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Establishment of the NIST Flashing Light Photometric Unit

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ABSTRACT

There is a need for accurate measurement of flashing lights for the proper maintenance of aircraft anticollision lights. A large variation in the measured intensities of anticollision lights has been a problem, and thus, NIST has undertaken the task to establish flashing-light photometric standards to provide calibration services in this area. A flashing-light photometric unit (lux second, [lx·s]) has been realized based on the NIST detector-based candela, using four standard photometers equipped with current integrators. Two different approaches have been taken to calibrate these standard photometers: one based on electrical calibration of the current integrator, and the other based on electronic pulsing of a steady-state photometric standard. The units realized using these two independent methods agreed to within 0.2 %. The relative expanded uncertainty (k=2) of the standard photometers, in the measurement of the white xenon flash, is estimated to be 0.6 %. The standard photometers are characterized for temporal response, linearity, and spectral responsivity, to be used for measurement of xenon flash sources of various waveforms and colors. Calibration services have been established at NIST for flashing-light photometers with white and red anticollision lights.

Keywords: anticollision light, calibration, flashing light, flash photometer, effective intensity, illuminance, luminous exposure, strobe light, photometry, standards

1. INTRODUCTION

The photometric measurement of flashing light is essential in the evaluation of various flashing-light sources used in many applications including photography and signaling in transportation. Among them, a need for accurate measurements of aircraft anticollision lights is being addressed by the Federal Aviation Administration (FAA) in reference to recent aircraft accidents. The White House Commission on Aviation Safety and Security is addressing the need for higher aviation safety and security standards[1]. FAA has specified the requirements for the intensity of anticollision lights[2] and is enforcing the maintenance of the anticollision lights on all commercial airplanes. However, a large variation in measurement results has been a problem and is ascribed to the absence of standardized measurement procedures and calibration standards for flashing lights. Thus, the National Institute of Standards and Technology (NIST) has undertaken the task to establish flashing-light photometric standards, while the measurement procedures for anticollision lights are being developed by the ARP5029 committee in the Society for Automotive Engineers (SAE).

In the specification of aircraft anticollision lights and other vehicle signals using flashing lights, the term effective intensity[†] (unit in cd) is widely used. The effective intensity is calculated from the integrated luminous intensity [cd·s][††] based on the Blondel-Rey equation[2,3]. The integrated luminous intensity is related to the integrated illuminance[†††] [lx·s] by the photometer-to-source distance. A few methods are known for deriving a flashing-light photometric unit from a steady-state photometric unit. In the 1960s, the effective intensity was obtained by calculation from the oscilloscope trace of

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[†] Effective intensity is described in Section 6 of this paper.

[††] As an aid to the reader, the appropriate coherent SI unit in which a quantity should be expressed is indicated in brackets when the quantity is first introduced.

[†††] This term is also called luminous exposure in Reference 4. This paper follows the terminology used in the SAE ARP5029.

photodetector signals[3,5]. In the 1950s to 1970s, the National Bureau of Standards used rotating sectors with a luminous intensity standard lamp creating repetitive light pulses of a known intensity to calibrate a photometer having a long time constant[5,6]. These methods were limited in accuracy compared to what can be achieved with the present technology. The Commission Internationale de l'Éclairage (CIE) recommends methods for the spectroradiometry of flashing lights[7], but not yet for photometric measurements.

To achieve state-of-the-art accuracy in flashing-light measurements, a flashing-light photometric unit (lux second, [lx·s]) has been realized at NIST using the detector-based method as previously employed in the realization of the candela[8]. Four flashing-light standard photometers equipped with current integrators were built and calibrated against the NIST illuminance standard photometers[8]. Two different approaches have been taken to calibrate these standard photometers; one based on electrical calibration of the current integrator, and the other based on electronic pulsing of a steady-state photometric standard. The units realized using the two independent methods were intercompared, and the uncertainty of the unit realization was evaluated. A procedure for calibration of flashing-light photometers for anticollision lights has also been established.

2. METHODS FOR REALIZATION OF THE FLASHING-LIGHT PHOTOMETRIC UNIT

Two independent methods are employed to derive the integrated illuminance unit [lx·s] to allow verification of the accuracy of the realized unit. With either method, the unit [lx·s] has been derived from the NIST illuminance unit [lx] based on the following analyses.

2.1 Electrical method

Figure 1 shows the principle of this method. A standard photometer consisting of a photodiode and a $V(\lambda)$ filter is first calibrated for illuminance responsivity [A/lx] using an illuminance standard (steady light). With the illuminance responsivity being R_s [A/lx], the responsivity of this photometer for integrated illuminance [lx·s] is equal to R_s [C/(lx·s)] since the ampere [A] is coulomb per second [C/s]. Then, when measuring flashing light, the standard photometer is connected to a current integrator. The photometer output current is integrated with the capacitance C [F]. The electric charge Q [C] in the capacitor is related to the capacitance and the output voltage V [V] by the well known formula

$$Q = C\,V. \tag{1}$$

The integrated illuminance E_f [lx·s] is given by

$$E_f = Q / R_s. \tag{2}$$

From eqs. (1) and (2), the responsivity R_f [V/(lx·s)] of the photometer including the current integrator is given by

$$R_f = R_s / C. \tag{3}$$

From the output voltage of the current integrator, the integrated illuminance E_f is obtained by

$$E_f = V / R_f. \tag{4}$$

The subscripts s and f in the variables represent steady light and flashing light, respectively. As shown in eq. (3), the derivation of the flashing-light photometric unit from the steady-state photometric unit in this method depends on the calibration of the capacitance C.

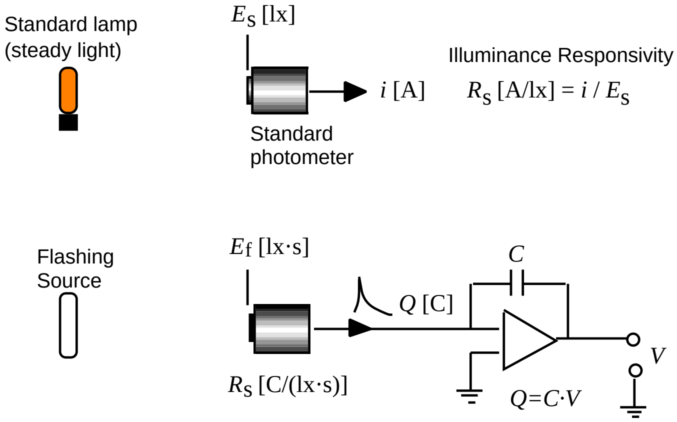


Figure 1. Derivation of the flashing-light photometric unit using the electrical method.

2.2 Pulsed photometry method

This method is an improvement over the well-known chopper method. Instead of using a light chopper, an electronic gate is used for much higher accuracy in the calibration. Figure 2 shows the principle of this method. The standard photometer is connected to a current integrator which has an input gate controlled by an accurate time base. The photometer head is placed at a point of known illuminance E_s [lx] under steady light illumination, and the input gate opens for T [s], and the output voltage V [V] is measured. The capacitor in the integrator is completely discharged before opening the gate. The responsivity R_f [V/(lx·s)] of the photometer including the current integrator is given by

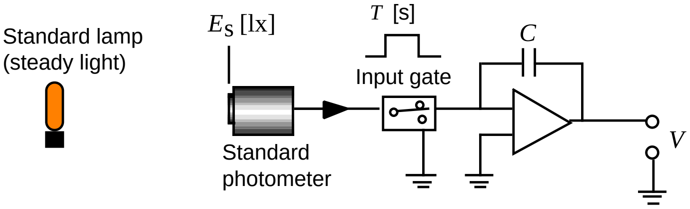


Figure 2. Derivation of the flashing-light photometric unit using the electrically-pulsed photometry method.

$$R_f = V / (E_s \cdot T). \tag{5}$$

In this method, the capacitances of the integrator need not be known. Instead, the calibration accuracy depends on the accuracy of the time base. It should be noted that the photodiode signal from the photometer should never be open (no-load condition) before integration starts. The no-load condition would yield an open voltage (~1 V) from the photodiode, which creates an additional charge in the junction capacitance in the photodiode and stray capacitance of the wires, which would flow into the integrator when the photodiode is connected, causing a serious error.

3. FLASHING-LIGHT STANDARD PHOTOMETERS

Four flashing-light standard photometers have been built for use as the primary standards for flashing-light measurements at NIST. The photometer consists of a photometer head and a current-integrator unit. Figure 3 shows the construction of the photometer head, which consists of a precision aperture, $V(\lambda)$ filter, and a silicon photodiode, and is equipped with a thermoelectric device which maintains the photodiode/filter temperature at ~25 °C ± 0.1 °C. The photodiode, Hamamatsu[†] S1226-8BQ, is chosen for fast rise time (200 ns at 100 Ω load) and other photometric characteristics. For calibration with steady light, the photometers are also equipped with detachable current-to-voltage converters with gain settings from 10^4 [V/A] to 10^{10} [V/A] which are calibrated with an uncertainty[††] of 0.02 %.

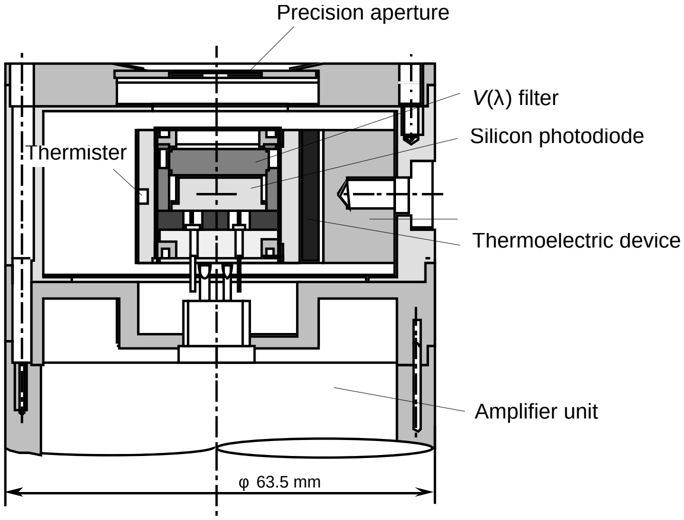


Figure 3. Construction of the NIST flashing-light standard photometer head.

The spectral responsivities of the photometer heads are matched to the $V(\lambda)$ function with CIE f_1' values[9]

[†] 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.

[††] Throughout this paper, all uncertainty values are given as a relative expanded uncertainty with coverage factor k=2, thus a two standard deviation estimate.

ranging from 1.7 % to 1.9 %. Since the anticollision lights have two colors (white and red) with dissimilar spectral power distributions from the CIE Illuminant A, the spectral mismatch correction factors[10] were evaluated for several different types of anticollision lights provided by the manufacturers. Figure 4 shows the spectral power distribution curves of the six anticollision lights, four white and two red, measured at NIST. Table 1 shows the results of the calculation. M011, S/N 111, S/N 112, and S/N 113 are the designations of the four standard photometers. These correction factors are used for the correction of the photometric responsivity of each standard photometer.

Table 1. Spectral mismatch correction factors of the NIST standard photometers for six different anticollision light sources.

					Spectral mismatch correction factors			
Source	color	x	y	CCT†[K]	M011	S/N 111	S/N 112	S/N 113
Type(A)	white	0.3206	0.3268	6095	0.9940	0.9956	0.9925	0.9968
Type(B)	white	0.3103	0.3214	6706	0.9933	0.9951	0.9917	0.9964
Type(C)	white	0.3130	0.3244	6526	0.9935	0.9953	0.9919	0.9965
Type(D)	white	0.3140	0.3226	6482	0.9937	0.9955	0.9921	0.9967
Type(E)	red	0.5475	0.3565	-	1.0109	1.0094	1.0106	1.0091
Type(F)	red	0.6615	0.3340	-	1.0209	1.0178	1.0206	1.0169

† Correlated color temperature

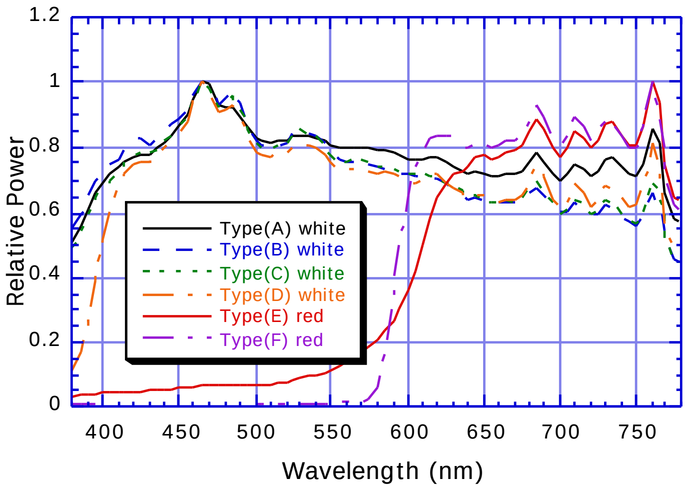


Figure 4. Spectral power distributions of the six different anticollision lights.

Four current integrator units have been built for use with each photometer head. Figure 5 shows the block diagram of the circuit. This integrator operates in two modes: calibration mode (for steady light measurement with the time-based method) and measurement mode (for flashing light). The circuit has two current integrator circuits to allow simultaneous measurement of two photometer heads. This feature is useful in correcting for individual variations of flashes when one photometer is calibrated against another.

The components were carefully chosen to assure fast response and stable operation. For operational amplifiers, Burr-Brown OPA627 is used for high slew rate (55 V/µs) and low bias current (1 pA). Polypropylene capacitors are used for low leakage conductance and capacitance stability. For switching, high speed reed relays (500 µs operate/release time) are used. The main integrator has three ranges (1000 lx·s, 100 lx·s, and 10 lx·s) and are capable of measuring over two orders of magnitude at each range with sufficient signal-to-noise ratios, thus covering a measurement range over four orders of magnitude.

Anticollision lights flash repeatedly at a rate of approximately 1 s^{-1}. Therefore, the photometer

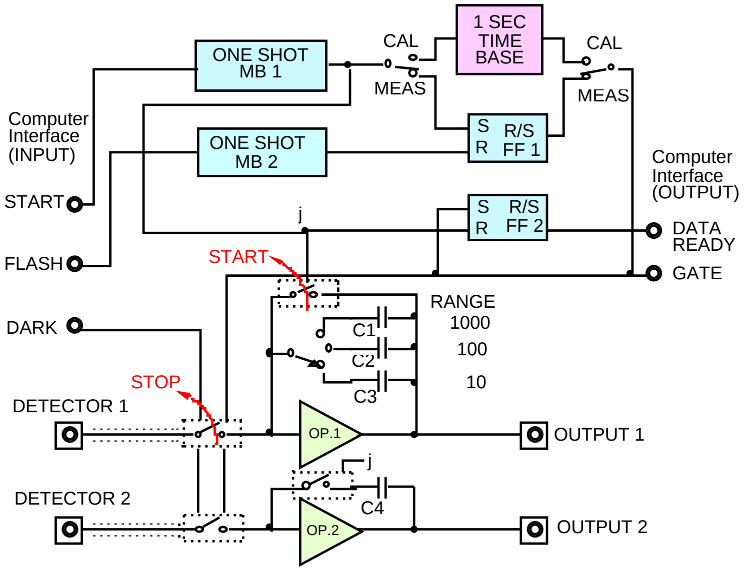


Figure 5. The circuit diagram of the current integrator.

operation must synchronize with the timing of the flashes. An additional photometer head is used to detect the starts of the flashes and to feed the signals (FLASH) to the integrator for synchronized operation. The current integrator is interfaced to a computer so that the data acquisition is also synchronized. The circuit operates as follows. The START signal initiates discharge of the capacitors (C1, C2, or C3, and C4) for 50 ms. Then, in the calibration mode, integration starts and continues for exactly 1 s. In the measurement mode, integration starts before the start of a flash and continues until a certain time (50 ms to 200 ms) after the start of the flash. In this way, the circuit will not miss the rising edge of the pulse. The measurement of the output voltages by the DVM starts immediately after integration has ended. Thus, each flash is measured and data is stored in the computer while measuring as many flashes as necessary.

There are small dark readings due to the input bias current and the offset voltage of the operational amplifier. The dark readings of the integrators are almost negligible (less than 0.1 %) at illuminance levels higher than 100 lx·s, but need to be corrected at lower illuminance levels, especially with integration for 1 s. The dark readings are taken in the DARK mode, in which the circuit is operated with the input gate switch kept open. At illuminance levels lower than 1 lx·s, the dark readings need to be corrected by light-dark measurement because the readings by the DARK mode are not exactly the same as the light-dark readings due to shunt resistance of the photodiode. The 1 s time base is a quartz-based timer and its pulse width was calibrated using a calibrated frequency counter to be 1.0000 s ± 0.0001 s. The operate/release time of the reed relays including bouncing is included in the uncertainty budget.

As mentioned in 2.2, it is important that the photodiode output be grounded before integration starts, particularly in calibration mode. To achieve this, the gate switch and the discharge switch are both closed before starting the integration. The integration is started by opening the discharge switch, and integration is ended by opening the gate switch.

4. LINEARITY MEASUREMENT

The linearity of the photometers needs to be evaluated since the instantaneous intensity of a xenon flash source at its peak is very high and can cause saturation in the photodiodes. The NIST flashing-light standard photometers (including the current integrators) were tested for linearity using a relative method, in which a test photometer was compared with a reference photometer of known linearity under illumination by a xenon flash source. The reference photometer (one of the standard photometers) was previously measured to have linear response up to an output current of 0.25 mA.

Figure 6 shows the arrangement for the linearity measurement. A xenon anticollision light system is used as the light source to create a maximum integrated illuminance level of 1000 lx·s for the photometer under test, while keeping the illuminance level for the reference photometer sufficiently low to limit its photocurrent to less than 0.25 mA. A glass plate reflects a small portion (~8 %) of the beam onto the reference photometer. A neutral density (ND) filter with a ~10 % transmittance is also used in front of the reference photometer when further reduction of illuminance is necessary. The beam barely overfills both photometers. With ND filters of various transmittances placed in front of the light source, the output voltages V_{ref} and V_{test} from both photometers are measured for repeated flashes. The ratio $V_{\mathrm{test}} / V_{\mathrm{ref}}$ should be constant as long as the photometer under test is linear. Since V_{ref} and V_{test} are measured simultaneously for the same time duration using the two-channel current integrator, the variation of individual flashes does not affect the results. The stability of the ratio $V_{\mathrm{test}} / V_{\mathrm{ref}}$ also indicates the repeatability of the photometers (including the current integrators) and the accuracy of alignment of the optical components. With our measurement system shown in Fig. 6, the standard

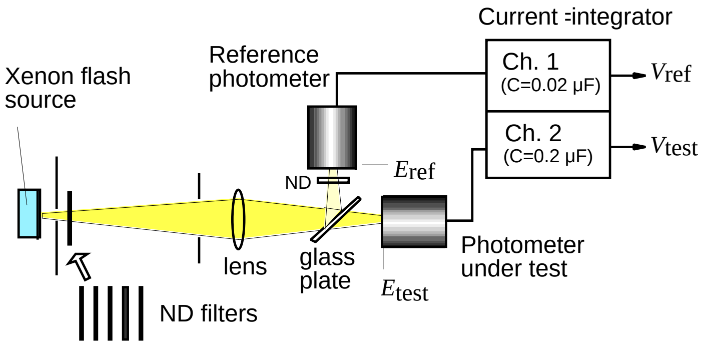
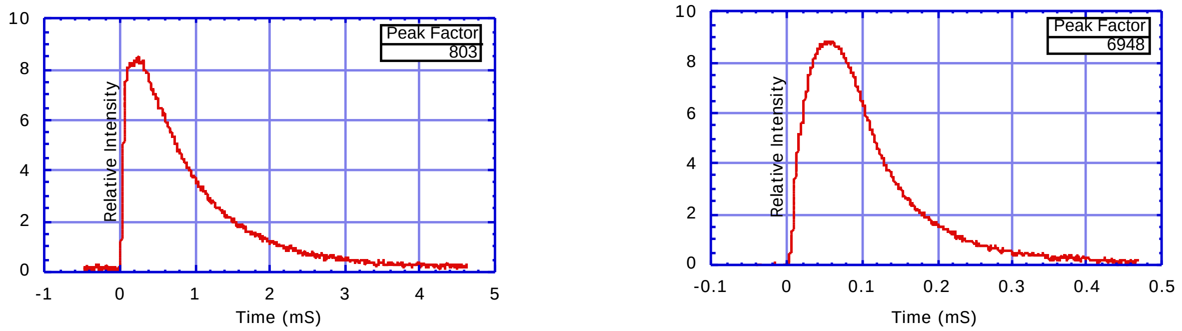


Figure 6. Arrangement for the photometer linearity measurement.



(a) (b)

Figure 7. Waveforms of the two xenon flash sources used in the linearity measurement.

deviation of the measured ratios V_{test} / V_{ref} at a level of ~100 lx·s was recorded to be 0.02 % to 0.04 %, while the variation of the individual flashes was 2 % to 10 % depending on the source used.

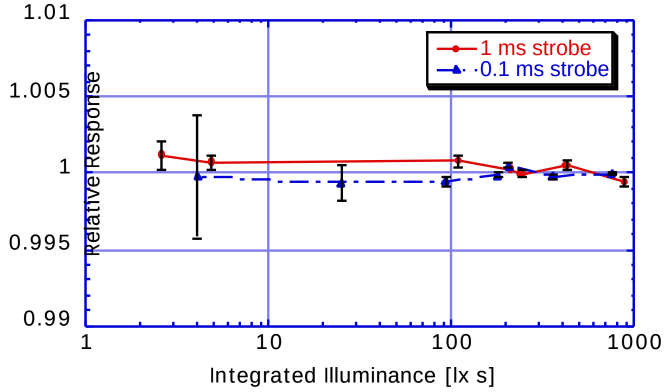


Figure 8. Results of the linearity measurement.

As the light source, two types of xenon anticollision lights having the half-pulse width of ~1 ms and ~0.1 ms, respectively, were used to check the consistency of results. Figure 7 shows the waveforms of these two sources measured with a high-speed current-to-voltage converter and a digital oscilloscope. Graph (a) is the longest pulse and graph (b) is the shortest pulse of the six anticollision lights. The peak factor is the ratio of the peak instantaneous illuminance [lx] to the integrated illuminance [lx·s]. From these values, the peak instantaneous illuminance at 1000 lx·s is calculated to be ~8 x 10^5 lx for 1 ms flashing light and 7 x 10^6 lx for 0.1 ms flashing light, corresponding to peak photocurrents of 1.8 mA and 16 mA, respectively. The photodiode was not reverse-biased because application of a 5 V reverse bias did not change the results by more than 0.1 %. The lower limit of the signal-to-noise ratio occurred at several lx·s because the measurements were made at a fixed range of the current integrators and because the integrated illuminance level for the reference photometer was further reduced when measuring the 0.1 ms flashing light.

The results of the linearity measurement for one NIST flashing-light photometer is shown in Fig. 8. Each plot is a mean value of the readings of 10 flashes, and the error bars indicate the standard deviations. The other photometers showed similar results. The data shows that the photometers have linear response for 1 ms or 0.1 ms flash at levels up to 1000 lx·s.

5. DERIVATION OF THE INTEGRATED ILLUMINANCE UNIT

The responsivities of the four NIST flashing-light standard photometers were calibrated using the two methods described in Section 2. For the electrical method, the photometer heads were first calibrated against the NIST illuminance standard photometers[11], under illumination by a 1000 W quartz halogen lamp operated at 2856 K, to determine the illuminance responsivities R_s [A/lx] of the photometer heads. The capacitances of all the current integrators were calibrated using a calibrated current source having an uncertainty of 0.065 %. The current offset of the source was corrected by zero readings. A current y [A] is fed to the detector input, and the current integrator was operated in the calibration mode (1 s integration). With the duration of the time base T [s] and the output voltage V [V], the capacitance C [F] is given by

$$C = y\, T / V \tag{6}$$

During repeated measurements of the same capacitors, noticeable changes (less than a few tenths of a percent) of the measured capacitance values were observed, the reason for which was determined to be temperature dependence of the capacitors. To assure the capacitances to be stable, all the current integrator units were warmed up for more than two hours before use.

Table 2. Calibration of capacitances in two methods.

Capacitor	Current source method [μF]	NIST Electricity Division [μF]	Ratio
C1	0.22293	0.22269	1.0011
C2	0.021709	0.021698	1.0005
C3	0.0022655	0.0022609	1.0020

To verify the accuracy of the capacitance calibration mentioned above, the capacitors of one of the units were also officially calibrated by the NIST Electricity Division. The calibration was performed using a capacitance bridge at 1 kHz with an uncertainty of 0.05 %, with the capacitors under test installed on the circuit board so that all the stray capacitances of wires are included. Table 2 shows the comparison of the capacitance calibrations with the two methods. The differences between the two methods may arise from the reed relay operating time and the difference in the measurement frequency. The uncertainty of the capacitance measurement using the current source is assessed to be 0.2 % from this comparison of results. The responsivities R_f [V/(lx·s)] of the flashing-light standard photometers at each range were determined using eq. (3).

For the pulsed photometry method, the flashing-light standard photometers were calibrated under illumination by a 1000 W quartz halogen lamp operated at 2856 K, with the current integrator operated in the calibration mode using the 1 s time base. The illuminance was determined with the NIST illuminance standard photometers, and the responsivities R_f [V/(lx·s)] of the flashing-light standard photometers were determined using eq. (5). Table 3 shows the results of the calibration of the flashing-light standard photometers using the two methods. The flashing-light responsivities R_f of the four photometers in the three ranges, determined with the two independent methods, agreed to within 0.2 %, well within the uncertainty of calibration. Both methods proved to be appropriate for this purpose.

Table 3. Results of the calibration of the flashing-light standard photometers using the two methods.

		Integrated illuminance responsivity [V/(lx·s)]			
Range	Method	M011	S/N 111	S/N 112	S/N 113
Range 1000	Electrical method	0.010489	0.010546	0.010670	0.010688
	Pulsed photometry	0.010478	0.010538	0.010672	0.010689
	Ratio	**1.0011**	**1.0008**	**0.9998**	**0.9999**
Range 100	Electrical method	0.10777	0.10438	0.10726	0.10449
	Pulsed photometry	0.10767	0.10431	0.10727	0.10447
	Ratio	**1.0010**	**1.0007**	**1.0000**	**1.0003**
Range 10	Electrical method	1.0309	1.0362	1.0531	1.0556
	Pulsed photometry	1.0299	1.0341	1.0534	1.0540
	Ratio	**1.0009**	**1.0021**	**0.9997**	**1.0015**

Table 4. Uncertainty budget for the realization of the integrated illuminance unit with the electrical method (for xenon flash, 10 lx·s to 1000 lx·s).

Factor	Relative expanded uncertainty [%] (k=2) Type A	 Type B
NIST illuminance unit[8]		0.39
Long-term drift of the NIST illuminance standard photometers[11]		0.15
Illuminance unit transfer to the flashing-light standard photometers[11]	0.14	
Linearity of the flashing-light standard photometers (>10 lx·s)		0.2
Calibration of capacitances		0.2
Short-term stability of capacitances		0.1
Signal decay for 1 s (> 10 lx·s)		0.2
Spectral mismatch correction (for white xenon flash)		0.1
Repeatability of the flashing-light standard photometers measuring xenon flashing light (>10 lx·s)	0.1	
Total uncertainty of the NIST integrated illuminance unit	**0.59**	

Table 5. Uncertainty budget for the realization of the integrated illuminance unit with the pulsed photometry method (for xenon flash, 10 lx·s to 1000 lx·s).

Factor	Relative expanded uncertainty [%] (k=2) Type A	 Type B
NIST illuminance unit[8]		0.39
Long-term drift of the NIST illuminance standard photometers[11]		0.15
Linearity of the flashing-light standard photometers (>10 lx·s)		0.2
Illuminance transfer in the pulsed photometric calibration[11]	0.14	
Uncertainty of the time base including the reed relay timing		0.1
Short-term stability of capacitances		0.1
Signal decay of the integrator for 1 s (>10 lx·s)		0.2
Spectral mismatch correction (for white xenon flash)		0.1
Repeatability of the flashing-light standard photometers measuring xenon flashing light	0.1	
Total uncertainty of the NIST integrated illuminance unit	**0.56**	

Tables 4 and 5 give the uncertainty budget for the realization of the integrated illuminance unit [lx·s] using the two methods, respectively. The signal decay of the output voltage of the current integrator is caused by the leak resistance of the capacitors and was measured in each range for 1 s integration time. The uncertainty of the spectral mismatch corrections was assessed from the uncertainty of the diode-array type spectroradiometer used to measure the relative spectral distributions of the calibration source. The repeatability of the flashing-light standard photometers was assessed from two times the standard deviation of the ratio measurements in the linearity measurement setup at an illuminance level of 10 lx·s using the 1 ms flash source.

6. CALIBRATION SCHEME FOR FLASHING-LIGHT PHOTOMETERS

Since xenon flash sources do not reproduce their photometric values well enough, a decision was made to use photometers as transfer standards in the calibration services. An arrangement as shown in Fig. 9 is used to perform the calibration of flashing-light photometers submitted by customers. The measurements are made in the NIST photometry bench[10] which is installed in a light-tight box to control stray light. A xenon anticollision light system is used as a source to provide illuminance, and photometers are calibrated for both white and red (Aviation Red[2]) flashing lights. Calibration in two colors also provides some information on the $V(\lambda)$ matching of the photometer under test.

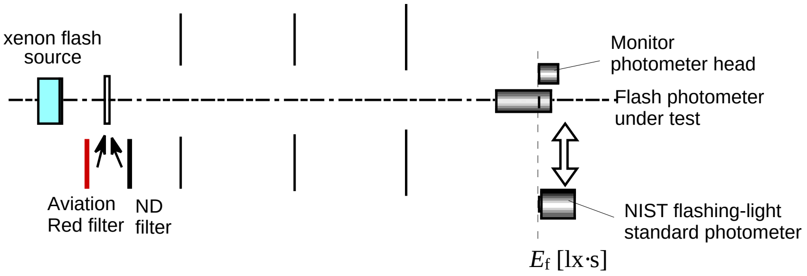


Figure 9. Arrangement for the calibration of flashing-light

Calibrations are normally performed at two illuminance levels (100 lx·s and 10 lx·s) for white anticollision light so that the linearity of the test photometer can also be checked. These illuminance levels correspond to effective intensities of 5000 cd and 500 cd at a photometric distance of 3.3 m. (The FAA's requirement for white anticollision lights is 400 cd.) A neutral density filter is inserted in the optical path to adjust the illuminance level, and an Aviation Red filter is inserted to conduct the calibration for red anticollision lights. The photometer under test is calibrated by substitution with the NIST flashing-light standard photometers. A monitor photometer is used to monitor the variations of individual flashes while substituting the standard photometer and a test photometer to allow corrections. The uncertainty of the calibration depends largely on the repeatability and the linearity of the photometer under test, and therefore, is reported individually.

Photometers under test are calibrated for integrated illuminance in lx·s. However, many of the anticollision-light photometers only indicate effective intensity. The calibration of such instruments is handled as follows. The effective intensity [cd] is defined by the Blondel-Rey equation[2,3]:

$$I_e = \frac{\int_{t_0}^{t_1} I(t)\,\mathrm{d}t}{0.2 + (t_1 - t_0)}\,, \tag{7}$$

where t_0 is the start time and t_1 is the end time of the flash. The term 0.2 (unit: in s) is the Blondel-Rey constant. The effective intensity is defined as the luminous intensity of a steady-state light source which gives equivalent conspicuity to that of a given pulse of light. If a flash photometer indicates effective intensity, the photometric distance (the distance between the photometer and the source) should be specified for the instrument. With the specified photometric distance d [m], the integrated illuminance E_f [lx·s] is calculated from the reading of effective intensity I_e [cd] by

$$E_f = (0.2 + t_1 - t_0)\, I_e / d^2. \tag{8}$$

The duration ($t_1 - t_0$) can be neglected in the practical measurements of xenon anticollision lights because the durations of most xenon anticollision lights are normally 1 ms or less and because there is no clear definition of the duration of a flash. Also, many types of commercial flash photometers are not equipped with a means to measure the duration of flashes.

Thus, photometers that only indicate effective intensity can be calibrated against standard photometers for integrated illuminance rather than against standard sources of effective intensity. There is no need for measuring the real distance between the calibration source and the photometer in the calibration setup, and the calibration source need not reproduce its light output since the calibration is performed using the detector-based procedure[10,11]. The reference plane of the test photometer head should be clearly defined by the user so that it can be aligned precisely to the same position as that of the standard photometer.

7. CONCLUSION

The flashing-light photometric unit (lux second, [lx·s]) has been realized based on the NIST detector-based candela, using four flashing-light standard photometers equipped with current integrators. Two different methods have been employed to calibrate these standard photometers: one based on electrical calibration of the current integrator, and the other based on electronic pulsing of a steady-state photometric standard. The units realized using the two independent methods agreed to within 0.2 %, and both methods proved to be appropriate. The relative expanded uncertainty (k=2) of the NIST flashing-light standard photometers, in the measurement of white xenon flashing light, is estimated to be 0.6 %, which is comparable to the uncertainty in steady-state photometry. A procedure has also been developed for calibration of flashing-light photometers with a substitution method, allowing corrections for the instability of the calibration source by a monitor photometer. The long-term stability of the capacitors in the current integrators is yet to be analyzed. The NIST flashing-light standard photometers including the current integrators will be calibrated on a periodical basis to provide such data.

The measurement procedure developed by the SAE ARP5029 committee will require traceability of all the anticollision-light photometers used for maintenance of commercial airplanes to the NIST flashing-light photometric unit. Calibration services are now available at NIST for flashing-light photometers to be calibrated for white and red anticollision-lights. The measurement of flashing-light sources other than aircraft anticollision lights may require different arrangements for calibrations since the flashing intervals and pulse shapes are different. Possible expansion of the flashing-light calibration capabilities will be considered in the future.

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