Instructor's Resource Manual to accompany

Electronic Devices and Circuit Theory

Eighth Edition

Containing Solutions to Problems in Text
Solutions to Laboratory Experiments
Test Item File

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Contents

Chapter 1. (Odd)

1. 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.

3. 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).

5. $\rho \cong 50\times10^3\,\Omega\cdot\text{cm}\,(Si)$, $\rho \cong 10^{-6}\,\Omega\cdot\text{cm}\,(Cu)$

(a) $R = \rho\dfrac{l}{A} = (50\times10^3\,\Omega\cdot\text{cm})\dfrac{(3\text{cm})}{(1\text{cm}^2)} = \underline{150\text{k}\Omega}$

(b) $R = \rho\dfrac{l}{A} = (50\times10^3\,\Omega\cdot\text{cm})\dfrac{(1\text{cm})}{(4\text{cm}^2)} = \underline{12.5\text{k}\Omega}$

(c) $R = \rho\dfrac{l}{A} = (50\times10^3\,\Omega\cdot\text{cm})\dfrac{(8\text{cm})}{(0.5\text{cm}^2)} = \underline{800\text{k}\Omega}$

(d) $R = \rho\dfrac{l}{A} = (10^{-6}\,\Omega\cdot\text{cm})\dfrac{(3\text{cm})}{(1\text{cm}^2)} = \underline{3\mu\Omega}$

$R_{Si} : R_{Cu} = \underline{50\times10^9 : 1}$

7. 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 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.

9. $W = QV = (6C)(3V) = \underline{18J}$

11. GaP Gallium Phosphide $E_g = 2.24\text{eV}$
ZnS Zinc Sulfide $E_g = 3.67\text{eV}$

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

15. Same basic appearance as Fig. 1.9 since Arsenic also has 5 valence electrons(pentavalent).

17. --

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

21. $k = 11{,}600/\eta = 11{,}600/2 = 5800 \quad (\eta = 2 \text{ for } V_D = 0.6V)$

$T_K = T_C + 273 = 100 + 273 = 373$

$$e^{kV/T_K} = e^{\frac{(5800)(0.6V)}{373}} = e^{9.33} = 11.27\times10^3$$

$I = I_s(e^{kV/T_K} - 1) = 5\mu A(11.27 \times 10^3 - 1) = \underline{56.35mA}$

23. (a)

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

(b) $y = e^0 = \underline{1}$

(c) For $V = 0V$, $e^0 = 1$ and $I = I_s(1-1) = \underline{0mA}$

25. 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.

27. $V_D \cong 0.66V$, $I_D = 2mA$

$$R_{DC} = \frac{V_D}{I_D} = \frac{0.65V}{2mA} = \underline{325\Omega}$$

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

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

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

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

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

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

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

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

$R_{DC} >> r_d$

33. $I_D = 1mA$, $r_d = 2\left(\frac{26mV}{I_D}\right) = 2(26\Omega) = \underline{52\Omega}$ vs 55Ω (#32)

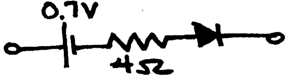
$I_D = 15mA$, $r_d = \frac{26mV}{I_D} = \frac{26mV}{15mA} = \underline{1.73\Omega}$ vs. 2Ω (#32)

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

(relatively close to average value of 24.4Ω (#34))

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

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.8V - 0.7V}{25mA - 0mA} = \frac{0.1V}{25mA} = 4\Omega$$



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

41. Log scale : $T_A = 25°C,\ I_R = \underline{0.5nA}$

$T_A = 100°C,\ I_R = \underline{60nA}$

the change is significant $60nA : 0.5nA = \underline{120:1}$

Yes - at 95°C I_R would increase to 64nA starting with 0.5nA (at 25°C) and doubling the level every 10°C.

43. $T = 25°C:\ P_{max} = 500mW$

$T = 100°C:\ P_{max} = 260mW$

$P_{max} = V_F I_F$

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

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

$714.29mA : 371.43mA = \underline{1.92:1} \cong \underline{2:1}$

45. (a) $V_R = -25V:\ C_T \cong \underline{0.75pF}$

$V_R = -10V:\ C_T \cong \underline{1.25pF}$

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

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

$V_R = -1V:\ C_T \cong \underline{3pF}$

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

(c) $0.194pF/V : 0.033pF/V = \underline{5.88:1} \cong \underline{6:1}$

Increased sensitivity near $V_D = 0V$

47. 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.

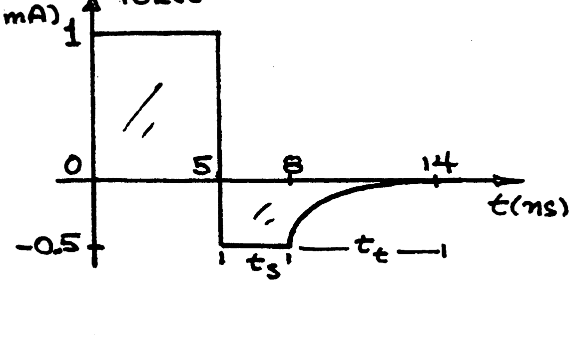
49. $I_f = \dfrac{10V}{10k\Omega} = 1mA \qquad I_{reverse} = \dfrac{5V}{10k\Omega} = 0.5mA$

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

$t_s + 2t_s = 9ns$

$t_s = \underline{3ns}$

$t_t = 2t_s = \underline{6ns}$



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

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

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

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

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

53. $\dfrac{(20V - 6.8V)}{(24V - 6.8V)} \times 100\% = 77\%$

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

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

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

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

At $I_Z = 0.1mA$, $T_C \cong \underline{-0.025\%/°C}$

55. 24V Zener:

$0.2mA : \cong 400\Omega$

$1mA : \cong 95\Omega$

$10mA : \cong 13\Omega$

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

57. Fig. 1.55 (f) $I_F \cong 13mA$

Fig. 1.55 (e) $V_F \cong \underline{2.3V}$

59. a. $1ms = 1000\mu s$, $f = 300Hz$

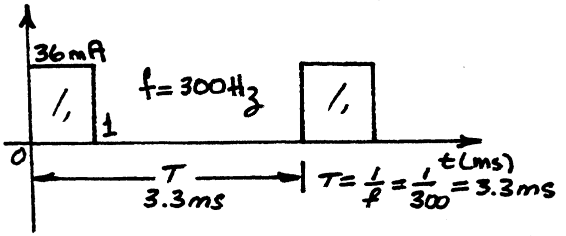
From Fig. 1.55(h) $\dfrac{I_{peak(max)}}{I_{dc(max)}} = 1.8$

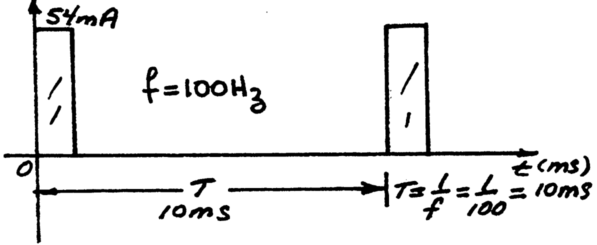
$$\therefore I_{peak(max)} = 1.8 I_{dc(max)} = 1.8(20mA) = \underline{36mA}$$

b. $1ms = 1000\mu s$, $f = 100Hz$

From Fig. 1.55(h) $\dfrac{I_{peak(max)}}{I_{dc(max)}} \cong 2.7$

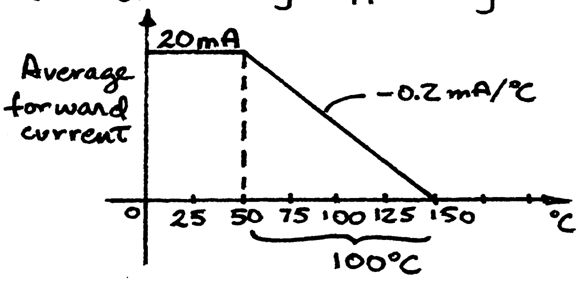
$$\therefore I_{peak(max)} = 2.7 I_{dc(max)} = 2.7(20mA) = \underline{54mA}$$





The plots above reveal that for the same duration pulse, the lower the frequency the higher the permitted current for the duration of the pulse — concurring with our expectations.

61. For the high efficiency red unit of Fig. 1.55:



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

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

Chapter 1.(even)

2. In the forward-bias region the 0V 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.

4. Semiconductor: materials with conduction characteristics lying between those of a conductor and insulator. Typically materials whose conduction level is a function of the "doping" levels.

Resistivity: that characteristic of materials that will determine level of opposition to the flow of charge(current) through the material.

Bulk resistance: (from additional reading and section 1.7) the actual resistance of a semiconductor material.

Ohmic contact resistance: (from additional reading and section 1.7) the resistance introduced by the connection between the metal lead and the semiconductor material.

6. Copper has 29 orbiting electrons with only one electron in the outermost shell. The fact that the outermost shell with its 29th 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.

8. —

10. $48\text{eV} = 48(1.6\times10^{-19}\text{J}) = 76.8\times10^{-19}\text{J}$

$$\phi = \frac{W}{V} = \frac{76.8\times10^{-19}\text{J}}{12\text{V}} = \underline{6.40\times10^{-19}\text{C}}$$

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

12. 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 then 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.

14. 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.

16. Same basic appearance as Fig. 1.11 since Boron also has 3 valence electrons(trivalent).

18. --

20. $T_K = 20 + 273 = 293$

$k = 11{,}600/\eta = 11{,}600/2$ (low value of V_D) $= 5800$

$I_D = I_s(e^{kV_D/T_K} - 1) = 50\times10^{-9}(e^{\frac{(5800)(0.6)}{293}} - 1)$

$= 50\times10^{-9}(e^{11.877} - 1) = \underline{7.197\,mA}$

22. (a) $T_K = 20 + 273 = 293$

$k = 11{,}600/\eta = 11{,}600/2 = 5800$

$I_D = I_s(e^{kV_D/T_K} - 1) = 0.1\mu A(e^{\frac{(5800)(-10V)}{293}} - 1)$

$= 0.1\times10^{-6}(e^{-197.95} - 1) = 0.1\times10^{-6}(1.07\times10^{-86} - 1)$

$\cong 0.1\times10^{-6} = 0.1\mu A$

and $I_D = I_s = \underline{0.1\mu A}$

(b) The result is expected since the diode current under reverse-bias conditions should equal the saturation value.

24.

$T = 20°C$: $I_s = 0.1\mu A$

$T = 30°C$: $I_s = 2(0.1\mu A) = 0.2\mu A$ (double every 10°C rise in Temperature)

$T = 40°C$: $I_s = 2(0.2\mu A) = 0.4\mu A$

$T = 50°C$: $I_s = 2(0.4\mu A) = 0.8\mu A$

$T = 60°C$: $I_s = 2(0.8\mu A) = \underline{1.6\mu A}$

$1.6\mu A : 0.1\mu A \Rightarrow 16:1$ increase due to rise in Temperature of 40°C.

26. From Fig. 1.24:

	−75°C	25°C	100°C	200°C
V_F @ 10mA	1.7V	1.3V	1.0V	0.65V
I_s	0.1μA	0.5μA	1μA	2μA

V_F decreased with increase in Temperature

$1.7V : 0.65V \cong \underline{2.6:1}$

I_s increased with increase in Temperature

$2\mu A : 0.1\mu A = \underline{20:1}$

28. At $I_D = 15mA$, $V_D = 0.82V$

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

As the forward diode current increases the static resistance decreases.

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

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

(c) quite close

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

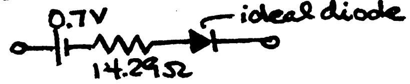
$I_D = 15mA$, $r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.8V - 0.78V}{20mA - 10mA} = \underline{2\Omega}$

34.

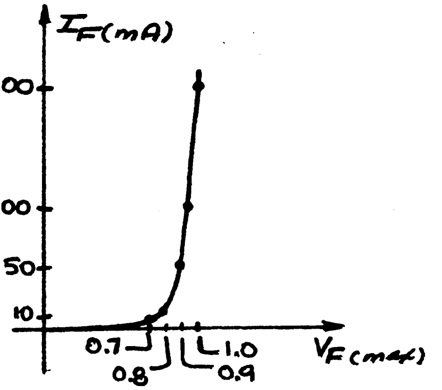
$$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9V - 0.6V}{13.5mA - 1.2mA} = \underline{24.4\Omega}$$

36.

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.9V - 0.7V}{14mA - 0mA} = \frac{0.2V}{14mA} = 14.29\Omega$$



38.



40. At $V_D = -25V$, $I_D = -0.2nA$ and at $V_D = -100V$, $I_D \cong -0.45nA$
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.

42. $I_F = 0.1mA$: $r_d \cong \underline{700\Omega}$

$I_F = 1.5mA$: $r_d \cong \underline{70\Omega}$

$I_F = 20mA$: $r_d \cong \underline{6\Omega}$

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

44. Using the bottom right graph of Fig. 1.36:

$I_F = 500mA$ @ $T = 25°C$

At $I_F = 250mA$, $T \cong \underline{104°C}$

46. From Fig. 1.37:

$V_D = 0V$, $C_D = \underline{3.3pF}$

$V_D = 0.25V$, $C_D = \underline{9pF}$

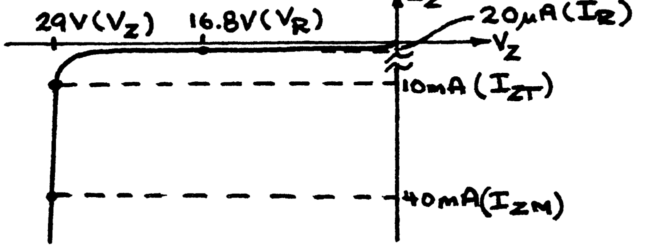
48. $V_D = 0.2V$, $C_D = 7.3pF$

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

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

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

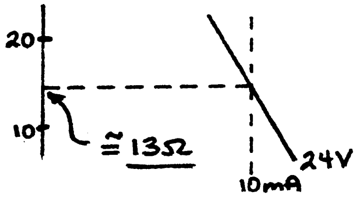
50.



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

$= \dfrac{(5V - 4.8V)}{5V(100° - 25°)} \times 100\% = \underline{0.053\%/°C}$

54.



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

58. (a) Relative efficiency @ 5mA ≅ 0.82
@ 10mA ≅ 1.02

$\dfrac{1.02 - 0.82}{0.82} \times 100\% = \underline{24.4\%}$ increase

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

(b) Relative efficiency @ 30mA ≅ 1.38
@ 35mA ≅ 1.42

$\dfrac{1.42 - 1.38}{1.38} \times 100\% = \underline{2.9\%}$ increase

ratio $\dfrac{1.42}{1.38} = \underline{1.03}$

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

60. (a) $\dfrac{0.75}{3.0} = 0.25$

From Fig. 1.55(i) $\measuredangle \cong \underline{75°}$

(b) $0.5 \Rightarrow \measuredangle = \underline{40°}$