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Gummel-Poon Model

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- Gummel-Poon Model is specially designed for very small BJT considering second-order effects.

It was described by Hermann Gummel and H.C. Poon in Bell Lab in 1970.

This model takes into account effect of low currents and at high level injection.

- This is a charge control model, rectifying drawbacks of Ebers-Moll model.

Considering the minority carrier movement in base for npn.

$$I_{Ep} = qA\mu_p P(x_n)\mathcal{E} - qAD_p \frac{dP(x_n)}{dx_n} \quad \text{—— (I)}$$

Assuming $n(x_n) = N_d(x_n)$

$$I_{Ep} = qA\mu_p P\left(\frac{-kT}{q}\frac{1}{n}\frac{dn}{dx_n}\right) - qAD_p\frac{dP}{dx_n}$$

$$= -\frac{qAD_p}{n}\left(P\frac{dn}{dx_n} + n\frac{dP}{dx_n}\right) \quad \text{—— (II)}$$

$$= \frac{-qAD_p}{n}\frac{d(Pn)}{dx_n} \quad \text{—— (III)}$$

$$\frac{-I_{Ep}\,n}{qAD_p} = \frac{d(Pn)}{dx_n} \quad \text{—— (IV)}$$

Integrating (IV) from $J_E(W_b = 0)$ to $J_C(W_b = W_B)$, considering I_{Ep} flowing from E to C.

$$-I_{Ep}\int_0^{W_b}\frac{n\,dx_n}{qAD_p} = \int_0^{W_b}\frac{d(pn)}{dx_n}\,dx_n$$

$$= p(W_b)\,n(W_b) - p(0)\,n(0) \quad \text{--- (V)}$$

As we know $pn = n_i^2$ — (VI) (for equilibrium)

and for non equilibrium values.

$$pn = n_i^2\, e^{\frac{F_n - F_p}{kT}} = n_i^2\, e^{qV/kT} \quad \text{--- (VII)}$$

$$\therefore \left.\begin{aligned} p(W_b)\,n(W_b) &= n_i^2\, e^{qV_{CB}/kT} \\ p(0)\,n(0) &= n_i^2\, e^{qV_{EB}/kT} \end{aligned}\right\} \quad \text{--- (VIII)}$$

$$I_{Ep} = \frac{-qAD_p n_i^2\left(e^{\frac{qV_{CB}}{kT}} - e^{qV_{EB}/kT}\right)}{\int_0^{W_b} n\,dx_n} \quad \text{--- (IX)}$$

- The integral in denominator corresponds to the integrated majority carrier charge in the base and known as base Gummel number Q_B

Now $$I_{Ep} = \frac{qAD_p n_i^2\, e^{\frac{qV_{EB}}{kT}}}{Q_B}$$ (-ve sign due to reverse bias) — (X)

Similarly $$I_{En} = \frac{qAD_p n_i^2\, e^{\frac{qV_{EB}}{kT}}}{Q_E}$$ — (XI) (Base e^- current flowing back into emitter)

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Q_E — Integrated majority carrier charge in emitter known as emitter Gummel number. — (V)

ns for analysing secondary effect like early effect or high injection effect

$$Q_B = \int_{0\,(V_{EB})}^{W_b\,(V_{CB})} n(x_n)\,dx_n \quad \text{— (XII)}$$

As eq (XII) is a biased dependent, so it justifying early effect.

Under high level injection the integrated majority carrier charge becomes greater than the integrated base dopant charge

$$\int_0^{W_b} n(x_n)\,dx_n > \int_0^{W_b} N_D(x_n)\,dx_n \quad \text{— (XIII)}$$

— I_{Ep} will increase less rapidly with emitter base volt. at high biases.

— As we know for the high level injection

$$\left.\begin{array}{l} I_C \propto I_{Ep} \propto e^{qV_{EB}/2KT} \\ \text{and } I_B \propto I_{En} \propto e^{qV_{EB}/KT} \end{array}\right\} \text{— (XIV)}$$

Hence for high V_{EB}

$$\beta = \frac{I_C}{I_B} \propto \frac{e^{qV_{EB}/2KT}}{e^{qV_{EB}/KT}} \propto e^{-qV_{EB}/2KT} \propto I_C^{-1}$$

Hence common emitter gain decreases at high injection le to excess majority carrier in base.

Base current injected in emitter can be given by

$$I_B \propto I_{En} \propto e^{qV_{EB}/nkT} \quad \text{——} \quad (XV)$$

— Large emitter current injected into the base is not li to be affected by the generation - recombination effects.

$$I_{Ep} \propto e^{qV_{EB}/kT} \quad \text{——} \quad (XVI)$$

— Hence for low V_{EB} ~~&~~ or low I_C current gain is given

$$\beta = \frac{I_C}{I_B} \propto \frac{e^{qV_{EB}/kT}}{e^{qV_{EB}/nkT}} \propto e^{qV_{EB}/kT\,(1-\frac{1}{n})}$$

$$\propto I_C^{[1-1/n]} \quad \text{——} \quad (XVII)$$

— From the graph it can be concluded that at low injection levels β is degraded by poor emitter injection efficiency and high current β decreases due to excess majority charge in base which degrades γ.

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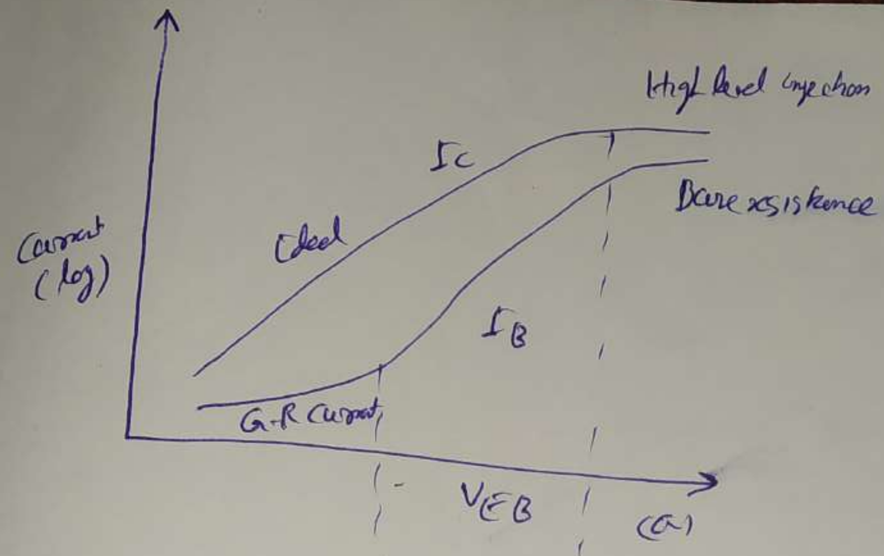

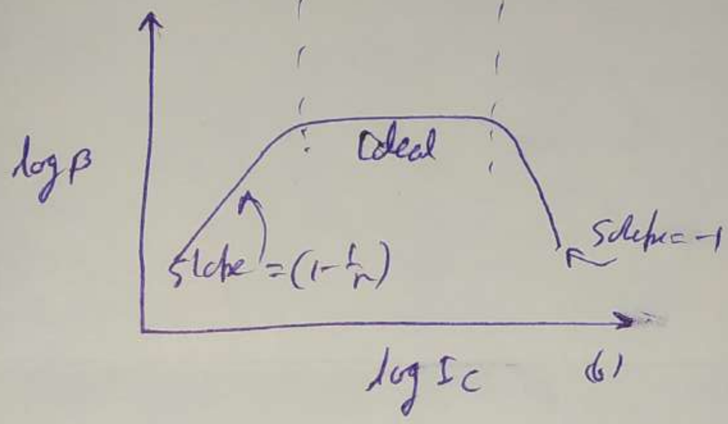

(a) → Gummel plot of log of collector and base currents as a func^n of emitter – base forward bias.

(b) → DC current gain I_C/I_B.