IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products

Draft 4.0

Status of LM-79

- LM-79 is currently in subcommittee draft (V 4.0) in the IESNA TPC Subcommittee D.
- Subcommittee D members have commented.
- Target completion July 2007.

Source: Ian Ashdown, TIR Systems Limited, Apr 2007

Who is involved in SSL standards development

- DOE SSL Commercialization Support Program
  - Energy Star, Consumer Product Testing Program, Standards Development
- PNNL (Pacific Northwest National Laboratory)
- Standards organizations (US, NAFTA and international), industry groups and manufacturers groups.

IESNA/ANSI WGs for IESNA/ANSI

•LIGHTING MEASUREMENTS TESTING & CALCULATION GUIDES

•LM-79 IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products

•LM-80 IESNA Approved Method for the Determination of the Lifetime of Solid-State Lighting Products

•RECOMMENDED PRACTICES AND ANSI STANDARDS

•RP-16 IESNA/ANSI Nomenclature and Definitions for Illuminating Engineering

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LED Measurement Procedures

- LED chip manufacturing produces individual LEDs with variation in characteristics including intensity, flux, chromaticity, forward voltage and thermal sensitivity.
- Manufacturers introduced 100% inspection and binning for intensity, chromaticity and forward voltage as a means of providing consistency to integrators.
- To accomplish this LED manufacturers developed test methods compatible with the high speed production processes.
- Methods developed are pulsed (e.g. 25 mS) and ratings for intensity or flux, CCT, chromaticity and color rendering are thus provided absent heating of the LED junction.
- Derating for junction temperature is separately characterized and reported for discrete LEDs and modules
- DOE CPTP shows that OEMs may be unaware of how their product designs affect LED performance and hence overall SSL performance. www.netl.doe.gov/ssl/comm_testing.htm

Analogously for Conventional Light Sources

- Peak methods fo measurement are noted in the corresponding LMs, accepted and applied to reduce measurement time in production test environements.
- Correction factors are developed for luminous flux, CCT, CRI and electrical operating values by comparison to the measured values from a limited number lamps which are fully stabilized.
- Only values corrected to the stable lamp operation are reported.

Generic LM

- Scope
- General
- Nomenclature and Definitions
- Ambient Conditions
- Power Supply Characteristics
- Ballast
- Circuit
- Seasoning
- Stabilization
- Non-stabilized Testing
- Handling/Positioning for Test
- Operating Position (orientation)
- Electrical Settings
- Electrical Instrumentation
- Test Methods for Total Luminous Flux measurement
- Luminous Efficacy of Source
- Test Methods for Color
- Uncertainty statement

SSL LM

- Differentiate SSL products and LED components
- General
- Define "SSL product"
- Ambient Conditions
- Power Supply Characteristics
- Limit by definition of SSL product
- Limit by definition of SSL product
- Seasoning of SSL Product
- Develop criteria for junction temperature control effect of power density
- Handling/Positioning for Test
- Address heat transfer to/from junction rather than location of discharge cold spot
- Electrical Settings
- Electrical Instrumentation
- More detailed/inclusive
- Luminous Efficacy of Source
- Goniocolorimetric addressed
- Uncertainty statement

Considerations related to LM-79

- **Differentiate SSL products and LED components/Define "SSL product"**
  - SSL products are devices which
    - incorporate LED-based sources,
    - are directly connected to the electric supply and
    - include the provisions required to maintain the design operating temperature of the LED-based sources in the application.

  - LM-79 will NOT address LED-based devices which require external power suppliers, controls or drivers.
    - The current definition includes LED luminaires and integrated LED lamps;

      it does not include LED packages, LED modules, LED arrays and non-integrated LED lamps.

  - LM-79 does not address form factor(s) as these are not standardized and those that ultimately have the largest market share are quite possibly not in existence today.

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Considerations related to LM-79

- **Ambient Conditions/Power Supply Characteristics**
  - Ambient temperature: 25ºC   1ºC; within 1 m at the same height
  - Air movement: 4 m/min (Readily available commercial measurement is limited to approximately 30 ft/min (~ 10m/min) due to limitations of air tunnel consistency)
  - AC Supply: 60Hz, total RMS harmonics <3% of fundamental

- **Power factor measurement is required for AC powered devices**
  - Power factor has been considered as it affects overall efficiency of the power supply system, reducing losses due to lower current and improving system voltage profile.

- **Ballast/Circuit :: Driver/Power Supply/Control System**
  - By definition, consideration is removed.

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Seasoning/Stabilization

- **Seasoning** currently recommended as 100 hours
- **Seasoning** performed at rated electrical and ambient conditions and in normal orientation
- **Stabilization** is a thermal process and by measurement has been found to be characteristically smoothly monotonic for LED-based sources

"The attainment of operational stability can be checked by monitoring the relative light output as the SSL product under test is being stabilized at constant ambient temperature and constant electrical input. It is considered that stability is reached when the flux output drift in 10 minutes is less than 1 %, as determined by

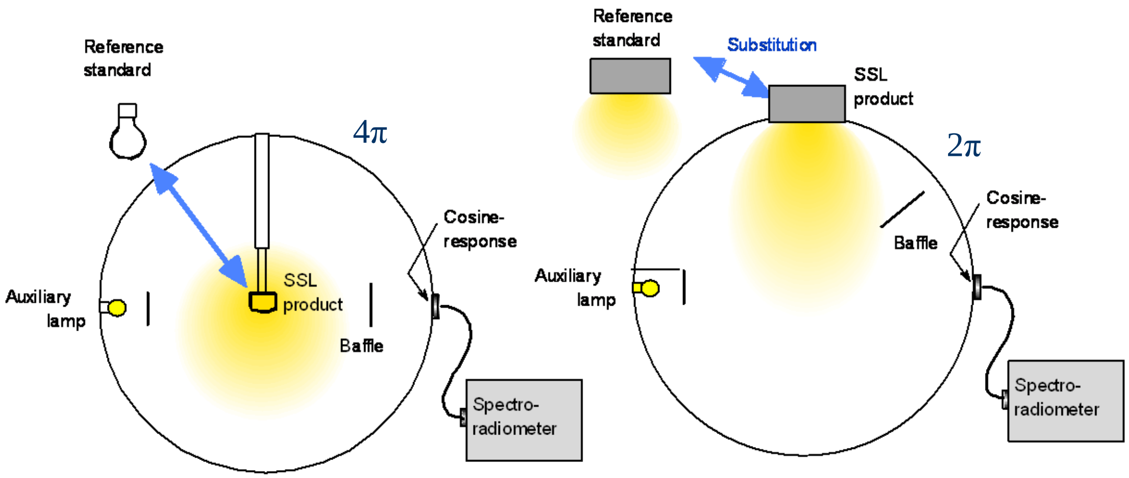
$$\Delta_{10}(t) = \left\{\Phi(t) - \Phi(t-10)\right\} / \Phi(t) \quad (1)$$

where *t* is the elapsed time (min) since turning on the SSL product and $\Phi(t)$ is the (relative) total luminous flux at time . Measurement can start when $\Delta_{10}(t)$ <0.01. The stabilization time shall be reported with the test results."

Handling/Positioning for Test/Operating Position (orientation)

- **Handling/Positioning for Test** is not addressed in LM-79. LMs for conventional light sources address this because of flexibility of hot filaments or damage of fragile filaments or the possibility of inadvertently changing the location of chemical additives for a discharge lamp.
- **Test/Operating Position (orientation)** is addressed as the design of the SSL product for maintenance of the LED device junction temperatures in the accepted range may be orientation dependent. SSL products are to be operated in their intended orientation.

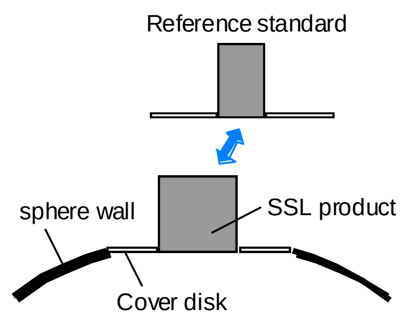
Total luminous flux - Sphere Measurement



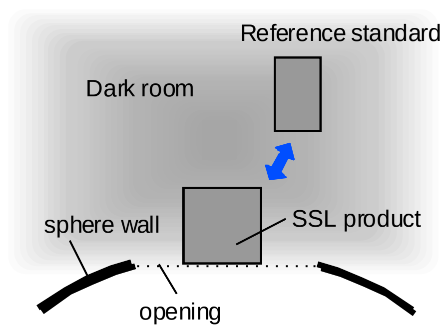
Recommended sphere geometries for total luminous flux measurement using a spectroradiometer. Left: for all types of SSL products, Right: for SSL products having only forward emission.

If the gap is not closed the surrounding test area must be darkened.

Mounting conditions of the SSL product under test.



(a) SSL product mounted with a cover disk.



(b) SSL product mounted without a cover disk.

External mounting of a test and calibration source must be such that the source and cover disk are flush with the sphere wall and the diameter of the opening shall be 1/3 or less than the sphere diameter.

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Sphere Spectroradiometer

$$\Phi_{\mathrm{TEST}}(\lambda) = \Phi_{\mathrm{REF}}(\lambda) \cdot \frac{y_{\mathrm{TEST}}(\lambda)}{y_{\mathrm{REF}}(\lambda)} \cdot \frac{1}{\alpha(\lambda)}$$

$$\Phi_{\mathrm{TEST}} = K_{\mathrm{m}} \int_{\lambda} \Phi_{\mathrm{TEST}}(\lambda) V(\lambda)\, \mathrm{d}\lambda$$

$$(K_{\mathrm{m}} = 683\ \mathrm{lm/W})$$

$$\alpha(\lambda) = \frac{y_{\mathrm{aux,TEST}}(\lambda)}{y_{\mathrm{aux,REF}}(\lambda)}$$

self-absorption factor
(NB spectral due to significant spectral variation of sphere throughput of high reflectance sphere)

$\Phi_{\mathrm{TEST}}(\lambda)$ total spectral radiant flux of a SSL product under test

$\Phi_{\mathrm{REF}}(\lambda)$ total spectral radiant flux of the reference standard

y_{TEST} spectroradiometer readings for SSL product under test

y_{REF} spectroradiometer readings for reference standard

$\Phi_{\mathrm{TEST}}(\lambda)$ measured total spectral radiant flux

Φ_{TEST} total luminous flux

Guidance

Preferred integrating sphere method as it theoretically eliminates spectral mismatch errors

$f_2 < 15\%$

Sphere size is selected to keep self-absorption insignificant, minimize ambient temperature changes by the device under test, accommodate the physical size of the device under test and maintain a satisfactory signal level.

Higher sphere reflectance minimizes the effect of differences in spatial distribution between test and calibration sources and increase signal level. However, self-absorption and drift effects are increase and there is more variation in spectral throughput.

Device under test total surface area should be 2% or less of the sphere surface area and its largest dimension should be less than 2/3 of the sphere diameter.

Detectors and auxiliary collecting spheres should be mounted flush to the inner sphere curvature.

Baffles should be minimal.

IESNA Testing Procedures Committee, *IESNA Guide to Spectroradiometric Measurements*, LM-58-1994 (bandwidth, scanning interval, wavelength accuracy, spectral stray light, detector nonlinearity, input optics)

Sphere Photometer

$$\Phi_{\mathrm{TEST}} = \Phi_{\mathrm{REF}} \cdot \frac{y_{\mathrm{TEST}}}{y_{\mathrm{REF}}} \cdot \frac{F}{\alpha}$$

Φ_{REF} total luminous flux (lumen) of the reference standard lamp,

y_{TEST} photometer signal for SSL product under test

y_{REF} photometer signal for reference standard

$$\alpha = \frac{y_{\mathrm{aux,TEST}}}{y_{\mathrm{aux,REF}}}$$ self-absorption factor

$$s_{\mathrm{rel}}(\lambda) = s_{\mathrm{ph,rel}}(\lambda)\ T_{\mathrm{rel}}(\lambda)$$

$s_{\mathrm{rel}}(\lambda)$ relative spectral responsivity of the total sphere system

$s_{\mathrm{ph,rel}}(\lambda)$ relative spectral responsivity of the photometer head

$T_{\mathrm{rel}}(\lambda)$ relative spectral throughput of the sphere

$$T_{\mathrm{rel}}(\lambda) = k \cdot \frac{\rho_{\mathrm{a}}(\lambda)}{1-\rho_{\mathrm{a}}(\lambda)}$$

F spectral mismatch correction factor

$$F = \frac{\int_\lambda S_{\mathrm{REF}}(\lambda) s_{\mathrm{rel}}(\lambda) \mathrm{d}\lambda \int_\lambda S_{\mathrm{TEST}}(\lambda) V(\lambda) \mathrm{d}\lambda}{\int_\lambda S_{\mathrm{REF}}(\lambda) V(\lambda) \mathrm{d}\lambda \int_\lambda S_{\mathrm{TEST}}(\lambda) s_{\mathrm{rel}}(\lambda) \mathrm{d}\lambda}$$

If *F* is not determined, *F*=1 is used and the uncertainty introduced should be considered.

f'_1 <3% (if f'1 >3% *F* must be applied)

f_2 <15%

Sphere size is selected to keep self-absorption insignificant, minimize ambient temperature changes by the device under test, accommodate the physical size of the device under test and maintain a satisfactory signal level.

Higher sphere reflectance minimizes the effect of differences in spatial distribution between test and calibration sources and increase signal level but results in greater variation of reflectance with wavelength which makes determination of the spectral throughput of the sphere more critical. Typical sphere-photometer systems use reduced reflectance coatings to flatten the spectral variation in throughput.

Device under test total surface area should be 2% or less of the sphere surface area and its largest dimension should be less than 2/3 of the sphere diameter.

Detectors or collecting spheres should be mounted flush to the inner sphere curvature.

Use of an auxiliary source similar in spectral distribution to the test source is beneficial especially when the test source is large or highly colored.

Considerations related to LM-79

Goniometer

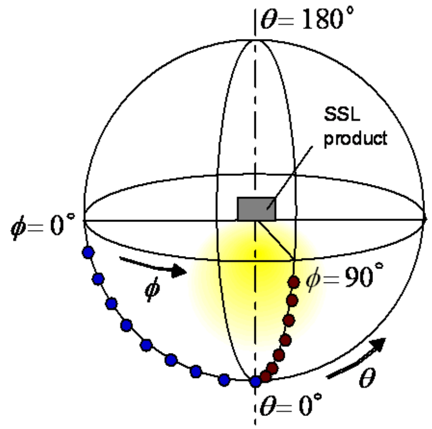
$$\Phi = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I(\theta,\phi) \sin\theta \, d\theta \, d\phi$$

$$\Phi = r^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} E(\theta,\phi) \sin\theta \, d\theta \, d\phi$$

$I(\theta,\varphi,)$ luminous intensity distribution of the source

$E(\theta,\varphi,)$ illuminance distribution

r measurement distance



Calculation of color parameters

$$x_a = \sum_{i=1}^{19} x(\theta_i) \cdot w_i \quad \text{with} \quad w_i = \frac{E(\theta_i) \cdot \Omega(\theta_i)}{\sum_{i=1}^{19} E(\theta_i) \cdot \Omega(\theta_i)}$$

$$\Omega(\theta_i) = \begin{cases} \cos(\theta_i) - \cos(\theta_i + \frac{\Delta\theta}{2}) & ;\text{for } \theta_i = 0° \\ \cos(\theta_i - \frac{\Delta\theta}{2}) - \cos(\theta_i + \frac{\Delta\theta}{2}) & ;\text{for } \theta_i = 10°, 20°, \ldots 170° \\ \cos(\theta_i - \frac{\Delta\theta}{2}) - \cos(\theta_i) & ;\text{for } \theta_i = 180° \end{cases}$$

$$\Delta\theta = 10°$$

Guidance

Type C goniophotometer to maintain orientation.

$f'_1 < 3\%$

$f_2(\varepsilon,\varphi) < 2\ \%$

5° grid for wide-angle intensity distribution. Smaller intervals or angle resolution are recommended where the luminous intensity is changing rapidly.

The range of the angular scan must cover the entire solid angle to which the SSL product emits light.

Goniophotometer dead angle must be considered.

Sensitivity to polarized light can cause significant errors when measuring the total luminous flux of SSL products that emit polarized light.

10° intervals for vertical angle θ

At least two φ (0° and 90°)

-DOE Target

- July 2007
- Implementation of the SSL Energy Star Program requires the existence of approved consensus standards
- NVLAP accreditation program is based on consensus standards

-Status

- Draft 4.0 September 2006 completed sub committee review (IESNA TPC SubD)
- Draft 5.0 in preparation (IESNA TPC SubD)

-Next Steps

- Complete IESNA TPC SubD work
- SubD vote to send to full TPC committee
- TPC comment/response
- TPC vote to send to IESNA Technical Review Committee
- TRC approval : Target date: July 2007