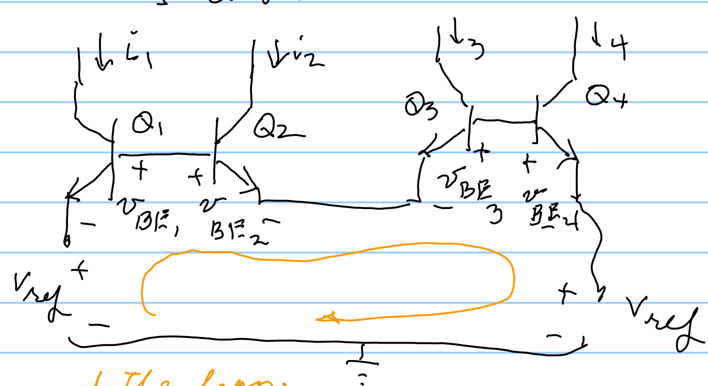
Note Title 12/6/2016

EE303H
12/06/16

translinear loops



$$i_c = A e^{v_{BE}/V_T}$$

$$v_{BE} = \ln\left(i_c/A\right)$$

KVL around the loop:

$$0 = -\cancel{V_{ref}} - v_{BE_1} + v_{BE_2} - v_{BE_3} + v_{BE_4} + \cancel{V_{ref}}$$

$$\Rightarrow \quad V_{BE_1} + V_{BE_3} = V_{BE_2} + v_{BE_4}$$

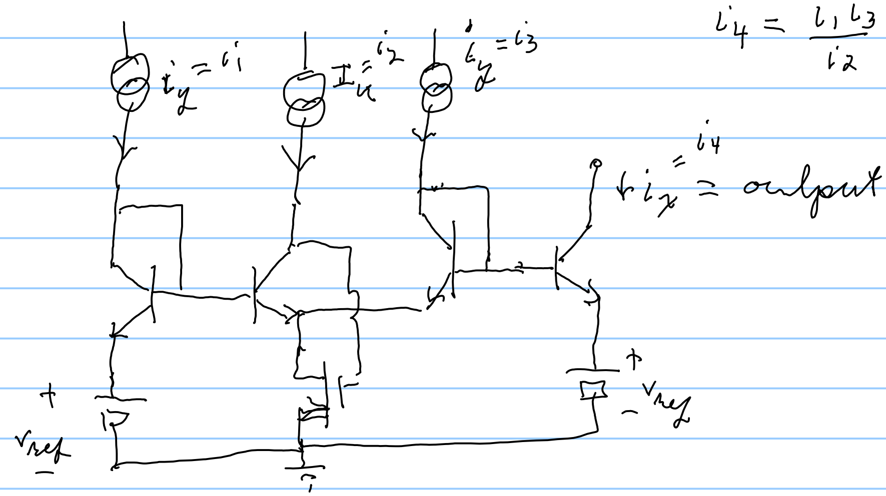
$$\ln\left(i_1/A_1\right) + \ln\left(i_3/A_3\right) = \ln\left(\frac{i_2}{A_2}\right) + \ln\left(i_4/A_4\right)$$

$$\Rightarrow \ln\left(\frac{i_1 i_3}{A_1 A_3}\right) = \ln\left(\frac{i_2 i_4}{A_2 A_4}\right) \Longrightarrow \text{exp both sides}$$

$$i_1 i_3 = \frac{A_1 A_3}{A_2 A_4} \cdot i_2 i_4 \quad = i_2 i_4 \Big|_{\text{if } A_i = A \text{ for } i=1,2,3,4}$$

$i_4 = i_1 i_3 / i_2$ allows product or division

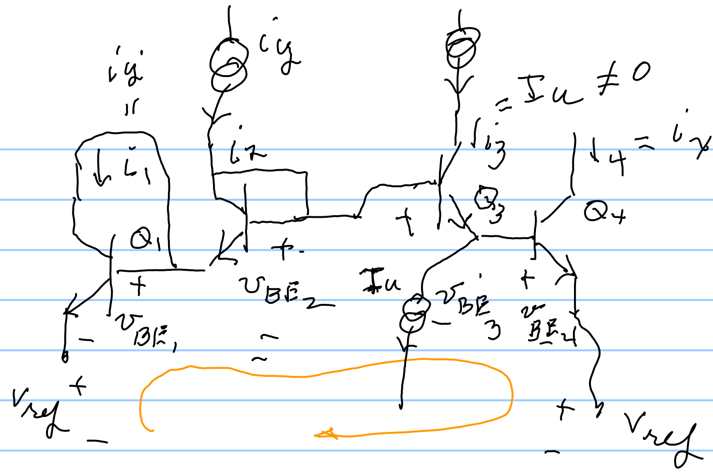
Needs bias current @ junction of Q_2 Q_3
to obtain $i_x = i_y^2 / i_u$; i_u = normalization



$$i_4 = \frac{i_1 i_3}{i_2} = \frac{i_y \cdot i_y}{I_u} \simeq i_y^2 / I_u$$

for $i_y \geq 0$

a similar connection



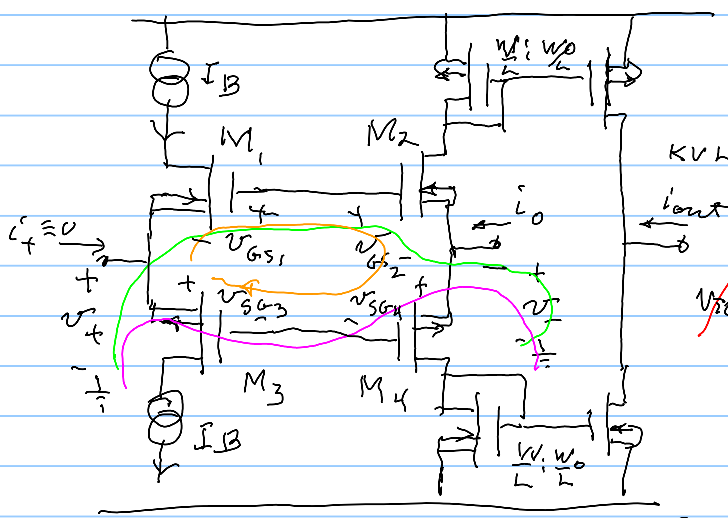
$$v_{BE_1} + v_{BE_2} = v_{BE_3} + v_{BE_4}$$

$$\ln(i_1 \cdot i_2) = \ln(i_3 i_4)$$

$$i_4 = i_1 i_2 / i_3$$

$$= i_x = i_y \cdot i_y / I_u = i_y^2 / I_u$$

MOS



$i_D = k(v_{GS} - V_{TO})^2$

for translinear loop

KVL $\quad 0 = -v_{GS_1} + v_{GS_2} + v_{SG_4} - v_{SG_3}$

$v_{GS_1} + v_{SG_3} = v_{GS_2} + v_{SG_4}$

$\cancel{V_{TO_n}} + \sqrt{\frac{I_B}{k_n}} + \cancel{|V_{TO_p}|} + \sqrt{\frac{I_B}{k_p}}$

$= \cancel{V_{TO_n}} + \sqrt{\frac{i_{2D}}{k_n}} + \cancel{|V_{TO_p}|} + \sqrt{\frac{i_{4S}}{k_p}}$

$v_{GS_n} = V_{TO_n} + \sqrt{\frac{i_D}{k_n}}$, $v_{SG_p} = |V_{TO_p}| + \sqrt{\frac{i_S}{k_p}}$ $\quad$ rt side

if $k_n = k_p = k \Rightarrow \sqrt{I_B}\left(\frac{1}{\sqrt{k_n}} + \frac{1}{\sqrt{k_p}}\right) = \frac{2}{\sqrt{k}}\sqrt{I_B} = \frac{1}{\sqrt{k}}\left(\sqrt{i_{2D}} + \sqrt{i_{4S}}\right)$

KVL
green loop: $0 = -v_+ - v_{GS_1} + v_{GS_2} + v_- \Rightarrow v_+ - v_- = v_{GS_2} - v_{GS_1}$

$0 = -v_+ + v_{SG_3} - v_{SG_4} + v_- \implies v_+ - v_- = v_{SG_3} - v_{SG_4}$

summing $\Rightarrow$ $2(v_+ - v_-) = v_{GS_2} - v_{GS_1} + v_{SG_3} - v_{SG_4} = v_{GS_2} - v_{SG_4}$

as I_B is same in M_1 & M_3 = zero

$\Rightarrow v_- = v_+ + \underbrace{\dfrac{v_{SG_4} - v_{GS_2}}{2}}$ desire $v_{SG_4} = v_{GS_2}$ for a virtual input connection

if i_o is very small then $v_{SG_4} \approx v_{GS_2}$ as usual for op amps

if w_o is large $\Rightarrow i_{out} = w_o i_o$