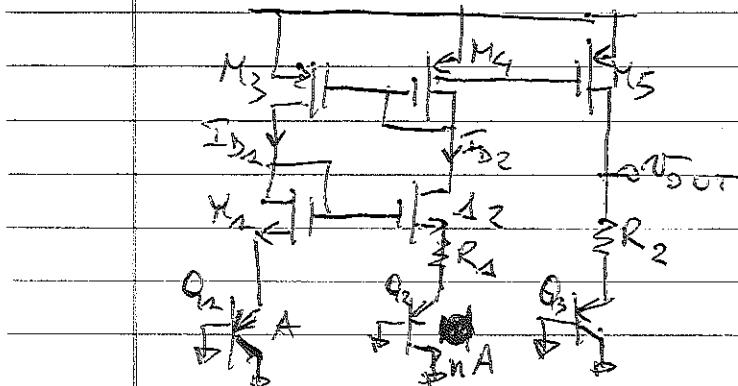


Discussion #5

02/25/2014

Problem 1

$$R_1 = 1k\Omega \quad R_2 = 2k\Omega$$

$$\left(\frac{V}{T}\right)_{M4} = 50/0.5 \quad I_{D1} = I_{D2} \approx 1\mu A$$

$$\lambda = \gamma = 0$$

$$\frac{\partial V_{BE}}{\partial T} = -1.5 \frac{mV}{K} \quad \frac{\partial K}{\partial T} = 0.088 \frac{mV}{K}$$

a) If  $\left(\frac{V}{T}\right)_S = \left(\frac{V}{T}\right)_{M3}$ , find  $n$  such that  $TG_F(300K) = 0$  for  $V_{out}$ .

$$KVL: V_{EB_1} + V_{GS_1} - V_{GS_2} - I_D R_1 - V_{EB_2} = 0$$

$$\text{Assume } V_{GS_1} = V_{GS_2}$$

$$\Rightarrow I_D = \frac{V_{EB_1} - V_{EB_2}}{R_1} = \frac{V_T \ln\left(\frac{I_D}{I_{S1}}\right) - V_T \ln\left(\frac{I_D}{I_{S2}}\right)}{R_1}$$

$$= \frac{V_T \ln(n)}{R_1}$$

The current  $I_D$  gets mirrored and flows into the output branch

$$\Rightarrow V_{out} = V_{EB_3} + I_D R_2 = V_{EB_3} + \frac{R_2}{R_1} V_T \ln(n)$$

$$\frac{\partial V_{out}}{\partial T} = \frac{R_2}{R_1} \ln(n) \frac{\partial V_T}{\partial T} + \frac{\partial V_{BE3}}{\partial T} = 0$$

$$- \frac{\partial V_{BE}}{\partial T} = - \frac{1.5 \frac{mV}{K}}{R_2 \cdot \frac{\partial V}{\partial T}} = \frac{0.087 \frac{mV}{K} \cdot 2}{R_1} = 8.62$$

$\Rightarrow n = 554.8 \Rightarrow \text{VERY LARGE!}$

b) Set  $(\frac{u}{z})_S = k (\frac{u}{z})_{1-4}$

Following the same steps:

$$V_{out} = \frac{R_2}{R_1} V_T \ln(n) \cdot 4 + V_{EB3}$$

$$\ln(n) = - \frac{\frac{\partial V_{BE}}{\partial T}}{\frac{\partial V_T}{\partial T} \cdot \frac{R_2}{R_1} \cdot 4} = - \frac{1.5 \frac{mV}{K}}{0.087 \frac{mV}{K} \cdot 2 \cdot 4} = 2.155$$

$\Rightarrow n = 8.6$  large area source?

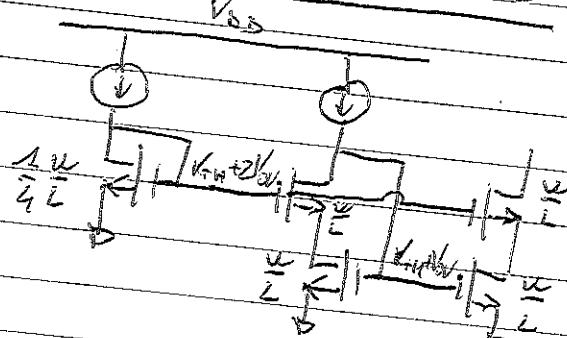
c) Set  $(\frac{u}{z})_S = \alpha (\frac{u}{z})_{1-4}$

$$n = e^{\left(\frac{8.62}{\alpha}\right)}$$

Now minimize for  $n + \alpha$

$$n = 4 \quad \alpha = 6.2 \quad \alpha + n = 10.2$$

## Current mirrors



$$R_{out} \approx g_m n^2$$

$$V_{out, min} \approx 2V_{DS}$$

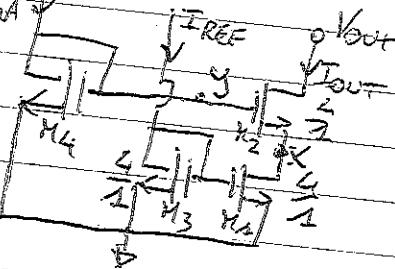
$$V_{out, max} \approx V_{TH} + 2V_{DS}$$

$$E = 0$$

OFTEN USED IN ADVANCED (LOW  $V_{DD}$ ) PROCESSES

### Problem 2

$$I_{REF} = 50 \mu A$$



$$V_T = 0.7V \quad K = 1.15 \text{ mA/V}^2$$

$$\gamma = 0.4 \quad A = 0.04 \text{ V}^{-1} \quad 2/\Phi_F = 0.7$$

- a) Ignoring Body effect, design the size of  $M_4$  to obtain  $V_{out, min} = 2V_{DS, min}$

$$V_{out, min} = 2V_{DS, min} \Rightarrow X = V_{DS, min} \quad \left\{ \begin{array}{l} Y = V_{GS1} + V_{GS2} = V_{DS, min} + V_{DS, min} \\ Y = V_{GS4} = V_{DS, min} + V_{DS, min} \end{array} \right.$$

$$\Rightarrow \sqrt{\frac{2I_{DS}}{K(\frac{W}{L})_4}} = \sqrt{\frac{2I_{DS}}{K(\frac{W}{L})_1}} + \sqrt{\frac{2I_{DS}}{K(\frac{W}{L})_2}} \Rightarrow \left(\frac{W}{L}\right)_4 = \frac{1}{4} \left(\frac{W}{L}\right)_1 = \frac{1 \mu m}{4 \mu m}$$

- b) Now consider BODY EFFECT. Compute  $V_{out, min}$

$$X = V_{DS, min} \Rightarrow V_{TH2} = V_{TH1} + \gamma \left( \sqrt{2\Phi_F + V_{SS}} - \sqrt{2\Phi_F} \right) = 0.747V$$

$$\text{with } V_{SS} = V_{GS1} = \sqrt{\frac{2I_{DS}}{K(\frac{W}{L})_1}} = 0.213V$$

Set  $\bar{I}_{D2} = \bar{I}_{D1}$

$$\frac{1}{2} K' \left( \frac{u}{L} \right)_1 (V_{GS1} - V_{TH0})^2 \left( 1 + \frac{2}{L} \frac{\bar{I}_{D1}}{K'} \right) = \frac{1}{2} K' \left( \frac{u}{L} \right)_2 \underbrace{(V_{GS2} - V_{TH0})^2}_{V_{DS2}} \underbrace{\left( 1 + \frac{2}{L} \frac{\bar{I}_{D2}}{K'} \right)}_{V_{DS2} + V_{TH0} - V_{TH1} - V_{DS1} - V_{DS2}}$$

$$\Rightarrow V_{DS1} = 16.985V !!$$

$V_{DS1}$  is too high. This is because we sized  $M_4$  neglecting the body effect, but when the B.E. is factored in again, it pushes  $M_1$  in triode region. In a practical scenario, we need to choose  $\left( \frac{u}{L} \right)_4 < \frac{1}{2} \left( \frac{u}{L} \right)_1$  to compensate for B.E.

c) Now reduce  $\bar{I}_{REF}$  to 5  $\mu A$ . Resize  $M_3 \& M_4$

$$V_{GS3} = V_{GS1} \rightarrow \sqrt{\frac{2\bar{I}_{D3}}{K' \left( \frac{u}{L} \right)_3} + V_{TH0}} = \sqrt{\frac{2\bar{I}_{D1}}{K' \left( \frac{u}{L} \right)_1} + V_{TH0}}$$

$$\Rightarrow \left( \frac{u}{L} \right)_3 = \left( \frac{u}{L} \right)_1 \cdot \frac{1}{2} = \frac{2 \mu m}{1 \mu m}$$

Igoring again the BODY EFFECT:

$$V_{GS4} = V_{GS2} + V_{DS1} \sqrt{\frac{2\bar{I}_{D4}}{K' \left( \frac{u}{L} \right)_4} + V_{TH0}} = \sqrt{\frac{2\bar{I}_{D2}}{K' \left( \frac{u}{L} \right)_2} + V_{TH2}} + \sqrt{\frac{2\bar{I}_{D1}}{K' \left( \frac{u}{L} \right)_1}}$$

$$\bar{I}_{D4} = \frac{\bar{I}_{D2}}{2} \Rightarrow \left( \frac{u}{L} \right)_4 = \frac{1}{8} \left( \frac{u}{L} \right)_2 = \frac{0.5 \mu m}{1 \mu m}$$