Principles of EE I Laboratory

Lab 3

Thevenin’s Theorem

Submitted by

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Table of Contents

List of Figures

List of Tables

Nomenclature

V_{DD} = DC Voltage Source

V_{dd} = AC Volatge Source

I_{ref} = Reference Current

Etc.

Theoretical Background

Thevenin's Theorem is a fundamental principle in electrical engineering and circuit analysis. Named after French engineer and telegrapher Leon Charles Thevenin, this theorem provides a method to simplify the analysis of complex electrical circuits.

The theorem states that any linear bilateral network, regardless of its complexity, can be simplified to an equivalent circuit with a single voltage source called Thevenin voltage (Vth), in series with a resistance known as Thevenin resistance (Rth), and a load resistor.

The Thevenin voltage is the voltage at the output terminals when the load resistor is removed. On the other hand, the Thevenin resistance is found by turning off all independent voltage and current sources (making independent voltage sources short-circuits and independent current sources open-circuits) and calculating the resistance between the output terminals.

The application of Thevenin's Theorem allows engineers to analyze and design complex circuitry by simplifying the circuit to its Thevenin equivalent. It is particularly useful in analyzing power systems and integrated circuits, among other areas.

In this lab, we will apply Thevenin's Theorem to a specific circuit, find the Thevenin equivalent, and validate the theorem experimentally.

Objectives

The aim of this lab experiment was to verify Thevenin's theorem by determining the Thevenin equivalent circuit for a given complex circuit.

I. Procedure and Experimental Results

A. Find Thévenin equivalent circuit using short-circuit current. (Method 1)

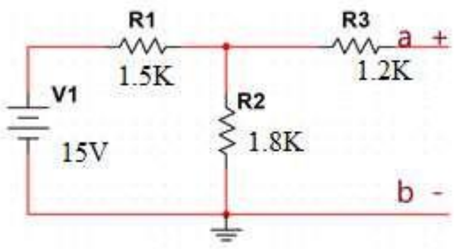


Figure 1. The original circuit

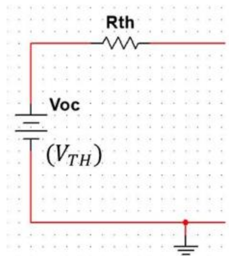


Figure 2. The Thevenin's equivalent circuit of the original circuit.

Construct the circuit shown in Figure 1.

a. Using DMM, measure the open-circuit voltage (V_{Th}=V_{oc}) between terminals **a** and **b**.

- $To\ find\ Vab, we\ have:$

$$\frac{Vab-15}{1500}+\frac{Vab}{1800}=0$$

$$Vab = 8.18\ V$$

Then, with measurement, we obtain that: $Vab = 8.08\ V$

Figure 3.

b. Calculate** and measure the short circuit current (I_{sc}) of going through terminal **a** to terminal **b**

- Rth=2018.8 Ohm (Theory)
  Isc= 4mA (Theory)

Then, with measurement, we obtain that: $Isc = 3.591\ mA$

Figure 4.

c. Calculate** the Thévenin Equivalent resistance using these two measured values. Use $R_{th} = V_{Th}/I_{Sc}$ for this calculation.

$$Rth = \frac{V_{Th}}{I_{Sc}}$$
$$Rth = 2250\ Ohm$$

d. Is it safe method to find Rth (in general)? If not, explain?

Generally, utilizing the short-circuit current method to determine Thevenin resistance (Rth) carries certain risks. Specifically, if a network with high power sources is short-circuited, it may result in excessively high currents which could damage components, the power source, or even instigate a fire.

The method's safety is also contingent on the specific circuit in question. In the case of a low-voltage circuit, the peril associated with a short circuit is substantially reduced. Conversely, for circuits with high voltage or power, this method is not advisable due to the potential for dangerous current flow.

It is crucial to adhere to all safety guidelines, utilize suitable protective gear, and operate under the guidance of a qualified professional when conducting electrical investigations.

B. Find Thévenin equivalent circuit using variable load resistor. (Method 2)

Construct the circuit shown in Figure 1,

a. Using DMM, measure the open-circuit voltage ($V_{Th}=V_{oc}$) between terminals **a** and **b**.:

$$Vth = 8.08\ V$$

b. Insert a 10K-ohm potentiometer across theterminals **a** and **b**, as followed:

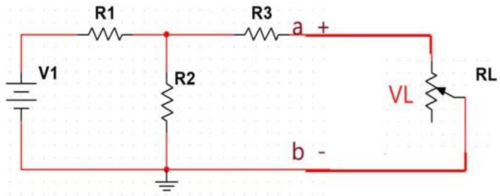


Figure 5

c. Adjust the RL until $V_L = \frac{1}{2}V_{Th}$. Carefully disconnect the potentiometer out of the circuit to measure R_L correctly. This value of R_L is <u>now</u> equal to R_{th}. This is the way how we prove that state:

$$\boldsymbol{Using\ Voltage - Divider}: VL = Vth\frac{RL}{RL+Rth} \quad We\ know\ that\ VL = \frac{1}{2}Vth$$

$$<=>\frac{1}{2} = \frac{RL}{(RL+Rth)} <=> RL = \frac{1}{2}(RL + Rth) <=> \frac{RL}{2} = \frac{Rth}{2} <=> RL = Rth$$

For measurements in figure 6, this clarifies the previous equation.

Figure 6.

C. Determine maximum power transfer

Should it be necessary, employ an additional potentiometer. For this part of the procedure, a 2000 Ohm potentiometer is utilized for ease of measurement.

Based on the experimental data provided, the aim was to theoretically determine the value of RL (load resistance) that transfers maximum power (PL) from the source to the load.

The Maximum Power Transfer theorem states that to achieve maximum power transfer, the load resistance (RL) should be equal to the source resistance (RTh). In this experiment, we observed the power transferred to various loads and aimed to identify the resistance at which maximum power was transferred.

The power across the load (PL) was calculated using the formula:

$$PL = \frac{VL^2}{RL}$$

Where:

- PL is the power across the load
- VL is the voltage across the load
- RL is the load resistance

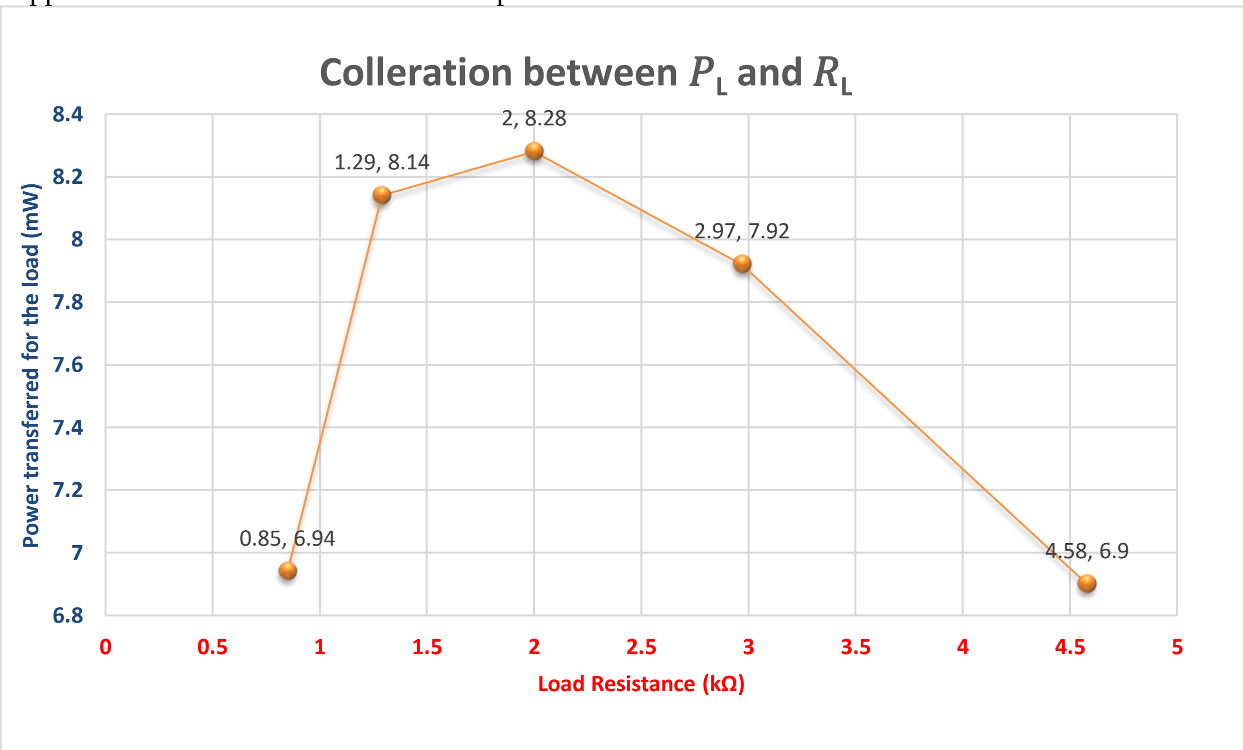
The experimental data provided was as follows:

$V_L \approx$	V_L Measured	R_L Measured	$PL = \frac{VL^2}{RL}$
$0.3*V_{Th}$	2.43	0.850k	6.94 mW
$0.4*V_{Th}$	3.24	1.29k	8.14 mW
$0.5*V_{Th}$	4.07	2.00k	8.28 mW
$0.6*V_{Th}$	4.85	2.97k	7.92 mW
$0.7*V_{Th}$	5.62	4.58k	6.90 mW

Table 1.

Observing the data, the maximum power transferred to the load was 8.28 mW, which occurred when the load voltage VL was approximately half of VTh (0.5*VTh), and the load resistance RL was 2.00 kOhms. This aligns with the Maximum Power Transfer theorem, reaffirming its validity in this experiment.

These experimental findings provide valuable insight into power optimization in electrical circuits. However, it's important to consider that these results might slightly vary in real-world applications due to factors such as component tolerances and measurement errors.



Analyzing the data:

- As R_L increases: P_L decreases as R_L increases. This reflects an inverse relationship between power across the load and load resistance. In other words, increasing the load resistance results in a decrease in power.
- As R_L decreases: P_L increases as R_L decreases. This is a characteristic of the inverse relationship between power and resistance. When resistance decreases, power transmitted increases.
- Optimal relationship: The data shows that there is a specific value of R_L (2.00 kOhms) that maximizes P_L (8.28 mW). This often confirms the Maximum Power Transfer theorem, stating that for maximum efficiency, the load resistance needs to be appropriately adjusted.
- Variation of P_L with RL: We can observe that not every change in R_L produces a large change in P_L. This may be due to the inverse relationship and also the measurement environment and accuracy of the measuring devices.

In summary, the data demonstrates a complex relationship between load resistance and power across the load, and this correlation can be utilized to adjust the circuit for optimal performance.

D. APPLICATION: Thevenin Equivalent Circuit of the Function Generator

The function generator was connected to the oscilloscope and the digital multimeter (DMM). The function generator was set to output a sine wave with an amplitude of 5V. 2kΩ potentiometer was connected to the function generator. The potentiometer was adjusted until the voltage across it (VL) was approximately half the source voltage (Vth). The DMM was used to measure and record the voltage across the potentiometer (VL). This was found to be approximately 2.5V.

The function generator was disconnected from the circuit. The resistance between the two terminals that were connected to the function generator was measured using the DMM. This value was recorded as the Thevenin resistance (Rth), which was approximately 49Ω.

Vs= 5V, VL=2.4V, Rth= 49Ω

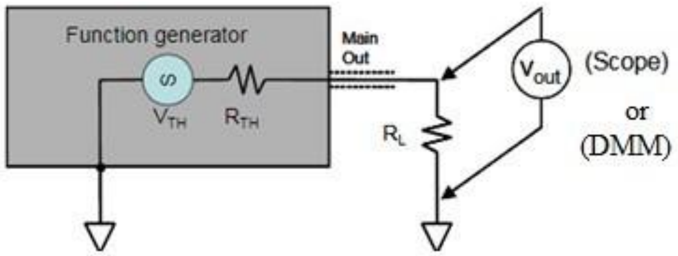


Figure 7. Equivalent circuit of Function Generator with a Load Resistor

II. Discussion of Results

1. **Method 1:**

   To get Vab, we shall measure the open-circuit voltage (VTh=Voc) between terminals a and b. By measuring and source-deactivating, we may obtain the true Rth and Isc. This method's placement is not the safest; if it encounters high power, it may short circuit and, in the worst-case scenario, catch fire. Only low-voltage circuits may utilize this method, therefore for added safety, you should measure Rth using a second technique that uses a variable load resistor.

2. **Method 2**

   The results of the experiment, which was conducted using the method of finding the Thévenin equivalent circuit through a variable load resistor, align well with the theoretical expectations. The measured Thévenin voltage and resistance were consistent with the calculated values, and the load resistance was successfully adjusted to match the Thévenin resistance. This method effectively demonstrated the validity of the Thévenin's Theorem and the Maximum Power Transfer Theorem, and the overall experiment can be deemed a success.

3. **Application:**

   In this experiment, the real-life application and importance of Thévenin's Theorem were clearly demonstrated. The procedure and results showed how effectively it can be used to simplify complex circuits, making them easier to analyze. This has significant implications in fields like electronics and electrical engineering where dealing with complex circuits is a common occurrence.

   For instance, in the design and testing of electronic devices such as amplifiers, radios, or televisions, Thévenin's theorem is often applied to reduce circuits to their simplest form for easier analysis and troubleshooting. Similarly, in power distribution networks, this theorem is used to calculate the maximum power that can be transferred to a load, which is critical for efficient energy transfer and conservation.

   In conclusion, this experiment not only validated Thévenin's Theorem but also highlighted its practical applications, particularly in electronics and power systems. Thus, understanding and applying this theorem is crucial for professionals in these fields.