

Report on Lab 2

Thévenin resistance and voltage of a power supply

This report presents a measurement of the Thévenin resistance and Thévenin voltage of the power supply used to power breadboard circuits in the Physics 252 laboratory course. The measurements are extracted from a linear fit of output voltage versus output current data and yield a Thévenin resistance of $R_{Th} = 0.070 \Omega \pm 5\%$ and a Thévenin voltage of $V_{Th} = 3.068 \text{ V} \pm 0.12\%$.

I. Introduction

This report summarizes the laboratory verification of Thévenin's theorem as applied to the operation of the power supply used to power breadboard circuits in the Physics 252 laboratory course. Thévenin's theorem states that any linear power supply can be represented as an ideal voltage source in series with a single resistor, regardless of the inner workings and engineering of the supply [1]. This powerful theorem allows circuit designers to greatly simplify the conceptual design and operation of an electrical circuit. While Thévenin's theorem does not indicate how to determine the Thévenin voltage nor the Thévenin resistance, this report details an experimental method for doing so, and successfully applies it to a laboratory power supply.

II. Theory

According to Thévenin's theorem any linear voltage source can be represented as an ideal voltage source with a Thévenin voltage, V_{Th} , in series with a Thévenin resistor of resistance R_{Th} , as shown in figure 1. The Thévenin model of a linear power supply produces the following voltage at the output of the supply leads when it is attached to an external load resistor, R_{Load} [1]:

$$V_{out} = \frac{R_{Load}}{R_{Th} + R_{Load}} V_{Th} \quad (1)$$

Equation 1 shows that when R_{Load} is much larger than R_{Th} , then $V_{out} \sim V_{Th}$, but when $R_{Load} \sim R_{Th}$, then $V_{out} < V_{Th}$.

According to Ohm's law, the current flowing through the load resistor obeys the relation $R_{Load} = V_{out} / I_{Load}$. If we replace R_{Load} with this expression in equation 1, then after a little bit of algebra we find that V_{out} and I_{Load} vary according to the following linear relation:

$$V_{out} = V_{Th} - R_{Th} I_{Load} \quad (2)$$

Equation 2 is an expression which includes only the quantities to be measured, V_{Th} and R_{Th} , and directly measurable quantities, V_{out} and I_{Load} .

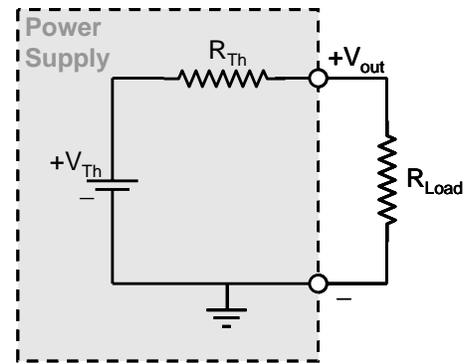


Figure 1: Thévenin model of a linear supply

III. Method

V_{Th} and R_{Th} are determined from a linear fit to V_{out} vs. I_{Load} data. V_{out} and I_{Load} are measured simultaneously for different load resistors, with a voltmeter and an ammeter (both meters are Beckman Industrial model 310), respectively. Figure 2 shows a representation of the experimental setup.

High power load resistors, with resistances in the range of 1.3Ω to 9Ω , were connected to the power supply used to power breadboard circuits in the Physics 252 laboratory course (E&L Instruments, C. A. D. E. T. II model # 325-1449). The ammeter leads, the wire-to-wire connections, and the internal ammeter resistance add up to a resistance in the range of 0.1Ω to 0.4Ω . In order to include these stray resistances as part of the effective load resistance, the voltmeter leads are attached directly to the power supply output connections.

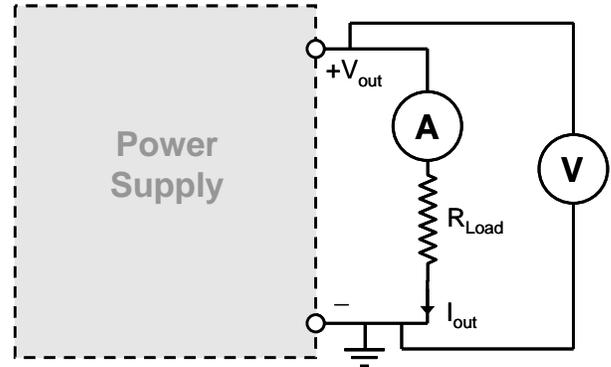


Figure 2: Experimental setup.

Data was taken over a range of load currents, from 0.15 A to 1.6 A . Above 1.6 A , the power supply output became unstable and the measurements of V_{out} and I_{Load} fluctuated too much to be reliable.

IV. Results and Analysis

The V_{out} vs. I_{Load} data from these measurements are plotted in figure 3 along with a linear least squares fit to the data.

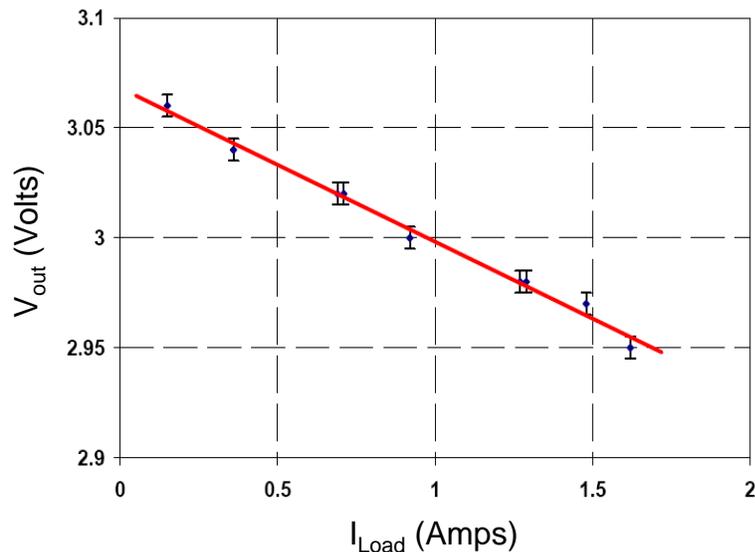


Figure 3: Plot of V_{out} vs. I_{out} . The red line is a linear least squares fit to the data. The horizontal error bars are too small to be visible on the scale of the plot.

The precision of the voltage measurements is estimated to be about 0.005 V, which is half of the least significant digit on the digital voltmeter. The precision on the current measurements is estimated to be 0.005 A by the same reasoning.

The data follow a linear trend as expected from Thévenin's theorem. A linear least squares fit using equation 2, with R_{Th} and V_{Th} as parameters, gives $R_{Th} = 0.070 \Omega \pm 5\%$ and $V_{Th} = 3.068 \text{ V} \pm 0.12\%$ with a reduced Chi-squared of $\chi_v^2 = 0.5$. The standard deviation of the residuals indicates that the estimated error on the voltage is closer to 0.003 V, while from the plot it is clear that the error on the current is too small to play any significant role in the error on the fit.

V. Conclusion

In conclusion, this report details the successful application of an experimental method for determining the Thevenin voltage and resistance of a power supply. The data support the validity of Thevenin's theorem for the breadboard power supply up to a current of 1.6 A. Above this current, the supply behaves erratically and consequently cannot be considered a linear device in this current range.

VI. References

[1] S. Aubin, J. Nelson, and W. Cooke, *Physics 252: Introduction to Analog Electronics*, course notes for Physics 252, chapter 2 p.3, College of William and Mary (2008).