International Association of Marine Aids to Navigation and Lighthouse Authorities

AISM Association of Internationale de Signalisation Maritime IALA

IALA Recommendation E-200-4

On

Marine Signal Lights

Part 4 - Determination and Calculation of Effective Intensity

Edition 1

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision

Recommendation on Marine Signal Lights – Determination and Calculation of Effective Intensity

(Recommendation E-200 Part 4)

THE COUNCIL:

RECALLING the function of IALA with respect to Safety of Navigation, the efficiency of maritime transport and the protection of the environment;

RECOGNISING that for the adequate performance of marine signal lights the performance of flashing lights needs to be determined;

RECOGNISING ALSO that there are several methods of determining the performance of flashing lights at the threshold of visual perception;

RECOGNISING FURTHER that there are no adequate methods for determining the performance of flashing lights at observer levels above the threshold of illuminance;

NOTING that defined standards for the determination of the performance of flashing lights should be used worldwide to ensure the quality of signal lights for mariners;

NOTING ALSO that this document only applies to marine Aid-to-Navigation signal lights that are installed after the publication date of this document;

CONSIDERING the proposals of the EEP Committee, their lights experts and the IALABATT/IALALITE working group;

ADOPTS the Recommendation on Marine Aid-to-Navigation Signal Lights in the annexes of this recommendation; and,

RECOMMENDS that IALA Members and other appropriate Authorities providing marine aids to navigation adopt the methods in accordance with this recommendation for the determination and calculation of effective intensity of a rhythmic light.

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Part 4 - Determination and Calculation of Effective Intensity

1 FOREWORD

Effective intensity is often misunderstood. An understanding of effective intensity should begin with a careful review of its definition:

Effective Intensity: Luminous intensity of a fixed light, of the same relative spectral distribution as the flashing light, which would have the same luminous range as the flashing light under identical conditions of observation.

The first thing to note is that two lights, with the same effective intensity, will have the same luminous range. The second thing to note is that a light's luminous range is the greatest distance that the light can be detected. Effective intensity is a concept that has meaning only at illuminance levels associated with the threshold of detection. At the threshold of detection a light source is just barely detectable, there is no discernment of a flash's colour or its duration, and the probability of detection is greater than chance, but not dependably high.

1.1 Applying Threshold Models at Supra-Threshold Illuminance Levels

When viewed at the threshold of detection an aid-to-navigation signal light is of almost no interest to the mariner. The probability of detection is not dependably high, and if the light is detected the light's colour and the duration of the flash cannot be discerned.

For these reasons, a 'practical threshold' of 0.2 microlux was agreed upon in 1933 at the International Technical Conference of Lighthouse Authorities. This is indeed a practical illuminance value for viewing aid-to-navigation lights viewed at night against a dark background. At 0.2 microlux a light can be dependably detected, light colour is discernable, and flash duration is discernable. But 0.2 microlux is not a threshold-of-detection illuminance level; it is a higher-than-threshold (supra-threshold) level. This leads to problem: effective intensity is a threshold concept, but because 0.2 microlux is well above threshold we should not apply effective intensity threshold models at 0.2 microlux. Yet this is what's been done for decades. A solution will be discussed below.

1.2 What Effective Intensity is Not

As described above, by definition, two lights with the same effective intensity have the same luminous range at the threshold of detection. Many users mistakenly believe that two lights with the same effective intensity will appear equally bright. There is nothing in the effective intensity definition that implies anything about equal brightness.

1.3 Apparent Intensity

At supra-threshold levels (for example 0.2 microlux) effective intensity has no meaning. But it is fair to compare the apparent brightness of two lights at any supra-threshold level. Here is a definition of the apparent intensity of a flashing light:

Apparent Intensity: the luminous intensity of a fixed (continuous) light that matches a spectrally similar flash of light in brightness.

There are a limited number of studies that have examined the apparent intensities of some simple flashes shapes. One of the findings is that apparent intensity is a function of the light's illuminance level.

1.4 An Example

Compare two lights, one with a square-wave, 3-second, 100 cd flash, and another with a steady 100 cd light. All of our effective models yield 60 cd for the effective intensity of the flashing light.

Imagine these 2 lights side-by-side. As a mariner steadily approaches these lights from a distance, this is what the mariner will see:

1 The first event will be detection of the 100 cd steady light.

2 The next event will be detection of the 60 cd (effective) flashing light.

3 As the mariner continues to close, the mariner will start to discern the colour of the lights, the duration of the flash for the flashing light, and the steady character of the steady light.

4 The mariner will then reach the point where the illuminance of the lights equals 0.2 microlux. Assuming a 10 nautical mile meteorological visibility, this will occur at a distance equal to the 'nominal range' that is published in the List of Lights (note that detection occurred at a greater distance). At this point colour and flash duration are easy to discern. Further, based on data from earlier research, the brightness of the 60 cd (effective) flashing light will closely match the brightness of the 100 cd steady light.

5 As the mariner continues to approach the lights, the apparent brightness of the flashing light will exceed the brightness of the steady light. The flashing light (with an effective intensity of 60 cd) will look brighter than the 100 cd steady light! It's clear that a light's effective intensity is not an indication of how it will appear at supra-threshold illuminance levels.

1.5 The Way Ahead

- It is recognized that the true threshold of detection point is of no practical interest to the mariner;
- Because effective intensity is a concept that has meaning only at the true threshold of detection, and because the threshold of detection is of no practical interest, IALA is investigating the ultimate elimination of the use of effective intensity;
- IALA will retain 0.2 microlux as a threshold illuminance level for practical use (recognizing that this is a practical threshold and not a true threshold of detection);
- At supra-threshold levels, IALA's goal is to develop and use apparent intensity models to compare brightness of lights with different flash patterns. The apparent intensity models would replace the current effective intensity models;
- Until robust apparent intensity models can be developed, IALA continues to recommend the use of effective intensity models at supra-threshold illuminance levels. Even though the use of effective intensity models at supra-threshold illuminance values is conceptually inconsistent, IALA will maintain the status quo until robust apparent intensity models can be developed;
- IALA reminds users that effective intensity models underestimate the performance (relative brightness) of lights with short flash durations compared to lights with longer flashes under practical viewing conditions.

2 INTRODUCTION

The recommended way of determining the intensity of the beam is by direct photometric measurement on a suitable measuring range as referred to in IALA Recommendation E200-3 on Marine Signal Lights Part 3 – Measurement (E200-3) [19]. In the case of a fixed light, the measurement results of [19] can supply all the information required for the prediction of performance. If, however, a light source is flashing or occulting, or if a pencil beam projection apparatus rotates, then for an observer at a given location there is a variation of luminous intensity from instant to instant of time. Usually this variation goes from zero or near-zero through a series of finite values falling again to zero. There is thus an 'appearance of light' of roughly definable duration. If the total duration of light is clearly less than that of the neighbouring durations of darkness, we speak of a 'flash'. If the total duration is not more than about 0.3 second, the human eye responds to the totality of visual experiences within the flash; the total effect, whether expressed in terms of the apparent luminosity of the flash when easily seen, or of the intensity of the flash when just seen, is a function of the instantaneous intensities within the flash. If a flash is found to be just seen in conditions in which a steady light of intensity I_e is also just seen at the same distance and in the same atmospheric conditions, the flash is said to have an effective intensity I_e. It is this effective intensity that should be used when calculating the luminous range of a light in any given atmospheric condition.

Where direct measurement is not possible, or where optical apparatus is under design and not yet built, intensity and flash duration figures may be calculated by the methods described in IALA Recommendation E-200-5 on Marine Signal Lights Part 5 - Estimation of the Performance of Optical Apparatus (E200-5) [20]. It should be remembered however, that the uncertainties of the resultant values of such calculation are much greater than those obtained by direct measurement.

3 SCOPE/ PURPOSE

The scope of this document is all flashing marine aid-to-navigation signal lights with a flash duration of five seconds or less. Lights with a flash duration of greater than five seconds may be considered as continuous or fixed lights.

The purpose of this document is to describe how to calculate the effective intensity of a given flash of light when viewed at achromatic threshold of illuminance. The apparent intensity of flashing lights viewed when the illuminance at the observer is greater than achromatic threshold (so-called 'supra-threshold') is not covered by this document (see Foreword).

In the absence of any suitable method that may be used at the illuminance levels described in IALA Recommendation E-200-2 on Marine Signal Lights Part 2 - Calculation, Definition and Notation of Luminous Range (E200-2) [18], the effective intensity calculated by the methods given in this document may be used to determine the luminous range of a flashing signal light.

4 DEFINITIONS

Achromatic threshold	The level of illuminance at the observer's eye at which a light source is just barely detectable, there is no discernment of colour or flash duration, and the probability of detection is greater than chance, but not dependably high
Observer illuminance	The illuminance in lumens per square metre (lux) or sea-mile candelas produced by a light that is incident on the eye of an observer when facing the direction of the light
Fixed (continuous) light	A light source of constant and consistent luminous intensity
Flashing light	A light with a repeating rhythmic character whose 'on' time within the character period is less than its 'off' time
Occulting light	A light with a repeating rhythmic character whose 'on' time within the character period is greater than its 'off' time
Effective Intensity	The luminous intensity of a fixed (continuous) light, of the same relative spectral distribution as a flashing light, which would have the same luminous range as a flashing light under identical conditions of observation
Apparent Intensity	The luminous intensity of a fixed (continuous) light that matches a spectrally similar flash of light in brightness

5 DESCRIPTION OF EFFECTIVE INTENSITY OF A RHYTHMIC LIGHT

The range at which an observer may just see a light flash may be described in terms of a single parameter which is called the 'effective intensity' of the flash. The eye does not analyse the variations of the luminous flux incident upon it during the course of a brief flash but reacts to the total visual impression of the flash of light. In particular, when the flash can just be seen it is possible to obtain a quantitative measure of the effectiveness of its light by comparing it with a steady light which is also just seen under the same conditions at the same range and by the same observer. Sufficient consistency is obtained in such observations to permit the evaluation of effective intensity of the flash as the intensity of the fixed light which is its equivalent for detection at the threshold of visual perception (achromatic threshold). In this document, methods of evaluating the effective intensity for various flash forms (distributions of luminous intensity with time) will be considered. The effective intensity is defined by the equivalence of fixed and flashing lights at threshold levels, and levels above threshold are not considered. Unless otherwise stated, the evaluations are for single flashes, i.e. the interval between successive flashes is assumed to be at least a few seconds.

To permit the use of methods of evaluation which shall be simple, universally applicable and of sufficient accuracy for practical purposes of marine aid-to-navigation provision, the other conditions of observation have been restricted to certain standard reference values, which have been chose to represent typical average conditions for marine observation of lights:

1 Young observer with normal vision.

2 The light seen in foveal vision and at achromatic threshold.

3 Subtense angle of light source at the eye of the observer $\leqslant 1'$.

4 Colour of light : White.

For observation by night, the level of background luminance has been assumed not to exceed 10^{-2} cd/m². For observation by day, the level of background luminance is dependent on diurnal and seasonal effects and on weather conditions. For the effect of such variations on the threshold of illuminance for vision of steady lights, see [18].

Although the threshold values of illuminance at the observer's eye are different for achromatic threshold and the levels of illuminance quoted in [18], the effective intensity calculated using methods given in this document may be used to determine the luminous range of a light, using the methods laid down in [18] and may be used to determine the nominal range of a light for publication in Lists of Lights.

The methods of evaluation given make use of time constants of the visual system denoted by C in the Schmidt-Clausen method and by A or *a* in all other methods. (It should be noted that, in the Method I, the time-constant is really C/F, where F is a "form-factor", less than unity for all non-rectangular flashes, the time-constant is only equal to C in the case of rectangular flashes). These constants are closely related to the more familiar time-constant *a* of the "Blondel-Rey expression for the effective intensity I_e of flashes of rectangular form, viz:-

$$\frac{I_e}{I_o} = \frac{t}{a+t}$$

equation 1

Where:

I_0 is the intensity of the flash at maximum

t is the duration of the flash.

In general these time-constants are dependent on the colour of the light exhibited, on the level of background luminance against which the light is seen, and on the angular subtense of the light source at the eye of the observer. *Under the reference conditions stated above. For night-*

time observation it is recommended that the values of C, A and "a" be taken equal to 0.2 second it is not considered necessary, for the purpose of calculation of effective intensity for practical marine applications, to take into account differences in the value of the time constant for different colours of lights. *For day-time observation and at all levels of background luminance of 100 cd/m² or more, it is recommended that the values of C, A and "a" be taken equal to 0.1 second.*

6 EVALUATION OF EFFECTIVE INTENSITY

The determination of effective intensity for any given flash proceeds from knowledge of the variation of the instantaneous luminous intensity with time. It is usually desirable both to determine the form of this variation and to scale the curve so that the ordinates are the values of luminous intensity at each instant. Photometric measurements of luminous intensity and of the distribution of luminous intensity with time have been described in [19], and the difficulties and limitations inherent in them have been discussed.

The classic work on evaluation of effective intensity was that of Blondel and Rey in 1911. The formula based on their experimental observations was limited in its application to flashes of rectangular or quasi-rectangular form. They indicated a possible formula, which might be applicable to flashes of non-rectangular form, and this was later elaborated by Douglas into the Method III described below. The Blondel-Rey-Douglas formula has been widely used and has given satisfactory results in practice.

It is known that results obtained by the various methods given below differ to some extent, but that the effect of these differences on the derived luminous range of the light is not significant in most practical applications. The differences may be more significant when a regulation requires that a light provide a specified luminous range; the values of luminous intensity calculated to meet the requirement may differ substantially according to the method of calculation selected. *It is recommended that the method applied should be clearly stated.*

Method I can also be applied when very short flashes are measured by comparison with standards of integrated intensity using time-integration photometers. It is not necessary to measure the complete flash form, but it is necessary to find also the maximum instantaneous intensity during the course of the flash (the so-called "peak intensity", I_o).

Method IV is suitable for applying to any flash form of any duration, even when the measurement photometer is not fast enough to faithfully record all fast transients.

6.1 Method I — The Method of Schmidt Clausen (also called the "Form Factor" Method)

The variation of instantaneous luminous intensity I with time t during a flash is described by the function I (t). This has a maximum value I_o, the peak intensity of the flash. The integrated intensity of the flash, viz. the integral of instantaneous intensity with respect to time taken over the whole of the flash, is denoted by

$$J = \int I dt$$

equation 2

According to Schmidt-Clausen, the effective intensity I_e of the flash is given by

$$I_e = \frac{J}{C + \frac{J}{I_o}}$$

equation 3

Where:

C is a visual time constant *to be taken as 0.2 second for night-time observation and 0.1 second for day-time observation.*

For longer flashes, such as those produced by revolving beams, it may be more convenient to express effective intensity in the following form:

$$I_e = \frac{I_0 t}{\frac{C}{F} + t}$$

equation 4

Where:

t = total duration of the flash

F = the Schmidt-Clausen form-factor defined by:

$$F = \frac{\int_{t_1}^{t_2} I(t).dt}{I_0 (t_2 - t_1)}$$

equation 5

Where:

t_1 = time of commencement of the flash

t_2 = time of cessation of the flash

If a graph is drawn of the form of the flash, and a rectangle is drawn enclosing this, so that the rectangle is of length $t_2 — t_1$ and of height equal to the maximum of intensity of the flash, then the form-factor is the ratio of the area under the graph to the area of the rectangle (Figure 2).

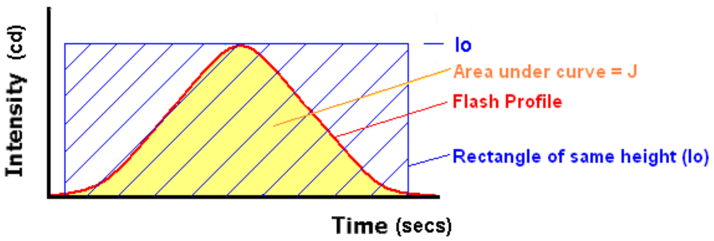

Figure 1 Graph of a flash profile and enclosing rectangle (Form Factor method)

The precise choice of limits t_1 and t_2 is unimportant, provided that they correspond to instants of zero intensity preceding and following the flash, respectively. Where no such instants exist, as may be the case for flashes produced by revolving beams, the intensity of which may never fall completely to zero, it will generally be sufficient to choose instants at which the instantaneous intensity is at a sufficiently low value (for example, 5% of the peak luminous intensity of the flash). This is equivalent to calculating the effective intensity of the flash which is considered as being superimposed over a steady luminous intensity equal to that at the chosen instants t_1 and t_2.

For extremely short flashes, t becomes negligible in comparison with C/F and equation (1) becomes

$$I_e = \frac{J}{C}$$

equation 6

Taking C = 0.2, this equation may be used for flashes shorter than 0.05 s. For these, the effective intensity is five times the integrated intensity (when the unit of time is the second).

6.2 The Problem of Repeated Flashes

The methods of Schmidt-Clausen and Blondel-Rey can be applied only to single flashes. In 1957 Douglas [9] proposed an extension of the Blondel-Rey-Douglas method to calculate the effective intensity of repeated flashes but his proposal is not considered to be of general validity and should be avoided. Rapidly-repeated flashes produce an effective intensity higher than that of a single flash of the same kind [12].

In the “Recommendations for the rhythmic characters of lights on aids to marine navigation”, May 1979 [17], IALA recommends a maximum rate of 300 flashes per minute for the Ultra Quick Light. By inference, characters with rates exceeding 300 flashes per minute are not recommended. For flash rates greater than 60 flashes per minute and less than or equal to 300 flashes per minute the effective intensity obtained using a single flash method (Schmidt-Clausen, Blondel-Rey or Blondel-Rey-Douglas) will result in an unacceptable underestimation of the effective intensity. For rapidly-repeating flashes (greater than 60 flashes/minute and less than or equal to 300 flashes/minute) the effective intensity of the flash pattern should be calculated using the Modified Allard Method (Method IV) taking into account at least 10 flashes.

It is recognized, however, that steady lights or lights with discernable flashes may be simulated by very-rapidly-repeated flashes recurring at rates in excess of the fusion frequency. For these, the intervals of darkness between flashes are not perceived and the Talbot-Plateau Law (see below) is used to model the effect of the very-rapidly-repeated flashes.

6.3 Talbot-Plateau Law for Very-Rapidly-Repeated Flashes

The effect of a train of identical flashes of any form repeated at a rate exceeding the flicker fusion frequency (~60Hz) is the same as the effect of a steady light with an intensity equal to the average intensity of the light with the very-rapidly-repeated flashes. This applies only over the period of very-rapidly-repeating flashes.

Over the period of time of the very-rapidly-repeating flashes the integrated intensity is:

$$J = \int_{\text{Flash}} I.dt$$

equation 7

The intensity of the light with the same effect is therefore:

$$I_{\text{average}} = J / T$$

equation 8

Where:

T corresponds to the period of integration in equation 7.

For an endless series of very-rapidly-repeated flashes the effective intensity will equal I_{average}. If the very-rapidly-repeating flashes collectively compose a discernable flash then the effective intensity of the light is calculated using a two-step process:

Step 1: Use Talbot-Plateau to find I_{average} during the discernable flash

Step 2: Use I_{average} and one of the 4 Methods in this recommendation to calculate the effective intensity.

For a satisfactory simulation of continuous light, a flash rate in excess of 1200 flashes per minute is likely to be necessary. The duration of flash will thus be somewhat less than 0.05 second, and there should be no difficulty in measuring J directly. An electrical integrating circuit may be used in conjunction with the measurement photometer to model Talbot-Plateau law in hardware. Digital integration may also be utilised in software, either in real-time measurements or to post-process measured results. Whatever method of integration is used, careful attention should be paid to measurement calibration.

6.4 Method II — The Method of Allard

This method also proceeds from the variation of instantaneous luminous intensity I as a function of time t, described by the function I(t). The corresponding instantaneous effective intensity is defined by a function i(t).

According to the theory of Allard these functions are related by the differential equation

$$\frac{di}{dt} = \frac{I(t) - i(t)}{A}$$

equation 9

Where:

A is the time-constant for visual response.

In this case, A is associated with the time required for the eye to respond to a light stimulus, and is a measure of the so-called 'inertia of vision'.

For practical calculations under the reference conditions of night-time observation, A is to be taken as 0.2 second.

Solutions of equation 9 yield values of i(t) at each instant during and after the course of a flash (see Fig. 2). If it is assumed that the visual impression is proportional to the light stimulus, and, in particular the assumption is made that the observer's eye remains in a constant state of adaptation during the variations of intensity within the flash, then equation 9 relates the instantaneous intensity I(t) during the flash to the luminous intensity i(t) of a fixed light which would result in the same visual response as that occurring in the eye at that instant. The assumption of constant adaptation is reasonable under the conditions of observation in which lights are seen at threshold levels by an observer.

The effective intensity I_e is the maximum value of i (t) during the duration of the flash.

An explicit solution of equation 9 may be obtained in integral form. From this it may be seen that, for flashes of very short duration, the effective intensity becomes:

$$I_e = \frac{J}{A}$$

equation 10

Where:

J = integrated intensity.

If the visual constant A be taken identical with C in Method I, it may be seen that the two methods give identical effective intensity for very short flashes.

It is generally more convenient to obtain solutions of equation 9 directly by computers rather than to use the explicit solution. The equation is identical with that for an electrical circuit consisting of a capacitor charged through a resistor from a time-varying voltage source.

The explicit solution of equation 9 is:

$$i(t) = \int_{t_1}^{t_2} \frac{I(u)}{A} e^{-\left(\frac{t-u}{A}\right)} du$$

equation 11

Where:

t_1 is a time before which there is no light exhibited.

For rotating optical systems and other apparatus producing flashes that do not fall to zeros of luminous intensity, the initial time t_1 should be taken at a level of luminous intensity not greater than 5% of the peak luminous intensity of the flash.

Any standard computer programme for the solution of first-order linear differential equations may be used to apply the Allard equation to measurement results. Ordinary difference methods are generally sufficient for this purpose. The effective intensity I_e is the maximum value of the solution i(t).

The Allard method can be readily applied to trains of rectangular flashes. For rapidly repeating pulses these agree closely with Talbot's Law. However, for longer flashes, results obtained by using the Allard method do not agree with those obtained by the methods of Schmidt-Clausen, Blondel-Rey and Blondel-Rey Douglas.

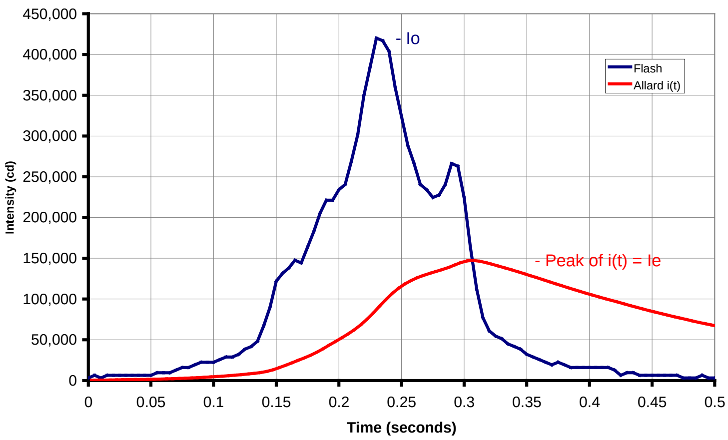

Figure 2 A flash profile and the resultant i(t) from the Allard formula

6.5 Method III — The Method of Blondel-Rey-Douglas

Blondel and Rey indicated that, for non-rectangular flash forms, a likely extension of their simple law would assume the form

$$I_e = \frac{\int_{t_1}^{t_2} I(t).dt}{a + t_2 - t_1}$$

equation 12

Where:

I(t) describes the variation of instantaneous luminous intensity I with time t;

a is the Blondel-Rey visual time-constant;

t_1 and t_2 are the initial and final instants of time, the determination of which remained ambiguous.

Douglas [9] suggested that the limits t_1 and t_2 should be chosen in such a way as to maximize the resulting effective intensity. He showed that this maximum occurred when $I(t_1) = I(t_2) = I_e$. For a single flash, equation (6) may be re-written as

$$a I_e = \int_{t_1}^{t_2} [I(t) - I_e].dt$$

equation 13

Where:

t_1 and t_2 are to be taken as those instants at which the instantaneous intensity rises above and drops below, respectively, the effective intensity I_e.

Since t_1 and t_2 are thus functions of I_e, and, in equation 13, I_e is a function of t_1 and t_2, iterative methods of solution have normally to be used to determine I_e. Figure 3 shows a graphical representation of equation 13 as applied to a particular flash form. The shaded column is of width *a*, and I_e has to be determined to make the two shaded regions have equal areas. This can be done by trying a succession of values of I_e and determining the areas by counting squares or by the use of a planimeter. A result of acceptable accuracy can generally be obtained after two or three trials. It is also possible to programme a digital computer to effect the necessary integrations and to adjust the trial value of I_e until the equality of equation 13 is established.

The extension of the method, as suggested by Douglas, to cover groups of flashes is not considered to be of general validity, and should be avoided.

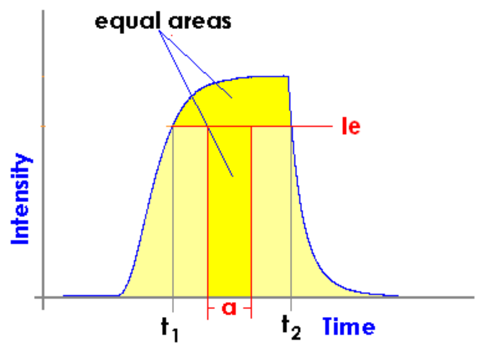

Figure 3 A flash profile showing the Blondel-Rey concept as suggested by Douglas

6.6 Method IV — The Method of Modified Allard

Given the shortcomings of the methods described above, CIE decided to work towards an improved effective intensity model based on the following criteria:

- The formula should agree with the Blondel-Rey (and the Form Factor method) for rectangular flashes.
- The formula should agree with published data for trains of flashes.
- The formula should not be demonstrably tricked by any potential complex form flashes.
- The formula should allow for simple measurement techniques.
- The formula should agree with published visual observation data for studied non-rectangular flash forms.

A CIE technical committee, CIE TC2-49, studied work done over many decades and noted the work done by Luizov and Bulanova, which was presented to an international conference in Washington in 1960. It recommended modifying the original Allard equation so that it agreed with the Blondel Rey formula for rectangular flashes. CIE TC2-49 further validated the method using data originally gathered by Schmidt-Clausen. Finally, work done by Mandler and Thacker in 1986 on repeated flashes was studied and good correlation was obtained by the Modified Allard method with their results.

In the Modified Allard Method, given that I(t) is the instantaneous luminous intensity of a flash, the effective intensity is determined by the peak of the following convolution:

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

equation 14

Where:

$q(t) = a/(a+t)^2$

a is 0.2 for night time use.

The flash starts at $t = 0$. The effective intensity I_e is given as the peak value of *i(t)*, such that

$$I_e = \max_{t_0 \le t \le t_1} \{i(t)\}$$

equation 15

The *q(t), a/(a +t)²*, shown in Figure 4, is the Modified Allard visual impulse response function plotted with that of the original Allard function $\frac{e^{-\frac{t}{a}}}{a}$.

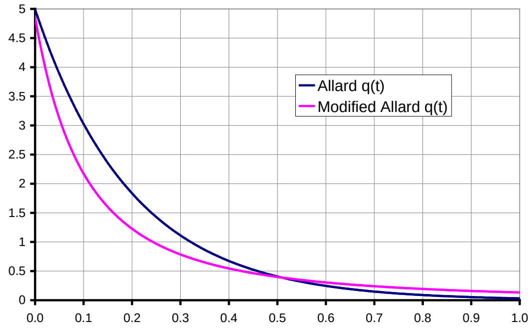

Figure 4 Visual impulse function of Allard and Modified Allard

The convolution can be obtained by calculating sum-products of the two functions, *I(t)* and the *q(t)* function, as the reverse *q(t)* function is moved along relative to *I(t).* This method is suitable for discrete data sets as obtained by digitised measurements of time-resolved flash data and gives rise to the discrete equation:

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

equation 16

Where:

I(t) is sampled at t_0, t_1, t_2, …., t_N over the entire flash duration.

A computer spreadsheet 'SUMPRODUCT' function may be used to convolve *I(t)* and reverse *q(t)* functions in order to determine the effective intensity of a measured flash profile. Discrete time steps for both functions should be the same.

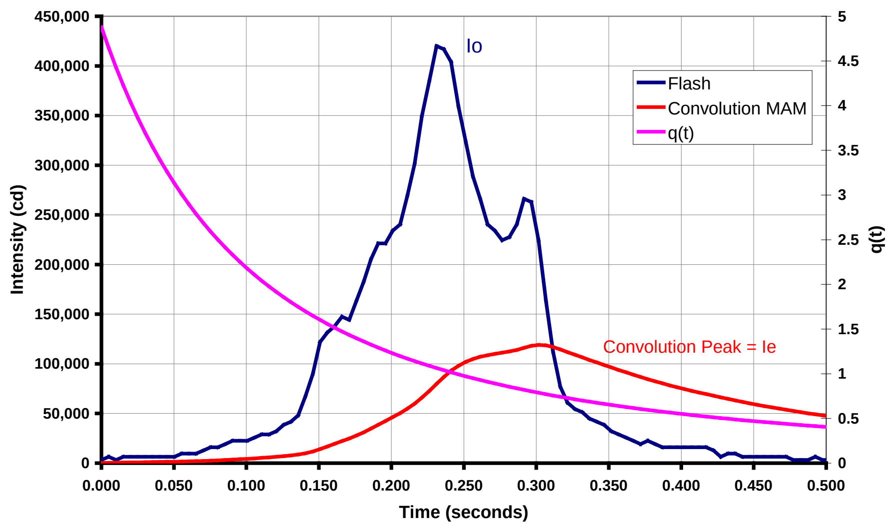

Figure 5 Flash profile with resultant convolution using the Modified Allard Method

The effective intensity value is the maximum of the convolution, such that:

$$I_e = \max_{t_0 \le t_j \le t_N} \{i(t_j)\}$$

equation 17

The advantages of the Modified Allard method are:

- It is mathematically equivalent to the Blondel-Rey (and Form Factor) equation for rectangular pulses;
- It is suitable for train of pulses as validated by the visual experimental data [12] as well as by computational analysis;
- There are no known forms of pulse of any duration for which the method produces anomalous results;
- The method can be realized by single readout analogue circuit, without requiring waveform recording and calculation by computer.

7 CONCLUSIONS

- Effective intensity is not an ideal method for determining the performance of a flashing Aid-to-Navigation signal light but, in the absence of any other suitable method, it may be used to calculate the luminous range of such a light until improved methods prevail;
- The Modified Allard method (see 6.6) is the method recommended for determining the effective intensity of a marine AtoN signal light of **any** flash profile or multiple flash profiles at any repetition rate;
- The Schmidt-Clausen and Blondel-Rey-Douglas methods (see 6.1 and 6.5) may be used to determine the effective intensity of **a single flash** of a marine AtoN signal light providing the flash profile is rectangular, neo-rectangular, trapezoidal or Gaussian. They should not be used where the flash profile fluctuates rapidly, nor should they be used for repeated flashes that flash at a rate greater than 60 flashes per minute;
- The Blondel-Rey method (see 6.5) may be used to determine the effective intensity of **a single flash** of a marine AtoN signal light **providing** the flash profile is rectangular. It should not be used for repeated flashes that flash at a rate greater than 60 flashes per minute;
- Where a light is flashed continuously at a rate greater than that of the flicker fusion frequency (~60Hz), the Talbot-Plateau law (see 6.3) should be used to model the effect of the very-rapidly-repeated flashes;
- If, and only if, it is impossible to measure the variation of instantaneous intensity with time, an estimation of effective intensity may be calculated from the Blondel-Rey formula, $I_e = \frac{I_0 \times t}{a+t}$, using values of Io and t calculated by methods outlined in [20].

8 SUMMARY

In the absence of a suitable method of quantifying the visual performance of a marine aid-to-navigation signal light, National Members and other appropriate Authorities providing marine aids to navigation services may use the **effective intensity** of a rhythmic light to calculate performance as follows:

1 For a rhythmic light of any flash profile and any flash repetition rate, the effective intensity of a flash or flashes should be calculated using the method of modified Allard.

2 For a **single flash** of a rhythmic light that has a trapezoidal, neo-rectangular or Gaussian flash profile, and in which flashes are exhibited at any rate up to 60 flashes per minute,

the effective intensity may be calculated using the method of Blondel-Rey-Douglas or Schmidt-Clausen.

3 For a **single flash** of a rhythmic light that has a rectangular profile, and in which flashes are exhibited at any rate up to 60 flashes per minute, the effective intensity may be calculated using the method of Blondel-Rey.

4 Where the character of the rhythmic light includes different flashes or appearances of light, the effective intensity is to be taken as the least of those derived from the different flashes.

5 If, and only if, it is impossible to measure the variation of instantaneous intensity with time, the effective intensity may be calculated from the Blondel-Rey formula:

$$I_e = \frac{I_0 \times t}{a + t}$$

Where:

I_0 is the peak instantaneous intensity during the flash calculated as described in [20]

t is the duration of the flash calculated as described in [20]

a is 0.2 for night time range and 0.1 for daytime range

6 For repeated flashes at a rate above the flicker-fusion frequency (~60Hz), intended to simulate continuous light, the effect of the very-rapidly-repeated flashes is to be modelled by the application of Talbot's Law.

7 The method of effective intensity applied shall be clearly stated.

8 [19] may be used to determine the luminous range of the resultant calculated intensities.

Where intensity has been calculated and not derived from measurement, the figure of intensity shall not be published but shall be applied to Table 1 of [18]. *The nearest rounded-off value of the 'nominal range' corresponding to the entered value of intensity shall be published as the nominal night-time range of the light. If a nominal daytime range is also required, Table 2 of* [18] *may be used in a similar way.*

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[19] IALA Recommendation E-200-3 on Marine Signal Lights Part 3 – Measurement (E200-3).

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APPENDIX 1 SYMBOLS

Symbol	*Meaning*	*Unit*
A	Time-constant in Allard's formula for effective intensity	s
a	Time constant in Blondel-Rey formula for effective intensity	s
C	Time constant in form-factor method for effective intensity	s
E	Illuminance at eye of an observer	lx
i	Instantaneous intensity	cd
I	Luminous intensity	cd
I_o	Maximum value of luminous intensity with a beam or within a flash	cd
I_e	Effective intensity of a flash	cd
J	Integrated intensity of a flash	cd.s
t	Duration of flash	s

APPENDIX 2 FURTHER EXPLANATION OF THE MODIFIED ALLARD METHOD

As discussed in 6.6, the Modified Allard method of calculating effective intensity is achieved by mathematical convolution. This process can better be described by considering the discrete data resulting from a measurement of the variation intensity over time with a digital recording device. Shown below is a typical flash profile from a rotating beacon and, with it, the visual impulse function.

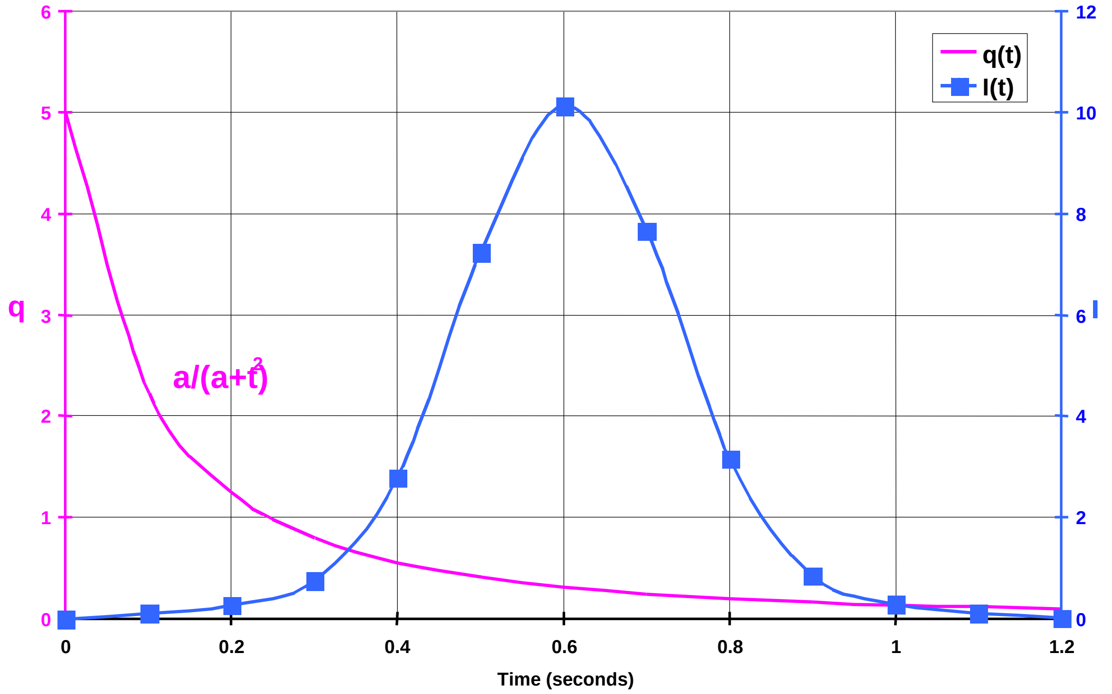

Figure 6 Plot of Intensity against Time I(t) and Visual Impulse Function q(t)

The squares marked on the flash plot are instances in time when the instantaneous intensity was recorded digitally. Both flash profile and visual impulse function can be shown as discrete values by a histogram:

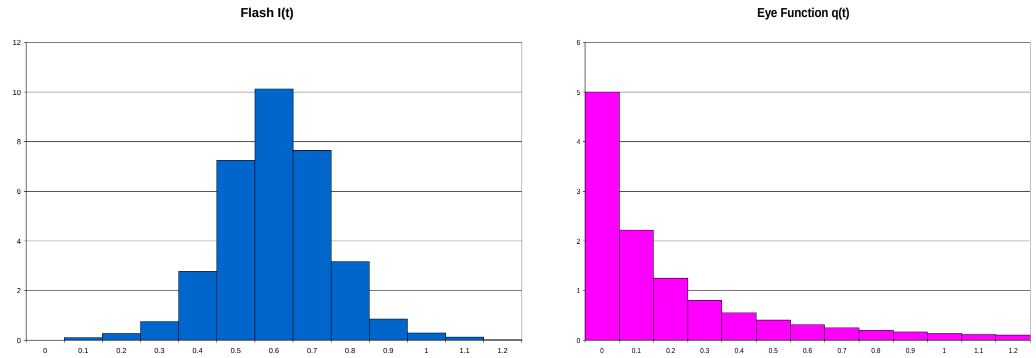

Figure 7 Histograms of Flash Profile I(t) and Visual Response Function q(t)

The convolution is achieved by stepping the reverse visual impulse function past the flash profile taking the sum product at each step as follows:

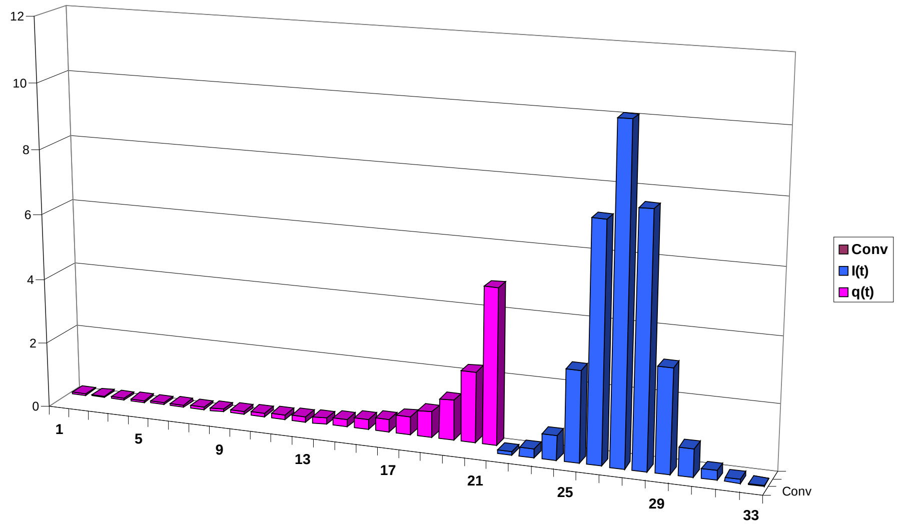

Figure 8 Convolution at t=0

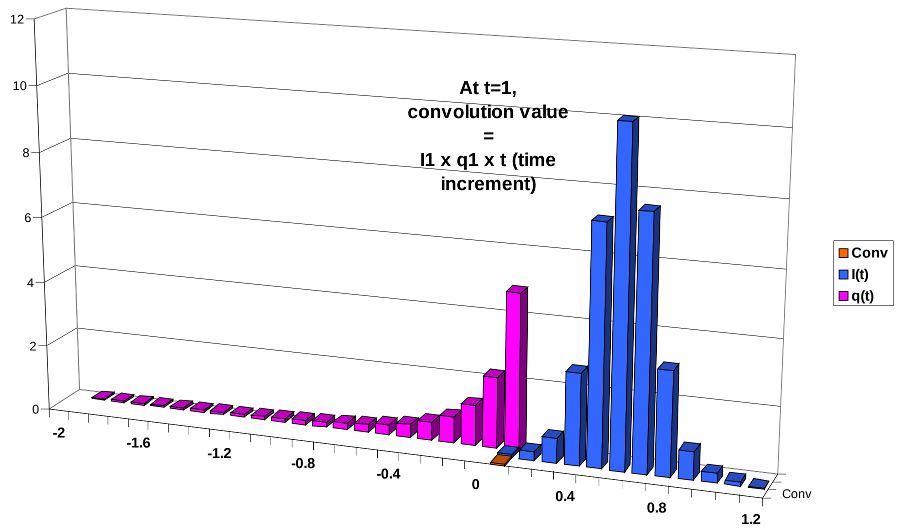

Figure 9 Convolution at t=1

At the first step, the value of q1 in the visual impulse function is multiplied by the value of I1 in the flash profile. This product is multiplied by the time increment in seconds to give the convolved value for t=1.

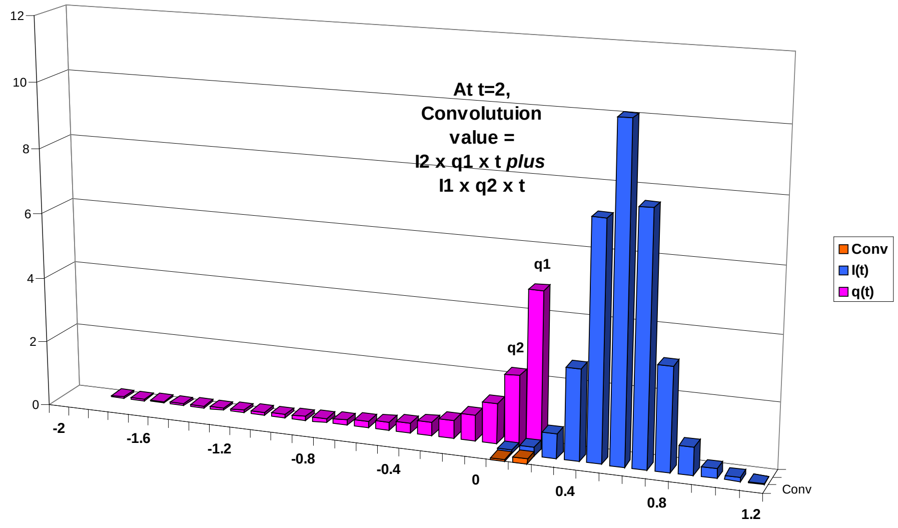

Figure 10 Convolution at t=2

At t=2, the value of q1 is multiplied by the value of I2, then the value of q2 is multiplied by I1. Both products are then added together and multiplied by the time increment. The result is the convolved value for t=2.

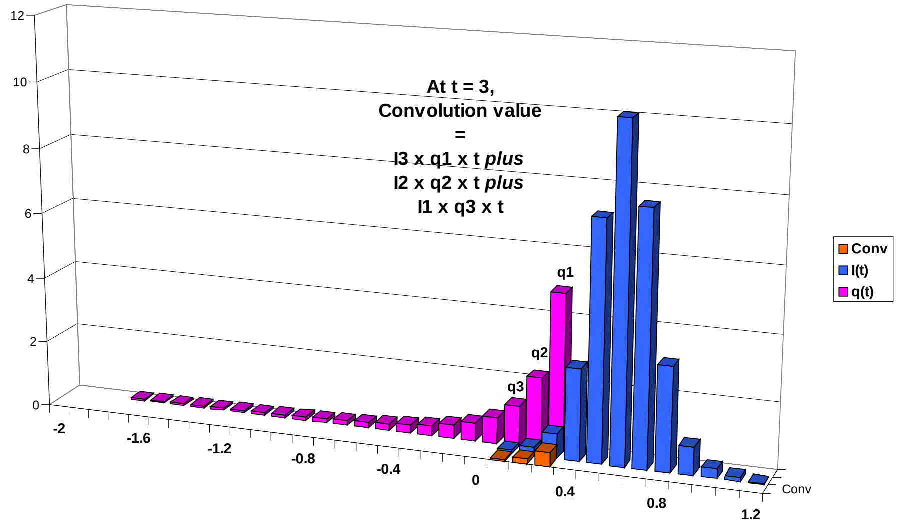

Figure 11 Convolution at t=3

At t=3, the value of q1 is multiplied by the value of I3, the value of q2 is multiplied by I2 and the value of q3 is multiplied by I1. These three products are then added together and multiplied by the time increment to obtain the resultant convolved value for t=3.

As this process is continued through steps 0 to 9 it is possible to see the convolution plot emerging:

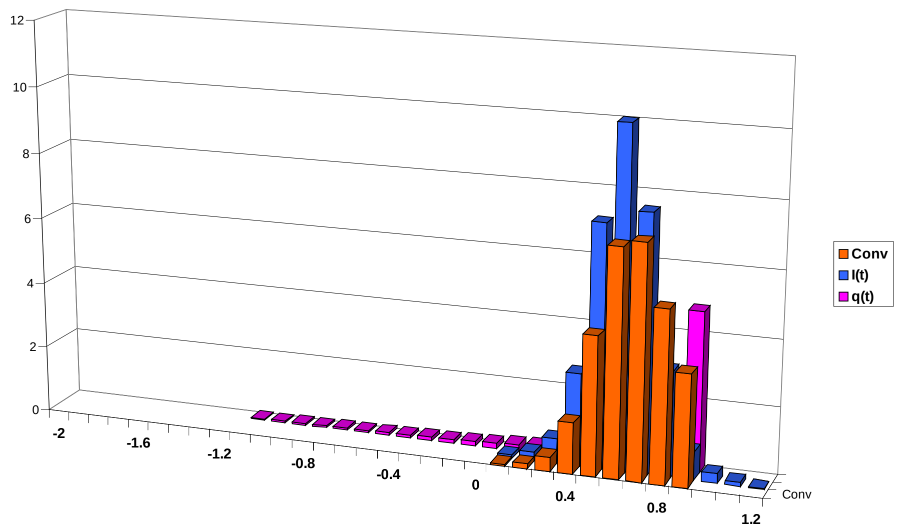

Figure 12 Convolution at t=9 showing a Convolved Maximum at t=7

Although rather crude, the histograms show the convolution process in discrete format. Reverting to the continuous format, the peak value of the convolution can be taken as the effective intensity value.

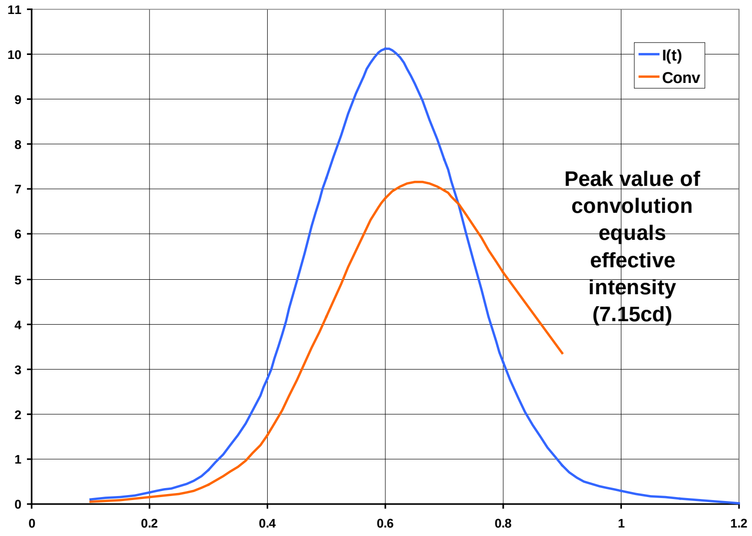

Figure 13 Continuous Graph of Flash Profile I(t) and Convolution

The discrete values of the flash profile, reversed visual impulse function and time increments can be entered into a spreadsheet. The SUMPRODUCT function may be employed to give a value of the convolution at each time increment. Of the resultant convolved values shown at each time increment, the maximum value should be taken to obtain the effective intensity.