Lab 6. Introduction to MOSFET

In this lab, you will be looking at metal-oxide-semiconductor field-effect transistors (MOSFETs), their operation and applications in real-world examples.

First, you will explore the basic function of a MOSFET. You will examine important characteristics such as threshold voltage and regions of operation. You will use simulation and circuit-building on the NI ELVIS III to investigate MOSFET characteristics. Finally, you will implement a circuit that exemplifies a real-world MOSFET application.

Learning Objectives

After completing this lab, you will be able to:

1. Discuss the characteristics, operation and application of MOSFETS
2. Identify the regions of operation and the threshold voltage of a MOSFET.
3. Manipulate the input of a MOSFET

Required Tools and Technology

Platform: NI ELVIS II/II+ Instruments used in this lab: ● Instrument 1: Function Generator ● Instrument 2: Oscilloscope ● Instrument 3: Variable Power Supply **Note:** The NI ELVIS Cables and Accessories Kit (purchased separately) is required for using the instruments.	View User Manual: https://bit.ly/36DFFrv https://bit.ly/36CnQZH (Credit to Clemson University) View Tutorials: https://bit.ly/35Ae9Kc (Credit to Colorado State University) Install Soft Front Panel support: https://bit.ly/2NbhTv6
Hardware: NI ELVIS II/II+ Default Prototyping Board	View Breadboard Tutorial: http://www.ni.com/tutorial/54749/en
Hardware: Electronics Kit	• Various values of resistors • A red LED • MOSFET, 2N7000 or similar
Software: NI Multisim Live	Access online http://multisim.com View Help http://multisim.com/help/

1. Background Information

Figure 1. Video Screenshot View the video here: youtu.be/1L9fesBVxh8

Video Summary

- MOSFET is an acronym that stands for: Metal-oxide-semiconductor field-effect transistor.
- MOSFETS today perform much of the same work as a Bipolar Junction Transistor (BJT) except that MOSFETS control voltage and a BJT controls current.
- A MOSFET is sensitive to damage that occurs from static discharge.

1.1. What Are MOSFETS and What Do They Do?

MOSFET is an acronym for metal-oxide-semiconductor field-effect transistor. A MOSFET is a type of transistor used primarily for amplifying or switching signals.
MOSFETs today perform many of the same functions as BJTs, except BJTs are current-controlled devices and MOSFETs are voltage-controlled. The most typical application of a MOSFET is as a voltage-controlled switch. A MOSFET can be thought of as a variable resistor, where the gate-source voltage difference controls the drain-source resistance. When there is no voltage difference between the gate-source, the drain-source resistance is very high and little to no current flows. When the gate-source voltage difference increases, the drain-source resistance is reduced and current will flow.

1.2. Why Are MOSFETS Important?

MOSFET technology represents some improvement over BJTs. Power MOSFETs are not subject to thermal run away and other failure modes common to BJTs. MOSFETs are sensitive to gate oxide damage before and during installation. Anti-static handling precautions should be used when dealing with MOSFETS. Another advantage of the MOSFET transistor compared to a regular transistor is that the MOSFET requires less than 1 mA of current to turn but is able to deliver a much higher current to a load of 10 to 50 A or more.

1.3. How Can We Use MOSFETS?

The MOSFET is now the most common type of transistor in both digital and analog circuits. Microprocessors contain millions of integrated MOSFET transistors on each device. The MOSFET devices provide the switching functions needed to operate the logic gates and data storage required by the microprocessor. Discrete MOSFET devices are used in power supplies, variable frequency drives, and other power applications where the devices may be required to switch hundreds or even thousands of watts.

1.4. MOSFET design

Metal Oxide Semiconductor Field-Effect Transistors or MOSFETs are one of the two most common types of transistor. It is cheap and easy to manufacture and miniaturize which makes it a highly attractive option for circuit integration. This process is made even easier since, unlike the bipolar junction transistor, multiple FETs can be manufactured on a single semiconductor substrate.

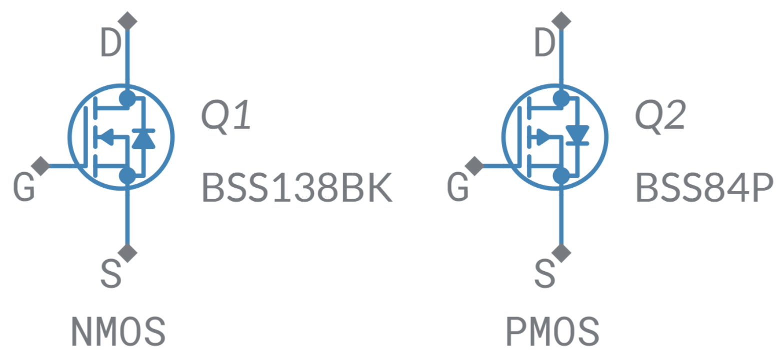


Figure 2. MOSFET schematic symbols with labelled terminals

Figure 2 shows the NMOS and PMOS transistors used on the TI Analog Electronics board. The symbol represents the physical structure of the transistor with the gate (G) separated from the drain (D) and source (S) semiconductor regions by an electrically insulated gap. The third center part of the FET symbol represents the semiconductor body of the transistor which is held at a controlled potential by a diode junction to the source. Both of these transistors also feature a bypass diode which prevents reverse-biasing of the transistor, though this is not part of all such devices.

Simplified versions of the schematic symbol are used on the board silkscreen as schematics often omit the body pin and bypass diode when they are not part of normal operation of the device.

1.5 MOSFET Operation

As the name implies, field effect transistors work by leveraging the electric field created when the gate voltage causes a charge differential across the insulator. This field attracts or repels free electrons or holes in the body of the transistor. The result is that the semiconductor under the gate can be *inverted* due to electrostatic field effects. When the base semiconductor inverts, it eliminates the reverse-biased diode junction which normally impedes current flow between the drain and source. In the case of an NMOS, the base is p-doped, and current flow is achieved by applying a positive charge to the gate, which induces the region of the base below the gate to become negatively charged, or n-type semiconductor. The strength of the field caused by the gate charge will determine the depth to which the base is inverted, and thus the width of the resulting *channel* between the drain and source. The effective resistance of the transistor to current flow is proportional to the cross-section of the channel, allowing for operation between the extremes of open and short-circuit.

Once current is allowed to flow, the movement of electrons though the base substrate results in a perpendicular field which causes the channel to widen at one end and narrow at the other. This is referred to as “pinching” and effectively creates a closed-loop current control device. At any given drain voltage, current flow will increase until the pinching effect increases the resistance sufficiently to stop it.

1.6. Cut-off, Triode and Saturation Regions

There are three distinct regions of operation which are possible with a MOSFET. In the cut-off region, the gate voltage is insufficient to form a current-channel and the transistor is “off”. If the drain voltage is sufficiently high, the resulting current flow is self-limiting due to pinching in the channel, so current flow is constant irrespective to changes in the drain voltage. The voltage at which this occurs is referred to as the *Overdrive Voltage* for that gate voltage.

The most interesting operating region for most applications is the “triode” region in which the current flow is related (non-linearly) to the drain potential. The parameters of this region, as well as the resulting I-V curves will be the explored over the course of this lab, but the relationship between the shapes of these I-V curves as a function of the gate voltage is key to the application of FETs in amplifier circuits presented in later labs.

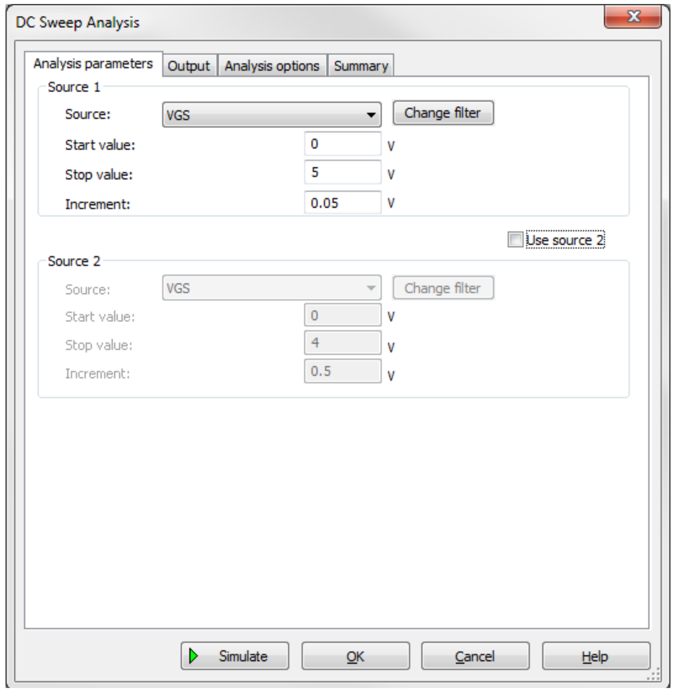
2. Exercise

2.1. Simulation

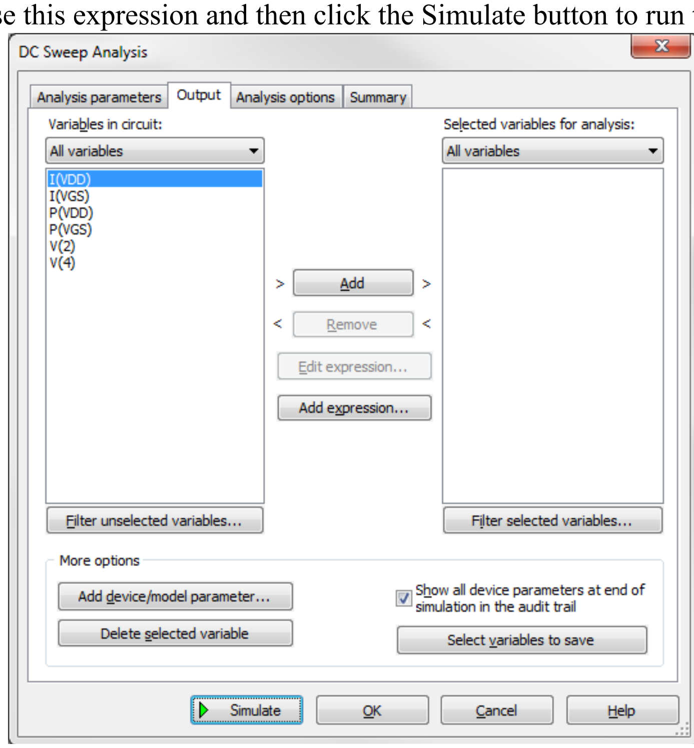
2.1.1. DC Sweeping: Drain Voltage vs. Source Current (Part 1)

In this exercise, you will simulate the DC behavior of a MOSFET in Multisim. You will identify the regions of operation of a MOSFET, which are similar to a BJT.

1. Launch Multisim and open the MOSFET Characteristics.ms13 circuit file.
   - **Note:** that this circuit uses an enhancement-mode N channel MOSFET.
   - With the Drain voltage set to 12V, the graph will show at what Gate voltage Source current begins to flow. This will be an indication of the threshold voltage of the MOSFET.
2. Multisim includes a tool to sweep through different voltage values and measure different output parameters (DC Sweep Analysis).
   - Select Simulate>>Analyses>>DC sweep from the shortcut menu to open this tool.
   - DC Sweep Analysis>>Analysis parameters
   - Source 1 determines which variable will be graphed along the X axis. We want to show Gate voltage, so set Source to VGS.
   - Set Start value to 0V.
   - Set Stop value to 5.0V
   - Set Increment to 0.05V



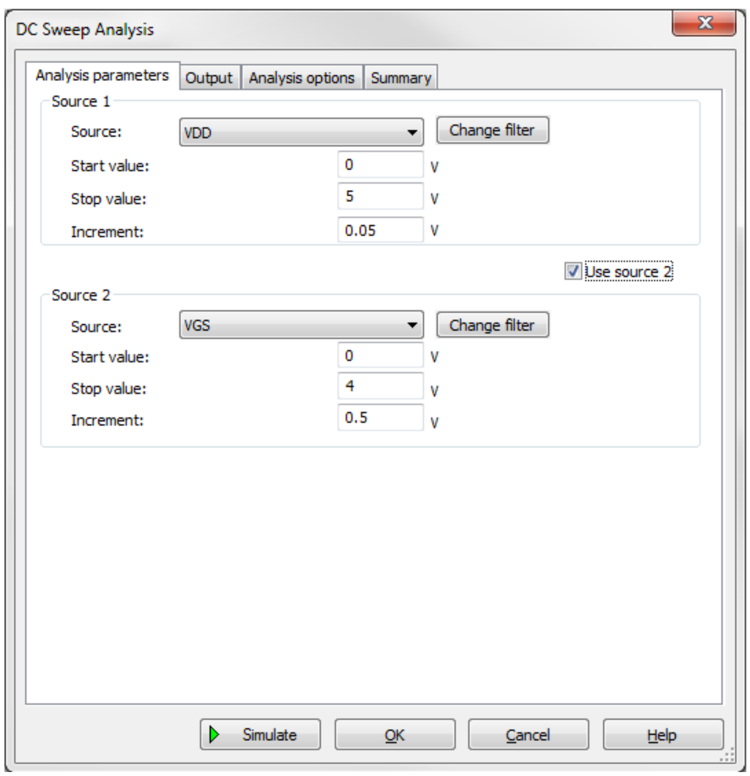
3. Select the Output tab.
4. We want the Source current to be graphed along the Y axis, but it isn't available on the list.
5. We can generate a graph showing the same behavior as the Source current by:
   - Selecting 'Add expression…'
   - Double-clicking '-' from the Functions list
   - 'I(VDD)' from the Variables list
6. The Expression should show –I(VDD).
7. Click OK to use this expression and then click the Simulate button to run the simulated sweep.



8. **Take a screenshot of your graph.**
9. When complete, close the graph.
   - **At what approximate Voltage value does the MOSFET begin conducting current?**
   - **$V_{threshold}$ = ?**

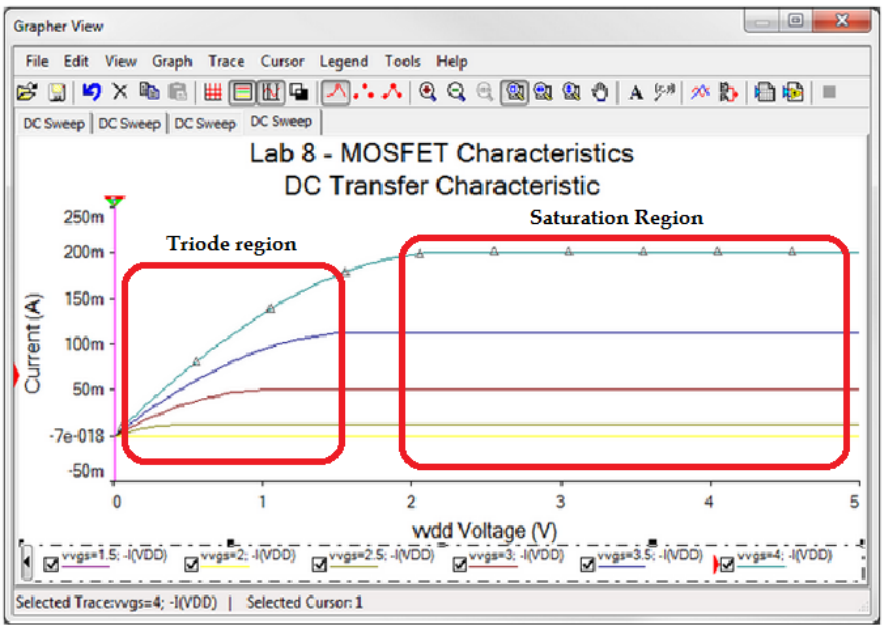
2.1.2. DC Sweeping: Drain Voltage vs. Source Current (Part 2)

1. Select Simulate>>Analyses>>DC sweep from the shortcut menu.
2. Select the Analysis parameters tab.
3. Source 1 determines which variable will be graphed along the X axis. We want to show Drain voltage, so set Source to VDD.
4. Set Start value to 0V.
5. Set Stop value to 5.0V
6. Set Increment to 0.05V.
7. Enable the Use source 2 checkbox.
8. Source 2 determines which variable will be used to create multiple plots. We want to create plots of Gate voltage, so set Source to VGS.
9. Set Start value to 0V.
10. Set Stop value to 4.0V.
11. Set Increment to 0.5V.



12. Select the Output tab.
13. We want the Source current to be graphed along the Y axis, but there isn't a selection for it on the list.
14. We can generate a graph showing the same behavior as the Source current by:
   - Selecting 'Add expression…'
   - Double-clicking '-' from the Functions list
   - 'I(VDD)' from the Variables list

15. The Expression should show –I(VDD).
16. Click OK to use this expression and then click the Simulate button to run the simulated sweep.
17. Take a screenshot of your graph.
18. Observe the Graph
    - **Note:** Some of the plots have 0 current flowing. These are the plots where the Gate voltage is less than the threshold voltage for the MOSFET. These fall in the Cutoff region of operation.
    - On the left side of the plots, where the current is still increasing, is the Linear region, also known as the **Triode region.**
    - Finally, when the current has stabilized, the MOSFET is in the **saturation region**, shown on the right of the graph.
    - When complete, close the graph, and close the circuit file.

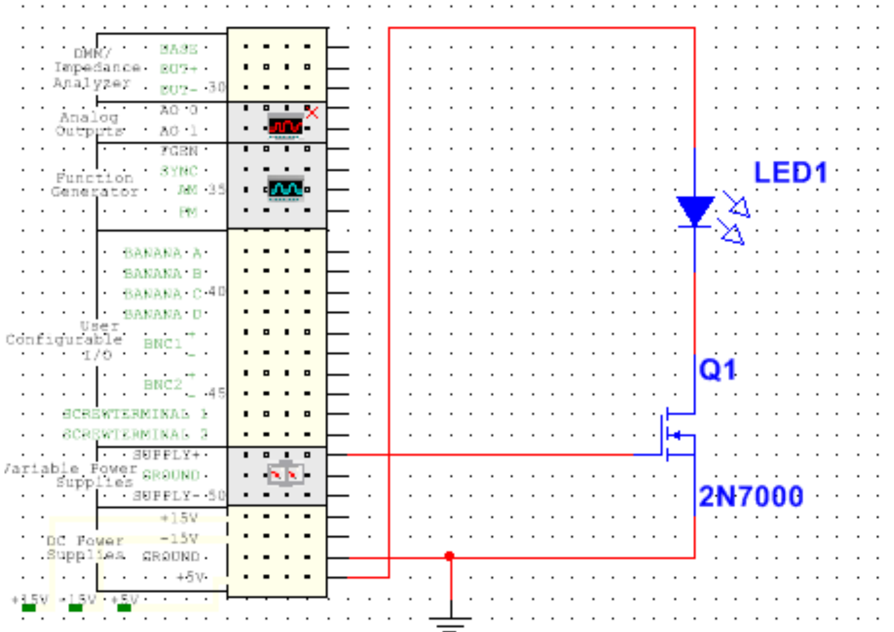


2.2. Experiments

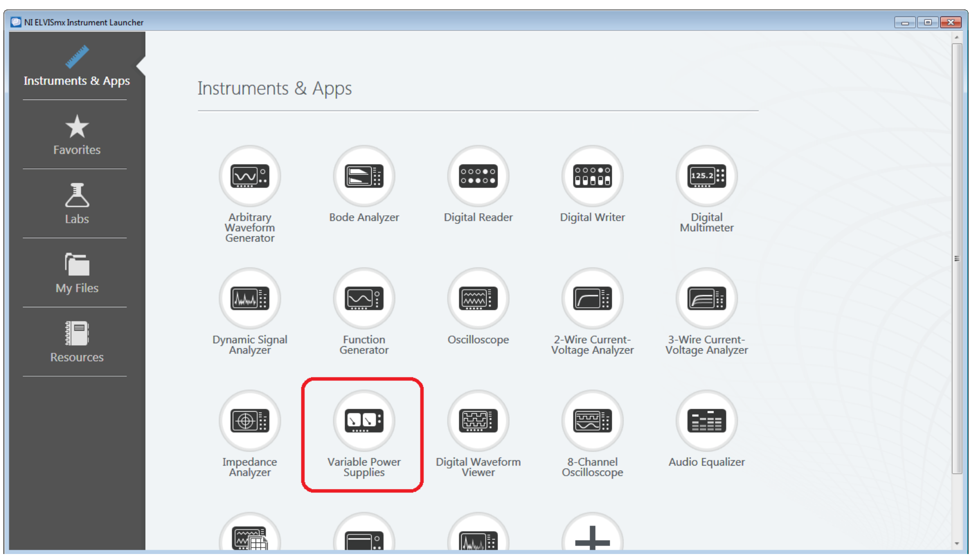
2.2.1. Region of Operation of a MOSFET

In this section, students will confirm the threshold voltage of a MOSFET.

1. Use the NI ELVIS II to set up the circuit shown.



2. Turn on the NI ELVIS II, open the NI ELVISmx Instrument Launcher and use the following instruments:
   - VPS (Variable Power Supply)
   -



3. Confirm the threshold voltage by increasing the Gate voltage until the LED turns on.
   - In the Variable Power Supply window, click the Run button to begin providing voltage to the Gate.
   - Increase the Supply + voltage until the LED just turns on.
   - Find the voltage value where decreasing the voltage by a small amount will turn the LED off and then increasing the voltage by a small amount will turn the LED on.

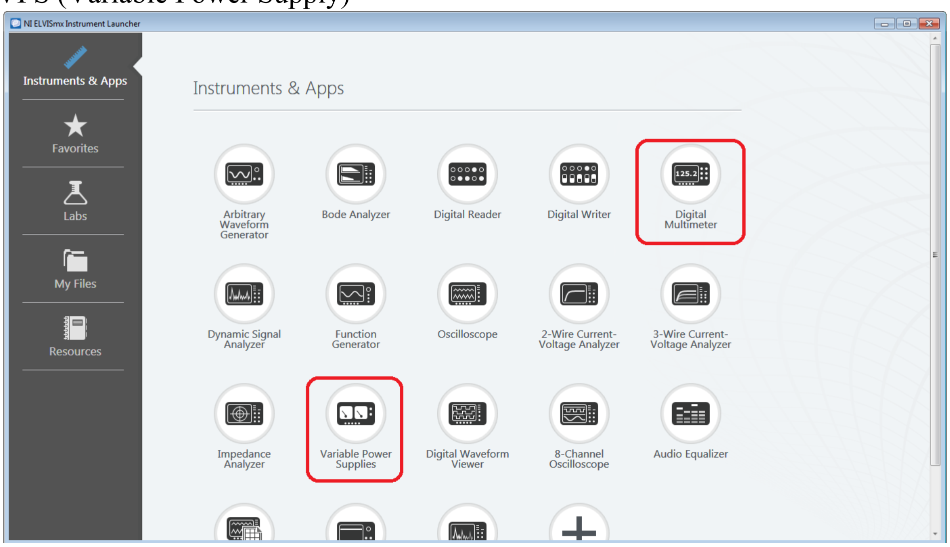
- This is the threshold voltage for the MOSFET. Record this value.
- $V_{threshold}$ =

4. Click the Stop button in the Variable Power Supply when you're done.
   - How does this voltage compare to the graph recorded when simulating the circuit previously?
   - Does this voltage correspond to the point on the graph where current began to flow? Explain.

2.2.2. MOSFET as a Switch

In this section, students will continue with the circuit they used in part 2 to implement a switch with a MOSFET. As seen, the Gate voltage can be used to turn on and off the flow of current through a MOSFET. In this way, a signal with a relatively small amount of voltage and power can control a much higher voltage or power signal.

1. Turn on the NI ELVIS II, open the NI ELVISmx Instrument Launcher and use the following instruments:
   - DMM (Digital multimeter)
   - VPS (Variable Power Supply)



2. In the Variable Power Supply window, click the Run button to begin providing voltage to the Gate.
3. Set the Supply + voltage to 5V and observe the LED.
4. Set the Supply + voltage to 0V and observe the LED.
5. Notice that as voltage is applied to the Gate, the MOSFET allows current to flow through the Drain-Source channel, and the LED turns on.
6. By applying a relatively small voltage, the MOSFET can turn on or off a higher power signal.
7. Click the Stop button in the Variable Power Supply.
   - When acting like an open switch, the MOSFET is operating in which region?
   - When acting like a closed switch, the MOSFET is operating in which region?
   - Does it matter how much current is flowing from the Variable Power Supply for a MOSFET to behave like a switch? Confirm how much current is flowing through the Gate.

APPENDIX

The following is the template of the ECE 3313 report. Note that the report must be typed using Microsoft Words/Excel. Please download the template from the Canvas website.

ECE 3313 Lab X Report Your Name

Title: Lab 1: Observation, Modeling, and Communication

NAME: **Partner:**

General Objective: One or two sentences that describe the objective of this specific lab.

1.0 Prelab Activities: If there is any

2.0 Background Activities: Read background information and summarize important theory, equation, etc.

3.0 Procedure: Describe step-by-step procedure, including circuit schematic, calculation, and etc.

4.0 Results: A lab often includes questions. Please include your answer under the result sections.

- **4.1 Simulation Results:** Make sure to fully discuss about the results, figure, etc.
- **4.2 Experimental Results:** Make sure to fully discuss about the results, figure, etc.

5.0 Conclusions

Remark: Your lab report should include ALL relevant calculations, pictures and work needed for completion of the experiment. Circuit output validation using Multisim is also required. Detailed explanations for decisions made throughout the lab need to be included in the Discussion section of your report as outlined in the Report Guidelines.