Application Note: Illuminance Measurements

Illuminance is the total amount of light received per unit of surface. Illuminance is usually expressed in lux units and an approximate illuminance scale can be seen in Table 1.

Table 1 Approximate scale of illuminance (lux)

Lighting condition	Lux
Full daylight	10,000
Overcast day	1,000
Very dark day	100
Twilight	10
Deep twilight	1
Full moon	0.1
Quarter moon	0.01
Starlight	0.001

Photoresistors, photodiodes and phototransistors are three low-cost ways of measuring illuminance. In this document, the focus is on the photoresistors. Photoresistors are also called photoconductive devices, photocells or light dependent resistors (LDR).

Photoresistors measure illuminance by having their electrical resistance vary with the level of exposure to light on their top surface. When light increases, resistance goes down. When light decreases, resistance goes up. As can be seen in Figure 1, photoresistor are made from a junction ("S" shape), whose electric resistance varies, and two electrodes (white). A thin film of cadmium sulfide, a semi-conductor material, is applied on the top surface of a ceramic substrate. A coat of epoxy is applied to protect the thin film.

Photoresistor have multiple applications, such as:

- Monitor the occupancy habits in a building;
- Monitor the relative transparency of liquids;
- Evaluating the sunlight available for crops;
- Night lights control;
- Photography light meter.

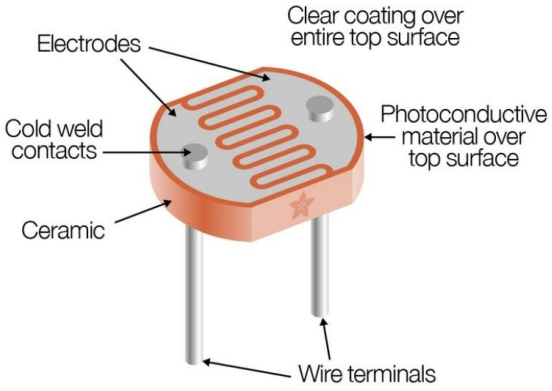

Figure 1 Schematic of the components of a photoresistor (credit: adafruit.com)

With its 16 channels dedicated to resistive sensors, the RDL device can operate simultaneously up to 16 distinct illuminance measurements.

The photoresistor sample that comes with the Jericho Starter kit is a bare wire GL5516 photoresistor (Figure 2). For convenience, photoresistors can be wired to lead wires and covered with a waterproof heat shrink, as seen in Figure 3.

Figure 2 Bare wire GL5516 CdS photoresistor

The GL5516 photoresistor is the most common photoresistor on the market. It is a small 5mm diameter sensor of the CdS type, which means it contains cadmium sulfide, a known carcinogenic substance. It is only sensitive to the visible spectrum (400 nm to 700 nm) - the epoxy coating is not transparent to infrared light. Other types of photoresistor exists that are only sensitive to infrared.

Figure 3 CdS photoresistor

In Figure 4 can be seen an example of application done by Jericho with the GL5516 photoresistor and a RDL controller. Using one photoresistor, illuminance was monitored inside an apartment, near a window, for 4 days. The use of a logarithmic scale for the y-axis (lux values) makes the analysis easier. It can be seen that there were some short peaks around noon (10000 lux), where direct sunlight momentarily hit the sensor. There were some medium value plateaus (1 lux) in the evening due to artificial lighting in the room and some very low values during the night (0.001 lux).

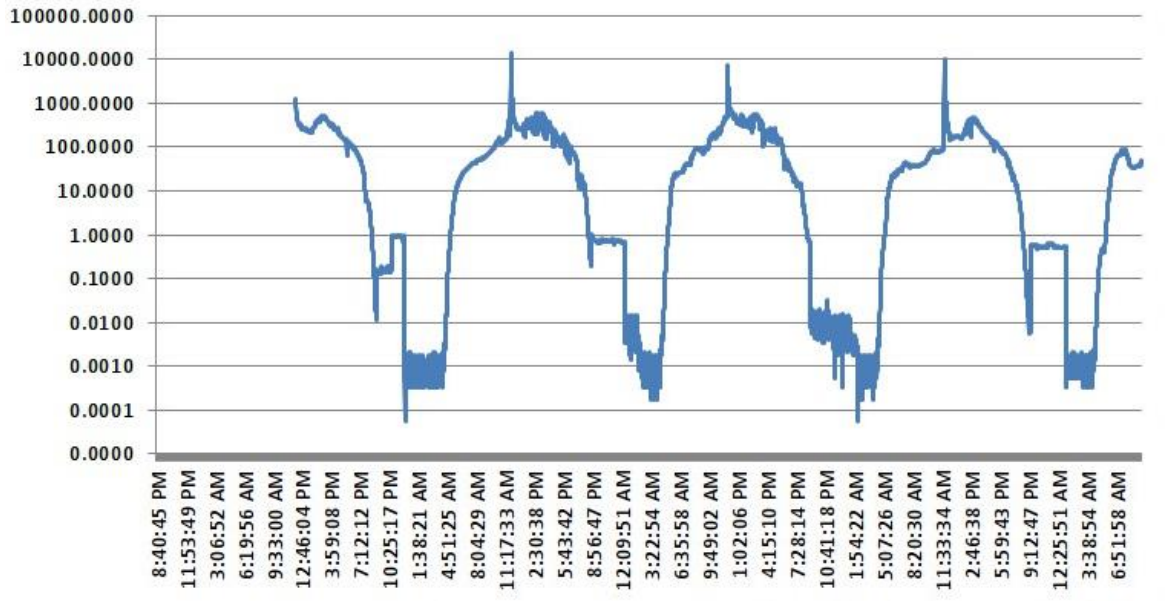

Figure 4 Illuminance (lux) as a function of time near a window, measured with a GL5516 photoresistor

How to use a photoresistor with the Jericho RDL

1. Connect the two photoresistor wires to the screw terminals of the resistive channels (C1 to C16). Photoresistors have no polarity so you can interchange the wires.

2. Through the serial command named ‘sensor’, modify the sensor configuration. For example, if you would like to have a photoresistor (P) in channel C2 and temperature (T) measurement in all other channels, you would type in: “TPTTTTTTTTTTTTT”, then press enter.
3. The RDL would then reset and print out illuminance readings on channel C2.

Illuminance-Resistance relationship

The relationship between illuminance levels and photoresistor values is non-linear, as can be seen in Figure 5. This means that, just like thermistors, a calibration of the photoresistor requires three reference points. The need to calibrate individual photoresistors largely depends on the application. The simple monitoring of building occupancy would not require the use of calibrated sensors in most cases, since relative values would suffice.

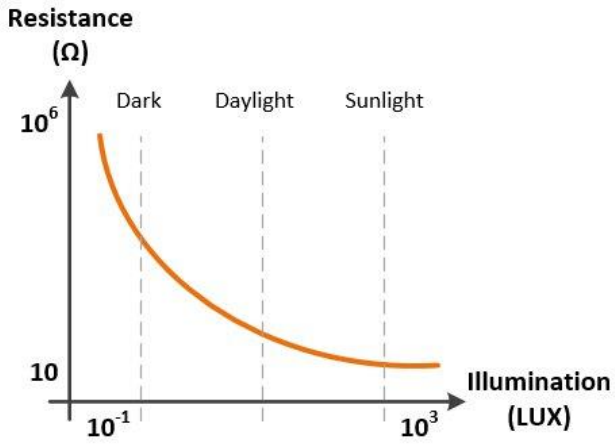

Figure 5 Typical non-linear relationship of photoresistors between illuminance and electrical resistance

In Figure 6 can be seen a typical figure as would be provided by a manufacturer. The width of the curve is a visual expression of measurement uncertainty. It can be noticed that the illuminance range is limited and the data has to be extrapolated for the complete range (i.e., dark night, full sunlight). In the case of the GL5516, Jericho already provides a general equation that should approximate the behavior of these units, without being a calibration curve specific to a given sensor. In the example of Figure 6, the manufacturer accuracy is ±100%. This means that if the measured lux value is 340 lux, it is very likely that the real luminosity at the surface of the sensor is between 0 and 680 lux.

Illuminance [Lux] = 10^((4.4451-log (R))/0.6)

where R is the Resistance, in ohms

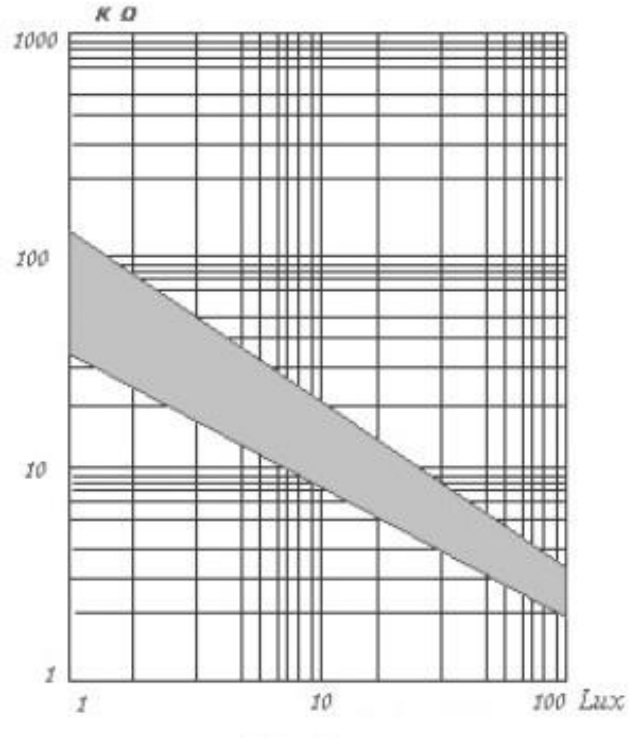

Figure 6 Typical log-log graph of the resistance function of illuminance for a GL5516 photoresistor (SHENZHEN SENBA OPTICAL & ELECTRONIC CO., LTD n.d.)

"Peak lumens" refers to the wavelength (nm) at which the sensitivity of the photoresistor device is maximal. In the case of the GL5516, the peak is approximately 540 nm.

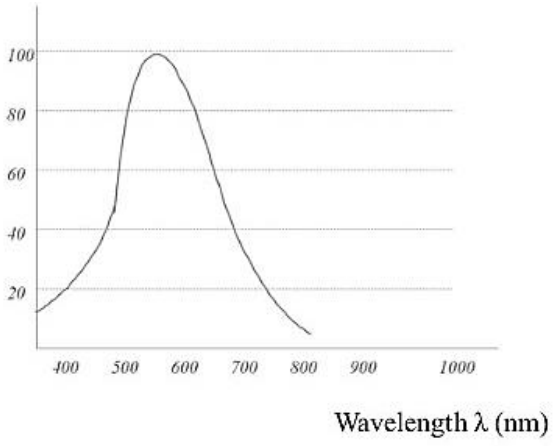

Figure 7 Relative response of the GL55 series photoresistor to the wavelengths of the light spectrum (SHENZHEN SENBA OPTICAL & ELECTRONIC CO., LTD n.d.)

Measurement temperature correction

Photoresistors are sensitive to temperature change (Figure 8). Therefore, the environment temperature can affect the accuracy of the readings. Also, as the device heats up from high levels of illuminance, the resistance will drift to a new value until the temperature of the photoresistor has stabilized with its environment through increased heat losses. This can be experienced firsthand by measuring the temperature of the photoresistor with one of the RDL thermistors. To correct this source of error, an advanced user could add temperature compensation to the raw photoresistor values, before converting resistance to illuminance.

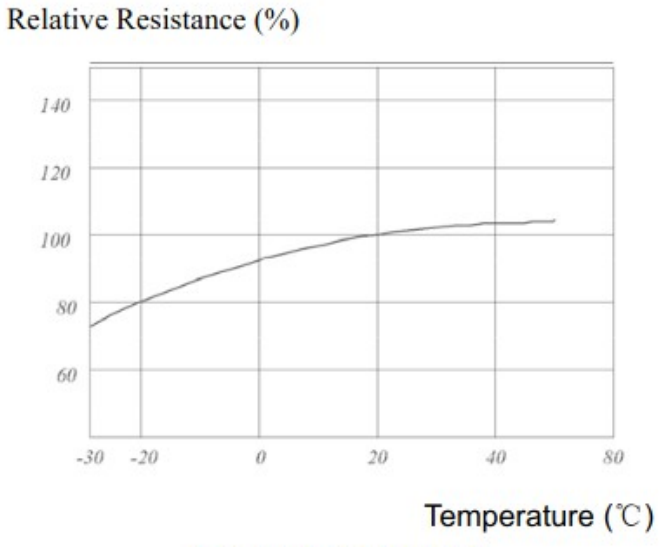

Figure 8 Relative resistance as a function of sensor temperature
(Excerpt from the specification sheet of the photoresistor GL5516)

Photoresistor life expectancy

As they are based on the photoelectric effect, photoresistors do not wear out easily, but they can be damaged or cracked. The device should last many years in normal conditions of use. The device must be stored and used between -30 and 70°C. Lead wires waterproofing is the property that is likely to be lost first.

Directional device

If the light comes mainly from a certain direction, the angle between the surface of the photoresistor and the light source will affect the measurement. The value read by the photoresistor is the illuminance value in the perpendicular direction to the sensor surface.

Physical mechanism of the photoresistor

When a photon with sufficient energy hits the material, an electron is dislodged and goes into the conductive band of the material and leaves a 'hole' behind. This allows the material to conduct electricity (lower resistance). When light disappears, the free electron goes back to its original place and does not contribute to the electric conductivity of the material.

General considerations about light measurements

- What is a lumen?
    - A lumen [lm] is the SI unit (International System of Units) of visible light flux. It is a unit of light per unit of time. Light bulbs are frequently characterized in lumens. For example, a typical 60 W incandescent light bulb emits approximately 800 lumens. It represents the total amount of light emitted by a source. One lux is equal to 1 lumen per square meter.
- What is a lux?
    - In the metric system, illuminance is expressed in "lux". It is defined as one lumen per square meter. A photoresistor can measure light density at a given point. The lighting requirements inside a building are usually expressed in lux. Illuminance is not equivalent to luminance.
- What is luminous intensity?
    - Luminous intensity is analogous to radiant intensity. However, luminous intensity is the sum of the visible light flux, while as radiant intensity is the sum of the whole light spectrum flux. Measuring radiant intensity cannot be done with a photoresistor.
- What are the other units related to light?
    - Candela: It is defined as a lumen per steradian (A steradian is to a sphere what a radian is to a circle). Which is luminous flux per unit solid angle. There are derived units such as milicandela.
    - Foot-candle: Non-SI unit for luminous intensity. It is equivalent to 10 lux.

Safety information about CdS photoresistor

- Does the sensor contain cadmium and how much?
    - Yes, the semi-conductor used is cadmium sulfide, in the form of a thin film. Cadmium is a poisonous substance that should not be inhaled or ingested. Cadmium is a known carcinogenic substance and is one of the six substances banned by the RoHS European directive (Restriction of Hazardous Substances). Cadmium is also a material in certain types of batteries that are less popular today with the prevalence of the lithium types.
- Am I allowed to use a CdS sensor in my country?
    - The RoHS only applies to the European Union. However similarly national and regional restrictions have been adopted around the world. Please consult your local officials.
- How should I dispose of the device?
    - Please, do not put the photoresistor in your regular trash. Like all electronic waste, the photoresistor must be sent to a local drop-off site that accepts dangerous materials (lead, mercury, arsenic, cadmium, etc.) Many electronic stores accept electronic waste.

References

Anon. 2022. “Illuminance.” *Wikipedia*.

EE Power. n.d. “Photoresistor - Resistor Types - Resistor Guide.” Retrieved July 13, 2022 (https://eepower.com/resistor-guide/resistor-types/photo-resistor/).

Lady Ada. n.d. “Photocells Overview.” *Adafruit Learning System*. Retrieved July 13, 2022 (https://learn.adafruit.com/photocells/overview).

SHENZHEN SENBA OPTICAL & ELECTRONIC CO., LTD. n.d. “CdS Photoresistor Manual: GL55 Series Photoresistor.” Retrieved July 13, 2022 (https://www.pedalpcb.com/datasheet/GL55_DATASHEET.pdf).