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TECHNICAL REPORT

Groundwork for Measurement of Effective Intensity of Flashing Lights

CIE 229:2018

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Descriptor: Photometry
Quantities related to photometric and other
measurements
Calibration

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5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

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This Technical Report has been prepared by CIE Technical Committee 2-49 of Division 2 "Physical Measurement of Light and Radiation" and has been approved by the Board of Administration as well as by Division 2 of the Commission Internationale de l'Eclairage. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 2-49 de la Division 2 "Mesures Physiques de la Lumière et des Radiations" et a été approuvé par le Bureau et Division 2 de la Commission Internationale de l'Eclairage. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

Dieser Technische Bericht ist vom Technischen Komitee CIE 2-49 der Division 2 "Physikalische Messungen von Licht und Strahlung" ausgearbeitet und vom Vorstand sowie Division 2 der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist.

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GROUNDWORK FOR MEASUREMENT OF EFFECTIVE INTENSITY OF FLASHING LIGHTS

Summary

The objective of this report is to lay the groundwork for developing a recommendation on the measurement of effective intensity of flashing lights used for signalling applications. It recommends a convolutional method that will rest on some defined visual impulse response function to calculate the effectivity intensity. As one of such realizations of convolutional methods, the Modified Allard Method with an infinite time window is described. However it is not yet an official recommendation due to the lack of experimental verification and the need for further research. This report also provides guidance on physical measurements of effective intensity for the described method, for flashing lights using any type of light sources including xenon flash tubes, light emitting diodes (LEDs) and rotating beacons, which produce pulse widths in the range from microseconds to seconds. This report does not cover specific measurement requirements for signalling light products. While this document refers to flashing lights, the described method applies also to occulting lights, isophase lights, and groups of flashes of varying duration.

TRAVAIL EXPLORATOIRE SUR LE SUJET DE LA MESURE DE L'INTENSITÉ EFFECTIVE DES LUMIÈRES PULSÉES

Résumé

L'objectif de ce rapport est de donner des recommandations concernant la mesure de l'intensité effective des lumières pulsées utilisées en signalisation. Le présent rapport technique recommande une méthode de convolution s'appuyant sur la fonction visuelle de réponse aux impulsions pour déterminer l'intensité effective. Parmi les méthodes de convolution, la méthode d'Allard modifiée avec fenêtre de temps infini est présentée. Cependant, il ne s'agit pas pour l'heure d'une recommandation officielle, car il manque encore des vérifications expérimentales et plus d'investigations sont requis. Ce rapport fournit également des méthodes pratiques pour la mesure physique de l'intensité effective avec la méthode recommandée, pour les lumières pulsées émises par tous les types de sources lumineuses, y compris les tubes flash au xénon, les diodes électroluminescentes (DEL) et les gyrophares, qui produisent des impulsions allant des microsecondes à une seconde. Ce rapport ne couvre pas les exigences spécifiques relatives aux équipements de signalisation lumineuse. Même si ce document fait référence aux lumières pulsées, la méthode décrite est également valable pour les feux à occultations, les feux isophases et les groupes de flash à impulsions variées.

GRUNDLAGEN FÜR DIE MESSUNG DER EFFEKTIVEN LICHTSTÄRKE VON BLINKLICHTERN

Zusammenfassung

Gegenstand dieses Berichtes ist es, Grundlagen für eine Empfehlung für die Messung der effektiven Lichtstärke von Blinklichtern bei Verwendung als Signallichter zu erstellen. Der Bericht empfiehlt für die Berechnung der effektiven Lichtstärke eine Faltungsmethode mit einer definierten visuellen Impulsantwortfunktion. Als eine Möglichkeit der Realisierung von Faltungsmethoden wird die modifizierte Allard-Methode mit einem infiniten Zeitfenster beschrieben. Es handelt sich dabei aufgrund fehlenden experimentellen Nachweises und der Notwendigkeit weiterer Forschung nicht um eine offizielle Empfehlung. Dieser Bericht gibt darüber hinaus eine Anleitung für die praktische Messung der effektiven Lichtstärke, basierend auf der empfohlenen Methode, die für Blinklichter aus beliebigen Lichtquellen geeignet ist mit Pulslängen im Bereich zwischen Mikrosekunden und Sekunden, und zwar einschließlich Xenon-Blitzlampen, Licht emittierende Dioden (LEDs) und rotierende Lichtbaken. Dieser Bericht befasst sich nicht mit den besonderen messtechnischen Anforderungen, die an Signallichter gestellt werden. Auch wenn dieses Dokument sich auf Blinklichter bezieht, ist die beschriebene

Methode ebenfalls gültig für Blinkfeuer, Gleichtaktfeuer und Gruppen von Blitzen unterschiedlicher Dauer.

1 Introduction

Flashing lights are widely used in many signalling applications in aviation, marine and land transportation. Flashing lights, such as aircraft anti-collision lights, marine aid-to-navigation lights, obstruction lights and emergency vehicle warning lights, are specified by their effective intensity (in candelas). These lights need to be measured and the effective intensity calculated to ensure that they meet specifications. Several different formulae have historically been used to determine the effective intensity. When these different formulae are applied to a given flash, their results often disagree. Development of a single standard method is desirable.

This Technical Report provides a groundwork for developing a recommendation on determination of effective intensity of flashing lights. It recommends a convolutional method that will rest on some defined visual impulse response function to calculate the effective intensity. As one of such realizations of convolutional methods, the Modified Allard Method with an infinite time window is described. However, it is not yet an official recommendation due to the lack of experimental verification and the need for further research.

This Technical Report also provides guidance on physical measurements of effective intensity, dealing with flashing lights with pulse widths in the range from microseconds to seconds. Xenon flash sources are commonly used, but recently LEDs are increasingly used for signalling sources. Some examples of the waveform of flashing light sources are shown in Figure 1. Gaussian flash profiles are also seen in aeronautical and marine beacons employing rotating optics.

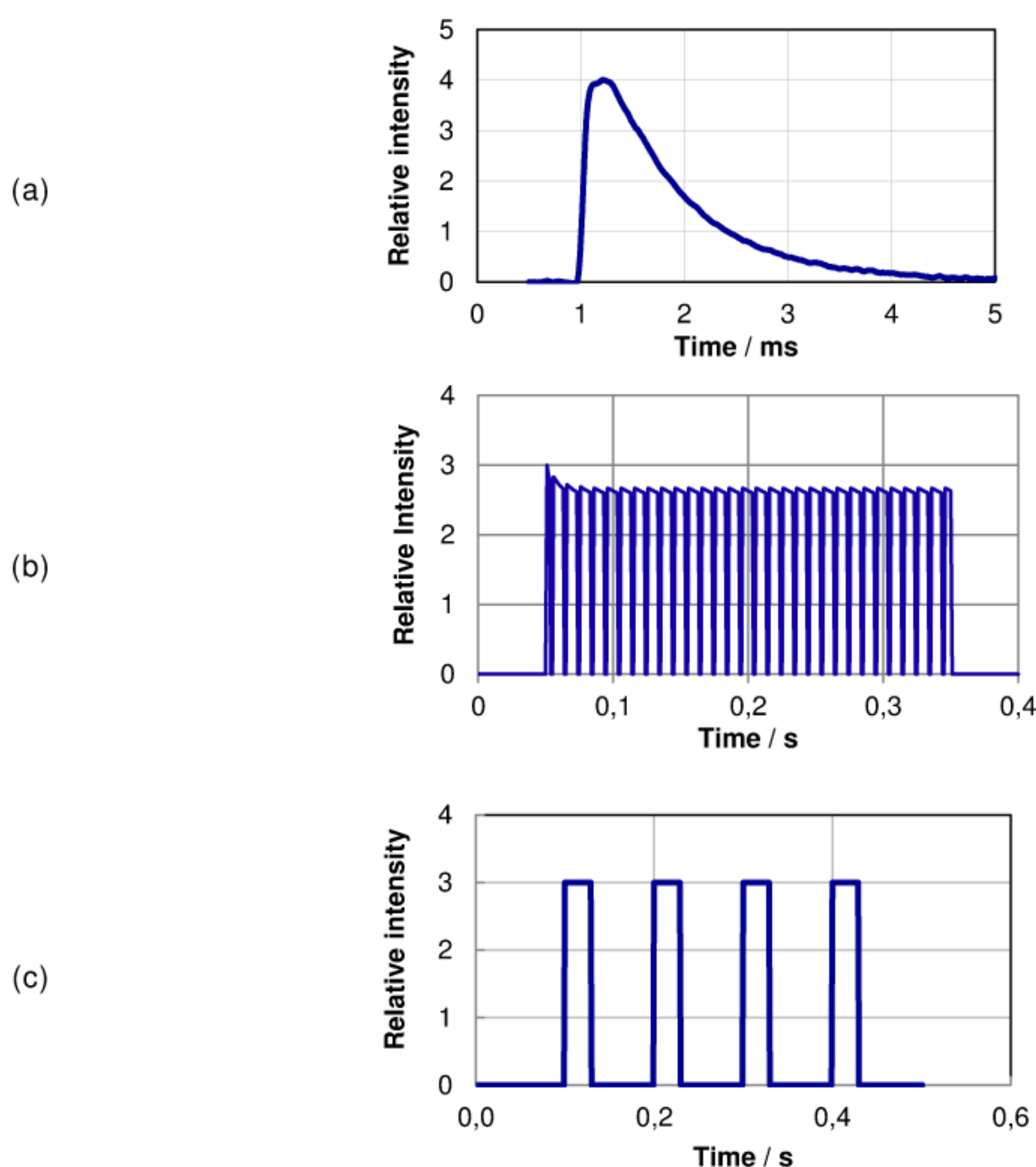


Figure 1 – Examples of waveforms of flashing lights – (a) xenon flash, (b) a pulse-width modulated LED flashing light, (c) a train of flashes from an LED flashing light

2 Terminology

The terminology in this document follows the definitions given in (CIE, 2011) and (CIE, 1993). The important terms used in this document, including quantities and units relevant to flashing lights, are listed below.

2.1

flashing light

rhythmic light in which every appearance of light (flash) is of the same duration and, except possibly for rhythms with rapid rates of flashing, the total duration of light in a period is clearly shorter than the total duration of darkness

[Source: CIE S 017/E:2011, Term 17-441 – modified: NOTE omitted.]

Note 1 to entry (only valid for this document): While this document refers to flashing lights, its recommendation applies also to occulting lights, isophase lights and groups of flashes of varying duration.

2.2

flash, <of light>

brief appearance of light, the intensity of which starts from a negligible amount, increases to significant levels and falls to a negligible amount

Note 1 to entry: Repetitions of flashes or trains of flashes (2.3) at a constant frequency form a flashing light (2.1)

2.3

train of flashes

group of two or more flashes, followed by a period of darkness

Note 1 to entry: A train of flashes can be an isolated group or regularly repeated in the form of a flashing light.

2.4

flash duration

duration of a flash (2.2) or a train of flashes (2.3)

Note 1 to entry: Some flashing lights have a long onset or decay time and it may be difficult to define their durations precisely.

Note 2 to entry: The flash duration of a train of flashes (2.3) is from the start of the first flash to the end of the last flash in a train of flashes.

2.5

luminous energy

Q , Q_v

time integral of the luminous flux, $\Phi(t)$, over a given duration, Δt

$$Q = \int_{\Delta t} \Phi(t) dt \quad (1)$$

Note 1 to entry: Luminous energy is expressed in lumen seconds (lm·s).

[Source: CIE S 017/E:2011, Term 17-733]

2.6

luminous exposure, <at a point of a surface, for a given duration>

H , H_v

quotient of the luminous energy, dQ , incident on an element of the surface containing the point over the given duration, by the area, dA , of that element

$$H = \frac{dQ}{dA} \quad (2)$$

[Source: CIE S 017/E:2011, analogous to first definition of Term 17-1021 “radiant exposure” – Equivalent definition moved to Note 2 to entry]

Note 1 to entry: Luminous exposure is expressed in lux seconds ($\text{lx} \cdot \text{s} = \text{lm} \cdot \text{s} \cdot \text{m}^{-2}$).

Note 2 to entry: The definition can also be expressed as: time-integral of the illuminance, E , at the given point, over the given duration, Δt

$$H = \int_{\Delta t} E(t) dt \quad (3)$$

2.7

time-integrated luminous intensity, <of a source, in a given direction>

J , J_v

quotient of the luminous energy, dQ , leaving the source and propagated in the element of solid angle, $d\Omega$, containing the given direction, by the element of solid angle

$$J = \frac{dQ}{d\Omega} \quad (4)$$

Note 1 to entry: Time-integrated luminous intensity is expressed in candela seconds ($\text{cd} \cdot \text{s} = \text{lm} \cdot \text{s} \cdot \text{sr}^{-1}$).

Note 2 to entry: The definition can also be expressed as: time-integral of the (instantaneous) luminous intensity, $I(t)$, over a given duration, Δt

$$J = \int_{\Delta t} I(t) dt \quad (5)$$

2.8

luminous range

greatest distance at which a given signal light can be recognized in any particular circumstance, as limited only by the atmospheric transmissivity and by the threshold of illuminance at the eye of the observer

[Source: CIE S 017/E:2011, Term 17-740 – modified: “circumstances” replaced by “circumstance”]

Note 1 to entry (only valid for this document): For a signal light to be recognized, it is generally accepted that the illuminance at the eye of the observer must be above achromatic threshold to ensure certainty of colour and rhythm. However, in this document, “luminous range” is used specifically in the meaning: distance at which a point source can be detected achromatically, i.e. in direct vision but without the requirement to recognize colour or duration.

2.9

effective intensity, <of a flashing light>

I_{eff}

luminous intensity of a fixed light, of the same relative spectral distribution as the flashing light, which would have the same luminous range (or visual range in aviation terminology) as the flashing light under identical conditions of observation

[Source: CIE S 017/E:2011, Term 17-360 – NOTE omitted]

Note 1 to entry: The effective intensity is expressed in candela (cd).

Note 2 to entry (only valid for this document): See Clause 3 for the prescribed formula.

Note 3 to entry (only valid for this document): The term “effective intensity” may also be applied to a single flash, not in a form of flashing light.

2.10 visual time constant

a

duration related to the human visual processing of a light signal, when a point source is focussed on the fovea at about the threshold of detection

Note 1 to entry: The visual time constant is expressed in seconds (s).

Note 2 to entry: Although there is no precisely-defined value for the visual time-constant, a value of 0,2 s is commonly used in effective intensity models for a dark-adapted observer.

Note 3 to entry: For research applications, the value of a is sometimes chosen to ensure the 'best fit' of a model to visual data.

2.11 visual impulse response function

$q(t)$

output signal in the human visual system, as a function of time, t , in response to an instantaneous visual input stimulus

Note 1 to entry: In this document, visual impulse response functions are used in the simple visual system model first proposed by Allard in 1876.

3 Determination of effective intensity

3.1 Recommendation for convolutional approach

The method described here is based on the convolution of a flash profile with a visual impulse response function, $q(t)$. The method was originally proposed by Allard (1876), using an exponential function of $q(t)$. A modified visual impulse response function was proposed by Luizov (1958), and was rediscovered and named Modified Allard Method (Ohno & Couzin, 2003). Further research on $q(t)$ that may produce more accurate results is in progress (see Annex F).

Given that $I(t)$ is the instantaneous luminous intensity of a flash or flashing light, the effective intensity, I_{eff} , is determined by the maximum value of the following convolution function $i(t)$:

$$i(t) = I(t) \otimes q(t)$$

$$I_{\text{eff}} = \max_{t=0}^{t=\infty} \{i(t)\} \quad (6)$$

where $q(t)$ is the visual impulse response function, which is determined so that, for rectangle flashes, the effective intensity calculated by Equation (6) agrees with the effective intensity, I_{eff} , calculated by the Blondel–Rey equation (Blondel & Rey, 1911):

$$I_{\text{eff}} = \frac{I_0 T}{a + T} \quad (7)$$

where I_0 is the instantaneous luminous intensity (in cd), T is the duration (in s) of the rectangle flash and a is the visual time constant. Equation (7) should be met for single rectangular flashes of any duration (not continuously repeating flashes).

The recommendation for on-going repetitive flashing lights is to calculate the effective intensity for an infinite duration.

3.2 Modified Allard Method with infinite time window

One of the realizations of the recommended approach described in 3.1 is the Modified Allard Method (herein after called "MAM"), which, in this report, is defined with an infinite time window. This method is described in detail, as it is considered to meet most of the criteria listed in 3.3.

However, this method is not officially recommended yet, as further experimental verification is needed and a new visual impulse response function may be developed in the future.

In the MAM, the visual impulse response function is given by

$$\begin{aligned} q(t) &= \frac{a}{(a+t)^2} & \text{if } t \geq 0 \text{ s,} \\ q(t) &= 0 & \text{if } t < 0 \text{ s} \end{aligned} \quad (8)$$

with a as the visual time constant, set to 0,2 s in this method (the observation starting at $t = 0$ s) and the effective intensity calculated by Equation (6).

Equation (6) applies over an infinite time interval for a flashing light or over an effectively finite time interval for a single flash. For practical measurement of flashing lights, the measurement time interval will be a finite time window long enough to approximate the effective intensity, I_{eff} , for the infinite time window (see Clause 4).

The Modified Allard visual impulse response function, $q(t)$, is shown in Figure 2, where it is plotted together with that of the original Allard visual impulse response function (see 3.2). Figure 3 shows an example of a flashing light and its convolution. The effective intensity, I_{eff} , is given as the peak value of $i(t)$ as illustrated in Figure 3. Note that, the convolution of each flash increases slightly as the flash is repeated, due to the long tail of the visual impulse response function, and converges to a final value at an infinite time interval.

The convolution function $i(t)$ can be expressed in an integral form as

$$i(t) = \int_{u=0}^t I(u) \cdot q(t-u) \, du . \quad (9)$$

For calculation, the convolution is most simply approximated by sum-products of the two functions, $I(t)$ and the reversed visual impulse response function, as the latter is moved along relative to $I(t)$, as

$$i(t_j) = \sum_{k=0}^N I(t_k) \cdot q(t_j - t_k) \Delta t_k \quad (10)$$

where t_j is the time at each sampling point j , Δt_k is the time interval of data and $I(t)$ is sampled at $t_0 (=0)$, t_1 , t_2 , ..., t_N over the entire flash duration.

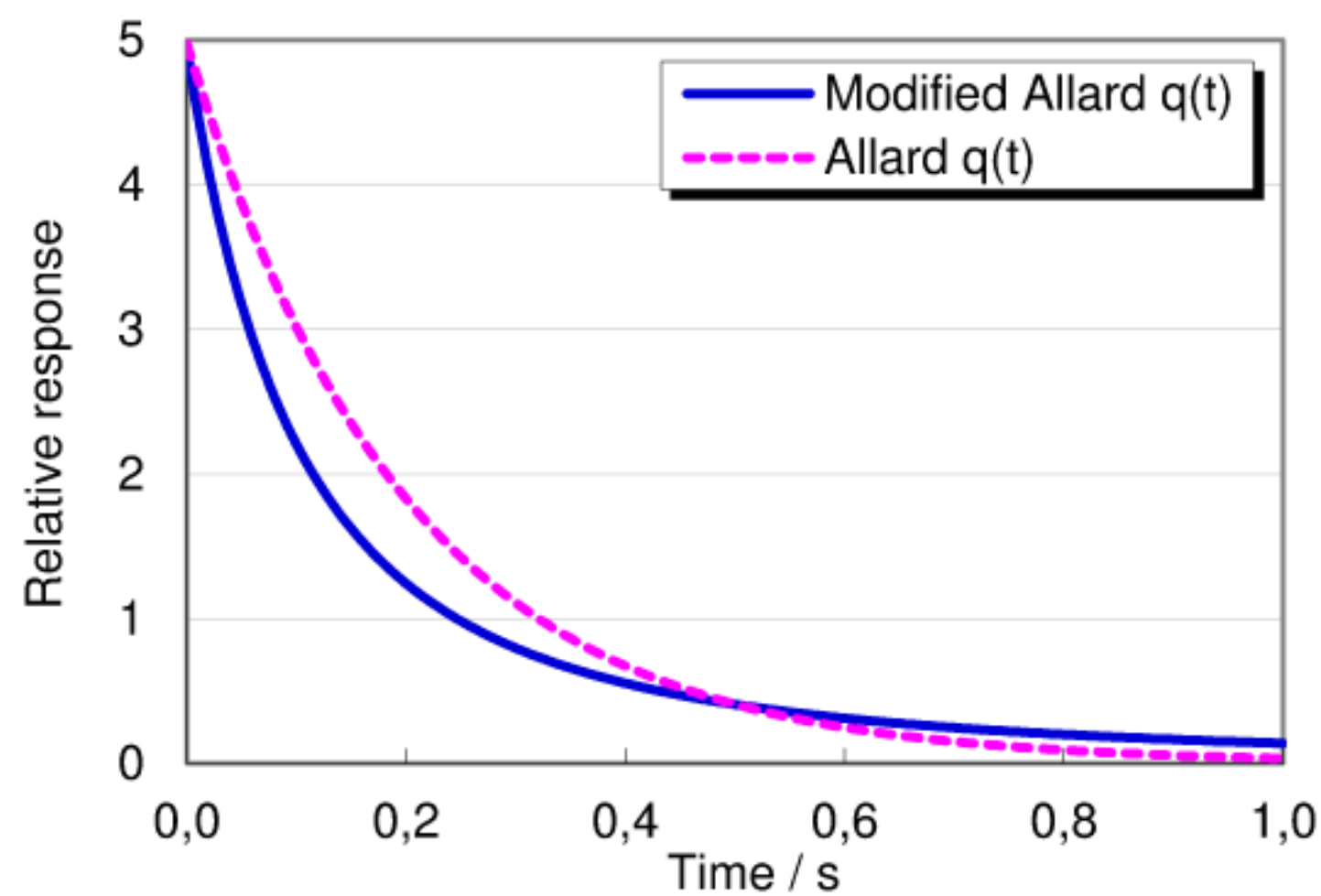


Figure 2 – The visual impulse response functions of the original Allard and the Modified Allard Method, where the visual time constant, a , equals 0,2 seconds for both methods

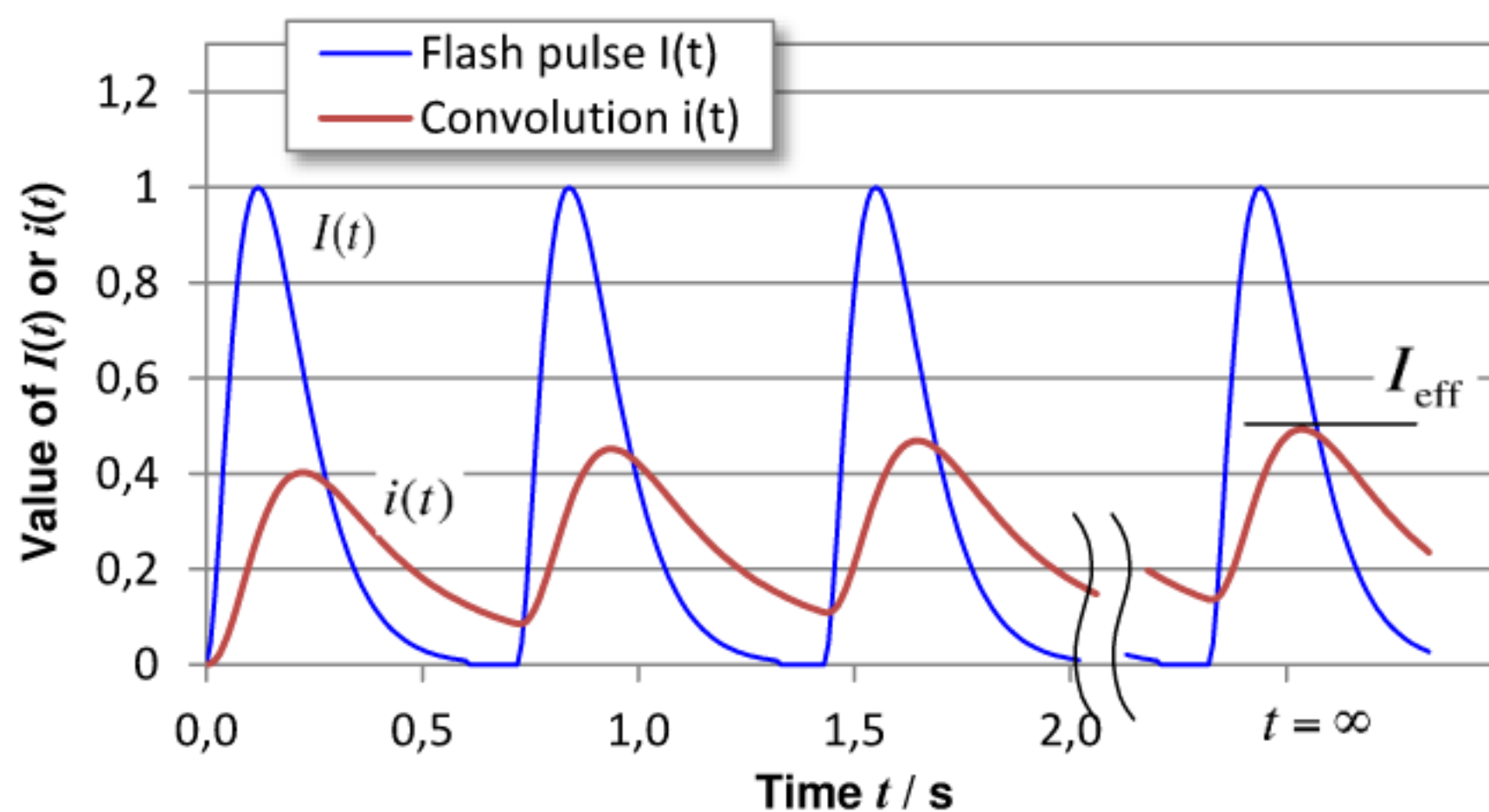


Figure 3 – Schematic of the convolution in Modified Allard Method

3.3 Selection criteria

The historical overview of several formulae for effective intensity is provided in Annex A, and a summary is provided in this clause. The Blondel–Rey equation (Blondel & Rey, 1911) or the Blondel–Rey–Douglas equation (Douglas, 1957)¹ have been most widely used and are known to have acceptable accuracy for rectangular pulses (Schmidt-Clausen, 1968). The treatment for non-rectangular pulses, however, is complex, requiring iterative computation and is not mathematically coherent. The Form Factor Method (Schmidt-Clausen, 1968) was developed as a practical method to measure effective intensity of non-rectangular pulses, allowing simple calculation from the peak and the integral of the waveform. This method, however, was found to fail for a train of flashes (Ohno & Couzin, 2003; IALA, 1977) and other specific forms of pulse. The Allard Method (Allard, 1876) used convolution but was not well known and not widely used. However, it was recommended to determine the effective intensity of trains of flashes (IALA,

¹ The formula for non-rectangular pulses in Blondel–Rey (Blondel & Rey, 1911) and that in Blondel–Rey–Douglas (Douglas, 1957) are equivalent (see Annex A), thus simply “Blondel–Rey” is used to represent both methods hereinafter in this document.

1977). A method that performs accurately for all forms of pulses (including trains of flashes) and that can be easily applied has long been desired.

The following basic criteria for a recommended effective intensity formula are considered:

- 1) The formula should agree with the Blondel–Rey equation (and the Form Factor Method) for rectangular flashes.

NOTE Blondel–Rey has been in common use for a long time, and so it is worthwhile here to maintain compatibility even though some empirical data do not support Blondel–Rey over Allard for rectangular flashes.

- 2) The formula should agree with published visual observation data for all studied flash forms.
- 3) The formula should agree with published data for trains of flashes.
- 4) The formula should not demonstrably fail for any potential flashes of complex form.

NOTE An example of a measured waveform that causes anomalous results in the case of Form Factor Method is shown in Figure 4. Other methods do not have a problem with this waveform.

- 5) The formula should allow for simple measurement techniques.

The Blondel–Rey formula does not meet criterion 5 for non-rectangular pulses as described above and also is problematic for criteria 3 and 4. The iterative solution does not produce a result for certain forms of pulse. It is also not recommended for trains of flashes (IALA, 1977; IALA, 1981). The Form Factor Method does not meet criterion 3, as identified experimentally (Mandler & Thacker, 1986) as well as computationally (Ohno & Couzin, 2003). It is also problematic for criterion 4. The results obtained for pulses with a very narrow peak superimposed on a broad pulse (an example shown in Figure 4) are demonstrably incorrect. The Allard Method is a simple model for the human visual system, based on a convolution of the flash profile with a visual impulse response function, and is mathematically coherent for any form of pulses, satisfying criterion 4. It was recommended for trains of flashes (IALA, 1977) (criterion 3), and the convolution can be easily achieved electronically (criterion 5). The Allard Method, however, does not meet criterion 1 as computationally shown (Reynolds, 1975; IALA, 1977; Ohno & Couzin, 2003). The results deviate from Blondel–Rey by 25 % to 30 % for rectangular flashes with durations from 0,2 s to 0,7 s, with a time constant $a = 0,2$ s. The MAM was developed to eliminate the problem for criterion 1 of the Allard Method, thus it basically satisfies all five criteria. Criterion 2 has been verified by analysing the experimental results for seven different forms of non-rectangular single flashes obtained by Schmidt-Clausen (1968). The results are shown in Annex C, which demonstrates that the results using the MAM among other methods, agree with the visual evaluation for the seven forms of pulse to an acceptable level. Mandler and Thacker reported visual experiments on trains of flashes (Mandler & Thacker, 1986), the results of which agreed extremely well with the results calculated using the MAM, which verifies criterion 3. The details of the analysis on the Mandler and Thacker data are described in Annex B.

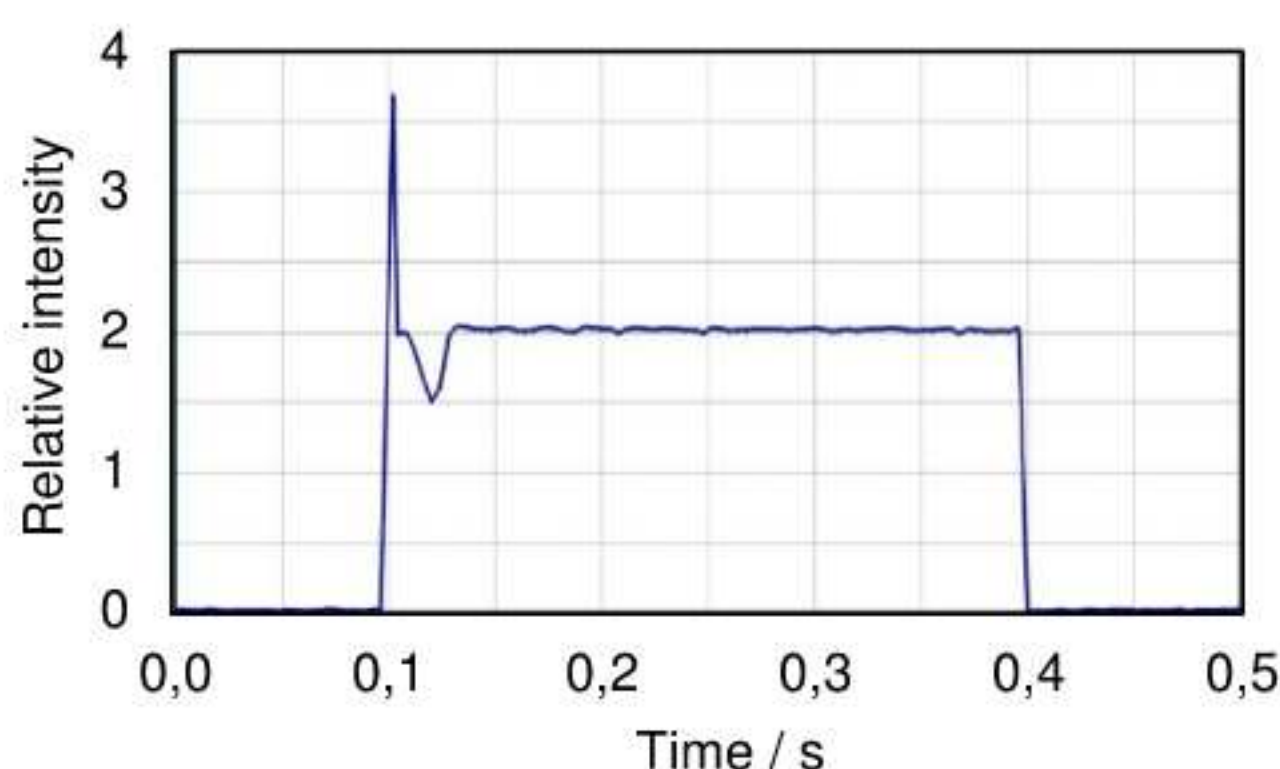


Figure 4 – An example of the measured waveform of a LED flashing light having a narrow peak