Electric Circuits I

Laboratory 6 – Thévenin Circuit and Maximum Power Transfer

Objective:

- Find an equivalent Thévenin equivalent circuit for a complex resistive circuit.
- Understand the power distribution of a network.

I. Equipment:

- DC Power Supply (Keysight EDU36311A)
- Digital Multimeter (Keysight EDU34450A)
- Breadboard for connecting resistors.
- 9 resistors between 1kΩ to 30kΩ.
- Resistance Decade R_{adj}.

II. Background & Theory

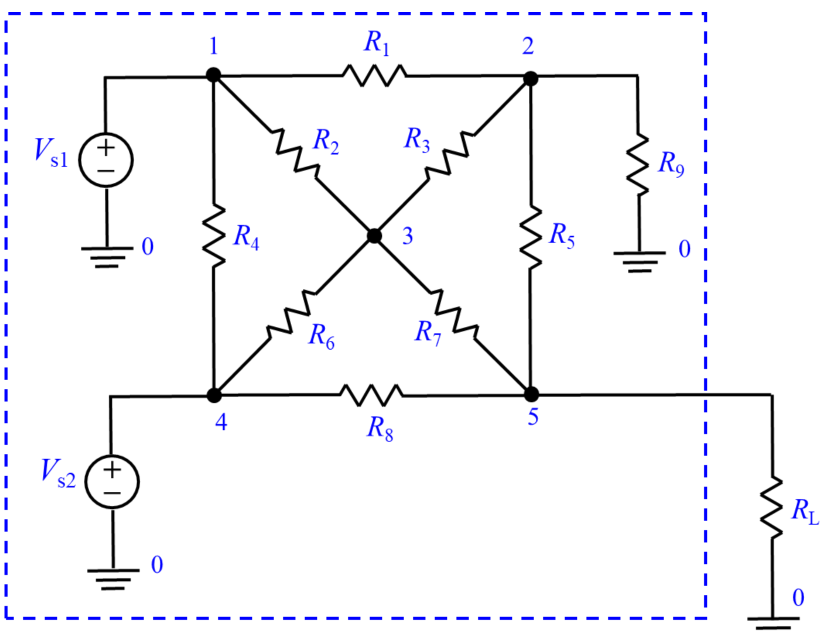

Figure 1 – A Power Distribution Network

A Thévenin circuit is a simplification technique when analyzing complex circuits where an equivalent circuit can replace one fixed portion of the whole circuit.

As shown in **Figure 1**, the resistive network in the blue dashed box can be replaced by a Thévenin equivalent circuit. The Thévenin equivalent circuit of the power distribution network is in **Figure 2**.

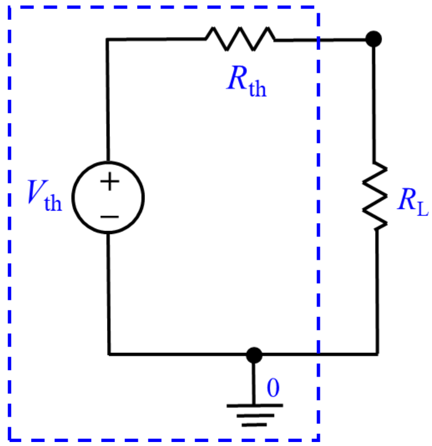

Figure 2 – A Power Distribution Network with Thévenin Equivalent Circuit

Once the resistive network is replaced with a Thévenin equivalent circuit, the power transferred to the resistive load is:

$$P(R_L) = R_L i^2 = R_L \left(\frac{V_{th}}{R_{th} + R_L}\right)^2$$

The power transferring function $P(R_L)$ is maximum when its derivative is zero:

$$\frac{dP(R_L)}{dR_L} = \frac{{V_{Th}}^2}{(R_{th} + R_L)^2} - \frac{2R_L {V_{th}}^2}{(R_{th} + R_L)^3} = 0$$

$$\Rightarrow {V_{th}}^2 (R_{th} + R_L) - 2R_L {V_{th}}^2 = 0$$

$$\Rightarrow R_{th} + R_L - 2R_L = 0$$

$$\Rightarrow R_L = R_{th}$$

Therefore, the maximum transfer of power from the circuit to the resistive load R_L when $R_L = R_{th}$. The maximum power transfer is:

$$P_{max} = \frac{(V_{th})^2 R_L}{(2R_L)^2} = \frac{(V_{th})^2}{4R_L} \qquad (1)$$

Table 1 – Standard Resistor Values (K = *1e3, M = *1e6)

1.0	5.6	33	160	820	3.9K	20K	100K	510K	2.7M
1.1	6.2	36	180	910	4.3K	22K	110K	560K	3M
1.2	6.8	39	200	1K	4.7K	24K	120K	620K	3.3M
1.3	7.5	43	220	1.1K	5.1K	27K	130K	680K	3.6M
1.5	8.2	47	240	1.2K	5.6K	30K	150K	750K	3.9M
1.6	9.1	51	270	1.3K	6.2K	33K	160K	820K	4.3M
1.8	10	56	300	1.5K	6.6K	36K	180K	910K	4.7M
2.0	11	62	330	1.6K	7.5K	39K	200K	1M	5.1M
2.2	12	68	360	1.8K	8.2K	43K	220K	1.1M	5.6M
2.4	13	75	390	2K	9.1K	47K	240K	1.2M	6.2M
2.7	15	82	430	2.2K	10K	51K	270K	1.3M	6.8M
3.0	16	91	470	2.4K	11K	56K	300K	1.5M	7.5M
3.3	18	100	510	2.7K	12K	62K	330K	1.6M	8.2M
3.6	20	110	560	3K	13K	68K	360K	1.8M	9.1M
3.9	22	120	620	3.2K	15K	75K	390K	2M	10M
4.3	24	130	680	3.3K	16K	82K	430K	2.2M	15M

4.7	27	150	750	3.6K	18K	91K	470K	2.4M	22M
5.1	30								

III. Prelab Assignment:

The prelab assignments should be completed and submitted to Camino before the lab.

1. Select 9 resistors (R_1 to R_9) from the standard resistor values in **Table 1** between 5kΩ to 30kΩ. Label them and write down their nominal values for later use.
2. Create a MATLAB script with V_{s1} = 10V and V_{s2} = 4V to determine the Thévenin equivalent circuit of the resistive network (the dashed blue box) in **Figure 1**:
   a. Calculate the Thévenin voltage by determining the open voltage V_{oc}: $V_{th} = V_{oc}$
   b. Calculate the Thévenin equivalent resistance R_{th} by determining the short current I_{sc}: *Note that many other methods besides calculating Isc can determine* R_{th}.

$$R_{th} = V_{oc} / I_{sc}$$

   c. Calculate the maximum power transfer to the resistive load R_L.

IV. Laboratory

Verify the results of MATLAB scripts of your prelab assignment with the TA before working on the lab procedures.

1. Use the digital multimeter to measure 9 resistors chosen in the prelab assignments. Record their measured values in **Table 2** below.

Table 2 – Resistance Values

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	
Nominal Values										kΩ
Measured Values										kΩ

2. With the measured values of R_1 to R_9, use the MATLAB script in the prelab assignments to recalculate the Thévenin voltage and resistance. Record the theoretical results in **Table 4**.
3. Build the circuit in **Figure 1** without R_L and set V_{s1} = 10V and V_{s2} = 4V.
   a. Measure the open voltage V_{oc}.
   b. Measure the Thévenin resistance with three options:
      - Option 1: Disconnect all independent sources before zeroing them. Measure the total resistance between nodes 5 and 0. The total resistance will be the Thévenin resistance R_{th}.

- Option 2: measure the short current I_{sc} between nodes 5 and 0. Calculate the Thévenin resistance R_{th} using V_{oc}: $R_{th} = V_{oc} / I_{sc}$.
- Option 3: Disconnect all independent sources before zeroing them. Apply a known voltage source V_1 between nodes 5 and 0 and measure the current I_1. The Thévenin resistance R_{th} will be: $R_{th} = V_1 / I_1$.

Table 3 – R_{th} Measurements

	Option 1	Option 2 $R_{th} = \frac{V_{oc}}{I_{sc}}$	Option 2 $R_{th} = \frac{V_1}{I_1}$
R_{th} (kΩ)			

4. Calculate the measured power transfer with the measured values of the Thévenin voltage and resistance. Record all measurements and calculations in **Table 4** and calculate percent errors.

Table 4 – Voltage and Resistance Measurements

	Theoretical (Meas. R)	Measured	Percent Error
V_{th} (V_{oc})			
R_{th}			
P_{max}			

5. If there are any discrepancies, explain them.
6. Select 9 values of R_L, ($0.5*R_{th} <$ 4 values $< R_{th}$, and $2*R_{th} <$ 4 values $< 3*R_{th}$). Round them off to available values on the resistance decade R_{adj}. Connect R_{adj} to the circuit in **Figure 1** as R_L. Adjust R_{adj} to the selected values, measure the voltage across R_L, and calculate the maximum power transfer P_{max}. Record all the values in **Table 5**.

Table 5 – Power Transfer

	R_L (kΩ)	Voltage V_{RL} (V)	Power P_{max} (W or mW)
R_{L1}			
R_{L2}			
R_{L3}			
R_{L4}			
R_{th}			
R_{L6}			
R_{L7}			

R_{L8}			
R_{L9}			

7. Derive comments or conclusions from the results.

Make sure to check off with the TA before leaving the lab section.

V. Laboratory Report:

Include the measurements, computations, and answers to questions from the laboratory procedure. Clearly label all steps.