Minority carrier Distributions and terminal currents

- Holes are injected in base at fwd biased emitter, these holes diffuses to collector junc^n. For the analysis first step is to solve for the excess hole distribution in base, second step is to evaluate I_E & I_C from the gradient of hole distribution on each side of base. Then I_B can be calculated from current summation or from a charge control anlaysis of recombination in base.

- Assumptions required for simplifying the calculation.

(i) Holes diffuse from E to C drift is negligible in the base region.

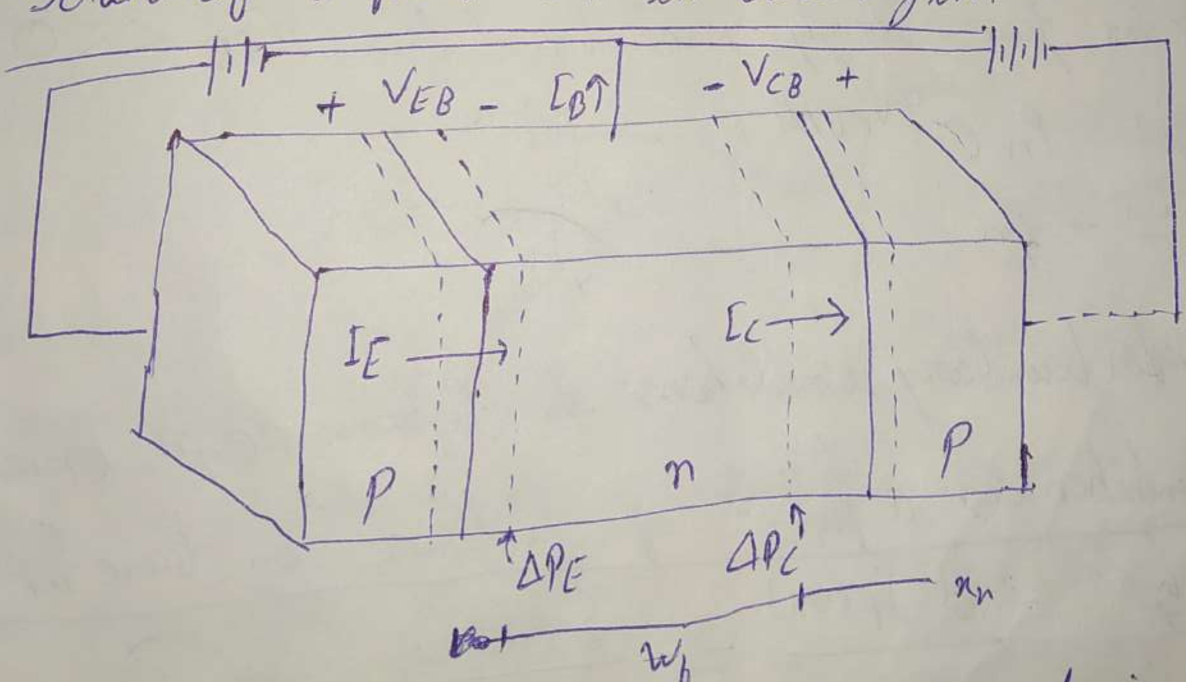
(ii) Emitter current is made up entirely of holes, emitter injection efficiency $\gamma = 1$.

(iii) Collector saturation current is negligible.

(iv) Active part of base and two junc^n are of uniform cross sectional area A, current flow in base is essentially one dimensional from E to C.

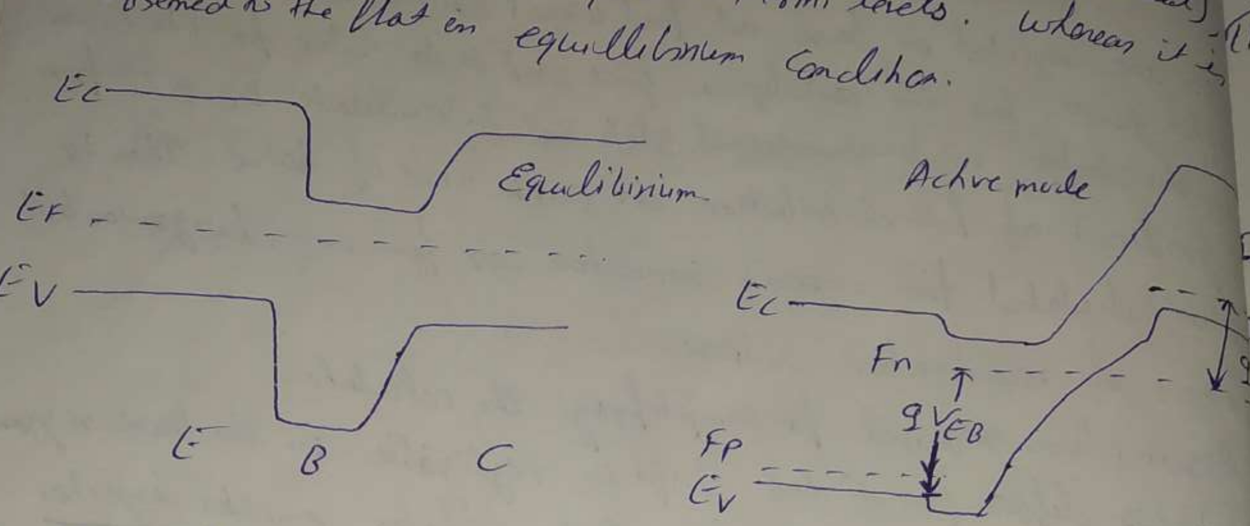
(V) All currents and volt. are steady state.

Solution of Diffusion eq^n in Base region:-



(a) Simplified pnp transistor geometry used in calculations.

- In an active mode (E-B junc^n forward and B-C junc^n reverse biased) fermi level split up into quasi-Fermi levels. whereas it is observed to be flat in equilibrium condition.



- Excess hole concentration at the edge of emitter depletion region ΔP_E & on collector side ΔP_C is given by.

$$\Delta P_E = P_n\left(e^{qV_{EB}/kT} - 1\right) \quad \text{—— (I)}$$

$$\Delta P_C = P_n\left(e^{qV_{CB}/kT} - 1\right) \quad \text{—— (II)}$$

if emitter junc^n is strong forward biased than $V_{EB} >> kT/q$
collector junc^n strongly reverse biased then $V_{CB} << 0$

$$\Delta P_E \simeq P_n e^{qV_{EB}/kT} \quad \text{—— (III)}$$

$$\Delta P_C \simeq -P_n \quad \text{—— (IV)}$$

Using proper boundary condition in diffusion eq^n excess hole concentration as a func^n of distance in base $\delta p(x_n)$ is given by

$$\frac{d^2\delta p(x_n)}{dx_n^2} = \frac{\delta p(x_n)}{L_p^2} \quad \text{—— (V)}$$

The solⁿ of eq (V) is given by

$$\delta p(x_n) = C_1 e^{x_n/L_p} + C_2 e^{-x_n/L_p} \quad \text{— (VI)}$$

$L_p \to$ diffusion length of holes in base region.

For any proper designed transistor $W_b << L_p$.

Approximate boundary conditions are

$$\delta p(x_n = 0) = C_1 + C_2 = \Delta P_E \quad \text{— (VII)}$$

$$\delta p(x_n = W_B) = C_1 e^{W_b/L_p} + C_2 e^{-W_b/L_p} = \Delta P_C \quad \text{— (VIII)}$$

After solving

$$C_1 = \frac{\Delta P_C - \Delta P_E e^{-W_b/L_p}}{e^{W_b/L_p} - e^{-W_b/L_p}} \quad \text{— (IX)}$$

$$C_2 = \frac{\Delta P_E e^{W_b/L_b} - \Delta P_C}{e^{W_b/L_p} - e^{-W_b/L_p}} \quad \text{— (X)}$$

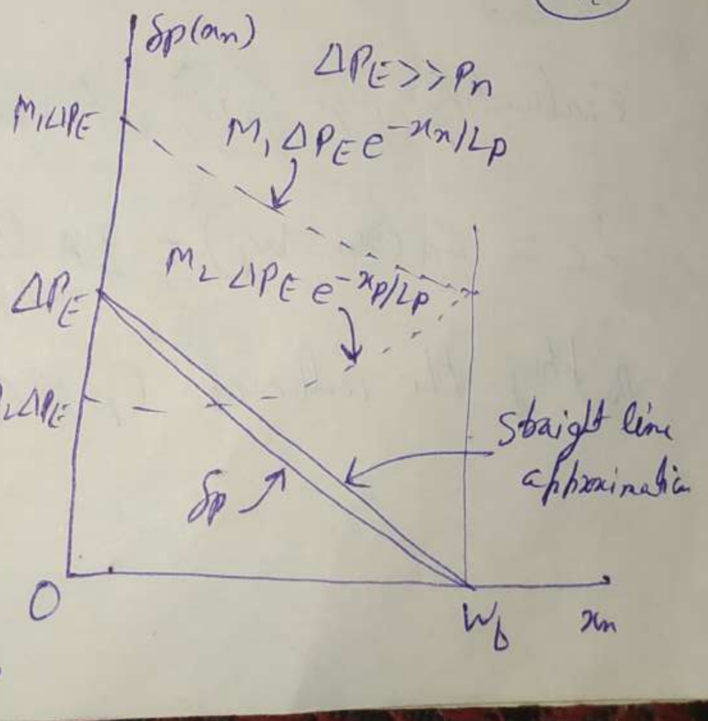
Applying (IX) & (X) in (VI) we have, excess hole distribution simplifies to

$$\delta p(x_n) = \Delta P_E \frac{e^{W_b/L_p} e^{-x_n/L_p} - e^{-W_b/L_p} e^{x_n/L_p}}{e^{W_b/L_p} - e^{-W_b/L_p}} \quad (\text{for } \Delta P_C \simeq 0) \quad \text{— (XI)}$$

All the terms in (XI) can be indicated in fig (2), a slight deviation from linearity is observed due to small value i_B introduce by recombination in base region.

$$M_1 = \frac{e^{W_b/L_p}}{e^{W_b/L_p} - e^{-W_b/L_p}}$$

$$M_2 = \frac{e^{-W_b/L_p}}{e^{W_b/L_p} - e^{-W_b/L_p}}$$



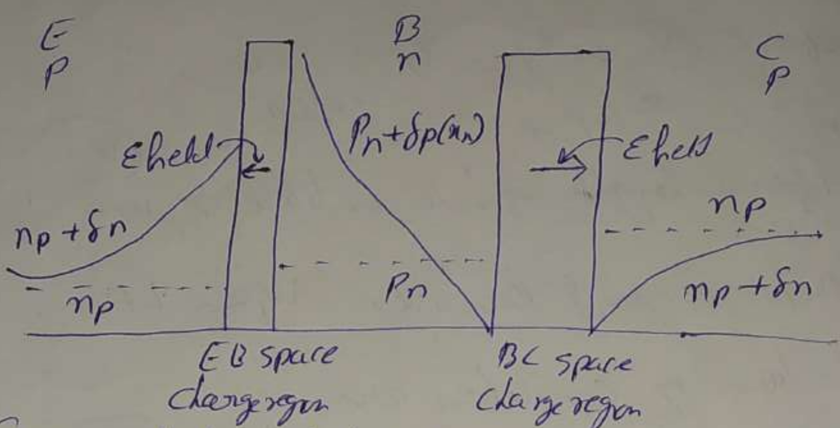


Fig:- Electron distributions in Emitter & collector.

Evaluation of Terminal Currents

Through the relation of hole current & distance we have (diffusion)

$$I_p(x_n) = -qAD_p \frac{d\,\delta p(x_n)}{dx_n} \quad \text{— (XII)}$$

(Diff - eq (VI) by x_n)

At $x_n=0$, gives hole component of emitter current

$$I_{Ep} = I_p(x_n=0) = qAD_p/L_p\,(C_2-C_1) \quad \text{— (XIII)}$$

Now consider I_C to be entirely made up of holes current neglecting e^- crossing from C to B in collector reverse saturation current.

Evaluating eq^n (XII) at $x_n = W_b$

$$I_C = I_p(x_n=W_b) = qA\frac{D_p}{L_p}\left(C_2 e^{-W_b/L_p} - C_1 e^{W_b/L_p}\right) \quad \text{— (XIV)}$$

putting the value of C_1 & C_2 from (IX) & (X) to (XIV) we get

$$I_{EP} = qA \frac{D_P}{L_P}\left[\frac{\Delta P_E(e^{W_b/L_P} + e^{-W_b/L_P}) - 2\Delta P_C}{e^{W_b/L_P} - e^{-W_b/L_P}}\right]$$

$$I_{EP} = qA \frac{D_P}{L_P}\left[\Delta P_E \operatorname{ctnh}\frac{W_b}{L_P} - \Delta P_C \operatorname{csch}\frac{W_b}{L_P}\right] \quad \text{— (XV)}$$

$$I_C = qA \frac{D_P}{L_P}\left[\Delta P_E \operatorname{csch}\frac{W_b}{L_P} - \Delta P_C \operatorname{ctnh}\frac{W_b}{L_P}\right] \quad \text{— (XVI)}$$

Now $I_B = I_E - I_C$

$$= qA \frac{D_P}{L_P}\left[(\Delta P_E + \Delta P_C)\left(\operatorname{ctnh}\frac{W_b}{L_P} - \operatorname{csch}\frac{W_b}{L_P}\right)\right]$$

$$I_B = qA \frac{D_P}{L_P}\left[(\Delta P_E + \Delta P_C)\tanh\frac{W_b}{2L_P}\right] \quad \text{— (XVII)}$$

Applying appropriate approximation in eq (XVII), it can also be written as

$$I_B = \frac{qAW_b\Delta P_E}{2\tau_P} \quad \text{— (XVIII)}$$

Current transfer Ratio :—

- In practicle transistor $\gamma \neq 1$ as some of e^- will diffuse to Emitter for PNP

Hence γ became $\gamma = \left[1 + \frac{L_P^n n_n \mu_n^p}{L_n^p p_p \mu_p^n}\tanh\frac{W_b}{L_P^n}\right]^{-1} \simeq \left[1 + \frac{W_b n_n \mu_n^p}{L_n^p p_p \mu_p^n}\right.$ — (XIX)

$$B = \frac{I_C}{I_{EP}} = \frac{\operatorname{csch} W_b/L_P}{\operatorname{ctnh} W_b/L_P} = \operatorname{sech}\frac{W_b}{L_P} \quad \text{— (XX)}$$