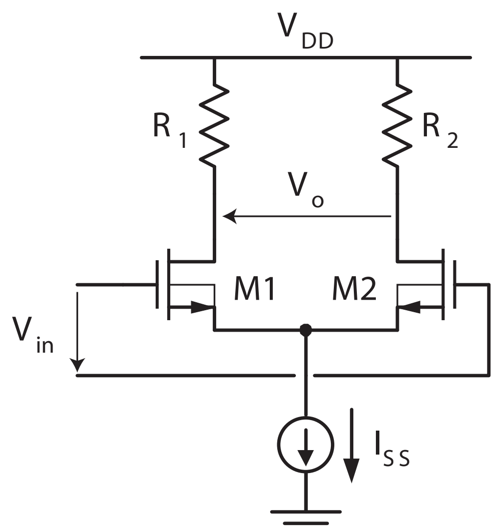
University of California, Berkeley *Spring 2006*
EECS 240 *Prof. A. Niknejad*

Problem Set 5 Solutions

1. The offset voltage Vos of an amplifier is defined as the input required to satisfy $V_o = 0$V. Calculate the variance of the offset voltage of the differential amplifier below as a function of $\sigma_{V_{th}}$, $\sigma_{\frac{\Delta R}{R}}$, I_{SS}, and V^*. Use the square-law approximation (i.e. $V_{od} = V^*$) and assume infinite transistor output resistance.



The solution is found by adjusting the output currents for zero output offset

$$I_{D1}R_{D1} = I_{D2}R_{D2}$$

This is equivalent to

$$\frac{\Delta I_D}{I_D} = \frac{\Delta R_D}{R_D}$$

Under this condition, assuming the offset voltage is small, the input voltage is given by

$$V_{os} = V_{GS1} - V_{GS2} = \Delta V_T + \frac{\Delta I_D}{g_m}$$

Substitution of the output trim condition yields

$$V_{os} = V_{GS1} - V_{GS2} = \Delta V_T + \frac{\Delta R_D}{R_D}\frac{I_D}{g_m}$$

or

$$V_{os} = V_{GS1} - V_{GS2} = \Delta V_T + \frac{\Delta R_D}{R_D}\frac{V^*}{2}$$

The variance of the offset voltage is therefore given by

$$\sigma^2_{V_{os}} = \sigma^2_{V_{th}} + \left(\frac{V^*}{2}\right)^2 \sigma^2_{\left(\frac{\Delta R}{R}\right)}$$

Reference:C:\Documents and Settings\Bernhard\My Documents\Lib\MathCAD\Default\defaults.mcd

EECS 240, Spring 2004, Midterm Solution

1) Noise

$$S_{ieq} = 4 \cdot k_B \cdot T \cdot \gamma \cdot \frac{V_{1star}}{I_{SS}} \cdot \left(1 + 2 \cdot \frac{V_{1star}}{V_{5star}} + \frac{V_{1star}}{V_{9star}}\right)$$

(ignoring flicker noise)

2) Offset

- Systematic offset is result of different VDS of M9 and M10
- Solution: cascode M9 with a divice with same size and bias as M11. Make sure it won't go into triode (due to M9 diode connection).

3) Bandwidth

$$g_{m1} = \frac{I_{SS}}{V_{1star}}$$

$$H(s) = \frac{C_s}{C_f} \cdot \frac{1 + s \cdot \frac{C_f}{g_{m1}}}{1 + \frac{s}{\omega_o}}$$

$$\omega_o = F \frac{g_{m1}}{C_L + C_f \cdot (1 - F)}$$

$$F = \frac{C_f}{C_f + C_s + C_i}$$

usually the zero is at a much higher frequency than the pole and can be ignored.

$$|H(s)| = 1$$

$$\omega_u = \omega_o \cdot \left(\frac{C_s}{C_f} - 1\right) = \frac{g_{m1}}{C_L + C_f \cdot (1 - F)} \cdot \frac{C_s}{C_f + C_s + C_i}$$

(approx)

4) Fast settling

Optimal settling for 2-pole response occurs for $p_2 = -K\omega_o$ $K = 3.3$

$$p_2 = -\frac{g_{m7}}{C_{x1}}$$

$$C_{x1} = \frac{g_{m7}}{K \cdot \omega_o} = \frac{1}{K \cdot F} \cdot \frac{V_{1star}}{V_{7star}} \cdot C_{Leff}$$

5) Slewing

$$V_{1star} = V_{istep\_max} \cdot \frac{C_s}{C_s + C_a} \qquad C_a = C_i + ser(C_f, C_L)$$

$$V_{istep\_max} = V_{1star} \cdot \left(1 + \frac{C_a}{C_s}\right)$$

$$V_{istep\_max} = V_{1star} \cdot \frac{(C_f \cdot C_s + C_f \cdot C_i + C_L \cdot C_s + C_L \cdot C_i + C_f \cdot C_L)}{C_s \cdot (C_f + C_L)}$$

6) Slewing time

initial step at amplifier input:

$$V_{x0} = V_{istep} \cdot \frac{C_s}{C_s + C_a}$$

slew rate at output:

$$SR_o = \frac{I_{SS}}{C_c} \qquad C_c = C_L + ser(C_f, C_s + C_i)$$

$$C_c = C_L + F \cdot (C_s + C_i)$$

slew rate at amp input:

$$SR_i = F \cdot SR_o$$

$$SR_i = F \cdot \frac{I_{SS}}{C_L + F \cdot (C_s + C_i)}$$

slewing time:

$$t_{slew} = \frac{V_{x0} - V_{1star}}{SR_i}$$

$$t_{slew} = \frac{V_{x0} - V_{1star}}{I_{SS}} \cdot \left(\frac{C_L}{F} + C_s + C_i\right)$$

Given

$$v_o \cdot s \cdot (C_f + C_L) - v_x \cdot (s \cdot C_f + g_m) = 0$$

$$v_x \cdot C_T - v_i \cdot C_s - v_o \cdot C_f = 0$$

$$\text{Find}(v_o, v_x) \rightarrow \begin{bmatrix} -v_i \cdot C_s \cdot \dfrac{(s \cdot C_f + g_m)}{\left(-s \cdot C_f \cdot C_T - s \cdot C_L \cdot C_T + s \cdot C_f^{\,2} + g_m \cdot C_f\right)} \\ -s \cdot v_i \cdot C_s \cdot \dfrac{(C_f + C_L)}{\left(-s \cdot C_f \cdot C_T - s \cdot C_L \cdot C_T + s \cdot C_f^{\,2} + g_m \cdot C_f\right)} \end{bmatrix}$$

$$v_o = -v_i \cdot \frac{C_s}{C_f} \cdot \frac{1 + s \cdot \dfrac{C_f}{g_m}}{1 - s \cdot \dfrac{C_f \cdot C_T + C_L \cdot C_T - C_f^{\,2}}{g_m \cdot C_f}}$$

$$\frac{C_f \cdot C_T + C_L \cdot C_T - C_f^{\,2}}{g_m \cdot C_f} = \frac{C_T + \dfrac{C_L}{F} - C_f}{g_m} = \frac{C_L}{F \cdot g_m} \cdot \left(\frac{C_T \cdot F}{C_L} - C_f \cdot \frac{F}{C_L} + 1\right)$$

$$C_T + \frac{C_L}{F} - C_f = \frac{F \cdot (C_s + C_i) + C_L}{F}$$

$$\frac{C_s}{C_f} \cdot \frac{1 + s \cdot \dfrac{C_f}{g_m}}{1 + \dfrac{s}{\omega_o}} \qquad\qquad \omega_o = F \frac{g_m}{C_L + C_f \cdot (1 - F)}$$

usually the zero is at much higher frequency than the pole --> ignore