This manual contains all relevant material necessary to complete Florida International University Mechanical and Materials Engineering's Instrumentation and Measurement Lab

# EML 3301L

## Laboratory Guide

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# Table of Contents

# Laboratory Safety

## What YOU should know

You need to develop the habit of asking yourself whether an operation is safe and ensuring that you have the adequate knowledge and training about the equipment/ experiment you are using and safe working practices for that equipment/ experiment. Tidiness and thinking ahead are important aspects of a safe working environment.

For your work in the undergraduate teaching laboratories the following rules apply; but you must use common sense and ask an instructor if you have any doubts about safety or a particular situation.

## General Laboratory Safety

1. Students are not permitted to work in the laboratories outside the specified times of laboratory classes unless they have been given specific permission to do so by the Department Lab Manager, who will then supervise the work.

2. Smoking and the consumption of food and drink are not permitted in the laboratories.

3. Apparatuses should be disconnected at the end of a session, unless you have asked for and been given permission by the Department Lab Manager to leave it assembled.

4. All accidents or breakages, however small, should be reported immediately to the Department Lab Manager.

5. Any dangerous incident or anything which is suspected to be an unsafe situation must be reported immediately to the Department Lab Manager or to the MME Department.

6. Bags and other personal items are not allowed to obstruct exits or pathways.

7. Solvents (propanol, acetone etc.) should only be used in a well-ventilated environment. They are highly flammable and should be kept away from ignition sources.

8. Students should be aware of the dangers of loose clothing or long hair when working with machinery or chemicals.

   a. Sandals or open toed shoes are not allowed to be worn in the lab. Doing so, will not allow you entrance to the lab.

## Electricity

Electricity is potentially lethal. Under normal circumstances, any voltage over 55V is to be treated as hazardous unless it is incapable of delivering a current in excess of 1mA.

1. Students are not permitted to work with exposed electrical mains or to perform any kind of maintenance work on the electrical mains or any of its circuitry, including plugs. Equipment requiring repair should be brought to the attention of the Department Lab Manager.

2. Before connecting any equipment/ experiment, a check should be made that all instruments and apparatuses are of a suitable rating for the experiment to be performed.

   a. Check also that all wires are of a suitable current capacity.

   b. All supply switches should be in the "**OFF"** position whilst connections are made (during disconnection as well).

   c. All power supplies should be switched off before changing any components.

3. Before switching on check that all connections are correct (if in doubt, ask).

4. Place apparatus so that short circuits cannot occur.

## Laboratory Rules:

1. No one is allowed to use the laboratory facilities without permission of the Department Lab Manager.

2. In order to use the laboratory facilities, you must schedule it at least 5 business days prior to the day of intended use.

3. No one is allowed to take out any equipment, devices and/or tools from the MME laboratories without permission of the Department Lab Manager.

4. Written permission or documentation is necessary when borrowing any equipment, devices and/or tools from the MME laboratories. The documentation must include the reason, usage, return date and signature of the Department Lab Manager. Return of the equipment must be punctual and without any damage.

5. Everyone must sign in before using the MME laboratories, and sign out when leaving.

6. No food, drink (except water), or gum is permitted in the laboratory.

7. Everyone must follow the instructions during any experiments.

8. When finishing with the experiments, everyone is responsible for putting back what was used to its original place and for shutting off the power.

9. Everyone is responsible for his or her own safety.

10. Everyone who uses the MME laboratory facilities is responsible to provide experimental documentation (with certain exemptions).

# Lab Report Format and Guide

## Required Format for Lab Reports

1. All laboratory reports must be done on a computer using a word processing software program.

   a. All mechanical engineering students have access to the computer laboratory, where all the computers have the software required to comply with this requirement.

2. Reports must be in Adobe PDF format.

3. Allow for a one inch margin on each edge of the paper.

4. The major headings in the report should be on the left-hand side and underlined.

5. Number all pages, including plots and appendices, at the bottom right-hand corner of the page.

6. The report (PDF) must be named in the following manner:
   **Class_Section_Experiemnt#_Group#_.pdf**

7. Remember, laboratory report grades are unduly influenced by the quality of the presentation of the report.

## Report Sections

All reports should contain the following sections:

1. **Title Page**

   a. The title page should include the experiment's title, group number, names of the members of your group, and the date of the experiment.

2. **Table of Contents, List of Tables, and List of Figures**

   a. A table of contents should be provided for ease of locating the desired material of the report. The table of contents gives page numbers for easy reference to the individual sections of the report, and provides an outline of the topics to be covered in the report.

   b. All tables in a report should be numbered and titled. The list of tables is the index to all tables in the report.

c. All figures in a report should be numbered and titled. The list of figures is the index to all figures in the report. All graphs and sketches are to be given figure numbers and titles.

## 3. Nomenclature

a. A list of all mathematical symbols with their respective units and description.

## 4. Abstract

a. The abstract is the last section that is written and the first section that is read of a technical report. All technical reports should begin with an abstract. The abstract is a summary or synopsis of the experiment written for the reader who wants to know whether or not he/she would be interested in reading the full text of the report. Therefore, the abstract should be self-contained and independent of the rest of the report.

b. The abstract should **not** exceed a full page in length; **and for the typical length of a lab report, the abstract is generally 3-4 sentences**.

c. The purpose of the abstract is to inform the reader of the important aspects of the work. Any new equipment or unusual procedures used to perform the work and the significance of the results obtained should be briefly presented in the abstract.

## 5. Body of report

a. The body of the report will contain eight (8) sub sections:

### i. Introduction

An introduction is not always necessary, but it is usually desirable to spend a few paragraphs describing the background of the project and the reasons for undertaking it. References to previous works of a similar nature are often cited, and the differences between those projects and the current study are presented. Any important notation or mathematical preliminaries can also be briefly given in the introduction.

### ii. Objective(s)

Briefly state the nature and purpose(s) of the experiment in a concise manner.

### iii. Procedure

This section should contain a brief description of the specimen, component, or structure used in the experiment (including its geometrical shape and significant dimensions), the material used in the experiment (including significant material

properties, if applicable), and a general description of the equipment used.  Then briefly describe the methods employed in obtaining the experimental results.

### iv.  Data, Results and Analysis

Experimental data and results should be presented in this section in a suitable fashion; i.e., tables and figures, following the outline given in the lab handout. If analytical (theoretical or predicted) values are also being calculated tabulated, and/or plotted, it should be done in this section (but comparison with the experimental results should be made in the discussion section).  The original data sheet(s) and sample calculations, however, should be in the Appendices.

### v.  Discussion

This section presents the theoretical and practical evaluation of the results reported in the previous section. The discussion should include the extent to which the objectives of the experiment have been achieved. The reliability, meaning, evaluation, and application of the results should be considered in this section. Compare the results with those which might be expected in practice, theory, or both. An important consideration when writing the discussion, is that any part of it that could have been written without doing the experiment, is not an evaluation of the work done, nor is it a conclusion drawn from the experiment.

### vi.  Conclusions and Recommendations

In this section the writer should summarize the findings of the report and draw attention to the significance of these results. Any deviations from accepted theory should be noted and their statistical significance discussed. Conclusions are to be drawn with reference to the previously stated objectives of the project. Each conclusion should be supported by reference to data and results, and should follow directly from the numerical results obtained.

Recommendations are often more important than conclusions. Recommendations should be made in this section on changes in the procedure or instrumentation of the experiment, which could make the experiment more accurate or effective. Few experimental projects are an end in themselves. Either the results are to be used for a purpose, or at least the experimenter sees more work that could be done to adequately accomplish the original project.

### vii.  References

List any books, reports, etc., cited in the previous sections of the report.  The references should be listed according to the order in which they were annotated in the report. References should be formatted according to MLA or IEEE guidelines.

### viii. Appendices

All information important to the completeness of the report, but either too detailed or cumbersome to include in the smooth flow of the report should be put in an appendix. This would include information such as original data collected, sample calculations, calibration data, computer programs, etc. For the laboratory reports on the experiments at least the following appendices must be present:

1. Appendix A: Apparatus

   A sketch or schematic of the experimental apparatus showing all instrumentation and control stations should be provided. A schematic diagram is adequate, but it must be neat and complete. Describe the experimental setup and the instruments used including limitations and relative accuracy. Full and accurate identification of all instrumentation should be given, including model and serial numbers or other unique identification.

2. Appendix B: Procedure

   A write-up of how the experiment was conducted should be provided. This write-up should be of sufficient detail that anyone, with the proper equipment and your report, could reconstruct the experiment and achieve the same results. This write-up should be factual, almost a log of the steps you went through in performing the experiment to the point of reporting the errors made, and later discovered, in conducting the study. Changes which you would recommend be made to the experimental procedures should be noted in the conclusions and recommendations section of the report. Preliminary tests, equalizing periods, duration of runs, and frequency of readings, should be recorded. Special precautions for obtaining accuracy and means for controlling conditions should be described. Independent variables and reasons for their selection should be given. This section is in much more detail than that of the "Procedure" section in the body of the report.

3. Appendix C: Calibration Data

   The calibration procedure and the results of the calibration process for all equipment should be included in this appendix section. Calibration plots may often be included in the body of the report to support the results of the experiment, however all the supporting material used to develop those charts or tables should be detailed here.

4. Appendix D: Experimental Data

   Scanned images of the original data sheets from an engineering laboratory notebook or from a plotter should be included. Along with all raw data obtained by other means (i.e. a data acquisition device).

5. Appendix E: Sample Calculations

Examples of calculations used in the experiment should be included in this appendix section. Mathematical developments of special equations should also be included here.

## Introduction to Data Analysis

In the following, "Error", does not mean mistake but rather refers to the uncertainty in a measurement. All measurements in practice and even in principle have some error associated with them; no measured quantity can be determined with infinite precision.

**Statistical Errors** (also known as Random Errors)

Most measurements involve reading a scale. The fineness of the scale markings (how close together the markings are) is limited and the width of the scale lines is nonzero. In every case, the final reading must be estimated and is therefore uncertain. This kind of scale-reading error is random; since we expect that half of the time the estimate will be too small, and the other half of the time the estimate will be too large. We expect that random errors should cancel on average, that is, many measurements of the same quantity should produce a more reliable estimate. Statistical errors can be controlled by performing a sufficiently large number of measurements. The error estimate on a single scale reading can be taken as half of the scale width. For example, if you were measuring length with a scale marked in millimeters, you might quote the reading as 17.0 mm ± 0.5 mm. If you measured the same length many times, you would expect the error on the measurement to decrease. This is indeed the case. The best estimate of the measured quantity is the mean or average of all the measurements. Simply add all the individual measurements together and divide by the number of measurements. The best estimate of the error associated with the mean value is called the "error on the mean" and is given by (the error on a single measurement) divided by (the square root of the number of measurements). Obviously, this will decrease as the number of measurements increases. The final reading for a quantity should be quoted as: (mean) ± (error on the mean).

## Error Propagation

*Addition and Subtraction*

If several quantities with associated random errors are given by: $\pm \Delta x$ , $y \pm \Delta y$ , ..., $z \pm \Delta z$ , then the sum or difference is given by $q \pm \Delta q$ where $\boldsymbol{q}$ might be

$$q = x + y - z$$

and the error on $q$ is propagated from the errors on $x, y, \ldots,$ and $z$ as follows:

$$\Delta q = \sqrt{(\Delta x)^2 + (\Delta y)^2 + \cdots + (\Delta z)^2}$$

Notice that the errors are added in quadrature, even when the quantities are being subtracted. The error always increases when adding or subtracting quantities.

*Multiplication and Division*

If several quantities with associated random errors are given by: $\pm \Delta x$, $y \pm \Delta y$, $\ldots$, $z \pm \Delta z$, then the product or quotient is given by $q \pm \Delta q$ where $q$ might be

$$q = \frac{x * y}{z}$$

and the error on $q$ is propagated from the errors on $x, y, \ldots,$ and $z$ as follows:

$$\frac{\Delta q}{q} = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \cdots + \left(\frac{\Delta z}{z}\right)^2}$$

**Systematic Errors**

These errors are more insidious than statistical errors. Systematic errors are difficult to detect, and the sizes of systematic errors are difficult to estimate. Increasing the number of measurements has no effect on systematic errors because the error is always in the same direction (all measurements too high, or all measurements too low). Careful instrument calibration and an understanding of the measurements being made, aid in prevention of these errors.

For example, suppose that you are using a stopwatch to time runners in the 100-meter dash. You are quite adept at making the measurement; but, unknown to you, the watch runs 5% fast. All times will be 5% too high. There will be no immediately obvious indication of a problem. If you happen to be familiar with the runners' normal times, you might notice that everyone seems to be having a slow day. To prevent such problems, one should calibrate the stopwatch with a known standard such as the Nation Institute of Standards and Technology's standard time service on short wave radio.

The guidelines for data recording are:

1. The error should have one significant figure

2. The number of decimal places in the measurement should be the same as the number of decimal places in the error.

3. Always remember: There is no such thing as "human error".

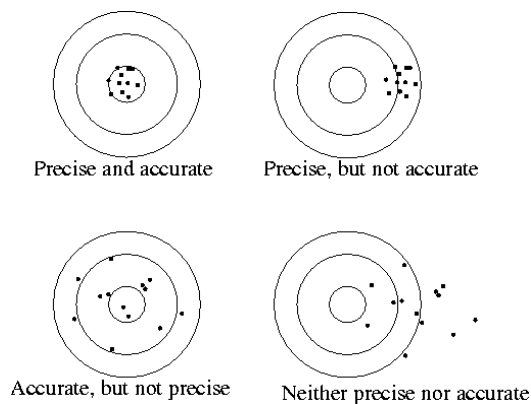4. Try to find the deeper cause for any uncertainty or variation in the data.



Figure 1: Difference between Precision and Accuracy

**Statistics and Error**

The second method of estimating error on measured quantities uses statistics as a tool. Now that we have some idea about the types of error found in the lab, random and systematic, we can discuss how statistics are used to describe them. Statistics can only be used to describe random error. All systematic error should have been eliminated from the experimental setup. On the other hand, random errors are made to order for a statistical description. If your balance reading is being influence by air current, sometimes your readings will be high, and sometimes low.

Whether or not the reading is high or low is pretty much a random thing. Statistics excel at describing these kinds of events. So, if you are sure all systematic errors have been eliminated, the rest, the random error, can be estimated statistically.

We make several assumptions in using statistics to describe errors. The main assumption is that the errors are normally distributed. The normal distribution, also called the Gaussian distribution or the bell-shaped curve, is one of the most common probability distributions. A probability distribution tells us about the probability of randomly selecting different values. For instance, if you roll a fair die (singular of dice); the probability that you get a two is 1/6. There are six possible outcomes, all equally likely. The probability that any one of the six faces will be up is 1/6. This type of probability distribution, in the continuous case, is call a uniform distribution and is graphed as a straight flat line. All values are equally likely. If you think about it for a moment, you will realize that all values aren't equally likely when it comes to errors. If your experiment is correctly set up, you should get only small errors. A value near the "correct" value

is more likely than a value far from it. This is exactly the type of probability described by the normal distribution.

In Figure 2, one example of the distribution is plotted with values on the x-axis vs. the probability of those values on the y-axis. In the figure, the curve is centered at zero and has a standard deviation of one. Both of these values can be adjusted to be most any value and will depend on the specific system being modeled; zero and one are just a convenient example.



(The Bell-Shaped Curve)

Mean and most probable value

Three Standard Deviations 99% of values are in here.

One Standard Deviation 67% of values are in here.
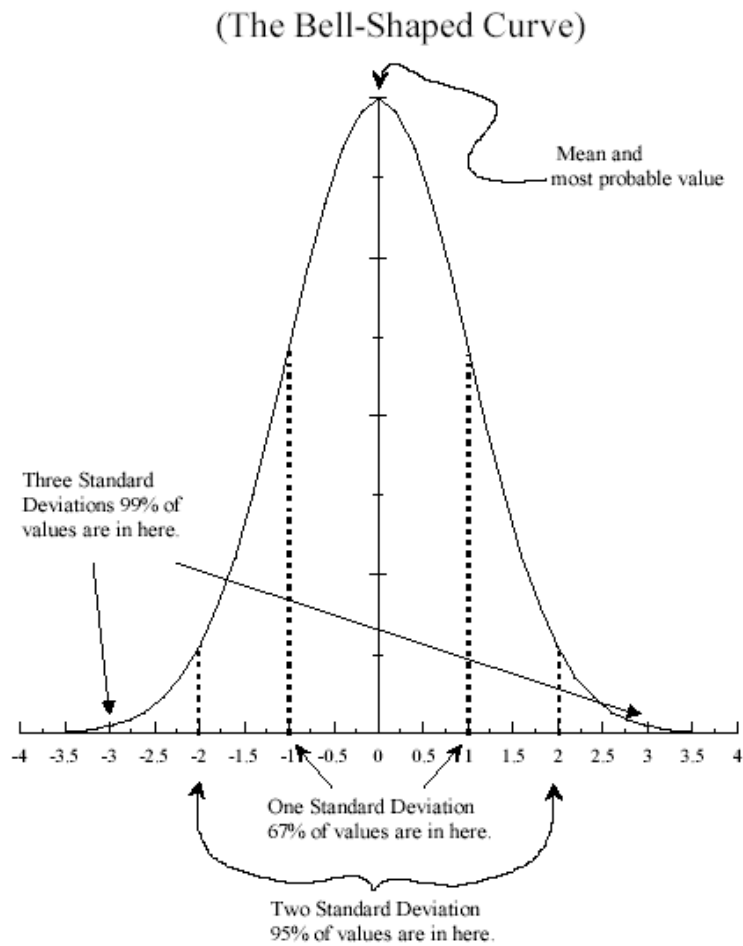
Two Standard Deviation 95% of values are in here.

Figure 2: Normal Probability Distribution

The normal distribution has a maximum probability in the middle, where the curve is the highest. This spot corresponds to the mean value of the random variable being measured. Also, we see that the probability drops off quickly away from the mean. How quickly? In other words, just how closely packed in toward the mean are the values. A measure of this is the standard deviation, σ. The standard deviation gives the width of the curve or the probability of finding a value far from the mean. In Figure 2, the standard deviation was selected to be one. For the normal distribution, 67% of randomly selected values will fall within one standard deviation of

the mean, which is within -1σ and +1σ. 95% of the randomly selected values will fall between -2 σ and +2 σ and 99% between +3 σ and -3 σ.

For the example distribution shown in Figure 2, 67% of the values will be between +1 and -1 (σ = 1), 95% between +2 and -2, and 99% between +3 and -3.

The formula for the mean is the same as always:

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

(In MS Excel: use function AVERAGE)

As with all measured quantities, we need to associate an error with the mean: The standard deviation can be found by:

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

(Excel: use function STDEV)

However, the standard deviation isn't quite right. It tells us about the probability of a given value being a certain distance from the true mean. What we want to know is, given the number of trials, what is the probability that out mean reflects the true mean? Such a quantity is given by the standard error,

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}}$$

(Excel: use function STEYX or simply $\frac{STDEV}{n^{0.5}}$ )

For measured data, the values used in calculations or the estimates in the results are:

**Estimated Value = Average ± (factor*standard error)**

When using statistics to estimate the error on your measurements; use the average value with the standard error as the uncertainty. The following table gives the factor values with the corresponding confidence level.

| Confidence Level | Factor |
|---|---|
| 50 % | 0.67 |
| 67 % | 1.0 |
| 95 % | 2.0 |
| 99 % | 2.6 |

Table 1: Confidence Level and Factor Correlation

**Rejection of Data**

Many scientists believe that data points should never be rejected since some important scientific discoveries have come from data that initially appeared "strange data". If an experimental result appears to be flawed the experiment should be repeated to check the particular data point(s). However, in a student lab with limited time it may not be practical to repeat an experiment. In this case we can sometimes reject a data point based on a consideration of the mean and standard deviation of the particular quantity being measured. Suppose we measure the acceleration of gravity 10 times, obtaining a mean value of $9.72\frac{m}{s^2}$ with a standard deviation of $0.2\frac{m}{s^2}$. Suppose we have one data point that has a value of $9.32\frac{m}{s^2}$, which is two standard deviations from our mean. The probability of getting a data point this far from the mean (or worse) in a single trial is 5% (making the usual statistical assumptions concerning the data distribution). Therefore, in ten measurements the probability of obtaining at least one data point this bad (or worse) would be ten times 5% or 50%. Chauvenet's Criterion states that if this calculated probability turns out to be less than 50% the data point can be rejected. Without this data point the standard deviation of the remaining points will be much less of course.

For example, let's say we make six measurements of the period of a pendulum and come up with 3.8, 3.5, 3.9, 3.9, 3.4, and 1.8 seconds. The 1.8 looks like it might be bad.

The standard deviation of this set of measurements is 0.8 seconds, and the mean is 3.4 seconds. The 1.8 therefore is two standard deviations away from the mean. The probability of getting a value deviant by 2 σ or more, on a single measurement, is 5% (recall the definition of the 2 σ confidence level). The probability of finding a single value this bad in six measurements, then, is 30%.

This is certainly not inconceivable; it may even seem reasonable to you now that this point should have come up. If this point is bad, however, then the standard deviation we used to calculate the probability has been contaminated. The true standard deviation is likely to be much smaller, and for this reason people commonly set the lower limit of probability to be 50%. If a point comes up to be less than 50%, which is likely to occur using this method, it can be thrown out.

In the example above, the point does indeed get thrown out, leaving us with a set of five measurements. The mean of this set is 3.7, and the standard deviation is 0.2; which is significantly smaller! In other words, the measurement we discarded was approximately 9 σ and the total probability of its occurrence was really astronomically small. Even if it were only 5 σ, the probability would only be about 4 in a million. Of course, to be rigorous you should check each point in your data set using this method, and after throwing out the first round of bad points, start all over again on the new set.

**Graphs**

Your graph is intended to present your data and results in an easily interpreted manner. The experimental results are contained in the plotted data points. In a sense, the data points are the heart of your graph. They are to contain as much information as possible and still be easily examined. Along with the data you recorded, you can also present the error or uncertainty on the data. These uncertainties are indicated by using error bars on your data points.
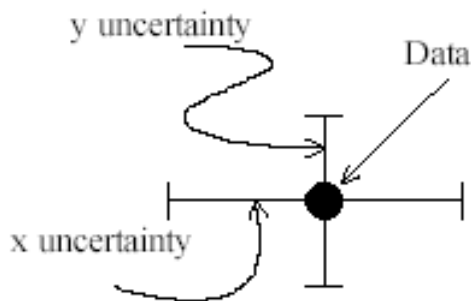


Figure 3: Data Point with X and Y Uncertainties

**Curve Fitting: Least Squares Fit (linear regression)**

A mathematical technique allows one to 'fit' a straight line to a set of data points. If you suspect that a set of data points lie on a straight line, then you need to be able to fit those points on that line. The equation for a straight line is given by:

$$y = mx + b$$

Where **m** is the slope of the straight line and **b** is the y-intercept (where the line crosses the y-axis). Given these two quantities the line can be drawn by selecting a set of x-values, inserting them into the equation for the line, and plotting the result. The *least squares method* allows us to find **m** and **b**.

In the laboratory you will have collected a set of data points, (x1, y1), (x2, y2), (x3, y3)… and wish to find the "best" straight line through them. Before we can do anything else, we must decide what is meant by the "best" line. By "best" we could mean the line that passes through the most points; we could also mean the line that clips the most error bars. We need a definition of "best". A simple and sufficient definition turns out to be that the "best" line through the data points is the line that minimizes the sum of the squares of the distances from the data points to the line. Minimization is a straight forward calculus problem. If the procedure is carried out, one finds:

$$m = \frac{\overline{XY} - \overline{X}\,\overline{Y}}{\overline{X^2} - \overline{X}\,\overline{X}} \qquad\qquad b = \overline{Y} - m\overline{X}$$

(Excel: uses the function SLOPE for the calculation of **m** and the function INTERCEPT for the calculation of **b**)

Where, the *over-bar* indicates the average of the values. Note that the average of x squared ($\overline{X}\,\overline{X}$) is not the same as the average of $X^2$. One difference is that the two averages treat negative values differently. Try calculating $\overline{X}\,\overline{X}$ and $\overline{X^2}$ for the two values 1 and -1.
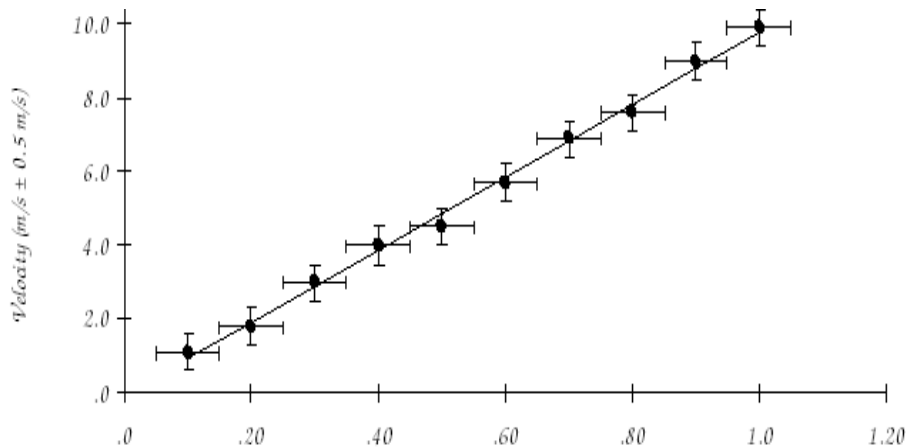
Sample graph:



Figure 4: Example of Line Fitting

In case of an exponential relationship (for example, $= ax^n$ ), the linear least squares method should be applied to the log-log plot of the results. For example, given:
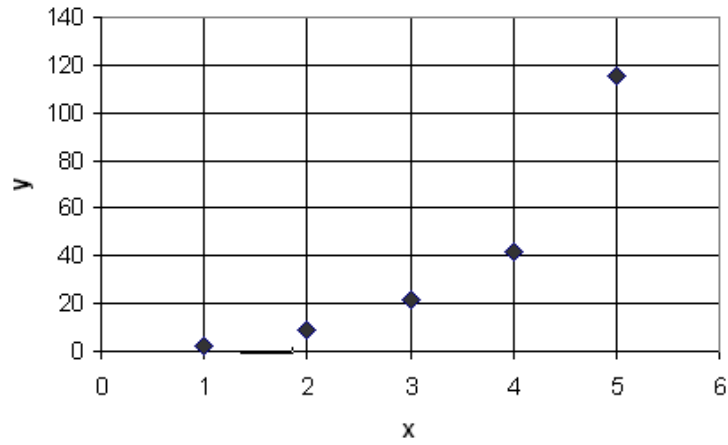
Figure 5: Example Data Points

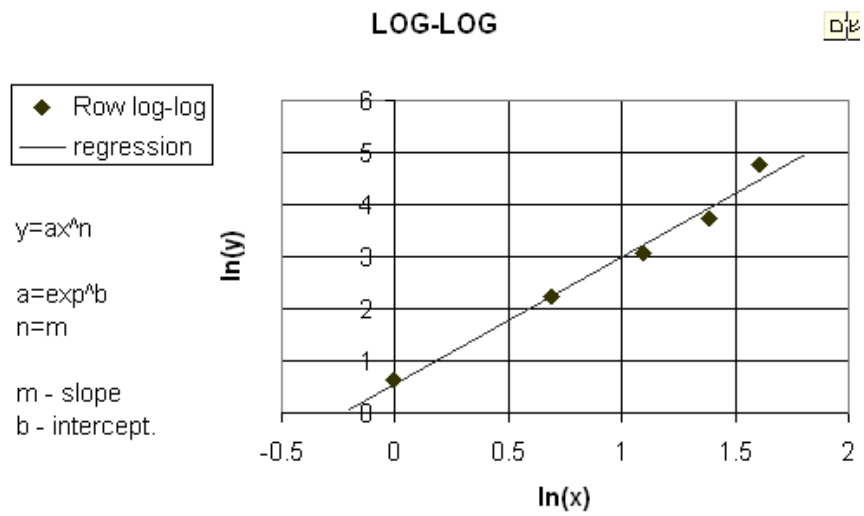Then the log-log plot with curve fitting would be:



Figure 6: Log-Log Curve Fitting Plot

# Experiment 1: Temperature Measurement

## Objective

1. To demonstrate thermocouples for temperature measurement.

2. To understand a static calibration of the thermocouples, and determine the linear relationship between the temperature and voltage.

3. To measure the dynamic response of a shielded thermocouple junction, and determine how closely the dynamic characteristics of the thermocouple approximate a first-order system.

## Introduction

A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature.

A thermocouple is available in different combinations of metals or calibrations. The four most common calibrations are J, K, T and E. Each calibration has a different temperature range and environment. Although the thermocouple calibration dictates the temperature range, the maximum range is also limited by the diameter of the thermocouple wire. That is, a very thin thermocouple may not reach the full temperature range.

The dynamic response of a thermocouple is similar to a first order system. A time constant, defined as the time required by a sensor to reach 63.2% of a step change in temperature under a specified set of conditions, can be used to represent a thermocouple dynamic characteristics. An exposed junction thermocouple is the fastest responding. Also, the smaller the probe sheath diameter, the faster the response, but the maximum temperature may be lower. However, that sometimes the probe sheath cannot withstand the full temperature range of the thermocouple type.

## Procedures

1. Use a thermocouple and a DMM to measure the temperature.

    Step 1. Note the thermocouple type and find the corresponding calibration table.

    Step 2. Set DMM (Digital Multi-Meter) in a DC measurement model.

    Step 3. Connect the thermocouple to the DMM, (positive to positive).

    Step 4. Measure and record room temperature from a thermometer and voltage of the thermocouple from DMM, and find the voltage from the calibration table.

    Step 5. Place one junction of the thermocouple into the water and heat the water.

    Step 6. Measure and record the temperature from a thermometer and voltage from the DMM when the water is being heated until reaching the boiling point. You may record the data in 5 °C increments.


2. Find the time constant of dynamic response of the shielded thermocouple.

    Step 1. Connect the thermocouple to a function recorder and set the recorder properly.

    Step 2. Place one junction of the thermocouple into the boiling water, and start the recorder.

    Step 3. After recorded data is steady, suddenly move the thermocouple junction from the boiling water into the cold water, and wait until recorded data is steady.

    Step 4. Suddenly move the thermocouple junction from cold water into the boiling water, and wait until recorded data is steady.

# Analysis and Discussions

1. Experimental Part I

   i. Use the calibration table to find the temperature for each measurement. The reference voltage equals the recorded voltage plus the room temperature voltage from the calibration table, and then subtract the recorded room temperature voltage.

   ii. Use experimental data to plot a temperature (from the alcohol thermometer) vs. voltage graphic, and interpolate a linear line.

   iii. Compare the temperatures from the alcohol thermometer to ones from the calibration table, and calculate the error for each measurement.

   iv. Discuss the results

2. Experimental Part II

   i. Calculate the time constant for both experimental cases.

   ii. Use the time constant from one case to generate a theoretical response of the first order system.

   iii. Plot both the experimental and theoretical dynamic responses on the same chart.

   iv. Compare the experimental data to the theoretical calculation, and discuss the results.

# Report Requirement

1. The report must follow the lab report format.

2. The report must be submitted electronically (**PDF**) by the due date.

3. The electronic file must have a file name of: EML3301L_section#_Exp#_Group#.pdf
   **Example: EML3301L_U01_Exp1_Grp1**.pdf

# Experiment 2: Strain Gauge

## Objective

This laboratory exercise is used to investigate the characteristics of strain gauges. A strain Gauge is a device whose electrical resistance varies in proportion to the amount of strain in the device. The most widely used gauge is the bonded metallic strain gage. Strain gauges can be a vital tool in determining the loads, stresses, and strains of structures. Upon successful completion of the experiment you should be able:

1. To become acquainted with applying strain gages and their use in measurements.

2. To perform a static calibration of a cantilevered beam for use as a force transducer.

3. To identify the relationship between the displacement of the end of the beam and the strain at the gage location to allow for a correlation between displacement and strain.

4. To investigate the dynamic response of this mechanical transducer.

# Nomenclature

| Symbol | Description | SI Unit |
|:---:|:---:|:---:|
| $P$ | Applied Load at the Tip of the Beam | $g$ , $kg$ , $lb_m$ |
| $L$ | Length from the Support to the Free End of the Beam | $cm$ , $m$ , $in$ |
| $E$ | Young's Modulus of the Beam | $kpsi$ , $GPa$ |
| $I$ | Moment of Inertia of the Beam $\left[\frac{b(h^3)}{12}\right]$ | $\frac{kg}{m^2}$ , $\frac{lb_m}{ft^2}$ |
| $b$ | Width of the Beam | $cm$ , $m$ , $in$ |
| $h$ | Thickness of the Beam | $cm$ , $m$ , $in$ |
| $\varepsilon$ | Strain on the Upper Surface of the Beam | - |
| $\Delta L$ | Change in Length of the Upper Surface of the Beam | $cm$ , $m$ , $in$ |
| $L_1$ | Distance from the Gauge to the Load ($P$) | $cm$ , $m$ , $in$ |
| $R$ | Resistance of the Gauge | $\Omega$ |
| $\Delta R$ | Change in Resistance of the Gauge | $\Omega$ |
| $G$ | Gauge Factor | - |
| $V_s$ | Source Voltage | $V$ |
| $V_0$ | Output Voltage | $V$ |

# Introduction

A strain gage is an electrically conducting device where the resistance of the device is directly proportional to the strain imposed. The strain gage is bonded to the specimen and the strain is transmitted from the specimen to the gage. This type of transducer is widely used to determine the strain over a small area of a component subjected to a deflection. If a relationship between force and strain for the instrumented component can be found, a strain gage transducer can be used to infer the value of an applied force.

The displacement of the tip of a cantilevered beam for a tip point load is known as:

$$y = \frac{PL^3}{3EI}$$

The strain on the upper surface of the beam is given by the formula:

$$\varepsilon = \frac{\Delta L}{L} = \frac{PL_1 h}{2EI}$$

The relationship between the change of length and the change in the resistance is:

$$\frac{\Delta R}{R} = G \frac{\Delta L}{L}$$

The relationship between strain and output voltage in a Wheatstone bridge circuit is:

$$\varepsilon = \frac{4}{G} \cdot \frac{V_0}{V_s}$$
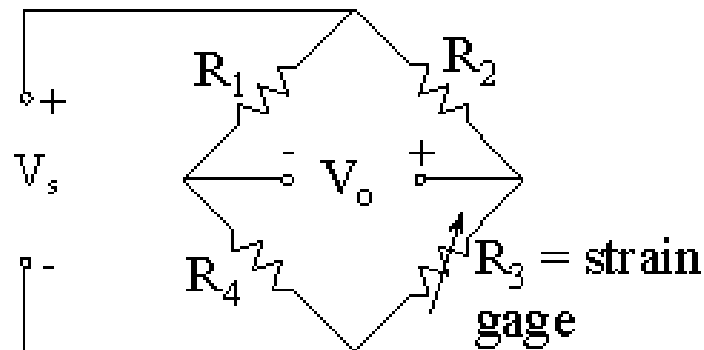
Figure 7 depicts a Wheatstone bridge.



Figure 7: Wheatstone Bridge

## Procedures

1. Static Characteristics.

   Step 1.  Measure the cross section of the beam to be tested, width ($b$) and thickness ($h$), and record the material composition of the beam and the gauge factor noted on the beam.

   Step 2.  Measure the resistance of the attached strain gauge.

   Step 3.  Place the beam as a cantilever for testing. Record the lengths from both the support and from the gauge to the free end of the beam.

   Step 4.  Connect the Wheatstone bridge circuit. Use a Digital Multi-meter to adjust the output voltage to as close to zero as possible.

   Step 5.  Apply a load at the tip of the cantilevered beam and record the voltage.

   Step 6.  Increase the load in uniform increments, and record the voltage for each case.


2. Dynamic Response.

   Step 1.  Connect the output to an oscilloscope.

   Step 2.  Impose a positive initial condition at the tip of the beam of the same order of magnitude as the maximum force condition of Part 1.

   Step 3.  Observe the dynamic response on the oscilloscope. The dynamic response of the cantilever beam can be modeled as a second order lightly damped system.

## Analysis and Discussions

1. Experimental Part I

    i. Plot a force vs. displacement graphic and use the least squares method to interpolate a line for the transducer.

    ii. What is the sensitivity of the strain gauge as a displacement transducer? And as a force transducer?

    iii. Compare the experimental results to the analytical calculation.

    iv. Discuss the results

2. Experimental Part II

    i. Describe the dynamic response of the beam.

    ii. What determines a second order system?

## Report Requirement

1. The report must follow the lab report format.

2. The report must be submitted electronically (**PDF**) by the due date.

3. The electronic file must have a file name of: EML3301L_section#_Exp#_Group#.pdf

    **Example: EML3301L_U01_Exp2_Grp1**.pdf

# Experiment 3: Data Acquisition

## Objective

This laboratory exercise is used to familiarize the student with the use of data acquisition software and equipment. Data acquisition software, like LabView, can be an indispensable tool for collecting measurements of all types. Current software also has the capability of exporting to such programs as Excel; making the investigator much more efficient than that of decades past. Upon successful completion of the experiment you should be able:

1. To understand basic concepts of data acquisition, such as A/D converting, resolution and sampling.

2. To develop a data acquisition solution with LabVIEW software.

3. To use statistical methods to analyze data.

# Introduction

Data acquisition (DAQ) is the process of gathering information in an automated fashion from analog and digital measurement sources such as sensors and devices during testing. It begins with a physical property, such as the temperature of a room, the intensity of a light source, the pressure inside a chamber and the force applied to an object; and uses PC-based measurement hardware and software to provide measurement results. These results are produced in many different ways; such as, display, recording, and analysis.

When building a basic DAQ system, four components should to be considered:

1. Sensing transducers
2. Signal conditioners
3. DAQ hardware
4. DAQ driver and software
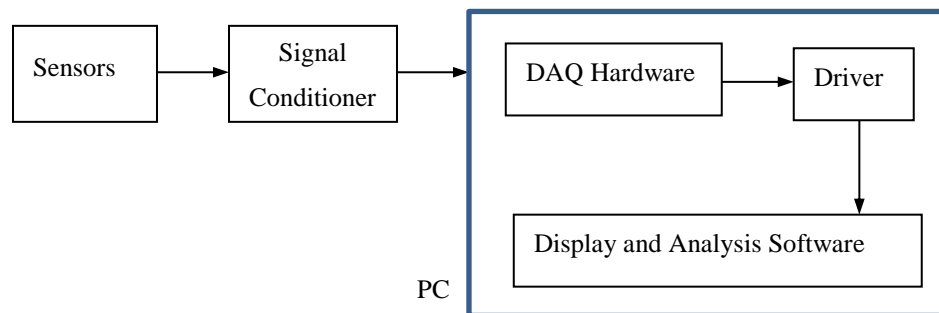


**Sensing transducers**

A sensing transducer is a device that converts a physical property into a measurable electrical signal; such as, a voltage or a current. There are specific transducers for many different applications; such as measuring temperature, pressure, or fluid flow.

**Signal conditioning**

The appropriate transducer converts physical properties into measurable signals. However, different signals need to be measured in different ways. A signal conditioner is used to filter out signal noise to obtain a clear and accurate measurement of the signals.

**DAQ hardware**

The DAQ hardware acts as the interface between the computer and the outside world. It primarily functions as a device that digitizes incoming analog signals in order for a computer to interpret them. It typically includes Analog Input/Output, Digital Input/Output, and a Counter/Timer.

**DAQ Driver and Software**

Software transforms PC and DAQ hardware into a complete data acquisition, analysis, and presentation tool. Driver software, such as NI-DAQmx, is the layer of software that allows communication to the hardware; it forms the middle layer between the application software and the hardware. Application software, such as, LabVIEW, provides a flexible, user-defined measurement system and allows the user to add presentation and analysis capabilities for quickly developing a prototype solution.

# Procedures

Part I: LabVIEW Applications

The National Instruments PIC-6221 board and LabVIEW software have been preinstalled in the laboratory PC's. The SCB-68 connector is used to connect to the input and output signals.

1.  Setup Temperature Measurement by Using IN PIC-6221 with LabVIEW Software:

    Step 1.  Connect the thermocouple to ACH2 (pin 65, positive) and ACH10 (pin 31, negative) of the SCB-68 connector.

    Step 2.  Set the five red configuration switches to the model of Temperature Sensors Enabled on Differential.

    Step 3.  NI-DAQmx Calibration

        i.  Open '*Measurement & Automation*' by double-clicking the icon on the desktop.
        ii.  From '*Devices and Interfaces*', then '*NI-DAQmx Devices*', right click on the '*PCI-6221*', and select '*Properties*'
        iii.  Under the '*Accessory*' tab, select '*SCB-68*' from the Accessory pull-down list, and then click '*OK*'.
        iv.  Right click on the '*PCI-6221*' again, and select '*Self-Calibrate*', then click '*OK*' to calibrate, and then click '*Finish*'.
        v.  On the working window, click the '*Calibration*' tab to check the results.
        vi.  Close the '*Measurement & Automation*' window.

    Step 4.  NI-DAQmx Configuration.

        i.  Open '*National Instruments LabVIEW 7.1*' by double-clicking the icon on the desktop. Click '*Continue*', and then click '*New*' in the next window
        ii.  Select '*VI from Template*', then '*DAQ*', then select '*Data Acquisition with DAQmx.vi*', and then click '*OK*'.
        iii.  In Window menu, select '*Tile Left and Right*'. In the right side window (RSW), delete the instruction (yellow) box by selecting it and then push the delete key on the keyboard.
        iv.  Right click on the '*DAQ Assistant*' from the RSW, and then select '*Property*'.
        v.  Open the '*Analog Input*' in the dialog window, then '*Temperature*', and then select '*Thermocouple*'.
        vi.  Under '*PIC-6221*', select the '*ai2 (CH2)*' in the next window, then click '*Finish*'.
        vii.  Select '*1 Sample*' in '*Acquisition Mode*' in the next window, then click '*test*' to view the Test window. In the test window, click on the '*Start*' button to see the temperature.

2.  Develop a software application to measure the temperature, use a temperature indicator.

3.  Develop a software application to measure the temperature, use a graphic display. (Recommend to use 1000 Hz as data sampling frequency and 100 data per sample)

4. Develop a software application to record the measurement data.

5. Develop a software application to monitor the temperature with an alarm.


Part II: Measurement of the internal resistance of a Digital Multi-Meter (DMM).

Step 1. Set the power supply output to *5 V DC*. Use DMM (set on *Voltage*) to measure the voltage directly from the power source and adjust the power supply to *5 V*.

Step 2. Set both resistors $R_1$ and $R_2$ to 1 $k\Omega$.

Step 3. Connect the circuit as displayed below.
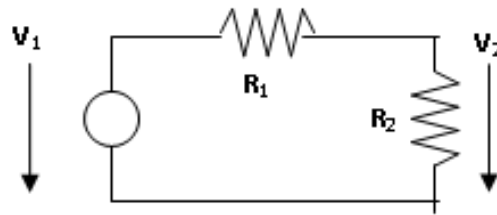


Step 4. Use the DMM (set on *Voltage*) to measure and record the voltage on the resistor $R_2$

Step 5. Repeat Steps 4 to 5 with both resistors $R_1$ and $R_2$ to 10 $k\Omega$, 100 $k\Omega$, 1 $M\Omega$, 2 $M\Omega$, 5 $M\Omega$, and 10 $M\Omega$.

## Analysis and Discussions

Part I: LabVIEW Applications

1.  Write your group's procedure for one of the above exercises (2 to 5)

2.  Data Sampling:

    i.   To measure a signal with 500 Hz frequency, what is minimum sampling frequency?

    ii.  If you use a 525 Hz sampling, what frequency will be found in the collected data?

3.  Resolution of A/D converting:

    i.   Find PCI-6221 data bus information from www.ni.com.

    ii.  If the PCI-6221 is used to measure a voltage signal from 0 to 5 V, what is the resolution of its A/D converting?

4.  Data Analysis

    i.   Use statistics method to calculate the average, μ, and the standard deviation, σ, of one of the recorded sample data set; and display the data in an Excel chart with one average line and two lines signifying the range within two standard deviations $(\mu \pm \sigma)$.


Part II: Measurement of the internal resistance of a DMM

1.  List the recorded data in a table.

2.  Use the experimental data to calculate the internal resistance of the DMM by using the following formula:

$$R_{DMM} = \frac{R_1 R_2 V_2}{R_2 V_1 - (R_1 + R_2)V_2}$$

Where:

$V_1$ is the signal source voltage ($V$)

$V_2$ is the load voltage measured by the DMM ($V$)

$R_1$ is the source output impedance ($\Omega$)

$R_2$ is the load input impedance ($\Omega$)

$R_{DMM}$ is the internal impedance of the DMM ($\Omega$)


Use the recorded data to calculate $R_{DMM}$, and use the average as the internal resistance of the DMM.

# Report Requirement

1. The report must follow the lab report format.

2. The report must be submitted electronically (**PDF**) by the due date.

3. The electronic file must have a file name of: EML3301L_section#_Exp#_Group#.pdf
   **Example: EML3301L_U01_Exp3_Grp1**.pdf

# Experiment 4: Passive Filter

## Objectives

This laboratory exercise is used to investigate passive filters. Electronic filters are used for many applications where an input signal needs separated. A common use of passive filters is in audio speakers, where the filters separate the low, mid, or high frequencies for the corresponding speaker. Upon successful completion of the experiment you should be able:

1. To understand basic functions of passive filters.

2. To practice basic high and low pass passive filters and demonstrate their characteristics.

3. To determine the cut-off frequency for the passive filters in both theoretical and experimental ways.

# Introduction

RC and RL passive filters are used for conditioning signals. They perform as low pass, high pass or band pass functions for input signals. A low pass filter eliminates the high frequency components of the input signals. A high pass filter eliminates the low frequency components of the input signals. A band pass filter passes the input signals only in a desired frequencies range. The ideal cutoff frequency of filters is that the gain between input and output signal keeps unchanged when the signal frequency is in the desired range, and the gain equals zero when the signal frequency is out of the designed range. The circuits of basic RC and RL passive filters are as the following.
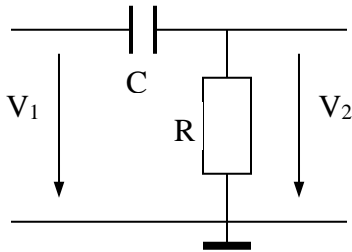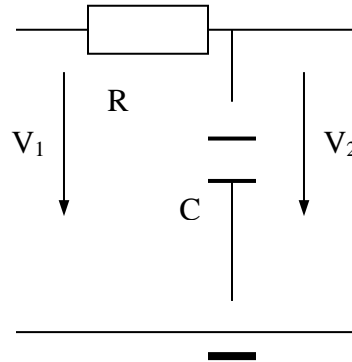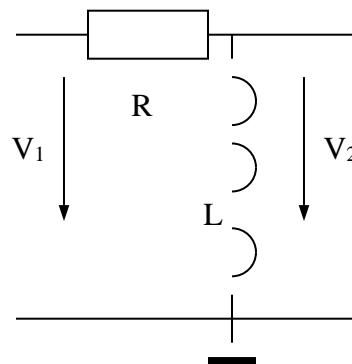


RC high pass filter                    RC low pass filter
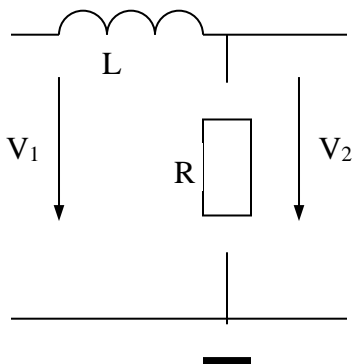


RL low pass filter                    RL high pass filter

The cut-off frequency can be calculated using the following formulas:

$$f_{cutoff} = \frac{1}{2\pi RC} \qquad\qquad f_{cutoff} = \frac{R}{2\pi L}$$

where: $f_{cutoff}$ = cut-off frequency, (Hz)

R = resistance ($\Omega$), C = Capacitance (F), L = inductance (H)

## Procedures

1. **RC Low Pass Filter**

   Step 1.    Use R = 10 kΩ and C = 0.047 μF to connect a RC low pass filter circuit.

   Step 2.    Apply a 100 Hz square wave signal with 4 V p-p to the input of the filter. Sketch the wave forms of both input and output signals. Record the oscilloscope settings.

   Step 3.    Chang the input signal to a sine waveform, and vary the frequency of the input signal from 100 Hz to 10 kHz, to record the amplitudes of both input and output signals.

   Step 4.    Find the cut-off frequency when output signal is at the approximate 70% of the amplitude of the input signal.

   Step 5.    Change the resistance R of the RC circuit to R = 5 kΩ, R = 2 kΩ and R = 1 kΩ, determine the cut-off frequencies for the filter in different resistances.

2. **RC High Pass filter**

   Step 1.    Use R = 10 kΩ and C = 0.047 μF to connect a RC high pass filter circuit.

   Step 2.    Apply a 10 kHz square wave signal with 4 V p-p to the input of the filter. Sketch the wave forms of both input and output signals. Record the oscilloscope settings.

   Step 3.    Repeat the step 3 to 5 of the part 1.

3. **RL Low Pass Filter**

   Step 1.    Use R = 10 kΩ and L = 0.1 H to connect a RL low pass filter circuit.

   Step 2.    Apply a 1 kHz square wave signal with 4 V p-p to the input of the filter. Sketch the wave forms of both input and output signals. Record the oscilloscope settings

   Step 3.    Chang the input signal to a sine waveform, find out the cut-off frequency when output signal is at the approximate 70% of the amplitude of the input signal.

## Analysis and Discussion

For Part 1 and Part 2

    a.  Plot the output voltage vs. frequency graphs for both RC low pass and high pass circuits, determine the cut-off frequency.

    b.  Plot a gain (20 $log_{10}$ |G|) vs. circular frequency ($log_{10}$ $\omega$) graph for RC low pass circuits.

    c.  Determine the cut-off frequencies for tested cases in part 1 and 2. Compare the experimental results to the theoretical calculations.

    d.  Compare the output signals of both the RC and RL circuit to the input square wave signals, discuss the results.

## Report Requirement

1. The report must follow the lab report format.

2. The report must be submitted electronically (**PDF**) by the due date.

3. The electronic file must have a file name of: EML3301L_section#_Exp#_Group#.pdf
   **Example: EML3301L_U01_Exp4_Grp1**.pdf

# Experiment 5: Operational Amplifier

## Objective

This laboratory exercise is used to familiarize the student with an Operational Amplifier (Op-amp). The Op-amp is one of the most common used components in electronic circuits. They can be used to compare voltages, in filters, in converters, etc. Upon successful completion of the experiment you should be able:

1. To understand basic functions of an Operational Amplifier.

2. To determine the gains for both inverting and non-inverting Operational Amplifier circuits.

## Introduction

Operational amplifier (Op Amp) was originally developed for the analogue computing to denote an amplifier circuit that performed various mathematical operations such as summation, subtraction, differentiation and integration. A common Op Amp has two voltage input terminals and a voltage output terminal. The ideal Op Amp is assumed to have infinite input impedance, 0 output impedance, infinite gain and infinite bandwidth.

General purpose Op Amp LM741CN is used in this experiment, which has 8 pins shown as the following:
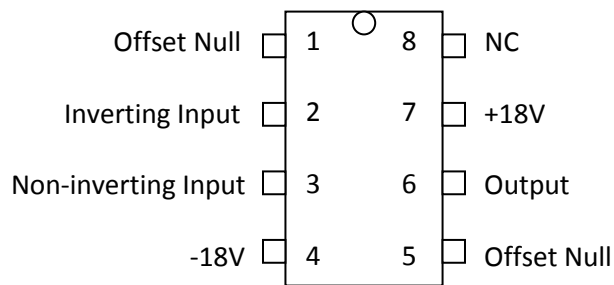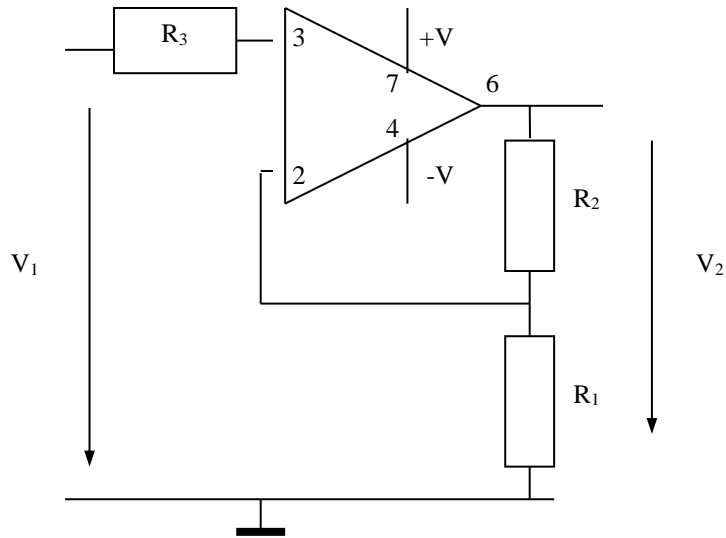


The inverting circuit is connected as the following:
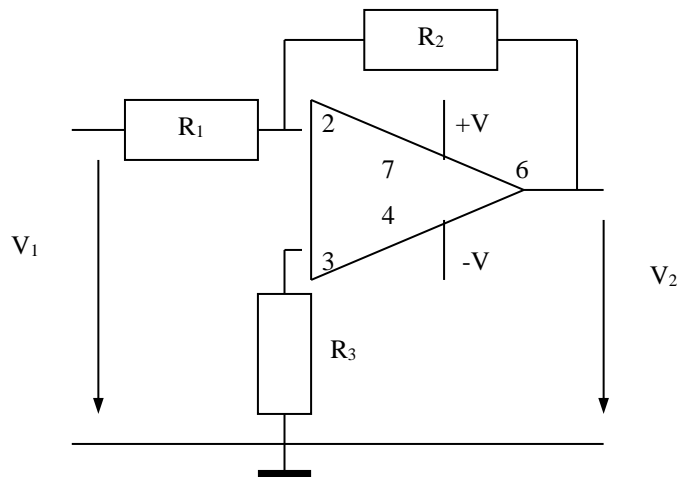


The relationship between input voltage signal $V_1$ and output voltage signal $V_2$ is:

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

The non-inverting circuit is connected as the following:



The relationship between input voltage signal $V_1$ and output voltage signal $V_2$ is:

$$V_2 = (1 + \frac{R_2}{R_1})V_1$$

# Procedures

**Inverting LM741N Operational Amplifier Circuit**

Step 1.  Turn on the DC Power Supply to set both A and B channels to 18 V, and then turn off the device.

Step 2.  Before turning on the Oscilloscope power make the following adjustments

      i.    DISPLAY SYSTEM CONTROLS:

          1.   Set the INTENSITY at midrange.

          2.   Turn the FOCUS knob completely clockwise.

      ii.    VERTICAL SYSTEM CONTROLS:

          1.   Set MODE switch to CH1, move both VOLTS/DIV switch to the least sensitive setting (completely count-clockwise), set the CAL controls in their locked position (completely clockwise).

      iii.    HORIZONTAL SYSTEM CONTROLS:

          1.   Set the SEC/DIV switch to 0.5 milliseconds (ms), turn the CAL knob completely clockwise.

      iv.    TRIGGER SYSTEM CONTROLS:

          1.   Set the TRIGGER MODE switch on AUTO, the SOURCE switch to CH1.

      v.    Turn on the Oscilloscope:

          1.   Fine tune the intensity and focus using the FOCUS and INTENSITY controls.

          2.   Adjust the trace position in both vertical and horizontal using CH1 POSITION control knob. Set the vertical position of CH1 to +2 div and CH2 to –2 div.

          3.   Adjust the voltage and frequency of both displayed input and output signals. (You may set VOLTS/DIV switch to 1 V/div for input signal and 1 V/div for output signal at the beginning; and set SEC/DIV switch to 0.2 ms)

          4.   Set MODE switch to Dual to display both signal on the same screen of the Oscilloscope.

Step 3.  Use 10 kΩ for both $R_1$ and $R_2$, and 5 kΩ for $R_3$ to connect the circuit displayed as above. Bring input signal from the Function Generator, and connect both input and output signal to the two channels of the Oscilloscope.

Step 4.  Turn on the DC Power Supply and Function Generator. Apply a 1 kHz sine wave with 4 V p-p to the Op Amp input.

Step 5.  Record the p-p voltages of both input and output signals and sketch the wave forms. Record the oscilloscope settings.

Step 6. Leave R1 unchanged, change R2 from 20 to 50 k$\Omega$, and record the p-p voltages of the input and output signals from the Oscilloscope.

Step 7. Increase the input voltage until the output signal just clipping. Record the p-p voltages of both input and output signals.

Step 8. Set input back to 4 V p-p and turn DC off switch on, and switch the Oscilloscope from AC to DC. Adjust the DC offset of the Function Generator in positive direction until the output signal just clipping. Record the input DC offset and sketch the wave forms of both input and output signals. Adjust the DC offset of the Function Generator in negative direction until the output signal just clipping. Record the input DC offset and sketch the wave forms of both input and output signals.

**Non-inverting LM741N Operational Amplifier Circuit**

Step 1. Use 20 k$\Omega$ for $R_1$ and 10 k$\Omega$ for $R_2$, and 1 k$\Omega$ for $R_3$ to connect the circuit displayed as above. Bring input signal from the Function Generator, and connect both input and output signal to the two channels of the Oscilloscope.

Step 2. Repeat Step 4 to 6 of the part 1.

## Analysis and Discussions

Part 1

1. Calculate the gain of the inverting circuit for each test case and compare the experimental results to theoretical calculations.

2. Explain what causes the output signal clipping. What are the clipping voltages in the experiment?

3. How are the AC and DC portion of the input signal amplified relative to each other?

4. If $R_1 = R_2$, what is the advantage to use the inverting Op Amp?

## Report Requirement

1. The report must follow the lab report format.

2. The report must be submitted electronically (**PDF**) by the due date.

3. The electronic file must have a file name of: EML3301L_section#_Exp#_Group#.pdf

   **Example: EML3301L_U01_Exp5_Grp1**.pdf