Lab 7. DC Models for Bipolar Transistors

In this lab, you will be looking at some of the crucial applications of transistors in the real world, why they are important, why we use them, and what they can do. A transistor, similar to a faucet, can control the flow of electrical current.

In this lab, you will look at the definition and the importance of a transistor and observe the patterns of behavior of a bipolar junction transistor (BJT) using several different methods.

Learning Objectives

After completing this lab, you will be able to complete the following activities:

1. Determine if the transistor is PNP or NPN;
2. Identify the base, collector, and emitter leads;
3. Measure the reverse breakdown voltage for the base-emitter junction;
4. Construct and use a circuit to plot the I_C vs. V_{CE} for different values of I_B;
5. Construct and use a circuit to plot I_B vs. V_{BE}.
6. Determine β_{DC}, I_{CEO}, R_{BB}, and V_0 and draw and label a DC model for a transistor.

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 • BJT, 2N3904 or similar
Software: NI Multisim Live	Access online http://multisim.com View Help http://multisim.com/help/

1. Background Information

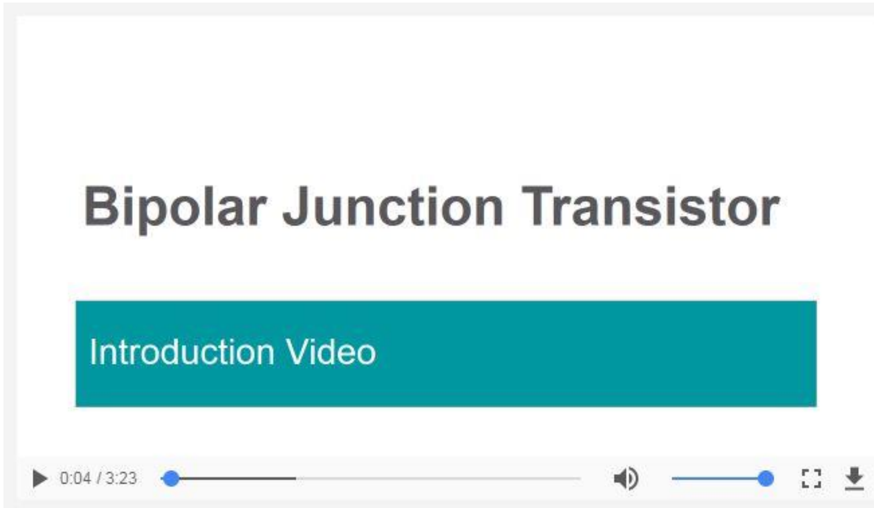

Figure 1. Video Screenshot. View the video here: youtu.be/YCD7nszsfFM

Video Summary

- A transistor controls the flow of electrical current.
- Transistors have two common applications: as switches, and as amplifiers.
- When you switch between the cut-off and saturation regions of a circuit, it is the same as the differences between an open and closed circuit.

1.1. What is a BJT?

A bipolar junction transistor (BJT) is a device with three terminals capable of amplifying a signal. A BJT is made up of three layers of N-type and P-type doped semi-conducting material. The terminals are known as base (B), collector (C) and emitter (E).

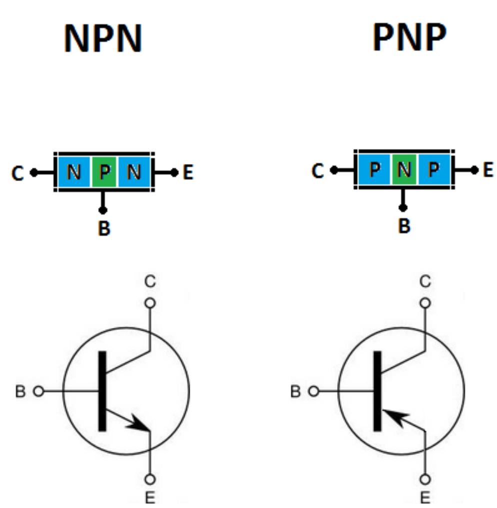

Figure 2. NPN and PNP transistors

A small current at the base is amplified to a larger current in a collector-emitter circuit.

An important feature is the current gain under direct current, beta (β_{DC}), which is the relationship between the current at the collector and that at the base. Another parameter is beta under alternate current (β_{AC}), which is the change in collector current divided by the change in base current.

1.3. What Do Transistors Do?

A transistor is similar to a faucet. As you know, a faucet controls water flow. A faucet can start, stop, and adjust flow. A transistor controls the flow of electrical current in much the same way.

1.4. Why Are Transistors Important?

Small, modern devices and mobile phones require transistors. Before the invention of transistors, electronic devices required large vacuum tubes.
Vacuum tubes were big, fragile, cumbersome, and hard to keep cool. With the invention of transistors, electronics became smaller and cheaper, allowing for more extensive access to them. Extensive access to electronics has shaped our society for the last 60 years. All of this was made possible because of the use of transistors in electronic devices.

1.5. BJT design

As the name suggests, a bipolar junction transistor functions by leveraging the flow of both negatively charged electrons and the positively charged *holes* in a doped semiconductor. A BJT is formed by placing two PN junctions together with opposite polarities, either PNP or NPN. Normally, this would simply act as an open circuit, since one or the other of the PN junctions would be strongly reverse biased. However when positive or negative current is injected into the middle layer of this semiconductor sandwich, the bias voltage across both junctions can be adjusted so as to control current flow from the emitter to the collector.

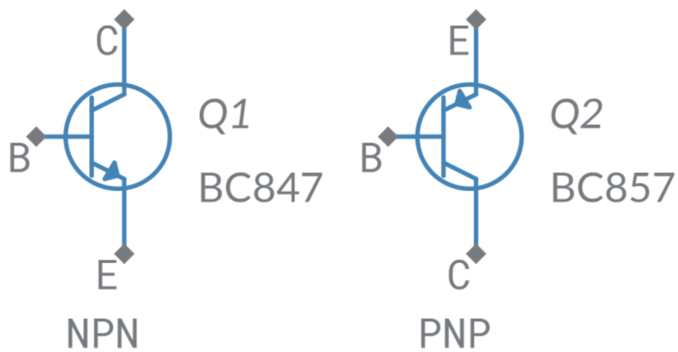

Figure 3. BJT schematic symbols with labelled terminals

Whereas with a field effect transistor we were interested in the gate voltage, with a junction transistor we are concerned with the current flow from the base to the emitter. This flow of current changes the charge distribution in the depletion region of the PN junctions of the transistor allowing for control of the total resistance across emitter to collector.

1.6. BJT operation

The operating mode of a BJT is determined by the bias state of the emitter-base and collector-base PN junctions. The modes are listed in table 1.

Table 1. BJT Operation mode

Mode	E-B junction bias	C-B junction bias
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

In the cutoff mode, both junctions are reverse biased and no current flows (excepting the very small reverse current of the PN junctions). Conversely when both junctions are forward biased in saturation mode, current can flow freely. These states correspond to the “off” and “on” states when a transistor is being used as a switch. Between these two extremes is the active mode, where only the emitter-base junction is forward biased, and the current flow from emitter to collector can be significantly changed using minor variations in the base current.

1.7. DC Models for Bipolar Transistors

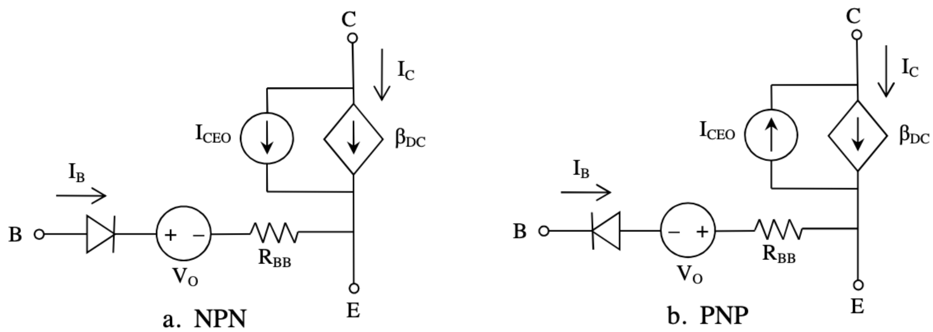

Figure 4. DC Models showing the base-emitter diodes

The models shown in Figure 4 include base-emitter diodes. These diodes indicate that current must flow into the base of the NPN and out of the base of the PNP. For the NPN, no base current will flow until V_{BE} is greater than V_O. For the PNP, no base current will flow until V_{BE} is less than V_O. Since these DC models are used for operating point design calculations, it is assumed that the base currents will have the correct polarity; therefore, the base-emitter diodes need not be shown.

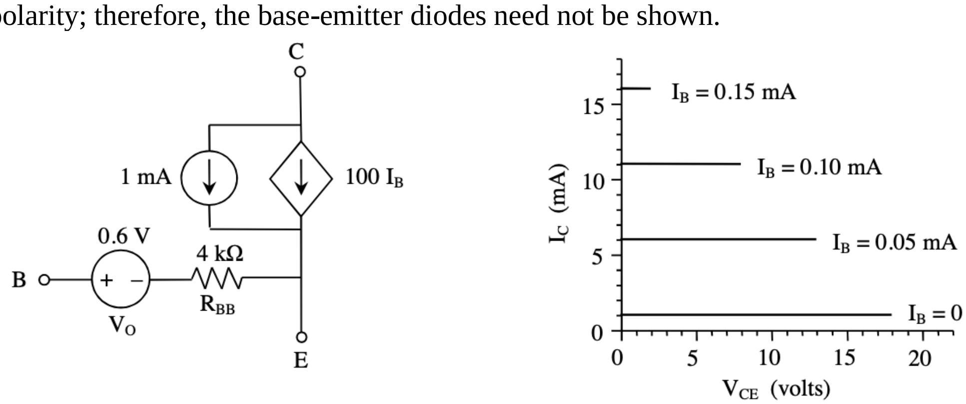

Figure 5. (Left) DC model for an NPN transistor, β_{DC} = 100, (Right) Collector characteristics for the DC model

Figure 5 (Left) shows a model for a particular transistor. The curves shown in Figure 5 (Right) are the *collector characteristics* of the transistor. Each curve (horizontal line segment) is the IV characteristic of the collector-emitter terminals for a constant base current. β_{DC} and I_{CEO} may be determined from the collector characteristics (and vice-versa):

I_{CEO} is the collector current that flows when $I_B = 0$. $I_{CEO} = 1$ mA. (Exaggerated for illustration)

From the model: $I_C = \beta_{DC} I_B + I_{CEO}$. Therefore, $\beta_{DC} = (I_C - I_{CEO}) / I_B$. $\beta_{DC} = 100$. V_O and R_{BB} are determined from the input curve (I_B vs. V_{BE}).

2. Exercises

2.1. Simulation of NPN

Multisim includes a tool to sweep through different voltage values and measure different output parameters called DC Sweep Analysis.

Build the following circuit in multisim

Use any NPN BJT (Found under the Transistor tab → NPN BJT)

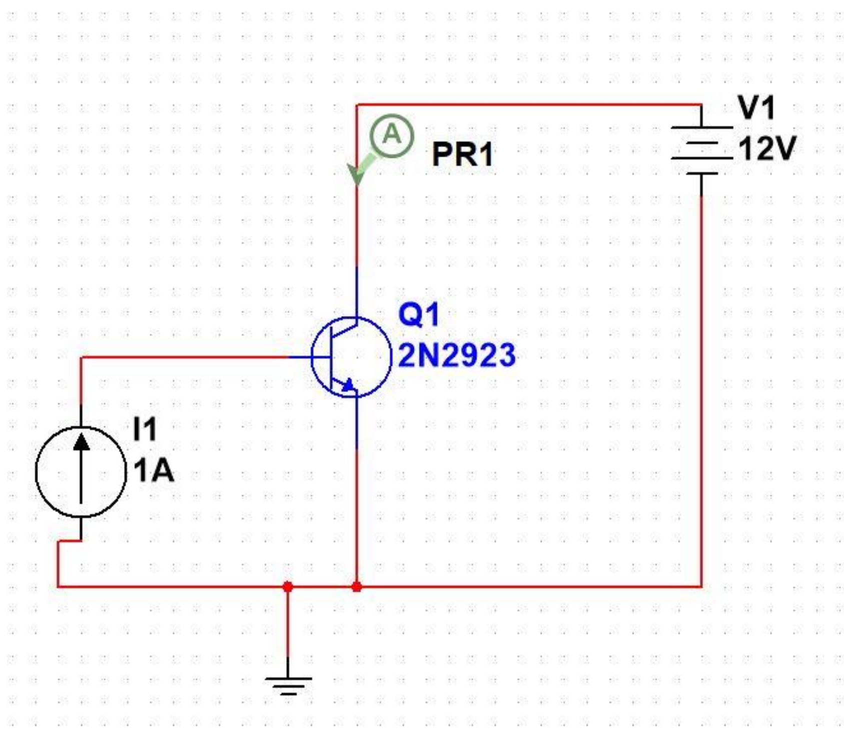

Figure 6: NPN circuit

1. Select Simulate → Analyses → DC sweep from the shortcut menu to open this tool.
2. DC Sweep Analysis → Analysis parameters
3. Source 1 determines which variable will be graphed along the X axis. We want to show Collector voltage, so set Source to VC.

4. Set Start value to 0 V.
5. Set Stop value to 1 V
6. Set Increment to 0.005V.
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 Base current, so set Source to IB.
9. Set Start value to 0.00015A. (this is .15mA)
10. Set Stop value to 0.0006A. (this is .6mA)
11. Set Increment to 0.0001125A. (this is .1125mA)

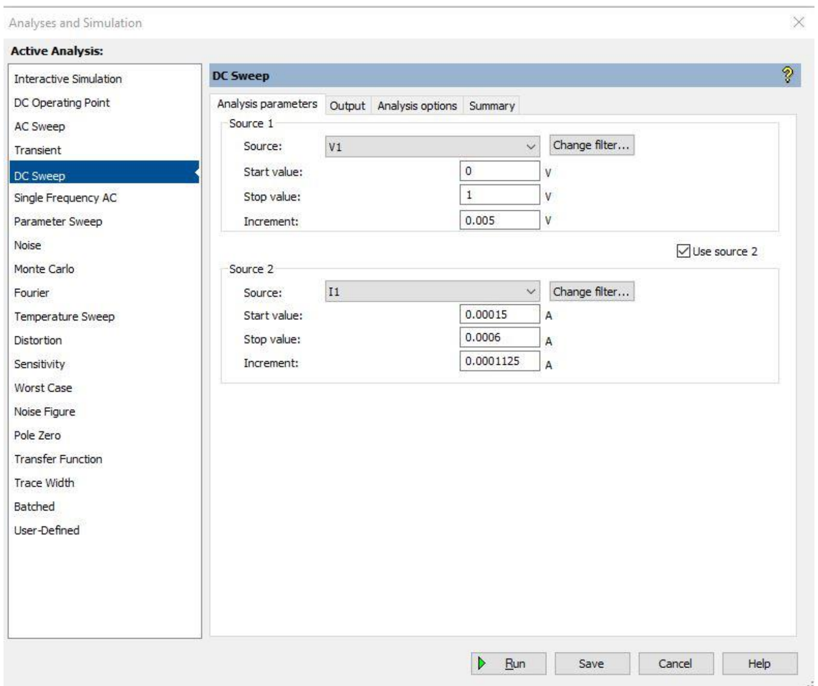

Figure 7 DC Sweep Settings

Running the Simulated Sweep

1. Select the Output tab.
2. We want the Base current to be graphed along the Y axis, so select I(Q1[IC]) from the variables list, and click Add.
3. Click the Simulate button to run the simulated sweep.

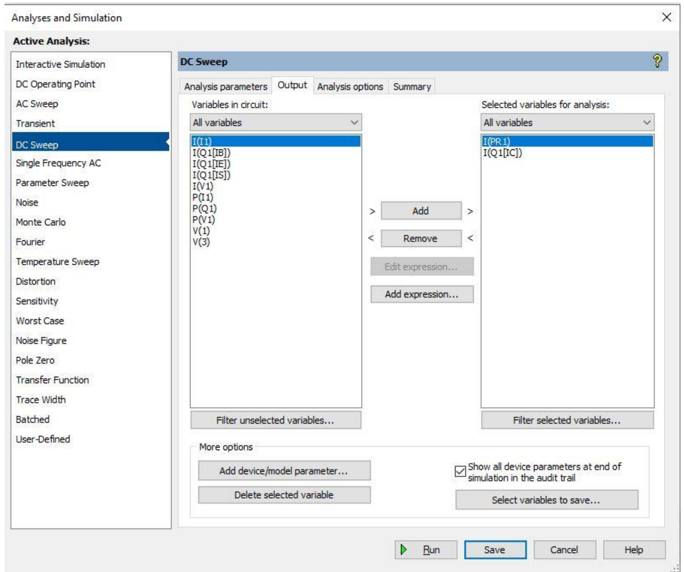

Figure 8 DC Sweep Output settings

Q.1) At what approximate Voltage value do the different plots start separating from each other?

2.2. Simulation: PNP Transistor

Construct the following circuit in multisim:

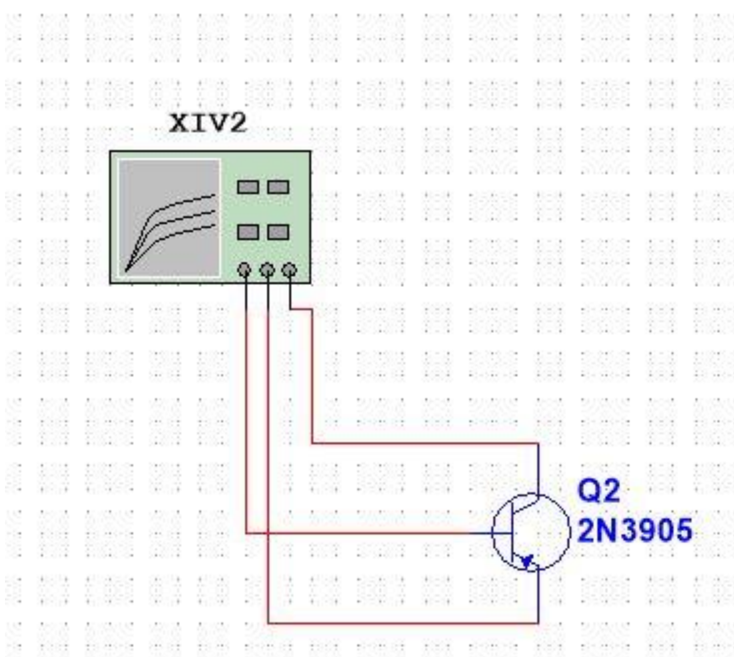

Figure 9 PNP Circuit

The IV Analyzer can be found under Simulate → instruments → IV Analyzer

For this any PNP BJT can be used (found under the transistor tab → PNP BJT category)

1. Double click the IV Analyzer
2. Set the component to BJT PNP (red box)
3. Select Simulate Parameter (Blue box)
4. Set the V_ce column as follows
    a. Start 0 V
    b. Stop 1 V
    c. Increment 50 mV
5. Set the I_b column as follows
    a. Start 1 mA
    b. Stop 10mA
    c. Num Steps 5

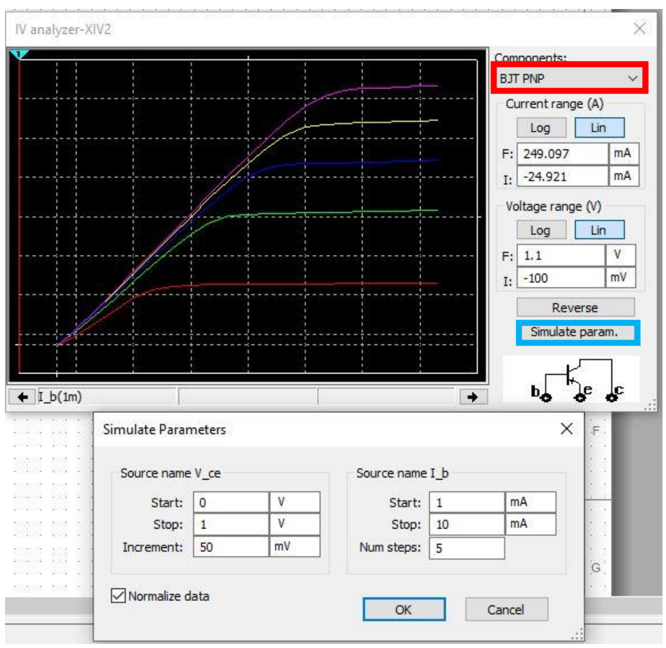

Figure 10 IV Analyzer Settings

Analyze the Results

Analyze the results. The graph shows 5 curves, each corresponding to the relationship between the Collector Emitter Voltage (V_{CE}) and the Collector Current (I_C) for different Base Currents (I_B).

Note: The five curves correspond to Base Currents of 1 through 10 mA. These plots represent the increasing current flowing through the transistor as the voltage increases at the Collector.

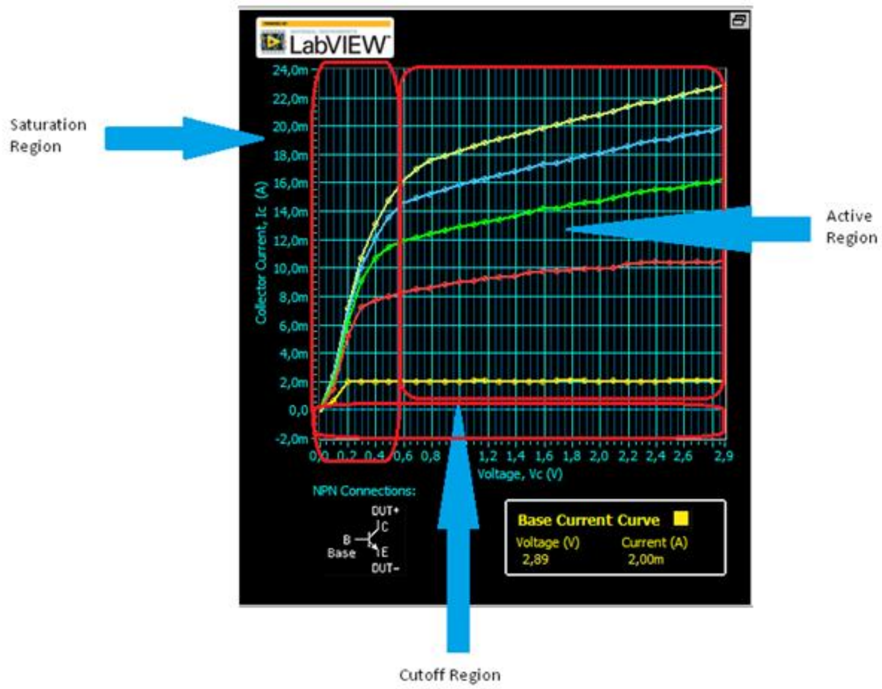

Figure 11: IV Curve generated from hardware

Using these characteristic curves, we can define 3 transistor regions of operation:

- **Cutoff region**: In this region, the transistor does not conduct current from the collector to the emitter (open interrupter).

- **Saturation region:** The transistor has a maximum V_{CE} known as V_{CE} sat. When V_{CE} drops below V_{CE}sat., the transistor will conduct the maximum possible Imax current, given the actual base current defined by the circuit's polarization. In practical terms, when the transistor operates under saturation, it will behave almost like a cable (closed interrupter).

- **Active region**: In this region, the collector current I_C behaves like a linear function of the base current defined by the β constant (depending on the type of transistor).

$$I_C = \beta I_B$$

For practical purposes, if we need the transistor to act like an interrupter, we will work in the cutoff and saturation regions. If on the other hand we need to use the transistor as an amplifier, we need to work in the active region.

These questions will help you review and interpret the concepts learned in this lab.

Q.2) How does this voltage (From Q1) compare to the graph recorded when simulating the circuit previously (the NPN vs the PNP) ?

Q.3) Does this voltage correspond to the point on the graph when current began to flow? Explain.

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.