Lecture 18: Biasing

- **Announcements**:
- This lecture is a recording, since the actual class was cancelled do to the planned power outage that shut down the university
- HW#6 online and due Friday, Oct. 18 (next week) via Gradescope
- Those in the Wednesday lab section
    - ↳ can turn their Lab#3 prelabs in one day after the servers come back
    - ↳ and should finish their Lab#3 by going to the lab when the stations are free
- Lab#4 is online, with prelab due next week
- Midterm 1 moved to next week, most likely Wednesday, Oct. 16, 4-5 p.m., in our regular room
- My Monday Office Hours will move to 5-6 p.m. on Oct. 14 and thereafter
- ---------------------------------------
- Lecture Topics:
    - ↳ BJT IV Curves
    - ↳ Parameter Independent Biasing for Discrete BJT's
    - ↳ Discrete MOS Biasing
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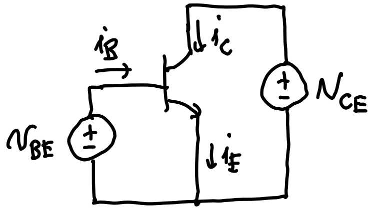
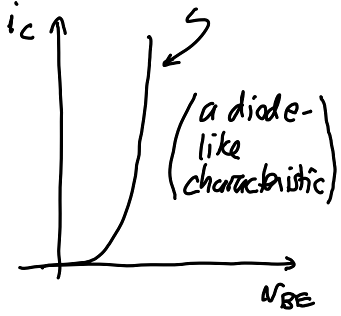
- Last Time:
- BJT biasing examples using approximations

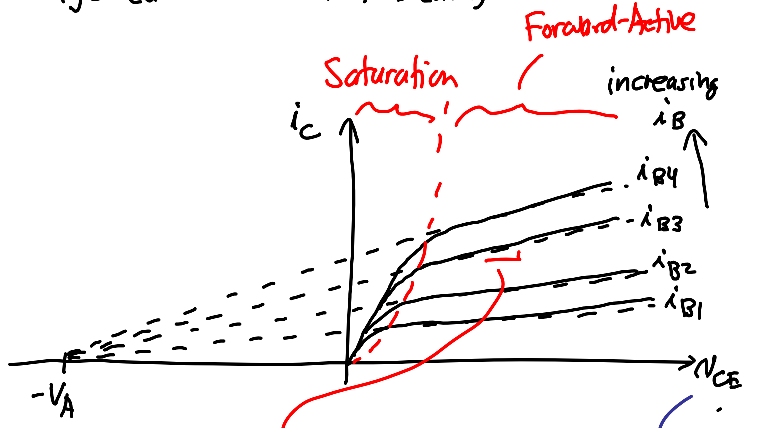
IV Characteristics of BJT's



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



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



Early Voltage ≙ 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}? $v_{CE} = v_{CB} + v_{BE}$

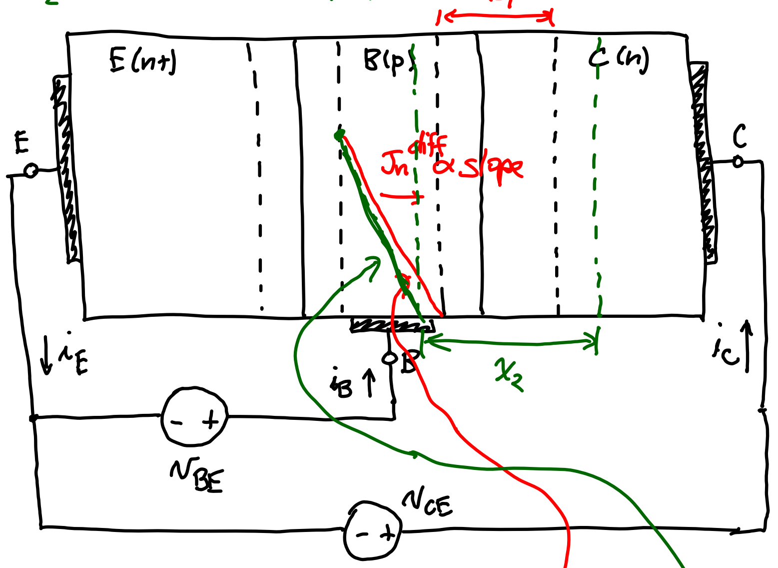
↖ diode turn-on = constant

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: $v_{CE1} \rightarrow x_1 \rightarrow i_{C1} \propto$ slope of this line

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

$v_{CB}\uparrow \rightarrow x\uparrow \rightarrow x_1 \rightarrow x_2 \rightarrow i_{C2} \propto$ slope of this line
$(x_2 > x_1)$

$\therefore i_{C2} > i_{C1}$

Thus: $v_{CE}\uparrow \rightarrow i_C\uparrow$ 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 " " " " "

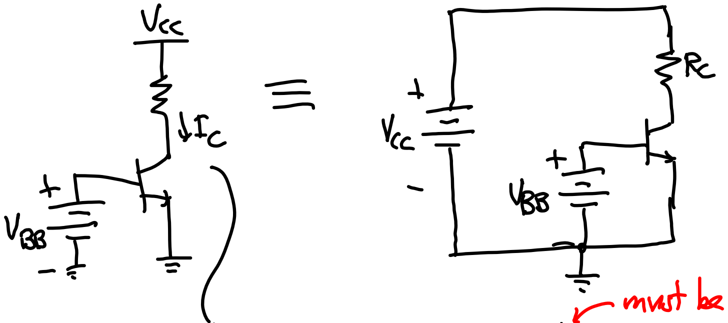
③ $V_{BE} = \frac{kT}{q}\ln\left(\frac{I_C}{I_S}\right)$ → depends on T & I_S

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

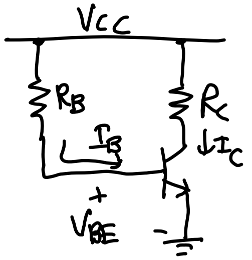
Varies directly w/ I_S X

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}:



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

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

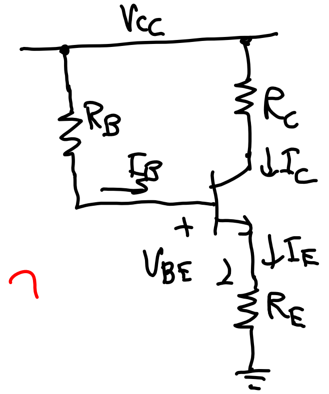
less dependence on V_T & I_S when $V_{CC} \gg V_{BE}$

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 $\frac{R_E}{\alpha} \gg \frac{R_B}{\beta}$

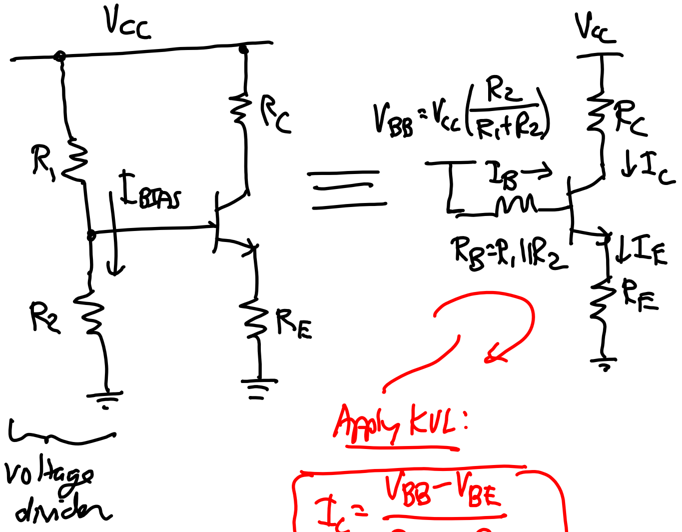
e.g., $\frac{R_E}{\alpha} \gtrsim 10 \frac{R_B}{\beta}$ is a good choice!

⇒ 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)



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 $V_{CE} \approx \frac{1}{3} V_{CC}$

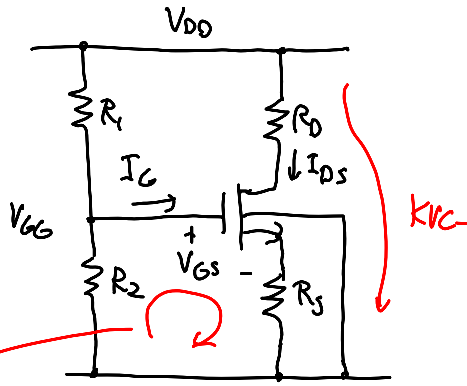
③ $V_{R_C} = I_C R_C \approx \frac{1}{3} V_{CC}$

④ $0.1 I_E < I_{BIAS} < I_E$

Good starting pts. ... 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

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

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

⇒ 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) → Get V_{GS}'

⑤ Back to ③ → iterate to convergence

⋮

⑥ Check operating pt. → saturated?

if yes → done

if no → assume linear & start over

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

⇒ on-chip, we generally use current mirrors...