University of California, Davis
Electrical and Computer Engineering

California State Summer School for Mathematics & Science

Cluster 8: Internet-of-Things

Lab 3

Transistor and Sensor Circuits

Introduction:

a. Purpose/ Scope

In this lab you will work with a discrete semiconductor device, i.e., the transistor. The transistor is of course the workhorse of modern computing. This lab is meant as a quick introduction to its functionality and usefulness in actual systems.

This lab also emphasizes a topic that we have seen in previous labs but haven't explored in great detail, namely transducers and their application to electrical engineering. Transducers are devices that convert one form of energy into another, or based on our previous statement, takes one form of information, and converts it into another. This can be the conversion of mechanical energy in the form of pressure or sound into electricity or light into electricity and vice versa. This lab aims to introduce you to different sensors/transducers and explore its dependencies (operating conditions), limitations, and applicability to engineering devices.

Although the systems you will build are simple, they are eloquent in their simplicity and are the basis to a wide variety of devices.

Resources/Lab Materials

Resources, specifically Energia programs for controlling and monitoring voltages are provided. You will not be expected to write your own code during this lab.

Lab Materials:

- 1x TI MSP432P401 LaunchPad Kit (Red kit)
- 2x Breadboard
- 1x Breadboard Booster Pack
- 1x blue LED
- Jumper wires
- 2x 330 Ohm resistor
- 1x 100k Ohm resistor
- 1x Photoresistor
- 1x Transistor PN2222A
- 1x Ruler

Lab Exercises:

Part A: Transistor Circuits

Description: In this portion of the lab, you will be working with transistors, specifically bipolar-junction transistors (BJTs). BJTs consist of three regions: a collector, an emitter, and a base (see figure below). BJTs are commonly used as current controlled switches in which the amount of current delivered to the base region controls the amount of current flowing through the collector. As the base current increases, so does the collector current. To illustrate the utility of BJTs, in the following exercise you will build an LED night light using another device called a photoresistor, a device with a resistance that decreases as light shines on it.

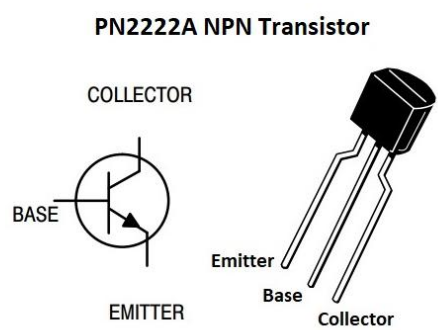

Fig. 1. Schematic symbol transistor and pin layout for PN2222A

Procedure:

1. Construct the circuit shown below. For the transistor shown in the diagram, the emitter pin will be connected directly to ground, the base is connected to the 100k Ohm resistor and photoresistor, and the collector is connected to the shorter end of the blue LED. A pin layout for the transistor is shown in Fig. 1.

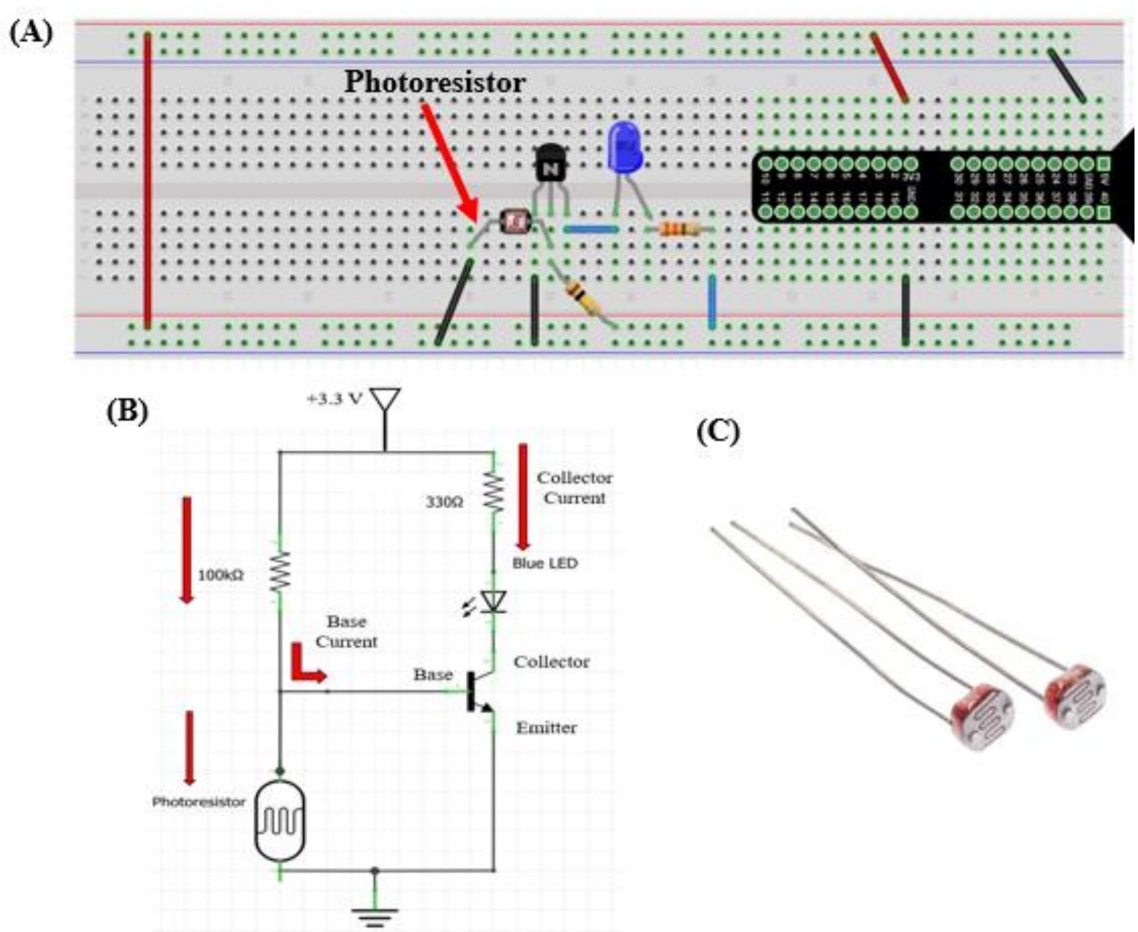

Fig. 2. (A) Diagram of circuit for part C. In the diagram, the leftmost pin of the transistor is the emitter while the rightmost is the collector. **(B)** Schematic of circuit illustrated in **(A)**. **(C)** Photoresistors used in circuit

2. Test your circuit by covering the photoresistor a little at a time and you should notice that the less light the photoresistor sees, the brighter the LED gets. If you turn out the lights in the room, the LED will be completely on. Demonstrate that your circuit is working appropriately to a TA and then answer the questions on the following page.

Questions:

1. Current flows down through the 100k Ohm resistor and splits between the base and the photoresistor. As light shines on the photoresistor, it's resistance decreases. As more light shines on the photoresistor, does more or less current flow through it? Why? Does current flow through the base? Why?

2. When it's dark, does more or less current flow through the LED than when light is shining on the photoresistor?

3. Now assume that the light on the photoresistor is decreased slowly until it's dark. Based on your answers to questions 1 and 2 and the discussion at the beginning of this exercise, explain the operation of this circuit in terms of the currents flowing through the photoresistor, the base, and the collector.

<u>Part B:</u> Temperature sensor

Description: In this exercise you will be using your microcontroller and a temperature sensor in a very simple circuit to toggle an LED on after the temperature exceeds a certain threshold, and toggle it off once it falls beneath that threshold. While turning on a LED is not very exciting, the LED can be easily replaced with some other process like turning on a sprinkler or sounding an alarm because there is a tremendous amount of heat from a fire. This exercise will provide an introduction to sensors and how they can control processes and provide information from the environment to be used when designing problem solutions.

<u>Procedure:</u>

1. First, construct the circuit shown below in Figure 3. The three terminal device shown is a LM35DZ temperature sensor and its pin layout is shown in Figure 1B. **WARNING:** the pin layout is if you are looking at the device from the bottom with the pins pointing at you. If you connect it backwards it will not work. You will know quickly because it will smell like something is burning and the device will get very hot quickly.

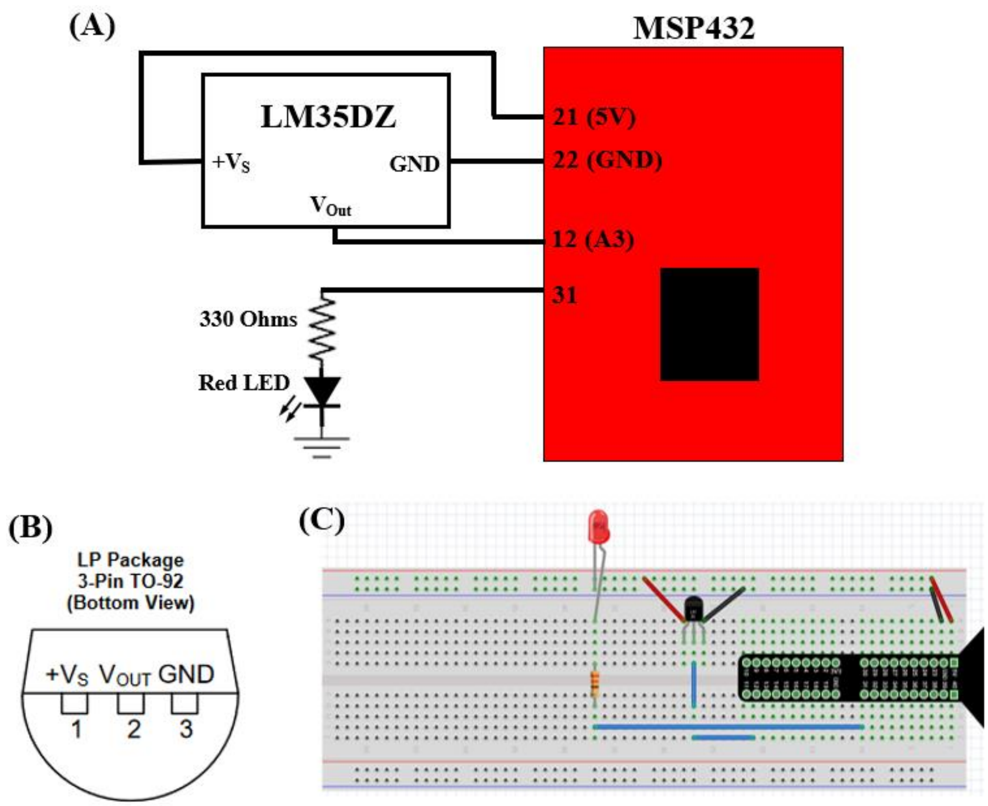

Fig. 3. (A) Schematic of temperature sensor circuit. **(B)** Pin layout for LM35DZ temperature sensor. **(C)** Diagram of circuit.

2. Next, copy the code segment below into Energia:

```
const int ledPin = 31;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(115200);
  pinMode(ledPin, OUTPUT);
}

void loop() {
  // put your main code here, to run repeatedly:
  int sensorValue = analogRead(A3);
  float temp_C = ((3.3*sensorValue/1023.0))/0.01;
  float temp_F = temp_C*(9.0/5.0)+32.0;
  Serial.println(temp_F);
  delay(1000);
}
```

Take a moment to look at the code an understand it as there will be some brief questions on it for this exercise. Run the code and open the serial monitor. You should see the ambient temperature printing to screen.

3. Now modify the Energia script to include the following lines and upload the program to the MCU:

```
const int ledPin = 31;
const float threshold = 80.0;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(115200);
  pinMode(ledPin, OUTPUT);
}

void loop() {
  // put your main code here, to run repeatedly:
  int sensorValue = analogRead(A3);
  float temp_C = ((3.3*sensorValue/1023.0))/0.01;
  float temp_F = temp_C*(9.0/5.0)+32.0;
  Serial.println(temp_F);
  delay(1000);
  if (temp_F >= threshold){
    digitalWrite(ledPin,HIGH);
  }
  else{
    digitalWrite(ledPin,LOW);
  }
}
```

Fig. 2. Segment of code to edit in Energia

4. Now place your hand near or gently on the temperature sensor. After a short time the LED should turn on. Once you have verified that the circuit is working correctly, answer the following questions.

Questions:

1. Refer to the variable named temp_C in the Energia code. At this point you should be familiar with this line of code, however, this time there is an added factor of 0.01 in the expression. Explain why this factor is included.

2. In this code, we defined a variable threshold. What is the purpose of this value and what would happen if we increased or decreased it?

<u>Exercise 3:</u> Light to electricity

Description: In this exercise you will work with a combination of an LED and a photoresistor and systematically analyze the dependencies of the photoresistor on separation distance and color of the light source. These aspects are common considerations when it comes to system design.

<u>Procedure:</u>

For this exercise you will need both of your bread boards and a ruler.

1. Construct the circuit shown below using two separate bread boards. Note: the photoresistor will be operated using the 3.3 V supply from the MCU while the LED will be using the 5 V from the MCU using jumper wires between the boards. The wires should be long as you will be moving the bread boards apart for your measurements. The long leg of the LED is connected to the power supply and the short leg is connected to the resistor.

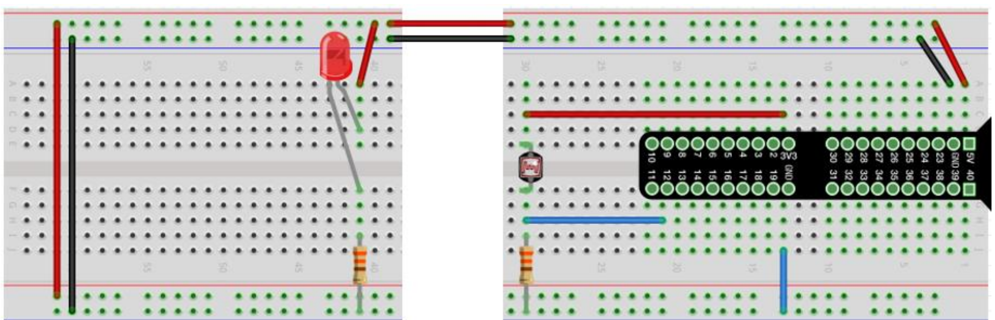

Fig. 4. Diagram of circuit for LED and photoresistor

2. We want the LED to be focused on the transducer. To do this tilt the LED and photoresistor so that they are pointing at each other and use the voltmeter to record the voltage across the photoresistor. A depiction of the LED, photoresistor configuration can be seen below in Figure 5.

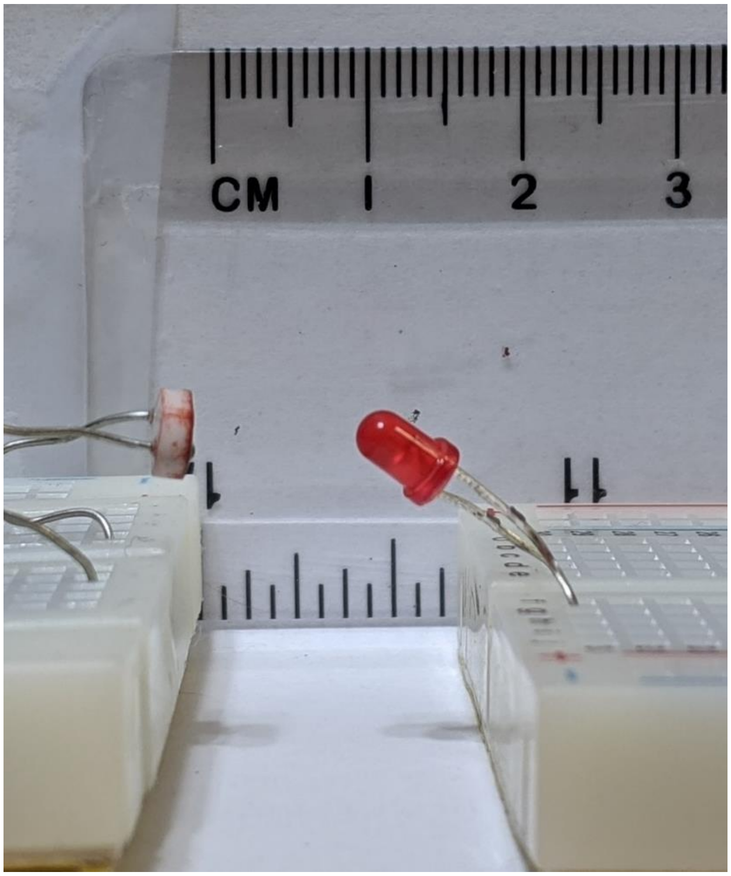

Fig. 5. Image of LED and photoresistor configured to point at each other and maximize the signal. The separation distance in this image is estimated to be 1 cm.

Use the ruler to measure the separation distance between the tip of the LED to the face of the photoresistor. Start with the LED resting on the face of the photoresistor and then slowly move the breadboards away from each other and record the voltage and distance at each separation. Start with the LED resting on the photoresistor and record the voltage every 0.5 cm until the LED and photoresistor are separated by 5 cm. **IMPORTANT:** the ambient light will noticeably affect the photoresistor so you should do this step in the dark or place a dark cloth or box over the circuit to decrease the ambient light.

3. Repeat this process over the same range but this time with a green LED and answer the questions that follow.

Questions:

1. Prepare a graph in excel or any other software you are comfortable with, showing distance on the x-axis and voltage on the y-axis for the both LEDs. Both curves should be on the same graph for comparison. The units for the x-axis should be **cm**, while the units of the y-axis will be volts. Make sure the axes are labeled and units are specified.

2. How does the response between the red LED and green LED compare and why do think this behavior is observed?

3. What do you think the behavior of the curve would be if a blue LED were used (shorter wavelength)? What about a longer wavelength LED (infrared)?