第6章 信号的运算电路

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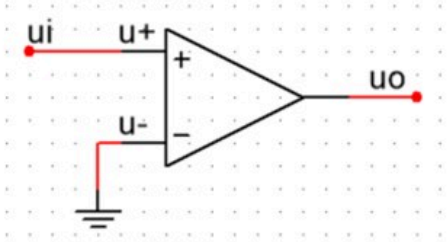
第6章 信号的运算电路

- 反向比例运算电路
- 同向比例运算电路
- 加法电路和减法电路
- 微分电路和积分电路
- 模拟乘法器
- 电压比较器
- 滞回特性的电压比较器
- 仪表放大器

运放的电压传输特性



➢电源电压为 $\pm V_{CC}=\pm 10V$　　$A_{ud}=10^4$

$|u_i|\leq 1mV$，运放处于线性区

A_{ud} 越大，线性区越小，当$A_{ud}\to\infty$时，线性区$\to 0$

➢理想集成运放

开环电压放大倍数$A_{ud}\to\infty$

差模输入电阻$R_{id}\to\infty$

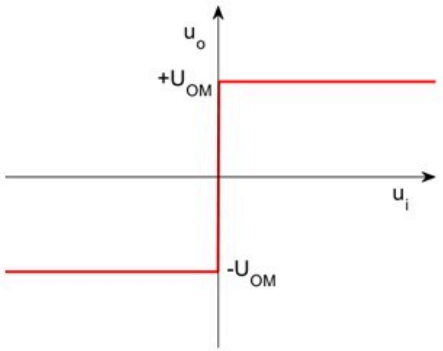
输出电阻$R_o\to 0$

➢ 运放工作在非线性区

正负饱和输出状态，电路开环工作或引入正反馈。

$u_+ > u_-$　　$u_o = +U_{OM}$

$u_+ < u_-$　　$u_o = -U_{OM}$



➢集成运放工作在线性区

为了扩大运放的线性区，引入负反馈。

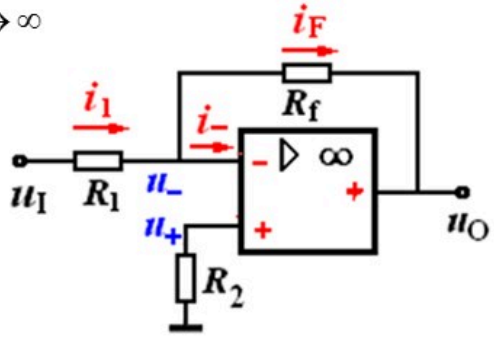
理想运放工作在线性区的条件：电路中有负反馈。

理想运放：

开环电压放大倍数$A_{ud} \to \infty$

差模输入电阻$R_{id} \to \infty$

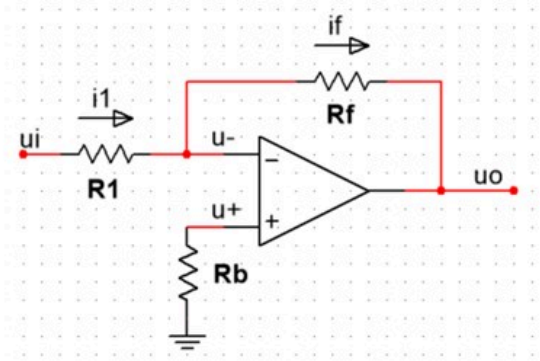
输出电阻$R_o \to 0$



$$u_o = A_{ud}(u_+ - u_-) = A_{ud}u_{id}$$

$$u_+ - u_- = u_o / A_{ud} \approx 0 \quad \to u_+ \approx u_- \text{ (虚短)}$$

$$i_+ \approx i_- = -u_{id} / R_{id} \approx 0 \quad \to i_+ \approx i_- \approx 0 \text{ (虚断)}$$

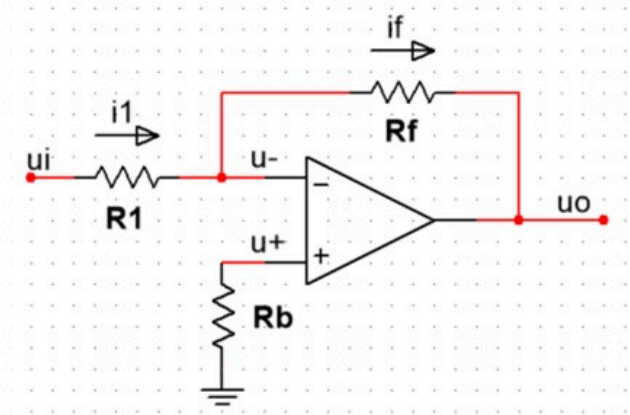


反向比例运算电路

一般实际运放工作在线性区时，参数很接近理想条件，满足虚短和虚断。

$u_+ \approx u_-$ (虚短)

$i_+ \approx i_- \approx 0$ (虚断)



$$i_+ \approx i_- \approx 0 \rightarrow i_1 = i_F$$

$$u_+ \approx u_- \approx 0 \rightarrow u_o = -i_F R_f$$

$$A_{uf} = \frac{u_o}{u_i} \approx \frac{-i_F R_f}{i_1 R_1} = -\frac{R_f}{R_1}$$

$u_+ \approx u_- \approx 0$ (虚地)

$$u_o = -\frac{R_f}{R_1} u_i$$

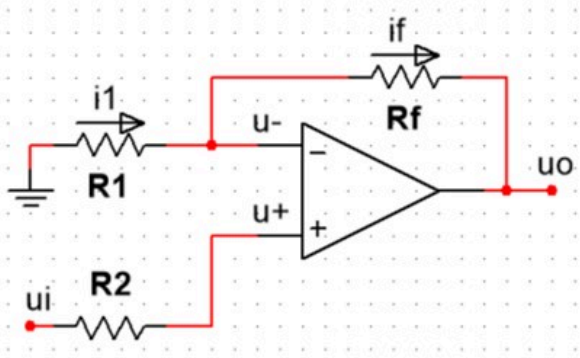
平衡电阻$R_b = R_1 // R_f$

运放两个输入端的外接电阻相等，处于平衡对称状态。

$R_1 = R_f \qquad A_{uf} = -1 \qquad u_o = -u_i$

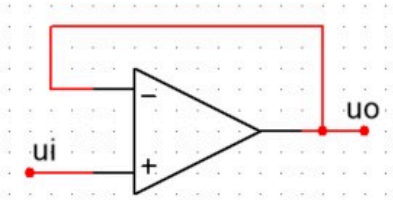
输出电压和输入电压相位相反，大小相等，称为反相器。

同相比例运算电路



$$R_1 = \infty, \quad R_f = 0 \qquad A_{uf} = 1$$

电压跟随器



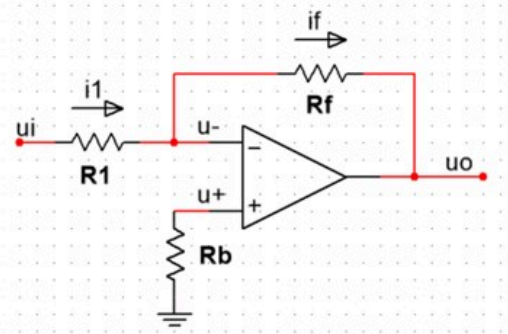
输出电压和输入电压相位相同，
大小成一定的比例关系。

$$u_+ \approx u_- = u_i \qquad i_1 \approx i_F$$

$$i_1 \approx i_F \rightarrow \frac{-u_i}{R_1} = \frac{u_i - u_o}{R_f} \qquad u_o = \left(1 + \frac{R_f}{R_1}\right) u_i$$

$$A_{uf} = \frac{u_o}{u_i} = 1 + \frac{R_f}{R_1}$$

例题1

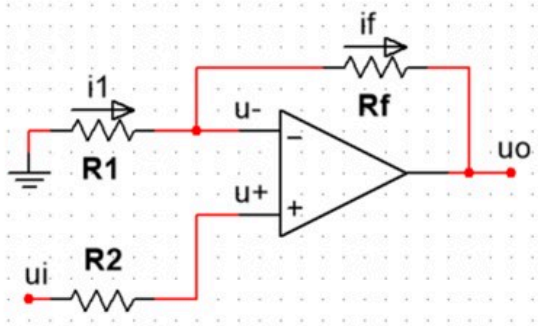


当 $R_1 = 2k\Omega, R_f = 4k\Omega, u_i = 1.5V$ 时，

输出电压 $u_o = (\quad)$

$$u_o = -\frac{R_f}{R_1}u_i = -\frac{4}{2}\times 1.5 = -3V$$

例题2

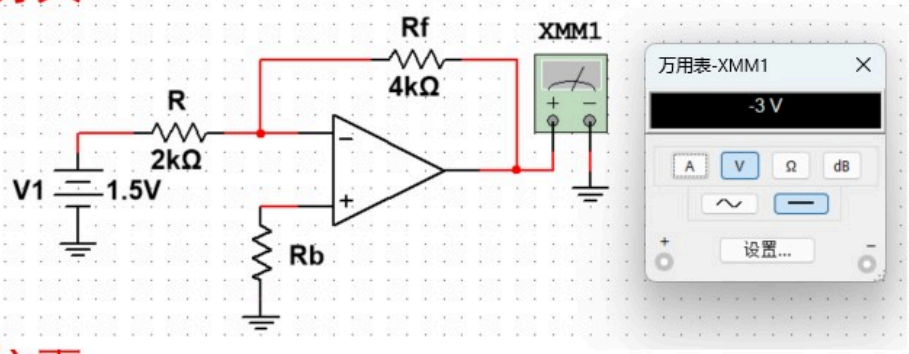


当 $R_1 = 2k\Omega, R_f = 2k\Omega, u_i = 2V$ 时，

输出电压 $u_o = (\quad)$

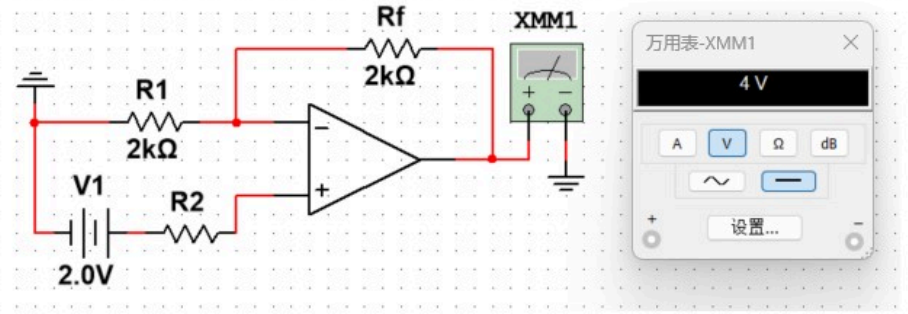
$$u_o = \left(1+\frac{R_f}{R_1}\right)u_i = \left(1+\frac{2}{2}\right)\times 2 = 4V$$

例题1—仿真



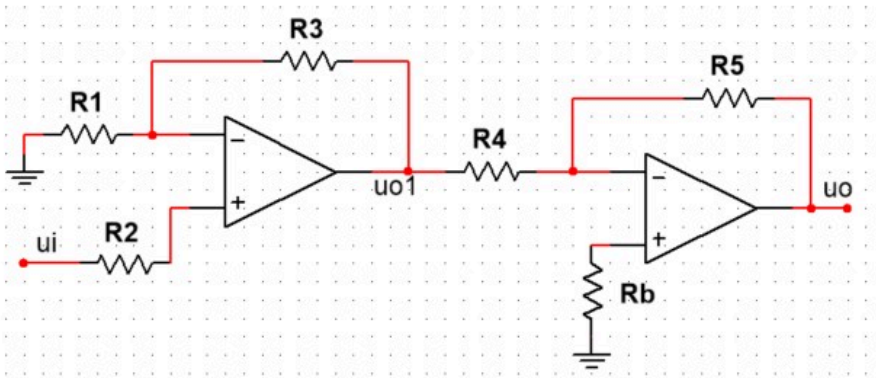
$$u_o = -\frac{R_f}{R_1}u_i = -\frac{4}{2}\times 1.5 = -3V$$

例题2—仿真



$$u_o = \left(1+\frac{R_f}{R_1}\right)u_i = \left(1+\frac{2}{2}\right)\times 2 = 4V$$

例题3



$$u_{o1}=\left(1+\frac{R_3}{R_1}\right)u_i$$

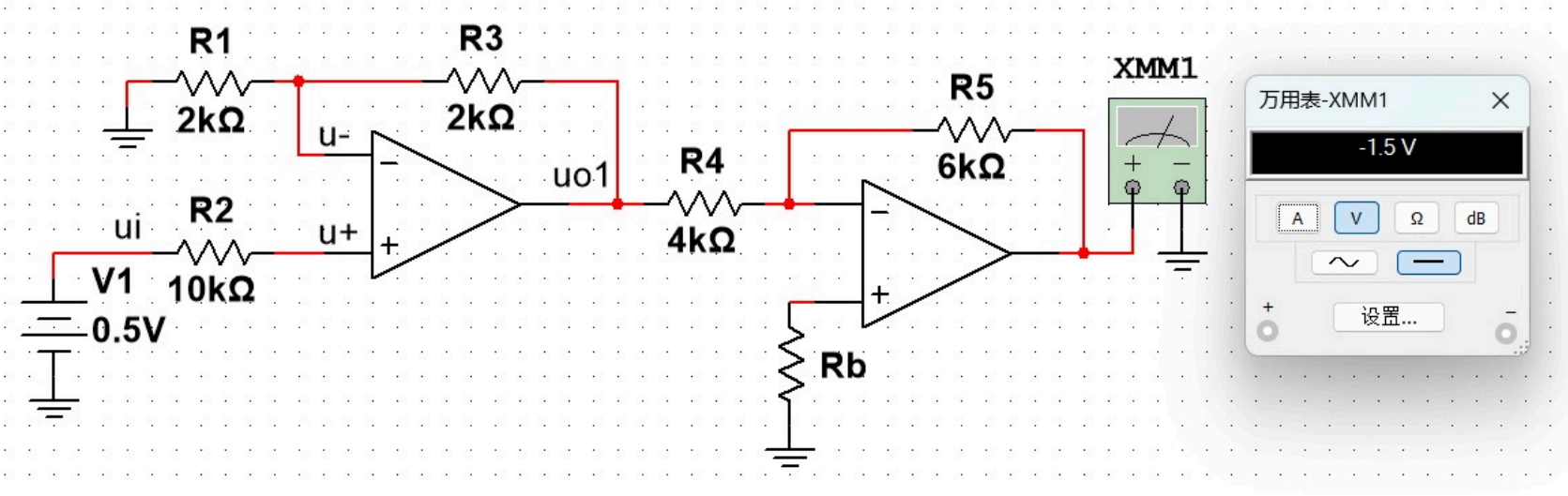
$$u_o=-\frac{R_5}{R_4}u_{o1}=-\frac{R_5}{R_4}\left(1+\frac{R_3}{R_1}\right)u_i$$

$$u_o=-\frac{6}{4}\left(1+\frac{2}{2}\right)u_i=-3u_i=-1.5V$$

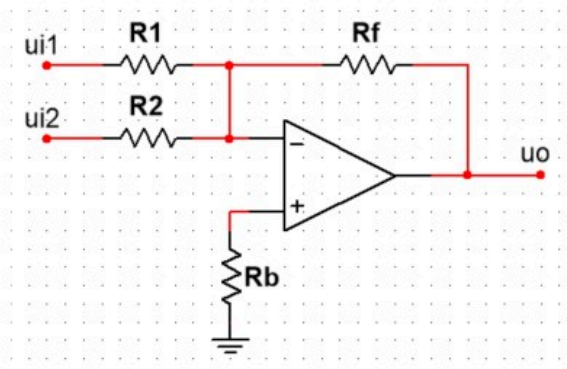
当 $R_1=R_3=2k\Omega, R_4=4k\Omega, R_5=6k\Omega, u_i=0.5V$ 时，

输出电压 $u_o=(\quad)$

➢例题3的仿真


R1
2kΩ
R3
2kΩ
u-
uo1
R4
4kΩ
R5
6kΩ
XMM1
万用表-XMM1
-1.5 V
A
V
Ω
dB
设置...
ui
R2
10kΩ
u+
V1
0.5V
Rb

反相加法运算电路



$$u_+ \approx u_- = 0 \qquad i_F = i_1 + i_2$$

$$-\frac{u_o}{R_f} = \frac{u_{i1}}{R_1} + \frac{u_{i2}}{R_2}$$

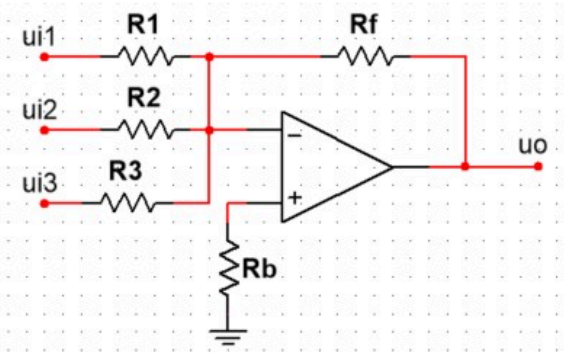
$$u_o = -R_f\left(\frac{u_{i1}}{R_1} + \frac{u_{i2}}{R_2}\right)$$

$$R_b = R_1 // R_2 // R_f$$

$$R_1 = R_2, \quad u_o = -\frac{R_f}{R_1}\left(u_{i1} + u_{i2}\right)$$

$$R_1 = R_2 = R_f, \quad u_o = -\left(u_{i1} + u_{i2}\right)$$

反相加法运算电路（叠加原理求解）



叠加原理

$$u_{i1} \neq 0, \quad u_{o1} = -\frac{R_f}{R_1} u_{i1}$$

$$u_{i2} \neq 0, \quad u_{o2} = -\frac{R_f}{R_2} u_{i2}$$

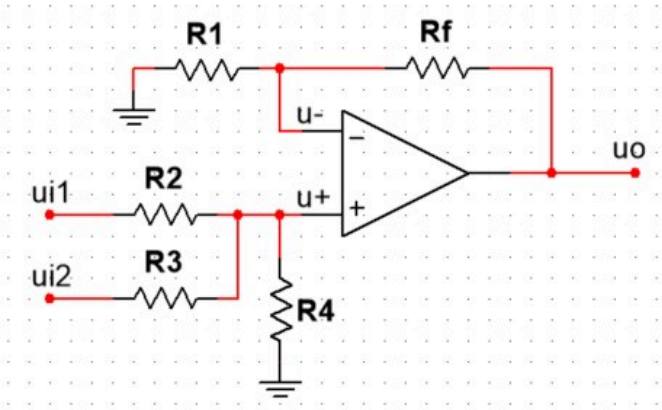
$$u_{i3} \neq 0, \quad u_{o3} = -\frac{R_f}{R_3} u_{i3}$$

$$R_b = R_1 // R_2 // R_3 // R_f$$

$$u_o = u_{o1} + u_{o2} + u_{o3} = -\left(\frac{R_f}{R_1} u_{i1} + \frac{R_f}{R_2} u_{i2} + \frac{R_f}{R_3} u_{i3} \right)$$

$$R_1 = R_2 = R_3 = R_f, \quad u_o = -\left(u_{i1} + u_{i2} + u_{i3} \right)$$

➢同相加法运算电路



$$R_1 // R_f = R_2 // R_3 // R_4$$

$u_{i2}=0, R_3$和R_4并联，然后和R_2串联

$u_{i1}=0, R_2$和R_4并联，然后和R_3串联

$$u_+ \approx u_-, \quad i_+ \approx i_- \approx 0$$

$$u_o = \left(1+\frac{R_f}{R_1}\right)u_+$$

$$u_+ = \frac{R_3 // R_4}{R_2 + R_3 // R_4}u_{I1} + \frac{R_2 // R_4}{R_3 + R_2 // R_4}u_{I2}$$

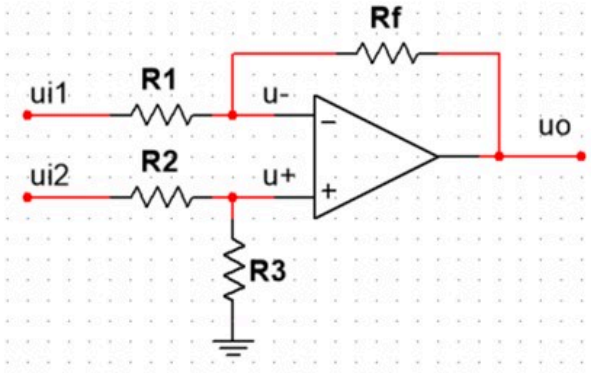
叠加原理

$$u_o = \left(1+\frac{R_f}{R_1}\right)\left(\frac{R_3 // R_4}{R_2 + R_3 // R_4}u_{I1} + \frac{R_2 // R_4}{R_3 + R_2 // R_4}u_{I2}\right)$$

$$R_2 = R_3 = R_4, \quad u_o = \frac{1}{3}\left(1+\frac{R_f}{R_1}\right)\left(u_{I1}+u_{I2}\right)$$

$$R_2 = R_3 = R_4, \quad R_f = 2R_1, \quad u_o = u_{I1} + u_{I2}$$

减法运算电路



$$u_+ \approx u_-, \quad i_+ \approx i_- \approx 0$$

$$u_- = \frac{u_o R_1}{R_1 + R_f} + \frac{u_{i1} R_f}{R_1 + R_f}$$ 叠加原理

$$u_+ = \frac{u_{i2} R_3}{R_2 + R_3} \qquad R_1 = R_2, R_f = R_3, \quad u_o = \frac{R_f}{R_1}(u_{i2} - u_{i1})$$

通过叠加原理

$$u_{i2} = 0, \quad u_{o1} = -\frac{R_f}{R_1} u_{i1}$$

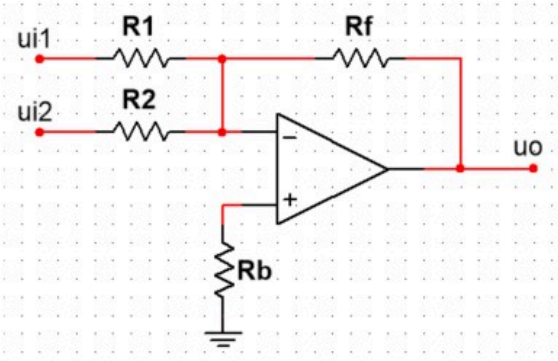
$$u_{i1} = 0, \quad u_{o2} = \left(1 + \frac{R_f}{R_1}\right) u_+ = \left(1 + \frac{R_f}{R_1}\right) \frac{R_3}{R_2 + R_3} u_{i2}$$

$$u_o = u_{o1} + u_{o2} = -\frac{R_f}{R_1} u_{i1} + \left(1 + \frac{R_f}{R_1}\right) \frac{R_3}{R_2 + R_3} u_{i2}$$

$$R_1 = R_2, R_f = R_3$$

$$u_o = u_{o1} + u_{o2} = \frac{R_f}{R_1}(u_{i2} - u_{i1})$$

例题4



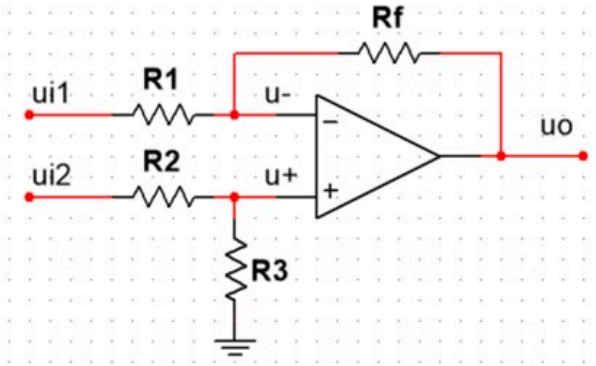
当 $R_1 = R_2 = 2k\Omega, R_f = 4k\Omega, u_{i1} = 1.5V, u_{i2} = 0.5V$ 时，

输出电压$u_o = (\quad)$

$$R_1 = R_2,\quad u_o = -\frac{R_f}{R_1}(u_{i1} + u_{i2})$$

$$u_o = -\frac{R_f}{R_1}(u_{i1} + u_{i2}) = -\frac{4}{2}(1.5 + 0.5) = -4V$$

例题5

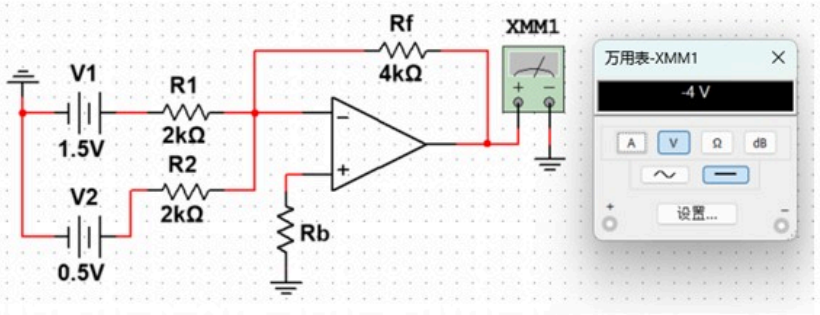


当 $R_1 = R_2 = 2k\Omega, R_3 = R_f = 4k\Omega, u_{i1} = 1.5V, u_{i2} = 2.5V$ 时，

输出电压$u_o = (\quad)$

$$u_o = \frac{R_f}{R_1}(u_{i2} - u_{i1}) = \frac{4}{2}(2.5 - 1.5) = 2V$$

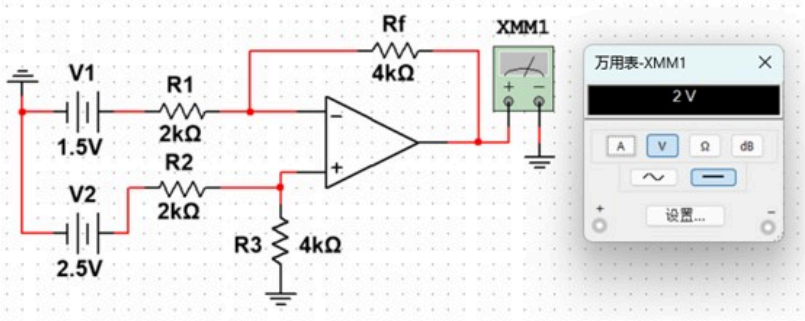
例题4



$$R_1 = R_2, \quad u_o = -\frac{R_f}{R_1}(u_{i1} + u_{i2})$$

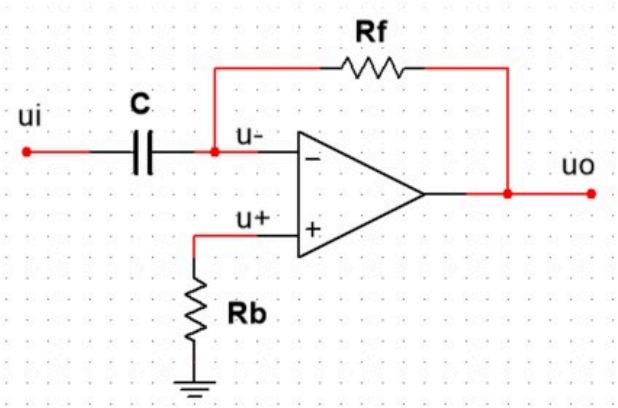
$$u_o = -\frac{R_f}{R_1}(u_{i1} + u_{i2}) = -\frac{4}{2}(1.5 + 0.5) = -4V$$

例题5



$$u_o = \frac{R_f}{R_1}(u_{i2} - u_{i1}) = \frac{4}{2}(2.5 - 1.5) = 2V$$

微分运算电路（了解）

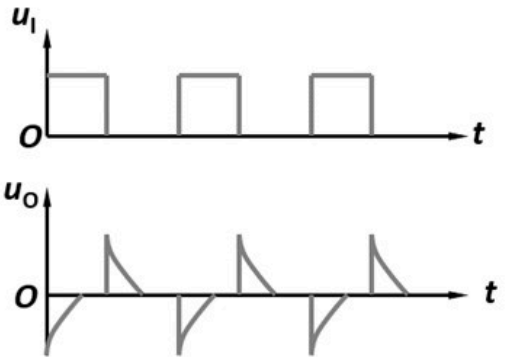


$$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$$

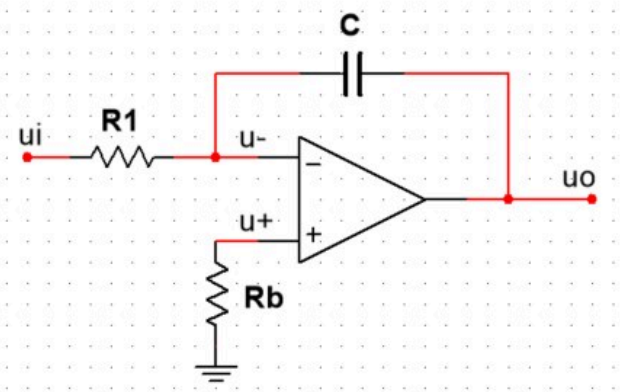
$$i_1 = i_F$$

$$u_o = -i_F R_f = -R_f C \frac{\mathrm{d}u_i}{\mathrm{d}t}$$

$$i_1 = C \frac{\mathrm{d}u_i}{\mathrm{d}t} \qquad \tau = R_f C \quad \text{时间常数}$$



积分运算电路（了解）



$$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$$

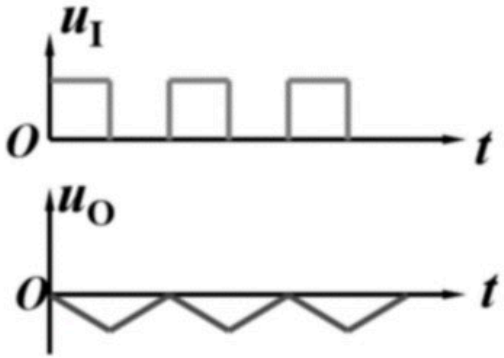
$$i_1 = \frac{u_i}{R_1} = i_C = -C\frac{\mathrm{d}u_o}{\mathrm{d}t}$$

$$u_o = -\frac{1}{R_1 C}\int_{t_0}^{t_1} u_i \mathrm{d}t + u_C(t_0)$$

$\tau = R_1 C$　　时间常数

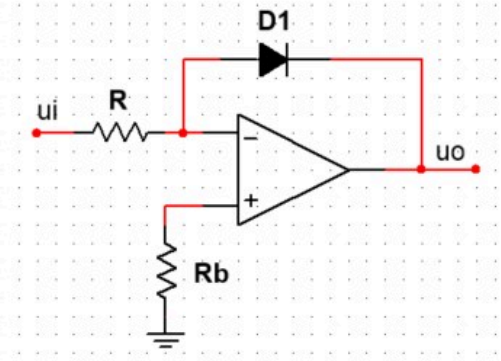
$u_i = U_I, \quad u_C(t_0) = 0$

$$u_o = -\frac{U_I}{R_1 C}t$$



对数运算电路（了解）

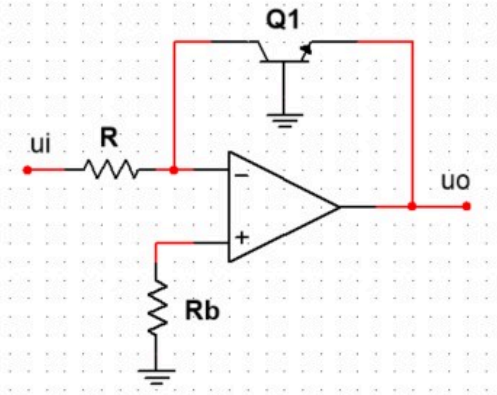
$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$



$$i_D = I_s(e^{u_D/U_T} - 1) \approx I_s e^{u_D/U_T} \qquad U_T = 26mV$$

$$i_D = i_1 = \frac{u_i}{R} \qquad u_o = -u_D$$

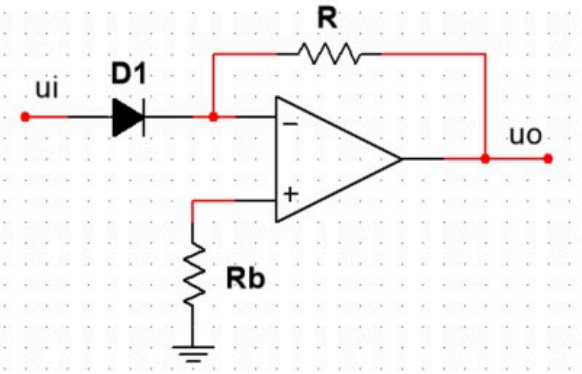
$$\frac{u_i}{R} = I_s e^{-u_o/U_T} \quad \rightarrow \quad u_o = -U_T \ln\left(\frac{u_i}{RI_s}\right)$$



采用晶体管的对数运算电路

指数运算电路（了解）

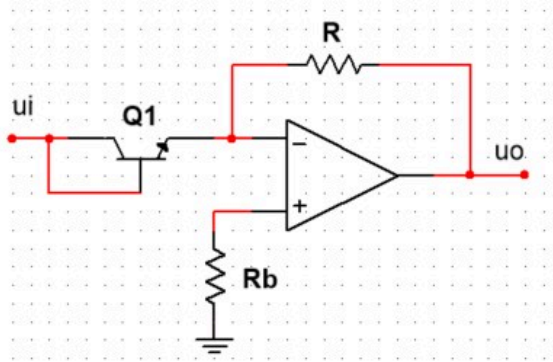
$$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$$



$$i_D = I_s(e^{u_i/U_T} - 1) \approx I_s e^{u_i/U_T} \qquad U_T = 26mV$$

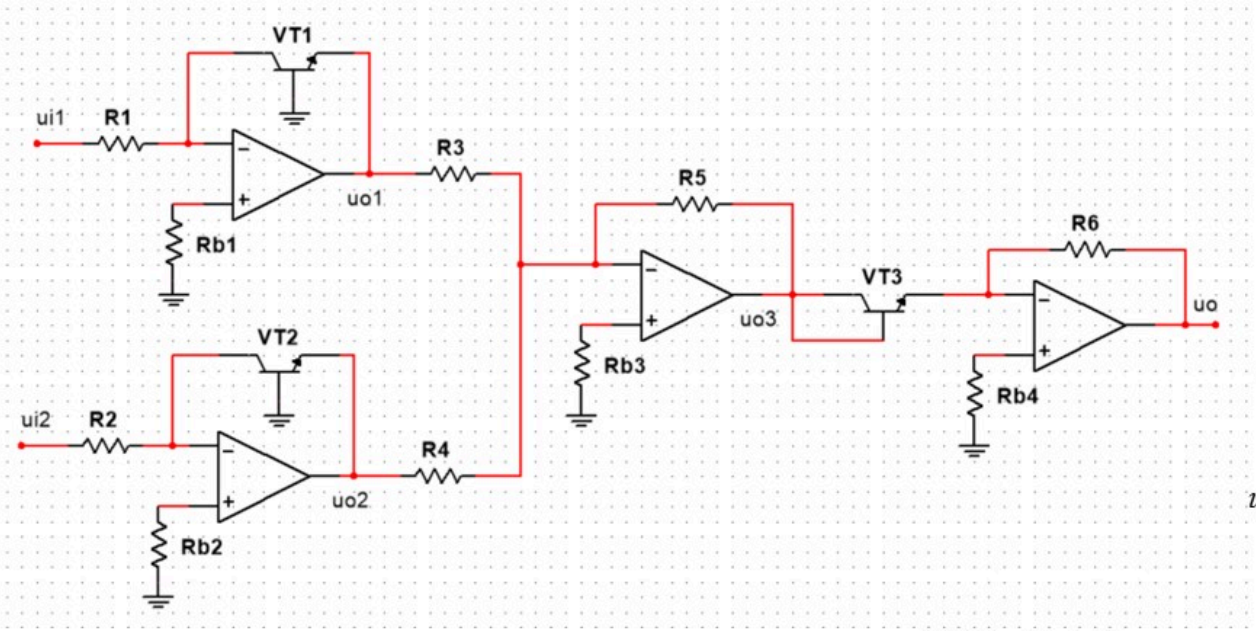
$$i_D = i_1 = -\frac{u_o}{R}$$

$$u_o = -i_1 R \approx -I_S R e^{u_i/U_T}$$



采用晶体管的指数运算电路

基于对数运算和指数运算的乘法电路（了解）



对数运算电路　　反相加法运算电路　　指数运算电路

$$u_{o1} = -U_T \ln\left(\frac{u_{i1}}{R_1 I_{s1}}\right)$$

$$u_{o2} = -U_T \ln\left(\frac{u_{i2}}{R_2 I_{s2}}\right)$$

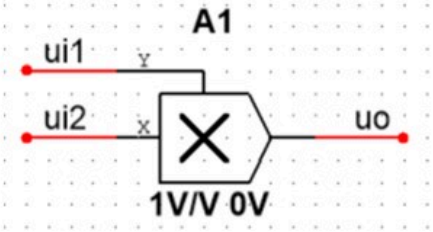
$$R_1 = R_2, \quad R_3 = R_4 = R_5$$

$$u_{o3} = -R_5\left(\frac{u_{o1}}{R_3} + \frac{u_{o2}}{R_4}\right) = U_T \ln\left(\frac{u_{i1}u_{i2}}{R_1 R_2 I_{s1} I_{s2}}\right)$$

$$u_o = -R_6 I_{S3} e^{u_{o3}/U_T} = -\frac{R_6 I_{S3}}{R_1 R_2 I_{S1} I_{S2}} u_{i1} u_{i2}$$

$u_{i1} > 0 \quad u_{i2} > 0$

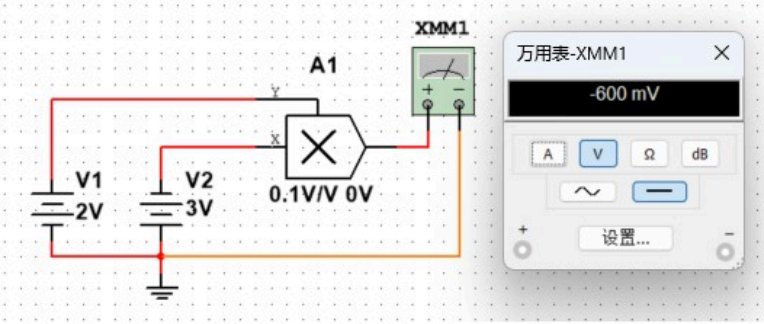
模拟乘法器

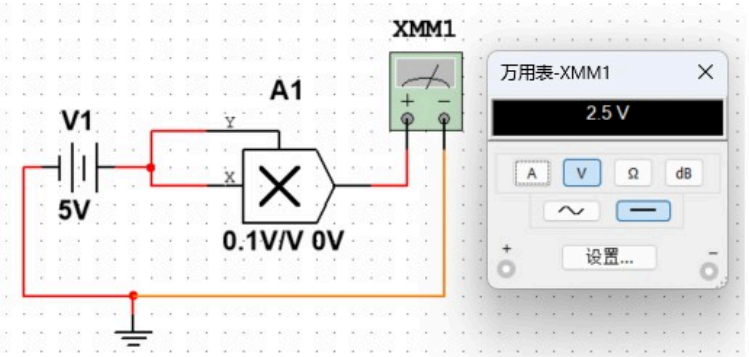


$$u_o = kXY = ku_{i1}u_{i2}$$

k增益系数

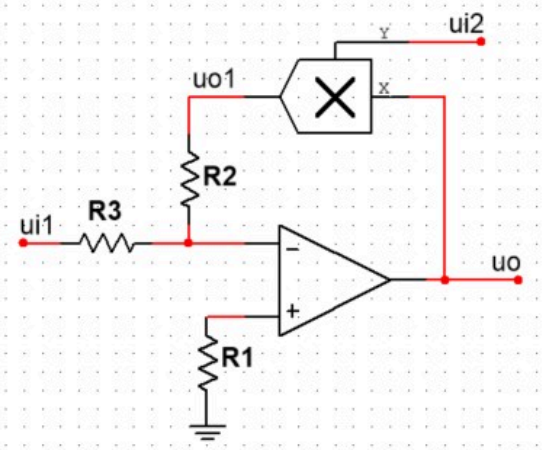
$$u_o = ku_{i1}u_{i2} = 0.1\times 2\times(-3) = -0.6V$$





$$u_o = ku_{i1}u_{i2} = 0.1\times 5\times 5 = 2.5V$$

模拟乘法器—除法运算（了解）



除法运算电路

$$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$$

R_2和R_3中的电流大小相等

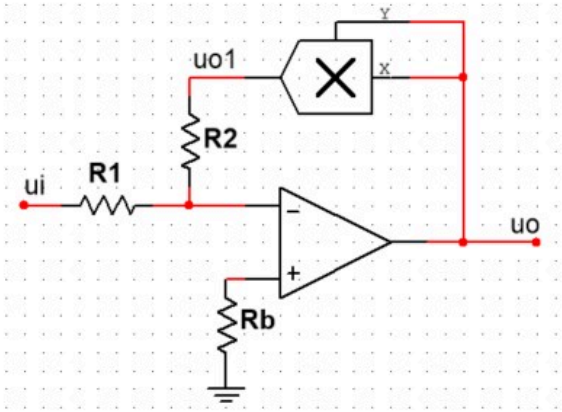
$$u_{i1} > 0, \quad u_{o1} < 0$$
$$u_{i1} < 0, \quad u_{o1} > 0$$

u_{i1}和u_{o1}反相，要求u_o和u_{o1}同符号。

当$k < 0$，$u_{i2} < 0$；当$k > 0$，$u_{i2} > 0$

$$\frac{u_{i1}}{R_3} = -\frac{u_{o1}}{R_2} = -\frac{k u_{i2} u_o}{R_2} \qquad u_o = -\frac{R_2}{k R_3}\frac{u_{i1}}{u_{i2}}$$

模拟乘法器—平方根运算（了解）



平方根运算电路

$$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$$

R_1和R_2中的电流大小相等

$$\frac{u_i}{R_1} = -\frac{u_{o1}}{R_2} = -\frac{ku_o^2}{R_2}$$

$$|u_o| = \sqrt{-\frac{R_2 u_i}{kR_1}}$$

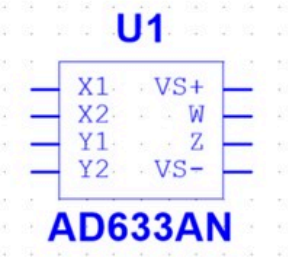
根号下的数大于零，u_i 和k 的符号相反。

u_o和u_i的极性相反。

$u_i > 0$ 和$k < 0$,　　$u_o = -\sqrt{-\frac{R_2 u_i}{kR_1}}$

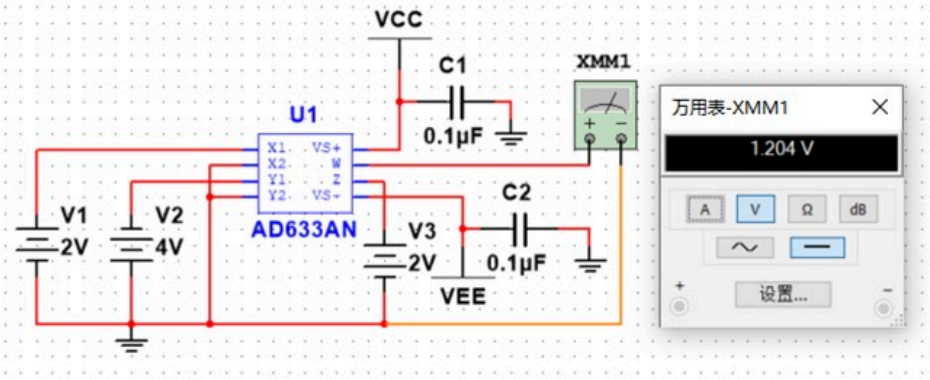
$u_i < 0$ 和$k > 0$,　　$u_o = \sqrt{-\frac{R_2 u_i}{kR_1}}$

模拟乘法器—仿真电路（了解）



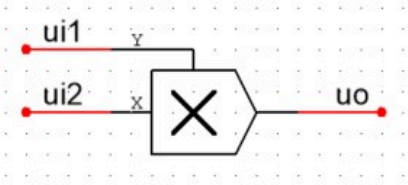
$$W=\frac{(X_1-X_2)\times(Y_1-Y_2)}{10}+Z$$

VS+接+15V，VS-接-15V



$$W=\frac{(2-0)\times(-4-0)}{10}+2=1.2\text{V}$$

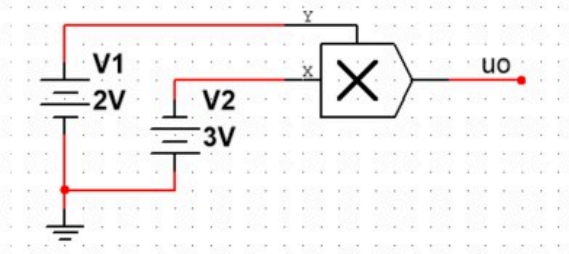
例题6



当 $k=0.1, u_{i1}=3V, u_{i2}=4V$ 时，
输出电压 $u_o=(\quad)$

$$u_o = ku_{i1}u_{i2} = 0.1\times 3\times 4 = 1.2V$$

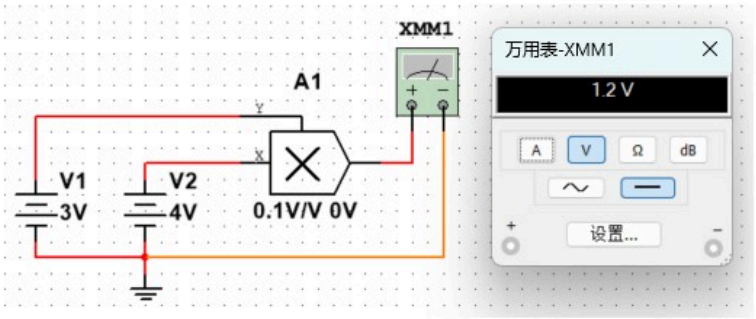
例题7



当 $k=0.1$ 时，输出电压 $u_o=(\quad)$

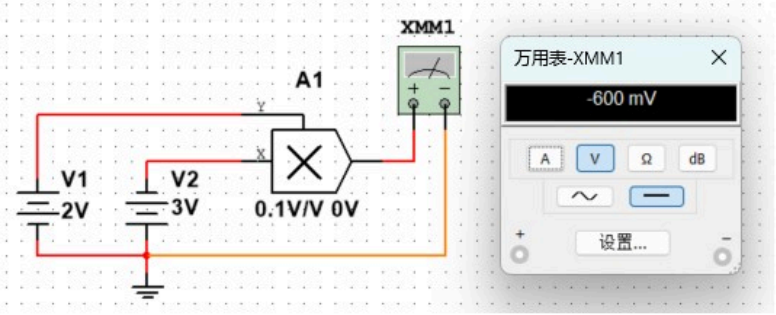
$$u_o = ku_{i1}u_{i2} = 0.1\times 2\times(-3) = -0.6V$$

例题6的仿真



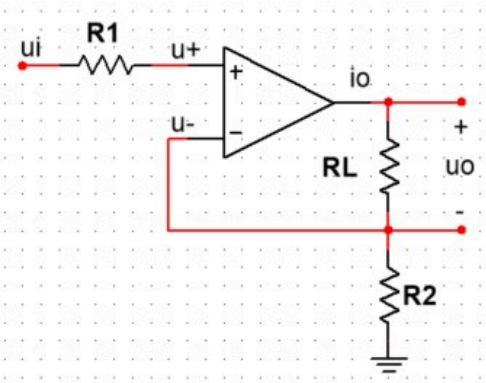
$$u_o = ku_{i1}u_{i2} = 0.1\times 3\times 4 = 1.2V$$

例题7的仿真



$$u_o = ku_{i1}u_{i2} = 0.1\times 2\times(-3) = -0.6V$$

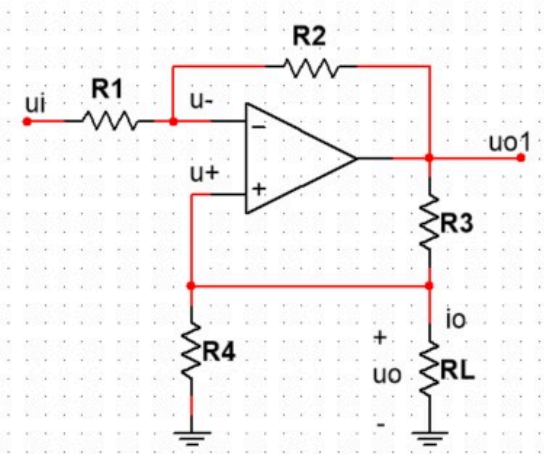
电压-电流变换器（了解）



$u_+ \approx u_-, \quad i_+ \approx i_- \approx 0$

$$i_o = \frac{u_i}{R_2}$$

负载上的输出电流与输入电压成正比，电压-电流变换器。



$u_+ \approx u_-, \quad i_+ \approx i_- \approx 0$

$$\frac{u_i - u_-}{R_1} = \frac{u_- - u_{o1}}{R_2}$$

$$u_- = \left(\frac{u_i}{R_1} + \frac{u_{o1}}{R_2}\right)\left(\frac{R_1 R_2}{R_1 + R_2}\right)$$

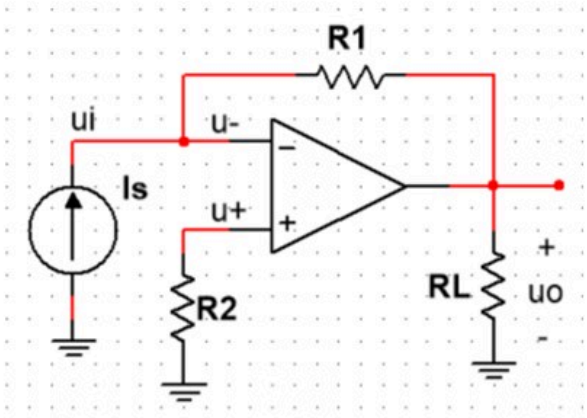
$$\frac{u_+}{R_4} + i_o = \frac{u_{o1} - u_+}{R_3}$$

$$u_+ = \left(\frac{u_{o1}}{R_3} - i_o\right)\left(\frac{R_3 R_4}{R_3 + R_4}\right)$$

$$\left(\frac{u_i}{R_1} + \frac{u_{o1}}{R_2}\right)\left(\frac{R_1 R_2}{R_1 + R_2}\right) = \left(\frac{u_{o1}}{R_3} - i_o\right)\left(\frac{R_3 R_4}{R_3 + R_4}\right)$$

$R_2/R_1 = R_3/R_4 = n \qquad i_o = -\frac{u_i}{R_4}$

电流-电压变换器

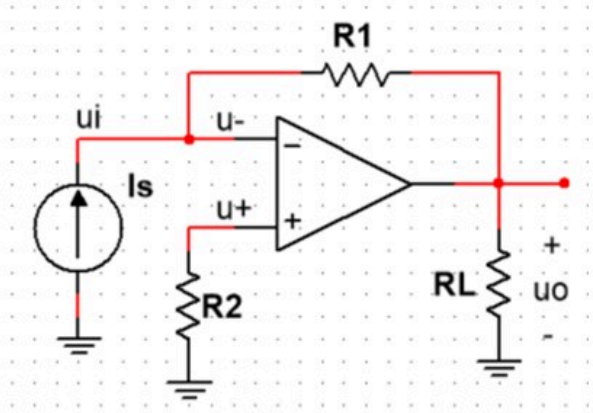


$$u_+ \approx u_- \approx 0, \quad i_+ \approx i_- \approx 0$$

$$u_0 = -I_s R_1$$

输出电压与输入电流成正比，电流-电压进行线性变换。

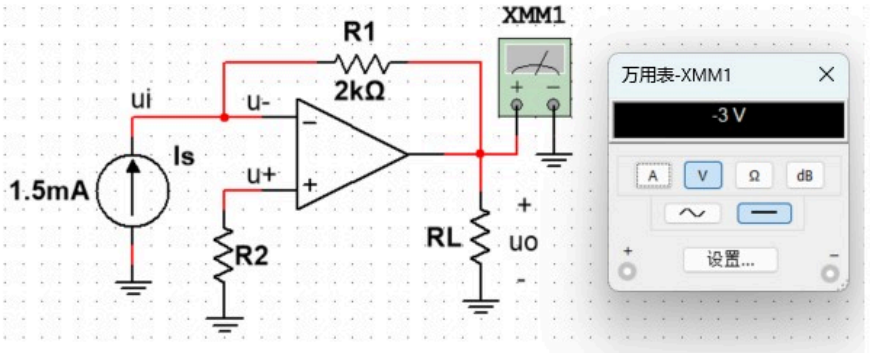
例题8

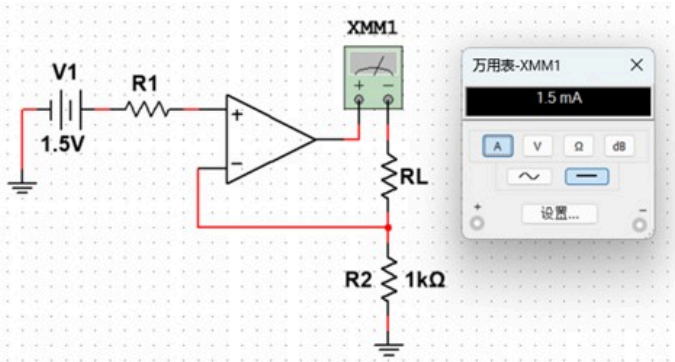


当 $R_1 = R_2 = 2k\Omega, R_L = 4k\Omega, I_s = 1.5mA$ 时，输出电压 $u_o = (\quad)$

$$u_0 = -I_s R_1 = -1.5 \times 2 = -3V$$

例题8的仿真





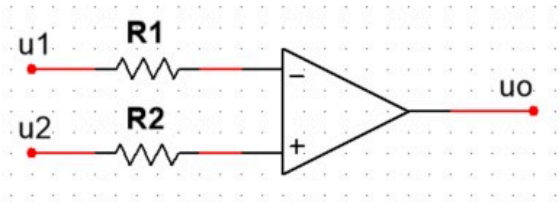
当 $R_1 = R_2 = 2k\Omega, R_L = 4k\Omega, I_s = 1.5mA$ 时，
输出电压 $u_o = (\quad)$

$$u_0 = -I_s R_1 = -1.5 \times 2 = -3V$$

$$u_+ \approx u_-, \quad i_+ \approx i_- \approx 0$$

$$i_o = \frac{u_i}{R_2} = \frac{1.5}{1k} = 1.5mA$$

电压比较器

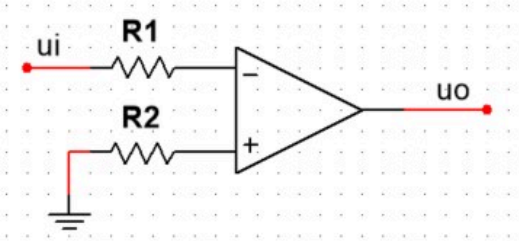


运放处于开环状态，工作于非线性工作区

$u_1 > u_2, \quad u_o = -U_{OM}$

$u_1 < u_2, \quad u_o = +U_{OM}$

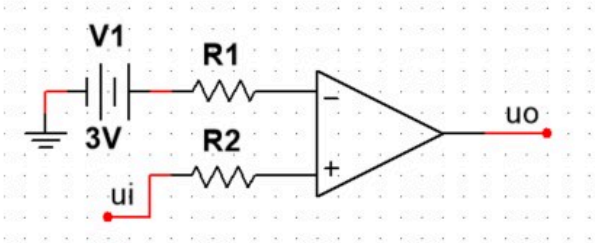
对于理想的运放，差模增益无穷大，同相输入端和反相输入端微小差别，输出电压为正的最大值或负的最大值。输出电压和输入电压不是线性关系，运放工作在非线性区域。



过零比较器

$u_i > 0, \quad u_o = -U_{OM}$

$u_i < 0, \quad u_o = +U_{OM}$

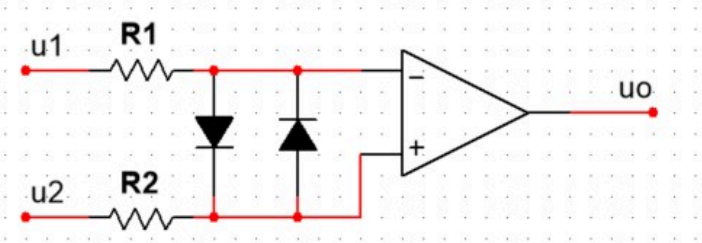


$u_i > V_1, \quad u_o = +U_{OM}$

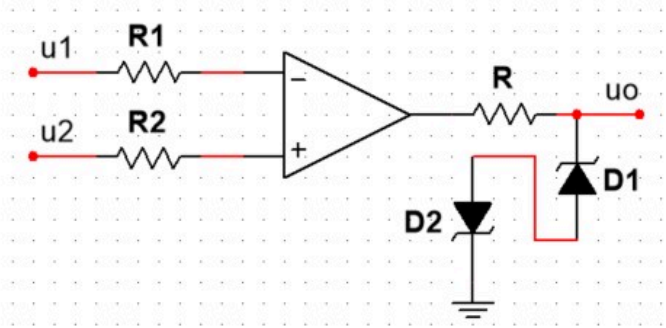
$u_i < V_1, \quad u_o = -U_{OM}$

电压比较器

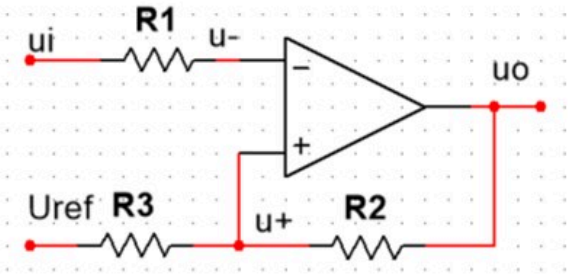
输入限幅



输出限幅

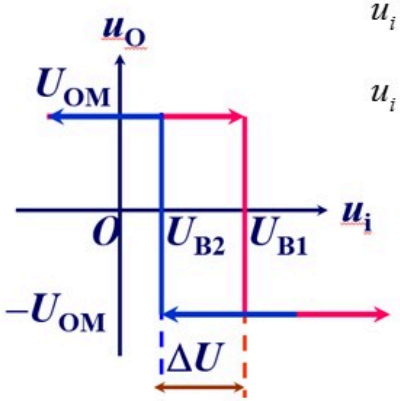


滞回特性的电压比较器



$u_i > u_+,\quad u_o = -U_{OM}$

$u_i < u_+,\quad u_o = +U_{OM}$



$u_i > U_{B1},\quad u_o = -U_{OM}$

$u_i < U_{B2},\quad u_o = U_{OM}$

$$U_{B1} = \frac{U_{ref}}{R_2 + R_3} R_2 + \frac{U_{OM}}{R_2 + R_3} R_3$$

$$U_{B2} = \frac{U_{ref}}{R_2 + R_3} R_2 - \frac{U_{OM}}{R_2 + R_3} R_3$$

叠加原理

u_i逐渐增大，与上门限U_{B1}比较

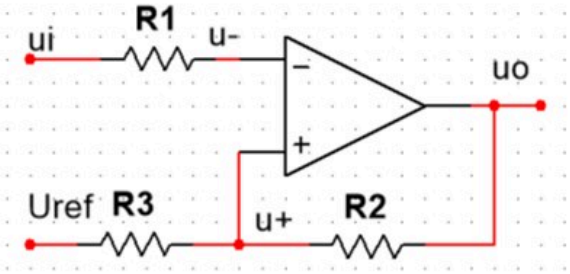
u_i逐渐减小，与下门限U_{B2}比较

u_i逐渐增大，$u_i < U_{B1},\quad u_o = U_{OM}$，当$u_i > U_{B1},\quad u_o = -U_{OM}$

u_i逐渐减小，$u_i > U_{B2},\quad u_o = -U_{OM}$，当$u_i < U_{B2},\quad u_o = U_{OM}$

回差电压$\Delta U = U_{B1} - U_{B2}$

滞回特性的电压比较器　　例题9



叠加原理

$$U_{B1}=\frac{U_{ref}}{R_2+R_3}R_2+\frac{U_{OM}}{R_2+R_3}R_3=\frac{1.5}{5+0.5}\times 5+\frac{10}{5+0.5}\times 0.5=2.28V$$

$$U_{B2}=\frac{U_{ref}}{R_2+R_3}R_2-\frac{U_{OM}}{R_2+R_3}R_3=\frac{1.5}{5+0.5}\times 5-\frac{10}{5+0.5}\times 0.5=0.45V$$

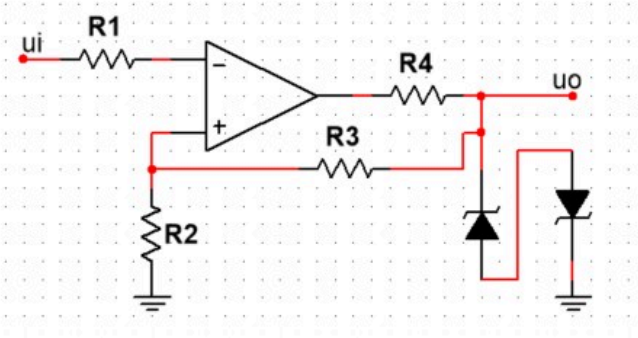
回差电压$\Delta U=U_{B1}-U_{B2}=2.28-0.45=1.83V$

当$R_2=5k\Omega, R_3=0.5k\Omega, U_{ref}=1.5V$，$\pm U_{OM}=\pm 10V$时，

上门限电压u_{B1}=(　　)，下门限电压u_{B2}=(　　)。

回差电压$\Delta U=$(　)。

滞回特性的电压比较器



电阻R_4为限流电阻
稳压二极管用于限制输出电压的幅值
输出电压u_o经电阻R_2和R_3分压后在电阻R_2的电压作为基准电压。

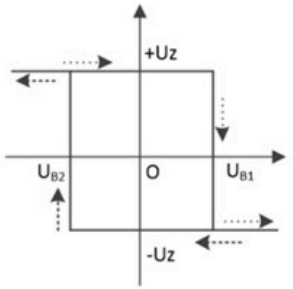
假设刚开始时输出电压大于零，输入电压由负向正变化，
输入电压大于U_{B1}时，输出电压由正变为负。
当输入电压由正向负变化，输入电压必须小于U_{B2}时，输出电压由负变为正。

输出为高电平时，基准电压为

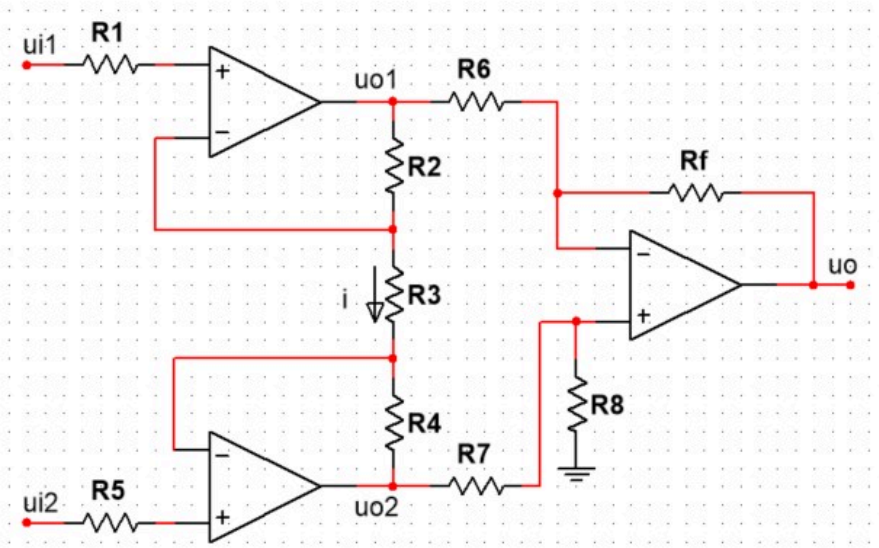
$$U_{B1}=\frac{u_O R_2}{R_2+R_3}=\frac{U_Z R_2}{R_2+R_3}$$

输出为低电平时，基准电压为

$$U_{B2}=\frac{u_O R_2}{R_2+R_3}=-\frac{U_Z R_2}{R_2+R_3}$$



仪表放大器（了解）



$$u_o = \frac{R_f}{R_6}\left(1+\frac{2R_2}{R_3}\right)(u_{i2}-u_{i1}) \qquad A_u = \frac{R_f}{R_6}\left(1+\frac{2R_2}{R_3}\right)$$

参数对称

$$R_1 = R_5,\quad R_2 = R_4,\quad R_6 = R_7,\quad R_f = R_8$$

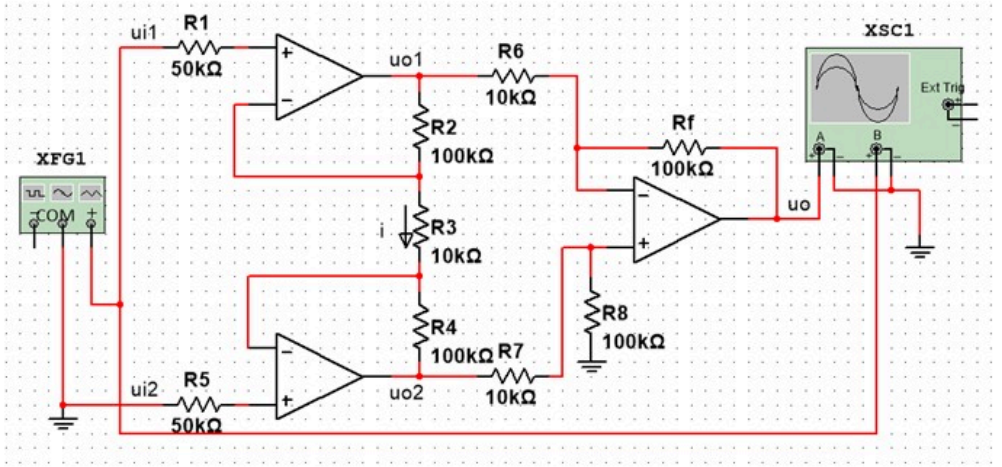
$$u_{id} = u_{i2} - u_{i1}$$

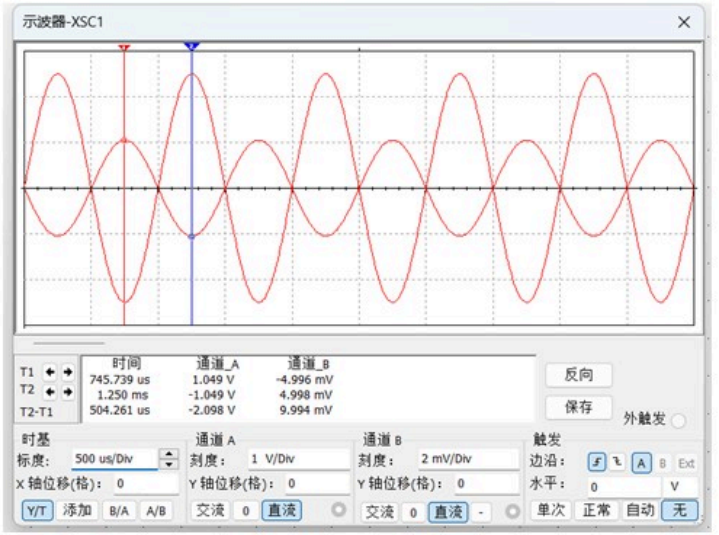
$$\frac{u_{i2}-u_{i1}}{R_3} = \frac{u_{o2}-u_{o1}}{2R_2+R_3}$$

$$u_{o2}-u_{o1} = \left(1+\frac{2R_2}{R_3}\right)(u_{i2}-u_{i1})$$

$$u_o = \frac{R_f}{R_6}(u_{o2}-u_{o1}) = \frac{R_f}{R_6}\left(1+\frac{2R_2}{R_3}\right)(u_{i2}-u_{i1})$$

➢仪表放大器的仿真（了解）





$$u_o = \frac{R_f}{R_6}(u_{o2} - u_{o1}) = \frac{R_f}{R_6}\left(1 + \frac{2R_2}{R_3}\right)(u_{i2} - u_{i1}) \qquad u_{i2} = 0$$

$$A_u = \frac{u_o}{u_{i2} - u_{i1}} = \frac{R_f}{R_6}\left(1 + \frac{2R_2}{R_3}\right) = \frac{100}{10} \times \left(1 + 2 \times \frac{100}{10}\right) = 210$$

$$A_u = \frac{u_o}{u_{i2} - u_{i1}} = \frac{1.049(\mathrm{V})}{4.996(\mathrm{mV})} \approx 210$$

总结

- 共有例题9个。