Lab 3 - Advanced Inputs and Outputs with the VEX Controller

DUE at the end of this lab

Group Assignment

1.0 Objectives

The purpose of this exercise is to gain familiarity with the basic concepts of electronic devices, and how they can be interfaced with microcontrollers. You will use these concepts to implement the sensors and outputs for your project.

The main activities are:

i) to investigate the electrical characteristics of a light emitting diode (LED),
ii) to show how the microcontroller can light an LED,
iii) to show how a light sensor built from a phototransistor works,
iv) to show how the light sensor is connected to the VEX controller.

2.0 Equipment

- Power supply box
- Potentiometer
- Digital multimeter
- Breadboard
- Various circuit components
- RobotC code for Lab 3

3.0 Introduction

In this exercise, you will see how a semiconductor light sensor can be used to detect the presence of objects in an area. You will also see how to connect an LED to the VEX controller and how to use the VEX controller to activate the LED based upon the state in the VEX software.

3.1 Basic Sensor Circuits Revisited

As was explained in the plenary lectures, the basic circuit for sensor connection to the VEX controller is the voltage divider circuit shown in Figure 1. The sensor has a resistance $\mathrm{R}(X)$ which is a function of X, an environment parameter of interest. The output voltage, V_1, is then given by

$$V_1 = \frac{\mathrm{R}(X)}{R(X)+R_1} V_{source}. \tag{1}$$

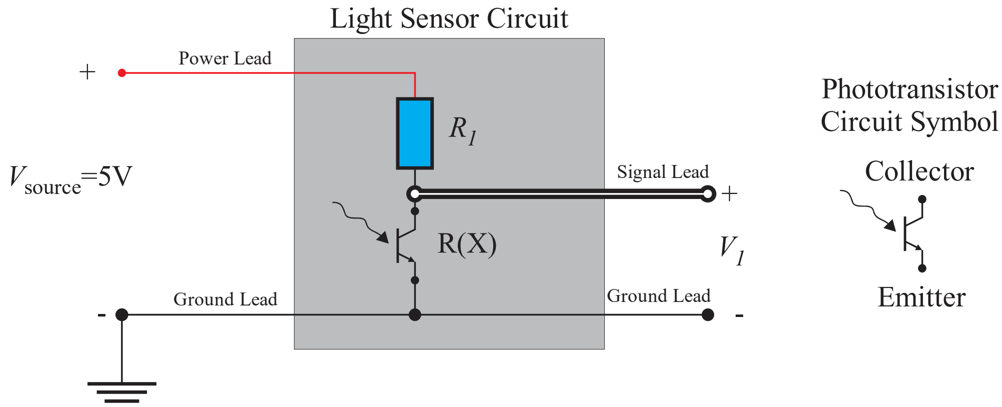


Fig. 1: Voltage divider circuit

3.1.1 Light Sensors

There are several devices available whose electrical characteristics change with the presence of light. A commonly employed type of light sensitive device is the phototransistor. To use the phototransistor, it is placed in the position of $R(X)$ in Figure 1. The phototransistor is essentially a specially treated material, known as a doped semiconductor, which is conductive ($R(X) \rightarrow 0$) when illuminated by light at specific wavelengths and is non-conductive ($R(X) \rightarrow \infty$) at other times. Referring to Equation (1), if the phototransistor is placed in our voltage divider, $V_1=0$ indicates intense light of the proper wavelength is detected as $R(X) \rightarrow 0\ \Omega$, while $V_1 \approx V_{source}$ indicates the presence of no light at the proper wavelength as $R(X) \rightarrow \infty\ \Omega$.

A phototransistor is a polarized device and, thus, must be inserted into the circuit in the correct orientation to work most effectively. The two terminals of the phototransistor are called the collector and emitter. For the best operation, the phototransistor should be inserted so there is a positive voltage applied to the collector terminal relative to the emitter terminal. If it is inserted backwards, the sensitivity of your phototransistor will be severely reduced. In this case, it will have a higher resistance when illuminated as compared to when it is properly installed which will lead to a smaller variation of the output voltage from the illuminated to non-illuminated state. For the voltage divider circuit of Figure 1, the collector terminal of the phototransistor is connected to the signal lead and the emitter terminal is connected to a ground lead of an ANALOG VEX port. When this is done, you can read a value proportional to the voltage V_1 with a function call within your RobotC programs.

The full physical explanation of phototransistor operation is fairly involved but it is not necessary to have a complete understanding of the phenomenon in order to use these devices. More information is available from reference [2] and these devices will be covered in detail in later courses of the engineering programs.

3.2 VEX Output Devices

As well as measuring values from sensors, the VEX controller can also be used to send controlled voltage levels out of its ports. Programming the controller to send a voltage output to the VEX motors is the most common output device used in this course. It is also possible to use the VEX to generate output signals from the DIGITAL ports. In this exercise, we will use a simple output device known as a light emitting diode (LED) to demonstrate this function.

Unlike a resistor, a diode is a polarized device similar to the phototransistor, in that the response to a negative voltage across the device's terminals is not just the reverse of the response to a positive voltage. A diode has two leads called the cathode and anode, respectively. If a positive voltage is applied from the anode to cathode then the diode conducts electricity readily, acting as a very low value resistor. In this case, the diode is said to be positively biased and an LED will emit light at this time. Diodes do not conduct electricity well if a negative voltage is applied from the anode to cathode; they act as a very high value resistor in this case. Diodes with negative voltages applied from the anode to cathode are said to be negatively biased. Negatively biased LEDs do not emit light. In this exercise, we will only use the LEDs in the positively biased or non-biased configurations. To keep the current flowing through the LED at a safe level, it is important to always have a resistor in series with the LED if it is directly connected to a voltage source.

An LED can be connected to the VEX controller in two ways. If the LED is to be continuously emitting light when the VEX controller is powered, you connect the LED in series with a resistor between the "Power" and "Ground" lines of one of the ports of the VEX controller. The resistor's value determines the maximum current flowing through the LED, with greater current (created by a smaller series resistance) causing the LED to generate a brighter light. However, an LED has a maximum current that it can manage without damage so a minimum series resistance is needed to protect the LED. If the LED's state is to be controlled in software, you may connect the LED between the "Signal" and "Ground" line of one of the DIGITAL ports when that port is configured to acts as a digital output port. The VEX controller's DIGITAL port's "Signal" lines cannot source (generate) enough current to damage most LEDs so a series resistance is usually not needed in this case. The signal line for a VEX DIGITAL port can only generate a maximum of about 5 mA of current. The circuit diagrams for these two LED configurations are shown in Figure 2.

In this lab, we will use LED which emit visible light for communicating conditions to the user. We will also LEDs which emit infrared (IR) light. IR light is not visible to the human eye but can be detected with special phototransistors which are tuned for IR light detection.

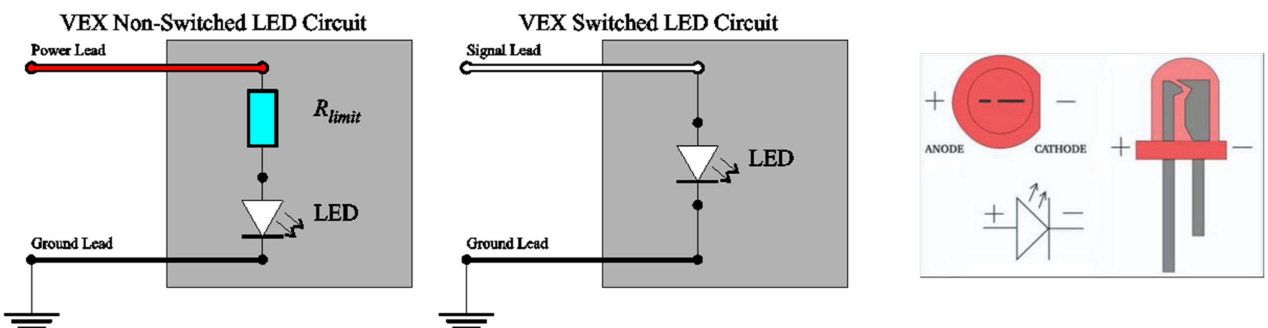


Fig. 2: VEX LED circuits: non-switched LED is always on when VEX controller is operating, and switched LED illumination state is controlled by software.

3.3 Interfacing sensors and outputs with the VEX Controller

To convert the sensor voltages to a digital value that can be processed by a computer, a device known as an Analog-to-Digital Convertor (ADC) is employed. The VEX controller has ADC units connected to each of its ANALOG ports to measure the voltage between the "Signal" connector and "Ground" connector. The ANALOG ports are capable of giving quantitative measurements which indicate the level of the voltage applied to each port. The ANALOG port values can be read as value between 0 and 4095 which maps to an input voltage from zero to five Volts.

The VEX DIGITAL ports can also provide a crude indication of the voltage applied to them. They can only indicate if the voltage applied is above 2.5 Volts, or below 0.6 Volts. If the port is configured for a switch input, the relevant DIGITAL port provides a zero-value output to the software when the input voltage is above 2.5 Volts. If the port is configured for a switch input, the DIGITAL port provides a one value to be output to the software when the output voltage is below 0.6 Volts. If the port is configured as a switch input, the port is configured as a 'Touch' switch, and the input voltage is between 0.6 Volts and 2.5 Volts, the output value could be either zero or one. The switch input configured is referred to in the literature as 'active low' indicating that the low voltage level, below 0.6 Volts in this case, provides a non-zero or 'active' output. For input voltages between 0.6 Volts and 2.5 Volts, the digital value will be maintained as the last value.

The VEX controllers' DIGITAL ports can also be configured to act as output ports, sending a +3.3 volt output signal when set to the 'high' condition or sending out a 0 volt signal when set to the 'low' condition. In addition, each ANALOG or DIGITAL port has a "Power" line that can supply a continuous +5 voltage supply to power a sensor, and a reference "Ground" line that is kept at 0 volts. The position of each connector for each of the ports is shown in Figure 3. Note the relative positions of the Ground, Power, and Signal lines relative to the notches on the VEX port. To connect your circuits to the VEX controller, it is necessary to connect the "Signal", "Power" and "Ground" lines to the proper pins of one of the ANALOG or DIGITAL ports. The ports must be configured for the desired sensor input within the VEX software. DIGITAL ports can also be configured for output in the RobotC software. This configuration will be discussed in the Section 4.0 of this laboratory experiment write-up.

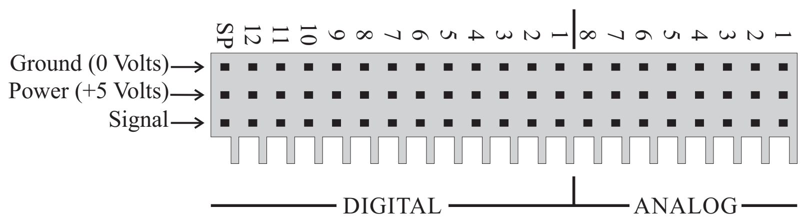


Fig. 3: VEX Analog/Digital Interface Ports

The RobotC software provides an interface where you can select the type of sensor connected to the ports. The type of sensor is selected by using the "Motors and Sensors Setup" wizard which can be found by going to the Robot tab and clicking on Motors and Sensors Setup in the RobotC environment.

4.0 Procedure

In this procedure, the electrical characteristics of LEDs and phototransistors will be investigated. How these devices can be used to transmit and detect light sources will be demonstrated. In addition, the connection of these devices to the VEX controller will be described.

In this lab, you will be using the breadboard from your kit. This breadboard consists of grids and lines of sockets which can hold the ends of wires, VEX connector pins, and component leads. The breadboard electrically connects the sockets as shown in Figure 4 where an orange/red line indicates an electrical connection (low resistance) between the sockets under the line.

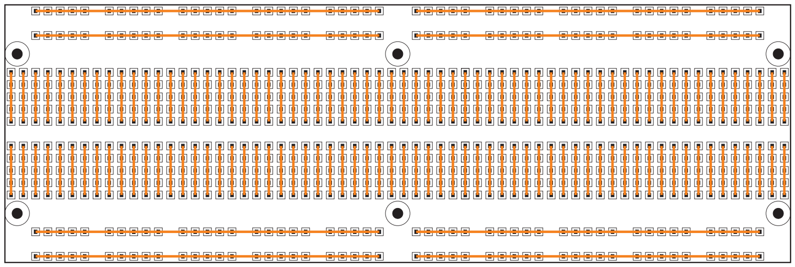


Fig. 4: Breadboard Connectivity (Lines Indicate Ports which are Electrically Connected)

If we wanted to build the circuit with two resistors in series, we could use the wiring shown in Figure 5.

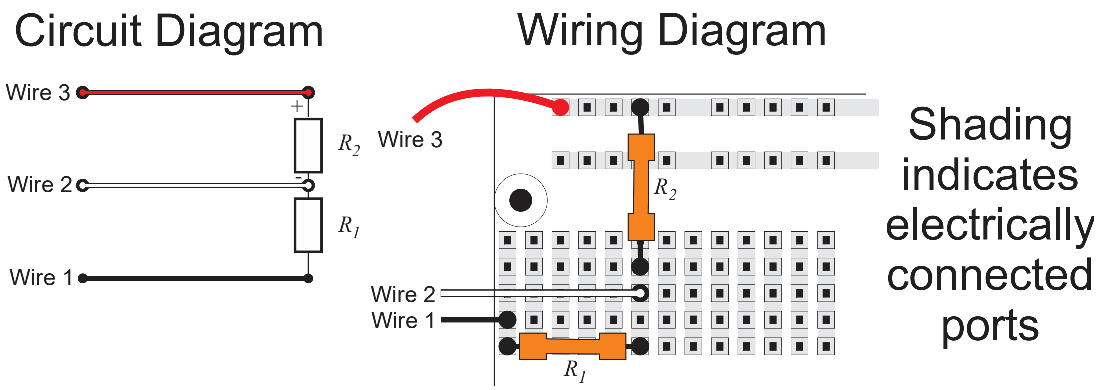


Fig. 5: Circuit Diagram and Breadboard Wiring for Two Series Resistors

4.1 Connecting output devices and sensors to the VEX

In this Section, a circuit connecting LEDs and a phototransistor to the VEX controller is analyzed.

Step 1 Build the circuit shown in Figure 6.

a. Ensure that your VEX controller is powered down before you make any connections.

b. Build the circuits for the VEX ports ANALOG 1, DIGITAL 1, and the IR LED in order. Initially use a 1000 Ω resistor for the bias resistor of the phototransistor circuit on ANALOG 1. Do not change the ports used, or the circuit will not communicate with the controller using the RobotC code supplied for this lab.

c. It is important that the LEDs and phototransistor are inserted in the correct directions. The infrared LED package base is rounded on the side with the wire lead for the anode and has a flattened portion on the side with the wire lead for its cathode. The phototransistor package's base has a flat side for its collector lead and a rounded side for its emitter lead. The anode lead on the visible light LED is longer than the cathode lead. If you view the visible light LED head on, the bottom of the package on the side towards the cathode lead is flattened just like the IR LED. Gently bend the phototransistor and IR LED lead wires about 90 degrees so the top part of the phototransistor and IR LED can face each other when they are aligned on the breadboard. Place them in the breadboard so that the IR LED and IR Phototransistor are 10 cm apart and facing each other. Make sure that the direct path between the active ends of the IR LED and phototransistor device is not obstructed.

STOP Ask your TA to check that your circuit is built correctly. This is worth marks so do not skip this step!

Step 2 Power on the VEX controller.

Step 3 Load the program.

a. Connect the orange USB to Serial cable from the computer to the VEX controller.

b. Open the ROBOTC Program by clicking on the icon on the desktop.

c. Open the LED sensor code which is on the desktop by going to: “File→Open and Compile” and then selecting “Lab_3_Code.c”.

d. Check the type of sensors configured for ports in1 and dgtl1. This can be done by selecting the “Robot→Motors and Sensors Setup” and then clicking on the “VEX 2.0 Analog Sensors 1-8” and the “VEX Cortex Digital Sensors 1-12” tabs in the “Motors and Sensors Setup” window. Make sure the sensors are set up as below:

Port	Port Number	Name	Sensor Type	Purpose
in1	Analog Port 1	InfraCollector	Light Sensor	IR detector (Input)
dgtl1	Digital Port 1	RedLED	Digital Output	Visible Light LED (Output)

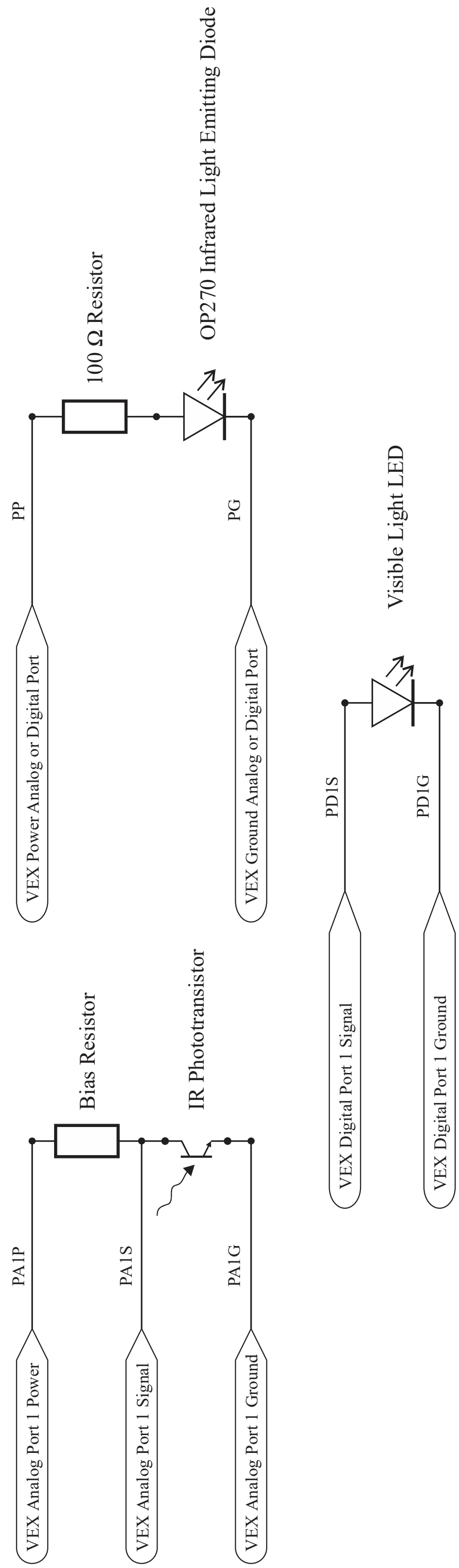
e. You will see the program listing show up in the main Robot C window and two additional windows pop up. The additional windows are the “Program Debug Window” and the “Sensors” window. If these windows do not open, you can find and open them by selecting the Robot→Debugger window options. In this lab, you will be using the “Sensors” window to track the value the VEX controller is currently reading from or writing to each of the controller’s ANALOG/DIGITAL ports.

f. Start the program on the VEX controller.

g. As soon as the program starts, the IR LED should be activated. Check that your IR LED is lit. The IR LED does not emit enough visible light for you to see with your eyes if it is on. Fortunately, most semiconductor-based imaging devices, such as the camera on some cellular telephones, are somewhat sensitive to IR light. If you set the camera to viewfinding mode, where the current image from the camera is shown on the phone screen, and aim the camera at the IR LED, you will see a blue light coming from the LED in the camera’s viewfinder when the IR LED is on. Some cellular telephone cameras have filters to block this IR light so don’t worry if you cannot see this light. You can also measure the voltage between the IR LED’s leads as well to detect if the LED is on; if the voltage over the LED is in the range of 0.5 to 2.0 volts then the LED is probably operating.

STOP Ask your TA to check that your work.

Circuit Diagram



Circut Notes:
- Signals for Power Ports Pins at 5 Volts whenever VEX controller is powered.
- Signals for Ground Ports Pins are at 0 Volts (ground) whenever VEX is powered.
- Infrared LED should be continuously on when VEX is powered.
  * The circuit for the OP270 Infrared LED can be hooked up the Power and Ground lines of any VEX Analog or Digital Port.
- Voltage of signal PA1S increases when phototransistor is exposed to infrared beam from LED.
- VEX Analog Port 1 is configured for Reflection Sensor.
- VEX Digital Port 1 is configured for Digital Output.
  * VEX Digital Port 1 outputs 3.3 V on signal line when 1 is written to port.
  * VEX Digital Port 0 outputs 0 V on signal line when 0 is written to port.

Fig. 6: LEDs and Phototransistor Circuit Diagram

Step 4 Check the sensors and program operation.

a. The program is designed to turn the visible light LED on when the value on the InfraCollector sensor port drops below the constant IR_SENSOR_THRESHOLD which should be set to the value of 1000.

b. Save your code. Recompile the program and download the code to the VEX controller.

c. Make sure that the VEX sensor port states are being updated continuously in the “Sensors” window. This can be done by clicking the “Continuous” button under the “Refresh Rate” heading in the “Program Debug” window.

d. Stop the program execution with the “Step Into” button in the “Program Debug” window.

e. Set the phototransistor to face the IR LED so that the InfraCollector sensor reads below the IR_SENSOR_THRESHOLD in the “Sensors” window.

f. Step through the program and confirm that the red visible light LED is turned on by the controller will be turned on by the code.

g. Block the direct path between the IR LED and phototransistor so the InfraCollector sensor reads above the IR_SENSOR_THRESHOLD value.

h. Step through the program and confirm that the red LED is now turned off properly by the controller.

STOP Ask your TA to check your work.

Step 5 Confirm that the IR LED and IR photodetector interact correctly.

a. Find the sensor port values when the direct path between the IR LED and phototransistor between are not block and when they are unobstructed. Measure the voltage between the signal line and the ground line on Analog port 1 for the two conditions. Measure the voltage the multimeter in your kit. Record the port values and the voltages in the table below.

b. Change the bias resistor to 100 Ω. Repeat the port and voltage measurements from part (a) above with the new bias resistor value.

c. Change the bias resistor to 1 000 000 Ω (1 MΩ). Repeat the port and voltage measurements from part (a) above with the new resistor value.

Bias Resistor Value	Low Port Value	Low Port Voltage	High Port Value	High Port Voltage
100 Ω				
1 000 Ω				
1 000 000 Ω (1 MΩ)				

Step 6 Find the correspondence between the values in the VEX software and the voltages applied to the VEX's ports.

a. Put the port values and voltages recorded above into the table below after ordering them from low to high.

Sensor Port Value	Voltage

b. From the recorded values in step a above, find the relationship between the software sensor port values and the true voltages. The final relationship should be approximately characterized by the parameters α and β in the equation $s = \alpha \times v + \beta$ where s is the sensor port value, and v is the voltage. Graph the sensor values against the input voltage values. Find good approximations for the parameter values of α and β.

Values: α=________________, β=_______________________

STOP

Ask your TA to check your work.

5.0 Concluding Remarks

At this point, you should understand how to use visible and IR light LEDs and understand how these sensors are connected to the VEX controller. You should also know how to use a phototransistor and how to connect this to the VEX controller.

Visible light LEDs are fairly cheap. If you need an output from the VEX to signal a software condition, the use of visible light LED is a fairly simple solution. Visible light LEDs cost only pennies per device, so you may be fairly liberal with their usage.

These circuits should only be considered as starting parts for your own sensor and output system designs. If you have some other sensor circuits you would like to try, discuss them with your lab instructor and if she or he approves of the design, construct them. Experiment with the connection of the other sensors in your kits such as the switches, potentiometer, and ultrasonic measurement sensors with the VEX controller. They may be useful for your project. If you use digital outputs, digital inputs and analog inputs on the VEX kits simultaneously.

6.0 End of Assignment Questions

1. What is the purpose of the biasing resistor, R_{limit}, in the LED circuit of Figure 2? How do you expect the brightness of the LED to change as the value of the resistor R_{limit} is lowered? What are the negative repercussions of using too low a value for the biasing resistor R_{limit}?

2. You wish to use the IR phototransistor circuit described in this lab to detect IR light. If you were going to connect this circuit to an ANALOG port on a VEX kit, what would be the configuration port setting under the RobotC "Motors and Sensor Setup" options to obtain a value indicating the level of IR light incident on the phototransistor? If this port setting is used, what would be the value read by the VEX software if there is only a small amount of IR light at the phototransistor, and what would be the expected change in the value read from the sensor when the phototransistor is exposed to intense IR light as opposed to when it is not exposed to any light? How does the value of the resistance in series with the phototransistor change the variation of voltage from when there is IR light versus when there is no light on the phototransistor?

References

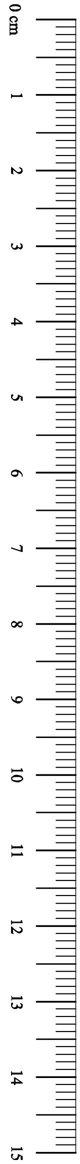
[1] R. A. Serway, *Physics for Scientists and Engineers with Modern Physics*, 2nd Edition, Saunders College Publishing, Philadelphia, PA, 1986.

[2] P. Horowitz and W. Hill, *The Art of Electronics*, 2nd Edition, Cambridge University Press, Cambridge, MA, 1989.

7.0 Grading Template

Deliverables

Marking breakdown	**Points**
<u>In Lab</u>: Step 1, (Wiring matches Figure 6 - 3 pts, wiring is done safely - 2 pts)	/5
<u>In Lab</u>: Step 3, (IR LED is activated – 2 pts)	/2
<u>In Lab</u>: Step 4 (Students can confirm that port settings are correct – 3pts, Students can turn red LED on and off by adding/removing obstruction between IR LED and phototransistor – 5 pts)	/8
<u>In Lab:</u> Step 6, students record voltages for different voltage levels - 3 pts, Students calculate good alpha and beta values – 7 pts	/10
End of Assignment Question 1	/5
End of Assignment Question 2	/10
Total points	**/40**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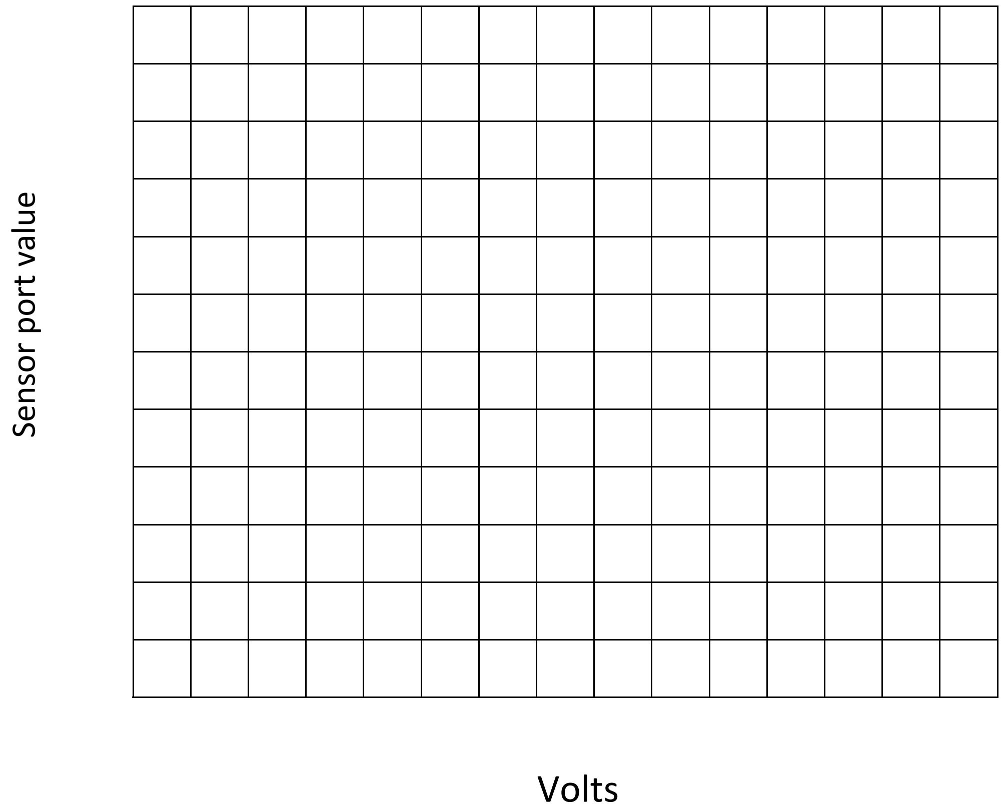
Sensor port value
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