Lecture 19: Biasing

- **Announcements**:
- HW#6 online and due Friday Oct. 12 via Gradescope
- PreLab#4 is online and due next week, as is Lab#3
- Lab#4 (the experimental part) will be online soon
- Midterm 1: Later today, Friday, Oct. 5, from 5-6:30 p.m., in 277 Cory
- Midterm Info Sheet online with updates from what we discussed last week
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- Lecture Topics:
  - ↳ BJT IV Curves
  - ↳ Parameter Independent Biasing for Discrete BJT's
  - ↳ Discrete MOS Biasing
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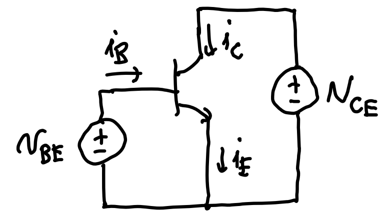
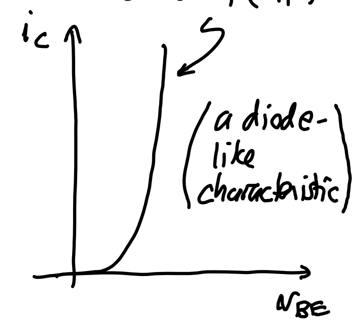
- **Last Time**:
- BJT biasing examples using approximations

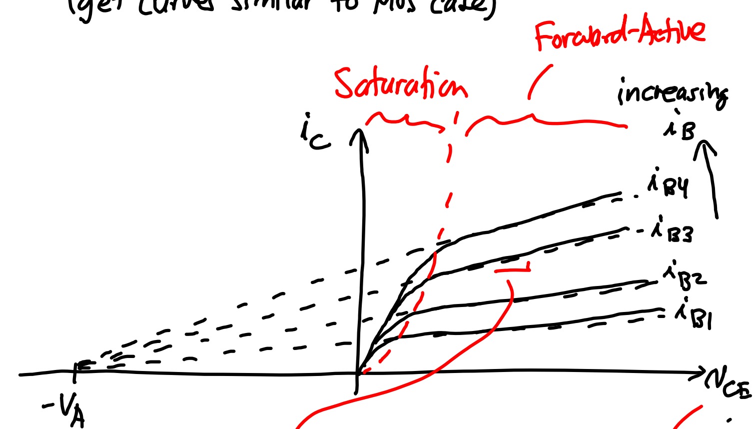
IV Characteristics of BJT's

$i_C = I_S \exp\left(\frac{v_{BE}}{V_T}\right)$





⇒ often more interested in $i_C = f(i_B, v_{CE})$:
(get curves similar to MOS case)



Early Voltage $\triangleq V_A$

Finite Slope: $\frac{1}{V_A}$

$i_C = \left[I_S \exp\left(\frac{v_{BE}}{V_T}\right)\right]\left[1 + \frac{v_{CE}}{V_A}\right]$

Why v_{CE}? $v_{CE} = v_{CB} + v_{BE}$

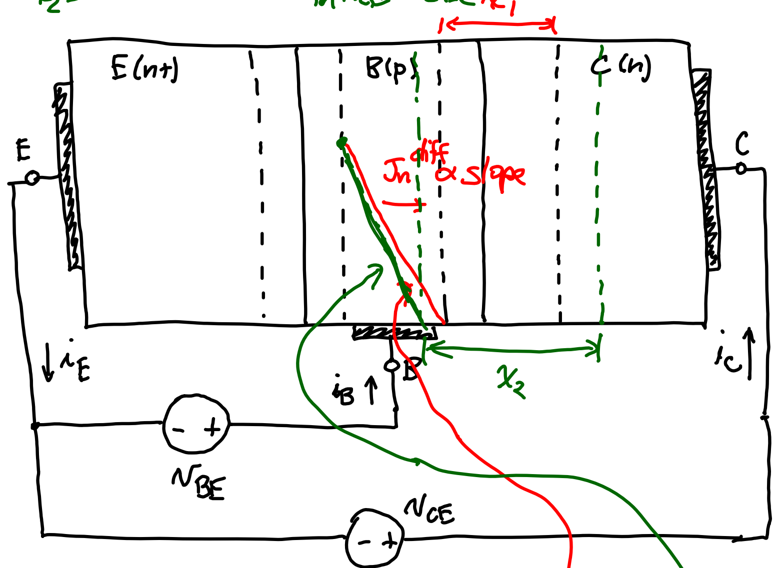
v_{BE}: diode turn-on = constant

v_{CB}: reverse-bias across BCJ → $\Delta v_{CE}\uparrow \cong \Delta v_{CB}\uparrow$

What happens physically?

$x_1 \triangleq$ depl. region width at BCJ for $v_{CE} = v_{CE1}$

$x_2 \triangleq$ " " " " for $v_{CE} = v_{CE2}$



① Case: $v_{CE1} \to x_1 \to i_{c1} \propto$ slope of this line

② Case: increase v_{CE}: $v_{CE} \to v_{CE2}$ ($v_{CE1} < v_{CE2}$)

$\to v_{CB}\uparrow \to x\uparrow \to x_1 \to x_2 \to i_{c2} \propto$ slope of this line ($x_2 > x_1$)

$\therefore i_{c2} > i_{c1}$

Thus: $v_{CE}\uparrow \to i_C\uparrow$ due to $x_{BCdepl}\uparrow$

Result: $i_C = f(i_B, v_{CE})$ in forward-active!

$$\boxed{i_C = \left[I_S \exp\left(\frac{v_{BE}}{V_T}\right)\right]\left[1 + \frac{v_{CE}}{V_A}\right]}$$

Parameter-Independent Biasing for Discrete BJT's

⇒ behavior of an analog ckt. depends heavily on its DC operating pt. (or DC Bias Point)

⇒ for BJT's, I_C is most important

⇒ must insure that I_C is stable against variations in β, V_{BE}, & I_S

① β is hard to control → varies from process to process

② I_S " " " " "

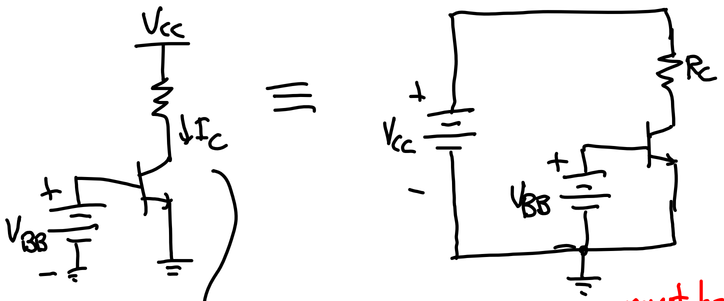
③ $V_{BE} = \frac{kT}{q} \ln\left(\frac{I_C}{I_S}\right)$ → depends on T & I_S

④ $V_T = \frac{kT}{q}$ → depends on T

⇒ need biasing strategies that suppress dependence on these

Compare Some Biasing Strategies

① Voltage Sources and R_C:



$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) = I_S \exp\left(\frac{V_{BB}}{V_T}\right)$$

must be very precisely set! X

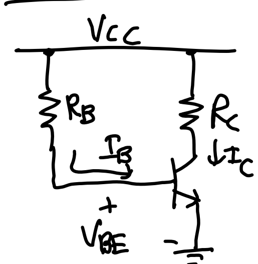
Varies directly w/ I_S X

exponential w/ V_T X

∴ strong dependence on I_S, V_T → NOT GOOD!

(plus, we don't normally have a V_{BB} in integrated ckts. ... just V_{CC})

② Base Resistor to V_{CC}:



$$I_B = \frac{V_{CC} - V_{BE(on)}}{R_B}$$

$$\Rightarrow I_C = \beta I_B = \frac{V_{CC} - V_{BE(on)}}{R_B/\beta}$$

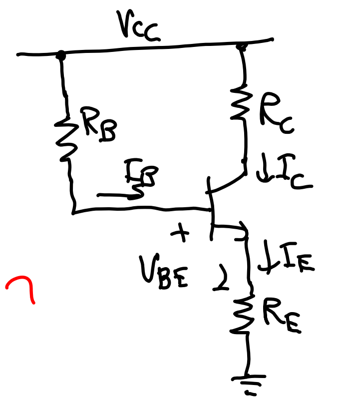
less dependence on V_T & I_S when $V_{CC} \gg V_{BE}$

BETTER! ✓

heavily dependent on β! X

NOT GOOD!

③ Base Resistor to V_{CC} Plus Emitter Resistor:



Apply KVL: $V_{CC} = I_B R_B + V_{BE} + I_E R_E$

$$= \frac{I_C}{\beta} R_B + V_{BE} + \frac{I_C}{\alpha} R_E$$

$$\boxed{I_C = \frac{V_{CC} - V_{BE}}{\frac{R_E}{\alpha} + \frac{R_B}{\beta}}}$$

For stability against ΔV_{BE}: Choose $V_{CC} \gg V_{BE}$

For stability against $\Delta\beta$: Need $\frac{R_E}{\alpha} \gg \frac{R_B}{\beta}$

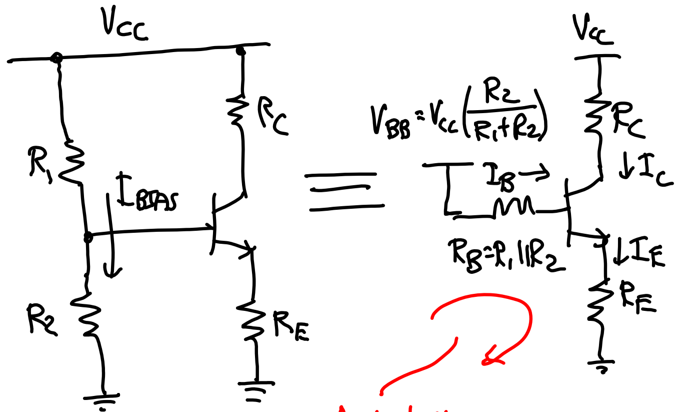
e.g., $\frac{R_E}{\alpha} \gtrsim 10\frac{R_B}{\beta}$ is a good choice!

⇒ Problem: To get needed I_B, need large R_B

⇒ reduce needed R_B by reducing voltage applied across it...

④ Standard Parameter Independent Biasing:

(for discrete BJT ckts, as opposed to IC's)



voltage divider

Apply KVL:

$$\boxed{I_C = \frac{V_{BB}-V_{BE}}{\frac{R_E}{\alpha}+\frac{R_B}{\beta}}}$$

Thus, for bias stability, want:

① $V_{BB} \gg V_{BE}$ → for insensitivity to V_{BE}

② $\frac{R_E}{\alpha} \gg \frac{R_B}{\beta}$ → for insensitivity to β

↳ rule of thumb: $\frac{R_E}{\alpha} \geq 10\frac{R_B}{\beta}$

③ $I_{BIAS} \geq 10 I_B$

want R_B = small → R_1 & R_2 small

want β = large → I_B = small

I_{BIAS} = large

For practical amplifier requirements: compromise:

① $V_{BB} \approx \frac{1}{3}V_{CC}$

② $V_{CE} \approx \frac{1}{3}V_{CC}$

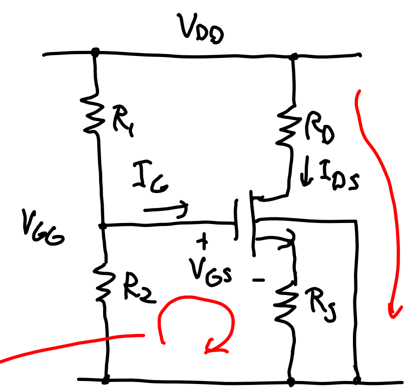
③ $V_{R_C} = I_C R_C \approx \frac{1}{3}V_{CC}$

④ $0.1 I_E < I_{BIAS} < I_E$

} Good starting pt. ... but not rules! → must adjust for a given design

MOS Biasing

⇒ can use a similar biasing strategy for discrete MOS ckts.



$V_{GG} = V_{DD}\left(\frac{R_2}{R_1+R_2}\right)$, $I_G = 0 \rightarrow V_G = V_{GG}$

KVL: $V_{GG} = V_{GS} + I_{DS}R_S$ (2)

$V_{DD} = I_{DS}R_D + V_{DS} + I_{DS}R_S + V_{SS}$ (1)

To find the DC operating point: (by hand)

① Assume saturation:

can often neglect

$$I_{DS} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_t)^2(1\cancel{+\lambda V_{DS}})$$

$$\text{w/ } V_t = f(V_{SB}) = V_{to} + \gamma\left(\sqrt{2\phi_f - V_{SB}} - \sqrt{2\phi_f}\right)$$

$\Rightarrow$ using (2): $V_{GG} = V_{GS} + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_t)^2 R_S$ (3)

② Solve for V_{GS} assuming $V_t = V_{to}$.

③ $V_S = V_{GG} - V_{GS} \rightarrow V_{SB} = V_S - V_{SS} \rightarrow$ find $V_t(V_{SB}) = V_t'$

④ Plug $V_t' = V_t(V_{SB})$ into (3) $\rightarrow$ Get V_{GG}'

⑤ Back to ③ $\rightarrow$ iterate to convergence

⋮

⑥ Check operating pt. $\rightarrow$ saturated?

if yes $\rightarrow$ done

if no $\rightarrow$ assume linear & start over

$\Rightarrow$ tedious, but effective for discrete (i.e., off-chip) MOS ckts.

$\Rightarrow$ on-chip, we generally use current mirrors...