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LED MEASUREMENT

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LED Measurement

The use of LEDs in many lighting applications is increasing. Various parameters of the light emission are measured to ensure proper performance specifications and to ensure individual LEDs conform. This paper discusses the types of measurement that might be required and the conditions for standardized testing.

MEASUREMENT TYPES AND TECHNIQUES.

There are several types of measurement that may be required. The type of measurement dictates WHAT is measured. For each type of measurement, there are various techniques that can be employed. The technique dictates HOW measurements are made.

Techniques of measurement

Photometry and colorimetry: How does it look to humans?
- quantities start with “photopic” or “luminous”

Radiometry: How much energy is involved?
- quantities start with “radiometric” or “radiant”

Spectroradiometry: How is the energy distributed spectrally?
- quantities start with “spectroradiometric” or “spectral”

Types of measurement

Total flux: Total light emitted in all directions from the entire device.
- quantities end with “flux”

Angular intensity: Light emitted in specific directions and solid angles from the entire device.
- quantities end with “intensity”

At a surface: Light hitting an object outside the device.
- quantities end with “irradiance” or “illuminance”

At the source: Light emitted in specific directions and solid angles from specific areas of the device.
- quantities end with “radiance” or “luminance”

The quantity and unit of measurement are derived from the combination of technique and type.

	Quantity	Unit of Measurement
Photometry + Total Flux =	Total luminous flux	*lumens*
Radiometry + Total Flux =	Total radiant flux	*Watts*
Spectroradiometry + Total Flux =	Total spectral flux	*Watts/nm*
Photometry + Angular Intensity =	Luminous intensity	*candelas = lumen/sr*
Radiometry + Angular Intensity =	Radiant intensity	*Watts/sr*
Spectroradiometry + Angular Intensity =	Spectroradiometric intensity	*Watts/(sr nm)*
Photometry + At a surface =	Illuminance	*lux = lumen/m^2*
Radiometry + At a surface =	Irradiance	*Watts/m^2*
Spectroradiometry + At a surface =	Spectral irradiance	*Watts/(m^2 nm)*
Photometry + At a source =	Luminance	*candelas/m^2 = lumen/(sr m^2)*
Radiometry + At a source =	Radiance	*Watts/(sr m^2)*
Spectroradiometry + At a source =	Spectral radiance	*Watts/(sr m^2 nm)*

MEASUREMENT OF LEDs

Now that we come to specifics on measuring LEDs it is useful to note general considerations that apply to all measurements. The optical properties of LEDs depend critically on two main parameters: temperature and current. It is important that these two parameters are controlled, otherwise repeated measurements on the same device could give different results. Ensure that the ambient temperature is kept as constant as possible, that the electrical connections to the leads (a dominant source of heat sinking) are reproducible, and that power supplies are current regulated.

LED chips are virtually ideal light sources: they are very small and close to point sources, they are reasonably uniform, their emission is Lambertian except at high angles, and many devices are almost monochromatic. This means there are no problems with measurements of chip LEDs. However, packaged LEDs present unique problems with almost any type of measurement. Packaged LEDs generally do not behave like small sources. They are non-uniform, and their emission is often highly angular. This means that results will depend on the exact conditions of measurement, and to achieve general agreement of results the conditions need to be standardized.

Angular intensity measurements

The only measurement type with agreed standard conditions is angular intensity. The conditions are specified in CIE Publication 127, and results are termed “averaged LED intensity” to show they were made under these set conditions[1]. So, applying the various techniques, we can measure *averaged LED luminous intensity*, *averaged LED radiant intensity* and *averaged LED spectral radiant intensity*. Actually, two sets of conditions are specified: Condition A and Condition B, as shown in Figure 1.

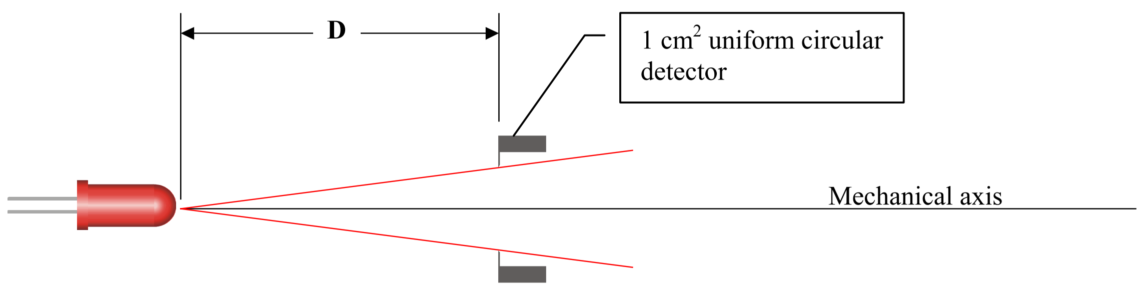

Figure 1. Diagram of standard conditions according to CIE Publication 127.

In each case, a uniform circular 1 cm^2 (11.3 mm diameter) detector is used. The difference between Conditions A and B is the distance from the tip of the LED to the detector (D): 316 mm for Condition A and 100 mm for Condition B. These distances correspond to solid angles of 0.001 sr and 0.01 sr, respectively. For a Lambertian source the two conditions should give the same result, but for highly directional sources they can be very different. Therefore, it is important to compare results only if the same conditions are used, even though the measurement quantities and units are the same for each condition.

Currently, the standard conditions of CIE Publication 127 are just a recommendation, but work continues to make this an ISO/CIE standard[2].

If angular intensity is the only measurement type for which there are standard conditions, what should be done for the other types of measurement? We will consider each of the other types in turn.

Total flux measurement

If angular intensity is measured for all possible angles, the sum of the results will be the total flux. This can take a long time, so total flux is more often measured in an integrating sphere, which gives the result in a single measurement.

Traditionally, measurements of total flux are made with the source at the center of a large sphere. The design requirements of the sphere and impact on measurements are discussed elsewhere and need not be repeated[3]. Provided these design requirements are met, there is no problem with such measurements in the case of LED packages. Unfortunately, LEDs are more commonly located *at the sphere wall* for such measurements, and this leads to many complications that only standard conditions can resolve.

The first of these problems is that measurements represent hemispherical emission from the LED, often called forward-looking or 2π flux. Although total flux and 2π flux are not the same thing, they are often confused. Since total flux is always larger than 2π flux, this confusion can sometimes be mistaken for disagreement between measurements.

The second problem is that measurements of 2π flux are sensitive to conditions of measurement: size of sphere and openings, the position of the LED, any design flaws in the sphere, and whether or not an auxiliary lamp is used.

The third problem is the selection of suitable standards. Calibrated LEDs, as identical as possible to those being tested, work best for photometric and radiometric measurements, but white light sources work best for spectroradiometric measurements. Sometimes the only standards or calibrations available to the user are inappropriate, and hence results may contain errors.

Work continues on describing standard conditions for such measurements[4]. Meanwhile, care should be taken in selecting equipment and ensuring equivalent conditions when comparing results.

Irradiance/Illuminance measurement

To measure irradiance or illuminance, all that is required is a clearly defined detector area that has good cosine response. All light, regardless of the direction it comes from, is measured and the properties of the source(s) make no difference to the conditions of measurement. LEDs present no problem to this type of measurement. So why do we need standard conditions? The fact is that many LED packages or LED clusters project very non-uniform light patterns onto a surface. The size and location of the detector within the pattern there affects results. Therefore, it is important to ensure conditions are identical when making comparisons.

Radiance/Luminance measurement

Generally, radiance or luminance measurements are made using a telescope (or microscope). The telescope images the LED, then an aperture placed at the image position isolates the portion of the LED to be measured. It is important that the aperture is smaller than the LED image in order to measure radiance or luminance.

Two types of telescopes may be used: reflex or direct viewing design. Each telescope has both advantages and disadvantages. The reflex telescope has advantages of cost, and the image and aperture planes are the same. The advantages of the direct viewing telescope are the lack of alignment, parallax or focusing errors while viewing, and the fact that the aperture can be seen during alignment (precluding any mix up on which aperture is used). Generally, the direct viewing design is preferred for LEDs because good alignment and lack of parallax are critical for non-uniform sources.

However, any measurement of radiance or luminance assumes one thing: the angular distribution of light is independent of the area being measured. Unfortunately, the lens on packaged LEDs makes this untrue! The reality is results depend critically on conditions of measurement, and there may be no condition that gives a "true" value."[5] How then should measurements be made? One option is to establish standard conditions, but there are other possibilities currently being discussed. If measurements are made on chip LEDs before packaging, or a packaged sample is cut and polished flat to remove the lens, then good values can easily be obtained. Alternatively, if the Condition A averaged LED intensity is divided by the emitting area of the chip, an "apparent radiance/luminance" can be obtained. This latter method does not give true radiance/luminance but does have the advantages of being relatively easy, avoiding the need for extra equipment, and is consistent with other measurements. Discussions continue on which method should be used[2]. Meanwhile, when comparing results, ensure the same method and conditions are used.

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[1] Commission Internationale de l'Éclairage: Measurement of LEDs, CIE **127**-1997

[2] Commission Internationale de l'Éclairage Technical Committee, **CIE TC2-46**

[3] ***Standard Spheres and Sphere Standards***, Dr. Richard Young, **Proceedings of the ALI Annual Seminar**, Aerospace Lighting Institute, **February 2001.**

[4] Commission Internationale de l'Éclairage Technical Committee, **CIE TC2-45**

[5] ***LED Measurement Instrumentation***, Dr. Richard Young, **Proceedings of the CIE 2nd. Advanced LED Symposium**, Commission Internationale de l'Éclairage, **May 2001**.