National Taiwan Normal University

CSU0007 - Basic Electronics Homework 6

100 points total. Due on 11:59PM, Friday, 6/12/2020.

Submit your answer via Moodle. Clearly state your analysis to earn full score.

Please tweak your image files to help save some ink! For example, grey-out the background color. Thanks!

請影像處理您的作業照片以節省列印墨水 (例如把背景顏色調淡)~ 謝謝!

By default, we assume that all MOSFETs have V_T=1 V, K=1 mA/V^2, and we use the SCS model.

1 Consider the MOSFET amplifier in Figure 8.1 in the textbook.

1.1 (20 points) Explain in your own words why in the small-signal model of this amplifier (Figure 8.16 in the textbook page 419), we would treat one end of the R_L as grounded (為何 R_L 的一端視為接地)?

1.2 (20 points) Suppose we want to make the magnitude of the small-signal gain equal to 10, and suppose that we are given V_S=15 V and R_L=15 kΩ. What should be the value of V_I for this purpose?

1.3 (20 points) Following Question 1.2, verify that with such a configuration, the MOSFET is indeed operating in the saturation region.

2 We have discussed the use of a *buffer* circuit to restore a distorted signal (page 63 in the lecture note; Section 6.9 in the textbook). We may implement a buffer circuit using a MOSFET circuit that is also called a *source follower* (the output signal would *follow* the change in the input signal). Before working on the following questions, be sure to study examples 7.8, 7.10, 7.11, and 8.4 in the textbook.

2.1 (20 points) Consider the source-follower circuit in Figure 7.24 on page 349, and instead we suppose that v_{IN}=3 V, K=1 mA/V^2, and V_T=1 V, and that the resistor has resistance equal to 2 kΩ. Assume that the MOSFET is operating in the saturation region. Determine the value of current i_D.

2.2 (10 points) Now, consider the circuit in Figure 7.45 on page 369. Suppose that we chose the DC voltage offset V_B=5 V and that v_A is a sinusoidal large signal. What could be the maximum possible peak-to-peak swing of v_A so that ~~v_A~~ v_{OUT} will not be clipped? (Review the phenomenon of clipping on page 351 in the textbook; note that on that page the example does not have any DC voltage offset).

2.3 (10 points) Now, suppose that v_A is a small signal. Further, suppose that a resistor R_L is attached to the output port, and therefore the circuit becomes as that of Figure 8.38 on page 436 in the textbook (Think of v_I=V_B+v_A where v_A is a small signal). Assuming that the MOSFET operates in the saturation region, and R_S=R_L=1 kΩ, V_{GS}=3 V, V_T=1 V, and K=1 mA/V^2. Determine the small-signal gain $|v_o/v_i|$.

(1.1) 參考 P86 in the note.

(1.2) $\left|\frac{v_o}{v_i}\right| = 10$

$\Rightarrow K(V_{GS}-V_T)R_L = 10$

$\Rightarrow 1\times10^{-3}(V_I-1)\cdot 15\times10^3 = 10$

$\Rightarrow \underline{V_I \approx 1.66}$ ※

(1.3) In this configuration,

$V_{GS} = v_I$ and $V_{DS} = v_O$

$i_D = \frac{K(v_I - V_T)^2}{2} \approx 0.21$

and since $i_D = \frac{V_S - v_O}{R_L} \Rightarrow v_O = V_S - i_D R_L = 11.73$

so indeed $V_{GS} - V_T < V_{DS}$ ※

(2.1) $\frac{v_{OUT}}{2\times10^3} = \frac{1\times10^{-3}[(3-v_{OUT})-1]^2}{2}$

$\Rightarrow v_{OUT} = 1$ or 4 → this is invalid ∵ for saturation region we must have $V_{GS} \geq V_T = 1$

$V_{GS} \rightarrow v_{IN} - v_{OUT}$

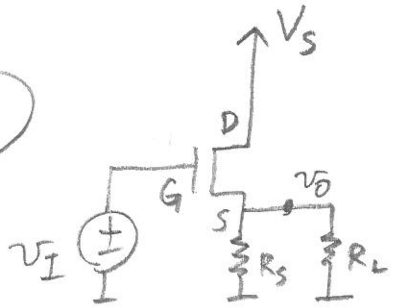
$\Rightarrow i_D = \frac{v_{OUT}}{2\times10^3} = \underline{0.5\ mA}$ ※

(2.2) Following Examples 7.10 and 7.11, we see that if $v_{IN} \leq 1$ the MOSFET will enter the cutoff region and v_{OUT} will equal to 0. Therefore, the maximum peak-to-peak swing of v_A is

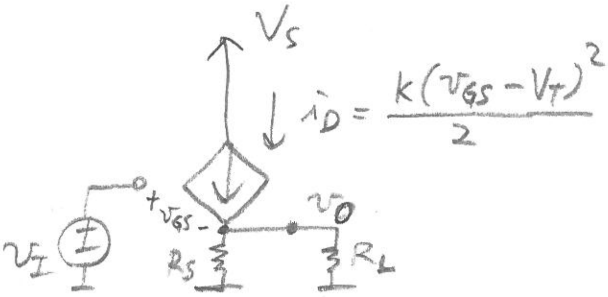
$(5-1)\times2 = 8\ V$

※

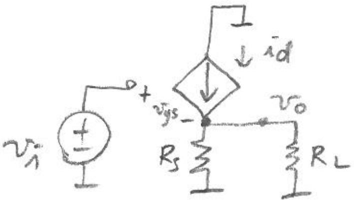
2.3

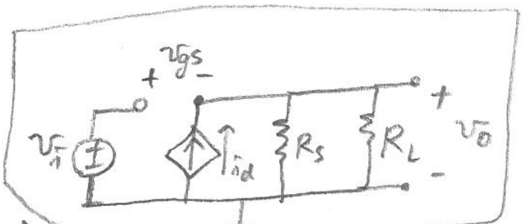


operating in the saturation region



small-signal model





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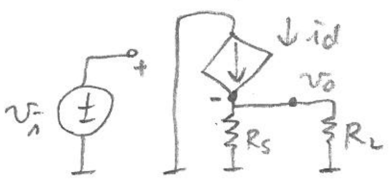

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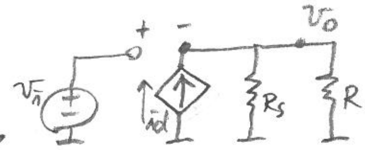

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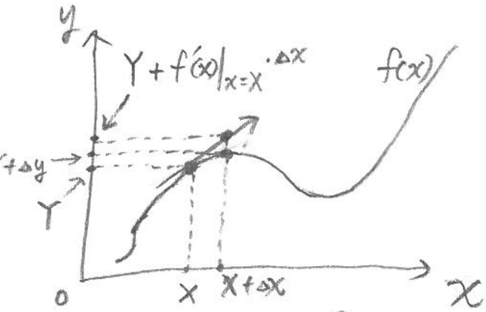

Now, let $f(v_{GS}) = i_D$, which is $\frac{K(v_{GS} - V_T)^2}{2}$

then $i_d = f'(v_{GS})\Big|_{v_{GS} = V_{GS}} \cdot v_{gs}$

$= K(V_{GS} - V_T) \cdot v_{gs}$ where $v_{GS} = V_{GS} + v_{gs}$

$(x = X + \Delta x)$ ← think this way

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

then we have $\underline{i_d = g_m \cdot v_{gs}}$

then $v_o = i_d \cdot (R_S /\!/ R_L)$

$= g_m \cdot v_{gs} \cdot (R_S /\!/ R_L)$

$= g_m \cdot (v_i - v_o) \cdot (R_S /\!/ R_L)$

$\Rightarrow v_o \left(\frac{1}{R_S /\!/ R_L} + g_m \right) = g_m \cdot v_i$

$$\Rightarrow \frac{v_o}{v_i} = \frac{g_m}{\frac{R_S + R_L}{R_S R_L} + g_m} = \frac{R_S R_L g_m}{R_S + R_L + R_S R_L g_m} = \frac{10^3 \times 10^3 \times [10^{-3}(3-1)]}{10^3 + 10^3 + 10^3 \cdot 10^3 \cdot [10^{-3}(3-1)]}$$

$= \underline{0.5}$ #

Note: $\frac{v_o}{v_i} < 1$ in such a source-follower circuit also explains why it can be used as a buffer (reduce voltage level) (see P63 in the note).