Experiment 3: The research of Thevenin theorem

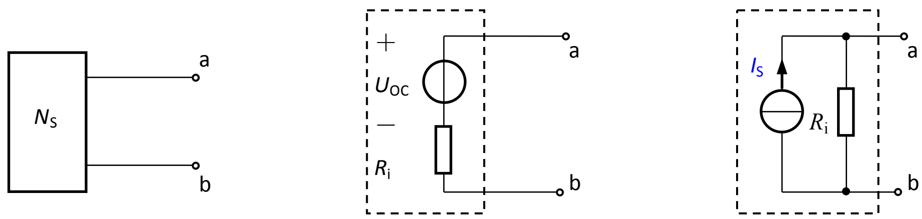
1. Purpose

a) Validate Thevenin theorem;
b) Master the methods to measure the equivalent parameters of linear two-terminal active network.
c) Study the conditions of the maximum output power in the linear two-terminal active network.

2. Principal and Illustration

A. Linear two-terminal active network and its equivalent circuit.

In any linear two-terminal active network $N_{S,}$ as shown in Figure 3-3-1(a), if only studying the external circuit of the network, we can regard the network as Thevenin equivalent circuit of resistance and voltage source in series, as shown in Figure 3-3-1(b), or Norton equivalent circuit of resistance and current source in parallel, as shown in Figure 3-3-1(c).



(a) Linear two-terminal active network (b)Thevenin equivalent circuit (c)Norton equivalent circuit

Thevenin theorem: Any linear active two-terminal network always can be replaced by voltage and current source for the external circuit. The voltage U_S of voltage source is equal to open circuit voltage U_{OC} of the two-terminal active network and its resistance R_i is equal to the equivalent resistance R_{eq} after all independent sources set to be zero.

B. Methods to measure the equivalent parameters of linear two-terminal active networks

(1) *Open circuit voltage method and short circuit current method*

Use a voltmeter to measure open circuit voltage U_{OC} between the output terminals of the network directly when the output terminals are open connected. Then, use an ammeter to measure the current I_{SC} of the network when the output terminals are short connected. The equivalent resistance of the two-terminal network can be estimated by:

$$R_{eq} = \frac{U_{OC}}{I_{SC}} \tag{3-3-1}$$

(2) *Voltage-current method*

Use a voltmeter and an ammeter to measure the external characteristic of the two-terminal active network, as shown in Figure 3-3-2. Utilize the external characteristic curve to calculate slope tan(φ). The equivalent resistance of the two-terminal network can be estimated by:

$$R_{eq} = \tan\varphi = \frac{\Delta U}{\Delta I} = \frac{U_{OC}}{I_{SC}} \tag{3-3-2}$$

If the internal resistance of two-terminal network is very small, it's not suitable to measure short circuit current. We can use voltage-current method in this case, to measure the open circuit voltage U_{OC}, and the output voltage U_N when the current of the two-terminal active network is fixed to I_N. The equivalent resistance of the two-terminal network can be estimated by:

$$R_{eq} = \frac{U_{OC} - U_N}{I_N} \tag{3-3-3}$$

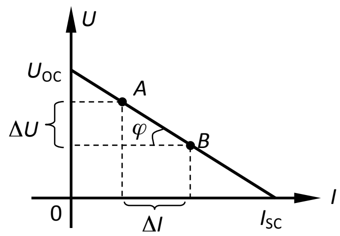


Figure 3-3-2 voltage-current characteristic of active two-terminal network

(3) *Half voltage method*

As shown in Figure 3-3-3, when load voltage is half of the open circuit voltage of the measured network, the resistance of load resistor is equal to the equivalent internal resistance R_{eq} of the two-terminal active network.

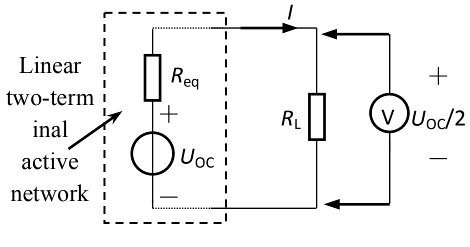


Figure 3-3-3 Use half voltage method to measure R_{eq} circuit

(4) *Zero Method*

If the two-terminal active network has a high internal resistance, using a voltmeter to directly measure it may cause a rather big error. In this case, we can use Zero method to eliminate the effect of the internal resistance of the Voltmeter.

The principal of zero method: comparing the two-terminal active network with a voltage-stabilized source of low internal resistance, when the output voltage of the voltage-stabilized source is equal to the open circuit voltage of the two-terminal active network, the voltmeter shows "0", as shown in figure 3-3-4. Then, open the electric circuit and measure the output voltage of the voltage-stabilized source, which is equal to the open circuit voltage of the measured active two-terminal network.

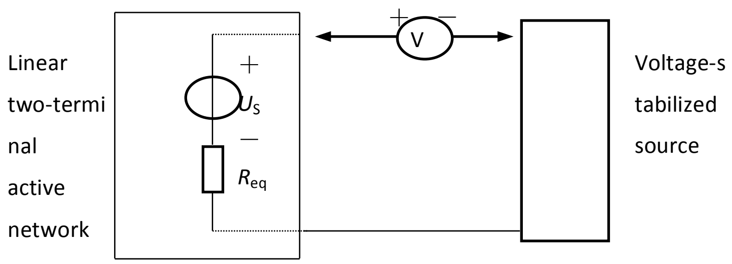


Figure 3-3-4 Use zero method to measure Us

3. Contents and Steps

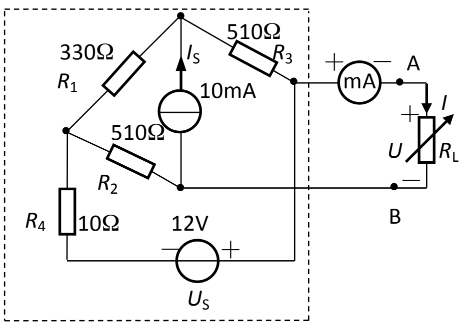


Figure 3-3-5 the external characteristic circuit of the two-terminal active network

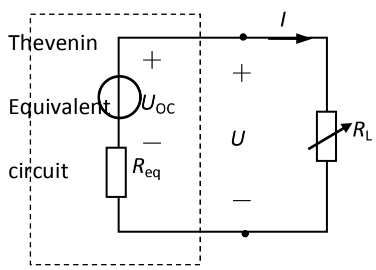


Figure 3-3-6 Thevenin equivalent circuit

A. Use open circuit voltage method and short circuit current method to measure U_{oc} and R_{eq} of the two-terminal active network

As show in Figure 3-3-5, the voltage-stabilized source Us and constant-current source Is are connected into the linear two-terminal active network. Open the circuit at load R_L to get the two terminals A and B, then, use a voltmeter to measure the voltage U_{AB} between A and B, and we will have $U_{OC} = U_{AB}$. Measure the current I_{sc} when the the circuit is short connected at load R_L. Record the corresponding voltages and currents into the Table 3-3-1.

Table 3-3-1. The measured data for U_{OC}, I_{sc}, R_{eq} of the two-terminal active network

U_{OC}(V)	I_{SC}(mA)	$R_{eq}=U_{OC}/I_{SC}(\Omega)$

B. Measure the external characteristics of the linear two-terminal active network

As shown in Figure 3-3-5, the variable resistance box R_L is connected between terminals A and B of the two-terminal active network. Change the resistance of R_L, as shown in Table 3-3-2, and measure the external characteristics of the network. Record the corresponding voltages and currents into the Table 3-3-2.

Table 3-3-2. The measured data for the external characteristics of active two-terminal network.

$R_L(\Omega)$	0	100	400	450	500	R_{eq}	550	600	800	1k	2k	5k	∞
U(V)													
I(mA)													

C. Validate Thevenin theorem.

Use a variable resistance box and choose the resistance equal to the equivalent resistance R_{eq}, as shown in Step "A". Then, connect the variable resistance box and DC voltage-stabilized source (equal to the measured open circuit voltage as shown in Step "A") in series and construct Thevenin equivalent circuit of the two-terminal active network, as shown in Figure 3-3-6.

Change the resistance of R_L, as shown in Table 3-3-3, and measure the external characteristics of the network. Record the corresponding voltages and currents into the Table 3-3-3.

Table 3-3-3. The measured data for the external characteristics of the Thevening equivalent circuit.

$R_L(\Omega)$	0	100	400	450	500	R_{eq}	550	600	800	1k	2k	5k	∞
U(V)													
I(mA)													

D. The study of the conditions of maximum power transfer.

Based on the data you record in Step “C”, calculate the power absorbed by R_L and record these values into Table 3-3-4.

Table 3-3-4. The measured data for studying the maximum power transfer conditions in Thevenin equivalent circuit.

$R_L(\Omega)$	0	100	400	450	500	R_{eq}	550	600	800	1k	2k	5k	∞
P(W)													

4. Questions

a) What is the condition of measuring I_{sc} in the short circuit experiment to obtain the Thevenin equivalent circuit?

b) Can we directly short connect the circuit in the experiment?

c) Summarize the methods to measure the open circuit voltage and equivalent internal resistance of the two-terminal active network, and compare their advantage and disadvantage.

5. Writing your reports

a) Based on the data you recorded in Step “B” and Step “C”, plot the respective voltage-current characteristics curves and validate the Thevenin theorem.

b) Based on the data you recorded in Step “D”, plot the curve of power P versus R_L as R_L changes continually, $P = f(R_L)$. Validate whether the maximum power transfer condition is correct or not. In other words, when $R_L = R_{eq}$, whether the power absorbed by the load R_L is the largest.