6/12/2020 9:30 PM

Solution

National Taiwan Normal University

CSU0007 - Basic Electronics Homework 5

100 points total. Due on 9AM, Monday, 6/8/2020.

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!

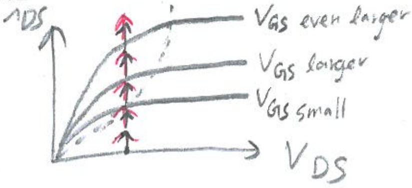
We assume all MOSFETs have V_T=1 V, K=1 mA/V^2, and we use the SCS model.

1 Explain the following concepts in your own words. You may use figures to illustrate your points.

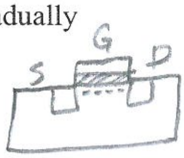
1.1 (10 points) Suppose that the MOSFET is in the cutoff region. If we fix voltage V_{DS} (and suppose that $V_{DS} > 0$) and gradually increase voltage V_{GS}, the MOSFET will move to the other two regions in the following order: → saturation → triode.

1.2 (10 points) Suppose that the MOSFET is in the triode region. If we fix voltage V_{GS} and gradually increase voltage V_{DS}, the MOSFET will move to the saturation in the end.

(1.1) Graphically,



You may also use



to explain.

The condition to enter the triode region is $V_{GS}-V_T \geq V_{DS}$, which implies the transition.

it's fine to ~~neglect~~ ignore the "=" sign, because in practice we would not operate a MOSFET at the boundary of regions. The "=" ~~sign~~ sign is for the purpose of illustration only.

(1.2) Graphically,

since the channel between S and D became stable.

(As a further study, think of what would happen if $V_{DS} \gg V_{GS}$.)

2 Consider the MOSFET circuit in Figure 1 and answer the following questions.

2.1 (10 points) Suppose V_{in}=3 V. Then i_{DS} = ?

2.2 (10 points) Suppose V_{in}=3 V, V_{out}=5 V, and R_L=10 kΩ. Then V_S = ?

(2.1) $V_{GS}=V_{in}$, and since $V_{GS}>V_T$ we see that the MOSFET operates in either the saturation region or the triode region (depending on V_{DS}). From the i_{DS}-V_{DS} relation

we see that $i_{DS} \leq \frac{K(V_{GS}-V_T)^2}{2} = 2\text{ mA}$ ※

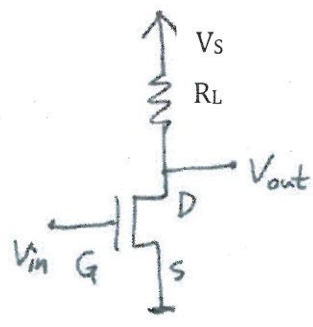


Figure 1

(2.2) According to condition $V_{GS}-V_T \leq V_{DS}$, $V_{out}=5V$ implies that the MOSFET is operating in the saturation region.

$i_D = \frac{V_S - V_{out}}{R_L}$ and $i_D = \frac{K(V_{GS}-V_T)^2}{2}$ lead to a conclusion that $V_S = \cancel{?V}$ 25 V ※

3 Consider the MOSFET circuit in Figure 2.

3.1 (5 points) Suppose V_2=4 V. What would be the range of V_1 for the MOSFET to operate in the saturation region?

3.2 (5 points) Suppose that the MOSFET is operating in the triode region. Could we make the MOSFET to move into the saturation region by just increasing V_2? If your answer is yes, give the range of V_2.

3.1 V_1 is equal to V_{GS}. V_2 is equal to V_{DS}.

$$\begin{cases} V_{GS} - V_T \geq 0 \\ V_{GS} - V_T \leq V_{DS} \end{cases} \Rightarrow 1\,V \leq V_1 \leq 5\,V$$

(Again, the equality sign does not matter 無傷大雅)

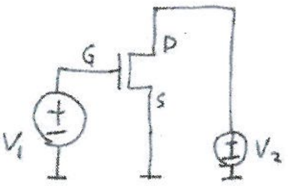
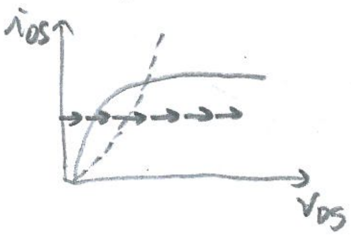


Figure 2

3.2 Yes, also see Question 1.2.



To move from the triode region to the saturation region, we nee to have $V_{DS} > V_{GS} - V_T$, in other word, $V_2 > V_1 - V_T$.

4 (10 points) Consider the MOSFET amplifier in Figure 3. Assume the MOSFET is operating in the saturation region. Suppose V_S=15 V, R_L=5 kΩ, and V_{in}=3V. Compute the gain for this configuration.

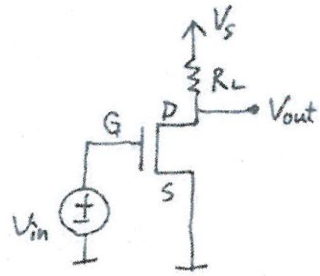


Figure 3

the gain $= \dfrac{V_{out}}{V_{in}}$ in this case.

From
$$\begin{cases} i_{DS} = \dfrac{K(V_{in} - V_T)^2}{2} \\ i_{DS} = \dfrac{V_S - V_{out}}{R_L} \end{cases}$$

we have $$\frac{1\times10^{-3}(3-1)^2}{2} = \frac{15 - V_{out}}{5\times10^3}$$

$$\Rightarrow V_{out} = 15 - 10 = 5\,V$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{5}{3}$$ ※

1 1 -15

$(9-V_{in}) \le 15-(9-V_{in})^2$

$\Rightarrow \frac{-1-\sqrt{1+60}}{2} \le 9-V_{in} \le \frac{-1+\sqrt{61}}{2}$

7.81

$9-\left(\frac{-1+\sqrt{61}}{2}\right) \le V_{in} \le 9-\left(\frac{-1-\sqrt{61}}{2}\right)$

$15-\frac{1\times10^{-3}(10-V_{in}-1)^2}{2}\cdot 2\times10^{3} = 15-(9-V_{in})^2$

5 Consider the MOSFET amplifier in Figure 4. Suppose that the MOSFET is in the saturation region, and V_S=15 V, R_1=5 kΩ, R_2=10 kΩ, and R_3=2 kΩ. (Note: If you've downloaded the earlier version of the lecture note, make sure you've made the following correction: the last equation on page 77 should have a square over the parenthesis.)

5.1 (5 points) If V_{in}=8 V. Find V_{out}.

5.2 (5 points) Find the minimum value of V_{in} for the MOSFET to stay in the saturation region.

5.3 (5 points) If we can change R_3, what is the maximum value of R_3 for the MOSFET to stay in the saturation region?

5.4 (5 points) What is the maximum V_{in} that will make the gain larger than or equal to 1?

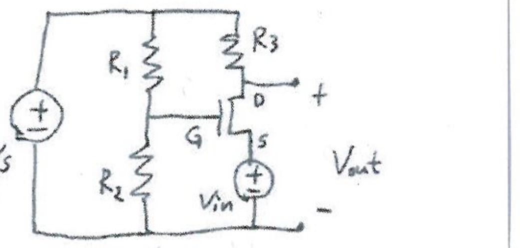


Figure 4

(5.1) V_{GS} = (the branch voltage across R_2) $- V_{in}$

$= \left(15\times\frac{10}{5+10}\right) - V_{in} = 10 - V_{in}$

$V_{out} = V_S - i_{DS}\cdot R_3$ (from $i_{DS} = \frac{V_S - V_{out}}{R_3}$)

$= V_S - \frac{K(V_{GS}-V_T)^2}{2}\cdot R_3 \Rightarrow \boxed{V_{out} = 15-(9-V_{in})^2}$

$V_{in} = 8\text{ V} \Rightarrow V_{out} = 14$ #

(5.2) $\begin{cases} V_{GS}-V_T \ge 0 \\ V_{GS}-V_T \le V_{DS} \end{cases} \Rightarrow \begin{cases} 10-V_{in}-1 \ge 0 \\ 10-V_{in}-1 \le \cancel{V_{out} = 15-(9-V_{in})^2} \\ \le V_{out}-V_{in} = 15-(9-V_{in})^2 - V_{in} \end{cases} \Rightarrow \begin{cases} V_{in} \le 9 \\ \cancel{5.59}\ 6.55 \le V_{in} \le \cancel{13.4}\ 11.45 \end{cases}$

$\Rightarrow$ minimum $V_{in} \approx \cancel{5.59}\ 6.55$ #

(5.3) following (5.1), from $V_{out} = V_S - \frac{K(V_{GS}-V_T)^2}{2}\cdot R_3$

$\Rightarrow V_{DS} = V_{out} - V_{in} = 15 - \frac{1\times10^{-3}(9-V_{in})^2}{2}\cdot R_3 - V_{in}$

the condition is $V_{DS} \ge V_{GS} - V_T$

$\Rightarrow 15 - \frac{1}{2}\times10^{-3}(9-V_{in})^2\cdot R_3 - \cancel{V_{in}} \ge (10-\cancel{V_{in}}) - 1$

if $V_{in} = 8\text{ V} \Rightarrow 15 - \frac{1}{2}\times10^{-3}\cdot R_3 \ge 9 \Rightarrow R_3 \le 12\text{ k}\Omega$ #

(5.4) $V_{out} = f(V_{in}) = 15-(9-V_{in})^2 \Rightarrow \frac{V_{out}}{V_{in}} \ge 1 \Rightarrow \frac{15-(9-V_{in})^2}{V_{in}} \ge 1 \Rightarrow 6 \le V_{in} \le 11$

~~gain = 切線斜率~~

~~= 一次微分~~

~~$f'(V_{in}) = 2(9-V_{in})$~~

~~$f'(V_{in}) \ge 1 \Rightarrow 2(9-V_{in}) \ge 1$~~

~~$\Rightarrow V_{in} \le 8.5$ V~~ #

BUT if $V_{in} > 9$

the MOSFET will enter the cutoff region, and

$i_{DS} = 0$, $V_{out} = V_S = 15$

Therefore, for $\frac{V_{out}}{V_{in}} \ge 1$, the maximum $V_{in} = 15$ V #

6 Consider the MOSFET amplifier in Figure 5.

6.1 (5 points) Apply the graphical analysis to explain the following phenomenon: if we decrease R_L, then the same V_{in} will produce a larger V_{out}.

6.2 (5 points) Apply the graphical analysis to illustrate an example that if we increase V_T, the valid range of V_{in} for the MOSFET to stay in the saturation region will decrease.

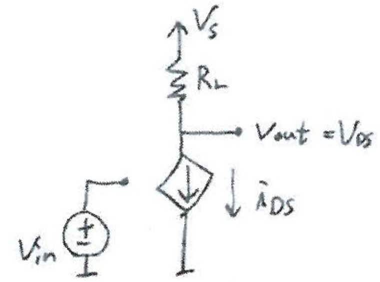
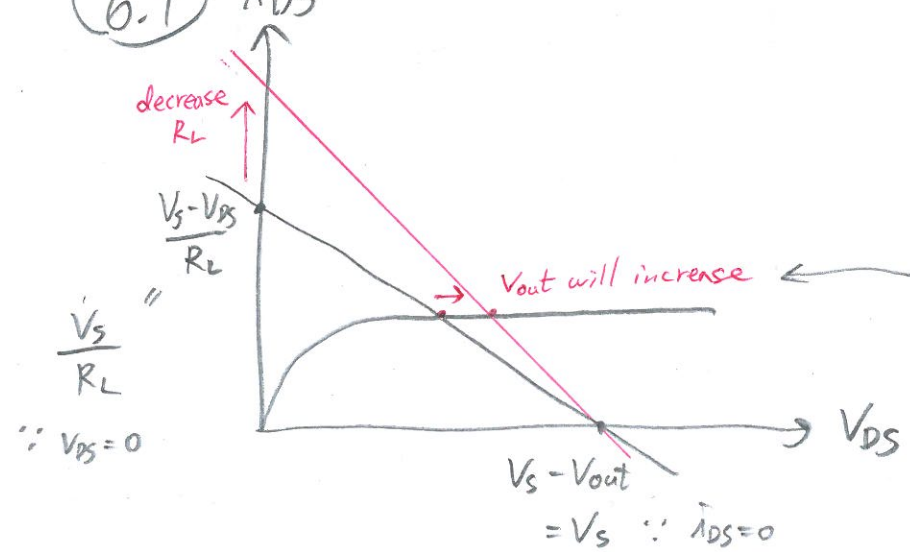


Figure 5

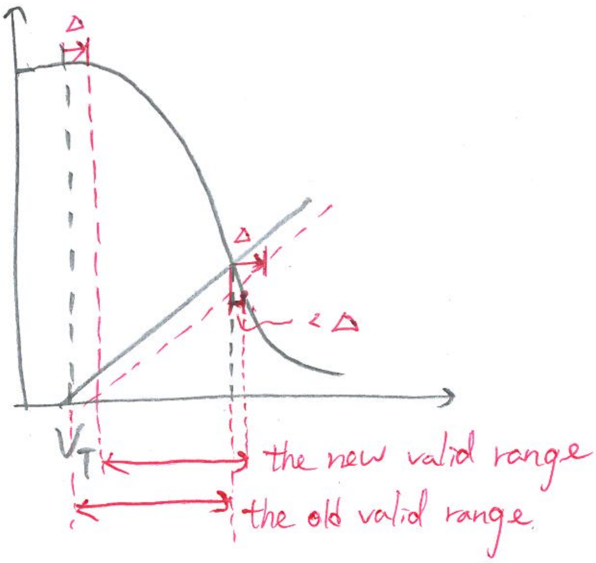
6.1



$\begin{cases} V_{GS} = V_{in} \text{ in this case.} \\ V_{out} = V_{DS} \end{cases}$

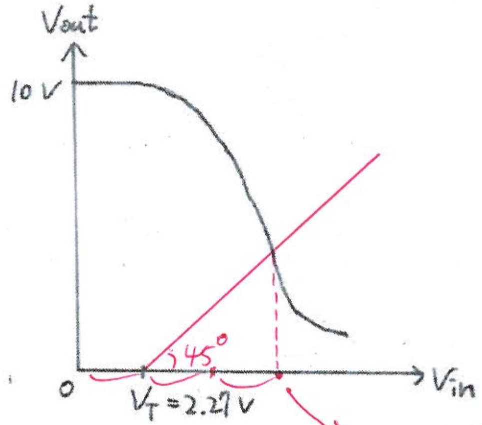
6.2 We've discussed this in class, saying that this analysis and observation make sense <u>only if</u> the V_{in}-V_{out} relation does not change as we change V_T.

↑ this necessary condition is not true, since changing V_T usually means we've changed the physical properties of the MOSFET.



7 Apply the graphical analysis for the following two questions. Consider the MOSFET amplifier in Figure 5.

7.1 (5 points) Suppose the following plot of V_{out}-V_{in} relation is accurate. To estimate the maximum V_{in} for the MOSFET to stay in the saturation region, which one of the following three estimation is better than the other two, and why? (A) 4.2 V; (B) 6.8; (C) 8.1.



around $3 \times 2.27 \approx 6.8$ V

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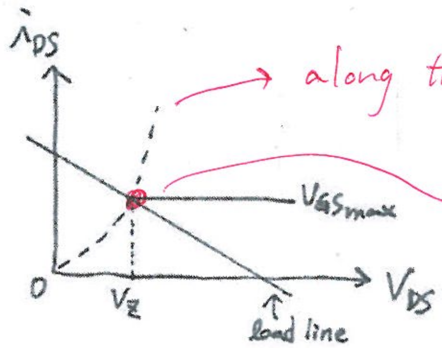
7.2 (5 points) Following Question 7.1, suppose V_{GSmax} in the following plot is our estimation of the maximum V_{in}. Determine the value of V_Z.



along this dotted curve we have $V_{DS} = V_{GS} - V_T$ (page 70 in the note)

at this intersection,

$$V_Z = V_{DS} = V_{GSmax} - V_T$$

$$\approx 6.8 - 2.27 = 4.53 \text{ V}$$

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