

School of Engineering

Department of Electrical and Computer Engineering

**14:332:223 Principles of Electrical Engineering I Laboratory – Fall 2024**

**Lab Experiment #2**

**Laboratory objectives:**

1. Learn the behavior resistors in series and parallel.
2. Learn how to design, analyze, build, and test voltage dividers.
3. Practice constructing equivalent circuit.
4. Learn about proportionality theorem.
5. Use LTSpice to simulate the behavior of circuits

**PART A: Tutorials**

Please check relevant tutorial in lab 1 manual.

**PART B: Circuit Theory and Elements**

B.1 Equivalent Circuits

**B.1.1 Resistors in series:** Given a network with multiple resistors in series as given in Figure 1, it can be converted into an equivalent single resistance where:

(1.1)

where *R*> 0 is the resistance in ohms (****).

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Figure 1: Resistors in series

The current flowing through all resistors, based on Kirchhoff Current Law (KCL), will be the same:

(1.2)

The sum of voltage drops across the individual resistors, based on Kirchhoff Voltage Law (KVL), will equal to the voltage drop across the equivalent resistance:

(1.3)

**B.1.2 Voltage divider:** The voltage across each resistor in Figure 1 is proportional to the individual resistance and the equivalent resistance as follows:

(1.4)

**B.1.3 Resistors in parallel:** Given a network with multiple resistors in parallel as given in Figure 2, it can be converted into an equivalent single resistance where:

(1.5)

where *R*> 0 is the resistance in ohms (****).

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Figure 2: Resistors in parallel

The sum of currents flowing through the individual resistors, based on KCL, is equal to the current flowing through the equivalent resistance:

(1.6)

The voltage drops across the individual resistors, based on KVL, is the same for all resistors and is equal to the voltage drop across the equivalent resistance:

(1.7)

**B.1.4 Current divider:** The current flowing through each resistor in Figure 2 is proportional to the individual resistance and the equivalent resistance as follows:

(1.8)

**B.2 Proportionality Theorem**

Linear resistive networks (circuit) refer to circuit that contains only resistors and sources which could be independent or dependent sources. For linear resistive network (circuits) the proportionality relationship can be written as:

(1.9)

## where *x* is an input to the system, *y* is an output and K is a proportionality constant. Input *x* is multiplied by a scalar constant K to produce output *y*.

## For example, for the electric circuit in Figure 3 all relationship between any two voltages and/or currents in the circuit may be expressed in terms of *R*1, *R*2, *R*3, and *R*o that will define a unique proportionality factor K.

## If we look at the relationship between Vin and Vo for the electric circuit in Figure 3, it can be represented as:

(1.10)

## where K is a scalar constant whose value depends on the values of the resistors in the circuit, *R*1, *R*2, *R*3, and *R*o.

## 

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Figure 3: Electric circuit A

## PART C: Pre-Lab

## C.1 Design a circuit (a network of resistors) that has an equivalent resistance of 24 using all the following three resistors: 12, 20, and 30. Draw the circuit.

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## C.2 For the circuit of Figure 3, choose values for resistors R1, R2, R3, and Ro (all resistances must be greater than 1 k). Given that the voltage source Vin = 10 V (show your work for each part):

## a. Determine the equivalent resistance *R*eq for *R*1, *R*2, *R*3, and *R*o in Figure 4.

## b. Find the current *i*s.

## c. Use voltage divider to determine the voltage across resistor R3.

## d. Use voltage divider to find the output voltage Vo.

## e. Determine the proportionality coefficient K.

## f. Simulate the circuit in Figure 3 with the selected resistor values using LTSpice, find all voltages and currents, including Vo. Include a printout of the LTSpice drawing and results.

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Figure 4: Equivalent circuits for the circuit in Figure 3

## PART D: In Lab Experiments

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**Lab Experiment #2**

## Date of lab experiment: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Lab section: \_\_\_\_\_\_\_\_\_\_ GROUP (A/B): \_\_\_\_\_\_

## Team members: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## 

**Laboratory instruments:**

* Power supply: Keithley 2231-30-3
* Digital Multimeter (DMM): Keysight (Agilent) 34461A
* Breadboard/Arduino set
* 1 k to10 k resistors by design resistor

## Experiment # 2.1: Resistors in parallel and in series & proportionality theorem

## Design:

## The TA will provide you with 4 resistors.

## Find the resistors values:

## *R*1 =\_\_\_\_\_\_\_\_\_\_\_

## *R*2 =\_\_\_\_\_\_\_\_\_\_\_

## *R*3 =\_\_\_\_\_\_\_\_\_\_\_

## *R*4 =\_\_\_\_\_\_\_\_\_\_\_

## Design a circuit, based on the circuit in Figure 3, such that the equivalent resistance in the range of 5k. to 8k. Choose where to place each one of the resistors and draw your design in the next page.

## Calculate the equivalent resistance for the network:

## *R*eq =\_\_\_\_\_\_\_\_\_\_\_

## Calculate the proportionality constant:

## =\_\_\_\_\_\_\_\_\_\_\_

## If the network is connected to a 10V voltage source, calculate the current that will be drawn from the source *i*in and the voltage Vo:

## *i*in =\_\_\_\_\_\_\_\_\_\_\_

## Vo =\_\_\_\_\_\_\_\_\_\_\_

## Draw your network of resistors here:

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## 

## Assuming your resistors have a tolerance, calculate the maximum and the minimum current you expect will be drawn from the voltage source.

## *i*in (min) =\_\_\_\_\_\_\_\_\_\_\_

## *i*in (max) =\_\_\_\_\_\_\_\_\_\_\_

## Have the TA verify that your design is correct and sign.

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## Wiring: wire the network of resistors you designed on the breadboard.

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## Measurements:

**Important:** ***Do not connect your board to the source BEFORE the instructor has approved your connections!***

* Connect a voltage source with an initial output voltage of 0 volts.
* Set the voltage source to 10V

## Measure the current *i*in (measured) and record it in Table 1.

## Measure the voltage across the right most resistor Vo (measured) and record it in Table 1.

* Slowly reduce the output voltage of the power supply from 10V to 0V in increments of 2V and measure the voltage V**o**.
* Enter the data in Table 1

**Table 1: Set values and measured values**

|  |  |  |  |
| --- | --- | --- | --- |
| Vnominal [V] | Vo (measured) | *i*in (measured) | K (calculated) |
| 10 |  |  |  |
| 8 |  |  |  |
| 6 |  |  |  |
| 4 |  |  |  |
| 2 |  |  |  |

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

* Replace the resistors network with a single resistor as close as possible to the calculated equivalent resistance.

## *R* used=\_\_\_\_\_\_\_\_\_\_\_

* Set the voltage source to 10V

## Measure the current *i*in (measured) =\_\_\_\_\_\_\_\_\_\_\_

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## Experiment # 2.2: Voltage divider design

## Design:

## Design a voltage divider with the following requirements:

## The voltage source supplies 10V at a maximum power of 0.3 mW

## The output voltage

## You may use 10kresistors, 20k resistors, and higher. You may combine several of these resistors in parallel and series to achieve the design requirements.

## Draw your network of resistors here:

## 

## Have the TA verify that your design is correct and sign.

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## Calculated the expected voltage source out current:

## *i*in =\_\_\_\_\_\_\_\_\_\_\_

## Assuming your resistors have a tolerance, calculate the maximum current you expect to be drawn from the voltage source.

## *i*in(max) =\_\_\_\_\_\_\_\_\_\_\_

## Calculate the maximum power delivered by the voltage source and verify that the design objective is met

## *P*in(max) =\_\_\_\_\_\_\_\_\_\_\_

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## Wiring: wire the network of resistors you designed on the breadboard.

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## Measurements:

**Important:** ***Do not connect your board to the source BEFORE the instructor has approved your connections!***

* Connect a voltage source with an initial output voltage of 0 volts.
* Set the voltage source to 10V

## Measure the source voltage *V*in (measured) and record it in Table 2

## Measure the voltage Vo (measured) and record it in Table 2

## Measure the current *i*in (measured) and record it in Table 2

* Slowly reduce the output voltage of the power supply from 10V to 0V in increments of 2V and measure the voltage V**in**, V**o** and the current *i*in .
* Enter the measured values in Table 2

**Table 2: Set values and measured values**

|  |  |  |  |
| --- | --- | --- | --- |
| Vnominal [V] | Vin(measured) | Vo (measured) | *i*in (measured) |
| 10 |  |  |  |
| 8 |  |  |  |
| 6 |  |  |  |
| 4 |  |  |  |
| 2 |  |  |  |

TA Verification: \_\_\_\_\_\_\_\_\_\_\_\_\_

## PART E: Post-Lab Report

The lab report should include a filled and signed copy of part D and analysis of the data based on the following questions and required simulation.

1. **Analysis for experiment 2.1:** 
   1. How does the measured current *i*in values in Table 1 compare with the predicted current range? Is it within range or not? If not, explain what other factors could impact the measured values.
   2. Calculate the theoretical range for the equivalent resistance *R*eq based on a 5% tolerance for the individual resistors.
   3. Calculate the measured *R*eq for each measured current *i*in values in Table 1. How does it compare to the calculated resistance and predicted range? Is it within range or not? If not, explain what other factors could impact the measured values.
   4. Calculate the theoretical range for the proportionality coefficient K based on a 5% tolerance for the resistors.
   5. Calculate the measured *K* for each measured output voltage Vo in Table 1. How does it compare to the calculated proportionality coefficient and the predicted range? Is it with range or not? If not, explain what other factors could impact the measured values.
2. **Analysis for experiment 2.2:**
   1. Calculate the voltage divider coefficient resulting from the measurements in Table 2, i.e. . Was the voltage divider design objective met? Explain.
   2. Calculate the power delivered by the voltage source using the measured current (*i*in)and voltage (Vin)? Was the design objective met? Explain.
   3. Calculate the range for the output voltage Vo(max) and Vo(min). How does the measured voltage values Vo in Table 2 compare with the predicted range?
3. **Simulation:**

## 3.1 Design a circuit (a network of resistors) that has an equivalent resistance of 30 using all the following six resistors: 101015020and 30.

## a. Draw the circuit.

## A close up of a logo Description generated with very high confidenceb. Simulate the network of resistors using LTSpice by adding a 1Volt voltage source to the network. Find the current flowing through the source and use it to verify the equivalent resistance.

## c. Repeat part 3.1.b in TinkerCAD. Place a Ammeter on your circuit to measure the current flowing into the circuit. Attach a schematic printout of the circuit and a URL to your TinkerCAD simulation

## 3.2 For the circuit of Figure 5, the resistors values are given as: *R*1=2.2k, *R*2=4.7k, *R*3=3.3k, *R*4=4.7k, *R*5=2.2k, and *R*6=3.3k. Use Delta-Wye transform for terminals a-c-b so that the network in Figure 5 is replaced by the network shown in Figure 6. Given that Vin=12V determine:

## a. The resistors values in Figure 6, Rx, Ry, and Rz. Show all work.

## b. The total power generated by the voltage source.

## c. Simulate the circuit in Figure 5 using LTSpice to find all voltages and currents. Use the results to calculate the power and verify the result in part (b). Include a printout of the LTSpice drawing and results.

## d. Simulate the circuit in Figure 6 using LTSpice to find all voltages and currents. Use the results to calculate the power and verify the result in part (b). Include a printout of the LTSpice drawing and results.

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Figure 5: Circuit for part E (3.2)

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Figure 6: Applying delta-wye transformation to the circuit in Figure 5