Report on the CIE Workshop: Photometry of Flashing Lights

Warsaw, Poland, June 25, 1999

Chairman: Yoshi Ohno, USA

INTRODUCTION

This workshop was organized jointly by CIE Division 2 and Division 1 to address issues of measurements of flashing lights related to both the physical measurement aspects (Div. 2) and human vision aspects (Div. 1).

Flashing lights are used in many applications, such as signaling devices (aircraft anticollision lights, roadway barricade lights, emergency vehicle warning lights, fire alarm lights, light houses, etc.), imaging devices (strobe lights for cameras, copy machines, image scanners, etc.), and measurement instruments (colorimeters and spectro-reflectometers). Needs on the uniform and accurate measurements of flashing lights have been recently raised in these areas. While some references are available (mostly published in the 1960s and 70s), there is no CIE publication that defines and gives recommendations on the photometry of flashing lights (note [1]).

A good example, in our daily life, of the effective signaling by flashing lights is found in a little LED message lamp on the telephone at the chairman's office. The red LED lamp used to blink when a message was recorded, and it was immediately recognized. Now the phone system has changed, and it no longer blinks. It takes much longer time (sometimes a few hours) before it can be recognized. When the LED is blinking, it takes less energy but works much more effectively.

One specific area that has recently drawn much attention is the measurement of aircraft anticollision lights. After a recent aircraft accident and many near-misses reported in the United States, the Federal Aviation Administration (FAA) issued a regulation on mandatory maintenance of the anticollision lights in commercial aircraft. The regulation created a need for written procedures for measurement of the effective intensity of anticollision lights. A task group was formed to draft ARP5029 by the Society of Automotive Engineers (SAE) A20B Aircraft Exterior Lighting Subcommittee. In the process of developing the document, a number of questions were raised on the photometry of flashing lights that have not been resolved. This issue has drawn international attention, and led to the formation of a CIE reportership R2-17 (Aviation Photometry) and a new technical committee TC2-49 (Photometry of Flashing Light).

This workshop was planned to collect the latest knowledge on the research and technologies available, identify the current problems in this area, and to provide inputs not only to this committee but also more widely to the future work of Divisions 1 and 2.

PRESENTATIONS

1. Historical Overview of Flashing Light Photometry

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An overview was given on research into the visual response to flashing lights, including work by Bunsen and Roscoe (1862), Bloch (1885), Allard (1876), and Blondel and Rey (1911). The Blondel-Rey equation [3], now widely used, was determined for achromatic threshold illuminance using rectangular light pulses in a dark background. It was shown that the duration of the integration (t_2-t_1) is not the entire pulse duration (t_3-t_0) but determined from the pulse shape by an integral equation. The Blondel-Rey constant (0.2 s) is actually not a constant but a variable as a function of field size, adaptation luminance, color, and pulse shape [4]. To describe the effective intensity for any pulse shape, the form factor method [2,4] has been introduced as an extension of the Blondel-Rey equation. The form factor is the ratio of the total area of the pulse waveform to the area of the rectangle which the waveform fits in. With this method, the effective intensity can be calculated from the integrated intensity (over the entire duration) and the peak intensity of the pulse. This method is adopted in the ECE Regulation 65 "Flashing Lights". Recent results on the spectral luminous efficiency of the human eyes for flashing lights were also presented. The Blondel-Rey constant (variable) has been analyzed as a function of wavelength, and shown to be largest for the blue and smallest for the yellow region. The relative spectral sensitivity for a light pulse of three different durations has been obtained. The results show much higher sensitivity in the blue region compared with the $V(\lambda)$ function [5].

2. Relevant Work in CIE Division 1

(Supplementary System of Photometry)

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Basic characteristics of the human visual system were described. It was shown that the visual system response is very complex, and must be characterized in three dimensions – spectral, spatial, and temporal. The photometry of flashing lights deals with the temporal characteristics. The visual response depends on the field size (foveal, peripheral), type of the task (detection, recognition of pattern, etc.), and transient (adaptation, etc). When a photometric system is defined, large variations of response depending on these parameters must be considered. Division 1 is establishing a photometric system based on apparent brightness at any luminance level, which is called the "supplementary system of photometry." Temporal aspects of light are regarded as one of the critical factors affecting apparent brightness. A need to introduce the efficiency of flashing light into the supplementary system of photometry will be considered.

3. Development of SAE ARP 5029 on the Measurement of Aircraft Anticollision Lights

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Anticollision lights are one of many methods of increasing pilot awareness of other aircraft so that collisions can be avoided. In the early 1990s, the FAA issued new maintenance requirements that aircraft anticollision lights be maintained by the airlines at or above the required certification effective intensity of 400 cd for both red and white anticollision lights (based on Blondel-Rey equation) in the horizontal plane. This led to industry concern about the accuracy and the uniformity of measurements. A task group ARP5029 was established under SAE A20 Aircraft Lighting Committee to develop an SAE Aerospace Recommended Practice (ARP) on the measurements of aircraft anticollision lights [6]. The document defines test constraints, develops detailed test procedures and equipment recommendations, specifies a photometer calibration source and traceability, and estimates the uncertainty for laboratory, shop and field measurements. In conjunction with the development of SAE ARP 5029, NIST developed a flash photometer calibration process (later presented by Y. Ohno). The document specifies the effective intensity based on the Blondel-Rey equation with an approximation of $\Delta t \approx 0$ since most of the anticollision lights used today are xenon flash with very short duration ($\approx$1ms), and the document covers only this type of source. The document (45 pages) was published in December 1998 after four year's efforts by more than 100 members. The document has limitations, and some questions remain unresolved: 1) Is the Blondel-Rey relationship the best way to determine the effective intensity? 2) Is 0.2 second the best constant? 3) Is it correct to use the photopic response when vision is mesopic? 4) Would a more orange color be better than aviation red for the red anticollision lights? 5) Is 400 cd the best compromise between glare and conspicuity? 6) How should multiple flashes be measured?

4. Establishment of the NIST Flashing-Light Photometric Scale

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Upon request from the FAA, NIST undertook the task to establish the flashing-light photometric scale to provide calibration services for anticollision light photometers. The work was completed in 1997. A photometric unit for flashing light, 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 were taken to calibrate these standard photometers: one based on electrical calibration of the current integrator, and the other based on electronic pulsing of the signal from a steady-state illuminance 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 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. See Ref. [7] for further details.

5. Frequency-Dependent Photocurrent Measurements of Flashing Lights

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Two circuits for flashing light measurements were discussed and compared. The first circuit has two stages. The first stage is a current-to-voltage converter that includes the photodiode sensor. This stage can be used to measure the frequency components of flashing light if the sensor has fast enough responsivity. The second stage is a voltage integrator with two controlled switches. One switch shorts the integrating capacitor before the start and the other one controls the timing of the integration (measurement) cycle. In the second circuit, the sensor and the integrating capacitor are combined in one stage. The fundamental gain equations (current-to-voltage gain, loop gain, and closed-loop voltage gain) of the two different measuring circuits are determined for the frequency interval of the frequency components of the flashed pulse to be measured. Accuracy requirements for the photocurrent-to-voltage conversion were discussed for the interval of all frequency harmonics of the flashing light pulse. The effect of pulse length and amplitude of the flashing signal and the capacitance of the photodiode sensor for the measurement nonlinearity were also discussed briefly.

6. Conspicuity of Point-Sequential Light Signals Used to Mark Emergency Vehicles

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A high intensity discharge (HID) short-arc lamp coupled with a fiber-optic distribution system interrupted by rotating dichroic filter assemblies can provide rapidly alternating sequences of intense light pulses of different colors at the focal point of a single lens. Such signals have unique properties that strongly influence the way they function as emergency vehicle markers. In a point-sequential light signal (PSL), pulses of different colors alternate without apparent temporal gaps at a single point. There are interactions of psychophysical properties across the color boundaries. These include sequential color and brightness effects that are quite striking, and not predicted by any current theory. These sequential signal interactions in turn affect the function of the light as an emergency vehicle marker. Flashing signal lights embody trade-offs of conspicuity and trackability. A highly conspicuous flash pattern may be hard to track in traffic where there is considerable visual background noise. Using point-sequential lights (PSLs), it is possible to design signals that are optimum for particular background and traffic environments. PSL cycle times and pulse duration ratios can be modified over a wide range of values. This initial series of investigations studied flash patterns incorporating two colors presented within a basic cycle time of 800 ms. The shorter duration color was present for 3%, 17%, 36%, 62% or 100% of the time occupied by the longer duration color. Perceptions of image size, color saturation and apparent point of origin varied with these ratios. A signal consisting of long red pulses interrupted by short white pulses seemed to provide a good combination of conspicuity and trackability. Photometric documentation of these signals is complex, since the changes in intensity and color at the pulse boundaries include a brief dark phase, and the light pulse onsets and offsets are asymmetrical and nonlinear.

7. Photography and Flash Exposures

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From the perspective of photographic film, essentially all exposures are "flash exposures", at least in the sense of being short duration. While xenon flash lamps are important "flash exposure" sources, steady state light (like daylight) sources plus some shuttering mechanism are more common. High precision in measurement and control of these short duration exposures is extremely important in the "flash exposing devices", the "sensitometers", used by those who design and build new films, where subtle differences in photographic properties between different coating formulations, etc. are easily masked by unintended variability in exposure sources. From a measurement perspective, there is much similarity in the metrology/photometry of flashes from xenon lamps and from flashes from a sensitometer. Some spectrally weighted integrated quantity of light, its spectral characteristics, and reproducibility of "flashes", from time to time and from one source to another, are similar concerns. For historical reasons, film sensitometry involves red, green and blue spectral sensitivity of films (itself derived from "spectral sensitometry") and measurements in photometric units. "Photographic flash lamp photometry" should include either spectral data or spectral weightings related to R, G, B film spectral sensitivities. Even flash duration may be similar; concern with "reciprocity effects" (different photographic sensitivities from the same quantity of exposing light, delivered over different exposure times) leads to sensitometer exposure times of 10^{-5} s at Kodak, derived from cw light-source sensitometers. Shorter times still, representative of laser printing, are used in "laser sensitometers." There are obvious differences as well: sensitometers generally have a low flash repetition rate, usually have (shuttered or scanned) continuous light sources (greater stability), and invoke no psychophysics. Given the need for high precision in sensitometry in creating new films, and the need to define exposures accurately to determine ISO speeds accurately, the photographic industry's greatest need in flash light photometry will be improved sensitometer photometry and spectral radiometry.

DISCUSSIONS

After all the presentations, an open discussion session was held for about 30 minutes with all the speakers as panelists. Some of the questions and discussions are reported below.

There were several questions on multiple flashes. D. King answered that there are a number of people in the airline industry who believe that multiple flashes provide a higher level of conspicuity than equally spaced single flashes. Schmid-Clausen mentioned that double flashes are effective in that the first flash directs your attention and the second flash gives precise information of the position. Multiple flashes can be treated as one flash by the form factor method (as given in the EC regulation) within a certain time delay (within ≈0.1s).

The blinking LED on the telephone that the chairman mentioned has smaller effective intensity than steady-state LEDs, yet produces a more effective signal than steady-state LEDs. Should we have a system of photometry that tells us this effect? Schmid-Clausen answered that it is a conspicuity field; with the same intensity, flashing LED is much more conspicuous than steady burning light.

What is the definition of pulse? If the emission is not zero between the flashes, how can we treat this as pulse? Schmid-Clausen answered that, based on his investigation, such effect (pulse on steady light) can be described by adaptation luminance for a certain luminance level. The time constant a changes as adaptation luminance changes. However, it was not investigated for various levels.

The Blondel-Rey equation requires the pulse shape to determine t_1 and t_2. Then what is the purpose of integrating the pulse? Should the measurement of only the time function $i(t)$ suffice? Dave King answered that, in case of xenon flash, the shape does not matter because t_2-t_1 is very small and the effect is negligible. Schmidt-Clausen answered that this was discussed in the late 60s with the US Coast Guard. Durations other than t_1, t_2 can be chosen as approximations similar to the form factor method. We know there are some gray zones and we cannot presently describe all cases. But why not start describing the effect and see what comes out of it.

F. Hengsteberger, Director of Div.2, mentioned that a guidance is now urgently needed from Div.1 because there are already applications out there and different formulae are widely used. We should find a compromise between what visual science requires and what is needed by practitioners. We have to give a useful starting point with some initial recommendation.

K. Sagawa, Director of Div. 1, answered that he basically agrees with having a joint work by Divs. 1 and 2 on this subject. However he sees a difficulty in finding good visual scientists in this area who can undertake this job. Research in this subject was active in 1960s, but not recently. He encourages young scientists to work in this area to contribute to CIE on this subject.

There were also questions and discussions on the effect of spatial properties, e.g., of LED barricade lights, effect of modulation by discharge lamps, and the effect of background illumination on the perception of flashing lights, the issues on modulation transfer function, equivalent luminance, measurement errors due to ambient light, etc.

CONCLUSIONS

There seems to be a consensus among the participants that a CIE document is urgently needed to define the effective intensity and give recommendations on the photometry of flashing lights. While the issues on physical measurements will be addressed in TC2-49, the chairman requested again that Div. 1 consider initiating work in this area. A great amount of information and new knowledge have been presented and discussed in this Workshop. The chairman thanked the speakers and the participants.

REFERENCES

[1] There are two related publications from CIE: (1) CIE Pub.105 Spectroradiometry of Pulsed Optical Radiation Sources (1993), which does not describe photometry, (2) Ref.[2], which is a scientific paper and not a CIE recommendation.

[2] H. J. Schmidt-Clausen, A Comparison of Different Methods for the Determination of the Effective Luminous Intensity of Signal Lights in the Form of Multiple Pulses, *CIE Journal*, Vol. 1, No.1, 18-22 (1982).

[3] A. Blondel and J. Rey, Sur la perception des lumières brèves à la limite de leur portée, *Journal de Physique*, Vol.1, p. 530 (1911).

[4] H. J. Schmidt-Clausen, The influence of the angular size, adaptation luminance, pulse shape, and light colour on the Blondel-Rey constant *a*, *The Perception and Application of Flashing Lights*, Adam Hilger Ltd, London, pp.94-111 (1971).

[5] H. J. Schmidt-Clausen, Investigation of the Spectral Luminous Efficiency and the Signal process in the Human Eye, paper presented at the EPRI, Lighting Research Office Fourth International Lighting Research Symposium: Vision at Low Light Levels, Orlando, Florida, May 19-21 (1998).

[6] SAE ARP 5029 Measurement Procedures for Strobe Anticollision Lights, Aerospace Recommended Practice (1998).

[7] Y. Ohno and Y. Zong, “Establishment of the NIST Flashing-Light Photometric Unit,” Proc., SPIE, Vol. 3140, Photometric Engineering of Sources and Systems, 2-11 (1997).

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