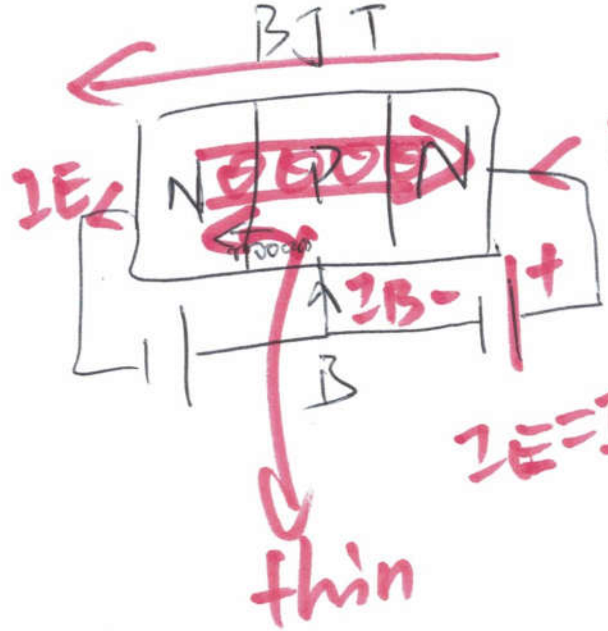
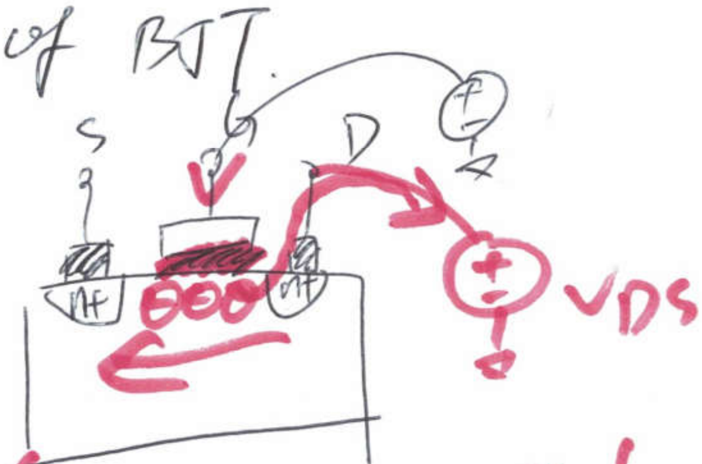
The DC Bias Point of BJT





$I_E = I_B + I_C$

voltage controlled current source (VCCS)

$g_m = \beta (V_{GS} - V_{TH})$

$= \sqrt{2 I_D \beta}$

$I_D = \frac{\beta}{2} (V_{GS} - V_{TH})^2$

$\beta = 100$

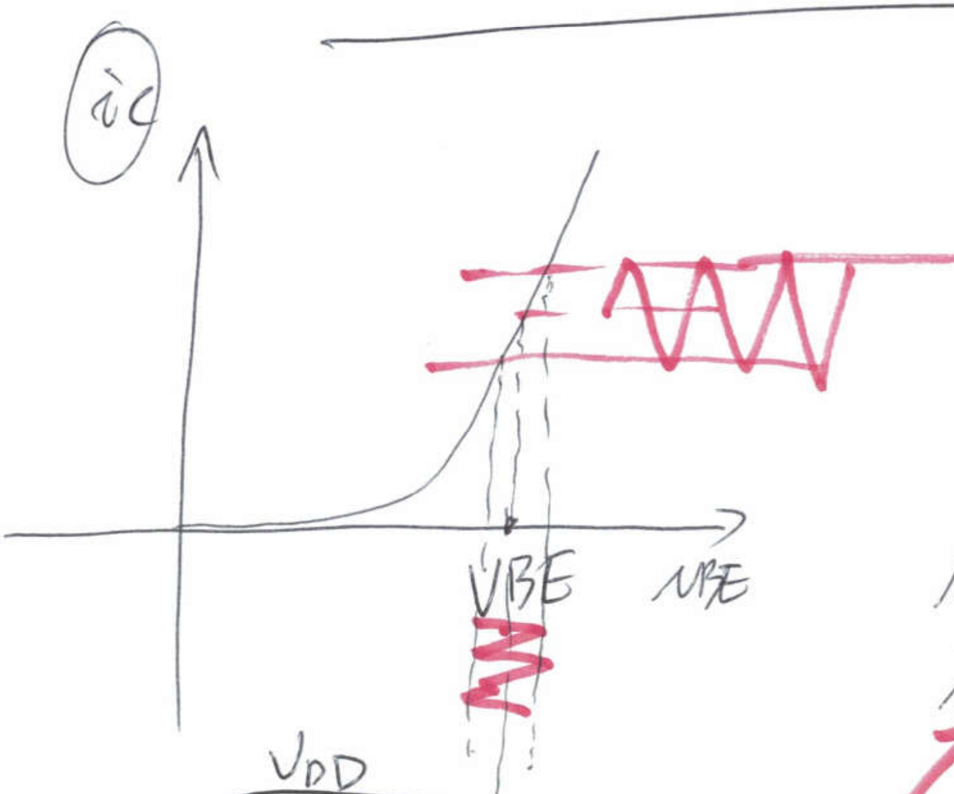
$$\begin{cases} I_B \cdot \beta = I_C \\ I_E = I_B + I_C \end{cases}$$

current controlled current source

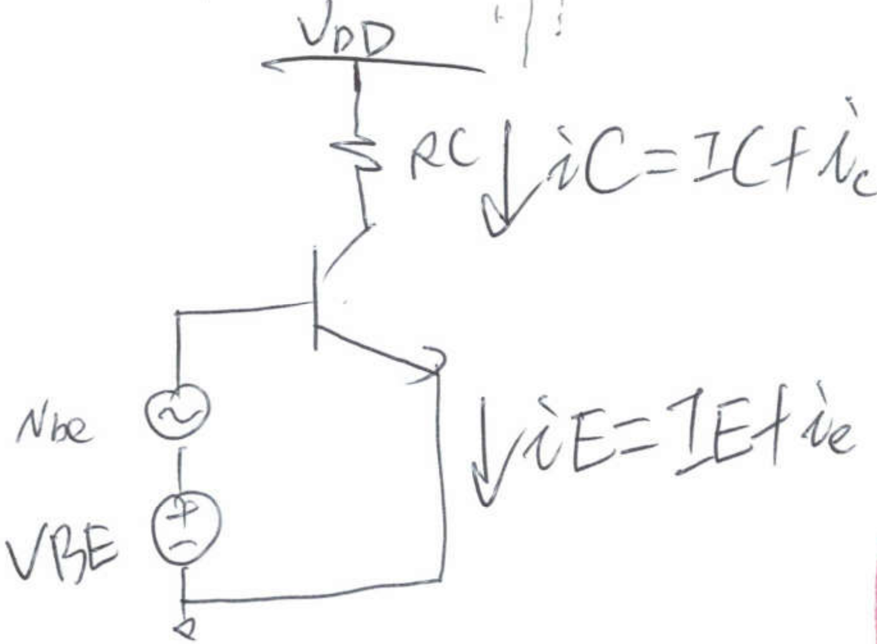
CCCS

BJT	CMOS
High power consumption Higher speed (RF)	smaller.

BJT DC operating Point



- V_{BE} : DC Bias Voltage
- v_{be} : AC small signal
- v_{BE} : $V_{BE} + v_{be}$



$$v_{BE} = V_{BE} + v_{be}$$

$$i_C = I_S e^{v_{BE}/V_T}$$

($V_T = 25\,mV$ in room-temp.)

$$\frac{\partial i_C}{\partial v_{BE}} = g_m = \frac{\partial (I_S \cdot e^{v_{BE}/V_T})}{\partial v_{BE}} = \frac{I_S \cdot e^{v_{BE}/V_T}}{V_T} \simeq \frac{I_C}{V_T}$$

$$i_c = g_m \cdot v_{be}$$

$$v_b = \frac{i_c}{\beta} = \frac{g_m v_{be}}{\beta} = \frac{I_C v_{be}}{V_T \cdot \beta} = \frac{I_B}{V_T} \cdot v_{be}$$

$$r_{be} = \frac{v_{be}}{i_b} = \frac{V_T}{I_B}$$

Example: $I_C = 0.5mA$, β change from 50 → 200, what are the possible ranges of g_m, I_B, are r_{be}?

$$g_m = \frac{I_C}{V_T} = \frac{0.5mA}{0.025V} = 20mA/V$$, doesn't change.

$$I_B = \frac{I_C}{\beta} \quad I_{B_1} = \frac{0.5mA}{50} \quad I_{B_2} = \frac{0.5mA}{200}$$

$$I_B \sim (0.01mA - 0.0025mA) = (2.5\mu A \to 10\mu A)$$

$$r_{be} \sim \left(\frac{0.025V}{2.5\mu A}, \frac{0.025V}{10\mu A}\right) = (2.5K, 10K)$$

$$I_C + I_B = I_E$$

$$I_C + \frac{I_C}{\beta} = I_E$$

$$\frac{\beta I_C + I_C}{\beta} = I_E$$

$$\frac{(1+\beta) I_C}{\beta} = I_E$$

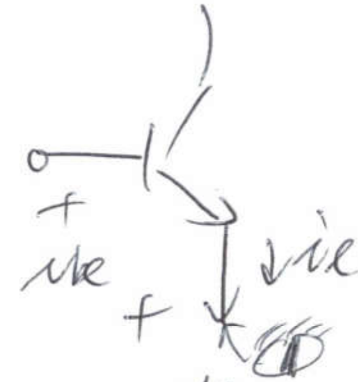
$$I_C = \frac{\beta}{1+\beta} I_E \quad \alpha$$

$$I_C = \alpha I_E$$

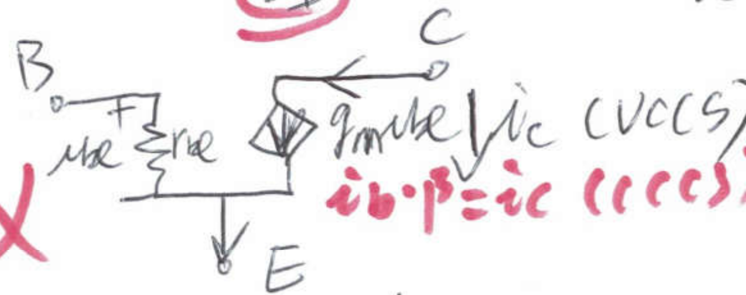
$$i_e = \frac{i_c}{\alpha} = \frac{g_m v_{be}}{\alpha} = \frac{I_C}{V_T} \cdot \frac{v_{be}}{\alpha} = \frac{I_E v_{be}}{V_T} \Rightarrow$$

$$\Rightarrow \frac{v_{be}}{i_e} = \frac{V_T}{I_E} = r_e$$

$$r_\pi = \frac{v_{be}}{i_b} = \frac{V_T}{I_B}$$

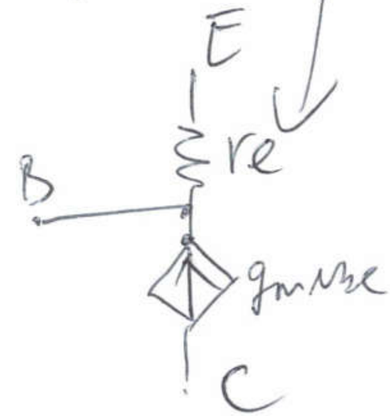


$$r_e = \frac{v_{be}}{i_e}$$



$i_b \cdot \beta = i_c$ (CCCS)

$$\beta = 100, \quad \alpha = \frac{100}{1+100} \approx 1$$



The Voltage Gain

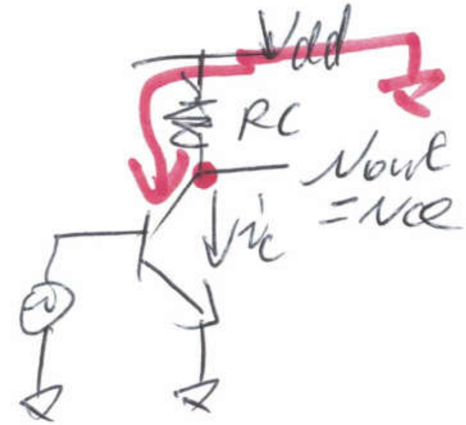
$$\text{Gain} = \frac{\text{Output}}{\text{Input}}$$

$$A_V = \frac{v_{ce}}{v_{be}} = \frac{-i_c \cdot R_C}{v_{be}}$$

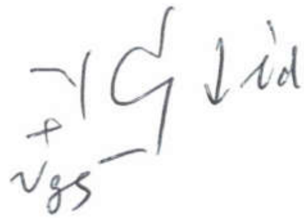
$$= \frac{-g_m v_{be} \cdot R_C}{v_{be}}$$

$$= -g_m R_C$$

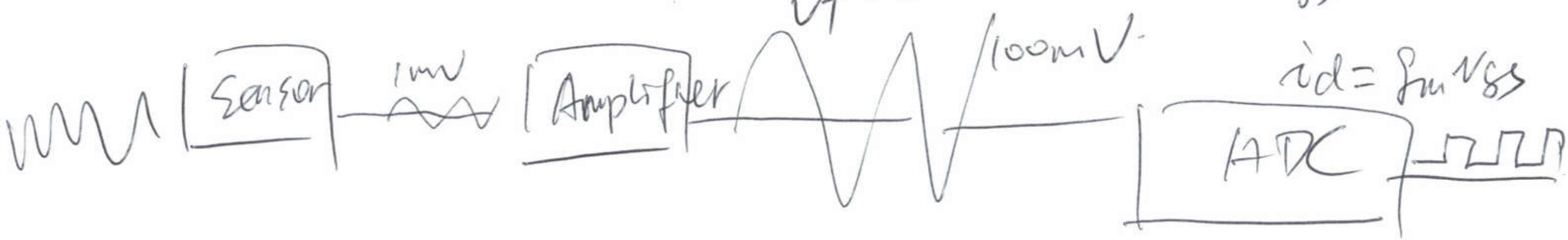
$$= -\frac{I_C}{V_T} R_C$$



$$v_{out} = -i_c \cdot R_C$$



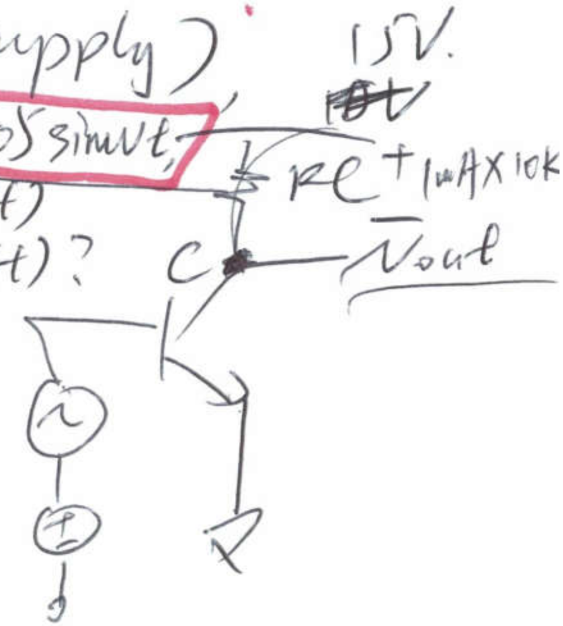
$$i_d = g_m v_{gs}$$



Example:

$I_C = 1mA$, $V_{CC} = 15V$ (power supply),

$R_C = 10K\Omega$, $\beta = 100$, if $v_{be} = 0.005\sin\omega t$, find $v_C(t)$, $i_B(t)$?



① $A_V = -g_m R_C = -\frac{I_C}{V_T} \cdot R_C$

$= -\frac{1mA}{0.025} \cdot 10K\Omega$

$= -0.04 \cdot 10K = -0.4K$

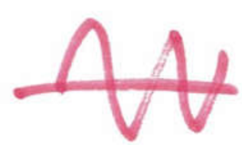
② $v_C(t) = V_C(t) + v_c(t) = 5V + (-i_c \cdot R_C)$

$= 5 + (-g_m v_{be}(t) \cdot R_C)$

$= 5 - \left(\frac{I_C}{V_T} \cdot R_C \cdot 0.005\sin(\omega t)\right)$

$= 5 - 0.4K \cdot 0.005\sin\omega t$

$= 5 - 2 \cdot \sin\omega t.$

5V 

③ $i_B(t) = I_B + i_b(t) = \frac{I_C}{\beta} + \frac{v_{be}(t)}{r_{be}} = \frac{I_C}{\beta} + \frac{v_{be}(t)}{V_T/I_B} = \ldots$