IR LED and Phototransistor Validation and Integration

Essential Specifications

To validate the selection of the IR LED and phototransistor components used in sensing the presence of the parts, several essential specifications were identified to be tested on the real circuit. First, the IR LED needed to provide a sufficient amount of lumens to the phototransistor in order to switch the device between the on and off state. Secondly, the phototransistor needed to have a narrow receiving angle so that the phototransistor would only receive the light from its respective IR LED. The phototransistor should also have a rise time significantly smaller than the time that the part with the smallest width would take to cross the path of the light beam. With these considerations in mind, we tested the sensor circuit to ensure the phototransistor and IR LED combination would fit our application.

Luminance

To test that the IR LED could sufficiently switch the state of the transistor, we constructed the circuit in Figure 1 and checked the output voltage with and without blocking light at varying distances. Using helping hands as seen in Figure 2, the phototransistor and IR LED were held steadily while the distance was varied. The IR LED easily controlled the state of the phototransistor. In fact, the IR LED was capable of switching the state of the transistor at distances over 40mm, which is nearly double the distance used in this application. As a result, we concluded that the IR LED and phototransistor met our first criterion.

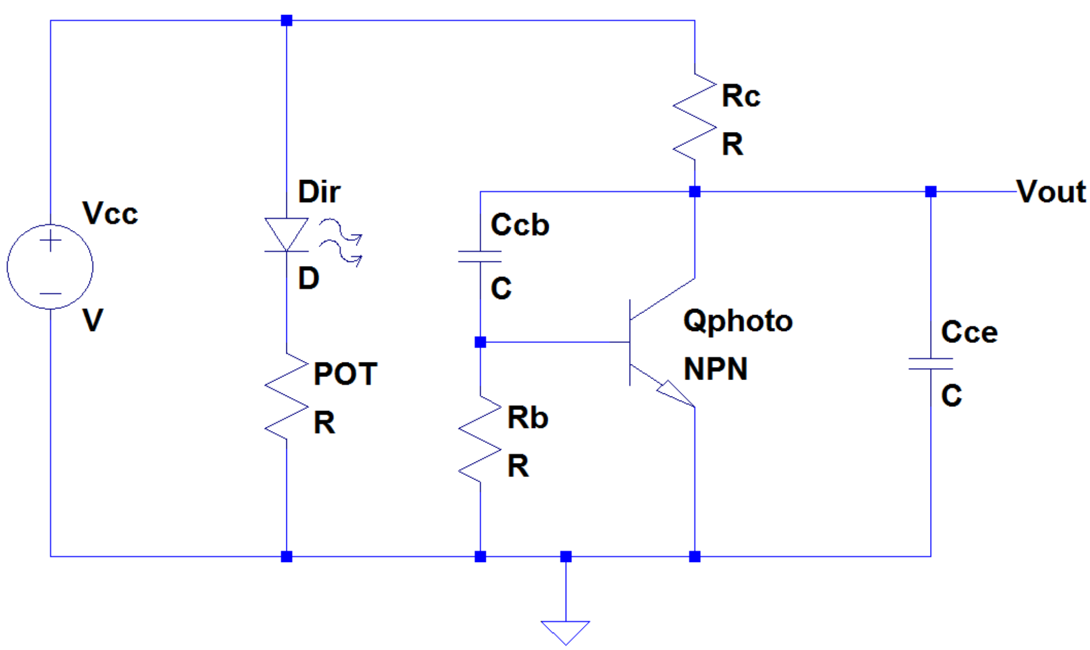

Figure 1. A schematic of the IR LED and phototransistor circuit.

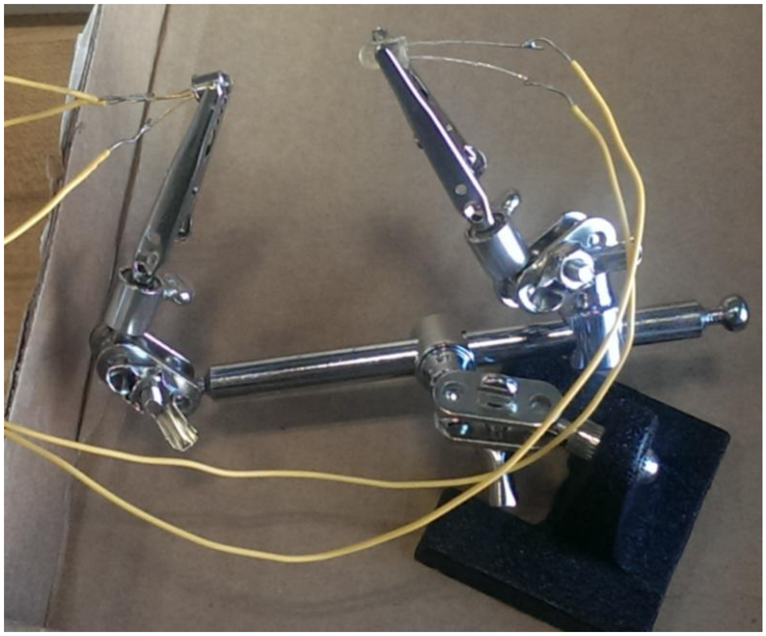

Figure 2. The apparatus for holding the IR LED and phototransistor system.

Receiving Angle

To test the receiving angle, the same test circuit used in the first test was constructed and the helping hands were similarly used. However, in this test, the lateral position of the IR LED was varied instead of the distance. During this test, we found that phototransistor was extremely sensitive to the lateral position of the IR LED. Through this test we determined that at the maximum output of lumens from the LED, the phototransistor could be switched on and off from a 3mm deviation from the centerline of the transistor. In comparison, the centerline of each pair will be at least 5mm away from its neighbor. Furthemore, we found that decreasing the amount of lumens output by the LED reduced the maximum deviation. When installed in the real funnel, the LEDs' brightness can be further tuned to prevent any interference. As a result, we concluded that the reception angle of the phototransistor is more than sufficient for avoiding interference in the application's configuration.

Rise Time

In order to evaluate the rise time of the circuit, we needed to identify the minimum rise time necessary for the transistor circuit. We identified that the rise time needed to sufficiently small so that the output voltage would reach greater than +3V before the object has completely passed through the path of the beam. To compute a nominal value of this, we examined the kinematics of the situation. We identified that the object would be in freefall and the shortest time interval for detection would occur when the object is at its greatest velocity. With these considerations, we computed the objects velocity at the bottom of the funnel. We found the velocity to be approximately 2.2m/s. Next, using the width of the smallest part, we computed the minimum time interval for detection. We computed the minimum time interval for detection to be approximately 4ms. As a result, we defined that the maximum acceptable rise time must be less than 4ms.

The rise time of the phototransistor was evaluated using the circuit depicted in Figure 1 and the physical configuration depicted in Figure 2. We used a 33kΩ and 11kΩ resistors for R_C and R_B, respectively, and 1nF and 47nF capacitors for C_{CE} and C_{CB} respectively. By blocking the light we evaluated the response of the phototransistor. Figure 3 displays the rise time of the sensor as observed by the oscilloscope using these values. As can be seen the rise time of the circuit is approximately 10ms, which is unacceptable by the criterion previously established.

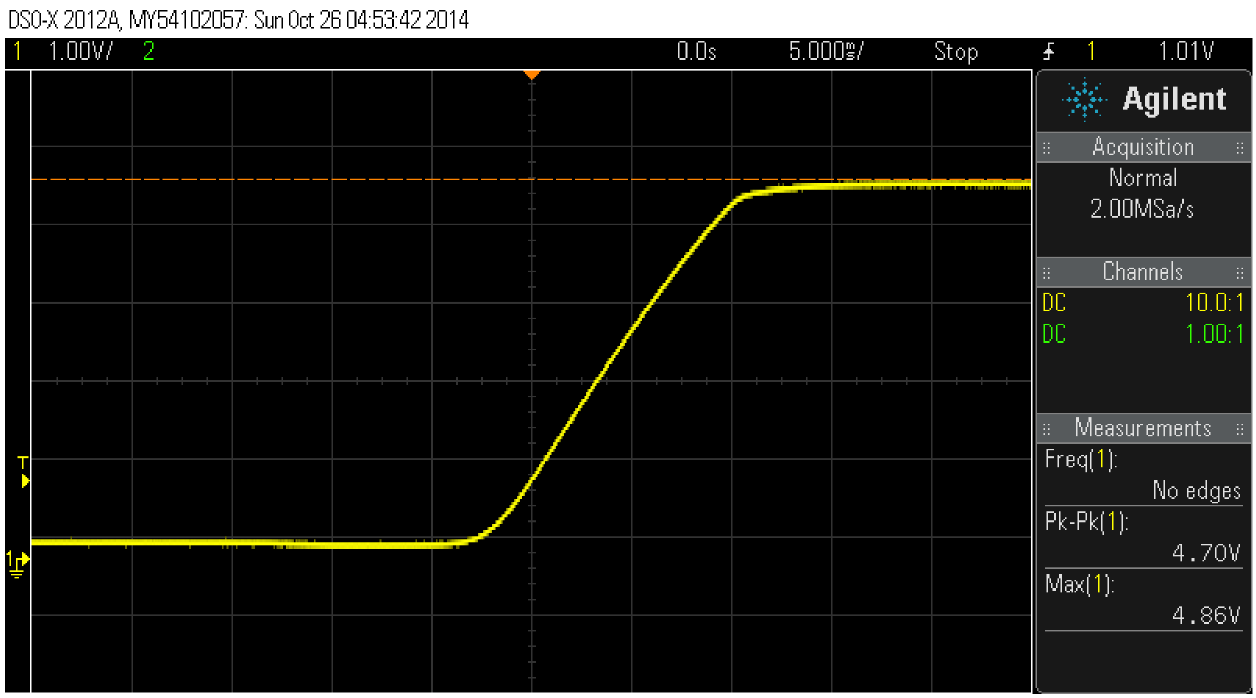

Figure 3. The waveform of the initial test of the phototransistor's rise time.

Since the configuration did not meet standards, we needed to adjust the time constant of the circuit. Initially, we decreased the value of C_{CE} which decreases the time constant. We changed the value of the capacitor to 1nF. The voltage output after the test as observed by the oscilloscope is depicted below in

Figure 4. As can be seen in the figure, changing this capacitor did not affect the rise time significantly.

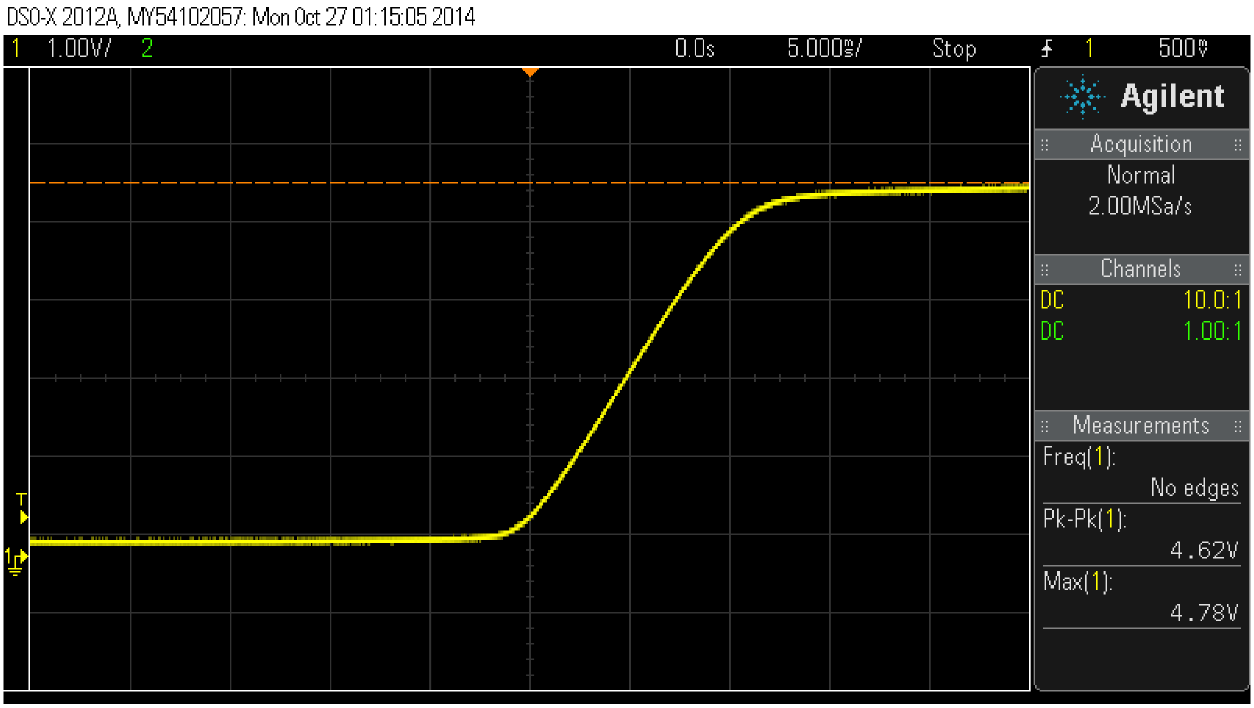

Figure 4. The waveform of the rise time due to changing C_{CE}.

Since C_{CE} did not affect the rise time significantly, we investigated the affect of C_{CB} on the time constant. We quickly realized that this capacitor, which is in parallel with the Miller Capacitance of the transistor, has a much greater effect of the time constant of the circuit due to the current gain of the transistor, β. As a result, we changed C_{CE} to 47pF and removed C_{CB} from the circuit. As a result, the circuit is configured as appears in Figure 5. We tested the circuit under this configuration and observed the rise time to be significantly improved to 350μs, as can be seen in Figure 6. Since the rise time is significantly lower than the criteria established earlier, the circuit meets our specifications.

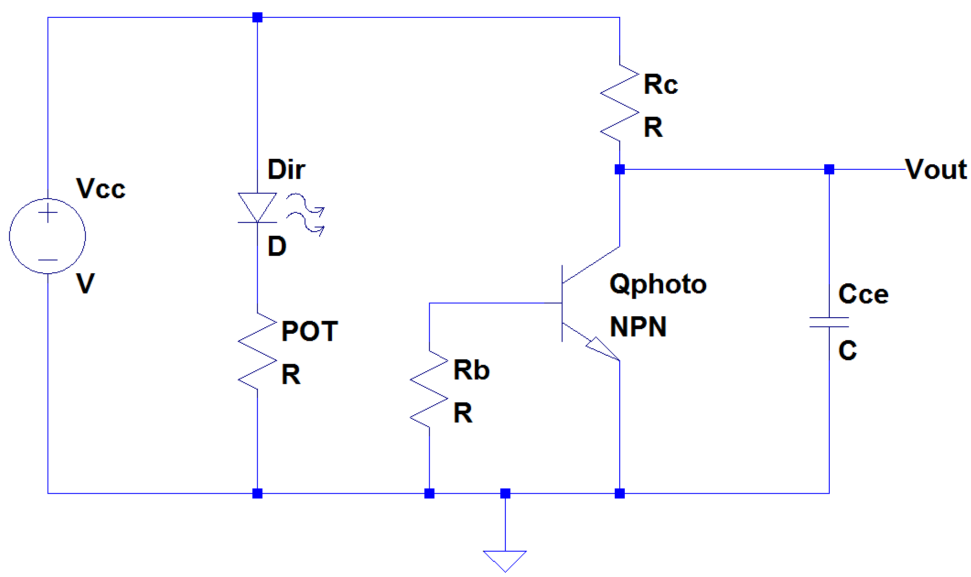

Figure 5. The schematic of the IR LED and phototransistor circuit removing C_{CB}.

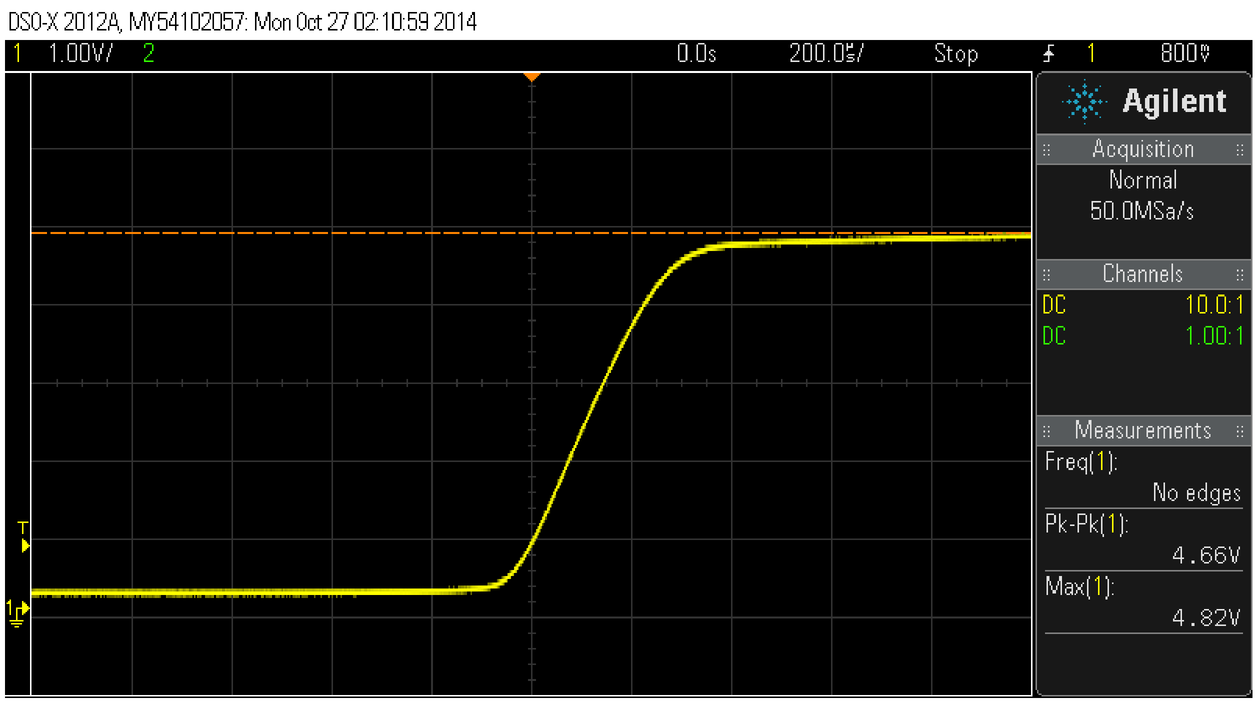

Figure 6. The waveform of the rise time due to removing C_{CB}.

Prototype Assembly

Lastly, with the criterion satisfied, we tested the sensor configuration with a scale prototype of the funnel assembly. The assembly is displayed below in Figure 7. We dropped various parts through the funnel and observed the waveform on the oscilloscope. Figure 8 displays the output waveform of the sensor circuit as one of the small parts falls through the funnel. The waveform demonstrates the waveform that the microcontroller needs to detect. Furthermore, the waveform also shows that the signal has extremely small amount of noise.

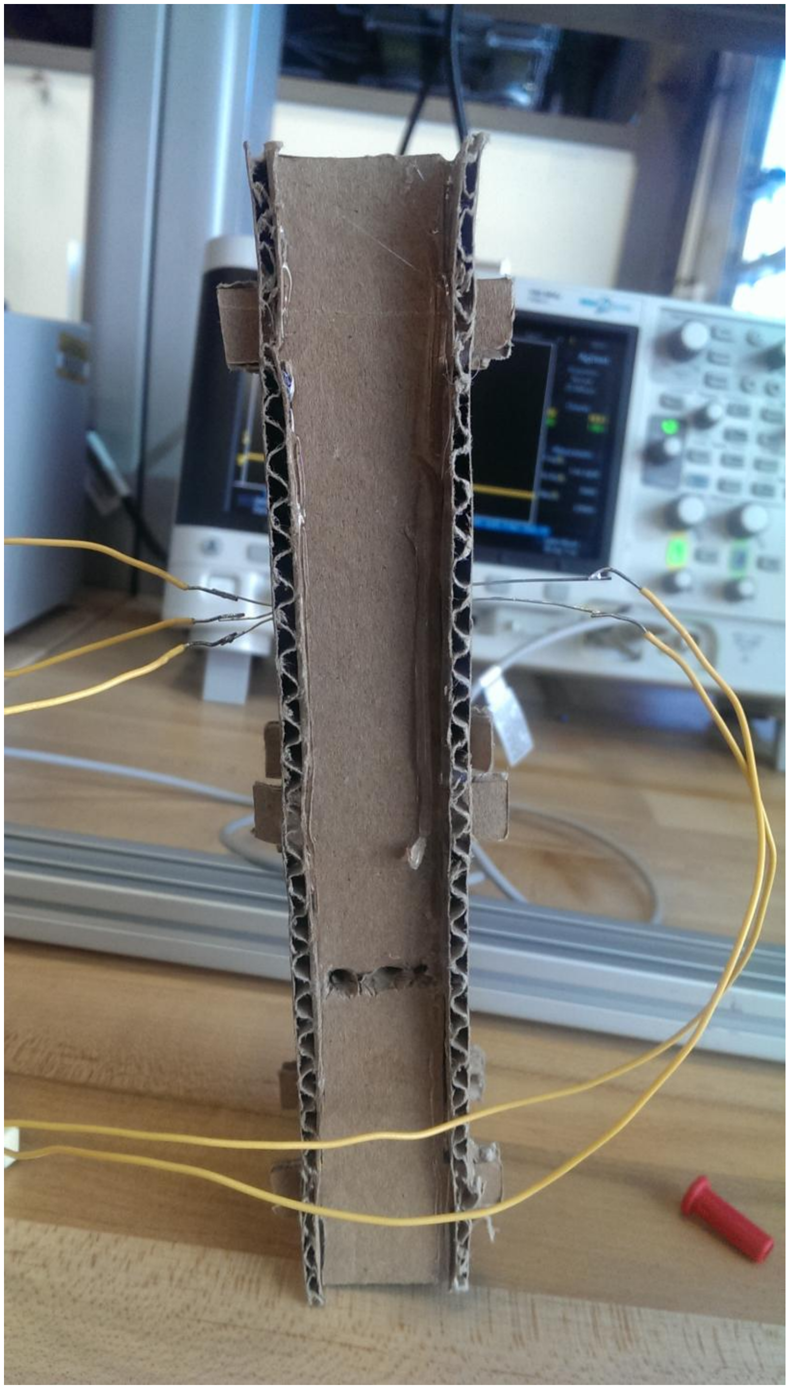

Figure 7. A prototype of the funnel assembly used to test the IR LED and phototransistor system.

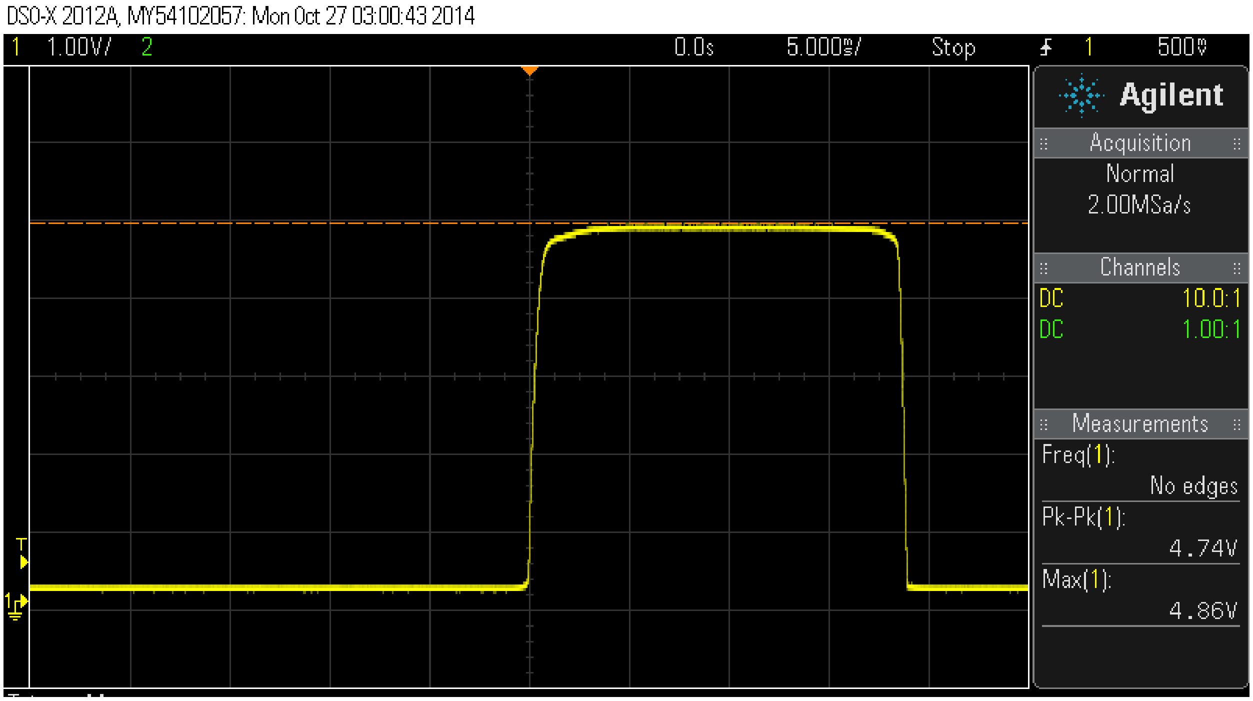

Figure 8. The waveform of the IR LED and phototransistor system due to a part moving through the beam.

Microcontroller Integration

With the characteristics of the sensor's response to an object falling through the funnel identified, the microcontroller was programmed to detect a part falling. We tested the microcontroller to see how fast it could read a digital pin using the Arduino library's digitalread() function. We measured that the average time to read a single pin was 8μs and the max time was 16μs. Since the goal is the scale the code to all eight sensors, we decided the Arduino library's digitalread() function would take too much time to poll each of the pins. To remedy this problem, we would simply attach the eight sensor lines to eight pins on the same pin register. With all the sensors attached to the same register, we can poll all eight pins at the same time. We tested the time to poll all eight pins with this method and we measured an average of 4μs and a max of 12μs. With the method of polling the pins determined, we wrote the following code:

```
void setup()
{
  DDRC = 0x00;
  Serial.begin(9600);
}

void loop()
{
  if(PINC!=0x00)
  {
    Serial.println("Part!");
    while(PINC!=0x00){}
 }
}
```

With the microcontroller programmed, the code was tested by dropping parts through the funnel. The microcontroller successfully detected all parts crossing the beam. Furthermore, extreme velocities were tested by throwing items through the funnel. Even with more velocity, the microcontroller and sensor system was able to successfully detect the presence of a part. As a result, the design was successfully verified and implemented.