(Solution)

CSU0007 Basic Electronics, Homework 5

- Four questions in total. Submit your work via Moodle before 9PM, Dec 19th, 2020 (Saturday).
- Textbook coverage: Section 7.1 to Section 7.6. Note that we use notations V_S and V_{CC} interchangeably.
- For all questions, consider the SCS model of a MOSFET. Clearly state your reasoning to earn full score.

1. (40 points) In this question, we review the fundamental properties of a MOSFET.
    1. (10 points) State the boundary condition between the saturation region and the triode region. $V_{GS} - V_T = V_{DS}$
    2. (10 points) In class, we showed that starting from the cut-off region, with the fixed value of V_{DS}, if we gradually increase the value of V_{GS} then then MOSFET will first enter the saturation region and then the triode region. Now, suppose we fix the value of V_{GS} (so that it is larger than V_T) and then gradually increase the value of V_{DS} from 0. In this setting, eventually, will the MOSFET go from which region to which region? triode → saturation
    3. (10 points) Under what condition will a MOSFET go from the saturation region to the cut-off region? $V_{GS} - V_T < 0$, i.e., $V_{GS} < V_T$
    4. (10 points) In which of the three regions will the MOSFET behave as a *dependent current source* where current i_{DS} is dependent on the value of V_{GS}? the saturation region
2. (15 points) Consider the MOSFET amplifier, version 1, as we've discussed in class (Figure 7.19 in the textbook), with the following setup: $V_T = 1$V, $V_S = 10$V, $K = 1$mA/V^2, and $R_L = 8$kΩ. Assume that the MOSFET always operates in the saturation region. Compute $\frac{v_O}{v_{IN}}$ for
    1. (5 points) $v_{IN} = 1.5$V
    2. (5 points) $v_{IN} = 1.7$V See page 2
    3. (5 points) $v_{IN} = 1.9$V
3. (25 points) Again, consider the MOSFET amplifier, version 1. Do the following analyses:
    1. (15 points) Given a constant V_S, consider the range of v_{IN} for the MOSFET to operate in the saturation region. Would the size of this range increase or decrease if we increase R_L? Why? Decrease, see Page 2
    2. (10 points) This type of amplifier has a property (you may call it a feature or a bug) that if both $V_T > 0$ and $V_S > 0$, then the output of the amplifier will never change, no matter what negative value of the input is (as long as the input is negative). Explain why. See page 2
4. (20 points) Now, consider the MOSFET amplifier, version 2, as we've discussed in class (Figure 7.46 in the textbook). Using the parameters specified in that figure, compute v_O for
    1. (5 points) $v_{IN} = -0.2$V see page 2
    2. (5 points) $v_{IN} = -0.1$V
    3. (5 points) $v_{IN} = 0$V
    4. (5 points) Following the question above, when $v_{IN} = 0$V, what would be the value of *current* flowing out from the voltage supply (i.e., from the leftmost voltage source in that figure in the textbook)?

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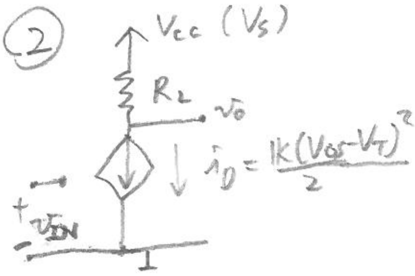
(2)



(2.1) $v_o = V_s - i_D \cdot R_L = 10 - \frac{1}{2}(1.5-1)^2 \times 8 = 9\text{ V}$

$\frac{v_o}{v_{IN}} = \frac{9}{1.5} \approx 6$

(2.2) $v_o = 10 - \frac{1}{2}(1.7-1)^2 \times 8 = 8.04\text{ V}$ $\quad \frac{v_o}{v_{IN}} \approx 4.73$

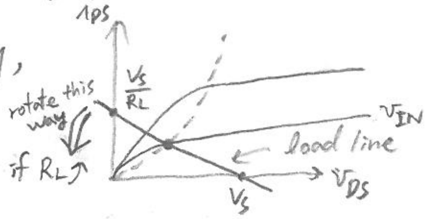
(2.3) $v_o = 10 - \frac{1}{2}(1.9-1)^2 \times 8 = 6.76\text{ V}$ $\quad \frac{v_o}{v_{IN}} \approx 3.56$

Think about $\frac{v_o}{v_{IN}}$ as the ratio of amplification, and we see that for different v_{IN} the ratio is different.

(3.1) We may analyze this in at least three ways:

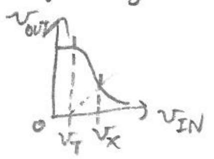
A. According to voltage divider, V_{DS} will decrease. Therefore the size of the saturation region $0 \le V_{GS} - V_T \le V_{DS}$ will decrease.

B. Graphically,



which means for the same v_{IN} the MOSFET will operate in the triode region instead. This implies that the size of the saturation region is decreased.

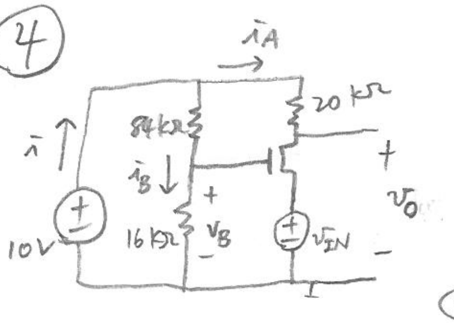
C. Analytically, we have $v_X = \frac{-1 + \sqrt{1 + 2V_s K R_L}}{K R_L} + V_T = \frac{-1}{K R_L} + \sqrt{\frac{1}{K^2 R_L^2} + \frac{2V_s}{K R_L}} + V_T$



which implies $v_X \downarrow$ if $R_L \nearrow$

(3.2) Because in this case $v_{GS} < v_T$, $v_{OUT} = V_S$ ※

(4)



$V_T = 1\text{ V}$

$K = 1\text{ mA/V}^2$

$V_B = 10 \times \frac{16}{16+84} = 1.6\text{ V}$

$V_{GS} = 1.6 - v_{IN}$

$v_o = 10 - \frac{1 \cdot (1.6 - v_{IN} - 1)^2}{2} \times 20 = 10 - 10(0.6 - v_{IN})^2$, provided that the MOSFET operates in the saturation region.

(4.1) $v_o = 3.6\text{ V}$

(4.2) $v_o = 5.1\text{ V}$

(4.3) $v_o = 6.4\text{ V}$

} you can verify that in these cases indeed the MOSFET operates in the saturation region.

(4.4) $i_B = \frac{10}{100\text{ k}\Omega} = 0.1\text{ mA}$

$i_A = \frac{1 \times (1.6 - 0 - 1)^2}{2} = 0.18\text{ mA}$

from KCL, we have $i = i_A + i_B = 0.28\text{ mA}$

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