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# Laboratory Manual

## For

# DC Electrical Circuit Analysis

## (Part one)

### Laboratory Staff

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# The Electrical Laboratory

## Objective

The laboratory emphasizes the practical, hands-on component of this course. It complements the theoretical material presented in lecture, and as such, is integral and indispensable to the mastery of the subject. There are several items of importance here including proper safety procedures, required tools, and laboratory reports. This exercise will finish with an examination of scientific and engineering notation, the standard form of representing and manipulating values.

## Lab Safety and Tools

If proper procedures are followed, the electrical lab is a perfectly safe place in which to work. There are some basic rules: No food or drink is allowed in lab at any time. Liquids are of particular danger as they are ordinarily conductive. While the circuitry used in lab is normally of no shock hazard, some of the test equipment may have very high internal voltages that could be lethal (in excess of 10,000 volts). Spilling a bottle of water or soda onto such equipment could leave the experimenter in the receiving end of a severe shock. Similarly, items such as books and jackets should not be left on top of the test equipment as it could cause overheating.

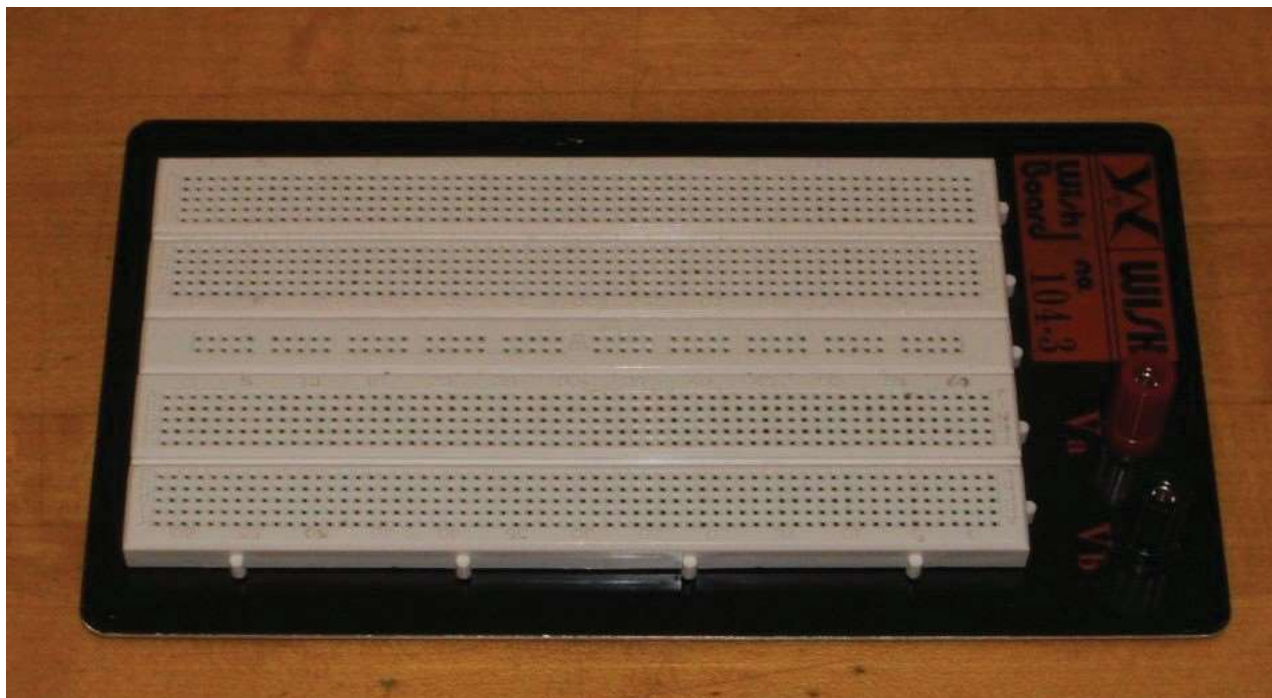
Each lab bench is self contained. All test equipment is arrayed along the top shelf. Beneath this shelf at the back of the work area is a power strip. All test equipment for this bench should be plugged into this strip. None of this equipment should be plugged into any other strip. This strip is controlled by a single circuit breaker which also controls the bench light. In the event of an emergency, all test equipment may be powered off through this one switch. Further, the benches are controlled by dedicated circuit breakers in the front of the lab. Next to this main power panel is an A/B/C class fire extinguisher suitable for electrical fires. Located at the rear of the lab is a safety kit. This contains bandages, cleaning swabs and the like for small cuts and the like. For serious injury, the Security Office will be contacted.

A lab bench should always be left in a secure mode. This means that the power to each piece of test equipment should be turned off, the bench itself should be turned off, all AC and DC power and signal sources should be turned down to zero, and all other equipment and components properly stowed with lab stools pushed under the bench.



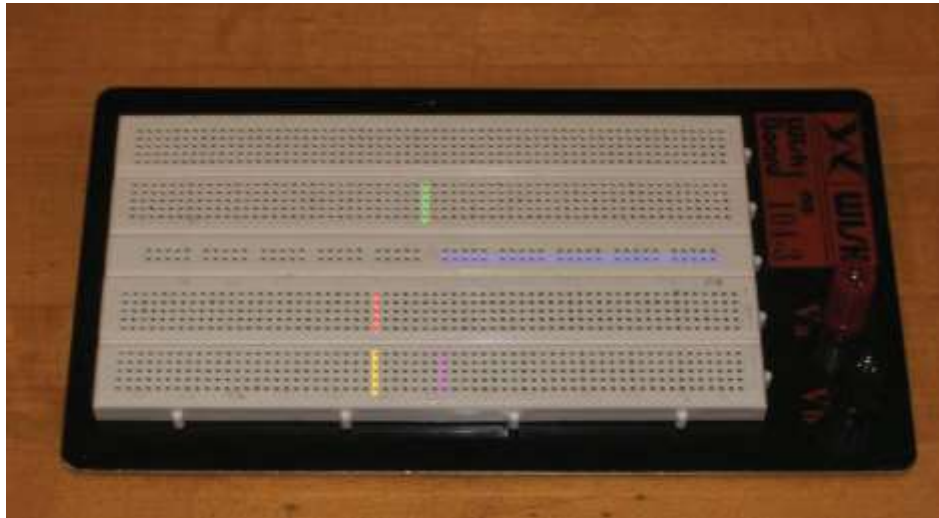
It is important to come prepared to lab. This includes the class text, the lab exercise for that day, class notebook, calculator, and hand tools. The tools include an electronic breadboard, test leads, wire strippers, and needle-nose pliers or hemostats. A small pencil soldering iron may also be useful. A basic DMM (digital multimeter) rounds out the list.

A typical breadboard or protoboard is shown below:



This particular unit features two main wiring sections with a common strip section down the center. Boards can be larger or smaller than this and may or may not have the mounting plate as shown. The connections are spaced 0.1 inch apart which is the standard spacing for many semiconductor chips. These are clustered in groups of five common terminals to allow multiple connections. The exception is the common strip which may have dozens of connection points. These are called *buses* and are designed for power and ground connections. Interconnections are normally made using small diameter solid hookup wire, usually AWG 22 or 24. Larger gauges may damage the board while smaller gauges do not always make good connections and are easy to break.

In the picture below, the color highlighted sections indicate common connection points. Note the long blue section which is a bus. This unit has four discrete buses available. When building circuits on a breadboard, it is important to keep the interconnecting wires short and the layout as neat as possible. This will aid both circuit functioning and ease of troubleshooting.



## Laboratory Reports

Unless specified otherwise, all lab exercises require a non-formal laboratory report. Lab reports are individual endeavors not group work. The deadline for reports is one week after the exercise is performed. A letter grade is subtracted for the first half-week late and two letter grades are subtracted for the second half-week late. Reports are not acceptable beyond one week late. A basic report should include a statement of the Objective (i.e., those items under investigation), a Conclusion (what was found or verified), a Discussion (an explanation and analysis of the lab data which links the Objective to the Conclusion), Data Tables and Graphs, and finally, answers to any problems or questions posed in the exercise.

## Scientific and Engineering Notation

Scientists and engineers often work with very large and very small numbers. The ordinary practice of using commas and leading zeroes proves to be very cumbersome in this situation. Scientific notation is more compact and less error prone method of representation. The number is split into two portions: a precision part (the mantissa) and a magnitude part (the exponent, being a power of ten). For example, the value 23,000 could be written as 23 times 10 to the 3<sup>rd</sup> power (that is, times one thousand). The exponent may be thought of in terms of how places the decimal point is moved to the left. Spelling this out is awkward, so a shorthand method is used where “times 10 to the X power” is replaced by the letter E (which stands for exponent). Thus, 23,000 could be written as 23E3. The value 45,000,000,000 would be written as 45E9. Note that it would also be possible to write this number as 4.5E10 or even 0.45E11. The





only difference between scientific notation and engineering notation is that for engineering notation the exponent is always a multiple of three. Thus, 45E9 is proper engineering notation but 4.5E10 isn't. On most scientific calculators E is represented by either an “EE” or “EXP” button. The process of entering the value 45E9 would be depressing the keys 4 5 EE 9.

For fractional values, the exponent is negative and may be thought of in terms how many places the decimal point must be moved to the right. Thus, 0.00067 may be written as 0.67E-3 or 6.7E-4 or even 670E-6. Note that only the first and last of these three are acceptable as engineering notation.

Engineering notation goes one step further by using a set of prefixes to replace the multiples of three for the exponent. The prefixes are:

E12 = Tera (T)	E9 = Giga (G)	E6 = Mega (M)	E3 = kilo (k)
E-3 = milli (m)	E-6 = micro ( $\mu$ )	E-9 = nano (n)	E-12 = pico (p)

Thus, 23,000 volts could be written as 23E3 volts or simply 23 kilovolts. Besides being more compact, this notation is much simpler than the ordinary form when manipulating wide ranging values. When multiplying, simply multiply the precision portions and add the exponents. Similarly, when dividing, divide the precision portions and subtract the exponents. For example, 23,000 times 0.000003 may appear to be a complicated task. In engineering notation this is 23E3 times 3E-6. The result is 69E-3 (that is, 0.069). Given enough practice it will become second nature that kilo (E3) times micro (E-6) yields milli (E-3). This will facilitate lab estimates a great deal. Continuing, 42,000,000 divided by 0.002 is 42E6 divided by 2E-3, or 21E9 (the exponent is 6 minus a negative 3, or 9).

When adding or subtracting, first make sure that the exponents are the same (scaling if required) and then add or subtract the precision portions. For example, 2E3 plus 5E3 is 7E3. By comparison, 2E3 plus 5E6 is the same as 2E3 plus 5000E3, or 5002E3 (or 5.002E6).

Perform the following operations. Convert the following into scientific and engineering notation.

- |           |               |
|-----------|---------------|
| 1. 1,500  | 2. 63,200,000 |
| 3. 0.0234 | 4. 0.000059   |
| 5. 170    |               |

Convert the following into normal longhand notation:

- |            |           |
|------------|-----------|
| 6. 1.23E3  | 7. 54.7E6 |
| 8. 2E-3    | 9. 27E-9  |
| 10. 4.39E7 |           |



---

Use the appropriate prefix for the following:

11. 4E6 volts

12. 5.1E3 feet

13. 3.3E-6 grams

Perform the following operations:

14.  $5.2E6 + 1.7E6$

15.  $12E3 - 900$

16.  $1.7E3 \cdot 2E6$

17.  $48E3 / 4E6$

18.  $20 / 4E3$

19.  $10 \text{ M} \cdot 2 \text{ k}$

20.  $8 \text{ n} / 2 \text{ m}$



# Resistor Color Code

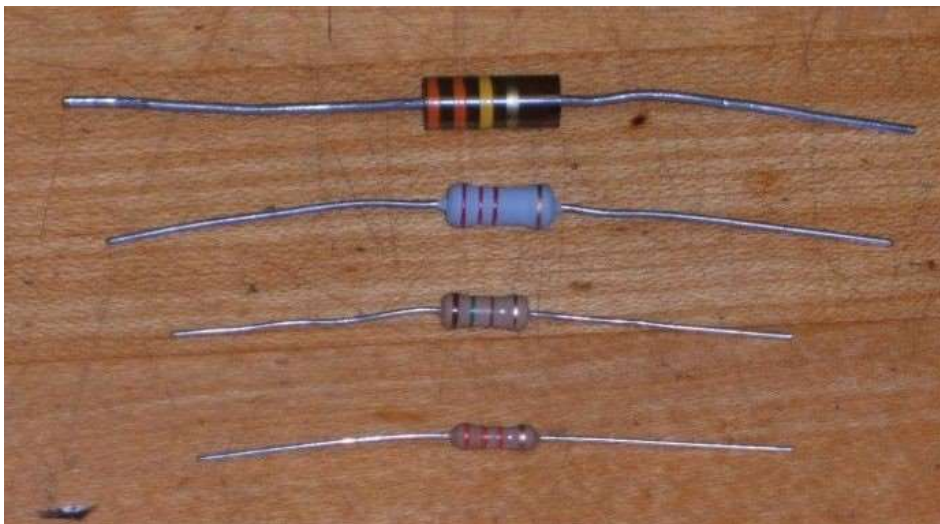
## Objective

The objective of this exercise is to become familiar with the measurement of resistance values using a digital multimeter (DMM). A second objective is to learn the resistor color code.

## Theory Overview

The resistor is perhaps the most fundamental of all electrical devices. Its fundamental attribute is the restriction of electrical current flow: The greater the resistance, the greater the restriction of current. Resistance is measured in ohms. The measurement of resistance in unpowered circuits may be performed with a digital multimeter. Like all components, resistors cannot be manufactured to perfection. That is, there will always be some variance of the true value of the component when compared to its nameplate or nominal value. For precision resistors, typically 1% tolerance or better, the nominal value is usually printed directly on the component. Normally, general purpose components, i.e. those worse than 1%, usually use a color code to indicate their value.

The resistor color code typically uses 4 color bands. The first two bands indicate the precision values (i.e. the mantissa) while the third band indicates the power of ten applied (i.e. the number of zeroes to add). The fourth band indicates the tolerance. It is possible to find resistors with five or six bands but they will not be examined in this exercise. Examples are shown below:







It is important to note that the physical size of the resistor indicates its power dissipation rating, not its ohmic value.

Each color in the code represents a numeral. It starts with black and finishes with white, going through the rainbow in between:

0 Black	1 Brown	2 Red	3 Orange	4 Yellow
5 Green	6 Blue	7 Violet	8 Gray	9 White

For the fourth, or tolerance, band:

5% Gold	10% Silver	20% None
---------	------------	----------

For example, a resistor with the color code brown-red-orange-silver would correspond to 12 followed by 3 zeroes, or 12,000 ohms (more conveniently, 12 k ohms). It would have a tolerance of 10% of 12 k ohms or 1200 ohms. This means that the actual value of any particular resistor with this code could be anywhere between  $12,000 - 1200 = 10,800$ , to  $12,000 + 1200 = 13,200$ . That is, 10.8 k to 13.2 k ohms. Note, the IEC standard replaces the decimal point with the engineering prefix, thus 1.2 k is alternately written 1k2.

Similarly, a 470 k 5% resistor would have the color code yellow-violet-yellow-gold. To help remember the color code many mnemonics have been created using the first letter of the colors to create a sentence. One example is the *picnic mnemonic* **Black Bears Robbed Our Yummy Goodies Beating Various Gray Wolves**.

Measurement of resistors with a DMM is a very straight forward process. Simply set the DMM to the resistance function and choose the first scale that is higher than the expected value. Clip the leads to the resistor and record the resulting value.

## Equipment

(1) Digital multimeter                      model: \_\_\_\_\_ srn: \_\_\_\_\_

## Procedure

1. Given the nominal values and tolerances in Table 3.1, determine and record the corresponding color code bands.
2. Given the color codes in Table 3.2, determine and record the nominal value, tolerance and the minimum and maximum acceptable values.
3. Obtain a resistor equal to the first value listed in Table 3.3. Determine the minimum and maximum



acceptable values based on the nominal value and tolerance. Record these values in Table 3.3. Using the DMM, measured the actual value of the resistor and record it in Table 3.3. Determine the deviation percentage of this component and record it in Table 3.3. The deviation percentage may be found via:  $\text{Deviation} = 100 * (\text{measured} - \text{nominal})/\text{nominal}$ . *Circle the deviation if the resistor is out of tolerance.*

4. Repeat Step 3 for the remaining resistor in Table 3.3.

## Data Tables

Value	Band 1	Band 2	Band 3	Band 4
27 @ 10%				
56 @ 10%				
180 @ 5%				
390 @ 10%				
680 @ 5%				
1.5 k @ 20%				
3.6 k @ 10%				
7.5 k @ 5%				
10 k @ 5%				
47 k @ 10%				
820 k @ 10%				
2.2 M @ 20 %				

Table 3.1



Colors	Nominal	Tolerance	Minimum	Maximum
red-red-black-silver				
blue-gray-black-gold				
brown-green-brown-gold				
orange-orange-brown-silver				
green-blue-brown -gold				
brown-red-red-silver				
red-violet-red-silver				
gray-red-red-gold				
brown-black-orange-gold				
orange-orange-orange-silver				
blue-gray-yellow-none				
green-black-green-silver				

Table 3.2

Value	Minimum	Maximum	Measured	Deviation
22 @ 10%				
68 @ 5%				
150 @ 5%				
330 @ 10%				
560 @ 5%				
1.2 k @ 5%				
2.7 k @ 10%				
8.2 k @ 5%				
10 k @ 5%				
33 k @ 10%				
680 k @ 10%				
5 M @ 20 %				

Table 3.3



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## Questions

1. What is the largest deviation in Table 3.3? Would it ever be possible to find a value that is outside the stated tolerance? Why or why not?
  
  
  
  
  
  
  
  
  
  
2. If Steps 3 and 4 were to be repeated with another batch of resistors, would the final two columns be identical to the original Table 3.3? Why or why not?
  
  
  
  
  
  
  
  
  
  
3. Do the measured values of Table 3.3 represent the exact values of the resistors tested? Why or why not?



# Ohm's Law

## Objective

This exercise examines Ohm's law, one of the fundamental laws governing electrical circuits. It states that voltage is equal to the product of current times resistance.

## Theory Overview

Ohm's law is commonly written as  $V = I * R$ . That is, for a given current, an increase in resistance will result in a greater voltage. Alternately, for a given voltage, an increase in resistance will produce a decrease in current. As this is a first order linear equation, plotting current versus voltage for a fixed resistance will yield a straight line. The slope of this line is the conductance, and conductance is the reciprocal of resistance. Therefore, for a high resistance, the plot line will appear closer to the horizontal while a lower resistance will produce a more vertical plot line.

## Equipment

- |                                |              |            |
|--------------------------------|--------------|------------|
| (1) Adjustable DC power supply | model: _____ | srn: _____ |
| (1) Digital multimeter         | model: _____ | srn: _____ |
| (1) 1 kΩ resistor              | _____        |            |
| (1) 6.8 kΩ resistor            | _____        |            |
| (1) 33 kΩ resistor             | _____        |            |

## Schematic

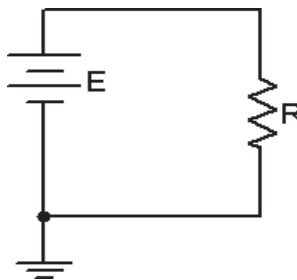


Figure 4.1





## Procedure

1. Build the circuit of Figure 4.1 using the 1 kΩ resistor. Set the DMM to measure DC current and insert it in-line between the source and resistor. Set the source for zero volts. Measure and record the current in Table 4.1. Note that the theoretical current is 0 and any measured value other than 0 would produce an undefined percent deviation.
2. Setting E at 2 volts, determine the theoretical current based on Ohm's law and record this in Table 4.1. Measure the actual current, determine the deviation, and record these in Table 4.1. Note that  $\text{Deviation} = 100 * (\text{measured} - \text{theory}) / \text{theory}$ .
3. Repeat step 2 for the remaining source voltages in Table 4.1.
4. Remove the 1 kΩ and replace it with the 6.8 kΩ. Repeat steps 1 through 3 using Table 4.2.
5. Remove the 6.8 kΩ and replace it with the 33 kΩ. Repeat steps 1 through 3 using Table 4.3.
6. Using the measured currents from Tables 4.1, 4.2, and 4.3, create a plot of current versus voltage. Plot all three curves on the same graph. Voltage is the horizontal axis and current is the vertical axis.

## Data Tables

E (volts)	I theory	I measured	Deviation
0	0		
2			
4			
6			
8			
10			
12			

Table 4.1 (1 kΩ)



E (volts)	I theory	I measured	Deviation
0	0		
2			
4			
6			
8			
10			
12			

Table 4.2 (6.8 k $\Omega$ )

E (volts)	I theory	I measured	Deviation
0	0		
2			
4			
6			
8			
10			
12			

Table 4.3 (33 k $\Omega$ )



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## Questions

1. Does Ohm's law appear to hold in this exercise?
2. Is there a linear relationship between current and voltage?
3. What is the relationship between the slope of the plot line and the circuit resistance?



# Series-Parallel DC Circuits

## Objective

This exercise will involve the analysis of basic series-parallel DC circuits with resistors. The use of simple series-only and parallel-only sub-circuits is examined as one technique to solve for desired currents and voltages.

## Theory Overview

Simple series-parallel networks may be viewed as interconnected series and parallel sub-networks. Each of these sub-networks may be analyzed through basic series and parallel techniques such as the application of voltage divider and current divider rules along with Kirchhoff's voltage and current laws. It is important to identify the most simple series and parallel connections in order to jump to more complex interconnections.

## Equipment

- |                                |                         |
|--------------------------------|-------------------------|
| (1) Adjustable DC power supply | model: _____ srn: _____ |
| (1) Digital multimeter         | model: _____ srn: _____ |
| (1) 1 kΩ                       | _____                   |
| (1) 2.2 kΩ                     | _____                   |
| (1) 3.3 kΩ                     | _____                   |
| (1) 4.7 kΩ                     | _____                   |
| (1) 6.8 kΩ                     | _____                   |

## Schematics

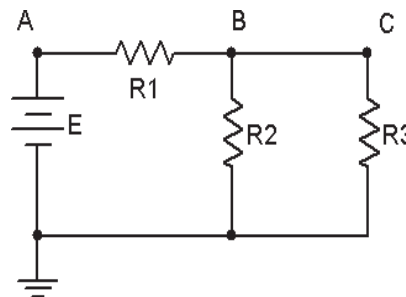


Figure 7.1

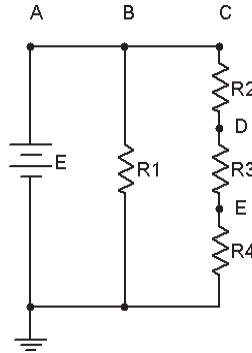


Figure 7.2

## Procedure

1. Consider the circuit of Figure 7.1 with  $R1 = 1\text{ k}$ ,  $R2 = 2.2\text{ k}$ ,  $R3 = 4.7\text{ k}$  and  $E = 10\text{ volts}$ .  $R2$  is in parallel with  $R3$ . This combination is in series with  $R1$ . Therefore, the  $R2, R3$  pair may be treated as a single resistance to form a series loop with  $R1$ . Based on this observation, determine the theoretical voltages at points A, B, and C with respect to ground. Record these values in Table 7.1. Construct the circuit. Set the DMM to read DC voltage and apply it to the circuit from point A to ground. Record this voltage in Table 7.1. Repeat the measurements at points B and C, determine the deviations, and record the values in Table 7.1.
2. Applying KCL to the parallel sub-network, the current entering node B (i.e., the current through  $R1$ ) should equal the sum of the currents flowing through  $R2$  and  $R3$ . These currents may be determined through Ohm's law and/or the current divider rule. Compute these currents and record them in Table 7.2. Using the DMM as an ammeter, measure these three currents and record the values along with deviations in Table 7.2.
3. Consider the circuit of Figure 7.2.  $R2, R3$  and  $R4$  create a series sub-network. This sub-network is in parallel with  $R1$ . By observation then, the voltages at nodes A, B and C should be identical as in any parallel circuit of similar construction. Due to the series connection, the same current flows through  $R2, R3$  and  $R4$ . Further, the voltages across  $R2, R3$  and  $R4$  should sum up to the voltage at node C, as in any similarly constructed series network. Finally, via KCL, the current exiting the source must equal the sum of the currents entering  $R1$  and  $R2$ .
4. Build the circuit of Figure 7.2 with  $R1 = 3.3\text{ k}$ ,  $R2 = 2.2\text{ k}$ ,  $R3 = 4.7\text{ k}$ ,  $R4 = 6.8\text{ k}$  and  $E = 20\text{ volts}$ . Using the series and parallel relations noted in Step 3, calculate the voltages at points B, C, D and E. Measure these potentials with the DMM, determine the deviations, and record the values in Table 7.3.





- Calculate the currents leaving the source and flowing through R1 and R2. Record these values in Table 7.4. Using the DMM as an ammeter, measure those same currents, compute the deviations, and record the results in Table 7.4.

## Simulation

- Build the circuit of Figure 7.1 in a simulator. Using the virtual DMM as a voltmeter determine the voltages at nodes A, B and C, and compare these to the theoretical and measured values recorded in Table 7.1.
- Build the circuit of Figure 7.2 in a simulator. Using the DC Operating Point simulation function, determine the voltages at nodes B, C, D and E, and compare these to the theoretical and measured values recorded in Table 7.3.

## Data Tables

Voltage	Theory	Measured	Deviation
V <sub>A</sub>			
V <sub>B</sub>			
V <sub>C</sub>			

Table 7.1

Current	Theory	Measured	Deviation
R <sub>1</sub>			
R <sub>2</sub>			
R <sub>3</sub>			

Table 7.2



Voltage	Theory	Measured	Deviation
$V_B$			
$V_C$			
$V_D$			
$V_E$			

Table 7.3

Current	Theory	Measured	Deviation
Source			
R1			
R2			

Table 7.4



---

## Questions

1. Are KVL and KCL satisfied in Tables 7.1 and 7.2?
2. Are KVL and KCL satisfied in Tables 7.3 and 7.4?
3. How would the voltages at A and B in Figure 7.1 change if a fourth resistor equal to 10 k was added in parallel with R3? What if this resistor was added in series with R3?
4. How would the currents through R1 and R2 in Figure 7.2 change if a fifth resistor equal to 10 k was added in series with R1? What if this resistor was added in parallel with R1?



# Superposition Theorem

## Objective

The objective of this exercise is to investigate the application of the superposition theorem to multiple DC source circuits in terms of both voltage and current measurements. Power calculations will also be examined.

## Theory Overview

The superposition theorem states that in a linear bilateral multi-source DC circuit, the current through or voltage across any particular element may be determined by considering the contribution of each source independently, with the remaining sources replaced with their internal resistance. The contributions are then summed, paying attention to polarities, to find the total value. Superposition cannot in general be applied to non-linear circuits or to non-linear functions such as power.

## Equipment

- (1) Adjustable dual DC power supply      model: \_\_\_\_\_ srn: \_\_\_\_\_
- (1) Digital multimeter                      model: \_\_\_\_\_ srn: \_\_\_\_\_
- (1) 4.7 k $\Omega$                                     \_\_\_\_\_
- (1) 6.8 k $\Omega$                                     \_\_\_\_\_
- (1) 10 k $\Omega$                                     \_\_\_\_\_
- (1) 22 k $\Omega$                                     \_\_\_\_\_
- (1) 33 k $\Omega$                                     \_\_\_\_\_

## Schematics

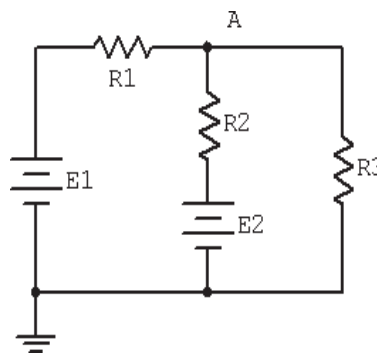


Figure 10.1

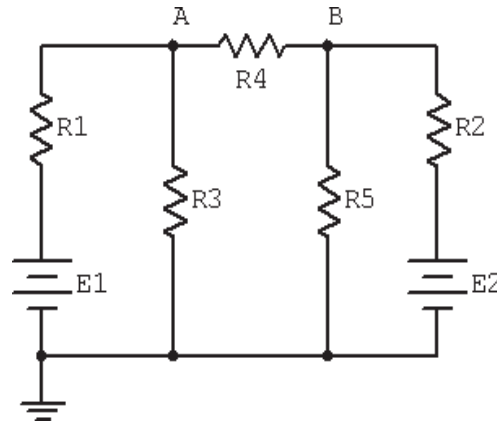


Figure 10.2

## Procedure

### Voltage Application

1. Consider the dual supply circuit of Figure 10.1 using  $E1 = 10$  volts,  $E2 = 15$  volts,  $R1 = 4.7$  k,  $R2 = 6.8$  k and  $R3 = 10$  k. To find the voltage from node A to ground, superposition may be used. Each source is considered by itself. First consider source  $E1$  by assuming that  $E2$  is replaced with its internal resistance (a short). Determine the voltage at node A using standard series-parallel techniques and record it in Table 10.1. Make sure to indicate the polarity. Repeat the process using  $E2$  while shorting  $E1$ . Finally, sum these two voltages and record in Table 10.1.
2. To verify the superposition theorem, the process may be implemented directly by measuring the contributions. Build the circuit of Figure 10.1 with the values specified in step 1, however, replace  $E2$  with a short. Do **not** simply place a shorting wire across source  $E2$ ! This will overload the power supply.
3. Measure the voltage at node A and record in Table 10.1. Be sure to note the polarity.
4. Remove the shorting wire and insert source  $E2$ . Also, replace source  $E1$  with a short. Measure the voltage at node A and record in Table 10.1. Be sure to note the polarity.
5. Remove the shorting wire and re-insert source  $E1$ . Both sources should now be in the circuit. Measure the voltage at node A and record in Table 10.1. Be sure to note the polarity. Determine and record the deviations between theory and experimental results.





6. Consider the dual supply circuit of Figure 10.2 using  $E1 = 10$  volts,  $E2 = 15$  volts,  $R1 = 4.7$  k,  $R2 = 6.8$  k,  $R3 = 10$  k,  $R4 = 22$  k and  $R5 = 33$  k. To find the current through  $R4$  flowing from node A to B, superposition may be used. Each source is again treated independently with the remaining sources replaced with their internal resistances. Calculate the current through  $R4$  first considering  $E1$  and then considering  $E2$ . Sum these results and record the three values in Table 10.2.
7. Assemble the circuit of Figure 10.2 using the values specified. Replace source  $E2$  with a short and measure the current through  $R4$ . Be sure to note the direction of flow and record the result in Table 10.2.
8. Replace the short with source  $E2$  and swap source  $E1$  with a short. Measure the current through  $R4$ . Be sure to note the direction of flow and record the result in Table 10.2.
9. Remove the shorting wire and re-insert source  $E1$ . Both sources should now be in the circuit. Measure the current through  $R4$  and record in Table 10.2. Be sure to note the direction. Determine and record the deviations between theory and experimental results.
10. Power is not a linear function as it is proportional to the square of either voltage or current. Consequently, superposition should not yield an accurate result when applied directly to power. Based on the measured currents in Table 10.2, calculate the power in  $R4$  using  $E1$ -only and  $E2$ -only and record the values in Table 10.3. Adding these two powers yields the power as predicted by superposition. Determine this value and record it in Table 10.3. The true power in  $R4$  may be determined from the total measured current flowing through it. Using the experimental current measured when both  $E1$  and  $E2$  were active (Table 10.2), determine the power in  $R4$  and record it in Table 10.3.



## Simulation

11. Build the circuit of Figure 10.2 in a simulator. Using the virtual DMM as an ammeter, determine the current through resistor R4 and compare it to the theoretical and measured values recorded in Table 10.2.

## Data Tables

Source	$V_A$ Theory	$V_A$ Experimental	Deviation
E1 Only			
E2 Only			
E1 and E2			

Table 10.1

Source	$I_{R4}$ Theory	$I_{R4}$ Experimental	Deviation
E1 Only			
E2 Only			
E1 and E2			

Table 10.2

Source	$P_{R4}$
E1 Only	
E2 Only	
E1 + E2	
E1 and E2	

Table 10.3



## Questions

1. Based on the results of Tables 10.1, 10.2 and 10.3, can superposition be applied successfully to voltage, current and power levels in a DC circuit?
2. If one of the sources in Figure 10.1 had been inserted with the opposite polarity, would there be a significant change in the resulting voltage at node A? Could both the magnitude and polarity change?
3. If both of the sources in Figure 10.1 had been inserted with the opposite polarity, would there be a significant change in the resulting voltage at node A? Could both the magnitude and polarity change?
4. Why is it important to note the polarities of the measured voltages and currents?



# Thévenin's Theorem

## Objective

The objective of this exercise is to examine the use of Thévenin's Theorem to create simpler versions of DC circuits as an aide to analysis. Multiple methods of experimentally obtaining the Thévenin resistance will be explored.

## Theory Overview

Thévenin's Theorem for DC circuits states that any two port linear network may be replaced by a single voltage source with an appropriate internal resistance. The Thévenin equivalent will produce the same load current and voltage as the original circuit to any load. Consequently, if many different loads or sub-circuits are under consideration, using a Thévenin equivalent may prove to be a quicker analysis route than “reinventing the wheel” each time.

The Thévenin voltage is found by determining the open circuit output voltage. The Thévenin resistance is found by replacing any DC sources with their internal resistances and determining the resulting combined resistance as seen from the two ports using standard series-parallel analysis techniques. In the laboratory, the Thévenin resistance may be found using an ohmmeter (again, replacing the sources with their internal resistances) or by using the matched load technique. The matched load technique involves replacing the load with a variable resistance and then adjusting it until the load voltage is precisely one half of the unloaded voltage. This would imply that the other half of the voltage must be dropped across the equivalent Thévenin resistance, and as the Thévenin circuit is a simple series loop then the two resistances must be equal as they have identical currents and voltages.

## Equipment

- |   |              |            |
|---|--------------|------------|
| (1) Adjustable DC power supply                  | model: _____ | srn: _____ |
| (1) Digital multimeter                          | model: _____ | srn: _____ |
| (1) 2.2 kΩ                                      | _____        |            |
| (1) 3.3 kΩ                                      | _____        |            |
| (1) 4.7 kΩ                                      | _____        |            |
| (1) 6.8 kΩ                                      | _____        |            |
| (1) 8.2 kΩ                                      | _____        |            |
| (1) 10 k potentiometer or resistance decade box |              |            |



## Schematics

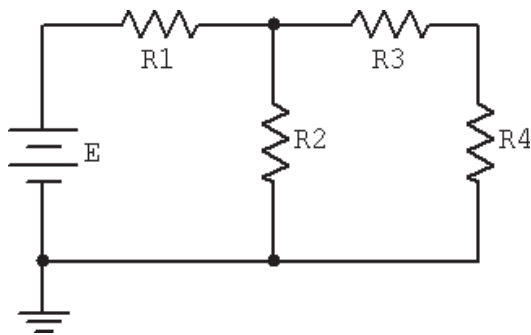


Figure 11.1

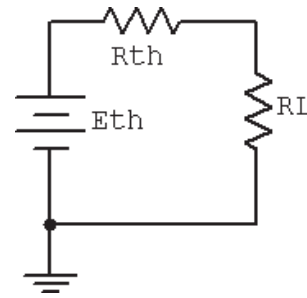


Figure 11.2

## Procedure

1. Consider the circuit of Figure 11.1 using  $E = 10$  volts,  $R1 = 3.3$  k,  $R2 = 6.8$  k,  $R3 = 4.7$  k and  $R4$  ( $R_{Load}$ ) = 8.2 k. This circuit may be analyzed using standard series-parallel techniques. Determine the voltage across the load,  $R4$ , and record it in Table 11.1. Repeat the process using 2.2 k for  $R4$ .
2. Build the circuit of Figure 11.1 using the values specified in step one, with  $R_{Load} = 8.2$  k. Measure the load voltage and record it in Table 11.1. Repeat this with a 2.2 k load resistance. Determine and record the deviations. Do not deconstruct the circuit.
3. Determine the theoretical Thévenin voltage of the circuit of Figure 11.1 by finding the open circuit output voltage. That is, replace the load with an open and calculate the voltage produced between the two open terminals. Record this voltage in Table 11.2.
4. To calculate the theoretical Thévenin resistance, first remove the load and then replace the source with its internal resistance (ideally, a short). Finally, determine the combination series-parallel resistance as seen from the where the load used to be. Record this resistance in Table 11.2.
5. The experimental Thévenin voltage maybe determined by measuring the open circuit output voltage. Simply remove the load from the circuit of step one and then replace it with a voltmeter. Record this value in Table 11.2.



6. There are two methods to measure the experimental Thévenin resistance. For the first method, using the circuit of step one, replace the source with a short. Then replace the load with the ohmmeter. The Thévenin resistance may now be measured directly. Record this value in Table 11.2.
7. In powered circuits, ohmmeters are not effective while power is applied. An alternate method relies on measuring the effect of the load resistance. Return the voltage source to the circuit, replacing the short from step six. For the load, insert either the decade box or the potentiometer. Adjust this device until the load voltage is half of the open circuit voltage measured in step five and record in Table 11.2 under “Method 2”. At this point, the load and the Thévenin resistance form a simple series loop as seen in Figure 11.2. This means that they “see” the same current. If the load exhibits one half of the Thévenin voltage then the other half must be dropped across the Thévenin resistance, in other words  $V_{RL} = V_{RTH}$ . Consequently, the resistances have the same voltage and current, and therefore must have the same resistance according to Ohm's law.
8. Consider the Thévenin equivalent of Figure 11.2 using the theoretical  $E_{TH}$  and  $R_{TH}$  from Table 11.2 along with 8.2 k for the load (RL). Calculate the load voltage and record it in Table 11.3. Repeat the process for a 2.2 k load.
9. Build the circuit of Figure 11.2 using the measured  $E_{TH}$  and  $R_{TH}$  from Table 11.2 along with 8.2 k for the load (RL). Measure the load voltage and record it in Table 11.3. Also determine and record the deviation.
10. Repeat step nine using a 2.2 k load.



## Data Tables

### Original Circuit

$R_4$ (Load)	$V_{Load}$ Theory	$V_{Load}$ Experimental	Deviation
8.2 k			
2.2 k			

Table 11.1

### Thévenized Circuit

	Theory	Experimental
$E_{TH}$		
$R_{TH}$		
$R_{TH}$ Method 2	X	

Table 11.2

$R_4$ (Load)	$V_{Load}$ Theory	$V_{Load}$ Experimental	Deviation
8.2 k			
2.2 k			

Table 11.3





---

## Questions

1. Do the load voltages for the original and Thévenized circuits match for both loads? Is it logical that this could be extended to any arbitrary load resistance value?
2. Assuming several loads were under consideration, which is faster, analyzing each load with the original circuit of Figure 11.1 or analyzing each load with the Thévenin equivalent of Figure 11.2?
3. How would the Thévenin equivalent computations change if the original circuit contained more than one voltage source?



# Maximum Power Transfer

## Objective

The objective of this exercise is to determine the conditions under which a load will produce maximum power. Further, the variance of load power and system efficiency will be examined graphically.

## Theory Overview

In order to achieve the maximum load power in a DC circuit, the load resistance must equal the driving resistance, that is, the internal resistance of the source. Any load resistance value above or below this will produce a smaller load power. System efficiency ( $\eta$ ) is 50% at the maximum power case. This is because the load and the internal resistance form a basic series loop, and as they have the same value, they must exhibit equal currents and voltages, and hence equal powers. As the load increases in resistance beyond the maximizing value the load voltage will rise, however, the load current will drop by a greater amount yielding a lower load power. Although this is not the maximum load power, this will represent a larger percentage of total power produced, and thus a greater efficiency (the ratio of load power to total power).

## Equipment

- |                                |                         |
|--------------------------------|-------------------------|
| (1) Adjustable DC power supply | model: _____ srn: _____ |
| (1) Digital multimeter         | model: _____ srn: _____ |
| (1) Resistance decade box      |                         |
| (1) 3.3 k $\Omega$ _____       |                         |

## Schematics

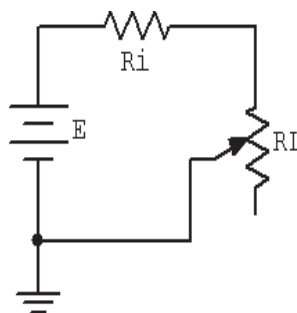


Figure 12.1



## Procedure

1. Consider the simple the series circuit of Figure 12.1 using  $E = 10$  volts and  $R_i = 3.3$  k.  $R_i$  forms a simple voltage divider with  $R_L$ . The power in the load is  $V_L^2/R_L$  and the total circuit power is  $E^2/(R_i+R_L)$ . The larger the value of  $R_L$ , the greater the load voltage, however, this does not mean that very large values of  $R_L$  will produce maximum load power due to the division by  $R_L$ . That is, at some point  $V_L^2$  will grow more slowly than  $R_L$  itself. This crossover point should occur when  $R_L$  is equal to  $R_i$ . Further, note that as  $R_L$  increases, total circuit power decreases due to increasing total resistance. This should lead to an increase in efficiency. An alternate way of looking at the efficiency question is to note that as  $R_L$  increases, circuit current decreases. As power is directly proportional to the square of current, as  $R_L$  increases the power in  $R_i$  must decrease leaving a larger percentage of total power going to  $R_L$ .
2. Using  $R_L = 30$ , compute the expected values for load voltage, load power, total power and efficiency, and record them in Table 12.1. Repeat for the remaining  $R_L$  values in the Table. For the middle entry labeled **Actual**, insert the measured value of the 3.3 k used for  $R_i$ .
3. Build the circuit of Figure 12.1 using  $E = 10$  volts and  $R_i = 3.3$  k. Use the decade box for  $R_L$  and set it to 30 ohms. Measure the load voltage and record it in Table 12.2. Calculate the load power, total power and efficiency, and record these values in Table 12.2. Repeat for the remaining resistor values in the table.
4. Create two plots of the load power versus the load resistance value using the data from the two tables, one for theoretical, one for experimental. For best results make sure that the horizontal axis ( $R_L$ ) uses a log scaling instead of linear.
5. Create two plots of the efficiency versus the load resistance value using the data from the two tables, one for theoretical, one for experimental. For best results make sure that the horizontal axis ( $R_L$ ) uses a log scaling instead of linear.



## Data Tables

$R_L$	$V_L$	$P_L$	$P_T$	$\eta$
30				
150				
500				
1 k				
2.5 k				
Actual=				
4 k				
10 k				
25 k				
70 k				
300 k				

Table 12.1

$R_L$	$V_L$	$P_L$	$P_T$	$\eta$
30				
150				
500				
1 k				
2.5 k				
Actual=				
4 k				
10 k				
25 k				
70 k				
300 k				

Table 12.2



---

## Questions

1. At what point does maximum load power occur?
2. At what point does maximum total power occur?
3. At what point does maximum efficiency occur?
4. Is it safe to assume that generation of maximum load power is always a desired goal? Why/why not?