

东南大学电工电子实验中心 实验报告

课程名称： 电路实验

第 8 次实验

实验名称： 黑箱电路元件判别及参数测试

院（系）： 自动化学院 专 业： 自动化

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实 验 室： 105 实验组别：

同组人员： 实验时间： 2023 年 12 月 26 日

评定成绩： 审阅教师：

一、实验目的

- (1) 运用欧姆定律和元件的阻抗特性解决实际问题。
- (2) 学会根据需选择激励源的类型、设定频率的高低，简化测量过程、提高测量精度。
- (3) 尝试从分析任务要求着手，应用已经学习过的知识，寻找解决问题的方法；同时也希望拓宽视野，体验解决问题方法的多样性。学习体验“分析任务-调查研究-设计电路-构建平台-实验测试-总结分析”的科学研究方法。

二、实验原理

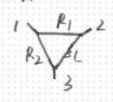
(1) 至少一个电阻条件下，枚举由 R、L、C 所有可能构成的“Y”型网络，分析每种可能网络各端口之间（1-2，2-3，1-3）的直流特性和交流特性（交流阻抗、幅度-频率，相位-频率）：

Y型	直流	交流特性
① RRL 	$1-2: R_{12} = R_1 + R_2$ $1-3: R_{13} = R_1 + r$ $2-3: R_{23} = R_2 + r$	$Z_{12} = R_1 + R_2$ $Z_{13} = R_1 + r + j\omega L$ $Z_{23} = R_2 + r + j\omega L$ $\omega \uparrow, Z \uparrow, \Delta \varphi \uparrow$ $\text{感性 } 0 < \varphi < 90^\circ$
② RRC 	$1-2: R_{12} = R_1 + R_2$ $1-3: R_{13} = \infty$ $2-3: R_{23} = \infty$	$Z_{12} = R_1 + R_2$ $Z_{13} = R_1 - j\frac{1}{\omega C}$ $Z_{23} = R_2 - j\frac{1}{\omega C}$ $\omega \uparrow, Z \downarrow, \Delta \varphi \downarrow$ $\text{容性 } -90^\circ < \varphi < 0$
③ RLL 	$1-2: R_{12} = R + r_1$ $1-3: R_{13} = R + r_2$ $2-3: R_{23} = r_1 + r_2$	$Z_{12} = R + r_1 + j\omega L_1$ $Z_{13} = R + r_2 + j\omega L_2$ $Z_{23} = r_1 + j\omega L_1 + r_2 + j\omega L_2$ $\omega \uparrow, Z \uparrow, \Delta \varphi \uparrow, \varphi < 90^\circ$ $\text{感性 } 0 < \varphi < 90^\circ$
④ RCC 	$1-2: R_{12} = \infty$ $1-3: R_{13} = \infty$ $2-3: R_{23} = \infty$	$Z_{12} = R - j\frac{1}{\omega C_1}$ $Z_{13} = R - j\frac{1}{\omega C_2}$ $Z_{23} = -j\frac{1}{\omega C_1} - j\frac{1}{\omega C_2}$ $\omega \uparrow, Z \downarrow, \Delta \varphi \downarrow$ $\text{容性 } -90^\circ < \varphi < 0$
⑤ RLC 	$1-2: R_{12} = R + r$ $1-3: R_{13} = \infty$ $2-3: R_{23} = \infty$	$Z_{12} = R + r + j\omega L$ $Z_{13} = R - j\frac{1}{\omega C}$ $Z_{23} = r + j\omega L - j\frac{1}{\omega C}$ $\omega \uparrow, Z \uparrow, \Delta \varphi \uparrow$ $\omega \uparrow, Z \downarrow, \Delta \varphi \downarrow$ $\omega \rightarrow 0 \text{ 或 } \infty, Z \rightarrow \infty$ $\omega = \frac{1}{\sqrt{LC}} \text{ 时 } Z _{\min} = r, \Delta \varphi = 0$ $\omega < \frac{1}{\sqrt{LC}} \text{ 感性 } 0 < \varphi < 90^\circ$ $\omega > \frac{1}{\sqrt{LC}} \text{ 容性 } -90^\circ < \varphi < 0$

(2) 至少一个电阻条件下，枚举由 R、L、C 所有可能的“△”型网络，分析每种可能网络各端口之间（1-2，2-3，1-3）的直流特性和交流特性（交流阻抗、幅度-频率，相位-频率）；

“△”型

① RRL:



直流:

$$1-2: R_{12} = R_1 \parallel (R_2 + R_3)$$

$$1-3: R_{13} = R_2 \parallel (R_1 + R_3)$$

$$2-3: R_{23} = R_3 \parallel (R_1 + R_2)$$

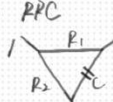
交流特性:

$$Z_{12} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2 + R_3 j\omega L}} \quad \omega \uparrow, |Z| \rightarrow R_1, \phi \text{ 不变}$$

$$Z_{13} = \frac{1}{\frac{1}{R_2} + \frac{1}{R_1 + R_3 j\omega L}} \quad \omega \uparrow, |Z| \rightarrow R_2, \phi \text{ 不变}$$

$$Z_{23} = \frac{1}{\frac{1}{R_3} + \frac{1}{R_1 + R_2 j\omega L}} \quad \omega \uparrow, |Z| \rightarrow R_3, \phi \text{ 不变}$$

② RPC:



直流:

$$1-2: R_{12} = R_1$$

$$1-3: R_{13} = R_2$$

$$2-3: R_{23} = R_1 + R_2$$

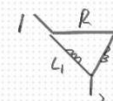
交流特性:

$$Z_{12} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2 - j\omega C}} \quad \omega \uparrow, |Z| \rightarrow R_1 \parallel R_2, \phi \text{ 不变}$$

$$Z_{13} = \frac{1}{\frac{1}{R_2} + \frac{1}{R_1 - j\omega C}} \quad \omega \uparrow, |Z| \rightarrow R_1 \parallel R_2, \phi \text{ 不变}$$

$$Z_{23} = \frac{1}{\frac{1}{R_1 + R_2} + \frac{1}{-j\omega C}} \quad \omega \uparrow, |Z| \rightarrow \infty, \phi \rightarrow 0$$

③ RLL:



直流:

$$1-2: R_{12} = R \parallel (R_1 + R_2)$$

$$1-3: R_{13} = R_1 \parallel (R + R_2)$$

$$2-3: R_{23} = R_2 \parallel (R + R_1)$$

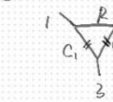
交流特性:

$$Z_{12} = \frac{1}{\frac{1}{R} + \frac{1}{R_1 j\omega L + R_2 j\omega L}} \quad \omega \uparrow, |Z| \rightarrow R, \phi \downarrow$$

$$Z_{13} = \frac{1}{\frac{1}{R_1} + \frac{1}{R + R_2 j\omega L}} \quad \omega \uparrow, |Z| \rightarrow \infty, \phi \downarrow$$

$$Z_{23} = \frac{1}{\frac{1}{R_2} + \frac{1}{R + R_1 j\omega L}} \quad \omega \uparrow, |Z| \rightarrow \infty, \phi \downarrow$$

④ RCC:



直流:

$$1-2: R_{12} = R$$

$$1-3: R_{13} = \infty$$

$$2-3: R_{23} = \infty$$

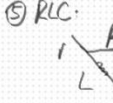
交流特性:

$$Z_{12} = \frac{1}{\frac{1}{R} + \frac{1}{-j\omega C_1 - j\omega C_2}} \quad \omega \uparrow, |Z| \rightarrow 0, \phi \downarrow$$

$$Z_{13} = \frac{1}{\frac{1}{-j\omega C_1} + \frac{1}{R - j\omega C_2}} \quad \omega \uparrow, |Z| \rightarrow \infty, \phi \downarrow$$

$$Z_{23} = \frac{1}{\frac{1}{-j\omega C_2} + \frac{1}{R - j\omega C_1}} \quad \omega \uparrow, |Z| \rightarrow \infty, \phi \downarrow$$

⑤ RLC:



直流:

$$1-2: R_{12} = R$$

$$1-3: R_{13} = R$$

$$2-3: R_{23} = R + R$$

交流特性:

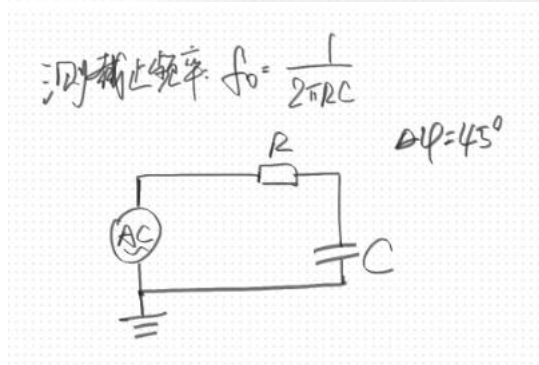
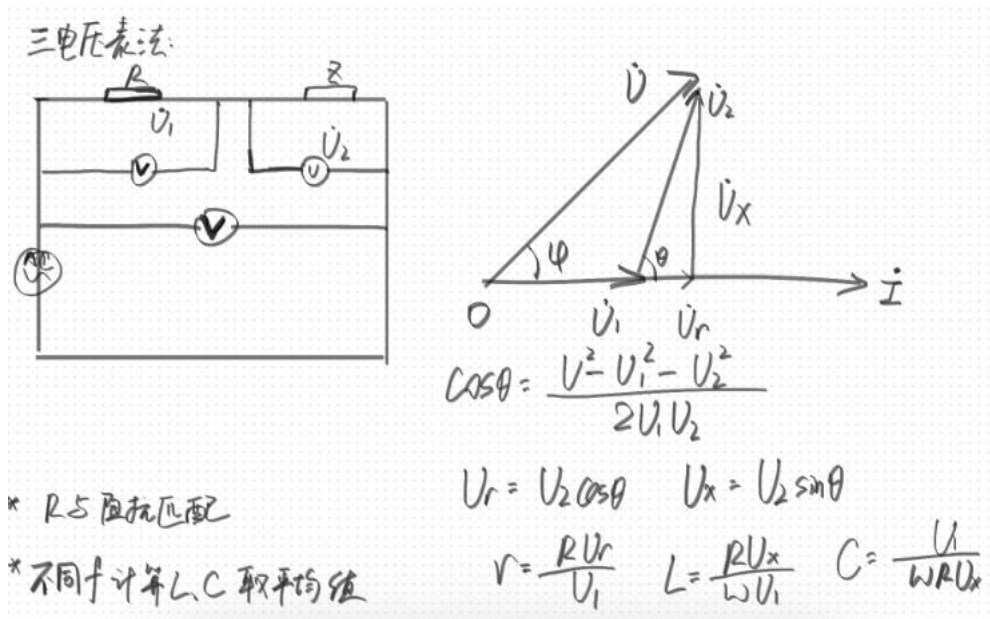
$$Z_{12} = \frac{1}{\frac{1}{R} + \frac{1}{R j\omega L - j\omega C}} \quad \omega \uparrow, |Z| \rightarrow R$$

$$Z_{13} = \frac{1}{\frac{1}{R j\omega L} + \frac{1}{R - j\omega C}} \quad \omega \uparrow, |Z| \rightarrow R$$

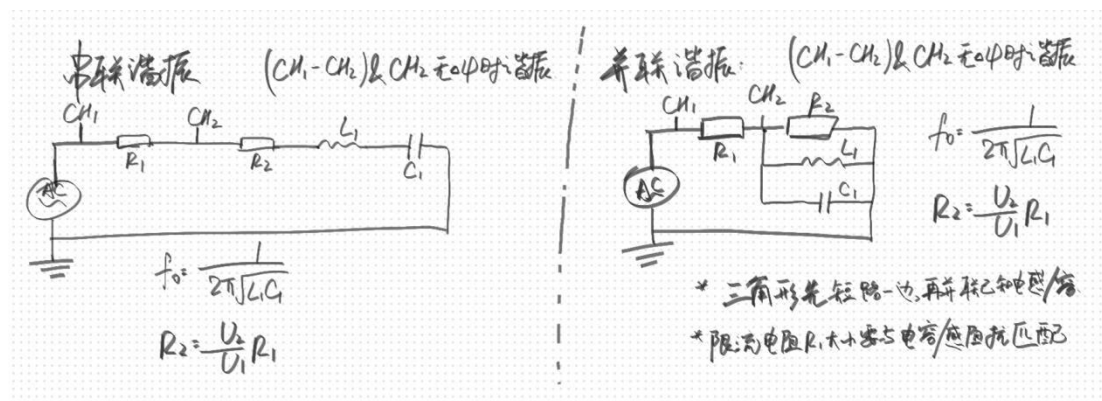
$$Z_{23} = \frac{1}{\frac{1}{-j\omega C} + \frac{1}{R + R j\omega L}} \quad \omega \uparrow, |Z| \rightarrow 0$$

$\omega < \frac{1}{\sqrt{LC}}$	$\omega = \frac{1}{\sqrt{LC}}$	$\omega > \frac{1}{\sqrt{LC}}$
$\phi \downarrow$	ϕ_{min}	$\phi \uparrow$
$\phi \uparrow$	ϕ_{max}	$\phi \downarrow$
$\phi \uparrow$	ϕ_{max}	$\phi \downarrow$

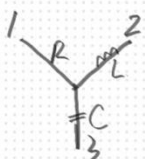
(3) 复习元件参数测量、三电压法测交流阻抗测量、电路频率响应实验的相关内容；



(4) 复习 RLC 串联谐振相关知识及串联判断测量方法；查找资料，了解 RLC 并联谐振相关知识及并联谐振判断测量方法。



(5) “Y”型连接, 假设三个元件分别为 RLC, 写出该电路中各元件性质的判断过程和元件参数计算过程;



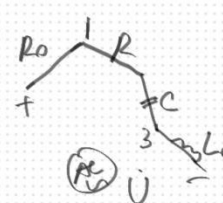
直流: $R_{12} = R + r$
 $R_{13} = \infty$
 $R_{23} = \infty$

交流: $Z_{12} = R + r + j\omega L$
 $|Z| = \sqrt{(R+r)^2 + (\omega L)^2}$
 $\varphi = \arctan\left(\frac{\omega L}{R+r}\right)$
 $\omega = 0, Z = R + r$
 $\omega \uparrow: |Z| \uparrow, \varphi \uparrow \text{ 且 } \varphi < 90^\circ$

$Z_{13} = R - j\frac{1}{\omega C}$
 $|Z| = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$
 $\varphi = \arctan\left(\frac{1}{\omega CR}\right)$
 $\omega \uparrow, |Z| \downarrow, \varphi \downarrow$

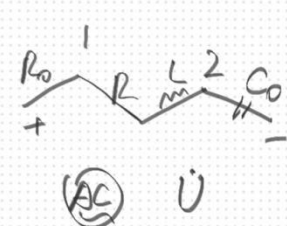
$Z_{23} = r + j\omega L - j\frac{1}{\omega C}$
 $\omega > \frac{1}{\sqrt{LC}}: |Z| \uparrow \rightarrow \infty, \text{感性}$
 $\omega < \frac{1}{\sqrt{LC}}: \omega \rightarrow 0, |Z| \uparrow \rightarrow \infty, \text{容性}$

利用串联谐振测元件参数:



$f_0 = \frac{1}{2\pi\sqrt{CL_0}}$ L_0 已知, 可求 C 值
 谐振频率 $C = \frac{1}{L_0 4\pi^2 f_0^2}$

$\frac{R_0}{U_0} = \frac{R}{U_R}$ 可求 R 值
 $R = \frac{U_R R_0}{U_0}$



同理右边求 C

(6) “△”型连接, 假设三个元件分别为 RLC, 写出该电路中各元件性质的判断过程和各元件参数计算过程。



直接: $\begin{cases} R_{12} = R \\ R_{13} = r \\ R_{23} = R+r \end{cases}$

或: 流

$$Z_{12} = \frac{1}{\frac{1}{R} + \frac{1}{r+j\omega L - j\frac{1}{\omega C}}}$$

$$\begin{cases} \omega \rightarrow \infty & Z=R \\ \omega = \frac{1}{\sqrt{LC}} & Z=0 \\ \omega < \frac{1}{\sqrt{LC}} & \omega \uparrow, |Z - \frac{1}{\omega C}| \downarrow, \varphi \downarrow \\ \omega > \frac{1}{\sqrt{LC}} & \omega \uparrow, |Z - \frac{1}{\omega C}| \uparrow, \varphi \uparrow \end{cases}$$

$$Z_{13} = \frac{1}{\frac{1}{r+j\omega L} + \frac{1}{R - j\frac{1}{\omega C}}}$$

$$\varphi = \arctan\left(\frac{R^2 C}{L - \frac{1}{\omega^2 C}}\right)$$

$$\begin{cases} 0 < \omega < \frac{1}{\sqrt{LC}} & \omega \uparrow, |\varphi| \uparrow \\ \omega = \frac{1}{\sqrt{LC}} & \varphi_{\max} \\ \omega > \frac{1}{\sqrt{LC}} & |\varphi| \downarrow \\ \omega \rightarrow \infty & Z_{13}=R \end{cases}$$

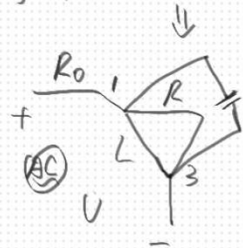
$$Z_{23} = \frac{1}{\frac{1}{-j\frac{1}{\omega C}} + \frac{1}{R+r+j\omega L}}$$

$$\varphi = \arctan\left(\frac{R^2}{\omega L^2 - \frac{1}{C}}\right)$$

$$\begin{cases} 0 < \omega < \frac{1}{\sqrt{LC}} & \omega \uparrow, \varphi \uparrow \\ \omega = \frac{1}{\sqrt{LC}} & \varphi_{\max} \\ \omega > \frac{1}{\sqrt{LC}} & \varphi \downarrow \\ \omega \rightarrow \infty & Z \rightarrow 0 \end{cases}$$

利用并联谐振测元件参数:

测 L, 先短路 23



再并联已知 C_0

$$\text{谐振时 } f_0 = \frac{1}{2\pi\sqrt{LC_0}}$$

$$\therefore L = \frac{1}{C_0 4\pi^2 f_0^2}$$

$$R = \frac{U_R R_0}{U_0}$$

测 C 同理

先短路再并联已知 L_0

三、实验内容

四、实验使用仪器设备（名称、型号、规格、编号、使用状况）

SDG1032X 信号源

SDG3055X-E 万用表

GDS1102B 示波器

Multisim 软件

五、实验总结

（实验出现的问题及解决方法、思考题（如有）、收获体会等）

六、参考资料（预习、实验中参考阅读的资料）

《电路基础》第 6 版