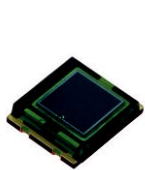




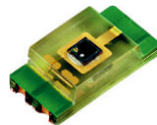
# Ambient Light Sensors - Circuit and Window Design

**Ambient light sensors** are used to detect light or brightness in a manner similar to the human eye. They are most commonly found in industrial lighting, consumer electronics, and automotive systems, where they allow settings to be adjusted automatically in response to changing ambient light conditions. By turning on, turning off, or adjusting features, ambient light sensors can conserve battery power and provide extra safety while eliminating the need for manual adjustments.

Vishay offers a wide variety of ambient light sensors in leaded and surface mount packages, with photodiode or phototransistor outputs, narrow to broad viewing angles or angles of half sensitivity, and automotive qualified to the AEC-Q101 standard (Table 1). Sensors that are automotive qualified have an "X01" in the part number.



TEM5510FX01

TEM6200FX01  
TEM6200FX01TEM6010FX01  
TEM6000X01

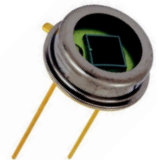
TEPT5600



TEPT4400



TEPT5700



BPW21R

Table 1

PART NUMBER	MOUNTING	SIZE (mm)	PEAK WAVELENGTH (nm)	BANDWIDTH (nm)	ANGLE OF HALF SENSITIVITY ( $\pm$ °)	LIGHT CURRENT <sup>(1)</sup> STANDARD A ( $\mu$ A)	LIGHT CURRENT <sup>(2)</sup> FLUORESCENT ( $\mu$ A)
<b>PHOTODIODE OUTPUT</b>							
<a href="#">TEM6010FX01</a>	SMD	2.0 x 4.0 x 1.0	540	430 to 610	60	0.04	0.03
<a href="#">TEM5510FX01</a>	SMD	4.2 x 5.0 x 1.1	540	430 to 610	65	1.00	0.70
<a href="#">TEM6200FX01</a>	SMD	1.2 x 2.0 x 0.85	540	430 to 610	60	0.04	0.03
<a href="#">BPW21R</a>	Leaded	TO5 - 8 mm	565	420 to 675	50	0.90	0.75
<b>PHOTOTRANSISTOR OUTPUT</b>							
<a href="#">TEM6200FX01</a>	SMD	1.2 x 2.0 x 0.85	550	450 to 610	60	12	7
<a href="#">TEM6000X01</a>	SMD	2.0 x 4.0 x 1.0	570	430 to 800	60	50	21
<a href="#">TEPT5700</a>	Leaded	5 mm, flat top	570	430 to 800	50	75	31
<a href="#">TEPT5600</a>	Leaded	5 mm	570	430 to 800	20	350	145
<a href="#">TEPT4400</a>	Leaded	3 mm	570	430 to 800	30	200	83

**Notes**

<sup>(1)</sup>  $E_v = 100$  lux,  $V_{CE} = 5$  V, CIE illuminant A, typical

<sup>(2)</sup>  $E_v = 100$  lux,  $V_{CE} = 5$  V, e.g., Sylvania color abbrev. D830, typical

## Ambient Light Sensors - Circuit and Window Design

### FILTERING

Most photodiodes and some phototransistors feature an epoxy filter that improves the relative spectral sensitivity to be closer to the sensitivity of the human eye; this is sometimes called the  $v(\lambda)$  curve. Part numbers that contain the letter “F” feature this epoxy. Figure 1 shows an ambient light sensor without the epoxy filter and figure 2 shows the sensor with the epoxy filter. With this epoxy filter the bandwidth ( $\lambda_{0.5}$ ) is reduced from 430 nm to 800 nm to 430 nm to 610 nm.

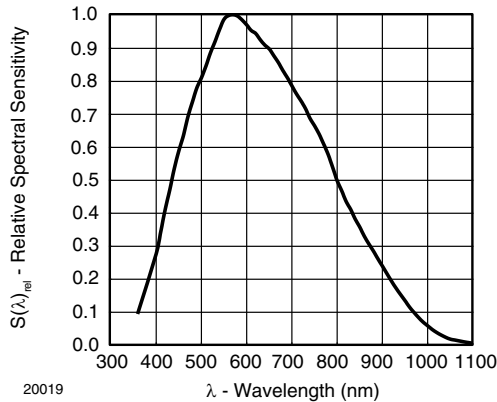


Fig. 1 - Graph without Epoxy Filter

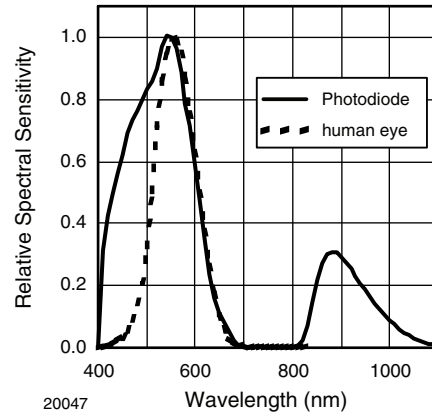


Fig. 2 - Graph with Epoxy Filter

### BINNING

Vishay offers phototransistor- and photodiode-based ambient light sensors. For a given irradiance, phototransistors may show lot-to-lot variability of the output current caused by variability of the photosensitivity of the chip and the transistor gain. The lot-to-lot variability of photodiodes is significantly lower because it is caused only by the variability of the photosensitivity. Vishay offers its ambient light sensors with phototransistor output in binned groups (Table 2). These groups cannot be ordered separately but each reel is marked with a label A, B, or C that will allow the user to select the appropriate load resistor to compensate for these wide tolerances.

Table 2 - TEMT6200FX01

TYPE DEDICATED CHARACTERISTICS ( $T_{amb} = 25\text{ }^{\circ}\text{C}$ , unless otherwise specified)						
PARAMETER	TEST CONDITION	BINNED GROUP	SYMBOL	MIN.	MAX.	UNIT
Photo current	$E_V = 100\text{ lux}$ , CIE illuminant A, $V_{CE} = 5\text{ V}$	A	$I_{PCE}$	7.5	15	$\mu\text{A}$
		B	$I_{PCE}$	12	24	$\mu\text{A}$
		C	$I_{PCE}$	19.5	39	$\mu\text{A}$

## Ambient Light Sensors - Circuit and Window Design

### CHOOSING THE LOAD RESISTOR

In order to minimize the output variability of the sensor, the load resistor ( $R_L$ ) needs to be selected based on the illuminance expected or measured in the application. A typical circuit for operating an ambient light sensor with phototransistor output is shown in Figure 3. For the TEMT6200FX01, the typical output current is  $4.6 \mu\text{A}$  at 20 lux. At 100 lux the output current ranges from  $7.5 \mu\text{A}$  to  $39 \mu\text{A}$ . With the binning mentioned previously, this 100 lux range is split into three bins. A different load resistor should be used for each bin so the output is relatively consistent for a given lux level.

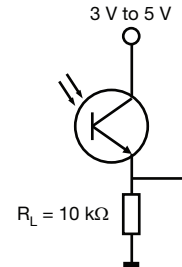


Fig. 3

Let's assume that the application detection range is from 10 lux to 1000 lux. With a  $10 \text{ k}\Omega$  load resistor, a voltage from  $0.023 \text{ V}$  to  $2.3 \text{ V}$  is produced. The photo current based on the voltage equates to  $2.3 \mu\text{A}$  to  $230 \mu\text{A}$ .

The goal in choosing the resistor is to have the same output voltage for the mean value of each bin, Table 3.

Table 3

PART NUMBER	BIN	PHOTO CURRENT, $I_{PCE}$ at 100 lux ( $\mu\text{A}$ )		
		MIN.	MEAN	MAX.
TEMT6200FX01	A	7.5	11.25	15
	B	12	18.00	24
	C	19.5	29.25	39

Table 4

BIN B	BIN A	BIN C
$I_{PCE} = 18 \mu\text{A}$ , $R_L = 10 \text{ k}\Omega$ $V = 18 \mu\text{A} \times 10 \text{ k}\Omega$ $V = 180 \text{ mV}$	$0.18 \text{ V} = 0.00001125 \text{ A} \times R_L$ $R_L = 0.18 \text{ V} / 0.00001125 \text{ A}$ $R_L = 16 \text{ k}\Omega$	$0.18 \text{ V} = 0.00002925 \text{ A} \times R_L$ $R_L = 0.18 \text{ V} / 0.00002925 \text{ A}$ $R_L = 6.2 \text{ k}\Omega$

By changing the resistor based on the bin, the overall tolerance of the TEMT6200FX01 is reduced from a factor of 5 (7.5 to 39) to a factor 2 (e.g. 12 to 24).

## Ambient Light Sensors - Circuit and Window Design

### OPERATING FROM 1 lux TO 100 000 lux

The sensitivity of TEMENT6200FX01 allows detection of ambient light from 1 lux to 100 000 lux. In many applications, the detection range of an ambient light sensor is from 1 lux to 1000 lux. The calculations for the load resistor on the previous page were for this range. The maximum allowable current for the TEMENT6200FX01 is 20 mA. Extrapolating the graph of the photo current versus illuminance in figure 4, a photo current of 18 mA is approximately equal to 100 000 lux. The relationship between photo current and ambient light is linear. Given the extremely low dark current for this part of 50 nA, and again extrapolating the graph, results in approximately 180 nA of photo current for 1 lux. The output current from 1 lux to 100 000 lux is 180 nA to 18 mA.

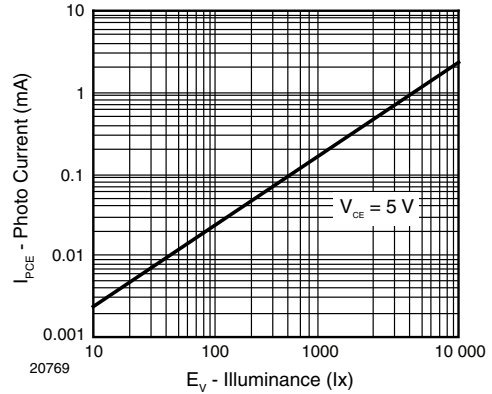


Fig. 4 - Photo Current vs. Illuminance

Depending on the sensitivity of the analog-to-digital converter, an operational amplifier could be placed at the output of the sensor as shown in figure 5. In this case, a load resistor of 10 kΩ results in an output voltage of 2 mV to 2.0 V for an ambient level of 1 lux to 1000 lux.

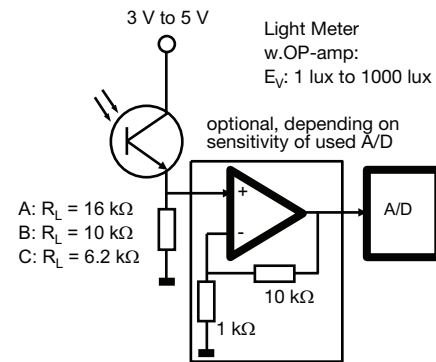


Fig. 5

$E_V = 1 \text{ lux to } 1000 \text{ lux}$   
 $I_{PCE} = 0.2 \mu\text{A to } 200 \mu\text{A}$   
 $R_L = 10 \text{ k}\Omega$   
 $V_{RL} = (0.2 \mu\text{A} \times 10 \text{ k}\Omega) \text{ to } (200 \mu\text{A} \times 10 \text{ k}\Omega)$   
 $V_{RL} = 2 \text{ mV to } 2 \text{ V}$

Operating over the full ambient range of 1 lux to 100 000 lux and using a 1 kΩ load resistor would result in an output voltage from 0.18 mV to 18 V. Given a typical operating voltage of 5 V or less, this circuit design is not adequate. The load resistor will need to switch based on the output of the operational amplifier (figure 6). Switching a low-ohm resistor that is in parallel to the divider resistor to ground when the operational amplifier is above a certain value, for example 3 V, allows full-range operation.

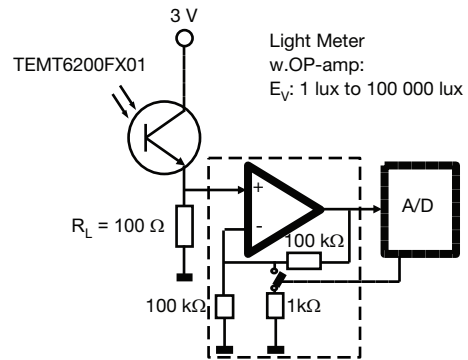


Fig. 6

<b>1 lux to 1000 lux</b>	<b>1000 lux to 100 000 lux</b>
$I_{PCE} = 180 \text{ nA to } 180 \mu\text{A}$	$I_{PCE} = 180 \mu\text{A to } 18 \text{ mA}$
$R_L = 100 \Omega \rightarrow$	$R_L = 100 \Omega$
$V_{RL} = 18 \mu\text{V to } 18 \text{ mV}$	$V_{RL} = 18 \text{ mV to } 1.8 \text{ V}$
with $v_a = 100$	with $v_a = 1$
$V_{ADC} = 1.8 \text{ mV to } 1.8 \text{ V}$	$V_{ADC} = 18 \text{ mV to } 1.8 \text{ V}$

## Ambient Light Sensors - Circuit and Window Design

### APPLICATION SCHEMATICS

Some simple application circuits for ambient light sensors with phototransistor output are shown below.

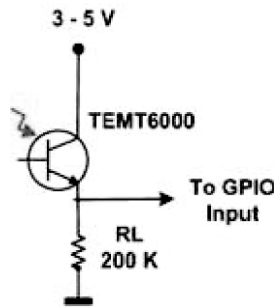


Fig. 7 - Switch, Output High at  $E_V > 25$  lux,  $I_{PCE}$ : 10  $\mu$ A,  $V_{OUT}$ : 2.0 V, Input Leakage Current: < 1  $\mu$ A

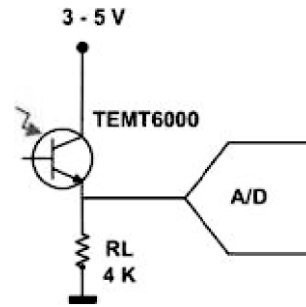


Fig. 10 - Light Meter,  $E_V$ : 10 lux to 1000 lux,  $I_{PCE}$ : 4  $\mu$ A to 400  $\mu$ A,  $V_{OUT}$ : 16 mV to 1.6 V

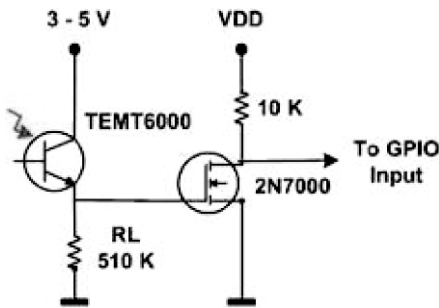


Fig. 8 - Switch, Output Low at  $E_V > 10$  lux,  $I_{PCE}$ : 4  $\mu$ A, Gate Threshold: 2.0 V, Input Leakage Current: < 1  $\mu$ A

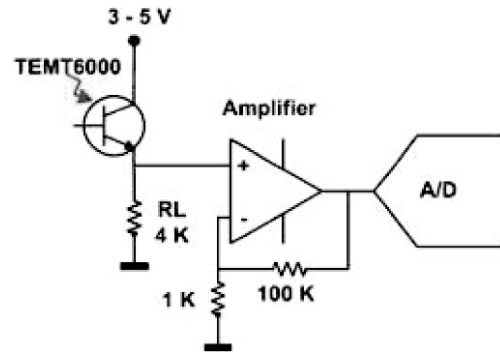


Fig. 11 - Low Illuminance Light Meter,  $E_V$ : 0.1 lux to 10 lux,  $I_{PCE}$ : 40 nA to 4  $\mu$ A,  $V_{OUT}$ : 16 mV to 1.6 V

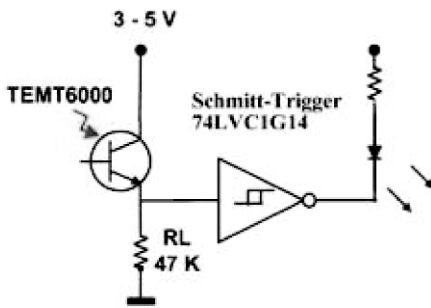


Fig. 9 - Light Switch, (Schmitt Trigger), Switch on at  $E_V < 100$  lux,  $I_{PCE}$ : < 40  $\mu$ A, Input Leakage Current: < 5  $\mu$ A

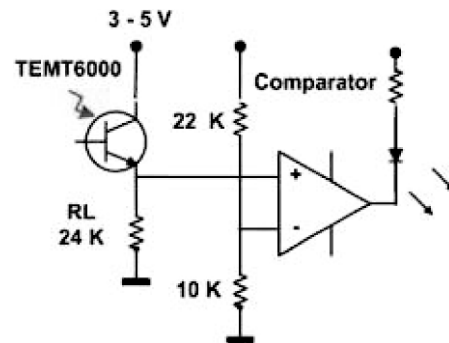


Fig. 12 - Light Switch, Switch On at  $E_V < 100$  lux,  $I_{PCE}$ : < 40  $\mu$ A

## Ambient Light Sensors - Circuit and Window Design

### PHOTODIODE-BASED AMBIENT LIGHT SENSORS

The basic characteristics of the ambient light sensors with photodiode outputs are shown in Table 5 below. All photodiode-based ambient light sensors have an additional epoxy filter that brings the relative spectral sensitivity close to the  $v[\lambda]$  or “Human Eye” curve. BPW21R comes with a color correction filter in its flat glass window that provides a similar effect. The low photocurrent output requires a noise-free amplification which can be achieved with the appropriate op amp. Examples of noise-free op amps that could be used with the photodiode output devices and related circuitry are shown on the next page.

Table 5 - TEMD6010FX01

BASIC CHARACTERISTICS ( $T_{amb} = 25\text{ }^{\circ}\text{C}$ , unless otherwise specified)						
PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Breakdown voltage	$I_R = 100\text{ }\mu\text{A}$ , $E = 0\text{ lux}$	$V_{(BR)}$	16			V
Reverse dark current	$V_{CE} = 10\text{ V}$ , $E = 0\text{ lux}$	$I_{ro}$		0.1	5	nA
Diode capacitance	$V_R = 0\text{ V}$ , $f = 1\text{ MHz}$ , $E = 0\text{ lux}$	$C_D$		60		pF
	$V_R = 5\text{ V}$ , $f = 1\text{ MHz}$ , $E = 0\text{ lux}$	$C_D$		24		pF
Reverse light current	$E_e = 1\text{ mW/cm}^2$ , $\lambda = 550\text{ nm}$ , $V_R = 5\text{ V}$	$I_{ra}$		1		$\mu\text{A}$
	$E_V = 100\text{ lux}$ , CIE illuminant A, $V_R = 5\text{ V}$	$I_{ra}$	0.03	0.04	0.09	$\mu\text{A}$
Temperature coefficient of $I_{ra}$	$E_V = 100\text{ lux}$ , CIE illuminant A, $V_R = 5\text{ V}$	$TK_{Ira}$		0.2		%/K
Angle of half sensitivity		$\phi$		$\pm 60$		deg
Wavelength of peak sensitivity		$\lambda_p$		540		nm
Range of spectral bandwidth		$\lambda_{0.5}$	430		610	nm

Compared to phototransistor-based ambient light sensors, the lot-to-lot variability of photodiodes is significantly lower because it is caused only by the variability of the photosensitivity resulting in tolerances of 20 % to 30 %. Variability of the output current of photodiode-based ambient light sensors is also due to chip size. A larger detection area or chip size will result in greater photo current. The TEMD5510FX01 and the BPW21R produce double the current of the TEMD6200FX01 and TEMD6010FX01. The TEMD5510FX01 contains a 7.5 mm<sup>2</sup> chip while the size of the sensitive area of the chip in the TEMD6x is just 0.27 mm<sup>2</sup>.

### APPLICATION SCHEMATICS FOR PHOTODIODE-BASED AMBIENT LIGHT SENSORS

A sensitive, FET-input type of photodiode preamplifier, with a very low input noise, should be used, such as:

- Linear Technology LTC6240
- Texas Instruments (OPA827)
- Burr-Brown (OPA128)
- Analog Devices (AD549)

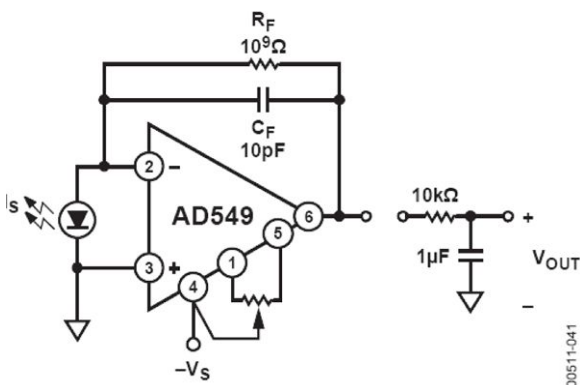


Fig. 13 - Photodiode Preamp

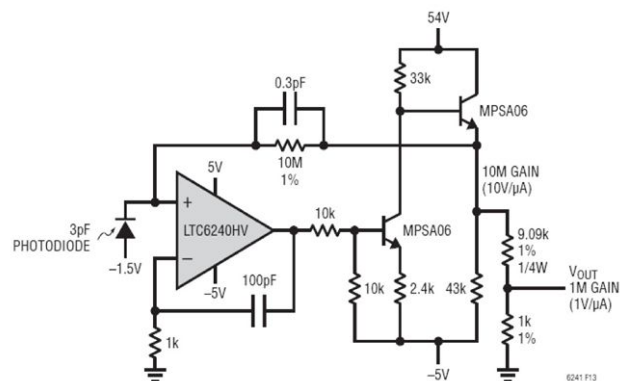
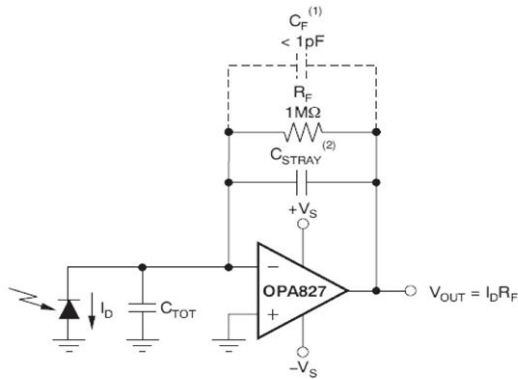


Fig. 14 - 1M Transimpedance Amplifier with 43 nV/Hz<sup>2</sup> Output Noise

## Ambient Light Sensors - Circuit and Window Design



NOTES: (1)  $C_F$  is optional to prevent gain peaking.  
(2)  $C_{STRAY}$  is the stray capacitance of  $R_F$  (typically, 2pF for a surface-mount resistor).

Fig. 15 - Transimpedance Amplifier

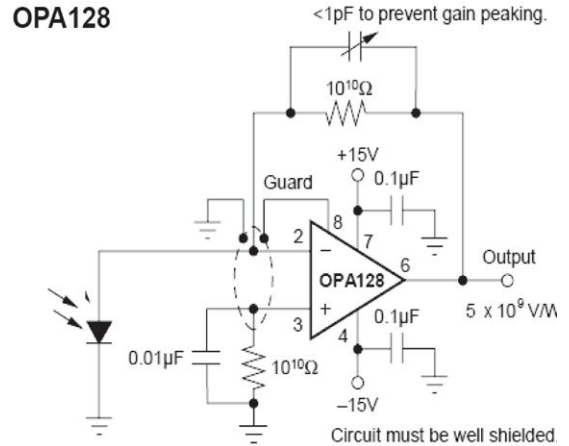


Fig. 16 - Sensitive Photodiode Amplifier

### WINDOW SIZE

If the ambient light sensor will be placed behind a window or cover, the window material should be completely transmissive to visible light (400 nm to 700 nm). For optimal performance the window size should be large enough to maximize the light irradiating the sensor. In calculating the window size, the only dimensions that the design engineer needs to consider are the distance from the top surface of the sensor to the outside surface of the window and the size of the window. These dimensions will determine the size of the detection zone.

First, the center of the sensor and center of the window should be aligned. Most ambient light sensors have an angle of half sensitivity of  $\pm 60^\circ$  as shown in figure 17 and 18.

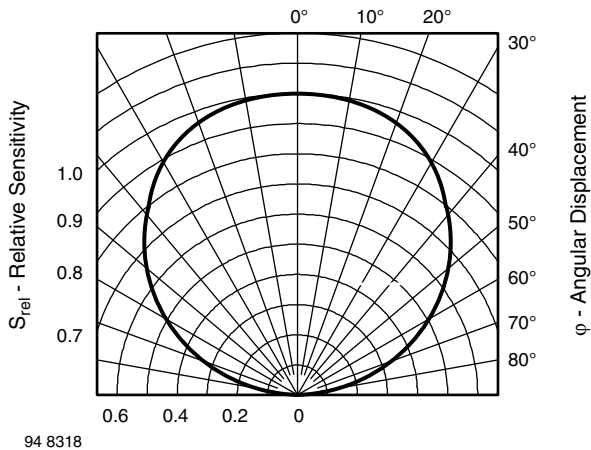


Fig. 17 - Relative Sensitivity vs. Angular Displacement

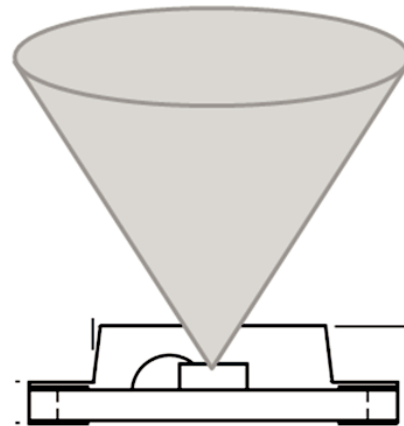


Fig. 18 - Angle of Half Sensitivity, Cone

## Ambient Light Sensors - Circuit and Window Design

With the assumption that the detection zone is a cone shaped region with an angle of  $\pm 60^\circ$ , the following are dimensions for the distance from the top surface of the sensor to the outside surface of the glass,  $d$ , and the width of the window,  $w$ .

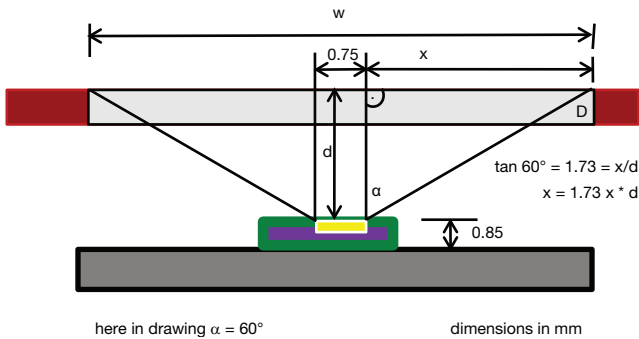


Fig. 19 - Angle of Half Sensitivity, Cone

### Calculation

$$\tan \alpha = x/d$$

$$\alpha = 60^\circ$$

$$\tan 60^\circ = 1.73$$

$$x/d = 1.73$$

$$x = (1.73)d$$

With the length of the chip equal to 0.75 mm, the width of the window can be calculated:

$$w = 0.75 \text{ mm} + 2 (1.73d)$$

Shown below are results for different distances from the sensor to the outside of the window surface.

d	x	CALCULATION	w
0.5	0.87	0.75 + 1.74	2.49
1.0	1.73	0.75 + 3.46	4.21
1.5	2.60	0.75 + 5.20	5.95
2.0	3.46	0.75 + 6.92	7.67
2.5	4.33	0.75 + 8.66	9.41
3.0	5.19	0.75 + 10.38	11.13

A smaller window size also could be used. If so, reference measurements should be made if the output is expected to be similar to a light meter.

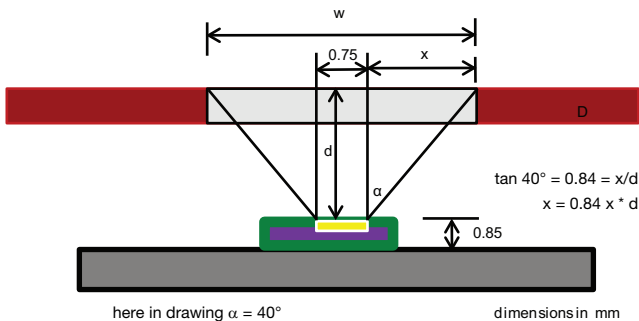


Fig. 20 - Angle of Half Sensitivity, Cone

### Calculation

$$\tan \alpha = x/d$$

$$\alpha = 40^\circ$$

$$\tan 40^\circ = 0.84$$

$$x/d = 0.84$$

$$x = (0.84)d$$

With the length of the chip equal to 0.75 mm, the width of the window can be calculated:

$$w = 0.75 \text{ mm} + 2 (0.84d)$$

Shown below are results for different distances from the sensor to the outside of the window surface.

d	x	CALCULATION	w
0.5	0.42	0.75 + 0.84	1.59
1.0	0.84	0.75 + 1.68	2.43
1.5	1.28	0.75 + 2.56	3.31
2.0	1.68	0.75 + 3.36	4.11
2.5	2.10	0.75 + 4.20	4.95
3.0	2.52	0.75 + 5.04	5.79





## Ambient Light Sensors - Circuit and Window Design

### TYPICAL ILLUMINANCE VALUES

ILLUMINANCE	EXAMPLE
10 <sup>-5</sup> lux	Light from Sirius, the brightest star in the night sky
10 <sup>-4</sup> lux	Total starlight, overcast sky
0.002 lux	Moonless clear night sky with airflow
0.01 lux	Quarter moon 0.27 lux full moon on a clear night
1 lux	Full moon overhead at tropical latitudes
3.4 lux	Dark limit of civil twilight under a clear sky
50 lux	Family living room
80 lux	Hallway/toilet
100 lux	Very dark overcast day
320 lux to 500 lux	Office lighting
400 lux	Sunrise or sunset on a clear day
1000 lux	Overcast day; typical TV studio lighting
10 000 lux to 25 000 lux	Full daylight (not direct sun)
32 000 lux to 130 000 lux	Direct sunlight