Eye Safety for Proximity Sensing Using Infrared Light-emitting Diodes

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Introduction

Active Proximity Sensing for Consumer products requires the use of a light-emitting component to illuminate the target object to be detected at some distance from the sensor. Typically, product designers do not want the illumination to interfere with the other functions of the product, or to distract the user during normal use. Therefore, Infrared Light-emitting Diodes (IR-LEDs) are used as the light-emitting components for proximity sensing. To further reduce the user awareness of the proximity function, the IR-LED and the proximity sensor are located under heavily tinted - but, infrared-transmitting - glass. While remaining unaware of any illuminating light source, the consumer indeed is exposed to low-levels of infrared radiation. All consumer products that emit light radiation - whether visible, ultraviolet, or infrared - must adhere to international standards that specify exposure limits for human eye safety.

The International Electrotechnical Commission (IEC) has established standards for human eye safety with various sources of light radiation. Document IEC-60825 deals with laser sources and IEC-62471 deals with lamp sources. Prior to 2006, light-emitting diodes were included in the laser safety standard. With the significant growth in Solid-state Lighting (SSL) the Commission transferred general illumination LED components to the lamp safety standard. However, LED applications in data transmission still are included in the laser standard while LED illumination applications are contained in the Lamp Standard. proximity sensing is an illumination application.

As a manufacturer of proximity sensor components - some with an integrated IR-LED - Intersil believes it is our responsibility to provide information for our customers to assist in their product design using proximity sensors and IR-LEDs. This Application Note serves as a guide for the product designer to Human Eye Safety when using Infrared light-emitting diodes in consumer products. Photobiological effects of exposure to near-infrared radiation are reviewed first, followed by brief explanations of the relevant sections of the IEC-62471 Standard document. Next, the Intersil Eye Safety Calculator is described. This calculator tool can be found on the Intersil Corporate Webpage.

Several examples using the Eye Safety Calculator are shown. The lamp (LED) Risk Groups are described and lastly, failure mode effects are discussed.

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Photobiological Effects of Near-infrared Exposure

Infrared, visible or ultraviolet electromagnetic radiation, in sufficient concentrations, can cause damage to the human eye. To date, Light-emitting Diodes (LEDs) have not been found to cause any damage. [1] But, with increases in LED efficiency and power, especially with application for Proximity sensing, which provides more chance for direct contact with the eye, it is critical to understand the effects of this type of exposure. The human eye can withstand only a finite amount of optical radiation, beyond which it can be irreversibly damaged.

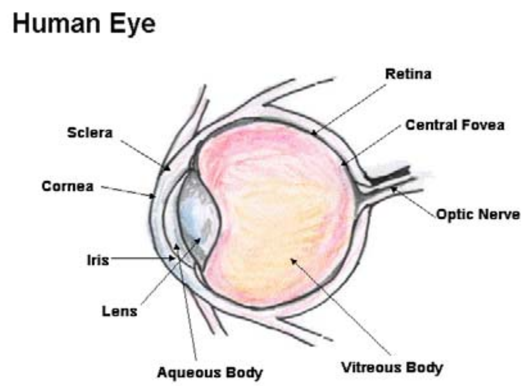

FIGURE 1. SCHEMATIC OF THE HUMAN EYE

Figure 1 shows a schematic diagram of the Human Eye. [2] The Eye contains two lens elements - the cornea and the lens. The cornea provides a fixed focusing capability while the lens provides a variable focusing capability, allowing for adjustment for near and far objects. Combined, these elements focus illumination on to the retina where the various photo-stimulated cells (Rods and Cones) convert the light energy into electro-biological stimulae that can be processed in the visual cortex of the human brain. All of the parts of the eye in the direct light path (cornea, aqueous humor, lens, vitreous humor, and retina) can be damaged by excessive exposure. The iris, which forms the pupil, provides a photo-stimulated aperture adjustment - reducing the pupil diameter in bright-light conditions to about 2mm and enlarging the pupil to about 7mm in very low-light conditions. This variable intensity capability prevents saturation of the retina in very bright-light conditions.

While human eye damage is much more acute from Ultraviolet (UV) and short-wavelength Blue-light exposure, excessive exposure to Near-Infrared (NIR, ~700nm to 1400nm wavelength) can cause damage to the cornea and the retina. Most Near-IR LEDs used in consumer products produce very low levels of NIR radiation and pose no threat to the human eye. However, under specific conditions and operational modes these components may produce sufficient NIR radiation to exceed IEC exposure limits.

The most common Bioeffects caused by excessive NIR exposure are Infrared Cataract (also known as "industrial heat cataract," "furnaceman's cataract," or "glassblower's cataract") and Retinal Thermal Injury. [3]

IEC-62471: Photobiological Safety of Lamps and Lamp Systems

It is strongly recommended that product designers implementing IR-LEDs in their designs obtain a copy of the IEC-62471 Standard document for reference.

Individuals in the vicinity of lamps (or, LEDs) and lamp systems should not be exposed to levels exceeding the limits developed in the IEC Standard document. The exposure limit (EL) values specified in the document are taken from various International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines which, in turn, are based on the best available information from experimental studies.

The exposure limits represent conditions under which it is believed that nearly all individuals in the general population may be repeatedly exposed without adverse health effects. [4] However, they do not apply to abnormally photosensitive individuals or to individuals concomitantly exposed to photosensitizing agents, which make individuals much more susceptible to adverse health effects from optical radiation. Such individuals, in general, are more susceptible to adverse health effects from optical radiation than individuals who are not abnormally photosensitive or concomitantly exposed to photosensitizing agents. The susceptibility of photosensitive individuals varies greatly and it is not possible to set exposure limits for this portion of the population.

The exposure limits in this standard apply to continuous sources where the exposure duration is not less than 0.01ms and not more than any 8-hour period, and should be used as guides in the control of exposure. The values should not be regarded as precisely defined lines between safe and unsafe levels.

The limits for exposure to broadband visible and IR-A radiation for the eye require knowledge of the spectral radiance of the source, L_λ, and total irradiance, E, as measured at the position(s) of the eye of the exposed person. Detailed spectral data of a light source are generally provided in the manufacturer's product datasheet.

Exposure limits are provided in clause 4.3 of IEC-62471.

The Exposure Limit specifications relevant for Near-IR-emitting components are provided in the following Clauses:

4.3.5 Retinal thermal hazard exposure limit

4.3.6 Retinal thermal hazard limit - weak visual stimulus, and

4.3.7 Infrared radiation hazard exposure limits for the eye (corneal hazard)

Clause 4.3.8, Thermal hazard exposure for the skin, may be included in this group for certain applications. However, for most non-laser semiconductor light sources the radiant emission is much too low to cause any dermal bioeffect even with quite prolonged exposure and, typically, is not necessary.

Prior to determining the Exposure Limit (EL) for the previously mentioned hazards, several preliminary calculations are required. As noted in the previous section the iris of the human eye allows the pupil diameter to vary typically from about 2mm to about 7mm, depending on direct illumination conditions. However, since there is very low photoresponse to near-infrared (IR-A) radiation, worst-case pupil diameter (7mm) must be used for all retinal hazard calculations.

For radiation in the wavelength range 380nm to 1400nm the area of the retina irradiated is an important element in determining the EL for both the blue light and retinal thermal hazards. Since the cornea and lens of the eye focus (the apparent source on the retina), the best method to describe the irradiated area is to relate this area to the angular subtense of the apparent source, α. Due to physical limitations of the eye, the smallest image that can be formed on the retina of a still eye is limited to a minimum value, $\alpha_{,min}$ even for a point source. In the IEC Standard the value for α_{min} is 0.0017 radian. Measurements of emitted radiation from apparent point sources, either pulsed or very high radiance continuous wave sources, that relate to the retinal thermal EL's at 0.25s (blink reflex time), should use the 0.0017 radian angular subtense as the measurement field of view.

For exposure times greater than about 0.25s, rapid eye movements begin to smear the image of the source over a larger angle, α_{eff} in the standard. For exposure times greater than ten seconds, the smeared image of a point source covers an area of the retina equivalent to an angle of about 0.011 radian. Thus the effective angular subtense, α_{eff}, to be used in measuring radiance to compare to the EL for the retinal thermal hazard at ten seconds exposure duration should be 0.011 radian. For continuity, the dependence of α_{eff} between 0.25s and 10s is assumed to increase from α_{min} to 0.011 radian as the square root of time, i.e., α_{eff} is proportional to $\alpha_{min} \bullet t^{0.5}$, i.e., $\alpha_{eff} = \alpha_{min} \bullet \sqrt{t/0.25}$. Little data is available to support this time dependence, so it should be used with caution. The time dependent relationship is normally not needed as the source radiance is usually evaluated at 0.25s or at 10s, as can be determined by reviewing the risk criteria described in Clause 6 of the IEC Standard. [5]

Infrared Radiation Hazard Exposure Limits for the Eye (Corneal Hazard)

The maximum allowed ocular exposure to infrared radiation, E_{IR}, over the wavelength range 780nm to 3000nm is defined as follows: For exposure times t ≤ 1000 seconds, the limit depends on the exposure time (t) itself shown by Equation 1.

$$E_{IR} = \sum_{\lambda = 780}^{\lambda = 3000} E_\lambda \bullet \Delta\lambda \le 18000 \bullet t^{-0.75} [W \bullet m^{-2}] \qquad \text{(EQ. 1)}$$

For exposure times t > 1000 seconds, the limit becomes a fixed value shown by Equation 2:

$$E_{IR} = \sum_{\lambda = 780}^{\lambda = 3000} E_\lambda \bullet \Delta\lambda \le 100 [W \bullet m^{-2}] \qquad \text{(EQ. 2)}$$

Where E_λ is the spectral irradiance in $W\text{-}m^{-2}\text{-}nm^{-1}$, $\Delta\lambda$ is the source spectral bandwidth in nm and t is the exposure duration in seconds.

In cold environments, the limit for t > 1000 s may be increased to $400W\text{-}m^{-2}$ at 0°C and $300W\text{-}m^{-2}$ at 10°C.

In many cases, the total irradiance, E_e, can be determined from the IR-LED datasheet specifications shown by Equation 3:

$$E_e = \frac{I_e}{d^2} \quad \text{(EQ. 3)}$$

Where I_e is the IR-LED radiant intensity in $W\text{-}sr^{-1}$ and d is the source-to-eye distance in meters.

Retinal Thermal Hazard Exposure Limit

The Retinal Thermal Limit comprises the integrated spectral radiance of the light source, L_λ, weighted by the burn hazard weighting function, $\mathcal{R}_\lambda$. However, the pupil diameter, source size of the emitter and the emitted wavelength are important parameters. For Near-IR light the visual stimulus is weak. The normal aversion response cannot respond to weak visual stimulus. Since the iris cannot contract the pupil, the fully dilated pupil (7mm) diameter must be used in these calculations. Limits of the angular subtense, α_{eff}, for the different exposure times are shown in Table 1. Below normal aversion response time of 0.25 seconds and for exposure times greater than 10 seconds, constant values are used. Between 0.25s to 10s, calculation of the angular subtense, α_{eff}, at a viewing distance, d, for a mean source extension, Z is shown in Equation 4:

$$\alpha = (Z / d) \quad \text{(EQ. 4)}$$

Where Z = (l+w)/2, l is the length and w the width of the active area of the light source.

TABLE 1. LIMITS OF THE ANGULAR SUBTENSE ON THE RETINA, α_{eff}, FOR THE DIFFERENT TIME RANGES [6]

TIME RANGE	ANGULAR SUBTENSE α_{eff} (RADIANS)
t < 0.25s	0.0017
0.25s < t < 10s	$0.011\sqrt{(t/10)}$
t > 10s	0.011

Thermal stress also is dependent on the wavelength weighted by the burn hazard weighting function, defined as Equation 5:

$$\mathcal{R}(\lambda) = 10^{\left\{\frac{700-\lambda}{500}\right\}} \quad \text{(EQ. 5)}$$

with the wavelength, λ, in nm. Thermal stress decays with increasing wavelength.

The retinal thermal hazard exposure limit for the burn hazard weighted radiance L_R for exposure times below 10s, is defined in IEC-62471 as Equation 6.

$$\lambda = 380 - 1400\text{nm}; \qquad 10\mu s \le t \le 10s$$

$$L_R = \sum_{\lambda = 380}^{\lambda = 1400} L_\lambda \bullet \mathcal{R}\lambda \bullet \Delta\lambda \le \frac{50000}{\alpha t^{0.25}}[W \bullet m^{-2} \bullet sr^{-1}] \quad \text{(EQ. 6)}$$

Where L_λ is the spectral radiance in $W\text{-}m^{-2}\text{-}nm^{-1}\text{-}sr^{-1}$. Angular subtense, α_{eff}, is in rad and t in s. For longer exposure times the spectral radiance is distinguished between the visible range (strong visual stimulus) and the Near-IR range (weak visual stimulus).

The exposure limit for the near infrared burn hazard weighted radiance L_{IR} for weak visual stimulus is defined in Equation 7.

$$\lambda = 780 - 1400\text{nm}; \qquad t > 10s$$

$$L_{IR} = \sum_{\lambda=780}^{\lambda=1400} L_\lambda \bullet \mathcal{R}(\lambda) \bullet \Delta(\lambda) \le \frac{6000}{\alpha}\left[W \bullet m^{-2} \bullet sr^{-1}\right] \quad \text{(EQ. 7)}$$

where L_λ is the spectral radiance in $W\text{-}m^{-2}\text{-}nm^{-1}\text{-}sr^{-1}$. Angular subtense, α_{eff}, is in rad and t in s. The burn hazard weighted radiance for weak visual stimulus can be approximated using IR-LED datasheet values as in Equation 8.

$$\left(L_{IR} \approx \frac{I_e \bullet \mathcal{R}(\lambda)}{\{(L + w)/2\}^2}\right) \quad \text{(EQ. 8)}$$

Intersil Eye Safety Calculator

To assist Intersil Proximity sensor customers with eye safety determination for their product designs, we provide a simple spreadsheet calculator accessible on the Intersil Corporate Webpage .

In the calculator, the user enters information in the *blue* fields and makes a selection from a drop-down menu in the *tan* fields. If an entered value is outside the acceptable range, the *blue* field will turn *yellow*.

The Calculator is subdivided into five sections. The first section, shown in Figure 2 on page 4, is for entering information about the IR-LED that the designer has chosen to use for the proximity sensing function. This information is available in the IR-LED manufacturer's product datasheet. There are several types of LED packages commonly used for proximity sensing: parabolic reflector, lensed, and bare-die. Typically, the bare-die option is valid only for proximity sensors with an integrated IR-LED - such as the Intersil ISL29043. In this case, the relevant information may be found in the Intersil ISL29043 datasheet. Based on the LED type, the active area of the source needed for the eye safety hazard determination is calculated.

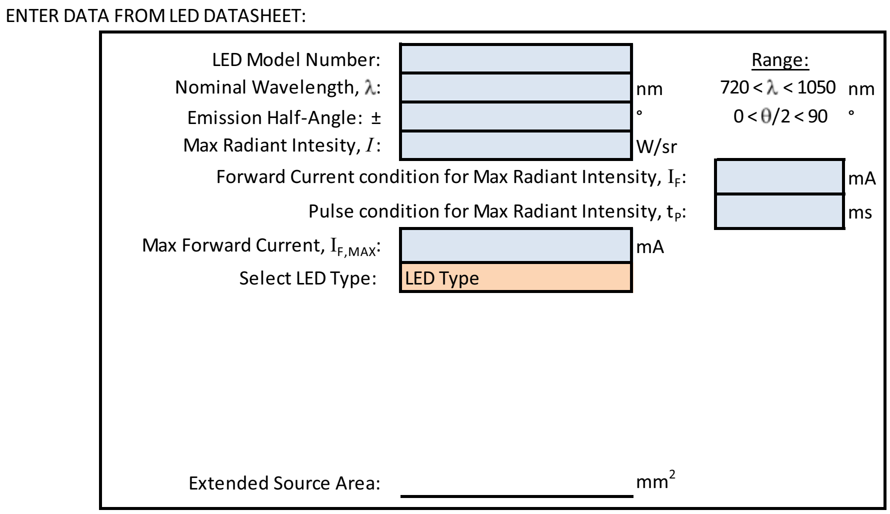

FIGURE 2. IR-LED DATA ENTRY SECTION

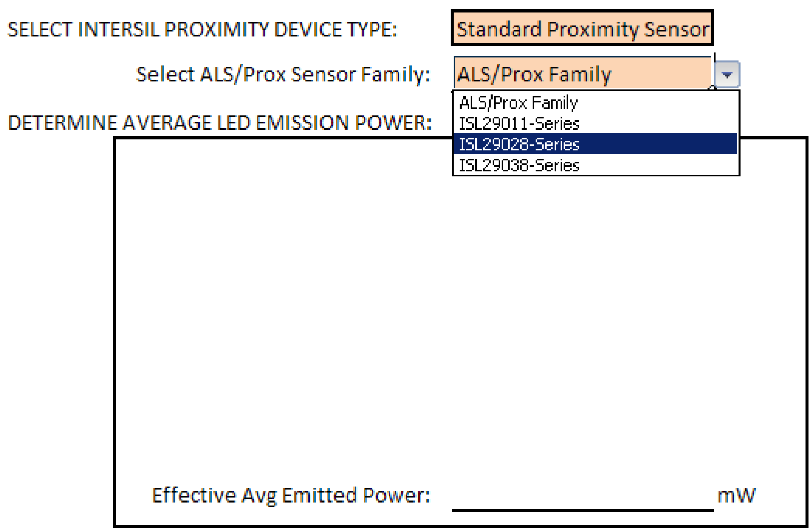

FIGURE 3. INTERSIL PRODUCT SELECTION

In the second section, Figure 3, the Intersil Proximity product is selected. Depending on this selection, additional information is required. For "Standard Proximity Sensors," there are three Intersil device families. Proximity operation is slightly different between these families. Upon selection of one of the three families, a product list will appear showing all of the Intersil products in each family. The designer should use this list to verify selection of the correct product family.

All Eye Safety calculations are highly dependent on the time duration of the IR-LED radiant output. Most Proximity sensing systems utilize pulsed operation.

Determining the average radiant emission flux for these cases can be complicated. The Calculator takes care of this calculation for the designer based on a few additional selection choices. Each of these selections directly relates to register settings for the particular Intersil Proximity product. The designer should have the appropriate Intersil product datasheet on hand for details regarding each of these selections. For each Intersil Proximity product family, the IR-LED drive current (IRDR Current) must be selected. For the ISL29011 family, select the Modulation Frequency, and for the ISL29028 and ISL29038 families, select the Proximity Sleep Time (see product datasheets for details).

The third section, Figure 4 on page 5, simply asks for the distance from the IR-LED to the Eye. The note in the Calculator references the IEC-62471 Standard that 200 millimeters is the correct distance for all IEC-62471 hazard calculations. The LED-Eye distance is left to be filled in so that the designer can determine at what distance the configuration may become unsafe.

The last two sections, Figure 5 on page 5, provide the results of the Eye-Safety calculations: Corneal Exposure in section four and Retinal Thermal Hazard in section five. To complete the calculation, the user should enter an exposure duration in seconds. Once this has been entered, the remaining results will be displayed.

For each calculation step in the Calculator, the relevant IEC-62471 Equation, or Table is referenced for convenience.

If the Exposure Time in the third section is less than 10s, the Retinal Thermal Hazard - Weak Visual Stimulus result will display, "N/A," since this result only is valid for exposure times exceeding 10s. If, based on the data entered and the conditions selected, the design should fail any of the Eye-Safety hazard calculations, the result field for that hazard will turn RED - clearly indicating the failure.

VIEWING CONDITION:

Fully Dilated Eye Pupil:	7	mm	Ref: IEC62471: Hazard Values reported for 200mm Source-Eye separation
Distance from LED to EYE:		mm	
Angular Subtense of Source, α:		r	
BURN HAZARD WEIGHTING FUNCTION, $\mathcal{R}(\lambda)$:			Ref: IEC62471, Table 4.2

FIGURE 4. VIEWING CONDITION - LED-TO-EYE DISTANCE

CORNEAL EXPOSURE HAZARD: $780 < \lambda < 3000$ nm

Exposure Time:		s	
Corneal Exposure, E_e:		W/m^2	Ref: IEC62471, Eqn. 4.11
Exposure Limit, E_{IR}:		W/m^2	Ref: IEC62471, Eqn. 4.11
Safety Factor, E_{IR}/E_e:			

RETINAL THERMAL HAZARD: $380 < \lambda < 1400$ nm

Exposure Time:	0	s	
Angular Subtense on Retina, α_{eff}:		r	Ref: IEC62471 Table 5.5
Burn Hazard Weighted Radiance, L_R:		$W/m^2/Sr$	Ref: IEC 62471 Eqn 4.9
Burn Hazard Weighted Radiance Limit:		$W/m^2/Sr$	Ref: IEC 62471 Eqn 4.9
Safety Factor, Limit/L_R:			
Retinal Thermal Hazard - Weak Visual Stimulus: $780 < \lambda < 1400$ nm			
Near Infrared Radiance, L_{IR}:		$W/m^2/Sr$	Ref: IEC 62471 Eqn 4.10
Retinal Thermal Hazard Limit:	**N/A**	$W/m^2/Sr$	Ref: IEC 62471 Eqn 4.10
Safety Factor, Limit/L_{IR}:	**N/A**		

FIGURE 5. EYE SAFETY HAZARD DETERMINATION

Example Calculations

For a mobile phone product design, select the OSRAM SFH4650-T IR-LED and the Intersil ISL29028A ALS/Proximity Sensor. Fill in the IR-LED data from the OSRAM SFH4650 datasheet: Nominal (Center) Wavelength is 850nm; Emission Half-Angle is 15°; Maximum Radiant Intensity (for the -T version) is 50mW/sr at 100mA drive current in 20ms pulses; Rated Maximum Forward Current is 100mA; LED Type is Parabolic Reflector with 1.0mm diameter. The resultant Active Area of the source, then, is 0.785mm^2, as shown in Figure 6.

The ISL29028A ALS/Proximity sensor product is in the ISL29028 family. The Proximity Sleep Time is chosen as 100ms (a typical value that reduces sensitivity to interior lamp flicker) and the IRDR current is chosen as 110mA. The resultant Effective Average Emitted Power is 0.055mW, as shown in Figure 7.

ENTER DATA FROM LED DATASHEET:

			Range:
LED Model Number:	SFH4650		
Nominal Wavelength, λ:	850	nm	$720 < \lambda < 1050$ nm
Emission Half-Angle: ±	15	°	$0 < \theta/2 < 90$ °
Max Radiant Intesity, I:	50	mW/sr	
Forward Current condition for Max Radiant Intensity, I_F:	100	mA	
Pulse condition for Max Radiant Intensity, t_P:	20	ms	
Max Forward Current, $I_{F,MAX}$:	100	mA	
Select LED Type:	Parabolic Reflector		
Enter Reflector Diameter:	1	mm	
Extended Source Area:	**0.785**	mm^2	

FIGURE 6. EXAMPLE LED DATA FOR SFH4650 IR-LED

SELECT INTERSIL PROXIMITY DEVICE TYPE:	Standard Proximity Sensor	
Select ALS/Prox Sensor Family:	ISL29028-Series	
DETERMINE AVERAGE LED EMISSION POWER:		
Select Prox Sleep Time:	100	ms
Select IRDR Current:	110 mA	
Effective Avg Emitted Power:	**0.054704595**	mW

FIGURE 7. INTERSIL PRODUCT SELECTION

The LED-to-eye distance of 200mm is entered to adhere to the IEC-62471 Standard. The resultant Angular Subtense, α, is 5 milli-radians, as shown in Figure 8. The Burn Hazard Weighting Function, $\mathcal{R}(\lambda)$, is 0.50, also shown in Figure 8. Lastly, the Exposure Time of 5s is entered in the Corneal Exposure Hazard section, as shown in Figure 9.

Figure 9 shows that, for this case, the Corneal Hazard is well within the Limit. The Safety Factor is 4 x 10^6 - i.e., the Corneal irradiance is one-four-millionth of the Corneal Hazard Limit according to the IEC Standard. Figure 9 further shows that since the entered Exposure Time is less than 10s, the Weak Visual Stimulus Retinal Thermal Hazard does not apply and that the Retinal Thermal Hazard is 2 x 10^5 below the IEC Standard Limit.

Now, consider the following case: The IRDR current for the ISL29028A is increased to 220mA; the LED-to-eye distance is reduced to a mere 1.0mm; and the Exposure Time is increased to 1000s (>16 minutes). The Angular Subtense of the source has increased to 1 radian due to the closeness to the Eye.

VIEWING CONDITION:

Fully Dilated Eye Pupil:	7	mm	Ref: IEC62471: Hazard Values reported for 200mm Source-Eye separation
Distance from LED to EYE:	200	mm	
Angular Subtense of Source, α:	**0.005**	r	
BURN HAZARD WEIGHTING FUNCTION, $\mathcal{R}(\lambda)$:	**0.501187**		Ref: IEC62471, Table 4.2

FIGURE 8. LED TO EYE DISTANCE ENTERED ACCORDING TO IEC STANDARD

CORNEAL EXPOSURE HAZARD: $780 < \lambda < 3000$ nm

Exposure Time:	5	s		
Corneal Exposure, E_e:	**0.001**	W/m^2		Ref: IEC62471, Eqn. 4.11
Exposure Limit, E_{IR}:	**5383.26**	W/m^2	**t<1000s**	Ref: IEC62471, Eqn. 4.11
Safety Factor, E_{IR}/E_e:	**3936236.50**			

RETINAL THERMAL HAZARD: $380 < \lambda < 1400$ nm

Exposure Time:	5	s		
Angular Subtense on Retina, α_{eff}:	**0.0078**	r		Ref: IEC62471 Table 5.5
Burn Hazard Weighted Radiance, L_R:	**34.909**	$W/m^2/Sr$		Ref: IEC 62471 Eqn 4.9
Burn Hazard Weighted Radiance Limit:	**6687403.05**	$W/m^2/Sr$		Ref: IEC 62471 Eqn 4.9
Safety Factor, Limit/L_R:	**191568.27**		**10 µs ≤ t ≤ 10 s**	
Retinal Thermal Hazard - Weak Visual Stimulus: $780 < \lambda < 1400$ nm				
Near Infrared Radiance, L_{IR}:	**34.909**	$W/m^2/Sr$		Ref: IEC 62471 Eqn 4.10
Retinal Thermal Hazard Limit:	**N/A**	$W/m^2/Sr$		Ref: IEC 62471 Eqn 4.10
Safety Factor, Limit/L_{IR}:	**N/A**			

FIGURE 9. EYE SAFETY HAZARD CALCULATION RESULTS

The Eye-Safety calculation results are shown in Figure 10. The total Corneal irradiance exceeds the Hazard Limit by approximately 7%. The Safety Factor has dropped to 0.93 (from 4 x 10^6, previously) and the result field has turned RED. Also, the warning, FAILS EYE SAFETY, is indicated next to the results field.

Since the Exposure Time now is greater than 10s, results are displayed for the Weak Visual Stimulus Retinal Thermal Hazard and the Safety Factor is only 8 x 10^3. The Retinal Thermal Hazard has increased by a factor of two. However, the Burn Hazard weighted Limit has decreased by a factor of eight, reducing the Safety Factor from 2 x 10^5 to 1 x 10^4, a factor of 16x.

CORNEAL EXPOSURE HAZARD: $780 < \lambda < 3000$ nm

Exposure Time:	1000	s	
Corneal Exposure, E_e:	**109.409**	W/m^2	FAILS EYE SAFETY
Exposure Limit, E_{IR}:	**101.22**	W/m^2	**t<1000s**
Safety Factor, E_{IR}/E_e:	**0.93**		

RETINAL THERMAL HAZARD: $380 < \lambda < 1400$ nm

Exposure Time:	1000	s	
Angular Subtense on Retina, α_{eff}:	**0.0110**	r	
Burn Hazard Weighted Radiance, L_R:	**69.817**	$W/m^2/Sr$	
Burn Hazard Weighted Radiance Limit:	**808308.82**	$W/m^2/Sr$	
Safety Factor, Limit/L_R:	**11577.46**		
Retinal Thermal Hazard - Weak Visual Stimulus:	$780 < \lambda < 1400$ nm		
Near Infrared Radiance, L_{IR}:	**69.817**	$W/m^2/Sr$	
Retinal Thermal Hazard Limit:	**545454.55**	$W/m^2/Sr$	
Safety Factor, Limit/L_{IR}:	**7812.58**		**t > 10 s**

FIGURE 10. FAILING EYE SAFETY HAZARD CALCULATIONS

Light Source Risk Groups

The IEC standards committee that developed the IEC-62471 standard included risk classification for both continuous-wave and pulsed lamps and LEDs. There are four risk groups, or classifications:

1. Exempt Group
2. Risk Group 1 (Low Risk)
3. Risk Group 2 (Moderate Risk)
4. Risk Group 3 (High Risk)

Relative to Near-Infrared illumination, the definitions for the four Risk Groups are as follows:

Exempt Group

The requirement is met by any device that does not pose:

- An infrared radiation hazard for the eye (E_{IR}) within 1000 seconds,
- A retinal thermal hazard (L_R) within 10 seconds, nor
- A near-infrared retinal hazard without a strong visual stimulus (L_{IR}) within 1000 seconds.

Risk Group 1 (Low Risk)

The requirement is met by any device that exceeds the limits for the Exempt Group but does not pose:

- An infrared radiation hazard for the eye (E_{IR}) within 100s
- A retinal thermal hazard (L_R) within 10s, nor
- A near-infrared retinal hazard without a strong visual stimulus (L_{IR}) within 100s.

Risk Group 2 (Moderate Risk)

The requirement is met by any device that exceeds the limits for Risk Group 1 but does not pose:

- An infrared radiation hazard for the eye (E_{IR}) within 10s
- A retinal thermal hazard (L_R) within 0.25s (aversion response), nor
- A near-infrared retinal hazard without a strong visual stimulus (L_{IR}) within 10s.

Risk Group 3 (High Risk)

Any device that exceeds the limits for Risk Group 2 is in Risk Group 3.

Pulsed device criteria apply for any single pulse, or any group of pulses within 0.25s. For repetitively pulsed devices (such as used for Proximity sensing), a device whose weighted radiant exposure or weighted radiance dose is below the Exposure Limit (EL) is evaluated using the continuous-wave risk criteria (see previous) using time averaged values of the pulsed emission. The time-averaged values needed for risk group classification are provided in the second section of the eye safety calculator based on the various LED pulse configurations for each Intersil product included in the calculator. Table 2 provides a summary of the IEC-62471 emission limits for the risk groups for continuous-wave emission.

TABLE 2. EMISSION LIMITS FOR RISK GROUPS [7]

RISK	ACTION SPECTRUM	SYMBOL	EMISSION LIMITS			UNITS
			EXEMPT	LOW RISK	MOD RISK	
Retinal Thermal	$\mathcal{R}(\lambda)$	L_R	$28000/\alpha$	$28000/\alpha$	$71000/\alpha$	$W{\cdot}m^{-2}{\cdot}sr^{-1}$
Retinal Thermal, Weak Visual Stimulus	$\mathcal{R}(\lambda)$	L_{IR}	$6000/\alpha$	$6000/\alpha$	$6000/\alpha$	$W{\cdot}m^{-2}{\cdot}sr^{-1}$
IR Radiation, Eye		E_{IR}	100	570	3200	$W{\cdot}m^{-2}$

Eye Safety Failure Mode Effects

While the IEC-62471 Safety Standard provides all of the requirements and evaluation procedures for eye safety for lamps and LEDs under normal continuous or pulsed operation, it does not address atypical operation of these devices. Atypical operation, or Failure Modes for LEDs, lamps and lasers typically are governed by national, rather than international organizations. In the United States, the primary governing body is the Occupational Safety and Health Administration (OSHA) in the US Department of Labor. Additional regulatory issues are covered by the Center for Devices and Radiological Health (CDRH) in the US Food and Drug Administration (FDA). Each of these US agencies publish documents pertaining to laser, lamp and LED safe operation.

When considering safe operation of light sources there are three (3) primary control measure types [8]:

1. Engineering (enclosures, interlocks, light-baffles)
2. Administrative (policies, procedures, training)
3. Personnel protection equipment (eyewear, clothing)

Unfortunately, when considering consumer products, the range of control measures is limited. Administrative control measures are limited to policies governing the manufacture of products containing light-emitting devices and personnel protective equipment provides no solution whatsoever. The emphasis is primarily on engineering control measures or engineered solutions.

Most infrared LEDs (and lasers) used in consumer products fall well within the Exempt Group, or Risk Group 1 (low-risk), as specified in IEC-62471. However, as shown in the previous example, with certain settings the SFH4560 IR-LED and the ISL29028A ALS/Proximity Sensor, can exceed eye safety limits if held 1mm from the eye continuously for nearly 17 minutes. Obviously, this is not typical use. More concerning is what may occur during or due to a device or circuit failure. A device failure of any of the Intersil ALS/Proximity Sensors is extremely unlikely to create a condition in which the LED is driven to, or beyond maximum output - based on the LED driver circuit design. However, a failure on the printed circuit board feasibly could cause a short that would connect the LED directly from the supply voltage to ground - producing continuous output at or above maximum radiant power for a short time period. In a variation of the previous example, a direct connection for the IR-LED across non-current-limited 5VDC would exceed the corneal hazard limit with the LED-to-eye distance of 10mm and an exposure time of only 12s.

As noted previously, there are several means by which failure modes may be managed through engineered solutions.

Enclosures

Most infrared emitting devices in consumer products are "hidden" from view by dark tinted glass or plastic - e.g., TV remotes. However, while eliminating consumer awareness of the device, the tinted material often transmits a very high percentage of the emitted IR radiation. Thus, the tinted material provides little, or no protection during a failure.

Light-baffles

Light-baffles provide a good means to limit the angular extent of the radiant emission. These not only provide a degree of protection for off-optical-axis viewers and reduce interference with other devices, but in some cases, can provide means to reduce power usage. However, light-baffles cannot protect against direct viewing during a failure situation.

Interlocks

An interlock provides an electronic, or mechanical interruption of the radiant emission whenever some specified condition is met - such as, shutting down a high-power light source when the lab door is opened. In simple consumer or commercial products, the interlock often disables the power source for the monitored device.

An example relevant for IR-LEDs and Proximity sensors is as follows:

a) Supply electrical power to the emitting device from an interruptible regulator or converter.

b) Insert a current-monitoring resistor in the LED bias.

c) Control LED power supply based on monitored bias current.

In the event of a PCB short, the LED bias current will exceed specified limits and be detected via the current-monitor. The current-monitor logic will disable the power supply, terminating radiant emission.

Although not a universal solution for Proximity sensing using IR-LEDs, the product designer should consider a practical solution to prevent exceeding eye safety limits during a system failure.

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- AN1436, “Proximity Sensors”

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