Final manuscript for J. IES, 27-2, 132-140 (1998)

High Illuminance Calibration Facility and Procedures

Yoshi Ohno

Optical Technology Division
National Institute of Standards and Technology
Metrology A320, Gaithersburg, MD 20899
Phone : (301) 975-2321
Fax : (301) 840-8551

Abstract

The range of calibration of illuminance meters and luminance meters has been normally limited to levels up to several thousand lx and several thousand cd/m^2 using a high-power luminous intensity standard lamp. The calibration of instruments at much higher levels is required in applications such as daylight measurement, evaluation of solar simulators, and testing light sources in imaging devices. A calibration facility and procedures have been developed at NIST utilizing the detector-based method to allow illuminance calibrations at levels up to 100 klx (about the level of direct sun light) and luminance up to 30 kcd/m^2, The calibration source is based on a commercial solar simulator source using a 1000 W xenon arc lamp with optical feedback control, and it is combined with a set of color glass filters that corrects the spectral power distribution to be close to CIE Illuminant A. The illuminance level can be varied without changing the color temperature significantly and without changing the distance. The developed source was evaluated for stability, spectral distribution, illuminance uniformity, and divergence of the beam. Experiments were also conducted to study the effect of heat by radiation on the glass filters used with the source and various diffuser materials, such as PTFE, opal glass, and acrylic, used to create luminance standards. The linearity and the effect of heat on standard photometers and commercial illuminance meters were also investigated, and appropriate procedures for high illuminance/luminance calibrations have been established.

Keywords: calibration, diffuser, illuminance, illuminance meters, luminance, luminance meters, luminous intensity, solar simulator, standard lamp, standard photometer

---

Introduction

Illuminance meters and luminance meters normally have a measurement range over several orders of magnitude, thus a large calibration range is required for such instruments. However, the calibration range is normally limited to levels up to several thousand lx and several thousand cd/m^2 using a typical photometric bench and a high power luminous intensity standard lamp[1,2] (e.g., a 1000 W lamp used at a 50 cm distance creates ~5000 lx). Calibrations at levels of an order of magnitude higher are often required for illuminance meters used in the measurement of daylight, solar simulators, lighting optics in imaging devices, and military applications. However, standard lamps that provide such a high illuminance have not been available.

The detector-based method has been introduced in the realization of the candela and the illuminance calibration work at the National Institute of Standards and Technology (NIST)[3,4]. With this method, the illuminance scale is provided by standard photometers, not by standard lamps. Therefore, the calibration sources need not be extremely stable over long periods; rather, needs to be stable only during each burning. Thus, various types of light sources other than incandescent standard lamps can be used, if they have appropriate short-term stability, spatial uniformity, and spectral power distributions. The illuminance scale can be extended, based on the wide linearity range of the standard photometers.

A calibration facility and procedures have been developed at NIST to establish the capability of illuminance calibrations at levels up to 100 klx (the level of direct sun light) and luminance up to 30 kcd/m^2 (luminance of a perfect diffuser at that level of illuminance). The calibration source is based on a commercial solar simulator source using a 1000 W xenon arc lamp with optical feedback control, and this source is combined with a set of color glass filters that corrects its spectral power distribution to match the CIE[†] Illuminant A (2856 K Planckian radiation). The illuminance level can be varied without changing the color temperature significantly and without changing the distance. The developed source was evaluated for stability, spectral distribution, illuminance uniformity, and other geometrical characteristics.

Experiments were conducted to study the effect of heat from radiation on the glass filters used with the source and various diffuser materials, such as PTFE, opal glass, and acrylic used to create a luminance surface. The linearity and the effect of heat on photometers and illuminance meters were also investigated, and appropriate procedures for high illuminance and luminance calibrations have been established.

[†] Commission Internationale de l’Eclairage (International Commission on Illumination)

Development of the calibration source

Design of the calibration source

In order to create an illuminance of 100 klx, a commercial solar simulator source (Oriel[††] model 81192) is utilized. This source consists of a 1000 W xenon arc lamp with an ellipsoidal reflector, an optical integrator, mirrors, and a collimating lens to create a parallel beam of light; and it employs an optical feedback control system to stabilize the lamp intensity. The monitor detector for the feedback control, initially consisting of only a silicon photodiode and an optical fiber bundle, was modified to include a $V(\lambda)$-correction filter. The source provides an illuminance field of approximately 300 klx in a 10 cm x 10 cm area at a distance 20 cm to 40 cm from the unit. The source is also equipped with interchangeable apertures to reduce the illuminance levels in several steps. The illuminance can also be varied by ± 20 % by adjusting the feedback control.

The solar simulator source has the spectral distribution of a typical xenon lamp, having a correlated color temperature of approximately 6500 K as shown in Fig. 1. However, it is an internationally recommended practice[5] to use a 2856 K Planckian source (CIE Illuminant A) for calibration of illuminance meters and luminance meters. To meet this requirement, a color correction filter was designed to match the output spectral power distribution to the CIE Illuminant A. Among many combinations of color glass filters, HOYA LA60 (16.5 cm x 16.5 cm) was chosen for appropriate spectral matching and high transmittance. Combination with a heat absorbing filter (HA50) was also included. The optimum thickness of the filter in three different combinations was determined by calculation using the data from the manufacturer. Figure 2 shows the calculated spectral power distributions of the source combined with these filters. The predicted correlated color temperatures (CCT) and illuminances are shown in Table 1. Filter C is intended to achieve the highest desired illuminance level, sacrificing the color temperature.

To evaluate these spectral corrections, the spectral mismatch errors[1,4] caused by the differences between the spectral power distributions of the filtered source and the CIE Illuminate

---

[††] Specific firms and trade names are identified in this paper to specify the experimental procedure adequately. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

A were calculated for two photometers used at NIST, Photometer A having an f_1' value[5] of 3.0 % and Photometer B, 6.0 %. The results, as shown in Table 2, indicate that the errors for medium-class illuminance meters ($f_1' \sim 6$ %), even with Filters B and C, are in an acceptable range. These errors, however, must be addressed in the uncertainty analysis if the calibration refers to CIE Illuminant A as the calibration source.

Figure 3 shows the experimental arrangement of the source. The color conversion filters are placed in front of the source. As the filters of calculated thickness (8.5 mm and 9.5 mm) were not commercially available, LA60 filters in thicknesses of 2.5 mm, 3.0 mm, and 3.5 mm were combined. The actual spectral power distributions of the source combined with each filter combination were measured with a spectroradiometer, yielding results within 50 K of the predicted color temperature and within 15 % of the predicted illuminance levels.

Illuminance stability of the source

The source as arranged in Fig. 3 was characterized for the stability of illuminance. The illuminance was measured on the optical axis at 30 cm from the source. A temperature-controlled standard photometer equipped with a diffuser was used within its linearity range and with precautions to avoid heating as described in the “Characterization of the photometers” section. Figure 4 shows the measurement results with no filter (line with symbol s) and with Filter A (line with symbol 8). The horizontal axis indicates the time from turning on a cold source. The source with no filter is stable to within 0.2 % whereas, with the filter, a change of more than 3 % was observed over 1 h. It was obvious that the transmittance of the filter changed due to the heat from radiation of 300 klx, causing the filter temperature to rise to about 65 °C. Such a large change of illuminance is not acceptable for a calibration source.

The same experiment was made with Filter B (with a heat absorbing filter). The individual filters were mounted close together, with the heat absorbing filter on the source side. In this configuration, there was about 4 % drop of illuminance after 15 min, and the filters were destroyed (cracked) at 20 min. This incident indicated that the radiation at this level was too intense for the heat absorbing filter (unless it was water-cooled); and, therefore, the heat absorbing filter was not used in the subsequent experiments.

To improve the illuminance stability of the source with the filter, the source arrangement was modified so that the fiber entrance of the monitor detector was placed after the filter to view the light emerging from the filter; thereby, the change of illuminance is corrected by the feedback control. With this modification, the change of illuminance from a cold start was reduced to about 0.6 %, and the illuminance was kept stable to within 0.2 % after 10 min from the start (line with symbol u in Fig. 4). The small initial change was presumably caused by the change of the temperature gradient in the filter, as the illuminance was measured on the optical axis whereas the monitor illuminance was taken near the edge of the filter.

Even though the illuminance was stabilized by the feedback control, the heating of the filter still slightly affects its spectral transmittance. The correlated color temperature of the source with Filter A decreased by 20 K at 10 min from a cold start, and further decreased by 8 K at 30 min from a cold start. The variations in color temperature with different apertures inside the source (to reduce the illuminance level to a minimum of 20 %) was also tested and found to be within 30 K. This variation of CCT normally does not affect the results of illuminance meter calibrations.

Characterization of the photometers

Two different types of standard photometers, Photometer 1 (temperature-monitored type) and Photometer 2 (temperature-controlled type)[6], both designed and built at NIST, were evaluated for use as reference standards to provide the illuminance unit. Photometer 1 is the same type as those currently used to maintain the NIST illuminance unit[3]. Both photometers are non-diffuser type, and employ a silicon photodiode (Hamamatsu S1226-8BQ) with a 0.3 cm^2 sensitive area.

Linearity of the standard photometers

The two standard photometers were first tested for their linearity by comparing them with another reference photometer which was previously measured to be linear up to 100 μA of photocurrent[4]. An opal diffuser was added to the front of this reference photometer to minimize the effect of heat, resulting in the output current of ~1 μA at 10^5 lx. The photometers were exposed to radiation only when the reading was taken (approximately 10 s) to minimize the effect of heat. The measurements were made for four different illuminance levels by using different apertures for the source. Figure 5 shows the results of the measurements. Both Photometers 1 and 2, with no diffuser attached, were found to have linear response up to an illuminance level of 110 klx (~250 μA of photocurrent) within the measurement uncertainty. The uncertainty of this measurement (± 0.3 %) was assessed from repeated measurements. The variation was caused presumably by the effect of heat on the reference and test photometers, though the precautions as described above were taken.

Effect of heat from radiation on photometers

It was expected that, when exposed to radiation at such a high illuminance level, the $V(\lambda)$ filter itself as well as the housing of a photometer would be heated, resulting in significant drift of its responsivity. To investigate this effect, the two standard photometers were tested for exposure to radiation at 100 klx for 50 min. Filter C was used to create this illuminance level. The shutter was closed while the source was allowed to stabilize and the photometer was mounted. The measurement started as the shutter opened.

Figure 6 shows the result of this test for Photometer 1 (temperature-monitored type). The line with symbol s indicates the raw signal from the photometer, and the line with symbol 6 shows the signal corrected for the change of the photometer temperature measured by the built-in temperature sensor[3]. The photometer temperature is also plotted (line with symbol 8) with the scale on the right hand side. The results show that the photometer signal with no correction drifted by ~1 % at only 10 min exposure. The drift is not well compensated even with the correction (see the line with symbol 6) due to the temperature gradient between the $V(\lambda)$ filter and the part of the photometer where the temperature sensor is embedded.

Photometer 1 was tested again with an opal diffuser (25 mm diameter) attached on its front surface to see if the temperature gradient was removed. Though the corrected signal was significantly improved (~ 0.4 % in 50 min.), the drift was still not perfectly compensated.

The same test was conducted for Photometer 2 (temperature-controlled type). The drift of the photometer signal was found to be surprisingly small (within 0.2 % in 30 min). Photometer 2 has a new design, where the temperature sensor is attached more closely to the $V(\lambda)$ filter and thermally insulated from the case, which allows more accurate measurement of the filter temperature[6].

A commercial illuminance meter was also tested for this effect. This illuminance meter has a black plastic housing and is equipped with a dome-shaped, plastic diffuser of ~25 mm diameter. It has no temperature control or monitor capability. After exposure to radiation, the reading of this illuminance meter first rose by 0.4 % (at 3 min), then decreased by more than 2 % in 30 min, and continued decreasing. After 50 min of exposure, the illuminance meter head was found contracted, resulting in a permanent change of its responsivity. This indicates how intense the heat is from this level of radiation.

To avoid such problems caused by the heat from radiation, the exposure time for the test photometer as well as for the standard photometer should be kept to the minimum necessary for taking readings (normally 10 s). The shutter should be closed immediately before and after a reading is taken, and the photometer head should be allowed to cool for some time before repeating measurement. Another experiment with the same illuminance meter at the same illuminance level showed that repeated readings with a 10 s exposure in 2 min intervals reproduced within 0.2 % over a 20 min period.

Geometrical Considerations

The high-illuminance calibration source used in this work has geometrical characteristics significantly different from normal luminous intensity standard lamps, and must be fully understood before using it in calibration work.

First, the illuminance variation as a function of distance from the front collimating lens was measured. The result is shown in Fig. 7. The measured data (s) are fitted to an inverse square law. As a result, the effective luminous intensity of the source is determined to be approximately 850 kcd, and the effective distance offset is 2.51 m. This means that, if a photometer head is placed 30 cm from the front lens of the source, it is equivalent to having a 2.8 m photometric distance. This is a great advantage compared to the case where a 1000 W incandescent lamp is used at 50 cm to create 5000 lx. An error of 1 mm in distance alignment causes a calibration error of 0.4 % at 50 cm and only a 0.07 % at 2.8 m.

The next concern is the divergence of the output beam, which can cause calibration errors for photometers having a narrow acceptance angle. The angular distribution of the incident flux was measured on the optical axis at 30 cm from the front lens by using a luminance meter with measurement angle of 0.33°. Figure 8 shows the results of the horizontal angular scans at vertical angles of 0° and 1°. The distributions for the vertical scans were similar. The range of distributions was found to be ± 2.5° for both horizontal and vertical angles. Photometers used with this source must have an accurate cosine response for this angle range. Figure 9 shows the angular responsivity of Photometers 1 and 2. The acceptance angle of Photometer 2 is extremely small (± 3°) and found barely acceptable for use with this high illuminance source.

Another important characteristic of the source is the spatial nonuniformity of illuminance as it may cause errors when photometers having different sizes of sensitive area are compared. Figure 10 shows the results of this measurement. The central part within ± 10 mm was found fairly uniform (± 0.5 %), but the errors associated with this characteristic should be included in the uncertainty analysis.

Luminance measurement

Once a high-illuminance source is established, a high-luminance surface can be created by combining it with a reflecting or transmitting diffuser of a known luminance coefficient to allow calibration of luminance meters. As it has been demonstrated that the level of illuminance at 100 klx has a significant heat content, it was expected that the diffusers might also be affected by the heat from this radiation. Three different types of diffusers (an acrylic plate, opal glass, and a pressed PTFE plaque) were tested for drift of luminance under a high level of illumination. As the initial test at 100 klx showed very small drifts (less than 0.3 % in 30 min for any of the samples), the illuminance level was increased to 300 klx (with no filter for the source) to see the effect more clearly. The source was first completely stabilized, then the diffuser was mounted with the shutter closed, and the measurement started as the shutter opened. The luminance was measured with Photometer 2 (temperature-controlled type) combined with a luminance adapter (Graseby Model 1120, modified to have 1° measurement angle). This photometer with the luminance adapter was tested, in advance, for the effect of heat from radiation. The test was conducted in a similar manner as described before, and showed no recognizable drift (less than 0.2 %) under continuous exposure to 50 kcd /m^2 for 30 min.

The results of the test for the three samples are shown in Fig. 11. The acrylic diffuser (line with symbol s) is 16.5 cm x 16.5 cm in size and 6 mm thick, creating 55 kcd/m^2. The opal glass (line with symbol 6) is 7.6 cm x 7.6 cm in size and flashed on 3 mm thick glass, creating 45 kcd/m^2. Both diffusers were arranged with 0° incidence and 0° viewing geometry. The pressed PTFE plaque (line with symbol 8) is 5 cm in diameter and arranged in 45°/45° geometry (normally 0°/45° should be used) due to the space limitation, creating 70 kcd/m^2. As the results show, no drift was observed with PTFE, and both transmitting diffusers were found to increase their luminance as a result of being heated by radiation. Caution should be used when using these transmitting diffusers at such high illuminance levels.

Configuration and procedures for calibration at NIST

Based on the experiments described above, the configuration and procedures for high illuminance calibration at NIST have been established. Figure 12 shows the arrangement of the facility. The photometer is placed 30 cm from the front lens of the source. The monitor detector is $V(\lambda)$-corrected. Filter A is used for color conversion and provides illumination of approximately 70 klx at 2850 K. The source can also be set to 100 klx at 3400 K using Filter C.

Even though the current NIST standard photometers are found to have a linear response at this illuminance level, another set of two standard photometers (temperature-controlled type) for high illuminance use has been prepared in order to avoid possible damage of the primary standard photometers due to heat cycles. The high-illuminance standard photometers are calibrated periodically against the NIST illuminance scale.

The calibration of illuminance meters is conducted as follows. The source is turned on under optical feedback and allowed to stabilize for at least 10 min. The shutter is always closed except when taking data. Caution should be exercised since the shutter and the filters become very hot. Flammable materials should not be used near the shutter, and sufficient air convection should be provided. The standard photometer and the illuminance meter under test are mounted in turn, and the reading is taken with the shutter open for 10 s. This comparison is repeated three times with intervals of more than 2 min. This set of measurements is repeated for different illuminance levels by changing the aperture of the source.

The uncertainty of the high-illuminance calibration is analyzed as shown in Table 3. The uncertainty depends on the characteristics of illuminance meters under test. This example assumes a commercial illuminance meter having an f_1' value of ~6 %, no sensitivity in the ultraviolet and infrared region, and a 3 and 1/2 digit display.

Conclusion

A high-illuminance calibration facility has been developed at NIST, which can provide a stable illuminance of 70 klx with a spectral power distribution approximated to CIE Illuminant A (2856 K), or an illuminance of 100 klx with quasi Planckian radiation of 3400 K. These levels are more than an order of magnitude higher than previously available with incandescent standard lamps. The effects of heat from radiation on several different types of photometers and diffusers have been investigated using this facility. Based on the results of the experiments, a procedure for high-illuminance calibration has been established, and calibration services for illuminance meters for up to 100 klx and luminance meters for up to 30 kcd/m^2 are now available.

Although the spectral power distribution of the source is well corrected to the CIE Illuminant A in the visible region, the infrared components were not well adjusted; and they are much higher than the 2856 K Planckian radiation in the 850 nm to 1000 nm region. By reducing the infrared components in this region, and thereby adjusting better to the Planckian distribution, the effect of heat on photometers and diffusers can be reduced.

For illuminance meter calibrations in general, incandescent standard lamps have been almost exclusively used; and therefore, the CIE Illuminant A (2856 K) is recommended for worldwide uniformity of calibration. However, from a practical point of view, the CIE Illuminant A need not be used in all cases. Theoretically, illuminance meters can be best calibrated with the same type of source for which the meters are used. For specific purposes, such as for solar irradiance measurements, illuminance meters can be calibrated for the xenon spectra (similar to CIE Illuminant D_{65}); in which case, the high-illuminance source described in this paper can be used with no correction filter.

This work was carried out with support from the U. S. Air Force. The author is grateful to Mr. Joe Velasquez and Mr. John Grangaard of the U. S. Air Force for providing the stimulus to conduct this research. Thanks are also due to Dr. Georg Sauter of Physikalisch-Technische Bundesanstalt (PTB), Germany, who stayed at NIST during this work and provided important suggestions and support in the experiments.

References

1. Ohno, Y., NIST SP 250-37 Photometric Calibrations (1997)
2. PTB, Measurement–Testing–Calibration (1992)
3. Cromer, C. L., Eppeldauer, G., Hardis, J. E., Larason, T. C., and Parr, A. C., “National Institute of Standards and Technology Detector-based Photometric Scale,” *Applied Optics* **32**-16, 2936-2948 (1993).
4. Ohno, Y., Cromer, C. L., Hardis, J. E., and Eppeldauer, G., “The Detector-based Candela Scale and Related Photometric Calibration Procedures at NIST,” *J. IES*, **23**-1, 88-98 (1994).
5. CIE Publication No. 69, Methods of Characterizing Illuminance Meters and Luminance Meters (1987).
6. Eppeldauer, G. and Ohno, Y., “Illuminance /Luminance Standard Photometer,” CORM96, Gaithersburg (1996)

Discussion

Again Dr. Ohno has presented a very comprehensive account of a new system used for calibrating to very high illuminance levels. I appreciate the thoroughness of the development of the work presented.

As this is now a detector-based system rather than one dependent on lamps only, how does this system compare to the current lamp-based system in terms of uncertainty? How strong is the correlation between this high level calibration system and the previous lamp-based system?

Thank you again for your continued work in this area.

R. B. Gibbons
Philips Lighting

My compliments to Dr. Ohno for a thorough description and analysis of the calibration program. My comment for Dr. Ohno:

With the outstanding linearity characteristics of silicon detectors over six or seven decades, it is unclear to me why such an elaborate setup is needed to "stretch" the calibration level only two orders of magnitude. I would think that using what has historically been available at the highest possible illuminance/luminance level would suffice with appropriate corrections for any heating effects. These corrections for heating could be determined by measuring response vs. temperature for the optical element(s) used. I would think this would be a simpler approach than setting up a complete calibration facility for the higher levels.

R. G. Collins
Osram Sylvania

Y. Ohno presents a clear and comprehensive description of the new method to perform calibration of high illuminance meters and luminance meters at NIST. Your presentation on the development of a calibration source was very detailed. Your work on the characterization of the illuminance stability of the source and on the thermal effects on the photometers and filter were most complete. Was there any attempt to characterize the thermal effect on the spectral transmittance of the color conversion filters? If so, what was the change in the spectral mismatch error for CIE Illuminance A due to the thermal effect?

The utilization of this new facility will fulfill a need for National realization of the high illuminance scale. Is there a low cost alternate to the solar simulator source for laboratories that would derive secondary standards from the NIST calibrated standard photometers? Will you be preparing a practitioner's guide? Another need within the industry is for calibration sources that will ensure accurate measurements of high intensity strobe sources. Will you be applying some of the results from this work to the characterization for time-based integrating photometers?

Dave Ellis
Intertek Testing Services

It was thus with some pleasure that I learned of Dr. Ohno's work and this paper being presented to this IESNA Conference. Even then it only goes partly along the way to the high values we have in measuring daylight availability around the world, nevertheless this is a considerable stepforward.

Question: In view of the desirability of reaching calibration values up to about 180,000 to 200,000 lux for daylight measurements, what are the possibilities of using this facility and procedures for reaching calibration values twice those that are reported in the paper?

J. D. Kendrick
University of Adelaide, Australia

Author's response

To R. Gibbons

As Dr. Gibbons mentioned, this is a good example of the applications of the detector-based methods. We introduced the detector-based method in our routine calibration work of luminous intensity and illuminance (at normal levels) several years ago. Compared with the lamp-based calibration method employed before, the detector-based method has reduced the calibration uncertainty by a factor of two. When we introduced the detector-based candela in 1992, the magnitude of the unit shifted by approximately 0.6 % from the previous blackbody-based unit.

To R. Collins

As Mr. Collins raised an interesting point. Our standard photometers showed no problem with their linearity at least up to 100 klx. This is probably true with many other commercial illuminance meters employing high quality silicon photodiodes as Mr. Collins pointed out. However, one can never assume it, and it must be proved experimentally. This is the reason for all the calibration work. If the linearity of the illuminance meters could be tested with a simple device up to the range we need, then we do not have to “calibrate” the instrument using a high illuminance source, and the calibration at much lower levels would suffice. However, unfortunately, with currently available technology, linearity measurement devices are more complicated and difficult to build than the high-illuminance source. Moreover, the linearity facility may need a similar light source to provide an illuminance of 100 klx. The high illuminance calibration facility we have developed can also be interpreted as a linearity testing device for illuminance meters.

Regarding the effect of heat for photometers, it cannot be simply evaluated from the individual components’ temperature characteristics due to the strong temperature gradient in the photometer head exposed to radiation. This is why our temperature-monitored photometers did not work well (Fig. 6). Nevertheless, we hope that this facility will be simplified in future when a new technology becomes available.

To D. Ellis

As Mr. Ellis pointed out, there is a strong thermal effect of the spectral transmittance of the color conversion filters. We found that the luminous transmittance decreased by 3 % during the warm-up period (Fig. 4). It was not mentioned in the paper, but the color temperature of the transmitted light also drifted by ~30 K, which is negligible in terms of spectral mismatch errors of the photometers.

Regarding low-cost alternatives to the solar simuator source, our approach, of course, is not the only solution for the high-illuminance calibration source. There are possibilities of utilizing, e.g., more elaborate optical systems with a tungsten lamp to create a light source for uniform, high illuminance.

Regarding the strobe source measurements, we have just completed the development of the flashing-light photometric unit (lx·s) in the form of standard photometers having pulse integration capability. This work was conducted under support by Federal Aviation Administration to improve the accuracies of aircraft anticollision light measurements. The calibration service for flashing-light photometers is now available.

To J. Kendick

The author appreciates his comments as an expert in daylight measurements. I hope our new facility will also be useful in providing accurate calibration of photometers in this area. I do not see much difficulties in going up to 200 klx. Our standard photometers are found to have a linear response up to higher than 300 klx. The solar simulator source, by itself, has an illuminance of ~300 lx, but with a color temperature of ~6500 K. As I mentioned in the conclusion, it would make more sense to calibrate the photometers for daylight measurement against a 6500 K source than a 2856 K source, even though it is an internationally accepted practice to use a 2856 K source for calibration of illuminance meters and luminance meters. In this particular situation, we can use the solar simulator source with no color conversion filters, and utilize its original illuminance level of 300 klx. I would like to discuss these and other issues more with experts in the daylight measurement community.

List of Figures

List of Tables

Table 1. Results of the calculation of the spectral corrections for the source.

	Filter combination	CCT [K]	Luminous transmittance	Predicted illuminance (lx)
A)	LA60/ 8.5 mm	2850	0.243	7.3×10^4
B)	LA60/ 9.5 mm + HA50/ 3 mm	2890	0.169	5.1×10^4
C)	LA60/ 6.0 mm	3500	0.335	1.0×10^5

Table 2. Relative spectral mismatch errors in photometer calibration in reference to CIE Illuminant A.

	CCT	Spectral mismatch error (%)	
Source	[K]	Photometer A	Photometer B
+ Filter A	2853	0.03	0.1
+ Filter B	2887	0.03	0.4
+ Filter C	3394	- 0.3	0.6
Source only	6634	1.2	2.0

Table 3. An example of an uncertainty budget for NIST high-illuminance calibration of an illuminance meter in a 10 klx to 70 klx range.

Uncertainty factor	Relative expanded uncertainty (k=2) [%] Type A	Type B
The NIST illuminance unit realization		0.38
Long-term drift of the NIST standard photometers		0.28
Transfer to high-illuminance (HI) standard photometers	0.2	
Spectral mismatch correction of the HI standard photometers		0.1
Linearity of the HI standard photometers		0.3
Drift of the HI standard photometer due to heat		0.2
Random noise and the stability of the source	0.2	
Stray light in the bench		0.2
Spectral mismatch error for CIE Illuminant A **		0.2
Illuminance nonuniformity **		0.3
Illuminance meter head alignment (distance and angle) **	0.1	
Display resolution of the illuminance meter (1 in 199) **	0.5	
Drift of the illuminance meter under test due to heat **		0.3
Nonlinearity of response in different illuminance levels **	0.7	
Overall uncertainty of calibration	**1.2**	

** Uncertainty value depends on the test item.

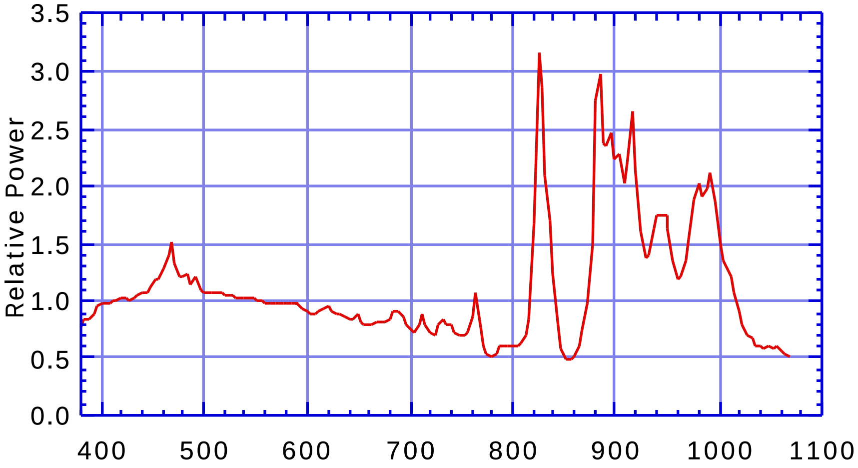

Figure 1. Spectral power distribution of the solar simulator source.

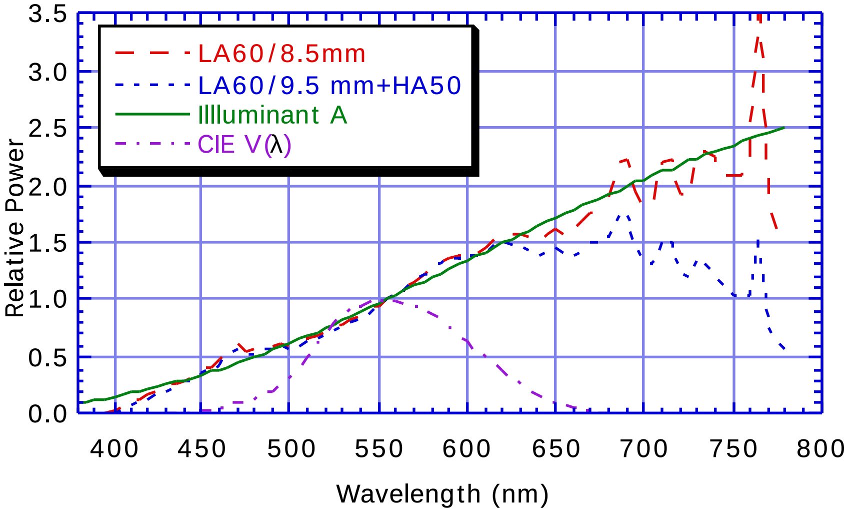

Figure 2. Calculated spectral power distributions of the source combined with the filters.

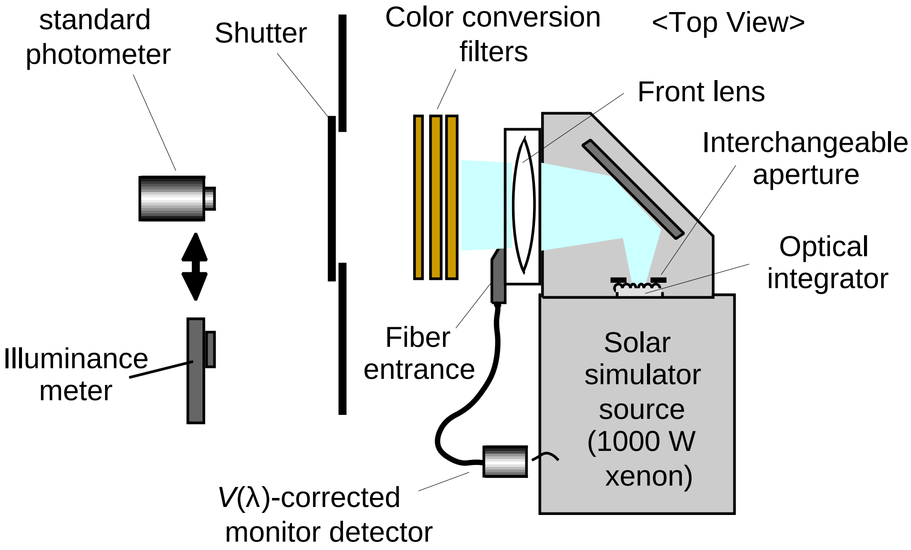

Figure 3. Experimental arrangement of the source.

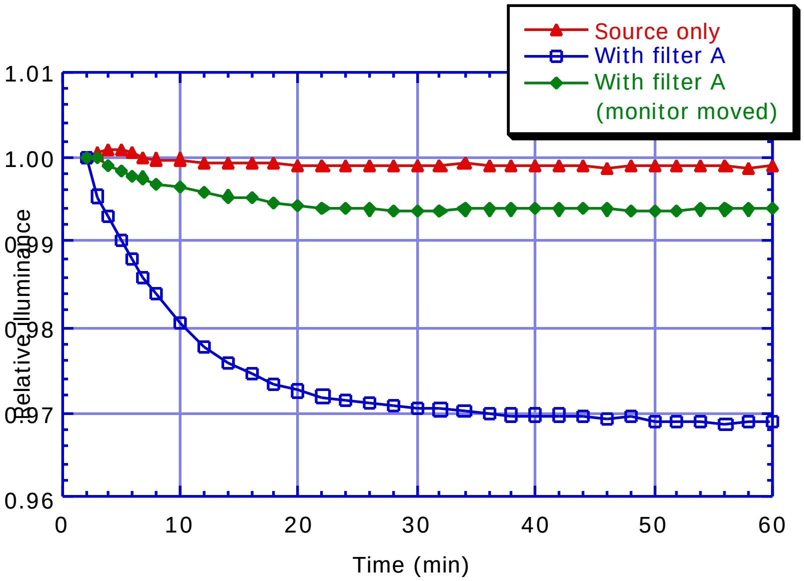

Figure 4. Drift of the illuminance of the source with and without the filter, from a cold start.

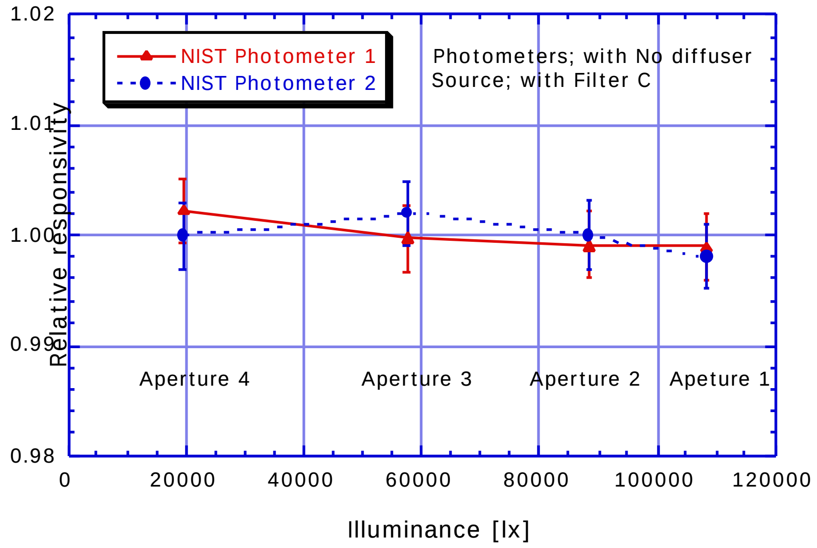

Figure 5. Linearity of Photometers 1 and 2.

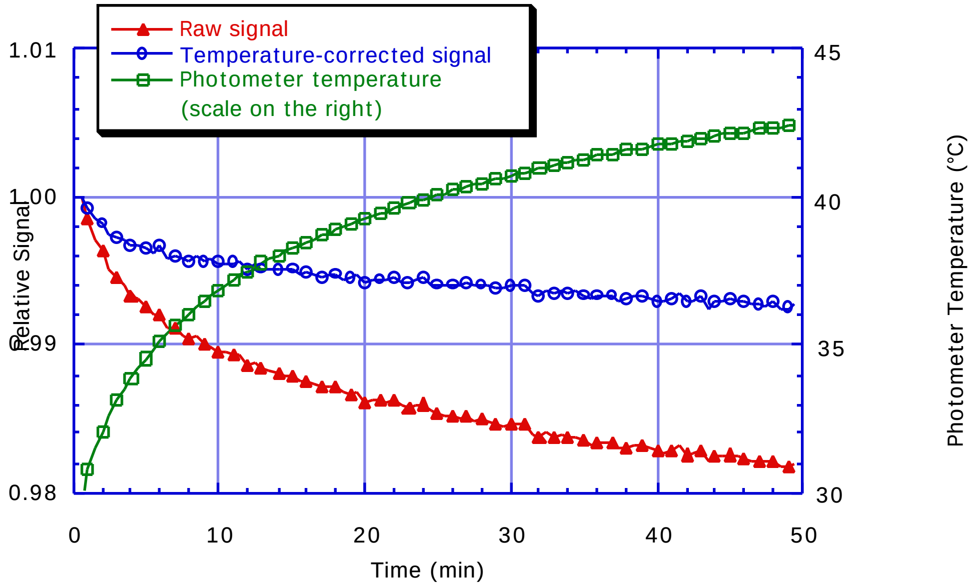

Figure 6. Drift of the signal from Photometer 1 (temperature-monitored type) under 100 klx illumination.

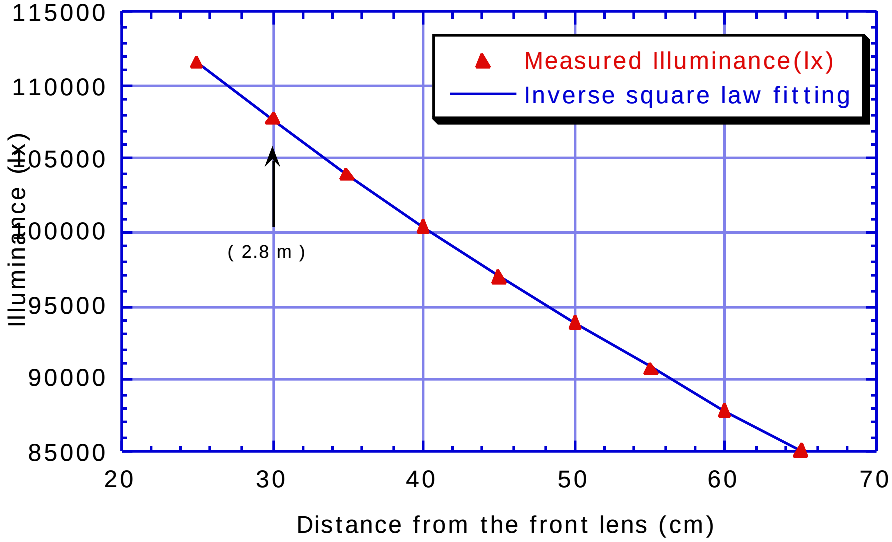

Figure 7. Illuminance variation as a function of distance.

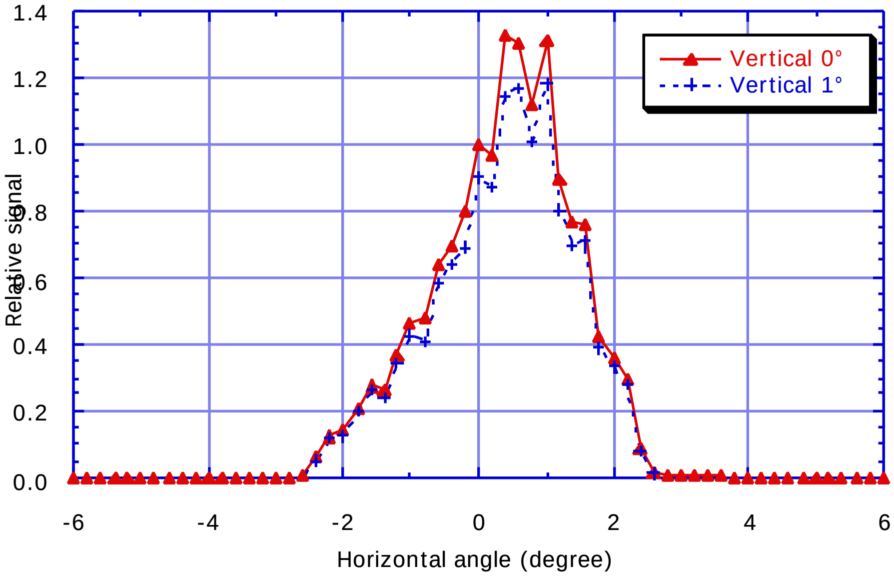

Figure 8. Angular distributions of the incident flux at 30 cm from the front lens on the optical axis.

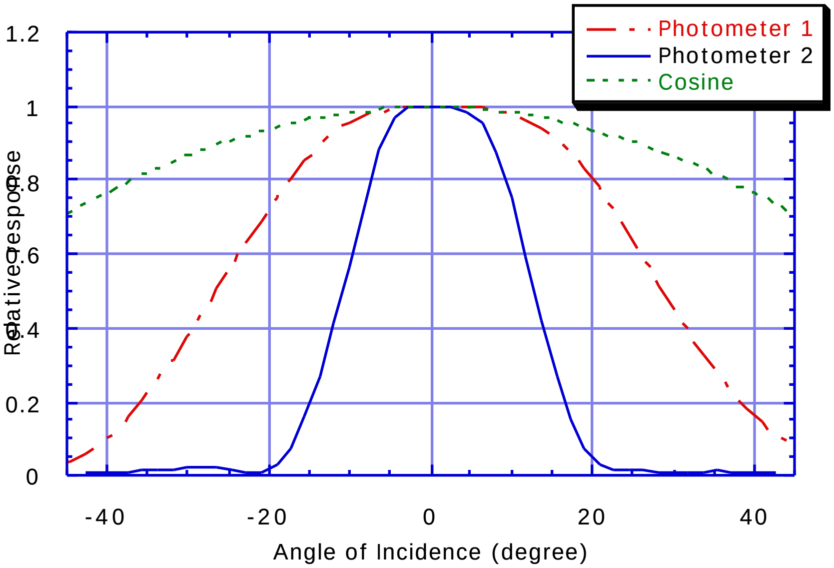

Figure 9. Angular responsivity of Photometers 1 and 2.

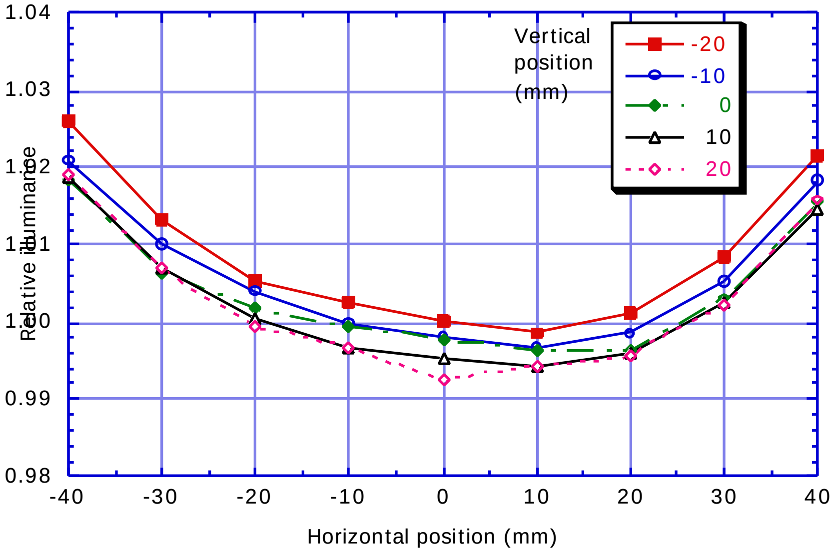

Figure 10. Spatial nonuniformity of illuminance at 30 cm from the front lens.

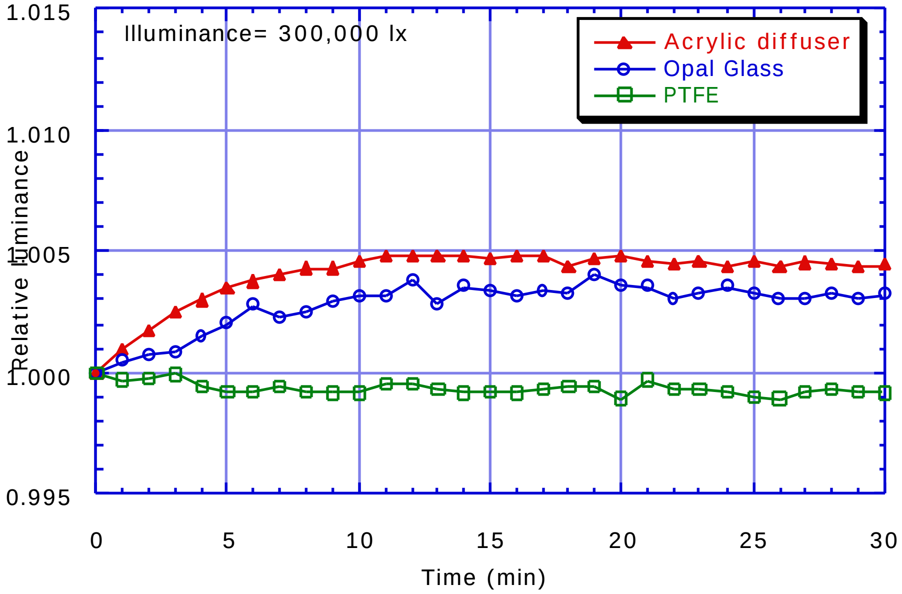

Figure 11. Drift of luminance of diffusers due to the effect of heat of radiation at 300 klx.

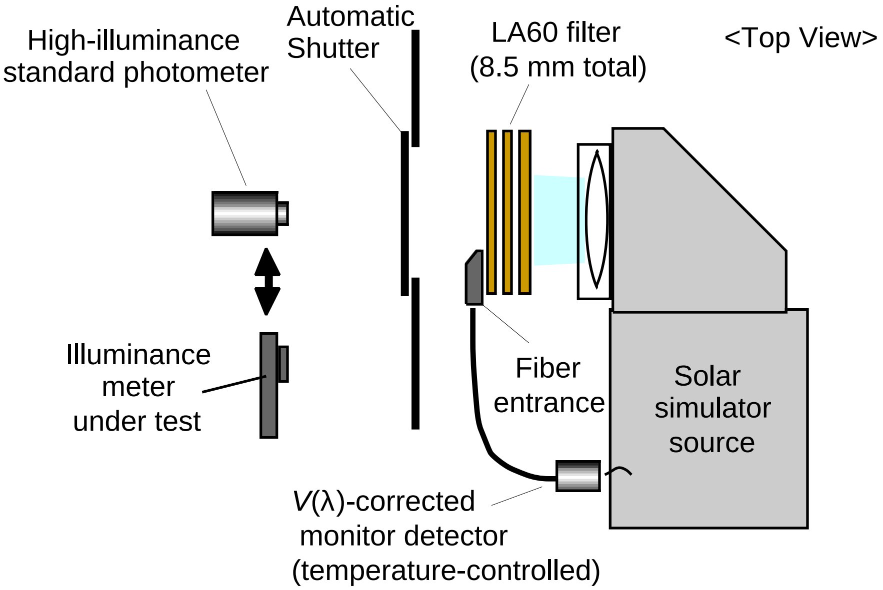

Figure 12. Configuration of the high illuminance facility for calibration work at NIST.