Optical unit and Calculation

I. Preface

For LED applications, intensity and optical power are two important characteristics. It is essential to understand how these characteristics are tested and what kind of devices measure which units. This application note explains the key optical units and provides sample calculations.

II. Color

When sunlight travels through a prism, the light divides into seven colors; violet, indigo, blue, green, yellow, orange, and red. These colors are considered monochromatic as they cannot be divided further. The visible spectrum is composed of monochromatic colors arranged in order of increasing wavelength.

As shown in Figure 1, monochromatic light can be defined as a single wavelength. In comparison a white LED has a distributed spectrum as shown in Figure 2.

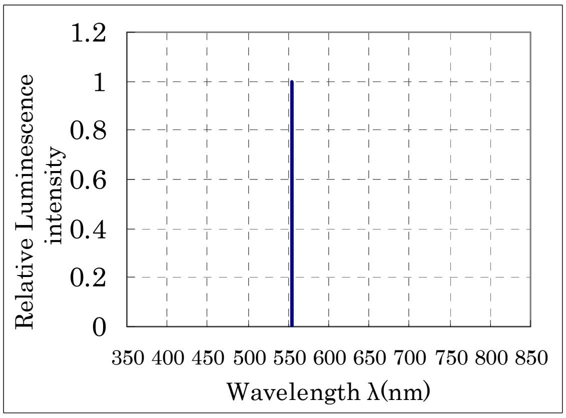


Figure 1: Spectrum Distribution
Monochromatic light of 555nm

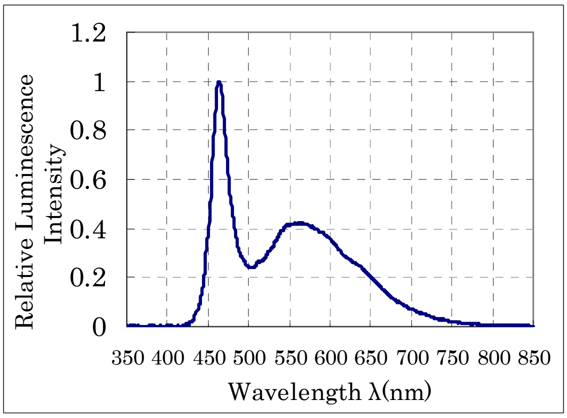


Figure 2: Spectral Distribution
White LED Light

III. Radiometric and Photometric quantities

i) Radiometry is defined by light energy (UV – IR) within a defined geometry over time.

ii) Photometry is governed by radiometric quantities weighted against the human eye sensitivity to visible light.

IV. Power (Flux)

i) Radiant Flux: The total power emitted by a light source per unit of time. (Watt)

Radiant Flux has no relationship to the eye's sensitivity to visible light. For example 1 Watt of energy in the UV spectrum is invisible to the human eye.

ii) Luminous Flux: Radiant flux factored by human eye sensitivity (Lumen)
(Integrate Radiant Flux by Spectral luminous Efficacy)

V. Luminous Efficiency & the human eye

The human eye is sensitive to a portion of the magnetic spectrum with wavelengths between 380 to 780 nanometers. The eye is most sensitive to light with a wavelength of 555nm*. The eye is least sensitive to 380 and 780 nm light. The relationship of eye sensitivity is plotted below in Figure 3. CIE (Commission Internationale de l'Eclairage = International Commission on Illumination) adopted the standard spectral luminous efficiency V [λ] in 1924.

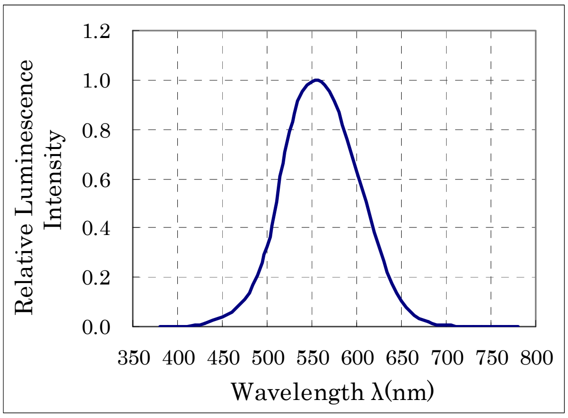


Figure 3: Standard Luminous Efficiency

*Note

i) This chart is valid for daytime use (photopic vision)

ii) Night vision has another plot with a peak at 507nm (scotopic vision)

iii) The eye sensitivity can be related as shown in the below example

Blue light 470nm is 1/10th as sensitive as green light 555nm.

Therefore for 1 mW of 470 and 555 nm light, the green light is 10x brighter.

VI. Relation between Radiant Flux and Luminous Flux

Luminous flux can be determined by multiplication of the radiant flux by the standard luminous efficiency and the maximum spectral luminous efficiency. The formula is shown below.

*Km (maximum spectral luminous efficiency) is 683 lm/W at 555nm in the photopic region of human vision. Therefore Luminous Flux = Km × Φe (λ) × V(λ)

Sample calculation of Luminous Flux(lm)

i) Monochromatic wavelength

a) 555nm (Green) Radiation Flux :1 watt

$683 \times 1 \times 10^{-3}$[W]×1.000=0.683[lm]

b) Wavelength:600nm Radiation flux: 3mW

a) The standard luminous efficiency coefficient of 600nm is 0.631. (Refer to Figure 1)

b) Luminous flux is:

$683 \times 3 \times 10^{-3}$[W] ×0.631=1.292919[lm]

ii) Light with distributed wavelength

For LEDs with a distributed spectra, the integral of the radiometric power at each wavelength is multiplied by the eye sensitivity plot from 380 to 780 nanometers and then multiplied by the maximum spectral luminous efficiency. The equation is shown below and the figure gives a bar representation of the integration.

$$\Phi_V[\mathrm{lm}] = Km\int_{380}^{780}\Phi_e[\lambda]\ V\ [\lambda]\ d\lambda$$

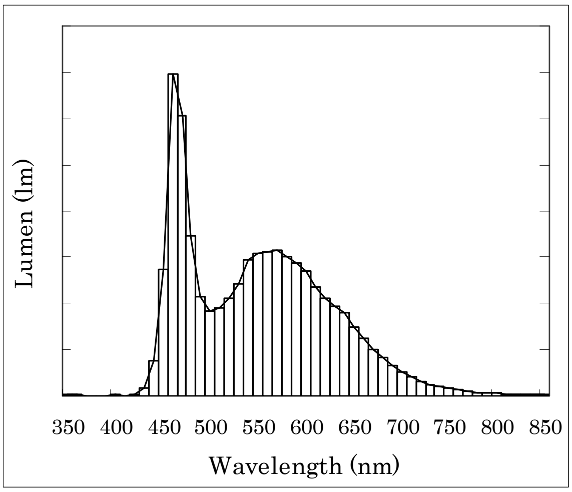


Figure 4: Spectral Distribution of White LED Light

VII. Solid Angle and Luminous Intensity

Luminous intensity is the luminous flux per unit solid angle from the point light source. (unit: cd=candela) It is expressed in lumens per steradian. (cd=lm/sr)

The solid Angle (steradian: sr) is an angle in the solid.

i) Solid angle is defined as the area on a sphere of radius r divided by r^2. (See figure 5)

1 steradian is a solid angle that radiated area (A) is r^2 on the sphere of radius r. Because the surface area of the sphere is $4\pi r^2$ the solid angle is calculated as follows.

$\omega[sr]=A/r^2$ ($\omega[sr]$: solid angle)

Moreover, because the surface area of the sphere is $4\pi r^2$ the solid angle is calculated as follows.

$\omega[sr]=A/r^2=4\pi r^2/r^2$

$=4\pi[sr]$

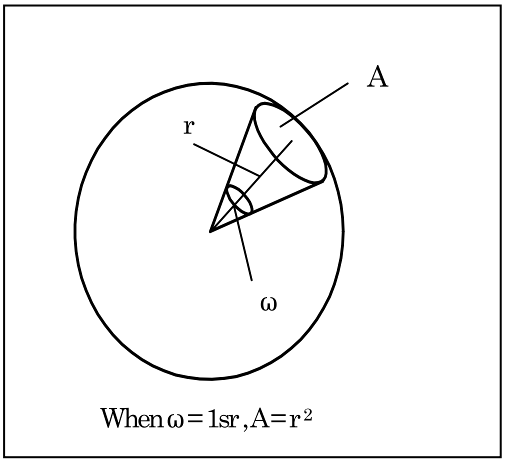


Figure 5: Solid Angle

ii) Luminous Intensity.

Luminous intensity is the flux per unit solid angle from a point light source. (unit: cd, candela) It is expressed in lumens per steradian cd=lm/sr. (Refer to figure 6).

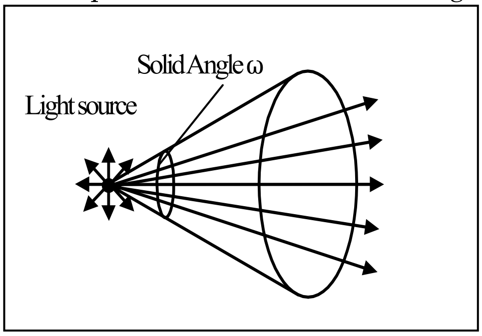


Figure 6: Luminous Intensity

For a point light source, the amount of light that passes in the cone is the same if the cone size changes according to a constant solid angle. Integrating luminous intensity over 2π steradian yields total flux.

VIII. Illuminance

Illuminance is the luminous flux per unit area of incident radiation away from the light source. (unit:Lux,lx) Illuminance can be considered the flux witin one square meter. lx = lm/ m^2. An example is shown below.

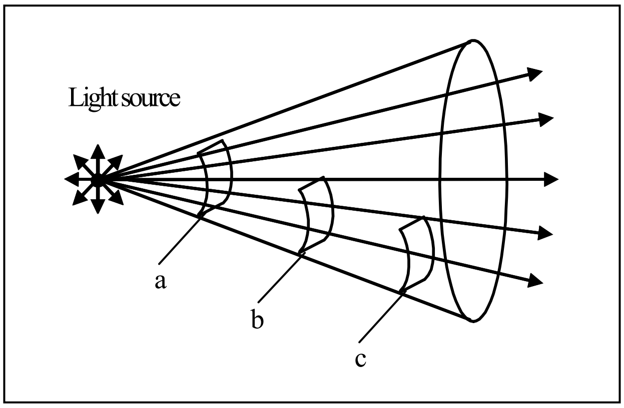


Figure 7: Illuminance

Please refer to Figure 7. Suppose a,b, and c have the same area ($1m^2$). The illuminance is shown by the amount of light (represented by arrows). The farther the distance, the fewer arrows are within the surface area and the lower the luminance.

IX. Relation between illuminance and luminous flux

Sample calculation :

What is the illuminance in 1 and 2m away from the light source?
(The light source: 1 lm and emits light evenly to all the direction.)

i) 1m away

As stated already, the illuminance is the value how much luminous flux (lumen) incident in 1 m^2.

a) Solid angle at 1 m^2 of radiated area:

ω [sr]=A/r^2=1/1^2=1[sr]

b) Luminous flux: 1 lm

c) Luminous flux/sr => Luminous flux/4π=1[lm]/4π [sr]

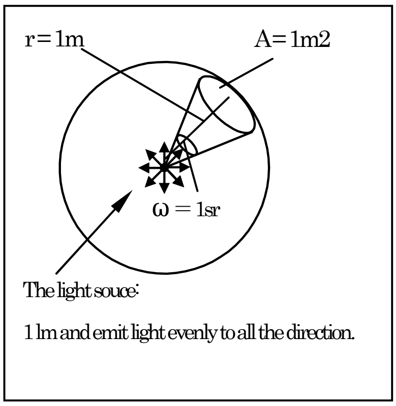


Figure 8: Illuminance and Luminous Flux

Luminous flux per 1sr is 1[lm]/4π [sr].

When the solid angle is 1sr, the radiated area in a place 1 m away, the incident luminous flux is 1/4π [lm].

The illuminance is calculated as follows.

lx=lm/m2

lx=1/4π [lm]÷1[m2]

=1/4π [lx]

ii) 2m away

a) Solid angle at 1 m^2 of radiated area: ω [sr]=A/r^2=1/2^2=1/4[sr]

b)Luminous flux

1/4π [lm]×1/4=1/16π [lm]

c) Illuminance

lx=1/16π [lm]÷1[m^2]

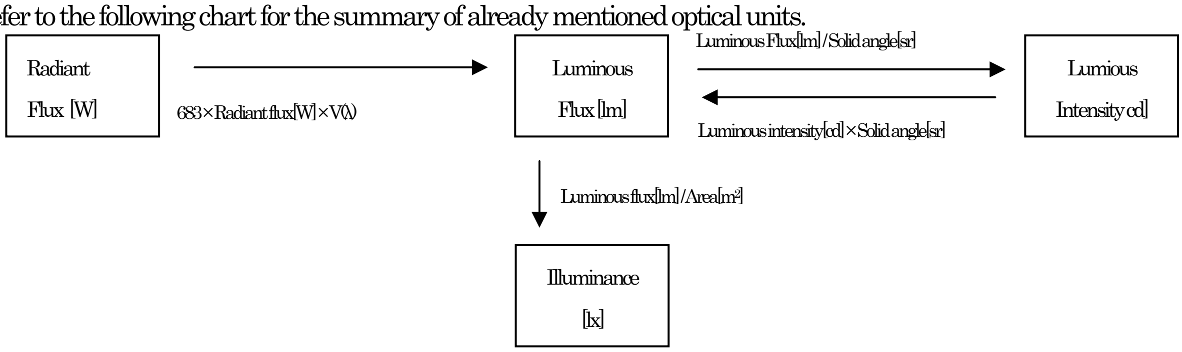
=1/16π [lx]

When the irradiation distance is doubled, the illuminance becomes 1/4.

This is called "Inverse square law".

X. Relation of the unit

Refer to the following chart for the summary of already mentioned optical units.



XI. Summary

A clear understanding the optical properties gives the user sufficient knowledge to specify and use To understand the meaning and the relation of the optical unit widen the use of optical information. Making good use of them according to the application is the key factor to use LEDs