Solution

# CSU0007 Basic Electronics, Homework 7

- Submit your work via Moodle before **5PM, Jan. 14th**. The solution will be available right after for you to prepare for the final exam on Jan. 15th.

1. (50 points) For the following difference amplifier, suppose that $I$=0.64mA, $V_{CC}$=3V, $R_L$=2kΩ, $K$=1mA/V$^2$, $V_T$=1V, and $v_{CM}$=2V.

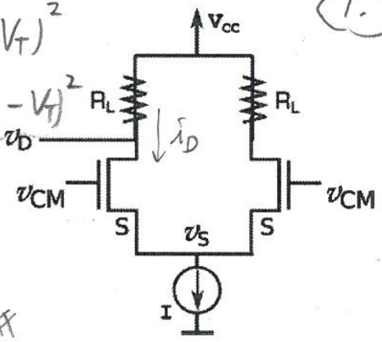
    1. (40 points) Suppose that both MOSFETs operate under the saturation discipline. Compute large signals $v_D$ and $v_S$.
    2. (10 points) Determine the maximum possible $v_{CM}$ for both MOSFET to remain in saturation.

(1.1) $i_D = \frac{I}{2} = \frac{V_{CC}-v_D}{R_L} = \frac{1}{2}K(v_{GS}-V_T)^2$

$= \frac{1}{2}K(v_{CM}-v_S-V_T)^2$

$\Rightarrow v_D = V_{CC} - \frac{I}{2}R_L = 2.36\text{ V}$ #

$\Rightarrow v_S = v_{CM} - V_T - \sqrt{\frac{I}{K}} = 0.2\text{ V}$ #




(1.2) We need $v_{GS}-V_T < v_{DS}$

$\Rightarrow (v_{CM}-v_S)-V_T < v_D - v_S$

$\Rightarrow v_{CM} < V_T + v_D = V_T + (V_{CC} - \frac{I}{2}R_L)$

$= 3.36\text{ V}$ #

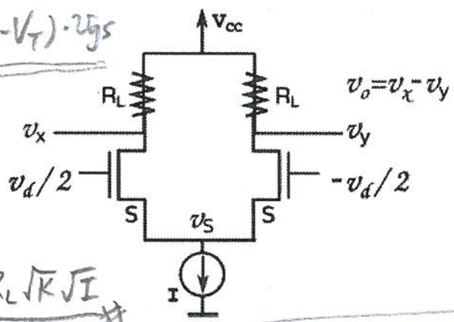
2. (30 points) In class, we've shown that $A_d = \frac{v_o}{v_d} = -g_m R_L$ for a difference amplifier:

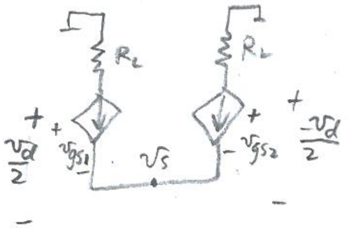
(2) $\frac{I}{2} + \Delta i = \frac{1}{2}K(V_{GS}-V_T)^2 + K(V_{GS}-V_T)\cdot v_{gs}$

$\Rightarrow V_{GS}-V_T = \sqrt{\frac{I}{K}}$

and since $g_m = K(V_{GS}-V_T)$

$\Rightarrow A_d = -g_m R_L = -K(V_{GS}-V_T)R_L = -R_L\sqrt{K}\sqrt{I}$ #



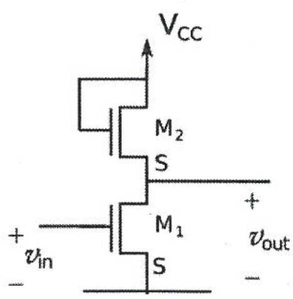




Now, assuming both MOSFETs are identical, show that, approximately, $A_d = -R_L\sqrt{K}\sqrt{I}$.

Hint: Consider that current $I/2 + \Delta i$ flowing through the left MOSFET and that current $I/2 - \Delta i$ flowing through the right MOSFET, where $\Delta i$ is of a small quantity.

This result gives us an insight: in order to improve the small-signal voltage gain, we may choose to increase $I$ the biasing current. In this way we keep $R_L$ the same, and thus the output resistance remains unchanged :)

3. (20 points) We've learned a way to wire a MOSFET for it to work like a resistor for a small-signal. Now, consider the following inverting amplifier, with the load resistor replaced by MOSFET $M_2$ (with parameter $K = K_2$). Suppose that $M_1$ (with parameter $K = K_1$) operates under the saturation discipline:

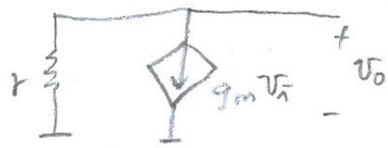


Show that the small-signal voltage gain, $\frac{v_{out}}{v_{in}}$, is equal to $-\sqrt{\frac{K_1}{K_2}}$.

Hint: The same amount of current should flow through both $M_1$ and $M_2$.

This result suggests a cool feature: recall that parameter $K$ for a MOSFET is in portion to the geometric length ($L$) and width ($W$) of the channel between source and drain, i.e., $K = K'(\frac{W}{L})$. Assuming that the two MOSFETs have identical $K'$ and $L$, then essentially, we may setup the voltage gain of this circuit by building the MOSFETs with the calculated relative channel widths :)

③ The small-signal resistance, $r$, from $M_2$ is $\frac{1}{K_2(V_{GS_2}-V_T)}$




$$\frac{v_o}{v_i} = -g_m \cdot r$$

$$= -K_1(V_{GS_1}-V_T) \cdot \frac{1}{K_2(V_{GS_2}-V_T)}$$

since $i_{D_1} = i_{D_2}$

$$\Rightarrow \frac{K_1(V_{GS_1}-V_T)^2}{2} = \frac{K_2(V_{GS_2}-V_T)^2}{2}$$

$$\Rightarrow \frac{V_{GS_1}-V_T}{V_{GS_2}-V_T} = \sqrt{\frac{K_2}{K_1}}$$

$$\Rightarrow \frac{v_o}{v_i} = -\sqrt{\frac{K_1}{K_2}}$$

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