{ k}\Omega}\right) = 43.8°$

   The voltage values were determined in Problem 4. V_R lags V_s by 43.8° because it is in phase with I. V_L and V_C are each 90° away from V_R and 180° out of phase with each other. See Figure 13-1.

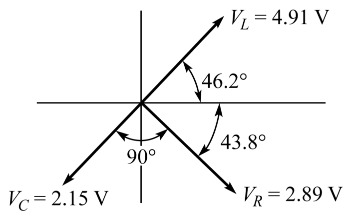


Figure 13-1

6. $R_{tot} = R_1 \parallel R_2 = 220\ \Omega \parallel 390\ \Omega = 141\ \Omega$
$L_{tot} = L_1 + L_2 = 0.5\text{ mH} + 1.0\text{ mH} = 1.5\text{ mH}$
$C_{tot} = C_1 + C_2 = 0.01\ \mu\text{F} + 1800\text{ pF} = 0.0118\ \mu\text{F}$
$X_{L(tot)} = 236\ \Omega$
$X_{C(tot)} = 540\ \Omega$
$Z_{tot} = \sqrt{R_{tot}^2 + (X_{L(tot)} - X_{C(tot)})^2} = \sqrt{(141\ \Omega)^2 + (304\ \Omega)^2} = 335\ \Omega$

(a) $I_{tot} = \dfrac{V_s}{Z_{tot}} = \dfrac{12\text{ V}}{335\ \Omega} = \mathbf{35.8\ mA}$

(b) $P_{\text{true}} = I_{tot}^2 R_{tot} = (35.8\text{ mA})^2(141\ \Omega) = \mathbf{181\ mW}$

(c) $P_r = I_{tot}^2 X_{tot} = (35.8\text{ mA})^2(304\ \Omega) = \mathbf{390\ mVAR}$

(d) $P_a = \sqrt{(P_{\text{true}})^2 + (P_r)^2} = \mathbf{430\ mVA}$

SECTION 13-3 Series Resonance

7. Because $X_C < X_L$, f_r is less than the frequency indicated.

8. $X_C = X_L$ at resonance.
$V_R = V_s = \mathbf{12\ V}$

9. $f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(1\text{ mH})(47\text{ pF})}} = 734\text{ kHz}$
$X_L = 2\pi f_r L = 2\pi(734\text{ kHz})(1\text{ mH}) = \mathbf{4.61\ k\Omega}$
$X_C = X_L = \mathbf{4.61\ k\Omega}$
$Z_{tot} = R = \mathbf{220\ \Omega}$
$I = \dfrac{V_s}{Z_{tot}} = \dfrac{12\text{ V}}{220\ \Omega} = \mathbf{54.5\ mA}$

10. $V_C = V_L = 100\text{ V}$ at resonance
$Z = R = \dfrac{V_s}{I_{max}} = \dfrac{10\text{ V}}{50\text{ mA}} = \mathbf{200\ \Omega}$
$X_L = X_C = \dfrac{V_L}{I_{max}} = \dfrac{100\text{ V}}{50\text{ mA}} = \mathbf{2\ k\Omega}$

11. $f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(82\ \mu\text{H})(1.5\ \text{nF})}} = \mathbf{454\ kHz}$

$X_L = 2\pi fL = 2\pi(454\ \text{kHz})(82\ \mu\text{H}) = 234\ \Omega$

$Q = \dfrac{X_L}{R} = \dfrac{234\ \Omega}{39\ \Omega} = 6$

$BW = \dfrac{f_r}{Q} = \dfrac{454\ \text{kHz}}{6} = 75.7\ \text{kHz}$

$f_{c1} = f_r - \dfrac{BW}{2} = 454\ \text{kHz} - \dfrac{75.7\ \text{kHz}}{2} = \mathbf{416\ kHz}$

$f_{c2} = f_r + \dfrac{BW}{2} = 454\ \text{kHz} + \dfrac{75.7\ \text{kHz}}{2} = \mathbf{492\ kHz}$

12. $I_{max} = \dfrac{V_s}{R} = \dfrac{3.0\ \text{V}}{39\ \Omega} = 77\ \text{mA}$

$I_{half\text{-}power} = 0.707 I_{max} = 0.707(77\ \text{mA}) = \mathbf{54\ mA}$

SECTION 13-4 Series Resonant Filters

13. (a) $f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(12\ \text{mH})(0.01\ \mu\text{F})}} = \mathbf{14.5\ kHz}$

(b) $f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(2\ \text{mH})(0.022\ \mu\text{F})}} = \mathbf{24.0\ kHz}$

These are bandpass filters.

14. (a) $R_{tot} = 10\ \Omega + 75\ \Omega = 85\ \Omega$

$f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(12\ \text{mH})(0.01\ \mu\text{F})}} = 14.5\ \text{kHz}$

$X_L = 2\pi(14.5\ \text{kHz})(12\ \text{mH}) = 1.09\ \text{k}\Omega$

$Q = \dfrac{X_L}{R_{tot}} = \dfrac{1.09\ \text{k}\Omega}{85\ \Omega} = 13$

$BW = \dfrac{f_r}{Q} = \dfrac{14.5\ \text{kHz}}{13} = \mathbf{1.12\ kHz}$

(b) $R_{tot} = 10\ \Omega + 22\ \Omega = 32\ \Omega$

$f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(2\ \text{mH})(0.022\ \mu\text{F})}} = 24.0\ \text{kHz}$

$X_L = 2\pi(24.0\ \text{kHz})(2\ \text{mH}) = 302\ \Omega$

$Q = \dfrac{X_L}{R_{tot}} = \dfrac{302\ \Omega}{32\ \Omega} = 9.44$

$BW = \dfrac{f_r}{Q} = \dfrac{24.0\ \text{kHz}}{9.44} = \mathbf{2.54\ kHz}$

15. (a) $f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(100\,\mu\text{H})(0.0022\,\mu\text{F})}}$ = **339 kHz**

$X_L = 2\pi(339\text{ kHz})(100\ \mu\text{H}) = 213\ \Omega$

$Q = \dfrac{X_L}{R} = \dfrac{213\ \Omega}{150\ \Omega} = 1.42$

$BW = \dfrac{f_r}{Q} = \dfrac{339\text{ kHz}}{1.42}$ = **239 kHz**

(b) $f_r = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(5\text{ mH})(0.047\,\mu\text{F})}}$ = **10.4 kHz**

$X_L = 2\pi(10.4\text{ kHz})(5\text{ mH}) = 327\ \Omega$

$Q = \dfrac{X_L}{R} = \dfrac{327\ \Omega}{82\ \Omega} = 3.99$

$BW = \dfrac{f_r}{Q} = \dfrac{10.4\text{ kHz}}{3.99}$ = **2.61 kHz**

SECTION 13-5 Parallel *RLC* Circuits

16. $X_L = 2\pi fL = 2\pi(12\text{ kHz})(15\text{ mH}) = 1.13\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(12\text{ kHz})(0.022\,\mu\text{F})} = 603\ \Omega$

$Y = \sqrt{\left(\dfrac{1}{R}\right)^2 + \left(\dfrac{1}{X_C} - \dfrac{1}{X_L}\right)^2} = \sqrt{\left(\dfrac{1}{100\ \Omega}\right)^2 + \left(\dfrac{1}{603\ \Omega} - \dfrac{1}{1.13\text{ k}\Omega}\right)^2}$

$= \sqrt{(0.01\text{ S})^2 + (16.58\times10^{-4}\text{ S} - 8.84\times10^{-4}\text{ S})^2} = 10.03\text{ mS}$

$Z_{tot} = \dfrac{1}{Y} = \dfrac{1}{10.03\text{ mS}}$ = **99.7 Ω**

17. $X_L = 2\pi(12\text{ kHz})(15\text{ mH}) = 1.13\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi(12\text{ kHz})(0.022\,\mu\text{F})} = 603\ \Omega$

Since $X_C < X_L$, the parallel circuit is **predominantly capacitive**.
The smaller reactance in a parallel circuit dominates the circuit response because it has the largest current.

18. $I_{tot} = \dfrac{V_s}{Z_{tot}} = \dfrac{5\text{ V}}{99.7\ \Omega}$ ≅ **50.2 mA**

$I_R = \dfrac{V_s}{R} = \dfrac{5\text{ V}}{100\ \Omega}$ = **50.0 mA**

$I_L = \dfrac{V_s}{X_L} = \dfrac{5\text{ V}}{1.13\text{ k}\Omega}$ = **4.42 mA**

$I_C = \dfrac{V_s}{X_C} = \dfrac{5\text{ V}}{603\ \Omega}$ = **8.29 mA**

$V_R = V_L = V_C = V_s$ = **5 V**

19. $X_L = 2\pi fL = 2\pi(10\text{ kHz})(10\text{ mH}) = 628\ \Omega$

$$B_L = \frac{1}{X_L} = \frac{1}{628\ \Omega} = 1.59\text{ mS}$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(10\text{ kHz})(15\text{ nF})} = 1.06\text{ k}\Omega$$

$$B_C = \frac{1}{X_C} = \frac{1}{1.06\text{ k}\Omega} = 942\ \mu\text{S}$$

$R_W = 80\ \Omega$

$$Q = \frac{X_L}{R} = \frac{628\ \Omega}{80\ \Omega} = 7.85$$

$$R_{p(\text{eq})} = R_W\left(Q^2+1\right) = 80\ \Omega\left(7.85^2+1\right) = 5.01\text{ k}\Omega$$

$$G_{p(\text{eq})} = \frac{1}{R_{p(\text{eq})}} = \frac{1}{5.01\text{ k}\Omega} = 200\ \mu\text{S}$$

The equivalent circuit is shown in Figure 13-2.

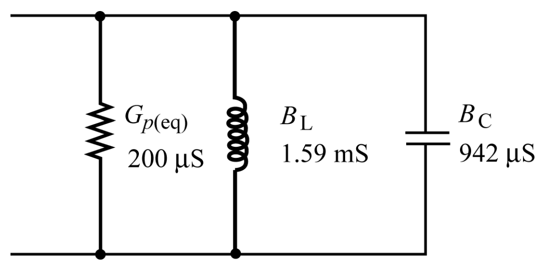


Figure 13-2

$$Y_{tot} = \sqrt{G_{p(\text{eq})}{}^2 + B_{tot}{}^2} = \sqrt{200\ \mu\text{S}^2 + (1.59\text{ mS} - 942\ \mu\text{S})^2} = 678\ \mu\text{S}$$

$$Z_{tot} = \frac{1}{678\ \mu\text{S}} = \mathbf{1.47\ k\Omega}$$

SECTION 13-6 Parallel Resonance

20. Z_r is infinitely large.

21. $$f_r = \frac{\sqrt{1-\frac{R_W^2 C}{L}}}{2\pi\sqrt{LC}} = \frac{\sqrt{1-\frac{(20\ \Omega)^2(47\text{ pF})}{50\text{ mH}}}}{2\pi\sqrt{(50\text{ mH})(47\text{ pF})}} = \mathbf{104\ kHz}$$

$X_L = 2\pi f_r L = 2\pi(103.82\text{ kHz})(50\text{ mH}) = 32.6\text{ k}\Omega$

$$Q = \frac{X_L}{R_W} = \frac{32.6\text{ k}\Omega}{20\ \Omega} = 1630$$

$Z_r = R_W(Q^2 + 1) = 20\ \Omega(1630^2 + 1) = \mathbf{53.1\ M\Omega}$

22. From Problem 21: $Z_r = 53.1\text{ M}\Omega$ and $f_r = 104\text{ kHz}$

$$I_{tot} = \frac{V_s}{Z_r} = \frac{6.3\text{ V}}{53.1\text{ M}\Omega} = \mathbf{119\ nA}$$

$$I_C = I_L = \frac{6.3\text{ V}}{\sqrt{(20\ \Omega)^2 + 32.6\text{ k}\Omega)^2}} = \mathbf{193\ \mu A}$$

SECTION 13-7 Parallel Resonant Filters

23. $Q = \dfrac{X_L}{R} = \dfrac{2\text{ k}\Omega}{25\ \Omega} = 80$

$BW = \dfrac{f_r}{Q} = \dfrac{5\text{ kHz}}{80} = \mathbf{62.5\ Hz}$

24. $BW = f_{c2} - f_{c1} = 2800\text{ Hz} - 2400\text{ Hz} = \mathbf{400\ Hz}$

25. $P = (0.5)P_r = (0.5)(2.75\text{ W}) = \mathbf{1.38\ W}$

26. $Q = \dfrac{f_r}{BW} = \dfrac{8\text{ kHz}}{800\text{ Hz}} = 10$

$X_{L(\text{res})} = QR_W = 10(10\ \Omega) = 100\ \Omega$

$L = \dfrac{X_L}{2\pi f_r} = \dfrac{100\ \Omega}{2\pi(8\text{ kHz})} = \mathbf{1.99\ mH}$

$X_C = X_L$ at resonance

$C = \dfrac{1}{2\pi f_r X_C} = \dfrac{1}{2\pi(8\text{ kHz})(100\ \Omega)} = \mathbf{0.199\ \mu F}$

27. Since $BW = \dfrac{f_r}{Q}$, the bandwidth is halved when Q is doubled.

So, when Q is increased from 50 to 100, BW decreases from 400 Hz to **200 Hz.**

28. $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

$L = \dfrac{1}{4\pi^2 f_r^2 C} = \dfrac{1}{4(3.14)^2(60)^2(200\ \mu\text{F})} = \mathbf{35.2\ mH}$

29. See Figure 13-3.

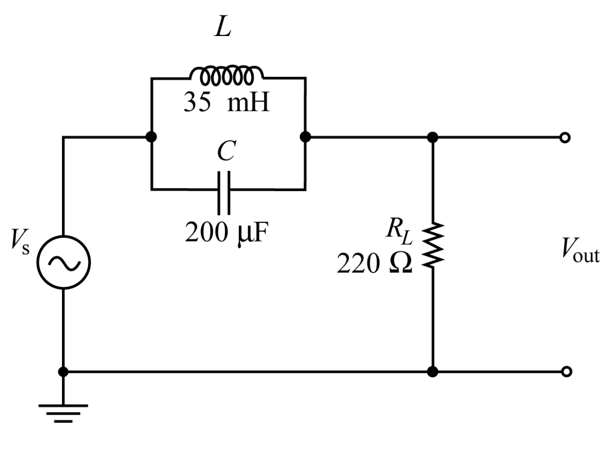


Figure 13-3

ADVANCED PROBLEMS

30. (a) $20\log\left(\frac{V_{out}}{V_{in}}\right) = 20\log\left(\frac{1\text{ V}}{1\text{ V}}\right)$ = **0 dB**

(b) $20\log\left(\frac{V_{out}}{V_{in}}\right) = 20\log\left(\frac{3\text{ V}}{5\text{ V}}\right)$ = **−4.4 dB**

(c) $20\log\left(\frac{V_{out}}{V_{in}}\right) = 20\log\left(\frac{7.07\text{ V}}{10\text{ V}}\right)$ = **−3 dB**

(d) $20\log\left(\frac{V_{out}}{V_{in}}\right) = 20\log\left(\frac{5\text{ V}}{25\text{ V}}\right)$ = **−14 dB**

31. $X_{L(tot)} = \dfrac{1}{\left(\dfrac{1}{X_{L1}} + \dfrac{1}{X_{L2}}\right)} = \dfrac{1}{\left(\dfrac{1}{5\text{ k}\Omega} + \dfrac{1}{10\text{ k}\Omega}\right)} = 3.33\text{ k}\Omega$

$Z_p = X_{L(tot)} \parallel R_2 = \dfrac{R_2 X_{L(tot)}}{\sqrt{R_2^2 + X_{L(tot)}^2}} = \dfrac{(10\text{ k}\Omega)(3.33\text{ k}\Omega)}{\sqrt{(10\text{ k}\Omega)^2 + (3.33\text{ k}\Omega)^2}} = 3.16\text{ k}\Omega$

$\theta_p = \tan^{-1}\left(\dfrac{R_2}{X_{L(tot)}}\right) = \tan^{-1}\left(\dfrac{10\text{ k}\Omega}{3.33\text{ k}\Omega}\right) = 71.6°$

Converting the parallel combination of R_2, X_{L1}, and X_{L2} to an equivalent series circuit:

$R_{eq} = Z_p\cos\theta_p = (3.16\text{ k}\Omega)\cos 71.6° = 997\ \Omega$

$X_{L(eq)} = Z_p\sin\theta = (3.16\text{ k}\Omega)\sin 71.6° = 3\text{ k}\Omega$

$Z_{(tot)} = \sqrt{(R_1 + R_{eq}^2)^2 + (X_{L(eq)} + X_C)^2} + \sqrt{(4297\ \Omega)^2 + (2000\ \Omega)^2} = 4740\ \Omega$

$I_{tot} = I_{R1} = I_C = \dfrac{V_s}{Z_{tot}} = \dfrac{10\text{ V}}{4740\ \Omega}$ = **2.11 mA**

$V_{R1} = I_{tot}R_1$ = (2.11 mA)(3.3 kΩ) = **6.96 V**

$V_C = I_{tot}X_C$ = (2.11 mA)(1.0 kΩ) = **2.11 V**

$V_{L1\text{-}L2\text{-}R2} = I_{tot}Z_p$ = (2.11 mA)(3.16 kΩ) = **6.67 V**

$I_{L1} = \dfrac{V_{L1}}{X_{L1}} = \dfrac{6.67\text{ V}}{5\text{ k}\Omega}$ = **1.33 mA**

$I_{L2} = \dfrac{V_{L2}}{X_{L2}} = \dfrac{6.67\text{ V}}{10\text{ k}\Omega}$ = **667 μA**

$I_{R2} = \dfrac{V_{R2}}{R_2} = \dfrac{6.67\text{ V}}{10\text{ k}\Omega}$ = **667 μA**

32. For $V_{ab} = 0$ V, $V_a = V_b$ in both magnitude and phase angle.
$X_{L1} = 226\ \Omega$; $X_{L2} = 151\ \Omega$

$$V_a = V_{L1} = \left(\frac{226\ \Omega}{\sqrt{(180\ \Omega)^2 + (226\ \Omega)^2}}\right)12\text{ V} = 9.38\text{ V}$$

It is not possible for V_{ab} to be 0 V because the *LC* branch has no resistance; thus, the voltage from *a* to *b* can only have a phase angle of 0°, 90°, or –90° (the branch will be either resonant, purely inductive, or purely capacitive depending on the value of X_C). Therefore, it is not possible for V_a to equal V_b in both magnitude and phase angle, which are necessary conditions.

33. $$X_C = \frac{1}{2\pi(3\text{ kHz})(0.22\ \mu\text{F})} = 241\ \Omega$$

$X_{L1} = 2\pi(3\text{ kHz})(12\text{ mH}) = 226\ \Omega$
$X_{L2} = 2\pi(3\text{ kHz})(8\text{ mH}) = 151\ \Omega$

$$I_{R1\text{-}L1} = \frac{V_s}{\sqrt{R_1^2 + X_{L1}^2}} = \frac{12\text{ V}}{\sqrt{(180\ \Omega)^2 + (226\ \Omega)^2}} = \mathbf{41.5\ mA}$$

$$I_{C\text{-}L2} = \frac{V_s}{X_C - X_{L2}} = \frac{12\text{ V}}{241\ \Omega - 151\ \Omega} = \mathbf{133\ mA}$$

$$\theta_{R1-L1} = \tan^{-1}\left(\frac{X_{L1}}{R_1}\right) = \tan^{-1}\left(\frac{226\ \Omega}{180\ \Omega}\right) = 51.5°$$

The resistive component of current in the left branch is:
$I_R = I_{R1-L1}\cos\ \theta_{R1-L1} = (41.5\text{ mA})\cos 51.5° = 25.8\text{ mA}$
The reactive component of current in the left branch is:
$I_X = I_{R1-L1}\sin\ \theta_{R1-L1} = (41.5\text{ mA})\sin 57.5° = 32.5\text{ mA}$
In the right branch $X_C > X_{L2}$, so I_{C-L2} is totally reactive and is 180° out of phase with I_X in the left branch.

$$I_{tot} = \sqrt{I_R^2 + (I_{C-L2} - I_X)^2} = \sqrt{(25.8\text{ mA})^2 + (133\text{ mA} - 32.5\text{ mA})^2} = \mathbf{104\ mA}$$

34. *For parallel resonance:* $$f_r = \frac{\sqrt{1 - \frac{R_W^2 C}{L_2}}}{2\pi\sqrt{L_2 C}} \cong \frac{1}{2\pi(25\text{ mH})(0.15\ \mu\text{F})} = \mathbf{2.6\ kHz}$$

$X_{L2} = 2\pi(2.6\text{ kHz})(25\text{ mH}) = 408\ \Omega$ $\qquad$ $$Q_p = \frac{X_{L2}}{R_{W2}} = \frac{408\ \Omega}{4\ \Omega} = 102$$

$Z_r = R_{W2}\left(Q_p^2 + 1\right) = 4\ \Omega(102^2 + 1) = 41.6\text{ k}\Omega$
$X_{L1} = 2\pi(2.6\text{ kHz})(10\text{ mH}) = 163\ \Omega$
Since Z_r is much greater than R, R_{W1}, or X_{L1} and is resistive, the output voltage is:
$V_{out} \cong V_s = \mathbf{10\ V}$

For series resonance: $$f_r = \frac{1}{2\pi\sqrt{L_1 C}} = \frac{1}{2\pi\sqrt{(10\text{ mH})(0.15\ \mu\text{F})}} = \mathbf{4.1\ kHz}$$

and
$X_C = X_{L1} = 2\pi(4.1\text{ kHz})(10\text{ mH}) = 258\ \Omega$
$X_{L2} = 2\pi(4.1\text{ kHz})(25\text{ mH}) = 644\ \Omega$

Since $X_C < X_{L2}$, the parallel portion of the circuit is capacitive.

$$Z_r = \sqrt{R_{W1}^2 + X_{L1}^2} - \frac{X_C\left(\sqrt{R_{W2}^2 + X_{L2}^2}\right)}{\sqrt{R_{W2}^2 + (X_{L2} - X_C)^2}} \cong 172\ \Omega$$

Assuming that Z_r is almost totally reactive:

$$V_{out} \cong \left(\frac{Z_r}{\sqrt{R^2 + Z_r^2}}\right)V_s = \left(\frac{172\ \Omega}{\sqrt{(860\ \Omega)^2 + (172\ \Omega)^2}}\right)10\text{ V } = \mathbf{1.96\ V}$$

35. $f_r = BW \times Q = (500\text{ Hz})(40) = 20\text{ kHz}$

$$X_C = \frac{2.5\text{ V}}{20\text{ mA}} = 125\ \Omega$$

$$C = \frac{1}{2\pi f_r X_C} = \frac{1}{2\pi(20\text{ kHz})(125\ \Omega)} = \mathbf{0.064\ \mu F}$$

$$Q = \frac{X_L}{R_W} = 40$$

$$R_W = \frac{X_L}{Q} = \left(\frac{1}{40}\right)X_L = 0.025X_L = 0.025(2\pi f_r L)$$

$$f_r = \frac{\sqrt{1 - \frac{R_W^2 C}{L}}}{2\pi\sqrt{LC}}$$

$$f_r^2 = \frac{1 - \left(\frac{R_W^2 C}{L}\right)}{4\pi^2 LC} = \frac{1 - \left(\frac{(0.025(2\pi f_r L))^2 C}{L}\right)}{4\pi^2 LC} = \frac{1 - 0.025 f_r^2 LC}{4\pi^2 LC}$$

In the above derivation, the term $(0.025(2\pi))^2 \cong 0.025$

$$f_r^2 4\pi^2 LC = 1 - 0.025 f_r^2 LC$$

$$f_r^2 LC(4\pi^2 + 0.025) = 1$$

$$L = \frac{1}{f_r^2 C(4\pi^2 + 0.025)} = \mathbf{989\ \mu H}$$

36. Refer to Figure 13-4.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad \text{Choose } C = 0.001\ \mu\text{F}$$

$$f_r^2 = \frac{1}{4\pi^2 LC}$$

(a) $f_r = 500\text{ kHz}$: $L_1 = \dfrac{1}{4\pi^2 f_r^2 C} = \dfrac{1}{4\pi^2(500\text{ kHz})^2(0.001\ \mu\text{F})} = \mathbf{101\ \mu H}$

(b) $f_r = 1000\text{ kHz}$: $L_2 = \dfrac{1}{4\pi^2 f_r^2 C} = \dfrac{1}{4\pi^2(1000\text{ kHz})^2(0.001\ \mu\text{F})} = \mathbf{25.3\ \mu H}$

(c) $f_r = 1500\text{ kHz}$: $L_3 = \dfrac{1}{4\pi^2 f_r^2 C} = \dfrac{1}{4\pi^2(1500\text{ kHz})^2(0.001\ \mu\text{F})} = \mathbf{11.3\ \mu H}$

(d) $f_r = 2000\text{ kHz: } L_4 = \dfrac{1}{4\pi^2 f_r^2 C} = \dfrac{1}{4\pi^2 (2000\text{ kHz})^2 (0.001\ \mu\text{F})}$ **= 6.3 μH**

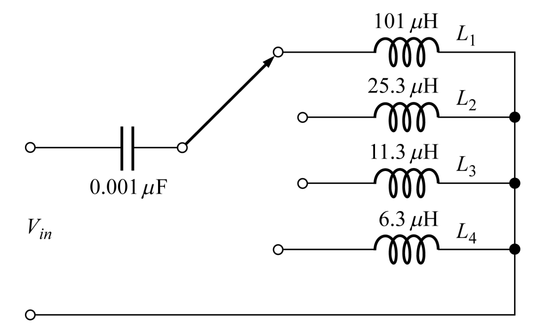


Figure 13-4

35. See Figure 13-5. The winding resistance is neglected because it contributes negligibly to the outcome of the calculations.

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$f_r^2 = \frac{1}{4\pi^2 LC}$$

$$C = \frac{1}{4\pi^2 f_r^2 L}$$

For f_r = 8 MHz, 9 MHz, 10 MHz, and 11 MHz:

$C_1 = \dfrac{1}{4\pi^2 (8\text{ MHz})^2 (10\ \mu\text{H})}$ **= 40 pF**

$C_2 = \dfrac{1}{4\pi^2 (9\text{ MHz})^2 (10\ \mu\text{H})}$ **= 31 pF**

$C_3 = \dfrac{1}{4\pi^2 (10\text{ MHz})^2 (10\ \mu\text{H})}$ **= 25 pF**

$C_4 = \dfrac{1}{4\pi^2 (11\text{ MHz})^2 (10\ \mu\text{H})}$ **= 21 pF**

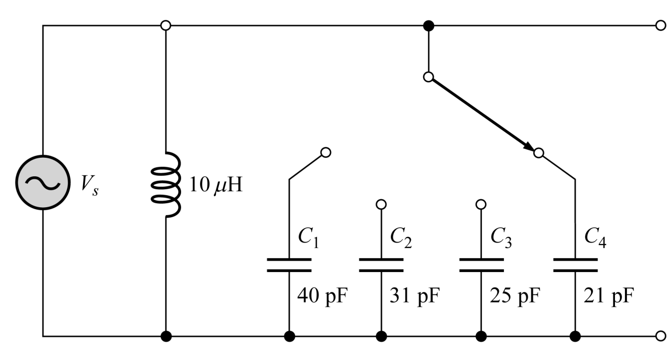


Figure 13-5

Multisim Troubleshooting Problems

38. *L* is open.

39. No fault

40. *C* is open.

41. *L* is shorted.

42. *C* is shorted.

43. *L* is shorted.

CHAPTER 14
TRANSFORMERS

BASIC PROBLEMS

SECTION 14-1 Mutual Inductance

1. $L_M = k\sqrt{L_1L_2} = 0.75\sqrt{(1\ \mu\text{H})(4\ \mu\text{H})} = \mathbf{1.5\ \mu H}$

2. $L_M = k\sqrt{L_1L_2}$

$$k = \frac{L_M}{\sqrt{L_1L_2}} = \frac{1\ \mu\text{H}}{\sqrt{(8\ \mu\text{H})(2\ \mu\text{H})}} = \mathbf{0.25}$$

SECTION 14-2 The Basic Transformer

3. $n = \dfrac{N_{sec}}{N_{pri}} = \dfrac{360}{120} = \mathbf{3}$

4. (a) $n = \dfrac{N_{sec}}{N_{pri}} = \dfrac{1000}{250} = \mathbf{4}$

   (b) $n = \dfrac{N_{sec}}{N_{pri}} = \dfrac{100}{400} = \mathbf{0.25}$

5. (a) In phase (b) Out of phase (c) Out of phase

SECTION 14-3 Step-Up and Step-Down Transformers

6. $n = \dfrac{N_{sec}}{N_{pri}} = \dfrac{150}{100} = 1.5$

   $V_{sec} = 1.5V_{pri} = 1.5(120\text{ V}) = \mathbf{180\ V}$

7. $N_{sec} = 2N_{pri} = 2(250\text{ turns}) = \mathbf{500\ turns}$

8. $n = \dfrac{N_{sec}}{N_{pri}} = \dfrac{V_{sec}}{V_{pri}} = 10$

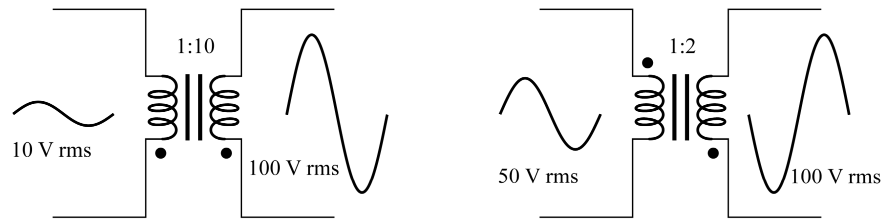
$V_{pri} = \left(\dfrac{1}{n}\right)V_{sec} = \left(\dfrac{1}{10}\right)60\text{ V} = \mathbf{6\ V}$

9. See Figure 14-1(a).

(a) $V_{sec} = nV_{pri} = \left(\dfrac{N_{sec}}{N_{pri}}\right)V_{pri} = 10(10\text{ V}) = \mathbf{100\ V\ rms}$

See Figure 14-1(b).

(b) $V_{sec} = nV_{pri} = \left(\dfrac{N_{sec}}{N_{pri}}\right)V_{pri} = 2(50\text{ V}) = \mathbf{100\ V\ rms}$



(a) In-phase (b) 180 degrees out-of-phase

Figure 14-1

10. $\dfrac{V_{sec}}{V_{pri}} = \dfrac{N_{sec}}{N_{pri}}$

$n = \dfrac{N_{sec}}{N_{pri}} = \dfrac{30\text{ V}}{120\text{ V}} = \mathbf{0.25}$

11. $V_{sec} = (0.2)(1200\text{ V}) = \mathbf{240\ V}$

12. $\dfrac{V_{sec}}{V_{pri}} = \dfrac{N_{sec}}{N_{pri}} = n = 0.1$

$V_{pri} = \left(\dfrac{1}{n}\right)V_{sec} = \left(\dfrac{1}{0.1}\right)(6\text{ V}) = \mathbf{60\ V}$

13. (a) $V_L = nV_{pri} = \left(\dfrac{N_{sec}}{N_{pri}}\right)V_{pri} = \left(\dfrac{1}{20}\right)120\text{ V} = \mathbf{6\ V}$

(b) $V_L = \mathbf{0\ V}$ (The transformer does not couple constant dc voltage)

(c) $V_L = nV_{pri} = \left(\dfrac{N_{sec}}{N_{pri}}\right)V_{pri} = 4(10\text{ V}) = \mathbf{40\ V}$

14. No, the voltages would not change.

15. (a) $V_L = (0.1)V_{sec} = (0.1)(100\text{ V}) = \mathbf{10\ V}$
(b) $V_{pri} = 20V_L = 20(12\text{ V}) = \mathbf{240\ V}$

16. Meter would indicate **10 V**.

SECTION 14-4 Loading the Secondary

17. $$\frac{I_{sec}}{I_{pri}} = \frac{N_{pri}}{N_{sec}} = \frac{1}{n} = \frac{1}{3}$$

$$I_{sec} = \left(\frac{1}{n}\right)I_{pri} = \left(\frac{1}{3}\right)100\text{ mA} = \mathbf{33.3\ mA}$$

18. $$\frac{V_{sec}}{V_{pri}} = \frac{I_{pri}}{I_{sec}}$$

(a) $$V_{sec} = nV_{pri} = \left(\frac{N_{sec}}{N_{pri}}\right)V_{pri} = \left(\frac{1}{2}\right)30\text{ V} = \mathbf{15\ V}$$

(b) $$I_{sec} = \frac{V_{sec}}{R_L} = \frac{15\text{ V}}{300\ \Omega} = \mathbf{50\ mA}$$

(c) $$I_{pri} = \left(\frac{V_{sec}}{V_{pri}}\right)I_{sec} = \left(\frac{15\text{ V}}{30\text{ V}}\right)50\text{ mA} = \mathbf{25\ mA}$$

(d) $P_L = I_{sec}R_L = (50\text{ mA})^2(300\ \Omega) = \mathbf{0.75\ W}$

SECTION 14-5 Reflected Load

19. $$R_{pri} = \left(\frac{1}{n}\right)^2 R_L = \left(\frac{1}{5}\right)^2 680\ \Omega = \left(\frac{1}{25}\right)680\ \Omega = \mathbf{27.2\ \Omega}$$

20. $$n = \frac{1}{50}$$

$$R_{pri} = \left(\frac{1}{n}\right)^2 R_L = 50^2(8\ \Omega) = \mathbf{20\ k\Omega}$$

21. $$I_{pri} = \frac{V_{sec}}{R_{pri}} = \frac{120\text{ V}}{20\text{ k}\Omega} = \mathbf{6.0\ mA}$$

22. $R_{pri} = 300\ \Omega$; $R_L = 1.0\ \text{k}\Omega$

$$n^2 = \frac{R_L}{R_{pri}}$$

$$n = \sqrt{\frac{R_L}{R_{pri}}} = \sqrt{\frac{1.0\ \text{k}\Omega}{300\ \Omega}} = \mathbf{1.83}$$

SECTION 14-6 Impedance Matching

23. $R_{pri} = \left(\frac{1}{n}\right)^2 R_L$

$$\left(\frac{1}{n}\right)^2 = \frac{R_{pri}}{R_L}$$

$$\frac{1}{n} = \sqrt{\frac{R_{pri}}{R_L}} = \sqrt{\frac{16\ \Omega}{4\ \Omega}} = \sqrt{4} = 2$$

$$n = \frac{1}{2} = \mathbf{0.5}$$

24. $n = 0.5$ from Problem 23.

$$R_{pri} = \left(\frac{1}{n}\right)^2 R_{\text{speaker}} = \left(\frac{1}{0.25}\right) 4\ \Omega = 16\ \Omega$$

$$I_{pri} = \frac{25\ \text{V}}{16\ \Omega} = 1.56\ \text{A}$$

$$I_{sec} = \left(\frac{1}{n}\right) I_{pri} = 2(1.56\ \text{A}) = 3.12\ \text{A}$$

$$P_{\text{speaker}} = I_{sec}^2 R_{\text{speaker}} = (3.12\ \text{A})^2(4\ \Omega) = \mathbf{38.9\ W}$$

25. $n = 10$ $\qquad n = \sqrt{\frac{R_L}{R_{pri}}}$ $\qquad n^2 = \frac{R_L}{R_{pri}}$

$$R_L = n^2 R_{pri} = 10^2(50\ \Omega) = 100(50\ \Omega) = \mathbf{5\ k\Omega}$$

26. $R_{pri} = \left(\frac{1}{n}\right)^2 R_L = \left(\frac{1}{10}\right)^2 R_L = (0.01) R_L$

For $R_L = 1\ \text{k}\Omega$, $R_{pri} = (0.01)(1\ \text{k}\Omega) = 10\ \Omega$

$$V_{R(pri)} = \left(\frac{10\ \Omega}{60\ \Omega}\right) 10\ \text{V} = 1.67\ \text{V}$$

$$P = \frac{(1.67\ \text{V})^2}{10\ \Omega} = \mathbf{0.278\ W}$$

For $R_L = 2\text{ k}\Omega$, $R_{pri} = (0.01)(2\text{ k}\Omega) = 20\ \Omega$

$$V_{R(pri)} = \left(\frac{20\ \Omega}{70\ \Omega}\right)10\text{ V} = 2.86\text{ V}$$

$$P = \frac{(2.86\text{ V})^2}{20\ \Omega} = \mathbf{0.408\ W}$$

For $R_L = 3\text{ k}\Omega$, $R_{pri} = (0.01)(3\text{ k}\Omega) = 30\ \Omega$

$$V_{R(pri)} = \left(\frac{30\ \Omega}{80\ \Omega}\right)10\text{ V} = 3.75\text{ V}$$

$$P = \frac{(3.75\text{ V})^2}{30\ \Omega} = \mathbf{0.469\ W}$$

For $R_L = 4\text{ k}\Omega$, $R_{pri} = 40\ \Omega$

$$V_{R(pri)} = \left(\frac{40\ \Omega}{90\ \Omega}\right)10\text{ V} = 4.44\text{ V}$$

$$P = \frac{(4.44\text{ V})^2}{40\ \Omega} = \mathbf{0.494\ W}$$

For $R_L = 5\text{ k}\Omega$, $R_{pri} = 50\ \Omega$

$$V_{R(pri)} = \left(\frac{50\ \Omega}{100\ \Omega}\right)10\text{ V} = 5\text{ V}$$

$$P = \frac{(5\text{ V})^2}{50\ \Omega} = \mathbf{0.500\ W}$$

For $R_L = 6\text{ k}\Omega$, $R_{pri} = 60\ \Omega$

$$V_{R(pri)} = \left(\frac{60\ \Omega}{110\ \Omega}\right)10\text{ V} = 5.45\text{ V}$$

$$P = \frac{(5.45\text{ V})^2}{60\ \Omega} = \mathbf{0.496\ W}$$

For $R_L = 7\text{ k}\Omega$, $R_{pri} = 70\ \Omega$

$$V_{R(pri)} = \left(\frac{70\ \Omega}{120\ \Omega}\right)10\text{ V} = 5.83\text{ V}$$

$$P = \frac{(5.83\text{ V})^2}{70\ \Omega} = \mathbf{0.486\ W}$$

For $R_L = 8\text{ k}\Omega$, $R_{pri} = 80\ \Omega$

$$V_{R(pri)} = \left(\frac{80\ \Omega}{130\ \Omega}\right)10\text{ V} = 6.15\text{ V}$$

$$P = \frac{(6.15\text{ V})^2}{80\ \Omega} = \mathbf{0.473\ W}$$

For $R_L = 9\ \text{k}\Omega$, $R_{pri} = 90\ \Omega$

$$V_{R(pri)} = \left(\frac{90\ \Omega}{140\ \Omega}\right)10\ \text{V} = 6.43\ \text{V}$$

$$P = \frac{(6.43\ \text{V})^2}{90\ \Omega} = \mathbf{0.459\ W}$$

For $R_L = 10\ \text{k}\Omega$, $R_{pri} = 100\ \Omega$

$$V_{R(pri)} = \left(\frac{100\ \Omega}{150\ \Omega}\right)10\ \text{V} = 6.67\ \text{V}$$

$$P = \frac{(6.67\ \text{V})^2}{100\ \Omega} = \mathbf{0.444\ W}$$

See Figure 14-2.

Figure 14-2

SECTION 14-7 Transformer Ratings and Characteristics

27. $P_L = P_{pri} - P_{\text{lost}} = 100\ \text{W} - 5.5\ \text{W} = \mathbf{94.5\ W}$

28. $\%\ \text{efficiency} = \left(\frac{P_{out}}{P_{in}}\right)100\% = \left(\frac{94.5\ \text{W}}{100\ \text{W}}\right)100\% = \mathbf{94.5\ \%}$

29. Coefficient of coupling = 1 − 0.02 = **0.98**

30. (a) $I_{L(max)} = \dfrac{P_a}{V_{sec}} = \dfrac{1\text{ kVA}}{600\text{ V}} = \mathbf{1.67\ A}$

(b) $R_{L(min)} = \dfrac{V_{sec}}{I_{L(\max)}} = \dfrac{600\text{ V}}{1.67\text{ A}} = \mathbf{359\ \Omega}$

(c) $X_C = \dfrac{V_{sec}}{I_L} = \mathbf{359\ \Omega}$

$C_{max} = \dfrac{1}{2\pi f X_C} = \dfrac{1}{2\pi(60\text{ Hz})(359\ \Omega)} = \mathbf{7.4\ \mu F}$

31. kVA rating = (2.5 kV)(10 A) = **25 kVA**

SECTION 14-8 Tapped and Multiple-Winding Transformers

32. $V_1 = \left(\dfrac{50}{500}\right)120\text{ V} = \mathbf{12.0\ V}$

$V_2 = \left(\dfrac{100}{500}\right)120\text{ V} = \mathbf{24.0\ V}$

$V_3 = \left(\dfrac{100}{500}\right)120\text{ V} = \mathbf{24.0\ V}$

$V_4 = V_2 + V_3 = \mathbf{48.0\ V}$

33. *For secondary 1:*

$n = \dfrac{V_{sec}}{V_{pri}} = \dfrac{24\text{ V}}{12\text{ V}} = \mathbf{2}$

For secondary 2:

$n = \dfrac{V_{sec}}{V_{pri}} = \dfrac{6\text{ V}}{12\text{ V}} = \mathbf{0.5}$

For secondary 3:

$n = \dfrac{V_{sec}}{V_{pri}} = \dfrac{3\text{ V}}{12\text{ V}} = \mathbf{0.25}$

34. (a) See Figure 14-3.

(b) 100 turns: $V_{sec} = \left(\dfrac{100}{2000}\right)240\text{ V} = \mathbf{12\ V}$

200 turns: $V_{sec} = \left(\dfrac{200}{2000}\right)240\text{ V} = \mathbf{24\ V}$

500 turns: $V_{sec} = \left(\dfrac{500}{2000}\right)240\text{ V} = \mathbf{60\ V}$

1000 turns: $V_{sec} = \left(\dfrac{1000}{2000}\right)240\text{ V} = \mathbf{120\ V}$

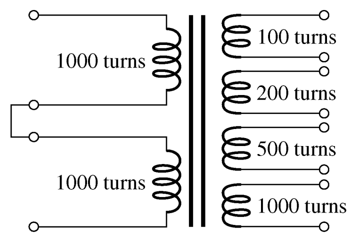


Figure 14-3

35. For both primaries:

Top secondary: $n = \dfrac{100}{1000} = \mathbf{0.1}$

Next secondary: $n = \dfrac{200}{1000} = \mathbf{0.2}$

Third secondary: $n = \dfrac{500}{1000} = \mathbf{0.5}$

Bottom secondary: $n = \dfrac{1000}{1000} = \mathbf{1}$

SECTION 14-9 Troubleshooting

36. Open primary winding. Replace transformer.

37. If the primary shorts, excessive current is drawn which potentially can burn out the source and/or the transformer unless the primary is fused.

38. Some, but not all, of the secondary windings are shorted or the primary voltage is lower than expected.

ADVANCED PROBLEMS

39. (a) N_{sec} = 400 turns + 300 turns = 700 turns

$$V_{L1} = nV_{pri} = \left(\frac{N_{sec}}{N_{pri}}\right)V_{pri} = \left(\frac{700}{1200}\right)60\text{ V} = \mathbf{35\ V}$$

$$I_{L1} = \frac{V_{L1}}{R_{L1}} = \frac{35\text{ V}}{12\ \Omega} = \mathbf{2.92\ A}$$

$$V_{L2} = \left(\frac{300}{1200}\right)60\text{ V} = \mathbf{15\ V}$$

$$I_{L2} = \frac{V_{L2}}{R_{L2}} = \frac{15\text{ V}}{10\ \Omega} = \mathbf{1.5\ A}$$

(b) $$\frac{1}{Z_{pri}} = \frac{1}{\left(\frac{N_{pri}}{N_{700}}\right)^2 R_{L1}} + \frac{1}{\left(\frac{N_{pri}}{N_{300}}\right)^2 R_{L2}} = \frac{1}{(2.94)(12\ \Omega)} + \frac{1}{(16)(10\ \Omega)}$$

$$= \frac{1}{35.3\ \Omega} + \frac{1}{160\ \Omega} = 0.0283\ \text{S} + 0.00625\ \text{S} = 0.0346\ \text{S}$$

$$Z_{pri} = \frac{1}{0.0346\ \text{S}} = \mathbf{28.9\ \Omega}$$

40. (a) $V_{pri} = 2400$ V

$$n = \frac{N_{sec}}{N_{pri}} = \frac{V_{sec}}{V_{pri}} = \frac{120\ \text{V}}{2400\ \text{V}} = \mathbf{0.05}$$

(b) $$I_{sec} = \frac{P_a}{V_{\text{sec}}} = \frac{5\ \text{kVA}}{120\ \text{V}} = \mathbf{41.7\ A}$$

(c) $I_{pri} = nI_{sec} = (0.05)(41.7\ \text{A}) = \mathbf{2.09\ A}$

41. (a) The lower 100 Ω resistor is shorted out by the meter ground; so, the full secondary voltage measured by the meter is:

$$V_{\text{meter}} = V_{\text{sec}} = nV_{pri} = \left(\frac{N_{sec}}{N_{pri}}\right)120\ \text{V} = \left(\frac{1}{6}\right)120\ \text{V} = \mathbf{20\ V}$$

(b) The common point between the 100 Ω resistors is ground. Both resistors are still in the secondary with one-half of the secondary voltage across each.

$$V_{\text{meter}} = \left(\frac{1}{2}\right)V_{sec} = \left(\frac{1}{2}\right)20\ \text{V} = \mathbf{10\ V}$$

42. *Position 1:*

$R_L = 560\ \Omega + 220\ \Omega + 1.0\ \text{k}\Omega = 1780\ \Omega$

$$n = \sqrt{\frac{R_L}{R_{pri}}} = \sqrt{\frac{1780\ \Omega}{10\ \Omega}} = \mathbf{13.3}$$

$N_{sec} = N_{sec1} + N_{sec2} + N_{sec3} = nN_{pri} = 13.3 \times 100 =$ **1330 turns**

Position 2:

$R_L = 220\ \Omega + 1.0\ \text{k}\Omega = 1220\ \Omega$

$$n = \sqrt{\frac{R_L}{R_{pri}}} = \sqrt{\frac{1220\ \Omega}{10\ \Omega}} = \mathbf{11.0}$$

$N_{sec} = N_{sec2} + N_{sec3} = nN_{pri} = 11.0 \times 100 =$ **1100 turns**

Position 3:

$R_L = 1.0\ \text{k}\Omega$

$$n = \sqrt{\frac{R_L}{R_{pri}}} = \sqrt{\frac{1000\ \Omega}{10\ \Omega}} = \mathbf{10}$$

$N_{sec} = N_{sec3} = nN_{pri} = 10 \times 100 =$ **1000 turns**

43. $R_{pri} = \dfrac{120\text{ V}}{3\text{ mA}} = 40.0\text{ k}\Omega$

$$R_{pri} = \left(\frac{1}{n}\right)^2 R_L$$

$$n^2 = \frac{R_L}{R_{pri}}$$

$$n = \sqrt{\frac{R_L}{R_{pri}}} = \sqrt{\frac{8\ \Omega}{40.0\text{ k}\Omega}} = \mathbf{0.0141}$$

This is 70.7 primary turns for each secondary turn.

44. $n = \dfrac{12.6\text{ V}}{120\text{ V}} = 0.105$

$$I_{pri(\max)} = \frac{10\text{ VA}}{120\text{ V}} = 83.3\text{ mA}$$

$$I_{sec(\max)} = \frac{83.3\text{ mA}}{0.105} = 794\text{ mA}$$

$$R_{L(\min)} = \frac{12.6\text{ V}}{794\text{ mA}} = \mathbf{15.9\ \Omega}$$

45. $n = \dfrac{10\text{ V}}{120\text{ V}} = 0.0833$

$I_{pri(max)} = (0.0833)(1\text{ A}) = 83.3\text{ mA}$
A fuse rated at **0.1 A** should be used.

Multisim Troubleshooting Problems

46. Partial short in transformer.

47. Secondary is open.

48. No fault.

49. Primary is open.

CHAPTER 15
TIME RESPONSE OF REACTIVE CIRCUITS

BASIC PROBLEMS

SECTION 15-1 The *RC* Integrator

1. $\tau = RC = (2.2\ \text{k}\Omega)(0.047\ \mu\text{F}) = \mathbf{103\ \mu s}$

2. (a) $5RC = 5(47\ \Omega)(47\ \mu\text{F}) = \mathbf{11.0\ ms}$
   (b) $5RC = 5(3300\ \text{k}\Omega)(0.015\ \mu\text{F}) = \mathbf{248\ \mu s}$
   (c) $5RC = 5(22\ \text{k}\Omega)(100\ \text{pF}) = \mathbf{11\ \mu s}$
   (d) $5RC = 5(4.7\ \text{M}\Omega)(10\ \text{pF}) = \mathbf{235\ \mu s}$

3. $\tau = 6\ \text{ms}$, $C = 0.22\ \mu\text{F}$
   $\tau = RC$
   $$R = \frac{\tau}{C} = \frac{6\ \text{ms}}{0.22\ \mu\text{F}} = 27.3\ \text{k}\Omega$$
   Use a standard **27 kΩ** resistor.

4. $t_{W(\text{min})} = 5\tau = 5(6\ \text{ms}) = \mathbf{30\ ms}$

SECTION 15-2 Response of *RC* Integrators to a Single Pulse

5. $v_C = 0.63(20\ \text{V}) = \mathbf{12.6\ V}$

6. (a) $v = 0.86(20\ \text{V}) = \mathbf{17.2\ V}$
   (b) $v = 0.95(20\ \text{V}) = \mathbf{19\ V}$
   (c) $v = 0.98(20\ \text{V}) = \mathbf{19.6\ V}$
   (d) $v = 0.99(20\ \text{V}) = \mathbf{19.8\ V}$ (considered 20 V)

7. See Figure 15-1.

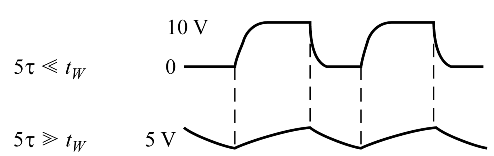


Figure 15-1

8. $\tau = RC = (1.0\ \text{k}\Omega)(1\ \mu\text{F}) = 1\ \text{ms}$
$v_{out} = 0.632(8\ \text{V}) = \mathbf{5.06\ V}$
The time to reach steady-state with repetitive pulses is **5 ms**.
See Figure 15-2 for output wave shape.

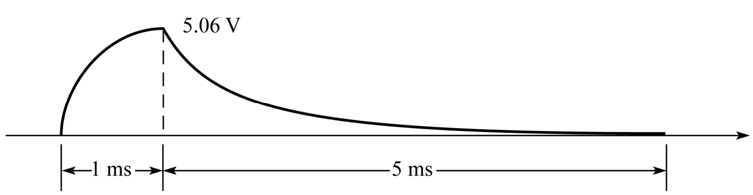


Figure 15-2

SECTION 15-3 Response of *RC* Integrators to Repetitive Pulses

9. $\tau = (4.7\ \text{k}\Omega)(10\ \mu\text{F}) = 47\ \text{ms}$
$5\tau = 235\ \text{ms}$
See Figure 15-3.

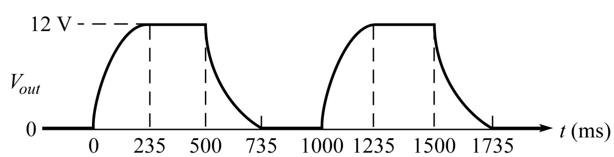


Figure 15-3

10. $T = \dfrac{1}{f} = \dfrac{1}{10\ \text{kHz}} = 100\ \mu\text{s} \quad t_W = 0.25(100\ \mu\text{s}) = 25\ \mu\text{s}$

1st pulse: 0.632(1 V) = 632 mV
Between 1st and 2nd pulses: 0.05(632 mV) = 31.6 mV
2nd pulse: 0.632(1 V − 31.6 mV) + 31.6 mV = 644 mV
Between 2nd and 3rd pulses: 0.05(644 mV) = 32.2 mV
3rd pulse: 0.632(1 V − 32.2 mV) + 32.2 mV = 644 mV

See Figure 15-4.

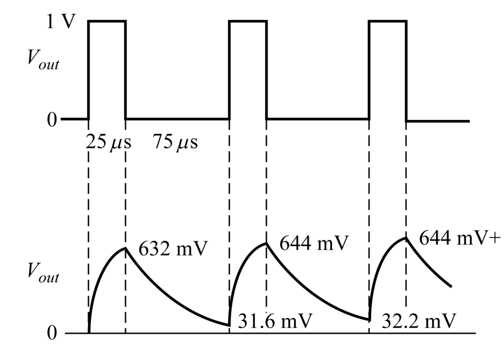


Figure 15-4

11. The steady-state output equals the average value of the input which is **15 V with a small ripple.**

SECTION 15-4 Response of *RC* Differentiators to a Single Pulse

12. See Figure 15-5.

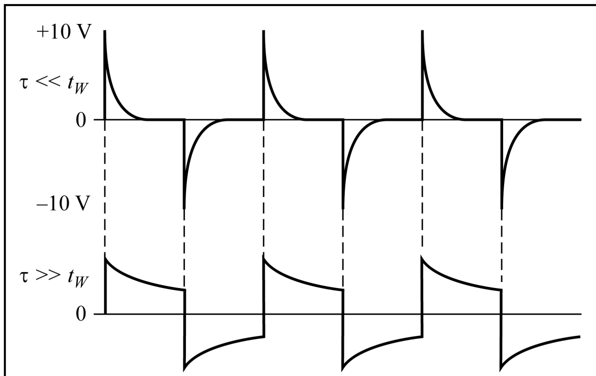


Figure 15-5

13. $\tau = (1.0\ \text{k}\Omega)(1\ \mu\text{F}) = 1$ ms
See Figure 15-6. Steady-state is reached in **5 ms**.

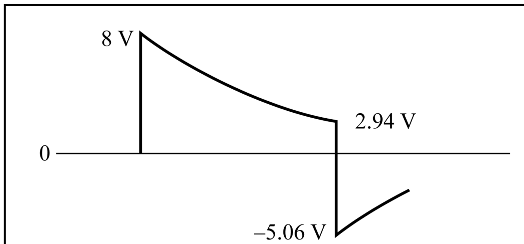


Figure 15-6

SECTION 15-5 Response of *RC* Differentiators to Repetitive Pulses

14. $\tau = (1.0\ \text{k}\Omega)(1\ \mu\text{F}) = 1\ \text{ms}$
See Figure 15-7.

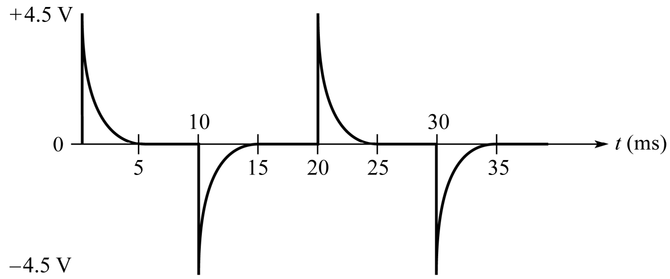


Figure 15-7

15. The output voltage is approximately the same wave shape as the input voltage but with an average value of **0 V**.

SECTION 15-6 Response of *RL* Integrators to Pulse Inputs

16. $\tau = \dfrac{10\ \text{mH}}{10\ \text{k}\Omega} = 1\ \mu\text{s}$

$5\tau = 5\ \mu\text{s}$

$V_{out(max)} = 0.632(8\ \text{V}) = 5.06\ \text{V}$

See Figure 15-8.

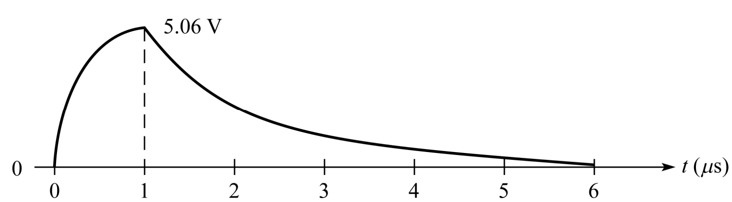


Figure 15-8

17. $\tau = \dfrac{50\ \text{mH}}{1.0\ \text{k}\Omega} = 50\ \mu\text{s}$

$5\tau = 250\ \mu\text{s}$

$V_{out(\text{max})} = 12\ \text{V}$

See Figure 15-9.

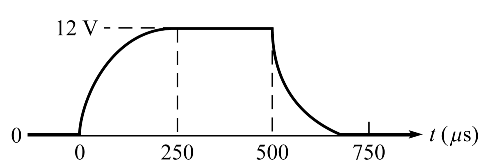


Figure 15-9

SECTION 15-7 Response of *RL* Differentiators to Pulse Inputs

18. (a) $\tau = \dfrac{100\ \mu\text{H}}{2.2\ \text{k}\Omega} = 45.4\ \text{ns}$

(b) At end of pulse,
$v_{out} = (10\ \text{V})e^{-2.2} = 1.11\ \text{V}$
See Figure 15-10.

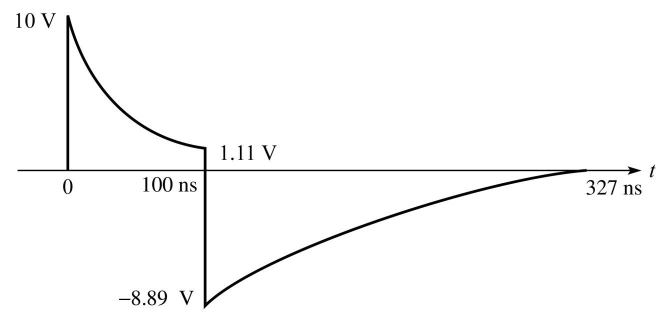


Figure 15-10

19. $\tau = \dfrac{100\ \mu\text{H}}{2.2\ \text{k}\Omega} = 45.4\ \text{ns}$

$5\tau = 227\ \text{ns}$
See Figure 15-11.

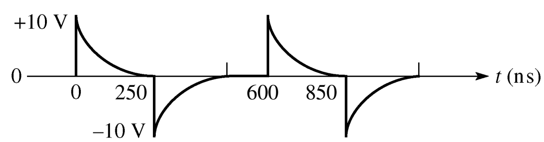


Figure 15-11

SECTION 15-8 Applications

20. $\tau = RC = (22\ \text{k}\Omega)(0.001\ \mu\text{F}) = 22\ \mu\text{s}$
$v_B = V_F(1 - e^{-t/RC}) = 10\ \text{V}(1 - e^{-440\mu\text{s}/22\mu\text{s}}) = \mathbf{10.0\ V}$

21. The output of the integrator is ideally a dc level which equals the average value of the input signal, **6 V** in this case.

SECTION 15-9 Troubleshooting

22. $\tau = RC = (3.3\ \text{k}\Omega)(0.22\ \mu\text{F}) = 726\ \mu\text{s}$
$5\tau = 5RC = 5(726\ \mu\text{s}) = 3.63\ \text{ms}$
(b) Since the output looks like the input, the **capacitor must be open** or the resistor shorted because there is no charging time.
(c) The zero output could be caused by an **open resistor or a shorted capacitor.**

23. $\tau = 726\ \mu\text{s}$; $5\tau = 5(726\ \mu\text{s}) = 3.63\ \text{ms}$
(b) **No fault.**
(c) **Open capacitor or shorted resistor.**

ADVANCED PROBLEMS

24. (a) Looking from the source and capacitor,

$$R_{tot} = \frac{(2.2\ \text{k}\Omega)(1.0\ \text{k}\Omega + 1.0\ \text{k}\Omega)}{4.2\ \text{k}\Omega} = 1.05\ \text{k}\Omega$$

$\tau = R_{tot}C = (1.05\ \text{k}\Omega)(560\ \text{pF}) = 588\ \text{ns} = 0.588\ \mu\text{s}$

(b) See Figure 15-12.

$v = 10e^{-2.6\mu s/0.588\mu s} = 120\ \text{mV}$

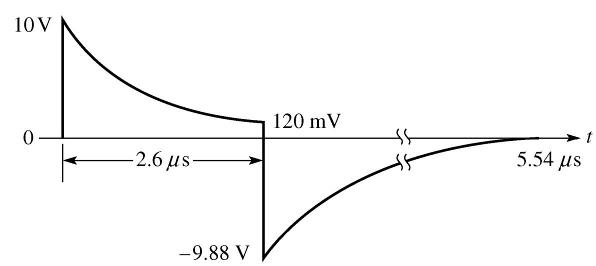


Figure 15-12

25. (a) Looking from the capacitor, the Thevenin resistance is 5 kΩ.

$\tau = (5\ \text{k}\Omega)(4.7\ \mu\text{F}) =$ **23.5 ms**; $5\tau = 5(23.5\ \text{ms}) = 118\ \text{ms}$

(b) See Figure 15-13.

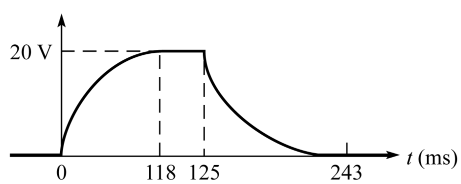


Figure 15-13

26. $L_{tot} = 8\ \mu\text{H} + 4\ \mu\text{H} = 12\ \mu\text{H}$

$$R_{tot} = \frac{(10\ \text{k}\Omega)(14.7\ \text{k}\Omega)}{24.7\ \text{k}\Omega} = 5.95\ \text{k}\Omega$$

$$\tau = \frac{L_{tot}}{R_{tot}} = \frac{12\ \mu\text{H}}{5.95\ \text{k}\Omega} = 2.02\ \text{ns}$$

This circuit is an **integrator.**

27. $v = V_F(1 - e^{-t/\tau})$

$2.5 = 5(1 - e^{-t/\tau})$

$2.5 = 5 - 5e^{-t/\tau}$

$5e^{-t/\tau} = 5 - 2.5$

$e^{-t/\tau} = \frac{2.5}{5} = 0.5$

$\ln e^{-t/\tau} = \ln 0.5$

$-\frac{t}{\tau} = -0.693$

$\tau = \frac{t}{0.693} = \frac{1\text{ s}}{0.693} = \mathbf{1.44\text{ s}}$

28. The scope display is correct. See Figure 15-14.

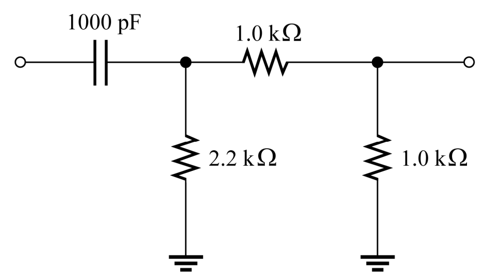


Figure 15-14

Multisim Troubleshooting Problems

29. Capacitor is open.

30. R_2 is open.

31. No fault

32. L_1 is open.

CHAPTER 16
DIODES AND APPLICATIONS

SECTION 16-1 Introduction to Semiconductors

1. Two types of semiconductor materials are **silicon** and **germanium**.

2. Semiconductors have **4** valence electrons.

3. In a silicon crystal, a single atom forms **4** covalent bonds.

4. When heat is added to silicon, **the number of free electrons increases.**

5. Current in silicon is produced at the **conduction band** and the **valence band** levels.

6. Doping is the process of adding trivalent or pentavalent elements to an intrinsic semiconductor in order to increase the effective number of free electrons or holes, respectively.

7. Antimony is an ***n*-type** impurity. Boron is a ***p*-type** impurity.

8. A hole is the absence of an electron in the valence band of an atom.

9. Recombination is the process in which an electron that has crossed the *pn* junction falls into a hole in the *p*-region, creating a negative ion.

SECTION 16-2 The Diode

10. The electric field across a *pn* junction is created by the diffusion of free electrons from the *n*-type material across the barrier and their recombination with holes in the *p*-type material. This results in a net negative charge on the *p* side of the junction and a net positive charge on the *n* side of the junction, forming an electric field.

11. **A diode cannot be used as a voltage source** using the barrier potential because the potential opposes any further charge movement and is an equilibrium condition, not an energy source.

12. Forward biasing of a *pn* junction is accomplished by connecting the positive terminal of a battery to the ***p*-type** material.

13. A series resistor is necessary to limit the diode current when a diode is forward-biased to prevent overheating.

SECTION 16-3 Diode Characteristics

14. To generate the forward bias portion of the diode characteristic curve, use the set-up shown in Figure 16-1.

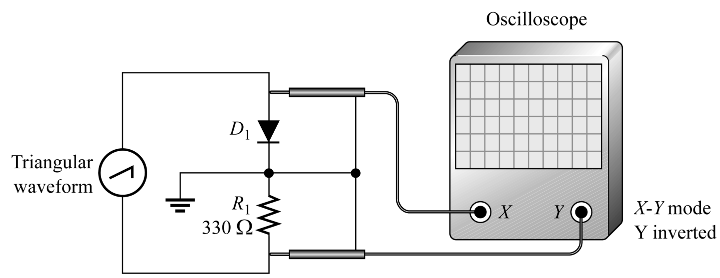


Figure 16-1

15. The barrier potential would decrease from 0.7 V to 0.6 V is there were an **increase in junction temperature.**

16. (a) The diode is **reverse-biased** because the anode is at 5 V and the cathode is at 8 V.
    (b) The diode is **forward-biased** because the anode is at ground and the cathode is at −100 V.
    (c) The diode is **forward-biased** by the positive voltage produced by the voltage divider.
    (d) The diode is **forward-biased** because its cathode is more negative than the anode due to the −20 V source.

17. (a) $V_R = 8\text{ V} - 5\text{ V} = 3\text{ V}$ (reversed biased)   (b) $V_F = 0.7\text{ V}$
    (c) $V_F = 0.7\text{ V}$ (d) $V_F = 0.7\text{ V}$

18. (a) The diode should be forward-biased with $V_F = 0.7\text{ V}$. The 25 V measurement indicates an **open** diode.
    (b) The diode should be forward-biased with $V_F = 0.7\text{ V}$. The 15 V measurement indicates an **open** diode.
    (c) The diode should be reverse-biased and the measured voltage should be 0 V. The 2.5 V reading indicates that the diode is **shorted**.
    (d) The diode is reverse-biased. The 0 V reading across the resistor indicates there is no current. From this, it cannot be determined whether the diode is functioning properly or is open.

19. $V_A = V_{S1} = \mathbf{25\text{ V}}$
    $V_B = V_A - 0.7\text{ V} = 25\text{ V} - 0.7\text{ V} = \mathbf{24.3\text{ V}}$
    $V_C = V_{S2} + 0.7\text{ V} = 8\text{ V} + 0.7\text{ V} = \mathbf{8.7\text{ V}}$
    $V_D = V_{S2} = \mathbf{8\text{ V}}$

SECTION 16-4 Diode Rectifiers

20. $V_{AVG} = \dfrac{V_p}{\pi} = \dfrac{200\text{ V}}{\pi} = \mathbf{63.7\ V}$

21. $V_{L(\text{peak})} = 50\text{ V} - 0.7\text{ V} = \mathbf{49.3\ V}$

$I_{L(\text{peak})} = \dfrac{49.3\text{ V}}{100\ \Omega} = \mathbf{493\ mA}$

See Figure 16-2.

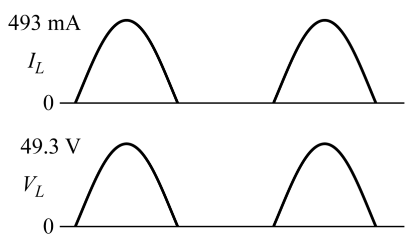


Figure 16-2

22. **Yes**, a diode with a PIV rating of 50 V can be used because the maximum reverse voltage is 50 V.

23. $V_{sec} = nV_{pri} = \left(\dfrac{N_{sec}}{N_{pri}}\right)120\text{ V} = (0.5)120\text{ V} = 60\text{ V rms}$

$V_{sec(\text{peak})} = 1.414(60\text{ V}) = 84.8\text{ V}$

$V_{RL(\text{peak})} = V_{sec(\text{peak})} - 0.7\text{ V} = \mathbf{84.1\ V}$

24. $V_{AVG} = \dfrac{2V_p}{\pi} = \dfrac{2(75\text{ V})}{\pi} = \mathbf{47.7\ V}$

25. (a) **Center-tapped full-wave rectifier.**

(b) $V_{sec} = 0.25(80\text{ V}) = 20\text{ V rms}$

$V_{sec(\text{peak})} = 1.414(20\text{ V}) = \mathbf{28.3\ V}$

(c) $\dfrac{V_{sec(\text{peak})}}{2} = \dfrac{28.3\text{ V}}{2} = \mathbf{14.2\ V}$

(d) See Figure 16-3.

(e) $I_{F(\text{peak})} = \dfrac{\dfrac{V_{sec(\text{peak})}}{2} - 0.7\text{ V}}{R_L} = \dfrac{14.2\text{ V} - 0.7\text{ V}}{1.0\text{ k}\Omega} = \dfrac{13.5\text{ V}}{1.0\text{ k}\Omega} = \mathbf{13.5\ mA}$

(f) PIV = $2V_{p(out)} = 2(13.5\text{ V}) = \mathbf{27.0\text{ V}}$

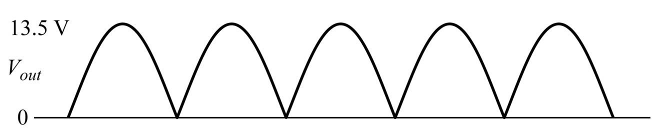


Figure 16-3

26. $V_{AVG} = = \dfrac{110\text{ V}}{2} = 55\text{ V}$ for each half of the transformer

$V_{AVG} = \dfrac{V_p}{\pi}$

$V_p = \pi V_{AVG} = \pi(55\text{ V}) = \mathbf{173\text{ V}}$

27. See Figure 16-4.

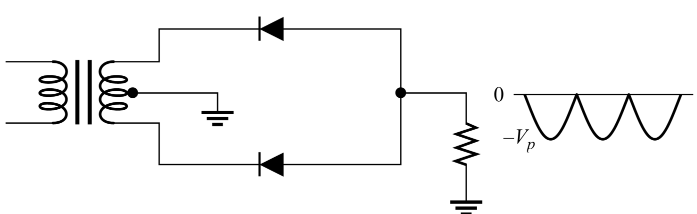


Figure 16-4

28. PIV $= V_p = \dfrac{\pi V_{AVG}}{2} = \dfrac{\pi(50\text{ V})}{2} = \mathbf{78.5\text{ V}}$

SECTION 16-5 Power Supplies

29. The ideal dc output voltage of a capacitor filter is the **peak value** of the rectified input.

30. $V_{in(peak)} = 1.414(120\text{ V}) = 170\text{ V}$

$V_A = (170\text{ V})\left(\dfrac{1}{3}\right) = 56.6\text{ V}$

$V_B = 56.6\text{ V} - 1.4\text{ V} = 55.2\text{ Vdc}$ (with ripple at 120 Hz)

See Figure 16-5.

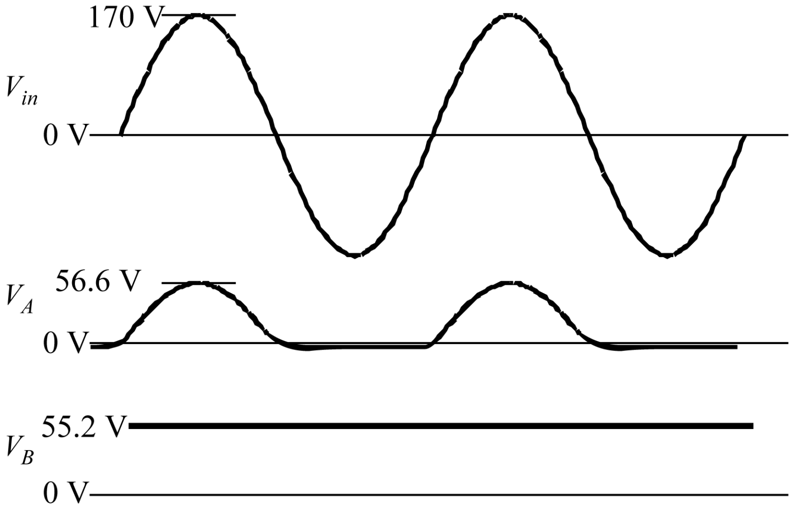


Figure 16-5

31. % load regulation $= \left(\dfrac{V_{NL} - V_{FL}}{V_{FL}}\right)100\%$

$= \left(\dfrac{12.6\text{ V} - 12.1\text{ V}}{12.1\text{ V}}\right)100\%$

$=$ **4.13%**

32. % line regulation $= \left(\dfrac{\Delta V_{\text{OUT}}}{\Delta V_{\text{IN}}}\right)100\%$

$= \left(\dfrac{4.85\text{ V} - 4.65\text{ V}}{9.35\text{ V} - 6.48\text{ V}}\right)100\%$

$=$ **6.97%**

SECTION 16-6 Special-Purpose Diodes

33. See Figure 16-6.

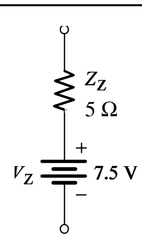


Figure 16-6

34. $Z_Z = \dfrac{\Delta V_Z}{\Delta I_Z} = \dfrac{38\text{ mV}}{1\text{ mA}}$ $= \mathbf{38\ \Omega}$

35. At 5 V; C = 20 pF
At 20 V; C = 11 pF
ΔC = 20 pF − 11 pF = **9 pF (decrease)**

36. From the graph, the diode reverse voltage that produces a capacitance of 25 pF is $V_R \cong$ **3 V**.

37. The microammeter reading will **increase** because the photodiode will conduct current when the LED is turned on.

38. The reverse current in a photodiode with no incident light is called **dark current.**

SECTION 16-7 Troubleshooting

39. $V_{AVG} = \dfrac{2V_p}{\pi} = \dfrac{2(120\text{ V})(1.414)}{\pi} \cong 108\text{ V}$
The output of the bridge is correct. However, the 0 V output from the filter indicates that the **capacitor is shorted** or $\boldsymbol{R_{surg}}$ **is open**.

40. (a) Output is correct.
(b) Incorrect, open diode.
(c) Output is correct.
(d) Incorrect, open capacitor.

41. (a) Readings are correct.
(b) Zener diode is open.
(c) Fuse is blown or switch is open.
(d) C_1 is open.
(e) Transformer winding is open or the bridge is open.

42. (a) Fuse is open. Replace fuse.
(b) Open transformer winding or connection. Verify and replace transformer.
(c) Open transformer winding or connection. Verify and replace transformer.
(d) C_1 is open. Replace capacitor.
(e) C_1 leaky. Replace capacitor.
(f) A diode is open. Isolate and replace.
(g) Fuse is blown or C_2 is shorted or IC regulator is bad or transformer is open or at least two bridge diodes are open. Isolate and replace.

Multisim Troubleshooting Problems

43. The diode is open.

44. D_2 is shorted.

45. No fault

46. D_2 is open.

47. D_1 is leaky.

48. Diode is shorted.

49. D_2 is open.

50. A bridge diode is shorted.

51. No fault

52. Zener diode D is open.

CHAPTER 17
TRANSISTORS AND APPLICATIONS

SECTION 17-1 DC Operation of Bipolar Junction Transistors

1. $I_C = I_E - I_B = 5.34\text{ mA} - 475\ \mu\text{A} = \mathbf{4.87\ mA}$

2. $\alpha_{DC} = \dfrac{I_C}{I_E} = \dfrac{8.23\text{ mA}}{8.69\text{ mA}} = \mathbf{0.947}$

3. $\beta_{DC} = \dfrac{I_C}{I_B} = \dfrac{25\text{ mA}}{200\ \mu\text{A}} = \mathbf{125}$

4. $I_B = 0.02I_E = 0.02(30\text{ mA}) = 0.6\text{ mA}$
   $I_C = I_E - I_B = 30\text{ mA} - 0.6\text{ mA} = \mathbf{29.4\ mA}$

5. $V_B = 2\text{ V}$
   $V_E = V_B - V_{BE} = 2\text{ V} - 0.7\text{ V} = 1.3\text{ V}$
   $I_E = \dfrac{V_E}{R_E} = \dfrac{1.3\text{ V}}{1.0\text{ k}\Omega} = \mathbf{1.3\ mA}$
   $I_C = \alpha_{DC}I_E = (0.98)(1.3\text{ mA}) = \mathbf{1.27\ mA}$
   $I_B = \dfrac{I_C}{\beta_{DC}} = \dfrac{1.27\text{ mA}}{49} = \mathbf{25.9\ \mu A}$

6. $V_B = 2\text{ V}$
   $V_E = V_B - V_{BE} = 2\text{ V} - 0.7\text{ V} = 1.3\text{ V}$
   $I_E = \dfrac{V_E}{R_E} = \dfrac{1.3\text{ V}}{1.0\text{ k}\Omega} = \mathbf{1.3\ mA}$
   $I_C = \alpha_{DC}I_E = (0.98)(1.3\text{ mA}) = \mathbf{1.27\ mA}$
   $I_B = \dfrac{I_C}{\beta_{DC}} = \dfrac{1.27\text{ mA}}{100} = \mathbf{12.7\ \mu A}$

7. $V_E = V_B - V_{BE} = 2\text{ V} - 0.7\text{ V} = \mathbf{1.3\ V}$

8. (a) $V_B = V_{BB} = \mathbf{10\ V}$
   $V_C = V_{CC} = \mathbf{20\ V}$
   $V_E = V_B - V_{BE} = 10\text{ V} - 0.7\text{ V} = \mathbf{9.3\ V}$
   $V_{CE} = V_C - V_E = 20\text{ V} - 9.3\text{ V} = \mathbf{10.7\ V}$
   $V_{BE} = \mathbf{0.7\ V}$
   $V_{BC} = V_B - V_C = 10\text{ V} - 20\text{ V} = \mathbf{-10\ V}$

(b) $V_B = V_{BE} = \mathbf{0.7\ V}$
$V_E = \mathbf{0\ V}$
$V_{R_B} = 4\text{ V} - 0.7\text{ V} = 3.3\text{ V}$
$$I_B = \frac{V_{R_B}}{R_B} = \frac{3.3\text{ V}}{4.7\text{ k}\Omega} = 702\ \mu\text{A}$$
$I_C = \beta_{DC} I_B = 50(702\ \mu\text{A}) = 35.1\text{ mA}$
$V_C = V_{CE} = V_{CC} - I_C R_C = 24\text{ V} - (35.1\text{ mA})(430\ \Omega) = \mathbf{8.91\ V}$
$V_{BC} = V_B - (V_{CC} - I_C R_C) = 0.7\text{ V} - 8.91\text{ V} = \mathbf{-8.21\ V}$

9. $$I_B = \frac{1\text{ V} - 0.7\text{ V}}{22\text{ k}\Omega} = \frac{0.3\text{ V}}{22\text{ k}\Omega} = \mathbf{13.6\ \mu A}$$
$I_C = \beta_{DC} I_B = 50(13.6\ \mu\text{A}) = \mathbf{680\ \mu A}$
$V_C = 10\text{ V} - (680\ \mu\text{A})(1.0\text{ k}\Omega) = \mathbf{9.32\ V}$

10. $$V_B = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{10\text{ k}\Omega}{22\text{ k}\Omega + 10\text{ k}\Omega}\right) 12\text{ V} = \mathbf{3.75\ V}$$
$V_E = V_B - V_{BE} = 3.75\text{ V} - 0.7\text{ V} = \mathbf{3.05\ V}$
$$I_E = \frac{V_E}{R_E} = \frac{3.05\text{ V}}{680\ \Omega} = \mathbf{4.48\ mA}$$
$I_C \simeq I_E = \mathbf{4.48\ mA}$
$V_C = V_{CC} - I_C R_C = 12.0\text{ V} - (4.48\text{ mA})(1.2\text{ k}\Omega) = \mathbf{6.62\ V}$

11. $V_{CE} = V_C - V_E = 6.62\text{ V} - 3.05\text{ V} = \mathbf{3.57\ V}$
Q point coordinates are at **4.48 mA** (I_C) and **3.57 V** (V_{CE})

SECTION 17-2 BJT Class A Amplifiers

12. $V_{out} = A_v V_{in} = 50(100\text{ mV}) = \mathbf{5\ V}$

13. $$A_v = \frac{V_{out}}{V_{in}} = \frac{10\text{ V}}{300\text{ mV}} = \mathbf{33.3}$$

14. $$A_v = \frac{R_C}{R_E} = \frac{500\ \Omega}{100\ \Omega} = 5$$
$V_c = A_v V_b = 5(50\text{ mV}) = \mathbf{250\ mV}$

15. $V_B = \left(\dfrac{4.7\text{ k}\Omega}{4.7\text{ k}\Omega + 22\text{ k}\Omega}\right)15\text{ V} = 2.64\text{ V}$

$V_E = V_B - V_{BE} = 2.64\text{ V} - 0.7\text{ V} = 1.94\text{ V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{1.94\text{ V}}{390\ \Omega} = 4.97\text{ mA}$

$r_e = \dfrac{25\text{ mV}}{4.97\text{ mA}} = 5.03\ \Omega$

$A_v = \dfrac{R_C}{r_e} = \dfrac{1.0\text{ k}\Omega}{5.03\ \Omega} = \mathbf{199}$

16. $V_B = \mathbf{2.64\ V}$ From Problem 15.
$V_E = \mathbf{1.94\ V}$ From Problem 15.
$I_C \cong I_E = 4.97\text{ mA}$
$V_C = 15\text{ V} - (4.97\text{ mA})(1.0\text{ k}\Omega) = \mathbf{10.03\ V}$

17. Ignoring loading effects,

$V_B = \left(\dfrac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\dfrac{12\text{ k}\Omega}{47\text{ k}\Omega + 12\text{ k}\Omega}\right)18\text{ V} = \mathbf{3.66\ V}$

$V_E = V_B - V_{BE} = 3.66\text{ V} - 0.7\text{ V} = \mathbf{2.96\ V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{2.96\text{ V}}{1.0\text{ k}\Omega} = \mathbf{2.96\ mA}$

$I_C \simeq I_E = \mathbf{2.96\ mA}$

$V_C = V_{CC} - I_C R_C = 18.0\text{ V} - (2.96\text{ mA})(3.3\text{ k}\Omega) = \mathbf{8.23\ V}$

$V_{CE} = V_C - V_E = 8.23\text{ V} - 2.96\text{ V} = 5.27\text{ V} = \mathbf{5.27\ V}$

18. From problem 17, $I_E = 2.96$ mA.

$R_{in} = \beta_{DC} r_e = \beta_{DC}\left(\dfrac{25\text{ mV}}{I_E}\right) = 100\left(\dfrac{25\text{ mV}}{2.96\text{ mA}}\right) = \mathbf{844\ \Omega}$

$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in} = 47\text{ k}\Omega \parallel 12\text{ k}\Omega \parallel 844\ \Omega = \mathbf{776\ \Omega}$

$A_v = \dfrac{R_C}{r_e} = \dfrac{3.3\text{ k}\Omega}{8.44\ \Omega} = \mathbf{393}$

$I_s = \dfrac{V_{in}}{R_{in(tot)}} = \dfrac{10\text{ mV}}{776\ \Omega} = 12.9\ \mu\text{A}$

$I_b = \left(\dfrac{R_1 \parallel R_2}{R_{in} + R_1 \parallel R_2}\right)I_s = \left(\dfrac{47\text{ k}\Omega \parallel 12\text{ k}\Omega}{776\ \Omega + 47\text{ k}\Omega \parallel 12\text{ k}\Omega}\right)12.9\ \mu\text{A} = 11.9\ \mu\text{A}$

$I_c = \beta_{ac} I_b = 70(11.9\ \mu\text{A}) = 835\ \mu\text{A}$

$A_i = \dfrac{I_c}{I_s} = \dfrac{835\ \mu\text{A}}{12.9\ \mu\text{A}} = \mathbf{64.7}$

$A_p = A_v A_i = (393)(64.7) = \mathbf{25{,}400}$

19. $V_B = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{3.3\text{ k}\Omega}{12\text{ k}\Omega + 3.3\text{ k}\Omega}\right)8\text{ V} = 1.72\text{ V}$

$V_E = V_B - V_{BE} = 1.72\text{ V} - 0.7\text{ V} = 1.02\text{ V}$

$I_E = \frac{V_E}{R_E} = \frac{1.02\text{ V}}{100\ \Omega} = 10.2\text{ mA}$

$r_e = \left(\frac{25\text{ mV}}{I_E}\right) = \left(\frac{25\text{ mV}}{10.2\text{ mA}}\right) = 2.44\ \Omega$

$A_{v(min)} = \frac{R_C}{R_E + r_e} = \frac{300\ \Omega}{100\ \Omega + 2.44\ \Omega}$ **= 2.93**

$A_{v(max)} = \frac{R_C}{r_e} = \frac{300\ \Omega}{2.44\ \Omega}$ **= 123**

20. $A_{v(max)} = \frac{R_C \parallel R_L}{r_e} = \frac{300\ \Omega \parallel 600\ \Omega}{2.44\ \Omega}$ **= 82**

21. $V_B = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{47\text{ k}\Omega}{47\text{ k}\Omega + 47\text{ k}\Omega}\right)5.5\text{ V} = 2.75\text{ V}$

$V_E = V_B - V_{BE} = 2.75\text{ V} - 0.7\text{ V} = 2.05\text{ V}$

$I_E = \frac{V_E}{R_E} = \frac{2.05\text{ V}}{1.0\text{ k}\Omega} = 2.05\text{ mA}$

$r_e = \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{2.05\text{ mA}} = 12.2\ \Omega$

$A_v = \frac{R_E}{r_e + R_E} = \frac{1.0\text{ k}\Omega}{12.2\ \Omega + 1.0\text{ k}\Omega}$ **= 0.988**

22. $R_{in(tot)} = R_1 \parallel R_2 \parallel \beta(R_E + r_e)$

$= 47\text{ k}\Omega \parallel 47\text{ k}\Omega \parallel 100(1.0\text{ k}\Omega + 12.2\ \Omega)$ **= 19.1 kΩ**

$V_{out(dc)} = V_E$ **= 2.05 V**

23. The voltage **gain is reduced** (by approximately 1% for a 1.0 kΩ load.)

SECTION 17-3 BJT Class B Amplifiers

24. *Bias current*

$$I_T = \frac{V_{CC} - 1.4\text{ V}}{R_1 + R_2} = \frac{20\text{ V} - 1.4\text{ V}}{780\ \Omega} = 23.85\text{ mA}$$

$V_{B1} = V_{CC} - I_T R_1 = 20\text{ V} - (23.85\text{ mA})(390\ \Omega) = \mathbf{10.7\ V}$

$V_{E1} = V_{B1} - V_{BE} = 10.7\text{ V} - 0.7\text{ V} = \mathbf{10\ V}$

$V_{B2} = V_{B1} - 1.4\text{ V} = 10.7\text{ V} - 1.4\text{ V} = \mathbf{9.3\ V}$

$V_{E2} = V_{B2} + 0.7\text{ V} = 9.3\text{ V} + 0.7\text{ V} = \mathbf{10\ V}$

$V_{CEQ1} = V_{C1} - V_{E1} = 20\text{ V} - 10\text{ V} = \mathbf{10\ V}$

$V_{CEQ2} = V_{E2} - V_{C2} = 10\text{ V} - 0\text{ V} = \mathbf{10\ V}$

25. $$V_{p(out)} = V_{CEQ} = \frac{V_{CC}}{2} = \frac{20\text{ V}}{2} = \mathbf{10\ V}$$

$$I_{p(load)} \cong I_{c(sat)} = \frac{V_{CEQ}}{R_L} = \frac{10\text{ V}}{16\ \Omega} = \mathbf{625\ mA}$$

26. $$\text{Efficiency} = \frac{P_{out}}{P_{in}}$$

$P_{out} = (0.71)(16.3\text{ W}) = \mathbf{11.6\ W}$

SECTION 17-4 The BJT as a Switch

27. $$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{5\text{ V}}{10\text{ k}\Omega} = \mathbf{0.5\ mA}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{0.5\text{ mA}}{150} = \mathbf{3.33\ \mu A}$$

$$I_{B(min)} = \frac{V_{IN(min)} - 0.7\text{ V}}{R_B}$$

$$V_{IN(min)} = R_B\left(I_{B(min)} + \frac{0.7\text{ V}}{R_B}\right)$$

$V_{IN(min)} = I_{B(min)}R_B + 0.7\text{ V} = (3.33\ \mu\text{A})(100\text{ k}\Omega) + 0.7\text{ V} = \mathbf{1.03\ V}$

28. $$I_{C(sat)} = \frac{15\text{ V}}{1.2\text{ k}\Omega} = 12.5\text{ mA}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{12.5\text{ mA}}{150} = 83.3\ \mu\text{A}$$

$$R_{B(min)} = \frac{V_{IN} - 0.7\text{ V}}{I_{B(min)}} = \frac{4.3\text{ V}}{83.3\ \mu\text{A}} = 51.6\text{ k}\Omega$$

SECTION 17-5 DC Operation of Field-Effect Transistors (FETs)

29. (a) The depletion region **narrows** when V_{GS} is increased from 1 V to 3 V.
    (b) The resistance **increases** when V_{GS} is increased from 1 V to 3 V.

30. The gate-to-source voltage of an *N*-channel JFET must be zero or negative in order to maintain the required reverse-bias condition.

31. See Figure 17-1.

Figure 17-1

32. The gate is insulated from the channel by an SiO_2 layer.

33. The *n*-channel D-MOSFET operates in **enhancement mode** when positive V_{GS} is applied.

34. $V_{GS(min)} = V_{GS(th)} = \mathbf{3\ V}$

35. (a) $V_S = (1\text{ mA})(1.0\text{ k}\Omega) = 1\text{ V}$
    $V_D = 12\text{ V} - (1\text{ mA})(4.7\text{ k}\Omega) = 7.3\text{ V}$
    $V_G = 0\text{ V}$
    $V_{DS} = V_D - V_S = 7.3\text{ V} - 1\text{ V} = \mathbf{6.3\ V}$
    $V_{GS} = V_G - V_S = 0\text{ V} - 1\text{ V} = \mathbf{-1\ V}$

    (b) $V_S = (3\text{ mA})(100\ \Omega) = 0.3\text{ V}$
    $V_D = 9\text{ V} - (3\text{ mA})(470\ \Omega) = 7.59\text{ V}$
    $V_G = 0\text{ V}$
    $V_{DS} = V_D - V_S = 7.59\text{ V} - 0.3\text{ V} = \mathbf{7.29\ V}$
    $V_{GS} = V_G - V_S = 0\text{ V} - 0.3\text{ V} = \mathbf{-0.3\ V}$

    (c) $V_S = (-5\text{ mA})(470\ \Omega) = -2.35\text{ V}$
    $V_D = -15\text{ V} - (-5\text{ mA})(2.2\text{ k}\Omega) = -4\text{ V}$
    $V_G = 0\text{ V}$
    $V_{DS} = V_D - V_S = -4\text{ V} - (-2.35\text{ V}) = \mathbf{-1.65\ V}$
    $V_{GS} = V_G - V_S = 0\text{ V} - (-2.35\text{ V}) = \mathbf{2.35\ V}$

36. (a) Depletion (b) Enhancement
    (c) Zero bias (d) Enhancement

37. (a) $V_{GS} = \left(\dfrac{10\text{ M}\Omega}{14.7\text{ M}\Omega}\right)10\text{ V} = 6.8\text{ V}$ **This one is on.**

    (b) $V_{GS} = \left(\dfrac{1.0\text{ M}\Omega}{11\text{ M}\Omega}\right)(-25\text{ V}) = -2.27\text{ V}$ **This one is off.**

SECTION 17-6 FET Amplifiers

38. (a) $A_v = g_m R_D = (3.8 \text{ mS})(1.2 \text{ k}\Omega) = \mathbf{4.56}$
    (b) $A_v = g_m R_D = (5.5 \text{ mS})(2.2 \text{ k}\Omega \parallel 10 \text{ k}\Omega) = \mathbf{9.92}$

39. (a) $$A_v = \frac{g_m R_S}{1 + g_m R_S} = \frac{(3000 \,\mu\text{S})(4.7 \text{ k}\Omega)}{1 + (3000 \,\mu\text{S})(4.7 \text{ k}\Omega)} = \mathbf{0.934}$$
    (b) $$A_v = \frac{g_m R_S}{1 + g_m R_S} = \frac{(4300 \,\mu\text{S})(100 \,\Omega)}{1 + (4300 \,\mu\text{S})(100 \,\Omega)} = \mathbf{0.301}$$

40. (a) $$A_v = \frac{g_m R_S}{1 + g_m R_S} = \frac{(3000 \,\mu\text{S})(4.7 \text{ k}\Omega \parallel 10 \text{ k}\Omega)}{1 + (3000 \,\mu\text{S})(4.7 \text{ k}\Omega \parallel 10 \text{ k}\Omega)} = \mathbf{0.906}$$
    (b) $$A_v = \frac{g_m R_S}{1 + g_m R_S} = \frac{(4300 \,\mu\text{S})(100 \,\Omega \parallel 10 \text{ k}\Omega)}{1 + (4300 \,\mu\text{S})(100 \,\Omega \parallel 10 \text{ k}\Omega)} = \mathbf{0.299}$$

SECTION 17-7 Feedback Oscillators

41. Unity gain around the closed loop is required for sustained oscillation.
    $A_{cl} = A_V B = 1$
    $$B = \frac{1}{A_v} = \frac{\mathbf{1}}{\mathbf{75}} = \mathbf{0.0133}$$

42. To ensure start up:
    $A_{cl} > 1$
    Since $A_v = 75$, ***B* must be greater than 1/75** in order to produce the condition.
    $A_v B > 1$.
    For example, if $B = 1/50$,
    $A_v B = 75(1/50) = 1.5$

43. (a) $$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = 909 \text{ pF}$$
    $$f_r = \frac{1}{2\pi\sqrt{LC_{eq}}} = \frac{1}{2\pi\sqrt{(0.1 \text{ mH})(909 \text{ pF})}} = \mathbf{528 \text{ kHz}}$$
    Oscillator is Colpitts.
    (b) $L_{eq} = L_1 + L_2 = 22 \,\mu\text{H}$
    $$f_r = \frac{1}{2\pi\sqrt{L_{eq} C}} = \frac{1}{2\pi\sqrt{(22 \,\mu\text{H})(0.002 \,\mu\text{F})}} = \mathbf{759 \text{ kHz}}$$
    Oscillator is Hartley.

SECTION 17-8 Troubleshooting

44. If R_5 opens, $V_{B2} \cong 0$ V and Q_2 will be in **cutoff**.
V_{C2} = **10 V**

45. (a) If the bypass capacitor, C_2, opens, the voltage gain of the first stage and thus the overall gain decreases. The dc voltages and the currents are not affected.
(b) If the coupling capacitor, C_3, opens, the signal will not reach the second stage so $V_{out} = 0$ V. The voltage gain of the first stage increases due to reduced loading. The dc voltages and currents are not affected.
(c) If the bypass capacitor, C_4, opens, the voltage gain of the second stage and thus the overall gain decreases. The dc voltages and currents are not affected.
(d) If C_2 shorts, R_4 is shorted, resulting in the dc bias voltages of the first stage being changed.
(e) If the BC junction of Q_1 opens, the signal will not pass through the first stage. The dc voltages at the base, emitter, and collector of Q_1 will change. The dc voltages and currents in the second stage are not affected.
(f) If the BE junction of Q_2 opens, the signal will not pass through the second stage. The dc voltages at the base, emitter, and collector of Q_2 will change. The dc voltages and currents in the first stage are not affected.

46. (a) Q_1 open drain to source: $V_{S1} = 0$ V, $V_{D1} = +V_{DD}$, no signal at Q_1 drain.
(b) R_3 open: $V_{S1} = 0$ V, V_{D1} floating, no signal at Q_2 gate.
(c) C_2 shorted: $V_{GS} = 0$ V, $I_D \cong I_{DSS}$.
(d) C_3 shorted: $V_{G2} = V_{D1}$, improperly biasing Q_2
(e) Q_2 open drain to source: $V_{S2} = 0$ V, $V_{D2} = +V_{DD}$, no signal at Q_2 drain

Multisim Troubleshooting Problems

47. Base-collector junction is open.

48. No fault

49. Drain and source are shorted.

50. R_2 is open.

51. No fault

52. C_2 is open.

53. C_1 is open.

CHAPTER 18
THE OPERATIONAL AMPLIFIER

SECTION 18-1 Introduction to the Operational Amplifier

1. **Practical op-amp**: High open-loop gain, high input resistance, low output resistance, and high CMRR.
   Ideal op-amp: Infinite open-loop gain, infinite input resistance, zero output resistance, and infinite CMRR.

2. Op-amp 2 is more desirable because it has a higher input resistance, a lower output resistance, and a higher open-loop gain.

SECTION 18-2 The Differential Amplifier

3. (a) Single-ended input, differential output
   (b) Single-ended input, single-ended output
   (c) Differential input, single-ended output
   (d) Differential input, differential output

4. $V_{E1} = V_{E2} = -0.7\text{ V}$

   $$I_{RE} = \frac{-0.7\text{ V} - (-15\text{ V})}{2.2\text{ k}\Omega} = \frac{14.3\text{ V}}{2.2\text{ k}\Omega} = 6.5\text{ mA}$$

   $$I_{E1} = I_{E2} = \frac{6.5\text{ mA}}{2} = 3.25\text{ mA}$$

   $$\alpha_1 = \frac{I_{C1}}{I_{E1}} = 0.98$$

   $$\alpha_2 = \frac{I_{C2}}{I_{E2}} = 0.975$$

   $I_{C1} = 0.98(3.25\text{ mA}) = 3.19\text{ mA}$
   $I_{C2} = 0.975(3.25\text{ mA}) = 3.17\text{ mA}$
   $V_{C1} = 15\text{ V} - (3.19\text{ mA})(3.3\text{ k}\Omega) = 4.47\text{ V}$
   $V_{C2} = 15\text{ V} - (3.17\text{ mA})(3.3\text{ k}\Omega) = 4.54\text{ V}$
   $V_{OUT} = V_{C2} - V_{C1} = 4.54\text{ V} - 4.47\text{ V} = 0.07\text{ V} =$ **70 mV**

5. $$\text{CMRR} = 20\log\frac{A_{v(d)}}{A_{cm}} = \frac{60}{0.09} = \mathbf{56.5\ dB}$$

6. $$A_{cm} = \frac{A_{v(d)}}{10^{\text{CMRR}/20}} = \frac{150}{10^{65/20}} = \mathbf{0.084}$$

7. (a) Single-ended mode
   (b) Differential mode
   (c) Common mode

8. See Figure 18-1. $V_{in1} = V_{in2}$

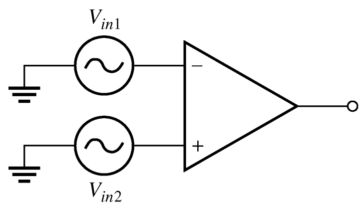


Figure 18-1

SECTION 18-3 Op-Amp Parameters

9. $I_{\text{BIAS}} = \dfrac{8.3\ \mu\text{A} + 7.9\ \mu\text{A}}{2} = \mathbf{8.1\ \mu A}$

10. Input bias current is the average of the two input currents.
Input offset current is the *difference* of the two input currents.
$I_{\text{OS}} = |I_1 - I_2| = |8.3\ \mu\text{A} - 7.9\ \mu\text{A}| = \mathbf{0.4\ \mu A}$

11. CMRR = 20 log 250,000 = **108 dB**

12. $\text{CMRR} = 20\log\left(\dfrac{A_{ol}}{A_{cm}}\right) = 20\log\left(\dfrac{175{,}000}{0.18}\right) = \mathbf{120\ dB}$

13. $\text{CMRR} = \dfrac{A_{ol}}{A_{cm}}$

$A_{cm} = \dfrac{A_{ol}}{\text{CMRR}} = \dfrac{90{,}000}{300{,}000} = \mathbf{0.3}$

14. $\text{Slew rate} = \dfrac{24\ \text{V}}{15\ \mu\text{s}} = \mathbf{1.6\ V/\mu s}$

15. $\Delta t = \dfrac{\Delta V_{out}}{\text{slew rate}} = \dfrac{20\ \text{V}}{0.5\ \text{V}/\mu\text{s}} = \mathbf{40\ \mu s}$

SECTION 18-5 Op-Amp Configurations with Negative Feedback

16. (a) Voltage-follower (b) Noninverting (c) Inverting

17. (a) $A_{cl(\text{NI})} = \dfrac{1}{B} = \dfrac{1}{1.5\text{ k}\Omega/561.5\text{ k}\Omega} = \mathbf{374}$

(b) $V_{out} = A_{cl(\text{NI})}V_{in} = (374)(10\text{ mV}) = \mathbf{3.74\text{ V}}$

(c) $V_f = \left(\dfrac{1.5\text{ k}\Omega}{561.5\text{ k}\Omega}\right)3.74\text{ V} = \mathbf{10\text{ mV}}$

18. (a) $A_{cl(\text{NI})} = \dfrac{1}{B} = \dfrac{1}{4.7\text{ k}\Omega/51.7\text{ k}\Omega} = \mathbf{11}$

(b) $A_{cl(\text{NI})} = \dfrac{1}{B} = \dfrac{1}{10\text{ k}\Omega/1.01\text{ M}\Omega} = \mathbf{101}$

(c) $A_{cl(\text{NI})} = \dfrac{1}{B} = \dfrac{1}{4.7\text{ k}\Omega/224.7\text{ k}\Omega} = \mathbf{47.8}$

(d) $A_{cl(\text{NI})} = \dfrac{1}{B} = \dfrac{1}{1.0\text{ k}\Omega/23\text{ k}\Omega} = \mathbf{23}$

19. (a) $A_{cl(\text{NI})} = \dfrac{1}{B} = \dfrac{1}{R_i/(R_f + R_i)} = \dfrac{R_f + R_i}{R_i}$

$R_f + R_i = R_iA_{cl(\text{NI})}$
$R_f = R_iA_{cl(\text{NI})} - R_i$
$R_f = R_i(A_{cl(\text{NI})} - 1) = 1.0\text{ k}\Omega(49) = \mathbf{49\text{ k}\Omega}$

(b) $A_{cl(\text{I})} = -\left(\dfrac{R_f}{R_i}\right)$

$R_f = -A_{cl(\text{I})}R_i = -(-300)(10\text{ k}\Omega) = \mathbf{3\text{ M}\Omega}$

(c) $R_f = R_i(A_{cl(\text{NI})} - 1) = 12\text{ k}\Omega(7) = \mathbf{84\text{ k}\Omega}$

(d) $R_f = -A_{cl(\text{I})}R_i = -(-75)(2.2\text{ k}\Omega) = \mathbf{165\text{ k}\Omega}$

20. (a) $A_{cl(\text{VF})} = \mathbf{1}$

(b) $A_{cl(\text{I})} = -\left(\dfrac{R_f}{R_i}\right) = -\left(\dfrac{100\text{ k}\Omega}{100\text{ k}\Omega}\right) = \mathbf{-1}$

(c) $A_{cl(\text{NI})} = \dfrac{1}{R_i/(R_i + R_f)} = \dfrac{1}{47\text{ k}\Omega/(47\text{ k}\Omega + 1.0\text{ M}\Omega)} = \mathbf{22.3}$

(d) $A_{cl(\text{I})} = -\left(\dfrac{R_f}{R_i}\right) = -\left(\dfrac{330\text{ k}\Omega}{33\text{ k}\Omega}\right) = \mathbf{-10}$

21. (a) $V_{out} = V_{in} =$ **10 mV, in-phase**

(b) $V_{out} = A_{cl}V_{in} = -\left(\dfrac{R_f}{R_i}\right)V_{in} = -1(10\text{ mV}) =$ **−10 mV, 180° out-of-phase**

(c) $V_{out} = \left(\frac{1}{R_i/(R_f + R_i)}\right)V_{in} = \left(\frac{1}{47\text{ k}\Omega/1.047\text{ M}\Omega}\right)10\text{ mV} = \mathbf{223\text{ mV, in-phase}}$

(d) $V_{out} = -\left(\frac{R_f}{R_i}\right)V_{in} = -\left(\frac{330\text{ k}\Omega}{33\text{ k}\Omega}\right)10\text{ mV} = \mathbf{-100\text{ mV, }180°\text{ out-of-phase}}$

22. (a) $I_{in} = \frac{V_{in}}{R_{in}} = \frac{1\text{ V}}{2.2\text{ k}\Omega} = \mathbf{455\ \mu A}$

(b) $I_f = I_{in} = \mathbf{455\ \mu A}$

(c) $V_{out} = -I_fR_f = -(455\ \mu\text{A})(22\text{ k}\Omega) = \mathbf{-10\text{ V}}$

(d) $A_{cl(\text{I})} = -\left(\frac{R_f}{R_i}\right) = -\left(\frac{22\text{ k}\Omega}{2.2\text{ k}\Omega}\right) = \mathbf{-10}$

SECTION 18-6 Op-Amp Resistances

23. (a) $B = \frac{2.7\text{ k}\Omega}{562.7\text{ k}\Omega} = 0.0048$

$R_{in(\text{NI})} = (1 + A_{ol}B)R_{in} = (1 + 175{,}000 \times 0.0048)10\text{ M}\Omega = \mathbf{8410\text{ M}\Omega}$

$R_{out(\text{NI})} = \frac{R_{out}}{(1 + A_{ol}B)} = \frac{75\ \Omega}{(1 + 175{,}000 \times 0.0048)} = \mathbf{89.2\text{ m}\Omega}$

(b) $B = \frac{1.5\text{ k}\Omega}{48.5\text{ k}\Omega} = 0.0309$

$R_{in(\text{NI})} = (1 + A_{ol}B)R_{in} = (1 + 200{,}000 \times 0.0309)1.0\text{ M}\Omega = \mathbf{6181\text{ M}\Omega}$

$R_{out(\text{NI})} = \frac{R_{out}}{(1 + A_{ol}B)} = \frac{25\ \Omega}{(1 + 200{,}000 \times 0.0309)} = \mathbf{4.04\text{ m}\Omega}$

(c) $B = \frac{56\text{ k}\Omega}{1.056\text{ M}\Omega} = 0.053$

$R_{in(\text{NI})} = (1 + A_{ol}B)R_{in} = (1 + 50{,}000 \times 0.053)2.0\text{ M}\Omega = \mathbf{5302\text{ M}\Omega}$

$R_{out(\text{NI})} = \frac{R_{out}}{(1 + A_{ol}B)} = \frac{50\ \Omega}{(1 + 50{,}000 \times 0.053)} = \mathbf{18.9\text{ m}\Omega}$

24. (a) $R_{in(\text{VF})} = (1 + A_{ol})R_{in} = (1 + 220{,}000)6.0\text{ M}\Omega = 1.32 \times 10^{12}\ \Omega = \mathbf{1.32\text{ T}\Omega}$

$R_{out(\text{VF})} = \frac{R_{out}}{1 + A_{ol}} = \frac{100\ \Omega}{1 + 220{,}000} = \mathbf{0.455\text{ m}\Omega}$

(b) $R_{in(\text{VF})} = (1 + A_{ol})R_{in} = (1 + 100{,}000)5.0\text{ M}\Omega = 500 \times 10^{9}\ \Omega = \mathbf{500\text{ G}\Omega}$

$R_{out(\text{VF})} = \frac{R_{out}}{1 + A_{ol}} = \frac{60\ \Omega}{1 + 100{,}000} = \mathbf{0.6\text{ m}\Omega}$

(c) $R_{in(\text{VF})} = (1 + A_{ol})R_{in} = (1 + 50{,}000)800\text{ k}\Omega = \mathbf{40\text{ G}\Omega}$

$R_{out(\text{VF})} = \frac{R_{out}}{1 + A_{ol}} = \frac{75\ \Omega}{1 + 50{,}000} = \mathbf{1.5\text{ m}\Omega}$

25. (a) $R_{in(\mathrm{I})} \cong R_i = \mathbf{10\ k\Omega}$
$R_{out(\mathrm{I})} = R_{out} = \mathbf{5.12\ m\Omega}$
(b) $R_{in(\mathrm{I})} \cong R_i = \mathbf{100\ k\Omega}$
$R_{out(\mathrm{I})} = R_{out} = \mathbf{67.2\ m\Omega}$
(c) $R_{in(\mathrm{I})} \cong R_i = \mathbf{470\ \Omega}$
$R_{out(\mathrm{I})} = R_{out} = \mathbf{6.24\ m\Omega}$

SECTION 18-7 Troubleshooting

26. (a) Faulty op-amp open R_1, no power supplies, or grounded output.
(b) R_2 is open, forcing open-loop operation.
(c) Nonzero output offset voltage. R_4 is faulty or needs adjustment.

27. The closed-loop voltage gain will increase to:
$$A_{cl} = \frac{100\ \text{k}\Omega}{1\ \text{k}\Omega} = \mathbf{100}$$
This increase is because the feedback resistance becomes the maximum potentiometer resistance (100 kΩ).

Multisim Troubleshooting Problems

28. R_i is open.

29. R_1 is open.

30. No fault

31. The op-amp is faulty.

32. C is open.

CHAPTER 19
BASIC OP-AMP CIRCUITS

SECTION 19-1 Comparators

1. (a) Maximum negative
   (b) Maximum positive
   (c) Maximum negative

2. $V_{p(out)} = A_{ol}V_{in} = (80{,}000)(0.15\text{ mV})(1.414) = 16.9\text{ V}$
   Since ±13 V is the peak limit, $V_{pp(out)}$ **= 26 V**

3. See Figure 19-1.

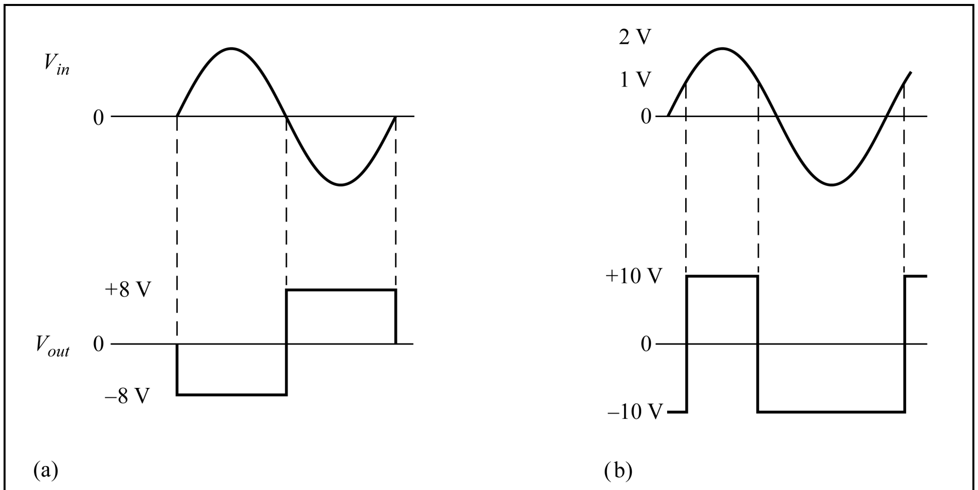


Figure 19-1

SECTION 19-2 Summing Amplifiers

4. (a) $V_{OUT} = -(1\text{ V} + 1.5\text{ V}) = \mathbf{-2.5\ V}$
   (b) $V_{OUT} = -\left(\frac{R_f}{R}\right)(-0.1\text{ V} + 1\text{ V} + 0.5\text{ V}) = -2.2(1.4\text{ V}) = \mathbf{-3.08\ V}$

5. (a) V_{R1} **= 1 V**
   V_{R2} **= 1.8 V**

(b) $I_{R1} = \dfrac{1\text{ V}}{22\text{ k}\Omega} = 45.5\ \mu\text{A}$

$I_{R2} = \dfrac{1.8\text{ V}}{22\text{ k}\Omega} = 81.8\ \mu\text{A}$

$I_f = I_{R1} + I_{R2} = 45.45\ \mu\text{A} + 81.82\ \mu\text{A} = \mathbf{127\ \mu A}$

(c) $V_{\text{OUT}} = I_f R_f = -(127\ \mu\text{A})(22\text{ k}\Omega) = \mathbf{-2.8\ V}$

6. $5V_{in} = \left(\dfrac{R_f}{R}\right)V_{in}$

$\dfrac{R_f}{R} = 5$

$R_f = 5R = 5(22\text{ k}\Omega) = \mathbf{110\ k\Omega}$

7. $V_{\text{OUT}} = -\left(\left(\dfrac{R_f}{R_1}\right)V_1 + \left(\dfrac{R_f}{R_2}\right)V_2 + \left(\dfrac{R_f}{R_3}\right)V_3 + \left(\dfrac{R_f}{R_4}\right)V_4\right)$

$= \left(\left(\dfrac{10\text{ k}\Omega}{10\text{ k}\Omega}\right)2\text{ V} + \left(\dfrac{10\text{ k}\Omega}{33\text{ k}\Omega}\right)3\text{ V} + \left(\dfrac{10\text{ k}\Omega}{91\text{ k}\Omega}\right)3\text{ V} + \left(\dfrac{10\text{ k}\Omega}{180\text{ k}\Omega}\right)6\text{ V}\right)$

$= -(2\text{ V} + 0.91\text{ V} + 0.33\text{ V} + 0.33\text{ V}) = \mathbf{-3.57\ V}$

$I_f = \dfrac{V_{\text{OUT}}}{R_f} = \dfrac{3.57\text{ V}}{10\text{ k}\Omega} = \mathbf{357\ \mu A}$

8. $R_f = 100\text{ k}\Omega$, $R_1 = \mathbf{100\ k\Omega}$, $R_2 = \mathbf{50\ k\Omega}$, $R_3 = \mathbf{25\ k\Omega}$, $R_4 = \mathbf{12.5\ k\Omega}$,

SECTION 19-3 Integrators and Differentiators

9. $\dfrac{\Delta V_{\text{OUT}}}{\Delta t} = \dfrac{-V_{\text{IN}}}{RC} = \dfrac{-5\text{ V}}{(56\text{ k}\Omega)(0.022\ \mu\text{F})} = \mathbf{-4.06\ mV/\mu s}$

10. See Figure 19-2.

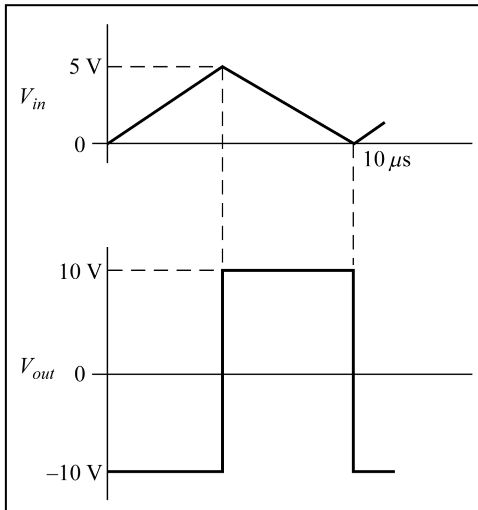


Figure 19-2

SECTION 19-4 Oscillators

11. $$\frac{V_{out}}{V_{in}} = \frac{1}{3}$$

$$V_{out} = \left(\frac{1}{3}\right)V_{in} = \frac{2.2\text{ V}}{3} = \mathbf{733\ mV}$$

12. $$f_r = \frac{1}{2\pi RC} = \frac{1}{2\pi(6.2\text{ k}\Omega)(0.022\ \mu\text{F})} = \mathbf{1.17\ kHz}$$

13. $$\frac{R_f + R_{\text{DS}} + R_3}{R_{\text{DS}} + R_3} = 3$$

$$3(R_{\text{DS}} + R_3) = R_f + R_{\text{DS}} + R_3$$
$$3R_{\text{DS}} + 3.0\text{ k}\Omega = 12\text{ k}\Omega + R_{\text{DS}} + 1.0\text{ k}\Omega$$
$$3R_{\text{DS}} - R_{\text{DS}} = 13\text{ k}\Omega - 3\text{ k}\Omega$$
$$R_{\text{DS}} = \frac{10\text{ k}\Omega}{2} = \mathbf{5\ k\Omega}$$

14. Negative excursions of V_{OUT} forward-bias D_1 causing C_3 to charge to a negative voltage, which increases the drain-source resistance of the JFET and reduces the gain.

15. $$f_r = \frac{1}{2\pi RC} = \frac{1}{2\pi(15\text{ k}\Omega)(0.01\ \mu\text{F})} = \mathbf{1.06\ kHz}$$

16. The circuit produces a triangular waveform.

$$f = \frac{1}{4R_1C}\left(\frac{R_2}{R_3}\right) = \frac{1}{4(22\text{ k}\Omega)(0.022\ \mu\text{F})}\left(\frac{56\text{ k}\Omega}{18\text{ k}\Omega}\right) = \mathbf{1.61\ kHz}$$

17. Change the frequency to 10 kHz by changing R_1 as follows:
The circuit produces a triangular waveform.

$$f = \frac{1}{4R_1C}\left(\frac{R_2}{R_3}\right)$$

$$R_1 = \frac{1}{4fC}\left(\frac{R_2}{R_3}\right) = \frac{1}{4(10\text{ kHz})(0.022\ \mu\text{F})}\left(\frac{56\text{ k}\Omega}{18\text{ k}\Omega}\right) = \mathbf{3.54\ k\Omega}$$

SECTION 19-5 Active Filters

18. (a) One pole, low pass
(b) One pole, high pass
(c) Two poles, band pass

19. (a) $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(4.7\text{ k}\Omega)(0.022\ \mu\text{F})}$ **= 1.54 kHz**

(b) $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(4.7\text{ k}\Omega)(0.0047\ \mu\text{F})}$ **= 7.20 kHz**

(c) $f_c = \dfrac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = \dfrac{1}{2\pi\sqrt{(12\text{ k}\Omega)^2(0.022\ \mu\text{F})(0.01\ \mu\text{F})}}$ **= 894 Hz**

20. (a) *For the low-pass stage:*

$$f_c = \frac{1}{2\pi\sqrt{R^2C_1C_2}} = \frac{1}{2\pi\sqrt{(10\text{ k}\Omega)^2(0.01\ \mu\text{F})(0.0047\ \mu\text{F})}} = 2.32\text{ kHz}$$

For the high-pass stage:

$$f_c = \frac{1}{2\pi\sqrt{R_3R_4C^2}} = \frac{1}{2\pi\sqrt{(22\text{ k}\Omega)(10\text{ k}\Omega)(0.01\ \mu\text{F})^2}} = 1.07\text{ kHz}$$

$BW = 2.32\text{ kHz} - 1.07\text{ kHz} =$ **1.25 kHz**

$f_r = \sqrt{(2.32\text{ kHz})(1.07\text{ kHz})} =$ **1.58 kHz**

(b) *For the low-pass stage:*

$$f_c = \frac{1}{2\pi\sqrt{R^2C_1C_2}} = \frac{1}{2\pi\sqrt{(15\text{ k}\Omega)^2(2200\text{ pF})(1000\text{ pF})}} = 7.15\text{ kHz}$$

For the high-pass stage:

$$f_c = \frac{1}{2\pi\sqrt{R_1R_2C^2}} = \frac{1}{2\pi\sqrt{(56\text{ k}\Omega)(27\text{ k}\Omega)(1500\text{ pF})^2}} = 2.73\text{ kHz}$$

$BW = 7.15\text{ kHz} - 2.73\text{ kHz} =$ **4.42 kHz**

$f_r = \sqrt{(7.15\text{ kHz})(2.73\text{ kHz})} =$ **4.42 kHz**

SECTION 19-6 Voltage Regulators

21. $V_{\text{OUT}} = \left(1 + \dfrac{R_2}{R_3}\right)V_{\text{REF}} = \left(1 + \dfrac{4.7\text{ k}\Omega}{1.8\text{ k}\Omega}\right)2\text{ V} =$ **7.22 V**

22. For $R_3 = 1.8\text{ k}\Omega$:

$$V_{\text{OUT}} = \left(1 + \frac{R_2}{R_3}\right)V_{\text{REF}} = \left(1 + \frac{4.7\text{ k}\Omega}{1.8\text{ k}\Omega}\right)2\text{ V} = 7.22\text{ V}$$

For $R_3 = 2(1.8\text{ k}\Omega) = 3.6\text{ k}\Omega$:

$$V_{\text{OUT}} = \left(1 + \frac{4.7\text{ k}\Omega}{3.6\text{ k}\Omega}\right)2\text{ V} = 4.61\text{ V}$$

The output voltage **decreases by 2.61 V** when R_3 is changed from 1.8 kΩ to 3.6 kΩ.

23. $V_{OUT} = \left(1 + \dfrac{4.7\text{ k}\Omega}{1.8\text{ k}\Omega}\right)2.7\text{ V} = \mathbf{9.75\text{ V}}$

24. $I_{L(max)} = \dfrac{0.7\text{ V}}{R_4}$

$R_4 = \dfrac{0.7\text{ V}}{I_{L(max)}} = \dfrac{0.7\text{ V}}{250\text{ mA}} = \mathbf{2.8\ \Omega}$

$P_{max} = I_{L(max)}^2 R_4 = (250\text{ mA})^2(2.8\ \Omega) = \mathbf{175\text{ mW}}$

Use a 0.25 W resistor.

25. $R_4 = \dfrac{2.8\ \Omega}{2} = 1.4\ \Omega$

$I_{L(max)} = \dfrac{0.7\text{ V}}{R_4} = \dfrac{0.7\text{ V}}{1.4\ \Omega} = \mathbf{500\text{ mA}}$

26. Q_1 conducts more when the load current increases, assuming that the output voltage attempts to increase. When the output voltage tries to increase due to a change in load current, the attempted increase is sensed by R_3 and R_4 and applied to the op-amp's noninverting input. The resulting difference voltage increases the op-amp's output, driving Q_1 more, and thus increasing its collector current.

27. $\Delta I_C = \dfrac{\Delta V_{R1}}{R_1} = \dfrac{1\text{ V}}{100\ \Omega} = \mathbf{10\text{ mA}}$

28. $V_{OUT} = \left(1 + \dfrac{R_3}{R_4}\right)V_{REF} = \left(1 + \dfrac{8.2\text{ k}\Omega}{3.9\text{ k}\Omega}\right)5\text{ V} = 15.5\text{ V}$

$I_{L1} = \dfrac{V_{OUT}}{R_{L1}} = \dfrac{15.5\text{ V}}{1.0\text{ k}\Omega} = 15.5\text{ mA}$

$I_{L2} = \dfrac{V_{OUT}}{R_{L2}} = \dfrac{15.5\text{ V}}{1.2\text{ k}\Omega} = 12.9\text{ mA}$

$\Delta I_L = 12.9\text{ mA} - 15.5\text{ mA} = -2.6\text{ mA}$

$\Delta I_S = -\Delta I_L = \mathbf{2.6\text{ mA}}$ (increase)

Multisim Troubleshooting Problems

29. R_2 is open.

30. Op-amp open.

31. No fault

32. C_1 is open.

CHAPTER 20
SPECIAL-PURPOSE OP-AMP CIRCUITS

SECTION 20-1 Instrumentation Amplifiers

1. $A_{v(1)} = 1 + \dfrac{R_1}{R_G} = 1 + \dfrac{100\text{ k}\Omega}{1.0\text{ k}\Omega} = \mathbf{101}$

   $A_{v(2)} = 1 + \dfrac{R_2}{R_G} = 1 + \dfrac{100\text{ k}\Omega}{1.0\text{ k}\Omega} = \mathbf{101}$

2. $A_{cl} = 1 + \dfrac{2R}{R_G} = 1 + \dfrac{200\text{ k}\Omega}{1.0\text{ k}\Omega} = \mathbf{201}$

3. $V_{out} = A_{cl}(V_{in(2)} - V_{in(1)}) = 201(10\text{ mV} - 5\text{ mV}) = \mathbf{1.005\ V}$

4. $A_v = 1 + \dfrac{2R}{R_G}$

   $\dfrac{2R}{R_G} = A_v - 1$

   $R_G = \dfrac{2R}{A_v - 1} = \dfrac{2(100\text{ k}\Omega)}{1000 - 1} = \dfrac{200\text{ k}\Omega}{999} = 200.2\ \Omega \cong \mathbf{200\ \Omega}$

5. $R_G = \dfrac{100\text{ k}\Omega}{A_v - 1}$

   $A_v = \dfrac{100\text{ k}\Omega}{R_G} + 1 = \dfrac{100\text{ k}\Omega}{2.0\text{ k}\Omega} + 1 = \mathbf{51}$

6. Using the graph in Figure 20-6 for $A_v = 51$, the BW is approximately **7 kHz**.

7. $R_G = \dfrac{100\text{ k}\Omega}{A_v - 1} = \dfrac{100\text{ k}\Omega}{24 - 1} = \mathbf{4.3\ k\Omega}$

8. $R_G = \dfrac{100\text{ k}\Omega}{A_v - 1} = \dfrac{100\text{ k}\Omega}{20.6 - 1} = \mathbf{5.1\ k\Omega}$

SECTION 20-2 Isolation Amplifiers

9. $A_{v(total)} = A_{v1}\,A_{v2} = (30)(10) = \mathbf{300}$

10. (a) $A_{v1} = \dfrac{R_{f1}}{R_{i1}} + 1 = \dfrac{18\ \text{k}\Omega}{8.2\ \text{k}\Omega} + 1 = 3.2$

$A_{v2} = \dfrac{R_{f2}}{R_{i2}} + 1 = \dfrac{150\ \text{k}\Omega}{15\ \text{k}\Omega} + 1 = 11$

$A_{v(tot)} = A_{v1}A_{v2} = (3.2)(11) = \mathbf{35.2}$

(b) $A_{v1} = \dfrac{R_{f1}}{R_{i1}} + 1 = \dfrac{330\ \text{k}\Omega}{1.0\ \text{k}\Omega} + 1 = 331$

$A_{v2} = \dfrac{R_{f2}}{R_{i2}} + 1 = \dfrac{47\ \text{k}\Omega}{15\ \text{k}\Omega} + 1 = 4.13$

$A_{v(tot)} = A_{v1}A_{v2} = (331)(4.13) = \mathbf{1{,}367}$

11. $A_{v2} = 11$ (from Problem 10)
$A_{v1}A_{v2} = 100$

$\dfrac{R_{f1}}{R_{i1}} + 1 = A_{v1} = \dfrac{100}{11} = 9.09$

Change R_{f1} (18 kΩ) to 66.3 kΩ.
Use **66.5 kΩ** ± 1% standard value resistor.

12. $A_{v1} = 331$ (from Problem 10)
$A_{v1}A_{v2} = 440$

$\dfrac{R_{f2}}{R_{i2}} + 1 = A_{v2} = \dfrac{440}{331} = 1.33$

Change R_f (47 kΩ) to 3.3 kΩ.
Change R_i (15 kΩ) to 10 kΩ.

13. Connect pin 6 to pin 10 and pin 14 to pin 15.

SECTION 20-3 Operational Transconductance Amplifiers (OTAs)

14. $g_m = \dfrac{I_{out}}{V_{in}} = \dfrac{10\ \mu\text{A}}{10\ \text{mV}} = \mathbf{1\ mS}$

15. $I_{out} = g_mV_{in} = (5000\ \mu\text{S})(100\ \text{mV}) = \mathbf{500\ \mu A}$
$V_{out} = I_{out}R_L = (500\ \mu\text{A})(10\ \text{k}\Omega) = \mathbf{5\ V}$

16. $g_m = \dfrac{I_{out}}{V_{in}}$

$I_{out} = g_m V_{in} = (4000\ \mu\text{S})(100\ \text{mV}) = 400\ \mu\text{A}$

$R_L = \dfrac{V_{out}}{I_{out}} = \dfrac{3.5\ \text{V}}{400\ \mu\text{A}}$ $= \mathbf{8.75\ k\Omega}$

17. $I_{\text{BIAS}} = \dfrac{+12\ \text{V} - (-12\ \text{V}) - 0.7\ \text{V}}{R_{\text{BIAS}}} = \dfrac{+12\ \text{V} - (-12\ \text{V}) - 0.7\ \text{V}}{220\ \text{k}\Omega} = \dfrac{23.3\ \text{V}}{220\ \text{k}\Omega} = 106\ \mu\text{A}$

$g_m = KI_{\text{BIAS}} \cong (16\ \mu\text{S}/\mu\text{A})(106\ \mu\text{A}) = 1.70\ \text{mS}$

$A_v = \dfrac{V_{out}}{V_{in}} = \dfrac{I_{out}R_L}{V_{in}} = g_m R_L = (1.70\ \text{mS})(6.8\ \text{k}\Omega) = \mathbf{11.6}$

18. The maximum voltage gain occurs when the 10 kΩ potentiometer is set to 0 Ω and was determined in Problem 17.

$A_{v(max)} = \mathbf{11.6}$

The minimum voltage gain occurs when the 10 kΩ potentiometer is set to 10 kΩ.

$I_{\text{BIAS}} = \dfrac{+12\ \text{V} - (-12\ \text{V}) - 0.7\ \text{V}}{220\ \text{k}\Omega + 10\ \text{k}\Omega} = \dfrac{23.3\ \text{V}}{230\ \text{k}\Omega} = 101\ \mu\text{A}$

$g_m \cong (16\ \mu\text{S}/\mu\text{A})(101\ \mu\text{A}) = 1.62\ \text{mS}$

$A_{v(min)} = g_m R_L = (1.62\ \text{mS})(6.8\ \text{k}\Omega) = \mathbf{11.0}$

19. The V_{MOD} waveform is applied to the bias input.
The gain and output voltage for each value of V_{MOD} is determined as follows using $K = 16\ \mu\text{S}/\mu\text{A}$. The output waveform is shown in Figure 20-1.

For $V_{\text{MOD}} = +8$ V:

$I_{\text{BIAS}} = \dfrac{+8\ \text{V} - (-9\ \text{V}) - 0.7\ \text{V}}{39\ \text{k}\Omega} = \dfrac{16.3\ \text{V}}{39\ \text{k}\Omega} = 418\ \mu\text{A}$

$g_m = KI_{\text{BIAS}} \cong (16\ \mu\text{S}/\mu\text{A})(418\ \mu\text{A}) = 6.69\ \text{mS}$

$A_v = \dfrac{V_{out}}{V_{in}} = \dfrac{I_{out}R_L}{V_{in}} = g_m R_L = (6.69\ \text{mS})(10\ \text{k}\Omega) = 66.9$

$V_{out} = A_v V_{in} = (66.9)(100\ \text{mV}) = \mathbf{6.69\ V}$

For $V_{\text{MOD}} = +6$ V:

$I_{\text{BIAS}} = \dfrac{+6\ \text{V} - (-9\ \text{V}) - 0.7\ \text{V}}{39\ \text{k}\Omega} = \dfrac{14.3\ \text{V}}{39\ \text{k}\Omega} = 367\ \mu\text{A}$

$g_m = KI_{\text{BIAS}} \cong (16\ \mu\text{S}/\mu\text{A})(367\ \mu\text{A}) = 5.87\ \text{mS}$

$A_v = \dfrac{V_{out}}{V_{in}} = \dfrac{I_{out}R_L}{V_{in}} = g_m R_L = (5.87\ \text{mS})(10\ \text{k}\Omega) = 58.7$

$V_{out} = A_v V_{in} = (58.7)(100\ \text{mV}) = \mathbf{5.87\ V}$

For V_{MOD} = +4 V:

$$I_{\text{BIAS}} = \frac{+4\text{ V} - (-9\text{ V}) - 0.7\text{ V}}{39\text{ k}\Omega} = \frac{12.3\text{ V}}{39\text{ k}\Omega} = 315\ \mu\text{A}$$

$g_m = KI_{\text{BIAS}} \cong (16\ \mu\text{S}/\mu\text{A})(315\ \mu\text{A}) = 5.04\text{ mS}$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{I_{out}R_L}{V_{in}} = g_mR_L = (5.04\text{ mS})(10\text{ k}\Omega) = 50.4$$

$V_{out} = A_vV_{in} = (50.4)(100\text{ mV}) = \mathbf{5.04\ V}$

For V_{MOD} = +2 V:

$$I_{\text{BIAS}} = \frac{+2\text{ V} - (-9\text{ V}) - 0.7\text{ V}}{39\text{ k}\Omega} = \frac{10.3\text{ V}}{39\text{ k}\Omega} = 264\ \mu\text{A}$$

$g_m = KI_{\text{BIAS}} \cong (16\ \mu\text{S}/\mu\text{A})(264\ \mu\text{A}) = 4.22\text{ mS}$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{I_{out}R_L}{V_{in}} = g_mR_L = (4.22\text{ mS})(10\text{ k}\Omega) = 42.2$$

$V_{out} = A_vV_{in} = (42.2)(100\text{ mV}) = \mathbf{4.22\ V}$

For V_{MOD} = +1 V:

$$I_{\text{BIAS}} = \frac{+1\text{ V} - (-9\text{ V}) - 0.7\text{ V}}{39\text{ k}\Omega} = \frac{9.3\text{ V}}{39\text{ k}\Omega} = 238\ \mu\text{A}$$

$g_m = KI_{\text{BIAS}} \cong (16\ \mu\text{S}/\mu\text{A})(238\ \mu\text{A}) = 3.81\text{ mS}$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{I_{out}R_L}{V_{in}} = g_mR_L = (3.81\text{ mS})(10\text{ k}\Omega) = 38.1$$

$V_{out} = A_vV_{in} = (38.1)(100\text{ mV}) = \mathbf{3.81\ V}$

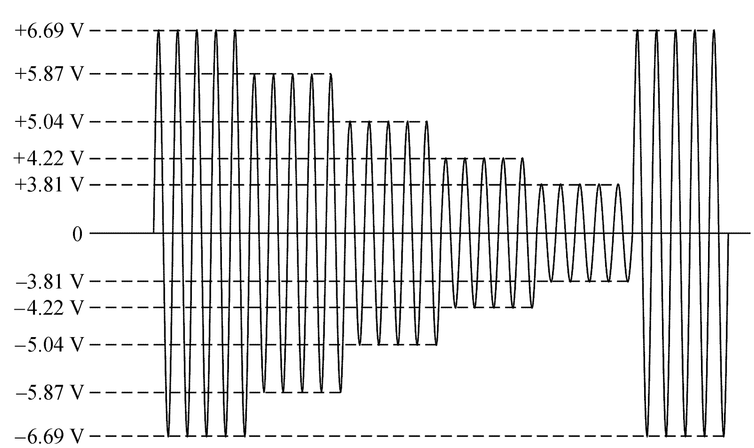


Figure 20-1

20. $$I_{\text{BIAS}} = \frac{+9\text{V} - (-9\text{ V}) - 0.7\text{ V}}{39\text{ k}\Omega} = \frac{17.3\text{ V}}{39\text{ k}\Omega} = 444\ \mu\text{A}$$

$V_{\text{TRIG}(+)} = I_{\text{BIAS}}R_1 = (444\ \mu\text{A})(10\text{ k}\Omega) = \mathbf{+4.44\ V}$

$V_{\text{TRIG}(-)} = -I_{\text{BIAS}}R_1 = (-444\ \mu\text{A})(10\text{ k}\Omega) = \mathbf{-4.44\ V}$

21. See Figure 20-2.

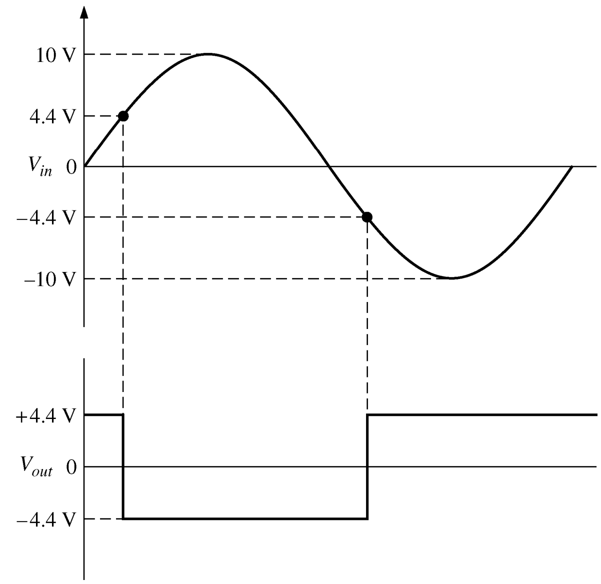


Figure 20-2

SECTION 20-4 Active Diode Circuits

22. (a) A sine wave with a positive peak at +0.7 V, a negative peak at −7.3 V, and a dc value of −3.3 V.
(b) A sine wave with a positive peak at +29.3 V, a negative peak at −0.7 V, and a dc value of +14.3 V.

23. See Figure 20-3.

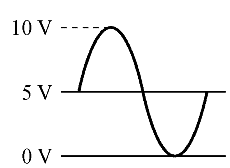


Figure 20-3

24. See Figure 20-4.

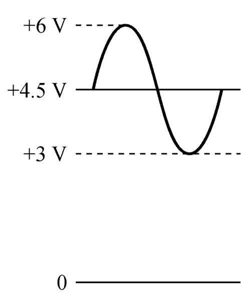


Figure 20-4

25. (a) See Figure 20-5(a).
(b) See Figure 20-5(b).

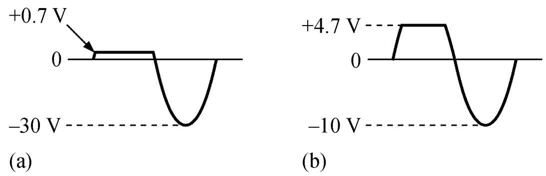


Figure 20-5

26. See Figure 20-6.

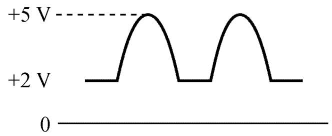


Figure 20-2

27. See Figure 20-7.

$$A_v = \frac{R_2}{R_1} = \frac{180\ \text{k}\Omega}{10\ \text{k}\Omega} = 18$$

$V_{out(p)} = A_v V_{in(p)} = 18(0.5\ \text{V}) = 9\ \text{V}$

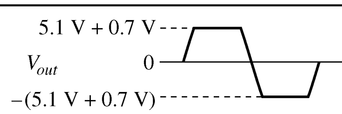


Figure 20-7

28. $$A_v = \frac{R_2}{R_1} = \frac{180\ \text{k}\Omega}{10\ \text{k}\Omega} = 18$$

$V_{out(p)} = A_v V_{in(p)} = 18(50\ \text{mV}) = 0.9\ \text{V}$

No limiting will occur because the peak output must be greater than 5.1 V + 0.7 V = 5.8 V.

29. $V_{out} = V_{p(in)} = 1.414(2.5\ \text{V}) = 3.54\ \text{V}$

SECTION 20-5 Current Sources and Converters

30. (a) $V_{IN} = V_Z = 4.7\text{ V}$

$$I_L = \frac{V_{IN}}{R_i} = \frac{4.7\text{ V}}{1.0\text{ k}\Omega} = \mathbf{4.7\text{ mA}}$$

(b) $$V_{IN} = \left(\frac{10\text{ k}\Omega}{20\text{ k}\Omega}\right)12\text{ V} = 6\text{ V}$$

$$R_i = 10\text{ k}\Omega \parallel 10\text{ k}\Omega + 100\ \Omega = 5.1\text{ k}\Omega$$

$$I_L = \frac{V_{IN}}{R_i} = \frac{6\text{ V}}{5.1\text{ k}\Omega} = \mathbf{1.18\text{ mA}}$$

31. See Figure 20-8.

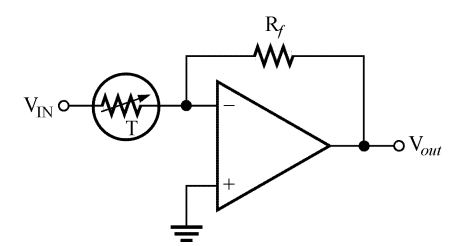


Figure 20-8

Multisim Troubleshooting Problems

32. R_G leaky

33. D_1 shorted

34. Diode is shorted.

35. Zener diode open

36. R_2 is open.

37. Diode is open.

CHAPTER 21
Measurement, Conversion, and Control

SECTION 21-1 Temperature Measurement

1. Assuming all are of the same type, the thermocouple exposed to the highest temperature (thermocouple C) produces the highest output. Note that thermocouple voltages are significantly different for different types as indicated in Figure 21-2 in the text.

2. The letters indicate the temperature range, coefficient, and voltage characteristic.

3. $V_{Thermocouple}$ = 20.869 mV (from Table 21-1 in the text)
$V_{Ambientjunction}$ = 0.25(4.277 mV) = 1.069 mV
The voltage across the op-amp inputs:
$V_{Thermocouple} - V_{Ambientjunction}$ = 20.869 mV − 1.069 mV = 19.80 mV
For the inverting amplifier:
$$A_v = -\frac{R_f}{R_i} = \frac{220\ \text{k}\Omega}{1.0\ \text{k}\Omega} = -220$$
V_{out} = (−220)(19.80 mV) = **−4.36 V**

4. When properly compensated, the input voltage to the amplifier is equal to the thermocouple voltage of 20.869 mV, so the output voltage is:
$$V_{out} = -\frac{R_f}{R_i}V_{in} = \frac{220\ \text{k}\Omega}{1.0\ \text{k}\Omega}(20.869\ \text{mV}) = \mathbf{-4.59\ V}$$

5. The bridge is balanced when
$R_W + R_{\text{RTD}} + R_W = 560\ \Omega$
$R_{\text{RTD}} = 560\ \Omega - 2R_W = 560\ \Omega - 20\ \Omega =$ **540 Ω**

6. The bridge is balanced when
$R_W + R_{\text{RTD}} = 560\ \Omega + R_W$
$R_{\text{RTD}} = 560\ \Omega + R_W - R_W = 560\ \Omega - 0\ \Omega =$ **560 Ω**

7. The results of problems 5 and 6 differ because in the three-wire circuit (text Figure 21-47), R_W has been added to both the RTD and the 560 Ω arms of the bridge which cancels the effect of R_W. In the two-wire circuit (text Figure 21-46), $2R_W$ appears only in the RTD arm of the bridge.

8. At the point in the bridge between R_1 and R_2:

$$V_{1\text{-}2} = \left(\frac{R_2}{R_1 + R_2}\right)(+15\text{ V}) = \left(\frac{10\text{ k}\Omega}{10\text{ k}\Omega + 10\text{ k}\Omega}\right)(+15\text{ V}) = +7.50\text{ V}$$

At a point in the bridge between R_3 and the RTD:

$$V_{3\text{-RTD}} = \left(\frac{R_{\text{RTD}}}{R_{\text{RTD}} + R_{32}}\right)(+15\text{ V}) = \left(\frac{697\ \Omega}{697\ \Omega + 750\ \Omega}\right)(+15\text{ V}) = +7.23\text{ V}$$

The bridge voltage applied to the inputs (across pins 1 and 3) of the amplifier is:

$V_{in} = V_{1\text{-}2} - V_{3\text{-RTD}} = 7.500\text{ V} - 7.225\text{ V} = 0.275\text{ V}$

The amplifier gain is:

$$A_v = \frac{100\text{ k}\Omega}{27\text{ k}\Omega} + 1 = 4.70$$

The amplifier output voltage is

$V_{out} = A_v V_{in} = (4.70)(0.275\text{ V}) = \mathbf{1.29\ V}$

SECTION 21-2 Strain, Pressure, and Flow Rate Measurements

9. $\Delta R = (GF)(R)(\varepsilon) = (2.5)(600\ \Omega)(3 \times 10^{6}) = \mathbf{4.5\ m\Omega}$

10. A strain gauge can be used to measure pressure by mounting it on a flexible diaphragm. As the diaphragm distends from increasing pressure, the strain gauge detects it.

11. The symbol in Figure 21-1(a) represents an absolute pressure transducer, which measures pressure relative to a vacuum.
The symbol in Figure 21-1(b) represents a gauge pressure transducer, which measures pressure relative to ambient pressure.
The symbol in Figure 21-1(c) represents a differential pressure transducer, which measures pressure relative to the other input.

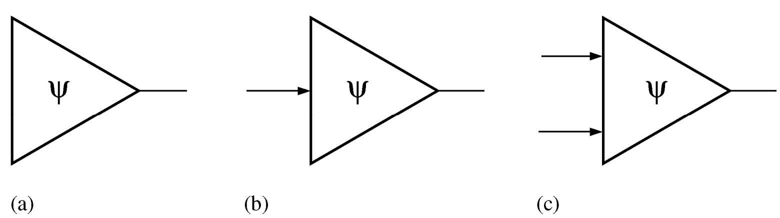


Figure 21-1

SECTION 21-4 Sample-and-Hold Circuits

12. See Figure 21-2.

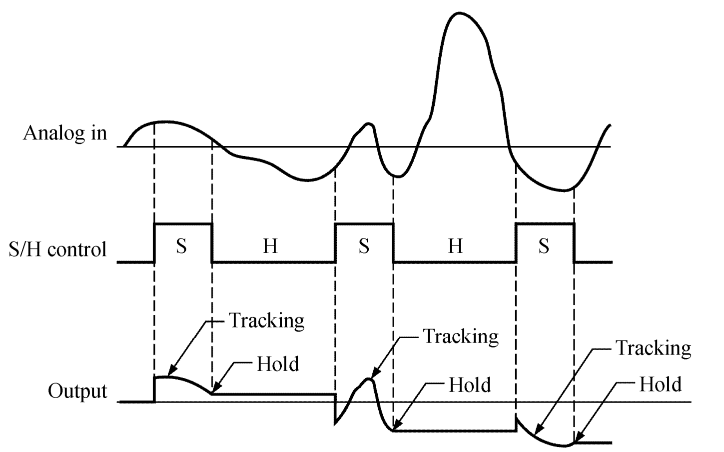


Figure 21-2

13. See Figure 21-3.

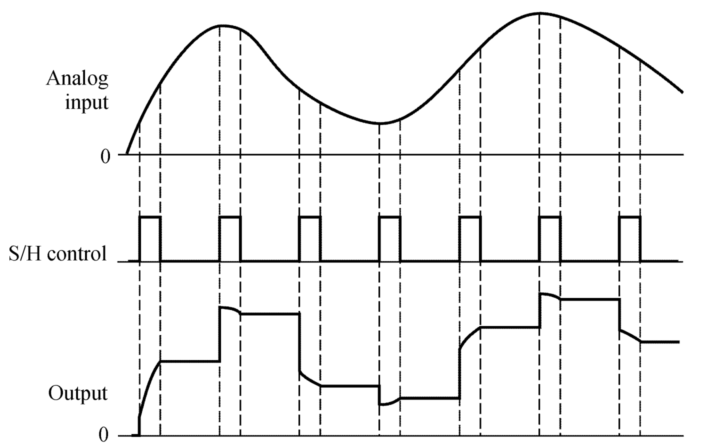


Figure 21-3

SECTION 21-6 Power-Control Circuits

14. An SCR can be triggered into forward conduction by a pulse on the gate terminal if the anode is positive with respect to the cathode. An SCR can also be triggered into forward conduction if the forward voltage exceeds the forward breakover-voltage.

15. See Figure 21-4.

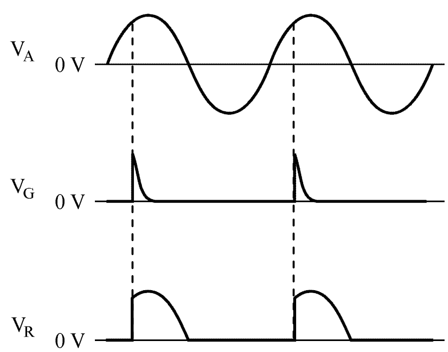


Figure 21-4

16. The output of the comparator is a square wave that is "in-phase" with the input sine wave with a peak voltage of approximately ±9 V. The output of the circuit is a series of positive triggers that rise from 0 V to 9 V, then decay in about 2 ms (measured on the 741 although the calculated is less). The positive triggers correspond to the rising edge of the sine wave.

17. Reverse the comparator inputs.