IEC 825-1 EYE SAFETY CLASSIFICATION OF SOME CONSUMER ELECTRONIC PRODUCTS

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ABSTRACT

The recently amended IEC 825-1 (and consequently CENELEC EN 60825-1) laser safety classification document, incorporates changes from the previous issue which although improve the maximum allowed emitted LED intensity, it still poses problems to the classification of free space optical link products. The changes from the previous issue are mainly concerned with LEDs, allow approximately 50 times higher output optical power from the previous specification.. We show that in spite of the changes, most of the existing free space optical links cannot be classified as class 1. Calculations are given for class 1 classification, based on Accessible Exposure Limits (AEL), of maximum permissible source intensity in mW/Sr, for typical products available in the Market..

Under the umbrella of consumer electronics a considerable number of products are now available making use of Infrared (IR) optical links. The most widespread application of this technology within the consumer electronics market is the television remote control unit. As consumers we now expect to control our televisions remotely and for the new generation of consumers-our children it is the 'norm'. There is hardly a household without remotely controlled televisions. More recently, new "living room entertainment" products have emerged, hi-fi systems using remote control units, and products such as wireless IR, hi-fi audio phones, allowing us to enjoy our music without disturbing others, and at the same time giving us freedom from trailing wires, Fig.1.

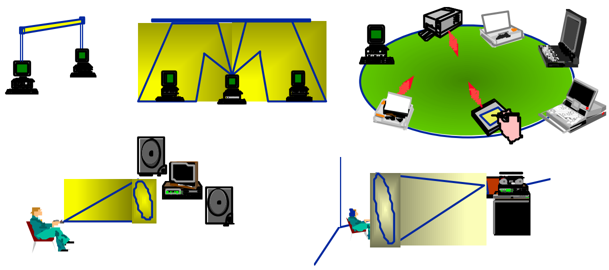

Figure 1: User models of free space IR links.

Computer manufacturers on the other hand have first introduced IR technology for calculators, and recently with the growth of the "mobile conscious" customers, products such as palmtop and laptop computers have appeared making use of IR ports. To a smaller scale, free space IR link technology has also appeared in computer networking. In other applications IR links are used as input devices, ranging from bar code readers, to customer checkout tills in supermarkets and shops for example.
A number of laboratories are exploring the possible future use of high speed IR links for ATM. Networking Personal Computers, portable and palmtop computers is also desirable

as well as direct wireless links to printers, (Fig. 1). The success of free space IR technology is attributed to a number of reasons. Firstly, low cost LEDs or IRLEDs together with low cost transceiver electronics are essential for the early adoption of the technology. This has allowed manufacturers to "test the ground", and to "educate" the customer on the advantages of the technology without incurring major cost premiums. Secondly, unlike radio links, freedom from regulatory bodies controlling the IR spectrum, and thirdly low power consumption.
This technology is part of a multi billion dollar business and needless to say of great importance to many manufacturers and consumers alike.
The Infrared Data Association, (IRDA), an industrial body of about one hundred companies interested to set an industry standard for IR links, has already adopted a standard data rate of 115.2kbit/s for the link and has voted in April 1995 for higher speeds, 1 and 4 Mbit/s. The IRDA standard has the momentum to become the industry standard for future wireless links, with tremendous market potential.
Eye safety of such products is taken for granted and very few of us are concerned when children are playing with TV remote control units. Certainly I am not aware of any accidents in this front. As a consumer however I would be sceptical in purchasing products with safety warning labels on them and I am sure manufacturers would be unhappy to realise that their product should be labelled as such.

Class 1 Eye Safety Specification

The natural focusing properties of the eye may concentrate the optical radiation (400-1400nm) and create exposure conditions which could damage the retina. The retina is the most sensitive part of the eye, and most vulnerable to thermal burns, Fig.2.
The wavelength, exposure duration, and pulse characteristics, distance from the eye, image size, are all factors relating to the maximum safe exposure.

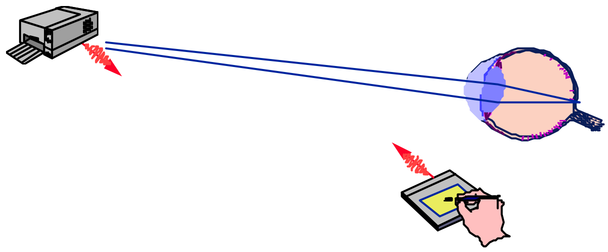

Figure 2: Eye retina, most sensitive to damage from IR

The majority of the products mentioned above utilise IREDs of wavelength between 750 nm-970 nm.
Most countries follow the hazard classifications as defined in the International Electrotechnical Commission (IEC) document IEC 825-1, which defines the maximum exposure limits.
The IEC 825-1 document has tighten the safety classification requirements of "free space radiator" laser products in the following two aspects:
Firstly the specification does not distinguish between laser diode and LED product emission levels and places them both in the same category.
Secondly, it required measurement of the emitted radiation over a circular aperture of 5 cm diameter, (to simulate the collection of an optical instrument of a stationary laser beam) at 10 cm of the radiating source, (near point of accommodation for children and myopics).
The two changes together imposed severe restrictions on safety classifications of existing and future products.
Manufacturers of IR products, felt that the LED products were overspecified, and have recently been working towards amending the IEC specification.

The most recent IEC 825-1, and consequently CENELEC EN 60825-1, amendments, concerning LEDs, are listed below:
a) The measurement capture aperture is now reduced to 7 mm at a distance 100 mm from the souce, for a time of 100 seconds.
This alone, increases the allowed MPE by approximately 50 times, from the older specification.
Also, for apparent sources subtending an angle ‘a’, measured at a min. distance of 100mm, greater than ‘a(min)’ within a circular aperture stop of 7mm diameter, positioned at a distance r from the source, depending upon the angular distance a (between a minimum of 1.5 mrad and a maximum of a(max) of the source.
The distance r, of the 7 mm measurement aperture from the source is determined by:

$$r = 100\sqrt{\frac{a + 0.46 mrad}{a_{\max}}} \quad mm$$

However, for CENELEC EN 60825-1, the specification would be amended so that the classification is done under worst single fault conditions. Maximum operating conditions are not sufficient. Further, CENELEC EN 60825-1 is equivalent to the law in Europe, hence it is important to comply with this specification.
This last condition may require additional circuitry avoiding its occurance.

In the following calculations, the optical attenuation in the eye and air is assumed negligible.
Table 1 summarises the results of the calculations, relating to typical IRLED products.

	Typical product, emission intensity	Max. Optical source Intensity IEC 825-1	Optical Power, Class 1 limit IEC 825-1
TV Remote	70-300 mW/Sr	91.8 mW/Sr	0.7 mW
Audio Phones	240 mW/Sr	577 mW/Sr	8.8 mW
IRDA links	40-500 mW/Sr	1165 mW/Sr	8.8 mW

Table 1: Calculated maximum optical source intensities and optical power on retina, for class 1 classification.

The IRDA links calculations correspond to 115.2 kbit/s standard data rate.
The table is a summary of the detailed calculations found in the appendix.

Future changes in IEC 825-1 document:

Table 1 indicates that some IR products do not comply with class 1 specification.
There is also the unknown factor, that of ‘worst single fault condition’ which may not be avoidable. The calculations in table 1, are for maximum operating conditions, which may not be enough. It very much depends on the product itself, if it is designed to avoid the worst single fault condition, or if it is radiating low enough energy which is class 1 even for the worst case result.
There may be a good case to argue for a modification in the time factor of 100 seconds the user may unintentionally view the radiating source, in view of the fact that the sources emit nearly invissible light. (It is difficult to focus to an invissible source for long periods of time.
Future product needs would require even faster data rate or bandwidth optical links, and as a result the optical power transmitted should be increased in order to maintain the link distance which is already small (a few meters), since receiver sensitivity improvement is not always a preferred alternative. This highlights the design and safety conflicts the industry is currently facing.

The main conclusion here is that the new IEC 825-1 safety specifications are a severe headache to product manufacturers, since some products have exceeded or are near the class 1 limit.

Finally, the fact that optical links are approaching and even exceed safety classification threshold limits already, demonstrates the need that safety limits must become integral part of product design from the onset of projects rather than being left as a last minute test that they conform prior to release.

APPENDIX: SAMPLE CALCULATIONS

TV Remote Control Units:

Pulse Position Modulation is commonly used as the modulation scheme in TV remote control units. Repeated pulse burst envelopes of 0.52 msec duration, with 20 pulses of $10 m\sec$ pulse width, and period of $25.8 m\sec$ have been measured in a typical device.
The position and number of pulses varies depending on the control function. The optical wavelength of the LED was 950 nm, and it is known that TV remote controllers' emission intensity lies in the region of 70-300 mW/Sr.

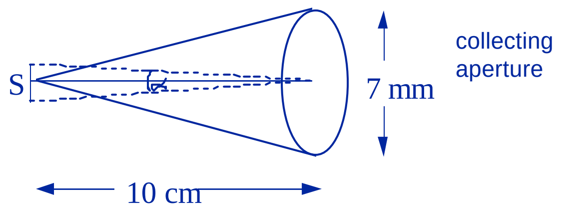

Figure 3: A 7 mm diameter aperture subtends the radiating source S at a solid angle $a_1 = 0.0076$ Sr. The radiation intensity captured must be less than the maximum specified by IEC.

The AEL for Class 1 products, and for wavelengths from 700-1050 nm is given by the general formula

$$AEL_s = 7 * 10^{-4} * t^{0.75} * C_4 * C_6 \ \ Joules \ ....(1)$$

where $C_4 = 10^{0.002(l - 700)}$ is a wavelength correction factor, t , is the exposure time, and

$$C_6 = 1 \qquad for\ a \le a_{\min}$$
$$C_6 = a / a_{\min} \qquad for\ a_{\min} \le a \le a_{\max}$$
$$C_6 = a_{\max} / a_{\min} \quad for\ a \ge a_{\max}$$

a is the solid angle in radians the source S subtends the aperture,

$a_{\max}$=0.1 rad,

$$a_{\min} = 11 mrad \ \ for\ t \ge 10\sec$$
$$= 1.5 mrad \ \ for\ t \le 0.75\sec$$
$$= 2t^{3/4}\ mrad \ \ for\ 0.75 \le t \le 10\sec$$

where C_6 is a correction factor for the finite size of the radiating source, and AEL_s is the AEL for a single pulse width.

For repetitively pulse or modulated laser the AEL is the most restrictive of:

a) The AEL from any single pulse within the pulse train should be less than AEL_s

b) The average power of a pulse train of duration equal to T should be less than the AEL for a single pulse of duration T.

c) The exposure from any single pulse within the pulse train should be less than AEL_s multiplied by the correction factor C_5

$$AEL_{train} = AEL_s * C_5$$

where $C_5 = N^{-1/4}$, N being the number of pulses in the pulse train within the appropriate time base.

a) A remote control unit LED with 5 mm dye, would subtend the 5 cm aperture with an angle $a = 50 mrads$. Hence

$$C_6 = 50 mrads / 1.5 mrads = 33.3,$$
$$C_4 = 10^{0.002(950-700)} = 3.16, \ \ and\ t = 10 m\sec,$$
$$then,\ AEL_s = 7 * 10^{-4} * (10ms)^{0.75} * 3.16 * 33.3 \ \ Joules$$
$$AEL_s = 13.1 mJ \ .$$

The peak power of this single pulse is 1.31 W.

b) For T=100 sec

$C_6 = 50\,mrad / 11\,mrad = 4.55 \quad hence$

$AEL_{(100s\,pulse)} = 7*10^{-4}*(100)^{0.75}*3.16*1 = 70\,mJ$

The max. power of this pulse is 0.7 mW.

This corresponds to 0.7/0.007625=91.8 mW/Sr source intensity.
Where 0.007625 is in Sr, the solid angle, the 7mm diameter aperture subtends the source, at a distance r from the source of 71.04 mm.
The distance r is calculated from the formula for r, given above, when a=50mrad. (5mm/100mm).

c) N=20 pulses/sec*100s=2000 pulses.

$C_5 = (2000)^{-0.25} = 0.15$

$AEL_{train} = AEL_s * C_5 = 13.1 mJ * 0.15 = 1.965 mJ$

The power of this pulse train is

$1.965 mJ / 25.8 ms = 76.1 mW$

From the above, case b) is the most restrictive, and becomes the limit.

Audio Phones

A typical audio phone transmitter may have up to 10 LEDs transmitting simultaneously at an optical wavelength of 870 nm. Left and right channels may be on sub carrier frequencies such as 2.25 MHz and 2.75 MHz. Assuming an effective sub carrier modulation frequency of 2.5 MHz, we can determine the ALE of a single period 'pulse' first as:

a) For f=2.5 MHz, T=400 ns and

$$\begin{aligned} AEL_s &= 2.*10^{-7}*C_6*C_4\ Joules \\ &= 2.*10^{-7}*33.3*3.16 \\ &= 21.0 mJ \end{aligned}$$

b) For T=100 secs, a single pulse would have:

$$\begin{aligned} AEL_{100s} &= 7.*10^{-4}*(100)^{0.75}*C_6*C_4\ Joules \\ &= 7.*10^{-4}*(100)^{0.75}*2.19*9.1 \\ &= 0.44\,J \end{aligned}$$

since $C_4 = 2.188 \ \ for \ \ l = 870\,nm \ \ and$
$C_6 = a_{\max} / a_{\min} = 100/11 = 9.1$

This energy, corresponds to 0.44/100=4.4 mW optical power.
Assuming 50% duty cycle, corresponds to 8.8 mW peak power, or 577 mW/Sr source intensity.

c) Finally for this case,

$$\begin{aligned} AEL_{train} &= AEL_s * C_5 \\ &= AEL_s * N^{-0.25} \\ &= 21.0*10^{-6}*(250*10^{6})^{-0.25} \\ &= 0.167\,mJ \end{aligned}$$

This energy must not be exceeded from a single pulse (oscillation half period in this case) within the train.
In terms of received optical power, the limit is $0.167\,mJ / 0.2\,m\sec = 0.835$ W.

From the above, case b) is more restrictive, and becomes the limiting AEL.

IRDA Links

Infrared optical links based on the Infrared Data Association (IRDA) standard, may operate currently up to 115 kbit/s. Proposals for higher speed links are planned for the near future, at 4 or 10 Mbit/s data rate.
Such links have LEDs emitting between 850-900 nm. For the calculations we assume 850 nm. We also assume a 5 mm source (LED dye) transmitting at 115.2 kbit/s
For the first requirement in IEC 825-1, we have:

a) $AEL_s = 2.*10^{-7}*C_6*C_4\ Joules$

In this case,

$C_4 = 2$
$a = 50\,mrad$,
$a_{\min} = 1.5$ mrad, (since the pulse duration is less than 0.7s), $a_{\max} = 100$ mrad, and
$C_6 = a / a_{\min} = 33.33$.
Hence $AEL_s = 2 * 10^{-7} * 2 * 33.33 = 13.33 mJ$
Dividing this number by the pulse duration, ($1.63 m\sec$), we obtain the maximum allowed peak power, under this condition.
Maximum peak pulse power=8.18 Watts.

For the second requirement we have:

b) T=100 secs,
$a = 50\,mrad, a_{\min} = 11 mrad$ and
$C_6 = a / a_{\min} = 4.55$, and $C_4 = 2$
Hence from the tables in IEC 825-1 we have:

$$AEL_{100s} = 7.*10^{-4} * (100)^{0.75} * C_6 * C_4 \ Joules$$
$$= 0.2\,J$$

Which translates into 2 mW optical power for this single pulse. In the IRDA specification, 9 out of 10 bits may be pulses, 4/16 of a bit period. Hence the maximum power of IRDA signal is:

$$(16 / 4) * (10 / 9) * 2.0 \ mW = 8.88 \ mW$$

In terms of source intensity, this corresponds to a maximum of 1165 mW/Sr.
c) Finally, in the same way as in the previous examples, the exposure from any single pulse within the pulse train shall not exceed the AEL for a single pulse multiplied by the correction factor C_5.
In this case C_5.=$(115200 * 100)^{-0.25}$=0.017, and since $AEL_s = 13.3 mJ$, then $AEL_{train} = 0.23 mJ$. Which corresponds to a maximum pulse power of 0.23/1.63=141 mW.

Out of cases a), b), and c), case b) is more restrictive and supersedes the other two.

References:
1: Deriving Exposure Limits: David Sliney, SPIE Vol. 1207 Laser Safety, Eyesafe Laser Systems, and Laser Eye Protection, 1990, pp 2-13
2. IEC 825-1 publication, 1993