Investigation of reverse-biased light-emitting diodes as photodetectors

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Abstract

We investigate the application of light-emitting diodes as photodetectors when reverse-biased. Inputs of varying shapes were compared with the output and it was shown that a light source in close proximity causes the reverse-biased LED to produce a small current that manifests in the temporal domain as a deformation in the output waveforms, and in the phase domain as a dent or flattening of the corresponding Lissajous curve. It was also shown that generally, LEDs with higher wavelength emissions produce a higher current when used as a photodetector.

Keywords: light emitting diode, photodetector, reverse bias, Darlington circuit.

1 Introduction

Photodiodes are forms of sensors that convert light energy or photons, into electrical voltage or current [1]. Diodes in general consist of a PN junction or when you join an N-type semiconductor with a P-type semiconductor. N-type semiconductors contain impurities that result into to excess in electrons while the P-type semiconductors have a lack of electrons or better known as holes [2]. When enough voltage is applied in forward-bias, when the P-region has a higher potential than the N-region, Electrons from the N-region move towards the P-region, cancelling the electrons and holes and giving off energy in the form of photons, in the case of a light emitting diode (LED). Photodiodes work the opposite way around. When photons are made to hit the photodiode, the energy is used to split apart the electron and hole pair moving them back to their respective regions. A larger depletion area is then created, which gives space for moving charges or a production of current explained in Figure 1. Knowing that photodiodes and LED's have the same component structure, it is actually possible to make an LED a light sensor just by connecting it in reverse-bias.

In this experiment, it is shown that it is actually possible for LEDs to work as a light sensor. Different LED's were used as light sensors configured in two different circuits and the input and output waveforms of a sine, square, and triangle wave for light at different distances were observed and compared. The sensitivity of the sensor for the two different set-ups were then observed.

This paper is organized as follows: In Section 2, we illustrate the experimental setup and materials used. In Section 3, we analyze and discuss the results. We then conclude and summarize the paper and give recommendations to improve similar experiments in Section 4.

2 Methodology

The circuit used were following the circuit diagrams in Figure 2. The probes of Channel 2 in an oscilloscope was connected to the LED to measure the change in voltage. A sine, triangle, and square wave was used as input voltage using the function generator. Using the phone flashlight as a light source, the output voltage for when the flashlight is in close, and middle distance from the light sensor were compared to when there is no light. This was done for both configurations and the sensitivity of the sensors for both circuits were also checked.

3 Results and Discussion

Here we characterize the sensitivity of LEDs as light sensors. Using the single transistor circuit, Fig. 3 shows the behaviour of the red LED sensor in a dark environment while Fig. 4 shows how the sensor is behaved when a flashlight is drawn close to it. The distortion on the sine wave output can be accounted to the current generated when the LED sensed the incoming photons. How the LED transformed into a light sensor is most evident on the difference in their IO curves. We observed similar response of red, yellow, and green LEDs and their respective sensitivities are shown in Fig. 5. Yellow LED sensor turned out to be the most sensitive evidently seen as having the drastic dent on its IO curve. On this part alone, it was successfully shown how reversed-biased LEDs can actually act as a light sensor.

Employing the same analysis but now with a Darlington circuit, Figs. 6, 7, & 8 shows how the red LED senses light at varying proximitites. One thing to note about using a Darlington circuit is that there is now a linearity in the response of the sensor. Meaning, the output follows the input, or consequently a line behaving IO curve. Looking at the output curves, the dips can be attributed to light being sensed by the LED. As we draw the flashlight in a closer proximity, the dips on the output becomes much more drastic. These dips resulted to the flat-lining on the IO response. Also, the maximum output voltage decreased as we increased the proximity, implying that more current is drawn to the circuit, which means more photons are sensed by the LED. Checking the behaviour for different input waveforms, Fig. 9 shows how capping is manifested on the output wave and the flat-lining on the IO curve if a triangular wave input is used while Fig. 10 showcased the decrease in the maximum voltage of the output for a close proximity light source. The red LED light sensor behaves well and similarly for varying input waveforms. It was shown that the maximum voltage of the output wave drops near proximity, hence we carried out the procedure for other LEDs using a sine wave input and compared their output voltage values. In Figure 11, all LEDs behaved similarly for a dark environment but as we draw the flashlight nearer, the output voltage drops differently. Yellow LED responded the most to light.

The results were consistent for both circuit configurations, where Yellow LED had the greatest response to a phone flashlight. According to Bryant, "An LED's spectral sensitivity depends on its color: they sense wavelengths shorter than or equal to their own emitted wavelength" [3]. It is because the tinted casing of an LED acts as a filter, allowing only a narrow band of light (it allows transmission of light with colors similar to the casing) [3]. The phone flashlight used was an warm-toned LED, with yellow and orange tones, which explains why the yellow LED sensed its light the most.

4 Conclusions

The behavior of light-emitting diodes in reverse-bias mode as photodetectors was investigated. Input voltages of different shapes were passed through the circuit was compared with the output. It was shown that a light source in close proximity to the reverse-biased

LED produced a current that manifests as a small deformation in the output waveform. This deformation also manifests as a dent in the ellipsoid when the input and output are plotted in phase space. Placing the photodetector in a Darlington circuit instead produces a linear phase space plot that flattens out in the first quadrant when a light source is in close proximity. It was also shown that generally, LEDs with higher wavelength emissions also produce a higher current when used as a photodetector.

References

[1] Electronics Hub (2018). What is a Photodiode? Working, Characteristics, Applications. Retrieved 12 March 2019 from https://www.electronicshub.org/photodiode-working-characteristics-applications/

[2] Hymel, Shawn (2016). T^3: Using LEDs as Light Sensors - News - SparkFun Electronics. Retrieved 13 March 2019 from https://www.sparkfun.com/news/2161

[3] J. Bryant (2014). LEDs are photodiodes too. Retrieved 17 March 2019 from https://www.analog.com/en/analog-dialogue/raqs/raq-issue-108.html

Appendix

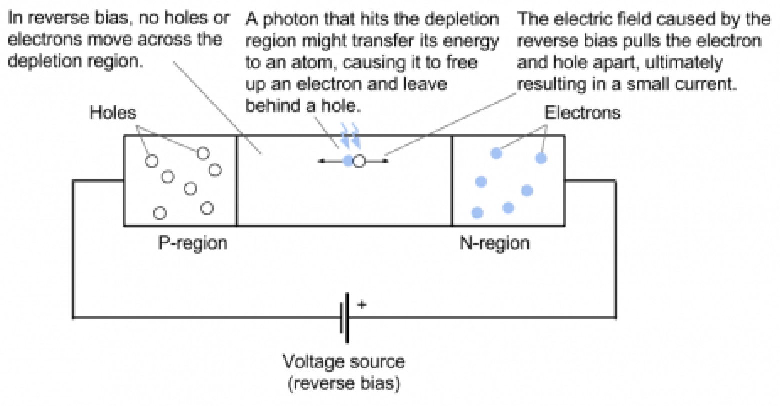
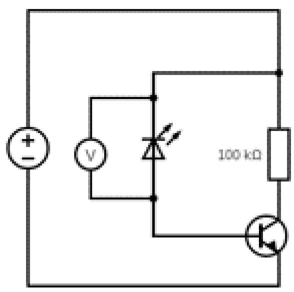
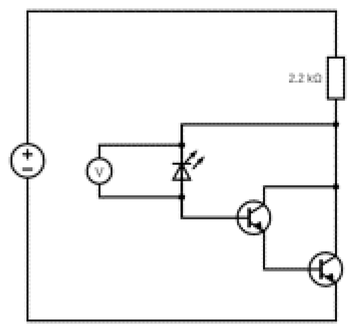


Figure 1: Production of current in a photodiode.[2]



(a) First circuit diagram.



(b) Darlington configuration

Figure 2: Circuit diagrams used in the experiment.

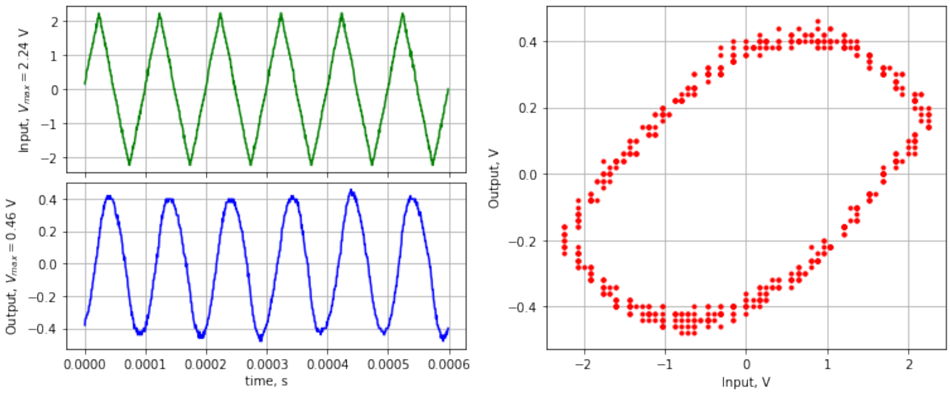


Figure 3: Using an triangular wave input (green), Red LED as a light sensor had a resulting output waveform (blue) and the IO-curve whenever there is no light in the proximity. This can be regarded as the static behavior of the sensor.

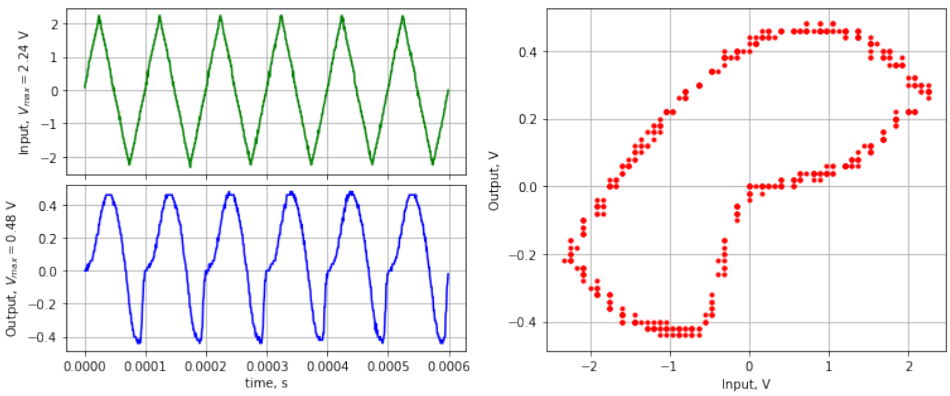


Figure 4: Upon positioning the light source (phone flashlight) right above the LED, the dips indicating that the LED senses light is manifested as the distorted sine wave output. Consequently, the voltage dips reflects as the dent on the corresponding IO curve.

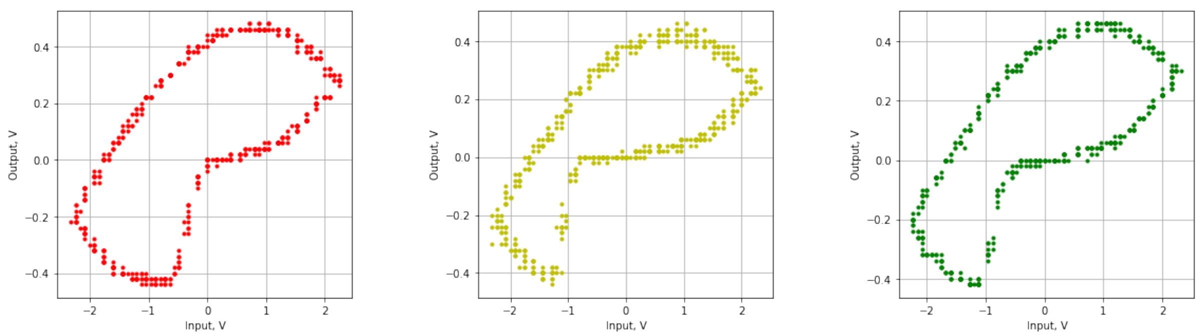


Figure 5: For the first circuit configuration, here we summarize the IO curves for red, yellow, and green LEDs (respectively) with the light source in a close proximity. Originally, the static characteristic of the light sensor is an elliptical IO curve, and therefore, these dented IO curves indicate that LEDs indeed senses the light.

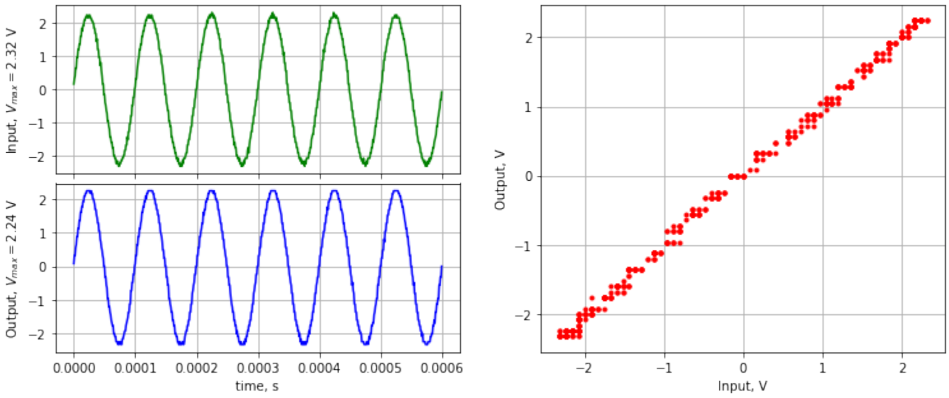


Figure 6: Using the Darlington circuit configuration, the input and output waveforms as well as the IO-curve show a linear static behavior of an (Red) LED light sensor.

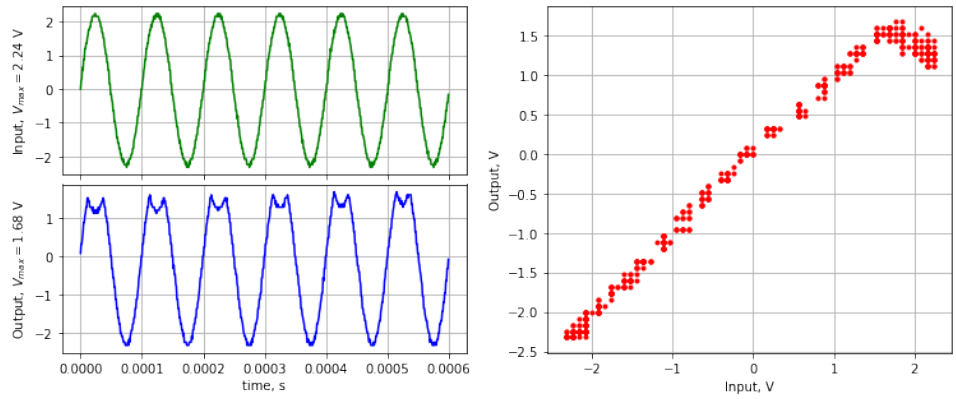


Figure 7: Flashlight at a medium distance is detected by the Red LED light sensor represented by the dips on the local maxima of the sine wave output. These dips caused the capping (flatlining) of the IO curve.

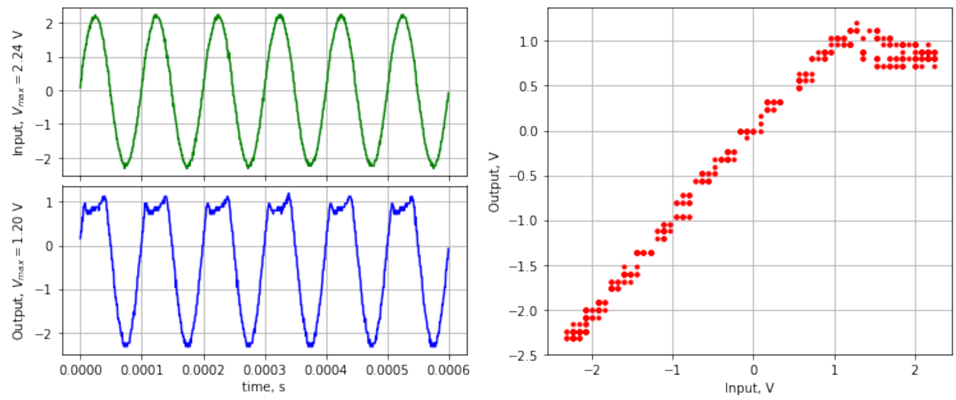


Figure 8: Bring in the light source in the nearest proximity, here we extract the maximum sensitivity of the Red LED light sensor. From an original input of 2.4 V, the maximum output yielded was 1.20 V.

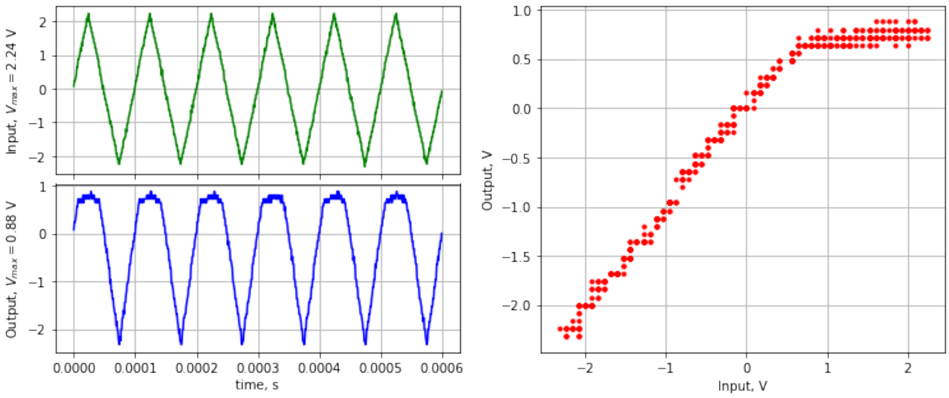


Figure 9: Red LED light sensor sensitivity for a close proximity light source using triangular wave input.

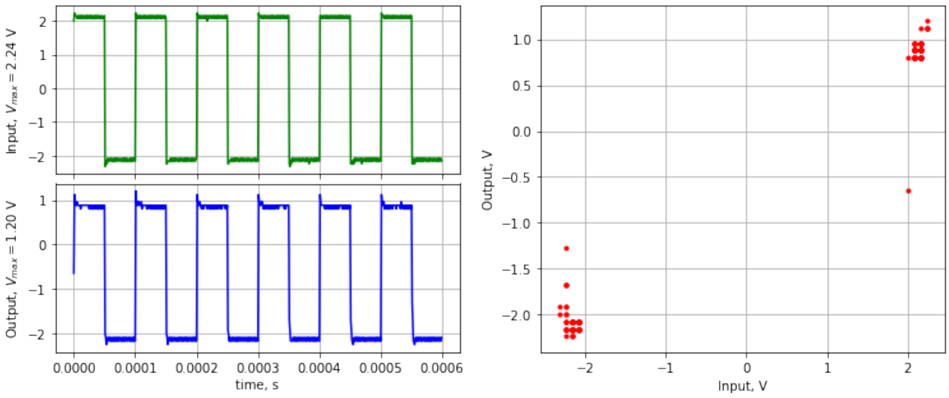


Figure 10: Red LED light sensor sensitivity for a close proximity light source using square wave input.

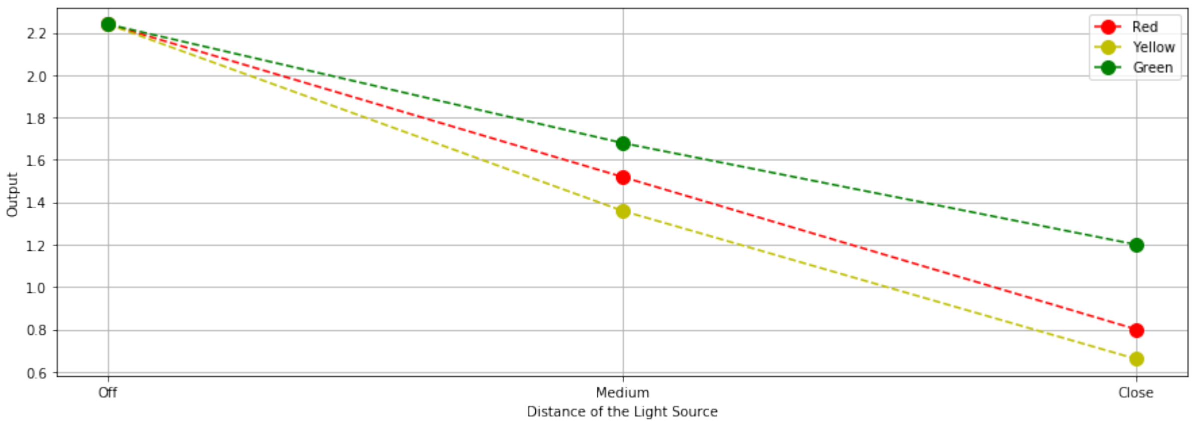


Figure 11: Using a sine wave input ($V_{max} = 2.24$ V), the plot shows the maximum voltage outputs for each LED (red, yellow, green) at different light source proximity. Yellow LED has the greatest sensitivity amongst the three.