LED Fundamentals

Radiometry & Photometry

08-03-2011

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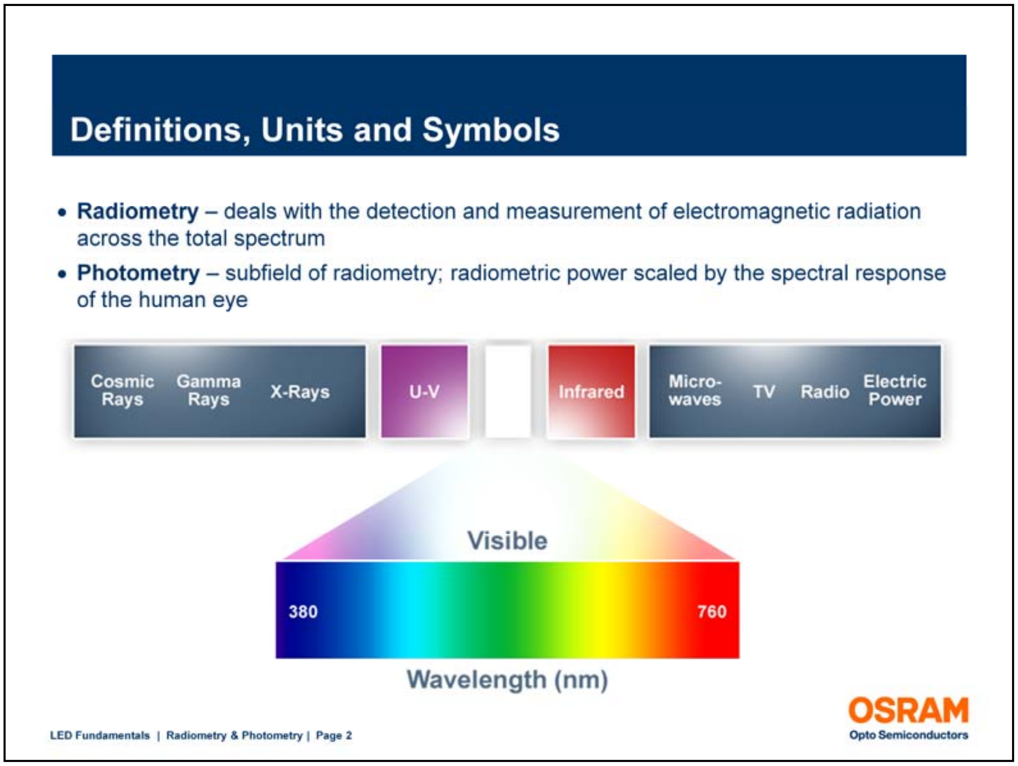
Welcome to this presentation on Radiometry and Photometry, part of OSRAM Opto Semiconductors‘ LED Fundamentals series.

In this presentation we will:

- define the terms “radiometry” and “photometry”
- discuss important photometric concepts.



Radiometry is the field which deals with the detection and measurement of radiation across the full electromagnetic spectrum, including ultraviolet, visible, and infrared radiation. Photometry is concerned only with the visible portion of the spectrum, from about 380 to 780 nanometers.

Definitions, Units and Symbols

- **Radiometry** – deals with the detection and measurement of electromagnetic radiation across the total spectrum
- **Photometry** – subfield of radiometry; radiometric power scaled by the spectral response of the human eye

Radiometric			Photometric		
Quantity	Symbol	Units	Quantity	Symbol	Units
Radiant Power	Φ_e	W	Luminous Flux	Φ_v	lumens (lm)
Radiant Intensity	I_e	W/sr	Luminous Intensity	I_v	lm/sr
Irradiance	E_e	W/m^2	Illuminance	E_v	lm/m^2
Radiance	L_e	W/m^2-sr	Luminance	L_v	lm/m^2-sr

"e" = "energetic"

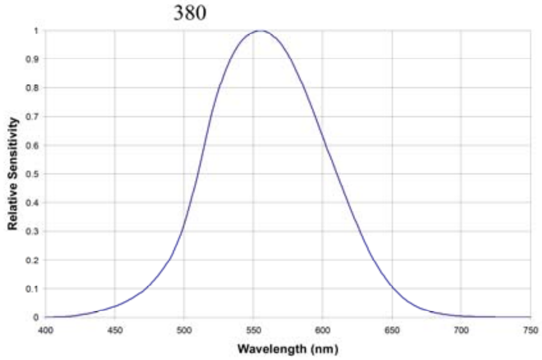
"v" = "visual"

The table summarizes the most common radiometric and photometric quantities.

Converting to Photometric Units

- Power (Watts) is converted to luminous flux (lumens) via the relation:

$$\Phi_v = K \int_{380}^{780} P_e(\lambda) V(\lambda) d\lambda$$



Φ_v = flux (lumens)

P_e = Power

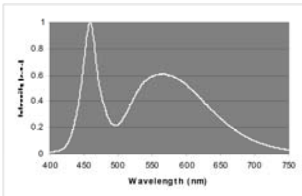
V = photopic response function of the human eye

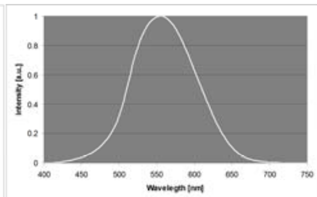
K = constant (683 lm/W for photopic)

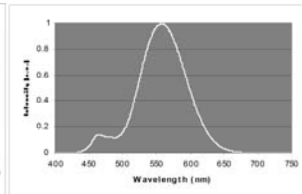
Radiometric power is converted to luminous flux via the integral equation. V-lambda is the spectral response of the human eye in daylight, otherwise known as the photopic curve. The unit of luminous flux is the lumen.

Convert Radiometric to Photometric

$P_e(\lambda)$ | $V(\lambda)$ → $P_v(\lambda)$







$$\Phi_v = K \int_{380}^{780} P_e(\lambda) V(\lambda)\, d\lambda$$

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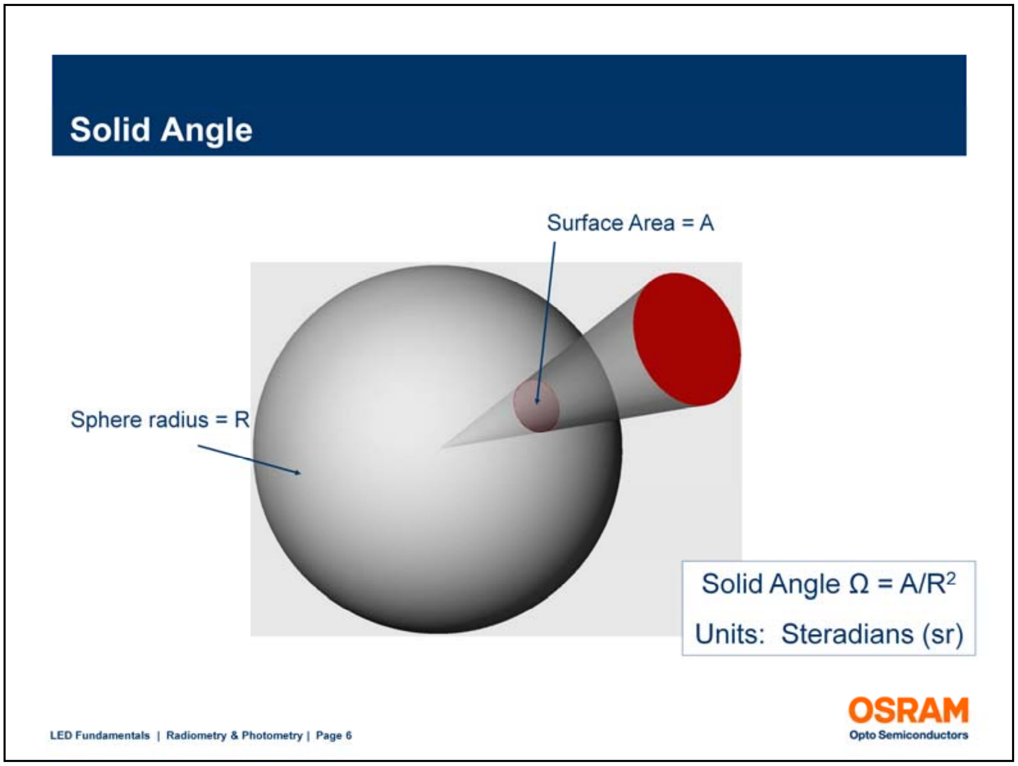
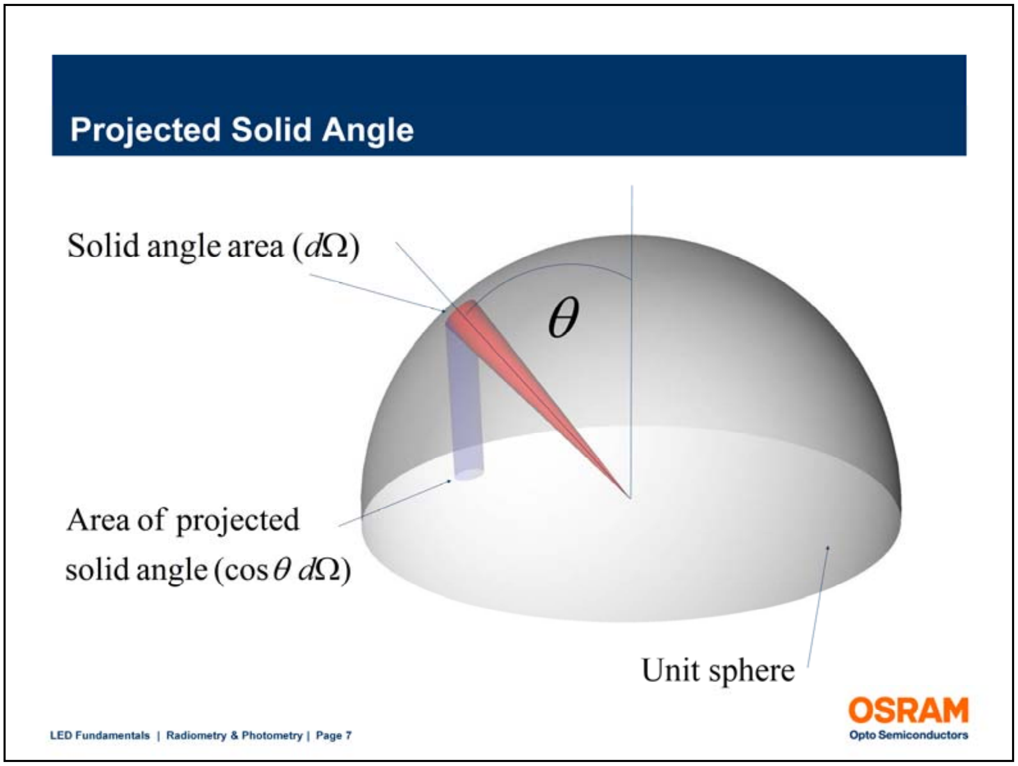
This slide shows graphically the radiometric spectral power distribution, P sub e, multiplied by the photopic curve V-lambda. By taking the area under the resulting P sub v curve and multiplying by the constant K, the luminous flux in lumens is calculated.



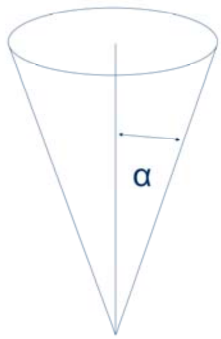
Solid angle is the 3 dimensional analog of an ordinary angle. In the figure, the edge of a circular disk, the bright red circle, is projected to the center of a sphere. The projection intersects the sphere and forms a surface area A.

Solid angle is the area A on the surface of a sphere of radius R divided by the radius squared. The units of solid angle are steradians. Note that it is a dimensionless quantity.



Projected solid angle takes into account the projected area when the viewpoint is other than the center of the sphere. The element of solid angle is shown in red. The area of projected solid angle is shown in blue.

Projected Solid Angle



$$d\Omega = \sin\theta \, d\theta \, d\phi$$

$$d\Omega_{proj} = \cos\theta \, d\Omega$$

$$\Omega_{proj} = \int_0^{2\pi} \int_0^{\alpha} \cos\theta \sin\theta \, d\theta \, d\phi$$

$$\Omega_{proj} = \pi \sin^2 \alpha$$

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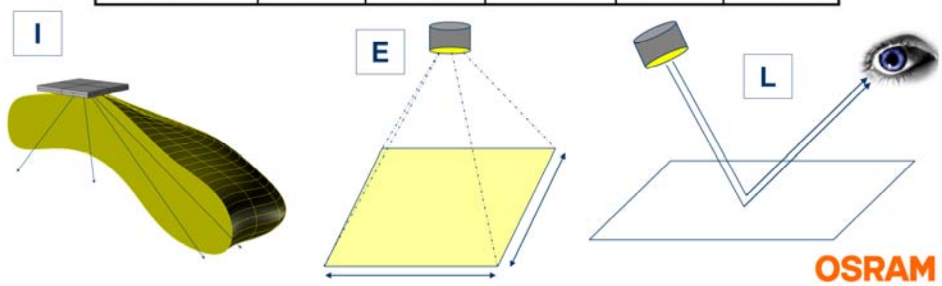
As an example, the projected solid angle for a cone of half angle alpha is calculated.

Photometric Units and Symbols

Photometric Units					
Quantity	**Symbol**	**Metric Units**	**Name**	**English Units**	**Name**
Luminous Flux	Φ	lumens (lm)	lumens		
Luminous Intensity	I	lm/sr	candela (cd) or candlepower		
Illuminance	E	lm/m^2	lux (lx)	lm/ft^2	Ft-candle
Luminance	L	cd/m^2	nits	cd/π*ft^2	Ft-Lambert



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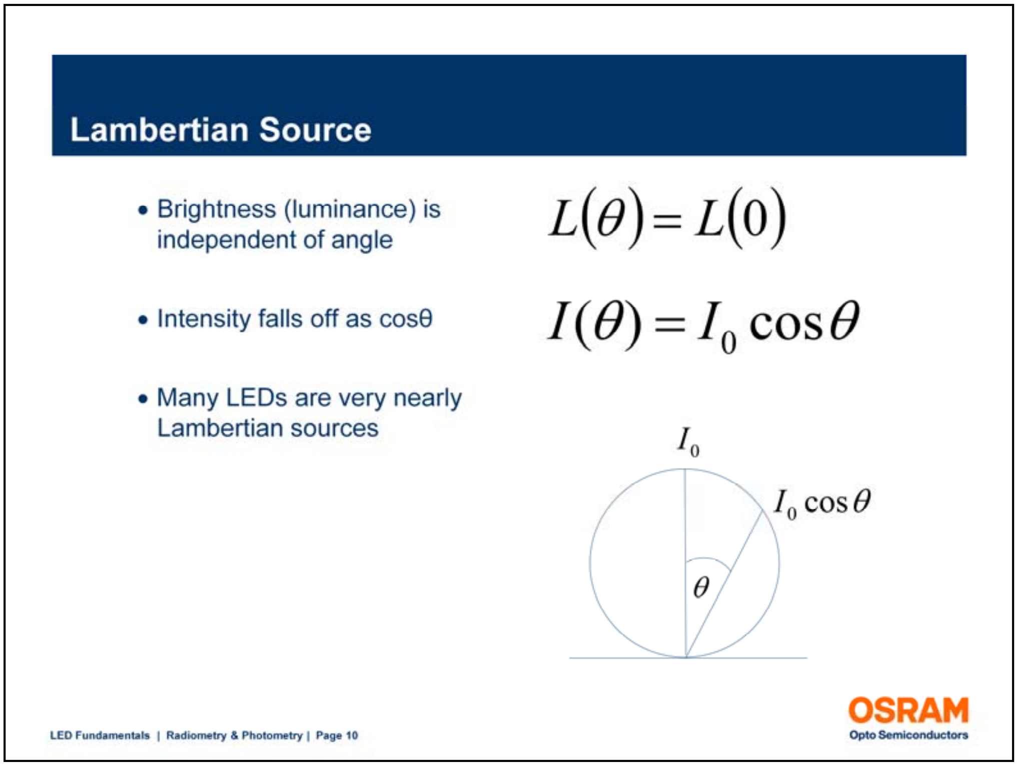
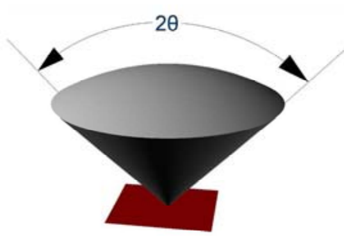
The most common photometric quantities are shown in the table. We have already discussed luminous flux. Luminous intensity, or just intensity, is “light in a direction”. The units of intensity are lumens per solid angle, or steradians. Note that intensity does not depend on measurement distance. The next quantity, illuminance, is “light falling on a surface”, with units of lumens per area. Finally, luminance is “light from a surface in a direction”. The units are lumens per area per solid angle; it is the perceived brightness.



A Lambertian source is defined as one in which the brightness (or luminance) is independent of angle – in other words, the off-axis luminance is the same as on-axis. Such a source has an intensity versus angle profile that falls off as the cosine of the angle. Historically, many LED sources have had nearly Lambertian beam distributions, simplifiying certain calculations.

Lambertian Source



Total flux in a 2θ cone:

$$\Phi = 2\pi \int_0^{\theta} I(\theta')\sin\theta' \, d\theta'$$

$$\Phi = 2\pi \int_0^{\theta} I_0 \cos\theta' \sin\theta' \, d\theta'$$

$$\Phi = I_0 \pi \sin^2 \theta$$

The total flux of a Lambertian source of 1 cd is π lumens.

LED Fundamentals | Radiometry & Photometry | Page 11

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Take the example of calculating the luminous flux within a certain cone angle. Substituting the intensity distribution of a Lambertian source into the equation makes the integration simple. For a so-called Lambertian LED, the total lumens is about three times the on-axis intensity.

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