Lec 10

- Summary of Diff Pair Operation
- Small-Signal Analysis

$$V_X - V_Y = -R_C I_{EE} \tanh \frac{V_{in1} - V_{in2}}{2V_T}$$

- Summary of Diff Pair Properties

① If $|V_{in1} - V_{in2}|$ is large, all of the tail current is "steered" to one side.

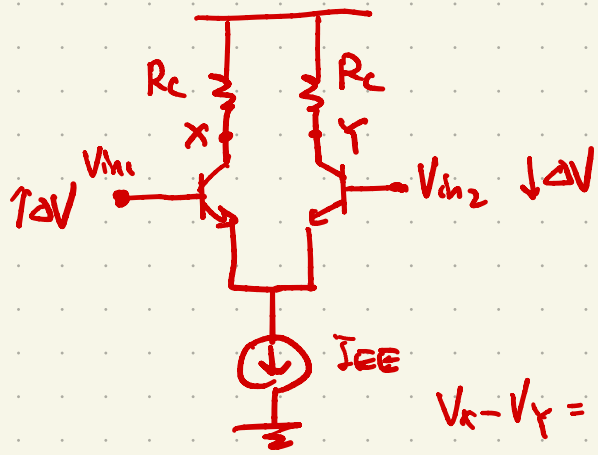
⇒ "current-steering" circuits

② if $V_{in1} = V_{in2}$ and $V_{CM,in}$ goes up and down ⇒ the currents & voltages do not change.

③ If $|V_{in1} - V_{in2}| \ll 2V_T$

$$\Rightarrow \text{slope} = -\frac{R_C I_{EE}}{2V_T}$$

Quiz: Can this circuit amplify?



$$V_X - V_Y = -R_C I_{EE} \tanh \frac{2\Delta V}{V_T}$$

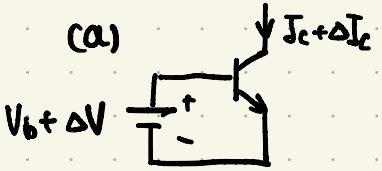
$$\approx -R_C I_{EE} \frac{2\Delta V}{V_T}$$

if greater than 1 ⇒ amp

• Small-Signal Analysis

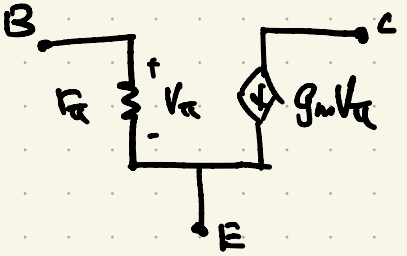
Two Basic Concepts:

(a)



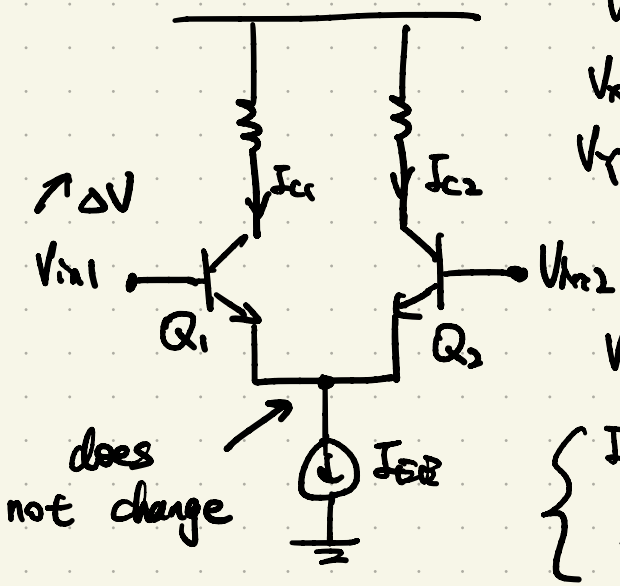
$$\Delta I_C / \Delta V = g_m = \frac{I_C}{V_T}$$

(b)



Lemma

If V_{in1} and V_{in2} change by equal and opposite amount and the change is small, then the tail node voltage does not change



$$V_R - V_F = -R_C I_{EE} \frac{2\Delta V}{2V_T}$$

$$V_R = V_{CC} - R_C I_{C1}$$

$$V_F = V_{CC} - R_C I_{C2}$$

$$V_R - V_F = -R_C (I_{C1} - I_{C2})$$

$$\begin{cases} I_{C1} - I_{C2} = I_{EE} \dfrac{\Delta V}{V_T} \\ I_{C1} + I_{C2} = I_{EE} \end{cases}$$

$$\Rightarrow I_{C1} = \frac{I_{EE}}{2}\left(1 + \frac{\Delta V}{V_T}\right)$$

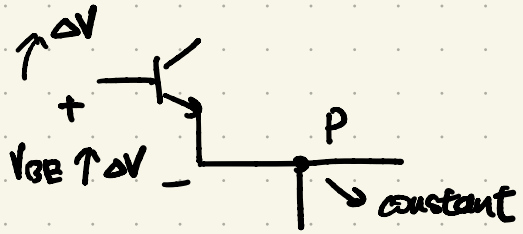
$$\Delta I_{C1} = \frac{I_{EE}}{2V_T}\Delta V$$

$$g_m = \frac{dI_C}{dV_{BE}}$$

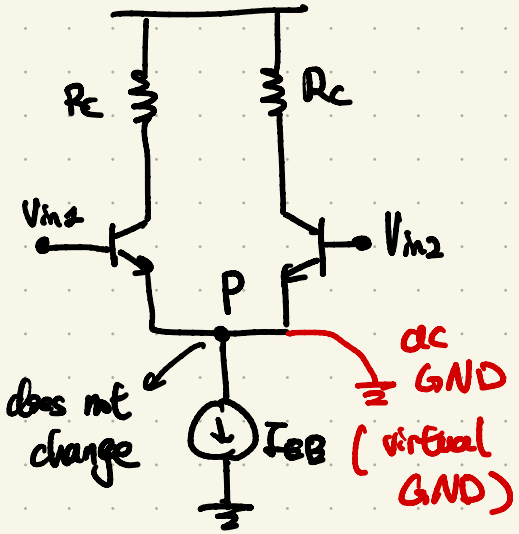
$$dI_C = g_m dV_{BE}$$

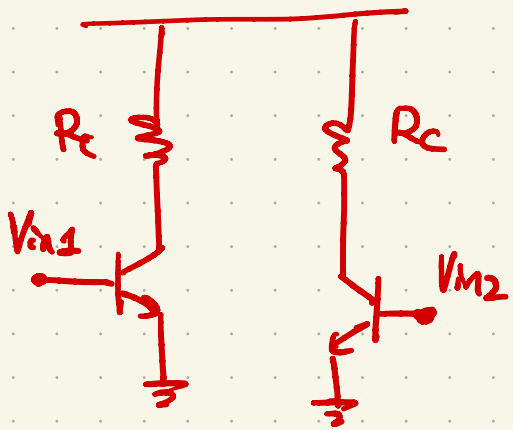
then

$$\Delta V_{BE} = \frac{\frac{I_{EE}}{2V_T}\Delta V}{\frac{I_{EE}}{2V_T}} = \Delta V$$



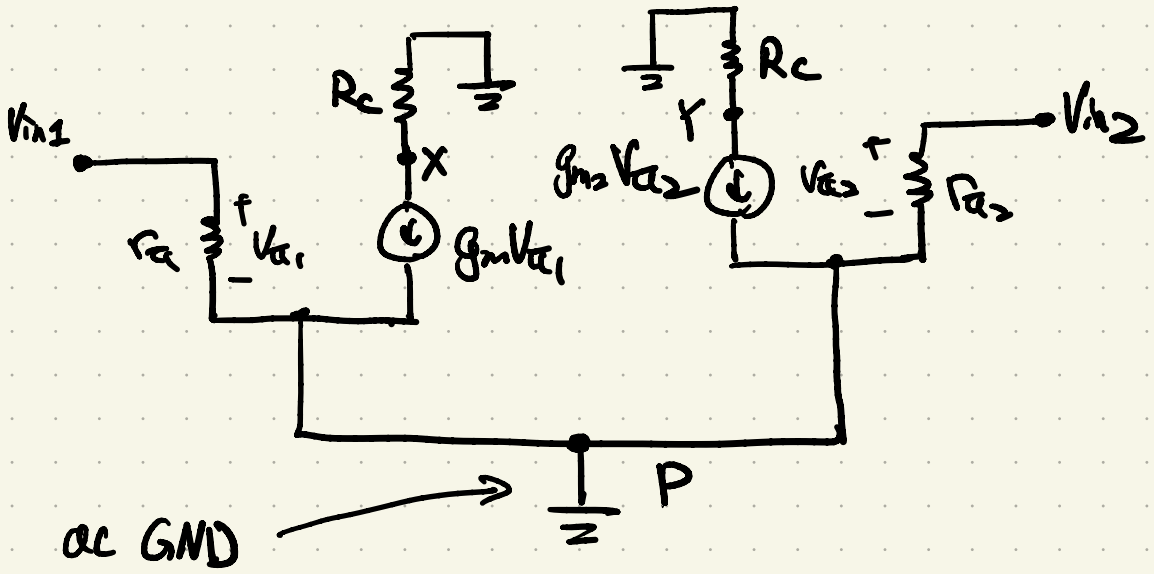
Small-Signal Behavior



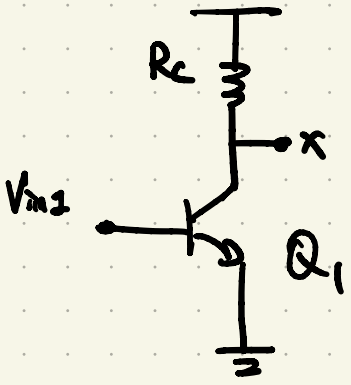


for small-signal analysis

Actual Small-Signal Model



Half Circuit



$A_V = -g_m R_c$

$V_X = -g_m R_c V_{in1}$

similarly: $V_Y = -g_m R_c V_{in2}$

$V_X - V_Y = -g_m R_c (V_{in1} - V_{in2})$

$$A_V = \frac{V_X - V_Y}{V_{in1} - V_{in2}} = -g_m R_c$$

$$= -\frac{R_c I_{EE}}{2V_T}$$

↑ differential gain