Lecture 19

Bipolar Junction Transistors (BJT): Part 3

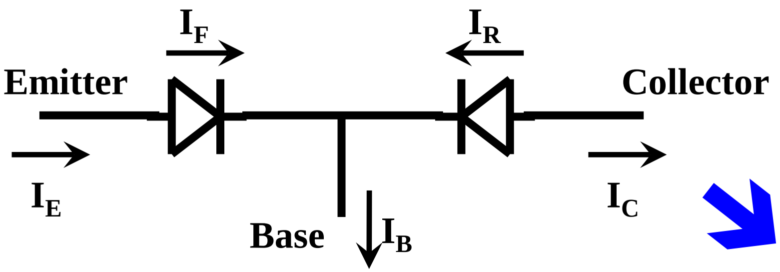
Ebers Moll Large Signal BJT Model, Using CVD model to solve for DC bias point

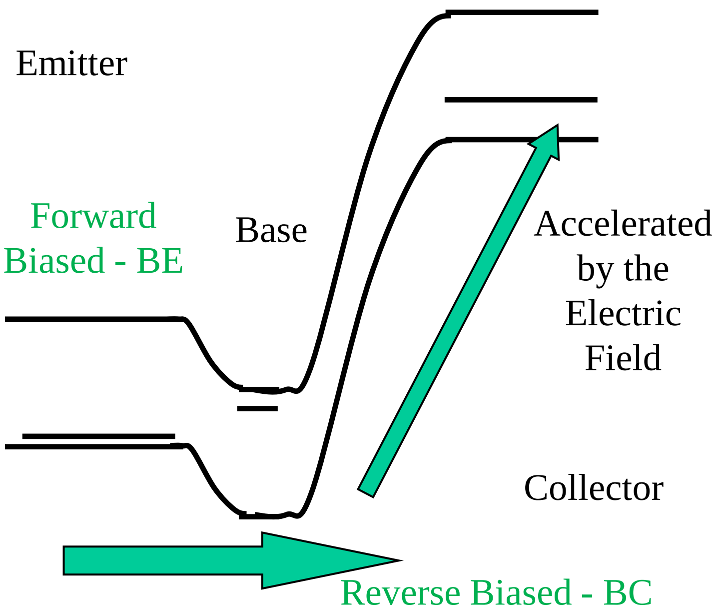
Reading:

Pierret 11.1

Development of the Large Signal Model of a BJT (Ebers-Moll Model)

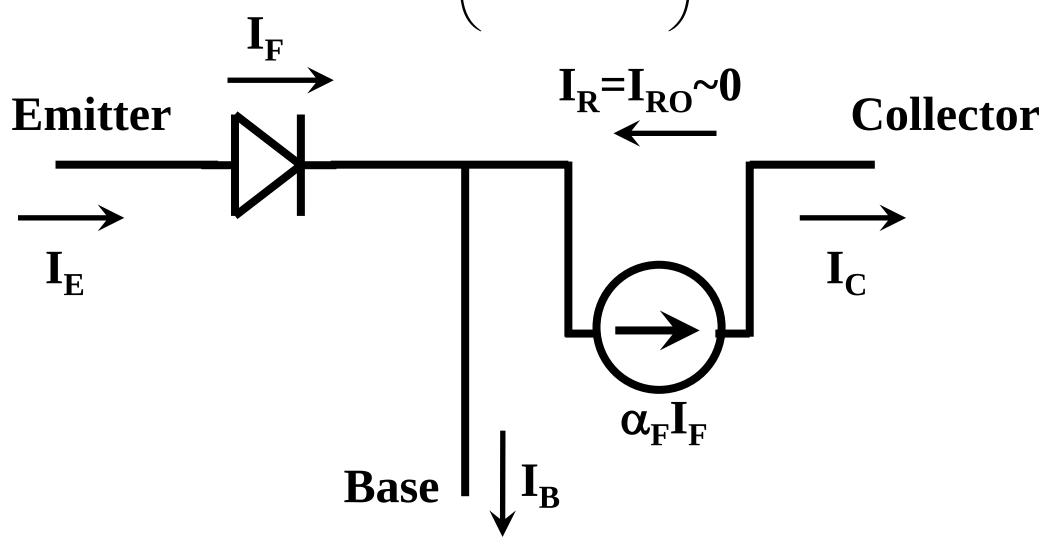
PNP in Active Mode





Ideal Diodes

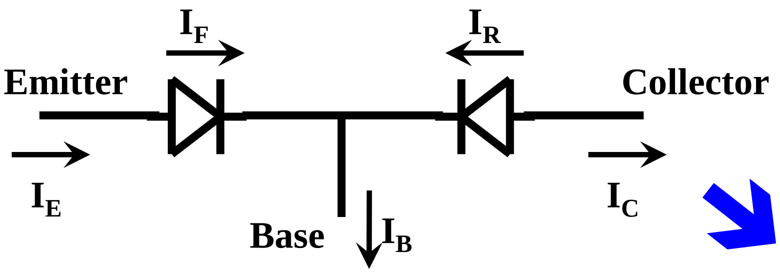
$$I_F = I_{F0}\left(e^{V_{EB}/V_T} - 1\right)$$



Note: Green arrows indicate directions and magnitude of hole motion.

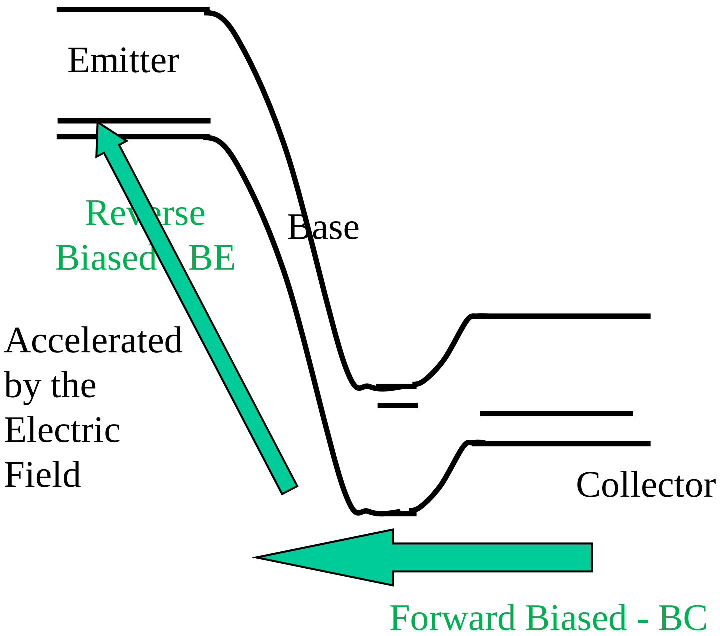
Development of the Large Signal Model of a BJT (Ebers-Moll Model)

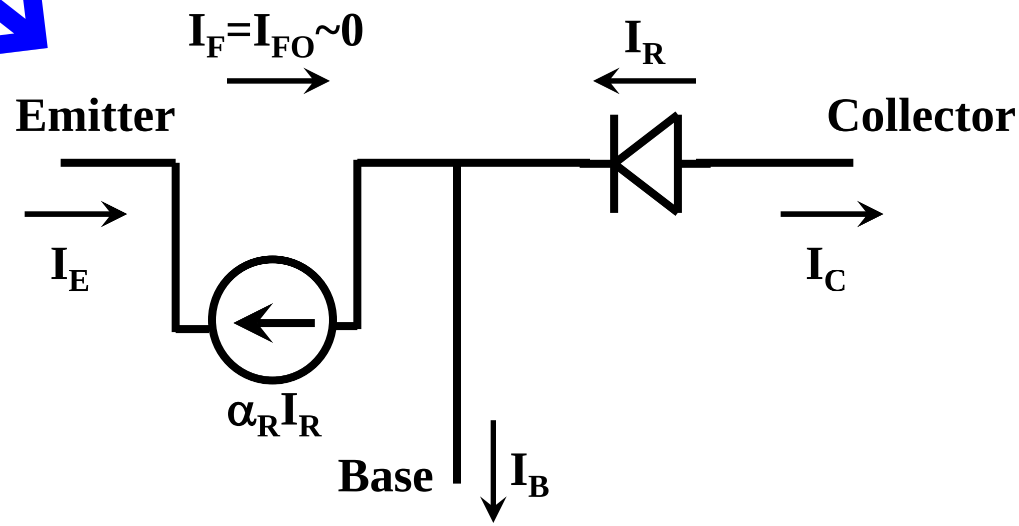
PNP in <u>Inverse</u> Active Mode



Ideal Diodes

$$I_R = I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$





In Inverse Active bias mode, the transistor still "sort of" works (may attenuate instead of amplify) but works poorly because the doping order of emitter, base and collector are reversed.

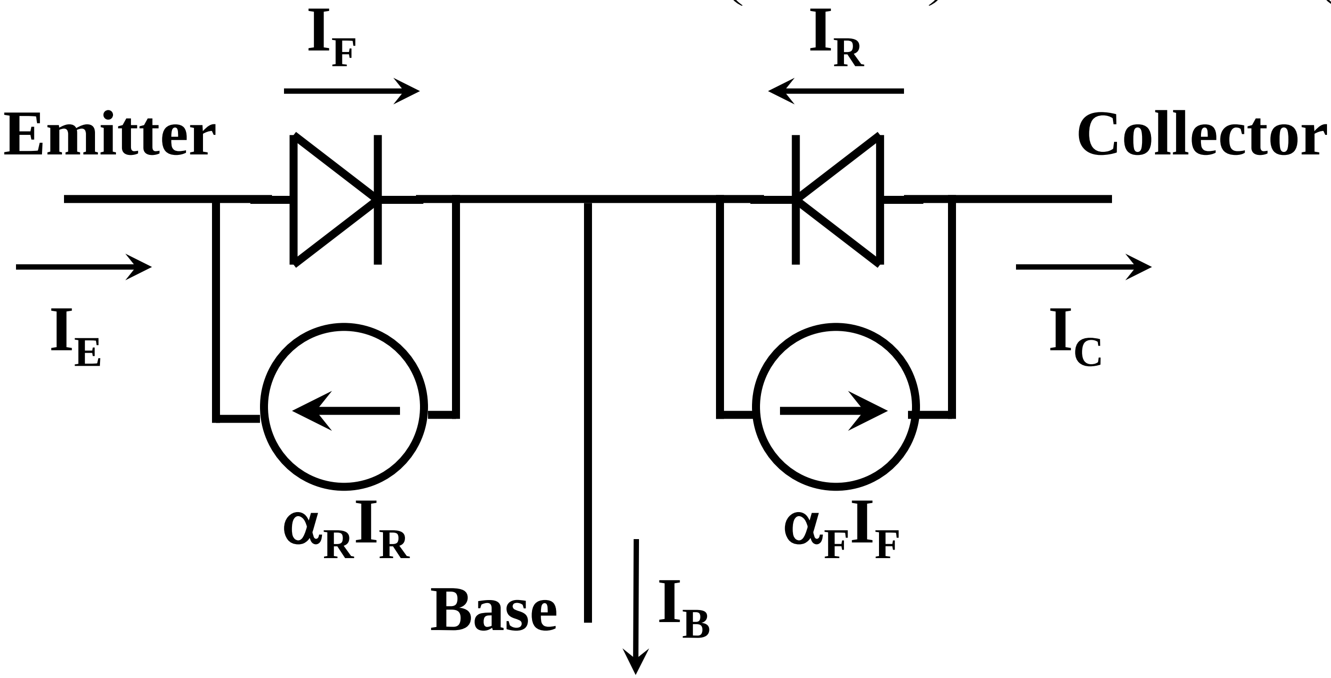
Note: Green arrows indicate directions and magnitude of hole motion.

Full Ebers Moll Model of a PNP

Ideal Diodes

Note: $A = \alpha_R I_{Ro} = \alpha_F I_{Fo}$

$$I_F = I_{F0}\left(e^{V_{EB}/V_T} - 1\right) \quad and \quad I_R = I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$



$$I_E = I_{F0}\left(e^{V_{EB}/V_T} - 1\right) - \alpha_R I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$

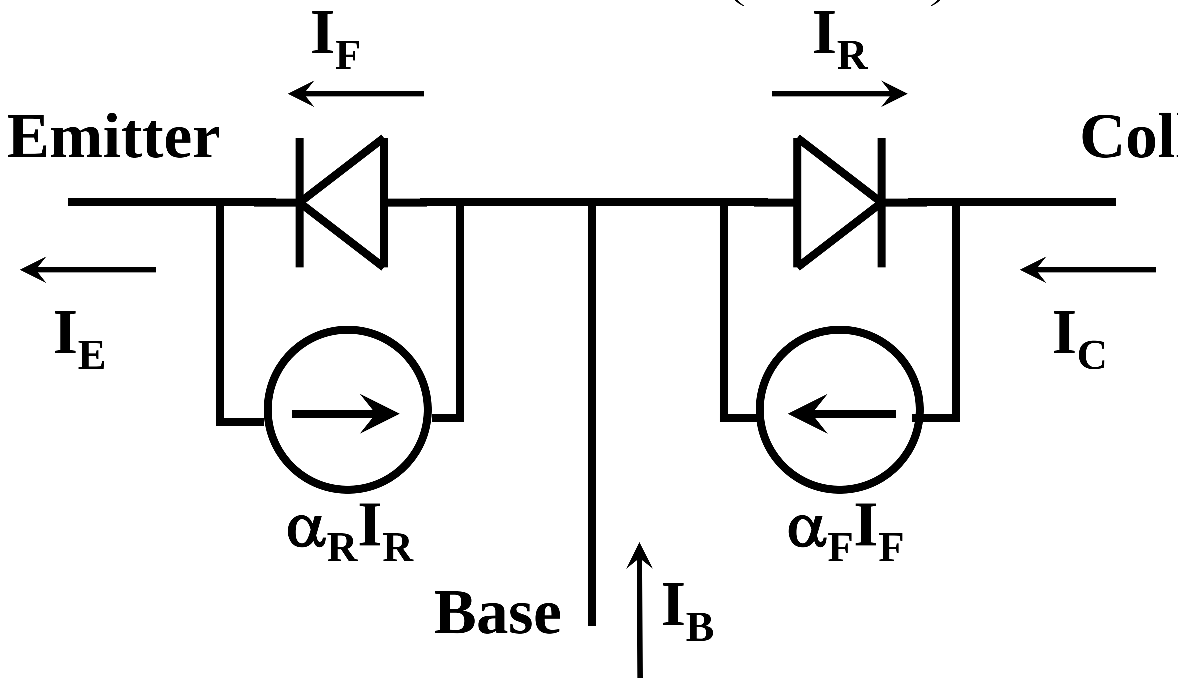
$$I_C = \alpha_F I_{F0}\left(e^{V_{EB}/V_T} - 1\right) - I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$

Development of the Large Signal Model of a BJT (Ebers-Moll Model)

Full Ebers Moll Model of a NPN

Ideal Diodes

$$I_F = I_{F0}\left(e^{V_{BE}/V_T} - 1\right) \quad and \quad I_R = I_{R0}\left(e^{V_{BC}/V_T} - 1\right)$$



$$I_E = I_{F0}\left(e^{V_{BB}/V_T} - 1\right) - \alpha_R I_{R0}\left(e^{V_{BC}/V_T} - 1\right)$$

$$I_C = \alpha_F I_{F0}\left(e^{V_{BE}/V_T} - 1\right) - I_{R0}\left(e^{V_{BC}/V_T} - 1\right)$$

Using the Ebers-Moll model requires mathematical complexity (and much pain). Thus, we have an approximate solution method* that allows a quick solution.

*I refer to as the “CVD/Beta Analysis”. This is just my term, not a universal name.

Quick Solution using a CVD/Beta Approach

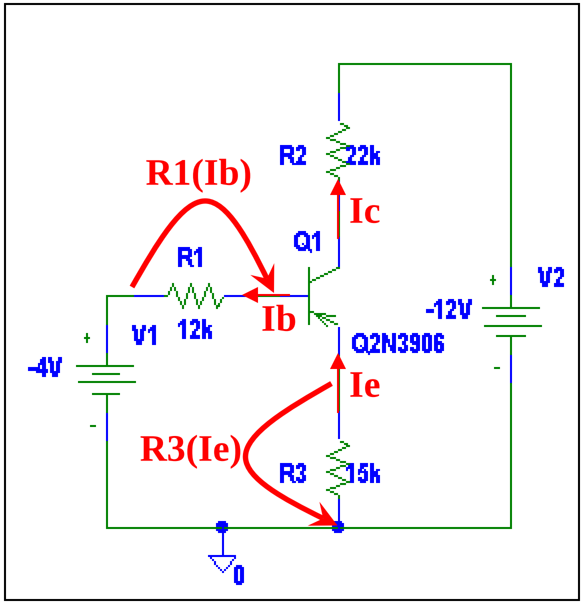
Consider the following pnp BJT circuit with a common emitter current gain, β_{DC}=180.7. Find Ib, Ic, and Ie assuming a turn on voltage of 0.7V.

Neglect Leakage currents

$$I_C = \alpha_{dc} I_E + I_{CBo}$$

$$I_C = \beta_{dc} I_B + I_{CEo}$$

$$I_E = I_B + I_C$$



$$0=-4V+I_B(12000)+V_{EB}+I_E(15000)$$

$$4V=I_B(12000)+0.7V+I_C(1/\alpha_{DC})(15000)$$

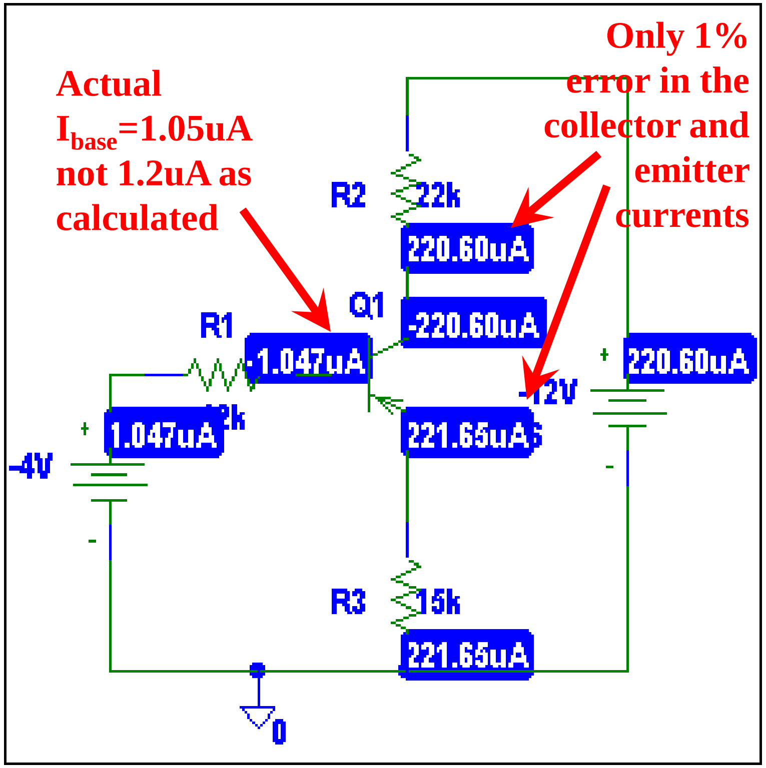
$$4V=I_B(12000)+0.7V+[\beta_{DC}I_B][(1+\beta_{DC})/ \beta_{DC}](15000)$$

$$3.3V=I_B[(12000)+(1+180.7)(15000)]$$

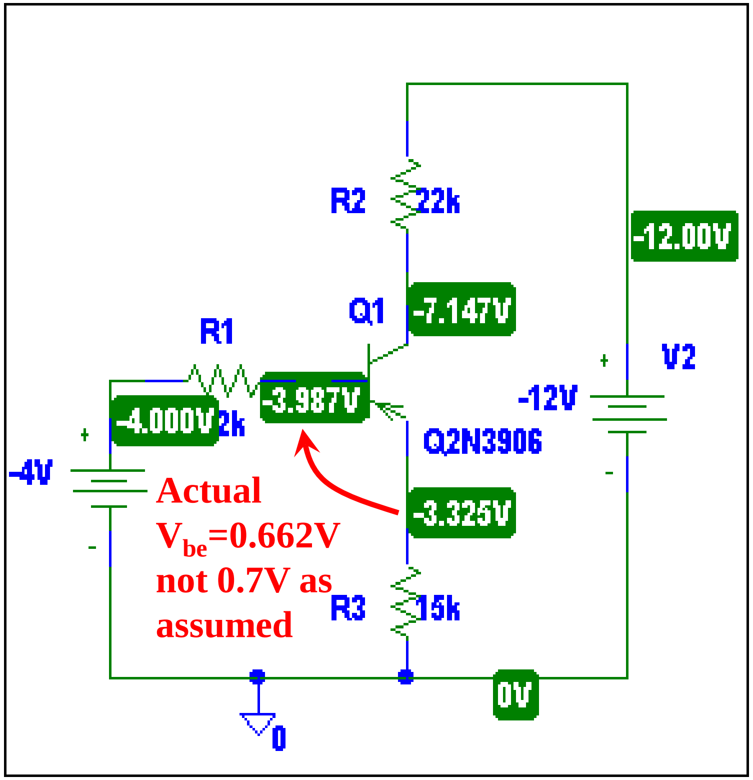
I_B= 1.2uA　　I_C=180.7I_B=218uA　　I_E=(181.7/180.7)I_C=219uA

Development of the Large Signal Model of a BJT (Ebers-Moll Model)

Compare our results using the CVD/Beta model to the full Ebers-Moll solution used in PSPICE…



Current into various nodes

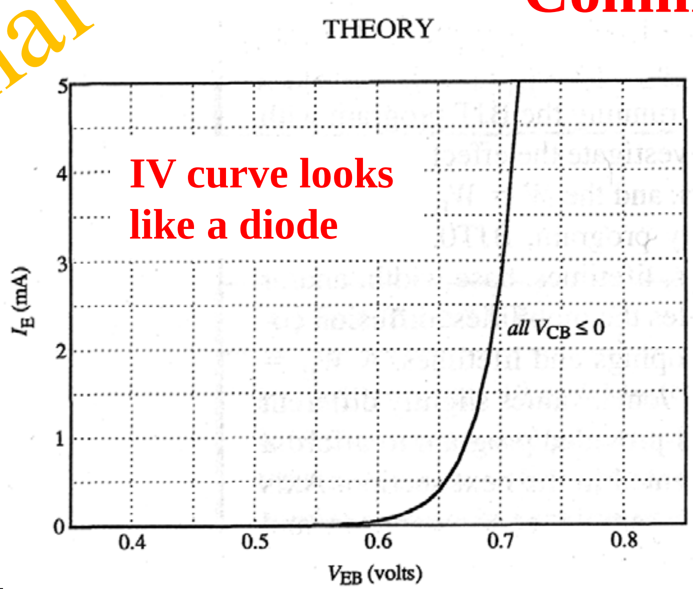


Voltage at various nodes

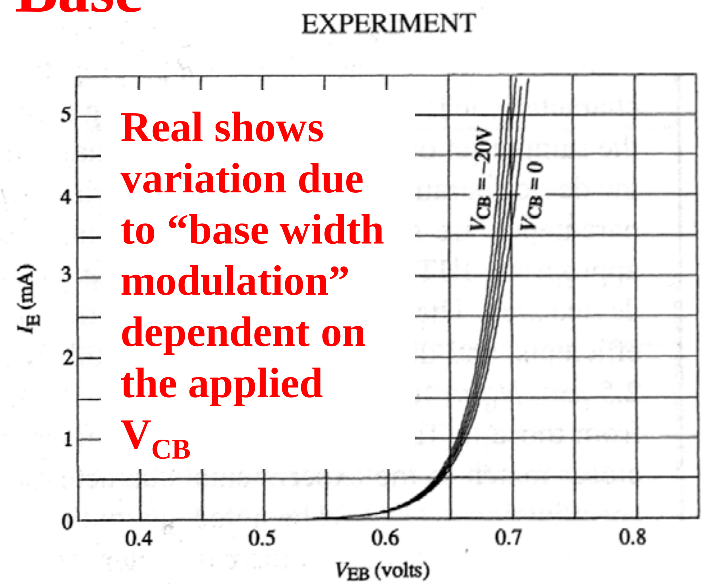
Development of the Large Signal Model of a BJT (Ebers-Moll Model)

Optional

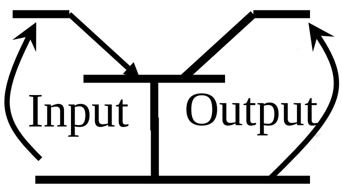
Common Base



IV curve looks like a diode

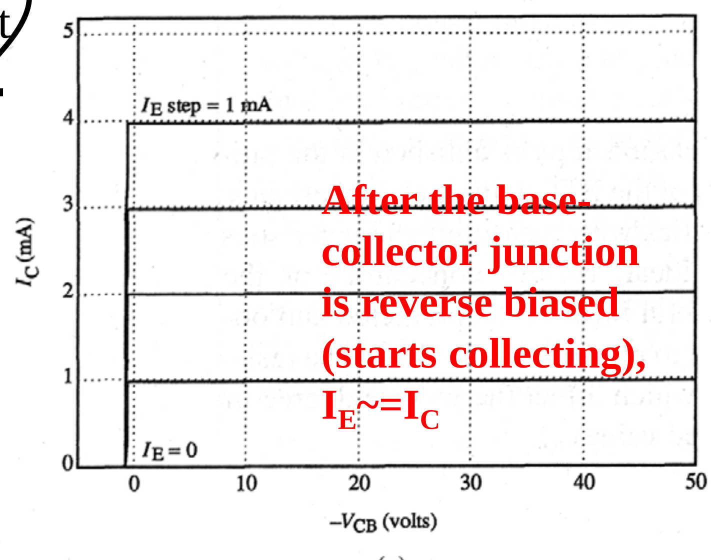


Real shows variation due to "base width modulation" dependent on the applied V_{CB}

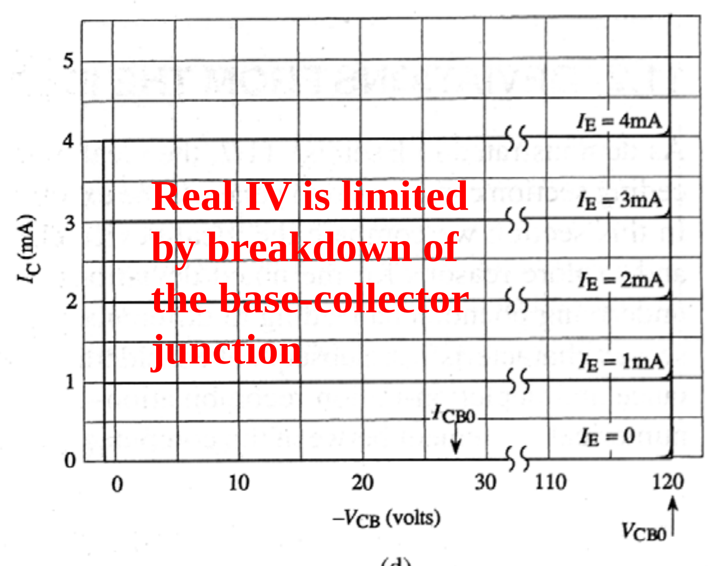


Input **Output**

I_E and V_{EB} $\quad$ I_C and $(-V_{CB})$



After the base-collector junction is reverse biased (starts collecting), $I_E \sim= I_C$

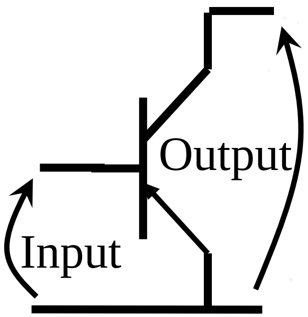


Real IV is limited by breakdown of the base-collector junction

Development of the Large Signal Model of a BJT (Ebers-Moll Model)

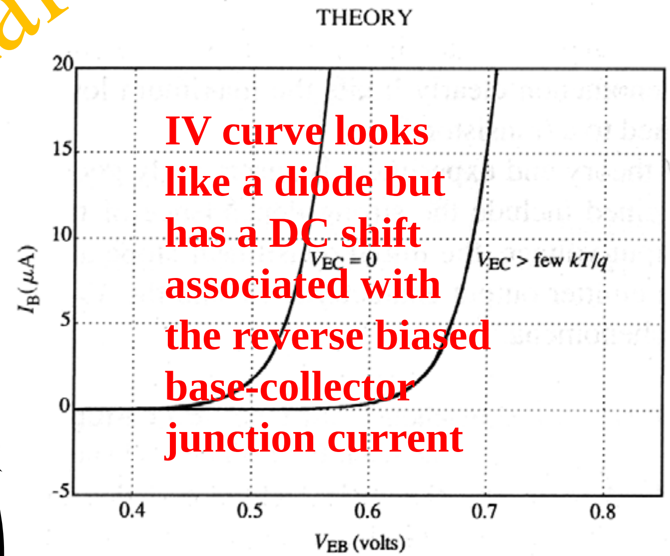
Optional

Common Emitter

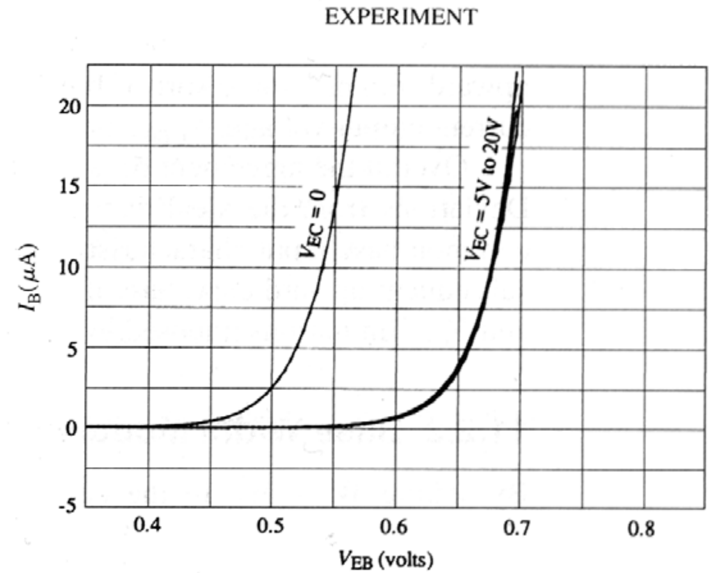


Input **Output**

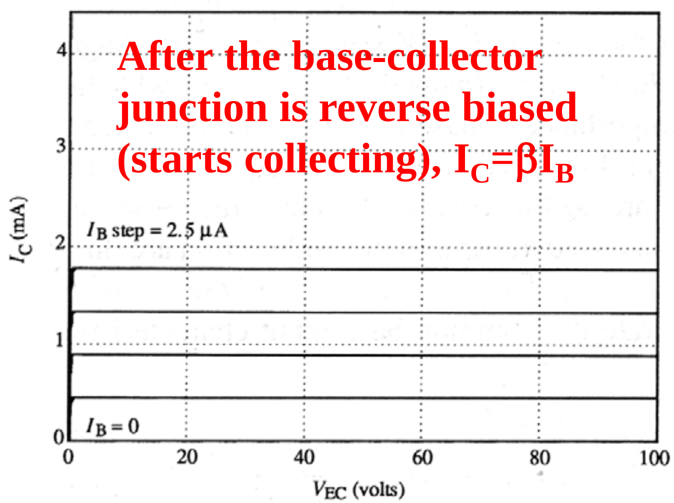
I_B and V_{EB} I_C and V_{EC}



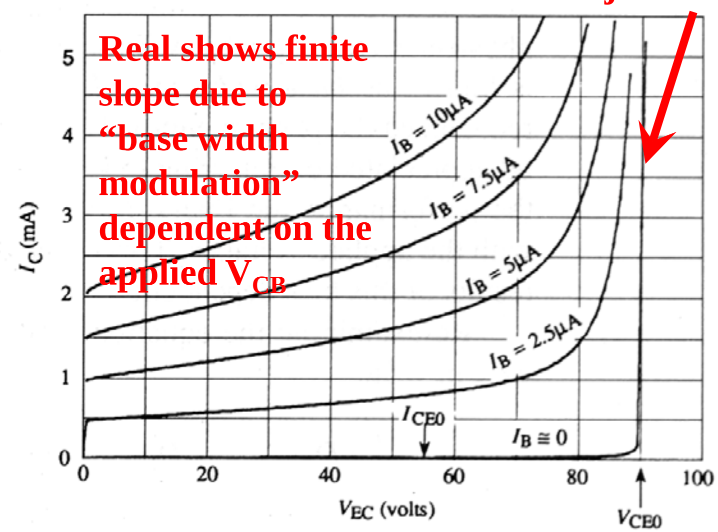
IV curve looks like a diode but has a DC shift associated with the reverse biased base-collector junction current



Real IV is limited by breakdown of the base-collector junction



After the base-collector junction is reverse biased (starts collecting), $I_C=\beta I_B$



Real shows finite slope due to "base width modulation" dependent on the applied V_{CB}

Development of the Large Signal Model of a BJT (Ebers-Moll Model)

Optional

$$I_E = \underbrace{qA\left(\frac{D_E}{L_E}n_{Eo} + \frac{D_B p_{Bo}}{L_B}\frac{\cosh\left(W/L_B\right)}{\sinh\left(W/L_B\right)}\right)}_{I_{F0}}\left(e^{V_{EB}/V_T}-1\right) - \underbrace{qA\left(\frac{D_B p_{Bo}}{L_B}\frac{1}{\sinh\left(W/L_B\right)}\right)}_{A}\left(e^{V_{CB}/V_T}-1\right)$$

*

$$I_C = \underbrace{qA\left(\frac{D_B p_{Bo}}{L_B}\frac{1}{\sinh\left(W/L_B\right)}\right)}_{A}\left(e^{V_{EB}/V_T}-1\right) - \underbrace{qA\left(\frac{D_C}{L_C}n_{Co} + \frac{D_B p_{Bo}}{L_B}\frac{\cosh\left(W/L_B\right)}{\sinh\left(W/L_B\right)}\right)}_{I_{R0}}\left(e^{V_{CB}/V_T}-1\right)$$

$$I_E = I_{F0}\left(e^{V_{EB}/V_T}-1\right) - A\left(e^{V_{CB}/V_T}-1\right)$$

$$I_C = A\left(e^{V_{EB}/V_T}-1\right) - I_{R0}\left(e^{V_{CB}/V_T}-1\right)$$

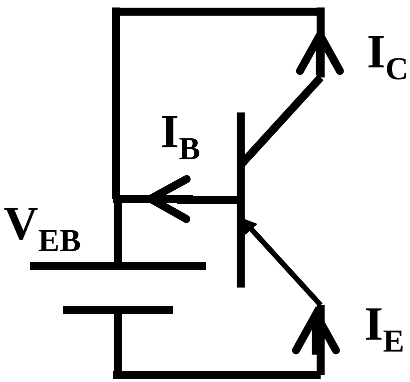
Development of the Large Signal Model of a BJT (Ebers-Moll Model)

Optional

$$I_E = I_{F0}\left(e^{V_{EB}/V_T} - 1\right) - A\left(e^{V_{CB}/V_T} - 1\right)$$

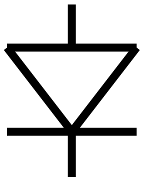
$$I_C = A\left(e^{V_{EB}/V_T} - 1\right) - I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$

When V_{CB}=0,



$$I_E = I_{F0}\left(e^{V_{EB}/V_T} - 1\right) \quad and \quad I_C = A\left(e^{V_{EB}/V_T} - 1\right)$$

Looks like a diode



$but,$

$$I_{F0} > A \qquad (see\,*)$$

$Thus,$

$$I_E = I_{F0}\left(e^{V_{EB}/V_T} - 1\right) \quad and \quad I_C = \alpha_F I_{F0}\left(e^{V_{EB}/V_T} - 1\right) \quad = \quad I_C = \alpha_F I_E$$

$$but, \quad I_C = \alpha_F I_E \rightarrow \alpha_F = \alpha_{DC} \quad common\ base\ current\ gain$$

The collector current is the fraction of the emitter current “collected”

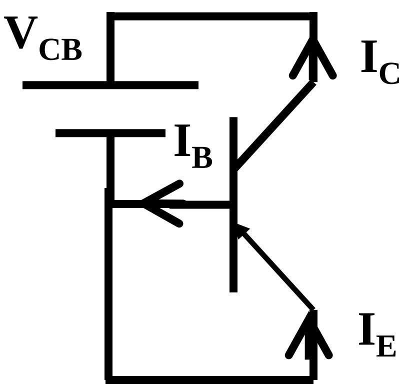
Development of the Large Signal Model of a BJT (Ebers-Moll Model)

Optional

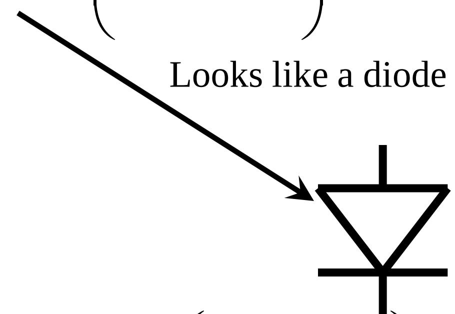
$$I_E = I_{F0}\left(e^{V_{EB}/V_T} - 1\right) - A\left(e^{V_{CB}/V_T} - 1\right)$$

$$I_C = A\left(e^{V_{EB}/V_T} - 1\right) - I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$

When $V_{EB}=0$,



$$I_E = -A\left(e^{V_{CB}/V_T} - 1\right) \quad and \quad I_C = -I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$



$$but,$$

$$I_{R0} > A \qquad (see\ *)$$

$$Thus,$$

$$I_E = -\alpha_R I_{R0}\left(e^{V_{CB}/V_T} - 1\right) \quad and \quad I_C = -I_{R0}\left(e^{V_{CB}/V_T} - 1\right)$$

$$but, \quad I_E = \alpha_R I_C \rightarrow \alpha_R \neq \alpha_{DC}$$

In Inverse Active mode, the emitter current is the fraction of the collector current "collected"