CMPE 460 Laboratory Exercise 3

Characterization of OPB745

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Contents

Abstract

The purpose of this laboratory exercise was to characterize the OPB745 photo-transducer and verify its capabilities as an opto-isolator. This was done by constructing both a circuit to collect data from the sensor and an apparatus to provide a testing environment for the sensor. The sensor was also tested with different load resistors, and its performance in relation to frequency was analyzed. The exercise was successful as the measurements collected portrayed the behavior of an opto-isolator and were able to map the distance from the component to a function of voltage/current.

Design Methodology

The schematic constructed to determine the voltage and current outputs at different distances from the OPB745 is shown below in Figure 1.

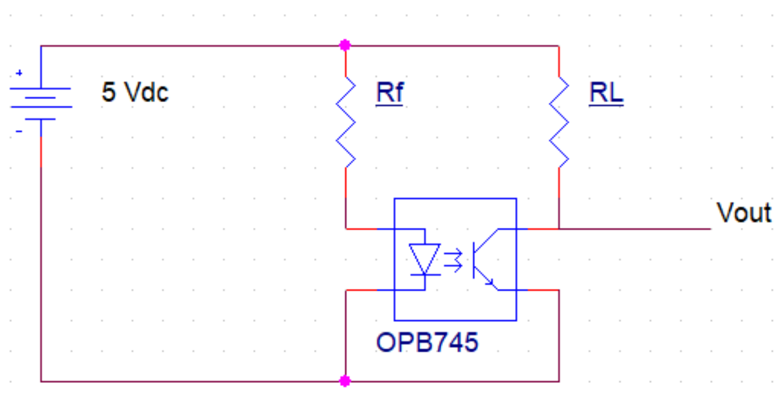

Figure 1: Schematic for Part 1

In order to limit the current through the OPB745, resistors were placed in series with both the diode and photo-transistor. The load resistor R_L for the photo-transistor was fixed at 10 kΩ and 20 kΩ. To determine the correct resistor to place in series with the diode, the voltage drop across the diode (obtained from the OPB745 datasheet) was subtracted from the source voltage, and then was divided by the forward current through the diode, also obtained from the datasheet. The forward current was 40 mA, so the R_f value was calculated to be $\frac{5-1.7\text{V}}{0.040\text{A}} = 82.5\Omega$.

The schematic shown from Figure 1 was then modified to include a function generator connected to an LS7406 inverter, where the output was then connected to the cathode of the diode from the OPB745. The output V_{out} was taken at the same node, but was fed through a 74LS14 Schmitt trigger and then measured. The new schematic is shown below in Figure 2.

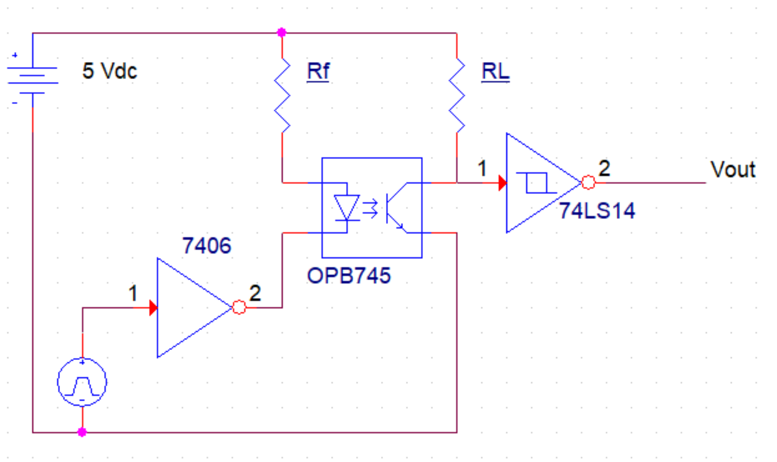

Figure 2: Schematic for Part 2

The function generator was connected to the input of the inverter in order to pulse the cathode of the diode from the OPB745 high and low. When the function generator produced a square wave, the diode was active during the peaks, since they were inverted and created a voltage differential between the anode and cathode of the diode. When the square wave pulsed a low signal, the voltage on the cathode was equal (or close to) the voltage on the anode, so the diode did not emit any light. The Schmitt trigger converted the output voltage (an analog signal) into a digital signal, by determining whether the voltage was above or below certain thresholds and outputted either V_{CC} or GND. The Schmitt trigger was used primarily for this conversion, as a small, simple analog to digital converter. It is preferable to an inverter, because with the inverter there would be small bursts where it would trigger and flip the output when the input voltage reached the midpoint of V_{CC} and GND. The Schmitt trigger prevents these quick switches and will continue outputting the previous value until the upper or lower threshold is triggered, resulting from a definite change on the input signal. Thus, a smoother square wave output was attainable.

The previously calculated R_f value was recalculated from Figure 1 because there was a voltage drop across the LS7406 inverter. By using the datasheet, the voltage drop was determined to be 0.7 V. The new R_f value was calculated by subtracting the voltage drop across the diode and inverter from V_S and dividing by the current through that branch, which is still 40 mA, the current drawn by the diode. The new R_f value was $\frac{5-1.7-0.7\text{V}}{0.04\text{A}} = 65\Omega$.

To properly test the OPB745, an apparatus was constructed out of 2 equal length PVC pipes. The pipes were black, so there is no chance that light could leak through and interfere with the light being emitted and measured by the OPB745. The pipes were concentric, so the smaller pipe could smoothly slide through the larger. On one end of the outer pipe, a piece of cardboard was attached with electrical tape, with a small rectangular hole cut in the center allowing for the light emitting/ light receiving end of the OPB745 to fit snugly. The inner pipe had a flat piece of aluminum foil taped over one end, and a printable metric ruler taped on the other end along the length of the pipe. The 0 mm endpoint lined up with the point where the aluminum foil was firmly pressed up against the piece of cardboard, which covered the light holes on the OPB745. As built, this apparatus made it easy to measure distances by sliding the inner pipe based on the metric ruler attached.

Results & Analysis

The voltages measured using the apparatus described in the Design Methodology section are recorded below in Table 1. There are multiple V_{out} columns, one for each varying load resistor.

Table 1: Table of Measured Voltages and Calculated Currents for the OPB745

	$R_L = 10\text{k}\Omega$		$R_L = 20\text{k}\Omega$	
Distance (mm)	V_{out} (V)	I_{RL} (mA)	V_{out} (V)	I_{RL} (mA)
0	4.72	0.472	4.40	0.220
1	0.830	0.083	0.786	0.0393
2	0.717	0.0717	0.687	0.03435
3	0.649	0.0589	0.589	0.02945
4	0.622	0.0622	0.603	0.03015
5	0.638	0.0638	0.623	0.03115
6	0.674	0.0674	0.650	0.0325
7	0.697	0.0697	0.689	0.03445
8	0.726	0.0726	0.710	0.0355
9	0.755	0.0755	0.737	0.03685
10	0.779	0.0779	0.758	0.0379
11	0.796	0.0796	0.779	0.03895
12	0.827	0.0827	0.799	0.03995
13	0.864	0.0864	0.808	0.0404
14	0.861	0.0861	0.811	0.04055
15	1.53	0.153	0.811	0.04055
20	2.63	0.263	0.824	0.0412
25	3.00	0.300	0.855	0.04275
30	3.27	0.327	1.20	0.06
35	3.68	0.368	2.50	0.125
40	4.18	0.418	3.60	0.180
45	4.43	0.443	4.33	0.2165
50	4.52	0.452	4.35	0.2175

Because the voltage and resistance values were measured and known, the current through the load resistor (I_{RL}) was calculated by using Ohm's Law, and dividing the voltage by the resistance. Because the order of magnitude is small, the current was recorded in mA.

The voltage measurements for both load resistors started out close to the source voltage at 0 mm, because no light was reflected when the holes on the OPB745 were completely covered. From 1 mm to 3 mm, both voltages drop close to GND, because the maximum amount of light was reflected back at close proximity. Then, as the distance increased, there was a steady increase in the voltage that was best modeled linearly, because as less and less light gets reflected back. The difference between the data sets for each load resistor was that the linear increase for the 10 kΩ load occurred around 15 mm, while the 20 kΩ load did not begin to steadily increase voltage until around 30 mm.

Current through both load resistors followed the same patterns as the voltage outputs, which was expected since current was the voltage divided by resistance, a fixed value. For the 10 kΩ load, the current began to increase linearly around 15 mm, while the 20 kΩ load resistor saw the linear trend begin around 30 mm. For both load resistors, the voltage measurements and current calculations were graphed versus the distance measured. Figure 3 shows the voltage outputs for the photo-transducer based on the distance of the reflective surface from the photo-transducer.

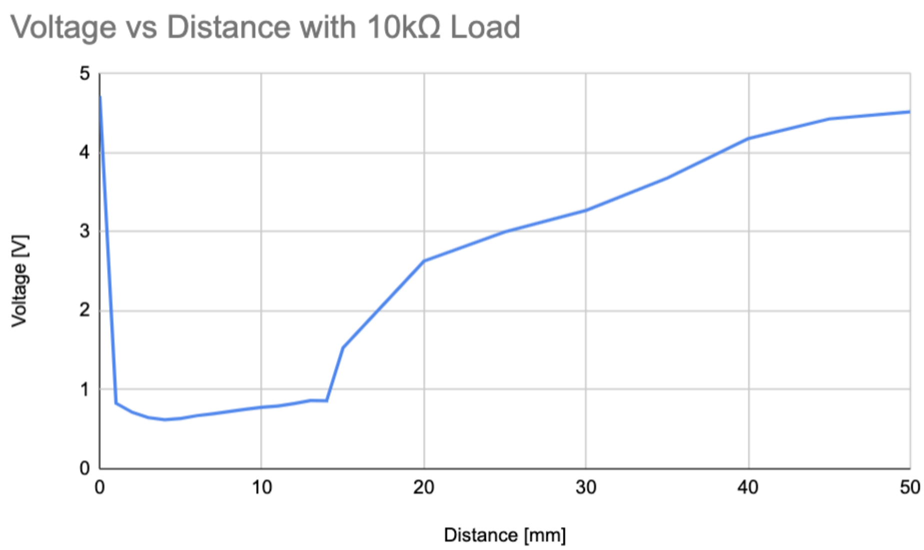

Figure 3: Voltage vs Distance Graph for Load Resistor of 10kΩ

Shown in Figure 3, the voltage started close to 5 V at 0 mm, and then steeply dropped off between 1 mm and 3 mm. It was not until around 15 mm that the graph turned into a linear trend with the voltage increasing relatively steadily from 15 mm to the maximum distance measured, 50 mm. Before 15 mm, the voltage was relatively constant at less than 1 V. The current at each distance measurement for the 10 kΩ load was also graphed, shown in Figure 4.

Figure 4: Current vs Distance Graph for Load Resistor of 10kΩ

As expected, the current graph looks very similar to the voltage graph, since they are directly proportional. The current began at a peak close to half of a mA at 0 mm, then dropped down when the voltage dropped once light is reflected at 1 mm. Like Figure 3, there was a sharp increase at 15 mm, when the graph began to follow a linear trend, increasing steadily back up to close to half of a mA. Like the voltage, graph, the current slope is close to 0 between 3 and 15 mm. The voltage output graph for the 20 kΩ load is shown in Figure 5.

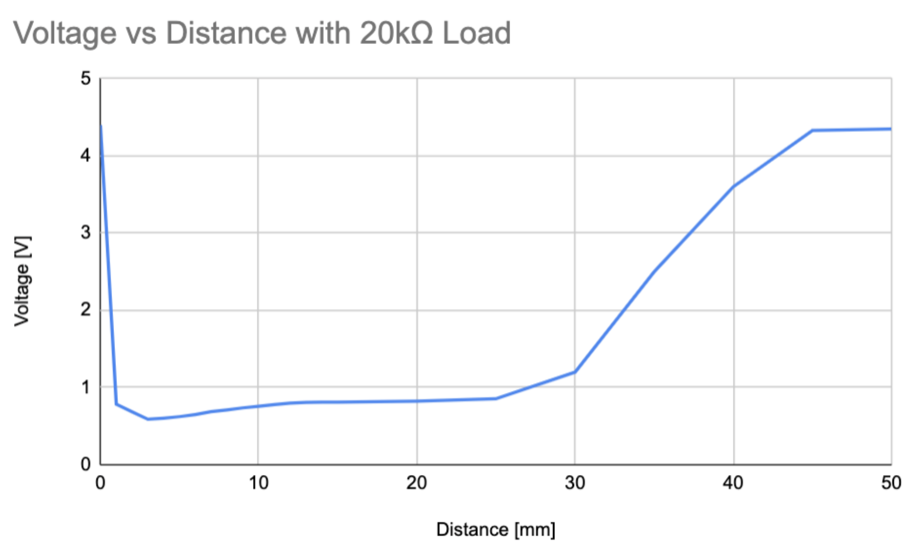

Figure 5: Voltage vs Distance Graph for Load Resistor of 20kΩ

The beginning of Figure 5 looked very similar to Figure 3, with both graphs starting close to 5 V at 0 mm, then dropping to the lowest value very quickly. Like Figure 3, Figure 5 also stayed flat after immediately falling, but unlike Figure 3, it did not begin to increase in the linear trend until the distance of the reflective surface is around 30 mm. Also like Figure 3, the voltage output from 3 mm to 30 mm hovers under 1 V, before slightly crossing 1 V around 22 mm. The current was also graphed for the 20 kΩ load, and is shown below in Figure 6.

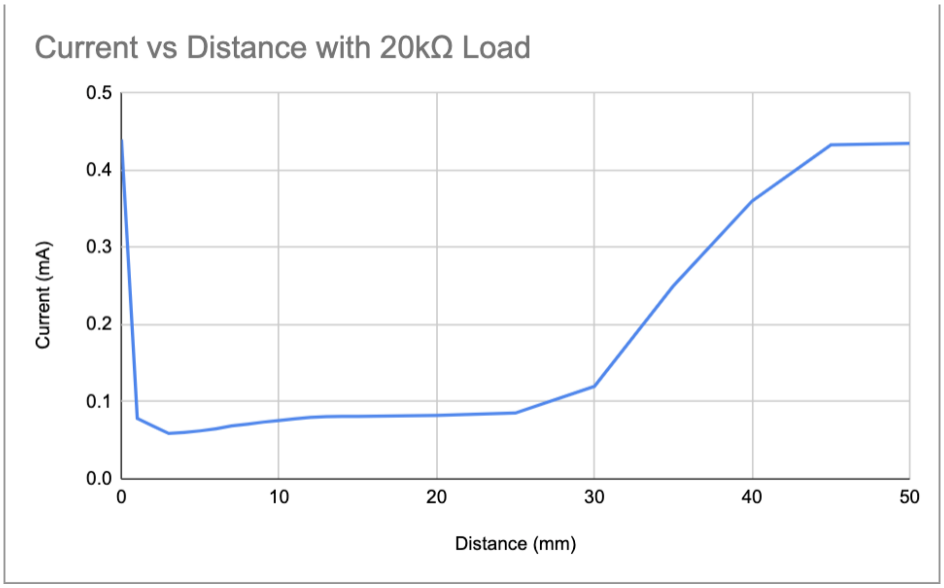

Figure 6: Current vs Distance Graph for Load Resistor of 20kΩ

As expected, and similar to the 10 kΩ load, the current through the 20 kΩ load followed the same trend as the voltage output from the 20 kΩ load, since they are directly proportional. Like Figure 4, Figure 6 began at a peak, and very quickly dropped down to close to 0 V after the reflective surface was removed from blocking all light from the OPB745. The current then slightly increased over the span of 30 mm, where at 30 mm it began to follow the same linear trend that the voltage did in Figure 5.

By using the function generator to control the pulse of the diode in the OPB745, maximum frequencies at which the circuit can operate were determined. Both the input signal from the function generator and the output signal from the 74LS14 Schmitt trigger are shown in Figures 7 to 10, in order to compare the input to the output and determine at what frequency the circuit failed. In all four figures, the top yellow wave is the output, and the bottom green wave is the input from the function generator. It is important to note that the distance at which the apparatus was set at was the same constant for both load resistors, and set at around 8 mm to allow for sufficient current flow through the OPB745. The highest passing frequency for the 10 kΩ load was 700 Hz, shown below in Figure 7.

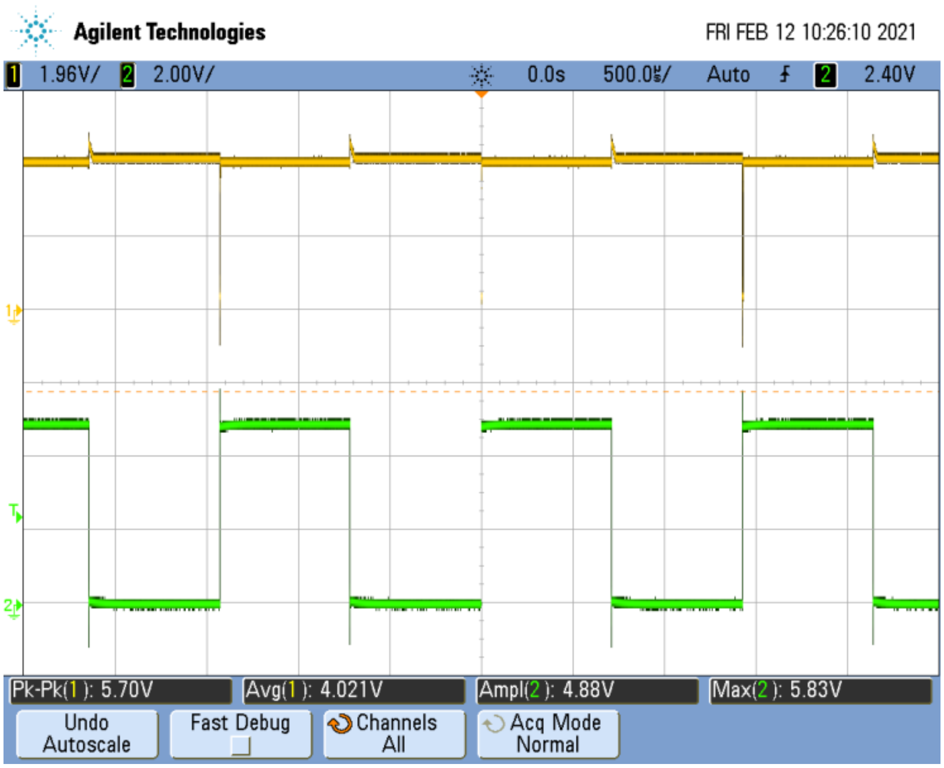

Figure 7: Oscilloscope Capture of 700Hz for Load Resistor of 10kΩ

The small pulses in the yellow wave demonstrate the circuit was just on the edge of continuing to function correctly, but the output pulse was incredibly short, and was nowhere near the width of the input, due to how close the circuit was to violating the necessary rise and fall times of the OPB745. However, because the output is observed to rise and fall, the circuit is deemed as functioning correctly. After increasing the frequency by another 100 Hz to 800 Hz, the circuit failed to function correctly. That oscilloscope capture is shown below in Figure 8.

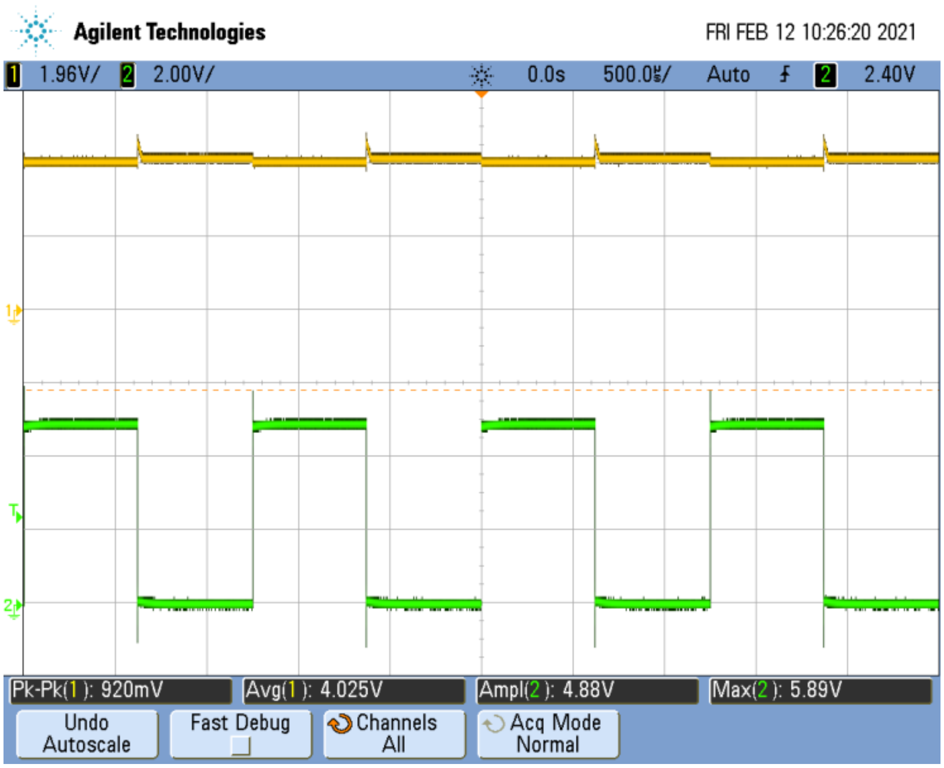

Figure 8: Oscilloscope Capture of 800Hz for Load Resistor of 10kΩ

Unlike Figure 7, Figure 8 has no downward pulses, meaning the circuit had now failed to correctly function and could not switch back and forth between a high and low output. This is because the rise and fall times were being violated, where the circuit was switching states before the output signal could stabilize, hence the flat yellow line in Figure 8. The same test was done for the 20 kΩ load resistor, with the highest passing frequency measured at 400 Hz. The oscilloscope capture at 400 Hz with the 20 kΩ load is shown below in Figure 9.

Figure 9: Oscilloscope Capture of 400Hz for Load Resistor of 20kΩ

Like Figure 7, there were small pulses in the yellow wave, which was connected to the output of the Schmitt trigger. The pulses proved that the circuit was functioning correctly, but because the pulses were so small, it was clear that the rise and fall times were close to being violated. This frequency, 400 Hz, was the maximum frequency at which the circuit could operate. The oscilloscope capture below in Figure 10 shows the circuit being run at 500 Hz.

Figure 10: Oscilloscope Capture of 500Hz for Load Resistor of 20kΩ

At 500 Hz, the yellow output wave had no pulses and was simply a flat line, similar to the oscilloscope capture in Figure 8 at the breaking frequency. Again, the rise and fall times for the OPB745 were being violated, where the output could not stabilize before the input switches and the output must try and stabilize again. However, in contrast to the 10 kΩ load, the 20 kΩ load circuit failed at 500 Hz instead of 800 Hz. In the datasheet for the OPB745, there was a graph of rise and fall times as they relate to the load resistance. The rise time peaked around 1 kΩ and leveled off, before dropping back down. However, the fall time followed a linear trend, and continued to increase as the load resistance increased. Therefore, the circuit with a 20 kΩ required a greater amount of time for the circuit to stabilize the output than the 10 kΩ load resistor circuit, because of the increased fall time. The oscilloscope captures confirm the expectation that the circuit with the smaller load resistance would operate at a higher frequency.

Conclusion

The laboratory exercise that was performed allowed for a better understanding of the process of characterizing transducers. Reading through the datasheets and utilizing the correct information in order to get a properly working opto-isolator was essential to the exercise. This exercise also gave insight on the measured results and how they can be applied to different types of components. The exercise was successful as the circuits constructed were able to produce expected results of an opto-isolator.

Questions

Question 1

The 74LS14 with Schmitt trigger differs from the 7406 inverter because it uses 2 edge trigger values when driving the output, whereas the 7406 uses 1 trigger edge. The advantage of the 74LS14 with Schmitt trigger is that it is more effective in converting an analog signal to a digital output when compared to an inverter, because there are 2 thresholds to determine high and low outputs. There are thresholds set for high and low values, and when those values are reached, the output is driven either high or low. However, any voltage falling between the 2 triggers is not going to change the output, and the output will be maintained until the opposite threshold is crossed. With a 7406, the output will flip back and forth very quickly when the values in the middle of the range cross just above and below the midpoint voltage, which creates a very inconsistent square wave output. This output will contain a collection of short, unexpected pulses in ranges that should be held at a smooth, constant output. An added benefit from the Schmitt trigger is that any noise that skews the voltages closer to the middle of the voltage range will be ignored and will not affect the output wave. The 74LS14 Schmitt trigger also switches very fast (5 - 10 ns), faster than 7406 inverter (10 - 15 ns).

Question 2

The voltage from the photo-transducer starts at close to the source voltage (5 V), because there is no way for any light to get reflected when the output diode is completely covered. Then, as soon as any light escapes that hole and gets reflected at a very close distance, the voltage drops down to the lower rail value (close to 0 V). As the distance increases, less light gets reflected, the voltage begins to increase from the lower rail up to the voltage source (upper rail).

Question 3

When doubling the load resistor from 10kΩ to 20kΩ, the maximum frequency that the circuit can operate at is halved. In this exercise, the maximum working frequency decreased from 700Hz to 400Hz, which is roughly half. This matches the expected behavior, where the maximum frequency is halved when the load resistance is doubled. In the OPB745 datasheet, there is a graph of Rise and Fall Time vs. Load Resistance. The rise time peaks at $R_L = 1\text{k}\Omega$, and then begins to drop lower again, so the rise time is not causing the frequency to fail. However, the fall time models a linear trend, and continues to increase as R_L increases from 1 kΩ to 10 kΩ and further onward. As such, when R_L increases from 10 kΩ to 20 kΩ, the fall time increases. Because the fall time is larger, the output cannot switch as quickly, since it takes longer for the output to reset as the function generator keeps switching. Furthermore, the max frequency is close to half when R_L doubles because the trendline in the datasheet's graph follows a linear-like trend.