

# EYE SAFETY ISSUES OF FREE SPACE OPTICAL LINKS

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The recent IEC 825-1 laser safety classification document, incorporates two major changes from previous issues which drastically affect free space optical link products. The changes are a) no distinction between laser and LED radiation for ocular exposure, and b) classification measurements should be done with a receiving aperture of 5 cm. We show that as a result, 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. It is deduced that if this latest classification is accepted widely, that the transmitted power of the links must be reduced, hence affecting the range of operation. It is clear that the manufacturers involved in this technology must take an active role in understanding the reasons behind the changes which have occurred and in the shaping of such regulations in a manner that it would be possible for this important technology to be incorporated safely into products.

**Dr. ANTHONY BOUCOUVALS**

**PERSONAL BIOGRAPHY**

Dr. Anthony Boucouvalas has joined Bournemouth University as a Reader in Communications Engineering. He has recently moved to Bournemouth from Hewlett Packard laboratories. Tony has eleven years industrial research experience in the field of fibre optics, optical communications, optical networks, optical instrumentation and sensors.

He said that "For the first time in my career I am free to work with interested companies in mutually beneficial projects. We are interested in multimedia technologies, and we see this as a major growth area. Under this 'umbrella', we also hope to do research in fibre optics and related fields". He can be contacted at: Bournemouth University, School of Electronics, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB Tel: 01202-595435.

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

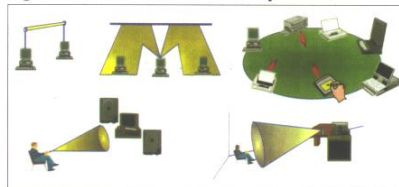
hardly a household without remotely controlled televisions. More recently, new 'living room entertainment' products have emerged, hi-fi systems using remote control units, and products such as wireless IR, hi-fi audio phones, allowing us to enjoy our music without disturbing others, and at the same time giving us freedom from trailing wires, Fig.1.

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

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Figure 1: User models of free space IR links.



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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.

Last year, saw the formation of Infrared Data Association, (IRDA), an industrial body of about one hundred companies interested to set an industry standard for IR links. IRDA 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 very sceptical in purchasing products with safety warning labels on them and I am sure manufacturers would be very 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 limits.

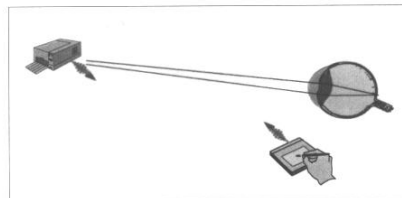


Figure 2: Eye retina, most sensitive to damage from IR

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 recent IEC 825-1 document has tightened 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 requires 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 impose severe restrictions on safety classifications of existing and future products. In the following calculations, the optical attenuation in the eye and air is assumed negligible.

The calculations also assume a 10 cm distance between the 5 cm aperture and the radiating source, as currently specified by IEC 825-1.

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	3.5 mW/Sr	0.7 mW
Audio Phones	240 mW/Sr	44.9 mW/Sr	4.4 mW
IRDA links	40-500 mW/Sr	60 mW/Sr	11.9 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. All product categories examined are outside or very near the border of class 1 specification.

### FUTURE CHANGES IN IEC 825-1 DOCUMENT

Table 1 indicates that IR products emit approximately an order of magnitude above class 1.

The 5 cm diameter receiving aperture and the non-distinction between lasers and LEDs has shifted the balance against product manufacturers of free space IR products at the moment. It is also obvious that the 5 cm viewing aperture is excessive, since it is not the normal operation mode of such products to be viewed with optical instruments, as it may be in the case of optical fibres, for example, where workers may use microscopes to view optical fibre ends. It is more appropriate to use a 7 mm diameter collection aperture, equivalent to the iris diameter. There may be a good case to argue for a modification in the correction factor  $C_s$ , dealing with the (see appendix below) finite source size.

What is clear however, is that manufacturers of such products must work within IEC to influence such decisions early on, hence avoiding unnecessary confusion on the issue, without compromising the safety of consumers. This I understand is already well underway.

Working group 1 consisting of delegates from all major manufacturers was given permission at the IEC TC 76 meeting last October, to generate an amendment proposal to the IEC 825-1 document. The changes are aimed to facilitate the use of LEDs in products within class 1. If the proposal is voted in, then IEC could enforce the changes by early next year.

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 a preferred alternative. This highlights the design and

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safety conflicts the industry is facing.

The main conclusion here is that the new IEC 825-1 safety specifications are severely restricting the existing as well as future product safety classification, based on free space IR links. This has resulted by the non-distinction in the spec., of radiation from LEDs and lasers, as well as from the change to a 5 cm diameter collection aperture in calculating the AEL.

There is a need for further discussion on safety calculations, the validity of the changes, as well as in influencing the specification process so as to allow this important technology to grow into future products without compromising consumer safety.

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.

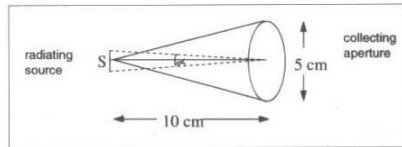
### APPENDIX: SAMPLE CALCULATIONS

#### 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 0µ sec pulse width, and period of 25.8µ 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 5 cm diameter aperture subtends the radiating source 5 at a solid angle  $\alpha$ , = 0.196Sr. 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  $AEL_s = 7 * 10^{-4} * t^{0.75} * C_a \text{ Joules ...}(1)$

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

$C_a = 1$  for  $a \leq a_{min}$   
 $C_a = a / a_{min}$  for  $a_{min} \leq a \leq a_{max}$   
 $C_a = a_{max} / a_{min}$  for  $a \geq a_{max}$

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

$a_{max} = 0.1$  rad,  
 $a_{min} = 11 \text{ mrad}$ , for  $t \geq 10 \text{ sec}$   
 $= 1.5 \text{ mrad}$ , for  $t \leq 0.75 \text{ sec}$   
 $= 21^{3/4} \text{ mrad}$ , for  $0.75 \leq t \leq 10 \text{ sec}$

where  $C_a$  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  $AEL_s$

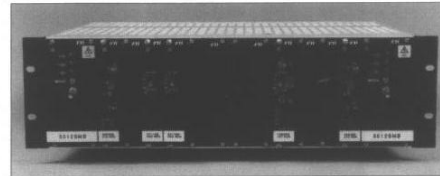
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b) The average power of a pulse train of duration equal to T should be less than the AEL for a single pulse of duration T.

c) The exposure from any single pulse within the pulse train should be less than AEL<sub>s</sub>, multiplied by the correction factor C<sub>3</sub>.

$AEL_{train} = AEL_s * C_3$   
 where  $C_3 = N^{-0.25}$ , 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  $a = 50mrads$ . Hence

$C_6 = 50mrads / 1.5mrads = 33.3$ ,  
 $C_4 = 10^{(0.002/0.950-700)} = 3.16$  and  $t = 10\mu sec$ ,  
 then,  $AEL_s = 7 * 10^{-4} * (10\mu s)^{0.75} * 3.16 * 33.3$  Joules  
 $AEL_s = 13.1\mu J$ .

The peak power of this single pulse is 1.31 W.

b) For T=100 sec

$C_4 = 50mrad / 11mrad = 4.55$  hence  
 $AEL_{(100s pulse)} = 7 * 10^{-4} * (100)^{0.75} * 3.16 * 1 = 70mJ$   
 The max. power of this pulse is 0.7 mW.

This corresponds to 0.7/0.196=3.57mW/Sr source intensity.

For unaided eye, (viewing naturally without spectacles etc.) for a 7 mm iris diameter, the above safety limit becomes 181 mW/Sr.

(Not in the IEC specification).

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

$C_3 = (2000)^{-0.25} = 0.15$   
 $AEL_{train} = AEL_s * C_3 = 13.1\mu J * 0.15 = 1.965\mu J$   
 The power of this pulse train is  
 $.965\mu J / 25.8\mu s = 76.1mW$

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

$AEL_s = 2 * 10^{-7} * C_6 * C_4$  Joules  
 $= 2 * 10^{-7} * 33.3 * 3.16$   
 $= 21.0\mu J$

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

$AEL_{100s} = 7 * 10^{-4} * (100)^{0.75} * C_6 * C_4$  Joules  
 $= 7 * 10^{-4} * (100)^{0.75} * 2.19 * 9.1$   
 $= 0.44J$

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

This energy, corresponds to 0.44/100=4.4 mW optical power.

Assuming 50% duty cycle, corresponds to 8.8 mW peak power, or 44.9 mW/Sr source intensity.

c) Finally for this case,

$AEL_{train} = AEL_s * C_3$   
 $= AEL_s * N^{-0.25}$   
 $= 21.0 * 10^{-6} * (250 * 10^6)^{-0.25}$   
 $= 0.167\mu J$

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  $0.167\mu J / 0.2\mu sec = 0.835 W$ .

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 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,

$C_4 = 2$   
 $a = 50mrad$   
 $a_{min} = 1.5 mrad$ , (since the pulse duration is less than 0.7s),  $a_{max} = 100 mrad$ , and  $C_6 = a / a_{min} = 33.33$ .  
 Hence  $AEL_s = 2 * 10^{-7} * 2 * 33.33 = 13.33\mu J$  Dividing this number by the pulse duration, (.63μsec), 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  
 $= 0.2J$

Which translates into 2 mW optical power for this single pulse. In the IRDA specification, 9 out of 10 bits may be pulses, 3/16 of a bit period. Hence the maximum power of IRDA signal is:

$(16 / 3) * (10 / 9) * 2.0 mW = 11.9 mW$

In terms of source intensity, this corresponds to a maximum of 60 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<sub>3</sub>.

In this case  $C_3 = (115200 * 100)^{-0.25} = 0.017$ , and since  $AEL_s = 13.3\mu J$ , then  $AEL_{train} = 0.23\mu J$ .

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 Slaney, SPIE Vol. 1207 Laser Safety, Eyesafe Laser Systems, and Laser Eye Protection, 1990, pp 2-13
2. IEC 825-1 publication, 1993

**BIOGRAPHY**

Anthony Boucouvalas graduated from Newcastle upon Tyne University in 1978. In 1979 he received his M.Sc. and D.I.C. degrees in Communication Engineering from Imperial College, where in 1982 he received his Ph.D. degree in Fibre Optics. Subsequently, he worked at GEC Research Laboratories, Hirst Research Centre Wembley, U.K., in the area of Fibre Optics, where he became Group Leader and Chief Scientist, until 1987. In 1987 he joined Hewlett Packard Laboratories in Bristol, as a Project Manager, and worked in the areas of Optical Communications, Optical Networks and Optical Instrumentation. In 1994 he joined Bournemouth University as a Reader in Communication Engineering. He has published over 50 technical publications and numerous patents.