Online Instructor's Manual
for

Electronic Devices and Circuit Theory

Eleventh Edition

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10 9 8 7 6 5 4 3 2 1

ISBN10: 0-13-278373-8

PEARSON

ISBN13: 978-0-13-278373-6

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Chapter 1

1. Copper has 20 orbiting electrons with only one electron in the outermost shell. The fact that the outermost shell with its 29^{th} electron is incomplete (subshell can contain 2 electrons) and distant from the nucleus reveals that this electron is loosely bound to its parent atom. The application of an external electric field of the correct polarity can easily draw this loosely bound electron from its atomic structure for conduction.

   Both intrinsic silicon and germanium have complete outer shells due to the sharing (covalent bonding) of electrons between atoms. Electrons that are part of a complete shell structure require increased levels of applied attractive forces to be removed from their parent atom.

2. Intrinsic material: an intrinsic semiconductor is one that has been refined to be as pure as physically possible. That is, one with the fewest possible number of impurities.

   Negative temperature coefficient: materials with negative temperature coefficients have decreasing resistance levels as the temperature increases.

   Covalent bonding: covalent bonding is the sharing of electrons between neighboring atoms to form complete outermost shells and a more stable lattice structure.

3. –

4. a. $W = QV = (12\ \mu C)(6\ \text{V}) = \mathbf{72\ \mu J}$

   b. $72 \times 10^{-6}\ \text{J} = \left[\dfrac{1\ \text{eV}}{1.6 \times 10^{-19}\ \text{J}}\right] = \mathbf{2.625 \times 10^{14}\ eV}$

5. $48\ \text{eV} = 48(1.6 \times 10^{-19}\ \text{J}) = \mathbf{76.8 \times 10^{-19}\ J}$

   $Q = \dfrac{W}{V} = \dfrac{76.8 \times 10^{-19}\ \text{J}}{3.2\ \text{V}} = \mathbf{2.40 \times 10^{-18}\ C}$

   6.4×10^{-19} C is the charge associated with 4 electrons.

6. | | | |
   |---|---|---|
   | GaP | Gallium Phosphide | E_g = **2.24 eV** |
   | ZnS | Zinc Sulfide | E_g = **3.67 eV** |

7. An *n*-type semiconductor material has an excess of electrons for conduction established by doping an intrinsic material with donor atoms having more valence electrons than needed to establish the covalent bonding. The majority carrier is the electron while the minority carrier is the hole.

   A *p*-type semiconductor material is formed by doping an intrinsic material with acceptor atoms having an insufficient number of electrons in the valence shell to complete the covalent bonding thereby creating a hole in the covalent structure. The majority carrier is the hole while the minority carrier is the electron.

8. A donor atom has five electrons in its outermost valence shell while an acceptor atom has only 3 electrons in the valence shell.

9. Majority carriers are those carriers of a material that far exceed the number of any other carriers in the material.
Minority carriers are those carriers of a material that are less in number than any other carrier of the material.

10. Same basic appearance as Fig. 1.7 since arsenic also has 5 valence electrons (pentavalent).

11. Same basic appearance as Fig. 1.9 since boron also has 3 valence electrons (trivalent).

12. –

13. –

14. For forward bias, the positive potential is applied to the *p*-type material and the negative potential to the *n*-type material.

15. a. $V_T = \dfrac{kT_K}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(20°\text{C}+273°\text{C})}{1.6\times10^{-19}\text{ C}}$
$= \mathbf{25.27\ mV}$

b. $I_D = I_s(e^{V_D/nV_T} - 1)$
$= 40\text{ nA}(e^{(0.5\text{ V})/(2)(25.27\text{mV})} - 1)$
$= 40\text{ nA}(e^{9.89} - 1) = \mathbf{0.789\ mA}$

16. a. $V_T = \dfrac{k(T_K)}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(100°\text{C}+273°\text{C})}{1.6\times10^{-19}}$
$= \mathbf{32.17\ mV}$

b. $I_D = I_s(e^{V_D/nV_T} - 1)$
$= 40\text{ nA}(e^{(0.5\text{ V})/(2)(32.17\text{ mV})} - 1)$
$= 40\text{ nA}(e^{7.77} - 1) = \mathbf{11.84\ mA}$

17. a. $T_K = 20 + 273 = 293$
$V_T = \dfrac{kT_K}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(293°)}{1.6\times10^{-19}\text{ C}}$
$= \mathbf{25.27\ mV}$

b. $I_D = I_s(e^{V_D/nV_T} - 1)$
$= 0.1\ \mu\text{A}\left(e^{-10/(2)(25.27\text{ mV})} - 1\right)$
$= 0.1\ \mu\text{A}(e^{-197.86} - 1)$
$\cong \mathbf{0.1\ \mu A}$

18. $V_T = \dfrac{kT_K}{q} = \dfrac{(1.38\times10^{-23}\text{ J/K})(25°\text{C} + 273°\text{C})}{1.6\times10^{-19}\text{ C}}$

$=25.70$ mV

$I_D = I_s(e^{V_D/nV_T} - 1)$

$8\text{mA} = I_s(e^{(0.5\text{V})/(1)(25.70\text{ mV})} - 1) = I_s(28\times10^8)$

$I_s = \dfrac{8\text{ mA}}{2.8\times10^8}$ = **28.57 pA**

19. $I_D = I_s(e^{V_D/nV_T} - 1)$

$6\text{ mA} = 1\text{ nA}(e^{V_D/(1)(26\text{ mV})} - 1)$

$6\times10^6 = e^{V_D/26\text{ mV}} - 1$

$e^{V_D/26\text{ mV}} = 6\times10^6 - 1 \cong 6\times10^6$

$\log_e e^{V_D/26\text{mV}} = \log_e 6\times10^6$

$\dfrac{V_D}{26\text{ mV}} = 15.61$

$V_D = 15.61(26\text{ mV}) \cong$ **0.41 V**

20. (a)

x	$y = e^x$
0	1
1	2.7182
2	7.389
3	20.086
4	54.6
5	148.4

(b) $y = e^0 = 1$

(c) For $x = 0$, $e^0 = 1$ and $I = I_s(1 - 1) =$ **0 mA**

21. $T = 20°\text{C}$: $I_s = 0.1\ \mu\text{A}$
$T = 30°\text{C}$: $I_s = 2(0.1\ \mu\text{A}) = 0.2\ \mu\text{A}$ (Doubles every 10°C rise in temperature)
$T = 40°\text{C}$: $I_s = 2(0.2\ \mu\text{A}) = 0.4\ \mu\text{A}$
$T = 50°\text{C}$: $I_s = 2(0.4\ \mu\text{A}) = 0.8\ \mu\text{A}$
$T = 60°\text{C}$: $I_s = 2(0.8\ \mu\text{A}) =$ **1.6 μA**

1.6 μA: 0.1 μA ⇒ 16:1 increase due to rise in temperature of 40°C.

22. For most applications the silicon diode is the device of choice due to its higher temperature capability. Ge typically has a working limit of about 85 degrees centigrade while Si can be used at temperatures approaching 200 degrees centigrade. Silicon diodes also have a higher current handling capability. Germanium diodes are the better device for some RF small signal applications, where the smaller threshold voltage may prove advantageous.

23. From 1.19:

	−75°C	25°C	100°C	200°C
V_F @ 10 mA	1.1 V	0.85 V	1.0 V	0.6 V
I_s	0.01 pA	1 pA	1 μA	1.05 μA

V_F decreased with increase in temperature

1.7 V: 0.65 V ≅ **2.6:1**

I_s increased with increase in temperature

2 μA: 0.1 μA = **20:1**

24. An "ideal" device or system is one that has the characteristics we would prefer to have when using a device or system in a practical application. Usually, however, technology only permits a close replica of the desired characteristics. The "ideal" characteristics provide an excellent basis for comparison with the actual device characteristics permitting an estimate of how well the device or system will perform. On occasion, the "ideal" device or system can be assumed to obtain a good estimate of the overall response of the design. When assuming an "ideal" device or system there is no regard for component or manufacturing tolerances or any variation from device to device of a particular lot.

25. In the forward-bias region the 0 V drop across the diode at any level of current results in a resistance level of zero ohms – the "on" state – conduction is established. In the reverse-bias region the zero current level at any reverse-bias voltage assures a very high resistance level − the open circuit or "off" state − conduction is interrupted.

26. The most important difference between the characteristics of a diode and a simple switch is that the switch, being mechanical, is capable of conducting current in either direction while the diode only allows charge to flow through the element in one direction (specifically the direction defined by the arrow of the symbol using conventional current flow).

27. $V_D \cong 0.7\text{ V}$, $I_D = 4\text{ mA}$

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.7\text{ V}}{4\text{ mA}} = \mathbf{175\ \Omega}$$

28. At $I_D = 15\text{ mA}$, $V_D = 0.82\text{ V}$

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.82\text{ V}}{15\text{ mA}} = \mathbf{54.67\ \Omega}$$

As the forward diode current increases, the static resistance decreases.

29. $V_D = -10$ V, $I_D = I_s = \mathbf{-0.1\ \mu A}$

$$R_{DC} = \frac{V_D}{I_D} = \frac{10\text{ V}}{0.1\ \mu\text{A}} = \mathbf{100\ M\Omega}$$

$V_D = -30$ V, $I_D = I_s = \mathbf{-0.1\ \mu A}$

$$R_{DC} = \frac{V_D}{I_D} = \frac{30\text{ V}}{0.1\mu\text{A}} = \mathbf{300\ M\Omega}$$

As the reverse voltage increases, the reverse resistance increases directly (since the diode leakage current remains constant).

30. $I_D = 10$ mA, $V_D = 0.76$ V

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.76\text{ V}}{10\text{ mA}} = \mathbf{76\ \Omega}$$

$$r_d = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.79\text{ V} - 0.76\text{ V}}{15\text{ mA} - 5\text{ mA}} = \frac{0.03\text{ V}}{10\text{ mA}} = \mathbf{3\ \Omega}$$

$R_{DC} >> r_d$

31. (a) $r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.79\text{ V} - 0.76\text{ V}}{15\text{ mA} - 5\text{ mA}} = \frac{0.03\text{ V}}{10\text{ mA}} = \mathbf{3\ \Omega}$

(b) $r_d = \frac{26\text{ mV}}{I_D} = \frac{26\text{ mV}}{10\text{ mA}} = \mathbf{2.6\ \Omega}$

(c) quite close

32. $I_D = 1$ mA, $r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.72\text{ V} - 0.61\text{ V}}{2\text{ mA} - 0\text{ mA}} = \mathbf{55\ \Omega}$

$I_D = 15$ mA, $r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.8\text{ V} - 0.78\text{ V}}{20\text{ mA} - 10\text{ mA}} = \mathbf{2\ \Omega}$

33. $I_D = 1$ mA, $r_d = 2\left(\frac{26\text{ mV}}{I_D}\right) = 2(26\ \Omega) = \mathbf{52\ \Omega}$ vs 55 Ω (#30)

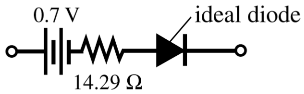
$I_D = 15$ mA, $r_d = \frac{26\text{ mV}}{I_D} = \frac{26\text{ mV}}{15\text{ mA}} = \mathbf{1.73\ \Omega}$ vs 2 Ω (#30)

34. $r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9\text{ V} - 0.6\text{ V}}{13.5\text{ mA} - 1.2\text{ mA}} = \mathbf{24.4\ \Omega}$

35. $r_d = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.8\text{ V} - 0.7\text{ V}}{7\text{ mA} - 3\text{ mA}} = \frac{0.09\text{ V}}{4\text{ mA}} = \mathbf{22.5\ \Omega}$

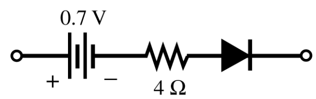
(relatively close to average value of 24.4 Ω (#32))

36. $r_{av} = \dfrac{\Delta V_d}{\Delta I_d} = \dfrac{0.9\text{ V} - 0.7\text{ V}}{14\text{ mA} - 0\text{ mA}} = \dfrac{0.2\text{ V}}{14\text{ mA}}$ = **14.29 Ω**



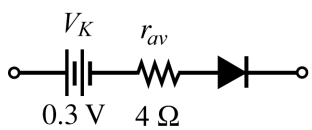
37. Using the best approximation to the curve beyond $V_D = 0.7$ V:

$r_{av} = \dfrac{\Delta V_d}{\Delta I_d} \cong \dfrac{0.8\text{ V} - 0.7\text{ V}}{25\text{ mA} - 0\text{ mA}} = \dfrac{0.1\text{ V}}{25\text{ mA}}$ = **4 Ω**



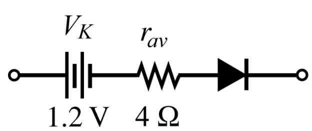
38. Germanium:

$$r_{av} = \frac{0.42\text{ V} - 0.3\text{ V}}{30\text{ mA} - 0\text{ mA}} = 4\ \Omega$$



GaAa:

$$r_{av} = \frac{1.32\text{ V} - 1.2\text{ V}}{30\text{ mA} - 0\text{ mA}} = 4\ \Omega$$



39. (a) $V_R = -25$ V: $C_T \cong$ **0.75 pF**
$V_R = -10$ V: $C_T \cong$ **1.25 pF**

$\left|\dfrac{\Delta C_T}{\Delta V_R}\right| = \left|\dfrac{1.25\text{ pF} - 0.75\text{ pF}}{10\text{ V} - 25\text{ V}}\right| = \dfrac{0.5\text{ pF}}{15\text{ V}}$ = **0.033 pF/V**

(b) $V_R = -10$ V: $C_T \cong$ **1.25 pF**
$V_R = -1$ V: $C_T \cong$ **3 pF**

$\left|\dfrac{\Delta C_T}{\Delta V_R}\right| = \left|\dfrac{1.25\text{ pF} - 3\text{ pF}}{10\text{ V} - 1\text{ V}}\right| = \dfrac{1.75\text{ pF}}{9\text{ V}}$ = **0.194 pF/V**

(c) 0.194 pF/V: 0.033 pF/V = 5.88:1 ≅ **6:1**
Increased sensitivity near $V_D = 0$ V

40. From Fig. 1.33
$V_D = 0$ V, C_D = **3.3 pF**
$V_D = 0.25$ V, C_D = **9 pF**

41. The transition capacitance is due to the depletion region acting like a dielectric in the reverse-bias region, while the diffusion capacitance is determined by the rate of charge injection into the region just outside the depletion boundaries of a forward-biased device. Both capacitances are present in both the reverse- and forward-bias directions, but the transition capacitance is the dominant effect for reverse-biased diodes and the diffusion capacitance is the dominant effect for forward-biased conditions.

42. $V_D = 0.2$ V, $C_D = 7.3$ pF

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6\text{ MHz})(7.3\text{ pF})} = \mathbf{3.64\ k\Omega}$$

$V_D = -20$ V, $C_T = 0.9$ pF

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6\text{ MHz})(0.9\text{ pF})} = \mathbf{29.47\ k\Omega}$$

43.
$$C_T = \frac{C(0)}{\left(1+|V_R/V_K|\right)^n} = \frac{8\text{ pF}}{\left(1+|5\text{ V}/0.7\text{ V}|\right)^{1/2}}$$
$$= \frac{8\text{pF}}{(1+7.14)^{1/2}} = \frac{8\text{ pF}}{\sqrt{8.14}} = \frac{8\text{ pF}}{2.85}$$
$$= \mathbf{2.81\,pF}$$

44.
$$C_T = \frac{C(0)}{\left(1+|V_R/V_k|\right)^{\mu}}$$
$$4\text{ pF} = \frac{10\text{ pF}}{\left(1+|V_R/0.7\text{ V}|\right)^{1/3}}$$
$$= (1+V_R/0.7\text{ V})^{1/3} = 2.5$$

$$1+V_R/0.7\text{ V} = (2.5)^3 = 15.63$$
$$V_R/0.7\ V = 15.63 - 1 = 14.63$$
$$V_R = (0.7)(14.63) = \mathbf{10.24\ V}$$

45. $I_f = \dfrac{10\text{ V}}{10\text{ k}\Omega} = 1$ mA

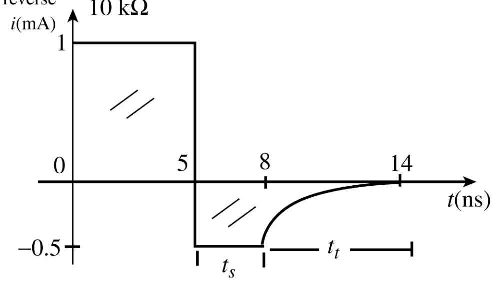
$t_s + t_t = t_{rr} = 9$ ns

$t_s + 2t_s = 9$ ns

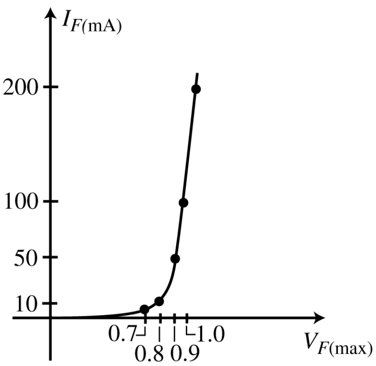
$t_s =$ **3 ns**

$t_t = 2t_s =$ **6 ns**

$I_{reverse} = \dfrac{5\text{ V}}{10\text{ k}\Omega} = 0.5$ mA



46.



47. a. As the magnitude of the reverse-bias potential increases, the capacitance drops rapidly from a level of about 5 pF with no bias. For reverse-bias potentials in excess of 10 V the capacitance levels off at about 1.5 pF.

b. 6 pF

c. At $V_R = -4$ V, $C_T = 2$ pF

$$C_T = \frac{C(0)}{\left(1+\left|V_R/V_k\right|\right)^n}$$

$$2\text{ pF} = \frac{6\text{ pF}}{\left(1+\left|4\text{V}/0.7\text{ V}\right|\right)^n}$$

$$\left(1+\left|4\text{ V}+0.7\text{ V}\right|^n\right) = 3$$

$$(6.71)^n = 3$$

$$n\log_{10} 6.71 = \log_{10} 3$$

$$n(0.827) = 0.477$$

$$n = \frac{0.477}{0.827} \cong \mathbf{0.58}$$

48. At $V_D = -25$ V, $I_D = -0.2$ nA and at $V_D = -100$ V, $I_D \cong -0.45$ nA. Although the change in I_R is more than 100%, the level of I_R and the resulting change is relatively small for most applications.

49. Log scale: $T_A = 25°\text{C}$, $I_R =$ **0.5 nA**
$T_A = 100°\text{C}$, $I_R =$ **60 nA**
The change is significant.
60 nA: 0.5 nA = **120:1**
Yes, at 95°C I_R would increase to 64 nA starting with 0.5 nA (at 25°C) (and double the level every 10°C).

50. $I_F = 0.1$ mA: $r_d \cong$ **700 Ω**
$I_F = 1.5$ mA: $r_d \cong$ **70 Ω**
$I_F = 20$ mA: $r_d \cong$ **6 Ω**

The results support the fact that the dynamic or ac resistance decreases rapidly with increasing current levels.

51. $T = 25°C$: $P_{max} = 500$ mW
$T = 100°C$: $P_{max} = 260$ mW
$P_{max} = V_F I_F$

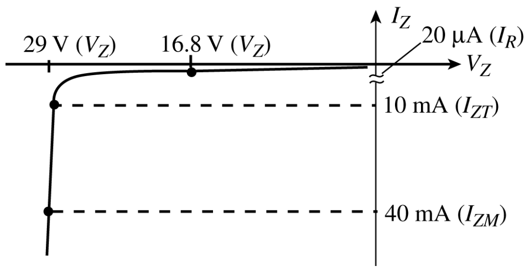
$$I_F = \frac{P_{max}}{V_F} = \frac{500\text{ mW}}{0.7\text{ V}} = \mathbf{714.29\text{ mA}}$$

$$I_F = \frac{P_{max}}{V_F} = \frac{260\text{ mW}}{0.7\text{ V}} = \mathbf{371.43\text{ mA}}$$

714.29 mA: 371.43 mA = 1.92:1 ≅ **2:1**

52. Using the bottom right graph of Fig. 1.37:
$I_F = 500$ mA @ $T = 25°C$
At $I_F = 250$ mA, $T \cong$ **104°C**

53.



54. $$T_C = +0.072\% = \frac{\Delta V_Z}{V_Z(T_1 - T_0)} \times 100\%$$

$$0.072 = \frac{0.75\text{ V}}{10\text{ V}(T_1 - 25)} \times 100$$

$$0.072 = \frac{7.5}{T_1 - 25}$$

$$T_1 - 25° = \frac{7.5}{0.072} = 104.17°$$

$$T_1 = 104.17° + 25° = \mathbf{129.17°}$$

55. $$T_C = \frac{\Delta V_Z}{V_Z(T_1 - T_0)} \times 100\%$$

$$= \frac{(5\text{ V} - 4.8\text{ V})}{5\text{ V}(100° - 25°)} \times 100\% = \mathbf{0.053\%/°C}$$

56. $$\frac{(20\text{ V} - 6.8\text{ V})}{(24\text{ V} - 6.8\text{ V})} \times 100\% = 77\%$$

The 20 V Zener is therefore ≅ 77% of the distance between 6.8 V and 24 V measured from the 6.8 V characteristic.

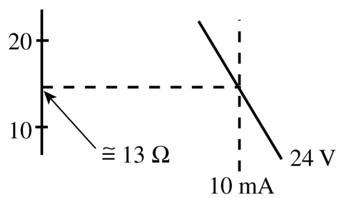
At $I_Z = 0.1$ mA, $T_C \cong 0.06\%/°C$

$$\frac{(5\text{ V} - 3.6\text{ V})}{(6.8\text{ V} - 3.6\text{ V})} \times 100\% = 44\%$$

The 5 V Zener is therefore ≅ 44% of the distance between 3.6 V and 6.8 V measured from the 3.6 V characteristic.

At $I_Z = 0.1$ mA, $T_C \cong$ **−0.025%/°C**

57.



58. 24 V Zener:

0.2 mA: ≅ **400 Ω**

1 mA: ≅ **95 Ω**

10 mA: ≅ **13 Ω**

The steeper the curve (higher dI/dV) the less the dynamic resistance.

59. $V_K \cong 2.0$ V, which is considerably higher than germanium (≅ 0.3 V) or silicon (≅ 0.7 V). For germanium it is a 6.7:1 ratio, and for silicon a 2.86:1 ratio.

60. $$0.67\ \cancel{eV}\left[\frac{1.6\times10^{-19}\text{ J}}{1\ \cancel{eV}}\right] = 1.072\times10^{-19}\text{ J}$$

$$E_g = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E_g} = \frac{(6.626\times10^{-34}\text{ Js})(3\times10^{8})\text{ m/s}}{1.072\times10^{-19}\text{ J}}$$

$$= \mathbf{1850\ nm}$$

Very low energy level.

61. Fig. 1.53 (f) $I_F \cong$ **13 mA**

Fig. 1.53 (e) $V_F \cong$ **2.3 V**

62. (a) Relative efficiency @ 5 mA ≅ **0.82**

@ 10 mA ≅ **1.02**

$$\frac{1.02 - 0.82}{0.82} \times 100\% = \mathbf{24.4\%}\text{ increase}$$

ratio: $\dfrac{1.02}{0.82} = 1.24$

(b) Relative efficiency @ 30 mA ≅ **1.38**

@ 35 mA ≅ **1.42**

$$\frac{1.42 - 1.38}{1.38} \times 100\% = \mathbf{2.9\%}\text{ increase}$$

ratio: $\dfrac{1.42}{1.38} = \mathbf{1.03}$

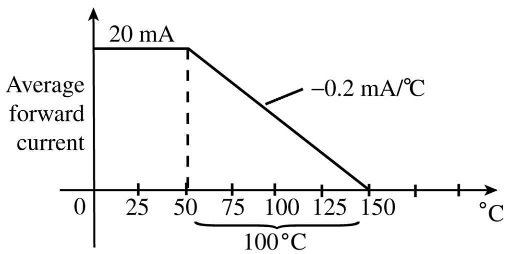
(c) For currents greater than about 30 mA the percent increase is significantly less than for increasing currents of lesser magnitude.

63. (a) $\frac{0.75}{3.0} = 0.25$

From Fig. 1.53 (i) $\measuredangle \cong$ **75°**

(b) $0.5 \Rightarrow \measuredangle =$ **40 °**

64. For the high-efficiency red unit of Fig. 1.53:



$$\frac{0.2 \text{ mA}}{°\text{C}} = \frac{20 \text{ mA}}{x}$$

$$x = \frac{20 \text{ mA}}{0.2 \text{ mA/°C}} = 100°\text{C}$$

Chapter 2

1. The load line will intersect at $I_D = \dfrac{E}{R} = \dfrac{12\text{ V}}{750\ \Omega} = 16$ mA and $V_D = 12$ V.

   (a) $V_{D_Q} \cong$ **0.85 V**
   $I_{D_Q} \cong$ **15 mA**
   $V_R = E - V_{D_Q} = 12\text{ V} - 0.85\text{ V} =$ **11.15 V**

   (b) $V_{D_Q} \cong$ **0.7 V**
   $I_{D_Q} \cong$ **15 mA**
   $V_R = E - V_{D_Q} = 12\text{ V} - 0.7\text{ V} =$ **11.3 V**

   (c) $V_{D_Q} \cong$ **0 V**
   $I_{D_Q} \cong$ **16 mA**
   $V_R = E - V_{D_Q} = 12\text{ V} - 0\text{ V} =$ **12 V**

   For (a) and (b), levels of V_{D_Q} and I_{D_Q} are quite close. Levels of part (c) are reasonably close but as expected due to level of applied voltage E.

2. (a) $I_D = \dfrac{E}{R} = \dfrac{6\text{ V}}{0.2\text{ k}\Omega} = 30$ mA
   The load line extends from $I_D = 30$ mA to $V_D = 6$ V.
   $V_{D_Q} \cong$ **0.95 V**, $I_{D_Q} \cong$ **25.3 mA**

   (b) $I_D = \dfrac{E}{R} = \dfrac{6\text{ V}}{0.47\text{ k}\Omega} = 12.77$ mA
   The load line extends from $I_D = 12.77$ mA to $V_D = 6$ V.
   $V_{D_Q} \cong$ **0.8 V**, $I_{D_Q} \cong$ **11 mA**

   (c) $I_D = \dfrac{E}{R} = \dfrac{6\text{ V}}{0.68\text{ k}\Omega} = 8.82$ mA
   The load line extends from $I_D = 8.82$ mA to $V_D = 6$ V.
   $V_{D_Q} \cong$ **0.78 V**, $I_{D_Q} \cong$ **78 mA**

   The resulting values of V_{D_Q} are quite close, while I_{D_Q} extends from 7.8 mA to 25.3 mA.

3. Load line through $I_{D_Q} = 10$ mA of characteristics and $V_D = 7$ V will intersect I_D axis as 11.3 mA.
   $I_D = 11.3\text{ mA} = \dfrac{E}{R} = \dfrac{7\text{ V}}{R}$
   with $R = \dfrac{7\text{ V}}{11.3\text{ mA}} = 619.47\text{ k}\Omega \cong$ **0.62 kΩ** standard resistor

4. (a) $I_D = I_R = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0.7\text{ V}}{1.5\text{ k}\Omega} = \mathbf{19.53\text{ mA}}$

$V_D = \mathbf{0.7\text{ V}}$, $V_R = E - V_D = 30\text{ V} - 0.7\text{ V} = \mathbf{29.3\text{ V}}$

(b) $I_D = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0\text{ V}}{1.5\text{ k}\Omega} = \mathbf{20\text{ mA}}$

$V_D = \mathbf{0\text{ V}}$, $V_R = \mathbf{30\text{ V}}$

Yes, since $E \gg V_T$ the levels of I_D and V_R are quite close.

5. (a) $I = \mathbf{0\text{ mA}}$; diode reverse-biased.

(b) $V_{20\Omega} = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$ (Kirchhoff's voltage law)

$I(20\ \Omega) = \dfrac{19.3\text{ V}}{20\ \Omega} = 0.965\text{ A}$

$V(10\ \Omega) = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$

$I(10\ \Omega) = \dfrac{19.3\text{ V}}{10\ \Omega} = 1.93\text{ A}$

$I = I(10\ \Omega) + I(20\ \Omega)$

$= \mathbf{2.895\text{ A}}$

(c) $I = \dfrac{10\text{ V}}{10\ \Omega} = \mathbf{1\text{ A}}$; center branch open

6. (a) Diode forward-biased,

Kirchhoff's voltage law (CW): $-5\text{ V} + 0.7\text{ V} - V_o = 0$

$V_o = \mathbf{-4.3\text{ V}}$

$I_R = I_D = \dfrac{|V_o|}{R} = \dfrac{4.3\text{ V}}{2.2\text{ k}\Omega} = \mathbf{1.955\text{ mA}}$

(b) Diode forward-biased,

$I_D = \dfrac{8\text{ V} + 6\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \mathbf{2.25\text{ mA}}$

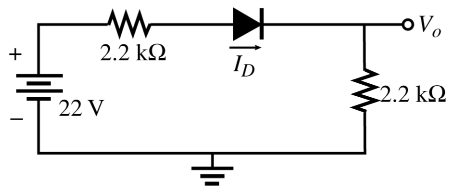
$V_o = 8\text{ V} - (2.25\text{ mA})(1.2\text{ k}\Omega) = \mathbf{5.3\text{ V}}$

7. (a) $V_o = \dfrac{10\text{ k}\Omega(12\text{ V} - 0.7\text{ V} - 0.3\text{ V})}{2\text{ k}\Omega + 10\text{ k}\Omega} = \mathbf{9.17\text{ V}}$

(b) $V_o = \mathbf{10\text{ V}}$

8. (a) Determine the Thevenin equivalent circuit for the 10 mA source and 2.2 kΩ resistor.

$E_{Th} = IR = (10 \text{ mA})(2.2 \text{ k}\Omega) = 22 \text{ V}$
$R_{Th} = 2.\ 2\text{k}\Omega$



Diode forward-biased

$$I_D = \frac{22 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega + 2.2 \text{ k}\Omega} = \mathbf{4.84\ mA}$$

$V_o = I_D(1.2 \text{ k}\Omega)$
$= (4.84 \text{ mA})(1.2 \text{ k}\Omega)$
$= \mathbf{5.81\ V}$

(b) Diode forward-biased

$$I_D = \frac{20 \text{ V} + 20 \text{ V} - 0.7 \text{ V}}{6.8 \text{ k}\Omega} = \mathbf{5.78\ mA}$$

Kirchhoff's voltage law (CW):
$+V_o - 0.7 \text{ V} + 20 \text{ V} = 0$
$V_o = \mathbf{-19.3\ V}$

9. (a) $V_{o_1} = 12 \text{ V} - 0.7 \text{ V} = \mathbf{11.3\ V}$
$V_{o_2} = \mathbf{1.2\ V}$

(b) $V_{o_1} = \mathbf{0\ V}$
$V_{o_2} = \mathbf{0\ V}$

10. (a) Both diodes forward-biased
Si diode turns on first and locks in 0.7 V drop.

$$I_R = \frac{12 \text{ V} - 0.7 \text{ V}}{4.7 \text{ k}\Omega} = 2.4 \text{ mA}$$

$I_D = I_R = \mathbf{2.4\ mA}$
$V_o = 12 \text{ V} - 0.7 \text{ V} = \mathbf{11.3\ V}$

(b) Right diode forward-biased:

$$I_D = \frac{20 \text{ V} + 4 \text{ V} - 0.7 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{10.59\ mA}$$

$V_o = 20 \text{ V} - 0.7 \text{ V} = \mathbf{19.3\ V}$

11. (a) Si diode "on" preventing GaAs diode from turning "on":

$$I = \frac{1 \text{ V} - 0.7 \text{ V}}{1 \text{ k}\Omega} = \frac{0.3 \text{ V}}{1 \text{ k}\Omega} = \mathbf{0.3\ mA}$$

$V_o = 1 \text{ V} - 0.7 \text{ V} = \mathbf{0.3\ V}$

(b) $$I = \frac{16 \text{ V} - 0.7 \text{ V} - 0.7 \text{ V} + 4 \text{ V}}{4.7 \text{ k}\Omega} = \frac{18.6 \text{ V}}{4.7 \text{ k}\Omega} = \mathbf{3.96\ mA}$$

$V_o = 16 \text{ V} - 0.7 \text{ V} - 0.7 \text{ V} = \mathbf{14.6\ V}$

12. Both diodes forward-biased:

$V_{o_1} = \mathbf{0.7\ V}$, $V_{o_2} = \mathbf{0.7\ V}$

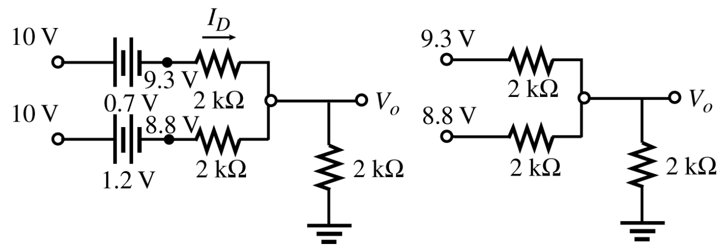
$$I_{1\,k\Omega} = \frac{20\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{19.3\text{ V}}{1\text{ k}\Omega} = 19.3\text{ mA}$$

$I_{0.47\,k\Omega} = 0\text{ mA}$

$I = I_{1\,k\Omega} - I_{0.47\,k\Omega} = 19.3\text{ mA} - 0\text{ mA}$

$= \mathbf{19.3\ mA}$

13.



Superposition: $$V_{o_1}(9.3\text{ V}) = \frac{1\text{ k}\Omega(9.3\text{ V})}{1\text{ k}\Omega + 2\text{ k}\Omega} = 3.1\text{ V}$$

$$V_{o_2}(8.8\text{ V}) = \frac{16\text{ k}\Omega(8.8\text{ V})}{1\text{ k}\Omega + 2\text{ k}\Omega} = 2.93\text{ V}$$

$$V_o = V_{o_1} + V_{o_2} = \mathbf{6.03\ V}$$

$$I_D = \frac{9.3\text{ V} - 6.03\text{ V}}{2\text{ k}\Omega} = \mathbf{1.635\ mA}$$

14. Both diodes "off". The threshold voltage of 0.7 V is unavailable for either diode.

$V_o = \mathbf{0\ V}$

15. Both diodes "on", $V_o = 10\text{ V} - 0.7\text{ V} = \mathbf{9.3\ V}$

16. Both diodes "on".

$V_o = \mathbf{0.7\ V}$

17. Both diodes "off", $V_o = \mathbf{10\ V}$

18. The Si diode with −5 V at the cathode is "on" while the other is "off". The result is

$V_o = -5\text{ V} + 0.7\text{ V} = \mathbf{-4.3\ V}$

19. 0 V at one terminal is "more positive" than −5 V at the other input terminal. Therefore assume lower diode "on" and upper diode "off".

The result:

$V_o = 0\text{ V} - 0.7\text{ V} = \mathbf{-0.7\ V}$

The result supports the above assumptions.

20. Since all the system terminals are at 10 V the required difference of 0.7 V across either diode cannot be established. Therefore, both diodes are "off" and

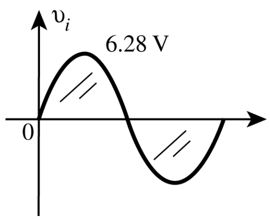
$V_o = \mathbf{+10\ V}$

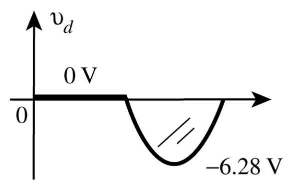
as established by 10 V supply connected to 1 kΩ resistor.

21. The Si diode requires more terminal voltage than the Ge diode to turn "on". Therefore, with 5 V at both input terminals, assume Si diode "off" and Ge diode "on".

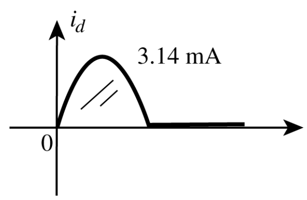
The result: $V_o = 5\text{ V} - 0.3\text{ V} = \mathbf{4.7\text{ V}}$
The result supports the above assumptions.

22. $V_{dc} = 0.318\, V_m \Rightarrow V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\text{ V}}$

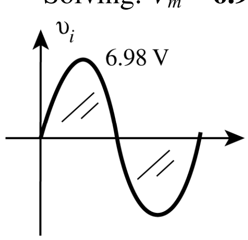


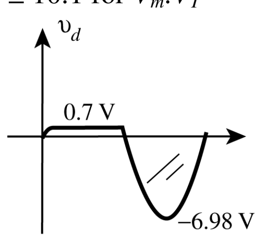


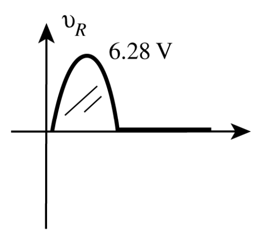
$I_m = \dfrac{V_m}{R} = \dfrac{6.28\text{ V}}{2\text{ k}\Omega} = \mathbf{3.14\text{ mA}}$

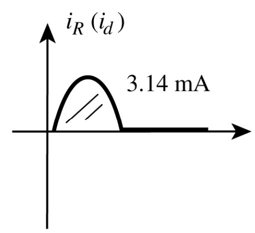


23. Using $V_{dc} \cong 0.318(V_m - V_T)$
$2\text{ V} = 0.318(V_m - 0.7\text{ V})$
Solving: $V_m = \mathbf{6.98\text{ V}} \cong 10{:}1$ for $V_m{:}V_T$

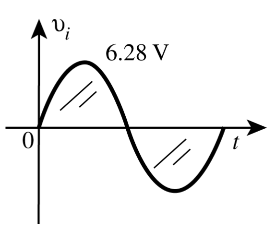


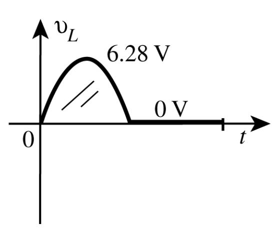




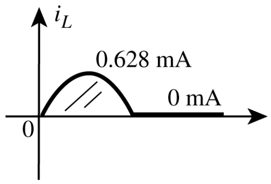


24. $V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\text{ V}}$



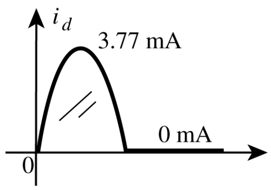


$I_{L_{max}} = \dfrac{6.28\text{ V}}{10\text{ k}\Omega} = \mathbf{0.628\text{ mA}}$

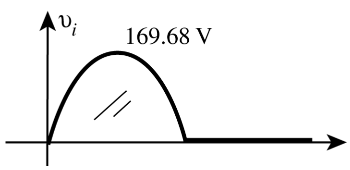


$I_{max}(2\ \text{k}\Omega) = \dfrac{6.28\ \text{V}}{2\ \text{k}\Omega}$ = **3.14 mA**

$I_{D_{max}} = I_{L_{max}} + I_{max}(2\ \text{k}\Omega) = 0.678\ \text{mA} + 3.14\ \text{mA} =$ **3.77 mA**



25. $V_m = \sqrt{2}\,(120\ \text{V}) = 169.68\ \text{V}$
$V_{dc} = 0.318V_m = 0.318(169.68\ \text{V}) =$ **53.96 V**



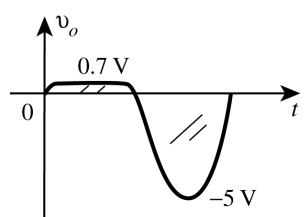
26. Diode will conduct when $v_o = 0.7$ V; that is,

$$v_o = 0.7\ \text{V} = \frac{1\ \text{k}\Omega(v_i)}{1\ \text{k}\Omega + 1\ \text{k}\Omega}$$

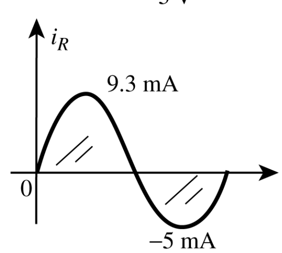
Solving: $v_i =$ **1.4 V**

For $v_i \geq 1.4$ V Si diode is "on" and $v_o =$ **0.7 V**.
For $v_i < 1.4$ V Si diode is open and level of v_o is determined by voltage divider rule:

$$v_o = \frac{1\ \text{k}\Omega(v_i)}{1\ \text{k}\Omega + 1\ \text{k}\Omega} = 0.5\ v_i$$



For $v_i = -10$ V:
$v_o = 0.5(-10\ \text{V})$
$=$ **−5 V**



When $v_o = 0.7$ V, $v_{R_{max}} = v_{i_{max}} - 0.7$ V
$= 10\ \text{V} - 0.7\ \text{V} = 9.3\ \text{V}$

$$I_{R_{max}} = \frac{9.3\ \text{V}}{1\ \text{k}\Omega} = 9.3\ \text{mA}$$

$I_{max}(\text{reverse}) = \dfrac{10\ \text{V}}{1\ \text{k}\Omega + 1\ \text{k}\Omega}$ = **0.5 mA**

27. (a) $P_{\max} = 14 \text{ mW} = (0.7 \text{ V})I_D$

$$I_D = \frac{14 \text{ mW}}{0.7 \text{ V}} = \mathbf{20 \text{ mA}}$$

(b) $I_{\max} = 2 \times 20 \text{ mA} = \mathbf{40 \text{ mA}}$

(c) $4.7 \text{ k}\Omega \,||\, 68 \text{ k}\Omega = 4.4 \text{ k}\Omega$

$V_R = 160 \text{ V} - 0.7 \text{ V} = 159.3 \text{ V}$

$$I_{\max} = \frac{159.3 \text{ V}}{4.4 \text{ k}\Omega} = 36.2 \text{ mA}$$

$$I_d = \frac{I_{\max}}{2} = \mathbf{18.1 \text{ mA}}$$

(d) Total damage, **36.2 mA > 20 mA**

28. (a) $V_m = \sqrt{2}\,(120 \text{ V}) = 169.7 \text{ V}$

$V_{L_m} = V_{i_m} - 2V_D$

$= 169.7 \text{ V} - 2(0.7 \text{ V}) = 169.7 \text{ V} - 1.4 \text{ V}$

$= 168.3 \text{ V}$

$V_{\text{dc}} = 0.636(168.3 \text{ V}) = \mathbf{107.04 \text{ V}}$

(b) $\text{PIV} = V_m(\text{load}) + V_D = 168.3 \text{ V} + 0.7 \text{ V} = \mathbf{169 \text{ V}}$

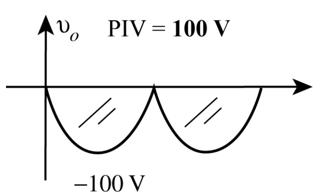
(c) $$I_D(\max) = \frac{V_{L_m}}{R_L} = \frac{168.3 \text{ V}}{1 \text{ k}\Omega} = \mathbf{168.3 \text{ mA}}$$

(d) $P_{\max} = V_D I_D = (0.7 \text{ V})I_{\max}$

$= (0.7 \text{ V})(168.3 \text{ mA})$

$= \mathbf{117.81 \text{ mW}}$

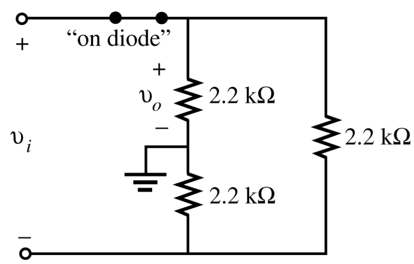
29.



$$I_{\max} = \frac{100 \text{ V}}{2.2 \text{ k}\Omega} = \mathbf{45.45 \text{ mA}}$$

30. Positive half-cycle of v_i:

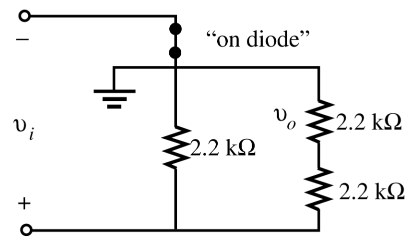
Network redrawn:



Voltage-divider rule:

$$V_{o_{\max}} = \frac{2.2\text{ k}\Omega(V_{i_{\max}})}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega}$$
$$= \frac{1}{2}(V_{i_{\max}})$$
$$= \frac{1}{2}(100\text{ V})$$
$$= \mathbf{50\text{ V}}$$

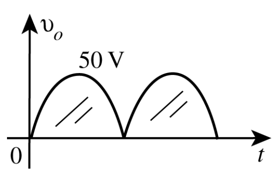
Negative half-cycle of υ_i:



Polarity of v_o across the 2.2 kΩ resistor acting as a load is the same.

Voltage-divider rule:

$$V_{o_{\max}} = \frac{2.2\text{ k}\Omega(V_{i_{\max}})}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega}$$
$$= \frac{1}{2}(V_{i_{\max}})$$
$$= \frac{1}{2}(100\text{ V})$$
$$= \mathbf{50\text{ V}}$$



$V_{dc} = 0.636V_m = 0.636\ (50\text{ V})$
$= \mathbf{31.8\text{ V}}$

31. Positive pulse of v_i:

Top left diode "off", bottom left diode "on"

2.2 kΩ ∥ 2.2 kΩ = 1.1 kΩ

$$V_{o_{\text{peak}}} = \frac{1.1\text{ k}\Omega(170\text{ V})}{1.1\text{ k}\Omega + 2.2\text{ k}\Omega} = 56.67\text{ V}$$

Negative pulse of v_i:

Top left diode "on", bottom left diode "off"

$$V_{o_{\text{peak}}} = \frac{1.1\text{ k}\Omega(170\text{ V})}{1.1\text{ k}\Omega + 2.2\text{ k}\Omega} = 56.67\text{ V}$$

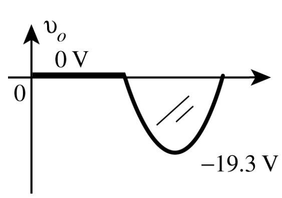
$V_{dc} = 0.636(56.67\text{ V}) = \mathbf{36.04\text{ V}}$

32. (a) Si diode open for positive pulse of v_i and v_o = **0 V**

For $-20\text{ V} < v_i \le -0.7\text{ V}$ diode "on" and $v_o = v_i + 0.7\text{ V}$.

For $v_i = -20\text{ V}$, $v_o = -20\text{ V} + 0.7\text{ V} =$ **−19.3 V**

For $v_i = -0.7\text{ V}$, $v_o = -0.7\text{ V} + 0.7\text{ V} =$ **0 V**



(b) For $v_i \leq 8$ V the 8 V battery will ensure the diode is forward-biased and $v_o = v_i - 8$ V.

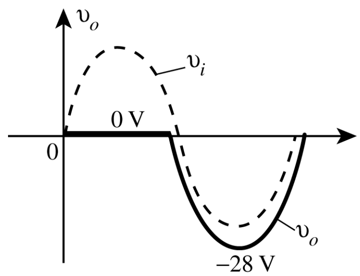
At $v_i = 8$ V

$v_o = 8 \text{ V} - 8 \text{ V} = \mathbf{0\ V}$

At $v_i = -20$ V

$v_o = -20 \text{ V} - 8 \text{ V} = \mathbf{-28\ V}$

For $v_i > 8$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

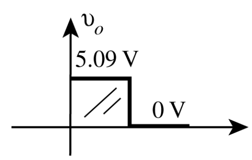


33. (a) Positive pulse of v_i:

$$V_o = \frac{1.8 \text{ k}\Omega(12 \text{ V} - 0.7 \text{ V})}{1.8 \text{ k}\Omega + 2.2 \text{ k}\Omega} = \mathbf{5.09\ V}$$

Negative pulse of v_i:

diode "open", $v_o = \mathbf{0\ V}$

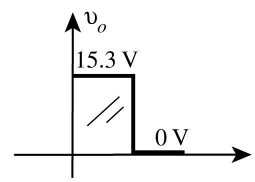


(b) Positive pulse of v_i:

$V_o = 12 \text{ V} - 0.7 \text{ V} + 4 \text{ V} = \mathbf{15.3\ V}$

Negative pulse of v_i:

diode "open", $v_o = \mathbf{0\ V}$



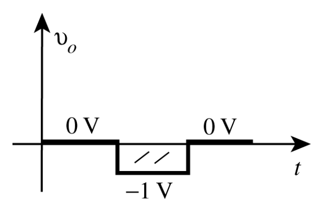
34. (a) For $v_i = 20$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

For $v_i = -5$ V, v_i overpowers the 4 V battery and the diode is "on".

Applying Kirchhoff's voltage law in the clockwise direction:

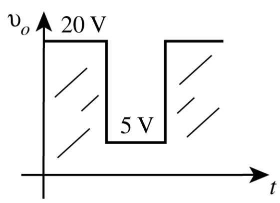
$$-5 \text{ V} + 4 \text{ V} - v_o = 0$$

$$v_o = \mathbf{-1\ V}$$

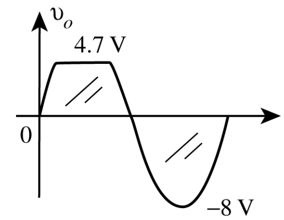


(b) For $v_i = 20$ V the 20 V level overpowers the 5 V supply and the diode is "on". Using the short-circuit equivalent for the diode we find $v_o = v_i = \mathbf{20\ V}$.

For $v_i = -5$ V, both v_i and the 5 V supply reverse-bias the diode and separate v_i from v_o. However, v_o is connected directly through the 2.2 kΩ resistor to the 5 V supply and $v_o = \mathbf{5\ V}$.



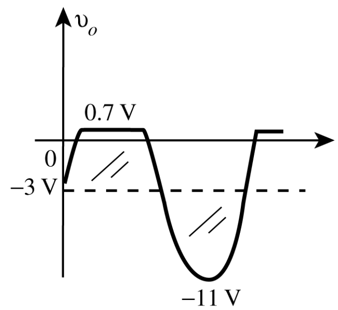
35. (a) Diode "on" for $v_i \geq 4.7$ V
For $v_i > 4.7$ V, $V_o = 4$ V + 0.7 V = **4.7 V**
For $v_i < 4.7$ V, diode "off" and $v_o = \boldsymbol{v_i}$



(b) Again, diode "on" for $v_i \geq 3.7$ V but v_o now defined as the voltage across the diode
For $v_i \geq 3.7$ V, v_o = **0.7 V**

For $v_i < 3.7$ V, diode "off", $I_D = I_R = 0$ mA and $V_{2.2\ \text{k}\Omega} = IR = (0\ \text{mA})R = 0$ V

Therefore, $v_o = v_i - 3$ V
At $v_i = 0$ V, v_o = **−3 V**
$v_i = -8$ V, $v_o = -8$ V − 3 V = **−11 V**

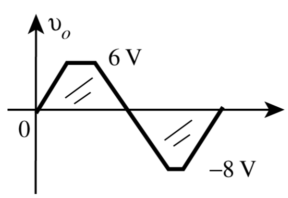


36. For the positive region of v_i:
The right Si diode is reverse-biased.
The left Si diode is "on" for levels of v_i greater than 5.3 V + 0.7 V = 6 V. In fact, v_o = **6 V** for $v_i \geq 6$ V.

For $v_i < 6$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.

For the negative region of v_i:
The left Si diode is reverse-biased.
The right Si diode is "on" for levels of v_i more negative than 7.3 V + 0.7 V = 8 V. In fact, v_o = **−8 V** for $v_i \leq -8$ V.

For $v_i > -8$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.



i_R: For $-8\text{ V} < v_i < 6$ V there is no conduction through the 10 kΩ resistor due to the lack of a complete circuit. Therefore, $i_R = 0$ mA.
For $v_i \geq 6$ V
$v_R = v_i - v_o = v_i - 6$ V
For $v_i = 10$ V, $v_R = 10$ V − 6 V = 4 V

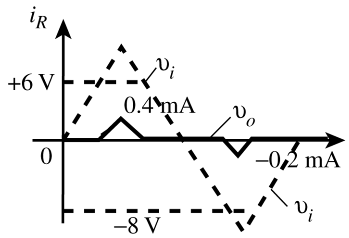
$$\text{and } i_R = \frac{4\text{ V}}{10\text{ k}\Omega} = \mathbf{0.4\ mA}$$

For $v_i \leq -8$ V
$v_R = v_i - v_o = v_i + 8$ V

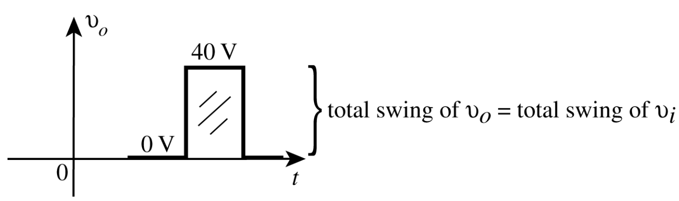
For $v_i = -10$ V

$$v_R = -10 \text{ V} + 8 \text{ V} = -2 \text{ V}$$

$$\text{and } i_R = \frac{-2 \text{ V}}{10 \text{ k}\Omega} = \mathbf{-0.2\ mA}$$

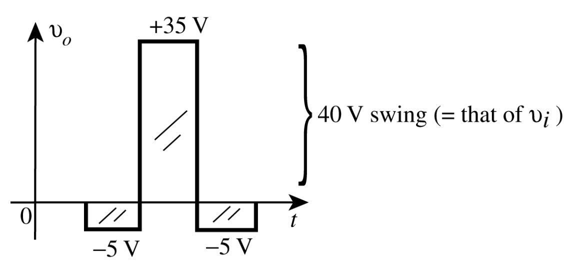


37. (a) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges to −20 V+. During this interval of time v_o is across the "on" diode (short-current equivalent) and $v_o = 0$ V.
When v_i switches to the +20 V level the diode enters the "off" state (open-circuit equivalent) and $v_o = v_i + v_C = 20 \text{ V} + 20 \text{ V} = +40 \text{ V}$

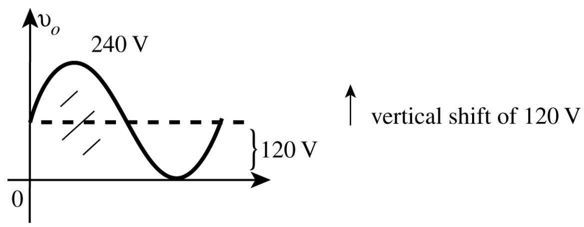


(b) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges up to −15 V+. Note that $v_i = +20$ V and the 5 V supply are additive across the capacitor. During this time interval v_o is across "on" diode and 5 V supply and $v_o = -5$ V.

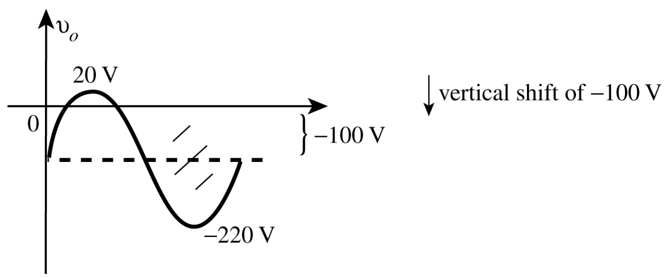
When v_i switches to the +20 V level the diode enters the "off" state and $v_o = v_i + v_C = 20 \text{ V} + 15 \text{ V} = 35 \text{ V}$.



38. (a) For negative half cycle capacitor charges to peak value of 120 V = 120 V with polarity (− —||— +). The output v_o is directly across the "on" diode resulting in v_o = **0 V** as a negative peak value.
For next positive half cycle $v_o = v_i + 120$ V with peak value of
v_o = 120 V + 120 V = **240 V**.



(b) For positive half cycle capacitor charges to peak value of 120 V − 20 V = 100 V with polarity (+ —||— −). The output v_o = 20 V = **20 V**
For next negative half cycle $v_o = v_i - 100$ V with negative peak value of
v_o = −120 V − 100 V = **−220 V**.

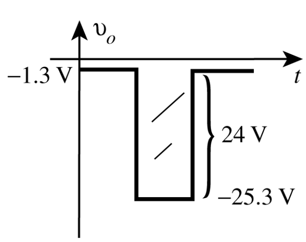


39. (a) $\tau = RC = (56\text{ k}\Omega)(0.1\ \mu\text{F}) = 5.6$ ms
5τ = **28 ms**

(b) $5\tau = 28\text{ ms} \gg \frac{T}{2} = \frac{1\text{ ms}}{2}$ = **0.5 ms**, 56:1

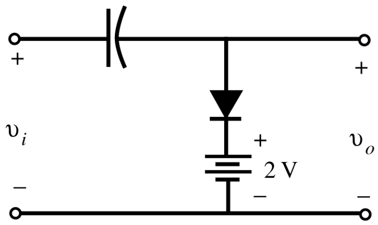
(c) Positive pulse of v_i:
Diode "on" and v_o = −2 V + 0.7 V = −1.3 V
Capacitor charges to 12 V + 2 V − 0.7 V = 13.3 V

Negative pulse of v_i:
Diode "off" and v_o = −12 V − 13.3 V = −25.3 V



40. Solution is network of Fig. 2.181(b) using a 10 V supply in place of the 5 V source.

41. Network of Fig. 2.178 with 2 V battery reversed.



42. (a) In the absence of the Zener diode

$$V_L = \frac{180\ \Omega(20\ \text{V})}{180\ \Omega + 220\ \Omega} = 9\ \text{V}$$

$V_L = 9$ V $< V_Z = 10$ V and diode non-conducting

Therefore, $I_L = I_R = \dfrac{20\ \text{V}}{220\ \Omega + 180\ \Omega} = \mathbf{50\ mA}$

with $I_Z = \mathbf{0\ mA}$
and $V_L = \mathbf{9\ V}$

(b) In the absence of the Zener diode

$$V_L = \frac{470\ \Omega(20\ \text{V})}{470\ \Omega + 220\ \Omega} = 13.62\ \text{V}$$

$V_L = 13.62$ V $> V_Z = 10$ V and Zener diode "on"

Therefore, $V_L = \mathbf{10\ V}$ and $V_{R_s} = 10$ V

$I_{R_s} = V_{R_s}/R_s = 10\ \text{V}/220\ \Omega = \mathbf{45.45\ mA}$

$I_L = V_L/R_L = 10\ \text{V}/470\ \Omega = \mathbf{21.28\ mA}$

and $I_Z = I_{R_s} - I_L = 45.45\ \text{mA} - 21.28\ \text{mA} = \mathbf{24.17\ mA}$

(c) $P_{Z_{\max}} = 400\ \text{mW} = V_Z I_Z = (10\ \text{V})(I_Z)$

$$I_Z = \frac{400\ \text{mW}}{10\ \text{V}} = 40\ \text{mA}$$

$I_{L_{\min}} = I_{R_s} - I_{Z_{\max}} = 45.45\ \text{mA} - 40\ \text{mA} = 5.45\ \text{mA}$

$$R_L = \frac{V_L}{I_{L_{\min}}} = \frac{10\ \text{V}}{5.45\ \text{mA}} = \mathbf{1{,}834.86\ \Omega}$$

Large R_L reduces I_L and forces more of I_{R_s} to pass through Zener diode.

(d) In the absence of the Zener diode

$$V_L = 10\ \text{V} = \frac{R_L(20\ \text{V})}{R_L + 220\ \Omega}$$

$10R_L + 2200 = 20R_L$

$10R_L = 2200$

$R_L = \mathbf{220\ \Omega}$

43. (a) $V_Z = 12\text{ V}, R_L = \dfrac{V_L}{I_L} = \dfrac{12\text{ V}}{200\text{ mA}} = \mathbf{60\ \Omega}$

$$V_L = V_Z = 12\text{ V} = \frac{R_L V_i}{R_L + R_S} = \frac{60\ \Omega(16\text{ V})}{60\ \Omega + R_s}$$

$$720 + 12R_s = 960$$

$$12R_s = 240$$

$$R_s = \mathbf{20\ \Omega}$$

(b) $P_{Z_{\max}} = V_Z I_{Z_{\max}}$

$= (12\text{ V})(200\text{ mA})$

$= \mathbf{2.4\ W}$

44. Since $I_L = \dfrac{V_L}{R_L} = \dfrac{V_Z}{R_L}$ is fixed in magnitude the maximum value of I_{R_s} will occur when I_Z is a maximum. The maximum level of I_{R_s} will in turn determine the maximum permissible level of V_i.

$$I_{Z_{\max}} = \frac{P_{Z_{\max}}}{V_Z} = \frac{400\text{ mW}}{8\text{ V}} = 50\text{ mA}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{8\text{ V}}{220\ \Omega} = 36.36\text{ mA}$$

$$I_{R_s} = I_Z + I_L = 50\text{ mA} + 36.36\text{ mA} = 86.36\text{ mA}$$

$$I_{R_s} = \frac{V_i - V_Z}{R_s}$$

or $V_i = I_{R_s} R_s + V_Z$

$= (86.36\text{ mA})(91\ \Omega) + 8\text{ V} = 7.86\text{ V} + 8\text{ V} = \mathbf{15.86\ V}$

Any value of v_i that exceeds 15.86 V will result in a current I_Z that will exceed the maximum value.

45. At 30 V we have to be sure Zener diode is "on".

$$\therefore\ V_L = 20\text{ V} = \frac{R_L V_i}{R_L + R_s} = \frac{1\text{ k}\Omega(30\text{ V})}{1\text{ k}\Omega + R_s}$$

Solving, $R_s = \mathbf{0.5\ k\Omega}$

At 50 V, $I_{R_S} = \dfrac{50\text{ V} - 20\text{ V}}{0.5\text{ k}\Omega} = 60\text{ mA}, I_L = \dfrac{20\text{ V}}{1\text{ k}\Omega} = 20\text{ mA}$

$I_{ZM} = I_{R_S} - I_L = 60\text{ mA} - 20\text{ mA} = \mathbf{40\ mA}$

46. For $v_i = +50$ V:

Z_1 forward-biased at 0.7 V

Z_2 reverse-biased at the Zener potential and $V_{Z_2} = 10$ V.

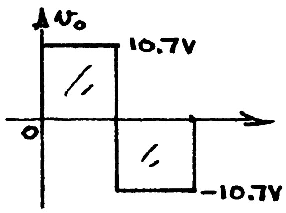
Therefore, $V_o = V_{Z_1} + V_{Z_2} = 0.7\text{ V} + 10\text{ V} = \mathbf{10.7\ V}$

For $v_i = -50$ V:

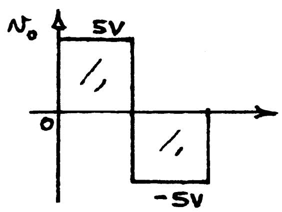
Z_1 reverse-biased at the Zener potential and $V_{Z_1} = -10$ V.

Z_2 forward-biased at -0.7 V.

Therefore, $V_o = V_{Z_1} + V_{Z_2} = \mathbf{-10.7\ V}$



For a 5 V square wave neither Zener diode will reach its Zener potential. In fact, for either polarity of v_i one Zener diode will be in an open-circuit state resulting in $v_o = v_i$.



47. $V_m = 1.414(120\text{ V}) = 169.68$ V

$2V_m = 2(169.68\text{ V}) = \mathbf{339.36\ V}$

48. The PIV for each diode is $\mathbf{2V_m}$

$\therefore \text{PIV} = 2(1.414)(V_{\text{rms}})$