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# LED Eye Safety

## Application Note 1109

**LED Device Classifications with Respect to AEL Values as defined in the IEC 825-1 Standard and European Norm EN60825-1**

### Introduction

Several Agilent Technologies (Agilent) Application Briefs (I-008, I-009 and I-015) have been written to explain the impact of recent changes to IEC (International Electrotechnical Commission) 825-1, which added light emitting diodes (LED) device classification to the laser safety standard for eye safety. In this document, light refers to visible and infrared electromagnetic radiation.

Application Brief I-008 gives an explanation of the actions taken by IEC Technical Committee (TC) 76 and CENELEC (European Committee for Electrotechnical Standardization) to correct the overclassification of LED devices during October 1994 through October 1995. During this time period, CENELEC adopted IEC 825-1 as EN60825-1 (EN = European Norm), but also allowed EN60825 (lasers only) to coexist until March 1, 1996. This action allowed manufacturers to ship their laser and LED based product under EN60825 (lasers only) until measurement methods and AEL (Accessible Emission Limit) classification of LED devices could be resolved.

During the October 1995 meeting in Sydney, Australia, IEC TC 76 voted to propose the following amendment for IEC 825-1:

1. LEDs will be included for regulation with the same AEL limit calculations and measurement conditions as lasers,

2. There is a choice of two (2) measurement methods:
   a. Measuring distance is fixed at 100 mm, but the diameter of the collecting aperture is variable based upon the apparent source size of the LED/laser.
   b. Measuring distance is variable based on the apparent source size of the LED/laser, but the collecting aperture diameter is fixed at 7 mm.

3. Calculation of apparent source size for multiple or non-circular sources is added.

4. All other rules for labeling and safety interlocks apply equally to LEDs and lasers.

The above measurement methods provide some relief for laser products which were formally measured at 100 mm fixed distance with the light output collected within a 50 mm diameter aperture. CENELEC has adopted the above proposal as Amendment 11 (October 1996) to EN 60825-1.

CENELEC, which adopts many IEC standards as European Norms, extended the date of withdrawal for EN60825 (lasers only) from March 1, 1996 to January 1, 1997, until their own review process was completed. This allowed equipment manufacturers to ship their products under the older EN60825 (lasers only regulated, no LEDs) until January 1, 1997.

Application Briefs I-009 and I-015 address visible LED device classification for Agilent's Optoelectronics Division. This application note will provide the same measurement information and list the AEL classifications for Agilent's CSSD (Communication Semiconductor Solutions Division) products, which cover a range of wavelengths from visible to infrared (IR).

## AEL (Accessible Emission Limit) Class Determination

AEL determination for LED and laser based products is done in two steps:

1. Calculate the AEL from the formulas provided in the IEC 825-1 and EN60825-1, Tables 1 - 4,
2. Measure the light output power and compare that actual value to the calculated value.

### 1. Calculation of AEL

Examples of visible LED AEL calculations are well covered in Agilent Technologies Application Brief I-015. The examples immediately below show the calculated AEL Class 1 limits for small sources for two common infrared wavelengths: 820 nm and 1300 nm.

Exposure time for LED based communication and illumination applications defaults to 100 seconds. Using this value, refer to Table 1 of IEC 825-1/EN60825-1. Find the appropriate wavelength category and extract the AEL Class 1 formula:

**Example 1:**
**For 820 nm, 100 seconds**

Limit = $7 \times 10^{-4}\ t^{0.75}\ C_4\ C_6$ **J**

$C_4 = 10^{0.002(\lambda - 700)} = 1.7378$
$C_6 = 1$ for $\alpha < \alpha_{min}$

where **J** is the energy in Joules, $\lambda$ is the wavelength in nanometers (nm), and t is the time in seconds (use the default value of 100). For a discussion of $\alpha_{min}$, refer to section 2 below.

Insert the values and calculate the AEL Class 1 limit in Joules:

Limit =
$7 \times 10^{-4}\ 100^{0.75}\ (1.7378)\ (1)$ **J**

Limit = 0.0385 Joules

Convert Joules to milliwatts by dividing by 100 seconds to obtain watts, and multiplying by 1000 to obtain milliwatts (mW):

**Limit = 0.385 mW**

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**Example 2:**
**For 1300 nm, 100 seconds**

Limit = $3.5 \times 10^{-3}\ t^{0.75}\ C_6\ C_7$ **J**
$C_7 = 8$
$C_6 = 1$ for $\alpha < \alpha_{min}$

where **J** is the energy in Joules, $\lambda$ is the wavelength in nanometers (nm), and t is the time in seconds (use the default value of 100). For a discussion of $\alpha_{min}$, refer to section 2 below.

Insert the values and calculate the AEL Class 1 limit in Joules:

Limit = $3.5 \times 10^{-3}\ 100^{0.75}\ (1)(8)$ **J**
Limit = 0.8854 Joules

**Limit = 8.854 mW**

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For devices with an apparent source size of less than 1.1 mm, for 820 nm, the **AEL Class 1** limit is **0.385 mW**; for 1300 nm, the **AEL Class 1** limit is **8.854 mW**.

A third example is for an emitter with larger source size. An infrared lamp at 875 nm wavelength has an apparent source size of 3.1 mm. The calculation proceeds similarly:

**Example 3:**
**For 875 nm, 100 seconds**

Limit =
$7 \times 10^{-4}\ t^{0.75}\ C_4\ C_6$ **J**

$C_4 = 10^{0.002(\lambda - 700)} = 2.2387$
$C_6 = \alpha / \alpha_{min} = 31/11 = 2.8182$

( $\alpha_{max}$ = 100 milliradians > $\alpha$ = 31 milliradians > $\alpha_{min}$ )

Insert the values and calculate the AEL Class 1 limit in Joules:

Limit =
$7 \times 10^{-4}\ 100^{0.75}\ (2.2387)\ (2.8182)$ **J**

Limit = 0.1397 Joules

Again, converting Joules to milliwatts (dividing by the time, 100 seconds), the **AEL Class 1 limit is:**

**1.397 mW**

The examples above were for the lowest AEL Class, Class 1. It is one of a number of classes with different interpretations and restrictions. Calculations for Class 2, Class 3A and Class 3B, corresponding to the Class 1 examples above, can be made using the information in Tables 2, 3 and 4 in the IEC and CENELEC documents. These are summarized in Table 1 on the following page.

### 2. Measurement of the Light Output Power

Under the new proposed amendment to IEC 825-1 (and CENELEC EN60825-1, Amendment 11) the measurement conditions are a function of apparent source size. The amendment defines the measurement conditions in terms of the angle subtended by the source at a distance of 100 mm. How to measure apparent source size is not clearly stated. However, the standard implies the following criterion be used:

> Determine the diameter of a circular aperture, which, placed in the plane of emission, would

**Table 1.**

| Class | Interpretation | Requirements |
|---|---|---|
| 1 | Safe under reasonably foreseeable conditions of operation | Explanatory label on product (optional); must declare class in customer information. |
| 2 | Eye protection is normally afforded by aversion responses including the blink reflex. (400-700 nm only) | Warning label and Class 2 explanatory label on product and in customer information. |
| 3A | Safe for viewing with the unaided eye. Direct intrabeam viewing with optical aids may be hazardous. | Warning label and Class 3A explanatory label on product and in customer information. |
| 3B | Direct intrabeam viewing is always hazardous. Viewing diffuse reflections is normally safe. | Warning label and Class 3B explanatory label on product and in customer information. |
| 4 | Capable of producing hazardous diffuse reflections | Warning label and Class 4 explanatory label on product and in customer information. |

allow 63.2% (1 – 1/e, where e is the base of natural logarithms approximately equal to 2.71828) of the output to pass.

Since many LEDs have a lens structure, the apparent source size may be determined from an optical image of the source.

Given the apparent source size, **a** (in mm), the angular subtense, $\alpha$, of the source at 100 mm distance is given by :

$\alpha = 1000 \times [2 \times \arctan((\mathbf{a}/2)/100)]$ milliradians (mr)

$\alpha \sim 1000 \times [\mathbf{a}/100]$ mr

Arctan is the inverse tangent or arc tangent function, expressed in radian angular measure; x denotes multiplication. A radian (or milliradian) is a measure of angle; an angle of 180 degrees is equivalent to an angle of $\pi$ radians.

Given the angular subtense, the measurement distance, **r**, and corresponding aperture diameter, **d**, (with x denoting multiplication) are determined by:

**r** = 100 mm
**d** = 7 mm
for $\alpha > 100$ mr

$\mathbf{r} = 100 \times \sqrt{(\alpha + 0.46 \text{ mr})/\alpha_{max}}$ mm
**d** = 7 mm
for 100 mr $\geq \alpha > 1.5$ mr

**r** = 100 mm
**d** = 50 mm
for $\alpha \leq 1.5$ mr

where $\alpha_{max}$ is 100 mr for all these calculations. $\alpha = 100$ mr corresponds to a source with **a**~10 mm; $\alpha = 1.5$ mr, corresponds to a source with **a**~ 0.15 mm.

The distance **r** can be expressed in terms of apparent source size, **a**, instead of angular subtense, $\alpha$. Substituting 1000**a** /100 for $\alpha$, and 100 milliradians for $\alpha_{max}$:

**r** = 100 mm
**d** = 7 mm
for **a** > 10 mm

$\mathbf{r} = 100 \times \sqrt{a/10 + 0.0046}$ mm
**d** = 7 mm
for 10 mm $\geq$ **a** > 0.15 mm

**r** = 100 mm
**d** = 50 mm
for **a** $\leq$ 0.15 mm

For the 3.1 mm source in Example 3 above, the measurement distance, **r**, would be
**56.1 mm.**

$\alpha_{min}$, referenced in the preceding section, is dependent on the exposure time. However, for the default case of 100 seconds, $\alpha_{min}$ takes on a value of 11 mr. This corresponds to an apparent device size of 1.1 mm. $\alpha_{min}$ is the smallest angular subtense that the eye can discern; smaller sources appear to be at least this large. Because of involuntary eye and head movements, in 100 seconds (actually, any time greater than 10 seconds) all small sources are “smeared” into a source which appears to be at least 11 mr in apparent angular subtense.

**3. Measurement Setup**

In order to perform the light output

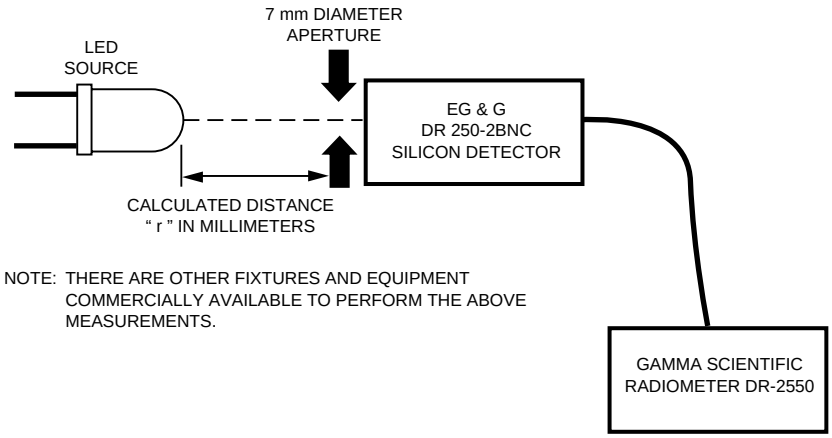


**Figure 1.**

power measurement, the following equipment is needed:
1. Radiometer
2. Detector capable of sensing light at the wavelength of the LED
3. 7 mm circular aperture
4. Variable positioner

**Procedure:**
1. Determine the measurement distance from the formula in section 2.
2. Place the aperture (and detector) at the calculated distance from the LED source, or the nearest optical surface if the LED is behind a window or lens.
3. Turn on the radiometer and detector.
4. Turn on the LED and align it to provide the highest radiometer reading (usually at or near the "head-on" alignment, along the optical axis).
5. Read the detector current (in amps, or milliamps, or microamps) from the radiometer.
6. Using the detector calibration chart or table, (provided by the detector manufacturer), find the detector responsivity which corresponds to the LED peak wavelength.
7. Calculate the power in watts using the following formula:

   Power (watts) =
   [Detector Current (amps)] ÷
   [Responsivity (amps/watt)]

8. Compare the measured power from Step 7 to the calculated AEL Class 1 limit. If the measured power is greater than the Class 1 limit, the actual classification is greater than Class 1 (probably Class 2 for visible LEDs, Class 3A for infrared LEDs). To determine the actual Class, refer to IEC 825-1 for the formulas. If, however, the measured power is less than the Class 1 limit, the source is operating as Class 1.

**4. Fault Conditions**
Quoting from IEC 825-1, Section 8 Tests, 8.1 General:
"Tests during operation shall be used to determine the classification of the product. Tests during operation, maintenance and service shall also be used as appropriate to determine the requirements for safety interlocks, labels and information for the user. Such **tests shall be made under each and every reasonably foreseeable single fault condition.**"

Thus, a manufacturer must determine what reasonably foreseeable single fault conditions may occur. Note the standard does not say "all possible single fault conditions." However, it is recommended that any single faults determined not to be reasonable by the manufacturer be investigated.

For manufacturers incorporating a procured part or module in their final products, two sets of single fault conditions must be considered:
1. Procured part single fault.
2. Failure of the final product exclusive of the targeted procured part which causes the procured part to exceed the AEL class limit.

For 1., the procured part can best be investigated for single fault conditions by the manufacturer, who must inform the customer.

For 2., the final manufacturer must determine the fault conditions (departure from normal operation) which can occur external to the procured part. Secondly, the impact of these fault conditions must be determined.

**5. Classification**
Considering the worst fault under 1. and 2. above, the final manufacturer must use this condition to determine the AEL Classification.

Quoting from IEC 825-1 Section 9 Classification, 9.3 Classification procedures:

"It is the responsibility of the manufacturer or his agent to provide correct classification of a

laser [or LED] product. The product shall be classified on the basis of that combination of output power(s) and wavelength(s) of the accessible laser [or LED] radiation over the full range of capability during operation at any time after manufacture which results in its allocation to the highest appropriate class."

This is not in full agreement with IEC 825-1 Section 8 Tests, 8.1 General:

"Tests during operation shall be used to determine the classification of the product. Tests during operation, maintenance and service shall also be used as appropriate to determine the requirements for safety interlocks, labels and information for the user. Such tests shall be made under each and every reasonably foreseeable single fault condition."

and with IEC 825-1 Section 1 Scope and object, 1.1 Scope:

"… classification by the manufacturer ... shows that the emission level does not exceed the AEL of Class 1 under all conditions of operation, maintenance, service and failure..."

All statements considered, it is recommended that classification be done under the worst reasonable single fault for **operation only. Maintenance** and **service** conditions shall be added to the operation conditions to determine requirements for interlocks (not treated here, and it is unlikely any LED products would require this; refer to IEC 825-1 for more information), labeling and user information.

**6. Labeling and Written Declaration**

Quoting from IEC 825-1 Section 5, Labeling:

"5.1 General  Each laser [or LED] product shall carry label(s) in accordance with the following clauses. The labels shall be permanently fixed, legible, and clearly visible during operation, maintenance or service, according to their purpose. They shall be positioned so that they can be read without the necessity for human exposure to laser [or LED] radiation in excess of the AEL for Class 1. Text borders and symbols shall be black on a yellow background except for Class 1 where this colour combination need not be used.

"If the size or design of the product makes labelling impractical, the label should be included with the user information or on the package.

"5.2 Class 1  Each Class 1 laser [or LED] product shall have affixed an explanatory label (figure 15) bearing the words:

**CLASS 1 LASER [**or **LED] PRODUCT**

or, at the discretion of the manufacturer, the same statement shall be included in the information for the user."

"5.3 Class 2  Each Class 2 laser [or LED] product shall have affixed a warning label (figure 14) and an explanatory label (figure 15) bearing the words:

**LASER [**or **LED] RADIATION DO NOT STARE INTO BEAM CLASS 2 LASER [or LED] PRODUCT**

"5.4 Class 3A  Each Class 3A laser [or LED] product shall have affixed a warning label (figure 14) and an explanatory label (figure 15) bearing the words:

**LASER [**or **LED] RADIATION DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 3A LASER [**or **LED] PRODUCT**

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## AEL Classification of OCD Products based on proposed IEC 825-1 amendment.

| Device Model Number | Wavelength (nm) | AEL Class 1 Limit (mW) | Total Output Power (mW) | IEC 825-1 AEL Class |
|---|---|---|---|---|
| HFBR-0300 | 1300 | 8.854 | 0.079 | 1 |
| HFBR-0400 | 820 | 0.385 | 0.199 | 1 |
| HFBR-13X2 | 1300 | 8.854 | 0.079 | 1 |
| HFBR-14X4 | 820 | 0.385 | 0.199 | 1*** |
| HFBR-15X1 | 660 | 0.221 | 0.174 | 1 |
| HFBR-15X2 | 660 | 0.221 | 0.355 | 1* |
| HFBR-15X3 | 660 | 0.221 | 0.355 | 1* |
| HFBR-15X4 | 660 | 0.221 | 0.355 | 1* |
| HFBR-15X6 | 660 | 0.221 | 0.204 | 1 |
| HFBR-15X7 | 650 | 0.221 | 1.000 | 1* |
| HFBR-1528 | 650 | 0.221 | 1.122 | 1* |
| HFBR-5103 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5104 | 1300 | 8.854 | 0.063 | 1 |
| HFBR-5105 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5106 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5107 | 820 | 0.385 | 0.063 | 1 |
| HFBR-5111 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5112 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5113 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5203 | 850 | 0.442 | 0.063 | 1 |
| HFBR-5204 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5205 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5207 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5301 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5302 | 1300 | 8.854 | 0.039 | 1 |
| HFBR-5320 | 1300 | 8.854 | 0.039 | 1 |
| HSDL-4220 | 875 | 1.397 | 1.461 | 3A** |
| HSDL-4230 | 875 | 2.550 | 1.766 | 1 |

* The classification of parts marked 1* appear from the table to be above Class 1. However, devices measured under the appropriate calculated conditions show operation to be below the AEL Class 1 limit.

** The classification for the part marked 3A** would be Class 3A for a maximum-efficiency part driven at the maximum rated current. Decreasing the current slightly would change the Class 3A to Class 1, so the final determination of classification is dependent on the design of the equipment.

*** HFBR-14X4 used with fibers of core diameters up to 100-µm is Class 1. However, when used with fiber of 200-µm ( 0.4 numerical aperture ) core diameter, drive currents below 45 mA will give Class 1 operation. Driving the HFBR-14X4 with a 200-µm core diameter fiber at currents above 45 mA may result in Class 3A operation.

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Data subject to change.



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