# LEDs as Sensors

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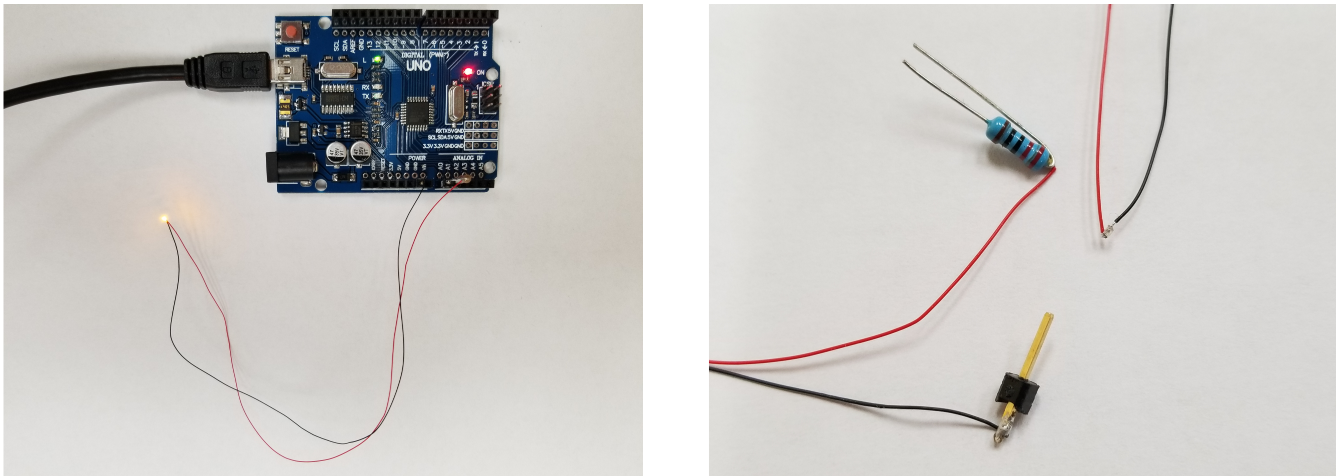


**Figure 1: (a) A simple Hot LED Anemometer using an Arduino Uno, resistor and LED. (b) A closeup of the 0402 LED wired for use as a wind sensor.**

## ABSTRACT

Imagine an LED that turns itself on and off in response to light levels, or one that you can blow out like a candle. These are circuits you can build with just an Arduino, a resistor, an LED and a little code. In this workshop, we examine some surprising properties of LEDs to create systems that sense light, temperature and wind.

## CCS CONCEPTS

• **Hardware** → **Sensors and actuators**.

## KEYWORDS

LED, sensor, anemometer, photodiode, light, temperature

**ACM Reference Format:**
Paul H. Dietz and Jennifer (Ginger) Alford. 2019. LEDs as Sensors. In *Proceedings of SIGGRAPH '19 Studio.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3306306.3328752

## 1 INTRODUCTION

Light Emitting Diodes (LEDs) are one of the most common and least expensive electrical components. They are ubiquitous. It is almost a rite of passage that every embedded systems developer begins by writing a program to blink an LED.

Despite our familiarity with these devices, there are a number of properties of LEDs that are less well known. These allow us to use LEDs as sensors.

## 2 PHOTODIODES

LEDs are photodiodes. In addition to emitting light, they can be used to detect light [Mims 1986]. A simple circuit model of an LED under reverse bias is shown in figure 2. Incident light generates a proportional photocurrent that flows in the opposite direction of current used to light the LED, and is proportional to the amount of light impinging on the device. When an LED is reversed biased (i.e. a negative voltage is applied), there is a small amount of charge that is stored in the junction dependent on the voltage. This gives rise to a junction capacitance which is in parallel with the parasitic capacitances of the package.

## 3 SENSING LIGHT

A simple circuit for measuring light with an LED [Dietz et al. 2003] is shown in figure 3. The LED and resistor are connected across two I/O pins. First, the LED is reverse biased. This charges up the junction capacitance of the LED. Then we set one of the I/O pins to input. This allows the photocurrent to discharge that capacitance. We can see when this discharging passes the digital logic threshold by monitoring the state of the input pin in software. The amount of time this takes is a measure of the light level. Bright lighting will cause a fast discharge, while darkness will be a very slow discharge.


*SIGGRAPH '19 Studio, July 28 - August 01, 2019, Los Angeles, CA, USA*

ACM ISBN 978-1-4503-6316-7/19/07.
https://doi.org/10.1145/3306306.3328752

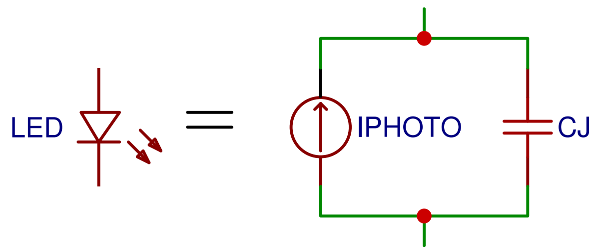


**Figure 2: A simple circuit model of an LED in reverse bias acting as a photodiode.**

Once the measurement is completed, the LED can then be lit. By switching among these states, it is possible to have the LED appear to be continuously lit while making repeated light measurements. A simple application is an automatic night light, turning on the LED only when it is dark.

As described, the light measurement takes a variable amount of time. If the LED is emitting for a fixed time, but taking a variable time for sensing, the apparent brightness will be constantly changing. To maintain a constant duty cycle, instead of waiting for the voltage to reach a threshold, one can look once after a fixed amount of time to see if the threshold was crossed. This yields a constant time measurement, preventing flicker.

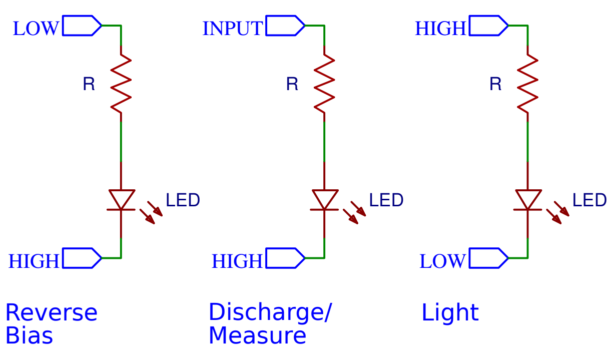


**Figure 3: Sequence of I/O pin states to measure light, and then emit light.**

## 4 MEASURING TEMPERATURE

The forward voltage drop of an LED is a function of temperature, dropping several millivolts per a degree C [Filippo et al. 2017]. Figure 4 shows a simple circuit that measures the forward voltage drop using the Arduino UNO analog to digital converter. If the LED is driven at higher currents, the dissipated power will causes its temperature to rise some amount above the ambient room temperature.

## 5 SENSING WIND

Hot wire anemometers measure wind speed by electrically heating a section of wire. The temperature rises to the point where the heat generated in the wire is equal to the heat that is being dissipated to the environment. Blowing air on the wire lowers its temperature, which changes the resistance of the wire. This allows the wind speed to be measured electrically.

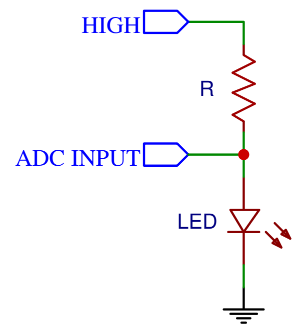


**Figure 4: Circuit for measuring LED temperature by measuring the forward voltage drop.**

We can apply the same technique to create a hot LED anemometer using the circuit of figure 4. When we blow on the LED to cool it down, there is a small rise in the forward voltage drop. Detecting this allows us to create an LED that you can blow out like a candle.

In order to get reasonably fast thermal response, it is important to choose an LED with as little thermal mass as possible. Additionally, connections to the LED must use very thin wires to minimize heat loss. We use an 0402-sized LED, connected with extremely thin wires (30 gauge or higher). This is shown in figure 1(b).

When run at modest current levels (e.g. 10mA), the temperature rise is fairly small, and the resulting voltage changes due to wind are in the millivolts. To measure this accurately using the Arduino UNO's 10 bit ADC, we find it helpful to average over many samples, increasing the effective resolution. With this technique, we were able to detect our blowing at the LED up to 1 meter away.

## ACKNOWLEDGMENTS

To Rita Kambil, for assembling the LED/resistor sets for the workshop, and James Scott for his unpublished work on LED interfaces. The workshop repository, containing the full presentation and all sample code is hosted by GitHub [Dietz 2018].

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