模拟与数字电路

Analog and Digital Circuits

课程主页 扫一扫

第 四 讲： **Single Transistor Amplifier (II)**

Lecture 4: **单晶体管放大器电路 （II）**

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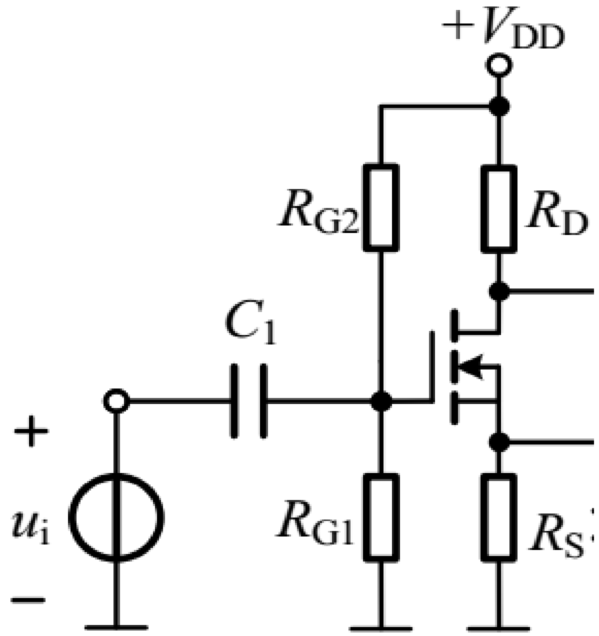
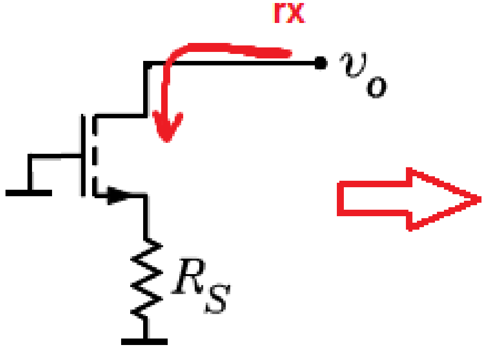
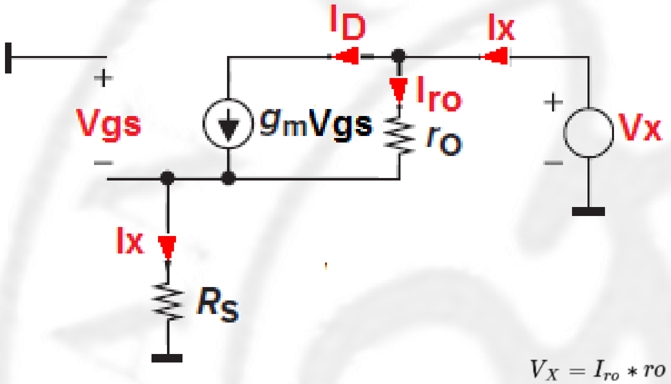
Instructor : Chixiao Chen

具有源级电阻的共源放大电路

- 小信号模型分析
  Common Source Amplifier with source degeneration







增益:

$$V_1 = V_{in} - I_D R_S = V_{in} - g_m V_1 R_S$$

$$\Rightarrow V_1 = \frac{V_{in}}{1+g_m R_S} \Rightarrow$$

$$\Rightarrow V_{out} = -g_m V_1 R_D$$

$$A_v \approx \frac{-g_m R_D}{1+g_m R_S}$$

输出电阻:

$$V_X = I_{ro} * ro + I_X * R_S$$

$$I_{ro} = I_X - gm * V_{GS}$$

$$V_X = (I_X - (gm\,(-I_X)\,R_S))\,ro + I_X R_S$$

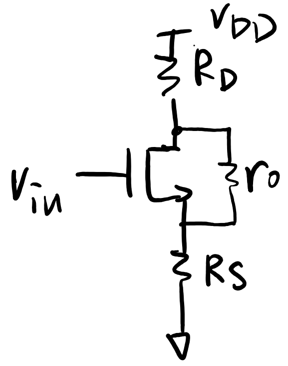
And solve for I_X

$$I_X = \frac{V_X}{R_S + ro + gm * R_S * ro}$$

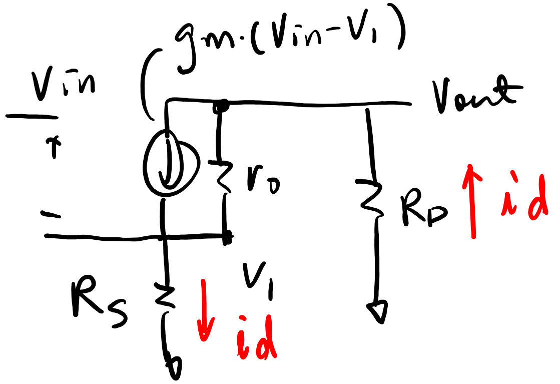
And finally we have

$$r_x = R_S + ro + gm * R_S * ro = ro(1 + gmR_S + \frac{R_S}{ro})$$

$$r_x = ro * (1 + gmR_S) + R_S$$



$\Rightarrow$



$$\begin{cases} i_D = -\dfrac{V_{out}}{R_d} & ① \\[2ex] i_D = g_m\cdot(V_{in}-V_1) + \dfrac{V_{out}-V_1}{r_o} & ② \\[2ex] i_D = \dfrac{V_1}{R_S} & ③ \end{cases}$$

联立 ①.③ $\quad -\dfrac{V_{out}}{R_d} = \dfrac{V_1}{R_S} \qquad V_{out} = -\dfrac{R_d}{R_S}V_1 \quad ④$

联立 ②.④③ $\quad \dfrac{V_1}{R_S} = g_m\cdot(V_{in}-V_1) + \dfrac{-R_d/R_S - 1}{r_o}\cdot V_1 \rightarrow g_m\cdot V_{in} = \left(\dfrac{1}{R_S} + g_m + \dfrac{R_d/R_S+1}{r_o}\right)V_1$

$A_V \Rightarrow$

$$\frac{V_{out}}{V_{in}} = \frac{-R_d/R_S \; V_1}{\frac{1}{R_S} + g_m + \frac{R_d/R_S+1}{r_o}}\cdot g_m$$

$$= -\frac{g_m R_d}{1 + g_m\cdot R_S + \frac{1}{r_o}(R_d+R_S)}$$

if $\frac{1}{r_o} \to 0 \quad A_V \doteq -\dfrac{g_m R_d}{1+g_m\cdot R_S}$

if $g_m\cdot R_S \gg 1 \quad A_V \doteq -\dfrac{R_d}{R_d}$

共栅放大电路

1. 静态分析

根据直流通路有

$$I_{DQ} = I$$

由 $I_{DQ} = K_n(V_{GSQ} - V_{TN})^2$

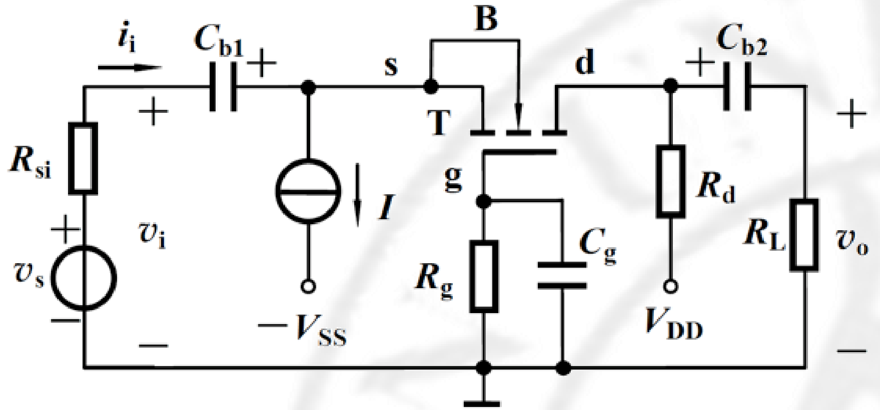
可得 V_{GSQ}

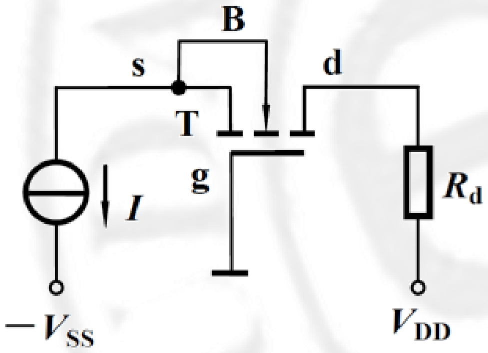
又 $V_S = -V_{GSQ}$　　$V_D = V_{DD} - I_{DQ}R_d$

所以 $V_{DSQ} = V_D - V_S$

$$= V_{DD} - I_{DQ}R_d + V_{GSQ}$$

需验证是否工作在饱和区





共栅放大电路

2. 动态分析

设λ=0

电压增益

$$v_i = -v_{gs}$$

$$v_o = -g_m v_{gs}(R_d \parallel R_L)$$

$$A_v = \frac{v_o}{v_i} = g_m(R_d \parallel R_L)$$

源电压增益

$$v_s = v_i + i_i R_{si} = -v_{gs} - g_m v_{gs} R_{si}$$

$$A_{vs} = \frac{v_o}{v_s} = \frac{g_m(R_d \parallel R_L)}{1 + g_m R_{si}}$$

输出与输入同相

输入电阻

$$R_i = \frac{v_i}{i_i} = \frac{-v_{gs}}{-g_m v_{gs}} = \frac{1}{g_m}$$

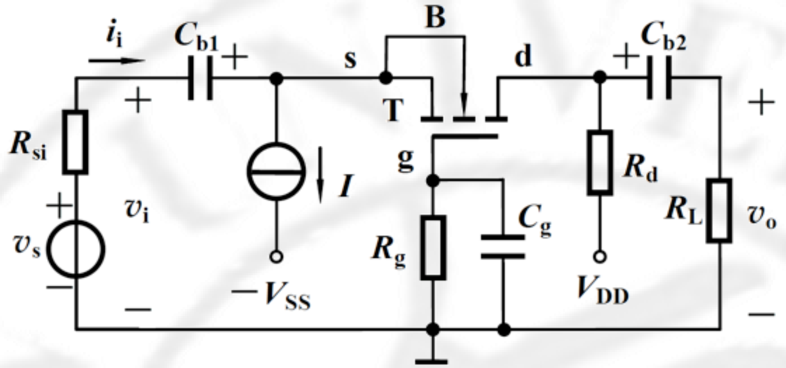
输入电阻远小于其它两种组态

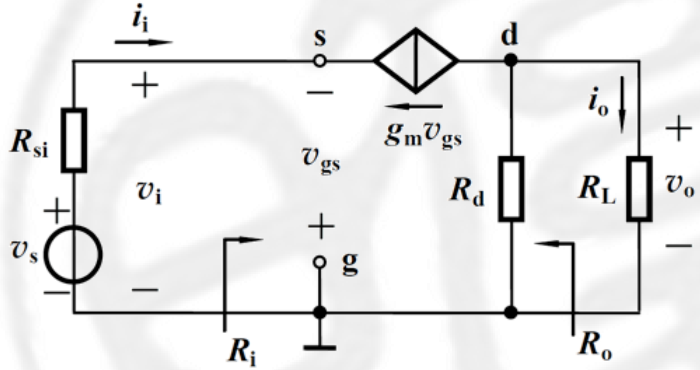
输出电阻

当$r_{ds} >> R_d$ 和 $r_{ds} >> R_{si}$时

$$R_o \approx R_d$$

与共源电路同相





共漏放大电路

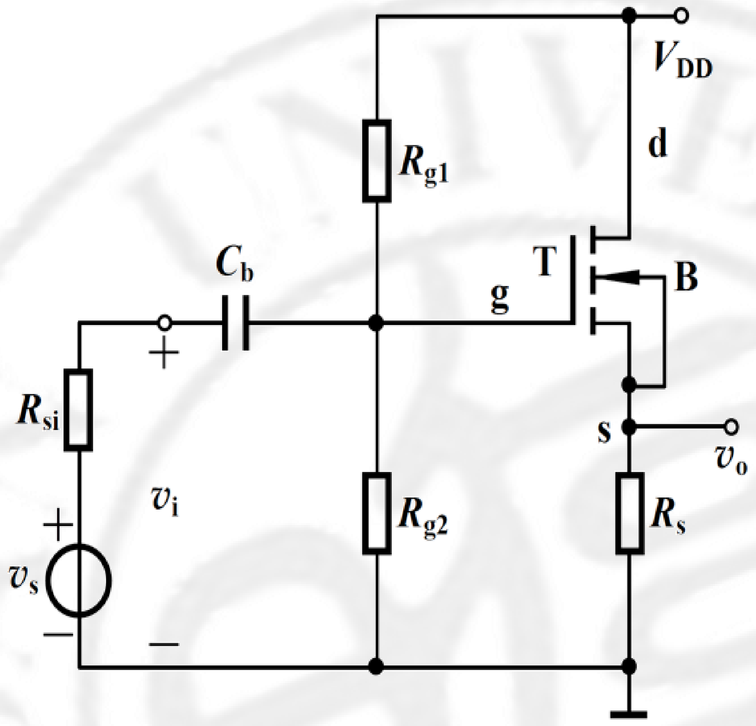
- 又称为源极跟随器

1. 静态分析

设MOS管工作于饱和区

$$
\begin{cases}
I_{DQ} = K_n(V_{GSQ} - V_{TN})^2 \\
V_{GSQ} = \dfrac{R_{g2}}{R_{g1} + R_{g2}} \cdot V_{DD} - I_{DQ}R_s \\
V_{DSQ} = V_{DD} - I_{DQ}R_s
\end{cases}
$$

需验证是否工作在饱和区



共漏放大电路

2. 动态分析

小信号等效电路

根据静态工作点可求得 g_m

$$g_m = 2K_n(V_{GSQ} - V_{TN})$$

电压增益

$$v_i = v_{gs} + v_o = v_{gs} + g_m v_{gs}(R_s \| r_{ds})$$
$$= v_{gs}[1 + g_m(R_s \| r_{ds})]$$

$$v_o = g_m v_{gs}(R_s \| r_{ds})$$

$$A_v = \frac{v_o}{v_i} = \frac{g_m v_{gs}(R_s \| r_{ds})}{v_{gs}[1 + g_m(R_s \| r_{ds})]}$$

$$= \frac{g_m(R_s \| r_{ds})}{1 + g_m(R_s \| r_{ds})} \approx 1$$

输出与输入同相，且增益小于等于1

源电压增益

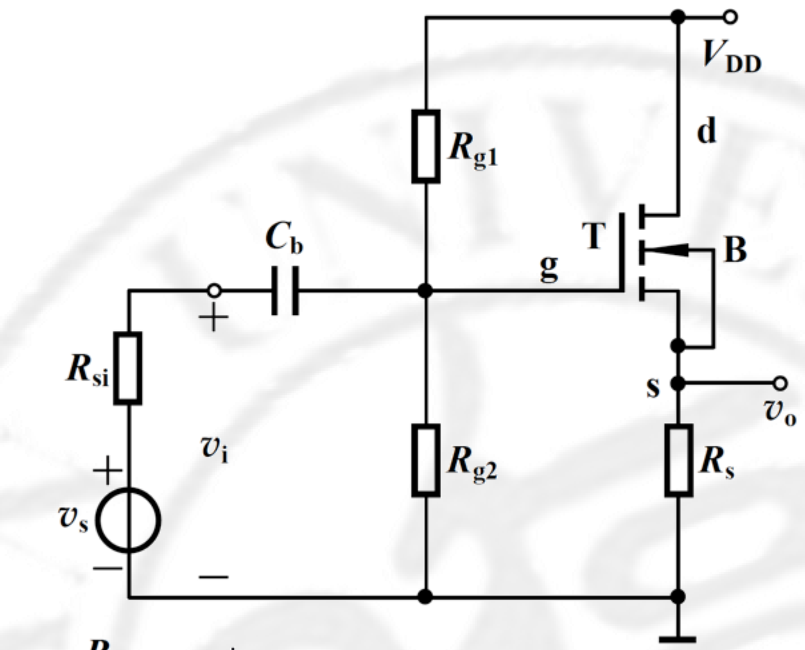
$$A_{vs} = \frac{v_o}{v_s} = \frac{v_o}{v_i} \cdot \frac{v_i}{v_s}$$

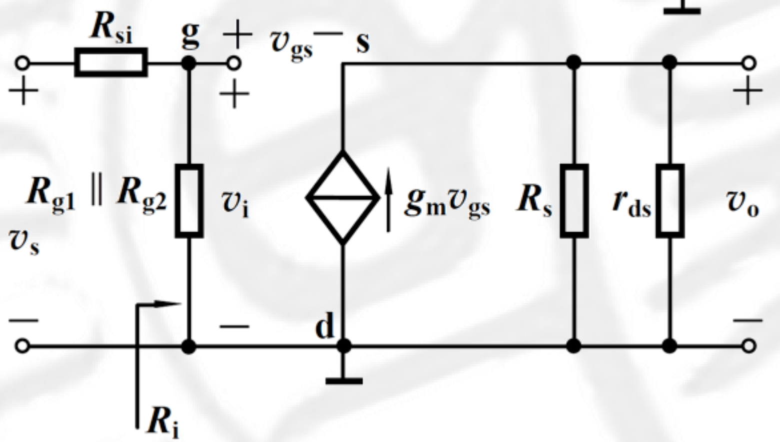
$$= \frac{g_m(R_d \| r_{ds})}{1 + g_m(R_d \| r_{ds})} \cdot \left(\frac{R_i}{R_i + R_{si}}\right)$$

输入电阻

$$R_i = R_{g1} \| R_{g2}$$

受静态偏置电路的影响，栅极绝缘的特性并未充分表现出来

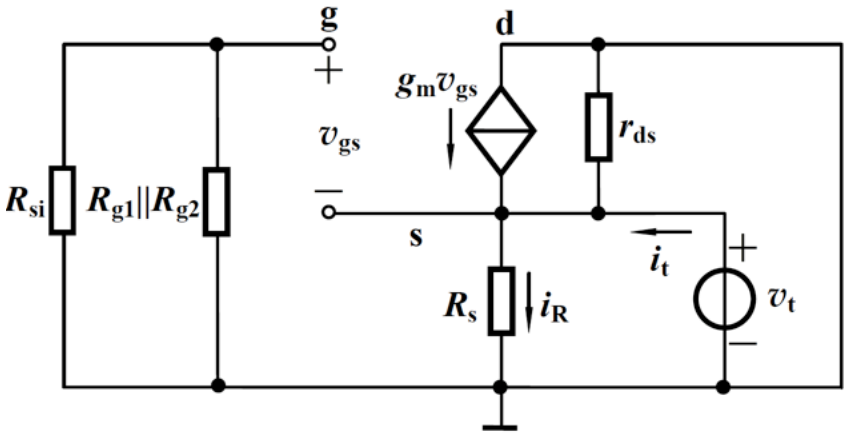


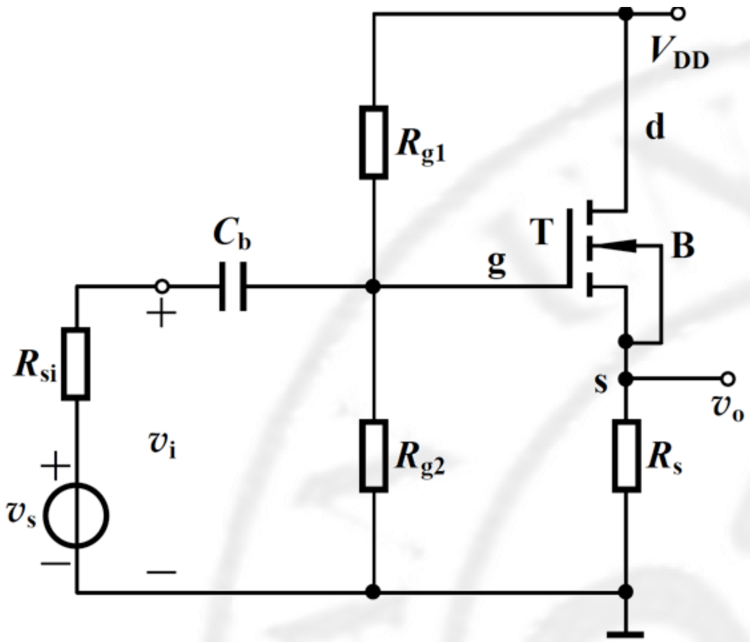


共漏放大电路

2. 动态分析

输出电阻



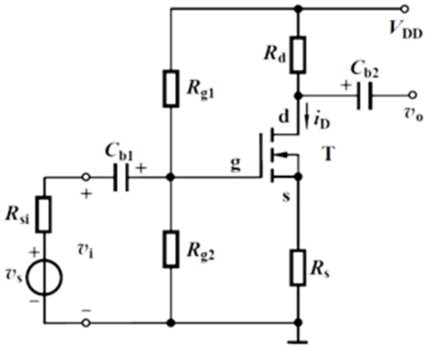
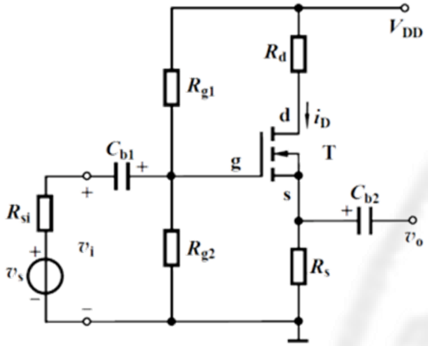
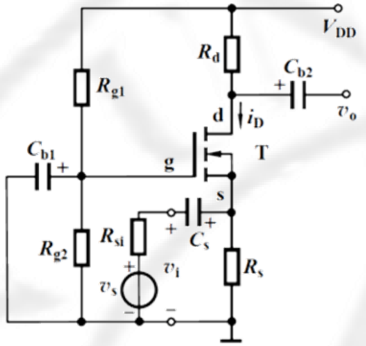


$$\begin{cases} i_T = \dfrac{v_T}{R_s} + \dfrac{v_T}{r_{ds}} - g_m v_{gs} \\ v_{gs} = -v_T \end{cases}$$

$$R_o = \frac{v_T}{i_T} = \frac{1}{\dfrac{1}{R_s} + \dfrac{1}{r_{ds}} + g_m} = R_s \parallel r_{ds} \parallel \frac{1}{g_m}$$

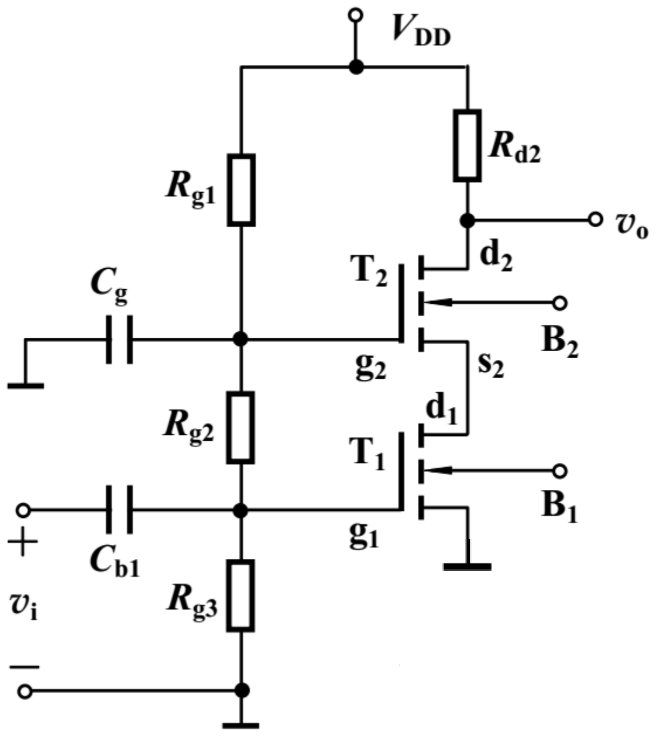
输出电阻较小

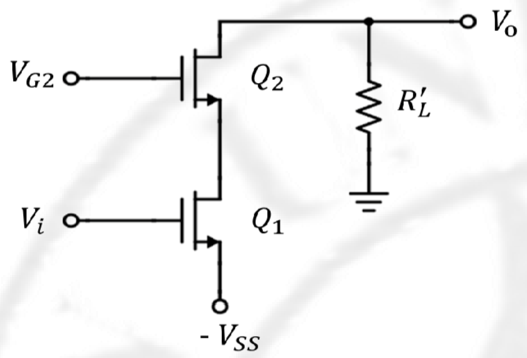
三种组态总结比较

	共源	共漏	共栅
			
电压增益	$A_v = -g_m(r_{ds} \parallel R_d)$	$A_v = \dfrac{g_m(R_s \parallel r_{ds})}{1+g_m(R_s \parallel r_{ds})} \approx 1$	$A_v = g_m(R_d \parallel R_L)$
输入电阻	很高	很高	$R_i \approx \dfrac{1}{g_m}$
输出电阻	$R_o \approx R_d$	$R_o = R_s \parallel r_{ds} \parallel \dfrac{1}{g_m}$	$R_o \approx R_d$

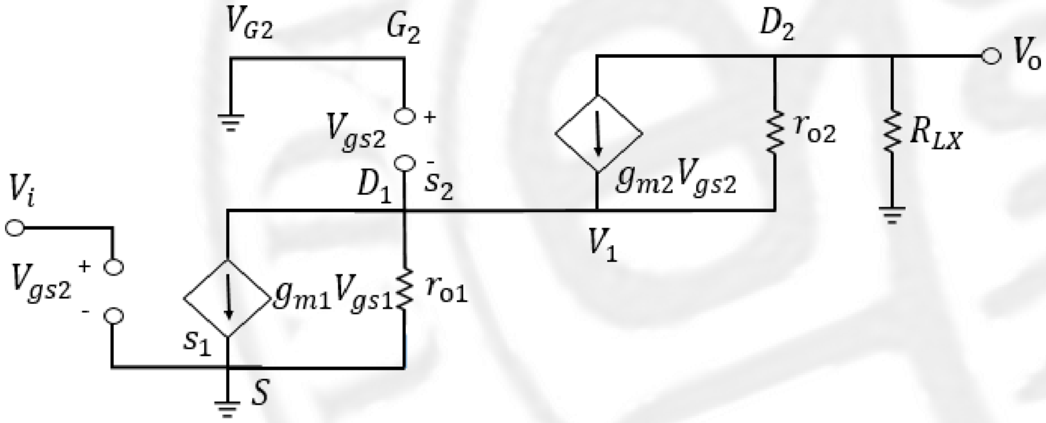
思考题： 共源共栅放大电路

- Cascode Amplifier

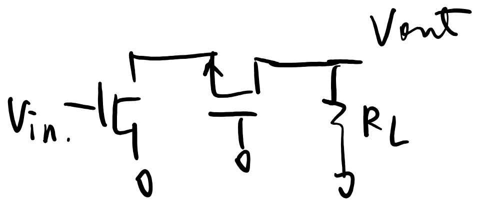




(a)



(b)



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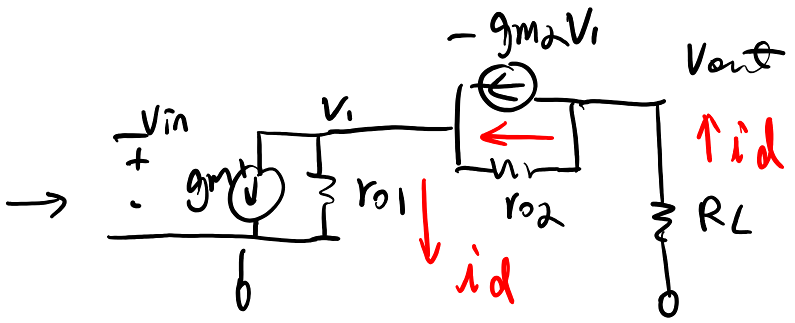


$$i_d = -\frac{V_{out}}{R_L} \quad ①$$

$$i_d = g_{m2}\cdot(-V_1) - \frac{V_1 - V_{out}}{r_{o2}} \quad ②$$

$$i_d = g_m\cdot V_{in} + \frac{V_1}{r_{o2}} \quad ③$$

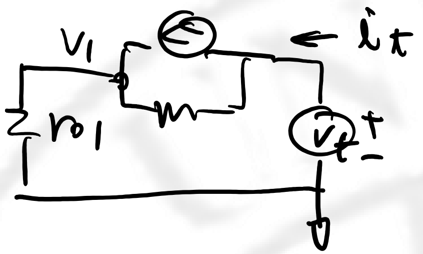
$$= \frac{1}{\frac{1}{g_m} // r_{o2}}$$

联立 ①+② $V_{out} = V_1\cdot\left(g_m+\frac{1}{r_{o2}}\right)\cdot R_L // r_{o2}$ ④

联立 ①·③·④ $V_{out}\left(\frac{1}{r_o}\cdot\frac{r_{o2} // \frac{1}{g_{m2}}}{R_L // r_{o2}} + \frac{1}{R_L}\right) = g_{m1}V_{in}$

$$A_v = \frac{V_{out}}{V_{in}} = g_{m1}\left(R_L // r_{o1}\cdot\frac{R_L // r_{o2}}{r_{o2} // \frac{1}{g_{m2}}}\right) \doteq \begin{cases} g_{m1}R_L & r_{o1}\text{或}r_{o2} \gg R_L \\ g_{m1}g_{m2}r_{o1}r_{o2} & R_L \gg r_{o1}\text{或}r_{o2} \end{cases}$$

输出电阻



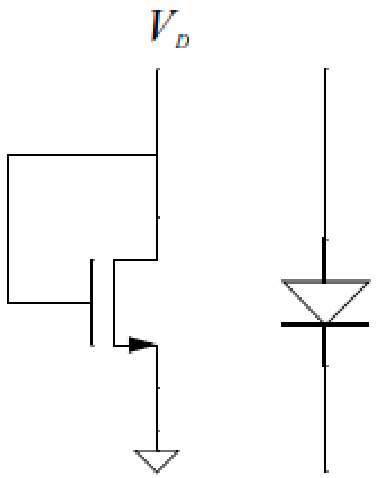
$$R_{out} = \frac{V_t}{i_t} = \frac{V_1 + \left(g_m+\frac{1}{r_{o2}}\right)\cdot r_{o2}\cdot V_1}{V_1/r_{o1}}$$

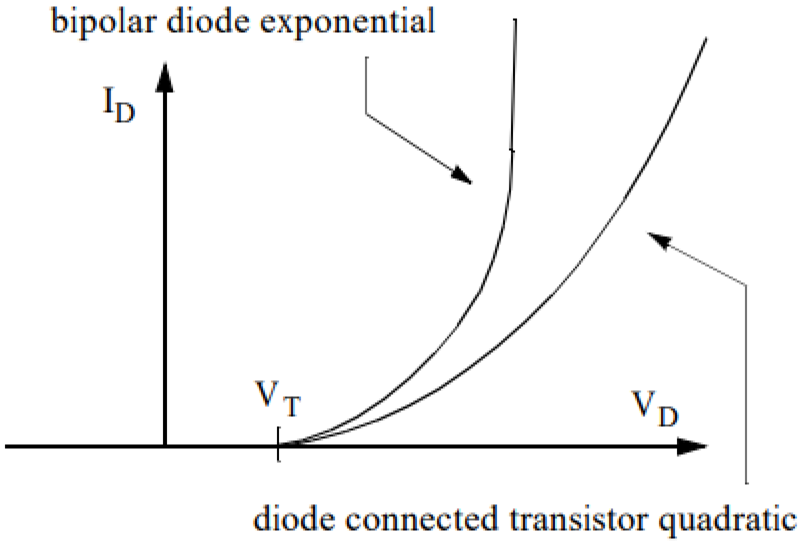
$$= g_{m2}r_{o1}r_{o2} + r_{o1} + r_{o2}$$

$$\doteq g_{m2}r_{o1}r_{o2}$$

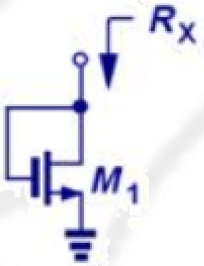
二极管偏置的晶体管

- Diode connected MOS



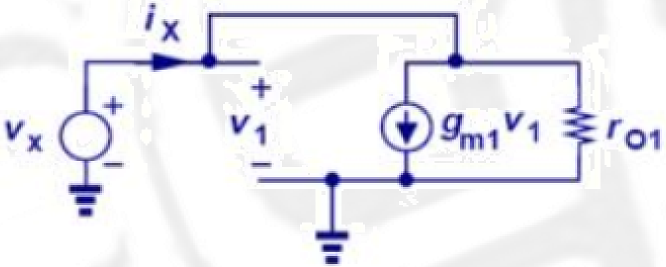


Diode-connected NMOSFET

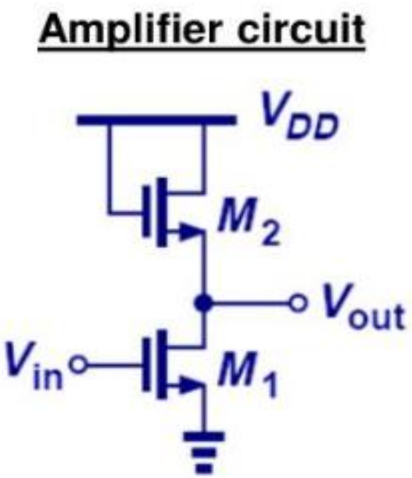


$$R_X = \frac{1}{g_{m1}} \| r_{o1}$$

Small-signal analysis circuit

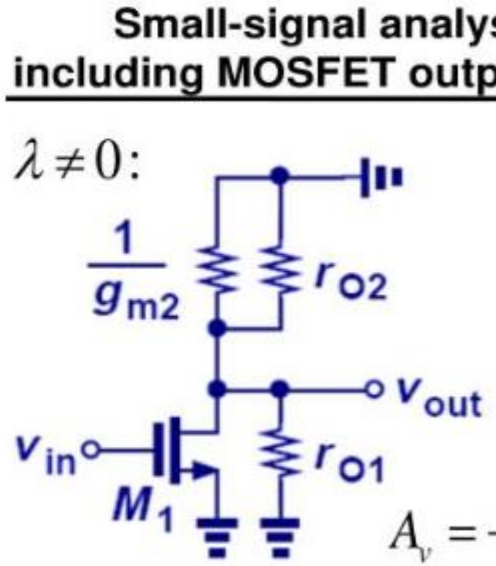


共源放大器 + 二极管偏置的放大电路



If $\lambda = 0$:

$$A_v = -g_{m1} \cdot \frac{1}{g_{m2}} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}$$

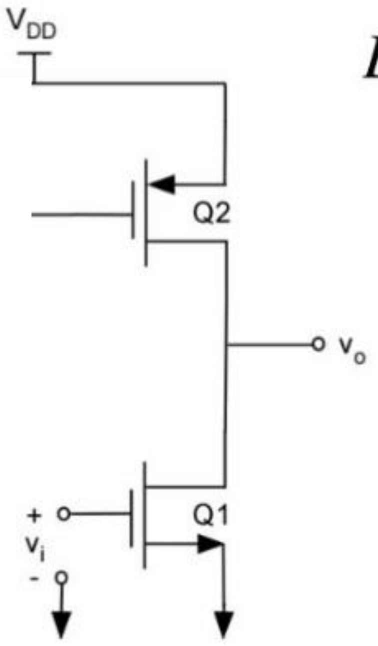


$$A_v = -g_{m1}\left(\frac{1}{g_{m2}} \parallel r_{O2} \parallel r_{O1}\right)$$

$$R_{out} = \frac{1}{g_{m2}} \parallel r_{O2} \parallel r_{O1}$$

$$I_{D,sat} = \frac{\mu_p \cdot C_{ox}}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_T)^2 \begin{cases} V_{GS} \leqslant V_T \\ V_{DS} \leqslant V_{GS} - V_T \end{cases}$$

共源放大器 + 有源负载



$$Let\ r_{ds1} = r_{o1}\ for\ Q_1$$

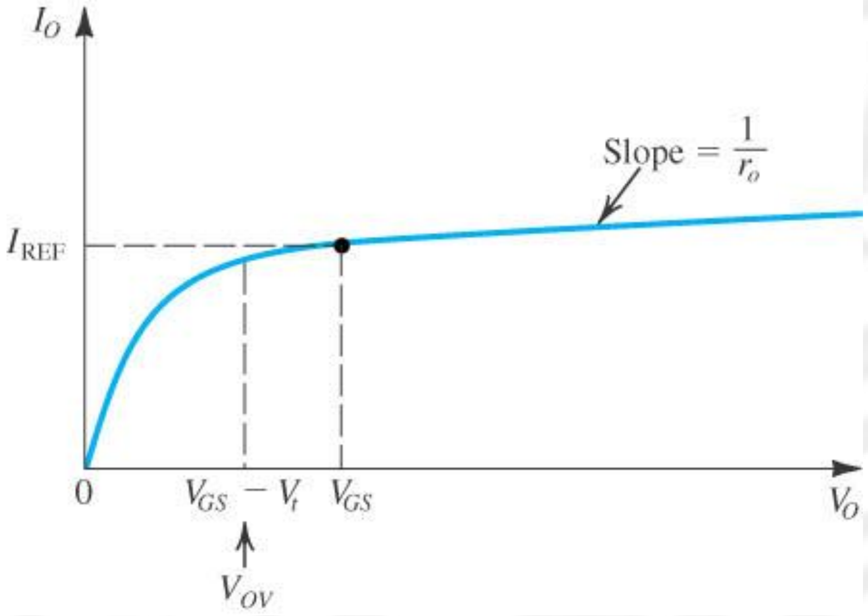
$$r_{ds2} = r_{o2}\ for\ Q_2$$

$$then,\ R_{out} = r_{o1} \parallel r_{o2}$$

$$A_{MB} = -g_{m1} R_{out}$$

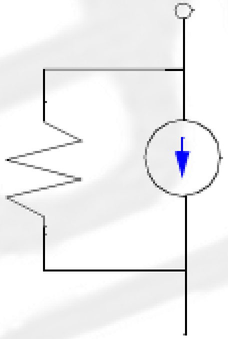
$$Let\ g_{o1} = \frac{1}{r_{o1}} = g_{ds1}$$

$$g_{o2} = \frac{1}{r_{o2}} = g_{ds2}$$



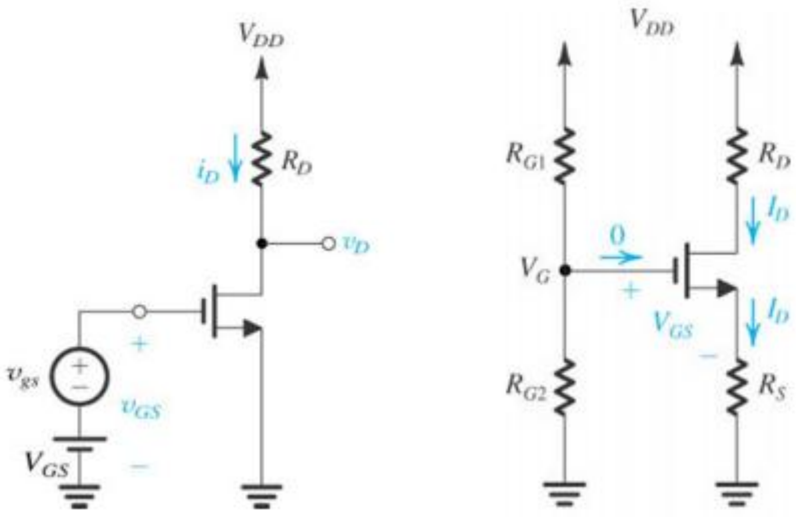
We get

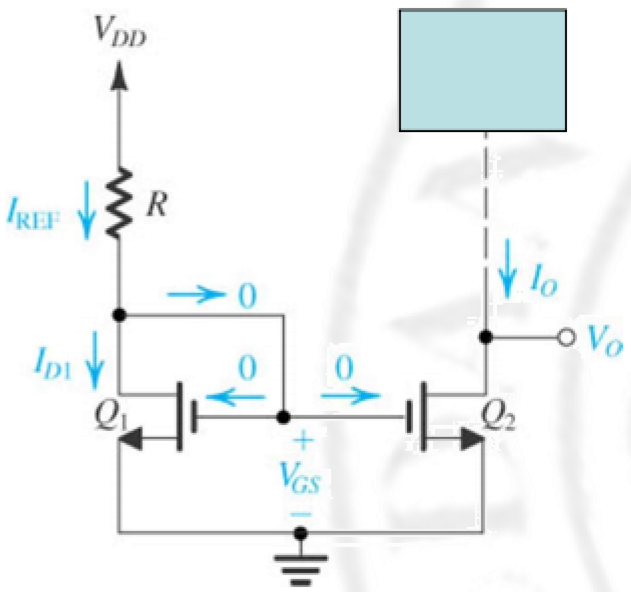
Small Signal



如何提供有源负载的偏置电压?

- 基于电阻分压的偏置电路
- 基于电流镜的偏置电路





$$I_{D1} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 (V_{GS} - V_t)^2$$

$$I_{D1} = I_{REF} = \frac{V_{DD} - V_{GS}}{R}$$

Assuming Q_1, Q_2 have same properties (k_n'),

$$I_O = I_{D2} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_2 (V_{GS} - V_{tn})^2$$

$$\frac{I_O}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1}$$

Limitation on V_o? $V_O \geq V_{GS} - V_t$

电流镜 + 有源负载