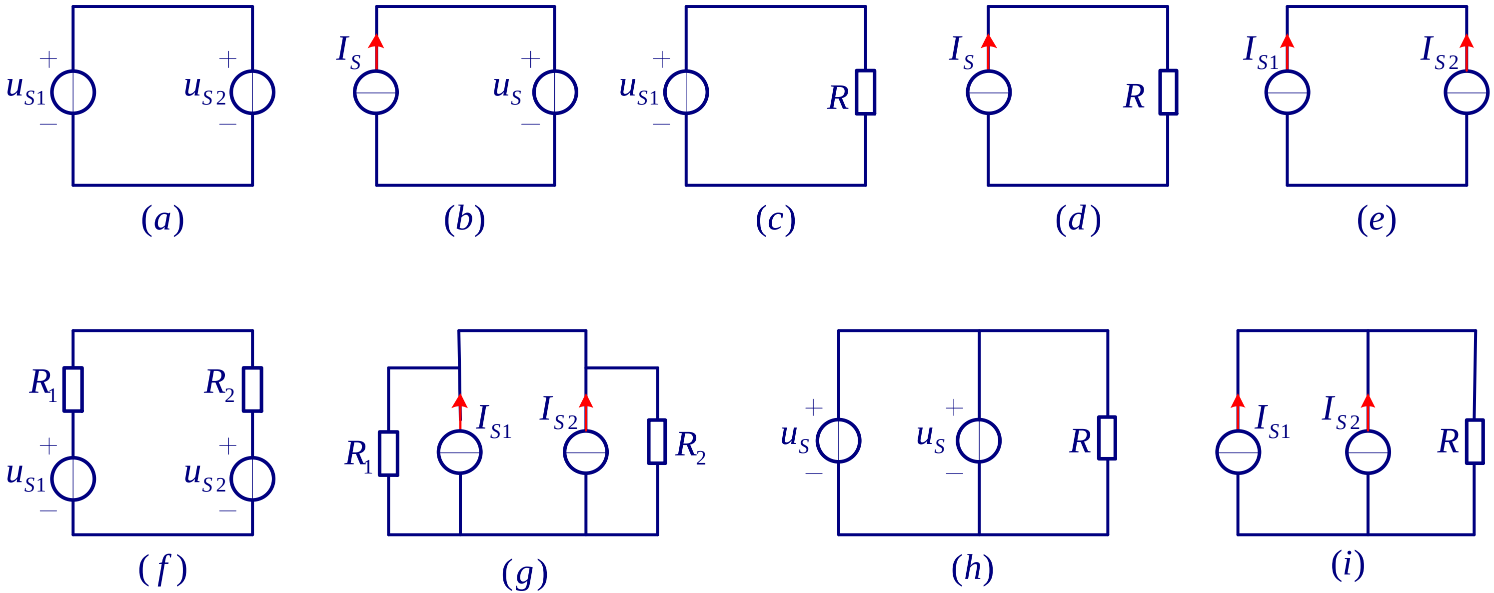
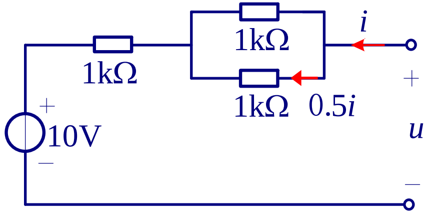
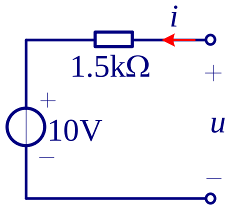
答疑：（解的情况） **检验：KCL、KVL（解的存在性与唯一性）**



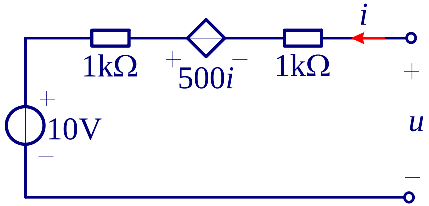
例：求图示电路的最简等效结构

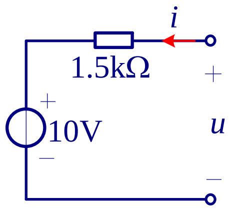


方法一：



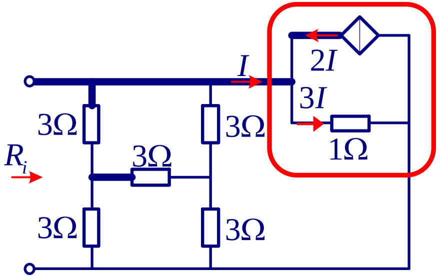
方法二：

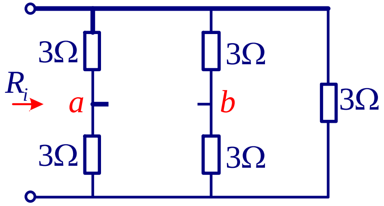




$$u = 2000i - 500i + 10 = 10 + 1500i$$

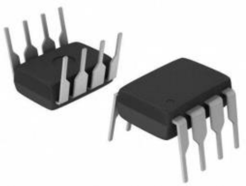
练习：求输入等效电阻 R_i

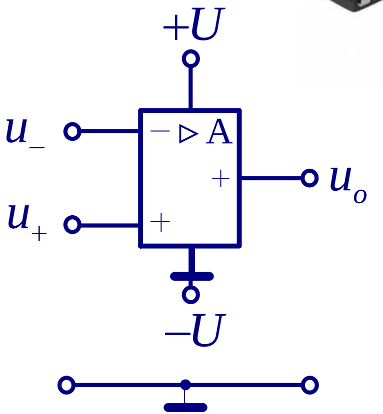


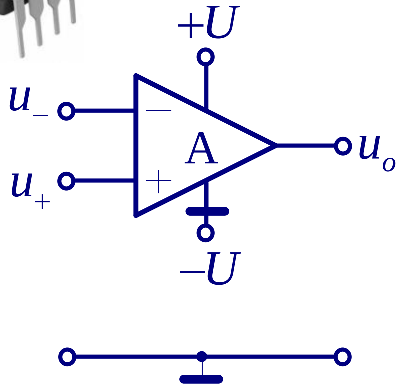


$$R_i = \frac{1}{\frac{1}{6} + \frac{1}{6} + \frac{1}{3}} = 1.5\Omega$$

4、运算放大器





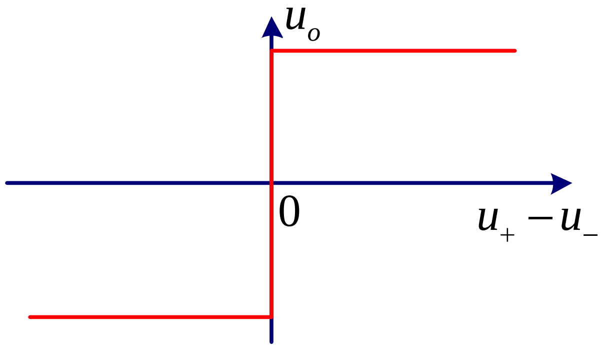


理想运算放大器： $R_o = 0,\ R_i \to \infty,\ \mathrm{A} \to \infty$

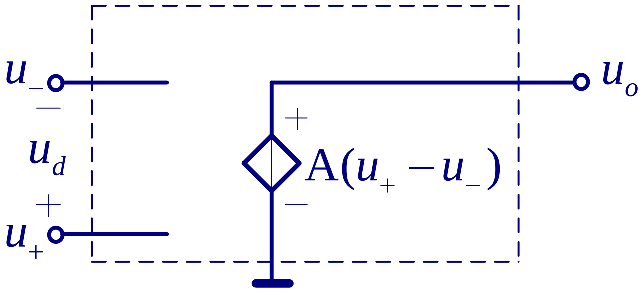
理想运放工作于线性区时 $u_+ - u_- = \dfrac{u_o}{\mathrm{A}} \to 0$

$u_+ \approx u_-$ ——虚短　　$i_+ = i_- = 0$ ——虚断

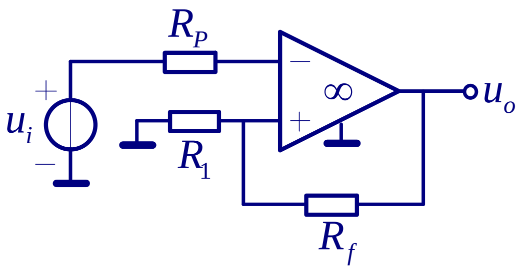
运算放大器的转移特性



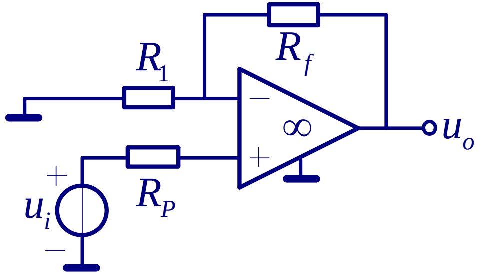
$$u_o = \mathrm{A}(u_+ - u_-) = \mathrm{A}u_d$$



思考：（虚短、虚断特性的应用条件）



(a)

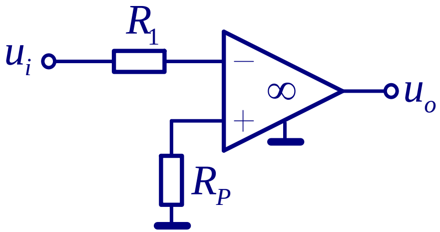


(b)

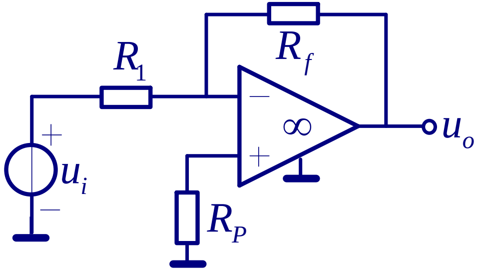
$$u_- = u_+ = u_i$$

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

同相比例放大



(c)



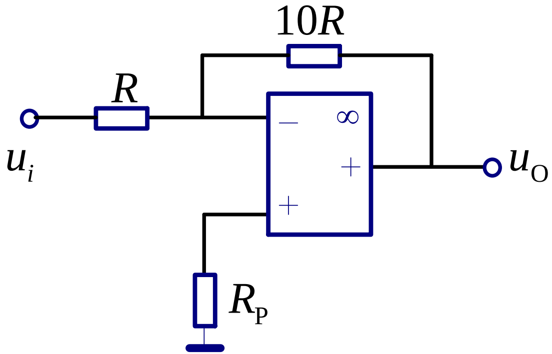
(d)

$$u_- = u_+ = 0$$

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

反相比例放大

例： 图示电路中，$u_i = 2\text{V}$且运放的饱和输出电压为±15V。试计算 u_O 和 u_-



$$u_- = u_+ = 0$$

$$u_o = -\frac{10R}{R}u_i = -10u_i = -20\text{V} < -u_{o(sat)}$$

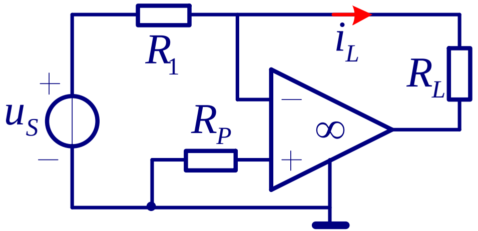
$$\therefore u_o = -u_{o(sat)} = -15\text{V}$$

$$\frac{u_i - u_-}{R} = \frac{u_- - u_o}{10R}$$

$$u_- = \frac{10u_i + u_o}{11} = \frac{10\times 2 - 15}{11} = \frac{5}{11}\text{V}$$

弥尔曼定理

$$\boxed{u_- = \frac{\dfrac{u_i}{R} + \dfrac{u_o}{10R}}{\dfrac{1}{R} + \dfrac{1}{10R}}} = \frac{10u_i + u_o}{11}$$

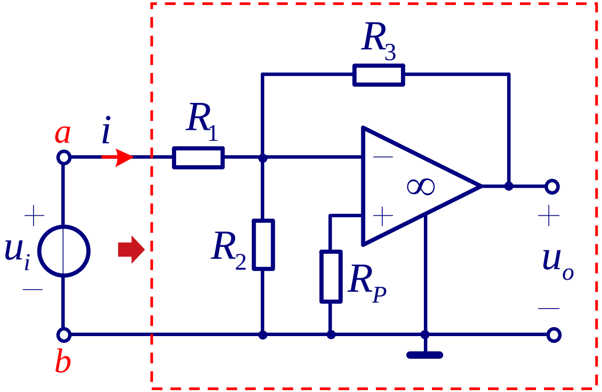


$$u_- = u_+ = 0$$

$$i_L = \frac{u_S}{R_1}$$

i_L与负载电阻大小无关。负载R_L相当于接在一个电流源上。图示电路具有将电压源转换成电流源的功能，称电源转换器。

例：求图示电路从ab端向运算放大器看的等效电阻R_{ab}



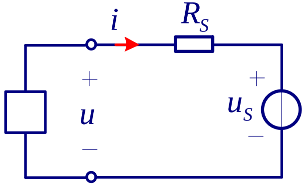
$$R_{ab} = \frac{u_i}{i}$$

$$u_- = u_+ = 0$$

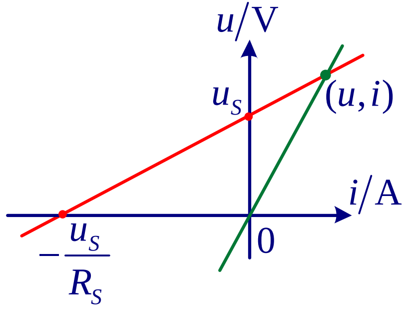
$$u_i = R_1 i$$

$$\therefore R_{ab} = R_1$$

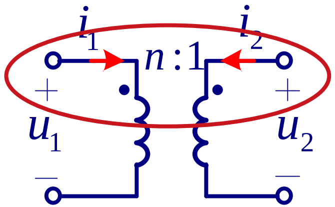
思考：含独立电源的网络是否可用端口电压电流之比得到其等效电阻？



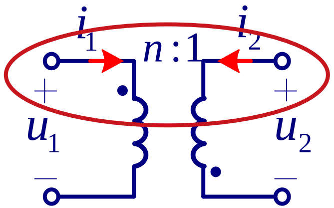
$$u = u_S + R_S i$$



5、理想变压器



$$\begin{cases} \dfrac{u_1}{u_2} = n \\ \dfrac{i_1}{i_2} = -\dfrac{1}{n} \end{cases}$$



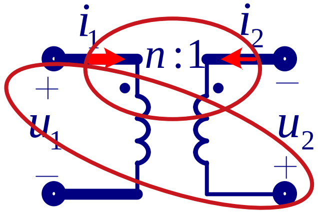
$$\begin{cases} \dfrac{u_1}{u_2} = -n \\ \dfrac{i_1}{i_2} = \dfrac{1}{n} \end{cases}$$

$$P_{吸收} = u_1 i_1 + u_2 i_2 = n u_2 \times \left(-\frac{1}{n} i_2\right) + u_2 i_2 = 0$$

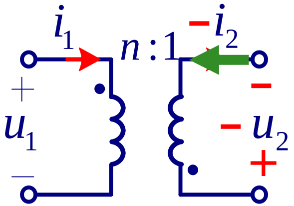
不储存能量不消耗能量的**无源**双口元件

$$w(-\infty, t) = \int_{-\infty}^{t} p(\xi) d\xi \geq 0$$

练习1：写出下图理想变压器的VCR

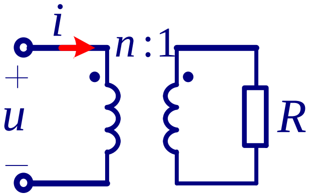


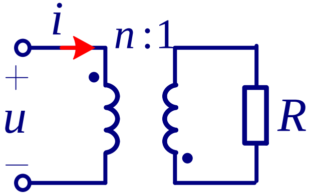
$$\begin{cases} \dfrac{u_1}{u_2} = -n \\ \dfrac{i_1}{i_2} = -\dfrac{1}{n} \end{cases}$$

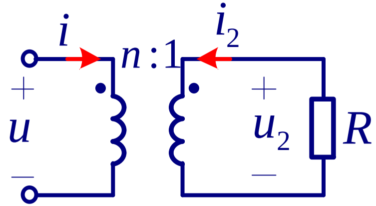


$$\begin{cases} \dfrac{u_1}{u_2} = -n \\ \dfrac{i_1}{i_2} = -\dfrac{1}{n} \end{cases}$$

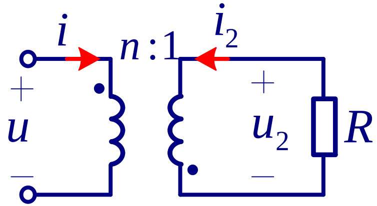
练习2：求出下图电路的端口特性







(a)



(b)

$$\begin{cases} \dfrac{u}{u_2} = n \\ \dfrac{i}{i_2} = -\dfrac{1}{n} \end{cases}$$

$$u_2 = -Ri_2$$

$$\begin{cases} \dfrac{u}{u_2} = -n \\ \dfrac{i}{i_2} = \dfrac{1}{n} \end{cases}$$

$$u_2 = -Ri_2$$

理想变压器的变阻特性

(a)图 $u = nu_2 = -nRi_2 = n^2 Ri$

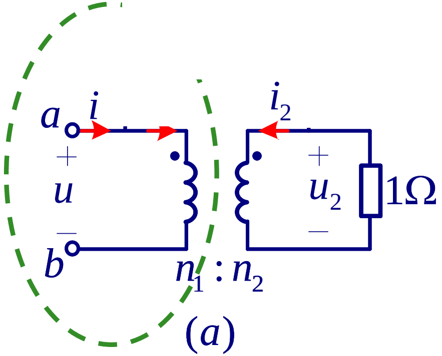
$$\frac{u}{i} = n^2 R$$

(b)图 $u = -nu_2 = nRi_2 = n^2 Ri$

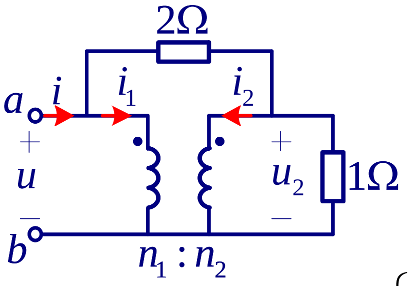
$$\frac{u}{i} = n^2 R$$

理想变压器是一种双口电阻元件

练习：求下图所示电路由ab端看进去的输入电阻R_{ab}



(a)



(b)

$$R_{ab} = \frac{u}{i}$$

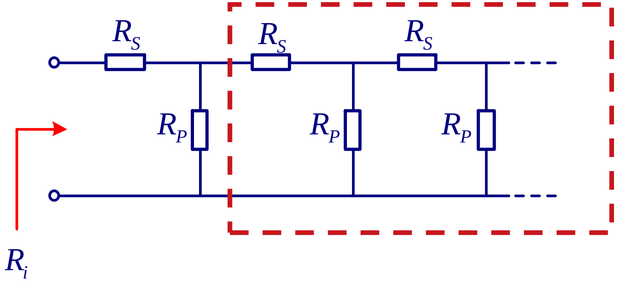
(a)图 $R_{ab} = \left(\frac{n_1}{n_2}\right)^2 R = \left(\frac{n_1}{n_2}\right)^2 \Omega$

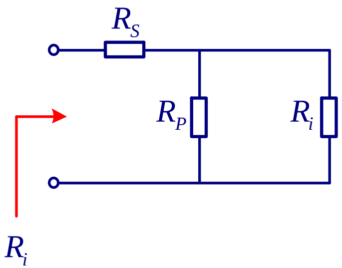
(b)图
$$\begin{cases} \dfrac{u}{u_2} = \dfrac{n_1}{n_2} \\ \dfrac{i_1}{i_2} = -\dfrac{n_2}{n_1} \\ u_2 = 1 \times (i - i_1 - i_2) \\ u - u_2 = 2 \times (i - i_1) \end{cases} \Rightarrow R_{ab} = \frac{2n_1^2}{(n_1 - n_2)^2 + 2n_2^2}$$

另：理想变压器对直流也适用

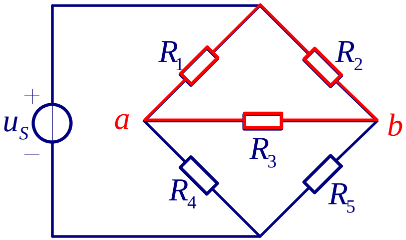
电路分析方法

1、等效

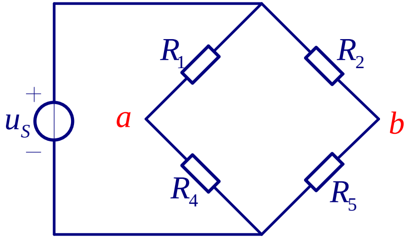




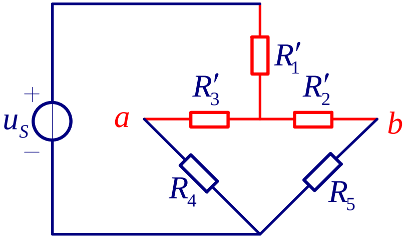
$$R_i = R_S + \frac{R_P \times R_i}{R_P + R_i}$$



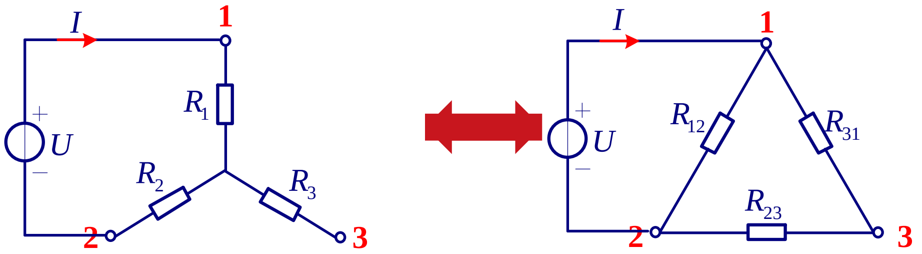
1)若 $\dfrac{R_1}{R_4} = \dfrac{R_2}{R_5}$ 则 $V_a = V_b$



2)若 $\dfrac{R_1}{R_4} \neq \dfrac{R_2}{R_5}$



星形-三角形连接(Y-Δ)的等效变换



$$\frac{I}{U}=\frac{1}{R_1+R_2} \qquad \frac{I}{U}=\frac{1}{R_{12}}+\frac{1}{R_{31}+R_{23}}$$

$$\therefore \frac{1}{R_1+R_2}=\frac{1}{R_{12}}+\frac{1}{R_{31}+R_{23}}$$

$$\frac{1}{R_2+R_3}=\frac{1}{R_{23}}+\frac{1}{R_{12}+R_{31}}$$

$$\frac{1}{R_3+R_1}=\frac{1}{R_{31}}+\frac{1}{R_{23}+R_{12}}$$

$$R_{12}=(R_1R_2+R_2R_3+R_3R_1)/R_3$$
$$R_{23}=(R_1R_2+R_2R_3+R_3R_1)/R_1$$
$$R_{31}=(R_1R_2+R_2R_3+R_3R_1)/R_2$$

$$R_1=R_{12}R_{31}/(R_{12}+R_{23}+R_{31})$$
$$R_2=R_{23}R_{12}/(R_{12}+R_{23}+R_{31})$$
$$R_3=R_{31}R_{23}/(R_{12}+R_{23}+R_{31})$$

若 $R_1=R_2=R_3$ 则 $R_{12}=R_{23}=R_{31}=3R$