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Making Sense of Light Sensors

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As electronics seamlessly weave their way into our lives, sensors play an increasingly important role. Light sensors are one of the simplest and cheapest, allowing their inclusion in multitudes of consumer products from nightlights to cameras. There are a multitude of ways to sense light. The array of available light sensors is presented, including trade-offs in resolution, dynamic range, and cost. Then, the use of integrated circuitry enables on-chip calibration, filtering, and increased resolution. These advances are discussed with respect to two application examples: an ambient light sensor for a laptop and cell phone display.

Types of Ambient Light Sensors

A spectrum of optical sensors is shown in Table 1. They are arranged from left to right in complexity. Considering reasonable order quantities, they are also ordered by cost. A discussion of the trade-offs will uncover what advantages can be bought with a few extra pennies per unit.

The simplest optical sensor is a photo resistor and can be identified by the meandering channel between two terminals. The low-end versions are made with cadmium sulfide, while the more expensive counterparts are gallium arsenide. GaAs allows the inclusion of a photo resistor in an IC and its small bandgap (1.4V at 300k) allows the low energy photons in infrared light to free electrons into the conduction band. The data from the reference part is only reported from 1Lux to 100Lux, yet a variety of resistance values are available.

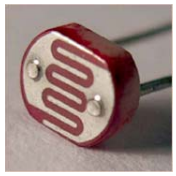
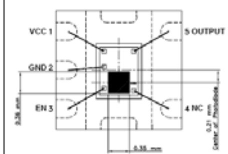
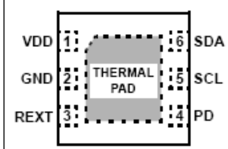
Photo diodes are the next step in complexity. When photons bombard the junction, current is produced. For optimal use, the diode should be reverse-biased. The amount of bias directly translates into quality of operation-larger reverse bias enhances speed and linearity while also increasing dark current and shot noise. Light will create forward current, subtracting from the reverse bias current. External circuitry can be added to linearize the diode's I-V curve, to amplify the signal, and to allow a disable function.

A photo transistor exhibits the same general characteristics of the photo diode, with the addition of amplification. It requires more bias current, but the noise associated with the current forces a shift in the sensitivity of the sensor to a higher lux range (1k to 100k instead of 7k to 50k). Response time is similar, and can be varied with biased. Current will also vary with detected signal level. A photo transistor is capable of determining coarse environmental levels like indoor/outdoor, day/night, and bright light/shade. External circuitry is still needed to calibrate the output signal and include an enable.

Shrinking device sizes have allowed the creation of a hybrid device like the EL7900. It places a photo diode and transimpedance amplifier in one package, as shown in Figure 1. This combination allows for lead length reduction and minimum parasitic capacitance on the amplifier inputs. This, of course, is the optimal condition for minimum noise, high frequency, and convenience. The low noise characteristics extend the sensitivity of the sensor down to 1Lux while keeping the upper limit of 100kLux. The power drawn is still dependent on the amount of light sensed, reaching 0.9mA for 1000Lux. To conserve power, a power down pin is included. This device is suitable for many situations, not just digital cameras. Before discussing these applications, there is one last device to discuss.

The ISL29001 family of devices offers a packaged solution for light sensing and calibration. The block diagram is shown in Figure 2. The temperature-compensated light sensor is a pin diode. The output from the sensor is calibrated and fed through a current amplifier before entering an integrating ADC (Analog-to-Digital Converter) which rejects 50/60Hz noise and I^2C interface deliver the digital output signal. Two major benefits of using an ADC are constant power usage and 15-bit resolution. In fact, the current draw is less than all of the other active devices in the table. The ADC has an internal 327.6kHz clock which sets the device response time to 100ms. Even with the increased delay, the serial 15-bit output signal allows the sensor to be suitable for a much wider range of applications.

TABLE 1. SUMMARY OF OPTICAL SENSOR OPTIONS

DEVICE	PHOTO RESISTOR	PHOTO DIODE	PHOTO TRANSISTOR	PHOTO DIODE AND CURRENT AMPLIFIER	PHOTO DIODE, CURRENT AMP, ADC AND FILTER
REFERENCE PART #	PDV-P500X 				
ACCURACY	Not Guaranteed	Not Guaranteed	±75%	±33%	15-Bit Resolution
CURRENT (100Lux	Varies	3µA	2.6mA (70kLux)	0.9mA	0.3mA
RANGE	1Lux to 100Lux	7kLux to 50kLux	1kLux to 100kLux	1kLux to 100kLux	0.3kLux to 10kLux
RESPONSE TIME	55ms	6ns	15µs	0.5ms	100ms
ENABLE FUNCTION	No	No	No	Yes	Yes

Applications for Ambient Light Sensors

Light sensors are ubiquitous in modern society. Some of these applications use reflected light with optical detection for position sensing, like bar code readers, laser printers and auto-focusing microscopes. Other applications use optical sensors to gauge the amount of ambient light, such as digital cameras, cell phones, and laptops. It is this second group that we'll investigate further.

Ambient light sensors are included in laptops to sense the ambient light, allowing for adjustment of the screen's backlight to comfortable levels for the viewer. The range of "comfortable levels" is dependent on the room's light. The relationship is shown in Figure 3. Understandably, a screen's brightness needs to increase as the ambient light increases. What is less obvious is the need to decrease the brightness in lower light conditions-for comfortable viewing and to save battery life.

In laptop design, ambient light sensors are typically placed next to the speakers where the case has an opening for light. These portals are commonly covered by a cross-hatch pattern to protect the speakers. Because of this protection (and the fact that the light sensor is next to the speaker instead of on top of it), the light is obstructed. The obstruction reduces the amount of light to be measured, requiring a solution with low-light accuracy. For the accuracy needed in low-light conditions, the best sensor choice is the integrated photo diode with an ADC. A sample solution is provided in Figure 4. Notice that the inclusion of a high-pass filter minimizes power supply noise from coupling into the backlight illumination.

A second common example is an ambient light sensor used in a cell phone where every mA-hour saved translates into longer battery life and happier customers. The enable/disable function is equally important for the battery-saving, power-down feature. The extension of battery life is remarkable. With the light sensor to adjust the back-light illumination, battery life is increased by at least a factor of 6! (assuming the backlight would remain on full-power without any feedback from a light sensor). Figure 5 shows the complete automatic back light control circuit for cell phones. The EL7900 senses ambient light intensity and outputs a proportional current. Equation 1 shows the relationship between light intensity (E) and output current (I_{OUT}).

$$I_{OUT} = E \cdot \frac{60\mu A}{100Lux} \quad \text{(EQ. 1)}$$

The light sensor output current injects into the feedback input of the White LED driver. In a bright environment, the light sensor sources more current into the feedback node; as a result, it reduces the White LED output current and reduces the White LED output light intensity. The relationship between ambient light intensity (E) and White LED output current is shown in Equation 2.

$$I_{LED} = \frac{V_{FB}}{R_{LED}} - \left(\left(E \cdot \frac{6\mu A}{10Lux}\right) \cdot \frac{R_S}{R_{LED}}\right) \quad \text{(EQ. 2)}$$

Conclusion

A wide variety of optical sensors are available in small packages at reasonable prices. Passive solutions have been serving consumers for decades in nightlights and still digital cameras. Active solutions have increased the range and usefulness of ambient light sensors. Typical active solutions integrate a photo transistor or a photo diode with a current amplifier. When greater resolution, low-light capability, power supply rejection, or a disabling function would be useful, the ISL29001 family extends the usefulness of typical ambient light sensors.

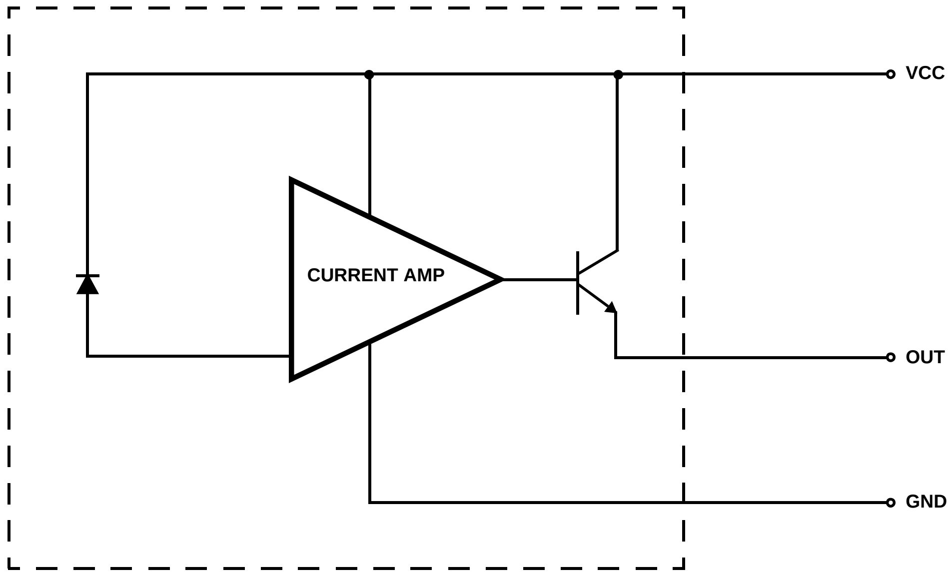


FIGURE 1. BLOCK DIAGRAM OF EL7900, AMBIENT LIGHT SENSOR WITH INTEGRATED CURRENT AMP

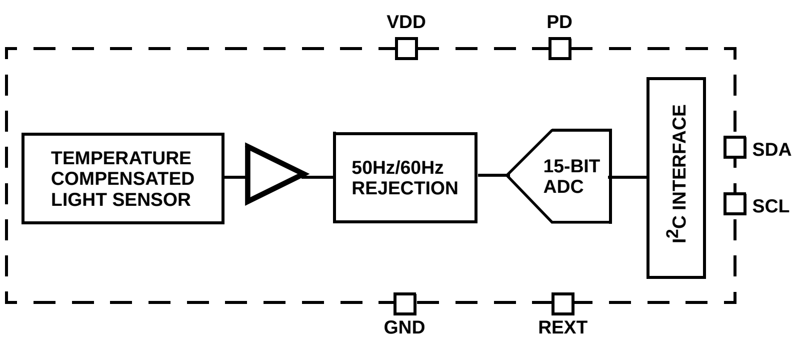


FIGURE 2. BLOCK DIAGRAM OF ISL29001, AMBIENT LIGHT SENSOR WITH ADC, ENABLE AND FILTER

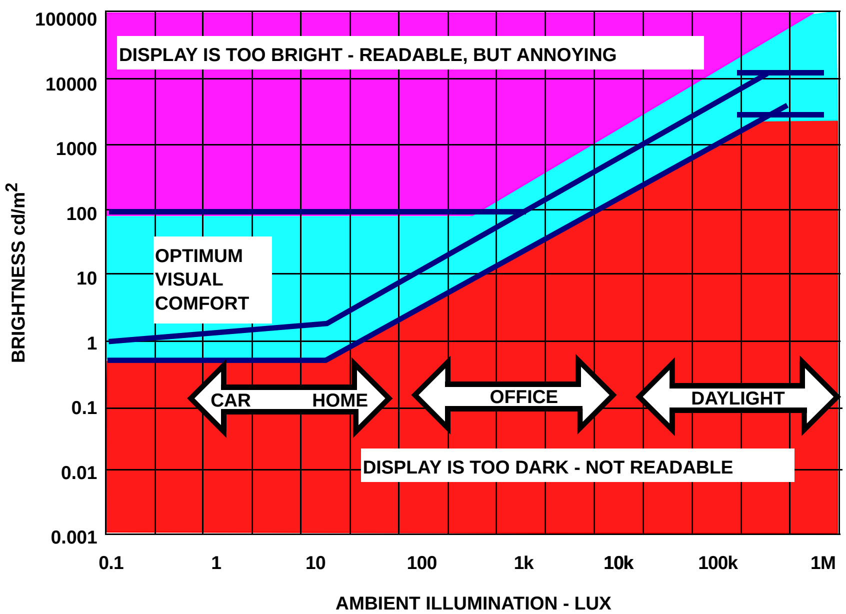


FIGURE 3. GRAPH OF DESIRED BRIGHTNESS WITH RESPECT TO AMBIENT ILLUMINATION

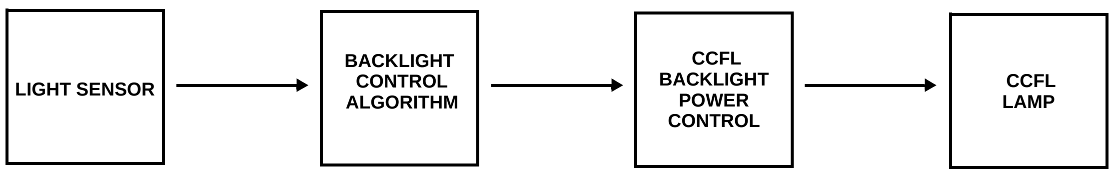


FIGURE 4. BLOCK DIAGRAM OF LIGHT SENSING SYSTEM IN A LAPTOP

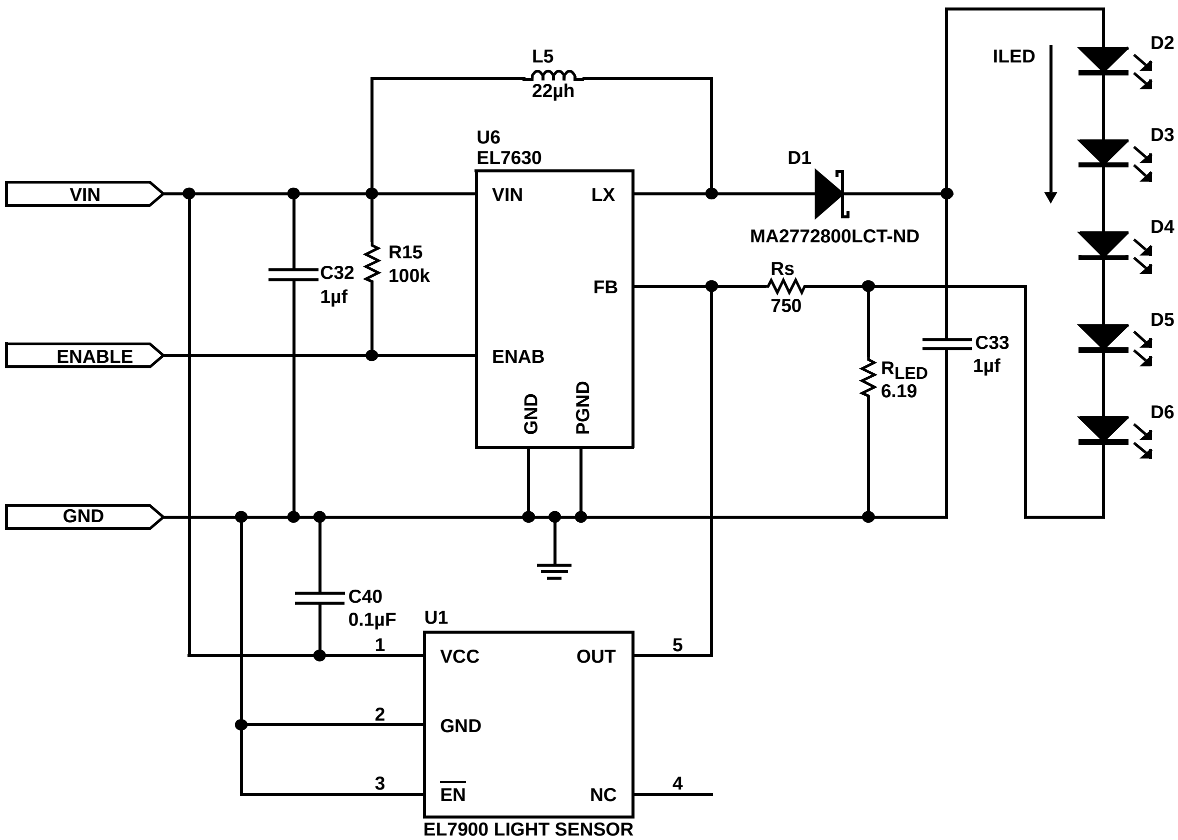


FIGURE 5. AUTOMATIC WHITE LED BACK LIGHT INTENSITY CONTROL CIRCUIT