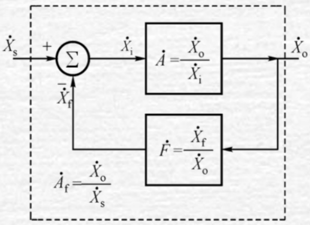


$$\dot{A}_f=\frac{\dot{X}_o}{\dot{X}_s}=\frac{\dot{A}\dot{X}_i}{\dot{X}_i+\dot{X}_f}=\frac{\dot{A}\dot{X}_i}{\dot{X}_i+\dot{F}\dot{X}_o}$$

$$=\frac{\dot{A}\dot{X}_i}{\dot{X}_i+\dot{A}\dot{F}\dot{X}_i}=\frac{\dot{A}}{1+\dot{A}\dot{F}}$$

$$\frac{dA_f}{A_f}=\frac{1}{1+AF}\cdot\frac{dA}{A}$$

失真信号：在输出幅度相同的情况下，失真信号减小为原来的 $1/(1+\dot{A}\dot{F})$

1、对输出电阻的影响

$R_{of}=\frac{R_o}{1+AF}\xrightarrow{\text{深度电压负反馈}}R_{of}\to 0$（从取样点）

$R_{of}=R_o(1+AF)\xrightarrow{\text{深度电流负反馈}}R_{of}\to\infty$（从取样点）

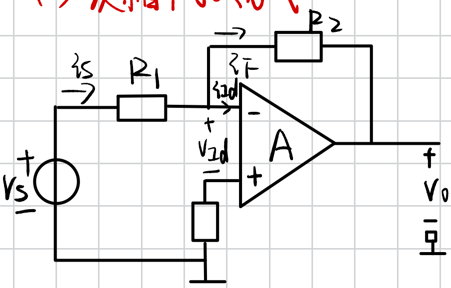
2、对输入电阻的影响

并联：$R_{if}=R_i/(1+AF)\xrightarrow{\text{深度负反馈}}R_{if}\to 0$（从求和点）

串联 $R_{if}=(1+AF)R_i\xrightarrow{\text{深度负反馈}}R_{if}=\infty$（从求和点）

一、比例运算

(1) 反相输入方式



$$\begin{cases} i_s=\frac{V_s}{R_1} \\ i_F=\frac{0-V_o}{R_2}\end{cases}\Rightarrow\frac{V_s-0}{R_1}=\frac{0-V_o}{R_2}$$

$\therefore V_o=-\left(\frac{R_2}{R_1}\right)V_s$

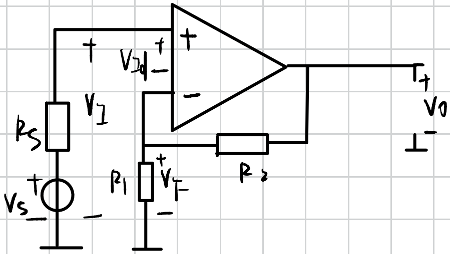
$A_{vf}=-R_2/R_1$

$R_{if}=0+R_1=R_1$

$R_{of}=0$

电压并联负反馈

(2) 同相输入方式



电压串联负反馈

当 R_1 开路时，$V_0=V_s$ 称为电压跟随器

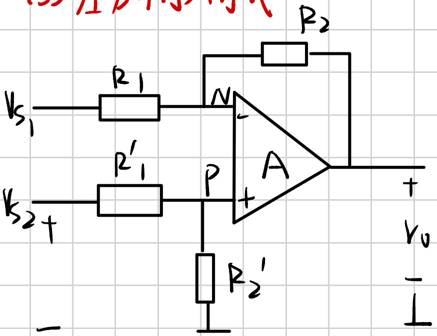
$$\begin{cases} V_F = V_0 \times \frac{R_1}{R_2+R_1} \\ V_S = V_F \end{cases} \rightarrow \therefore V_0=(1+\frac{R_2}{R_1})V_s$$

$$A_{vf}=1+\frac{R_2}{R_1}$$

$R_{if}=\infty$

$R_{of}=0$

(3) 差分输入方式



$V_0=V_0'+V_0''$

$=-\frac{R_2}{R_1}V_{S1}+V_{S2}\cdot\frac{R_2'}{R_1'+R_2'}\times(\frac{R_2}{R_1}+1)$

$R_{if}=R_1+R_1'$

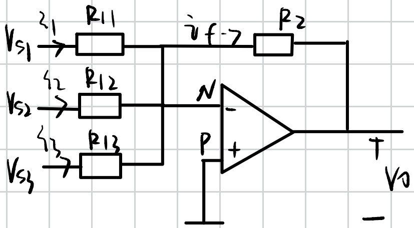
$R_{of}\to 0$

当 $R_1'=R_1$，$R_2'=R_2$ 时

$V_0=\frac{R_2}{R_1}(V_{S2}-V_{S1})$ 减法运算电路

二、求和运算

(1) 反相求和运算



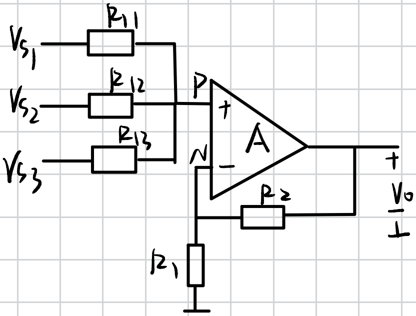
N 点虚地

$i_1+i_2+i_3=i_f$

$\frac{V_{S1}}{R_{11}}+\frac{V_{S2}}{R_{12}}+\frac{V_{S3}}{R_{13}}=-\frac{V_0}{R_2}$

$V_0=-(\frac{R_2}{R_{11}}V_{S1}+\frac{R_2}{R_{12}}V_{S2}+\frac{R_2}{R_1}V_{S3})$

(2)同相求和运算



$$V_o \times \frac{R_1}{R_2+R_1} = V_p$$

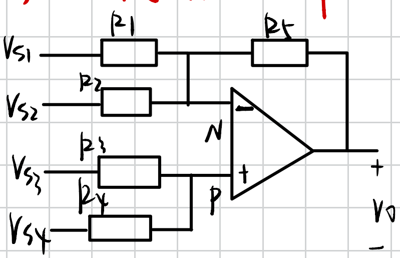
$$V_o = V_p\left(\frac{R_2}{R_1}+1\right)$$

$$V_p = \frac{R_{12}//R_{13}}{R_{11}+R_{12}//R_{13}} V_{s1} + \cdots$$

$$= (R_{11}//R_{12}//R_{13})\left(\frac{V_{s1}}{R_{11}}+\frac{V_{s2}}{R_{12}}+\frac{V_{s3}}{R_{13}}\right)$$

$$\therefore V_o = \left(1+\frac{R_2}{R_1}\right)(R_{11}//R_{12}//R_{13})\left(\frac{V_{s1}}{R_{11}}+\frac{V_{s2}}{R_{12}}+\frac{V_{s3}}{R_{13}}\right)$$

(3)双端输入求和运算

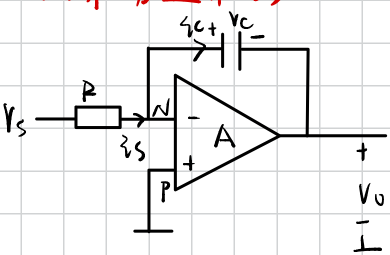


利用叠加定理：

$$V_o = -\frac{R_5}{R_1}V_{s1} - \frac{R_5}{R_2}V_{s1} + \left(1+\frac{R_5}{R_1//R_2}\right)\frac{R_4}{R_3+R_4}V_{s3} + \left(1+\frac{R_5}{R_1//R_2}\right)\frac{R_3}{R_3+R_4}V_{s4}$$

三、积分和微分运算电路

(1)积分运算电路

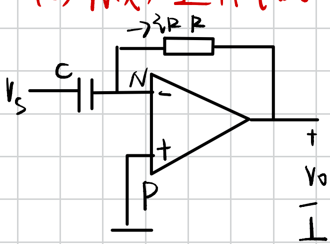


$$i_s = \frac{V_s}{R}$$

$$V_N = V_p = 0$$

$$V_o = -V_c = -\frac{1}{C}\int i_c \, dt = -\frac{1}{RC}\int V_s \, dt$$

(2)微分运算电路



$$i_R = -\frac{V_o}{R} = i_c = C\frac{dV_s}{dt}$$

$$\therefore V_o = -RC\frac{dV_s}{dt}$$