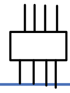
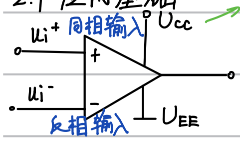


第二章 集成运算放大器的基本应用电路

2.1 应用基础



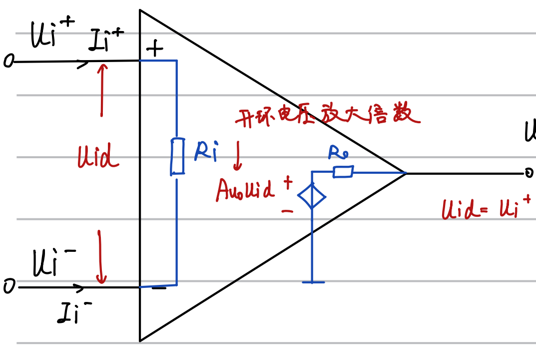
单电源

5个管脚

单输出

画电路时通常省略电源

△模型



$u_{id}=u_i^+-u_i^-$（差模电压）

净输入

△理想条件

① 输入电阻 $R_i\to\infty$

② 输出电阻 $R_o\to 0$

③ 放大倍数 $A_{u_0}\to\infty$

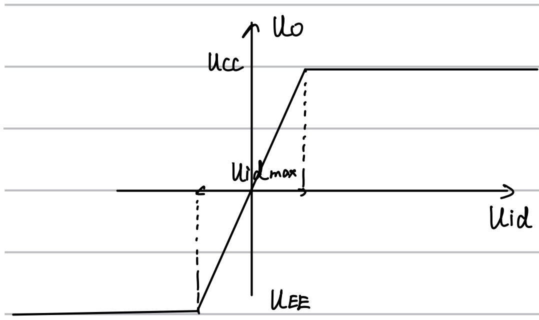
④ $I_i^+=I_i^-\to 0$

⑤ A_{u_0} 与频率无关

虚断（①、④）

关系

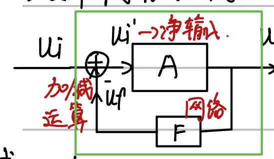
△传输特性



理想情况下，$u_{idmax}\to 0$ $\quad u_i^+\approx u_i^-$ 虚短

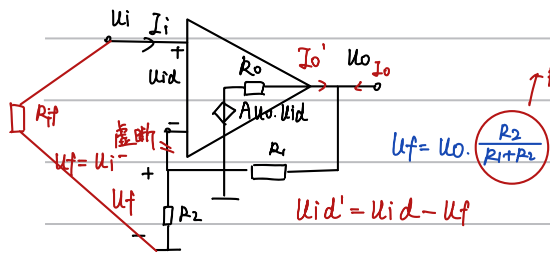
2.2 引入电阻负反馈

2.2.1 同相比例放大器（引入到同相输入端）



A_{uf}：闭环放大倍数

减：$u_i'=u_i-u_f=u_i-Fu_o$ 无源网络 $F<1$ 有源网络 $F>1$



$u_f=u_o\cdot\dfrac{R_2}{R_1+R_2}$

$u_{id}'=u_{id}-u_f$

$\because$ 虚短 $\therefore u_i^+=u_i^-$（u_i，u_f）

$\therefore u_i^-=u_o\cdot\dfrac{R_2}{R_1+R_2}=u_i^+=u_i$

$A_{uf}=\dfrac{u_o}{u_i}=\dfrac{R_1+R_2}{R_2}=1+\dfrac{R_1}{R_2}$

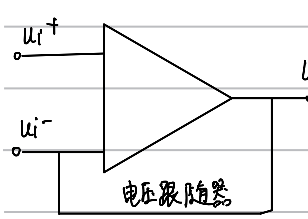
输入电阻 $R_{if}=\dfrac{u_i}{I_i}$

$I_i=\dfrac{u_{id}}{R_i}=\dfrac{u_i^+-u_i^-}{R_i}=0$

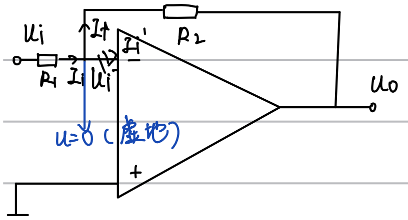
$R_{if}\to\infty$

输出电阻 $R_{of}=\dfrac{u_o}{I_o}$

$u_i\to 0$，$R_o\to 0$，$I_o=I_o'\to\infty$，$R_{of}=0$



2.2.2 反相比例放大器



① 电压

$u_i^+ = u_i^-$ (虚短)

(叠加定理) $u_i^- = \frac{R_2}{R_1+R_2} u_i + \frac{R_1}{R_1+R_2} u_o = 0$

∴ $R_2 u_i + R_1 u_o = 0$

$A_{uf} = \frac{u_o}{u_i} = -\frac{R_2}{R_1}$

② 电流

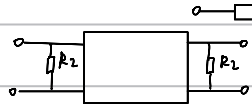
虚断 $I_i' = 0 \Rightarrow I_i - I_f = 0,\ I_i = I_f$

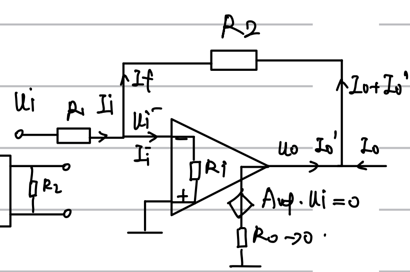
$I_i = \frac{u_i - u_i^-}{R_1}$, $u_i^- = u_i^+$ (虚短) $= 0$, $I_i = \frac{u_i}{R_1}$

$I_f = \frac{u_i^- - u_o}{R_2} = \frac{-u_o}{R_2}$

$\frac{u_i}{R_1} = -\frac{u_o}{R_2} \Rightarrow \frac{u_o}{u_i} = -\frac{R_L}{R_1}$

③ $R_{if} = \frac{u_i}{I_i}$





$R_{if} = R_1 + R_2 // R_i$ （$R_i \to \infty$）

$R_i' = \frac{u_{id}}{I_f}$

$I_f = \frac{u_{id} - u_o}{R_2} = \frac{1 - \frac{u_o}{u_{id}}}{R_2} \cdot u_{id} = \frac{u_{id}}{\frac{R_2}{1-A_{uo}}} = \frac{u_{id}}{\frac{R_2}{1+|A_{uo}|}}$

$R_i' = \frac{R_2}{1+|A_{uo}|} \to 0$

$R_{if} = R_1$

④ $R_{of} = \frac{u_o}{I_o}\Big|_{u_i=0} = 0$

$u_o = A_{uf} \cdot u_i = 0$

$u_o = -R_o \cdot I_o' = 0$, $R_o \to 0 \Rightarrow I_o' \to \infty$

$u_o - u_i^- = 0 = R_2(I_o + I_o') \Rightarrow I_o + I_o' = 0$

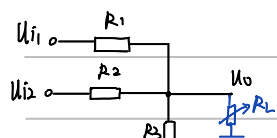
∴ $I_o \to \infty$, $u_o \to 0 \Rightarrow R_{of} \to 0$

负反馈：反馈都在反相端

△等效解题，无电流流过的电阻，接在地与地之间，可忽略

2.3 相加器

2.3.1 同相相加器



无源加法器

$u_o = \underbrace{\frac{R_2//R_3(//R_L)}{R_1+R_2//R_3(//R_L)}}_{a_1} u_{i1} + \underbrace{\frac{R_1//R_3(//R_L)}{R_2+R_1//R_3(//R_L)}}_{a_2} u_{i2}$

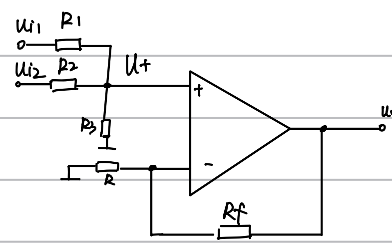
$= a_1 u_{i1} + a_2 u_{i2}$

问题：① 只衰减，无放大（$a_1, a_2 < 1$）

② 若加上变化负载则影响系数

③ 信号源互不独立（R_1影响a_2，R_2影响a_1）

△(有源)同相相加器



此时，$u_o = (1+\frac{R_f}{R}) u_+$

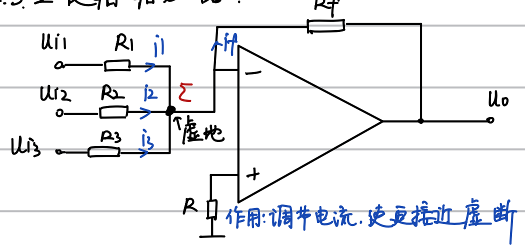
$= (1+\frac{R_f}{R}) \cdot (\frac{R_2//R_3}{R_1+R_2//R_3} u_{i1} + \frac{R_1//R_3}{R_2+R_1//R_3} u_{i2})$

可放大（系数>1），负载不影响系数

若取 $R_1 = R_2$，$u_o = (1+\frac{R_f}{R}) \cdot \frac{R_1//R_3}{R_1+R_1//R_3} \cdot (u_{i1}+u_{i2})$

$= k \cdot (u_{i1}+u_{i2})$

2.3.2 反相 相加器.



应有: $i_1=\frac{u_{i1}}{R_1}$, $i_2=\frac{u_{i2}}{R_2}$, $i_3=\frac{u_{i3}}{R_3}$

$i_f=i_1+i_2+i_3=\frac{u_{i1}}{R_1}+\frac{u_{i2}}{R_2}+\frac{u_{i3}}{R_3}=-\frac{u_o}{R_f}$

∴ $u_o=-\frac{R_f}{R_1}u_{i1}-\frac{R_f}{R_2}\cdot u_{i2}-\frac{R_f}{R_3}\cdot u_{i3}$

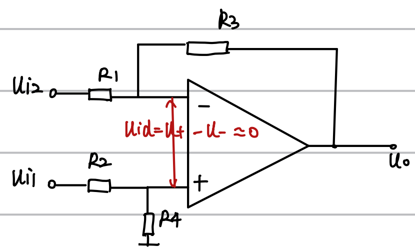
若 $R_1=R_2=R_3=R$

则 $u_o=-\frac{R_f}{R}(u_{i1}+u_{i2}+u_{i3})$ 信号源相互独立

2.4 相减器

2.4.1 基本相减器(差动放大器)

$u_o=a_1u_{i1}-a_2u_{i2}$



叠加定理 $u_{i2}=0$ 同相放大器

$u_{o1}=u_{i1}\cdot\frac{R_4}{R_2+R_4}(1+\frac{R_3}{R_1})$

$u_{i1}=0$ 反相放大器.

$u_{o2}=u_{i2}\cdot(-\frac{R_3}{R_1})$

$u_o=u_{o1}+u_{o2}=\frac{R_4}{R_2+R_4}(1+\frac{R_3}{R_1})u_{i1}-\frac{R_3}{R_1}u_{i2}=a_1u_{i1}-a_2u_{i2}$

若 $R_1=R_2$, $R_3=R_4$ 则 $u_o=\frac{R_3}{R_1}(u_{i1}-u_{i2})$

2.4.2 精密相减器(仪用放大器)

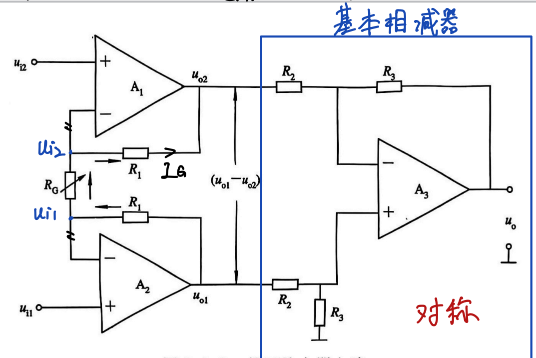


图 2.4.8 仪用放大器电路

$u_o=\frac{R_3}{R_2}(u_{o1}-u_{o2})$

∵虚断 ∴ $u_{o1}-u_{o2}=u_{RG}+2u_{R1}$

其中 $u_{RG}=u_{i1}-u_{i2}$ (虚短)

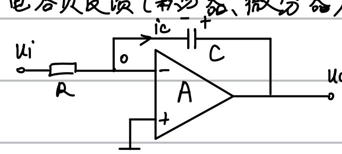
$I_G=\frac{u_{i1}-u_{i2}}{R_g}$, $u_{R1}=\frac{R_1}{R_g}(u_{i1}-u_{i2})$

∴ $u_{o1}-u_{o2}=(1+\frac{2R_1}{R_g})(u_{i1}-u_{i2})$

∴ $u_o=\frac{R_3}{R_2}(1+\frac{2R_1}{R_g})(u_{i1}-u_{i2})$ 只需调节一个电阻

2.5 电容负反馈(积分器、微分器)

△积分器



$u_o(t)=-\frac{1}{C}\cdot\int i_C(t)dt$

$=-\frac{1}{C}\int\frac{u_i(t)}{R}dt$

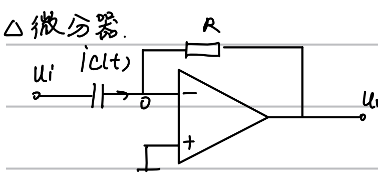
$=-\frac{1}{RC}\int u_i(t)dt$

$=-\frac{1}{j\omega CR}\int u_i(t)dt$, $|A_u(j\omega)|=\frac{1}{\omega CR}$, $\Delta\varphi(j\omega)=-90°$ (相对于标准反向而言)

180°

$180°-90°=90°$

△微分器.



$u_o=u_i\cdot(-\frac{R}{\frac{1}{j\omega C}})=-j\omega CR\cdot u_i$

$|A_u(j\omega)|=\omega CR$

$\Delta\varphi(j\omega)=90°$

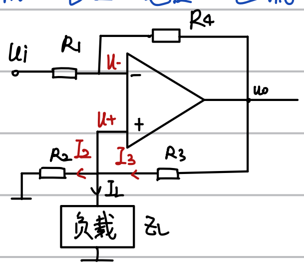
$$i_C(t)=C\cdot\frac{du_i(t)}{dt}$$

$$u_o(t)=-RC\cdot\frac{du_i(t)}{dt}$$

(I/V)

2.6 V/I 变换器

电流→电压与电压→电流



$I_2+I_L=I_3$ （求 I_2, I_3）

$I_3=\frac{u_o-u_+}{R_3}$, $I_2=\frac{u_+}{R_2}$

$$\frac{u_i-u_-}{R_1}=\frac{u_--u_o}{R_4}$$

(或叠加定理)

$$u_--u_o=\frac{R_4}{R_1}(u_i-u_-)\Rightarrow u_-=\frac{R_4}{R_1+R_4}u_i+\frac{R_1}{R_1+R_4}u_o$$

$$\therefore u_+=\frac{R_4}{R_1+R_4}u_i+\frac{R_1}{R_1+R_4}u_o=I_2R_2$$

$$I_3=\frac{u_o-u_+}{R_3}=\frac{R_4(u_o-u_i)}{(R_1+R_4)\cdot R_3}$$

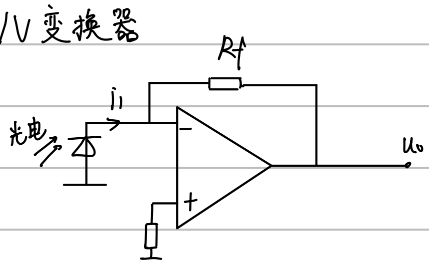
$$I_2=\frac{R_4}{(R_1+R_4)R_2}u_i+\frac{R_1}{(R_1+R_4)R_2}u_o$$

R_1R_3 ‖

$$I_L=I_3-I_2=\frac{R_2R_4-R_1R_3}{(R_1+R_4)\cdot R_2R_3}u_o-\frac{R_2R_4+R_3R_4}{(R_1+R_4)R_3R_2}u_i$$

令 $R_1R_3=R_2R_4$，得 $I_L=-u_i\cdot\frac{1}{R_2}$

I/V 变换器



$$u_o=-i_1R_f$$