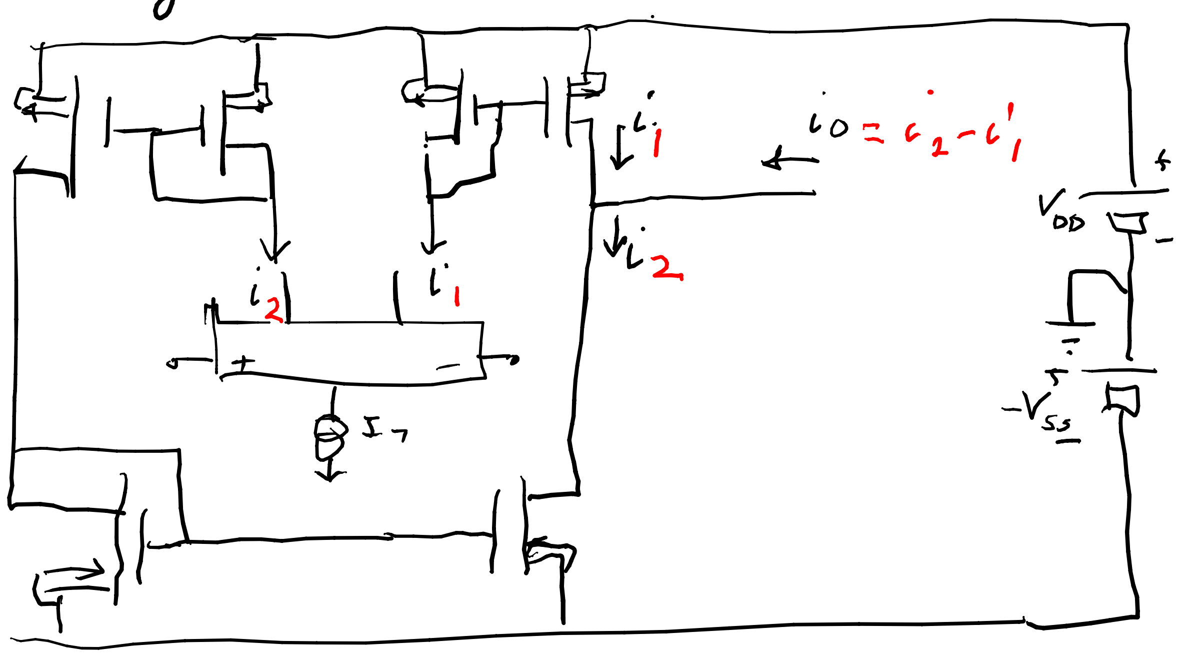
$$i_o = \begin{cases} I_T & v_i \ge \sqrt{I_T/a} \\ \sqrt{2I_T a}\, v_i \sqrt{1-\frac{a v_i^2}{2I_T}} & -\sqrt{I_T/a} \le v_i \le +\sqrt{I_T/a} \\ -I_T & v_i \le -\sqrt{I_T/a} \end{cases}$$

$a = \frac{KP}{2}\frac{W}{L}$

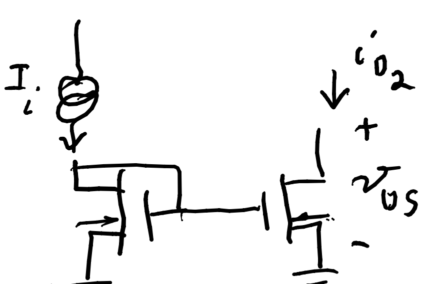
$$\frac{di_o}{dv_i} = G_m = \sqrt{2I_T a}\cdot\sqrt{1-\frac{a v_i^2}{2T}} + \sqrt{2I_T a}\, v_i \frac{1\times(-2a v_i/2I_T)}{\sqrt{1-\frac{a v_i^2}{2I_T}}}$$

@ $v_i = 0$, slope near origin ⇒ $\sqrt{2Ia} = G_m$ @ $v_i = 0$

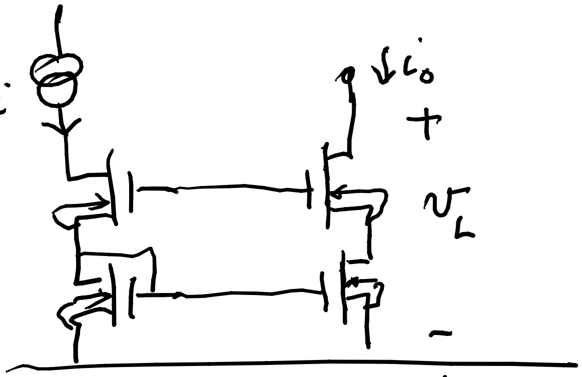
VCCS = voltage controlled current source



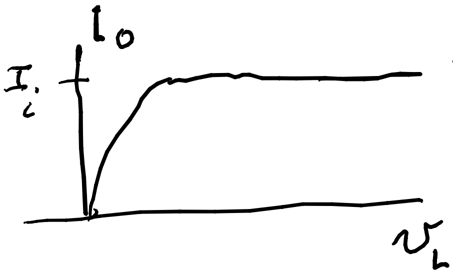
Improved current mirror ⇒ use cascode connection



simple

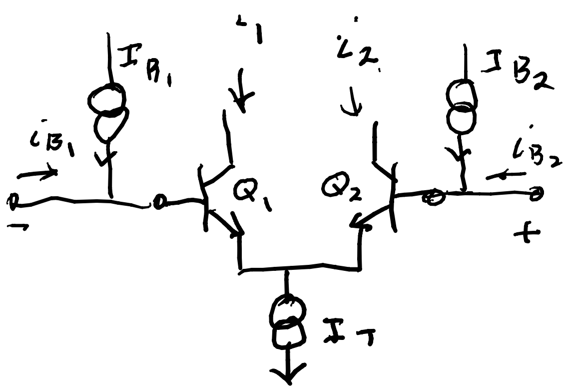


cascode



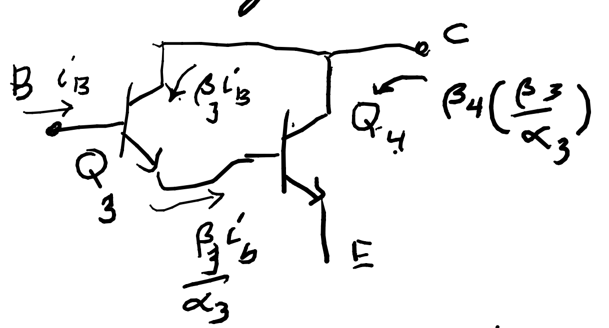
← larger output range

BJT diff pair



i_{B_1} & $i_{B_2} \neq 0$

Use Darlington pairs for Q_1 & Q_2

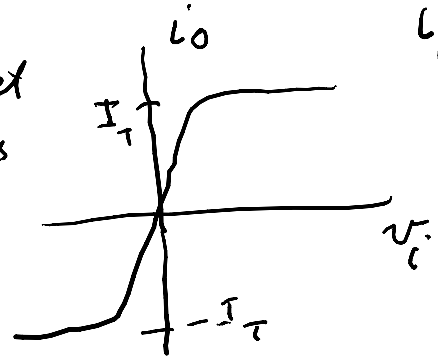


$$i_C = \beta_3 i_B + \frac{\beta_4 \beta_3}{\alpha_3} i_B$$

$$\approx \beta_3 \beta_4 i_B$$

$$i_o = I_T \tanh\left(\frac{v_i}{2V_T}\right)$$

Here still get for BJT diff pair



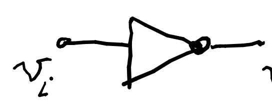
$$\tanh x = \frac{\sinh x}{\cosh x} = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$

$$\frac{di_o}{dv_i} = I_T \frac{d \tanh(v_i/2V_T)}{dv_i} = \frac{I_T}{2V_T} \cdot \frac{d \tanh(x)}{dx} \Rightarrow$$

$$\frac{d\left[(e^x - e^{-x})/(e^x + e^{-x})\right]}{dx} = \frac{e^x + e^{-x}}{e^x + e^{-x}} + (-1)\frac{(e^x - e^{-x})(e^x - e^{-x})}{(e^x + e^{-x})^2} = 1 - \tanh^2 x$$

$$\frac{di_o}{dv_i} = \frac{I_T}{2V_T}\left(1-\tanh^2(v_i/2V_T)\right); \quad G_m\Big|_{v_i=0} = \frac{I_T}{2V_T}$$

Inverters



using CMOS