Lab 1

Introduction to Electrical Circuits and Measurements

Goals for Lab 1

- Become familiar with how to make common electrical measurements using a digital multimeter (DMM).
- Learn to use a potentiometer to function as a variable resistor and also as a variable voltage divider.
- Design, build and test circuitry to allow a 9V battery to function as a variable voltage source capable of producing any voltage in the range 2-5V.

Introduction

Throughout the course of the semester, you will become familiar with some basic equipment that is used in the practice of electrical engineering. In order to allow students the flexibility to do the lab work on their own schedule, we will be using a Portable Measurement Device (PMD) to emulate most of the bench lab equipment. Currently, the device we use in ECEN 214 is the Analog discovery 2 (AD2) but there are other devices with similar functionality. Even though your PMD will allow your laptop to have the same look and feel of the bench lab equipment, we also want students to get their hands on the real bench equipment. So, in several labs, including this one, you will follow up the measurements you make with your PMD with similar measurements using the bench equipment.

There is a separate appendix to the lab manual for each piece of equipment that you can use to familiarize yourself with the function and operation of that piece of equipment. These appendices will also provide a convenient reference throughout the semester if you need help with any equipment. Prior to starting this lab, you should look at the following appendices:

Appendix A – Bench Digital Multimeter (DMM): HP Model 34401A

Appendix E – Analog Discovery 2 System

Appendix F – Breadboards

Appendix H – Resistor Codes

Theory

The goal of this lab is to develop circuitry that can be used to transform a fixed DC voltage source (e.g., a battery) into a variable DC voltage source. We will be using a voltage divider circuit to achieve that end where one or more of the resistors in the voltage divider is variable. A basic voltage divider circuit is illustrated in Figure 1.1. In our case, the voltage source V_1 will be a battery and the goal is to be able to vary the voltage V_2 that appears at the output of the voltage divider by varying the values of the resistors R_1 and/or R_2.

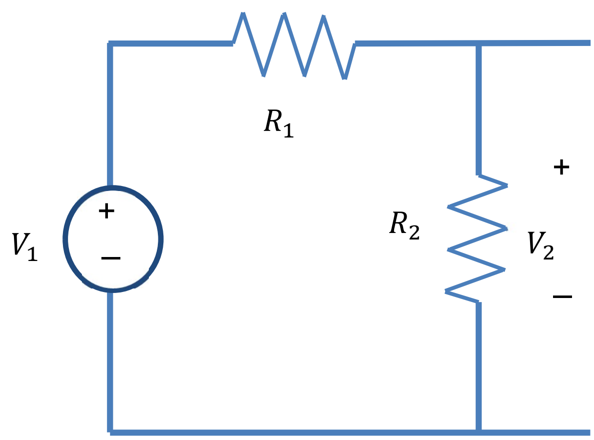
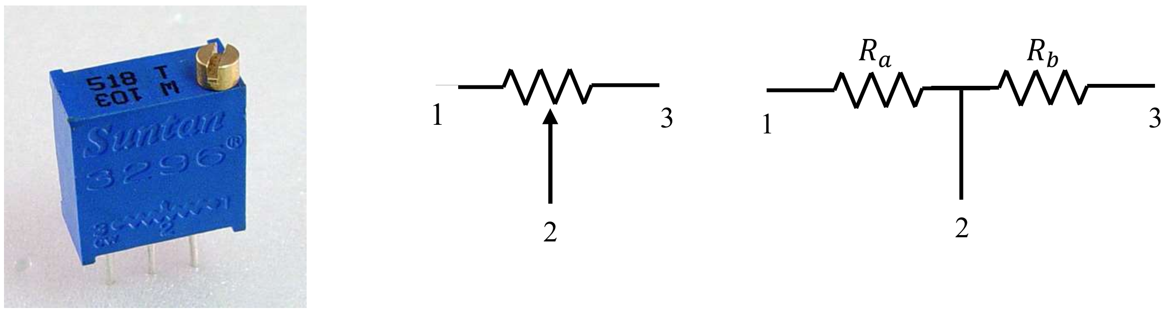


Figure 1.1 – A voltage divider circuit

The output voltage of the voltage divider circuit is given by:

$$V_2 = V_1 \frac{R_2}{R_1 + R_2}$$

In order to make it easy to adjust the values of the various resistors, we will use a potentiometer (a.k.a, a "pot") to adjust the values of one or more of the resistors in the circuit. Figure 1.2(a) shows a picture of a typical pot. You can envision the pot as a resistive band laid out in a linear fashion with a slider that can be moved anywhere within the length of the resistive material (see Figure 1.2(b)). The slider essentially splits the resistance into two parts as shown in Figure 1.2(c). The two resistances R_a and R_b must sum to a constant value which is usually printed on the package. For example, a $10k\Omega$ pot must have $R_a + R_b = 10k\Omega$. By connecting all three terminals up to a circuit, the pot basically functions as a variable voltage divider. You can also use the pot as a variable resistor by leaving terminal 3 (or terminal 1) disconnected.



(a) (b) (c)

Figure 1.2 – (a) A typical pot, (b) its schematic, and (c) an equivalent circuit.

We will consider three different configurations in this lab; 1) resistor R_1 will be variable and R_2 will be fixed, 2) resistor R_1 will be fixed and R_2 will be variable, and 3) both resistors R_1 and R_2 will be (jointly) variable.

Finally, a voltage source is supposed to provide the same voltage regardless of what load we put across its terminals. When our variable voltage source is loaded as shown in Figure 1.3, the voltage divider equation needs to be modified as the resistor R_2 in the unloaded circuit is now replaced by a parallel combination of R_2 and R_L in the loaded circuit.

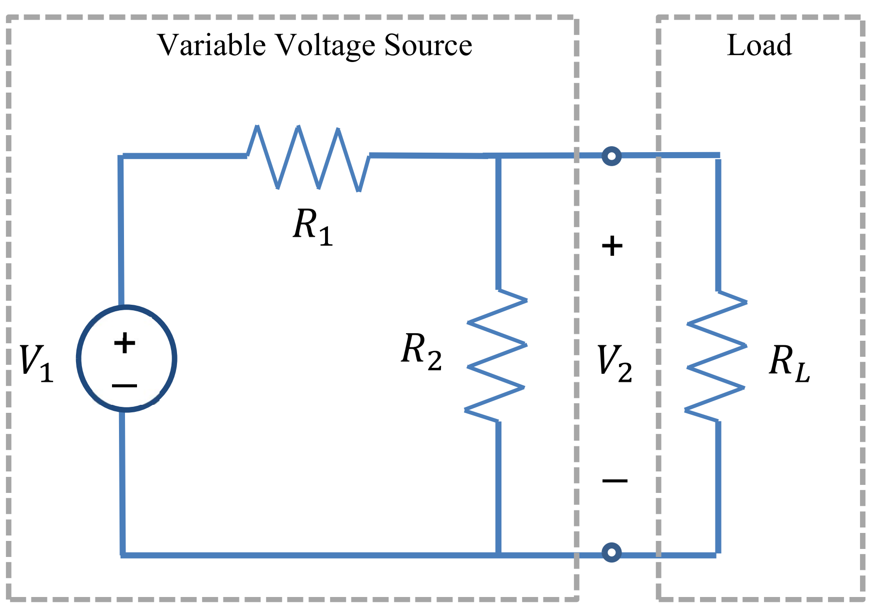


Figure 1.3 – A loaded voltage divider circuit

The modified voltage divider equation then becomes:

$$V_2 = V_1 \frac{(R_2||R_L)}{R_1 + (R_2||R_L)}$$

Where:

$$R_2||R_L = \frac{R_2 R_L}{R_2 + R_L}$$

In this lab, you will investigate to what extent the load resistance causes the output voltage V_2 to change.

Prelab

Be sure to read the entire document for Lab 1. **Items in bold should be handed in as part of your written prelab.**

1. Suppose we construct a voltage divider circuit as shown in Figure 1.1 where the voltage source V_1 is a 9V battery. Furthermore, we will implement resistor R_1 using two terminals of a 10k pot so that R_1 is variable over the range $0 \leq R_1 \leq 10k\Omega$. **Find the largest value of the resistor $\boldsymbol{R_2}$ that will allow the output voltage to vary over a range that includes at least $\boldsymbol{2.0V \leq V_2 \leq 5.0V}$. Show how you arrived at this value. Then, choose a resistor (or combination of resistors) from your parts kit that will get you as close as possible to (but no larger than) your calculated value for $\boldsymbol{R_2}$.**
2. Repeat Problem 1, but this time resistor R_1 is fixed and resistor R_2 is implemented using two terminals of a 10k pot so that R_2 is variable over the range $0 \leq R_2 \leq 10k\Omega$. **Find the largest value of the resistor $\boldsymbol{R_1}$ that will allow the output voltage to vary over a range that includes at least $\boldsymbol{2.0V \leq V_2 \leq 5.0V}$. Show how you arrived at this value. Then, choose a resistor (or combination of resistors) from your parts kit that will get you as close as possible to (but no larger than) your calculated value for $\boldsymbol{R_1}$.**
3. Repeat Problem 1, but this time both resistors R_1 and R_2 are implemented using the three terminals of a 10k pot so that R_1 and R_2 are both variable such that $0 \leq R_2 \leq 10k\Omega$ and $R_1 + R_2 = 10k\Omega$. **Find the range of values for $\boldsymbol{R_2}$ that will cause the output voltage to vary over the range $\boldsymbol{2.0V \leq V_2 \leq 5.0V}$. Show how you arrived at this range.**

Procedure –

Parts needed for this Experiment:

1 – 9V Battery with battery holder with leads

1 – 10k pot

A selection of various resistors

Task 1 – Fixed DC Voltage Source Measurement

The first voltage source to be measured in this lab is that of a household 9V battery. Connect leads to the terminals of the battery (using the battery holder in your parts kit). Then connect the battery leads to two different nodes in your breadboard as shown in Figure 1.4. Measure the voltage produced by the battery using your voltmeter in your PMD or the DMM in the lab and **record the DC voltage observed in your lab notebook**.

Note: Do not worry if your battery does not measure exactly 9V. If your battery is old, it may not measure a full 9V and if your battery is fresh, it may measure slightly more than 9V.

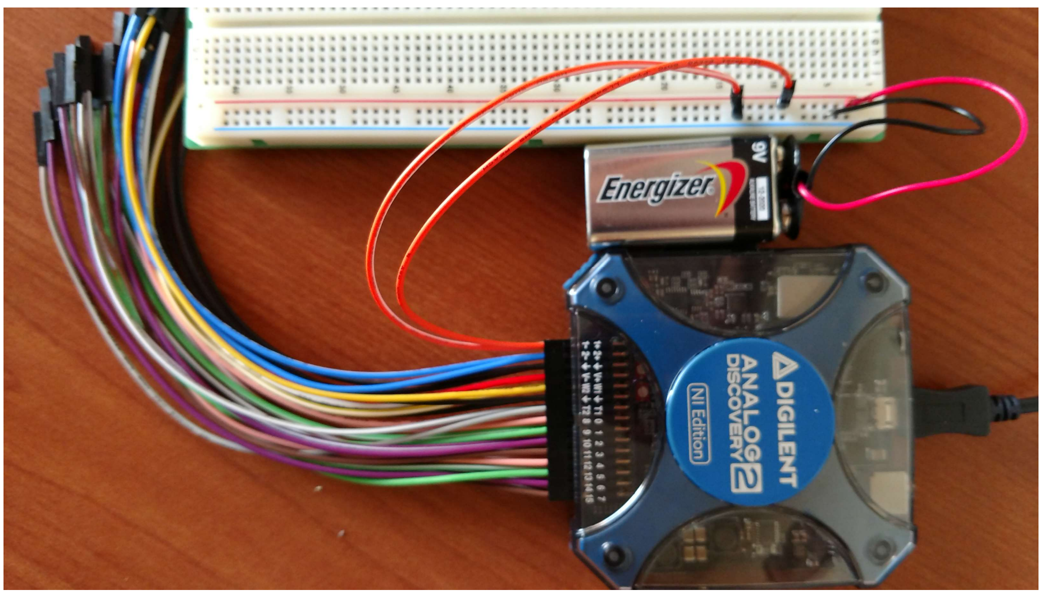


Figure 1.4 – Measuring the voltage output of a battery.

Next, place a load resistor across the terminals of the battery and re-measure the voltage across the battery terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.**

Task 2 –Variable DC Voltage Source Measurement

A. Construct the voltage divider circuit of Figure 1.1 where the voltage source V_1 is a 9V battery and the resistor R_1 is implemented using two terminals of the 10k pot so that R_1 is variable over the range $0 \leq R_1 \leq 10k\Omega$. The resistor R_2 should be the fixed resistor (or combination of resistors) you chose in Problem 1 of the prelab. Measure the range of voltages that appear at the output of your voltage divider as you vary the resistance of the pot over its full range. **Record in your lab book the largest and smallest voltages that you measure.** Adjust the pot so that the unloaded output of the voltage divider is 5V (or as close as you can get it). Then, place a load resistor across the output terminals of the voltage divider (as illustrated in Figure 1.3) and re-measure the voltage across the voltage divider output terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.** Adjust the pot so that the unloaded output of the voltage divider is 2V (or as close as you can get it). Then, place a load resistor across the output terminals of the voltage divider (as illustrated in Figure 1.3) and re-measure the voltage across the voltage divider output terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.**

B. Construct the voltage divider circuit of Figure 1.1 where the voltage source V_1 is a 9V battery and the resistor R_2 is implemented using two terminals of the 10k pot so that R_2 is variable over the range $0 \leq R_2 \leq 10k\Omega$. The resistor R_1 should be the fixed resistor (or combination of resistors) you chose in Problem 2 of the prelab. Measure the range of voltages that appear at the output of your voltage divider as you vary the resistance of the pot over its full range. **Record in your lab book the largest and smallest voltages that you measure.** Adjust the pot so that the unloaded output of the voltage divider is 5V (or as close as you can get it). Then, place a load resistor across the output terminals of the voltage divider (as illustrated in Figure 1.3) and re-measure the voltage across the voltage divider output terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.** Adjust the pot so that the unloaded output of the voltage divider is 2V (or as close as you can get it). Then, place a load resistor across the output terminals of the voltage divider (as illustrated in Figure 1.3) and re-measure the voltage across the voltage divider output terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.**

C. Construct the voltage divider circuit of Figure 1.1 resistors R_1 and R_2 are implemented using the three terminals of a 10k pot so that R_1 and R_2 are both variable such that $0 \leq R_2 \leq 10k\Omega$ and $R_1 + R_2 = 10k\Omega$. Measure the range of voltages that appear at the output of your voltage divider as you vary the resistance of the pot over its full range. **Record in your lab book the largest and smallest voltages that you measure.** Adjust the pot so that the unloaded output of the voltage divider is 5V (or as close as you can get it). Then, place a load resistor across the output terminals of the voltage divider (as illustrated in Figure 1.3) and re-measure the voltage across the voltage divider output terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.** Adjust the pot so that the unloaded output of the voltage divider is 2V (or as close as you can get it). Then, place a load resistor across the output terminals of the voltage divider (as illustrated in Figure 1.3) and re-measure the voltage across the voltage divider output terminals. Repeat this measurement for four different load resistances of $R_L = 100\Omega$, $1k\Omega$, $10k\Omega$, and $100k\Omega$. **Record your measured voltages for each case in your lab book.**

Before you leave the lab …

After you have completed all of your measurements, show your lab book to your TA and have him/her initial your data page(s) in your lab book. You will need to include a copy of your signed data page(s) in your lab report. Your TA may ask you questions about the measurements you took or may ask you to demonstrate how you took some of your measurements. If you did all of your measurements with your PMD, your TA may also take some time to show you how to use the digital multi-meter in the lab.

Some things to think about and discuss in your lab report

- We designed the voltage divider circuit to provide a variable output voltage that could produce any voltage in the range $2V \leq V_2 \leq 5V$. However, we saw that when the output of the voltage divider was loaded, the voltage output degraded. For each of the three configurations, what sensitivity did the circuit have to load resistance? For example, what range of load resistances could the circuit tolerate and still produce the designed (unloaded) voltages to within an error of say 10%.
- If we wanted to make the circuits you used less sensitive to load resistances, how could/would you change things? For example, would it be better to use larger or smaller resistors in the voltage dividers and what difference would it make to the sensitivity?
- It is generally desirable that there be not much power absorbed in the resistors of the voltage divider (we would rather see power delivered to the load). Towards that end, would we be better off using larger or smaller resistor values in the voltage divider?

Lab Report Requirements

Lab reports should be professional looking documents. Please avoid improper formatting, misspelled words and grammar mistakes. You must follow the specified format. Please see your TA if you have any questions. In general, lab reports should include:

1. A title page with the names of all the people in your group, your section number, and the name of your TA. It should also include the date(s) the lab measurements were performed and the date the lab report is due.
2. A write up for the lab:
   A. Procedure – summarize, in your own words, the procedures for each task and how you did them. Do not regurgitate the procedures step-by-step. Typically, you should include a couple of sentences per task.
   B. Data Tables – Retype the data you collected in tables.
   C. Data Plots – Present your data in a visual form.
   D. Sample calculations – Type the method you used for any calculations.
   E. Discussion – For each task, be sure to address any questions or discussion items brought up in the lab manual.

F. Conclusion – Write a few sentences expressing what you learned in this lab. Feel free to write about any suggestions to improve the lab or discuss any problems you encountered.

Please keep your lab reports as concise as possible. Include what is required but get to the point.