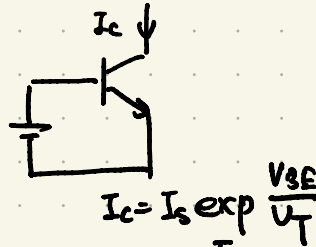# Lec 9

- Detailed Analysis of Bipolar Diff Pair.
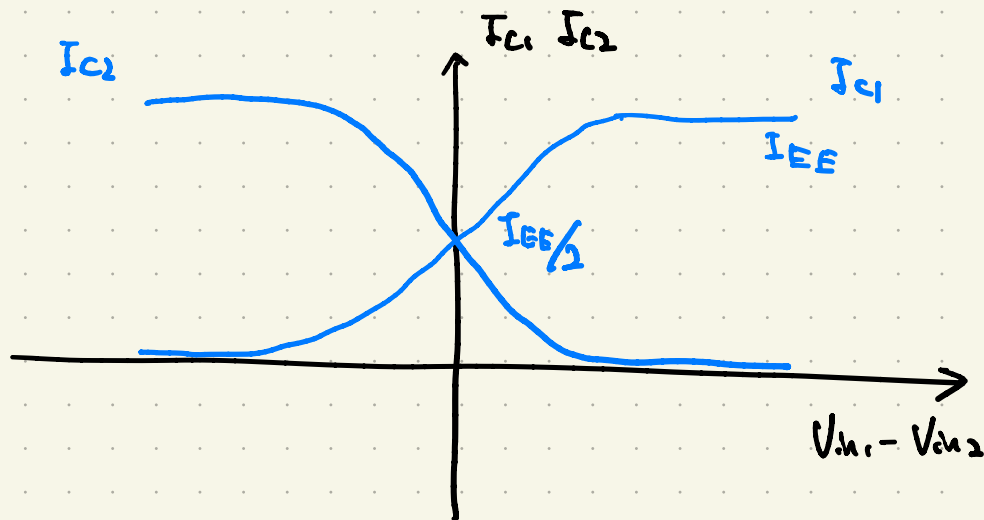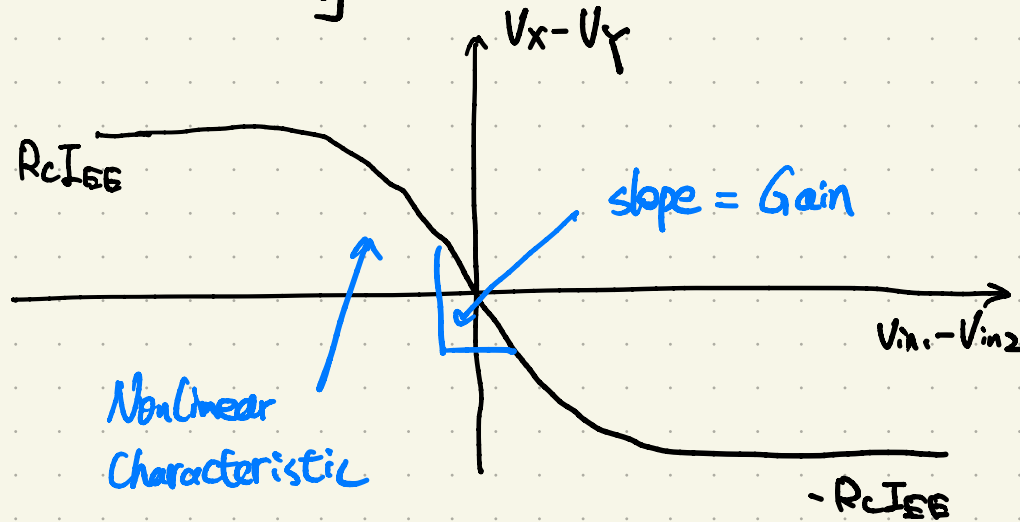 Large-signal Response
  (Input-Output charac.)

$$I_c = I_s \exp \frac{V_{BE}}{V_T}$$

$$V_{BE} = V_T \ln \frac{I_c}{I_s}$$

- Intuitive Study

$V_X - V_Y$

$R_C I_{EE}$

slope = Gain

Nonlinear Characteristic

$V_{in_1} - V_{in_2}$

$-R_C I_{EE}$

$I_{C_1} \ I_{C_2}$

I_{C_2}

I_{C_1}

I_{EE}

$I_{EE}/2$

$V_{in_1} - V_{in_2}$

Objective: Derive equations for I_{C_1}, I_{C_2}, V_X, V_Y and $V_X - V_Y$ as a function of $V_{in_1} - V_{in_2}$
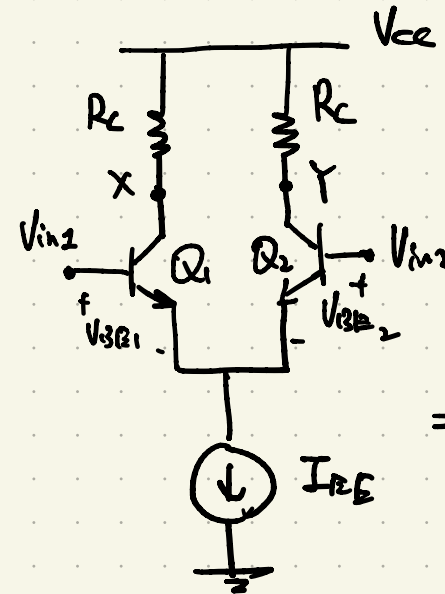
$$V_{in_1} - V_{BE_1} = V_{in_2} - V_{BE_2}$$

$$V_{in_1} - V_{in_2} = V_{BE_1} - V_{BE_2}$$

$$= V_T \ln \frac{I_{C_1}}{I_S} - V_T \ln \frac{I_{C_2}}{I_S}$$

$$\Rightarrow \begin{cases} V_{in_1} - V_{in_2} = V_T \ln \frac{I_{C_1}}{I_{C_2}} \\ I_{C_1} + I_{C_2} = I_{EE} \end{cases}$$

then we get:

$$\begin{cases} I_{C_2} = \dfrac{I_{EE}}{1 + \exp \dfrac{V_{in_1} - V_{in_2}}{V_T}} \\[4ex] I_{C_1} = \dfrac{I_{EE}}{1 + \exp \dfrac{V_{in_2} - V_{in_1}}{V_T}} \end{cases}$$
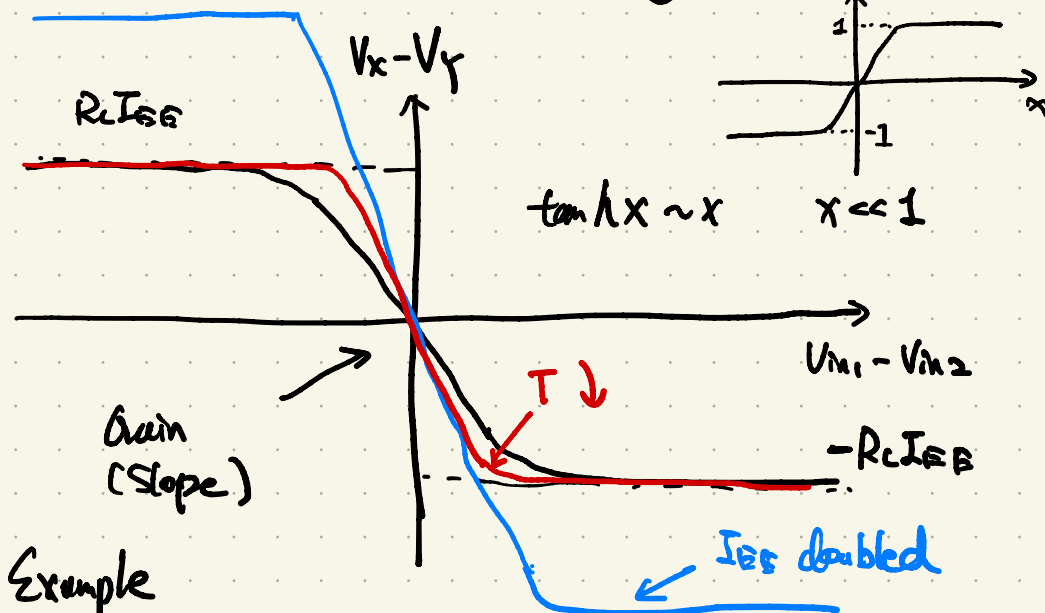
observations:

$$\begin{cases} ① \ V_{in_1} = V_{in_2} \Rightarrow \dfrac{I_{EE}}{2} \\[2ex] ② \ V_{in_1} - V_{in_2} \text{ positive enough} \\ \quad I_{C_1} \rightarrow I_{EE} \quad I_{C_2} \rightarrow 0 \end{cases}$$

$$V_x = V_{cc} - R_c I_{c1} = V_{cc} - R_c \frac{I_{EB}}{1 + \exp \frac{V_{in2} - V_{in1}}{V_T}}$$

$$V_Y = V_{cc} - R_c I_{c1} = V_{cc} - R_c \frac{I_{EE}}{1 + \exp \frac{V_{in1} - V_{in2}}{V_T}}$$

$$\boxed{V_x - V_Y = -R_c I_{EE} \tanh \frac{V_{in1} - V_{in2}}{2V_T}}$$

$\tanh x \sim x \qquad x \ll 1$

$V_x - V_Y$

$R_c I_{EE}$

$V_{in1} - V_{in2}$

$-R_c I_{EE}$

$T \downarrow$

Gain
(Slope)

I$_{EE}$ doubled

Example

Find the slope of the charac. around

$V_{in1} - V_{in2} \approx 0$

If $\dfrac{V_{in1} - V_{in2}}{2V_T} \ll 1 \Rightarrow \tanh \dfrac{V_{in1} - V_{in2}}{2V_T} \approx \dfrac{V_{in1} - V_{in2}}{2V_T}$

$$\Rightarrow V_x - V_Y \approx -R_c I_{EE} \frac{V_{in1} - V_{in2}}{2V_T}$$

$$\text{slope} = -\frac{R_c I_{EE}}{2}$$

Example

What happens to the charac. if

I_{EE} is doubled?

R_c is doubled?

(same as I_{EE} doubled)

Example

What happens if the ambient temperature drops considerably?

slope $\uparrow$