Laser and LED retina hazard assessment with an eye simulator

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Abstract

Optical radiation entering the eye is focused on the retina and produces a focal spot of relatively high energy/power density, depending naturally on the amount of energy or power entering the eye. The size of this focal spot is the critical factor in determining the hazard classification of an optical source.
For laser beams and some other light sources this focal spot is extremely small and hence - the high optical hazard of point sources like laser radiation.
Hazard classification of laser products is commonly conducted by computational methods, assuming the laser source specifications as provided by the device manufacturer are correct.
At the 2009 International Laser Safety Conference we presented a new method of measuring the spot size on the retina by using an eye simulator consisting of a gradual index lens and a beam profiler and its application to the analysis of a laser beam defined by the device manufacturer as a "totally diffused beam".
In this paper we present other applications of the method and measurement results of different point and extended sources, such as a LED array, a laser beam through a telescope and a bulb projector. We then compare this measurement method to computational methods according to IEC safety standards of light and laser sources (IEC 60825 2nd ed. 2007-03, Safety of laser products – Part 1: Equipment classification and requirement (Ref2), and IEC 62471 1st ed. 2007 Photobiological safety of lamps and lamp systems (Ref 1),.
We also include a new calculation method for multiple spots on the retina.

Key Words:

Laser and LEDs Retina hazard assessment, Point source, Extended source, Spot size

Introduction

Laser beam through a telescope, LED array with lenses and a bulb projector radiation when entering the eye, is focused on the retina and may produce there an extremely high energy or power density. If the total amount of energy is high enough they can cause thermal damage. One of the main considerations in the retinal hazard **(**wavelength range of 400 nm to 1400 nm at IEC 60825-1 or 380 nm to 1400 nm at IEC 62471) is the size of the focal spot on the retina - the smaller this becomes, the higher the power/energy density and consequently - the higher the hazard. The smallest focal spot size considered in the updated laser safety standard - the ANSI Z136.1 (2007) Safe Use of Lasers (Ref 1), is 20-30 μm. This spot size is nearly the diffraction limit of the human eye. The retinal spot diameter of 25 μm is equivalent to considering the maximum focal length of the eye, f = 17.2 mm (a lens in air eye model). This angular subtense is the planar angle subtended by the diameter of the apparent source at the eye lens (for illustration - see Figure 1).

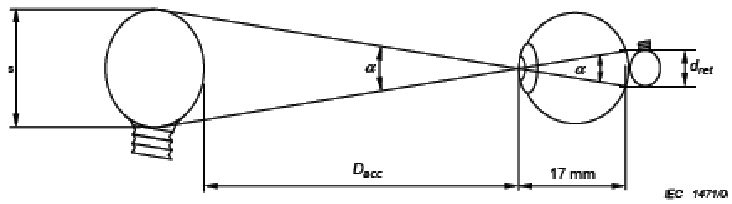

Figure 1: Angular subtence of the extended source (ref 4)

Light emitting diodes (LEDs) have been removed from the scope of IEC 60825-1 2nd ed. and now included in IEC 62471 1st ed.

Measurement of source size for determination of α the angle subtended by a source requires the determination of the 50% emission points of the source. Spectral uniformity should be sufficient. Spectral region from 380 nm to 1400 nm (visible plus IR-A) within which the normal ocular media transmit optical radiation to the retina and in this standard the value for α_{min} is 0.0017 radian (for blink reflex time),

For times greater than about 0.25 second, rapid eye movements begin to smear the image of the source over a larger angle, called α_{eff} in this standard. For exposure times of ten seconds the smeared image of a point source covers an area of the retina equivalent to an angle of about 0.011 radian and for times greater than 10000 s, α_{eff} is set to 0.1 radian.

The retinal thermal hazard exposure limit for a pupil diameter of 7 mm is,

$$L_R = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \leq \frac{50000}{\alpha \cdot t^{0.25}} \quad W \cdot m^{-2} \cdot sr^{-1} \quad (10\mu s \leq t \leq 10s)$$

where:
L_λ is the spectral radiance in $W \cdot m^{-2} \cdot sr^{-1}\ nm^{-1}$,
R(λ) is the burn hazard weighting function,
t is the viewing duration (or pulse duration if the lamp is pulsed), in seconds,
Δλ is the bandwidth in nm,
α is the angular subtense of the source in radians.

The irradiance (E) = radiance (L) X solid angle (Ω), when $\Omega \approx \frac{\pi\alpha^2}{4}$ for distance^2 << Area

We will not analyze thermal hazard exposure limit for weak visual stimulus for near infrared (780 nm to 1400 nm for a pupil diameter of 3 mm). Please notice the low transmission and absorption from 1200 nm (see Figure 2 below) that decreased significantly the retinal burn hazard. Another factor in this wavelength is that the thermal injury is caused by radiation volume absorption and it less depended on the spot size.

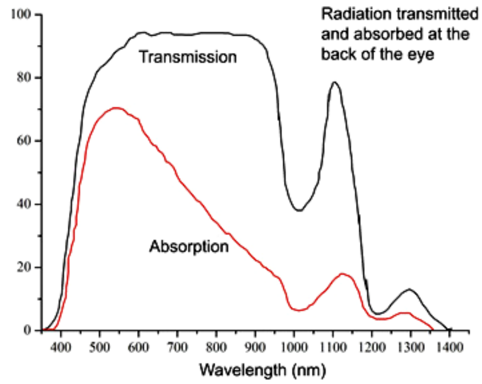

Figure 2:Radiation transmitted and absorbed at the back of the eye
(From Institute Pasteur (2007)

In the IEC 60825-1 (Ref 3), the minimum angular subtense is 1.5 mrad and the maximum angular subtense is 100 mrad. The optical radiation source is defined as "point source" when $\alpha \leq 1.5$ mrad and "extended source" for $\alpha > 1.5$ mrad. For an extended source the MPE should be multiplied by $C_6 = \alpha / \alpha_{min}$ according to IEC (Ref 3) or C_E according to ANSI Z 136.1 (Ref 2).

The Experimental System

In order to measure the image size on the retina, different measurement methods can be used according to the IEC and ANSI standards.

The method presented here utilizes a beam profiler - OPHIR BeamStar FX 66 - which incorporates a high resolution CMOS array (1280 x 960 pixels), pixel spacing - 7.5µm X 7.5µm, with a ±6% linearity of power, Spatial Uniformity of ± 5% and with a 10 bit true system dynamic range, to simulate the retina. The eye optics (air model) is simulated by a gradient index of 18 mm focal length lens (Gradium®) with a 7 mm aperture. The aperture diameter is designed according to the standard requirements (ref. 2). This system has a fixed focal length and a mechanical focusing mechanism. Figure 3 shows the measurement device with the focusing mechanism.

Figure 3, the artificial eye method measurement device

We can use cut off filters to limit the system response to wavelengths of 380 or 400 to1100nm. In order to measure higher power lasers without CMOS array damage, different neutral density filters or attenuators could be added in front of the lens. The system software provides a best fit to the Gaussian curve at 50% of the peak (D_{50}).

Experimental

The first measurement was made using Helium-Neon laser (632 nm), with a low beam divergence. Figure 4 shows the image and beam profile on the CMOS without the 18 mm lens.

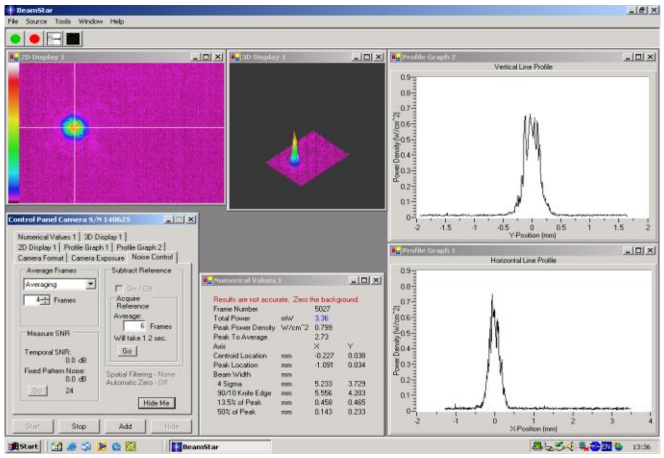

Figure 4, Helium Neon at 100 mm distance - bare beam

The exit beam D_{50} that had been measured was 233 µm. In comparison, figure 5 represents the "retinal" focal image as obtained with our measurement device. We can see that the beam was focused at a spot of 23 µm diameter only (point source).

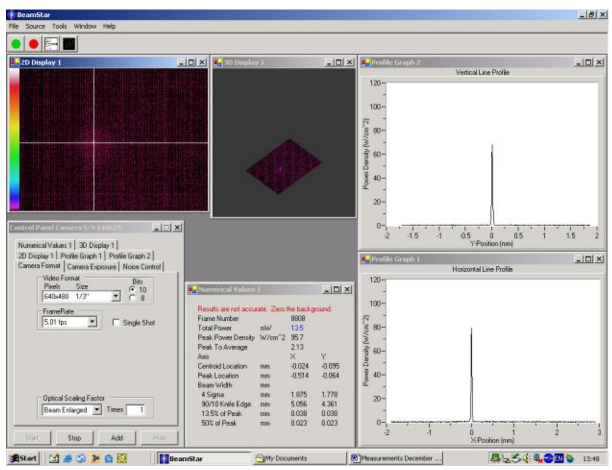

Figure5, same HeNe laser at 100 mm distance in our measurement device

The extremely small size of the focal spot is apparent in the beam profile, and the fact that the whole power emitted by the laser is concentrated in a very small spot is evident.
In order to see the effect of using a binocular, we added a Magnification of x7 Telescope in front of our measurement device. The D_{50} spot size that had been measured was 173 µm (very close to X7 Telescope magnification) see figure 6.

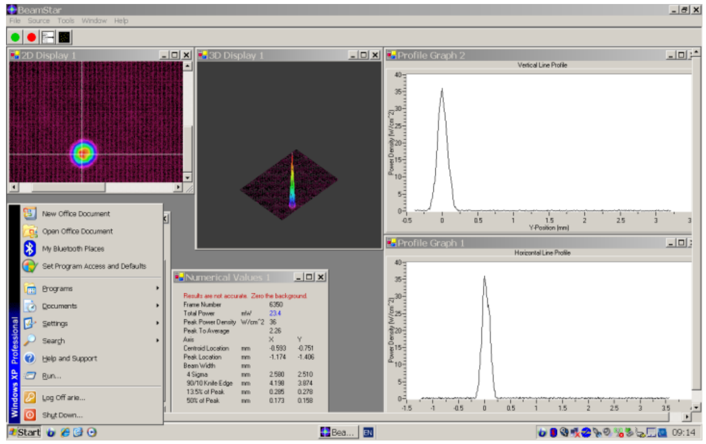

Figure 6, Magnification of x7 Telescope in front of our measurement device

We also measured 3 LEDs with lenses arranged in a straight line form (see figure 7).

Figure 7, 3 LEDs with lenses

In order to calculate the angular dimension of this source, we can treat this LEDs array as an oblong source. The angular subtense of an oblong source shall be determined by the arithmetic mean of the maximum and minimum angular dimensions of the source.

In Figure 8, we see each LED beam profile. Instead of treating it as an oblong source, we will calculate the angular dimensions using a new method. First, we measure the D_{50}, and then we will calculate the total area of the three spot sizes in this case.
This could only be done if the distance between the LEDs is long enough comparing to the spot size diameter. After completing the calculation of the total area of the three beams' spot size, we will calculate the equivalent diameter ($D_{eq.}$) as follows:

Area of $\sum LED\ spot\ size = \frac{\pi}{4}(d_1)^2 + \frac{\pi}{4}(d_2)^2 + \frac{\pi}{4}(d_3)^2 = \frac{\pi}{4}(D_{eq.})^2$

If we assume that the LED diameters are identical, then $d_1 = d_2 = d_3$, and

$$\frac{\pi}{4}(D_{eq.})^2 = 3\ \frac{\pi}{4}(d_1)^2$$

Therefore $D_{eq.} = d_1 \sqrt{3}$

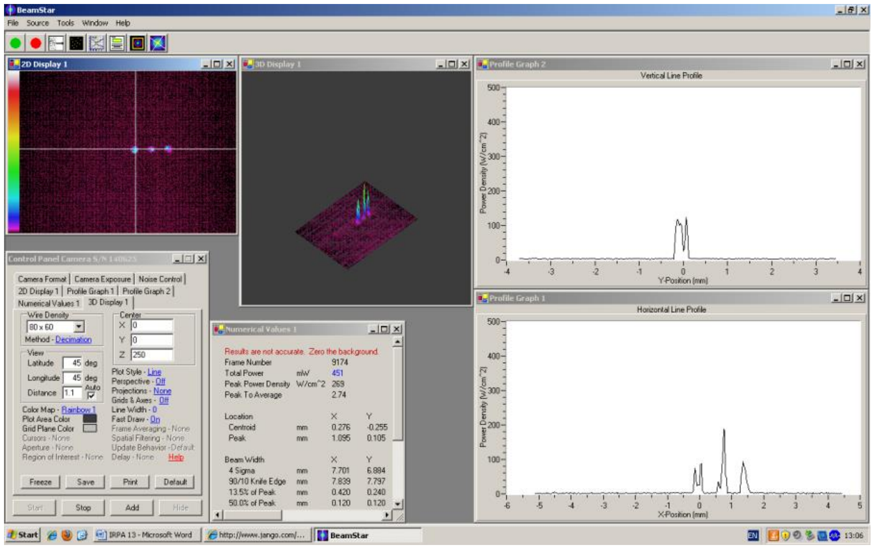

Figure 8, 3 Red LEDs at a 40 cm distance from our measurement device

In figure 9, we see that the LED spectrum is monochromatic, and by the quality of the beam profile, this radiation has the character of a typical laser radiation.

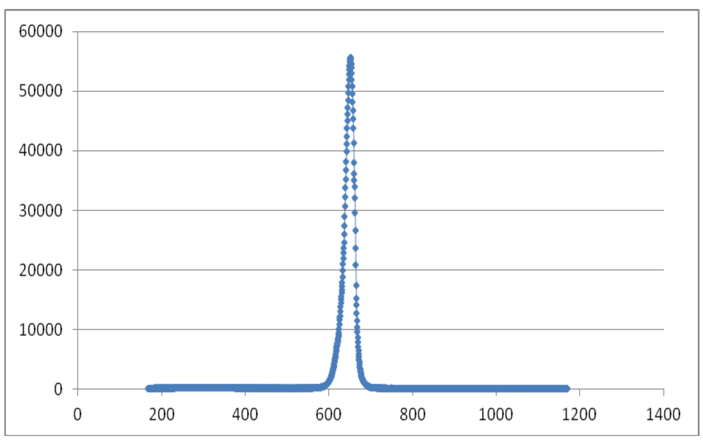

Figure 9, the LEDs' spectrum

In another measurement, we measured a bulb projector (see figure 10).

Figure 10, bulb projector

Looking at the beam profile in our measurement device (Figure 11), we can easily see that the beam has a unique spatial profile. This case should be analyzed according to the IEC 62471 1st ed. 2007 Photobiological safety of lamps and lamp systems (Ref 1),
We can clearly see that the 50% of the peak (D_{50}) criterion does not represent the power density on the retina.
Therefore, we advise that when we have a beam profile like that, the measurement of the extended source size should be based on the 'hot spot' area of the projector (the area confined by the yellow line). Please note that since this lamp is not monochromatic, the beam profile wavelength response should be equal through a wide wavelength range.

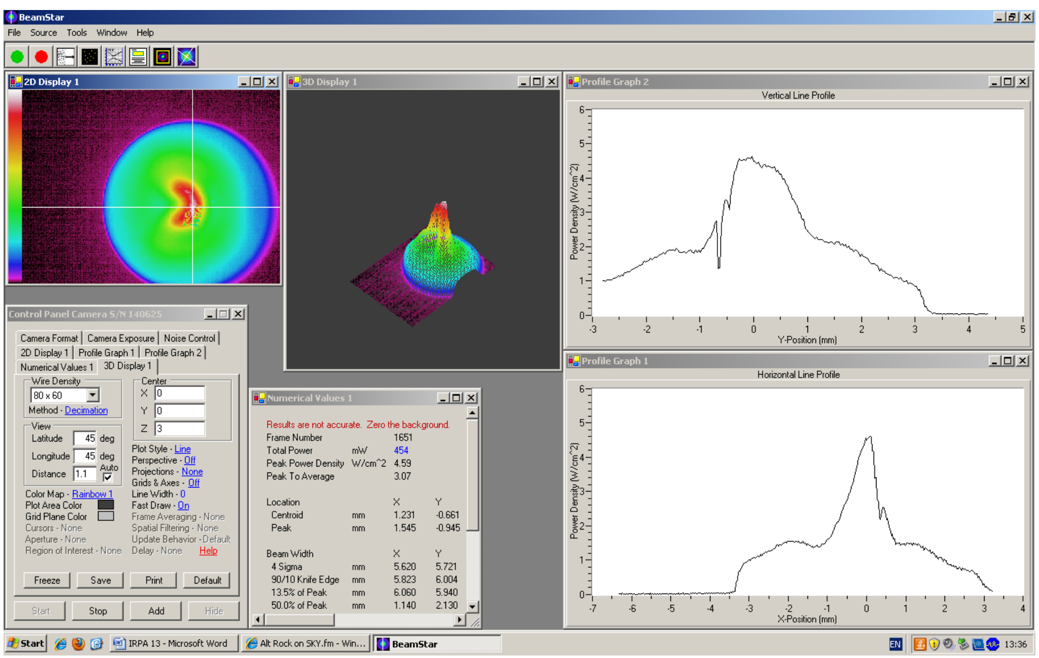

Figure 11, a bulb projector at a distance of 40 cm

Discussion

We have designed and constructed an "artificial eye" measurement device consisting of a gradual-index lens with optical properties similar to those of the human eye, and a beam profiler as a "retina". This device greatly simplifies the laser hazard assessment for real-world laser and other optical radiation sources.

We used this device to examine the following cases:

a. Looking into a laser beam through a binocular. In this case, we provide a measurement tool for measurement of the source size rather than calculating it as it has been done in Ref. 6. This measurement method also allows us to measure laser beams as seen by our retina with atmospheric effects like turbulence, scattering and absorption.
b. Looking at a LED array. In this case, based on the beam profile and the spectrum measurement, we can see if this optical source behaves like a laser or not and we also developed a more accurate method for hazard assessment than the presently used methods.
c. Looking at a bulb projector. In this case we can see a unique beam profile and calculate the hazard in a more accurate way.

This system allows us to easily distinguish point sources from extended sources. For extended sources, the use of the 50% of peak irradiance criterion provides us with a conservative result of the spot size on the retina.

Another important feature of our measurement device is the ability to measure the most hazardous distance to various lasers, LED arrays and other optical sources.

This measurement system enables us to implement more accurate risk assessments for different optical radiation sources comparing to the presently used methods.

Referrences

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