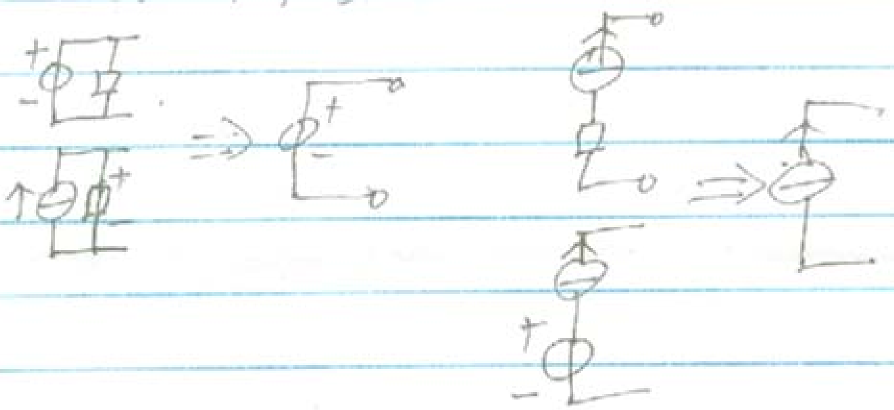
电路分析

一、KCL，KVL → 回路

结点，高斯面，

电阻的串并混 Δ-Y.

电源的串并，多余元件



功率：吸收，发出.

$p = ui$（关）

$p = -ui$（非关）

二、电路的基本分析方法

1. 网孔电流法

步骤：网孔电流，沿网孔列KVL方程.

电流源的处理：

①设电流源两端电压

② 列超网孔的KVL.

2. 节点电压法（电位法）：列KCL方程（参考点不列）

变量

结点间电压源的处理：

① 设电压源支路的电流

② 列超节点的KCL方程

③ 选电压源的一端为参考节点.

3. 回路分析法：沿基本回路列写KVL方程.

变量：基本回路电流.

只有1条连支

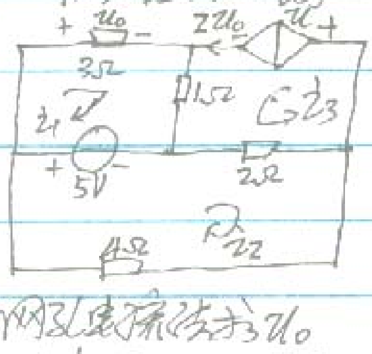
树的选取：尽可能把电压源与电压控制量选为树支，

、、、、电流源与电流 ———— 连支。

4. 割集分析法：变量为树支电压，

对基本割集列KCL方程.

高斯面只切割1条树支，其它为连支。



解：

$$\left.\begin{aligned} &3i_1+1\times(i_1+i_3)-5=0\\ &5+2(i_2+i_3)+4i_2=0\\ &i_3=2u_0\\ \text{辅助：}\ &u_0=3i_1 \end{aligned}\right\} \Rightarrow \begin{aligned} &i_1=0.5A\\ &i_2=-1.83\\ &i_3=3A\\ &u_0=1.5V \end{aligned}$$

用网孔电流法求 u_0

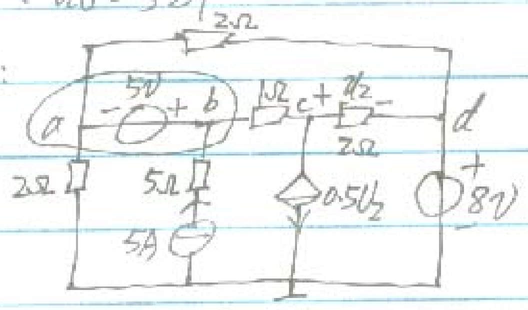
及5V电源发出的功率

$$P_{5V}=5(i_1-i_2)=11.65W$$

解二：设 u

$$
\begin{cases}
3i_1 + 1\times(i_1+i_3) - 5 = 0 \\
5 + 2(i_2+i_3) + 4i_2 = 0 \\
u + 1\times(i_3+i_1) + 2(i_3+i_2) = 0 \\
i_3 = 2u_0 \\
u_0 = 3i_1
\end{cases}
$$

例2:

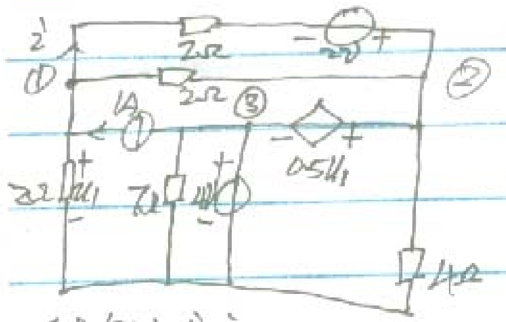


节点法求受控源吸收的功率。

解：结点电压如图：u_a, u_b, u_c, u_d.

$$
\left.\begin{aligned}
&\text{广义结点：}\frac{u_a}{2} - 5 + \frac{u_b-u_c}{1} + \frac{u_a-u_d}{2} = 0 \\
&c:\ \frac{u_c-u_b}{1} + 0.5u_2 + \frac{u_c-u_d}{2} = 0 \\
&u_d = 8V \\
&\text{辅助：}u_2 = u_c - u_d \\
&u_b - u_a = 5
\end{aligned}\right\}
\quad \text{得：}
\begin{aligned}
u_a &= 7V \\
u_b &= 12V \\
u_c &= 10V \\
u_d &= 8V
\end{aligned}
$$

$$P_{0.5u_2} = +0.5u_2 u_c = 10W.$$



结点法求 i。

解：① $\frac{u_1}{2}-1+\frac{u_1-u_2}{2}+\frac{u_1-u_2+2}{2}=0$

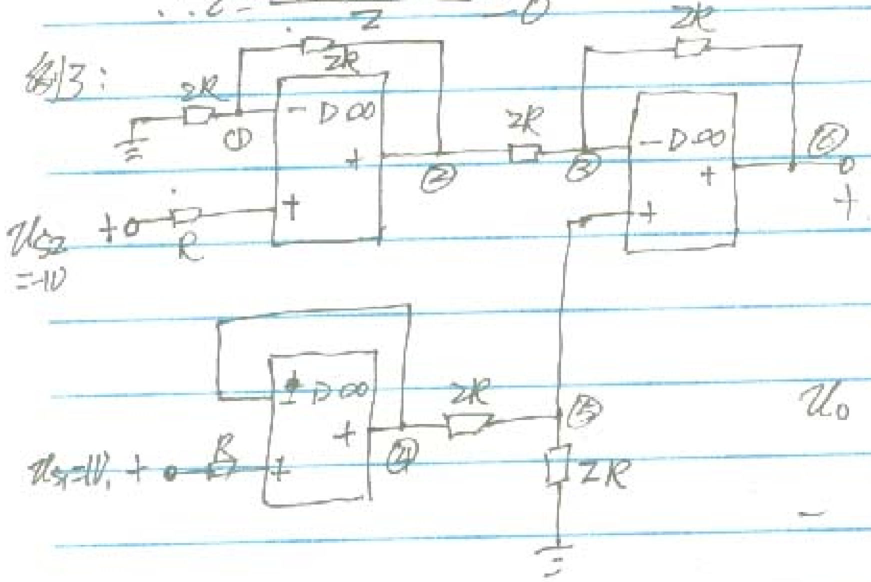
③：$u_3=4V$

②：$u_2=0.5u_1+4$

得：$u_1=4V$，$u_2=6V$，$u_3=4V$.

$\therefore i=\frac{u_1-u_2+2}{2}=0$

例3：



求 u_0.

虚短、虚断

解：① $\frac{u_1}{2R}+\frac{u_1-u_2}{2R}=0$

③ $\frac{u_3-u_2}{2R}+\frac{u_3-u_0}{2R}=0$

⑤ $\frac{u_5-u_4}{2R}+\frac{u_5}{2R}=0$

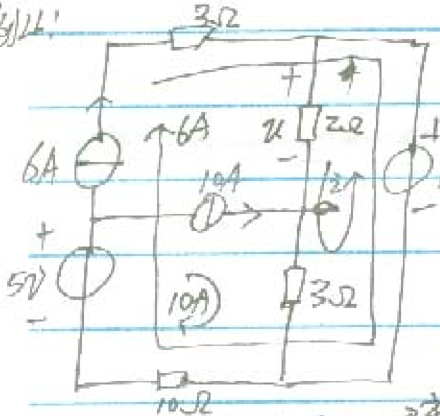
$u_1=1V$

$u_4=1V$

$u_3=u_5$

$\therefore u_0=-1V.$

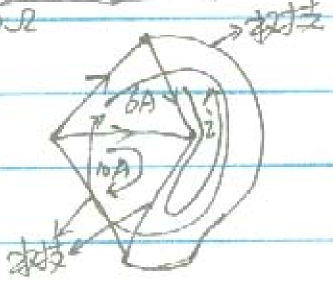
例11：



回路法求u.

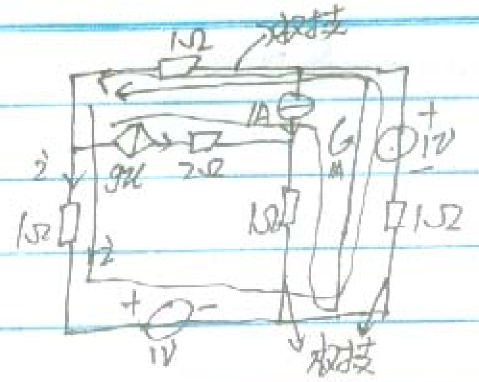
解：

拓扑图.



$2i+3(i+10)-12=0 \qquad \therefore i=-3.6A$

$u=2i=-7.2V.$



若 $i=0$, $g=?$

列网孔的KVL: $\begin{cases} 1\times i+1+1\times(i+1+gu)-1+1\times(i+gu)=0 \\ u=-1\times(i+1+gu) \end{cases}$

$\therefore i=\frac{g-1}{g+3}$ $\therefore g=1$时满足条件

三、基本定理

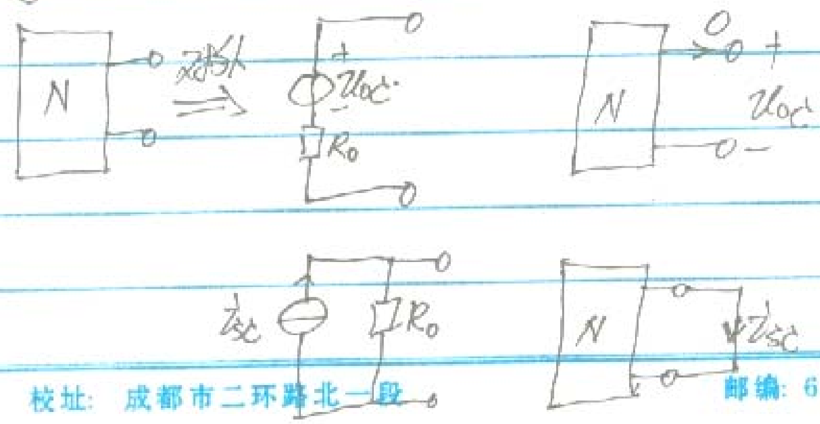
1、叠加定理

$i=k_1u_{s1}+k_2u_{s2}+\cdots+k_3i_{s1}+k_4i_{s2}+\cdots$

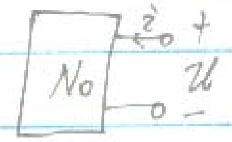
电压源置零 → 短路

流 ——→ 开路

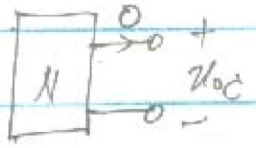
2、戴维南

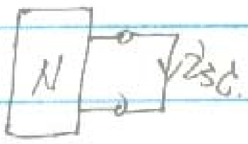


R_0：① R的串并，$\Delta \leftrightarrow Y$，(N_0网络)

② 

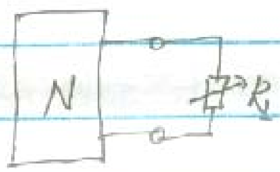
$R_0=\frac{u}{i}$

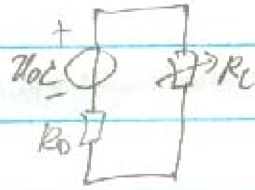
③ 



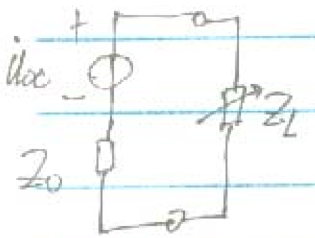
$R_0=\frac{u_{oc}}{i_{sc}}$

3. 最大功率传输

① 



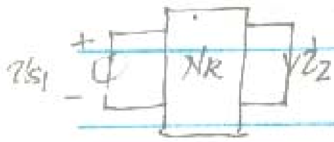
当 $R_L=R_0$ 时，$P_{max}=\left(\frac{u_{oc}}{R_0+R_0}\right)^2 R_0$

② 

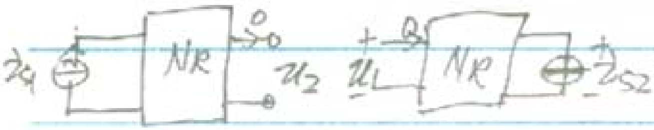
$Z_L=Z_0^{*}=R_0-jX_0$

$P_{max}=\left(\frac{U_{oc}}{2R_0}\right)^2 R_0$

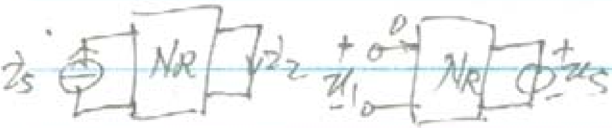
4. 互易定理



$\frac{i_2}{u_{s1}}=\frac{i_1}{u_{s2}}$



$$\frac{u_2}{i_{S1}}=\frac{u_1}{i_{S2}}$$



$$\frac{i_2}{i_S}=\frac{u_1}{u_S}$$

5. 特勒根定理

两个具有相同拓扑图的网络

$$\begin{cases}\sum u_k i_k' = 0 \\ \sum u_k' i_k = 0\end{cases}$$

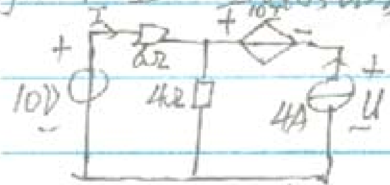
6. 替代

支路电压→电压源

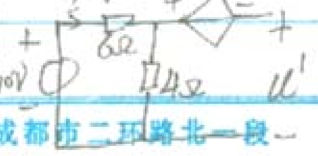
支路电流→电流源

7. 对偶

例：用叠加定理求U和10V电源发出的功率



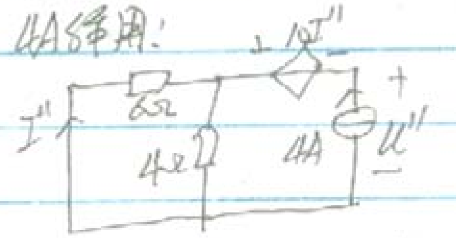
解：10V作用



∴ $I'=1A$. $U'=-10I'+4I'$

$=-10I'-6I'+10=-6V$

4A作用:



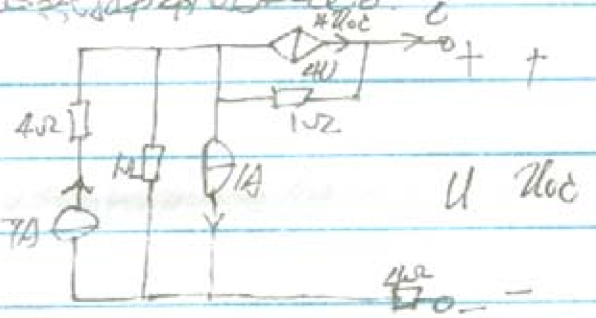
$\therefore I'' = -\frac{4}{4+6} \times 4 = -1.6A$

$u'' = -10I'' - 6I'' = 25.6V$

$\therefore U = u' + u'' = 19.6V.$

$P_{10V} = 10I = 10(I' + I'') = -6W$

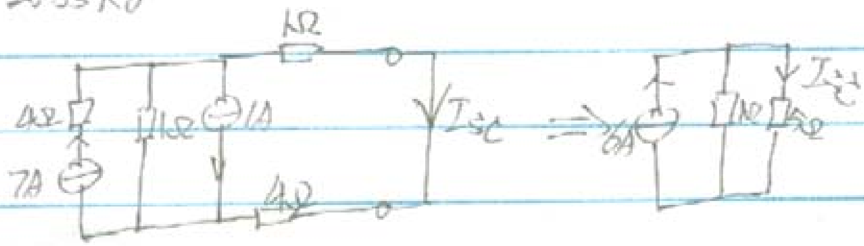
求戴维南等效电路



解: 1) 求 u_{oc}

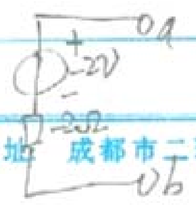
$u_{oc} = 1 \times 4u_{oc} + 1 \times (7-1) \quad \therefore u_{oc} = -2V.$

2) 求 R_0

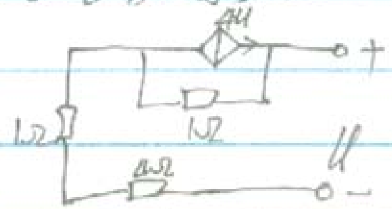


$I_{sc} = 1A.$

$\therefore R_0 = \frac{u_{oc}}{I_{sc}} = -2\Omega$

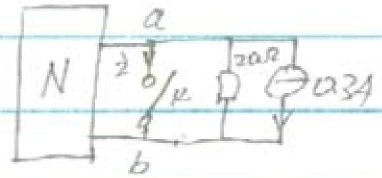


外加电源法求 R_0



$U=1\times(I+4U)+5I$　　∴ $R_0=\frac{U}{I}=-2\Omega$.

解:

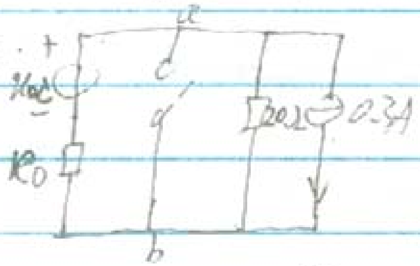


K打开时 $u_{ab}=4V$.

闭合: $i_2=1.2A$

求网络N的戴维南电路.

解:

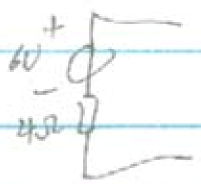


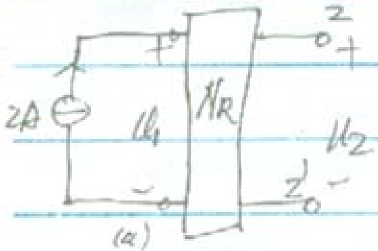
$(\frac{1}{R_0}+\frac{1}{20})u_{ab}=\frac{u_{oc}}{R_0}-0.3$ ……①

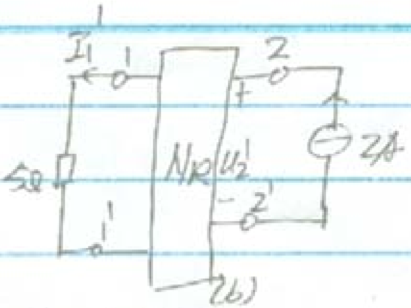
$1.2=\frac{u_{oc}}{R_0}-0.3$ ……②

∴ $u_{oc}=6V$, $R_0=4\Omega$

∴







N_R为线性电阻网络，图(a)测得$U_1=10V$，

$U_2=5V$，求图b的电流I_1'。

解：法1、应用特勒根定理：

$10I_1'+U_2(-2)+\sum U_k I_k'=0$ ……①

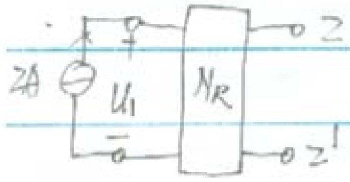
$5I_1'(-2)+U_2'\times 0+\sum U_k' I_k=0$ ……②

$\because U_k I_k' = I_k R_k I_k' = I_k U_k'$

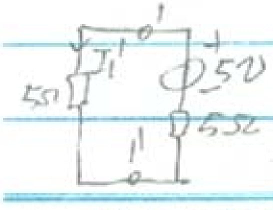
$10I_1'+5(-2)=5I_1'(-2)$ $\therefore I_1'=0.5A$

方法2：求图b 1-1'左侧戴——

由图(a)，互易定理得：$U_{OC}=5V$



$R_0=\frac{U_1}{2}=5\Omega$

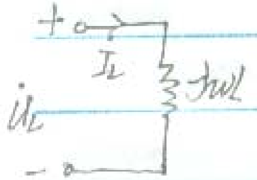


$I_1'=\frac{5}{10}=0.5A$

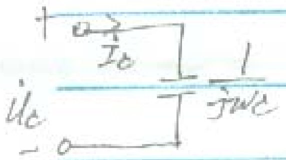
五、正弦交流稳态电路

1. R、L、C

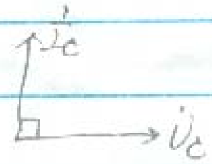
$\dot{U}_R = R\dot{I}_R$



$\dot{U}_L = j\omega L\dot{I}_L$



$\dot{U}_C = \frac{1}{j\omega C}\dot{I}_C$



2. 功率

有功功率 $P = UI\cos\varphi$，$\underbrace{\frac{U^2}{R},\ I^2R}_{}$ 电阻

无功 — $Q = UI\sin\varphi$ （VAr）

复功：$\tilde{S} = \dot{U}\dot{I}^* = S\angle\varphi = P + jQ$ （VA）

视在功率 $S = UI$ （VA）

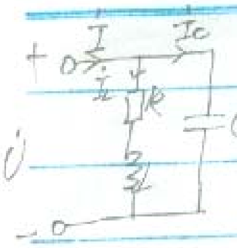
功率因数：$\cos\varphi$.

3. 方法

结点法，回路法.

定理：相量图.

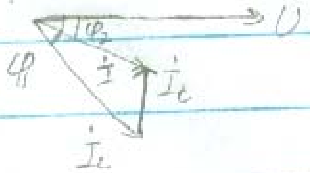
4. 功率因数的提高.



已知：U, P, ω → 角频率

$\cos\varphi_1 \to \cos\varphi_2$

求 C.

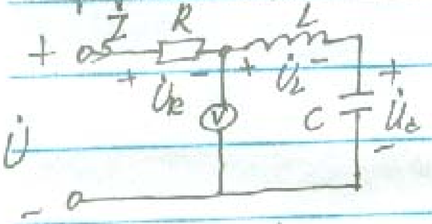


$$\frac{1}{\omega C} = \frac{U}{I_C}$$

并C前：$P = U I_L \cos\varphi_1$　可求 I_L

$\therefore I = \dfrac{P}{U\cos\varphi_2}$　　$\therefore I_C = I_L \sin\varphi_1 - I\sin\varphi_2$

5. 串联谐振



$$\omega_0 L = \frac{1}{\omega_0 C} \quad \therefore \omega_0 = \frac{1}{\sqrt{LC}}$$

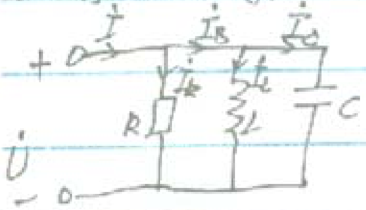
特点：输入阻抗值 $Z = R$

$\dot{U}$ 与 $\dot{I}$ 同相位，

U 一定，I 为最大。　　$Q = \dfrac{\omega_0 L}{R} = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$

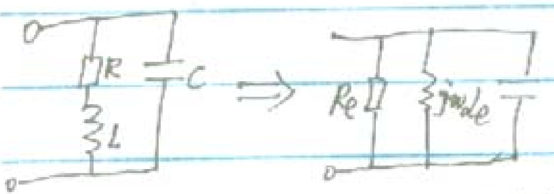
电抗上电压为零

6. 并联谐振.



$\omega_0 L = \frac{1}{\omega_0 C}$.

$I_B = 0$、$Z_e = R$ $\dot U$与$\dot I$同相



若 $\frac{\omega_0 L}{R} = Q \gg 1$ 则 $L_e \approx L$、$R_e = \frac{(\omega_0 L)^2}{R}$

7. 互感

1. 同名端：知绕向

不 ： ： ：k, U_S. 电（交流）

— — — — 顺串，反串.

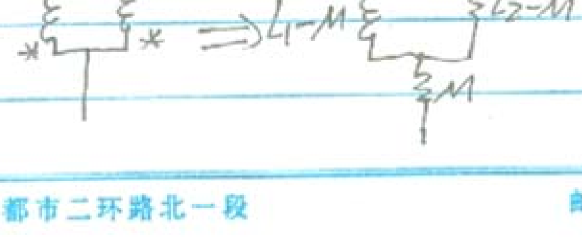
2. 分析计算

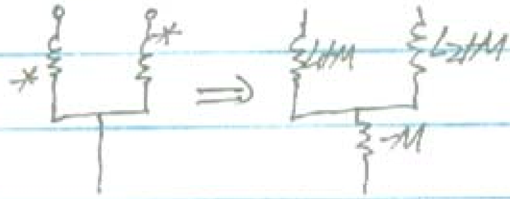
a. 有公共端：去耦合

顺串：$L = L_1 + L_2 + 2M$

反 ： ： $L = L_1 + L_2 - 2M$.

并联
有公端：



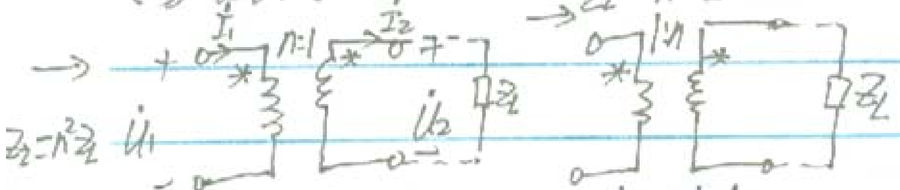


ii. 无互接.

受控源表示互感电压.

(2) 理想变压器.

$Z_2=\frac{1}{n^2}Z_L$



$\dot U_1=n\dot U_2$　　　$\dot U_1=\frac{1}{n}\dot U_2$

$\dot I_1=\frac{1}{n}\dot I_2$

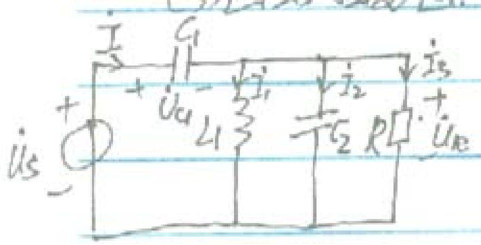
例: 已知 $\omega=10^3\ rad/s$, $C_1=10\mu F$, $C_2=4\mu F$,

$R=50\Omega$, 且知 $I_1=I_2$

图: 求 (1) L_1 的值.

(2) 若 $\dot U_R=100\angle 0^\circ V$, $\dot U_s=?$

(3) 画出相量图.



解: (1) $\omega=\frac{1}{\sqrt{L_1C_2}}$ (谐振)

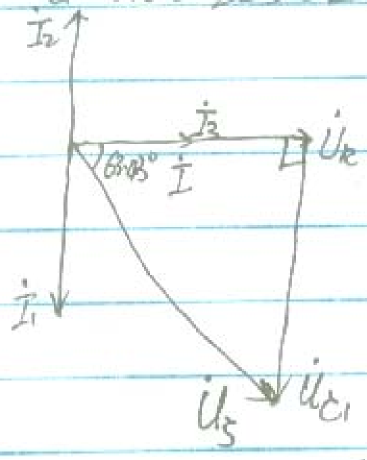
$\therefore L_1=0.25H$

(2) $\dot I=\dot I_3=\frac{\dot U_R}{50}=2\angle 0^\circ A$

$\dot U_{C_1}=\frac{1}{j\omega C_1}\dot I=-j200V$

∴ $\dot{U}_S = \dot{U}_{C1} + \dot{U}_R = 223.6\angle -63.43^\circ V$

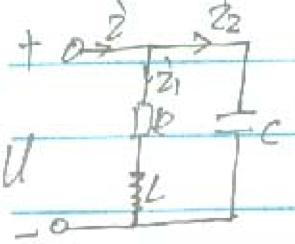
(3)



例：已知 $u = 200\sin 100t$ V，$i = 5\sin 100t$ A，

$R = 20\Omega$.

求 (1) 画出相量图. (2) 求 L、C 的值.



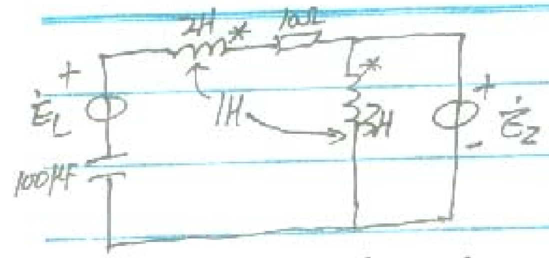
解：$Y = j\omega C + \frac{1}{R + j\omega L}$

$= \frac{R}{R^2 + (\omega L)^2} + j\underbrace{\left[\omega C - \frac{\omega L}{R^2 + (\omega L)^2}\right]}_{=0}$

∵ 谐振 ∴ $\frac{I}{U} = \frac{R}{R^2 + (\omega L)^2} = \frac{5}{200}$ ……①

$\omega C = \frac{\omega L}{R^2 + (\omega L)^2}$ ……②

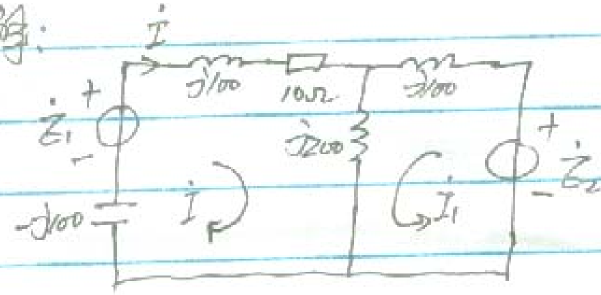
得：$\omega L = 20\Omega \rightarrow L = 0.2H$，$C = 250\mu F$.



已知：$\omega=100rad/s$, $\dot{E}_1=10\angle 30^\circ V$, $\dot{E}_2=5\angle 60^\circ V$.

求$\dot{U}$与$\dot{I}$及$\dot{E}_1$发出的有功、无功.

解：

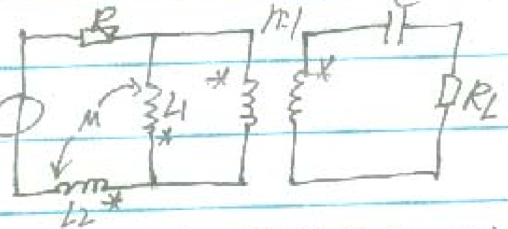


$$\begin{cases}(10+j100+j200-j100)\dot{I}+j200\dot{I}_1=\dot{E}_1\\ j200\dot{I}+(j100+j200)\dot{I}_1=\dot{E}_2\end{cases}$$

$\therefore \dot{I}=0.11\angle -64.67^\circ A$，而 $\dot{U}=\dot{E}_2=5\angle 60^\circ V$.

$\tilde{S}=\dot{E}_1\dot{I}^*=-0.09+j1.096VA$ $\therefore P=-0.09W$, $Q=1.096var$

例：



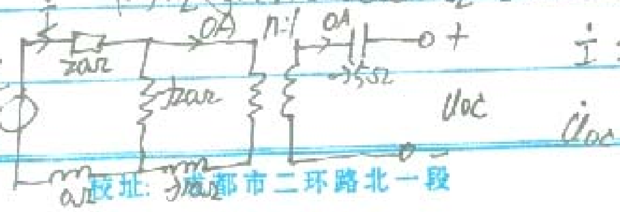
已知 $u_s=100\cos(10t)(V)$

$R=20\Omega$, $L_1=3H$, $L_2=1H$.

$M=1H$, $C=0.02F$.

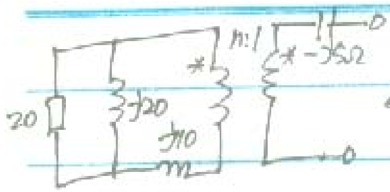
问R_L为何值时R_L可获最大功率？$P_{max}=?$

解：



$\dot{I}=\frac{50\sqrt{2}}{20+j20}$

$\dot{U}_{oc}=\frac{1}{n}j20\dot{I}=\frac{50}{n}\angle 45^\circ V$



$$\leftarrow Z_0 = -j5 + \frac{1}{n^2}\left(j10 + \frac{j400}{20+j20}\right)$$

虚部为0, → n.

$$\cancel{\frac{10}{n^2} - 5 = 0 \to n = 2}$$

$R_L = R_0$.

$$\left(\frac{U_{oc}}{2R}\right)^2 R_0 = P_{max}.$$

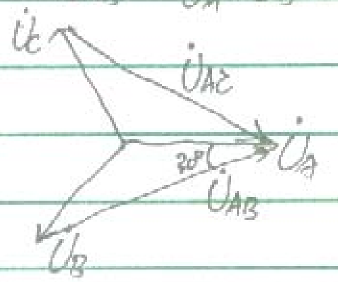
√ 三相电路

一、对称

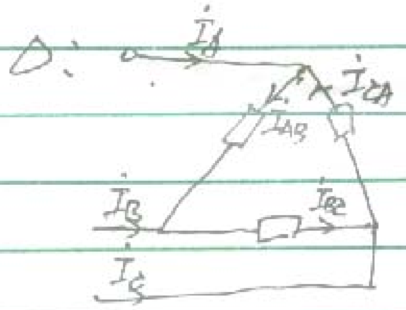
有效值相等，f相同，初相位依次相差120°，正序

二、Y、Δ接相线

Y：$\dot{U}_{AB}=\dot{U}_A-\dot{U}_B=\sqrt{3}\dot{U}_A\angle 30°$ ，$\dot{U}_{AC}=\sqrt{3}\dot{U}_A\angle -30°$



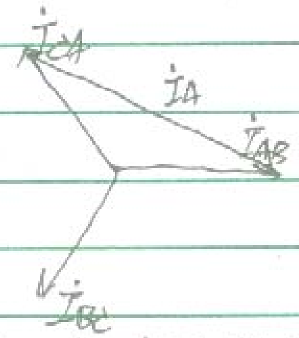
Δ：



$\dot{I}_A=\dot{I}_{AB}-\dot{I}_{CA}=\sqrt{3}\dot{I}_{AB}\angle -30°$

$\dot{I}_{CA}=\frac{\dot{I}_A}{\sqrt{3}}\angle 150°$

$\dot{I}_{BC}=\frac{\dot{I}_A}{\sqrt{3}}\angle -90°$



三、对称三相电路的计算

单相(A)

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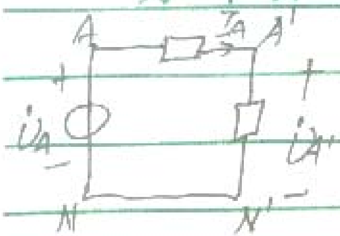
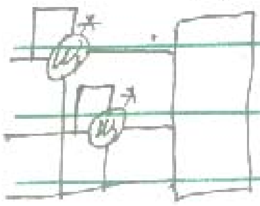


四、功率测量

$P=3U_pI_p\cos\varphi=\sqrt{3}U_lI_l\cos\varphi$，$\varphi$为相电压与相电流的相位差



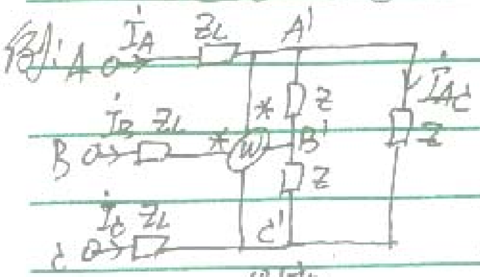
$P=W_1+W_2$

$W_1=U_{AC}I_A\cos\varphi_1$ → U_{AC}与I_A的相位差

五、不对称

普通正弦交流分析方法

例：

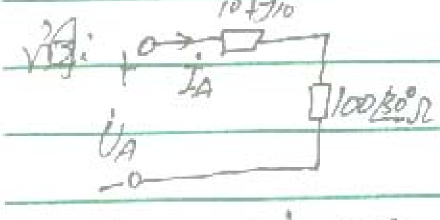


三相对称 $Z_l=10+j10\ \Omega$

负载 $Z=300\angle30^\circ\ \Omega$

电源线电压 $U_l=380V$，求 $\dot{I}_{AC}$，$\dot{U}_{A'B'}$ 和W的读数

解：



设 $\dot{U}_A=220\angle0^\circ V$

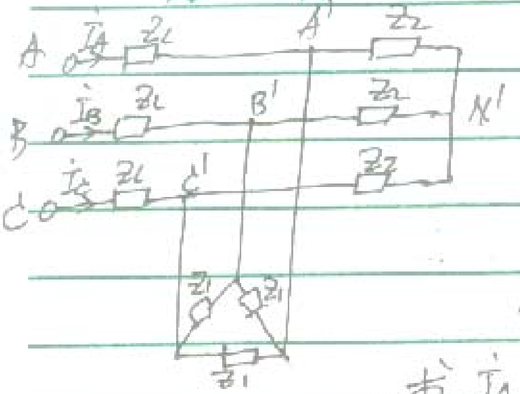
$\dot{I}_A=1.93\angle-31.24^\circ A$

$\dot{U}_{A'}=193\angle-1.84^\circ$

$\dot{U}_{A'B'}=\sqrt{3}\dot{U}_{A'}\angle30^\circ=334.28\angle28.16^\circ V$

∴ $\dot{I}_{AC}=-\dot{I}_{CA}=-\frac{\dot{I}_A}{\sqrt{3}}\angle150^\circ$

$W=U_{AC'}I_B\cos\varphi=\sqrt{3}\times193\times1.93\cos120^\circ=-322.58W$



电源对称.

已知 $\dot{U}_{A'B'} = 380\angle 30^\circ V$.

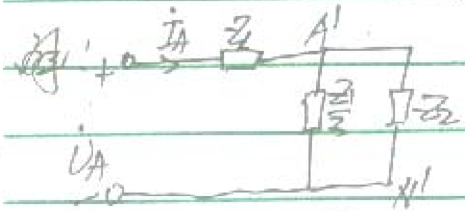
$Z_L = 0.2 + j0.2\Omega$, Z_1, Z_2 为感性负载

△接的总功率为 10kW, $\cos\varphi_1 = 0.8$

Y ——— 7.5kW, $\cos\varphi_2 = 0.88$.

求 $\dot{I}_A$, $\dot{I}_B$, $\dot{I}_C$ 及 $\dot{U}_{AB}$

解:



$$Z_1: I_{P1} = \frac{P_1}{3U_{P1}\cos\varphi_1} = \frac{10^4}{3\times 380\times 0.8} = 10.96A.$$

$$Z_1 = \frac{U_{P1}}{I_{P1}}\angle\varphi_1 = \frac{380}{10.96}\angle\varphi_1 = 34.67\angle 36.87^\circ \Omega.$$

$$Z_2: I_{P2} = \frac{P_2}{3\underbrace{U_{P2}}_{=220}\cos\varphi_2} = 12.95A.$$

$$\therefore Z_2 = \frac{U_{P2}}{I_{P2}}\angle\varphi_2 = 16.99\angle 28.36^\circ \Omega$$

$\dot{U}_{A'} = 220\angle 0^\circ V$

$$\dot{U}_A = Z_L\left(\frac{\dot{U}_{A'}}{\frac{Z_1}{3}} + \frac{\dot{U}_{A'}}{Z_2}\right) + \dot{U}_{A'} = 230.63\angle 1.41^\circ V$$

$$\dot{U}_{AB} = \sqrt{3}\,\dot{U}_A\angle 30^\circ = 399.46\angle 31.41^\circ V.$$

$$\dot{I}_A = \frac{\dot{U}_{A'}}{\frac{Z_1}{3}} + \frac{\dot{U}_{A'}}{Z_2} = 31.92\angle -33.42^\circ A.$$

$\therefore \dot{I}_B = 31.92\angle -153.42^\circ A$. $\dot{I}_C = 31.92\angle 86.6^\circ A$.

十、周期性非正弦电流电路.

1. 傅立叶级数展开.

$$f(t)=C_0+\sum_{k=1}^{\infty}C_k\cos(k\omega t+\varphi_k)$$

2. 步骤

叠加

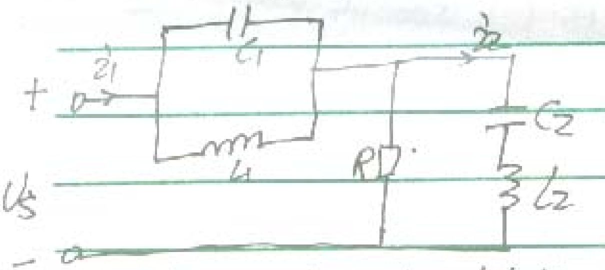
(1) 直流作用: C→开, L→短

(2) 各次谐波作用: 相量法.

(3) 瞬时值叠加.

(4) 有效值. $I=\sqrt{I_0^2+I_1^2+\cdots}$

(5) 有功功率: $P=U_0I_0+U_1I_1\cos\varphi_1+U_2I_2\cos\varphi_2+\cdots$



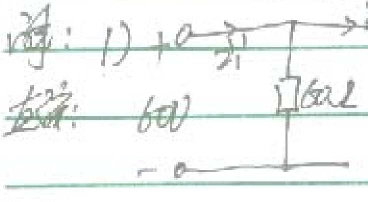
已知 $u_S=60+60\sqrt{2}\cos\omega t+20\sqrt{2}\cos2\omega t$,

$\omega L_1=\omega L_2=\frac{1}{\omega C_2}=100\Omega$, $\frac{1}{\omega C_1}=400\Omega$,

$R=60\Omega$.

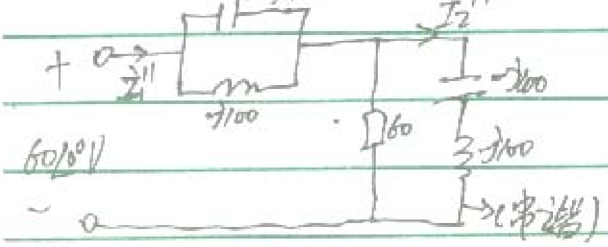
求: i_1, i_2 及其有效值, 电路吸收的有功功率.

解: 1) 直流:



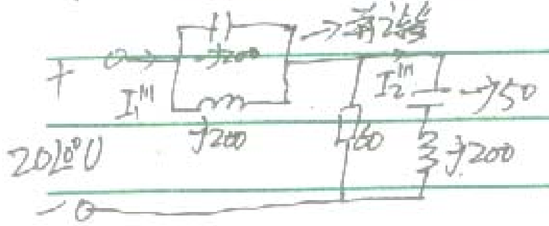
$\therefore i_1'=1A$, $i_2'=0$

2) 基波作用.



$$I_1''=I_2''=\frac{60}{\frac{j100(-j400)}{j100-j400}}=-j0.45A$$

3) 二次谐波作用　　　$\dot{I}_1''' = \dot{I}_2''' = 0$.



$i_1 = 1 + 0.45\sqrt{2}\cos(\omega t - 90°)A$.　$i_2 = \cancel{0.5}\ 0.45\sqrt{2}\cos(\omega t - 90°)A$.

$I_1 = \sqrt{1^2 + 0.45^2} = 1.097A$　$I_2 = 0.45A$.

$P = 60 \times 1 + 60 \times 0.45\cos(0 + 90°) = 60W$.

X　双口网络

1. 参数.

$$\begin{bmatrix}\dot{U}_1\\ \dot{U}_2\end{bmatrix} = \begin{bmatrix}Z_{11} & Z_{12}\\ Z_{21} & Z_{22}\end{bmatrix}\begin{bmatrix}\dot{I}_1\\ \dot{I}_2\end{bmatrix}\qquad \begin{bmatrix}\dot{U}_1\\ \dot{I}_1\end{bmatrix} = \begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}\dot{U}_2\\ -\dot{I}_2\end{bmatrix}$$

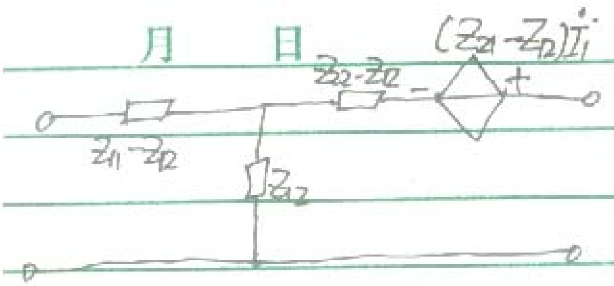
$$\begin{bmatrix}\dot{I}_1\\ \dot{I}_2\end{bmatrix} = \begin{bmatrix}Y_{11} & Y_{12}\\ Y_{21} & Y_{22}\end{bmatrix}\begin{bmatrix}\dot{U}_1\\ \dot{U}_2\end{bmatrix}\qquad \begin{bmatrix}\dot{U}_1\\ \dot{I}_2\end{bmatrix} = \begin{bmatrix}H_{11} & H_{12}\\ H_{21} & H_{22}\end{bmatrix}\begin{bmatrix}\dot{I}_1\\ \dot{U}_2\end{bmatrix}.$$

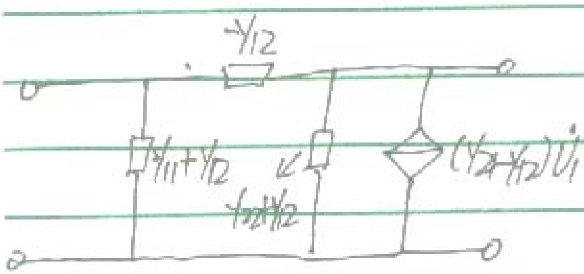
$\dot{U}_1 = A\dot{U}_2 - B\dot{I}_2$　令 $\dot{I}_2 = 0$, $A = \frac{\dot{U}_1}{\dot{U}_2}\Big|_{\dot{I}_2 = 0}$

令 $\dot{U}_2 = 0$, $B = \frac{\dot{U}_1}{-\dot{I}_2}\Big|_{\dot{U}_2 = 0}$

互易：$Z_{12} = Z_{21}$、$Y_{12} = Y_{21}$　$AD - BC = 1$.　$H_{12} = -H_{21}$.

2. 等效电路.



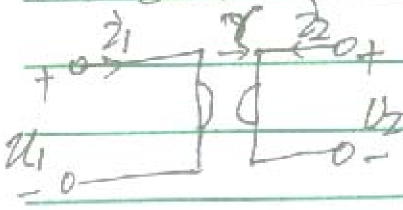


互易时受控源为零。

3. 联接

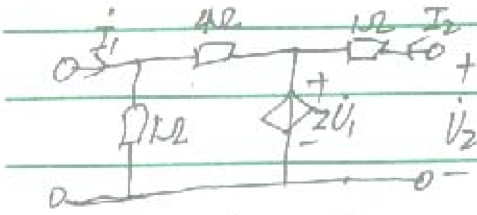
级联: $T=T_1T_2$, 串: $Z=Z_1+Z_2$, 并: $Y=Y_1+Y_2$.

4. 回转器.



$$\begin{cases} u_1=-r i_2 \\ u_2=r i_1 \end{cases}$$

求T参数.

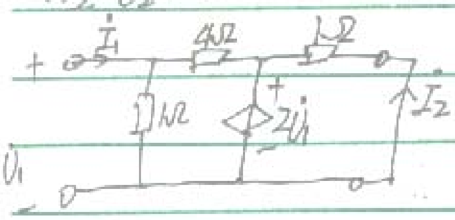


解: $\begin{cases} \dot{U}_1=A\dot{U}_2-B\dot{I}_2 \\ \dot{I}_1=C\dot{U}_2-D\dot{I}_2 \end{cases}$

令 $\dot{I}_2=0$, $\dot{U}_2=2\dot{U}_1$ $\therefore A=\frac{1}{2}$

$\dot{I}_1=\frac{\dot{U}_1}{1}+\frac{\dot{U}_1-2\dot{U}_1}{4}=\frac{3}{8}\dot{U}_2$ $\therefore C=\frac{3}{8}S$

令 $\dot{U}_2=0$



$\dot{I}_2=-\frac{2\dot{U}_1}{1}$ ∴ $B=\frac{\dot{U}_1}{-\dot{I}_2}\Big|_{\dot{U}_2=0}=0.5\Omega$

$\dot{I}_1=\frac{\dot{U}_1}{1}+\frac{\dot{U}_1-2\dot{U}_1}{4}=-\frac{3}{8}\dot{I}_2$

∴ $D=\frac{\dot{I}_1}{-\dot{I}_2}\Big|_{\dot{U}_2=0}=\frac{3}{8}$

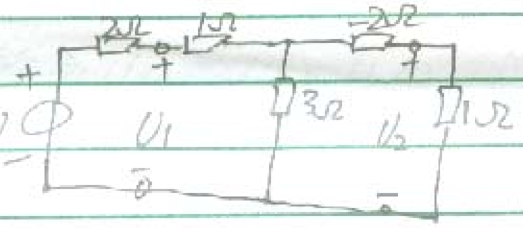
∴ $T=\begin{bmatrix}0.5 & 0.5\\ \frac{3}{8} & \frac{3}{8}\end{bmatrix}$

例:

已知: $U_S=3V$, 网络N中 $Z=\begin{bmatrix}4 & 3\\ 3 & 1\end{bmatrix}\Omega$

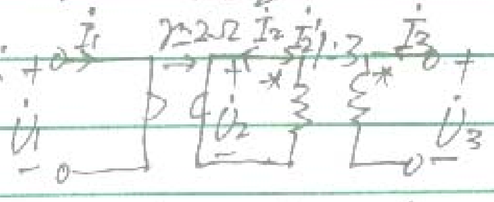
求 U_1、U_2 的值.

解:



$U_1=-1V$, $U_2=-3V$.

例:



解: 回转器: $\begin{cases}\dot{U}_1=-2\dot{I}_2\\ \dot{I}_1=0.5\dot{U}_2\end{cases}$ $\Rightarrow T_1=\begin{bmatrix}0 & 2\\ 0.5 & 0\end{bmatrix}$

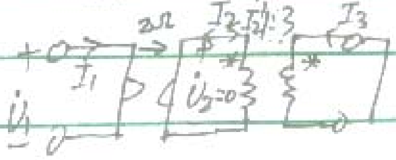
变压器: $\begin{cases}\dot{U}_2=\frac{1}{3}\dot{U}_3\\ \dot{I}_2'=-3\dot{I}_3\end{cases}$ $\Rightarrow T_2=\begin{bmatrix}\frac{1}{3} & 0\\ 0 & 3\end{bmatrix}$

∴ $T=\begin{bmatrix}0 & 2\\ 0.5 & 0\end{bmatrix}\begin{bmatrix}\frac{1}{3} & 0\\ 0 & 3\end{bmatrix}=\begin{bmatrix}0 & 6\\ \frac{1}{6} & 0\end{bmatrix}$

方法二：令 $\dot I_3=0$，则 $\dot U_1=0 \to A=0$

$\dot U_2=\frac{1}{3}\dot U_3$，$\dot I_1=0.5\dot U_2=\frac{1}{6}\dot U_3 \to C=\frac{1}{6}S$.

令 $\dot U_3=0$.



$$\begin{cases}\dot U_1=A\dot U_3-B\dot I_3\\ \dot I_1=C\dot U_3-D\dot I_3\end{cases}$$

$\dot U_1=-2\dot I_2=-2(+3\dot I_3)=-6\dot I_3$

$\to B=6\Omega$.

$\dot I_1=0.5\dot U_2=0 \to D=0$.

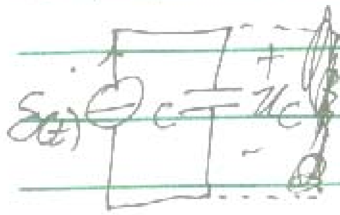
八、线性电路的时域分析.

1. 换路定则.

1) 一般 $i_L(0_+)=i_L(0_-)$，$u_C(0_+)=u_C(0_-)$ 冲激除外

多个电容的结点：$\sum Cu_C(0_+)=\sum Cu_C(0_-)$ } [illegible]不变

多个电感的回路：$\sum Li_L(0_+)=\sum Li_L(0_-)$

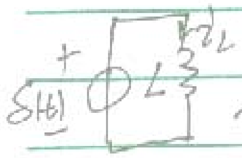


$u_C(0_+)=u_C(0_-)+\frac{1}{C}\int_{0_-}^{0_+}\delta(t)dt$

$=u_C(0_-)+\frac{1}{C}$

$i_L(0_+)=i_L(0_-)+\frac{1}{L}\int_{0_-}^{0_+}\delta(t)dt$

$=i_L(0_-)+\frac{1}{L}$



2. 初值的确定. 先求 $u_C(0_-)$，$i_L(0_-)$.

换路定则 $\to u_C(0_+)$，$i_L(0_+)$

0_+ 时刻电路：C → 电压源($u_C(0_+)$) L → 电流源.

确定其它的 0_+ 值

三、一阶电路

$y(t)=y_p(t)+[y(0_+)-y_p(0_+)]e^{-\frac{t}{\tau}}$

$y(0_+)$. $y_p(t)$：特解 {直流 → C 开路 L 短 呈稳态特解; 正弦 → 相量法 → $y_p(t)$}

τ：RC、$\frac{L}{R}$

R：从动态元件两端看进去的等效电阻（戴维南等效）

$\varepsilon(t)\to S(t)$ } 零状态
$S(t)\to h(t)$

$\varepsilon(t)=\begin{cases}1 & t>0\\ 0 & t<0\end{cases}$

$t<0$ $t>0$

$\varepsilon(t)$

$h(t)$：$\frac{dS(t)}{dt}$

零输入响应法

引言：$0_-\to 0_+$ 保证 $u_c(0_+)$、$i_L(0_+)$

二、二阶电路

(1) 列方程

(2) 确定 $u_c(0_+)$、$\frac{du_c}{dt}\Big|_{0_+}$

(3) $y(t)=y_p(t)+y_h(t)$
特解 齐次解通解

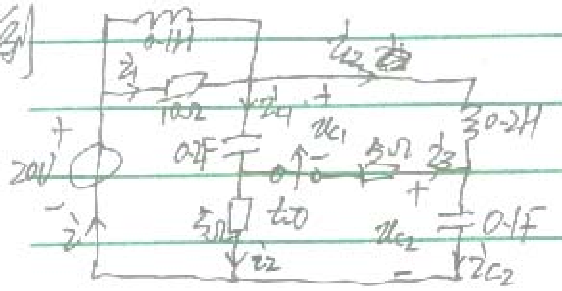
$y_h(t)=k_1e^{p_1t}+k_2e^{p_2t}$（不为实根）

$y_h(t)=Ke^{-\alpha t}\sin(\omega t+\varphi)\ (P_1=-\alpha+j\omega)$

$=e^{-\alpha t}[K_1\cos\omega t+K_2\sin\omega t]$

$y_h(t)=(K_1+K_2t)e^{pt}$（临界）

例



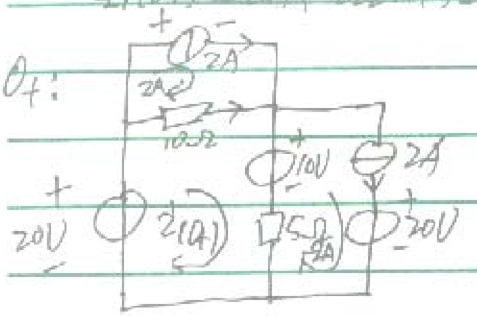
电路原为稳态 $t=0$ 时打开 K，求 0_+ 各支路电流及 $\frac{di_1}{dt}\Big|_{0_+}$

解：$i_{L1}(0_-)=i_{L2}(0_-)=2A$

$u_{C1}(0_-)=10V,\ u_{C2}(0_-)=20V.$

$i_{L1}(0_+)=2A,\ i_{L2}(0_+)=2A.\ u_{C1}(0_+)=10V.\ u_{C2}(0_+)=20V.$

0_+:



网孔：$(10+5)i(0_+)=20+2\times10-10+2\times5$

$\therefore i(0_+)=\frac{8}{3}A$

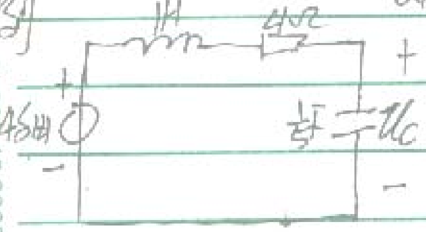
$i_{C2}(0_+)=2A$

$i_1(0_+)=\frac{2}{3}A.\ i_{C1}(0_+)=\frac{2}{3}A,\ i_3=0$

$i_2(0_+)=\frac{2}{3}A$

$0.1\times\frac{di_{L1}}{dt}\Big|_{0_+}=10i_1(0_+)\quad\therefore\frac{di_{L1}}{dt}\Big|_{0_+}=\frac{200}{3}$

例



零状态电路，求 $u_C(0_+)$，$\frac{du_C}{dt}\Big|_{0_+}$

解：$\frac{1}{5}\frac{d^2u_C}{dt^2}+4\times\frac{1}{5}\frac{du_C}{dt}+u_C=4\delta(t)$

$0_-\sim 0_+$ 积分

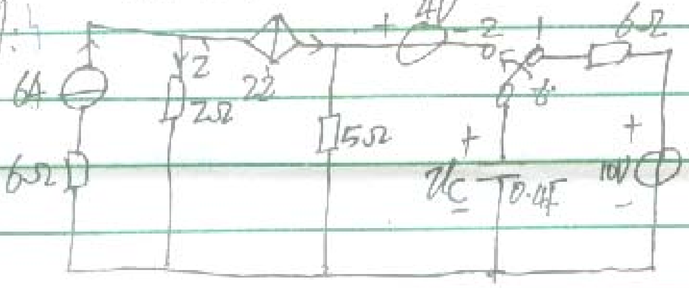
$$\frac{1}{5}\Big[\frac{du_C}{dt}\Big|_{0_+}-\underbrace{\frac{du_C}{dt}\Big|_{0_-}}_{=0}\Big]+\frac{4}{5}\Big[u_C(0_+)-\underbrace{u_C(0_-)}_{=0}\Big]=4$$

u_C不可能含$\delta(t)$，u_C有没有可能含$\varepsilon(t)$，(不可能含)

∴ $u_C(0_+)=u_C(0_-)=0$

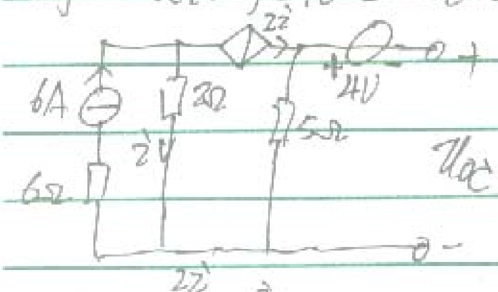
∴ $\frac{du_C}{dt}\Big|_{0_+}=20$

例：



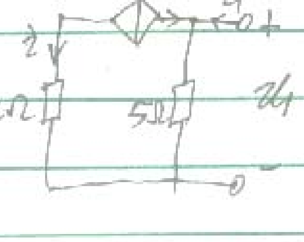
$t<0$为稳态，求$t\geq0$的$u_C(t)$

解：$u_C(0_-)=10=u_C(0_+)$



$i=\frac{6}{3}=2A$

$u_{oc}=-4+5\times2i=16V$

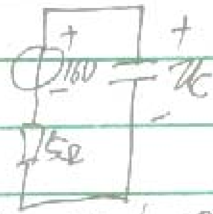


$2i=-i\Rightarrow i=0$ ∴ $u_1=5i_1$

∴ $R_0=5\Omega$

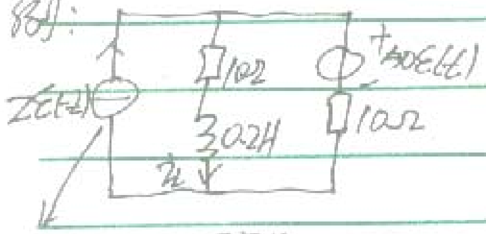
$\tau = R_0 C = 2s$

$u_C(\infty) = 16V.$



$\therefore u_C(t) = 16 + (10-16)e^{-\frac{t}{2}} = 16 - 6e^{-0.5t} \quad (t \geq 0).$

例:



求 $i_L(t)$

($t<0$, 有效. $t>0$, 不起作用)

解: 方法一: $t<0$ $i_L(0_-) = 1A$ $i_L(t) = 1A.$

$t \geq 0$ $i_L(0_+) = 1A$, $i_L(\infty) = \frac{50}{20} = 2.5A.$

$\tau = \frac{L}{R} = \frac{0.2}{20} = \frac{1}{100} s.$

$\therefore i_L(t) = 2.5 + [1 - 2.5]e^{-100t} \quad (t \geq 0)$

$i_L(t) = \varepsilon(-t) + [2.5 - 1.5e^{-100t}]\varepsilon(t) A$

方法2: 叠加

① $2\varepsilon(-t)$: $i_L' = 1 \quad (t<0)$. $i_L' = e^{-100t} \quad (t \geq 0)$

$\therefore i_L' = \varepsilon(-t) + e^{-100t}\varepsilon(t) A.$

② $50\varepsilon(t)$: $i_L'' = (2.5 - 2.5e^{-100t})\varepsilon(t) A.$

$\therefore i_L = i_L' + i_L''$

复频域分析:

1. $\varepsilon(t) \to \frac{1}{s}$ 运算.

1

$\delta(t) \leftrightarrow 1$.　$e^{-\alpha t} \leftrightarrow \frac{1}{s+\alpha}$，$\sin \omega t \leftrightarrow \frac{\omega}{s^2+\omega^2}$

$\cos \omega t \leftrightarrow \frac{s}{s^2+\omega^2}$　　$t \leftrightarrow \frac{1}{s^2}$

2. 叠加：

复频域位移：

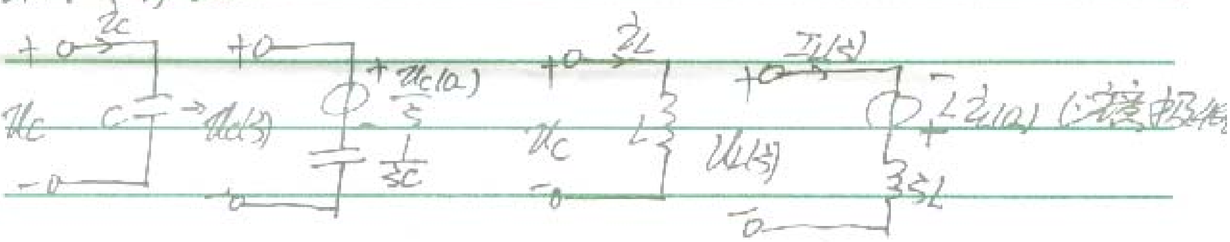
$f(t)e^{-\alpha t} \leftrightarrow F(s+\alpha)$

$\frac{df}{dt} \leftrightarrow sF(s)-f(0_-)$.

3. 反变换

部分分式展开：

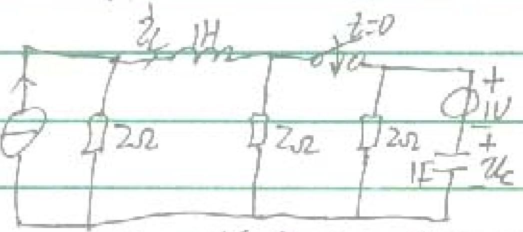
4. 运算电路



5. 网络函数（零状态）

$$H(s)=\frac{Y(s)}{F(s)}=\frac{\mathcal{L}[y_f(t)]}{\mathcal{L}[f(t)]}=\mathcal{L}[h(t)]$$

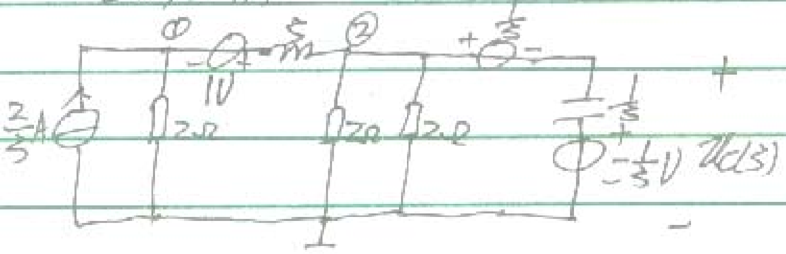
稳定：$H(s)$的所有极点位于S平面的左半平面



$t<0$ 稳态. $t>0$ 的 $u_C(t)$.

解: $u_C(0_-)=-1V$.

$i_L(0_-)=1A$.



$$\begin{cases}(\frac{1}{2}+\frac{1}{3})U_1-\frac{1}{3}U_2=\frac{2}{s}-\frac{1}{s}\\(\frac{1}{3}+\frac{1}{2}+\frac{1}{2}+s)U_2-\frac{1}{3}U_1=\frac{1}{s}\end{cases}$$

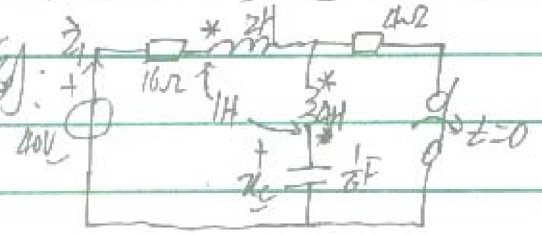
$\therefore U_2=\frac{s+4}{s(s^2+3s+3)}$

$u_C(s)=U_2-\frac{1}{s}=\frac{1}{3s}+\frac{-\frac{4}{3}s-3}{s^2+3s+3}$

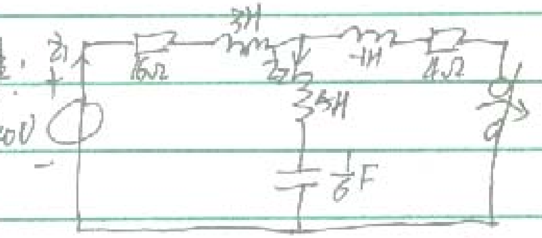
$=\frac{1}{3s}+\frac{-\frac{4}{3}(s+\frac{3}{2})-\frac{2}{\sqrt{3}}\cdot\frac{\sqrt{3}}{2}}{(s+\frac{3}{2})^2+(\frac{\sqrt{3}}{2})^2}$

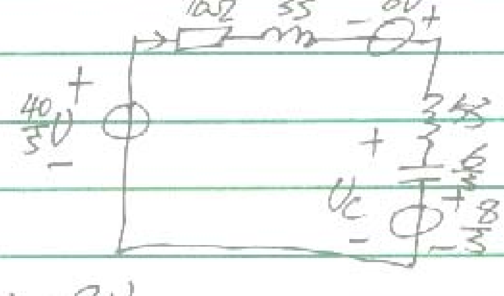
$\therefore u_C(t)=\frac{1}{3}-\frac{4}{3}e^{-\frac{3}{2}t}\cos\frac{\sqrt{3}}{2}t-\frac{2}{\sqrt{3}}e^{-\frac{3}{2}t}\sin\frac{\sqrt{3}}{2}t$

例:



解:





$i_1(0_-)=2A$, $i_2(0_-)=0$. $u_C(0_-)=8V$

十、状态方程及输出方程

1. 选 u_C, i_L 为状态变量

独立!

回路：电容、电压源，少选一个 u_C

结点：电感、电流源：——— i_L

二、列写状态方程组

① C→电压源 L→电流源 →求 $i_C = C\frac{du_C}{dt}$

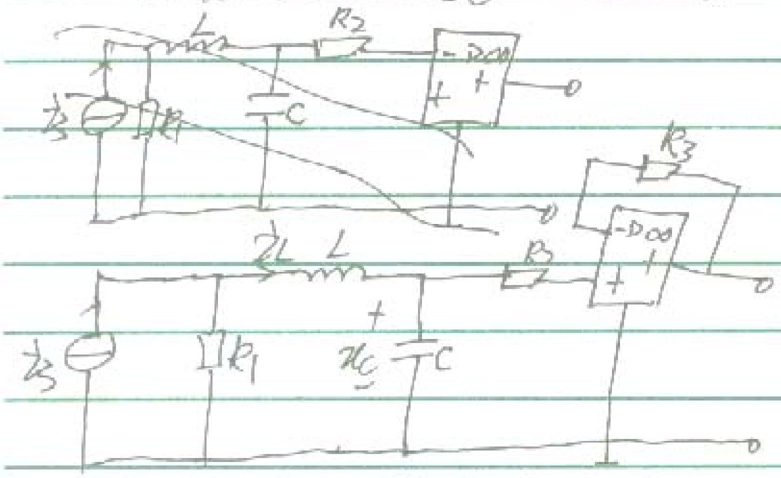
$u_L = L\frac{di_L}{dt}$

② 线性特有网时：写C的基本割集的KCL方程

写L —— 回路 —— KVL ——.

3. 输出方程：

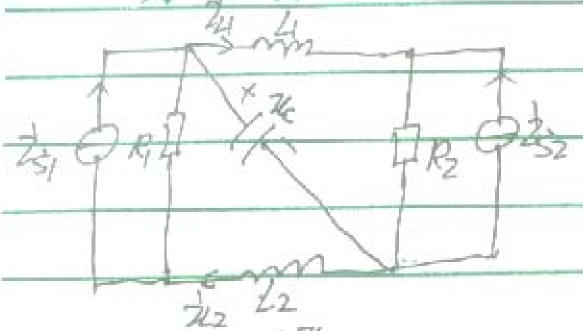
代数方程：电路图7(1)

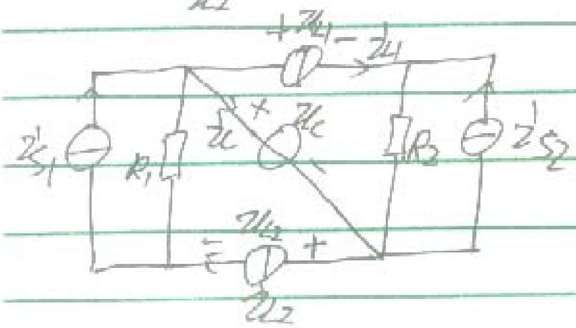


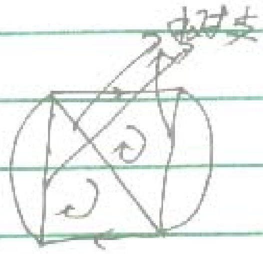
解：选 u_C i_L 为状态变量

$$\begin{cases} C\frac{du_C}{dt} = i_L \\ \dfrac{L\frac{di_L}{dt}+u_C}{R_1} + i_L = i_S \end{cases}$$

$$\begin{bmatrix} \frac{du_C}{dt} \\ \frac{di_L}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & -\frac{R_1}{L} \end{bmatrix} \begin{bmatrix} u_C \\ i_L \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{R_1}{C} \end{bmatrix} i_S$$







$$\begin{bmatrix} \frac{du_C}{dt} \\ \frac{di_{L1}}{dt} \\ \frac{di_{L2}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{C} & \frac{1}{C} \\ \frac{1}{L_1} & -\frac{R_2}{L_1} & 0 \\ -\frac{1}{L_2} & 0 & \frac{R_1}{L_2} \end{bmatrix} \begin{bmatrix} u_C \\ i_{L1} \\ i_{L2} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & \frac{R_2}{L_1} \\ -\frac{R_1}{L_2} & 0 \end{bmatrix} \begin{bmatrix} i_{S1} \\ i_{S2} \end{bmatrix}$$

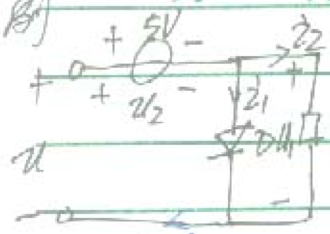
十、非线性电阻电路.

(1) 图解法：$\begin{cases} \text{曲线相加} \to \text{二端口伏安特性.} \\ \text{曲线相交} \end{cases}$

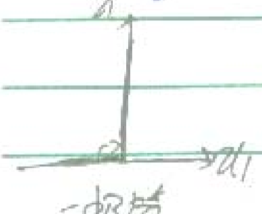
(2) 分段线性法.

(3) 小信号分析.

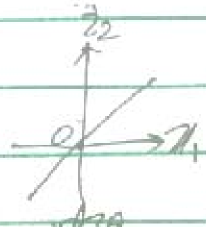
例



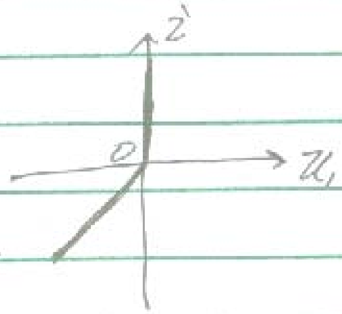
D为理想二极管，画出 $u \sim i$

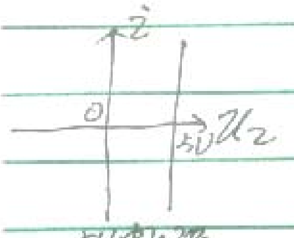


二极管

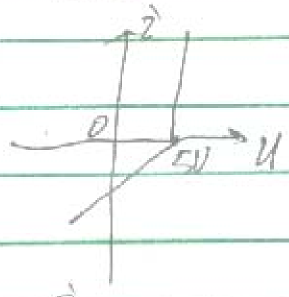


电阻

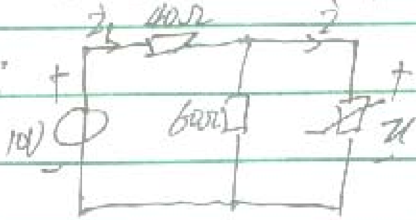




5V电压源



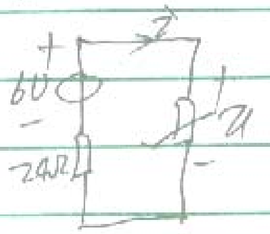
例：



$i = 0.5u^2$

求 i 与 i_1

解：



KVL: $u + 24i = 6$

$\therefore 12u^2 + u - 6 = 0$

$\therefore u = \begin{cases} \frac{2}{3}V \\ -\frac{3}{4}V \end{cases} \Rightarrow i = \begin{cases} 0.222A \\ 0.2813A \end{cases}$

$i_1 = i + \frac{u}{60} = \begin{cases} 0.233A \\ 0.269A \end{cases}$ $\therefore \begin{cases} i = 0.222A \\ i_1 = 0.233A \end{cases}$

$\begin{cases} i = 0.2813A \\ i_1 = 0.269A \end{cases}$