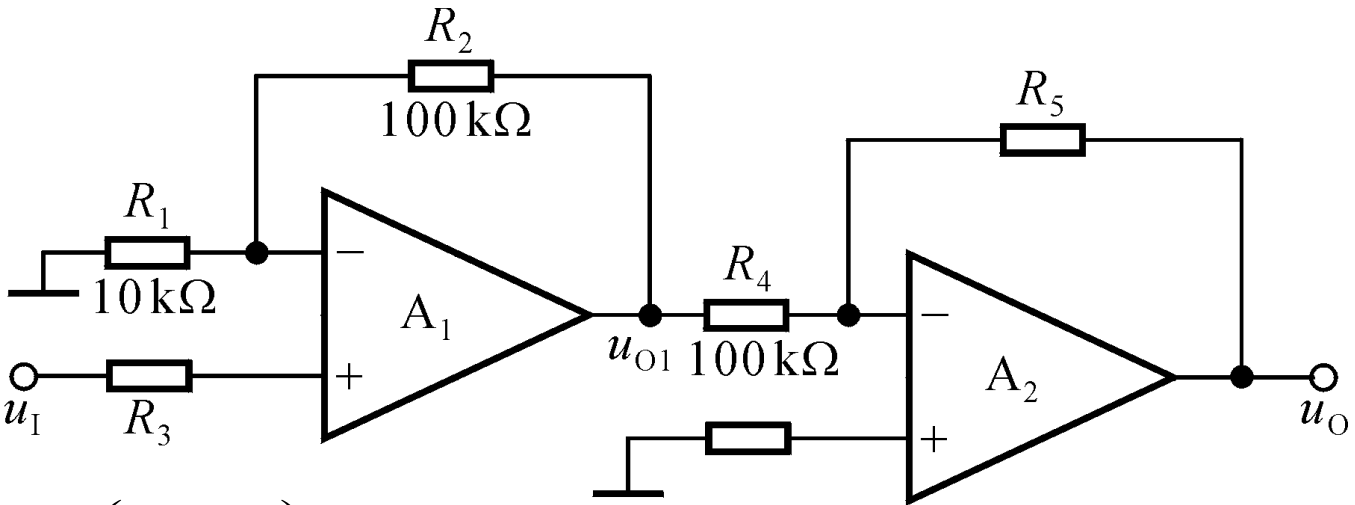
6.1.2 比例运算电路

例：电路如图所示，u_o=-55u_I，（1）求R_5的值；（2）若u_I与地接反，求输出电压与输入电压的的关系



（1）

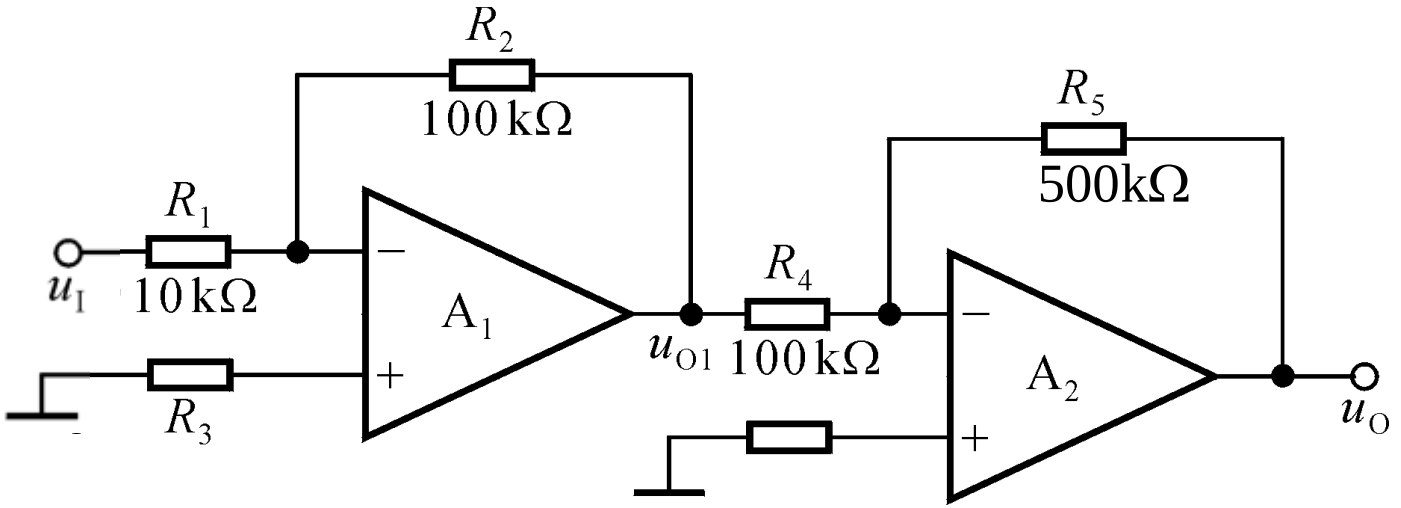
$$u_{O1}=\left(1+\frac{R_2}{R_1}\right)u_I=11u_I$$

$$u_O=-\frac{R_5}{R_4}u_{o1}=-\frac{R_5}{100\text{k}\Omega}\times 11u_I=-55u_I$$

$$R_5=500\text{k}\Omega$$

6.1.2 比例运算电路

例：电路如图所示，u_o=-55u_I，（1）求R_5的值；（2）若u_I与地接反，求输出电压与输入电压的的关系



（2）

$$u_{O1} = -\frac{R_2}{R_1}u_I = -10u_I$$

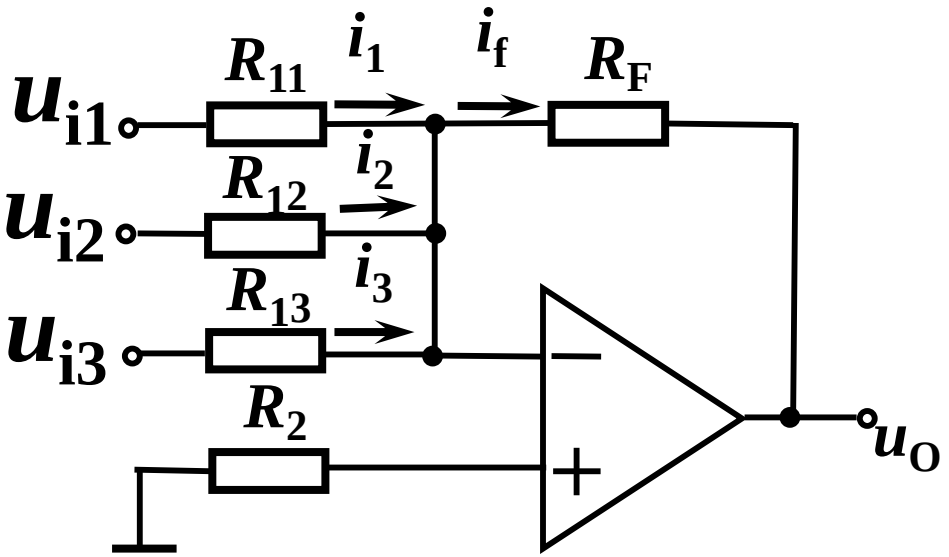
$$u_O = -\frac{R_5}{R_4}u_{o1} = -5\times(-10)u_I = 50u_I$$

6.1.3 加减法运算电路

一、反相加法电路

虚断 $i_P = 0 \quad i_N = 0$

虚短 $u_P = u_N = 0$



$R_2 = R_{11} // R_{12} // R_{13} // R_F$

KCL

$$u_o = -\left(\frac{R_F}{R_{11}}u_{i1} + \frac{R_F}{R_{12}}u_{i2} + \frac{R_F}{R_{13}}u_{i3}\right)$$

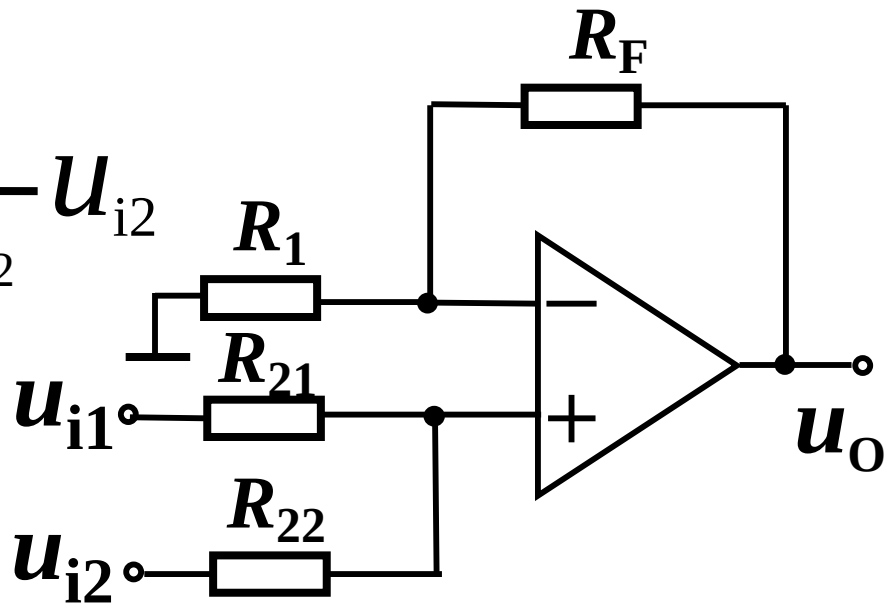
6.1.3 加减法运算电路

二、同相加法电路

虚断

$$u_{\mathrm{P}}=\frac{R_{22}}{R_{21}+R_{22}}u_{\mathrm{i1}}+\frac{R_{21}}{R_{21}+R_{22}}u_{\mathrm{i2}}$$

$$u_{\mathrm{N}}=\frac{R_1}{R_1+R_{\mathrm{F}}}u_{\mathrm{O}}$$



$R_{21}//R_{22}=R_1//R_{\mathrm{F}}$

虚短 $u_{\mathrm{P}}=u_{\mathrm{N}}$

$$u_{\mathrm{o}}=\left(1+\frac{R_{\mathrm{F}}}{R_1}\right)\left(\frac{R_{22}}{R_{21}+R_{22}}u_{\mathrm{i1}}+\frac{R_{21}}{R_{21}+R_{22}}u_{\mathrm{i2}}\right)$$

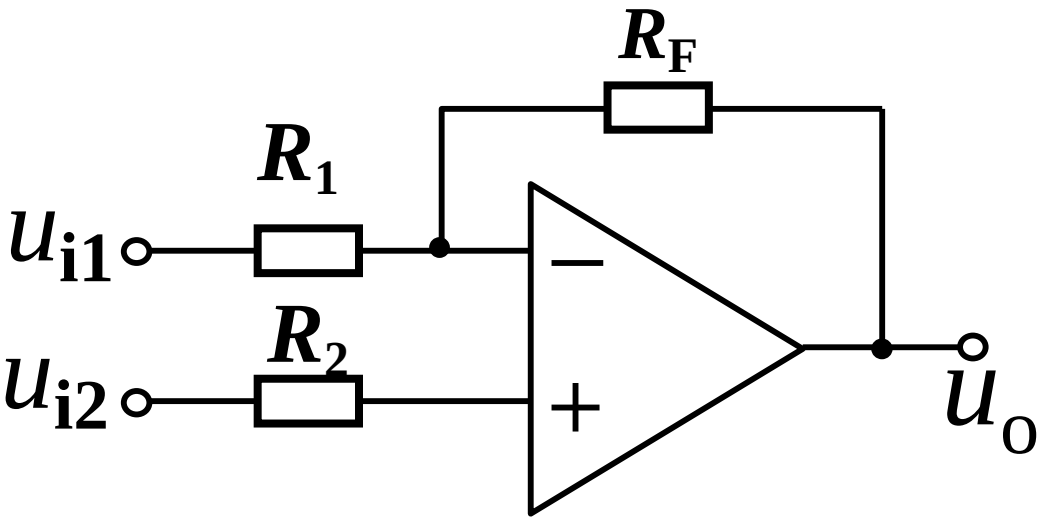
6.1.3 加减法运算电路

三、减法运算电路

叠加定理

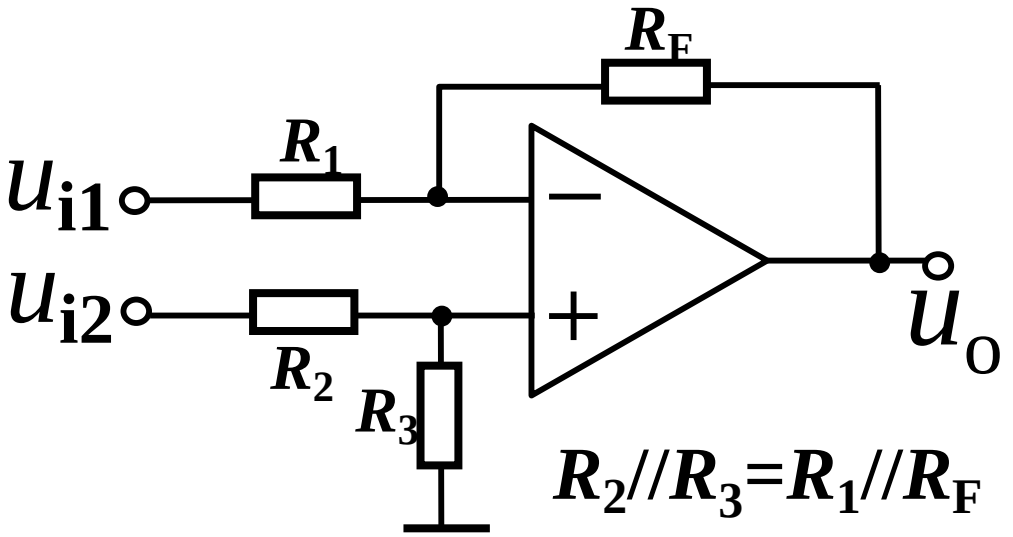
$$u_o' = -\frac{R_F}{R_1}u_{i1}$$

$$u_o'' = (1+\frac{R_F}{R_1})\ u_{i2}$$



$$u_O = \left(1+\frac{R_F}{R_1}\right)u_{i2} - \frac{R_F}{R_1}u_{i1}$$

6.1.3 加减法运算电路



$$u_o' = -\frac{R_F}{R_1}u_{i1}$$

$$u_o'' = (1+\frac{R_F}{R_1})\ u_P = (1+\frac{R_F}{R_1})\frac{R_3}{R_2+R_3}u_{i2}$$

$$u_o = (1+\frac{R_F}{R_1})\frac{R_3}{R_2+R_3}u_{i2} - \frac{R_F}{R_1}u_{i1}$$

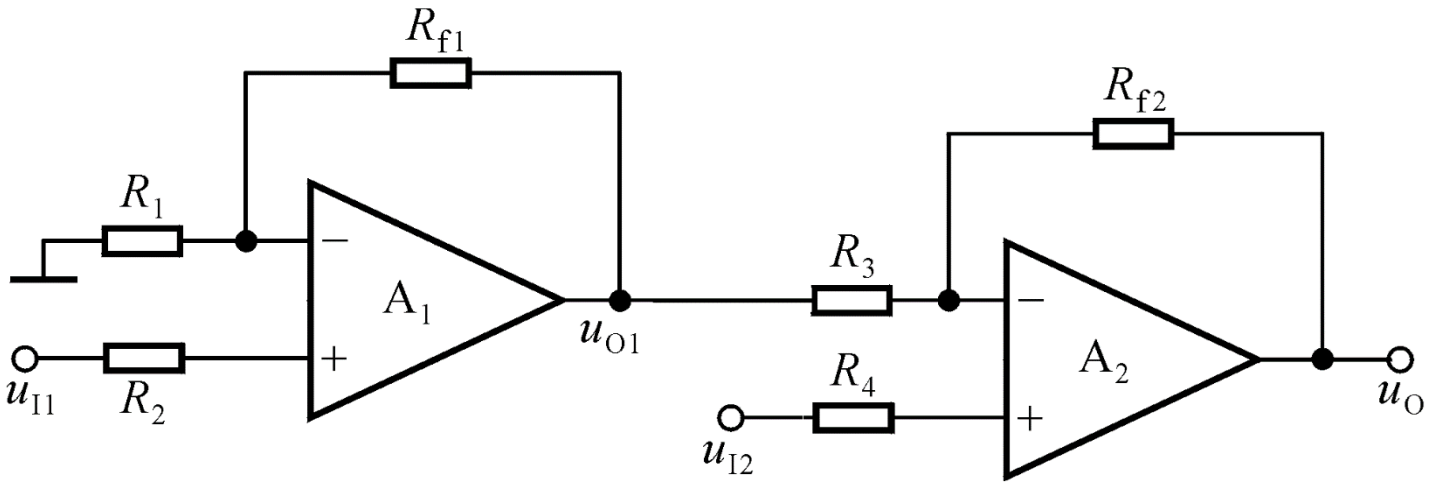
当$R_1 = R_2 = R$, $R_3 = R_F$时，

$$u_o = \frac{R_F}{R}(u_{i2} - u_{i1})$$

加减运算电路

例

- 电路形式：



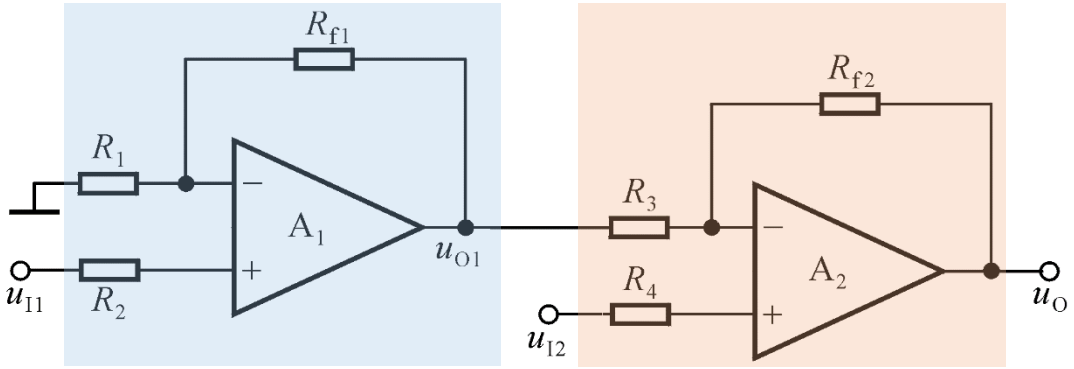
第一级同相比例放大电路，第二级为同相比例与反相比例相结合的放大电路。

加减运算电路

- 计算放大倍数

第一级：同相比例

$$u_{O1}=\left(1+\frac{R_{f1}}{R_1}\right)u_{I1}$$



第二级：同相-反相比例

$$u_O=-\frac{R_{f2}}{R_3}u_{O1}+\left(1+\frac{R_{f2}}{R_3}\right)u_{I2}$$

$$\frac{R_{f2}}{R_3}\cdot\frac{R_{f1}}{R_1}=1$$

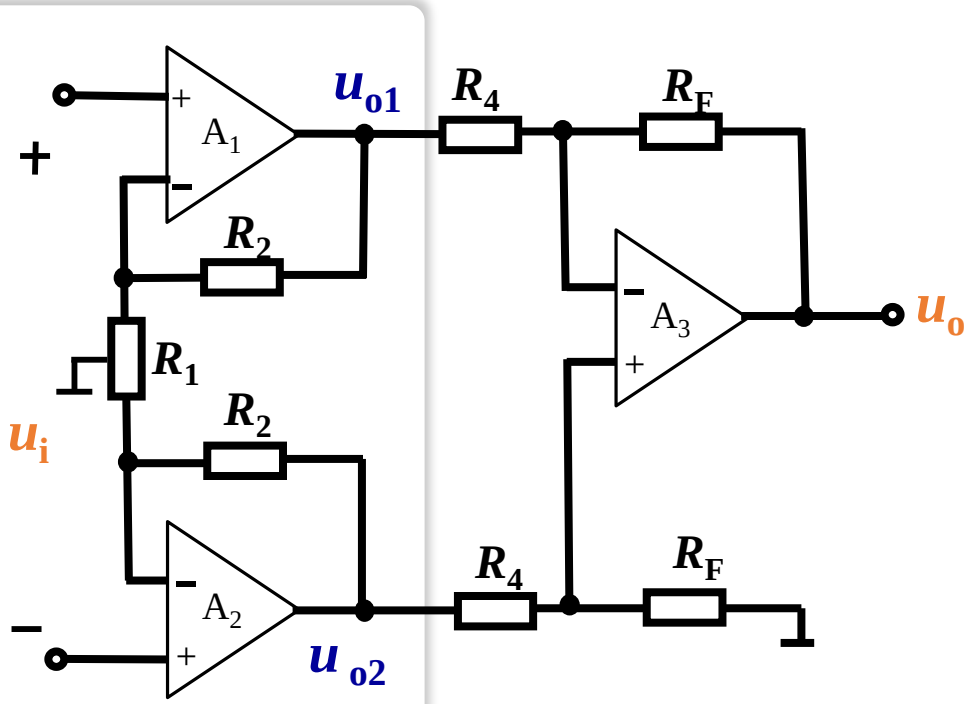
整理得到

$$u_O=-\frac{R_{f2}}{R_3}\left(1+\frac{R_{f1}}{R_1}\right)u_{I1}+\left(1+\frac{R_{f2}}{R_3}\right)u_{I2}$$

$$u_O=\left(1+\frac{R_{f2}}{R_3}\right)(u_{I2}-u_{I1})$$

6.1.3 加减法运算电路

例:求电压放大倍数



$$A_u = A_{u1}A_{u2}$$

$$A_{u1} = 1 + \frac{R_2}{\frac{1}{2}R_1} = 1 + \frac{2R_2}{R_1}$$

$$u_{o1} - u_{o2} = (1 + \frac{2R_2}{R_1})u_i$$

$$u_o = -\frac{R_f}{R_4}(u_{o1} - u_{o2})$$

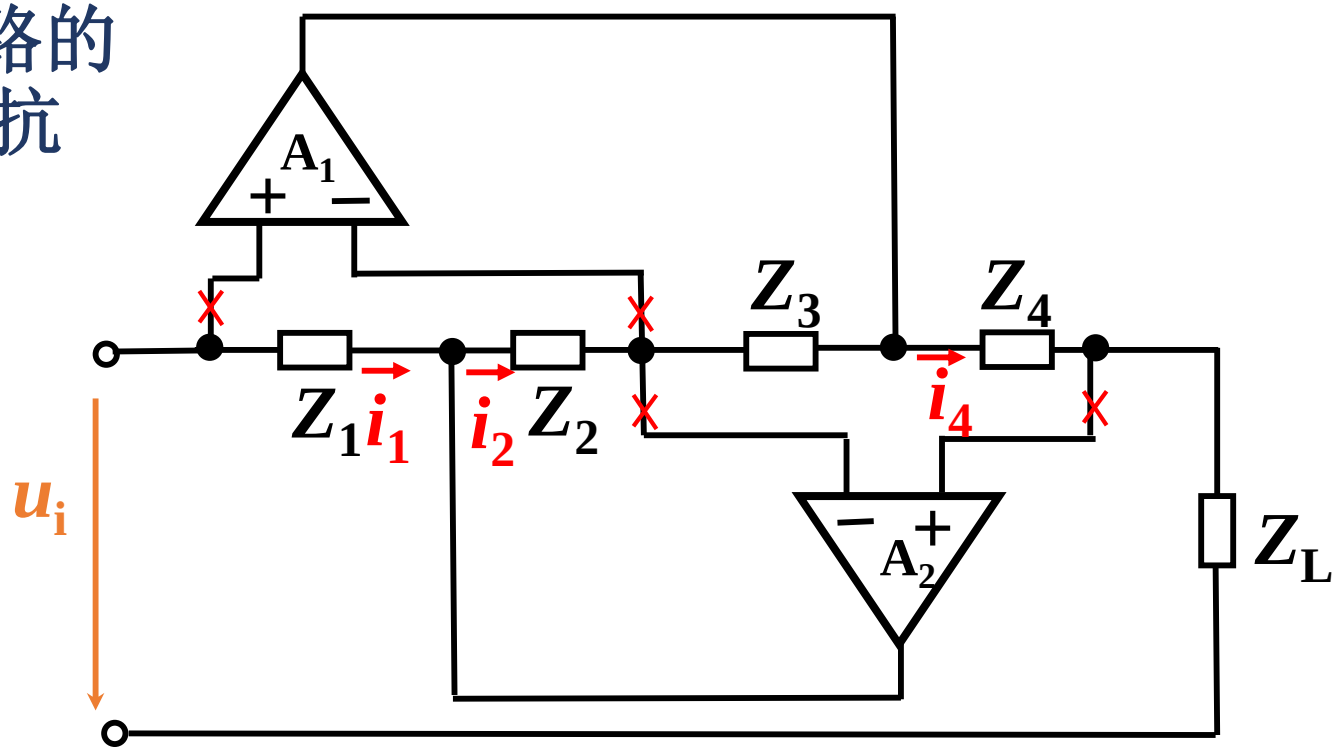
测量放大电路

$$u_o = -\frac{R_F}{R_4}(u_{o1} - u_{o2}) = -\frac{R_F}{R_4}(1 + \frac{2R_2}{R_1})u_i$$

放大倍数高　输入电阻高　共模抑制能力强

6.1.3 加减法运算电路

例:求该电路的输入等效阻抗



$$\dot{I}_1 Z_1 = -\dot{I}_2 Z_2$$

$$\dot{I}_2 Z_3 = -\dot{I}_4 Z_4$$

$$\dot{I}_4 = \frac{U_\mathrm{i}}{Z_\mathrm{L}}$$

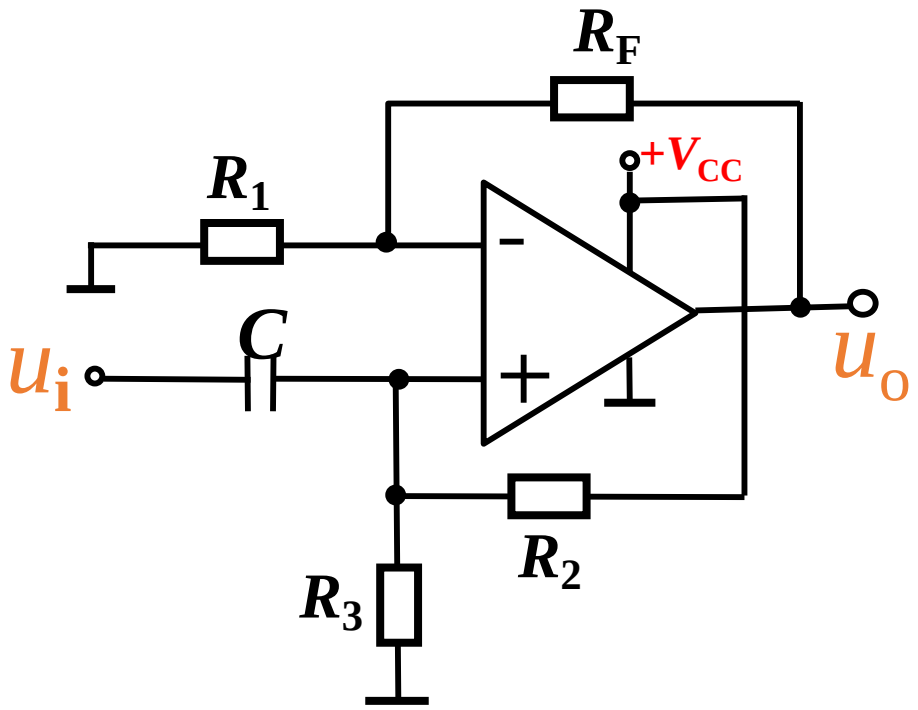
$$\Longrightarrow \quad Z_\mathrm{i} = \frac{\dot{U}_\mathrm{i}}{\dot{I}_1} = \frac{Z_1 Z_3}{Z_2 Z_4} Z_\mathrm{L}$$

6.1.3 加减法运算电路

例:电路如图所示，电容对交流信号可视为短路

(1)求静态输出电压

（2）求电压放大倍数



（1）静态

$$u_P = \frac{R_3}{R_2 + R_3} V_{CC}$$

$$U_o = (1 + \frac{R_F}{R_1}) \frac{R_3}{R_2 + R_3} V_{CC}$$

（2）

$$u_P = u_i$$

$$A_{uf} = 1 + \frac{R_F}{R_1}$$

作业

6.6

6.9

6.10

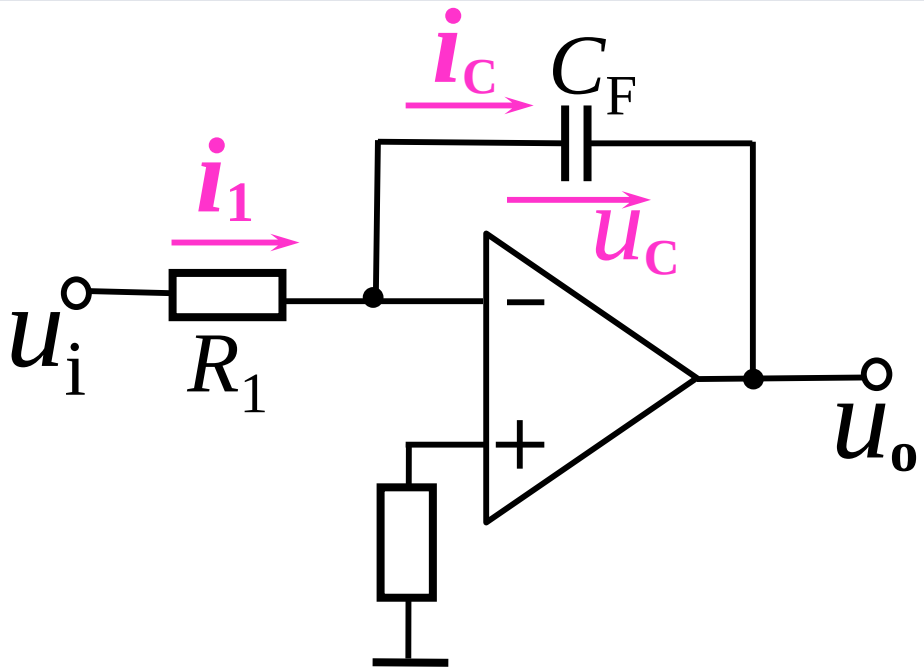
6.1.4 积分和微分运算电路

一、积分运算电路

$$i_C = C_F \frac{du_C}{dt}$$

由虚断和虚地

$$i_C = \quad i_1 = \frac{u_i}{R_1}$$



$$u_o = -u_C$$

$$\frac{u_i}{R_1} = -C_F \frac{du_o}{dt}$$

$$u_o = -\frac{1}{R_1 C_F}\int u_i dt$$

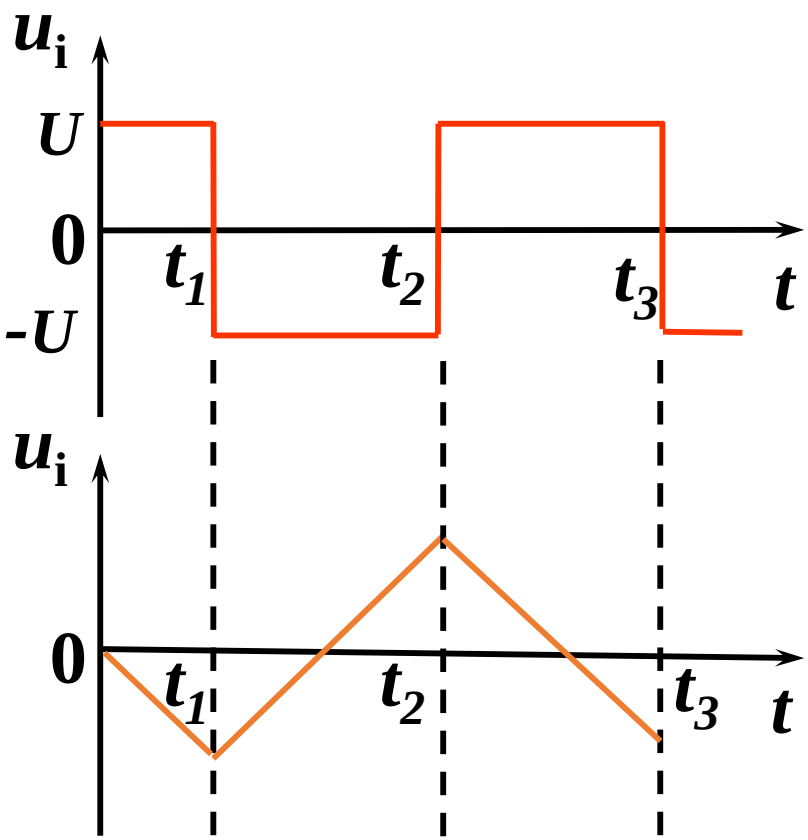
若开始积分前，电容已储能，则

$$u_o = -\frac{1}{R_1 C_F}\int_{t_o}^{t} u_i dt + u(t_o)$$

6.1.4 积分和微分运算电路

$$u_o = -\frac{1}{R_1 C_F}\int_{t_o}^{t} u_i dt + u(t_o)$$

电容初始储能为0



$$u_o = -\frac{U}{R_1 C_F} t \qquad 0 \le t \le t_1$$

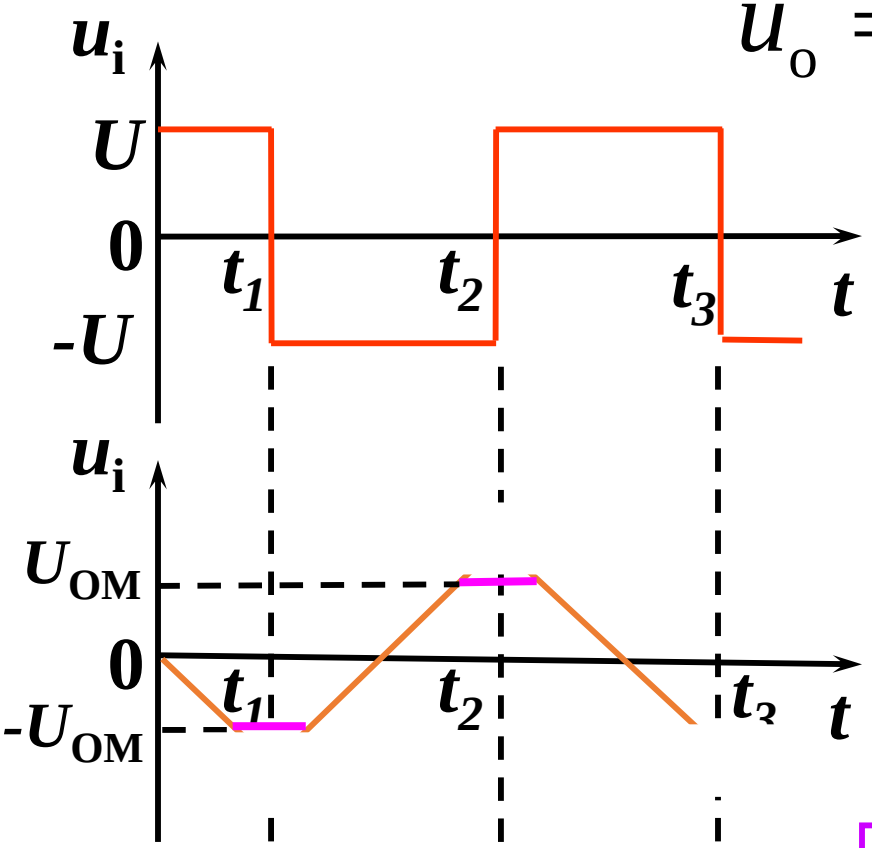
$$u_o = \frac{U}{R_1 C_F}(t - t_1) + t(t_1)$$

$$t_1 \le t \le t_2$$

$$u_o = -\frac{U}{R_1 C_F}(t - t_2) + t(t_2)$$

$$t_2 \le t \le t_3$$

6.1.4 积分和微分运算电路



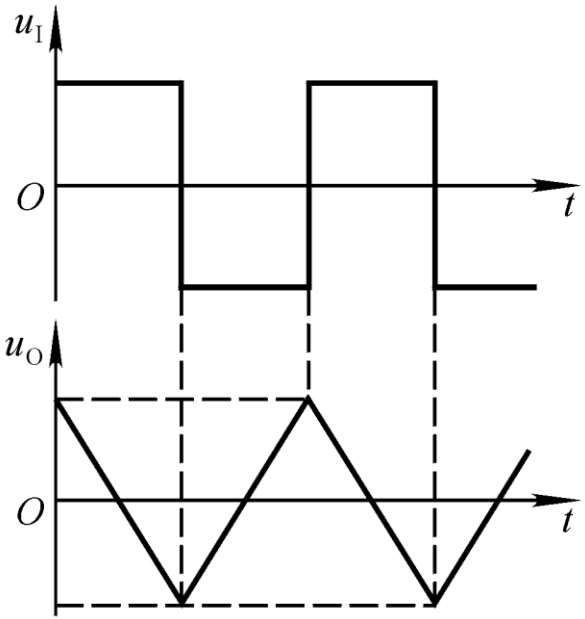
$$u_o = -\frac{1}{R_1 C_F}\int_{t_o}^{t} u_i dt + u(t_o)$$

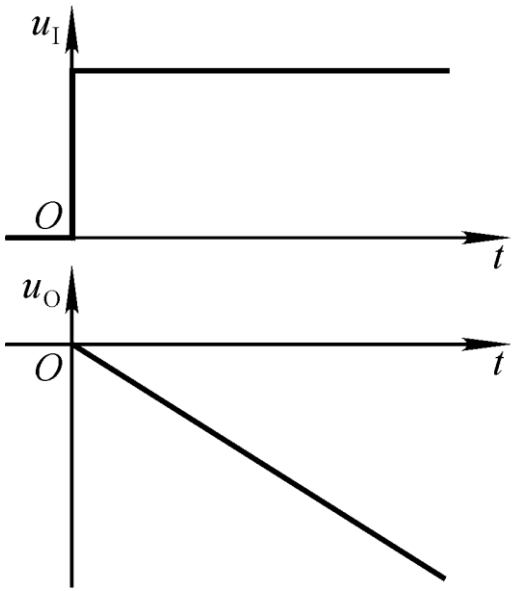
注意：$u_o \le U_{om}$

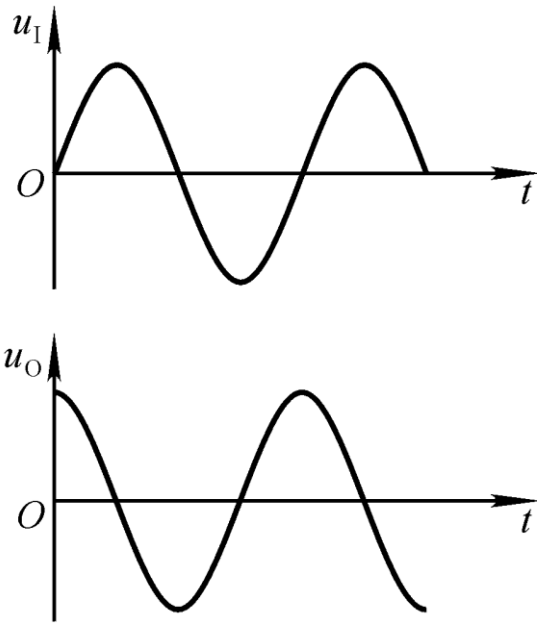
积分和微分运算电路

积分电路的典型应用：

波形变换（输入方波）、线性积分（输入阶跃）和相位移位（输入正弦）。



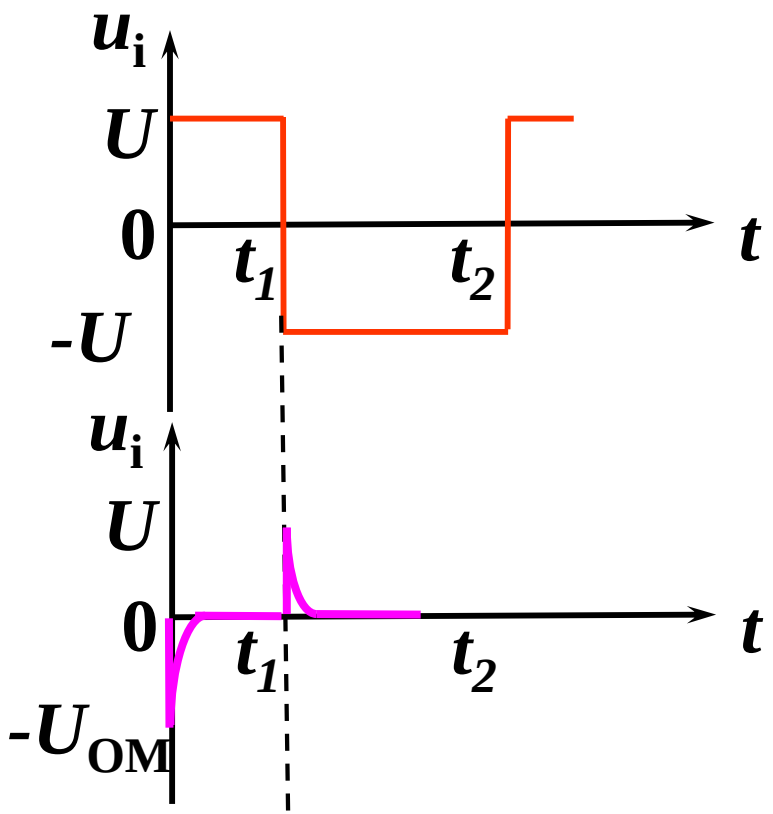


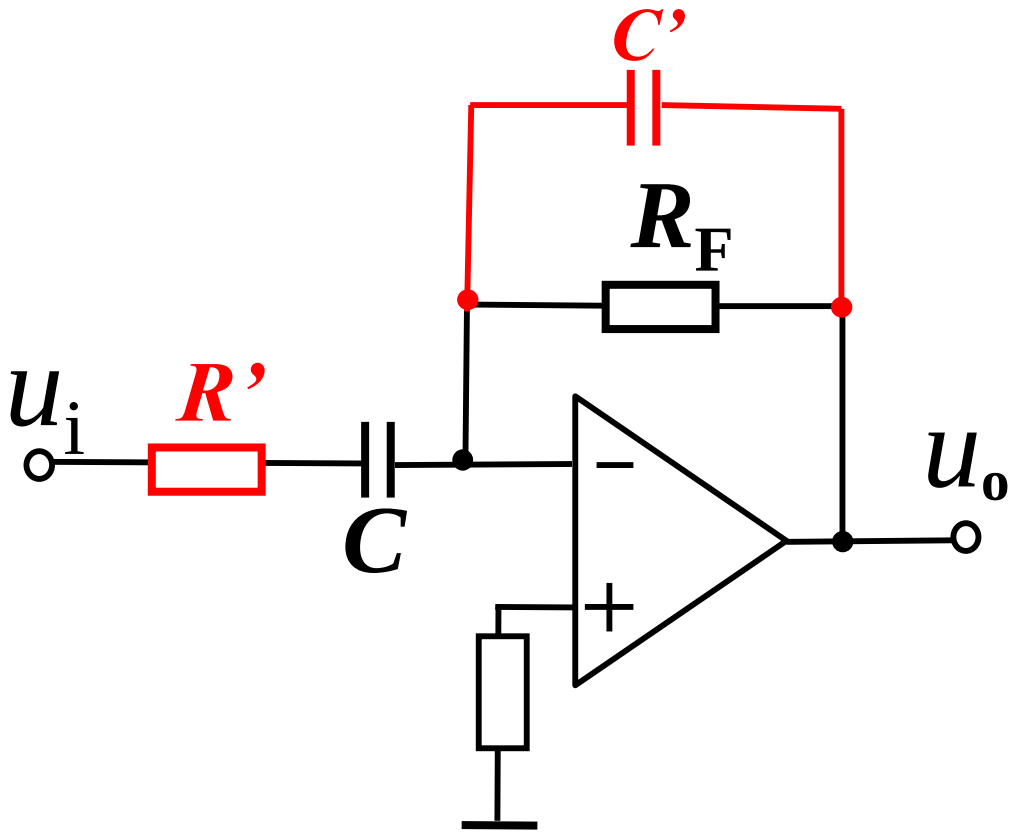


6.1.4 积分和微分运算电路

二. 微分运算电路

$$u_o = -R_F C \frac{du_i}{dt}$$





6.1.4 积分和微分运算电路

求输出电压和输入电压的关系

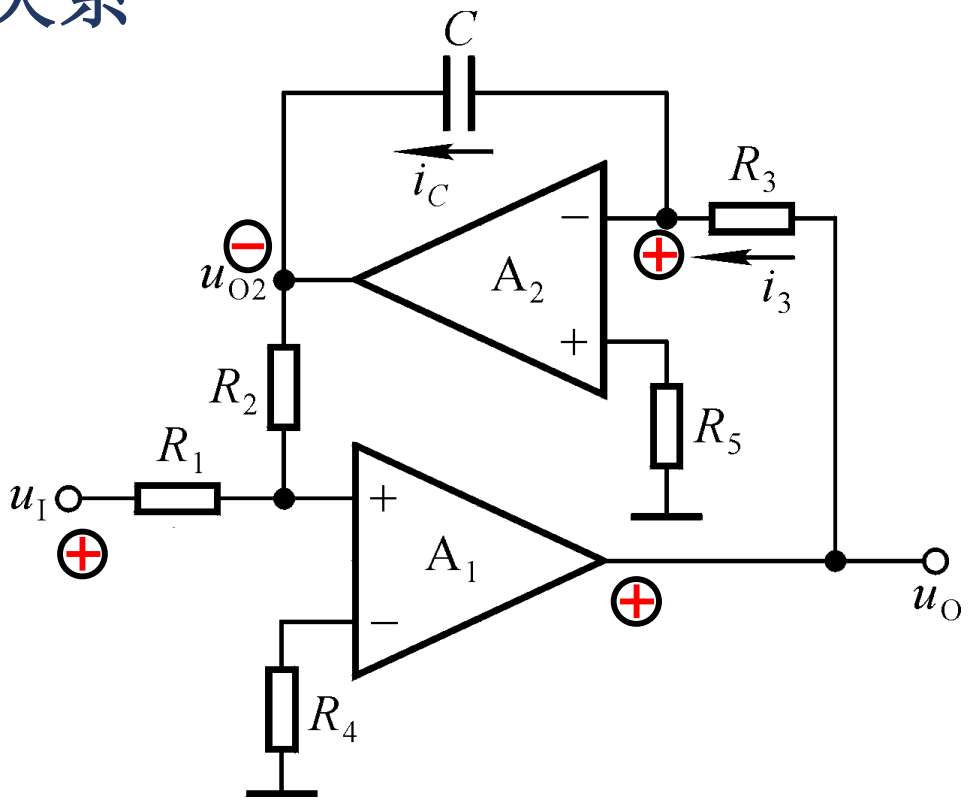
$$\frac{u_{\mathrm{I}}}{R_1}=-\frac{u_{\mathrm{O2}}}{R_2}$$

$$u_{\mathrm{O2}}=-\frac{R_1}{R_2}\cdot u_{\mathrm{I}}$$

$$u_{\mathrm{O2}}=-\frac{1}{R_3C}\int u_{\mathrm{o}}\mathrm{d}t$$

$$-\frac{R_2}{R_1}u_{\mathrm{I}}=-\frac{1}{R_3C}\int u_{\mathrm{o}}\mathrm{d}t$$

$$u_{\mathrm{O}}=\frac{R_2R_3C}{R_1}\cdot\frac{\mathrm{d}u_{\mathrm{I}}}{\mathrm{d}t}$$



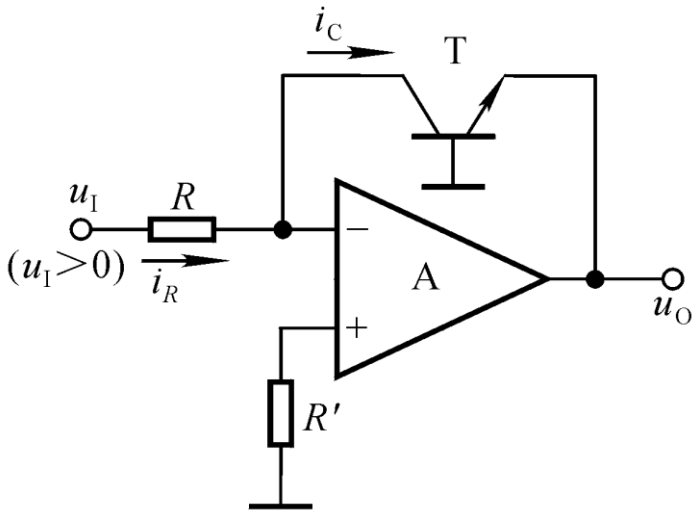
逆函数型微分电路

集成运放的负反馈通路为某种运算电路，则整个电路实现其逆运算。

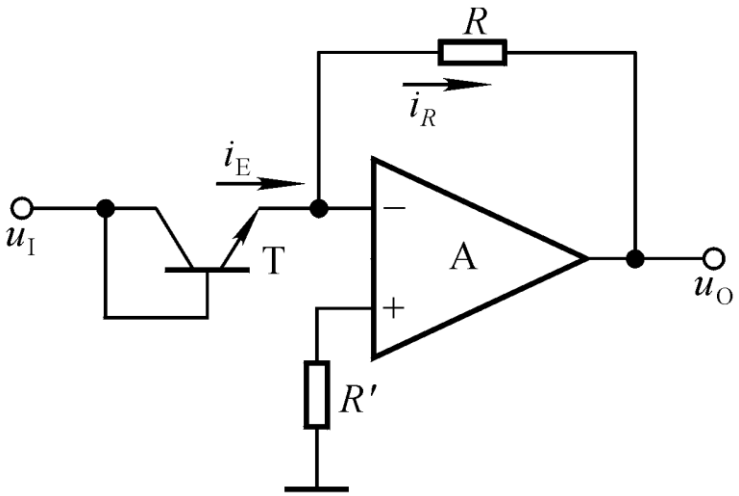
6.1.6 乘法运算和除法运算电路

北京航空航天大學 BEIHANG UNIVERSITY

对数运算电路

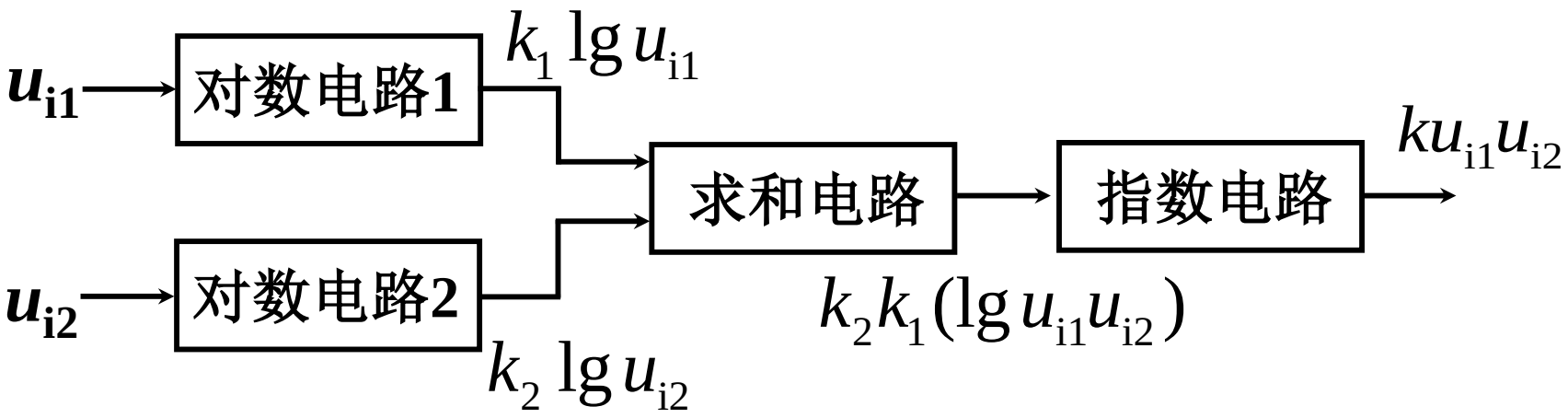


指数运算电路



6.1.6 乘法运算和除法运算电路

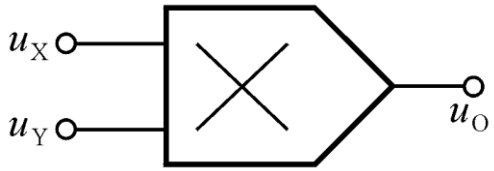
一. 乘法运算电路



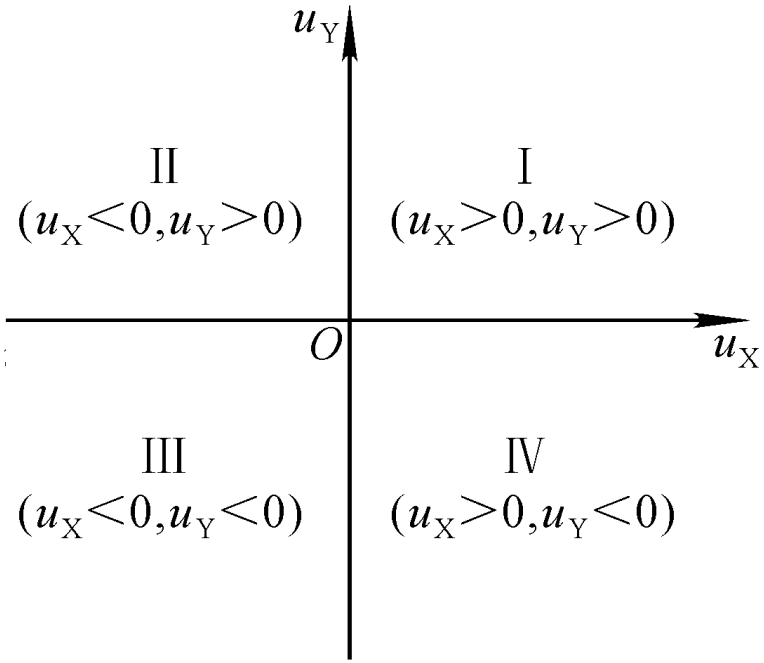
6.1.6 乘法运算和除法运算电路

模拟乘法器

有两个输入端、一个输出端，输入的两个模拟信号是互不相关的物理量，输出电压是它们的乘积。



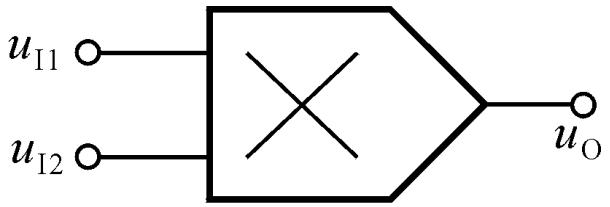
$$u_O = ku_X u_Y$$



6.1.6 乘法运算和除法运算电路

模拟乘法器的主要应用

- 乘法运算

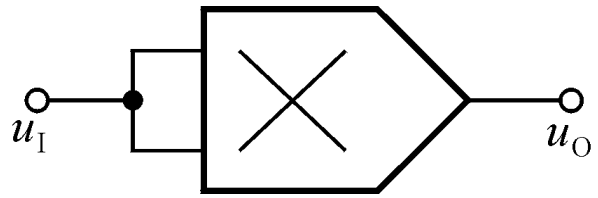


$$u_O = k u_{I1} u_{I2}$$

实际模拟乘法器的 k 常为 $+0.1V^{-1}$ 或 $-0.1V^{-1}$。

若 $k = +0.1V^{-1}$，$u_{I1} = u_{I2} = 10V$，则 $u_O = 10V$。

- 乘方运算



$$u_O = k u_I^2$$

$$u_I = \sqrt{2} U_i \sin \omega t$$

$$u_O = 2k U_i^2 \sin^2 \omega t$$

$$= 2k U_i^2 (1 - \cos 2\omega t)$$

实现了二倍频