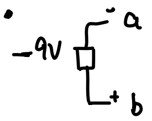
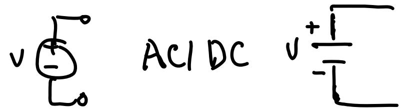
- $1e = 1.602\times10^{-19}$ C $\Leftrightarrow$ $1C = 6.24\times10^{18}$ e
- $i = \frac{dq}{dt}$

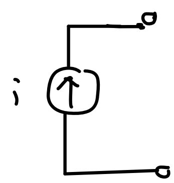
  $Q = \int_{t_0}^{t} i\, dt$
- 

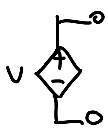
  $b - a = -9V$
- $p = \frac{dw}{dt} = \frac{dw}{dq}\cdot\frac{dq}{dt} = vi$
- current enters {positive / negative} terminal of an element $p = +vi$ / $p = -vi$
- 

  absorb supply.
- conservation of energy $\Sigma p = 0$.
- $w = \int_{t_0}^{t} p\, dt = \int_{t_0}^{t} vi\, dt$
- 

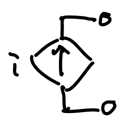
  AC/DC DC only

  independent voltage source

  independent current source
- 

  dependent voltage soure

  current source
- $v = iR$ for PSC 提供能量

  $v = -iR$ for ASC 吸收能量
- $p = vi = i^2R = \frac{v^2}{R} = \frac{i^2}{G} = v^2G$ $i = vG$ $G = \frac{1}{R}$ conductance
- b branch (支路) n nodes (节点) m meshes (回路)

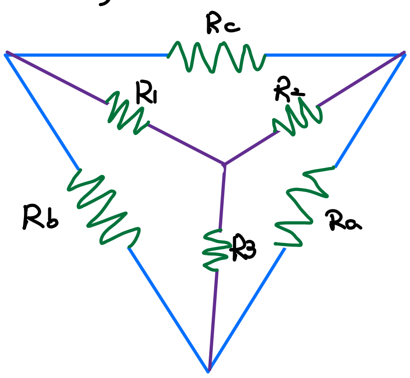
  $b = m + n - 1$
- Kirchhoff's current law (KCL): 过一节点 $\Sigma i = 0$. $\Sigma I_{进} = \Sigma I_{出}$

  voltage law (KVL): sum of all voltages around a closed path (or loop) is zero. ΣV drops $= \Sigma V$ rises.

- Principle of voltage division: $U_n = \dfrac{R_n}{\sum_{n=1}^{N} R_n} V$

  current division: $i_n = \dfrac{G_n}{\sum_{n=1}^{N} G_n} i$.

- Wye - Delta Transformations



① Delta ⇒ Wye ($\pi \to Y$)

$$\begin{cases} R_1 = \dfrac{R_b R_c}{R_a + R_b + R_c} \\ R_2 = \dfrac{R_a R_c}{R_a + R_b + R_c} \\ R_3 = \dfrac{R_a R_b}{R_a + R_b + R_c} \end{cases}$$

② Wye ⇒ Delta ($Y \to \pi$)

$$\begin{cases} R_a = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_1} \\ R_b = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_2} \\ R_c = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_3} \end{cases}$$

L3. Nodal Analysis

1. circuit with only independent current sources. N nonreference nodes.

$$\begin{bmatrix} G_{11} & G_{12} & \cdots & G_{1N} \\ G_{21} & G_{22} & \cdots & G_{2N} \\ \vdots & \vdots & & \vdots \\ G_{N1} & G_{N2} & \cdots & G_{NN} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} = \begin{bmatrix} i_1 \\ i_2 \\ \vdots \\ i_N \end{bmatrix}$$

G_{NN} = sum of conductances connected to node k

G_{kj} = 负的 k,j 间 conductances之和

i_k = independent current sources 之和，流入为正

2. 若有 Voltage sources

* 俩 nonreference nodes 间的电压源称 supernode (见L3, P37)

与此 supernode 平行的 elements 也合并

Mesh Analysis (只用于平面电路)

1. circuit with only independent current sources. N nonreference nodes.

$$\begin{bmatrix} R_{11} & R_{12} & \vdots & R_{1N} \\ R_{21} & R_{22} & \vdots & R_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ R_{N1} & R_{N2} & \vdots & R_{NN} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ \vdots \\ i_N \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_N \end{bmatrix}$$

R_{NN} = sum of resistances in mesh k

R_{kj} = 负的 k,j 间 resistances 之和

V_k = 顺时针电压源之和，电压上升为正

2. 若有 current source

① current source 只在一个mesh，则为 mesh current (L3, P73)

② c.s. 在两 mesh 间，为 supermesh (L3, P75)

用法： nodal analysis
- 多并联，电流源，supernodes
- node voltage required
- node 少

mesh analysis
- 多串联，电压源，supermesh
- branch、mesh currents required
- mesh 少

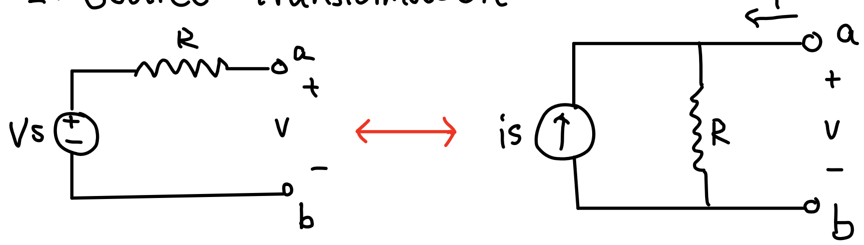
L4 1. Superposition 叠加.

多个 independent sources 可分别求其 contribution.

dependent sources 不可分离出来

eg 见 L4 / P21

2. Source Transformation



$v_s = i_s R$ or $i_s = \frac{v_s}{R}$

3. Thevenin's Theorem

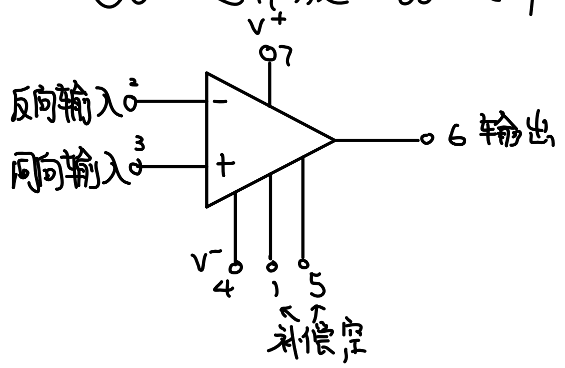
① network has no dependent sources: turn off all independent sources. R_{th} is equivalent resistance between a & b.

② network has dependent sources: turn off all independent sources. apply a voltage source V_o (or current source i_o) at terminal a & b and determine the resulting current i_o. $R_{th} = \frac{V_o}{i_o}$.

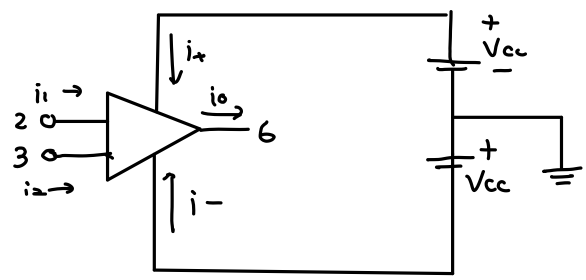
4. 诺顿定理

二端电路可用电流源 I_N 和与之并联的电阻 R_N 构成的等效电路替代. I_N 流入端口的短路电流, R_N 独立电流源关闭时端口的等效电阻.

C5 运算放大器 (operational amplifer, op amp)

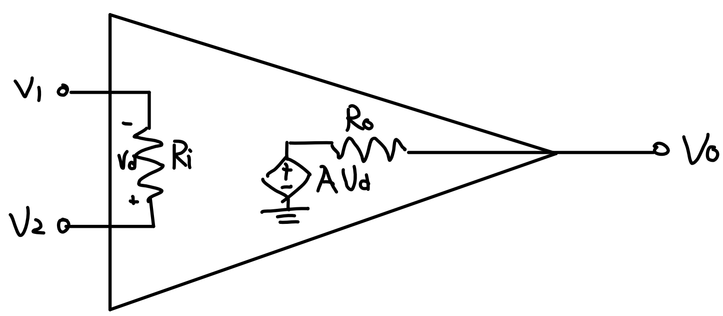


供电电路



$$i_o = i_1 + i_2 + i_+ + i_-$$

非理想运放等效图:



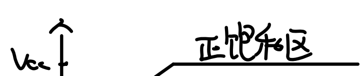
$$V_d = V_2 - V_1$$

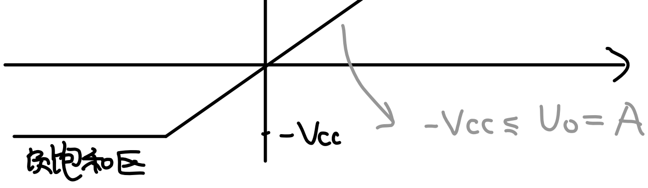
$$V_o = AV_d = A(V_2 - V_1)$$

A 称为开环电压增益

输出电压和输入电压之比称闭环增益

输出电压值不超过 $|V_{cc}|$





$-V_{cc} \le V_o = AV_d \le V_{cc}$

- 理想运算放大器

特点： 1. 开环增益无穷大 $A \approx \infty$

2. 输入电阻无穷大 $R_i \approx \infty$

3. 输出电阻为零 $R_o \approx 0$

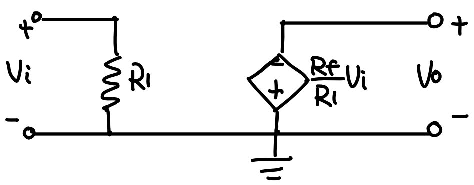
∴ 性质： 1. 两输入电流均为零 $i_1 = 0$ $i_2 = 0$,

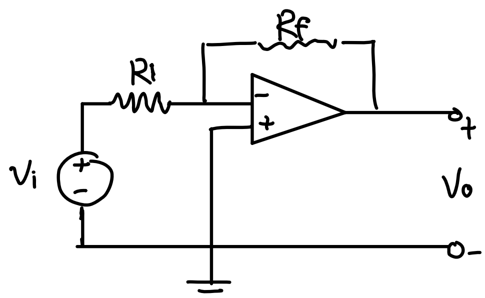
2. 两输入端电压差为零 $V_d = V_2 - V_1 = 0$ $V_1 = V_2$

- 反向放大器 Inverting amplifier

同向输入端接地，V_i 通过电阻 R_1 接入反向输入端．反馈电阻 R_f 接在反向输入端与输出端之间．

有 $V_o = -\frac{R_f}{R_1} V_i$ 电压增益 $A = \frac{V_o}{V_i} = -\frac{R_f}{R_1}$

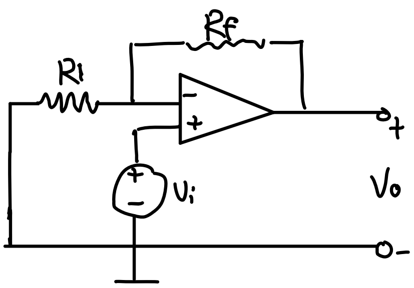




- 同向放大器 Noninverting amplifier

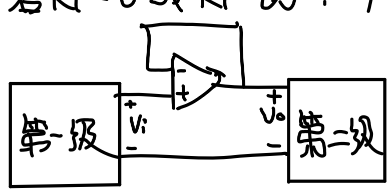
输入电压 V_i 直接与同向输入端相连，电阻 R_1 接在反向输入端与地之间．

$V_o = (1 + \frac{R_f}{R_1}) V_i$



若 $R_f = 0$ 或 $R_1 = \infty$． $A = 1$．电压跟踪器

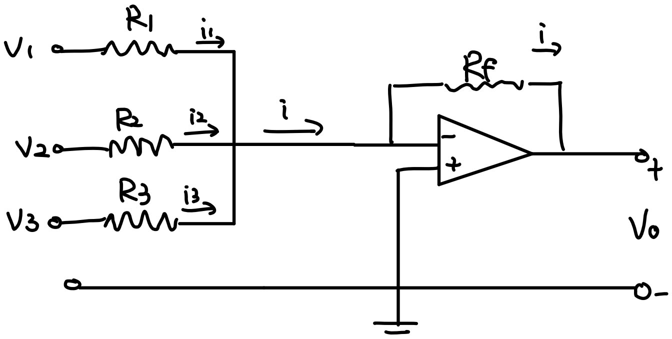
$(V_o = V_i)$



• 加法放大器 Summing amplifier

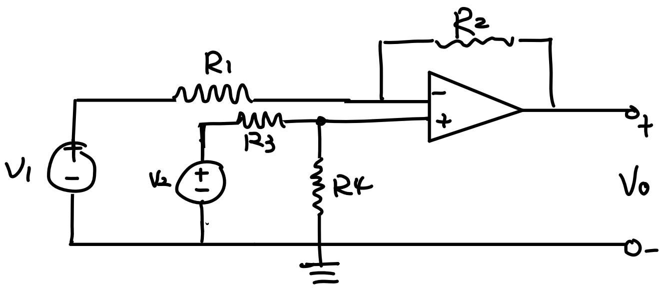
将多个输入合并，在输出端产生这些输入加权和的运放，

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$



• 差分放大器 Difference amplifier

只对两输入信号差输进行放大和抑制共模信号的器件



$$V_o = \frac{R_2(1+R_1/R_2)}{R_1(1+R_3/R_4)}V_2 - \frac{R_2}{R_1}V_1$$

$V_1 = V_2$ 时 $V_o = 0$ 需要 $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

∴ 差分放大器 $V_o = \frac{R_2}{R_1}(V_2 - V_1)$

若 $R_2 = R_1$ 且 $R_3 = R_4$. 则为减法器

$V_o = V_2 - V_1$