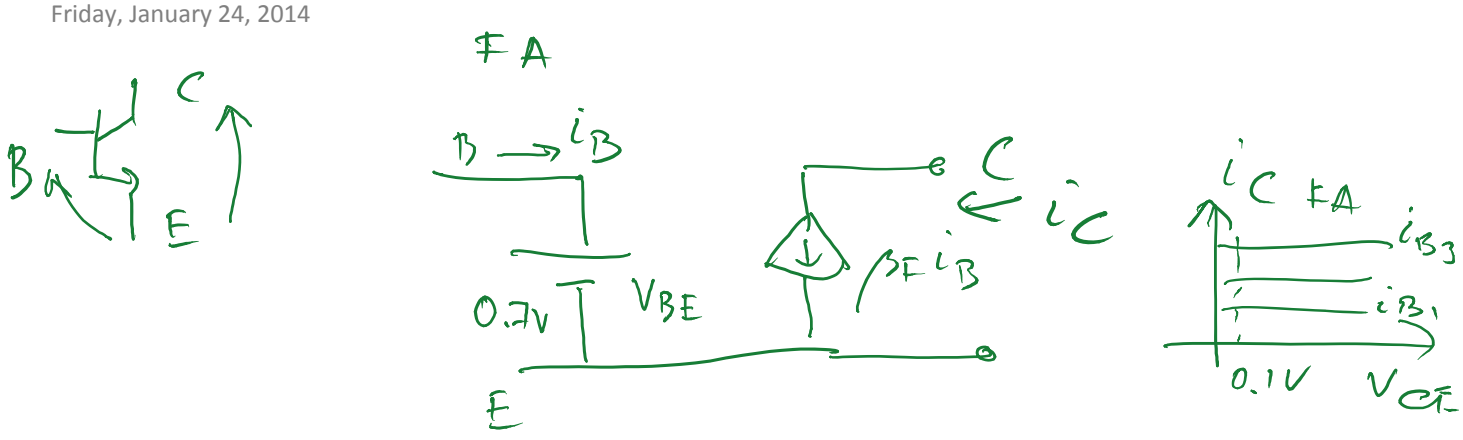
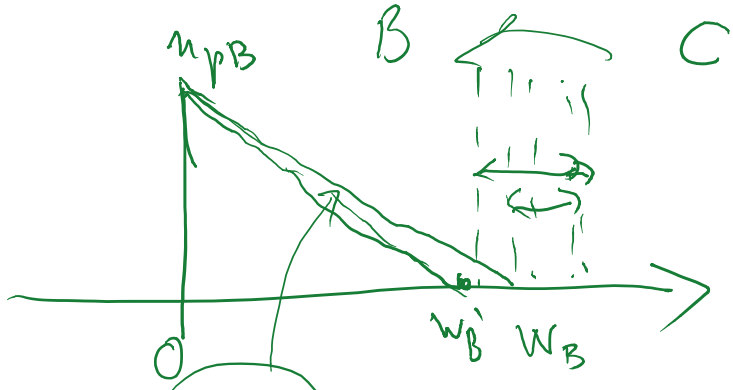
Lecture 3 - BJT SSM and biasing

EE140 Spring 2014
Vladimir Stojanović

Friday, January 24, 2014



Early effect - effect of V_{CE}



$$I_C = -AqD_{nB}\cdot\frac{dn_{pB}(x)}{dx} = -\frac{n_i^2}{N_{AB}\cdot W_B}\cdot e^{\frac{V_{BE}}{V_T}}$$

$$V_{CE} = V_{BE} + V_{BC}$$

V_{BE} ≈ 0.7V

$$\frac{\partial I_C}{\partial V_{CE}} = -\frac{I_C}{W_B}\cdot\frac{dW_B}{dV_{CE}}$$

V_{CE} ↑ → W_B ↓ → I_C ↑

Early voltage: $V_A = \frac{I_C}{\frac{\partial I_C}{\partial V_{CE}}} = -W_B\cdot\frac{dV_{CE}}{dW_B} \simeq -W_B\frac{1}{\frac{\partial W_B}{\partial V_{CB}}}$ ($dV_{CE} \to dV_{CB}$)

$V_A \simeq 15$–100 V

$V_A \approx 15 \ldots 100\,V$ ∂V_{CE}

∂V_{CB}

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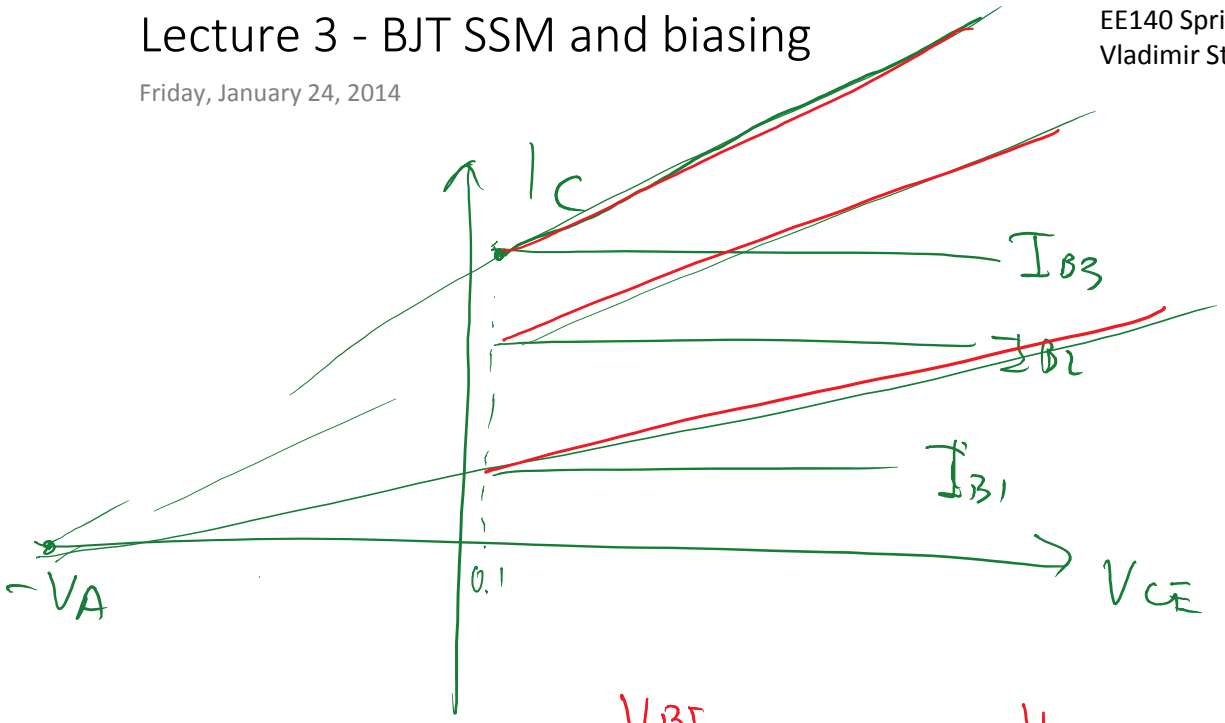
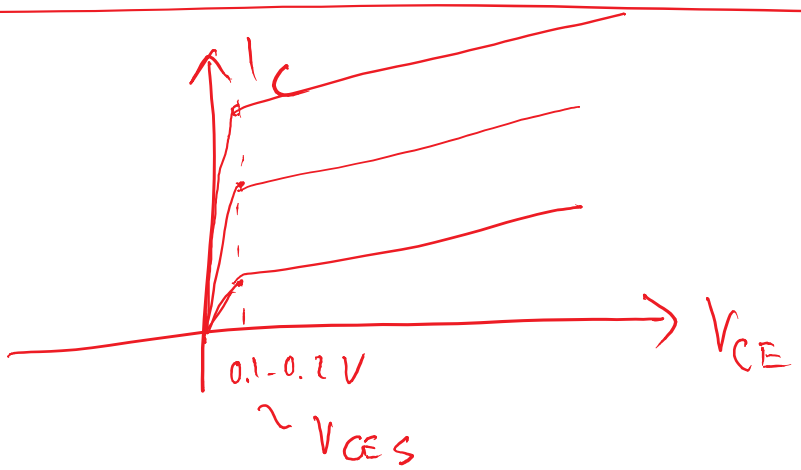


$$I_C = I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right)$$

Saturation:

BE	BC
F	F



$V_{BE} \simeq 0.7\,V$

$V_{CE} \simeq 0.1 - 0.2\,V$ Circuits set KVL

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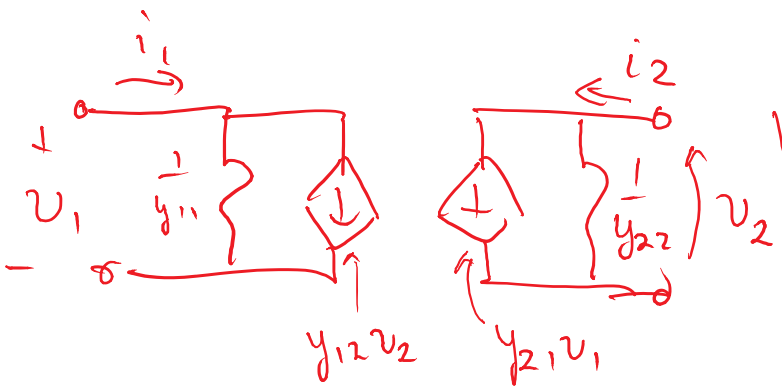
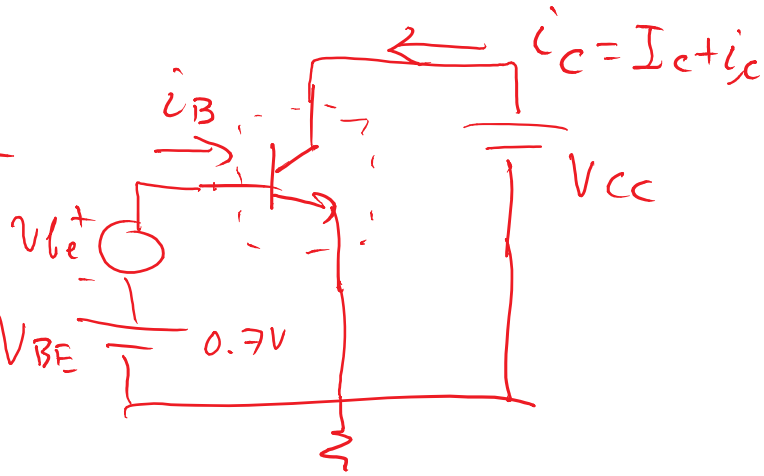
Small - signal :



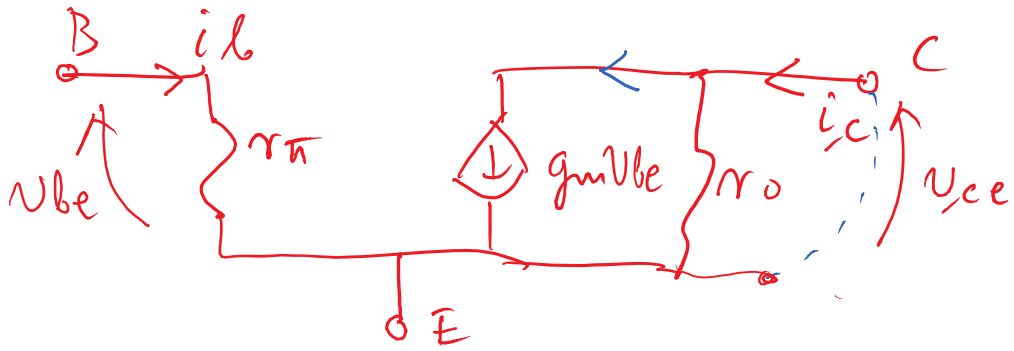


$$y_{11} = \left.\frac{i_1}{v_1}\right|_{v_2=0}$$

$$y_{22} = \left.\frac{i_2}{v_2}\right|_{v_1=0}$$

h FA

π - model



Model parameters:

r_π, g_m, r_o

① $g_m = \left.\frac{i_c}{v_{be}}\right|_{v_{ce}=0}$ (y_{21})

$$g_m = \frac{\partial i_C}{\partial v_{BE}} = \frac{\partial}{\partial v_{BE}}\left(I_S e^{\frac{v_{BE}}{V_T}}\right) = \frac{I_S}{V_T} e^{\frac{v_{BE}}{V_T}} = \frac{I_C}{V_T}$$

$$\boxed{g_m = \frac{I_C}{V_T}} \qquad V_T = \frac{kT}{q}$$

$$g_m = \frac{1}{V_T} \qquad V_T = \frac{kT}{q}$$

(2) input resistance r_π :

$$r_\pi = \left.\frac{v_{be}}{i_b}\right|_{v_{ce}=0} = \left.\frac{\partial v_{BE}}{\partial i_B}\right| = \left.\frac{\partial v_{BE}}{\partial \left(\frac{i_C}{\beta_0}\right)}\right|_{V_{CE}=\text{const}} = \left.\frac{\beta_0}{g_m}\right|_{V_{CE}=\text{dc}}$$

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

(3) Output resistance :

$$r_o = \left.\frac{v_{ce}}{i_c}\right|_{v_{be}=0} = \left.\frac{\partial v_{CE}}{\partial i_C}\right| = \left.\frac{1}{\frac{\partial i_C}{\partial v_{CE}}}\right|_{V_{BE}=\text{const}} =$$

$$= \left.\frac{1}{\frac{\partial}{\partial v_{CE}}\left(I_S e^{\frac{V_{BE}}{V_T}} \cdot \left(1+\frac{v_{CE}}{V_A}\right)\right)}\right|_{V_{BE}=\text{const}} = \frac{V_A}{I_C}$$

$$\boxed{r_o = \frac{V_A}{I_C}}$$

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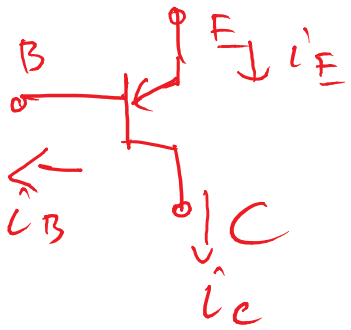
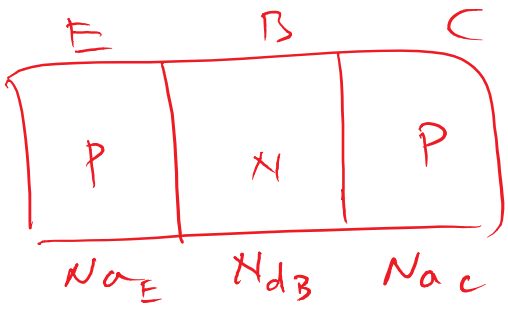
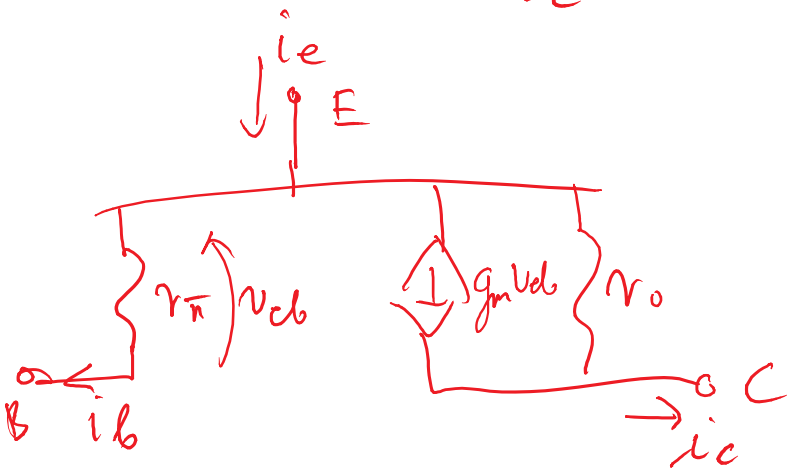
PNP







Summary:

$$g_m \cdot r_\pi = \beta_0$$

$$g_m = \frac{I_C}{V_T}$$

$$r_o = \frac{V_A}{I_C}$$

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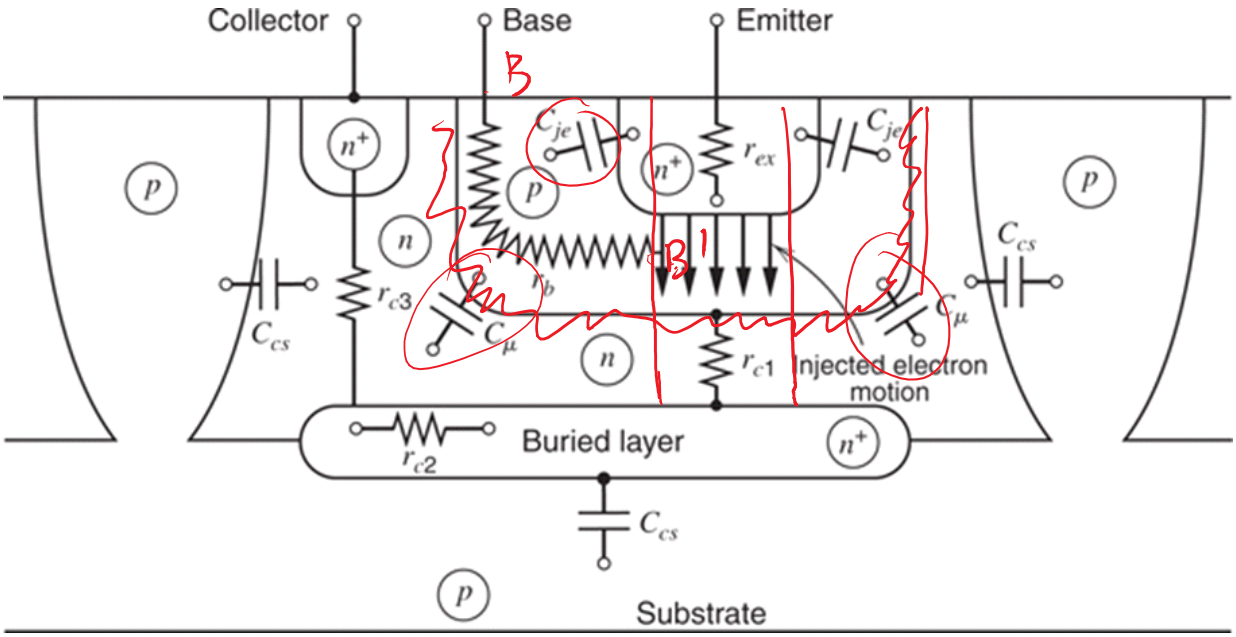
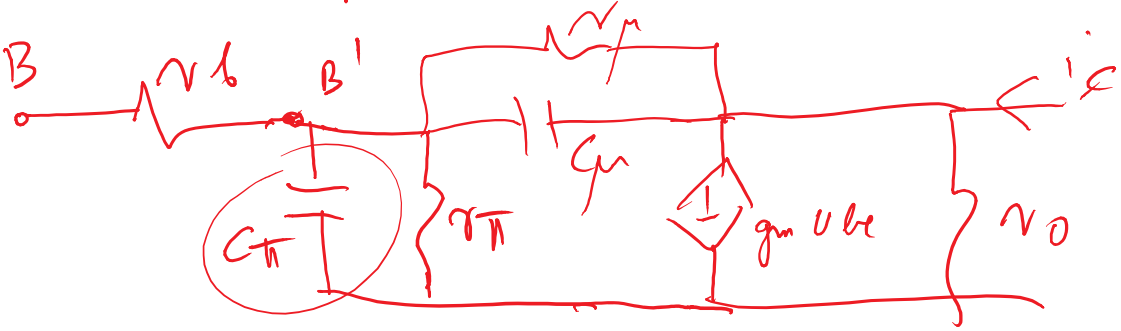
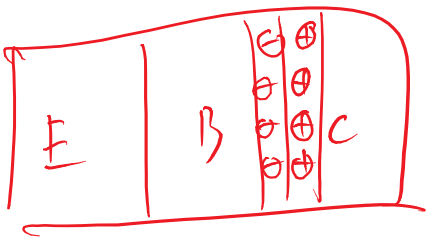


More complete model



C_μ - base - collector depletion cap

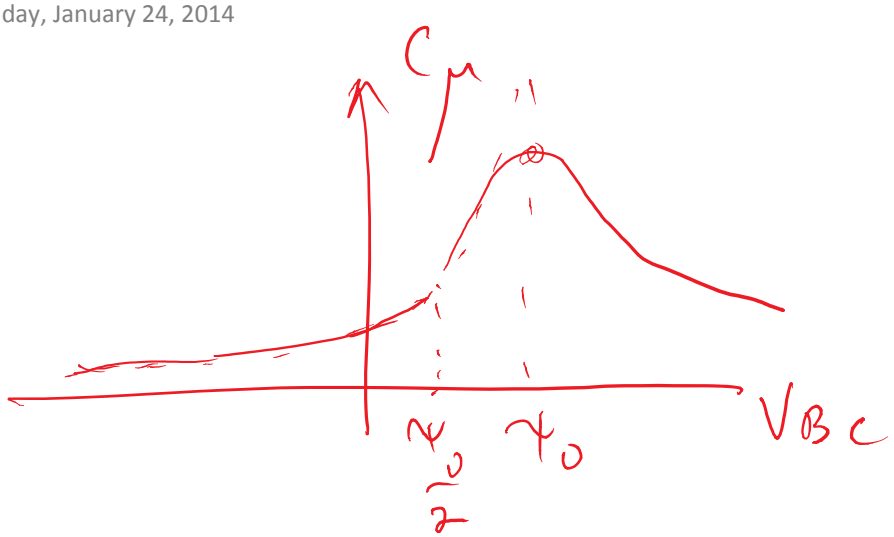
$$C_\mu = \frac{C_{\mu 0}}{\sqrt{1 + \frac{V_{CB}}{\psi_0}}}$$



ψ_0 - built-in potential

$$\psi_0 = V_T \ln \frac{N_{AB} N_{DC}}{n_i^2}$$

$$C_\mu = A \sqrt{q \frac{\varepsilon N_{AB} N_{DC}}{2(N_{AB} + N_{DC})}}$$



C_π : Base – Emitter

① junction-capacitance (C_{je})

② diffusion-capacitance

$\tau_F = \frac{Q_E}{i_C}$ ← charge in "transit"

$= \frac{\Delta Q_E}{\Delta i_C} \Rightarrow$ $q_e = \tau_F \cdot i_c = C_b \cdot v_{be}$

$C_b = \frac{\tau_F \cdot i_C}{v_{be}} \overset{g_m}{=} \tau_F g_m$

$C_\pi \approx C_b$ since $C_{je} \ll C_b$

Collector – Base resistance

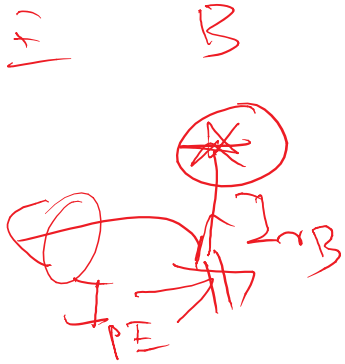
NPN

$$r_\mu = \frac{\Delta V_{CE}}{\Delta i_{rB}} = \frac{\Delta V_{CE}}{\Delta i_c} \cdot \frac{\Delta i_c}{\Delta i_{rB}} \simeq 10\beta_0 r_0$$

$\simeq 10/\beta_0$

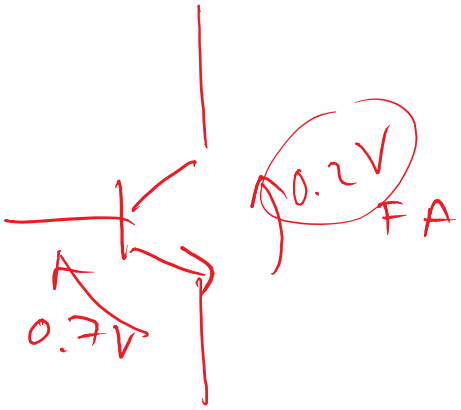
r_0

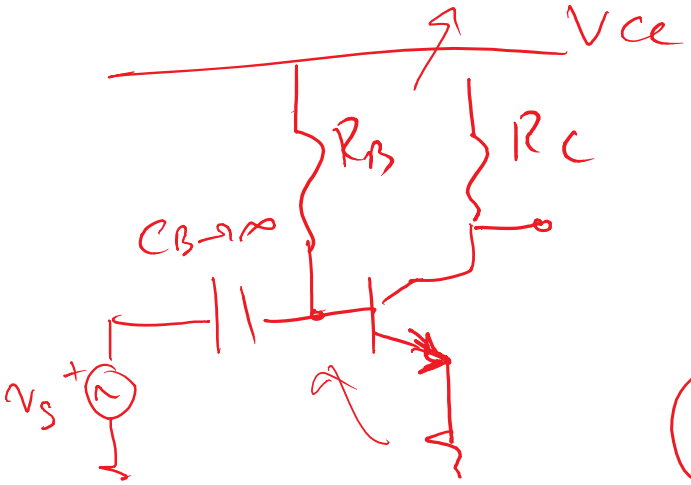
$\frac{\Delta i_c}{\Delta i_B} \simeq \beta_0$



b, c

$I_{BE} >> I_{rB}$





Problem:

1. β_F dependent
2. Vce dependent
3. Thermal runaway

$T\uparrow, I_C\uparrow, T\uparrow, I_C\uparrow$

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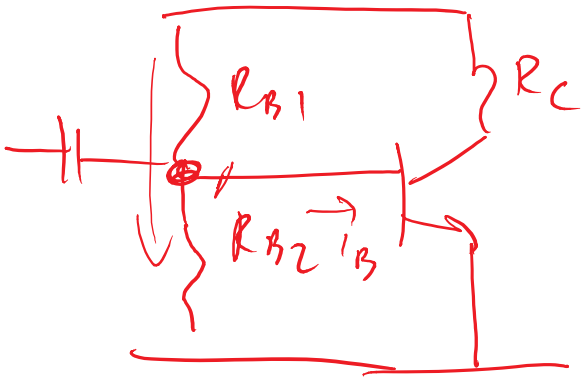
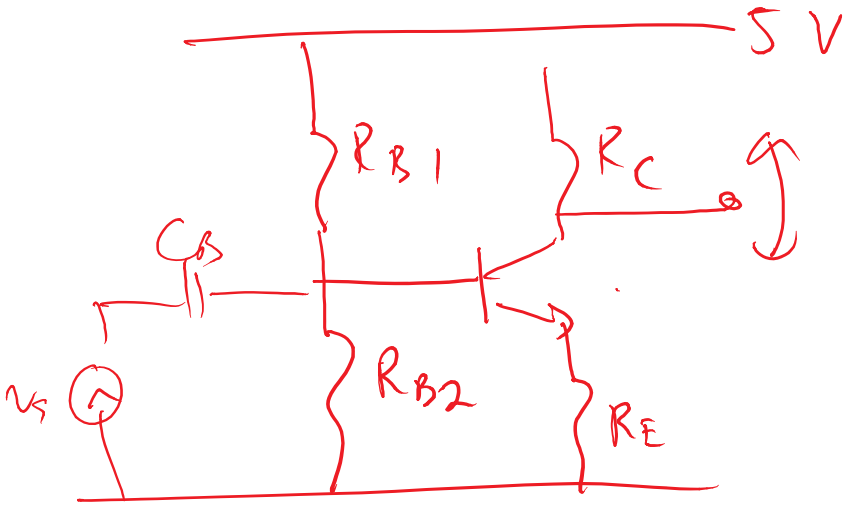


$$I_C \sim I_S e^{\frac{V_{BE}}{V_T}}$$



Challenge Problem.
Find R_{B1}, R_{B2}, R_C and R_E so that Ic=1mA and output voltage swing is maximized.
Assume V_{CES} = 0.1V.

$I_C = 1mA$, max out swing

$\beta_F = 100$, $V_{CC} = 5V$, $V_A = 100V$,
