Lab 5

Thevenin Equivalents of Lab Equipment

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Date: October 11, 2024

1 Introduction

In this lab, the concept of Thevenin equivalents was explored, a powerful tool in electrical engineering used to simplify complex circuits. By representing a complex circuit as a combination of a voltage source and an impedance, circuit analysis became more manageable. This approach was particularly useful in systems such as ECG amplifiers or RF amplifiers in cell phones, where understanding the interaction between sub-circuits was essential for effective design and analysis. Through practical experiments, the Thevenin equivalents of lab equipment, such as oscilloscopes and signal generators, were determined, using measurement techniques like voltage division to calculate key parameters, including Thevenin voltage and resistance. By the end of the lab, insights were gained into how simplified models enabled the design and analysis of complex systems with greater ease.

2 Results

Part 1

The resistance of the oscilloscope was measured using an ohmmeter and found to be $R_{osc} = 0.999\ M\Omega$.

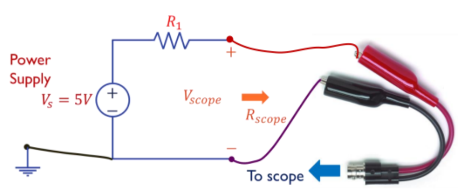

Figure 1: Setup for measuring the Thevenin resistance of the oscilloscope. [1]

The setup in Figure 1 constructed.

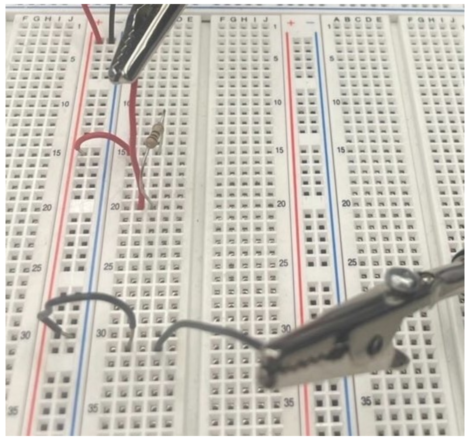

Figure 2: Setup for measuring the Thevenin resistance of the oscilloscope.

The circuit found in Figure 2 was used to measure the Thevenin resistance of the oscilloscope. The resistance of the resistor used was $R = 0.969\ M\Omega$. A voltage of $V_{in} = 5.000\ V$ was applied to the circuit. The voltage across the oscilloscope was measured to be $V_{osc} = 2.540\ V$. This proves that the the resistance of the oscilloscope is $R_{osc} = 0.999\ M\Omega$.

Part 2

The open circuit voltage of the signal generator was measured to be $V_{Th} = 1.000\ V$. The 100 Ω resistor was connected to the signal generator in order to measure the Thevenin resistance. See Figure 3 for the setup.

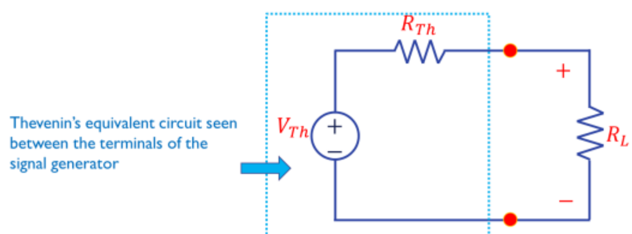

Figure 3: Measuring the Thevenin's equivalent circuit of the signal generator.

The actual resistance of the resistor was $R = 98.812\ \Omega$. The voltage measured was 655.0 mV. This proves that the resistance of the signal generator is $R_{sig} = 52.04\ \Omega$.

$$V_L = V_{Th}\frac{R_L}{R_{Th} + R_L} \rightarrow 0.655 = 1\frac{98.8}{R_{Th} + 98.8} \rightarrow R_{Th} = 52.04\ \Omega$$

This comes very close to the marked value of 50 Ω on the signal generator. A 47 Ω resistor was connected to the signal generator. The actual resistance of $R_L = 46.771\ \Omega$ The voltage measured was 480 mV.

$$V_L = V_{Th}\frac{R_L}{R_{Th}+R_L} \rightarrow 0.480 = 1\frac{46.771}{R_{Th}+46.771} \rightarrow R_{Th} = 50.669\ \Omega$$

This value is very close to the marked value of 50 Ω on the signal generator and very close to the calculated value of 52.04 Ω.

Part 3

Voltage Change Due to Oscilloscope Connection

When an oscilloscope is connected to a signal generator, the input resistance of the oscilloscope and the output impedance of the signal generator form a voltage divider, which affects the voltage measured by the oscilloscope.

- Let
  1. V_{open} be the open-circuit voltage (without the oscilloscope).
  2. Z_{out} be the output impedance of the signal generator.
  3. R_{in} be the input resistance of the oscilloscope.
- Voltage Division: When the oscilloscope is connected, the voltage seen by the oscilloscope, V_{load}, is:

  $$V_{\text{load}} = V_{\text{open}} \cdot \frac{R_{\text{in}}}{Z_{\text{out}}+R_{\text{in}}}$$

- Percentage Change in Voltage: The percentage change in voltage is given by:

  $$\%\text{Change} = \left(1 - \frac{V_{\text{load}}}{V_{\text{open}}}\right) \times 100$$

  Substituting for V_{load}:

  $$\%\text{Change} = \left(1 - \frac{R_{\text{in}}}{Z_{\text{out}}+R_{\text{in}}}\right) \times 100$$

  Simplifying:

  $$\%\text{Change} = \left(\frac{Z_{\text{out}}}{Z_{\text{out}}+R_{\text{in}}}\right) \times 100$$

Thus, the percentage change in the open-circuit voltage when the oscilloscope is connected depends on the ratio of the signal generator's output impedance to the sum of the output impedance and the oscilloscope's input resistance.

Condition on Input Resistance for Minimal Effect

To ensure that the oscilloscope or voltmeter does not affect the circuit's voltage by more than 1%, the input resistance of the meter or oscilloscope should be significantly larger than the Thevenin equivalent resistance of the circuit.

- Let
  1. R_{th} be the Thevenin equivalent resistance of the circuit.
  2. R_{in} be the input resistance of the oscilloscope or voltmeter.
- Voltage Division: The condition for less than 1% voltage change is:

$$\frac{R_{\text{in}}}{R_{\text{th}} + R_{\text{in}}} \geq 0.99$$

- Rearranging:

$$R_{\text{in}} \geq 99 \cdot R_{\text{th}}$$

Thus, the input resistance of the oscilloscope or voltmeter should be at least 100 times the Thevenin equivalent resistance to ensure a voltage change of less than 1%.

3 Discussion and Conclusion

In this lab, the Thevenin equivalent models of both the oscilloscope and the signal generator were determined through practical experiments. By applying voltage division principles, we accurately measured the Thevenin resistance and open-circuit voltage for each device. For the oscilloscope, the measured Thevenin resistance of $R_{osc} = 0.999\ M\Omega$ was consistent with expected values, demonstrating the high input resistance typically required to minimize loading effects on circuits under test. Similarly, the Thevenin resistance of the signal generator was calculated as $R_{sig} = 52.04\ \Omega$, closely matching its rated output impedance.

These results emphasize the importance of understanding the interaction between measuring instruments and the circuits they probe. For instance, the effect of the oscilloscope's input resistance on the measured voltage was demonstrated, showing how even a high-resistance instrument can alter the voltage reading if not properly accounted for. By ensuring that the input resistance of the measuring device is significantly larger (at least 100 times) than the circuit's Thevenin resistance, voltage measurement errors can be minimized to less than 1%.

The lab provided valuable insights into the practical use of Thevenin equivalents, highlighting how these simplified models enable more efficient circuit analysis.

This knowledge is particularly relevant in designing and troubleshooting complex systems, where understanding the loading effects of various components and instruments is crucial for accurate measurements and overall system performance.

Overall, the experiments successfully reinforced the theoretical concepts and provided a solid foundation for understanding how lab equipment interacts with circuits, ensuring accurate and reliable measurements in future engineering practice.

4 References

[1] Dr. Iman Salama. "Lab 5 – Thevenin Equivalents of Lab Equipment" Northeastern University. 11 October 2024.