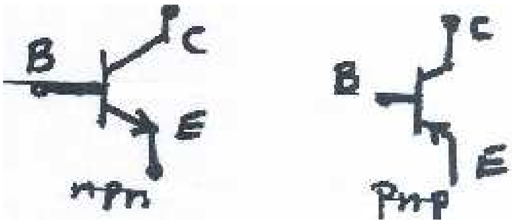
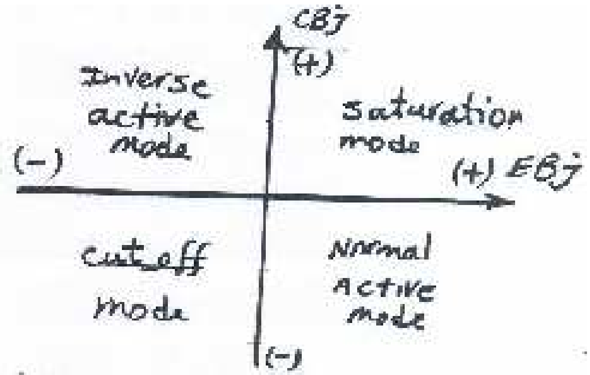
CH.4 : BIPOLAR Junction Transistors (BJTS)

Definition : (Tran (Sear) + (Re) sistor: it transfers α current across α resistor) – An active S/C device (made of Si, Ge, Ga As, etc) having 3 electrode. Conduction is by means of ē s (α n elementary particle with smallest mg. Charge and H+S (mobile ē vacancies equivalent to a positive charge)



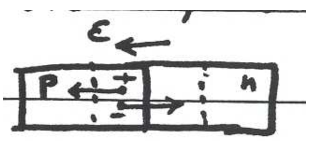
Important Feature: Current there 2 terminals can be controlled by small changes in current (or voltage) at the 3rd terminal. This control feature allows us to amplify small Ac signals or to switch the device from on state to OFF.

There are 4 possible modes of operation determined by the terminal voltage polarities:



4.1) principles of operation:

Consider α Pn junction reverse biased fazing α reverse saturation which is caused by EGp creation within α diffusion length of the junction, swept by the ε field at the junction. This current does not depend on how fast these EGPS are swept but how often they are generated*!*

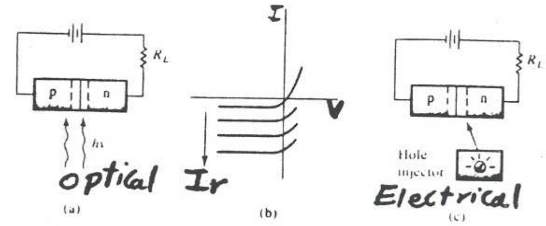


Observation: This reverse saturation can be increased therefore by increasing the rate of EHP generation possible method are:

1. **optical excitation of EHPs with light (Hf>Eg).**

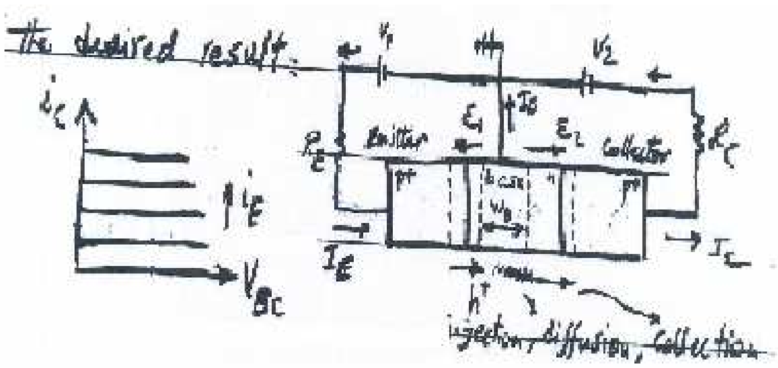
2. **thermal excitation of EHPS by raising temp (T.300k).**
3. **electrical injection of minority carriers around the junction.**

The result is α controllable reverse current (independent of bias voltage) which is practically proportional to the rate of EHP generation of minority carrier injection rate.



The third method 9which is injection of minority carriers) is realizable by the use of a forward bias Pn junction.

For example, if the minority carriers are H+ s then α forward biased P+n junction will inject H+s into the n-region of a reverse biased np+ junction woll create the desired result.



I_E flows in and I_c flows out

Requirements to have α good transistor (x tor) PnP:

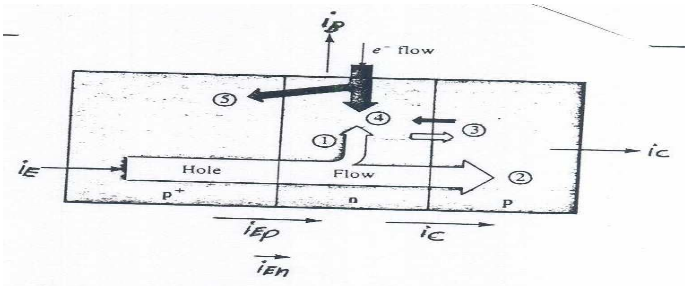
1. Small n-region — $W_b << L_p$, W_b = width of neutral region
2. T_p should be long. ⟹ $L_p = \sqrt{D_p T_p}$
3. current I_E should be composed entirely of H+ s ⟹ dope base lighter than Emitter.

Base current I_B ideally should be zero but in practice is non zero and is caused by:

a)$^{h+}$ recombination in the base.
b) e^- injection into the emitter region

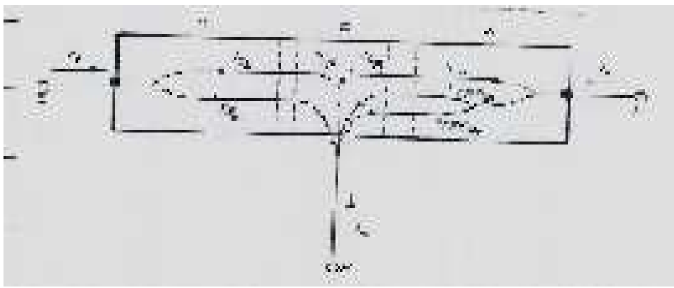
<u>In Summary</u> :

P^+np Xtor →



Summary of hole and electron flow in a p-n-p transistor with proper biasing: (1) injected holes lost to recombination in the base; (2) holes reaching the reverse-biased collector junction; (3) thermally generated electrons and holes making up the reverse saturation current of the collector junction; (4) electrons supplied by the base contact for recombination with holes; (5) electrons injected across the forward-biased emitter junction.

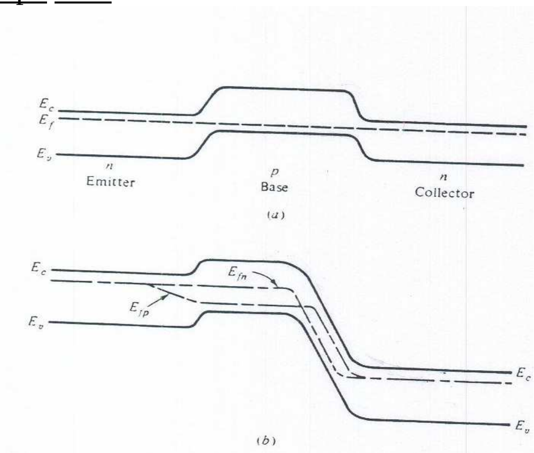
Npn Xtor →



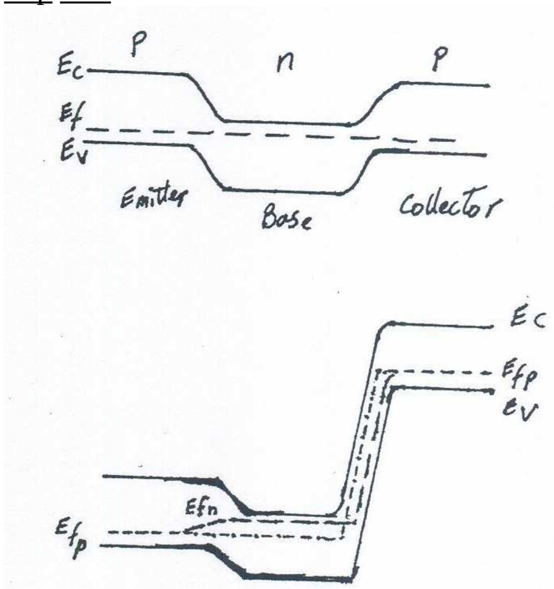
Schematic diagram identifying the various components of the base current of an n^--p-n transistor, biased in the active region, as well as the emitter and collector currents; $l_{\varepsilon p}$ represents the emitter hole detect current, $l_{\varepsilon p}$ - l_{on} represents the base electron recombination current and l_{ceo} represents the collector leakage current, which includes both the diffusion component as well as the space-charge-generated current.

- Band diagrams

<u>npn</u> <u>Xtor</u>



<u>Pnp</u> <u>xtor</u>

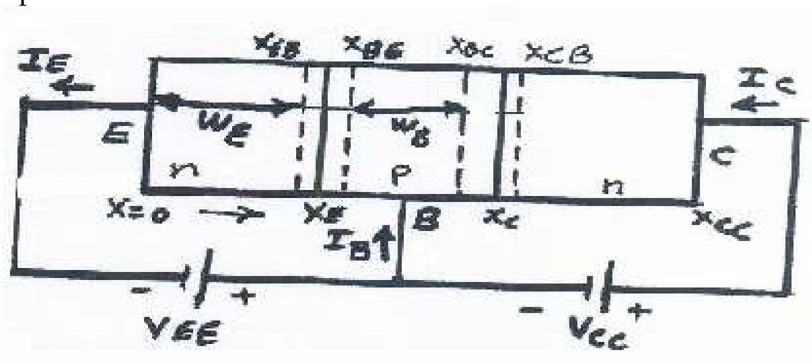


Note: Wherever E_{fn} or E_{fp} has a non zero slope, there is $^{\alpha}$ current flow

$$\left(j_n \,\alpha\, \frac{dE_{fn}}{dx} \;,\; j_p \,\alpha\, \frac{dE_{fp}}{dx} \right)$$ Due to minority carriers

4.2) <u>Device Analysis</u>

Consider an npn Xtor as shown:



Assume abrupt junctions at $x_{E1}xc$:

$o < x < x_E$	$(N_d)_E$	(4.37)
$x_E < x < x_c$	$(N_\alpha)_B$	(4.38)
x_c N $x < x_{Cc}$	$(N_d)_c$	(4.39)

- 2 Transition regions : 1) x_{BE} - x_{EB} 2) x_{CB} - x_{BC} (4.40)

- Active width of the base is: $W_B = x_{BC} - x_{BE}$ (4.41)

Also define: $W_E = X_{EB}$ (see above) (4.42)

$$\alpha_{DC} = \frac{IC}{IE} = \text{DC current transfer ration} \leq 1 \quad (4.43)$$

$$\alpha_o = \frac{\partial IC}{\partial IE} = \text{Small-signal low freq. } \alpha \leq 1 \quad (4.44)$$

In practice $\alpha_{DC} \simeq$ o<o (4.45)

Note: α is also called the common-base current gain

$B_{DC} = \frac{I_C}{I_B} =$ Base to collector current amplification factor (also called common-emitter current gain)

$$I_E = I_C + I_B \Longrightarrow B_{DC} = \frac{\alpha_{DC}}{1 - \alpha_{DC}} \quad (4.46)$$

Note: as $\alpha_{DC} \longrightarrow 1$ $B_{DC} \longrightarrow \infty$

$$\alpha_{DC} = \frac{I_C}{I_E} = \frac{I_C}{I_{nc}} \times \frac{I_{nc}}{I_{nE}} \times \frac{I_{nE}}{I_E} = M \times \alpha_T \times \gamma \quad (4.47)$$

where

$I_E = I_hE + I_{PE}$ h $I_C = I_{nc} + I_{pc}$

$\gamma \equiv \frac{I_{nE}}{I_E}$ = Emitter Efficiency

$\alpha_T \equiv \frac{I_{nc}}{I_{nE}}$ = Base Transport factor

$M \equiv \frac{I_C}{I_{nC}}$ = Collector Multiplication factor

(1) find γ:

$$\gamma = \frac{I_{nc}}{I_{nE}} = \frac{l_{nE}}{l + l_{pE}} = \frac{1}{1 + \frac{l_{pE}}{l_{nE}}} \quad (4.48)$$

$\therefore 0 \leq \gamma \leq 1$

$$\left[\quad \left(\frac{qV_{BE}}{\quad} \right) \quad \right]$$

$l_E = l_E$ exp kT - 1

using Eq. 3.29 gives :

(4.49)

$$I_E = q n_i^2 A \left[\underbrace{\frac{D_{nB}}{N_{aB} L_{nB} \tanh (W_B/L_{nB})}}_{I_{nEs}} + \underbrace{\frac{D_{pE}}{N_{dE} L_{pE} \tanh (W_E/L_{pE})}}_{I_{pEs}} \right] -$$

$I_{nE} = I_{nEs} (e^{qVBE/KT} -1)$ (4.50 a)

$I_{pE} = I_{pEs} (e^{qVBE/KT} -1)$ $\Longrightarrow$

$$\gamma = \left[1 + \frac{D_{pE} L_{nB} N_{aB} \tanh (W_B/L_{nB})}{D_{nB} L_{pE} N_{dE} \tanh (W_E/L_{pE})} \right]^{-1}$$

Eq. (3.50) indicates that the most important factor in controlling "γ" is the ration of

$\frac{N_{aB}}{N_{dE}} = \frac{\text{Base doping density}}{\text{emitter doping density}}$

This ratio can be made as small as possible in theory only, But in practice doping the emitter too high makes it degenerate and emitter acts very much like α metal, Eg. ↓ and $(ni)_{equi}$ ↑ $\Longrightarrow$ $\gamma_{practical} < \gamma_{theoretical}$

Note: $\gamma \simeq (1 + D_p N_{aB} W_B / D_n N_{dE} W)^{-1} = (1 + \sigma p W_B / \sigma_n W_E)^{-1}$

$\gamma \simeq 1 - \sigma p\, W_B / \sigma_n W_E$ for $\sigma p/\sigma n << 1$ (4.50c)

proof of eqs. (4.50b) & (4.50c)

1) $\sigma p = q\, p_o\, \mu p \simeq q\, N_{aB}\, \mu p$ (base conductivity)

$\sigma n = q\, n_o\, \mu n \simeq q\, N_{dE}\, \mu n$ (Emitter conductivity)

$\sigma p/\sigma n = \frac{N_{aB}}{N_{dE}} \frac{\mu p}{\mu n} = \frac{N_{aB}}{N_{dE}} \frac{D_p}{D_n}$

(since $\frac{Dp}{\mu p} = \frac{Dn}{\mu n} = \frac{KT}{q}$; einstein's relation)

2) $\tanh \frac{W_B}{Ln} \sim \frac{W_B}{Ln}$ (narrow base)

$\tanh \frac{W_E}{Lp} \sim \frac{W_E}{Lp}$ (small emitter)

3) $\frac{1}{1+\alpha} \simeq 1 - \alpha$ for $\alpha << 1$

combining (1), (2) & (3) with eq. (4.50 a) gives eq. (4.50b) & (4.50 c)

(2) finding α_T :

$$\alpha_T = \frac{I_{nC}}{I_{nE}}$$

In the base regions ignoring drift current:

$$I_n(x) = qAD_{nB} \frac{dn}{dx} \qquad (4.51)$$

need to find n'(x) subject to:

B.C: at X_{BE} ⟹

$$n'(x_{BE}) = n_{0B}\left[\exp\left(\frac{qV_{BE}}{kT}\right) - 1\right] \qquad (4.52)$$

and at x_{BC} ⟹

$$n'(x_{BC}) = n_{0B}\left[\exp\left(\frac{qV_{BC}}{kT}\right) - 1\right] \simeq -n_{oB} \simeq 0 \text{ for } V_{BC} >> V_T \qquad (4.53)$$

Reverse biased

Using B.C. given above & combined with appropriate subscript changes in eq. (3.26) ⟹

$$N'(x) = \frac{n_{oB} \sinh[(x_{BC} - x) / L_{nB}]}{\sinh(W_B/L_{nB})}\left[\exp\left(\frac{qV_{BE}}{kT}\right) - 1\right] \qquad (4.54)$$

$$\therefore \quad \frac{dn'}{} = - \frac{n_{oB} \cosh[(x_{BC} - x)/L_{nB}}{\sinh(W_B/L_{nB})}\left[\exp\left(\frac{qV_{BE}}{kT}\right) - 1\right] \qquad (4.55)$$

substituting in Eq. (4.51), gives:

$$\alpha_T = \frac{I_{nC}}{I_{nE}} = \frac{qD_{nB}\, dn'/dx|x_{BC}}{qD_{nB}\, dn'/dx|x_{BE}} \qquad (4.56a)$$

$$\alpha_T = \frac{\cosh 0}{\cosh (W_B/L_{nB}} = \text{sech}\, \frac{W_B}{L_{nB}} \qquad (4.56b)$$

$\operatorname{sech} y \simeq 1 - y^2/2 \qquad y \ll 1$

when $W_B \ll L_{nB} \Longrightarrow$

$$\alpha_T \approx \frac{1}{1 + W_B^2 / 2L_{nB}^2} \approx 1 - \frac{W_B^2}{2L_{nB}^2} \qquad (4.57)$$

Note: $W_B \downarrow \Longrightarrow \alpha_T \uparrow$

And $W_B = f(V_{BE}, V_{BC})$ $\therefore$ α_T is bias dependent.

(3) finding M

from eq. (3.35) $\Longrightarrow$

$$M = \left[1 - \left(\frac{-V_{BC}}{(V_{B\gamma})_{BC}}\right)^m\right]^{-1} \qquad (4.58)$$

where m = 3 for sin & $(V_{B\gamma})_{BC}$ = BKdn volt. At BCj.

$\therefore$ eq. 4.47 $\Longrightarrow$ $\alpha_{dc} = \gamma\, \alpha_T M$

$$= \left[1 + \frac{D_{pE} L_{nB} N \alpha_B \tanh \frac{W_B}{L_{nB}}}{D_{nB} L_{pE} NdE \tanh \frac{W_B}{L_{pB}}}\right]^{-1} \operatorname{sech} \frac{W_B}{} \left\{1 - \left[-\frac{V_{BC}}{}\right]^m\right\}^{-1} \qquad (4.59)$$

Then eq. 4.46 $\Longrightarrow$

$$\beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}} = \frac{1}{1/\alpha_{dc} - 1}. \qquad (4.60)$$

$$\beta_{dc} \approx \left[\left(1 + \frac{D_{pE} L_{nB} N_{aB} \tanh \frac{W_B}{L_{nB}}}{D_{nB} L_{pE} N_{dE} \tanh \frac{W_E}{L_{pE}}}\right)\left(1 + \frac{W_B^2}{2L_{nB}^2}\right)\left\{1 - \left[-\frac{V_{BC}}{V_B(BC)}\right]^m\right\} - 1\right]^{-1}$$

Ignoring small terms.

$$\beta_{dc} \approx \left\{\frac{D_{pE} L_{nB} N_{aB} \tanh \frac{W_B}{L_{nB}}}{D_{nB} L_{pE} N_{dE} \tanh \frac{W_E}{L_{pE}}} + \frac{W_B^2}{2L_{nB}^2} - \left[-\frac{V_{BC}}{V_B(BC)}\right]^m\right\}^{-1} \qquad (4.61)$$

In eq. (4.61) for β_{DC}, the first terms (which is related to γ) is the dominant term for modern BjTs and therefore:

(4.62)

$$\beta_{dc} = \frac{D_{nB} L_{pE} N_{dE} \tanh \frac{W_E}{L_{pE}}}{D_{pE} L_{nB} N_{aB} \tanh \frac{W_B}{L_{nB}}}$$

Note 1: The factor with the most impact on β_{DC} is N_{dE} / N_{aB} Ratio assuming a constant doping.

For non const. doping and small region widths compared with Ln (or Lp) we need to use:

$$\tanh \frac{W_B}{L_{nB}} \simeq \frac{W_B}{L_{nB}} \quad , \qquad \tanh \frac{W_E}{L_{pE}} \simeq 1 \qquad \left(\frac{W_E}{L_{pE}} >> 1\right) \tag{4.63a}$$

Substitute in eq. (4.62)

$$\therefore \beta_{DC} \simeq \frac{D_{nB} N_{dE} L_{pE}}{D_{pE} N_{aB} W_B} = \frac{\mu n \; N_{dE} L_{pE}}{\mu p \; N_{aB} W_B} \qquad \text{const. doping}$$

Note: $\frac{D_{nB}}{\mu n} = \frac{D_{pE}}{\mu p}$

(4.63b)

$$\Longrightarrow \quad \Rightarrow \beta_{DC} = \frac{G_E}{G_B} \quad \text{where} \quad G_B = \int_{x_{nE}}^{x_{nC}} \frac{N_{aB}}{D_{nB}} dx \qquad G_E = \int_0^{x_{nE}} \frac{N_{dE}}{D_{pE}} dx$$

G_B = Gummel Number determines β_{DC} and thus the doping profile or grading of the "base" is very importantin Xtor Design.

Note 2: as $N_{aB} \downarrow \Longrightarrow G_B \downarrow \Longrightarrow \beta_{DC} \uparrow$ & $W_B \downarrow$

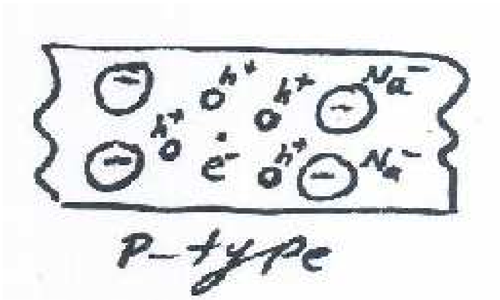
$\therefore$ as $|V_{BC}| \uparrow \rightarrow W_B \downarrow$ (more) $\Longrightarrow$ punch thru Bkdn for low V_{BC}

4) **<u>Emitter Heavy Doping effects and Band gap narrowing</u>**

<u>Observation</u> :

- Experimental results on BjT have indicated that the injection efficiency ® of eq.(4.50 b) gives an <u>optimistic</u> prediction. This is attributed to a heavy doping effect in the emitter region called "band gap narrowing"

- According to this mode, the activation energy necessary to peporate or free an ē is reduced due to an existence of a dense cloud of holes (from the impurities)



- This in effect reduces the energy gap (Eg).

e.g. N-type si :

$N_d = 5 \text{ X } 10^{17} / cm^3 \Longrightarrow \Delta Eg = 15.9$ mev

$N_d = 5 \text{ X } 10^{19} / cm^3 \Longrightarrow \Delta Eg = 159$ mev

- Empirically ΔEg is found to be :

$\Delta Eg = 22.5 \, (n/10^{18})^{½}$ (mev)   (N-type s/c)   (4.63 c)

Where n = density of <u>majority</u> carriers.

- Therefore the new effective intrinsic carrier density due to the reduced band gap now becomes:

$(ni)_{eff} = N_C \, N_V \; e^{-(Eg-\Delta Eg)/KT} = ni^2.e^{\Delta Eg/KT}$ (4.63d)

- the "electron-hole density product" in the "E" under equil. Conditions then becomes:

$n_o p_o = (ni)^2_{eff} \, ni^2. \, e^{\Delta Eg/KT}$

or

$p_o = ni^2. \, e^{\Delta Eg/KT} \Longrightarrow (p_o)_{new} = (p_o)_{old} \, e^{\Delta Eg/KT}$ (4.63e)

- Heavy "E" doping reduces Eg bY ΔEg $\Longrightarrow (p_o)_{new} \uparrow \Longrightarrow \gamma\downarrow$

γ↓ since the effect of EG ↓ was not previous included in Eq. (4.50 b)

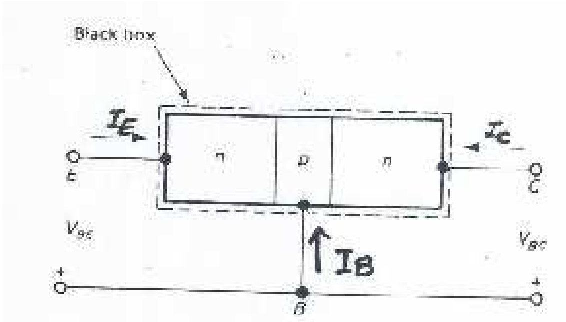
- Eq. (4.50 b) may be now corrected to account for ΔEg by introducing

$$(N_{dE})_{eff} = N_{dE} \left[ni^2 / (ni)^2_{eff} \right] = N_{dE}\, e^{-\Delta Eg/KT} \qquad (4.64)$$

a) I_B, I_C, I_E: Calculations (EBers – moll eqs.)

- In order to analyze BjTs, It is convenient to model it as a two-port circuit element. We use a common-Base config. With an npn Xtor (shown below) as a black box:

The common-Base transistor circuit connection for an n-p-n transistor represented as a "black box," with two input ports and two output ports. Note that V_{BC} is positive when the base potential is positive relative to the collector. In addition, $V_{CB} = -V_{BC}$



- By analogy with the junction diode I-V equations, we expect similar types of I-V relationship for a BjT, which consist basically of two coupled diodes:

$$I_E = A_{11}(e^{qV_{BE}/kT} - 1) + A_{12}(e^{qV_{BC}/kT} - 1)$$

and

$$I_C = A_{21}(e^{qV_{BE}/kT} - 1) + A_{22}(e^{qV_{BC}/kT} - 1), \qquad (4.64\ a)$$

where A_{12} & A_{21} are coupling coeffs.

Eqs. (4.64 a) referred to as the Ebers-moll eqs., are in a form which is very useful for Xtor modeling particularly in computer-aided ckt analysis, and are not restricted to low level injections or any specific mode.

From eqs. (4.52) & (4.53):

$$n'(x_{BE}) = \Delta n_E(0) = n_{oB}\left[e^{qV_{BE}/kT} - 1\right] \qquad (4.64b)$$

$$n'(x_{BC}) = \Delta n_C(W_B) = n_{oB}\left[e^{qV_{BC}/kT} - 1\right]$$

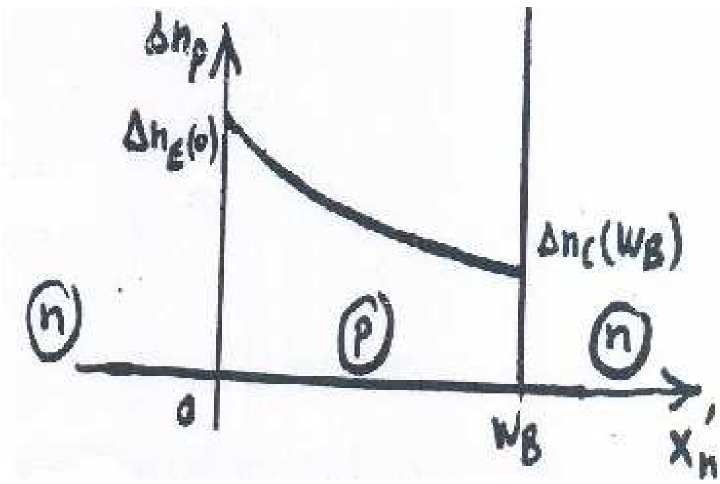
$$\therefore \ eq\,(4.64a) \Rightarrow \begin{cases} I_E = a_{11}\,\Delta n_E(0) + a_{12}\,\Delta n_C(W_B) \\ I_C = a_{21}\,\Delta n_E(0) + a_{22}\,\Delta n_C(W_B) \end{cases}$$

(4.64 c)

Note: In this form of Eqs. (4.64 C), BjT currents are seen to be <u>linearly</u> dependent on the excess minority carrier concentrations at the <u>emitter</u> and <u>collector</u> edges of the base region, therefore superposition can be used in this case.

- This is in contrast with the <u>nonlinear</u> relations in terms of V_{BE} & V_{BC} of eq. (4.64a)

Excess minority carrier distribution in the base →



b) <u>Elbers – Moll parameters in terms of physical device parameters</u>

- BjT's I_E & I_C can be derived by considering the <u>excess</u> minority carrier flow similar to pn junction diodes.

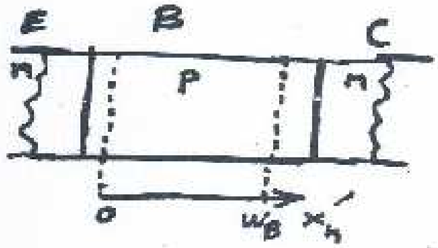
From the continuity eqn & eq. 2.12: (4.64 d)

$$D_n \frac{d^2 n'(x)}{dx^2} = \frac{n'(x)}{\tau_n}$$

Solution is:

$$n'(x) = B e^{-x_n/L_n} + C e^{x_n/L_n}$$

B.C. $\begin{cases} (1)\ \Delta n_E(0) = n_{0B}\left[e^{qV_{BE}/kT} - 1\right] = n'(0) \\ (2)\ \Delta n_C(W_B) = n_{0B}\left[e^{qV_{BC}/kT} - 1\right] = n'(W_B) \end{cases}$



$0 \leq x'_n \leq W_B$ (4.64f)

Use B.C. & eq. (4.64e) $\Rightarrow \begin{cases} B = \dfrac{\Delta n_E(0) e^{W_B/L_n} - \Delta n_C(W_B)}{e^{W_B/L_n} - e^{-W_B/L_n}} \\ C = \dfrac{\Delta n_C(w) - \Delta n_E(0) e^{-W_B/L_n}}{e^{W_B/L_n} - e^{-W_B/L_n}} \end{cases}$ (4.64 g)

To get good current gain, in practice $W_B/L_n << 1$ (4.64 h)

$\therefore e^{\pm X'_n} \simeq 1 \pm X'_n$, $x << 1$ (4.64i)

Thin Base Analysis

Using B.C & Assumption of $W_B/L_n << 1$ yeilds

$n'(X'_n) \simeq \frac{C - B}{Ln} X'_n + (B + C)$ $o \leq X'_n \geq W_B$ (4.64j)

This is an approximate Linear distribution for $n'(x)$ in the thing base ($/L_n << 1$) for all values V_{BE} & V_{BC}, (i.e. all 4 possible models)

Assuming $\gamma = 1$, I_E is exclusively minority ē diffusion current flow in the base:

$$I_E = qAD_n \frac{\partial n'(x_n')}{\partial x_n'}\Big|_{x_n'=0} \Rightarrow I_E = qAD_n (C-B)/L_n$$

$$I_C = -qAD_n \frac{\partial n'(x_n')}{\partial x_n'}\Big|_{x_n'=W_B} \Rightarrow I_C = \frac{qAD_n}{L_n}\left(Be^{W_B/L_n} - Ce^{-W_B/L_n}\right)$$

(4.64 K)

using derived values of B & C as given by eqs. (4.64f), we may write eqs (4.64K) & (4.64 l) in the standard Ebers-Moll format as follows:

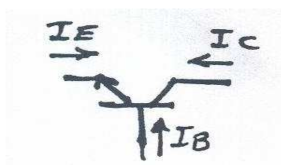
$$\begin{cases} IE = a_{11}\ \Delta n_E(o) + a_{12}\ \Delta n_c\ (W_B) \\ I_C = a_{21}\ \Delta n_E(o) + a_{22}\ \Delta n_C\ (W_B) \end{cases} \qquad (4.64\ m)$$

Where : $a11 = a22 = \frac{-q\ A_{Dn}}{L_n}\ ct_n h\left(\frac{W_B}{L_n}\right)$

Assuming $W_B/L_n << 1 \Longrightarrow$ $\begin{cases} a_{11} = a_{22} = \frac{-q\ A_{Dn}}{W_B} - \frac{qAW_B}{3T_n} \\ a_{12} = a_{21} = \frac{-q\ A_{Dn}}{W_B} - \frac{qAW_B}{6T_n} \end{cases}$

(4.64 p)

since	$\csc h\ (y) \simeq \frac{1}{y} + \frac{y}{3}$	$y<<1$
	$\sec h\ (y) \simeq 1 + \frac{y^2}{2}$	$y<<1$
	$\text{ctn}\ h\ (y) \simeq \frac{1}{y} + \frac{y}{6}$	$y<<1$
	$\tan h\ (y) \simeq 1 + \frac{y^3}{3}$	$y<<1$



Base current is given by : $I_B = - I_E - I_C$

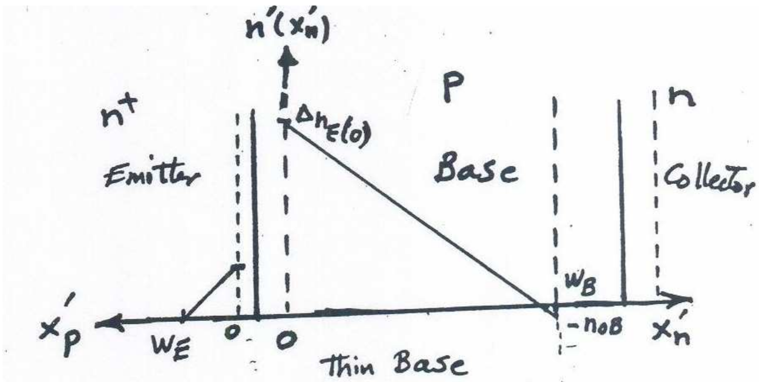
$$I_B = - [(a_{11} + a_{21})\, \Delta n_E(o) + (a_{12} + a_{22}\_\ \Delta n_C(W_B)] \qquad (4.64\ q)$$

EXAMPLE : Active Mode:

B_E junction : FWD bias
B_C junction : Rev. bias

$\therefore\ \Delta n_E(o) \neq o$ (minority carrier injection)

$\Delta n_C\,(W_B) = -n_{oB} \simeq o$ (minority carrier extraction)



$(W_B/L_n<<1)$

$$I_E = \frac{-\,q\,A_{Dn}}{W_B}\ \text{ctnh}\ \frac{W_B}{L_n}\ \Delta n_E(o) \qquad (4.64\ r)$$

$$I_C = \frac{-\,q\,A_{Dn}}{L_n}\ \text{csch}\left(\frac{W_B}{L_n}\right) \Delta n_E(o) \qquad (4.64\ s)$$

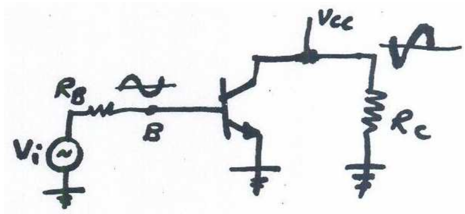
$$I_B = \frac{-\,q\,A_{Dn}}{L_n}\ \tanh\left(\frac{W_B}{2L_n}\right) \Delta n_E(o) \qquad (4.64\ t)$$

When $W_B/L_n << 1$, eq. (4.64t) for I_B gives :

$$\boxed{I_B \simeq q\, AW_B\, \Delta n_E(o)/2Tn} \quad , W_B/L_n << 1 \qquad (4.64u)$$

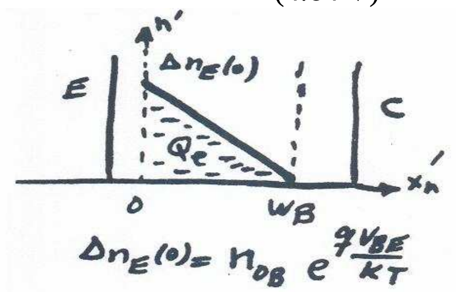
c) <u>Base Recombination current</u>

- Although I_B normally is small, it nevertheless plays an essential role in BjT operation; for example in CE config. an i/p current supplied to the Base lead is amplified and appears at the o/p (collector)



- One function of the base current is to supply a majority hole for each minority ē lost by recombination in transit from "E" to "c".

- In steady state, I_B represents the h^+ flow that must be supplied in order to maintain the almost <u>linear</u> excess minority carriers distribution in base which must be replenished every T_n secs. $\therefore I_B = \frac{Q_e}{T_n}$ (4.64 V)



Q_e = steady state total charge of excess ē in base

$Q_e = -(\frac{1}{2}\,\Delta n_E(o)\,W_B).\,(q\,A)$

$\therefore\; I_B = q\,AW_B\,\Delta n_E(o) / 2T_n$ (4.64 W)

eq. (4.64w) for I_B was derived earlier for a thing base and is the same a5 eq. (4.64u).

from eq. (3.64K) $\Longrightarrow I_E \simeq - I_C = qAD_n \overbrace{\frac{\partial n'(x'n)}{\partial x'n}}^{\text{slope}}\Bigg|_{x'n = 0}$

$I_C \simeq + q\,A\,D_n\,\frac{\Delta n_E\,(o)}{W_B}$ (4.64x)

For a thin base, we require good current gain ($\beta >> 1$):

$$\beta = \left| \frac{I_C}{I_B} \right| = \frac{q A D_n \, \Delta n_E(0)/W_B}{q A W_B \, \Delta n_E(0)/2\tau_n}$$

$$\beta = \frac{2 D_n \tau_n}{W_B^2} >> 1 \longrightarrow \boxed{\frac{W_B^2}{2 L_n^2} << 1} \quad \text{(study)}$$

$\therefore$ good current gain and a Linear minority ē distribution in the base region require a very thin base compared with minority carrier diffusion length (Ln), which confirms our thin-base assumption!

<u>4.3) - Frequency response</u>

- The current gain of a BjT is a function of freq. so if we assume γ and M are indep. Of freq these base transport factor (α_T) is the only freq. dep. Factor.

- The following analysis will lead to αn α – cutoff freq. (W_α) excluding capacitive and resistive parasitic effects. If these effects are taken into account, the current gain will fall off at a lower freq. then W_α :

(4.65)

$$W_{Tdc} = \text{sech} \ \underline{W_B} \approx \alpha_{dc}$$

From eq. (3.36a)

$$L_{nB}^{*} = \frac{L_{nB}}{(1 + j\omega\tau_{nB})^{1/2}}$$

(4.66)

substituting in α_{Tdc} yields

$$\alpha(\omega) \approx \text{sech} \left[\frac{W_B}{L_{nB}} (1 + j\omega\tau_{nB})^{1/2} \right]$$

(4.67)

or using the Laplace transform variables s in place of $j\omega$.

$$\alpha(s) \approx \text{sech} \left[\frac{W_B}{L_{nB}} (1 + s\tau_{nB})^{1/2} \right]$$

(4.68)

which can also be written

$$\alpha(\tau) = \left\{\cosh\left[\frac{W_B}{L_{nB}}(1 + j\omega\tau_{nB})^{1/2}\right]\right\}^{-1} \tag{4.69}$$

The hyperbolic cosine can be expanded in a Taylor series to give

$$\cosh x = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \cdot$$