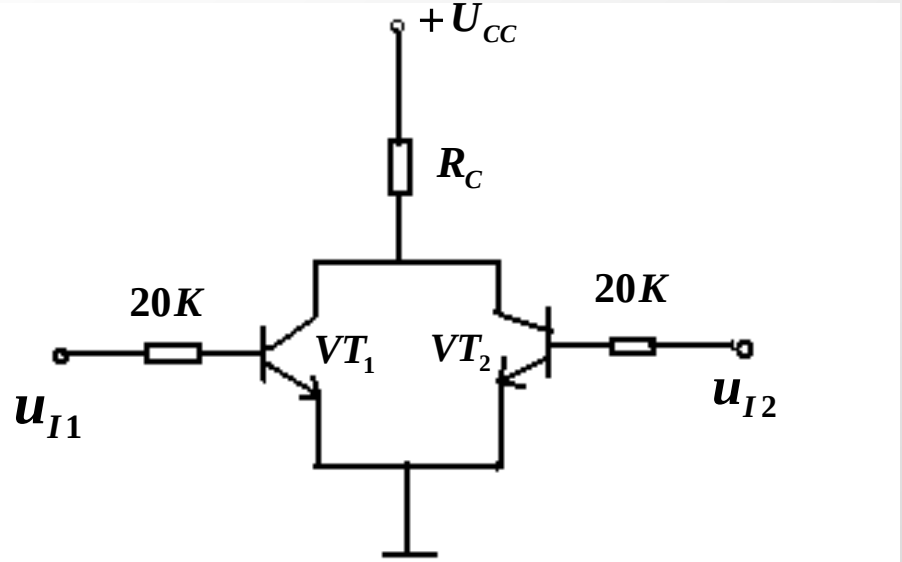
第二章复习

- 放大器的主要性能指标和传输特性（理解）
- 放大器的基本分析方法—图解法（理解）和微变等效电路法（掌握）
- 双极晶体管和场效应管的偏置电路（理解）
- 双极晶体管和场效应管放大器的基本组态CE(CS),CB(CG),CC(CD)以及射极（源极）带电阻的CE(CS)放大器、放大器的基本组成、工作原理及主要特点（掌握）

- 双极晶体管和场效应管有源负载放大器（理解）
- 多级放大器的耦合（理解）及主要性能指标的计算（理解）

例1：

电路如图所示，两管参数相同，$\beta = 40$，$U_{BE} = 0.7V, U_{CES} = 0.3V$ 试求下列情况下的 U_{CE}



(1) $U_{CC} = 20V, R_C = 1K\Omega$

$u_{I1} = 3V, u_{I2} = 6V$

(2) $u_{I1} = 6V$，其它参数同（1）

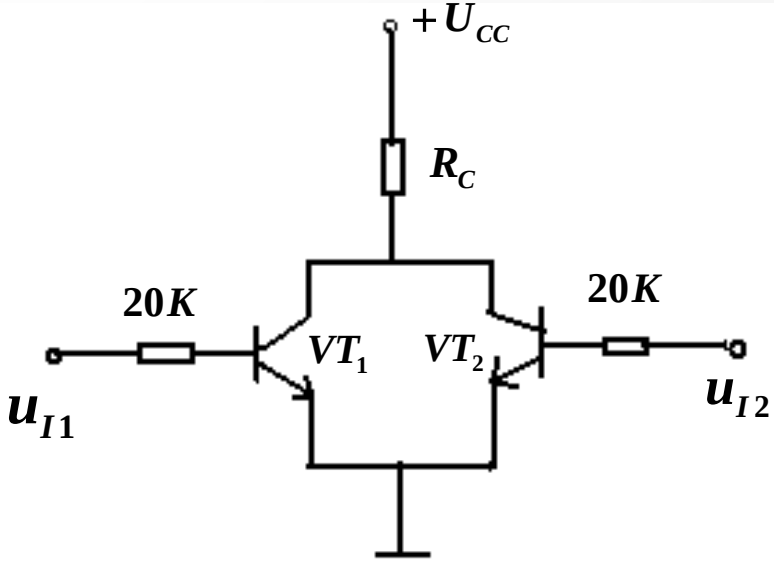
(3) $U_{CC} = 10V$，其它参数同(1)

(4) $U_{CC} = 10V, R_C = 500\Omega$

其它参数同(1)

考查要点：三极管工作状态

解：设四种条件下三极管均处于放大状态，因此公式$I_{CQ}=\beta I_{BQ}$成立



(1)$U_{CC}=20V$，$R_C=1K\Omega$

$u_{I1}=3V$，$u_{I2}=6V$

$$I_{B1}=\frac{u_{I1}-0.7}{20k\Omega}=\frac{3-0.7}{20}=0.115mA$$

$$I_{B2}=\frac{u_{I2}-0.7}{20k\Omega}=\frac{6-0.7}{20}=0.265mA$$

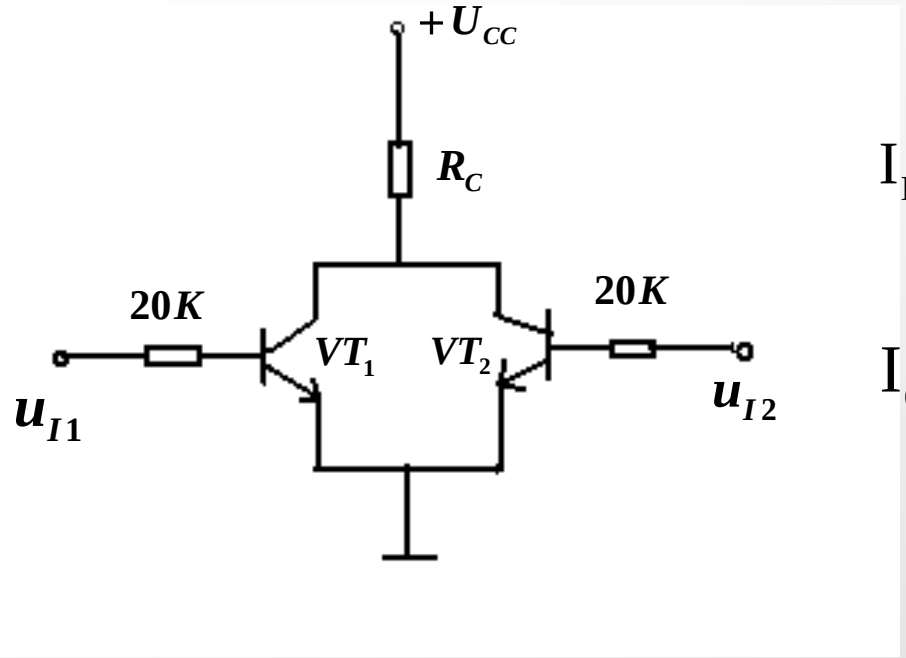
$$I_{C1}=\beta I_{B1}=4.6mA$$

$$I_{C2}=\beta I_{B2}=10.6mA$$

$$U_{CE}=U_{CC}-(I_{C1}+I_{C2})R_C=20-(4.6+10.6)\times 1=4.8V$$

$U_{CE}>U_{CES}$，因此假设成立。

(2)$u_{I1}=6V$,其它参数同（1）



$$I_{B1}=I_{B2}=\frac{u_{I2}-0.7}{20k\Omega}=\frac{6-0.7}{20}=0.265mA$$

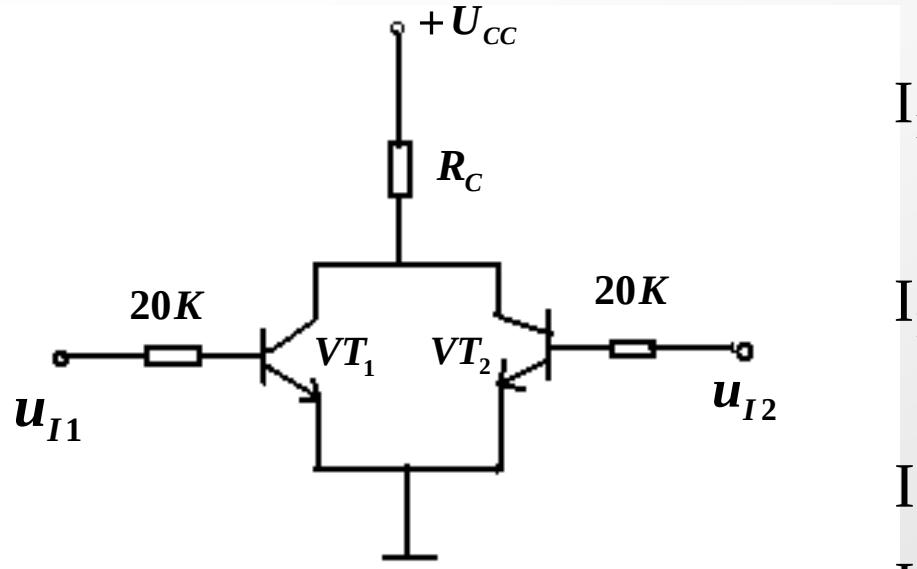
$$I_{C1}=I_{C2}=\beta I_{B2}=10.6mA$$

$$U_{CE}=U_{CC}-(I_{C1}+I_{C2})R_C=20-(10.6+10.6)\times 1=-1.2V$$

U_{CE}<0，因此假设不成立，此时管子进入饱和区。因此，

$U_{CE}=U_{CES}=0.3V$

(3)$U_{CC}=10V$,其它参数同(1)



$$I_{B1}=\frac{u_{I1}-0.7}{20k\Omega}=\frac{3-0.7}{20}=0.115mA$$

$$I_{B2}=\frac{u_{I2}-0.7}{20k\Omega}=\frac{6-0.7}{20}=0.265mA$$

$$I_{C1}=\beta I_{B1}=4.6mA$$

$$I_{C2}=\beta I_{B2}=10.6mA$$

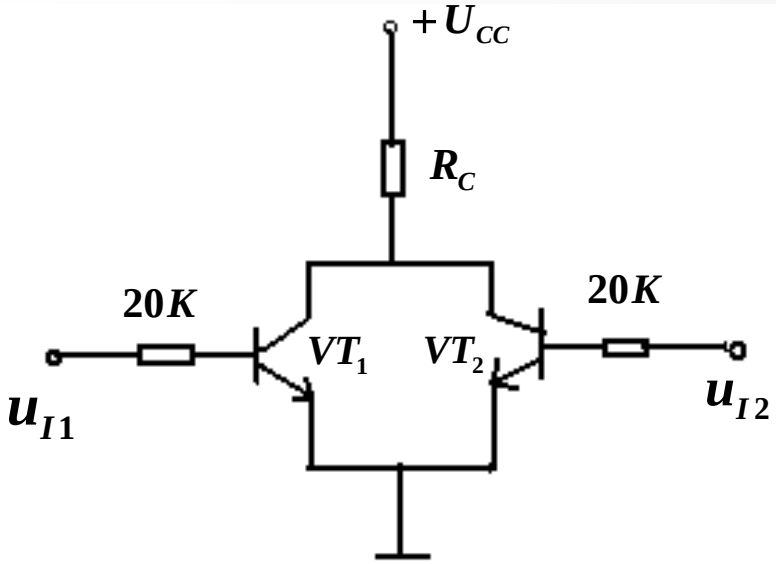
$$U_{CE}=U_{CC}-(I_{C1}+I_{C2})R_C=10-(4.6+10.6)\times 1=-5.2V$$

U_{CE}<0，因此假设不成立，此时管子进入饱和区。因此，

$$U_{CE}=U_{CES}=0.3V$$

(4)$U_{CC}=10V, R_C=500\Omega$

其它参数同(1)



$$I_{B1}=\frac{u_{I1}-0.7}{20k\Omega}=\frac{3-0.7}{20}=0.115mA$$

$$I_{B2}=\frac{u_{I2}-0.7}{20k\Omega}=\frac{6-0.7}{20}=0.265mA$$

$$I_{C1}=\beta I_{B1}=4.6mA$$

$$I_{C2}=\beta I_{B2}=10.6mA$$

$$U_{CE}=U_{CC}-(I_{C1}+I_{C2})R_C=10-(4.6+10.6)\times 0.5=2.4V$$

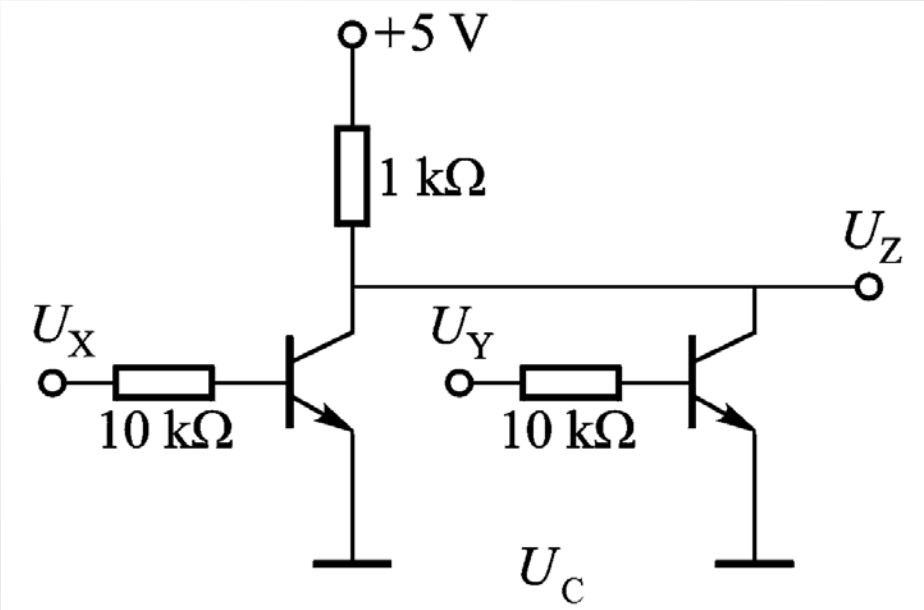
$U_{CE}>U_{CES}$，因此假设成立。

例2：（作业2-7）电路如图所示，已知$\beta=100$

（1）UX=5V，UY= 0V时，UZ= ？

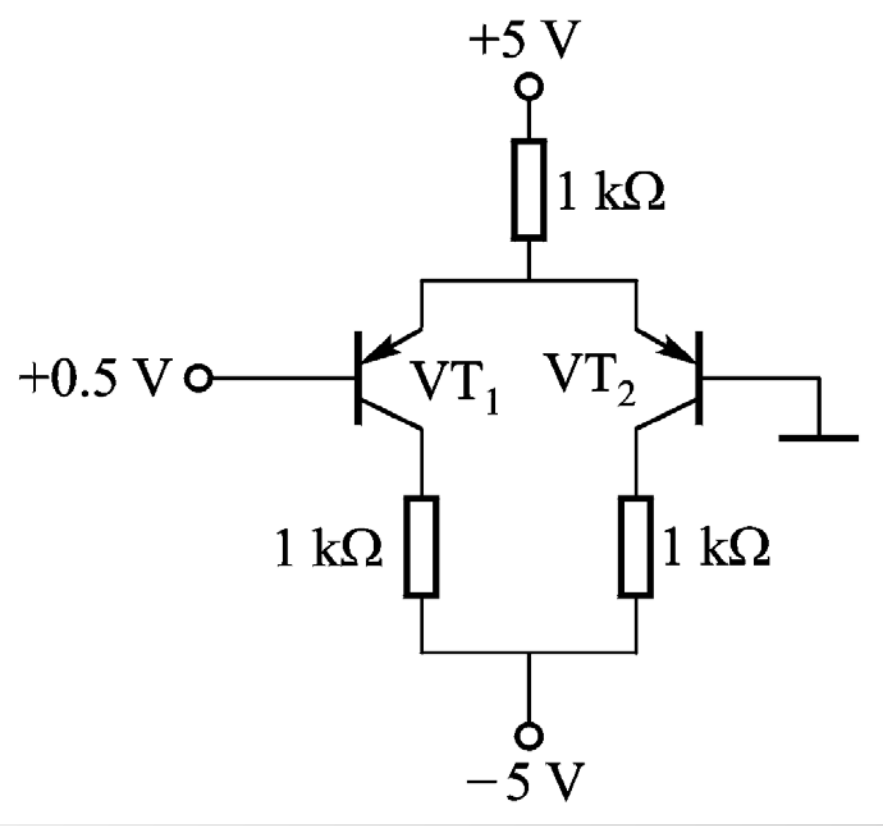
（2）UX=0V，UY= 0V时，UZ= ？

（3）UX=5V， UY= 5V时，UZ= ？



例3：（作业2-8）电路如图所示。已知 $U_{EB}=0.7V$

求： U_{CE1}和U_{CE2}

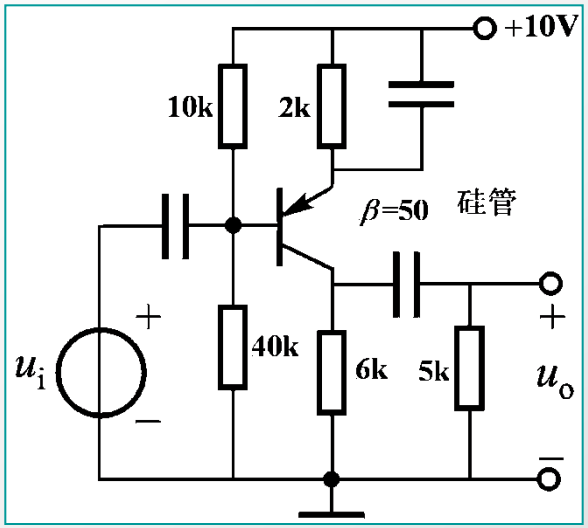


例4. 电路如图所示，要求：

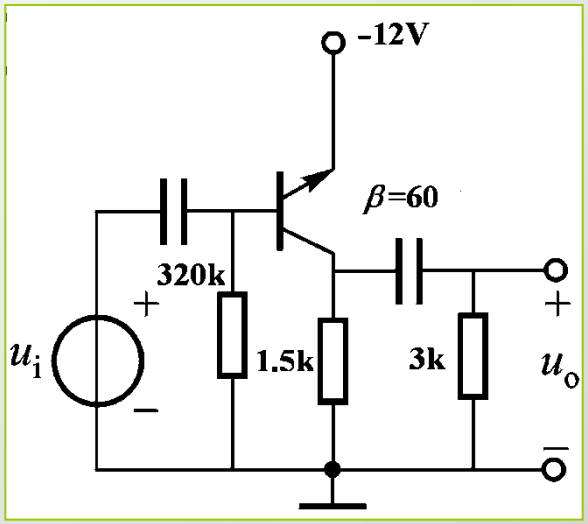
（1）分析图(a)、(b)、(c)各为何种组态？

（2）分别求 I_{CQ}、U_{CEQ}；

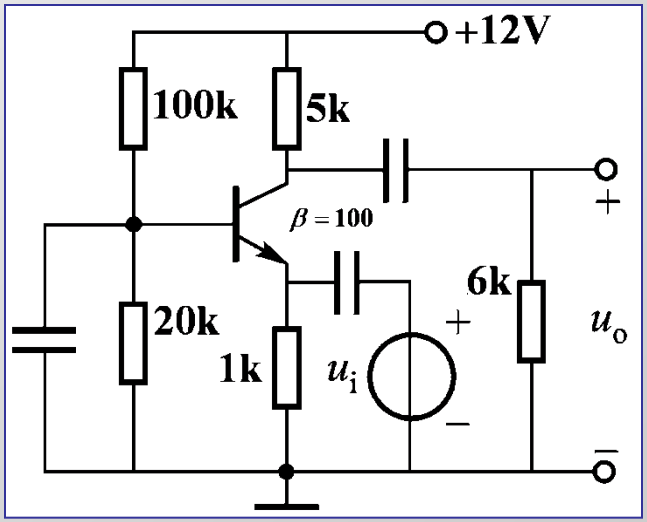
（3）设 $r_{bb'}=100\Omega$，电容对交流视为短路，计算 R_i、$\dot{A}_{um}$和R_o。



（a）



（b）

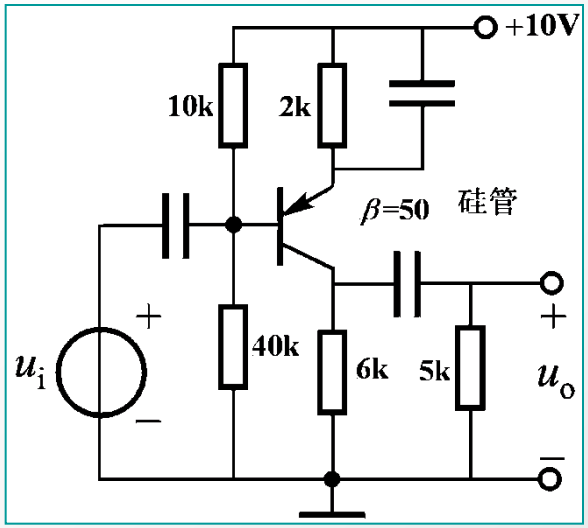


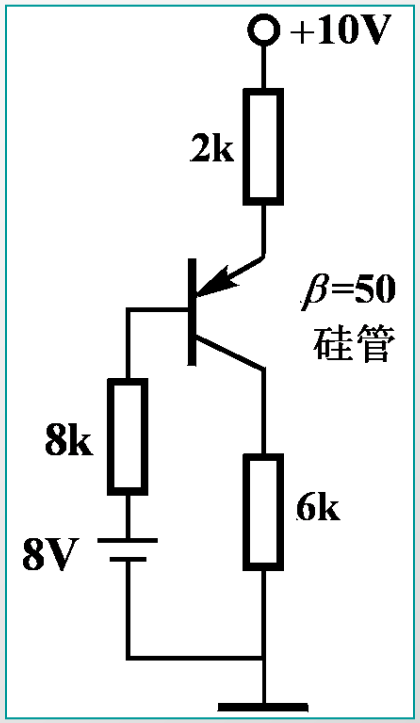
(c)

解：图（a）

（1）CE组态；

（2）放大器（a）的直流通路如图所示，





$$10\times\frac{40}{10+40}=8\text{V}$$

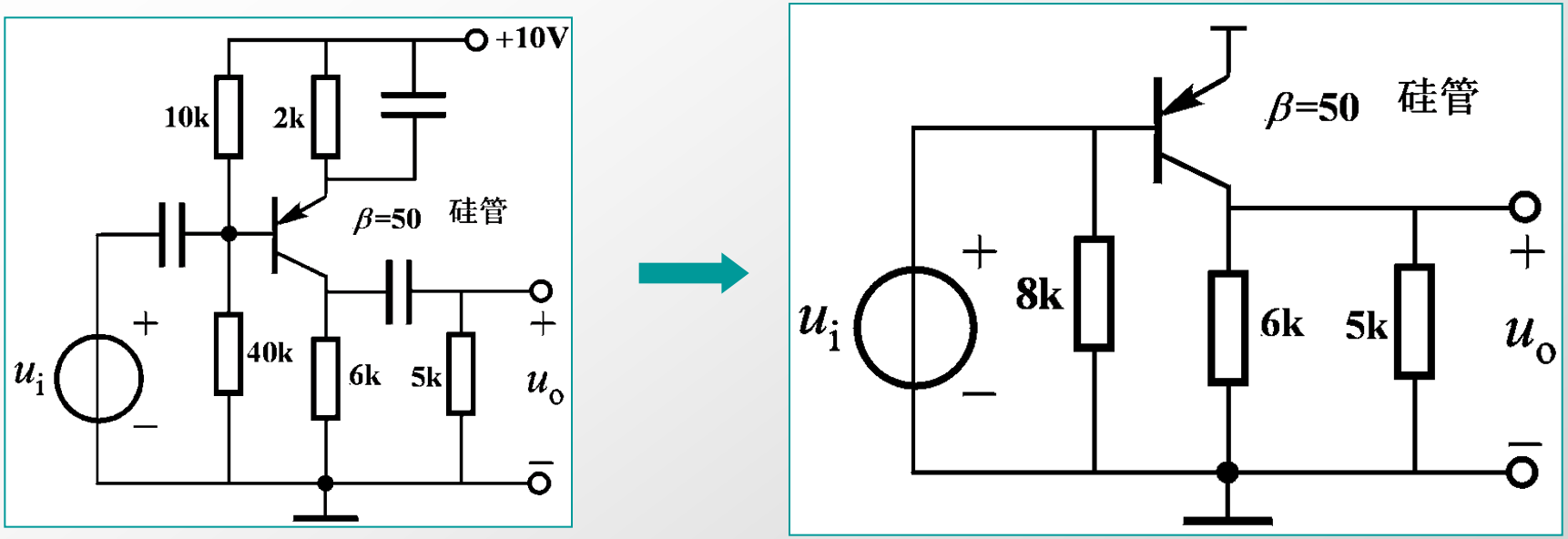
$$10\text{k}\,//\,40\text{k}=8\text{k}$$

$$I_{BQ}=\frac{10-8-U_{EB}}{8+(50+1)\times 2}=\frac{2-0.7}{110}=0.012\text{mA}$$

$$I_{CQ}=50I_{BQ}=0.6\text{mA}$$

$$U_{CEQ}\approx(2+6)I_{CQ}-10=-5.2\text{V}$$

（3）放大器（a）的交流通路如图所示，



$$h_{ie} = r_{bb'} + \frac{26\text{mV}}{I_{BQ}} = 100 + \frac{26\text{mV}}{0.012\text{mA}} = 2.27\text{k}\Omega$$

$$R_i = 8 // h_{ie} = 8 // 2.27 \approx 1.77\text{k}\Omega$$

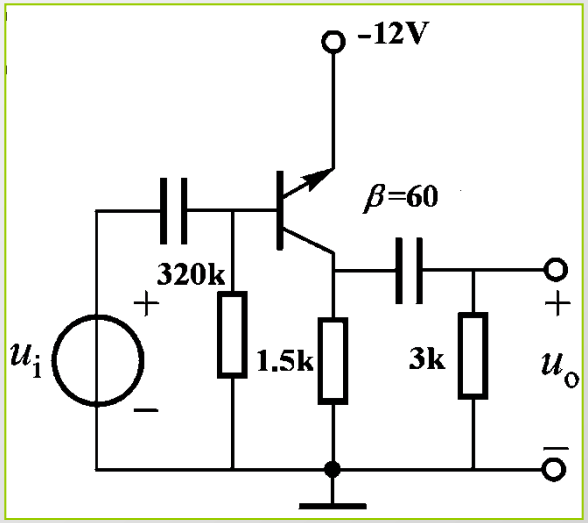
$$\dot{A}_{um} = \frac{\dot{U}_o}{\dot{U}_i} = \frac{-h_{fe} R'_L}{h_{ie}} = -\frac{50 \times (5 // 6)}{2.27} \approx -60$$

$$R_o = R_c = 6\text{k}\Omega$$

图（b）

（1）CE组态

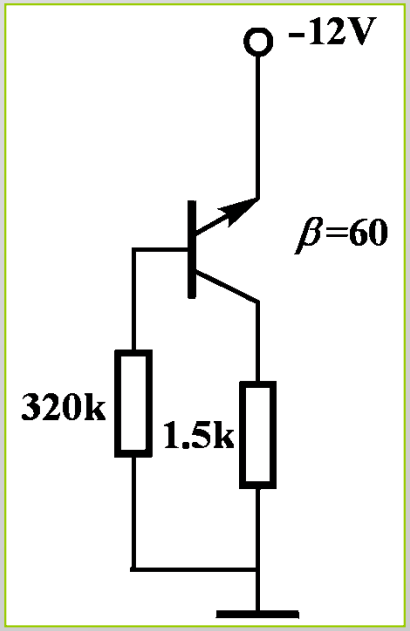
（2）放大器（b）的直流通路如图所示，

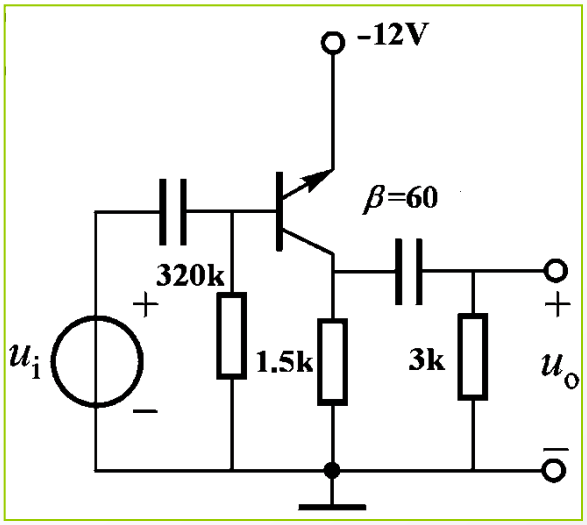


$$I_{BQ}=\frac{12-U_{BE}}{320}=\frac{12-0.7}{320}=0.035\text{mA}$$

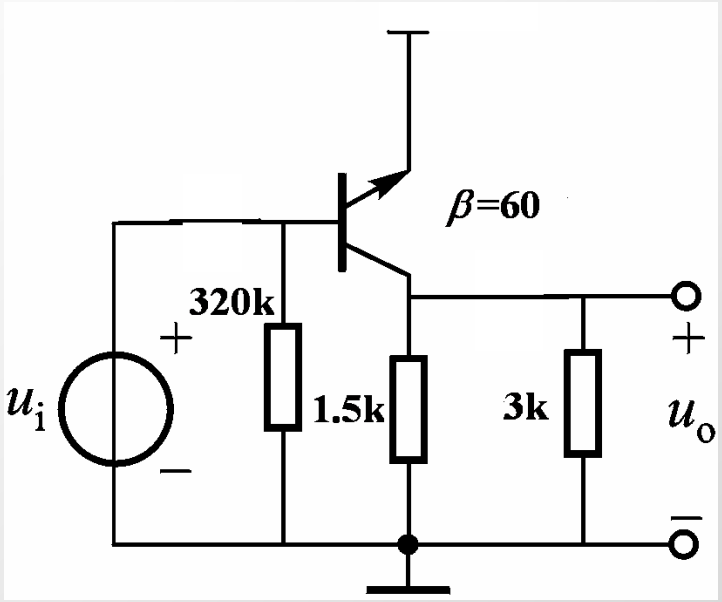
$$I_{CQ}=60I_{BQ}=2.1\text{mA}$$

$$U_{CEQ}=12-1.5I_{CQ}=8.85\text{V}$$





（3）放大器（b）的交流通路如图所示，



$$h_{ie} = r_{bb'} + \frac{26\text{mV}}{I_{BQ}} = 100 + \frac{26\text{mV}}{0.035\text{mA}} = 0.84\text{k}\Omega$$

$$R_o = R_c = 1.5\text{k}\Omega$$

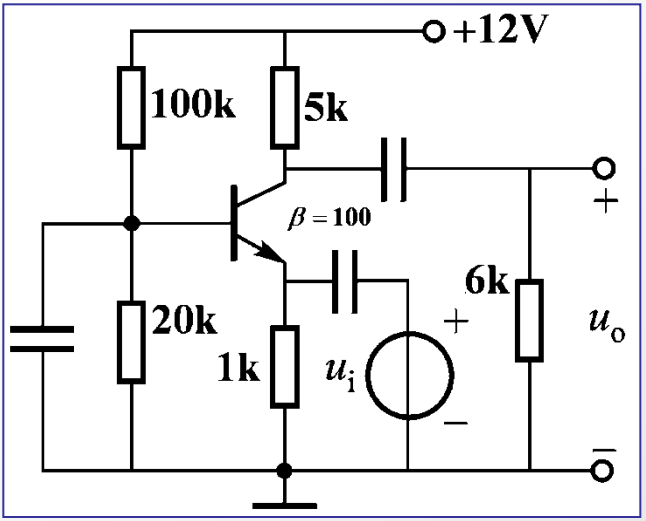
$$R_i = h_{ie} \,//\, 320 = 0.84 \,//\, 320 \approx 0.84\text{k}\Omega$$

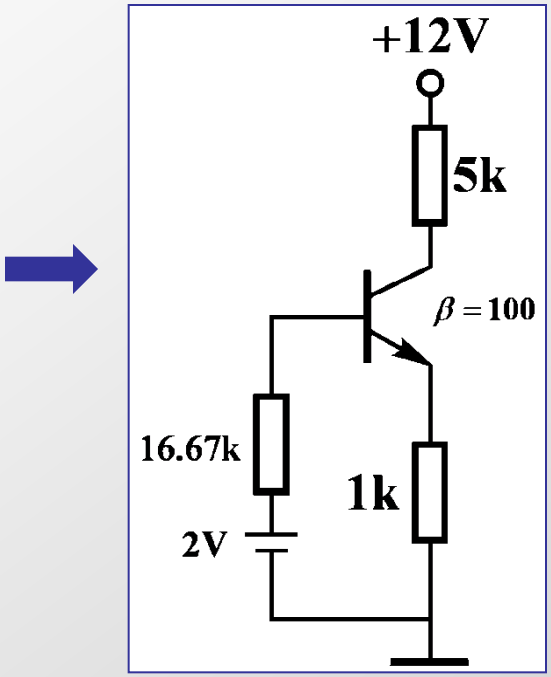
$$\dot{A}_{um} = \frac{\dot{U}_o}{\dot{U}_i} = \frac{-h_{fe} R'_L}{h_{ie}} = -\frac{60 \times (1.5 \,//\, 3)}{0.84} \approx -71.43$$

图（c）

（1）CB组态

（2）放大器（c）的直流通路如图所示，





$$12\times\frac{20}{100+20}=2\text{V}$$

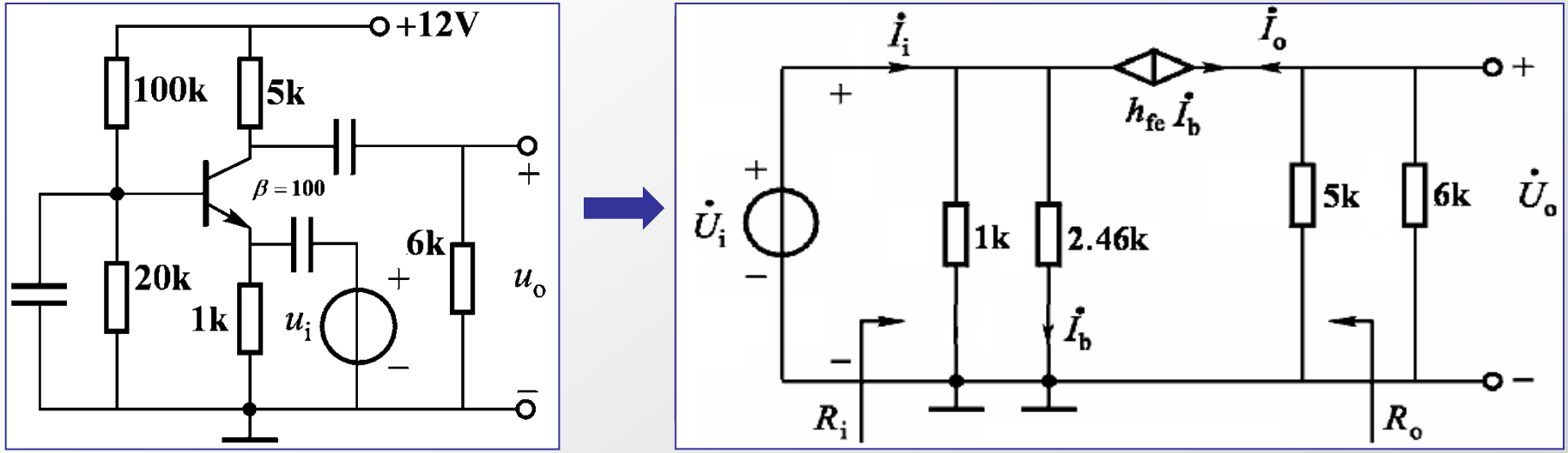
$$100\text{k}\,//\,20\text{k}=16.67\text{k}$$

$$I_{BQ}=\frac{2-U_{BE}}{16.67+(100+1)\times 1}=\frac{2-0.7}{117.67}=0.011\text{mA}$$

$$I_{CQ}=100I_{BQ}=1.1\text{mA}$$

$$U_{CEQ}\approx 12-(1+5)I_{CQ}=5.4\text{V}$$

（3）放大器（c）的交流通路如图所示，



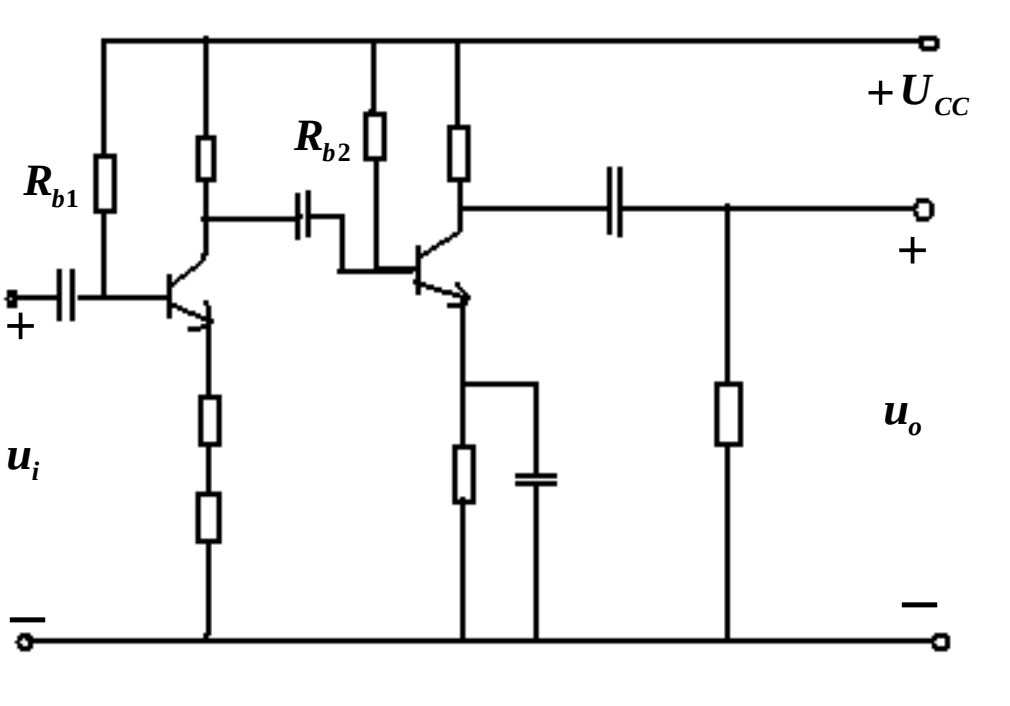
$$h_{ie} = r_{bb'} + \frac{26\text{mV}}{I_{BQ}} = 100 + \frac{26\text{mV}}{0.011\text{mA}} = 2.46\text{k}\Omega$$

$$R_i = R_e // \frac{h_{ie}}{1+h_{fe}} = 1 // \frac{2.46}{101} = 0.024\text{k}$$

$$\dot{A}_{um} = \frac{\dot{U}_o}{\dot{U}_i} = \frac{h_{fe}R'_L}{h_{ie}} = \frac{100\times(5//6)}{2.46} \approx 110.87$$

$$R_o = R_c = 5\text{k}\Omega$$

例5：两级放大电路如图所示，输入电压为正弦信号，输出电压出现底部失真，如果想输出电压不失真，保持输入电压不变，如何调整 R_{b1}, R_{b2}



$a) R_{b1}\uparrow, R_{b2}\uparrow$

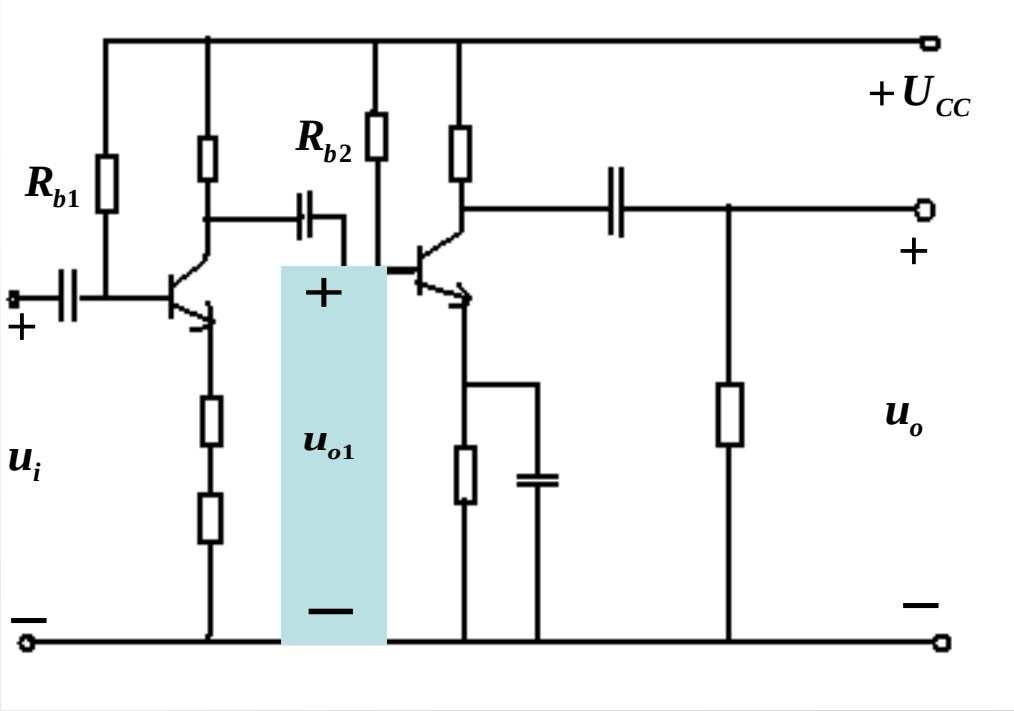
$b) R_{b1}\downarrow, R_{b2}\downarrow$

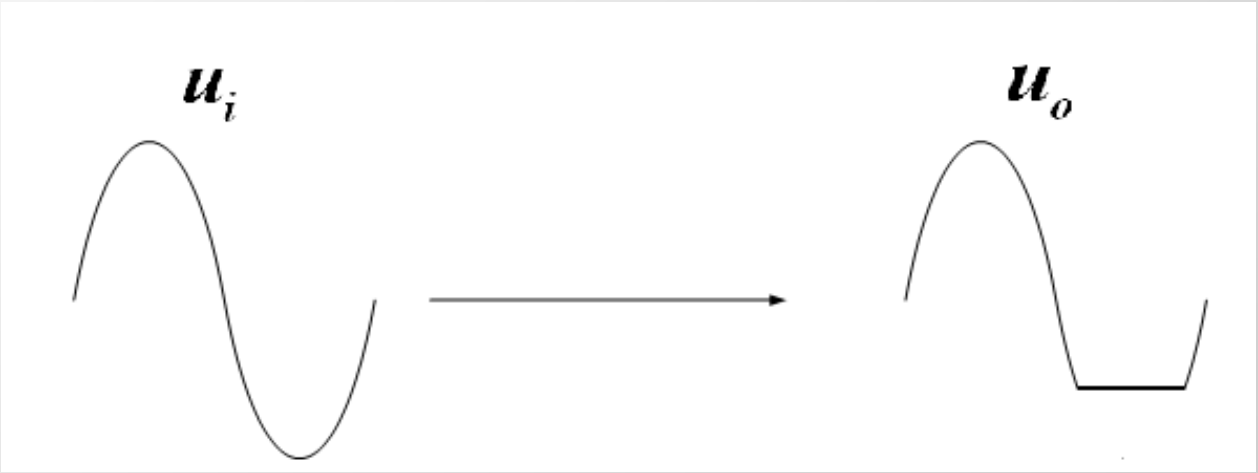
$c) R_{b1}\uparrow, R_{b2}\downarrow$

$d) R_{b1}\downarrow, R_{b2}\uparrow$

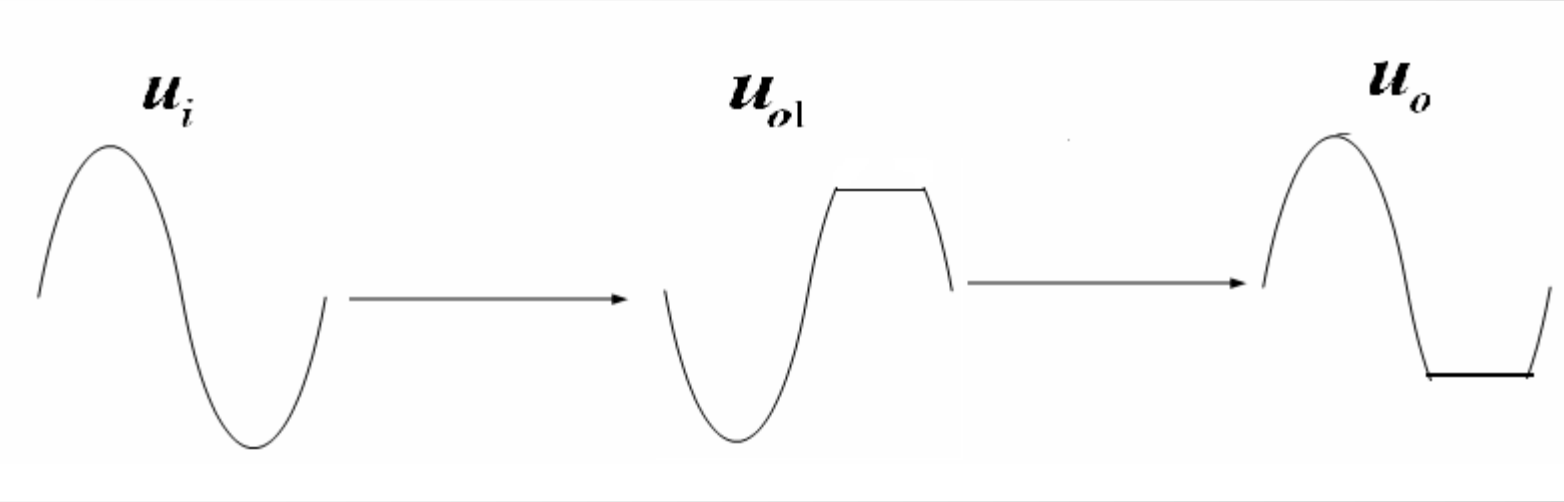
考查要点：非线性失真

解： 电路为CE-CE组态，即输入电压经过两次反相得到输出



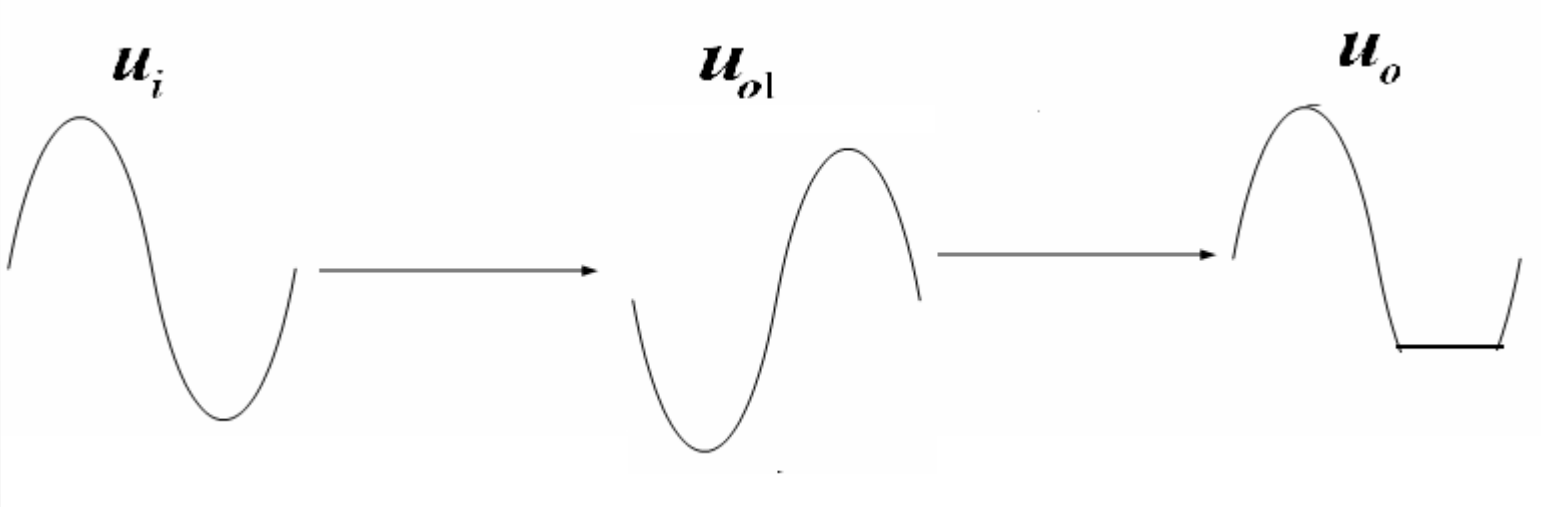


（1）u_{o1}已经失真,第二级未失真



对于u_{o1}，出现顶部失真，即为截止失真，因此表明是由于Q1点过低造成的，要使Q1点升高，就要增大I_{BQ1}，因此R_{b1}的值应下降。

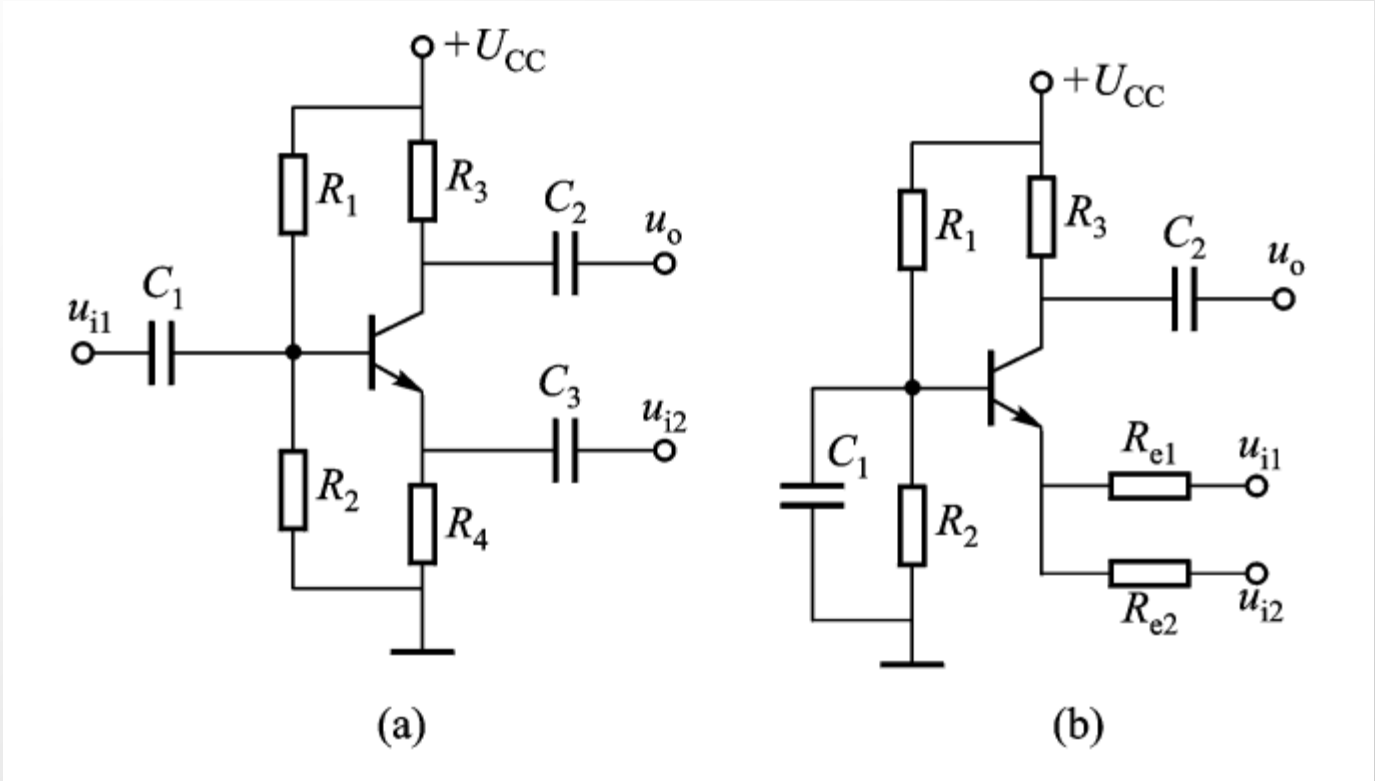
（2）u_{o1}无失真，第二级电路失真



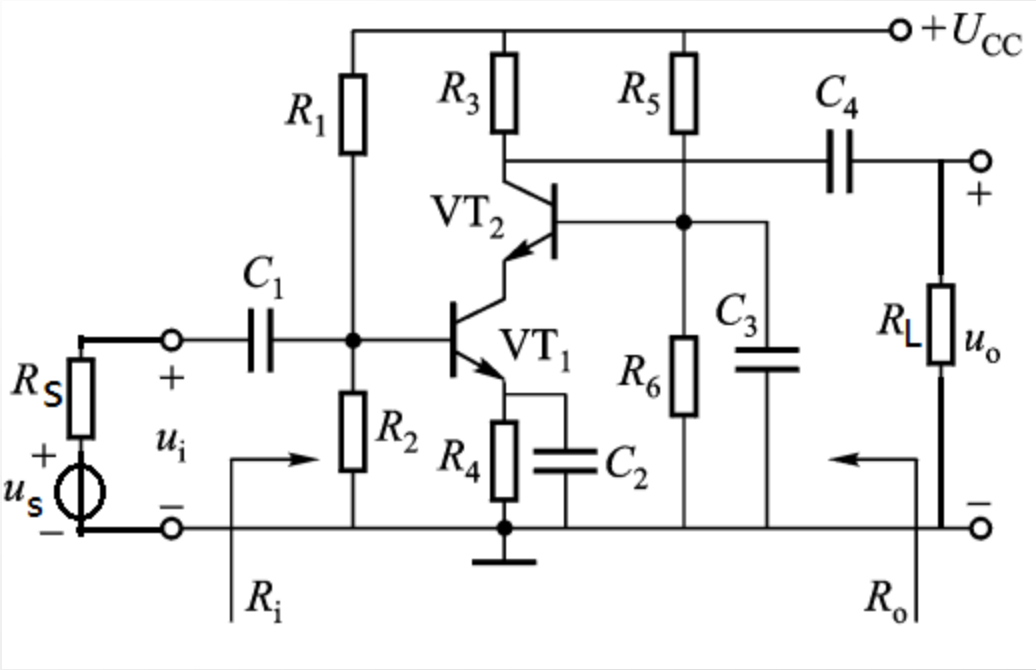
对于u_{o2}，出现底部失真，即为饱和失真，因此表明是由于Q2点过高造成的，要使Q2点降低，就要减小I_{BQ2}，因此R_{b2}的值应上升。

因此，正确答案为d)

例6（作业2-19）电路如图所示，已知h参数，写出输出电压和输入信号之间的关系式。



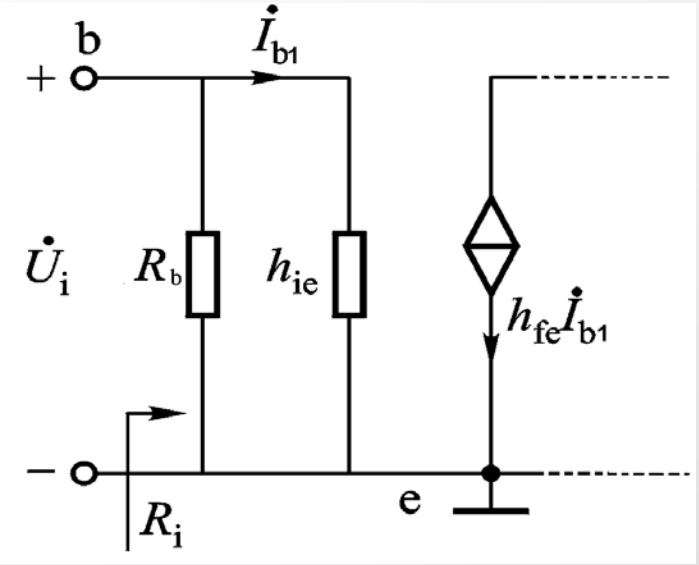
例7：电路如图所示，两管参数相同，$\beta = 50, h_{ie} = 1.38K\Omega$，$C_1$~$C_4$对交流短路，求 $\dot{R}_i, \dot{A}_{um}, \dot{A}_{usm}, R_o$

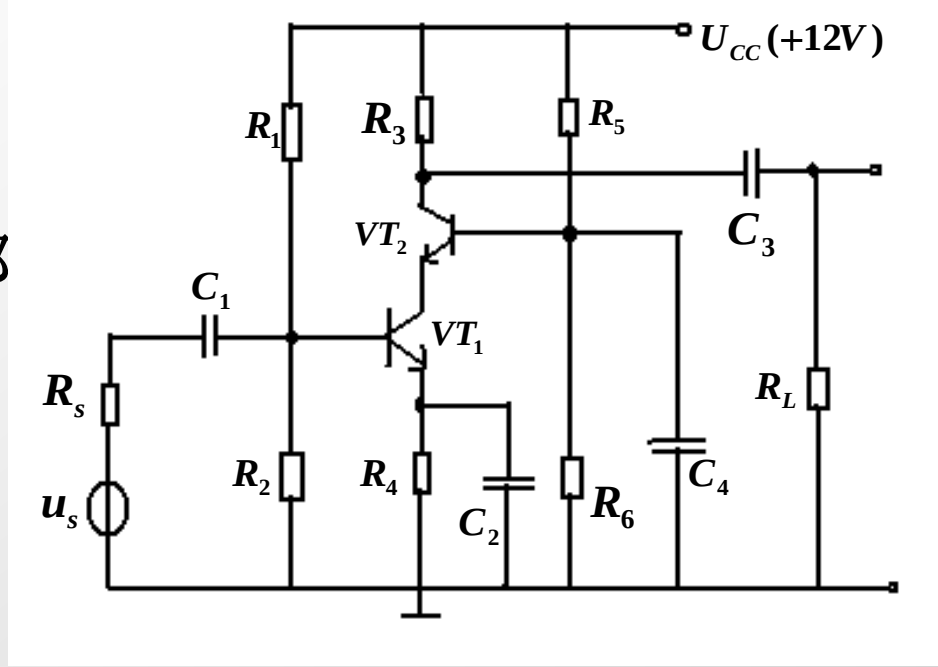


$$R_s = 1K, R_1 = 15K,$$
$$R_2 = 5K, R_3 = 2.4K,$$
$$R_4 = 2K, R_5 = 15K,$$
$$R_6 = 15K, R_L = 2.4K$$

1)R_i

由于R_4被C_2短路，因此输入部的等效电路如图所示





其中：

$R_b=R_1//R_2=3.75K\Omega$

可见输入电阻和后面的电路无关，因此，可得输入电阻为

$R_i=R_1//R_2//h_{ie}=1.069K\Omega$

2) $\dot{A}_{um}$

$$\dot{A}um = \dot{A}_{um1} \bullet \dot{A}_{um2}$$

$$\dot{A}_{um1} = -\frac{h_{fe} R'_{L1}}{h_{ie1}} \qquad R'_{L1} = R_{i2} = \frac{h_{ie2}}{1 + h_{fe}}$$

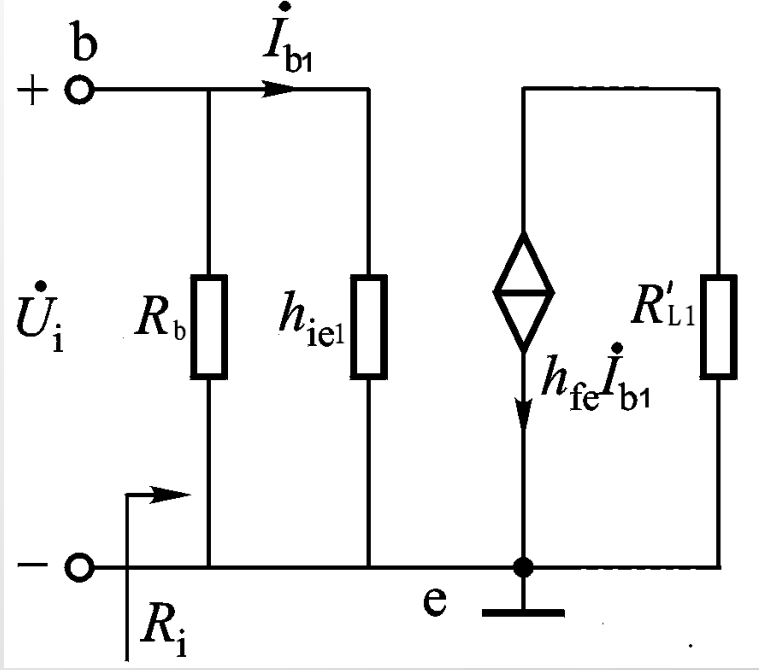
$$\dot{A}_{um2} = \frac{h_{fe} R'_{L2}}{h_{ie2}} \qquad R'_{L2} = R_3 // R_L$$

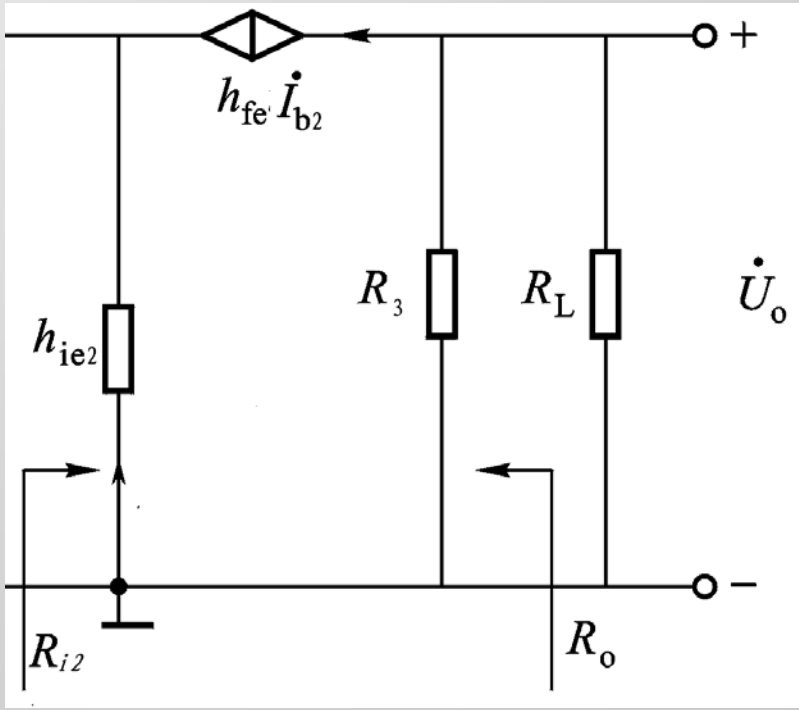
$$\dot{A}_{um} = \dot{A}_{um1} \bullet \dot{A}_{um2} = -\frac{h_{fe} R_{i2}}{h_{ie1}} \times \frac{h_{fe} R'_{L2}}{h_{ie2}}$$

$$= -\frac{h_{fe}}{h_{ie1}} \times \frac{h_{ie2}}{1 + h_{fe}} \times \frac{h_{fe}}{h_{ie2}} \times (R_3 // R_L)$$

$$= -\frac{50}{1.38} \times \frac{1}{50} \times 50 \times (2.4 // 2.4)$$

$$\doteq -42.63$$

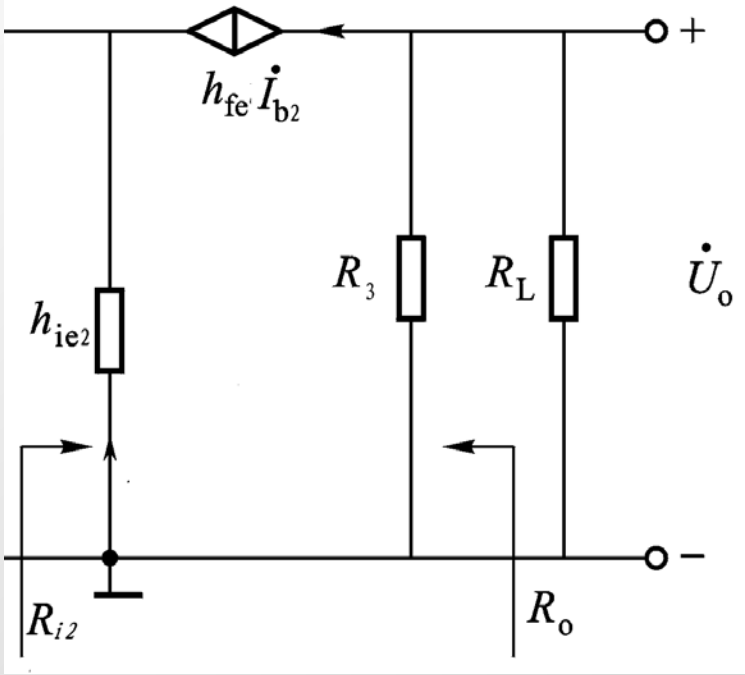




3) $\dot{A}_{usm}$

$$\dot{A}_{usm} = \frac{R_i}{R_i + R_s} \times \dot{A}_{um}$$

$$= \frac{1.069}{1.069 + 1} \times (-42.63) \doteq -22.03$$



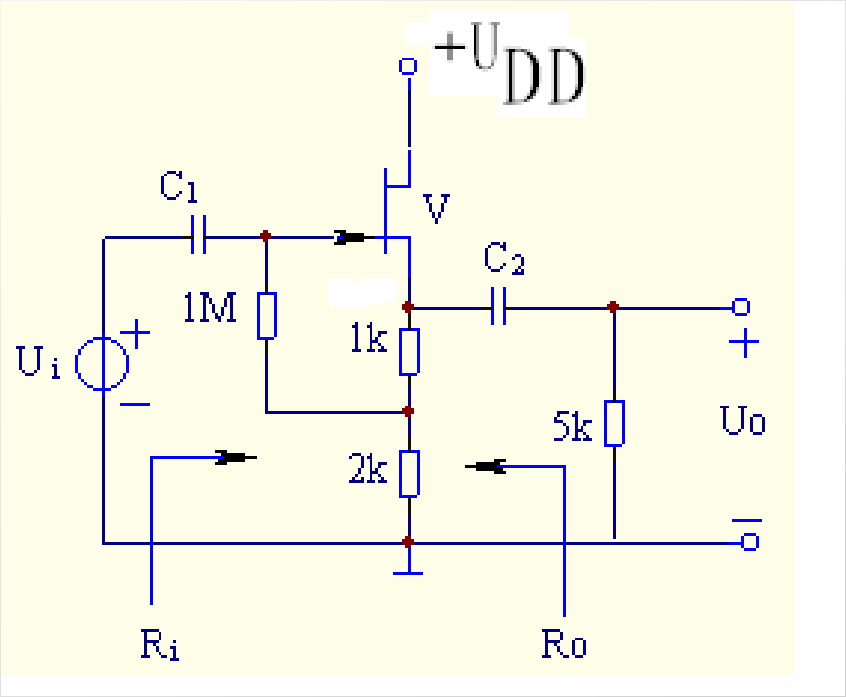
4) R_o

$$R_o = R_3 = 2.4K\Omega$$

例8：2—23题，增加已知$U_{DD}=12V$

(1)I_{DQ}, U_{GSQ}, U_{DSQ}

(2)R_i, A_{um}, R_o



解：

（1）静态工作点分析（解析法）

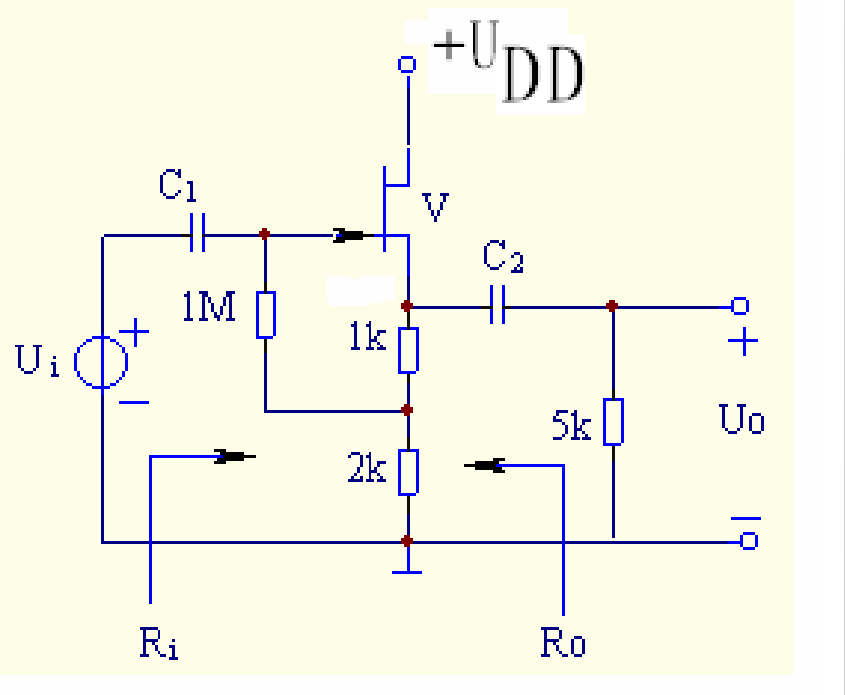
$$\begin{cases} I_D = I_{DSS}\left(1-\dfrac{U_{GS}}{U_{GS(off)}}\right)^2 = 8\left(1-\dfrac{U_{GS}}{-4}\right)^2 \\ U_{GS} = -I_D \times 1 \end{cases}$$

$$\Rightarrow I_{DQ} = 2mA$$

$$U_{GSQ} = -2V$$

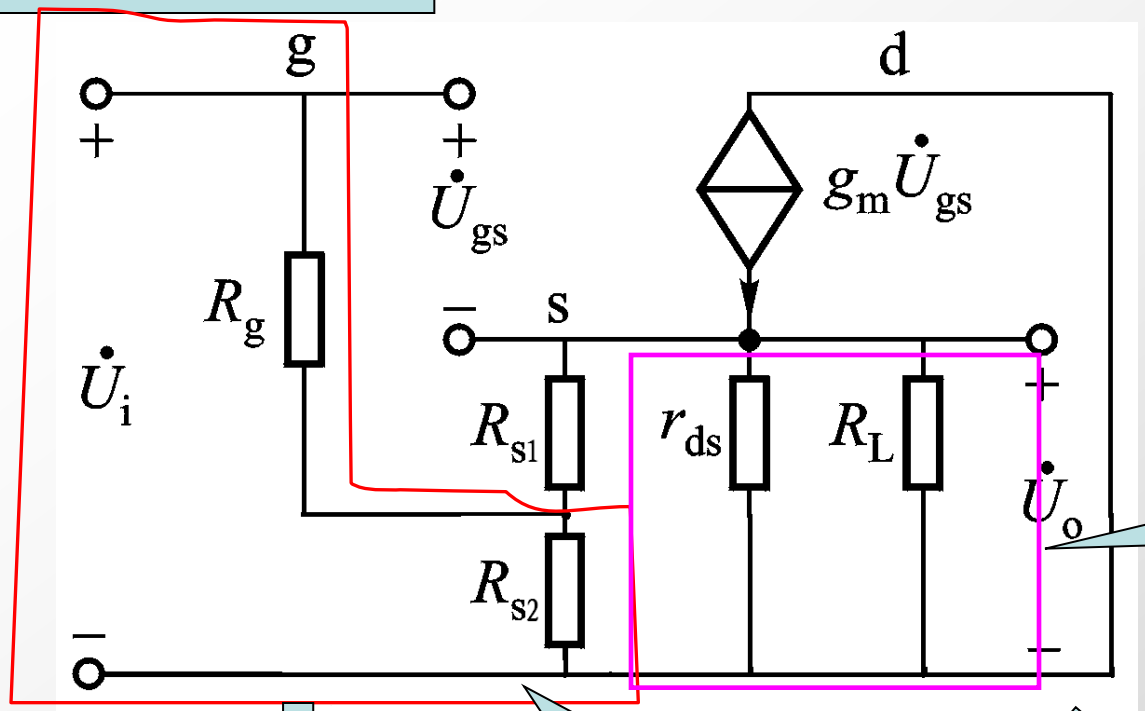
$$g_m = 2mS$$

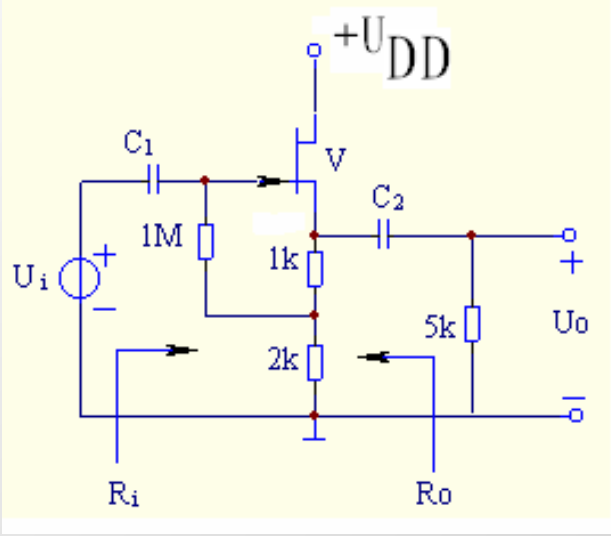
$$U_{DSQ} = 12 - I_{DQ} \times 3 = 6V$$



（2）动态分析

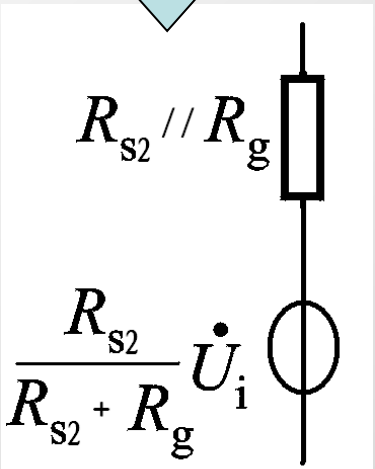
等效电路如图所示

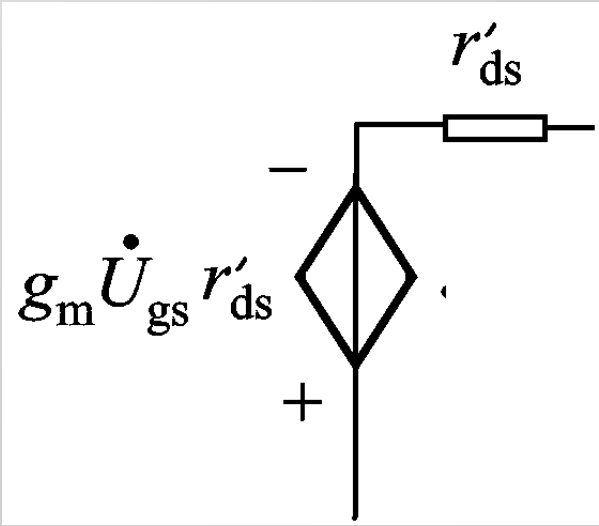




翻到上面和电压源并联，并进行并串变换

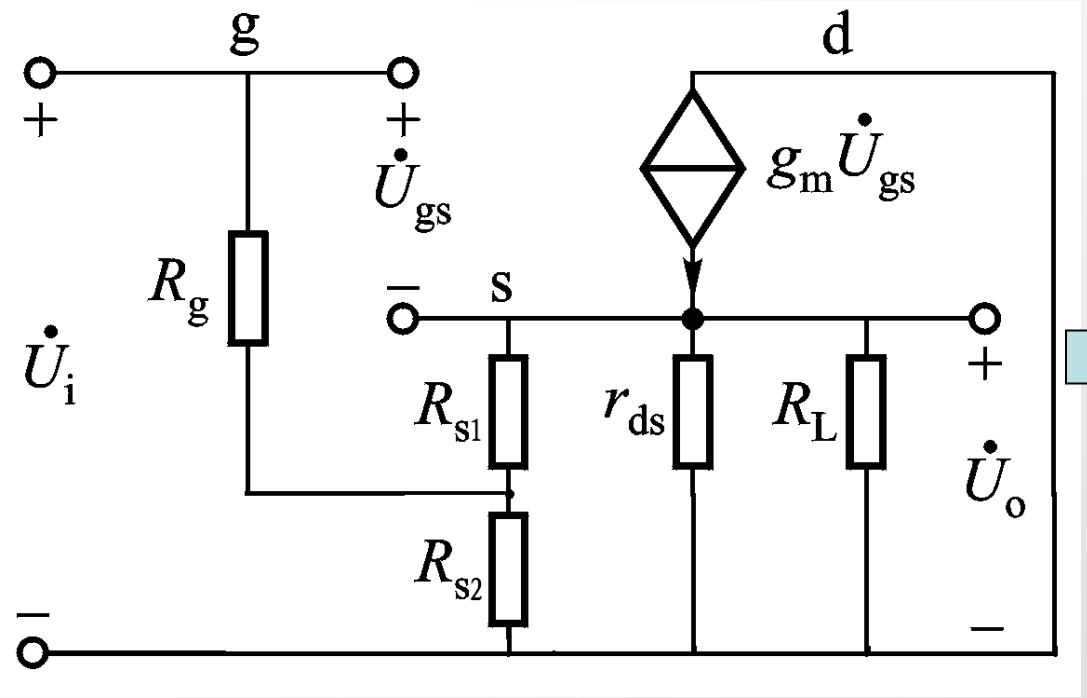
做戴维南等效

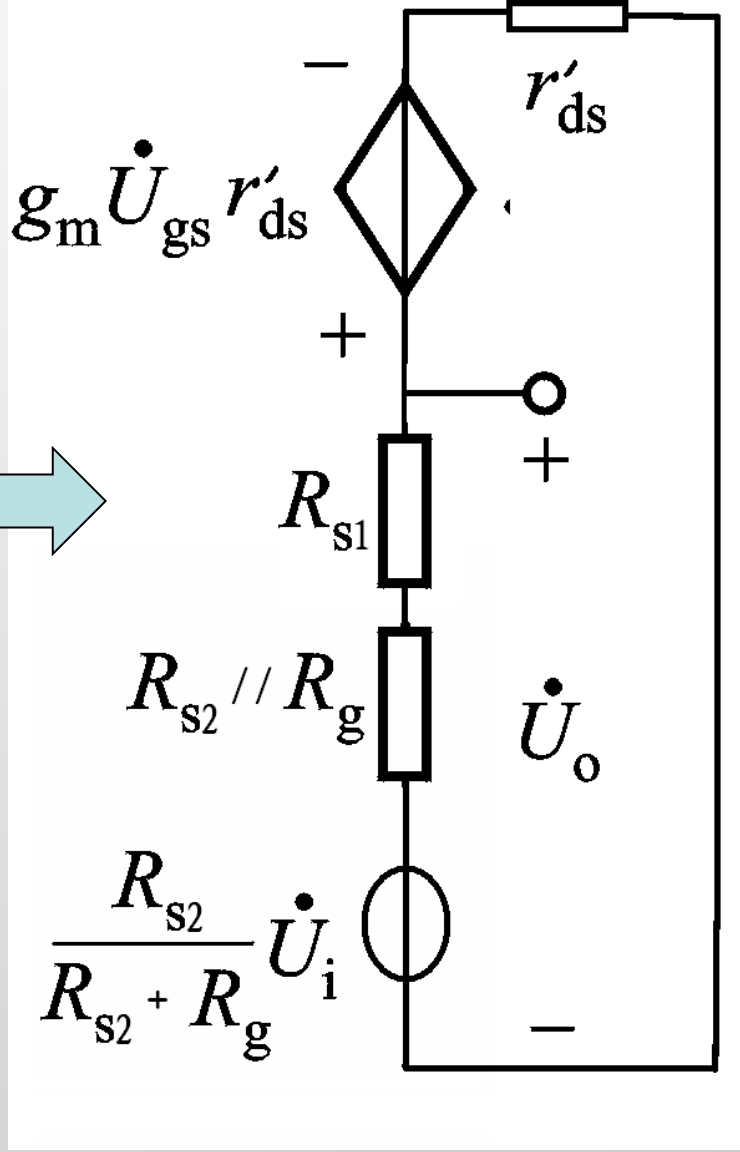




$$r'_{ds} = r_{ds} // R_L$$

经过化简后的等效电路如图所示





$$\boldsymbol{r'_{ds}} = \boldsymbol{r_{ds}} \,//\, \boldsymbol{R_L} = 20\,//\,5 = 4\mathrm{K}\Omega$$

$$\boldsymbol{R_{s2}} \,//\, \boldsymbol{R_g} = 2\mathrm{K}\,//\,1\mathrm{M} \doteq 2\mathrm{K}$$

$$\frac{\boldsymbol{R_{s2}}}{\boldsymbol{R_{s2}} + \boldsymbol{R_g}} = \frac{2\mathrm{K}}{1\mathrm{M} + 2\mathrm{K}} \doteq 0.002$$

$$r'_{ds} = r_{ds} \,//\, R_L = 20 \,//\, 5 = 4\mathrm{K}\Omega$$

$$R_{s2} \,//\, R_g = 2\mathrm{K} \,//\, 1\mathrm{M} \doteq 2\mathrm{K}$$

$$\frac{R_{s2}}{R_{s2} + R_g} = \frac{2\mathrm{K}}{1\mathrm{M} + 2\mathrm{K}} \doteq 0.002$$

$$\dot{A}_{um} = \frac{\dot{U}_o}{\dot{U}_i}$$

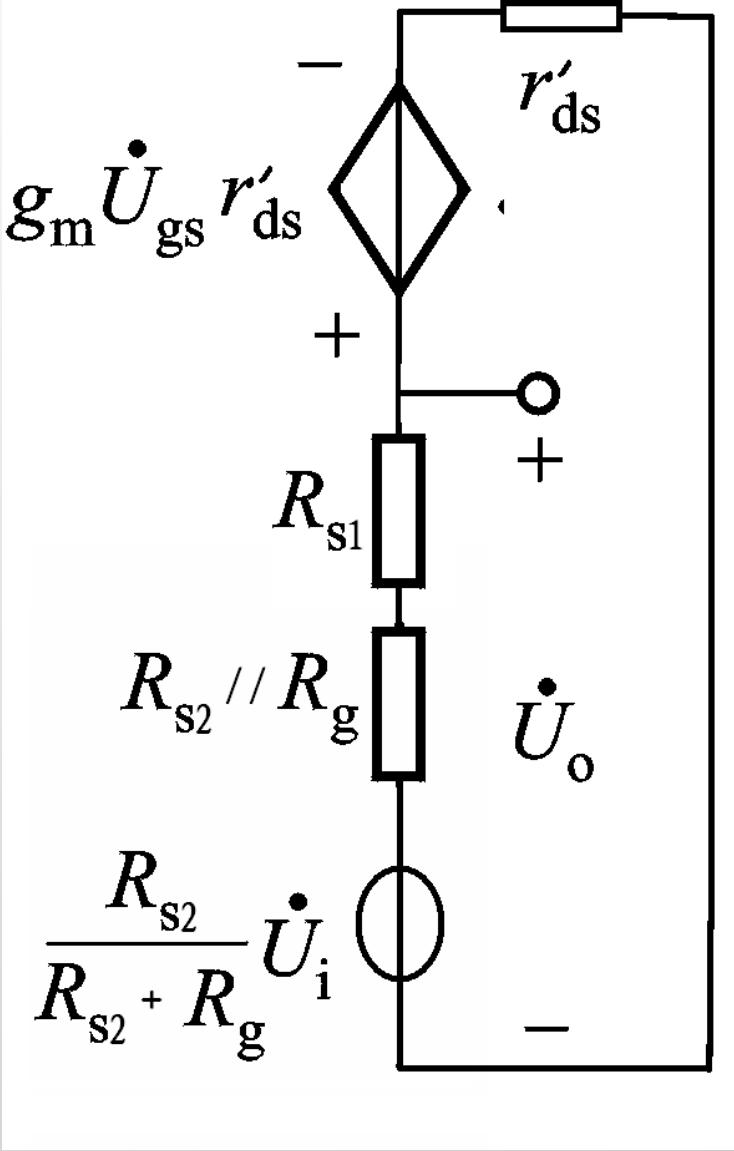
设回路中的电流为 $\dot{I}_d$

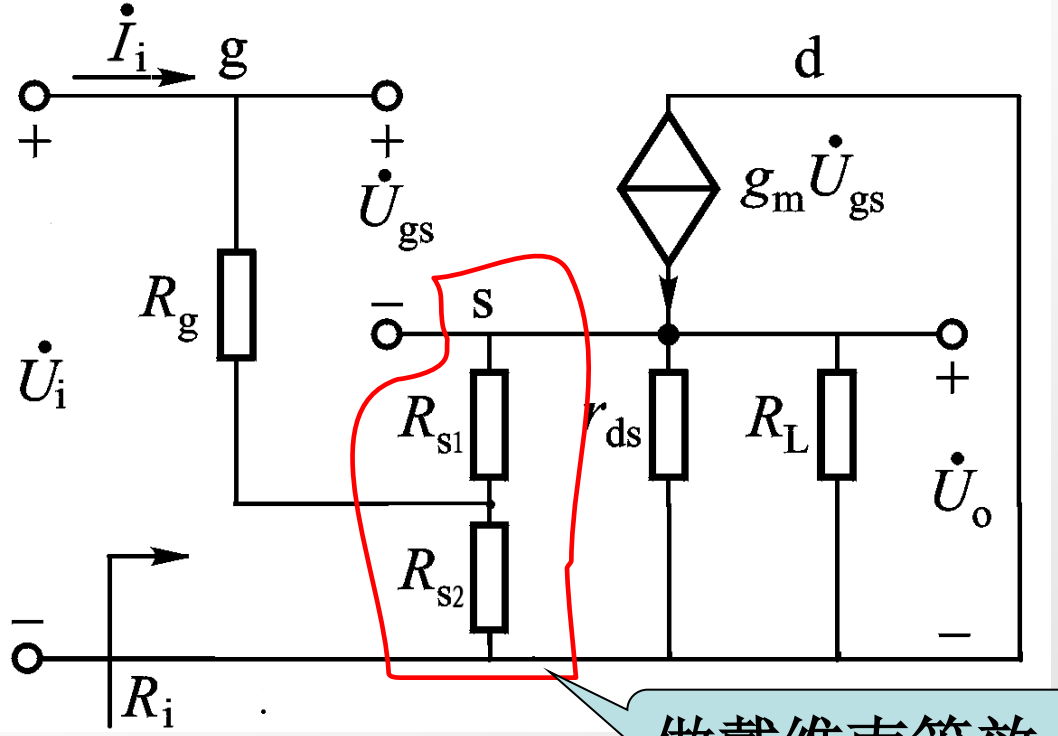
$$\dot{I}_d = \frac{8\dot{U}_{gs} - 0.002\dot{U}_i}{\dot{r}_{ds} + R_{s1} + (R_{s2} \,//\, R_g)}$$

$$\dot{U}_{gs} = \dot{U}_i - \dot{U}_o$$

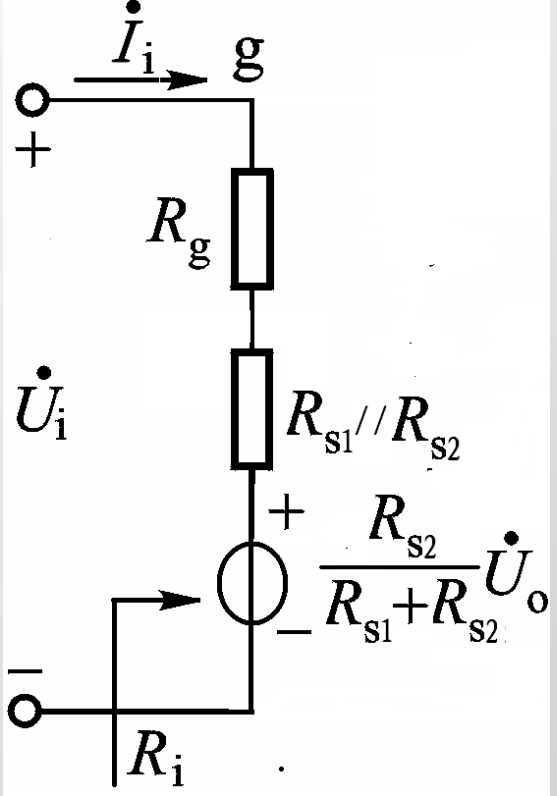
$$\dot{U}_o = 3\dot{I}_d + 0.002\dot{U}_i$$

$$\dot{A}_{um} = \frac{\dot{U}_o}{\dot{U}_i} \doteq 0.77$$





做戴维南等效

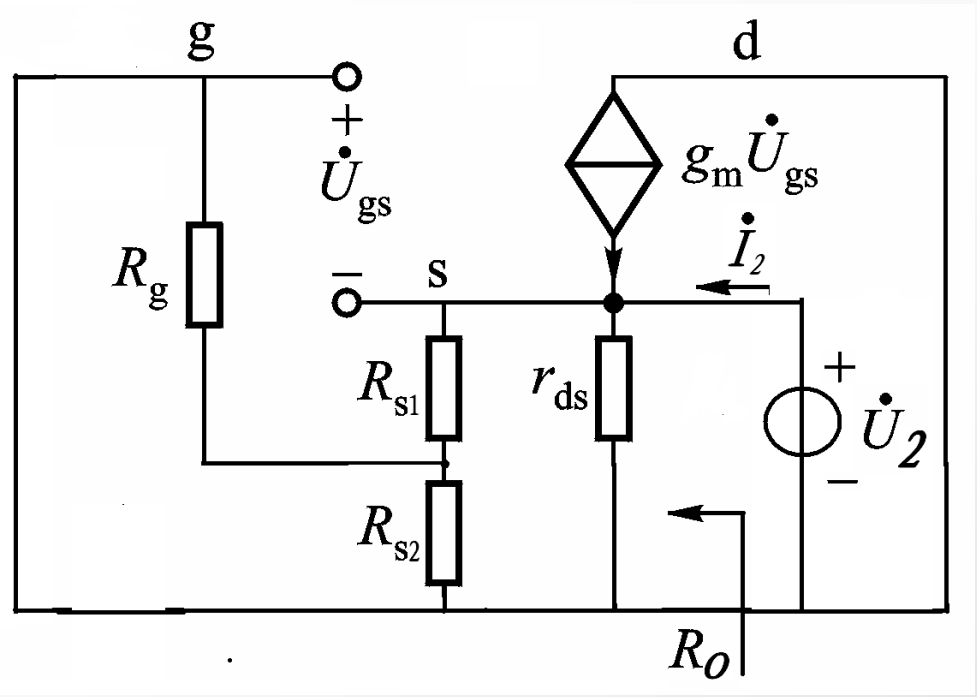


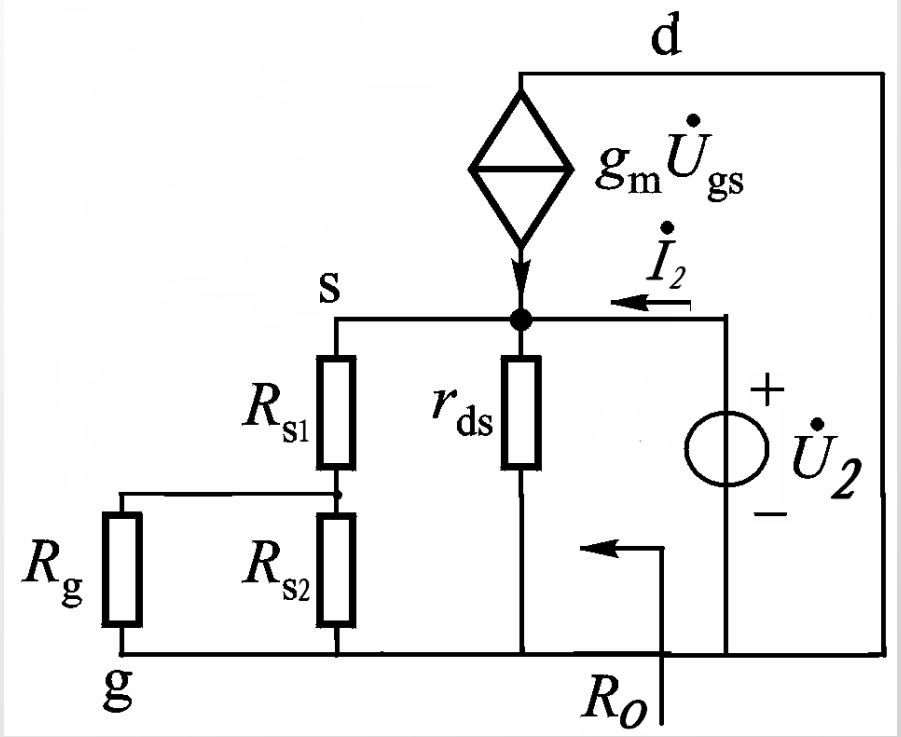
由于s点的电位即为输出电压，因此从R_{s2}两端向右看的戴维南等效后如图所示

$$\text{且}\ \frac{R_{s2}}{R_{s1}+R_{s2}}\dot{U}_o=\frac{R_{s2}}{R_{s1}+R_{s2}}\dot{A}_{um}\dot{U}_i$$

$$\therefore R_i=\frac{R_g+R_{s1}//R_{s2}}{1-\dfrac{R_{s2}}{R_{s1}+R_{s2}}\dot{A}_{um}}$$

$$=\frac{1000+0.67}{1-0.67\times0.77}\doteq 2.05\text{M}$$





由图可知 $\dot{U}_{gs} = -\dot{U}_2$

$$\frac{\dot{U}_2}{R_{s1} + (R_{s2} // R_g)} + \frac{\dot{U}_2}{r_{ds}} = -g_m\dot{U}_2 + \dot{I}_2 \qquad R_{s2} // R_g \approx R_{s2}$$

$$R_o = \frac{1}{g_m} // r_{ds} // (R_{s1} + R_{s2}) = 0.2 // 20 // 3 = 0.42\text{K}\Omega$$