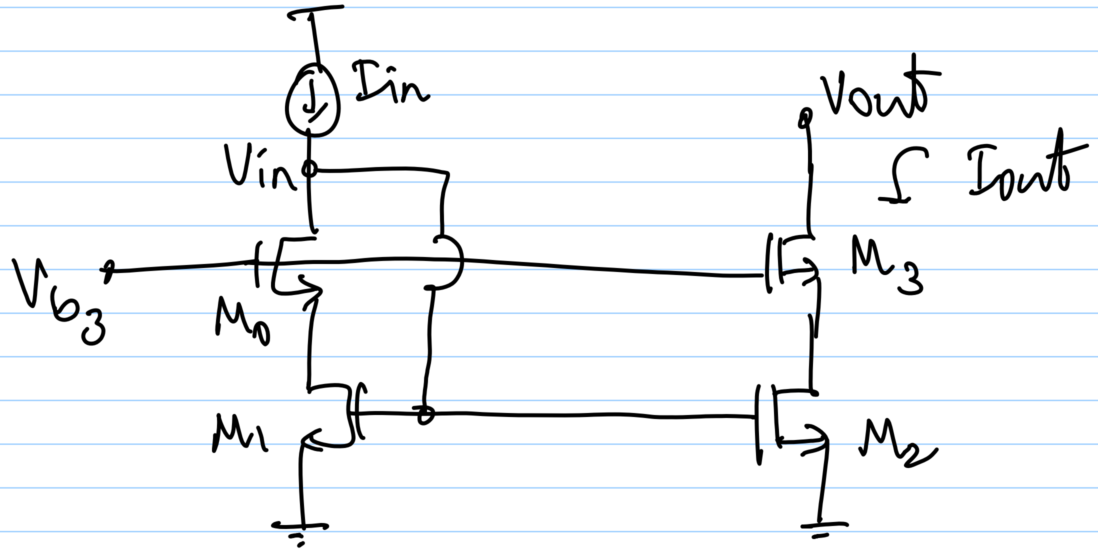
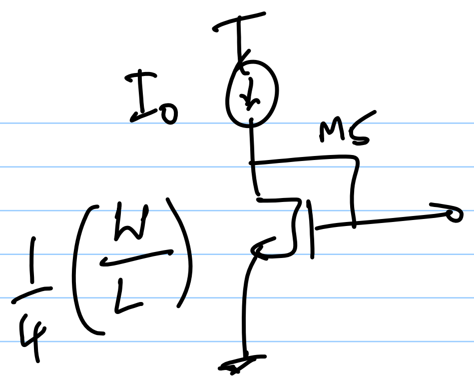
12/1/12

Lec 6



How to generate V_{b3}?

1)



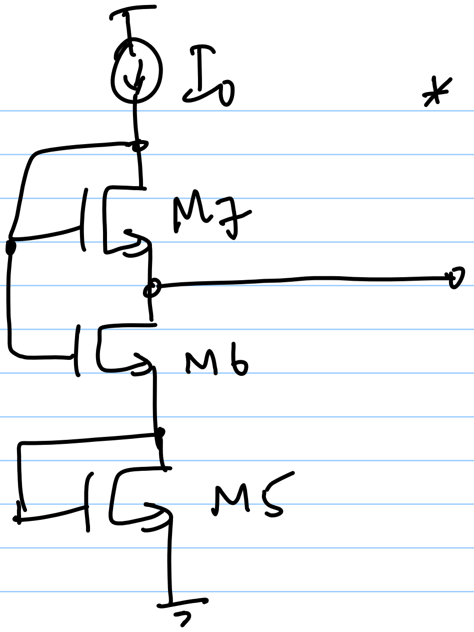
$V_{b3} = V_{T_5} + 2V_{DSAT}$

→ $V_{T_5} < V_{T_3}$ due to body effect

⇒ $V_{DS_2} < V_{DSAT}$

∴ some margin is required

2)



* M_7 has very large W/L

$\Rightarrow V_{GS7} \simeq V_{T7}$

$V_{b3} = V_{GS5} + V_{DS6}$

$= V_{GS5} + V_{GS6} - V_{T7}$

$\simeq V_{T5} + 2V_{DSAT}$

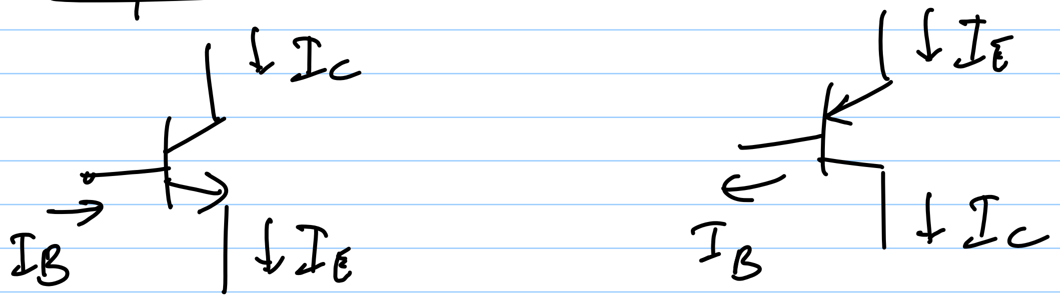
however, note that $V_{T7} \neq V_{T6}$

* For more types, see

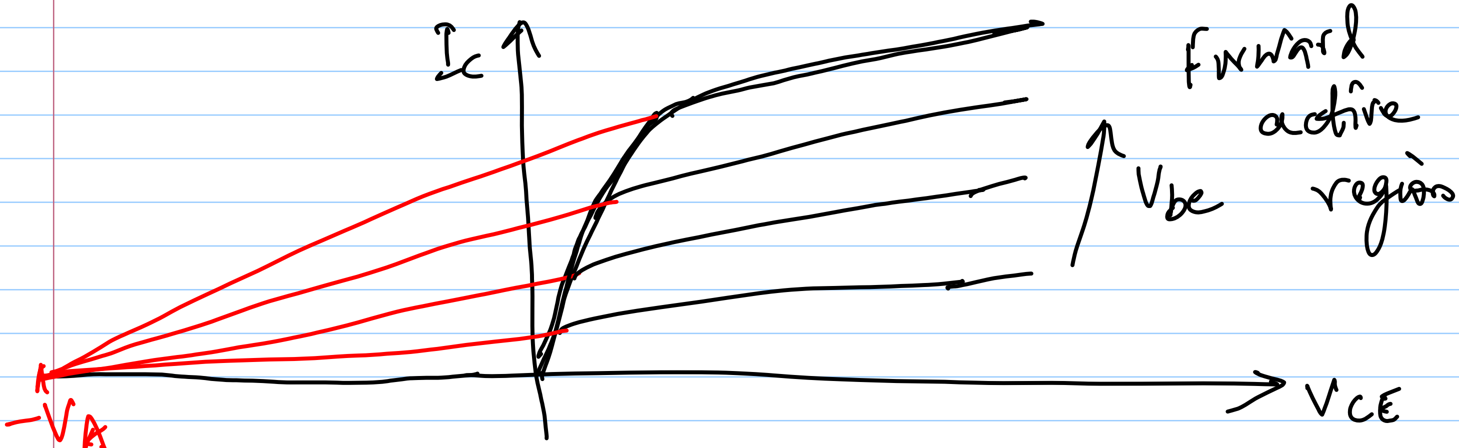
Razavi – figs 5.14 & 5.15

Gray & Meyer – figs 4.11, 4.12 & 4.13

Bipolar Devices



$I_E = I_B + I_C$



$$I_C = I_S \, e^{V_{BE}/V_T} \left(1 + \frac{V_{CE}}{V_A}\right)$$

$-V_A$ = early voltage

$$V_T = \frac{kT}{q} \simeq 26\,mV$$

* due to base width modulation

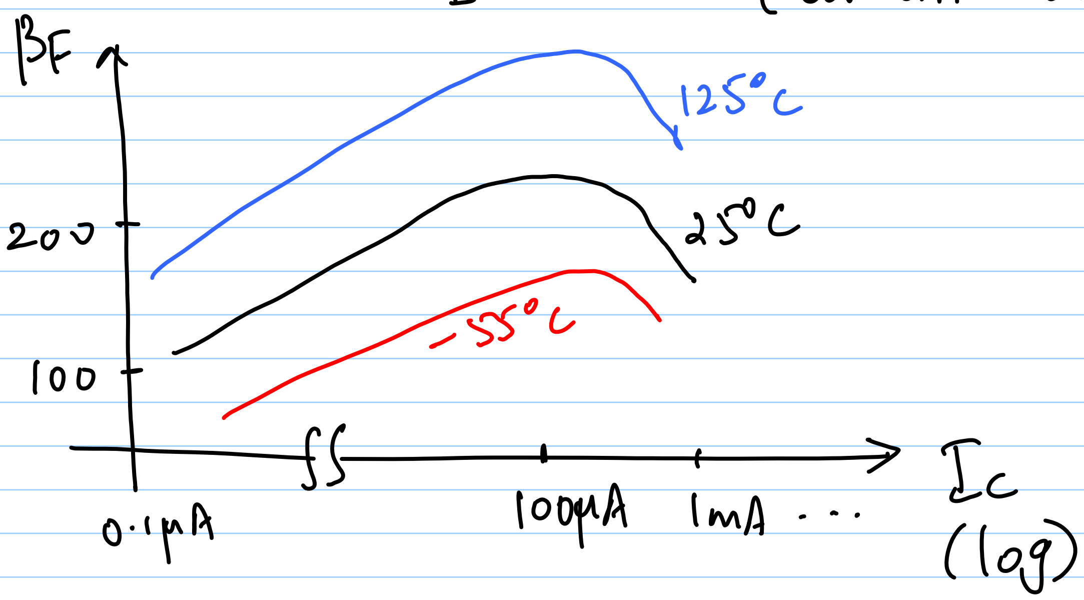
1) $r_o = \frac{\partial I_c}{\partial V_{CE}}$; $V_A = \frac{I_c}{\partial I_c / \partial V_{CE}}$

$$\Rightarrow r_o \simeq \frac{I_c}{V_A}$$

V_A is independent of I_c etc. & is a fixed process parameter

2) $g_m = \frac{\partial I_c}{\partial V_{be}} = \frac{I_c}{V_T}$

$\beta_F = \frac{I_c}{I_B}$ ← function of I_c (current density)



$$I_B = I_C / \beta_F \Rightarrow \delta I_B = \frac{d}{dI_C}\left(\frac{I_C}{\beta_F}\right) \cdot \delta I_C$$

$$\Rightarrow \beta_0 = \frac{\delta I_C}{\delta I_B} = \frac{i_c}{i_b} = \left[\frac{d}{dI_C}\left(\frac{I_C}{\beta_F}\right)\right]^{-1}$$

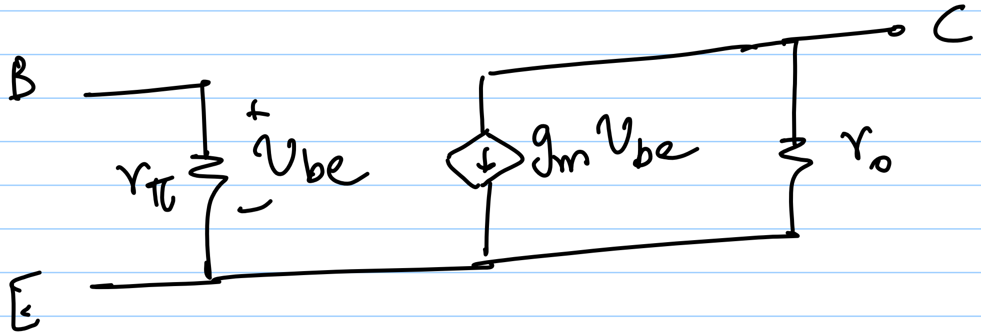
β_0 ← small-signal current gain

$\beta_0 \neq \beta_F$ in general

3) Input res. $r_\pi = \left(\frac{\partial I_b}{\partial V_{be}}\right)^{-1}_{Q\text{-pt.}}$

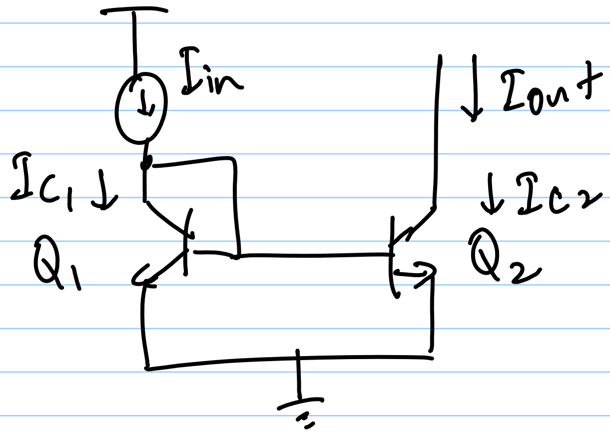
$$r_\pi = \frac{\beta_0}{g_m}$$

low-freq model:



Bipolar CMs

Simple CM:



$I_{C_2} = I_{out}$

$V_{be_1} = V_{be_2}$

$$V_T \ln \frac{I_{C_1}}{I_{S_1}} = V_T \ln \frac{I_{C_2}}{I_{S_2}}$$

$$\Rightarrow \quad \frac{I_{C_2}}{I_{C_1}} = \frac{I_{S_2}}{I_{S_1}}$$

$I_S \propto A_{EB}$ ← EB jn. area – design parameter

assume identical transistors

$I_{S_1} = I_{S_2} \Rightarrow I_{C_1} = I_{C_2} = I_{out}$

$$I_{in} = I_{C_1} + I_{b_1} + I_{b_2}$$

$$= I_{C_1} + \frac{I_{C_1}}{\beta_F} + \frac{I_{C_2}}{\beta_F}$$

$$= I_{out}\left[1 + \frac{2}{\beta_F}\right]$$

$$I_{out} = \frac{I_{in}}{1 + \frac{2}{\beta_F}}$$

← gain error due to finite β_F

If you have n mirror legs,

$$I_{out} = \frac{I_{in}}{1 + \frac{(n+1)}{\beta_F}}$$

If $Q_1 \neq Q_2$, $I_{S_1} \neq I_{S_2}$

$$\Rightarrow I_{in} = I_{C_1}\left(1 + \frac{1}{\beta_F}\right) + \frac{I_{C_2}}{\beta_F}$$

$$= I_{out}\left[\frac{1}{\beta_F} + \frac{I_{S_1}}{I_{S_2}}\left(1 + \frac{1}{\beta_F}\right)\right]$$

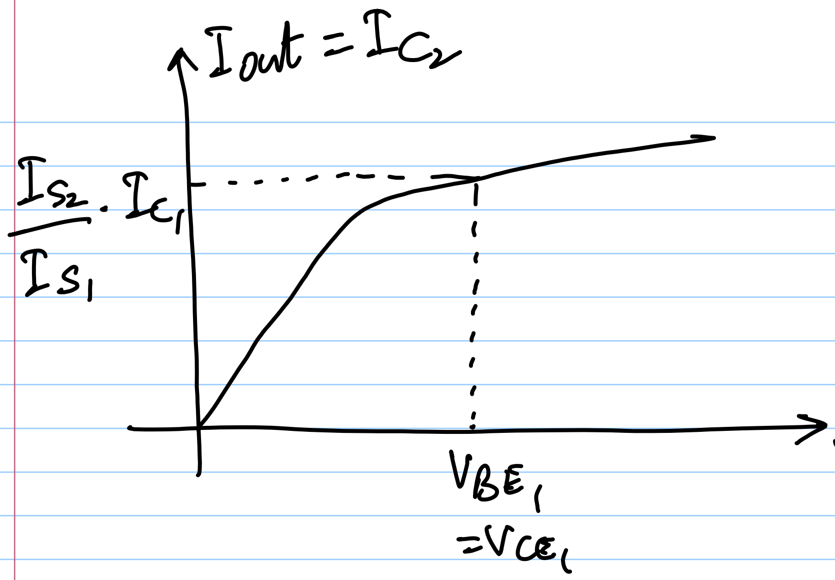
$$I_{out} = \frac{(I_{S_2}/I_{S_1})\, I_{in}}{1 + \frac{(1 + I_{S_2}/I_{S_1})}{\beta_F}}$$

Output impedance errors:

$$I_{C_1} = I_{S_1} e^{V_{BE_1}/V_T}\left(1 + V_{CE_1}/V_{A_1}\right)$$

$$I_{C_2} = I_{S_2} e^{V_{BE_2}/V_T}\left(1 + V_{CE_2}/V_{A_2}\right)$$

$$\Rightarrow I_{out} = \frac{(I_{S_2}/I_{S_1}) \cdot I_{in}}{1 + \frac{(1 + I_{S_2}/I_{S_1})}{\beta_F}} \cdot \left[1 + \frac{V_{CE_2} - V_{CE_1}}{V_A}\right]$$



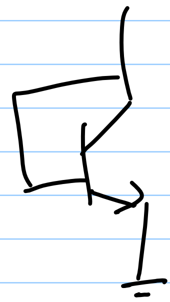
even with $\beta_F = \infty$, CM is balanced only @ 1 pt.

Error term

$$\epsilon = \frac{1 - \left(\frac{V_{CE_2} - V_{CE_1}}{V_A}\right)}{1 + \frac{1 + I_{S_2}/I_{S_1}}{\beta_F}} - 1 \approx \frac{V_{CE_2} - V_{CE_1}}{V_A} - \frac{1 + I_{S_2}/I_{S_1}}{\beta_F}$$

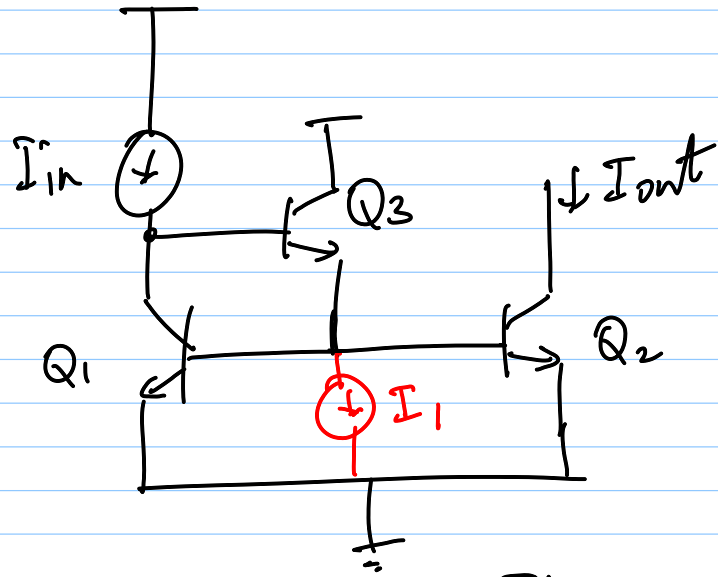
$$V_{out_{min.}} = V_{CE_{SAT_2}} \sim 0.2V$$

$$R_{in} = \frac{1}{\frac{1}{g_m}\left(1 + \frac{1}{\beta_0}\right) + \frac{1}{r_o}} \approx \frac{1}{g_m}$$



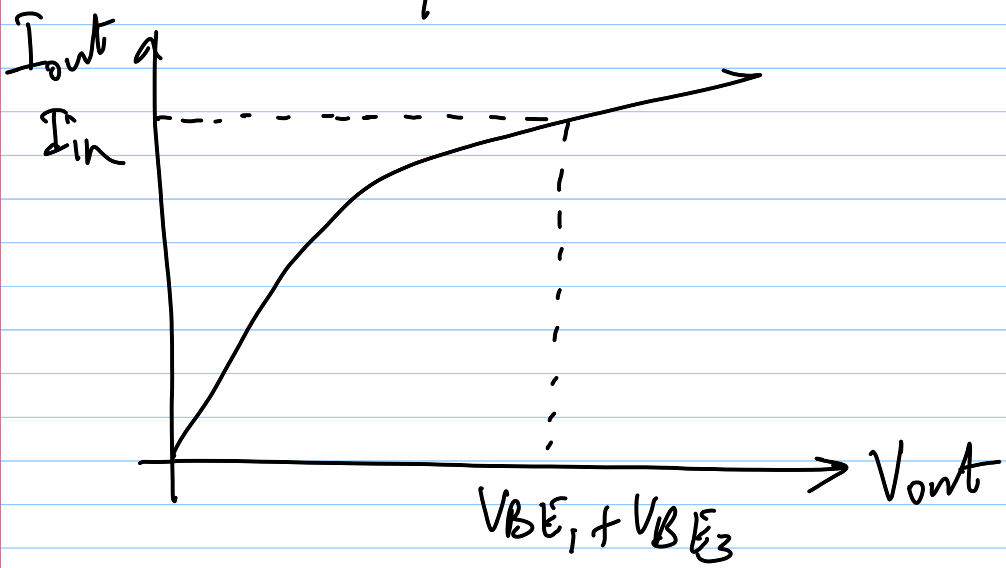
$$R_{out} = r_o$$

Simple CM with β-helper



$$I_{out} = \frac{I_{in}}{1 + \frac{2}{\beta_F(\beta_F+1)}} \simeq I_{in}\left[1 - \frac{2}{\beta_F(\beta_F+1)}\right]$$

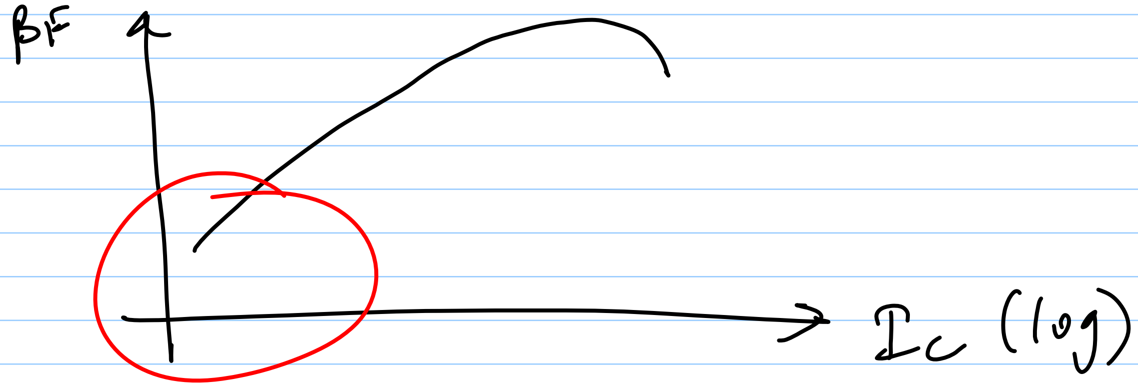
$$\epsilon \propto \frac{1}{\beta_F^2}$$



↑ $V_{in_{DC}}$ is different (different balance point)

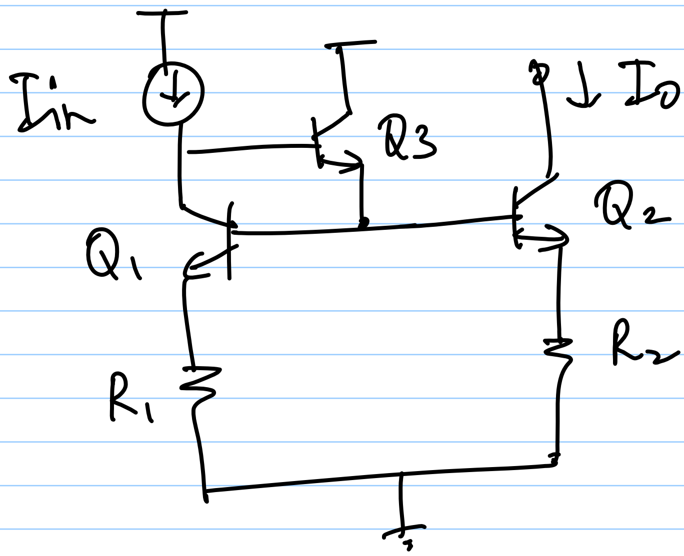
β_{F_3} could be very small

$I_{E_3} = I_{b_1} + I_{b_2}$ ← very small



⇒ add c.s. to increase I_{E_3}

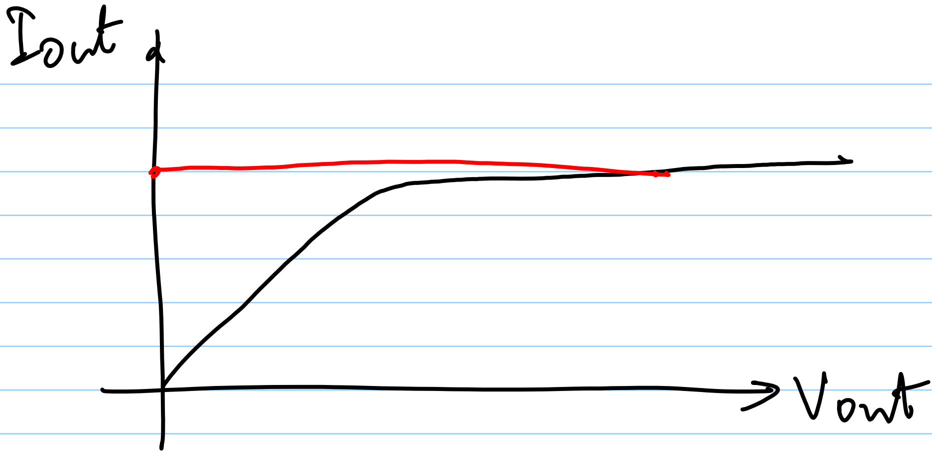
BJT CM w/ Emitter degen.:



* R_1 & R_2 improve matching of I_{C_1} & I_{C_2}
* R_1 & R_2 increase R_{out}

$$R_{out} \approx r_{o_2}(1 + g_{m_2} R_2)$$

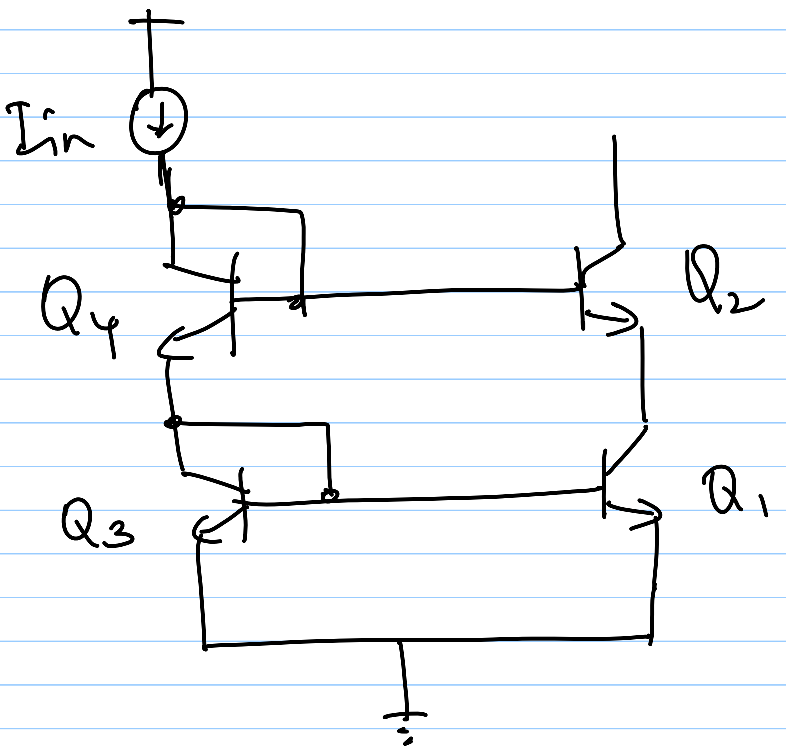
ϵ reduces (H.W.)



$V_{in} = I_{in} R_1 + V_{BE_1} + V_{BE_3}$

$V_{out_{min.}} = I_{out} R_2 + V_{CESAT_2}$

BJT cascode



$V_{in} = V_{BE_3} + V_{BE_4}$

$V_{CE_1} = V_{BE_3} + V_{BE_4} - V_{BE_2}$

$\simeq V_{BE_3}$

$V_{out_{min.}} = V_{BE_3} + V_{CESAT_2}$

$\sim 900mV$

$R_{out} \simeq \frac{\beta_0 r_{o_2}}{2}$

high $R_{out} \leftrightarrow V_{out\,min.}$ tradeoff

Other types:

- → Wilson & Balanced Wilson C.M.
- → Widlar C.S.
- → Bipolar peaking C.S.