电子电路基础

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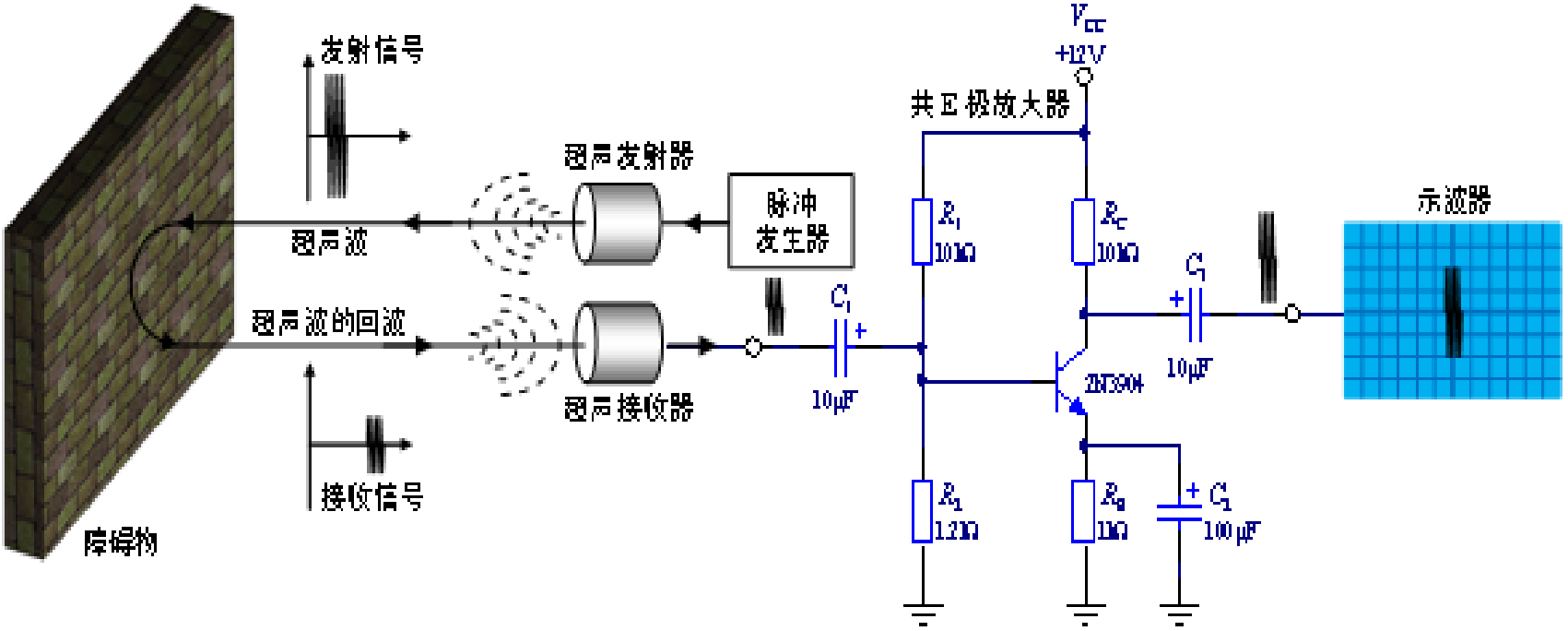
Analog Circuits

基本放大电路及分析

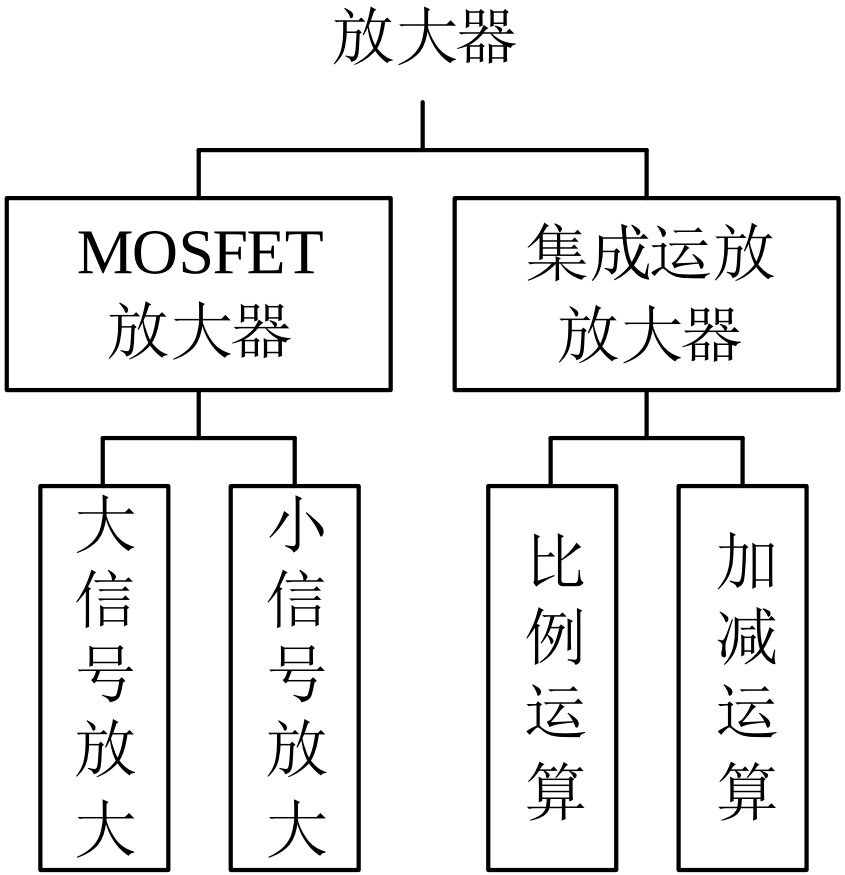
问题引入



基本放大电路及分析

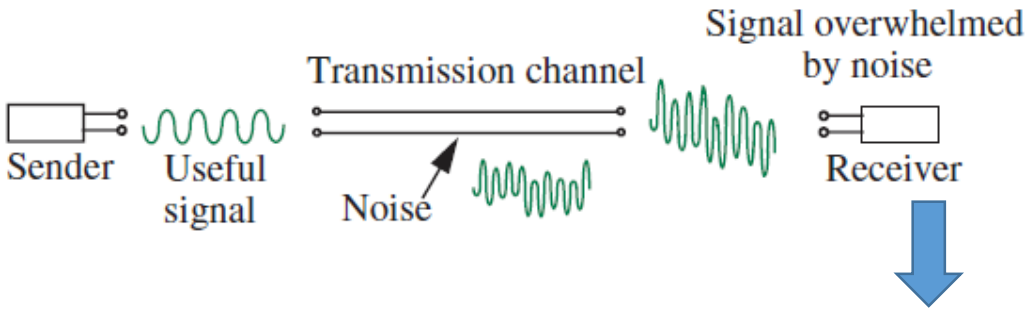
- 放大电路基本概念
- MOSFET基本放大器
- 放大器的大信号分析
- 放大器的小信号分析

基本放大电路及分析



放大器基本概念

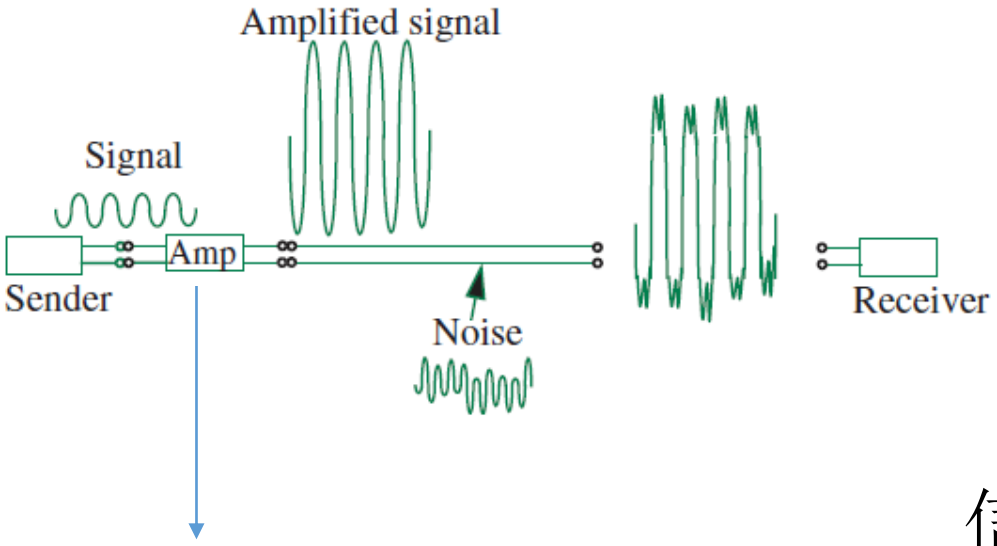
信号传输中面临的问题



信噪比
误码率

放大器基本概念

信号传输中面临的问题

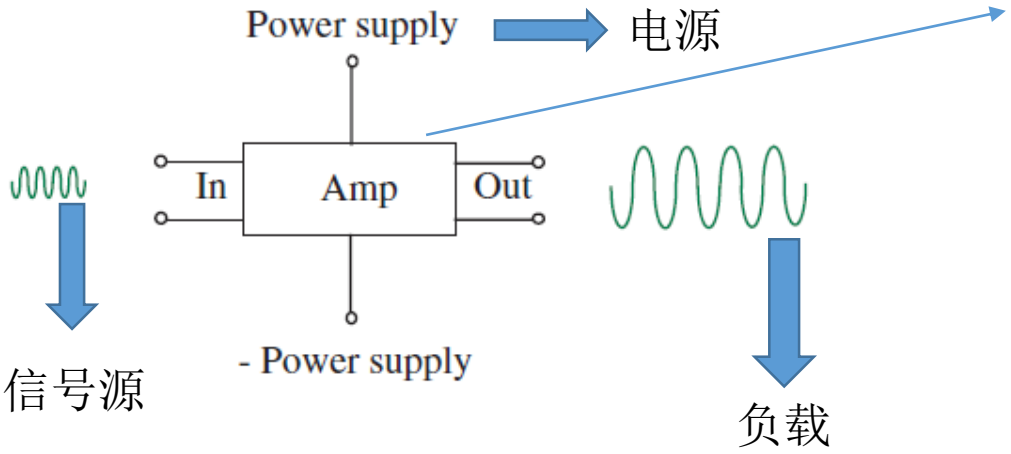


信噪比提高

拓展：放大器会引入噪声吗？

放大器基本概念

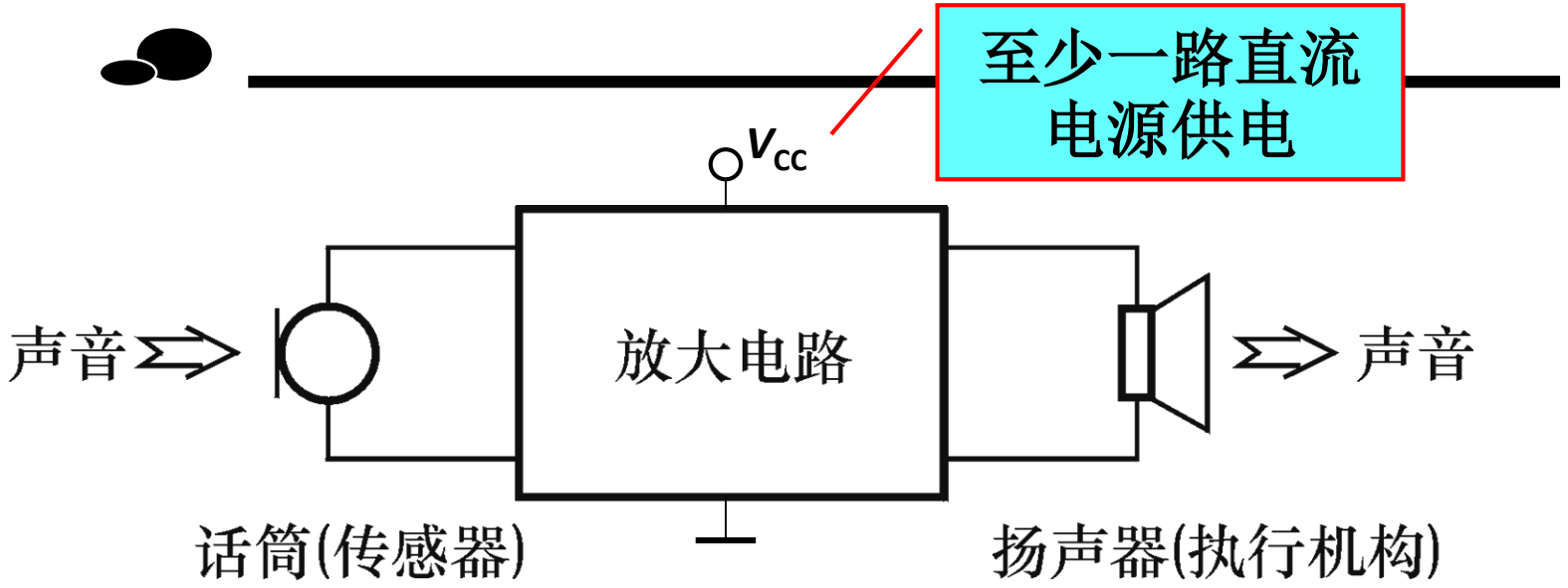
信号放大



是二端口网络吗？

公共端---地

放大器的基本要素



放大的对象：变化量（通常情况）

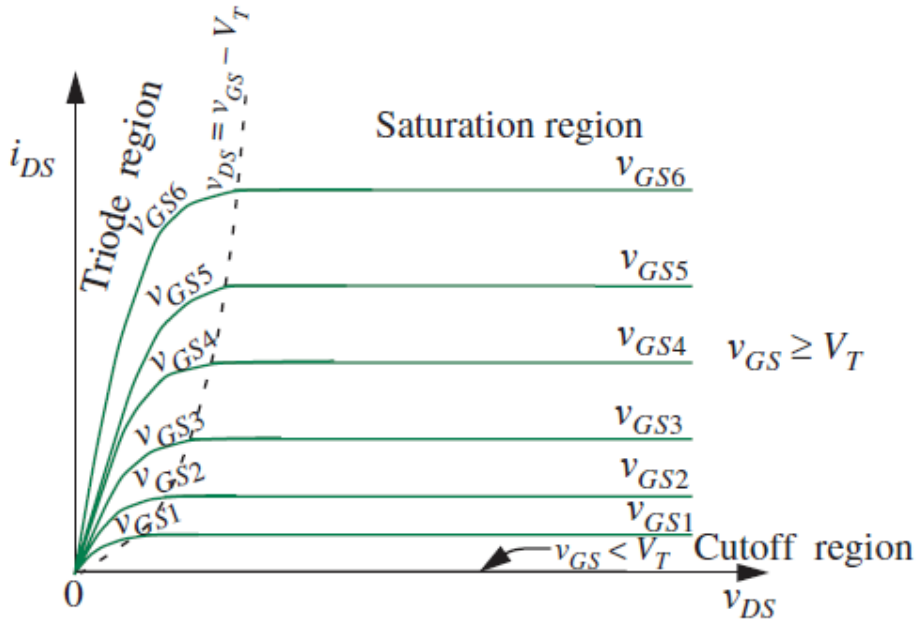
放大的本质：能量的控制与转换

放大的特征：功率放大（电压或电流）

放大的基本要求：不失真或失真小于一定值

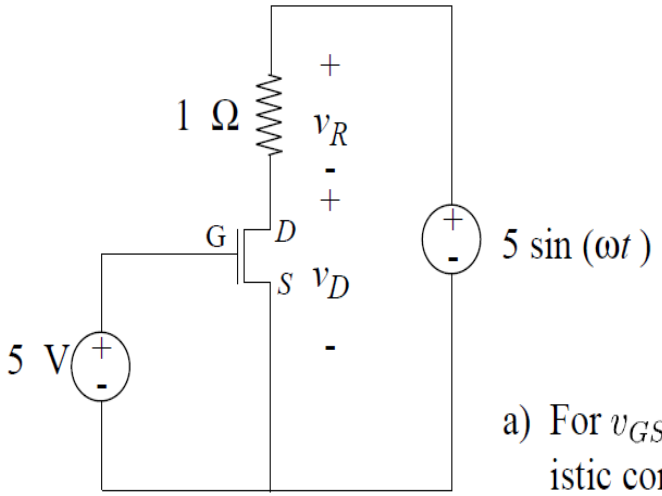
放大电路的实现—MOSFET放大器

怎样利用MOSFET特性构成信号放大电路？



设置

练习7.5 （P261）如图所示电路，讨论晶体管工作状态



a) For $v_{GS} = 5V$, what value of R_{ON} makes the MOSFET i_{DS} versus v_{DS} characteristic continuous between its triode and saturation regions of operation.

b) Plot v_R versus v_D for the circuit shown in Figure 7.4. This circuit is useful in plotting the MOSFET characteristics. Assume that $K = 1mA/V^2$ and $V_T = 1V$. Use the value of R_{ON} calculated in (a). Use a volt scale for v_D and a millivolt scale for v_R.

作答

分析

a) Boundary between triode and saturation regions is when $v_{DS} = v_{GS} - V_T = 5 - V_T$

At this point, $i_{DS} = \frac{K}{2}(5 - V_T)^2$

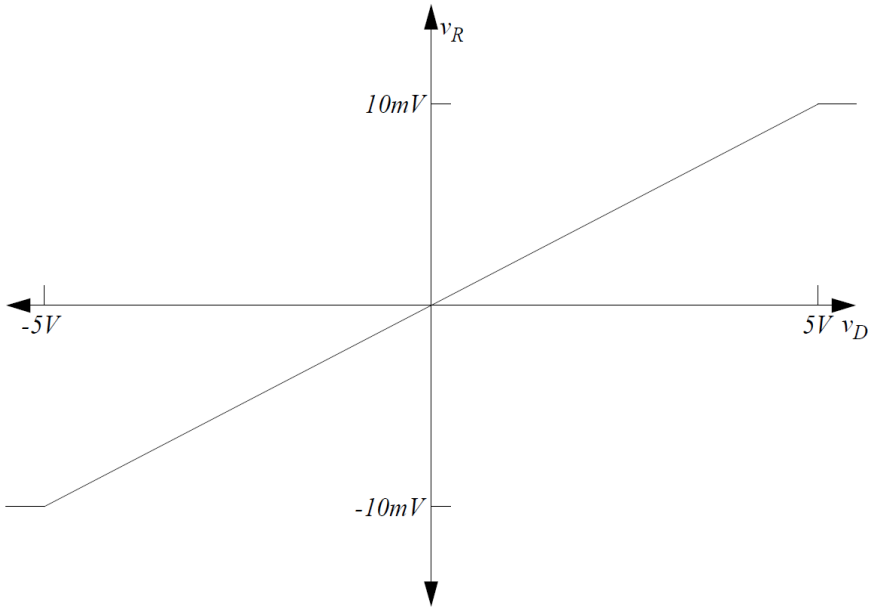
$R_{ON} = \frac{v_{DS}}{i_{DS}} = \frac{5-V_T}{\frac{K}{2}(5-V_T)^2}$

$R_{ON} = \frac{2}{K(5-V_T)}$

分析

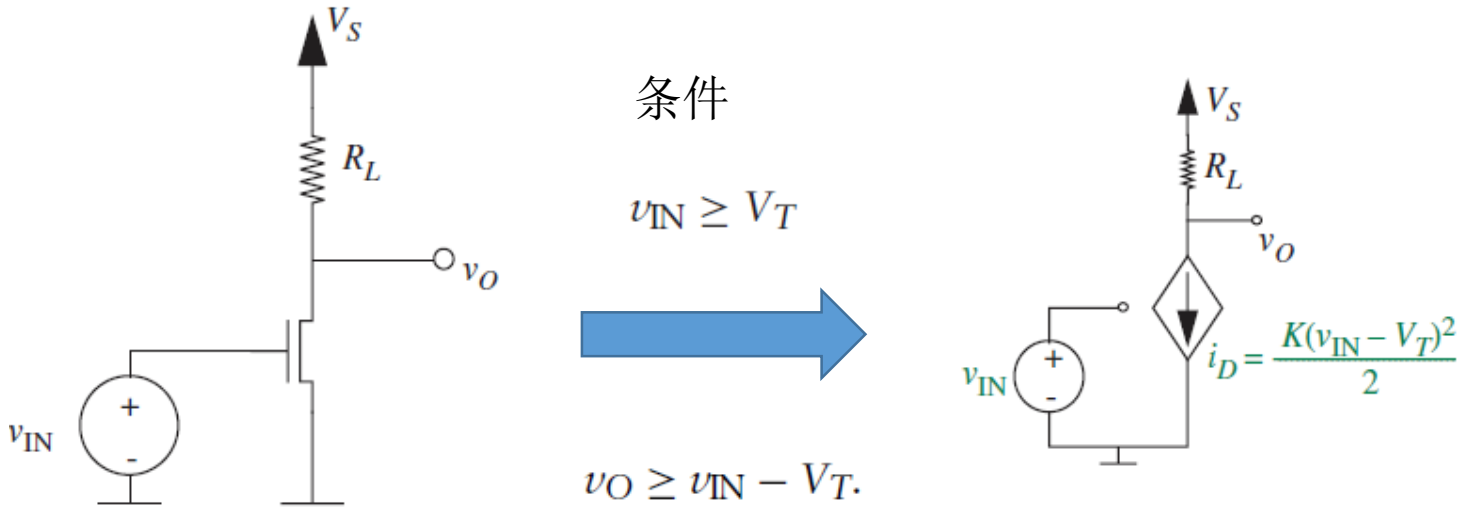
b) $R_{ON} = 500\Omega$

MOSFET is in triode region for $v_D \leq 4volts$. In triode region, $v_R = \frac{v_D}{500}$. In saturation region, $v_R = 8mV$.



拓展：负半轴存在吗？

放大电路的实现—MOSFET放大器



基本放大电路

放大电路的实现—MOSFET放大器

思考：当输入正弦信号，输出还是正弦信号吗？
如何改进电路？

放大电路的实现—MOSFET放大器

输出电压与输入电压关系

$$v_O = V_S - i_D R_L.$$

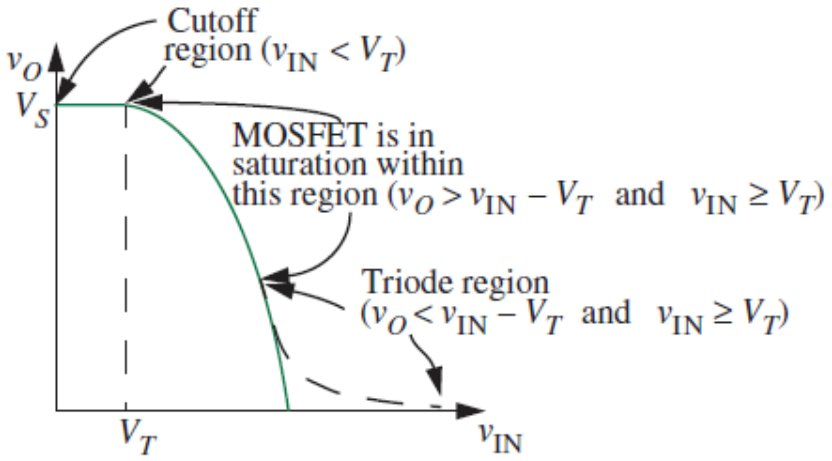
$$i_D = \frac{K(v_{IN} - V_T)^2}{2}.$$

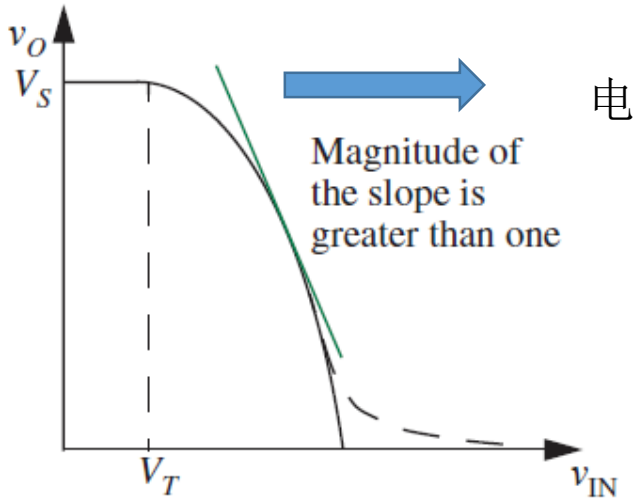
$$v_O = V_S - K\frac{(v_{IN} - V_T)^2}{2}R_L.$$

非线性关系

放大电路的实现—MOSFET放大器

输出电压与输入电压关系





电压增益

放大电路的实现—MOSFET放大器

取一组参数

$$V_S = 10\ \text{V}$$
$$K = 1\ \text{mA/V}^2$$
$$R_L = 10\ \text{k}\Omega$$
$$V_T = 1\ \text{V}.$$

$$v_O = V_S - K\frac{(v_{IN} - V_T)^2}{2}R_L$$
$$= 10 - (10^{-3})\left(\frac{(v_{IN} - 1)^2}{2}\right)10 \times 10^3$$
$$= 10 - 5(v_{IN} - 1)^2.$$

v_{IN}	v_{OUT}
1	10
1.4	9.2
1.5	8.8
1.8	6.8
1.9	6
2	5
2.1	4.0
2.2	2.8
2.3	1.6
2.32	1.3
2.35	0.9
2.4	~ 0

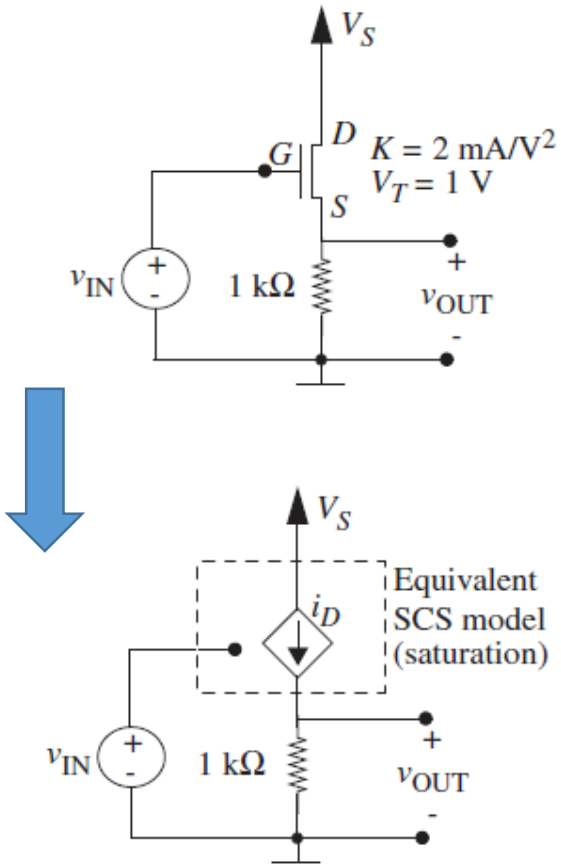
分析数据
结论？

放大电路的实现—MOSFET放大器

- 输出与输入比较，输入1-2.4V，输出10-0V？
- 增益是非线性的；
- 随着输入信号增大，输入趋于？

放大电路的实现—MOSFET放大器

例



$v_{IN} = 2$ V

$v_{OUT}^2 - 3v_{OUT} + 1 = 0.$

$v_{OUT} = 0.4$ V

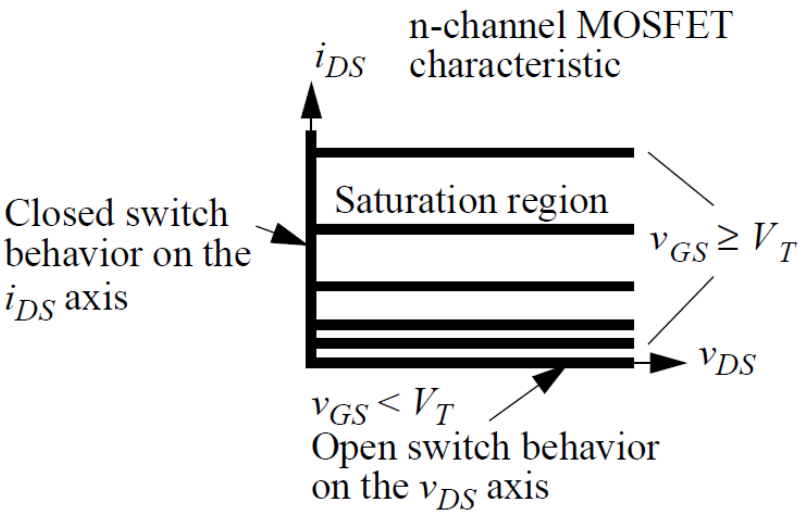
$i_D = 0.4$ mA.

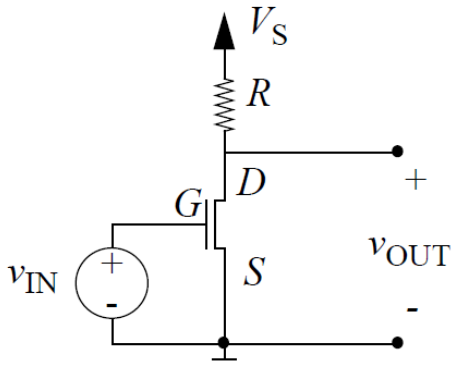
?

主观题 10分

设置

MOSFET晶体管V-I特性及基本放大电路如图





a) Determine v_{OUT} as a function of v_{IN} for $0 \leq v_{IN}$.

b) What is the lowest value of v_{IN} for which $v_{OUT} = 0$?

c) Assume that $V_S = 15$ V, $R = 15$ kΩ, $V_T = 1$ V and $K = 2$ mA/V^2. Graph v_{OUT} versus v_{IN} for 0 V $\leq v_{IN} \leq$ 3 V.

d) On the input-output graph, identify the regions over which the MOSFET behaves as an open circuit, behaves as a short circuit, and exhibits saturated behavior.

作答

分析

a) When there is current going through R, the current is limited by two quantities: either $\frac{V_S}{R}$ or $\frac{K}{2}(v_{GS} - V_T)^2$, whichever is lower. If the limit is V_S/R, then the MOSFET is in the closed-switch region. If the limit is $\frac{K}{2}(v_{GS} - V_T)^2$, then the MOSFET is in the saturation region.

open-switch region For $v_{GS} \leq V_T$, the MOSFET is open, therefore $v_{OUT} = V_S$.

saturation region When v_{GS} begins to exceed V_T, the quantity $v_{GS} - V_T$ is still small, so the current is limited by $\frac{K}{2}(v_{GS} - V_T)^2$. This current determines the output voltage, which is given by $v_{OUT} = V_S - \frac{KR}{2}(v_{IN} - V_T)^2$.

closed-switch region i_{DS} increases until it reaches $\frac{V_S}{R}$ at some gate voltage V_{IN_T}. Now v_{DS} drops to zeros, and both i_{DS} and v_{DS} are no longer affected by the increase in v_{GS}.

In summary,

$$v_{OUT} = \begin{cases} V_S & 0 \leq v_{IN} \leq V_T \\ V_S - \frac{KR}{2}(v_{IN} - V_T)^2 & v_T \leq v_{IN} \leq V_{IN_T} \\ 0 & V_{IN_T} \leq v_{IN} \leq V_{IN_{MAX}} \end{cases}$$

分析

b) The lowest value of v_{IN} for which $v_{\mathrm{OUT}} = 0$ occurs when v_{IN} is at the *transition* between the saturation region and the closed-switch region. At this point, the saturation region current limit and the closed-switch region current limit are the same,

$$i_{\mathrm{DS}} = \frac{V_{\mathrm{S}}}{R} = \frac{K}{2}(V_{\mathrm{IN_T}} - V_{\mathrm{T}})^2$$

Solving for $V_{\mathrm{IN_T}}$ we get

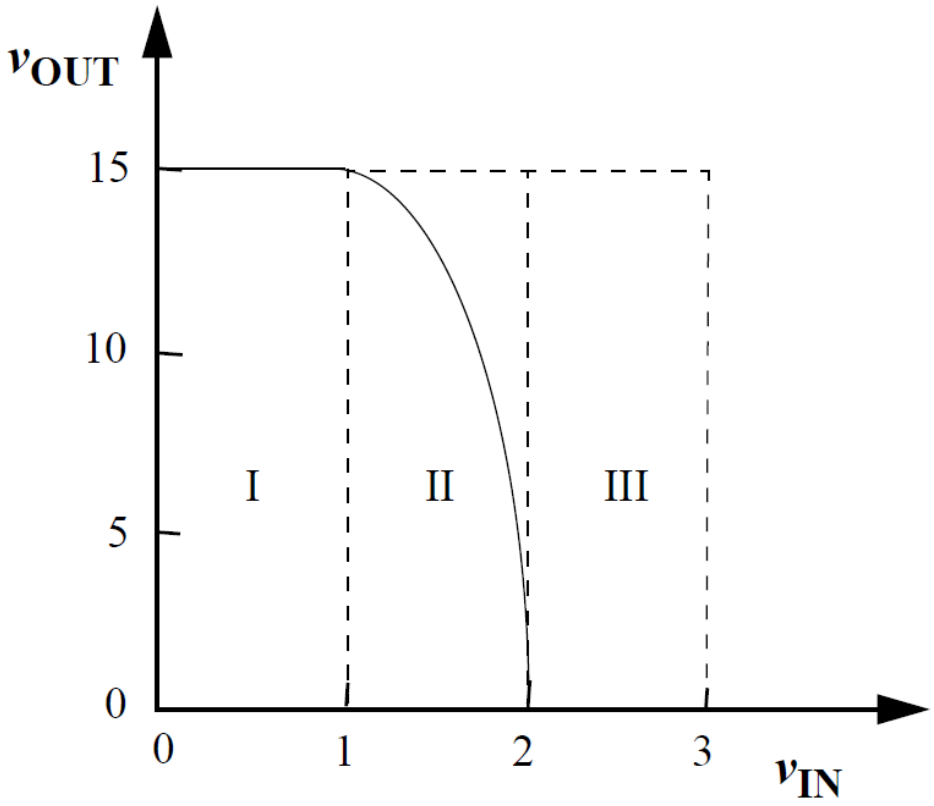
$$V_{\mathrm{IN_T}} = \sqrt{\frac{2V_{\mathrm{S}}}{KR}} + V_{\mathrm{T}}$$

分析

c) Combining the results of part (a) and (b), we obtain the following equations.

$$v_{\mathrm{OUT}} = \begin{cases} 15 & 0 \le v_{\mathrm{IN}} \le 1 \\ 15 - 15(v_{\mathrm{IN}} - 1)^2 & 1 \le v_{\mathrm{IN}} \le 2 \\ 0 & 2 \le v_{\mathrm{IN}} \le 3 \end{cases}$$

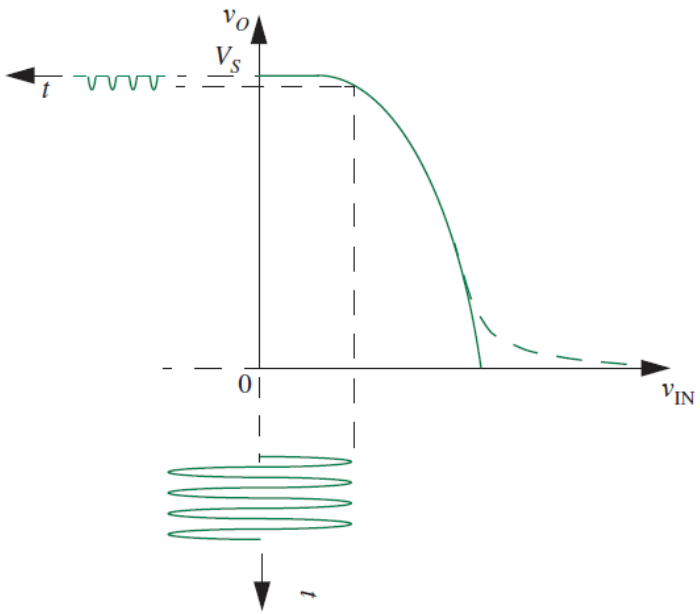
分析



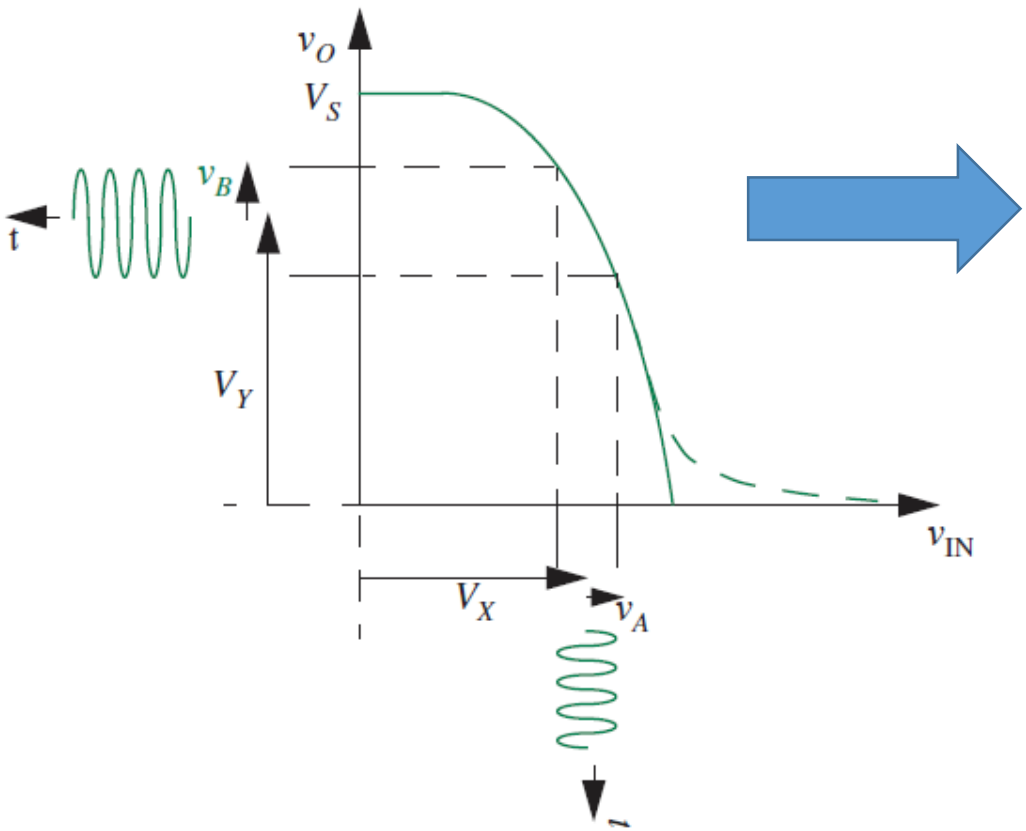
MOSFET放大器的偏置

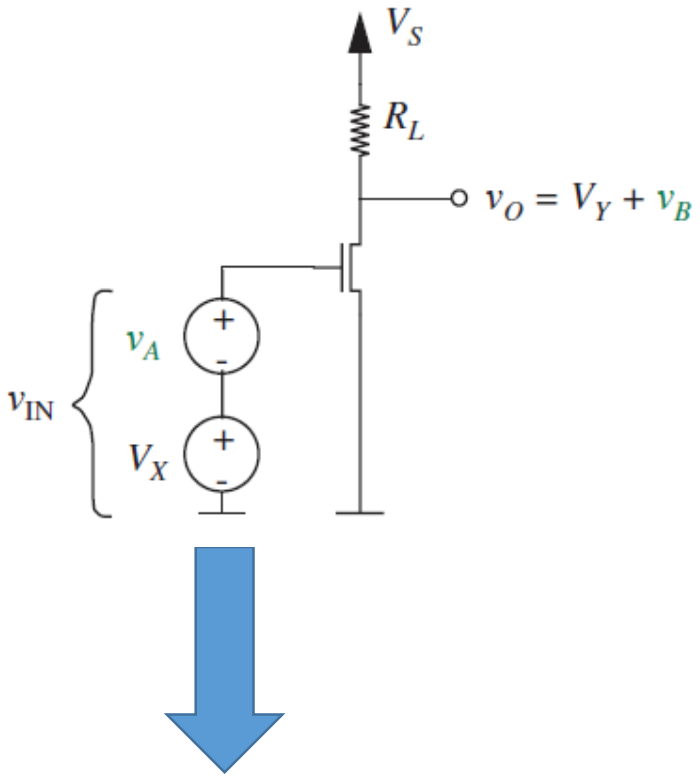
- 问题：输入信号幅度低于截止时，会出现什么现象？如何解决？

截止失真



MOSFET放大器的偏置





DC偏置（工作点）

MOSFET放大器的大信号分析

放大器分析

- 大信号分析（信号幅度变化范围较大）
- 小信号分析（信号幅度围绕工作点在较小的范围内变化）

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MOSFET放大器的大信号分析

- 大信号分析主要解决的问题？

  1 如何得到输入输出电压的关系？

  2 在放大状态下，有效输入范围，相应的输出范围？

MOSFET放大器的大信号分析

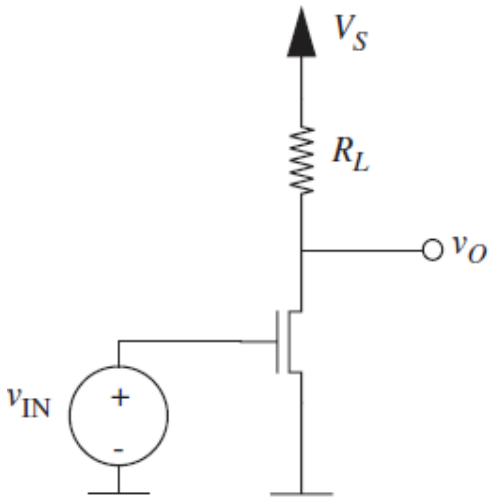
- 放大区域输入输出电压的关系

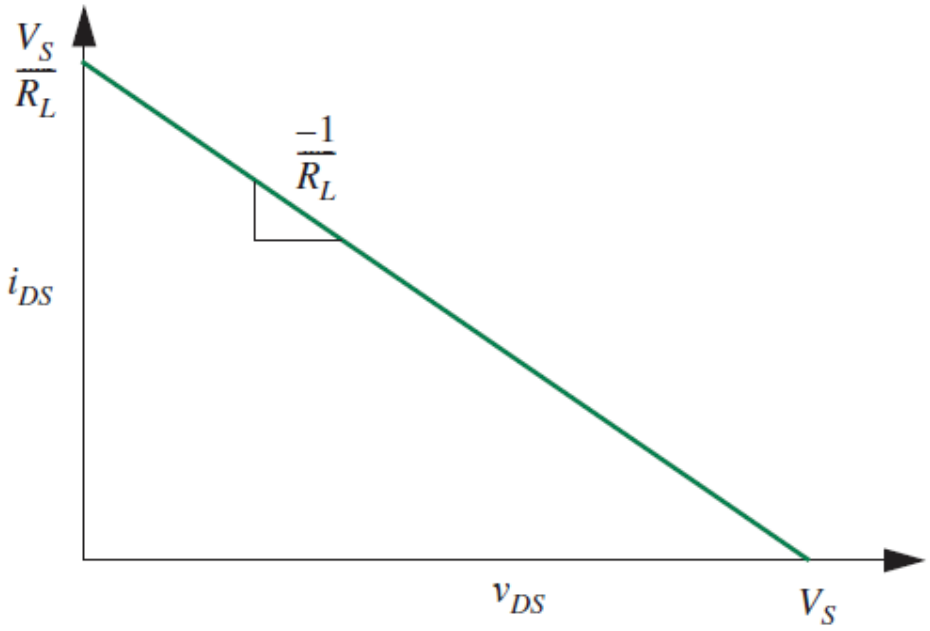
方法
- 大信号模型，求解非线性方程
- 图解方法

MOSFET放大器的大信号分析

负载线

$$v_{DS} = V_S - i_{DS}R_L.$$



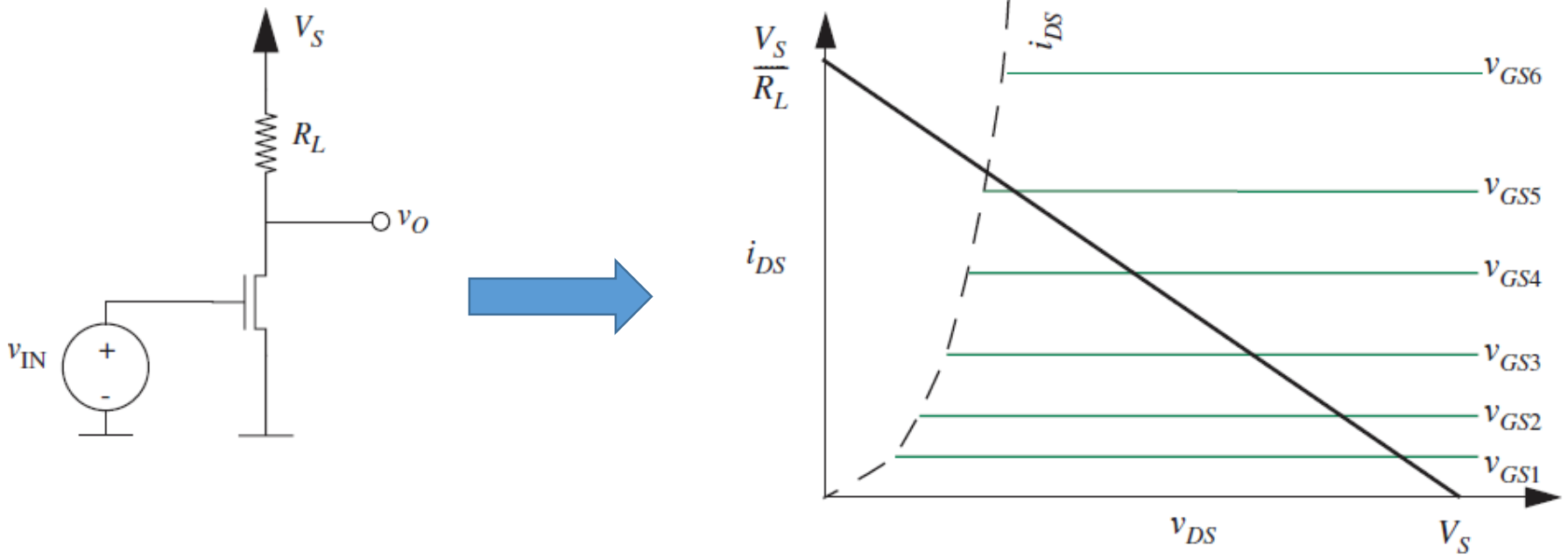


$$i_{DS} = \frac{V_S}{R_L} - \frac{v_{DS}}{R_L}.$$

MOSFET放大器的大信号分析

负载线

$$v_{DS} = V_S - i_{DS}R_L.$$



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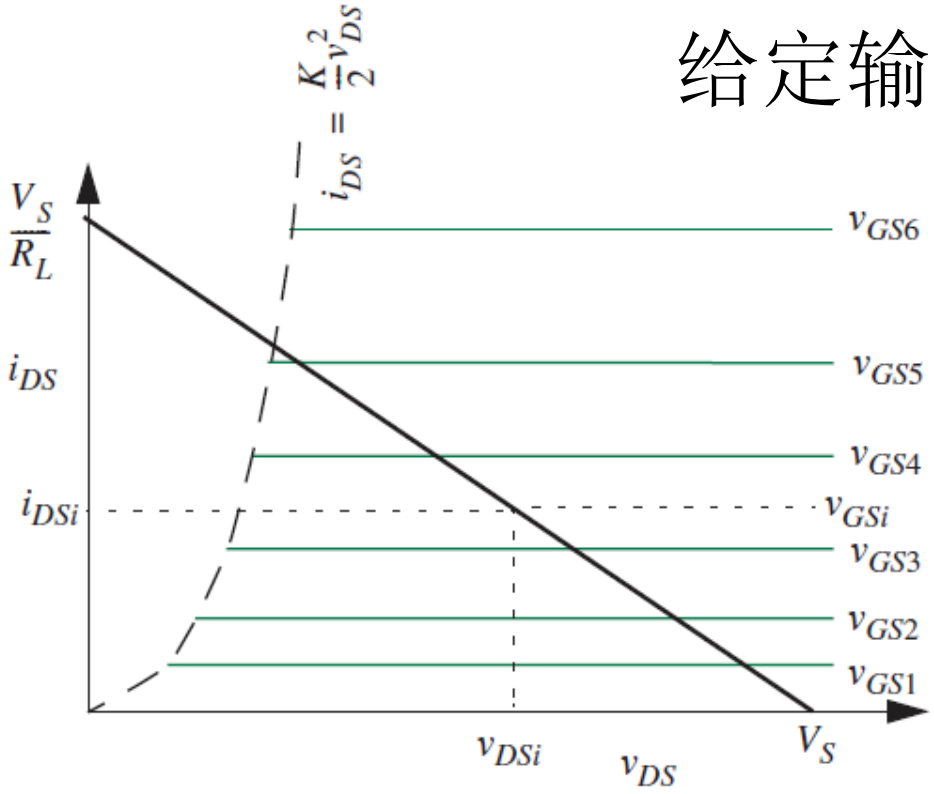
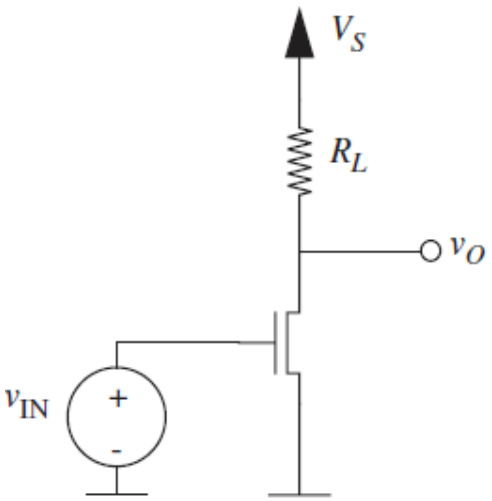
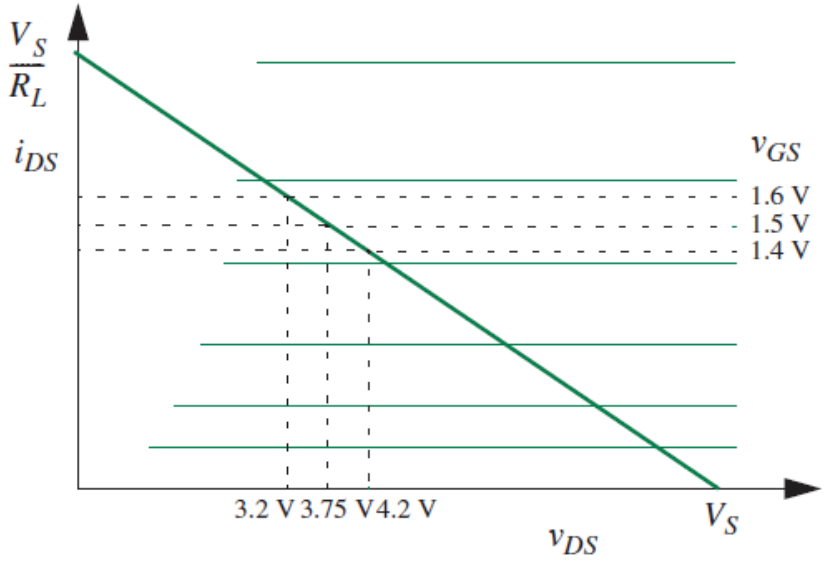
MOSFET放大器的大信号分析

给定输入可以得到对应输出



MOSFET放大器的大信号分析



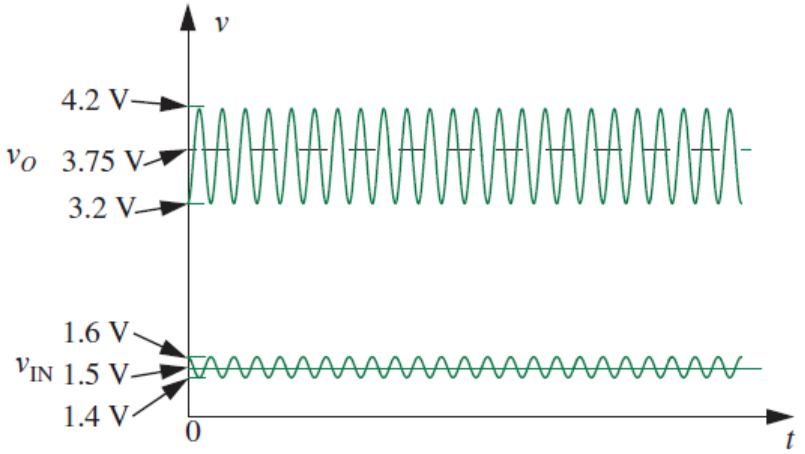


$R_L = 10\ \text{k}\Omega$

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

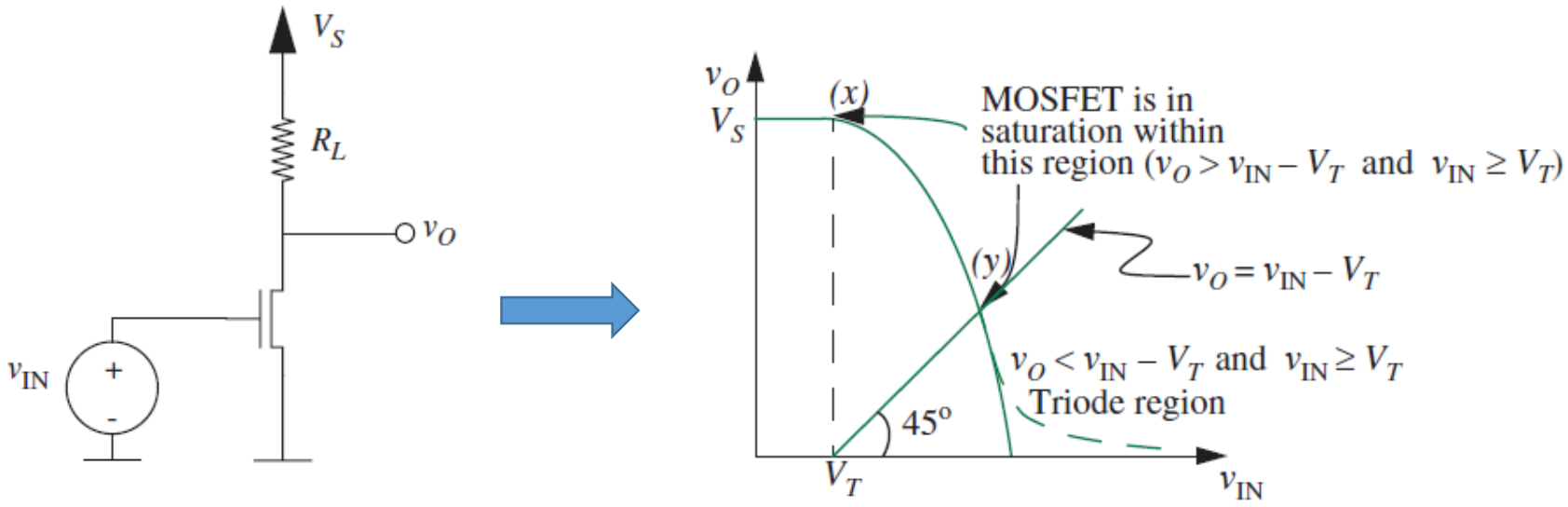
$V_S = 5\ \text{V}$

$V_T = 1\ \text{V}.$



MOSFET放大器的大信号分析

有效电压范围和工作点



MOSFET放大器的大信号分析

1 最低有效输入电压

$$\text{lowest valid input voltage} = V_T.$$

晶体管处于截止状态，输出电压是 ------？

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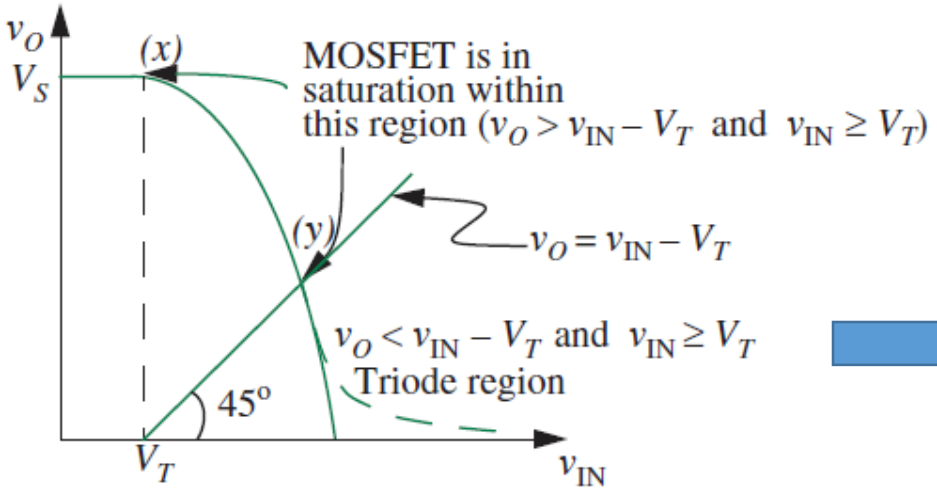
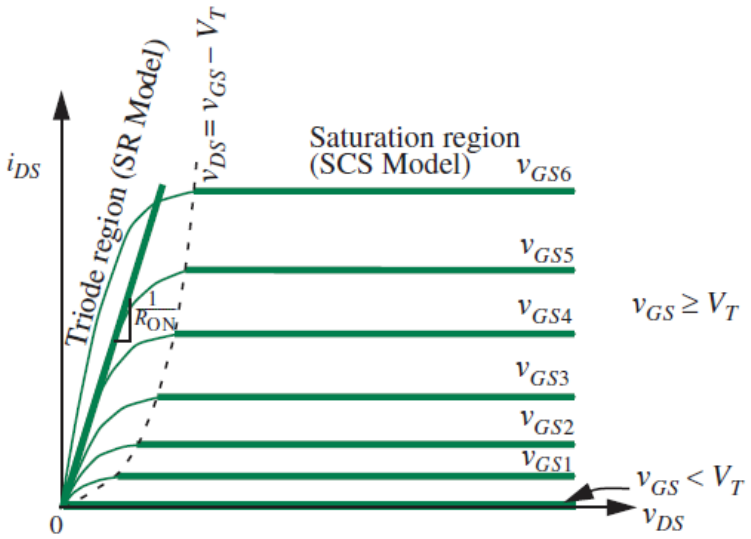
MOSFET放大器的大信号分析

2 最高有效输入电压





进入三极管区域

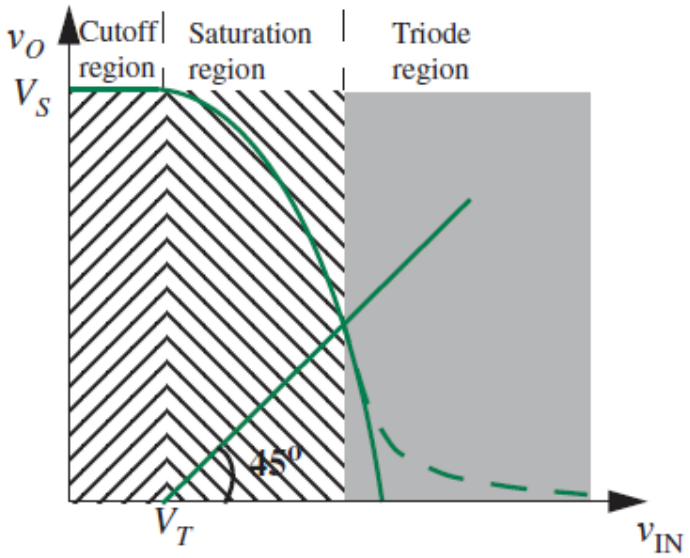
MOSFET放大器的大信号分析

讨论有哪些方法？

（1）图解，求交点；

（2）解析，方程组求解。

MOSFET放大器的大信号分析



问题：

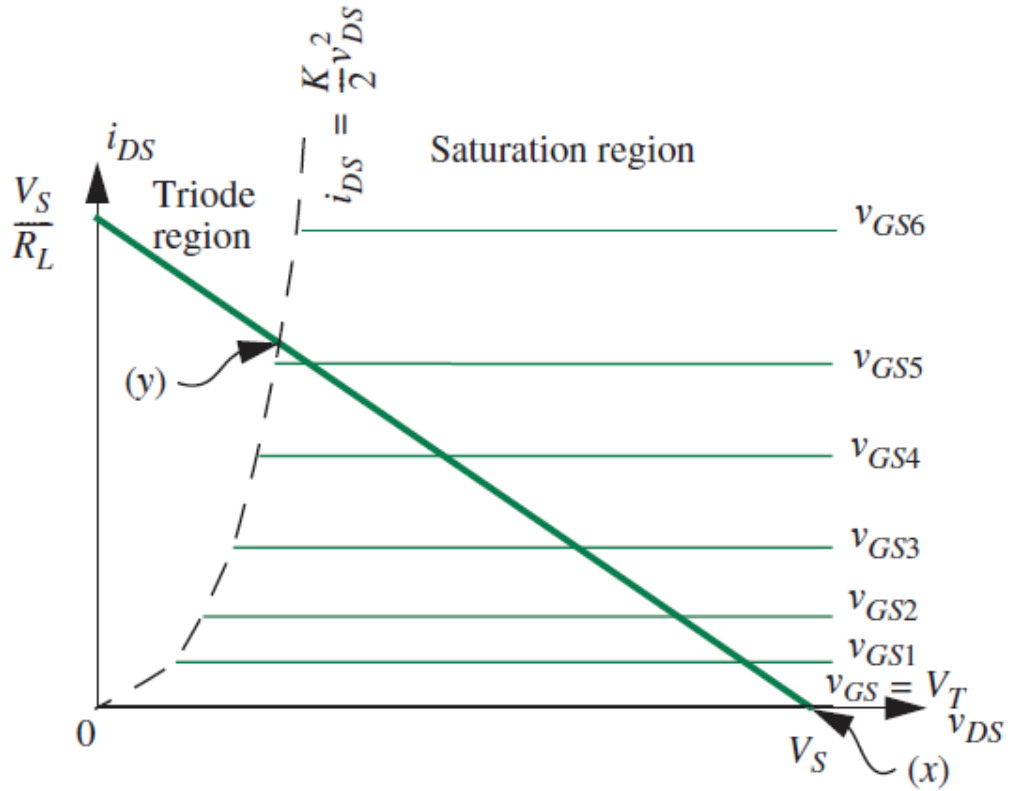
（1）输入有效电压范围？

（2）输出有效电压范围？

（3）对应的漏极电流？

MOSFET放大器的大信号分析

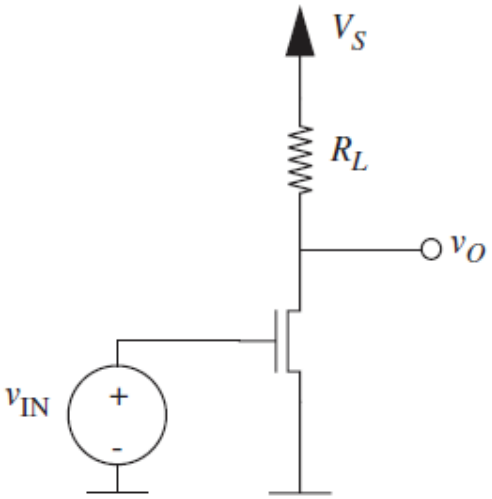
思考根据下图如何求解输入输出范围？

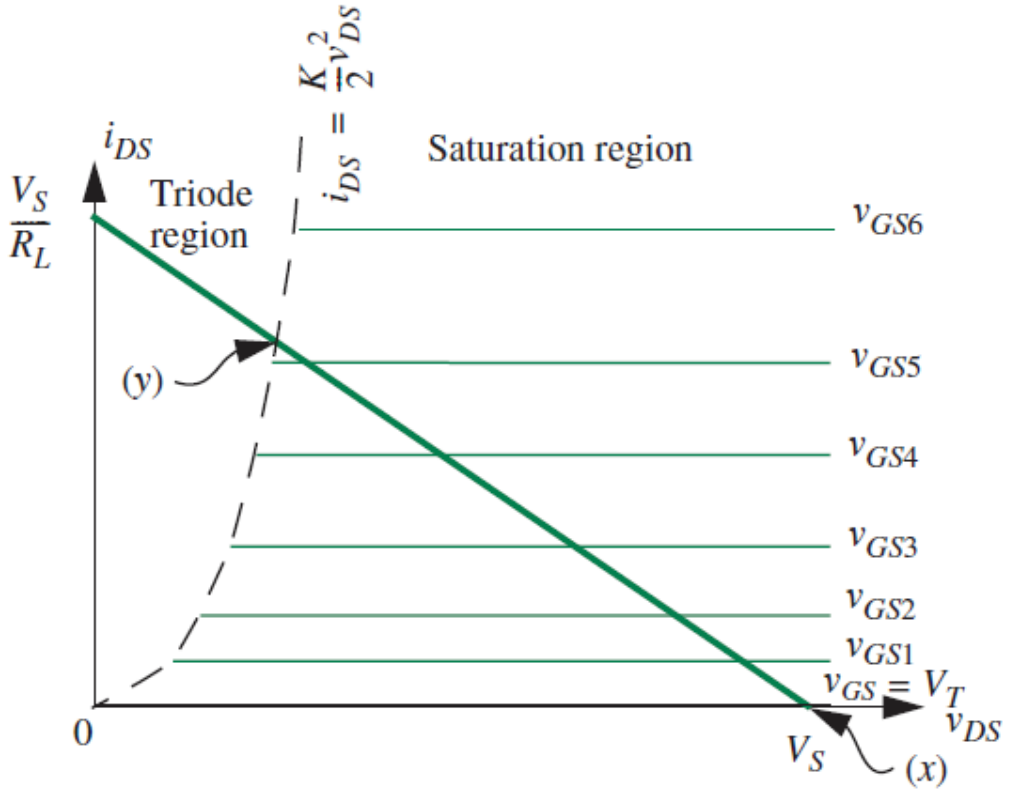


主观题 10分

设置

放大有效输入输出范围?





正常使用主观题需2.0以上版本雨课堂

作答

MOSFET放大器的大信号分析

放大器输入输出范围？

最大有效输入范围 $$V_T \rightarrow \frac{-1+\sqrt{1+2V_S R_L K}}{R_L K} + V_T$$

最大有效输出范围 $$V_S \rightarrow \frac{-1+\sqrt{1+2V_S R_L K}}{R_L K}.$$

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MOSFET放大器的大信号分析

- 工作点---偏置电压， 对放大器性能影响很大
- 根据放大器不同性能要求，选择工作点依据不同（查阅资料，有哪些性能要求？）
- 放大器设计优化

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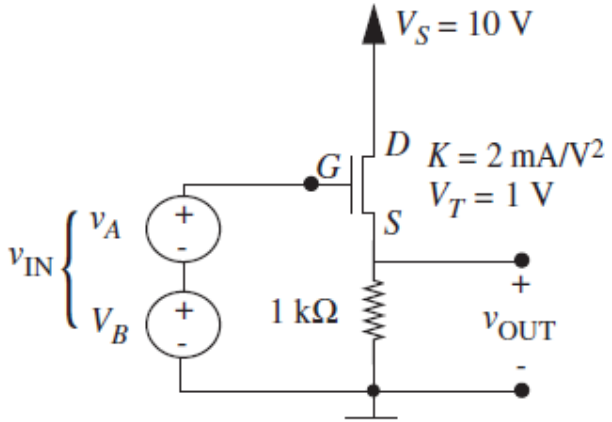
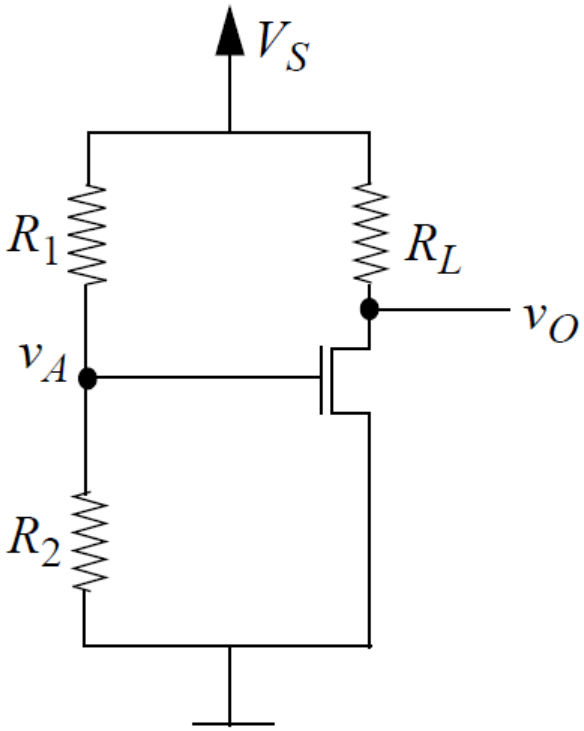
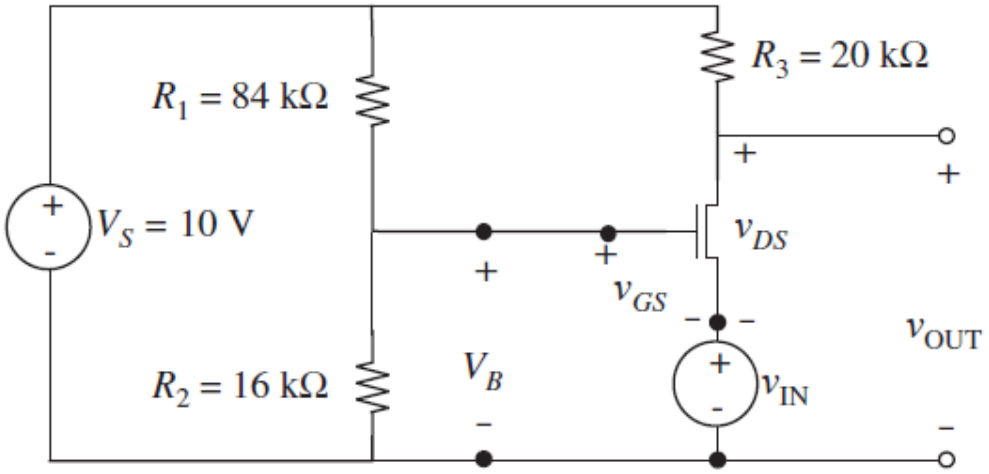
MOSFET放大器的大信号分析





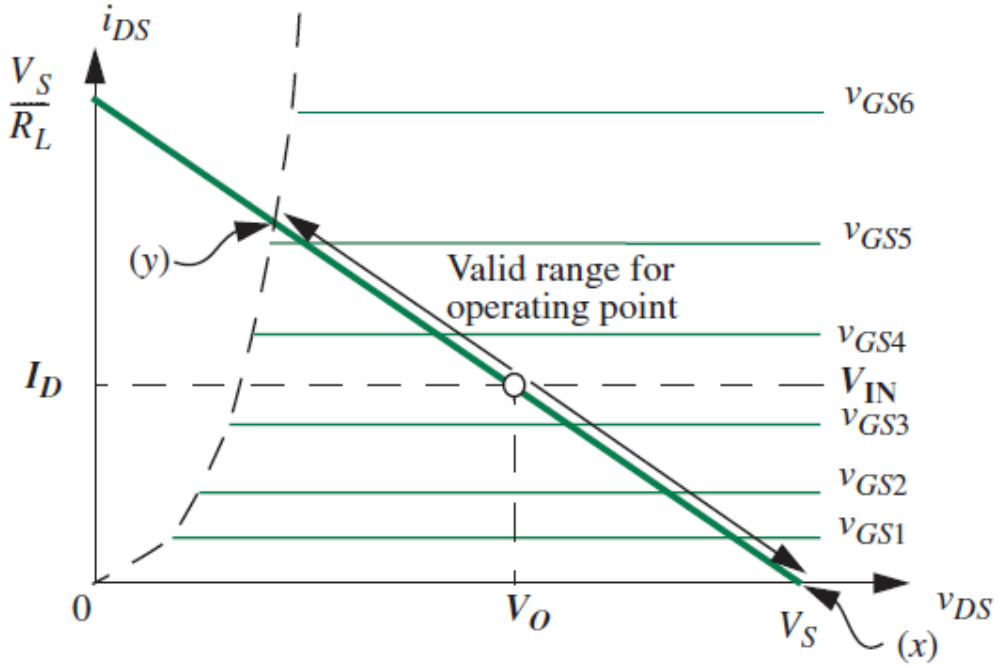
MOSFET放大器的大信号分析

例7.12（P247）



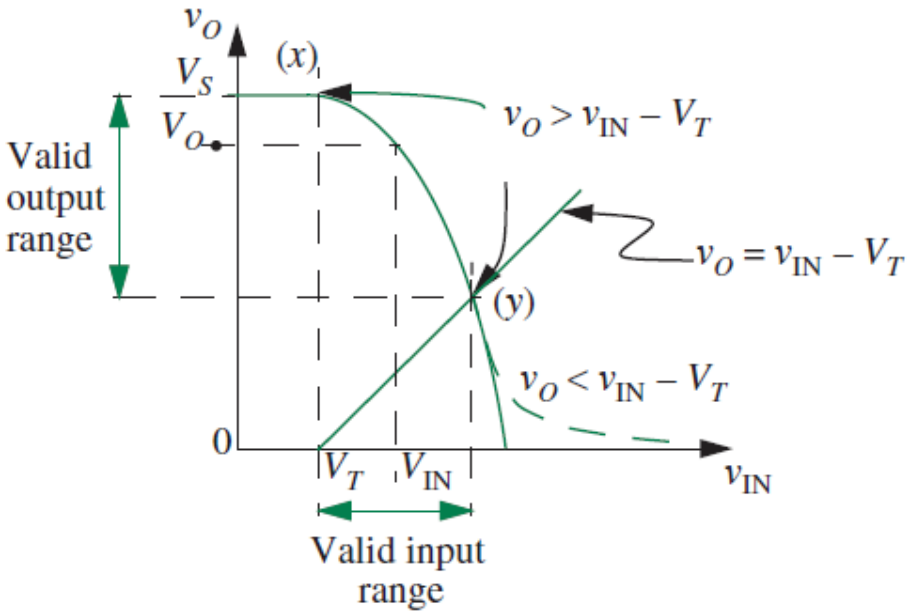
MOSFET放大器的大信号分析

◆ 工作点有效范围



MOSFET放大器的大信号分析

◆ 为使输入信号变化范围最大，选择有效输入范围的中点作为工作点



MOSFET放大器的大信号分析

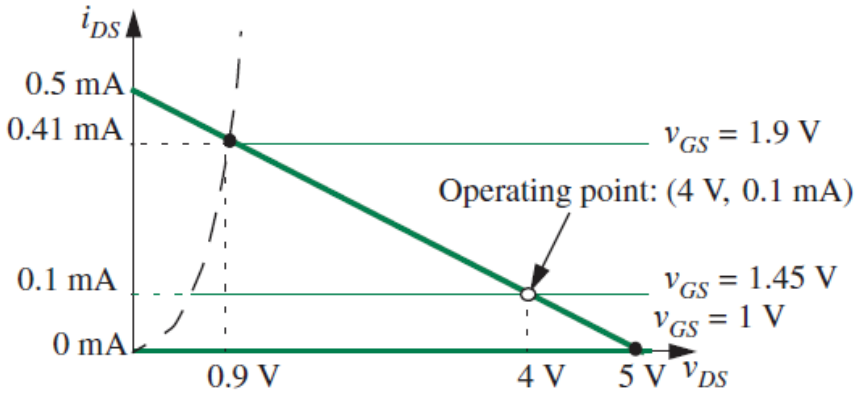
- 例

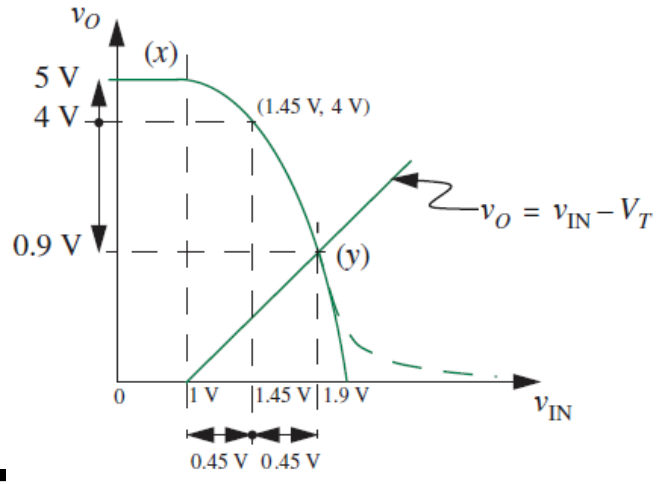
$R_L = 10\ \text{k}\Omega$

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

$V_S = 5\ \text{V}$

$V_T = 1\ \text{V}$

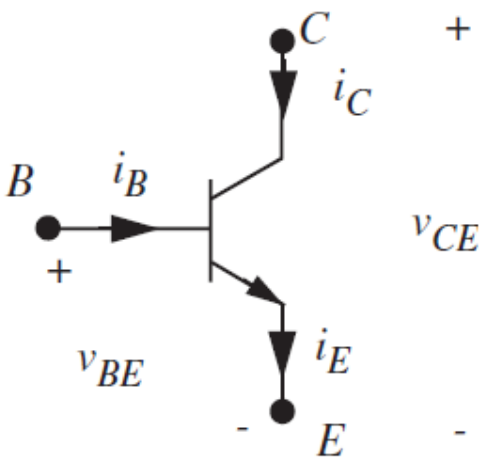


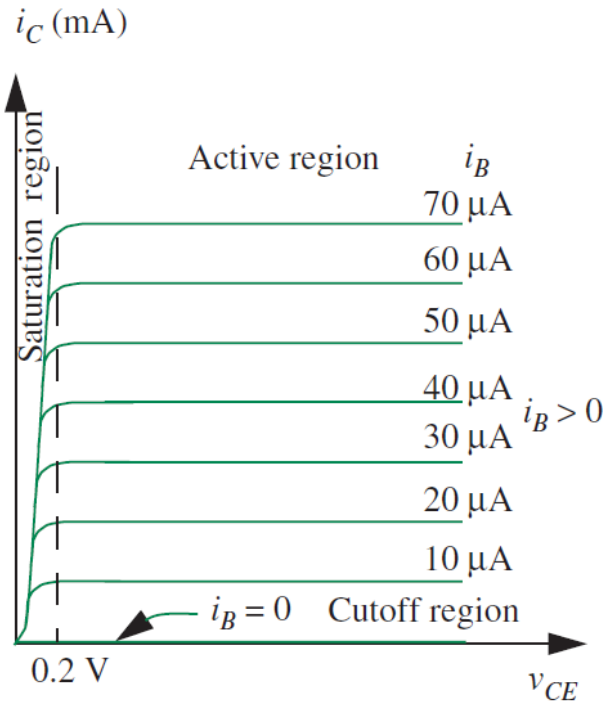


- 输出是中点吗？

MOSFET放大器的大信号分析

◆ BJT相关内容要求通过例7.13—7.16以及查阅资料自学。





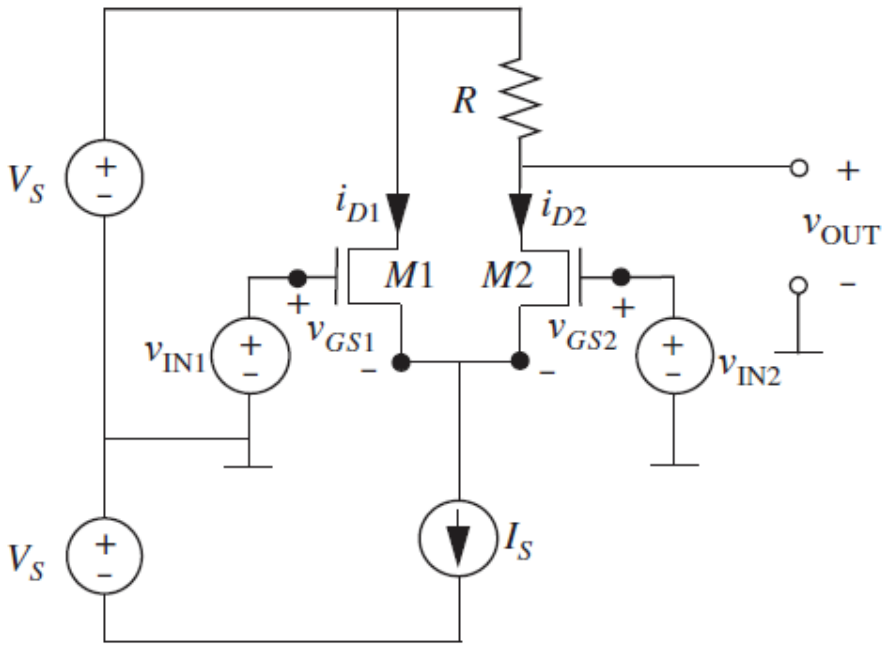
发射结正偏
集电结反偏

$$i_C = \beta i_B$$

MOSFET放大器的大信号分析

- 讨论如何放大两个信号的差？对电路有什么要求？

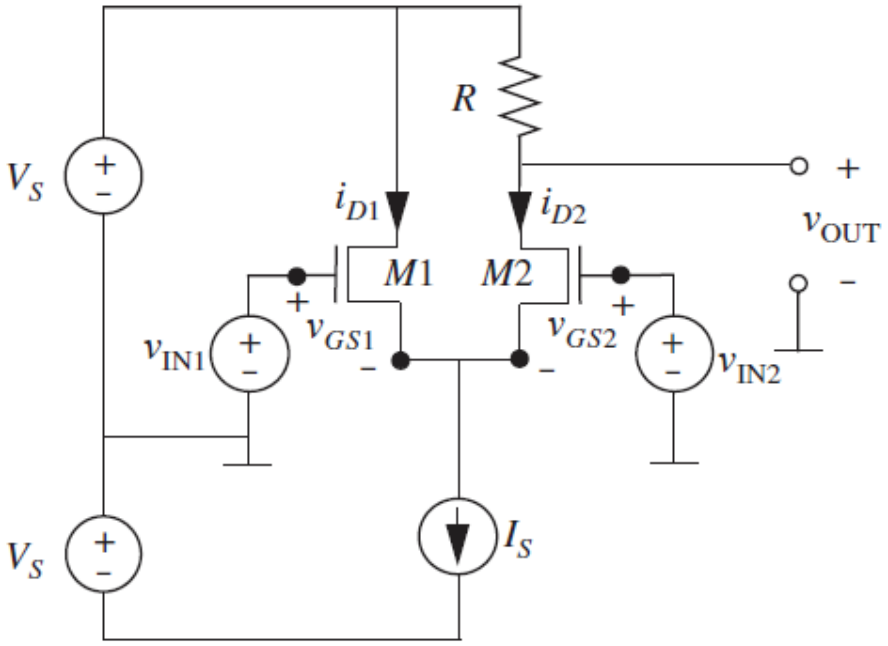
例7.19



主观题 10分

设置

给出下图的输出电压表达式，讨论如何保证晶体管工作在饱和区



正常使用主观题需2.0以上版本雨课堂

作答

MOSFET放大器的大信号分析

- 输入输出关系

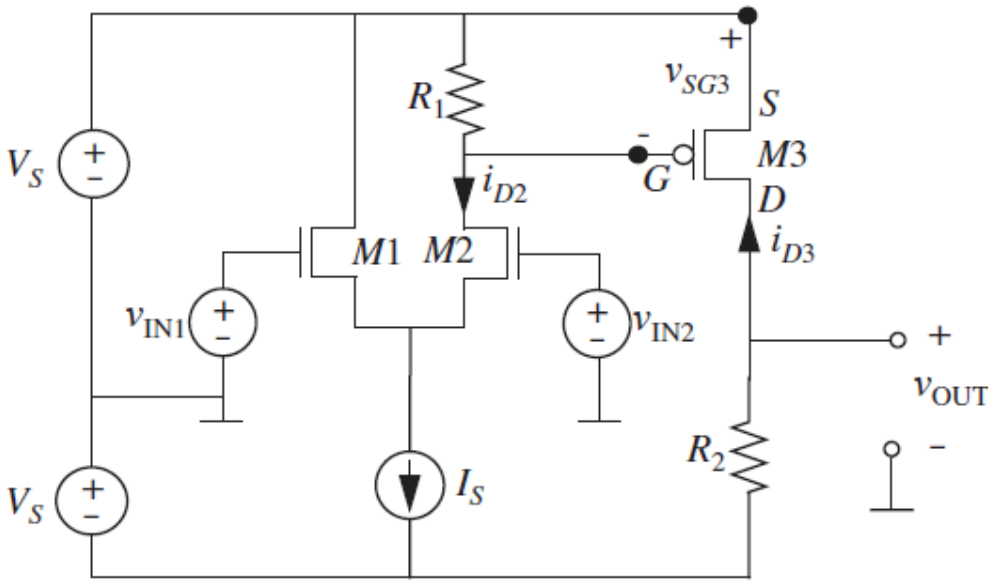
$$i_{D2} = \frac{K}{8}\left(\sqrt{\frac{4I_S}{K} - (v_{IN1} - v_{IN2})^2} - v_{IN1} + v_{IN2}\right)^2$$

$$v_{OUT} = V_S - \frac{RK}{8}\left(\sqrt{\frac{4I_S}{K} - (v_{IN1} - v_{IN2})^2} - v_{IN1} + v_{IN2}\right)^2$$

MOSFET放大器的大信号分析

- 讨论如何解决差为零，输出也为零

例7.21

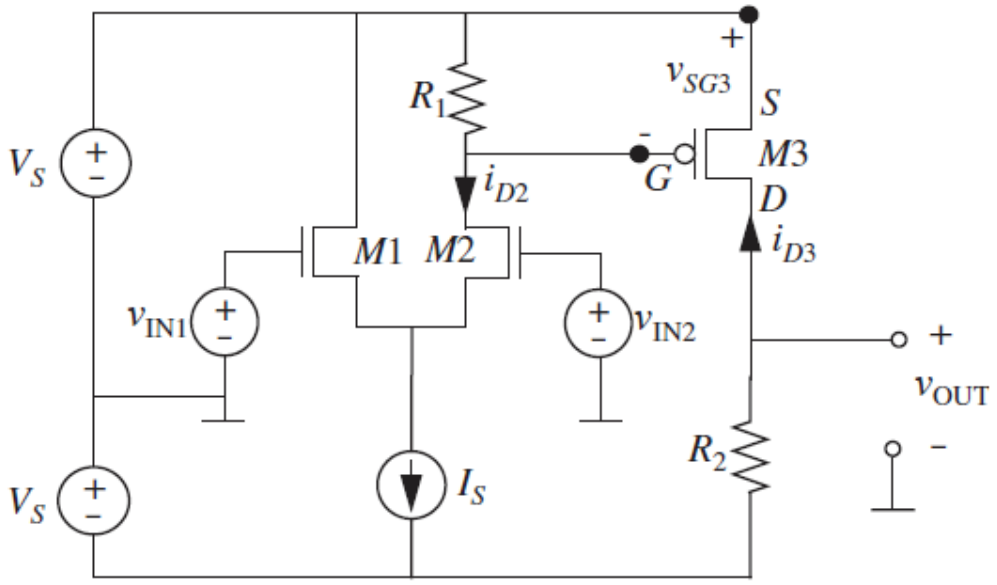


P沟道MOSFET

主观题 10分

设置

分析电路，输入信号差为零，输出电压为零的条件



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作答

分析

$$v_{\mathrm{OUT}} = \frac{R_2 K_p}{2}\left(\frac{R_1 K_n}{8}\left(\sqrt{\frac{4I_S}{K_n} - (v_{\mathrm{IN1}} - v_{\mathrm{IN2}})^2} - v_{\mathrm{IN1}} + v_{\mathrm{IN2}}\right)^2 + V_{Tp}\right)^2 - V_S.$$

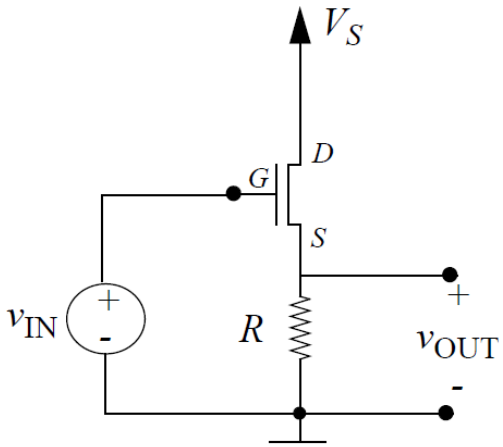
输入信号差为零，输出为零的条件

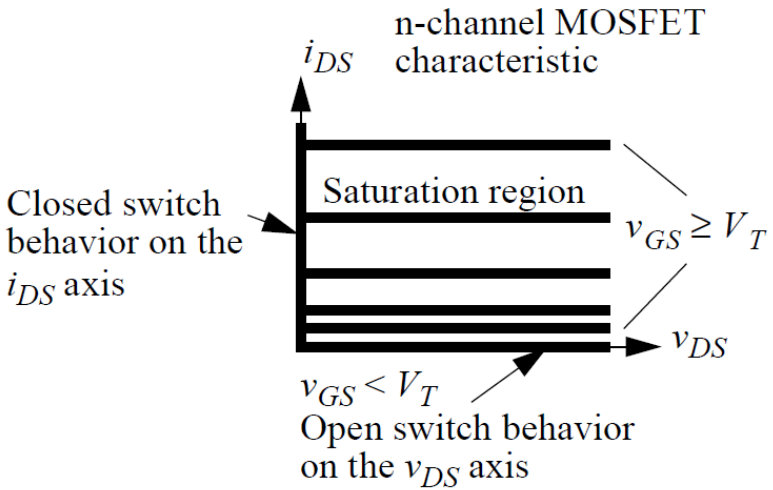
$$V_S = \frac{R_2 K_p}{2}\left(\frac{R_1 I_S}{2} + V_{Tp}\right)^2.$$

主观题 10分

设置

源极跟随器（缓冲器）电路如图，MOSFET晶体管V-I特性如图，分析大信号特性。





（1）晶体管工作在饱和区，给出输出-输入关系？

（2）Determine the range of v_{IN} over which the assumption of saturated MOSFET operation holds. What is the corresponding range for v_{OUT}?

(3) 与例题7.10（P242）比较

正常使用主观题需2.0以上版本雨课堂

作答

分析

$$v_{\mathrm{OUT}} = \left[\frac{\sqrt{(2/RK) + 4(v_{\mathrm{IN}} - V_{\mathrm{T}})} - \sqrt{2/RK}}{2} \right]^2 .$$

$$V_{\mathrm{S}} \geq v_{\mathrm{OUT}} \geq 0V$$

$$V_T \leq v_{IN} \leq V_S + V_T$$

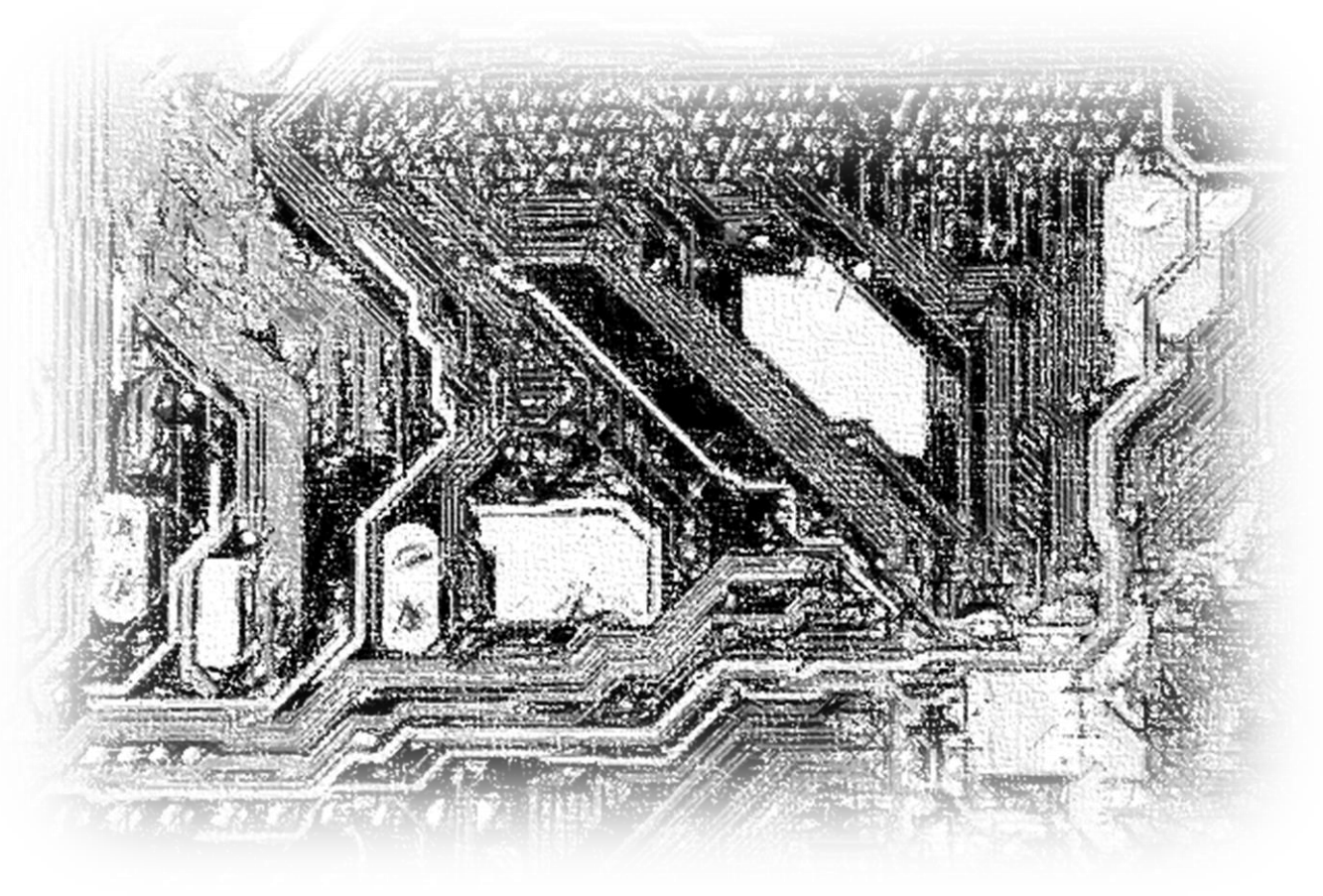
总结

大信号分析：列写非线性方程，结合图解法分析。

MOSFET放大器的大信号分析

- 习题： 练习7.10 P263
  问题 7.6， 7.11

建议讨论题：
问题7.3，7.4， 问题7.8



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谢谢！

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