EE 110  
Introduction to Engineering & Laboratory Experience  
Saeid Rahimi, Ph.D.  
Lab 3  
DC Measurements II: Circuit Laws and Voltage Dividers

In the last lab we discussed the basic concepts of voltage, current and resistance, and learned about various resistor combinations. Today we will discuss the basics of an all-important topic of circuit laws which will be the foundation of analysis of circuits. We will then apply the concept to make a voltage divider.

Two circuit laws help us analyze branching and division of currents and voltages in electronic circuits:

1. The circuit current law is also called Kirchoff’s Current Law (KCL). Suppose the electric current in the branch of a circuit is $I$. Assume this current branches off into two branches at the junction point $P$, leading to a current $I_1$ in the first branch and $I_2$ in the second branch. The KCL states that $I = I_1 + I_2$, which seems to be fairly logical.

2. The Circuit voltage law is also called Kirchoff’s Voltage Law (KVL). This law states that in a closed circuit the voltage provided by a battery is equal to the sum of voltages across the resistors in the circuit. Consider the following circuit consisting of a battery of voltage $V$ and three resistors. The KVL indicates that $V = V_1 + V_2 + V_3$.

The details of KVL and KCL and their applications will be treated in your 200-level courses. Today we will first experimentally verify the KVL and KCL and then use the KVL to create a
voltage divider. The idea is to employ KVL to divide the voltage of a battery into desired smaller voltages. You can use your laboratory power supply or the Analog Discovery Scope (DS) as a source of voltage (battery) to do this experiment at the lab or at home. This laboratory exercise will help you construct simple circuits that will subdivide voltage of a battery. For example, suppose you need a 3.5 V voltage or a 5 V voltage for your experiments and all you have available is a 9 V or 12 V battery. This is what a voltage divider circuit does. Of course, you can utilize a voltage regulator device for achieving the desired voltages, but here we will cover some basic ideas that are used in many circuit analysis applications. In a similar fashion one can use the KCL to create a desired smaller current using a larger current. There are also ways to obtain a larger voltage from a small voltage source (not treated in this lab). Let us do some basic exercises without any theoretical analysis of the circuit (you will see plenty of more advanced analysis in the future).

A. Voltage Law Measurement: Start with the following simple circuit, which includes a 5 V battery connected to resistors in series, $R_1 = 1 \, \text{k}\Omega$, and $R_2 = 330 \, \Omega$. The circuit voltage law states that the battery's voltage equals the sum of voltages across the two resistors $R_1$ and $R_2$, which are connected in series:

$$V_1 = V_{R_1} + V_{R_2}$$

Construct the circuit on your breadboard and use your multimeter to measure the voltages $V_{R_1}$ and $V_{R_2}$. Compare your measurements with the expected values that are presented here without proof.

$$V_{R_1} = \left[ \frac{R_1}{R_1 + R_2} \right] V_1, \quad V_{R_2} = \left[ \frac{R_2}{R_1 + R_2} \right] V_1$$

**Note:** It is wise to place an On/Off switch in the circuit so the battery is not drained when the circuit is not in use.

**Reminder:** Carefully measure the value of your resistors prior to inserting them in the circuit. Compare the calculated results and the measured results for $V_{R_1}$ and $V_{R_2}$ and make a note of the error in each case.
V1 measured | R1 measured | R2 measured
---|---|---

<table>
<thead>
<tr>
<th>VR1 measured</th>
<th>VR1 calculated</th>
<th>% error</th>
<th>VR2 measured</th>
<th>VR2 calculated</th>
<th>% error</th>
</tr>
</thead>
</table>

B. Current Law Measurement: Connect the two resistors in parallel. Measure the voltage across R₁ and R₂ and divide by the resistance of each resistor to calculate the current in each branch (I₁ and I₂). Next, calculate the equivalent resistance of the two parallel resistors (Rₑ). The result should be less than the smallest resistance. Draw the equivalent circuit consisting of V₁ and Rₑ, and calculate the total current in the circuit (I = V₁/Rₑ). Now verify that the circuit current (I) is equal to the sum of currents in the two branches: I = I₁ + I₂

Note that instead of measuring current directly, we measure voltages across resistors and use Ohm’s law to find the current through the resistor (I = V/R)

![Circuit Diagram]

<table>
<thead>
<tr>
<th>V1 measured</th>
<th>R1 measured</th>
<th>R2 measured</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>I₁</th>
<th>I₂</th>
<th>I measured = I₁ + I₂</th>
<th>I calculated = V₁/Rₑ</th>
<th>% error</th>
</tr>
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</table>

C. Voltage Divider Measurement

1. The purpose of this part of the experiment is to create a 1.5 V and a 3.5 V voltage from the 5 V output of the DC power supply at your lab station. In order to achieve this goal you will need to connect at least two resistors in series to the battery. The voltage across one of the resistors should read 1.5 V and the voltage of the other resistor should be 3.5 V.

Calculation: You should determine the minimum number of resistors you need to build such a voltage divider. Select R₁ to have a resistance of 1 kΩ. Calculate the values of the rest of the required resistors. Show your calculation to your instructor before constructing the circuit.
Draw a circuit diagram, construct the circuit and using a multimeter demonstrate that you have achieved the goal.

<table>
<thead>
<tr>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>VR1</th>
<th>VR2</th>
<th>VR3</th>
<th>VR4</th>
</tr>
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</table>

**Hint:** One simple way to divide a 5 V source into a 2 V source and a 3 V source is to connect the 5 V source in series with one of the following pairs of resistors in series:

(2 Ω and 3Ω), (200 Ω and 300Ω), (2 k Ω and 3 kΩ), etc…

Note that you will draw less battery current if you chose large resistor values.

2. Next, design a voltage divider circuit which will deliver the following three voltages: 1 V, 1.5 V, and 2.5 V. Determine the value of the resistors and construct the circuit. Verify the desired voltages and show the results to your instructor.

<table>
<thead>
<tr>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>VR1</th>
<th>VR2</th>
<th>VR3</th>
<th>VR4</th>
</tr>
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Question 1: How many different voltages can you obtain in this circuit? Identify the ends of each resistor with letters A, B, C, etc., and give the voltages between any two points: $V_{AB}$, $V_{BC}$, $V_{AC}$, etc.

Question 2: Calculate the maximum current that your circuit can supply. What would you change if there is a need for a larger current in the circuit?

Recommendation for actual circuits: When using a battery as the power source, it will drain out if the circuit is left connected. It is a good practice to connect a toggle switch (Off/On) in series with the battery so you can turn it off when the voltage divider is not in use. Here, of course, connecting and disconnecting the wire connected to the battery can act as an effective On/Off switch.

**D. A Variable Voltage Divider Measurement**

Let us replace one of the resistors in the circuit of part A with a variable resistor (potentiometer). You should have a 10 k potentiometer in your toolkit. Before inserting the potentiometer in the circuit, measure and record its minimum and maximum resistance by turning its control screw. Insert the potentiometer in the circuit as shown in the diagram below. Add a toggle switch as shown in the diagram. Use your voltmeter to monitor the voltage $V_{AB}$ across the constant resistor.

Now change the value of the variable resistor by turning the screw of the potentiometer and observe the reading of the voltmeter. Make a note of the maximum and minimum voltage that you observe when you change the resistance of the potentiometer from minimum to maximum. You are observing a variable voltage divider at work. You can use your 5 V source instead of the 12 V battery shown in the diagram.
<table>
<thead>
<tr>
<th>Battery voltage</th>
<th>Fixed resistor</th>
<th>Variable resistor min</th>
<th>Variable resistor max</th>
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<table>
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<tr>
<th>Resistor voltage min</th>
<th>Resistor voltage max</th>
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![Circuit Diagram]

12 V

10 k

1 k

C

B

A