York University
Dept. of Electrical Engineering and Computer Science

A laboratory Manual for Electric Circuits Lab
EECS2200

Fall 2015-2016

ACKNOWLEDGEMENT

Prof Mokhtar Aboelaze developed this manual for EECS2200. Mr. Konstantin Bolshakov, who took this course in 2013, invested a lot of time and energy to improve this manual. Mr. Syed Islam updated this manual in Fall 2015.

PREFACE

This laboratory manual is intended for use in EECS2200 Electric Circuits. Every care was taken in preparing this manual, however no one is perfect. If you find any typos or errors in this manual, please contact the course director.

To the student:

The objective of this lab is to get you familiar with the instruments used in electric and electronic circuits measurements. It will introduce you to the concept of "lab book" and to how to design, implement and test simple electric circuits.
The lab will be done in groups of 2. Each lab consists of 2 parts. The prelab part will be done before you arrive to the lab. It will be submitted at the beginning of every lab. Then you have to do the experiment and record results. At the beginning of the next lab you should submit the lab report for the previous lab.
Each lab covers a specific topic in the course that will be clear from the lab title. It is your responsibility to read the theoretical part from the textbook and the course notes before you go to the lab.
After you connect the circuit on the breadboard, check with the TA before connecting power. Please read the safety rules and troubleshooting hints before you start your first lab. Please be alert and use common sense during the experiment.
You have to maintain a laboratory book or journal, the TA must sign each page before you leave the lab. The journal will be checked once or twice during the term in order to be sure that you successfully did that part. Tips for maintaining a good journal are explained in this manual, please read "Appendix A: Laboratory Notebook" carefully.
The TA is there to help you, if you have any question ask the TA. A simple question might save you a lot of time and trouble later. Remember, you are dealing with expensive equipment.

To the TA:

Please read the experiment before you come to the lab. In the lab you have to approve the schematic diagram and the circuit connection before the students power up the experiment. Your job is to prevent any accidental mishaps that might injure students or destroy any equipment.

To the course Director:

The course director's responsibility is to be sure that the lab is properly equipped, the TA is qualified to run the lab, the marked reports are returned to the students in a timely manner, and supervising the TA.

APPENDICES

LAB 0: READ BEFORE YOU START

Please read carefully what you have to do in every lab

- Prepare the perlab and submit it in the first 15 min of the lab.
- Experiments are performed in groups of 2.
- The lab part describes the circuit you have to implement. The nominal values for every component will be given. However, in reality a 10 KΩ resistor is not actually a 10 KΩ resistor, it is 10 KΩ ±tolerance. The tolerance usually is 5% or 10%. So, for every circuit you implement you have to measure the actual values.
- Record the values that you measured, and everything that you measured, in your lab notebook. The TA must sign every page of the notebook BEFORE you leave the lab.
- Submit the lab report for the previous week at the beginning of every lab.

LAB 1: Resistance, Voltage, and Current Measurements

OBJECTIVE:

The objectives of this lab are

- To learn how to use equipment such as a) power supply, b) multi-meter.
- To learn how to construct circuits using breadboard.
- To learn how to measure resistance, voltage and current using multi-meter.
- To verify the results using the constructed circuit in the lab.

PRELAB

1. Find the voltage V_{out} in Fig. L1.1, where R1 = 4.7 KΩ, R2 = 6.8 KΩ. If a load with resistance of 5.6KΩ is attached to the output terminal, what is the voltage of V_{out}?
2. Find the voltage across each resistor (V_{RX}) and the current in each resistor (I_{RX}) in Fig L1.2. Assume the following values for the resistors: R_1 = 1 KΩ, R_2 = 4.7 KΩ, R_3 = 10 KΩ, R_4 = 4.7 KΩ, R_5= 1 KΩ, V_1= 5V, V_2= 7V.

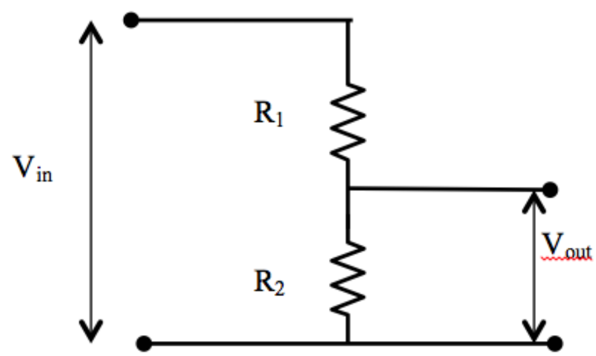


Fig.L1.1 Voltage Divider

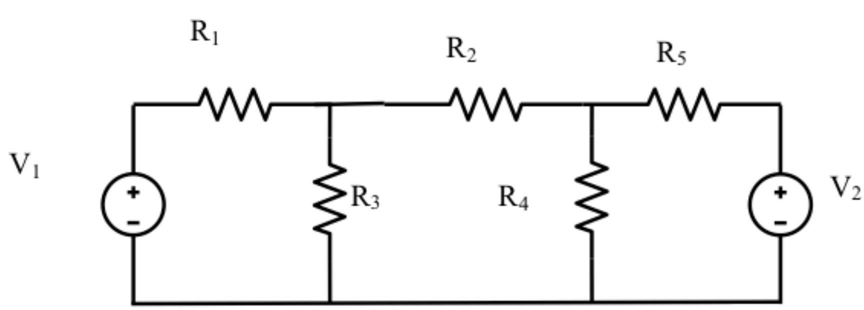


Fig. L1.2 Series parallel circuit

LAB

Part I: Voltage Dividers

In this part, you will construct a voltage divider based on Fig. L1.1 and measure the output voltage V_{out}. Please follow the steps below.

1. Choose two resistors R1 = 4.7 KΩ, R2 = 6.8 KΩ. Measure the actual values of R_1 and R_2 using multi-meter, and record the values.
2. Calculate V_{out} using the measured resistances instead of the nominal values.
3. Connect the resistors and voltage source as shown in Fig.L1.1 using breadboard.
4. Set V_{in} to 10V. Measure V_{out} and record it. What is the ratio of V_{out}/V_{in}?
5. Is the measured V_{out} the same as you calculated in Step 2? If not, why?
6. Is the measured V_{out} the same as you calculated in prelab? If not, why?
7. Choose a resistor R_L=5.6KΩ, measure and record its value. Calculate the V_{out} based on measured R_L.
8. Load the output with the R_L. Is the measured V_{out} the same as you calculated in Step 7? If not, why? Is the measured V_{out} the same as you calculated in prelab? If not, why? (In your report, discuss the effect of load.)

Part II: DC Measurements

In this part, you will construct a circuit based on Fig. L1.2 and measure the output voltage V_{out} and current passing through R_4. Please follow the steps below.

1. Choose resistors: R_1 = 1 KΩ, R_2 = 4.7 KΩ, R_3 = 10 KΩ, R_4 = 4.7 KΩ, R_5= 1 KΩ. Measure their values and record them.
2. Construct the circuit in Fig. L1.2 using a breadboard.
3. Set V_1 to 5 V (always measure it with a voltmeter, do not depend on the displayed value). Set V_2 to 7V.
4. Measure the voltages across the resistors. Show the values you measured in a table like the following. Comments on the measured and calculated results.

	Prelab	Measured
VR1		
VR2		
VR3		
VR4		
VR5		

5. Measure the currents flowing through R_4 by inserting multi-meter as shown in Fig. L1.3. Comments on the measured and calculated results.

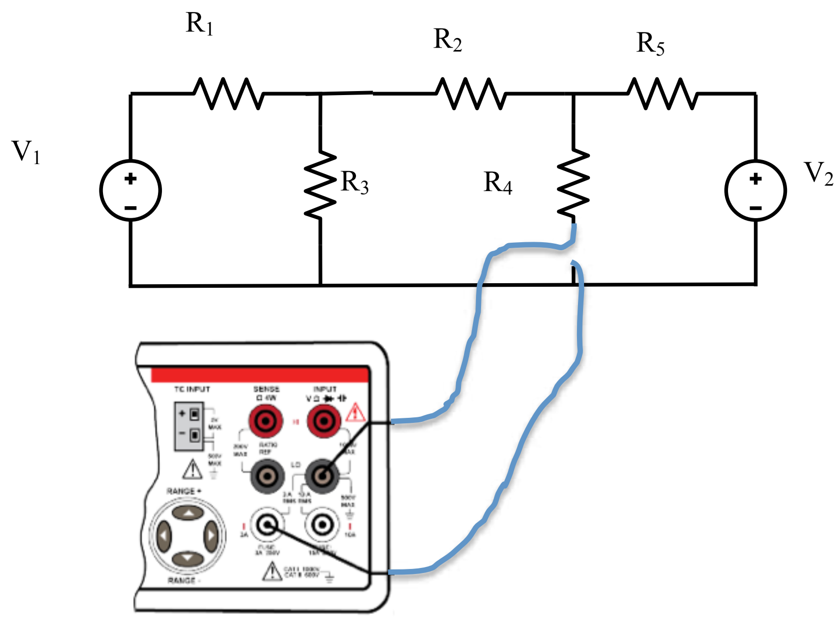


Fig. L1.3 Current measurement

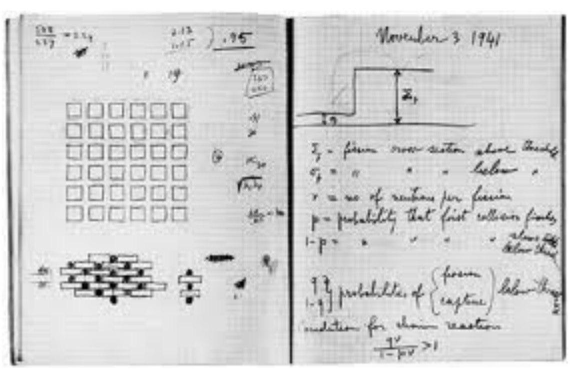
APPENDIX A: Laboratory Notebook

Keeping a complete and accurate lab notebook is a very important part of your engineering education. Lab notebooks are a complete record of what you do in the lab. You record in it your thoughts, experiments you ran, assumptions, and results. Your lab notebook can play a vital role in protecting your intellectual property (IP) (Although it is highly unlikely that you need IP protection for your experiments in this course).

If you ask an IP lawyer what to write in the notebook? The answer would be "everything". However, we will try to simplify this for you.

First a notebook must be bound not spiral, the idea is that in a bound notebook you can't remove (or add) pages without being clearly noticed.

Bound notebook



Enrico Fermi lab notebook (from University of Chicago library)

In your notebook you must include your thoughts, what do you want to achieve from the experiment together with the results.

A good rule of thumb (actually 2 rules) are the following:

- Can someone with your technical background read the notebook, understand what you did, and can reproduce the same results.
- If you come back 6 months from now, can you read your notebook and understand your thoughts at the time, and being able to modify or expand on your work

The notebook is not only used to protect your IP, but it is also used to document compliance with procedures especially testing procedures, safety standards, or environmental protection regulation and standards. Every page in the notebook must be sequentially numbered signed, and dated (use unambiguous dating, for example use May, 8, 2012 not 5/8/2012 since the later may means May 8th or August 5th depending on where you are in the world). Use pens not pencils in your notebook. Errors must be crossed with a single line not obliterated. Sometimes you can learn a lot from your mistakes. Any alteration to the notebook must be signed and dated. Also, it is a good idea to leave few blank pages at the beginning of the notebook; you might want to make a table of contents later. What to include in the notebook can be detailed by the 5 W's used by newspapers. The list is very exhaustive and is given only for information purpose; in this course we will use a simpler model. For more information about the lab notebook please take a look at the following reference.

J. B. McCormack et al "The complementary roles of laboratory notebooks and laboratory reports" IEEE Transactions on Education. Vol. 34, No. 1 February 1991 pp 133-137

The 5 W's are

Who

Experimenters

Sponsors

Witnesses

What

Brainstorming possible solutions

Experimental design

Results: samples and raw data

Analysis of data

Difficulties encountered

When

Projected completion date

Explanation of delays

Progress

Where

Location of equipment

Location of models and samples

Address of author

Why

Statement of problem

Authorization and funding

Rational for engineering decisions

In this course, you are responsible for the following in your notebook

- Numbering, dating and signing every page
- Use X or Z for parts that you did not use in the page
- Start every experiment on a new page
- Include experiment title, objectives, data collected, and observation (any deviation from what you expected, any difficulties you faced, …)
- Describe your results.

In this course, you have to write in the notebook the values of the components you are using; for every component, write the nominal value and the value that you actually measured (there is a tolerance between these two values). Failing to do this, you will get ZERO in the experiment.

APPENDIX B: Resistor Color Code

There are many types of resistors, both fixed and variable. Axial-lead resistors (mainly used in labs using breadboard), surface mount resistors (used in printed circuit boards), variable resistor (potentiometer), and thermistor (thermistor is a resistor its value depends on the temperature and could be used to measure temperature). In this lab we will be dealing mainly with axial-lead carbon resistor.

Figure 1. Different types of resistors

You can get the value of the axial-lead resistor using the color-code. The color code is a 4-bands of color (5 bands for precision resistors) that determine the value of the resistor.
For 4 colors resistors, the first two colors determine the digits, the third one is the multiplication factor, and the last one is the tolerance. For 5 colors, the first three colors determine the digits; the last two are for multiplication factor and tolerance. The value of every color is shown in the following table

Color		value	MULTIPLIER	Tolerance
BLACK		0	$X10^0$	
BROWN		1	$X10^1$	
RED		2	$X10^2$	
ORANGE		3	$X10^3$	
YELLOW		4	$X10^4$	
GREEN		5	$X10^5$	
BLUE		6	$X10^6$	
VIOLET		7	$X10^7$	
GRAY		8	$X10^8$	
WHITE		9	$X10^9$	
Gold		-	$X10^{-1}$	± 5%
Silver		-	$X10^{-2}$	± 10%
None		-	-	± 20%

Capacitors

There are three basic types of capacitors, electrolytic capacitors, film capacitors, and ceramic disk capacitor

Disk ceramic Electrolytic Film capacitor

Figure 3. Different types of capacitors

Electrolytic capacitors are made of aluminum or tantalum plates. A very thin layer of insulation is formed electrolytically (electrochemical reaction) on one of the plates. This layer could be very thin, so a large capacitors could be made. The tolerance of the capacitor value is not good though. Another point with electrolyte capacitors is they have to be connected in a specific way (one plate to the positive voltage and the other to the negative voltage). If they were wrongly connected, the chemical process forming the insulation may be reversed. *The long lead is connected to the positive voltage*.

Disk ceramic capacitors use ceramic for insulation, ceramic has a very high dielectric constant (100-200 times that of regular plastic). They are suitable for high frequency.

Film capacitors have a very good performance with good tolerance. They are bulky though.

Capacitors usually display their values. For large capacitors, the value may be written on the capacitor (22µF). Smaller capacitors display the values in a compact form. They use three digits and a letter (x y z) and a letter. The three digits display the value in pF as xy * 10^z pf (for example 234 = 23*10^4 pF = 230 nF. The letter indicates the tolerance (J=5%, K=10%, M=20%). Also the operating voltage is written. For example

123K 330V means 12*10^3pF=12 nF with10% tolerance and max. V=330V

Breadboards

Breadboard is a plastic board with holes in it that are used to prototype simple circuits. IC chips are inserted in these holes and wires are used to connect them according to the schematic. In this lab, you will be using breadboards to implement the circuit in every lab session.

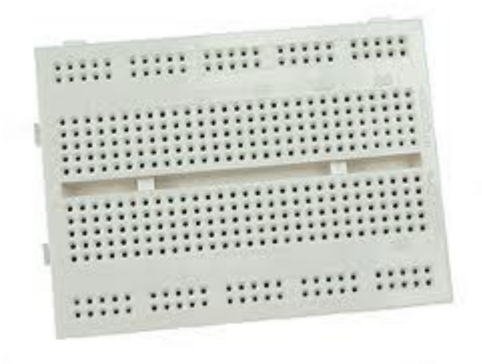


Figure 4. Breadboard

If you open the breadboard, you will find that these holes are connected with wires. For example, in Figure 5 below, all the holes in the top row are connected together. The same for the second top row, the bottom row and the second bottom row as shown in the figure below. These rows are usually used for power rails. For example the top row is connected to the power supply and the second top row to ground. If you want to connect power to any location in the breadboard, connect a wire to one of the holes in the top row and connect the other end of the line to where you want power to be

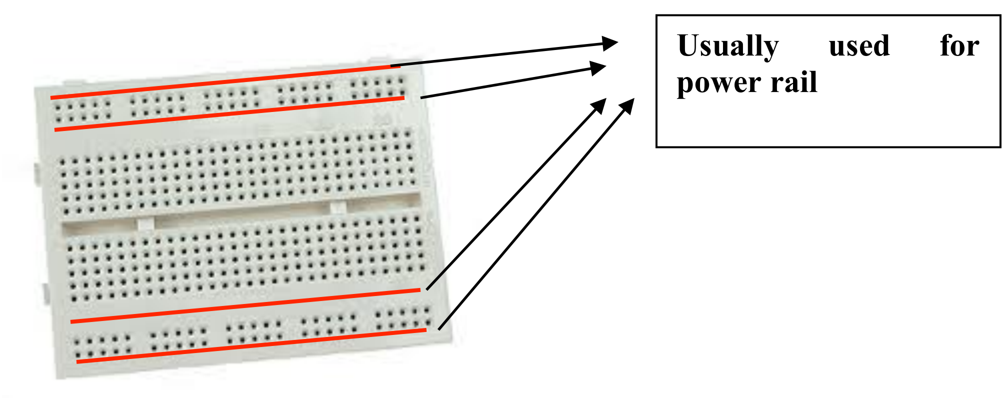


Figure 5. B readboard showing the power rail

The middle matrix of holes are used for connection. Each column of holes in one side is connected internally by a wire as shown below (blue lines).

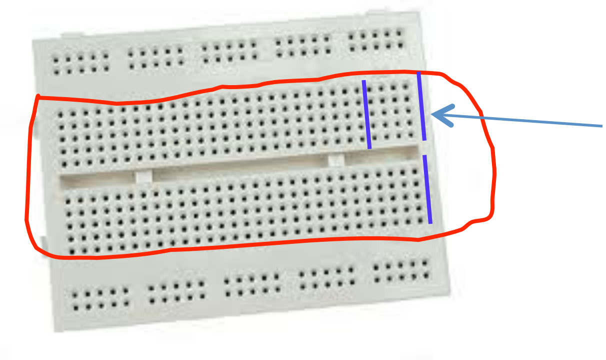


Figure 6. Breadboard showing the matrix connection

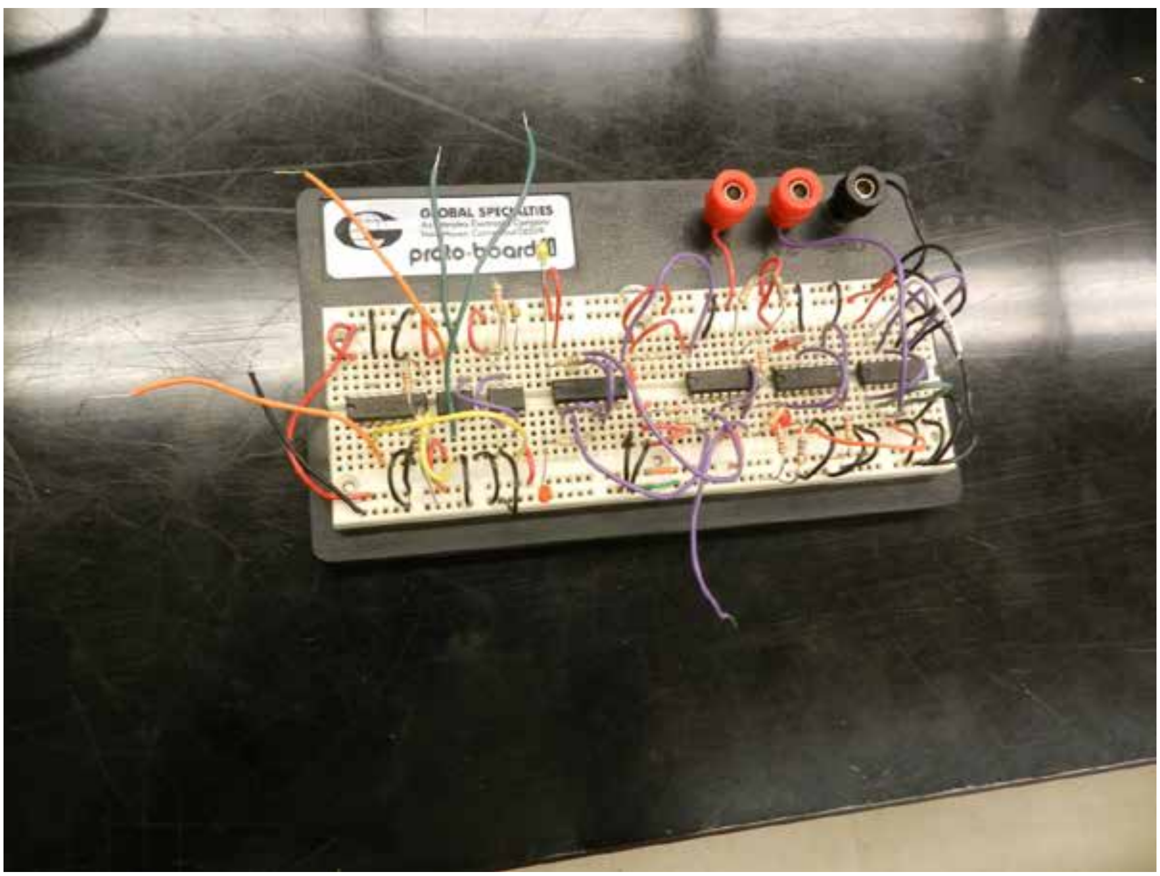


Figure 7. Breadboard with the connection

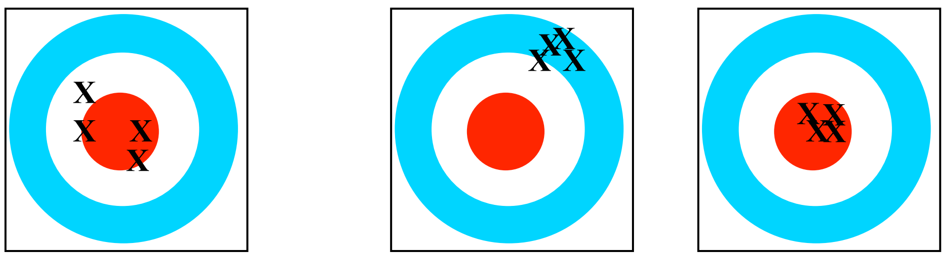
APPENDIX C: ERRORs and ERROR PROPAGATION

Introduction

When we measure something, there is always an inherent error in the measurement. Here, we would like to differentiate between accuracy and precision.

Accuracy: accuracy refers to how close the measured value to the correct value.

Precision: precision refers to how close different measurements agree with each other. A classic example is used to differentiate between these 2 quantities is shown below.



Accurate not precise **Precise not accurate** **Accurate and precise**

Figure 8. The difference between accuracy and precision

The error could be because of the inherent variability of the measured quantities (measuring pollution in the air by taking air samples will change from a place to a place). Or, if we measure the resistance of a resistor, there is always variations in the resistor produced by the same process and have the same nominal value. Another source of error is the measuring device. The measuring device may introduce some error into the measurements. Another source of error is visual interpolation, when you look at the hand of an analog device.

So, we assume that the measured quantity is

Measured value = true value ± error

Error propagation

Now we know the error associated with a measurement, but what if we use these measurements to calculate other values, what is the error in the calculated value?

For example, we measured two lines, the first line is $x_1 = 10 \pm 1$ and the second is $x_2 = 15 \pm 2$. We know for sure that the first line is between 9 and 11, the second line is between 13 and 17. What is the error in the variable $y = x_1 + x_2$

We know for sure that y is between 22 and 28. To make this more formally,

Assume that the quantities X,Y, and Z are measured, with error δX, δY, and δZ respectively, then

Addition:

$$R = X + Y - Z$$

$$\delta R = \delta X + \delta Y + \delta Z$$

That equation puts an upper bound on the error. If we assume that the error is independent and random, a better approximation is given as

$$\delta R = \sqrt{(\delta X)^2 + (\delta Y)^2 + (\delta Z)^2}$$

So, if we consider the above example, the error is

$\delta R = \sqrt{(1)^2 + (2)^2} = \sqrt{5} = 2.24$ and the length is 25 ± 2.24 i.e. between 22.76 and 27.24

Multiplication or division

$$R = \frac{XY}{Z}$$

$$\frac{\delta R}{|R|} \approx \frac{\delta X}{|X|} + \frac{\delta Y}{|Y|} + \frac{\delta Z}{|Z|} \qquad \text{"approximation"}$$

$$\delta R = |R|\sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2}$$

Multiplication by a constant

$$R = CX$$

$$\delta R = |C|\delta X$$

Polynomial functions

$$R = X^n$$

$$\delta R = |n|\frac{\delta X}{|X|} \cdot |R|$$

General function

If the function we are calculating could be expressed as a general function of X, Y, Z, … Then

$$R = f(X, Y, Z, \cdots)$$

$$\delta R = \sqrt{\left(\frac{\partial f}{\partial X} \cdot \delta X\right)^2 + \left(\frac{\partial f}{\partial Y} \cdot \delta Y\right)^2 + \left(\frac{\partial f}{\partial Z} \cdot \delta Z\right)^2 + \cdots}$$

The rules we mentioned above are a special case of this rule.

Sometimes engineers do not specify the precision of the quantity, instead they imply it by using a specific number of significant digits, for example 123400, or 123.4, or 0.001234 all of these implies 4 significant digits. The implied error here is one half the unit in the right most significant digit

123400 implies an error of 50, that is 123400 ± 50 i.e. between 123350 and 123450

123.4 implies 123.4 ± 0.05 i.e. 123.35 and 123.45

0 .001234 implies 0.001234 ± 0.0000005 i.e. between 0.0012335 and 0.0012345

When performing arithmetic operations on such numbers, the rule of thumb is for addition and subtraction we round the result to the last decimal place in the least precise number. While in multiplication or division, we round the result to a number of significant figures that is equal to the number of significant figures in the number with the least number of significant figures.

For example

```
   12.012
+  2.1
    7.23456
-----------------
   21.34656   that is rounded to 21.3 (2.1 contains one decimal place)
```

While if we multiply

```
  6.1234
X
  2.83
-----------
17.329222   rounded to 17.3
```

if we multiply

```
1234.23
2.83
----------------
3492.8709   rounded to 3490
```

Random errors

Random errors result from many sources

Human errors: A good example is when a human is measuring time using a stop watch. His/her reflexes may not be very sharp, the measured period of time may vary from person to a person, and for the same person by repeating the experiment many times.

Variations in the quantities to be measured this is an inherent random variations in the productions of the same element

How to estimate these?

You should repeat the experiment many times; measure the quantity each time (x). A measure of the quantity is the average

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

The sample variance is

$$\sigma_x = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2}$$

For random normal, 68% of the measured values will be within the range $\bar{x} \pm \sigma_x$

The standard error of the mean is

$$s_{\bar{x}} = \frac{\sigma}{\sqrt{N}}$$

APPENDIX D: Safety rules and Operating Procedures

It is very important to follow the safety rules. These rules are to protect you personally and to avoid injuries (or may be even death). These rules are also important to protect the equipment in the lab; some of this equipment is very expensive.

General safety rules

- No eating, drinking, or smoking in the lab
- Perform the experiment you are supposed to, do not perform unauthorized experiments.
- Read the handout before you start.
- Follow the instructions by the TA or the lab engineer.
- Be always neat.

Electrical safety Rules

You are working in an electrical/Computer engineering lab. All the equipment in the lab is electrical. Electricity can harm or kill you. You have to be very careful in order to not hurt yourself.

Most people think that electric shocks can kill, and that depends on the severity of shocks (voltage). The higher the voltage, the more harm the shock can cause. However, that is not completely true. Current not voltage that cause harm. Surprisingly, very small amount of current can cause death. For example you can get 1000 Volts shock at home in winter when you touch a door knob or a faucet. While, 1 Ampere can easily (very easily) kill you.

The effect of current is shown below

Current	Effect
1-5mA	Sensation
5-20mA	Muscle contraction (you might not be able to let go)
20-100mA	Pain, difficulty in breathing
100-300mA	Ventricular fibrillation
>300mA	Possible death

Having said that, the actual harm depends on many factors. The point of entry and exit of the current plays a very important role. Current passing through the heart causes a lot more harm that current flowing between two fingers in the same hand. For example, if you touch a live wire with your hand, and the current will flow to ground through your shoes, it will most probably passes through your heart. Touching live wire and ground with 2 fingers in the same hand will probably not flow through the heart.

Another factor is the skin being wet or dry. The skin resistance drops dramatically if it is wet (less resistance means more current for the same voltage source).

Some safety tips for you

- Always power down all electrical equipment while connecting the circuit. After the circuit is connected, check it one more time and then you can power the equipment. If any doubt, check with the TA.
- Do not touch any wire without powering down the equipment.
- If you want to make changes to the circuit, power it down first, and then do any changes.
- Keep your hands dry (more resistance means less current).
- Avoid extension cords, if you have to, check with the TA or the lab engineer before using them.
- If you are going to leave your bench, even for a short time, power the circuit down.
- Report any faulty equipment (or you think they are faulty) to the TA or the lab engineer.

- If you smell any burning plastic smell, disconnect the circuit right away and report it to the TA or lab engineer.
- Voltage above 50V (RMS) AC, and a little higher than that for DC is considered dangerous, use extra care in such a situation.

- If someone suffers a serious electric shock, he/she may be knocked unconscious. If he/she is still in contact with a live wire, immediately turn off the power before touching that person.
- Call for emergency medical assistance, you may administer first-aid if you are familiar with that.
- Do not use water to extinguish electrical fire.
- If you are using soldering iron, it can get very hot, be careful.
- Use wrist strap if you will be touching chips, especially CMOS chips, it could be damaged very easily.

Trouble Shooting Hints

1. Be sure that the power is ON, as simple as this is it is a major reason of complaining "the circuit is not working"
2. All the ground connections are connected properly
3. Be sure that the measuring equipment is connected properly.
4. You should have a schematic diagram of the circuit before staring implementation. Go through the circuit and the schematic to be sure the circuit actually implements the schematic diagram.
5. All supply voltages are connected and are working properly. Sometimes you have to measure the supply voltage to be sure it is identical to what is shown on the display.
6. If everything up to this point is O.K. (very unlikely), you might have a defective component (breadboard, resistor …) or a device. In this case, you have to trace your circuits measuring voltages at different nodes and comparing them with what you expect.
7. The TA is always there to help you.

APPENDIX E: Report Format

You are required to submit a prelab and a lab report for every lab session. All prelab and lab reports should be neatly written or typed.

Prelab Report

Prelab report is submitted at the beginning of the lab. You should prepare it before you arrive at the lab. No late submission of prelab report will be accepted, i.e. you receive a zero mark for the prelab if you do not submit it before the lab.

The first page of the prelab/lab report is as follows:

York University
Dept. of Computer Science and Engineering
EECS 2200
Electric Circuits
Lab (Prelab) Report
Lab x
Lab name
Submitted by : name 1
name 2
Date

The work in this report is our own. We have read and understood York University academic dishonesty policy and we did not violate the senate dishonesty policy in writing this report.
Signature

____________________ ____________________

For the prelab, you just need to answer the questions as required in each lab.

For the lab report, it should consist of the following sections.

Abstract: A brief statement (few sentences) mentioning what you did in the lab and your results.

Equipment: Please list equipment used in the lab.

Analysis: If you were asked to perform any theoretical calculations, they should be presented in this section.

Experiment setup and results: That is the main part of your lab report. If you constructed any circuits, a schematic diagram should be drawn to represent the circuit. The components measured and other measurements should be presented in this section.

Simulation results: If you were asked to perform any simulation, the simulation results should be mentioned in this section. Code is also presented here if you were asked to.

Discussion: If you were asked to compare experimental work to theoretical work, or to explain parts of your experiment, it should be presented in this section.

Conclusion: State what parts of the lab objectives you achieved, any difficulties you met, you can even mention some suggestions to the labs in order to increase the students experience in your opinion.