Lighting Systems Design, Inc.

Member since 1990, International Laser Display Association

Discussion of a 10 mWatt/cm^2 Level of Laser Illumination

What is 10 microwatts per square centimeter? It is a measure of the concentration of power (power/unit area) called irradiance. This is more informative than simply the power of the beam or the size of the beam, although both together can give you the irradiance.

Example:

20 Watt laser
Beam diameter = 0.2 cm diameter (typical)
Beam divergence = 0.001 radian (~1/10 degree)
Area of beam at laser = 3.14 x (0.2)^2/4 = 0.0314 square centimeters
Irradiance = 20/0.0314 = 637 Watts per square centimeter

Example 2:

20 Watt laser
Beam divergence = 0.001 radian (1 milliradian)
Range = 10 miles (1,609,000 centimeters)
Beam diameter = range x divergence = 1609 centimeters
Area of beam at 10 miles = 3.14 x (1609)^2/4 = 2,032,271 square centimeters
Irradiance = 20/2032271 = 9.84 microwatts per square centimeter

Moreover, since the pupil of the eye is substantially less than 1 square centimeter (0.39 sq. cm), the actual accessible power (that which can enter the pupil) is about 3.8 microwatts. The resulting retinal irradiance, taking into account the focusing effect of the lens, is about 1.6 watts/cm^2.

Area of beam on retina = 2.27 x 10^-6 cm^2 (based on 17 micron diameter)
Irradiance = 3.8 x 10^-6/2.27 x10^-6 = 1.67 Watts/cm^2

The best comparison for a 10 microwatt per square centimeter beam from a laser is a candle. It is a bright source of small dimensions, producing a similar retinal irradiance. A 1000 watt Stage light, as another comparison, produces a retinal irradiance of 7.5 watts/cm^2 , about 4.5 times "brighter" than the laser exposure.

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Next we can look at time of exposure. If the viewer is moving at some velocity relative to the beam, and at some angle relative to the beam, and the beam diameter is known through calculation, the time of passage across the beam can be calculated. This is based on the concept of a viewer in a commercial aircraft intercepting the beam.

Beam diameter at 10 miles = 1609 cm
Velocity of viewer = 150 mph = 6705 cm per second
Time of intercept = 1609/6705 = 0.24 seconds

Since the time of exposure is less that one second, the accessible exposure is reduced proportionally. 9.84 microwatts per square centimeter times 0.24 seconds yields an exposure of 2.36 microjoules per square centimeter. If we then multiply the radiant exposure by the pupil area, we find an accessible exposure of 0.94 microjoules.

9.84 * 0.24 = 2.36 microjoules/cm^2
2.36 * 0.4 = 0.94 microjoules accessible exposure

If the angle of the flight path relative to the beam approaches parallel, the time of intercept increases. At a 5 degree relative angle (nearly parallel), exposure time increases to 2.98 seconds. However, the irradiance decreases proportionally, as the aircraft is no longer crossing a circle, rather an ellipse instead. Regardless of the angle of intercept, the radiant exposure will not increase.

Area of ellipse = PI x ab, where a and b are the major and minor radii
Minor radius = 804.5 cm
Major radius = 10,000 cm
Ellipse is 1609 by 20000 cm
Area =25,274,113 cm^2
Power/area = 20/25,274,113 = 7.91323 $x10^{-7}$ W/cm^2
Time of exposure = 20000/6705 = 2.98 seconds
Radiant exposure = 7.91323 x $10^{-7} W/cm^2$ x 2.98 seconds = 2.36 $microjoules/cm^2$

Thus the accessible radiant exposure is constant, regardless of angle of intercept.
However, this longer exposure time does not take into account the aversion response, which typically takes place in less than 1/4 of a second. This would limit the accessible exposure to the first case, or about 1 microjoule entering the eye. If the light is too bright, a normal blink response is the characteristic reaction to the exposure.

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