**Lab 5: Thevenin equivalent circuit**

**Objectives**

1) Understand the experimental procedure to determine Thevenin voltage and Thevenin resistance.

2) Validate Thevenin theorem through experimental measurements of a linear circuit and its Thevenin equivalent circuit.

3) Validate the condition for maximum power transfer to a load for a Thevenin circuit.

**Background**

Using the Thevenin theorem, a complex two-terminal linear circuit having a load element, as well as multiple passive elements (e.g., resistors) and active elements (e.g., independent sources), can be replaced by the load attached to a simple Thevenin equivalent circuit. The equivalent circuit consists of:

1. a single source referred to as the **Thevenin voltage** (Vth), and
2. a single fixed-value resistor called the **Thevenin resistance** (Rth).

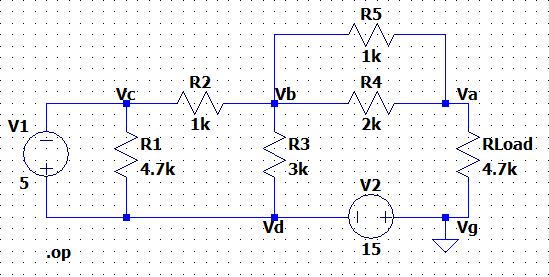
The Thevenin voltage is the open-circuit voltage across the two terminal ports of the load. It can be readily obtained through direct measurement. The Thevenin resistance can be obtained with either of the following approaches:

1. Method-1: Measure the Thevenin resistance after deactivating all the independent sources of the original circuit. The measurement is done by applying a test source to the load terminals and determining the current-voltage relationship of the source. This method always works.
2. Method-2: Determine the Thevenin resistance as the ratio of the Thevenin open-circuit voltage to the short-circuit current (also known as the Norton current): Rth = Voc/Isc. This method only works for the circuits that have independent sources.

**Measure all the resistor and source voltage values, and use the actual resistor and voltage source values (not nominal values) in all your LTspice simulations.**

**Part 1: Thevenin equivalent circuit – measurement and simulation**

Construct the following circuit. Measure the current ILoad flowing through the 4.7k load resistor RLoad, from node Va to node Vg. Use LTspice simulation to obtain the theoretical value of ILoad and compare with the measured value.



Load current:

|  |  |
| --- | --- |
|  | Load current I\_load (mA); from Va to ground |
| Measured value |  |
| Theoretical value |  |

Now we find the Thevenin voltage (open-circuit voltage) Vth = Voc. Remove the 4.7k load resistor RLoad and measure the open circuit voltage Voc across the two load terminal ports. Use LTspice simulation to obtain the theoretical value of Voc (using nodal or mesh analysis) and compare with the measured value.

Thevenin open-circuit voltage Vth = Voc

|  |  |
| --- | --- |
|  | Thevenin voltage Vth = Voc = Va; unit is V |
| Measured value |  |
| Theoretical value |  |

The Thevenin resistance Rth can be determined by two methods.

**Method-1**: This method works for all circuit types, including circuits that do not have independent sources. It consists of these steps:

(1) After removing the load, deactivate all independent sources in the circuit – replace voltage source with a wire; replace current source with an open.

(2) Connect a test voltage source to the two load terminal ports, and apply a test voltage to the circuit. Determine the test current flowing out of the test voltage source.

(3) Determine the Thevenin resistance Rth = Vtest / I test.

For this experiment, apply a test voltage of 10 V, measure the test current, and obtain the measured value of the Thevenin resistance Rth. Use LTspice simulation to obtain the theoretical value Rth and compare with the measured value. Then simply use a DMM to directly measure the Rth, and compare with the previously obtained values of Rth. Why is using a DMM the same as applying a test source and determining the source’s current-voltage relationship?

Thevenin resistance Method-1

|  |  |  |  |
| --- | --- | --- | --- |
|  | Vtest (V) | Itest (mA) out of test source into node Va | Rth (kΩ) = Vtest / Itest |
| Measured |  |  |  |
| Theoretical |  |  |  |
| Using a DMM to directly measure Rth | | |  |

**Method-2**: This method only works for circuits with independent sources, which is often the case.

(1) Remove the load, and measure the open circuit voltage Voc between the two load terminals.

(2) Measure the short circuit current Isc between the two load terminals.

(3) Determine the Thevenin resistance Rth = Voc / I sc.

Apply this method (LTspice simulation and actual measurement) to determine Rth. Recall that you have already obtained the Voc (both measured and theoretical) in Part 1, so you only need to determine Isc here. Explain why the Rth method 2 will not work for circuits that don’t have independent sources.

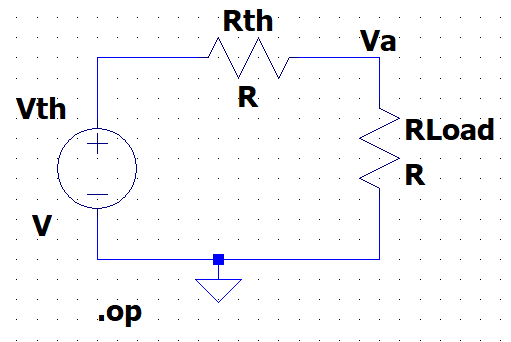
Thevenin resistance Method-2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Voc (V) | Isc (mA) from Va to Vg | | Rth (kΩ) = Voc / Isc |
| Measured |  |  | |  |
| Theoretical |  |  | |  |
| Why doesn’t Rth method 2 work for circuits that don’t have independent sources? | | |  | |

**Part 2: Thevenin equivalent circuit construction**

Now that we have determined both Vth and Rth, we can construct a Thevenin circuit that is equivalent to our original circuit. Construct the Thevenin equivalent circuit by using the Vth and Rth that you have determined in Part 1. The load resistance RLoad should remain as 4.7kOhm. To implement the Rth, you will need to use a variable resistor. The easiest method is to use a decade box. Alternatively, you may use a potentiometer set to the proper resistance.

Determine the current ILoad flowing through the load resistor RLoad, from node Va to ground. Compare this ILoad with the ILoad that your previously measured in Part 1. If they are equal, then it will verify that the circuit here is the Thevenin equivalence of the circuit in Part 1.



Load current comparison between Thevenin and the original circuits

|  |  |
| --- | --- |
| Measured load current ILoad (mA) from Thevenin circuit |  |
| Measured load current ILoad (mA) from circuit at Part 1 |  |
| Is this Thevenin circuit equivalent to the original circuit? (Yes / No): | |

**Part 3: Maximum power transfer to load – measurement and simulation**

When a load resistor RLoad is attached to a circuit with two load terminal ports, the load will draw current and consume power. It can be proven that when the load has the same resistance as the circuit’s Thevenin resistance Rth, i.e., when RLoad = Rth, then maximum power will be transferred to the load. Such a maximum power value is Vth2 / (4 Rth).

We will verify this maximum power transfer principle here. Revise your Thevenin equivalent previously built in Part 2 by replacing the original 4.7k load with a variable load resistor. The best approach here is to use a decade box. If you used a decade box previously in Part 2, and you have only one decade box available, think about how you may replace the decade box in Part 2 by an equivalent element.

Set the initial value of your variable load to be 1kOhm. Measure the load voltage VLoad across the load, and also monitor the load current ILoad (but this is optional). Calculate the power transfer to the load. Think about how you may obtain the load power PLoad from VLoad and RLoad. Is it necessary to measure the load current ILoad to calculate load power?

Increase the load resistance to various values, and perform the necessary measurements to determine the load power. The amount of increment of the load resistance will be based on your judgment. If the increment is too small, you will get detailed data at the expense of spending a lot of time. If the increment is too big, you will save time but may miss important details. Suggested increment is in the 0.1kOhm to 0.2kOhm range. When the variable resistance approaches the Thevenin resistance Rth, reduce the load resistance increments to 0.05kOhm. When the load resistance is far from Rth, you may use larger increments again.

Record your data in a table, which should at least include columns for RLoad, VLoad (measured), and PLoad. Optionally, you may include a column for the load current ILoad. Plot the load power transfer PLoad as a function of RLoad. Referring to your plot, at what value of RLoad do you have the maximum power transfer to the load? How close does this value compare with Rth? Explain why maximum power transfer happens at Rload = Rth.

Load power transfer: highlight the load resistance at maximum power transfer to the load

|  |  |  |  |
| --- | --- | --- | --- |
| Adjusted RLoad (kOhm) | Measured load voltage VLoad (V) | **Optional:** Measured load current ILoad (mA) | Calculated PLoad (mW) |
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Plot of PLoad vs. RLoad:

Now use LTspice to simulate the circuit that you have built. For the load resistor, enter a variable value {RL}, and use a step directive to simulate. Plot the load power against the load resistance. Screenshot the LTspice circuit and the output plot to include in your lab report. Compare this simulation result with the result of the physical build circuit.

**Data tables**

**Part 1:**

Load current:

|  |  |
| --- | --- |
|  | Load current I\_load (mA); from Va to ground |
| Measured |  |
| Theoretical |  |

Thevenin open-circuit voltage Vth = Voc

|  |  |
| --- | --- |
|  | Thevenin voltage Vth = Voc = Va; unit is V |
| Measured |  |
| Theoretical |  |

Thevenin resistance Method-1

|  |  |  |  |
| --- | --- | --- | --- |
|  | Vtest (V) | Itest (mA) out of test source into node Va | Rth (kΩ) = Vtest / Itest |
| Measured |  |  |  |
| Theoretical |  |  |  |
| Using a DMM to directly measure Rth | | |  |

Thevenin resistance Method-2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Voc (V) | Isc (mA) from Va to Vg | | Rth (kΩ) = Voc / Isc |
| Measured |  |  | |  |
| Theoretical |  |  | |  |
| Why doesn’t Rth method 2 work for circuits that don’t have independent sources? | | |  | |

**Part 2:**

Load current comparison between Thevenin and the original circuits

|  |  |
| --- | --- |
| Load current ILoad (mA) from Thevenin circuit |  |
| Load current ILoad (mA) from circuit at Part 1 |  |
| Is this Thevenin circuit equivalent to the original circuit? (Yes / No): | |

**Part 3:**

Load power transfer: highlight the load resistance at maximum power transfer to the load

|  |  |  |  |
| --- | --- | --- | --- |
| Adjusted RLoad (kOhm) | Measured load voltage VLoad (V) | **Optional:** Measured load current ILoad (mA) | Calculated PLoad (mW) |
|  |  |  |  |
|  |  |  |  |
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**Plot of PLoad vs. RLoad:**

**Attach the screenshots of LTspice circuits and output image.**