Ans. The conductivity σ is

$$\sigma = e(n\mu_n + p\mu_p). \tag{i}$$

Also,
$$p = \frac{n_i^2}{n} \tag{ii}$$

Substituting for p from (*ii*) in (*i*) gives

$$\sigma = e\left(n\mu_n + \frac{n_i^2}{n}\mu_p\right) \tag{iii}$$

Differentiating (*iii*) with respect to n we obtain

$$\frac{d\sigma}{dn} = e\left(\mu_n - \frac{n_i^2}{n^2}\mu_p\right). \tag{iv}$$

For a minimum value of σ, we have $d\sigma/dn = 0$. Thus from (*iv*) we get $n = n_i\,(\mu_p/\mu_n)^{1/2}$. Putting this value of n in (*iii*), we obtain for the minimum conductivity

$$\sigma_m = 2\, e\, n_i\, (\mu_n\, \mu_p)^{1/2}.$$

4. *Find (i) the conductivity and (ii) the resistance of a bar of pure silicon of length* 1 cm *and cross sectional area* 1 mm^2 *at* 300 K. *Given,* $\mu_n = 0.13$ m^2/(V.s.), $\mu_p = 0.05$ m^2/(V.s), $n_i = 1.5 \times 10^{16}$ /m^3, *and* $e = 1.6 \times 10^{-19}$ C. **(Uttaranchal, 2002)**

Ans. (*i*) The intrinsic conductivity is

$$\sigma_i = n_i\, e(\mu_n + \mu_p) = 1.5 \times 10^{16} \times 1.6 \times 10^{-19}\,(0.13 + 0.05)$$
$$= 4.32 \times 10^{-4} \text{ S/m.}$$

(*ii*) The desired resistance is

$$R = \frac{l}{\sigma_i \alpha} = \frac{0.01}{4.32 \times 10^{-4} \times 10^{-6}} = 0.2315 \times 10^8 \text{ ohm.}$$
$$= 23.15 \text{ M}\Omega.$$

5. *A sample of* Ge *is doped to the extent of* 10^{14} *donor atoms*/cm^3 *and* 5×10^{13} *acceptor atoms*/cm^3. *At* 300 K, *the resistivity of intrinsic* Ge *is* 60 ohm cm. *If the applied electric field is* 2V/cm, *find the total conduction current density. Assume* $\mu_p/\mu_n = 1/2$ *and* $n_i = 2.5 \times 10^{13}$/cm^3 *at* 300 K. **(Uttaranchal, 2002)**

Ans. The conductivity of the intrinsic material is

$$\sigma_i = en_i\,\mu_n\,(1 + \mu_p/\mu_n)$$

Here,
$$\sigma_i = \frac{100}{60} \text{ S/m} = \frac{5}{3} \text{ S/m}, \; n_i = 2.5 \times 10^{19}\,/\text{m}^3, \text{ and } \mu_p/\mu_n = 1/2.$$

Hence,
$$\mu_n = \frac{\sigma_i}{en_i(1+\mu_p/\mu_n)} = \frac{5}{3 \times 1.6 \times 10^{-19} \times 2.5 \times 10^{19} \times 3/2}$$
$$= 0.2778 \text{ m}^2/(\text{V.s})$$

and
$$\mu_p = \frac{\mu_n}{2} = 0.1389 \text{ m}^2/(\text{V. s})$$

For the doped sample, let n be the electron concentration and p be the hole concentration. As the sample is electrically neutral, we have

$$N_d + p = N_a + n$$

where N_d is the donor concentration and N_a is the acceptor concentration, assumed to be fully ionized. Also, from the mass-action law, $np = n_i^2$. So,

$$N_d + \frac{n_i^2}{n} = N_a + n$$

or $$n^2 + (N_a - N_d)\, n - n_i^2 = 0$$

or $$n = \frac{1}{2}\left[(N_d - N_a) \pm \sqrt{(N_d - N_a)^2 + 4n_i^2}\,\right]$$

n being positive, the negative sign before the radical is rejected, giving

$$n = \frac{1}{2}\left[(N_d - N_a) + \sqrt{(N_d - N_a)^2 + 4n_i^2}\,\right]$$

Given, $N_d = 10^{20}/\text{m}^3$, $N_a = 5 \times 10^{19}/\text{m}^3$, and $n_i = 2.5 \times 10^{19}/\text{m}^3$.

Hence, $$n = \frac{10^{19}}{2}\left[5 + \sqrt{25 + 4 \times 6.25}\,\right]$$
$$= 6.036 \times 10^{19}\ /\text{m}^3,$$

and $$p = \frac{n_i^2}{n} = \frac{6.25}{6.036} \times 10^{19} = 1.035 \times 10^{19}\ /\text{m}^3.$$

The conductivity of the doped sample is

$$\sigma = e\,(n\mu_n + p\mu_p) = 1.6 \times (6.036 \times 0.2778 + 1.035 \times 0.1389)$$
$$= 2.9\ \text{S/m}.$$

It is assumed here that the carrier mobilities in the doped sample are the same as those in the intrinsic material. This is justified by the low doping level and by the fact that Coulomb scattering by the ionized impurities is weak at 300 K.

The applied electric field is $F = 2$ V/cm = 200 V/m. So, the total conduction current density is

$$J = \sigma F = 2.9 \times 200 = 580\ \text{A/m}^2 = 0.058\ \text{A/cm}^2.$$

3 **6.** *Germanium has an intrinsic concentration of* $2.5 \times 10^{19}\ \text{m}^{-3}$ *at* 300 K. *It is doped with* 5×10^{19} *arsenic atoms* per m^3. *Assume that all the As atoms are ionized. If the electron and the hole mobilities are* 0.38 *and* 0.18 m^2/(V.s), *respectively, determine the conductivity of the doped germanium.*

5 valent

Ans. Let n, p and N_d be respectively the electron, hole and donor concentrations in the semiconductor. Since the donor As atoms are all ionized, there are N_d positive charges per m^3. The total positive charge concentration is $N_d + p$. The negative charge concentration is n. As the semiconductor is electrically neutral, we have

$$N_d + p = n \qquad (i)$$

If n_i is the intrinsic concentration, we obtain

$$p = \frac{n_i^2}{n} \qquad (ii)$$

(i) and (ii) give

$$N_d + \frac{n_i^2}{n} = n \quad \text{or,} \quad n^2 - n N_d - n_i^2 = 0$$

or, $$n = \frac{1}{2}\left(N_d \pm \sqrt{N_d^2 + 4n_i^2}\right).$$

Since n is positive, the negative sign before the radical must be discarded.

Hence, $$n = \frac{1}{2}\left(N_d + \sqrt{N_d^2 + 4n_i^2}\right).$$

Here, $n_i = 2.5 \times 10^{19}$ m^{-3} and $N_d = 5 \times 10^{19}$ m^{-3}.

Therefore, $$n = 2.5 \times 10^{19}(1 + \sqrt{2}) = 6.035 \times 10^{19} \text{ m}^{-3}.$$

From (*ii*) we get $$p = \frac{(2.5 \times 10^{19})^2}{6.035 \times 10^{19}} = 1.036 \times 10^{19} \text{ m}^{-3}.$$

The conductivity of the doped sample is

$$\sigma = e(n\mu_n + p\mu_p)$$

where μ_n = electron mobility = 0.38 m^2/(V.s),

μ_p = hole mobility = 0.18 m^2/(V.s), and

e = electronic charge = 1.6×10^{-19} coulomb.

So, $$\sigma = 1.6 \times 10^{-19}(6.035 \times 10^{19} \times 0.38 + 1.036 \times 10^{19} \times 0.18)$$
$$= 3.966 \text{ S/m}.$$

7. *The band gap of a specimen of gallium arsenide phosphide is 1.98 eV. Determine the wavelength of the electromagnetic radiation that is emitted upon direct recombination of electrons and holes in this sample. What is the colour of the emitted radiation?* **(C.U. 2007)**

Ans. If λ is the required wavelength, we have

$$\lambda = \frac{ch}{E_g},$$

where c = velocity of light in vacuum = 3×10^8 m/s,

h = Planck's constant = 6.6×10^{-34} J.s,

and E_g = band gap = 1.98 eV = $1.98 \times 1.6 \times 10^{-19}$ J.

So, $$\lambda = \frac{3 \times 10^8 \times 6.6 \times 10^{-34}}{1.98 \times 1.6 \times 10^{-19}} \text{ m} = 625 \text{ nm}.$$

As λ is in the red region of the visible light, the colour of the emitted radiation is red.

8. *A rectangular semiconductor specimen,* 2 mm *wide and* 1 mm *thick, gives a Hall coefficient of* 10^{-2} m^3/C. *When a current of* 1 mA *is passed through the sample, a Hall voltage of* 1 mV *is developed. Find the magnetic field and the Hall field.*

Ans. We have

$$R_H = \frac{V_H b}{I B} \quad \text{or,} \quad B = \frac{V_H b}{I R_H}$$

Here R_H = Hall coefficient = 10^{-2} m^3/C, V_H = Hall voltage = 10^{-3} V, b = width = 2×10^{-3} m, and I = current = 10^{-3} A. Hence the magnetic field is

$$B = \frac{10^{-3} \times 2 \times 10^{-3}}{10^{-3} \times 10^{-2}} = 0.2 \text{ T}.$$

The Hall field is

$$F_H = \frac{V_H}{t}.$$

Here, t = thickness = 10^{-3} m. So, $F_H = \frac{10^{-3}}{10^{-3}} = 1$ V/m.

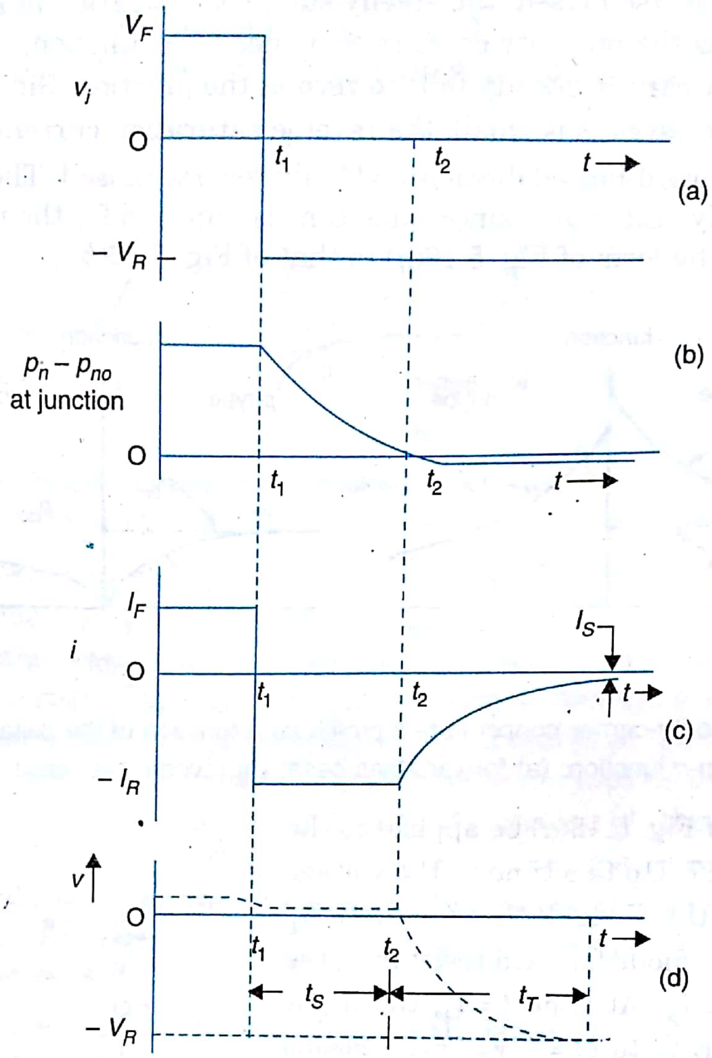

Fig. 5.18(a) Input voltage, (b) excess hole concentroation at the junction, (c) diode current, and (d) diode voltage ; all plotted as a function of time.

5.7 SOLVED PROBLEMS

1. *The reverse saturation current at* 300 K *of a p-n junction* Ge *diode is* 5 μA. *Find the voltage to be applied across the junction to obtain a forward current of* 50 mA.

Ans. The current I for an applied voltage V is given for a Ge p-n diode by

$$I = I_s \left[\exp\left(\frac{eV}{k_B T}\right) - 1\right]$$

Here I = 50 mA = 50 × 10^{-3} A, I_s = 5 μA = 5 × 10^{-6} A, and T = 300 K. So,

$$\exp\left(\frac{eV}{k_B T}\right) = \frac{I}{I_s} + 1 = \frac{50 \times 10^{-3}}{5 \times 10^{-6}} + 1 = 10^4$$

or

$$V = \frac{k_B T}{e} \ln 10^4 = \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}} \times 2.303 \times 4 = 0.238 \text{ volt.}$$

2. *Calculate the ratio of the current for a forward bias of* 0.06 V *to the current for the same value of reverse bias applied to a* Ge *p-n diode at* 27°C.

Ans. The current I and the bias voltage V for a Ge diode are related by

$$I = I_s\left[\exp\left(\frac{eV}{k_BT}\right) - 1\right],$$

where I_s is the reverse saturation current at the absolute temperature T, e is the electronic charge, and k_B is Boltzmann's constant. For a forward bias $V = 0.06$ volt, we have for the current

$$I_1 = I_s\left[\exp\left(\frac{e \times 0.06}{k_BT}\right) - 1\right] \qquad (i)$$

For a reverse bias of $V = -0.06$ volt, the current is

$$I_2 = I_s\left[\exp\left(\frac{-e \times 0.06}{k_BT}\right) - 1\right] \qquad (ii)$$

From (*i*) and (*ii*), we get

$$\frac{I_1}{I_2} = \frac{\exp\left(\frac{0.06e}{k_BT}\right) - 1}{\exp\left(\frac{-0.06e}{k_BT}\right) - 1} \qquad (iii)$$

Now, $$\frac{0.06e}{k_BT} = \frac{0.06 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times (27 + 273)} = 2.319$$

Hence, $$\frac{I_1}{|I_2|} = \frac{\exp(2.319) - 1}{|\exp(-2.319) - 1|} = 10.16$$

3. *The current flowing through a p-n junction* Si *diode is* 60 mA *for a forward bias of* 0.9 volt *at* 300 K. *Determine the static and dynamic resistance of the diode.*

Ans. The current through the silicon diode is $I = 60$ mA $= 60 \times 10^{-3}$ A. The forward bias is $V = 0.9$ volt. So, the static resistance is

$$r_{dc} = \frac{V}{I} = \frac{0.9}{60 \times 10^{-3}} = 15 \text{ ohm}.$$

The dynamic resistance is

$$r_{ac} = \frac{26\eta}{I}$$

where $\eta = 2$ for Si and I is in mA.

Therefore, $$r_{ac} = \frac{26 \times 2}{60} = 0.87 \text{ ohm}.$$

4. *A silicon pn junction diode operates at* 27°C. *If the applied forward bias is increased, the current I is doubled. Calculate the increase in the bias voltage. Assume* $I >> I_s$.

Ans. Let the current be I for the forward bias voltage V, and the current be $2I$ for the forward bias voltage V_1. Then, by the diode equation with $I >> I_s$,

$$I = I_s \exp\left(\frac{eV}{\eta k_BT}\right) \qquad (i)$$

and $$2I = I_s \exp\left(\frac{eV_1}{\eta k_BT}\right) \qquad (ii)$$

Dividing (*ii*) by (*i*) we obtain

$$\exp\left[\frac{e(V_1 - V)}{\eta k_B T}\right] = 2$$

or,
$$V_1 - V = \frac{\eta k_B T}{e}\ln 2 = \frac{2\times 1.38\times 10^{-23}\times(273+27)}{1.6\times 10^{-19}}\ln 2$$
$$= 35.9 \times 10^{-3}\text{ V} = 35.9\text{ mV},$$

which is the required increase in the bias voltage.

5. *Find the bias for which the reverse current in a silicon pn junction diode is half its saturation value at room temperature.*

Ans. Let the bias be V. Then, by the diode equation,

$$I = -\frac{I_s}{2} = I_s\left[\exp\left(\frac{eV}{\eta k_B T}\right) - 1\right] \quad \text{or,} \quad \exp\left(\frac{eV}{\eta k_B T}\right) = \frac{1}{2}$$

or,
$$V = \frac{\eta k_B T}{e}\ln\left(\frac{1}{2}\right) = \frac{2\times 1.38\times 10^{-23}\times 300}{1.6\times 10^{-19}}\ln(0.5) = -35.9\times 10^{-3}\text{ V}$$
$$= -35.9\text{ mV}.$$

The negative sign means reverse bias.

6. *Calculate the rise in temperature if the reverse saturation current in a pn junction diode increases by a factor of* 50.

Ans. The reverse saturation current I_s doubles for every 10°C rise in temperature. If I_{s1} is the value of I_s at temperature T_1 and I_{s2} that at temperature T_2, then

$$I_{s2} = I_{s1}\times 2^{(T_2 - T_1)/10}$$

So,
$$\frac{T_2 - T_1}{10}\log_{10} 2 = \log_{10}\left(\frac{I_{s2}}{I_{s1}}\right) = \log_{10} 50$$

whence
$$T_2 - T_1 = \frac{10}{\log_{10} 2}\times\log_{10} 50 = 56.4°\text{C}.$$

7. *The p-n junction diode used in* Fig. 5.20 *has a cutin voltage of* 0.6 V *and a forward resistance of* 150 ohm. *If the diode can dissipate a maximum power of* 200 mW, *calculate the maximum permissible value of the battery voltage* V_B.

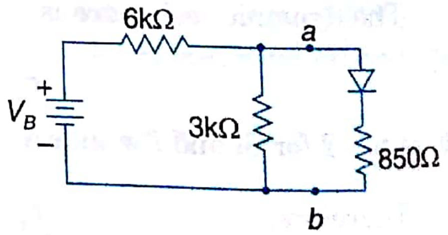

Fig. 5.20 Figure for problem 7.

Ans. In Fig. 5.21., the diode is replaced by its equivalent circuit and the circuit to the left of the terminals *a*, *b* by its Thevenin's equivalent form. Since the diode can dissipate a maximum power of 200 mW, the maximum safe diode current i will satisfy the relationship

$$P = 200\times 10^{-3} = i^2 r + Vi = 150\, i^2 + 0.6i$$

or,
$$150i^2 + 0.6i - 0.2 = 0.$$

Solving this equation for i and noting that i is positive, we get i = 34.6 mA.

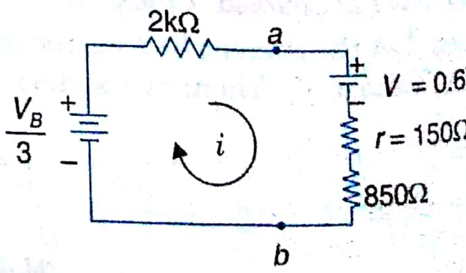

Fig. 5.21 Reduced form of Fig. 5.20.

In Fig. 5.21,
$$i = \frac{(V_B/3) - 0.6}{3} = 34.6$$

or,
$$V_B = 313.2\text{ V},$$

which is the maximum permissible battery voltage.

where the resistances are in kΩ and the currents are in mA. Putting the given numerical values in these equations one obtains

$$2I - I_Z = 12 \qquad (i)$$

and

$$2I - 3I_Z = 6 \qquad (ii)$$

Subtracting (*ii*) from (*i*) gives $I_Z = 3$ mA.

The power dissipated in the Zener diode is $P_Z = V_Z I_Z = 3 \times 3$ mW $= 9$ mW, which does not exceed the maximum power limit of 20 mW.

11. *In the circuit of* Fig. 5.23, *the Zener diode is nonideal, having a knee voltage* V_{Z0} = 9V *and a dynamic resistance* r_Z = 5 ohm. *If the supply voltage* V_s *varies from* 15 *to* 30 V, *determine the range of variation of the output voltage* V_0. *Comment on the result.*

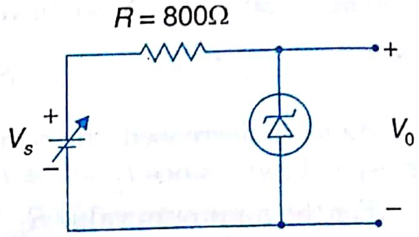

Fig. 5.23 Figure for Problem 11.

Ans. The nonideal Zener diode is represented by its equivalent circuit consisting of a dc source voltage V_{Z0} in series with the resistence r_Z.The circuit of Fig. 5.23 then reduces to the circuit of Fig. 5.24. The current through the Zener diode is

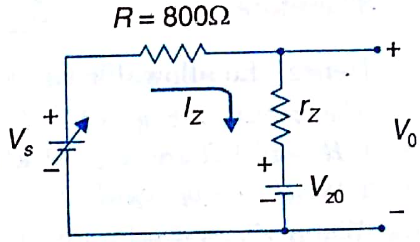

Fig. 5.24

$$I_Z = \frac{V_s - V_{Z0}}{R + r_Z}$$

When V_s = 15 V, I_Z is a minimum, say, $I_{Z\,(\min)}$. So,

$$I_{Z(\min)} = \frac{15 - 9}{800 + 5} = 7.45 \times 10^{-3}\,A = 7.45 \text{ mA}.$$

The corresponding minimum output voltage is

$$V_{0(\min)} = r_Z I_{Z\,(\min)} + V_{Z0} = 5 \times 7.45 \times 10^{-3} + 9 = 9.037 \text{ V}$$

When V_s = 30 V, I_Z attains its maximum value $I_{z\,(\max)}$, where

$$I_{Z\,(\max)} = \frac{30 - 9}{800 + 5} = 0.026 \text{ A} = 26 \text{ mA}.$$

The maximum output voltage is

$$V_{0(\max)} = r_Z I_{Z(\max)} + V_{Z0} = 5 \times 0.026 + 9 = 9.13 \text{ V}$$

Thus the output voltage V_0 varies in the range 9.037 V to 9.13 V.

Comment. Though V_s is doubled, V_0 varies very little, reflecting that the Zener diode serves as a reference diode.

12. *In the circuit of* Fig. 5.11, V = 35 V, I_Z = 25 mA, *and* I_L = 5 mA. *If the knee voltage of the Zener diode is* V_{Z0} = 7 V *and its dynamic resistance is* r_Z = 6 Ω, *what is the value of the resistance R ?*

Ans. The Zener voltage is $V_Z = V_{Z0} + r_Z I_Z = 7 + 6 \times 0.025 = 7.15$ V.

The current through R is $I = I_Z + I_L = 25 + 5 = 30$ mA.

So,

$$R = \frac{V - V_Z}{I} = \frac{35 - 7.15}{30 \times 10^{-3}} = 928.3 \text{ ohm}.$$

REVIEW QUESTIONS

6.11 SOLVED PROBLEMS

1. *A diode, the forward resistance of which is* 50 ohm, *supplies power to a load resistance* 1200 ohm *from a* 20 V (rms) *source. Calculate (i) the dc load current, (ii) the ac load current, (iii) the dc voltage across the diode, (iv) the dc output power, (v) the conversion efficiency, and (vi) the percentage regulation.*

Ans. As one diode is employed, the circuit is a half-wave rectifier. The peak load current is

$$I_m = \frac{V_m}{R_f + R_L} = \frac{20\sqrt{2}}{50 + 1200} = 0.0226 \text{ A}$$

(*i*) The dc load current is

$$I_{dc} = \frac{I_m}{\pi} = 7.19 \times 10^{-3} \text{ A}$$

(*ii*) The rms ac load current is

$$I'_{rms} = (I^2_{rms} - I^2_{dc})^{1/2},$$

where I_{rms} = rms load current $= \dfrac{I_m}{2} = 0.0113$ A

Hence, $I'_{rms} = [0.0113^2 - 7.19^2 \times 10^{-6}]^{1/2} = 0.872 \times 10^{-2}$ A

(*iii*) The dc voltage across the diode is

$$I_{dc} R_f = 7.19 \times 10^{-3} \times 50 = 0.3595 \text{ V}$$

(*iv*) The dc output power is

$$P_{dc} = I^2_{dc} \, R_L = 7.19^2 \times 10^{-6} \times 1200 = 0.062 \text{ W}$$

(*v*) The conversion efficiency is

$$\eta = \frac{40.6}{1 + R_f / R_L} = \frac{40.6}{1 + 50/1200} = 39 \text{ per cent.}$$

(*vi*) The percentage regulation is

$$\frac{V_{NL} - V_{RL}}{V_{RL}} \times 100 = \frac{I_{dc} R_f}{I_{dc} R_L} \times 100 = \frac{R_f}{R_L} \times 100 = \frac{50}{1200} \times 100 = 4.17\%$$

2. *A full-wave rectifier uses a double-diode, the forward resistance of each element being* 100 ohm. *The rectifier supplies current to a load resistance of* 1000 ohm. *The primary-to-total secondary turns ratio of the centre-tapped transformer is* 10 : 1. *The transformer primary is fed from a supply of* 240 V (rms). *Find (i) the dc load current, (ii) the direct current in each diode, (iii) the dc power output, (iv) the ripple voltage across the load resistance, (v) the percentage regulation, and (vi) the efficiency of rectification.*

Ans. The rms secondary voltage is $V_s = V_P/n$, where V_P is the rms primary voltage of the transformer and n is the primary-to-secondary turns ratio. Here $V_s = 240/10 = 24$ V. The secondary voltage from the centre tap is 24/2 = 12 V (rms). The corresponding peak voltage is $V_m = 12\sqrt{2} = 17$ V.

(*i*) The dc load current is $I_{dc} = 2\, I_m/\pi$, where I_m is the peak current through the load resistance. We have

$$I_m = \frac{V_m}{R_f + R_L} = \frac{17}{100 + 1000} = 0.0154 \text{ A.}$$

Hence, $$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 0.0154}{3.14} = 9.84 \times 10^{-3} \text{ A.}$$

(*ii*) The direct current supplied by each diode is $I_{dc}/2 = 4.92 \times 10^{-3}$ A

(*iii*) The dc power output is

$$P_{dc} = I_{dc}^2 R_L = 9.84^2 \times 10^{-6} \times 1000 = 0.0968 \text{ W}$$

(*iv*) The ripple voltage across the load is

$$I'_{rms} R_L = (I_{rms}^2 - I_{dc}^2)^{1/2} R_L.$$

Here, $I_{rms} = I_m/\sqrt{2} = 0.0154/\sqrt{2} = 0.0109$ A.

So, $I'_{rms} R_L = (0.0109^2 - 9.84^2 \times 10^{-6})^{1/2} \times 1000 = 4.69$ V

(*v*) The percentage regulation is

$$\frac{R_f}{R_L} \times 100 = \frac{100}{1000} \times 100 = 10\%.$$

(*vi*) The efficiency of rectification is

$$\frac{81.2}{1 + R_f / R_L} = \frac{81.2}{1.1} = 73.8\%$$

3. *A bridge rectifier feeds a load resistance of* 2500 Ω *from a* 30 V (rms) *supply. Each diode of the rectifier has a forward resistance of* 50 Ω. *Calculate (i) the dc load voltage, (ii) the ripple voltage at the output, and (iii) the percentage regulation.*

Ans. (*i*) The bridge circuit gives full-wave rectification. So, the dc load current is $I_{dc} = 2 I_m/\pi$, where I_m is the peak load current. Since two diodes in series conduct simultaneously, we have

$$I_m = \frac{V_m}{2 R_f + R_L} = \frac{30\sqrt{2}}{2 \times 50 + 2500} = 0.0163 \text{ A}.$$

Therefore, $I_{dc} = \dfrac{2I_m}{\pi} = 0.0104$ A

The dc load voltage is $V_{dc} = I_{dc} \times R_L = 0.0104 \times 2500 = 26$ V.

(*ii*) The ripple voltage at the output is

$$I'_{rms} R_L = (I_{rms}^2 - I_{dc}^2)^{1/2} R_L.$$

Here, $I_{rms} = I_m/\sqrt{2} = 0.0115$ A

Hence, $I'_{rms} R_L = (0.0115^2 - 0.0104^2)^{1/2} \times 2500 = 12.3$ V

(*iii*) The percentage regulation is

$$\frac{2R_f}{R_L} \times 100 = \frac{2 \times 50}{2500} \times 100 = 4\%.$$

4. *The output voltage across the load resistance of an inductor filter connected to a bridge rectifier shows a dc value of* 20 V *and a peak-to-peak ripple voltage of* 1 V. *Calculate the ripple factor and the percentage ripple.*

Ans. The peak ripple voltage is $V_p = \dfrac{V_{pp}}{2} = \dfrac{1}{2} = 0.5$ V.

The rms ripple voltage is $V'_{rms} = \dfrac{V_p}{\sqrt{2}} = \dfrac{0.5}{\sqrt{2}} = 0.354$ V.

The ripple factor is $\gamma = \dfrac{V'_{rms}}{V_{dc}} = \dfrac{0.354}{20} = 0.0177$

% ripple = ripple factor × 100% = 1.77%.

allowed for the transistor to go over to cutoff through the active region. This accounts the fall time t_f. The rise time and the fall time are determined by the collector transition capacitance.

If the transistor is not driven into saturation, the storage time t_s does not appear. So, for a shorter turn-off time, the transistor is not allowed to go into saturation.

To hasten the switching, a capacitor is often connected in parallel with the resistor R_s in Fig. 7.14. As the voltage across the capacitor cannot change instantaneously, the capacitor momentarily acts as a short circuit whenever the input voltage v_i changes abruptly. The full force of the input voltage change is thus immediately transferred to the base of the transistor to speed up the switching.

Observation

The circuit elements which contain no internal sources of energy are known as *passive elements*. In such elements, the output power cannot be larger than the input power. Typical resistors, inductors, and capacitors are examples of passive circuit elements. On the contrary, the systems having internal sources of energy are called *active systems*. Generators, amplifiers, and oscillators are examples of such systems. The output power in an active system can exceed the input power due to the internal energy source which adds power to the input signal. A transistor in an amplifier circuit operates in the active region of its characteristics and provides this internal source of energy. So, the transistor in the amplifier serves as an *active element*.

An ordinary *p-n* junction diode acts as a resistor, and so it is a passive element. However, a tunnel diode operating over the negative-differential-resistance part of its characteristic contains an internal source of energy and so can work as an amplifier or oscillator. Thus, although it is a *p-n* junction diode, a tunnel diode can serve as an active element.

7.13 SOLVED PROBLEMS

1. *A transistor having* $\alpha = 0.99$ *is used in a common-base amplifier. If the load resistance is* 4.5 k Ω *and the dynamic resistance of the emitter junction is* 50 Ω, *find the voltage gain and the power gain.*

Ans. The voltage gain is

$$A_V \approx \alpha \frac{R_L}{r_e}$$

Here $\alpha = 0.99$, $R_L = 4.5\ \text{k}\,\Omega = 4500\ \Omega$, and $r_e = 50\ \Omega$.

Hence, $$A_V = 0.99 \times \frac{4500}{50} = 89.1$$

The power gain is

$$A_P = \text{current gain} \times \text{voltage gain} = 0.99 \times 89.1 = 88.2$$

2. *An n-p-n transistor with* $\alpha = 0.98$ *is operated in the* CB *configuration. If the emitter current is* 3 mA *and the reverse saturation current is* $I_{CO} = 10\ \mu\text{A}$, *what are the base current and the collector current?* **(cf. C.U. 2006)**

Ans. The collector current I_C for an emitter current I_E is given by

$$I_C = -\alpha I_E + I_{CO}$$

For an *n-p-n* transistor, I_E is negative. Therefore,

$$I_C = \alpha I_E + I_{CO}$$

Since $\alpha = 0.98$, $I_E = 3$ mA, and $I_{CO} = 10\ \mu\text{A} = 10 \times 10^{-3}$ mA, we have

$$I_C = 0.98 \times 3 + 10^{-2} = 2.95\ \text{mA}.$$

Also, from Kirchhoff's current law,

$$I_E + I_C + I_B = 0$$

For an *n-p-n* transistor, I_E is negative. Hence,

$$-I_E + I_C + I_B = 0$$

or,
$$I_B = I_E - I_C = 3 - 2.95 = 0.05 \text{ mA} = 50\ \mu\text{A}..$$

3. *A transistor having* $\alpha = 0.975$ *and a reverse saturation current* $I_{CO} = 10\ \mu$A, *is operated in* CE *configuration. What is* β *for this configuration? If the base current is* 250 μA, *calculate the emitter current and the collector current.*

Ans. We have
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.0975}{0.025} = 39.$$

Also, the collector current is

$$I_C = \beta I_B + (\beta + 1) I_{CO}$$
$$= 39 \times 0.25 + (39 + 1) \times 0.01\text{mA} = 10.2 \text{ mA}$$

Since
$$\alpha = \left| \frac{I_C - I_{CO}}{I_E} \right|,$$

we have
$$0.975 = \frac{10.2 - 0.01}{I_E}$$

whence $I_E = 10.4$ mA.

4. *A transistor is operating in the* CE *mode* (Fig. 7.16). *Calculate* V_{CE} *if* $\beta = 125$, *assuming* $V_{BE} = 0.6$ V. **(cf. C.U. 1991, 2002)**

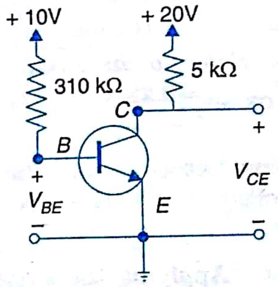

Fig. 7.16 Figure for Problem 4.

Ans. When $V_{BE} = 0.6$ V, the base current is

$$I_B = \frac{10 - V_{BE}}{310 \text{ k}\Omega} = \frac{10 - 0.6}{310} \text{ mA}$$
$$= 0.0303 \text{ mA}$$

Now, $\beta = 125$. Therefore,

$$I_C = \beta I_B = 125 \times 0.0303 \text{ mA}$$
$$= 3.79 \text{ mA} = 3.79 \times 10^{-3} \text{ A}.$$

Again,
$$V_{CE} = 20 - I_C \times 5 \times 10^3 \text{ V}$$
$$= 20 - 3.79 \times 5 = 1.05 \text{ V}.$$

5. *A silicon n-p-n transistor having* $\beta = 100$ *and* I_{CO} = 22nA *is operated in the* CE *configuration* (Fig. 7.17). *Assuming* $V_{BE} = 0.7$ V, *determine the transistor currents and the region of operation of the transistor. What happens if the resistance* R_C *is indefinitely increased?* **(cf. C.U. 1994, 2006)**

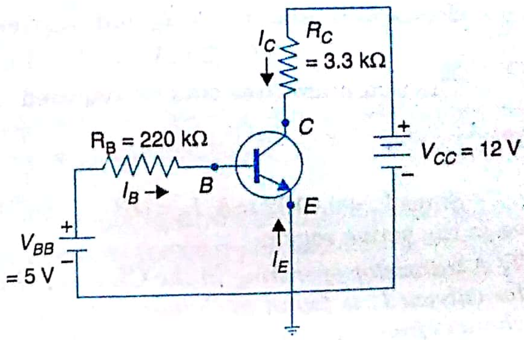

Fig. 7.17 Figure for Problem 5.

Ans. Since the base is forward-biased, the transistor is not cut off. So it is either in the active region or in the saturation region.

Let us assume that the transistor is in the active region. Application of Kirchhoff's voltage law to the base circuit gives

$$I_B R_B + V_{BE} = V_{BB}$$

or
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{220} \text{ mA}$$
$$= 0.0195 \text{ mA}$$
$$= 19.5\ \mu\text{A}.$$

Here, $I_{C0} << I_B$. Therefore,

$$I_C \approx \beta I_B = 100 \times 195 \times 10^{-3}\text{ mA} = 1.95\text{ mA}.$$

To justify the assumption that the transistor operates in the active region, we must show that the collector junction is reverse-biased. Applying Kirchhoff's voltage law to the collector circuit, we get

$$I_C R_C + V_{CB} + V_{BE} = V_{CC}$$

or,

$$\begin{aligned} V_{CB} &= V_{CC} - I_C R_C - V_{BE} \\ &= 12 - 1.95 \times 3.3 - 0.7 \\ &= 4.86\text{ V}. \end{aligned}$$

A positive value of V_{CB} implies that for the *n-p-n* transistor, the collector junction is reverse-biased. Therefore, the transistor is actually in the active region.

The emitter current is $\quad I_E = -(I_C + I_B) = -(1.95 + 0.0195)\text{ mA}$

$$= -1.97\text{ mA}.$$

The negative sign indicates that I_E actually flows in the direction opposite to the arrow-head shown in Fig. 7.17.

I_E

In the active region, I_B and I_C do not depend on the collector circuit resistance R_C. So, if R_C is gradually increased, we see from the collector circuit equation that at one stage V_{CB} becomes negative. The transistor is then no longer in the active region; it goes over to the saturation region.

6. *Refer to the circuit of* Fig. 7.18. *At saturation,* V_{BE} *and* V_{CE} *are* $V_{BE,\,sat} = 0.85$ V *and* $V_{CE,\,sat} = 0.22$ V. *If* $h_{FE} = 110$, *is the transistor operating in the saturation region?*

(cf. C.U. 1998)

Ans. Let us assume that the transistor operates in the saturation region. Applying Kirchhoff's voltage law to the base circuit we get

$$R_I I_B + V_{BE} + R_E (I_C + I_B) = V_{BB} \qquad (i)$$

Applying the same to the collector circuit we obtain

$$R_2 I_C + V_{CE} + R_E (I_C + I_B) = V_{CC} \qquad (ii)$$

Substituting the numerical values, expressing I_B and I_C in mA, and rearranging, (i) and (ii) are written as

$$49.2\, I_B + 2.2\, I_C = 4.15 \qquad (iii)$$

and

$$2.2\, I_B + 5.5\, I_C = 8.78 \qquad (iv)$$

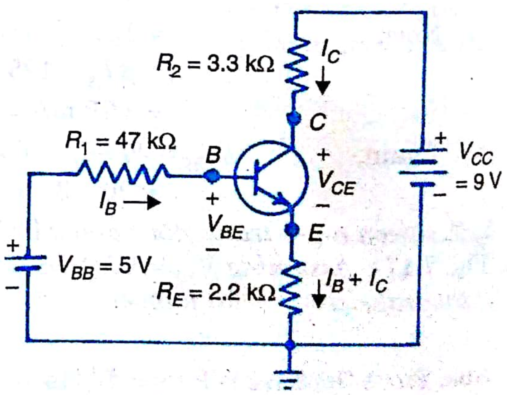

Fig. 7.18 Figure for Problem 6.

Solving (iii) and (iv) for I_B and I_C gives

$$I_B = 0.0132\text{ mA}, I_C = 1.591\text{ mA}.$$

The minimum base current required for saturation is

$$(I_B)_{\min} = \frac{I_C}{h_{FE}} = \frac{1.591}{110} = 0.0145\text{ mA}.$$

Since $I_B = 0.0132$ mA, $I_B < (IB)_{\min}$. So, the transistor is not in the saturation region. It must be in the active region.

7. *A transistor operating in the* CE *mode draws a constant base current* I_B *of* 30 μA. *The collector current* I_C *is found to change from* 3.5 mA *to* 3.7 mA *when the collector-emitter voltage* V_{CE} *changes from* 7.5 V *to* 12.5 V. *Calculate the output resistance and* β *at* $V_{CE} = 12.5$ V. *What is the value of* α?

(C.U. 2002)

The less the NF, the less noisy the device. For transistors, NF is smaller for lower emitter currents and for higher collector voltages. For not too high frequencies, the transistor noise decreases with increasing frequency *f* approximately as 1/*f*. This noise is called *flicker noise* or *1/f noise*. The NF is the same for both CB and CE configurations. Noise considerations thus do not favour one configuration from the other.

8.14 SOLVED PROBLEMS

1. *An n-p-n transistor is used as a* CE *amplifier and has the collector-to-base bias arrangement of* Fig. 8.4. *Given:* $\beta = 99$, $V_{BE} = 0.7$ V, $V_{CC} = 12$ V, $R_L = 2$ kΩ, *and* $R_B = 100$ kΩ. *Find the Q-point analytically and the stability factors S, S′, and S″.*

Ans. Substituting the given values in Eq. (8.12), we have

$$12 = (I_C + I_B) \times 2 \times 10^3 + I_B \times 10^5 + 0.7 \qquad (i)$$

Also, $$I_C \approx \beta I_B = 99\, I_B \qquad (ii)$$

Solving (*i*) and (*ii*) for I_B and I_C, we get $I_B = 37.7$ μA and $I_C = 3.73$ mA. Equation (8.10) gives $V_{CE} = 4.47$ V. The Q-point on the output characteristics is defined by the values of I_C and V_{CE} found above.

The stability factors are

$$S = \frac{\beta + 1}{1 + \beta R_L/(R_L + R_B)} = \frac{99 + 1}{1 + 99 \times 2/(2 + 100)} = 34$$

$$S' = -\frac{\beta}{R_B + R_L(1+\beta)} = -\frac{99}{100 \times 10^3 + 2 \times 10^3 \times 100} = -3.3 \times 10^{-6} \text{ A/V}$$

$$S'' \approx \frac{V_{CC} - V_{BE} - I_C R_L}{R_B + R_L(1+\beta)} = \frac{12 - 0.7 - 3.73 \times 2}{100 \times 10^3 + 2 \times 10^3 \times 100} = 1.28 \times 10^{-5} \text{ A}$$

2. *A* Ge *transistor with* $\beta = 49$ *has the self-biasing arrangement of* Fig. 8.5. *Given:* $V_{CC} = 10$ V, $R_L = 1$ kΩ, $V_{CE} = 5$ V, $I_C = 4.9$ mA, *and* $V_{BE} = 0.2$ V. *The stability factor S is desired to be* 10. *Obtain the values* R_1, R_2, *and* R_e.

Ans. The base current is

$$I_B = \frac{I_C}{\beta} = \frac{4.9}{49} = 0.1 \text{ mA.}$$

From Eq. (8.23), we obtain

$$R_e = \frac{V_{CC} - V_{CE} - I_C R_L}{I_C + I_B} = \frac{10 - 5 - 4.9 \times 1}{4.9 + 0.1} \text{ k}\Omega = 20 \text{ ohm.}$$

Substituting the given values in Eq. (8.27), we obtain

$$10 = 50\,\frac{1 + R_T/20}{50 + R_T/20}$$

whence $$R_T = \frac{R_1 R_2}{R_1 + R_2} = 255\ \Omega \qquad (i)$$

Equation (8.21) gives

$$I_B R_T + V_{BE} + (I_B + I_C) R_e = V_T = \frac{R_2 V_{CC}}{R_1 + R_2}$$

or, $$0.1 \times 10^{-3} \times 225 + 0.2 + (0.1 + 4.9) \times 10^{-3} \times 20 = \frac{R_2 \times 10}{R_1 + R_2}$$

or, $$\frac{R_2}{R_1 + R_2} = 0.03225 \qquad (ii)$$

From (*i*) and (*ii*) we get $R_1 = 6.977$ kΩ and $R_2 = 232.5$ Ω.

3. *The* CB *h-parameters of a transistor are* h_{ib} = 30 ohm, $h_{rb} = 4 \times 10^{-4}$, $h_{fb} = -0.99$, *and* $h_{ob} = 0.9 \times 10^{-6}$ S *for a suitable operating point. The amplifier is used in the* CB *mode with a load resistance of* 6 kΩ. *Calculate the current gain, the input resistance, the output resistance, the voltage gain, and the power gain.*

Ans. Current gain, $$A_I = -\frac{h_{fb}}{1 + h_{ob} R_L} = \frac{0.99}{1 + 0.9 \times 10^{-6} \times 6 \times 10^3} = 0.985.$$

Input resistance, $$R_i = h_{ib} - \frac{h_{fb}\, h_{rb}\, R_L}{1 + h_{ob} R_L}$$

$$= 30 + \frac{0.99 \times 4 \times 10^{-4} \times 6 \times 10^3}{1 + 0.9 \times 10^{-6} \times 6 \times 10^3} = 32.4\ \Omega.$$

Output resistance,

$$R_o = \frac{h_{ib}}{h_{ib}\, h_{ob} - h_{fb}\, h_{rb}} = \frac{30}{30 \times 0.9 \times 10^{-6} + 0.99 \times 4 \times 10^{-4}} = 70.92\ \text{k}\Omega.$$

Voltage gain,

$$A_V = A_I \frac{R_L}{R_i} = 0.985 \times \frac{6 \times 10^3}{32.4} = 182.4.$$

Power gain,

$$A_P = A_I A_v = 0.985 \times 182.4 = 179.7.$$

4. *A transistor amplifier in* CE *configuration couples a source of internal resistance* 1 kΩ *to a load of* 20 kΩ. *Find the input and the output resistances if* $h_{ie} = 1$ kΩ, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 150$ *and* $1/h_{oe} = 40$ kΩ. **(C.U. 1989)**

Ans. Current gain, $$A_I = -\frac{h_{fe}}{1 + h_{oe} R_L} = -\frac{150}{1 + \frac{20}{40}} = -100.$$

Input resistance,

$$R_i = h_{ie} + A_I h_{re} R_L = 1000 - 100 \times 2.5 \times 10^{-4} \times 20 \times 10^3 = 500\ \Omega.$$

Output resistance,

$$R_o = \frac{R_g + h_{ie}}{R_g\, h_{oe} + h_{ie}\, h_{oe} - h_{fe}\, h_{re}} = \frac{1000 + 1000}{(1/40) + (1/40) - 150 \times 2.5 \times 10^{-4}} = 160\ \text{k}\Omega.$$

5. *A* CE *amplifier uses a transistor with* $h_{ie} = 1$ kΩ, $h_{fe} = 100$, $h_{re} = 5 \times 10^{-4}$, *and* $h_{oe} = 25 \times 10^{-6}\ \Omega^{-1}$. *The load resistance is* 5 kΩ. *Find the current amplification and the overall voltage and power gains for a source resistance of* 1 kΩ.

Ans. Current amplification,

$$A_I = -\frac{h_{fe}}{1 + h_{oe} R_L} = -\frac{100}{1 + 25 \times 10^{-6} \times 5 \times 10^3} = -88.89$$

Input resistance,

$$R_i = h_{ie} + A_I h_{re} R_L = 10^3 - 88.89 \times 5 \times 10^{-4} \times 5 \times 10^3 = 777.8\ \Omega$$

or, $5I_B + 0.7 + 7(\beta + 1) I_B = 15$ (where I_B is in mA)

or, $$I_B = \frac{14.3}{705} = 0.0203 \text{ mA} = 20.3\ \mu\text{A}$$

$$I_C = \beta I_B = 99 \times 0.0203 = 2.01 \text{ mA}$$

$$I_E = (\beta + 1)\, I_B = 2.03 \text{ mA}$$

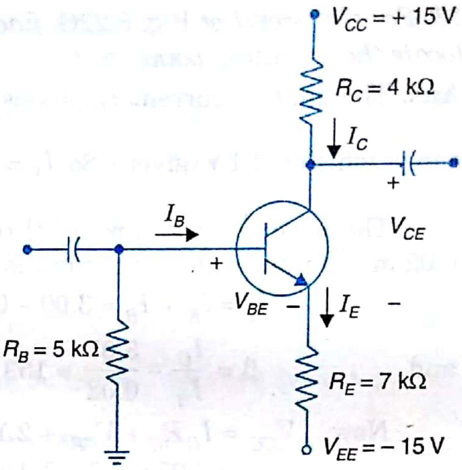

Fig. 8.22F

Applying Kirchhoff's voltage law in the output circuit, we get

$$I_C R_C + V_{CE} + I_E R_E = V_{CC} - V_{EE}$$

or, $$2.01 \times 4 + V_{CE} + 2.03 \times 7 = 15 + 15$$

whence $$V_{CE} = 7.75 \text{ V}$$

If β increases by 20% its new value is

$$\beta = 99 \times 1.2 = 118.8$$

Now, $$I_B = \frac{14.3}{5 + 7 \times 119.8} = 0.017 \text{ mA} = 17\ \mu\text{A}$$

and $$I_C = 118.8 \times 0.017 = 2.02 \text{ mA}$$

The percentage increase in I_C is $\dfrac{2.02 - 2.01}{2.01} \times 100\% = 0.5\%$.

Comment. Since a 20% increase in β produces a mere 0.5% enhancement of I_C, the circuit provides a good stabilization against changes in β.

12. *In the circuit of* Fig. 8.5, $R_1 = 82$ kΩ, $R_2 = 16$ kΩ, $R_L = 2.2$ kΩ, $R_e = 750$ Ω, $V_{CC} = 22$ V, $V_{BE} = 0.7$V *and* $\beta = 100$. *Determine the operating point. (Neglect I_{CO}).* **(cf. U.P. Tech. U., 2002)**

Ans. Applying Thevenin's theorem to the left of the terminals *B*, *G* we obtain for the Thevenin voltage

$$V_T = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{16 \times 22}{82 + 16} = 3.59 \text{ V}$$

and for the Thevenin resistance

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{82 \times 16}{82 + 16} = 13.4 \text{ k}\Omega$$

The base current I_B is related to the collector current I_C by $I_B = \dfrac{I_C}{\beta}$. Applying Kirchhoff's voltage law to the base circuit of Fig. 8.6 we get

$$I_B (R_T + R_e) + I_C R_e = V_T - V_{BE}$$

or, $$I_B = \frac{V_T - V_{BE}}{R_T + R_e + \beta R_e} = \frac{3.59 - 0.7}{13.4 + 0.75 + 100 \times 0.75} = 0.0324 \text{ mA} = 32.4\ \mu\text{A}$$

So, $$I_C = \beta I_B = 3.24 \text{ mA}$$

Applying Kirchhoff's voltage law to the collector circuit of Fig. 8.6 gives

$$I_C (R_L + R_e) + I_B R_e + V_{CE} = V_{CC}$$

or, $$3.24 \times (2.2 + 0.75) + 0.0324 \times 0.75 + V_{CE} = 22$$

whence $$V_{CE} = 12.4 \text{ V}.$$

The operating point is specified by $I_C = 3.24$ mA, $V_{CE} = 12.4$ V.

13. *For the circuit of* Fig. 8.22G, *find the values of* β, V_{CC}, *and* R_B. *Draw the dc load line and locate the operating point on it.* **(cf. U.P. Tech. U., 2001)**

Ans. The emitter current I_E passes through R_E, the voltage across which is 2.1 V (given). So, $I_E = \dfrac{2.1}{R_E} = \dfrac{2.1}{0.68}$ mA = 3.09 mA.

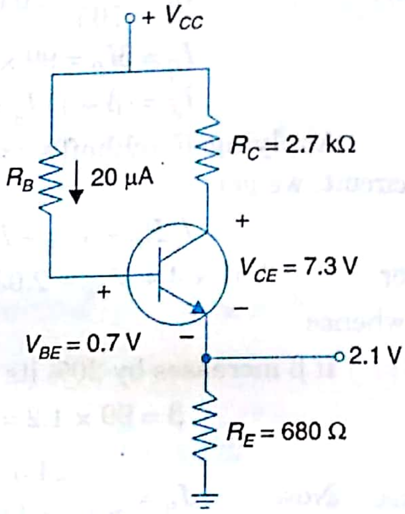

Fig. 8.22G

The base current flowing through R_B is I_B = 20 μA = 0.02 mA. So, the collector current is

$$I_C = I_E - I_B = 3.09 - 0.02 = 3.07 \text{ mA}$$

and
$$\beta = \frac{I_C}{I_B} = \frac{3.07}{0.02} = 153.5$$

Now,
$$V_{CC} = I_C R_C + V_{CE} + 2.1$$
$$= 3.07 \times 2.7 + 7.3 + 2.1 = 17.7 \text{ V}$$

The voltage across R_B is

$$V_{CC} - (V_{BE} + 2.1) = 17.7 - 2.8 = 14.9 \text{ V}$$

Hence,
$$R_B = \frac{14.9}{0.02} = 745 \text{ k}\Omega.$$

To draw the DC load line, we neglect the base current in R_E. The equation for the DC load line is then

$$V_{CE} = V_{CC} - (R_C + R_E)\, I_C = 17.7 - 3.38\, I_C$$

where V_{CE} is in volt and I_C is in mA.

The intercept of the load line on the V_{CE}-axis is

$$OA = V_{CC} = 17.7 \text{ V},$$

and that on the I_C-axis is

$$OB = \frac{V_{CC}}{R_C + R_E} = \frac{17.7}{3.38} = 5.24 \text{ mA}.$$

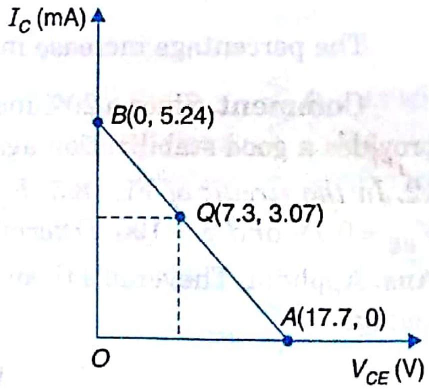

Fig. 8.22H

The DC load line is the straight line *AB* (Fig. 8.22H).

The coordinates of the operating point *Q* on the load line are (7.3 V, 3.07 mA).

14. *In the* CE *amplifier circuit of* Fig. 8.22I, R_1 = 72 kΩ, R_2 = 8 kΩ, R_L = 2kΩ, R_e = 700 Ω, *and* R_C = 2 kΩ, *and* V_{CC} = 15 V, *Assume* β = 120 *and* V_{BE} = 0.7 V. *(i) Draw the dc load line and find the Q-point. (ii) Draw the ac load line. (iii) If the input ac signal* v_i *has the amplitude of* 1 mV, *find the amplitude of the output voltage* v_0. *Take the input resistance of the amplifier,* R_{in} = 1.5 kΩ. *All the capacitors act as ac shorts.*

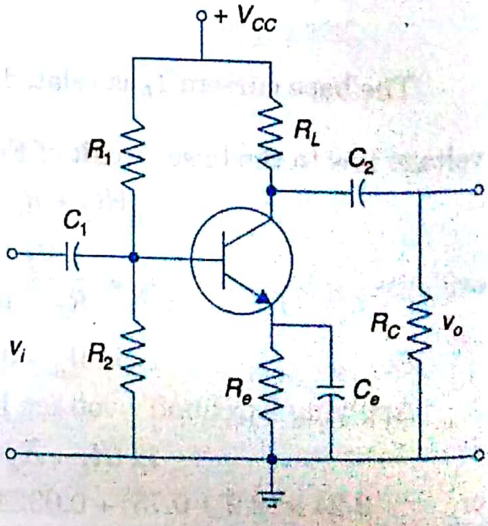

Fig. 8.22I

Ans. Applying Thevenin's theorem to the left of the base and the ground terminals yields for the Thevenin voltage

$$V_T = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{8 \times 15}{72 + 8} = 1.5 \text{ V}$$

and for the Thevenin resistance

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{72 \times 8}{72 + 8} = 7.2 \text{ k}\Omega$$

where V_{EB} is the emitter-base voltage of the *pnp* transistor T, V_Z is the voltage across the Zener diode Z, and V_I is the voltage drop across the resistances R_1 and R_2.

Suppose that there is an increase in the load current I_L due to a change in the load resistance R_L. Since I_L is the collector current of T, an increase of I_L increases the emitter current of T, thereby enhancing the voltage drop V_I. Since V_Z is constant, Eq. (10.49) shows that V_{EB} decreases when V_I enhances. Consequently, the collector current or the load current decreases, and the regulation is achieved.

The resistance R_2 is made variable to fix the output current at a desired level. The circuit then maintains the current at this level as the load resistance R_L changes. The resistance R_3 connected to the base of the transistor gives the current for the Zener diode operation. A small part of the current through R_3 is supplied by the transistor base current, so that a lower current passes through the Zener diode. A sufficient current must be carried by R_3 in order that the Zener diode remains fired as R_L changes. The load current remains fairly constant till the load resistance R_L becomes so large that the voltage drop across it equals the voltage drop across R_3.

Note that while a voltage regulator acts more or less like an ideal voltage source, a current regulator behaves like an ideal current source. The internal impedance of an ideal voltage source is zero but that of an ideal current source is infinite.

10.7 SOLVED PROBLEMS

1. *An amplifier has a voltage gain of* – 100. *The feedback ratio is* – 0.04. *Find (i) the voltage gain with feedback, (ii) the amount of feedback in* dB, *(iii) the output voltage of the feedback amplifier for an input voltage of* 40 mV, *(iv) the feedback factor, and (v) the feedback voltage.*

Ans. (*i*) The voltage gain with feedback is

$$A_f = \frac{A}{1+A\beta} = \frac{-100}{1+(-100)(-0.04)} = -20.$$

(*ii*) The amount of feedback in dB is

$$F = 20 \log_{10}\left|\frac{A_f}{A}\right| = 20 \log_{10}\left(\frac{1}{5}\right) = -13.98 \text{ dB}.$$

(*iii*) The output voltage with feedback is

$$V_0 = A_f V_i = -20 \times 40 \times 10^{-3} = -0.8 \text{ V}.$$

(*iv*) The feedback factor is

$$-A\beta = -(-100 \times -0.04) = -4.$$

(*v*) The feedback voltage is

$$V_f = \beta V_0 = -0.04 \times -0.8 = 32 \text{ mV}.$$

2. *The open-loop gain of an amplifier changes by* 20 *per cent due to changes in the parameters of the active amplifying device. If a change of gain by* 2 *per cent is allowable, what type of feedback has to be applied ? If the amplifier gain with feedback is* 10, *find the minimum value of the feedback ratio and the open-loop gain.*

Ans. Negative feedback has to be applied for gain stability. We have

$$\frac{d A_f}{A_f} = \frac{1}{1+A\beta}\frac{dA}{A}.$$

Here $\dfrac{dA}{A} = 20\%$ and $\dfrac{d A_f}{A_f} = 2\%$. So, $1 + A\beta = \dfrac{dA}{A}\Big/\dfrac{d A_f}{A_f} = \dfrac{20}{2} = 10$ (*i*)

Also, the gain with feedback is

$$A_f = \frac{A}{1+A\beta} \quad \text{or,} \quad 10 = \frac{A}{10} \text{ or } A = 100,$$

which gives the open-loop gain.

We have from (*i*)

$$1 + 100\,\beta = 10 \quad \text{or,} \quad \beta = 0.09.$$

3. *The open-loop gain of an amplifier is* – 80 *and it gives an output distortion voltage of* 0.1 V. *If the tolerable output distortion voltage with negative feedback is* 0.05 V, *find the reverse transmission factor.*

Ans. We have for the output distortion voltage with feedback

$$V_{Df} = \frac{V_D}{1+A\beta} \quad \text{or,} \quad 1 + A\beta = \frac{V_D}{V_{Df}} = \frac{0.1}{0.05} = 2$$

or, $$A\,\beta = 1 \text{ or, } \beta = \frac{1}{A} = \frac{1}{-80} = -0.0125.$$

4. *In the circuit of* Fig. 10.19, T_1 *and* T_2 *are two silicon transistors. Find the following quantities: (i) voltages at A and B, (ii) base current of* T_1 *and emitter current of* T_2, *(iii) the current through the Zener diode, and (iv) power dissipation in* T_1. *Given,* β = 50 *for* T_1. **(cf. C.U. 1998)**

Ans. (*i*) Let V_A and V_B be the voltages of the points *A* and *B*, respectively, with respect to ground. From Fig. 10.19 we obtain

$$\frac{V_B}{10\text{ V}} = \frac{640\ \Omega}{(640+360)\Omega}$$

whence V_B = 6.4 V.

Then the base-emitter voltage drop for T_2 is

$$V_B - 5.6 = 6.4 - 5.6 = 0.8 \text{ V}.$$

We assume the same value of 0.8 V for the base-emitter voltage drop V_{BE} for T_1. Then $V_A + 0.8 = 10$ V, whence $V_A = 9.2$ V.

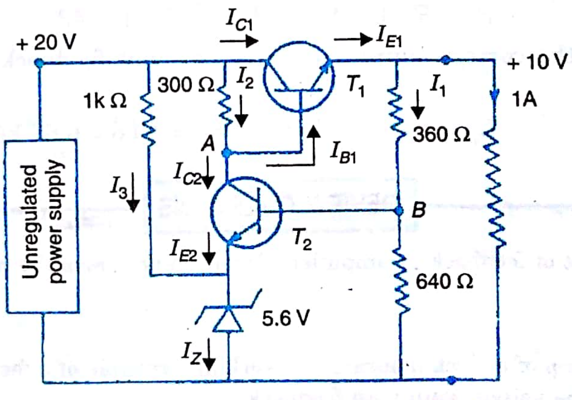

Fig. 10.19 Figure for Problem No. 4.

(*ii*) The current I_1 is

$$I_1 = \frac{10\text{ V}}{(360+640)\Omega} = 0.01 \text{ A}$$

The emitter current of T_1 is $I_{E1} = I_1 + 1 = 1.01$ A.

If I_{C1} and I_{B1} are the collector and the base currents of T_1, respectively, we have $I_{C1} = -I_{B1} + I_{E1}$, or $\beta I_{B1} = -I_{B1} + I_{E1}$, where β (for T_1) is 50 (given).

So, $I_{B1} = I_{E1}/(\beta + 1) = 1.01/51\text{A} = 19.8$ mA.

The current through the 300 Ω resistance is

$$I_2 = \frac{20 - V_A}{300} = \frac{20 - 9.2}{300}\ \text{A} = 36\ \text{mA}.$$

The collector current of T_2 is $I_{C2} = I_2 - I_{B1} = 36 - 19.8 = 16.2$ mA. The emitter current of T_2 is $I_{E2} \approx I_{C2} = 16.2$ mA (assuming that the base current of T_2 is negligibly small).

(*iii*) The current I_3 through the 1 kΩ resistance is

$$I_3 = \frac{(20 - 5.6)\ \text{V}}{1\text{k}\Omega} = 14.4\ \text{mA}.$$

The current through the Zener diode is $I_Z = I_3 + I_{E2} = 14.4 + 16.2 = 30.6$ mA.

(*iv*) The collector-emitter voltage drop for T_1 is $V_{CE} = 20 - 10 = 10\text{V}$. The power dissipation in T_1 is $P_1 = V_{CE} I_{C1} = 10 \times 0.99$, since $I_{C1} = \beta I_{B1} = 50 \times 19.8\ \text{mA} = 0.99$ A.

Therefore, $P_1 = 9.9$ W.

5. *The voltage gain of a transistor amplifier is 50. Its input and output resistances are 1 kΩ and 40 kΩ, respectively. If the amplifier is provided with 10% negative voltage feedback in series with the input, calculate the voltage gain, and the input and the output resistances.*

(K.U. 2004)

Ans. By the problem, the feedback voltage V_f is 10 per cent of the output voltage V_0, i.e., $V_f = 0.1\, V_0$. Hence, the feedback fraction is $\beta = V_f/V_0 = 0.1$. The gain of the feedback amplifier is $A_f = A/(1 + A\beta)$, where A is the voltage gain of the internal amplifier. Since $A = 50$,

$$A_f = \frac{50}{1 + 50 \times 0.1} = \frac{50}{6} = 8.33.$$

The input and the output resistances of the feedback amplifier are respectively given by

$$R_{if} = R_i\,(1 + A\beta) \text{ and } R_{of} = R_o/(1 + A\beta)$$

where R_i and R_o are the corresponding quantities without feedback. Given, $R_i = 1$ kΩ and $R_o = 40$ kΩ. So,

$$R_{if} = 1 \times 6 = 6\ \text{k}\Omega \text{ and } R_{of} = 40/6 = 6.67\ \text{k}\Omega.$$

REVIEW QUESTIONS

1. Explain the concept of feedback in amplifiers. What do you mean by positive and negative feedback? (*cf. C.U. 1985*)
2. Explain with the help of a block diagram the working principle of a feedback amplifier. Find out an expression for the voltage gain with feedback. (*C.U. 1982, 1990, 2003*)
3. Define the following terms: Degenerative feedback, regenerative feedback, feedback ratio, feedback factor, and dB of feedback.
4. What are the different ways of sampling the output signal in a feedback amplifier? Name the four feedback topologies.
5. Draw the circuit diagram of an emitter follower and explain the nature of feedback in this circuit. What is the feedback topology of the emitter follower?