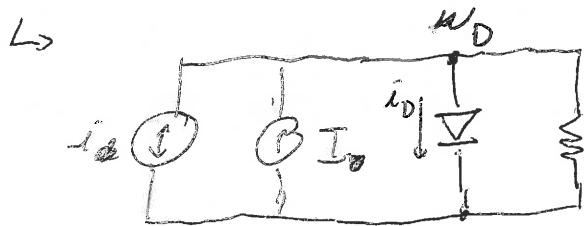
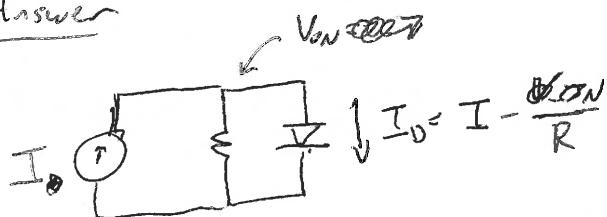


Next Time

Small signal review example

You guys

- ↳ Draw small sig eq. Ckt.
- ↳ find $V_d, I_d, i_d, V_{D_s}, V_{B_s}, i_0$
- ↳ use switch model for large signal problem
- ↳ switches on at V_{on}

Answer

- Switch model fixes V_{on}
- Large signal problem

$$+ \quad i_d \text{ (1)} \quad R_s \quad r_d = \frac{n\phi_{th}}{I_0}$$

$$R_{eff} = r_d // R = \frac{R n\phi_{th} / I_0}{R + n\phi_{th} / I_0} = \frac{nR\phi_{th}}{RI_0 + nR\phi_{th}}$$

$$V_d = I_d R_{eff}$$

$$i_d = \frac{R}{r_d + R} = \frac{RI_0}{n\phi_{th} + RI_0}$$

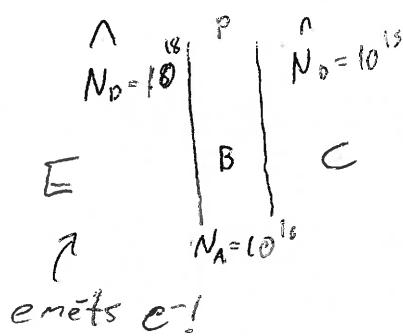
$$\begin{aligned} V_d &= V_{on} + i_d R_{eff} \\ i_d &= I - \frac{V_{on}}{R} + \frac{RI_0}{n\phi_{th} + RI_0} \end{aligned}$$

• What is a BJT

→ A transistor ~ (from transconductance + varistor)

→ Made of Bipolar Junctions

→ Two types: npn & pnp, and names are suggestive



emits e^- !

Backwards current!

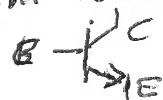
- pnp like backwards version, cover @ end/Next time

- Trivially, see two diodes



- it floats, can measure $V_{BE,ON}$

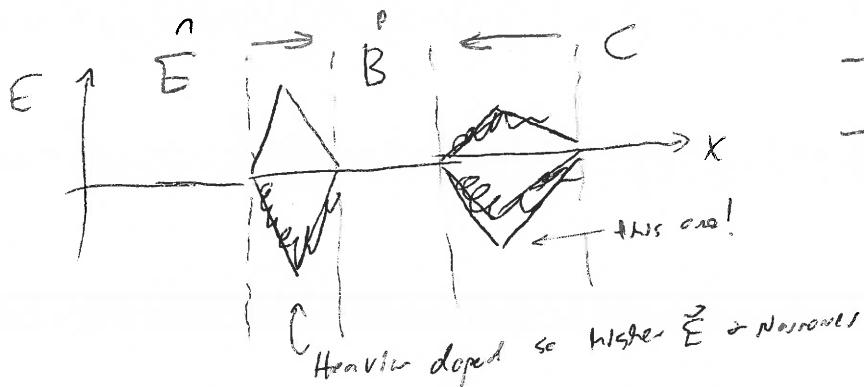
- symbol reflects this



- Different b/c are junctions highly doped

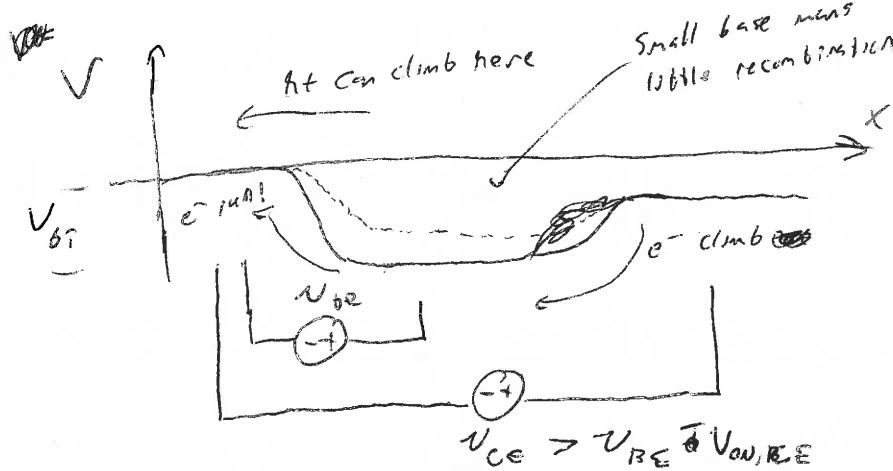
- What doesn't look like 2 diodes?

- Very thin base



- Note $\vec{E} = -\nabla V$

- Integrate E again as easy way to see \vec{E} fields & barriers effects



- Apply V_{BE} & lower diode barrier like last time, inject holes & diffuse over

- Barrier reduced to V_{BE} allows e^- in from ~~emitter~~ collector

- These drift from B to C!

- EXTRA current on top of diode!

- Turns out, it's linear!

- α_F is ratio of C injected into base vs. arrive at collector

$$\alpha_F = \frac{I_C}{I_E} \leftarrow \text{nice \% tried to device physics}$$

\leftarrow recombination efficiency $\sim 99.9\%$

- But we're excited about gain!

$$\beta_F = \frac{I_C}{I_B} = \frac{\alpha_F}{1-\alpha_F} \leftarrow \text{From } I_E = -(I_C + I_B)$$

\leftarrow Careful! Varies w/ Temp., I_E , linear over
base cond.

\hookrightarrow usually 50-200 in our transistors



\hookrightarrow To inject I_B , get $I_C = \beta I_B$ ← linearly controlled

\hookrightarrow same mechanism $\sim e^{kT}$ over some
base region

$\hookrightarrow I_B = I_{ES} (e^{\frac{V_{BE}}{kT}} - 1)$ $\% \text{ diode (core! FAR only)}$

- We've been talking about case w/ V_{BE} fwd. bias, V_{CE} rev. bias
(called fwd. active)

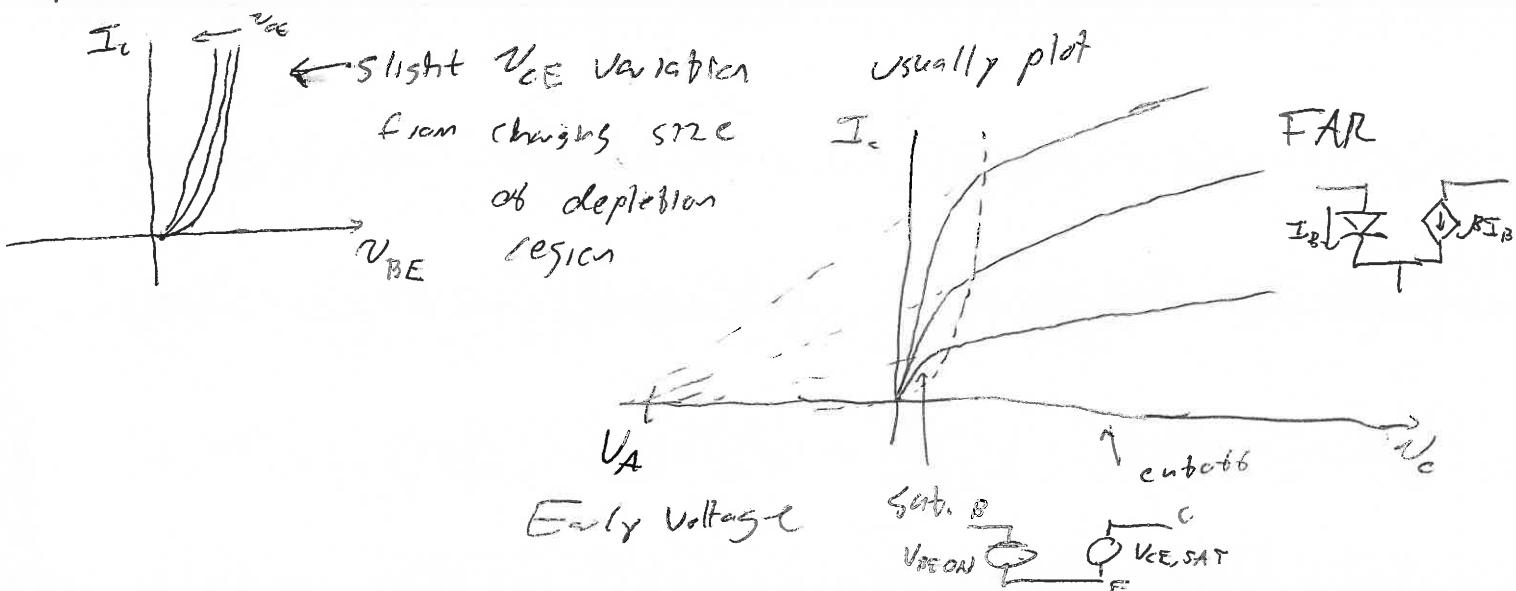
\hookrightarrow could fwd. bias both

\hookrightarrow called saturation

$\hookrightarrow \beta$ greatly reduced \sim usually used in digital \sim "switch like"

$\hookrightarrow V_{CE}$ must be small, $\sim V_{CE,ON} - V_{BE,ON} \sim 0.05-0.3V \sim V_{CE,SAT}$

- Let's plot this behavior & make schematics



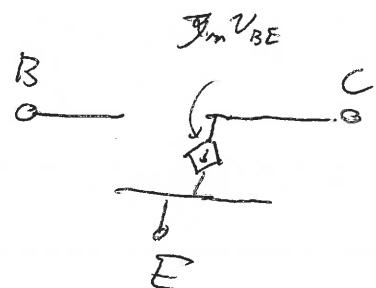
Let's make a small signal model

- Multiple terminals, take derivative for each

- I'll do $\frac{dI_C}{dV_{BE}} = \frac{d}{dV_{BE}} \beta I_{ES} (e^{\frac{V_{BE}}{\phi_{th}}} - 1)$

$$= \frac{\beta}{\phi_{th}} I_{ES} (e^{\frac{V_{BE}}{\phi_{th}}}) - \text{D}$$

$$\approx \frac{I_C}{\phi_{th}} \leftarrow \text{called } g_m$$



You suggest

- Find the BE component, express using $B \approx g_m$

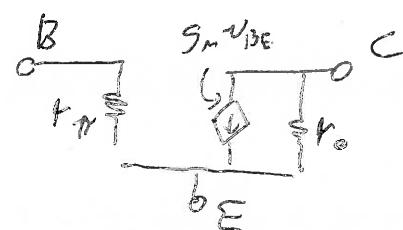
- Figure out what type of component at CE, bias polar is set to value

$$\frac{dI_B}{dV_{BE}} = \frac{d}{dV_{BE}} I_{ES} (e^{\frac{V_{BE}}{\phi_{th}}} - 1)$$

$$= \frac{1}{\phi_{th}} I_{ES} e^{\frac{V_{BE}}{\phi_{th}}}$$

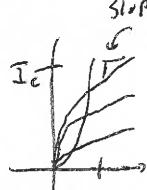
$$\approx \frac{I_B}{\phi_{th}} \rightarrow \frac{I_C/B}{\phi_{th}} \rightarrow \frac{g_m}{B}$$

$$r_{\pi} = g_m / B = I_B / \phi_{th}$$



- Looks more details of operation (rev. active, breakdown)
- Look @ PNP soon

- Resistor \Rightarrow No b/c slope is linear in plot \Rightarrow I_C relates I_C to V_{CE}



$$\text{Value: } r_o = \frac{I_C}{V_A}$$