Annex 1 to Liaison note

From

The Ad-Hoc Expert WG on Lights

DRAFT
E-200 Series of Recommendations on Marine Signal Lights

AISM Association of Internationale de Signalisation Maritime IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

DRAFT

IALA Recommendation E-200-0

On

Marine Signal Lights

Part 0 - Overview

Edition 0.3

March 2008

20ter, rue Schnapper, 78100
Saint Germain en Laye, France
Telephone +33 1 34 51 70 01 Telefax +33 1 34 51 82 05
E-mail - iala-aism@wanadoo.fr Internet - http://iala-aism.org

Recommendation on Marine Signal Lights, Part 0 - Overview

(Recommendation E-200-0)

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 the need to provide guidance within which the colours and colour boundaries of lights on aids to navigation should be determined;

RECOGNISING ALSO that that such guidance should enable a common approach to be made world-wide, thus greatly assisting mariners, who, while passing through waters of different authorities, should not be confused by light colours that are ambiguous;

RECOGNISING FURTHER that this document supersedes the IALA "Recommendations for the Colours of Light Signals on Aids-to-Navigation" dated December 1977;

NOTING this document applies only to marine Aid-to-Navigation lights installed after its published date;

NOTING ALSO that from three years after the date of this Recommendation, all lanterns placed in service should have colour coordinates in either the IALA Optimum or IALA Temporary regions but that to avoid colour confusion, the IALA Optimum region is preferred;

NOTING FURTHER that from ten years after the date of this Recommendation, all lanterns placed in service should have colour coordinates in the IALA Optimum region;

CONSIDERING that to be reviewed by Secretariat - for example.

ADOPTS the Recommendation on Marine Signal Lights in the annexes of this recommendation; and,

RECOMMENDS that National Members and other appropriate Authorities providing marine aids to navigation services [action to be taken].

* * *

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
30 June 2005	First draft version	Revised by specialized working group tasked with amalgamating a number of older IALA recommendations and look into the usage of blue lights.
13 February 2008	Second draft version	Updated slightly after Ad Hoc Group meeting in Koblenz January 2008
2008-02-21	proposal	Frank
2008-03-20	Third draft	Omar

Table of content

Annex 1
The E-200 series of Recommendations on Marine Signal Lights

1 INTRODUCTION

1.1 Background

Mariners of all times have needed Visual Aids to Navigation. The first application of a system of signal lights for navigational purposes is believed to have been made for maritime purposes. AtoN technology developed over time and major developments in light sources and optics had been achieved before the beginning of the 20th Century. A lot of investigation in physics, meteorology and physiology were carried out for marine lights and later the results were used e.g. for railroad and aeronautical lights.

Throughout its 50 years history IALA has provided guidance on both engineering aspects and management aspects of Aids to Navigation to its members. Consequently IALA has published numerous recommendations and guidelines on the technical aspects of visual aids. The number of relevant documents has made it increasingly complicated for members to get a thorough understanding of the basic theory and recommended methods and mathematical models used. Furthermore the developments in light source technologies (Light Emitting Diodes) has revealed some shortcomings of the model recommended for calculating effective intensity.

This development has led to the need to review and amalgamate a number of IALA documents into one set of interrelated documents, making it easier for members to acquire relevant information on various aspects of visual aids to navigation.

Need to mention new aspects of colour and intensity measurement and in particular issues related to Effective Intensity.

1.2 Superseded documents

This series of recommendations supersede the following IALA recommendations:

- IALA Recommendation for the colours of light signals on aids to navigation (Dec. 1977);
- IALA Recommendation on the determination of the luminous intensity of a marine aid to navigation light (Dec. 1977);
- IALA Recommendation on the calculation of the effective intensity of a rhythmic light (Nov. 1980);
- Draft IALA Recommendation E-122 on the photometry of marine aids to navigation signal lights (Oct 2004);
- Recommendation for the notation of luminous intensity and range of lights (1966);

- Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day (1974).

The content of the abovementioned recommendations has been updated and amalgamated into this new series of recommendation.

1.3 Scope of the E-200 series or recommendations

The E-200 series of recommendations gives guidance on the recommended basic characteristics of marine signal lights i.e. luminous intensity (brightness), spectral properties (colour), how to measure their temporal characteristics and how to estimate how well the signal is perceived by the mariner from a distance.

This series of recommendations does not give guidance on the technical design of marine signal lights, their operation or management.

1.4 Purpose of this document

The purpose of this first part of the E-200 series of recommendations is to give some background information and an overview of the recommendations in the series as well as to give guidance to readers on where to find specific topics.

2 Overview of the E-200 series of Recommendations

2.1 General

The series consists of:

- Part 0 – Overview
- Part 1 – Colours
- Part 2 – Notation of Luminous Intensity and Range
- Part 3 – Measurement
- Part 4 – Determination and Calculation of Effective Intensity
- Part 5 – Calculation of the Performance of Optical Apparatus

2.2 A short description of the individual parts of the E-200 series

Part 0 – Overview (this document) gives some background information and an overview of the recommendations in the series as well as to give guidance to readers on where to find specific topics.

Part 1 – Colours describes the recommended spectral characteristics i.e. recommended colour chromaticity regions of marine signal lights. Information on how and why these regions have been adjusted is given. A new recommended chromaticity region for blue lights is defined and some guidance on the use of blue lights is given.

Part 2 –Notation of Luminous Intensity and Range describes how the illumination at the eye of an observer varies with distance and how to quantify Luminous Range. A definition of Luminous Intensity is given as well as criteria for calculating Nominal Luminous Range. The necessary formulae to be used for these calculations are described. These are useful when calculating the luminous range of an existing light as well as when calculating the required luminous intensity of a new light with a given required range.

Part 3 – Measurement describes the recommended principles for measuring the characteristics of marine signal lights. Recommendations are given on laboratory procedures and equipment as well as details of methods such as zero length photometry, telephotometry, tristimulus colorimetry and spectroradiometry.

Part 4 – Determination and Calculation of Effective Intensity describes how to calculate the Effective Intensity of a flashing signal light. It gives an overview of existing methods for calculating effective intensity and recommends that the Schmidt Clausen method be used for this purpose.
Note that this is the old stuff and that the work of the ad-hoc group has revealed that we need to recommend another method or perhaps multiple methods for determining effective intensity. Hopefully a completely rewritten E-200-4 will be submitted to EEP11 as a late paper. Certainly a discussion will tale place in WG4 at EEP11.

Part 5 – Calculation of the Performance of Optical Apparatus describes how to calculate the performance of optical apparatus (intensity) when direct measurement is impossible or impractical. It is intended as a guide to estimation of the luminous intensity and angle of divergence of the beam from various types of beam projection apparatus when data can be obtained by direct measurement on similar but not identical combinations of light source and optical system. The methods described are referred to as comparison or “ratio-ing” techniques.

2.3 How to use the E-200 series of Recommendations

(Section needs to be developed further)

There are two main ways of using the E-200 series of recommendations, Top Down and Bottom Up.

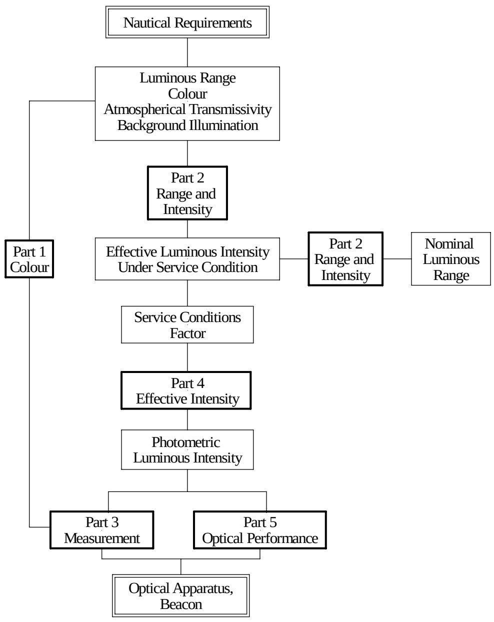
Top-Down

From the nautical requirements, the required effective luminous intensity under given service conditions can be derived. If the design of the optical apparatus is known the photometric intensity can hereafter be calculated.

Bottom-Up

For a given beacon the photometric intensity can be measured or calculated by the tools of part 3 or 5. The result is then used to obtain the values for the effective intensity under given service conditions and the luminous range.

The figure below gives the link between the parts of the recommendation:



In most cases the colour of a signal light (part 1) can be treated separately. It has however influence on the description of the nautical requirements and on the measurement (part 3).

Action	**What part of E-200 to use**
Decide Operational requirement	Not covered by E-200
Selecting the colour of a light source	1
Calculate the Luminous Range	2
Calculate the Nominal Luminous Range	2
Estimate the Required Intensity	2
Estimate the influence of background lighting	2
Estimate the influence of meteorological visibility	2

3 Index of selected topics

Selected topics – in what part can they be found?

(A table of content for the whole series basically)

Background Lighting

4 General Definitions (TBC)

(in Koblenz 2008 the WG agreed that definitions should be in the individual parts and/or the revised IALA Dictionary. This has later been challenged and is under consideration).

5 References

[1] IALA Recommendation for the colours of light signals on aids to navigation (Dec. 1977);

[2] IALA Recommendation on the determination of the luminous intensity of a marine aid to navigation light (Dec. 1977);

[3] IALA Recommendation on the calculation of the effective intensity of a rhythmic light (Nov. 1980);

[4] IALA Recommendation E-122 on the photometry of marine aids to navigation signal lights (Oct 2004);

[5] Recommendation for the notation of luminous intensity and range of lights (1966);

[6] Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day (1974).

AISM Association of Internationale de Signalisation Maritime IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

DRAFT

IALA Recommendation E-200-1

On

Marine Signal Lights

Part 1 – Colours

Edition 0.11

February 2008

20ter, rue Schnapper, 78100
Saint Germain en Laye, France
Telephone +33 1 34 51 70 01 Telefax +33 1 34 51 82 05
E-mail - iala-aism@wanadoo.fr Internet - http://iala-aism.org

Recommendation on Marine Signal Lights, Part 1 – Colours

(Recommendation E-200-1)

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 the need to provide guidance within which the colours and colour boundaries of lights on aids to navigation should be determined;

RECOGNISING ALSO that that such guidance should enable a common approach to be made world-wide, thus greatly assisting mariners, who, while passing through waters of different authorities, should not be confused by light colours that are ambiguous;

RECOGNISING FURTHER that this document supersedes the IALA "Recommendations for the Colours of Light Signals on Aids-to-Navigation" dated December 1977;

NOTING this document applies only to marine Aid-to-Navigation lights installed after its published date;

NOTING ALSO that from three years after the date of this Recommendation, all lanterns placed in service should have colour coordinates in either the IALA Optimum or IALA Temporary regions but that to avoid colour confusion, the IALA Optimum region is preferred;

NOTING FURTHER that from ten years after the date of this Recommendation, all lanterns placed in service should have colour coordinates in the IALA Optimum region;

CONSIDERING that to be reviewed by Secretariat - for example.

ADOPTS the Recommendation on Marine Signal Lights in the annexes of this recommendation; and,

RECOMMENDS that National Members and other appropriate Authorities providing marine aids to navigation services

* * *

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
16 August 2005	First draft version	Revised to by specialized working group tasked with amalgamating a number of older IALA recommendations and look into the usage of blue lights.
03 November	Second Draft	Revised after comments by USCG.
11 November	Third Draft	Revised to include statement about flashing blue lights.
10 March 2006	Fourth Draft	Revised after IALA WG meeting at Harwich UK, including comments from WG members.
10 October 2006	Fifth Draft	Revised for EEP8
12 October 2006	Sixth Draft	Revised after EEP8 Meeting (WG4 – Chair S. Doyle). Green Temporary boundary moved to finish at 540nm.
15 January 2008	Seventh Draft	Revised after EEP10 where a 'retrospective' clause was suggested for existing or 'legacy' lights.
25 January 2008	Eighth Draft	Amended to include Larry Jaeger's comments on 3 years and 10 years .
29 January 2008	Ninth Draft	Amended during Koblenz Meeting – additional information on LED technology and change of Class A (new term for permanent boundaries) white and red
8 February 2008	Tenth Draft	Amended after Koblenz Meeting and checks by Larry to include expanded diagram for all regions and redrawn colour confusion graphs
20 March 2008	Eleventh Draft	Changed all references to "IALA Class A" to "IALA Optimum" (references to CIE class A remain). Also amended numbering of figures 3.1 - 3.3

Table of Content

Annex 1 – Colour Regions

IALA Recommendation E-200-1
Marine Signal Lights
Part 1 – Colours

1 Introduction

1.1 Scope / Purpose

This document describes the IALA recommended chromaticity regions for marine signal lights and gives background information on how and why the chromaticity regions have been adjusted compared to previous IALA recommendations. This document supersedes the IALA "Recommendations for the Colours of Light Signals on Aids-to-Navigation" dated December 1977.

1.2 History

In 1968, IALA recommended a three-colour signal light system utilising red, green and white. In 1977, after the introduction of the IALA buoyage system, a fourth colour, yellow, was introduced and the original colour boundaries amended to reduce colour confusion. Historically, the colour boundaries associated with marine AtoN signal lights have been tighter than those for road and rail signals because marine AtoN signal lights are usually viewed over greater distances. This has two consequences:

- the light subtends a narrow angle in the observer's eye (virtually a point source);
- the illuminance from the light at the eye of the observer is very low.

Both factors can lead to an increased risk of colours being confused by the observer and tighter boundaries reduce the risk of colour confusion. Accordingly, the colour regions recommended herein only apply to marine AtoN signal lights. They do not conform to the regional boundaries specified in [2].

1.3 Requirements for an Additional Colour

Due to the proliferation of lights and lighting affecting the marine environment, there is a demand for a fifth colour in the marine AtoN signal light system to increase conspicuity of marine AtoN lights in some areas. The additional colour chosen is blue. Work carried out by Soon and Cole [3] suggests that blue is a suitable signal colour, and indeed may be a more reliable signal colour than yellow in some circumstances. Work done by CIE in the 1990's [5], leading to the CIE Standard for the Colours of Light Signals, S004/E-2001 [2], also recommends blue as a signal colour. However, S004/E-2001 [2] recommends that a maximum of four colours be used in any one colour system; this document recommends the use of five.

1.4 Colour Model

The colour model used throughout this recommendation is the chromaticity chart used in the CIE 1931 standard colorimetry system and *x, y* chromaticity chart.

2 Changes Made to Chromaticity Regions

2.1 Colour Regions

The "general" colour regions recommended in 1977 [1] have been discontinued. The "general" regions were applicable to the part of the population that has good colour vision and accommodated existing, or legacy, lights that included glass filters and gas/oil lights. The narrower "preferred" regions [1] have largely been retained, being applicable to a more composite population, taking into account that a certain percentage of the population has impaired colour vision. These new regions are called "IALA Optimum regions". Users of marine AtoN's are not necessarily subject to compulsory eye testing and may therefore have defective colour vision.

However, there is a need to ensure that light sources currently in use as marine AtoNs are not proscribed by tighter boundaries. Accordingly, some colour regions have been assigned "IALA Temporary" boundaries that will be valid for ten years after the publication of this recommendation. Each IALA Temporary region includes the corresponding IALA Optimum region.

2.2 Changes Made to Colour Boundaries

An important reason for recommending the preferred regions is that they take into account the problems of people with defective colour vision, who are becoming more numerous at sea with the rapid growth of yachting as a leisure activity.

The boundaries of the IALA 1977 "general" regions have been abandoned and in some cases replaced with IALA Temporary regions. Recommended regions are as follows:

- The red IALA Optimum boundary is different from that of the 1977 "preferred" region [1] in that the region has been extended towards the blue so that region is in agreement with CIE class A[2] and EN 14744[8]. The boundaries towards purple and yellow follow those given in [2]. For protanopes lacking a red-sensitive retinal pigment, long-wavelength reds will not be seen. A red region cut-off at $y = 0.29$ is for such observers. A red IALA Temporary region (which includes the red IALA Optimum region but is extended) has been provided to include a legacy of red filtered lights.
- The yellow IALA Optimum boundary follows that of the 1977 "preferred" region [1] except that the boundary towards the red has been aligned with the D65 point at 6500°K. Additionally, a yellow IALA Temporary region has been provided. This includes the yellow Optimum region but has an extended area towards red, which should include many yellow light-emitting diode (LED) light sources. The yellow IALA Optimum region is relatively small, close to the spectral locus. Longer wavelengths of yellow, known to improve low luminance recognition, were deliberately excluded from the IALA Optimum region in order to reduce potential confusion with white lights of low colour temperature, e.g. oil and gas, as well as filament lamps run below their design voltage to increase lamp-life. Although many marine signal lights have been updated since 1977, some of these low colour temperature sources are still in operation. Furthermore, the colour of a white light can shift along the Planckian locus, to a lower colour temperature, due to the effects of atmospheric extinction over distance. The proliferation of high-pressure sodium street lighting has also had an impact on the conspicuity of yellow and yellowy-white lights, reducing their usefulness in some areas. With a

chromaticity close to the yellow IALA Optimum region, a background of high-pressure sodium lighting can effectively mask a foreground yellow signal. A further reason for the tight boundaries of the IALA Optimum region is to help reduce the likelihood of yellow/green confusion for protanomalous or protanope observers.

- The green IALA Optimum boundary follows that of the 1977 “preferred” region [1] except for the boundary towards the yellow, which has been aligned with that given in CIE S004/E-2001 [2] and EN 14744 [8]. “Yellow-greens” have been excluded from the green region in order to reduce the risk of confusion between green and red by protanomalous or protanope observers (see Annex 3). This also compensates in part for the increase in the size of the red region. A green IALA Temporary region has been provided, which has an extended boundary towards the white, in order to include a legacy of green-filtered incandescent lights sources - and towards the yellow, to 540nm, to include some green high-power LEDs. The CIE green class A region, as laid down in their standard S004/E-2001 [2], shows the boundary extending further towards the blue than the IALA 1977 [1] preferred green region. Although this has been identified as a useful area of signal green, there is the concern of increased confusion with blue and white in a five-colour system (CIE recommends a maximum of four colours in any one system).
- The white IALA Optimum boundary follows that of the 1977 “preferred” region [1] on three of its boundary lines but the boundary towards the yellow has been extended to include incandescent filament lamps at 2856˚K (x-value of 0.453). The white region extends to beyond 9,500ºK (x-value of 0.285) and will include the majority of devices fitted with white phosphor-conversion LED’s (pcLED’s). Such devices are widely deployed by AtoN providers and many users prefer their colour, especially when viewed with a dark-adapted eye against a background of “yellowy” artificial lighting. A white IALA Temporary region has been provided that extends the white boundary towards the yellow. The extent of this IALA Temporary boundary towards yellow has an *x* value corresponding to a colour correlated temperature (CCT) of 2,500ºK (x-value of .48) that will include the majority of incandescent filament lamps operated at their designed voltage.
- A blue IALA Optimum region has been added. This region is a truncated version of that recommended in [2]. The truncated region is designed to reduce the risk of colour confusion with white and possibly green at low illuminance levels. It will also exclude the chromaticity values of most filtered blue lights (see Annex 2 of this recommendation for further discussion and recommendations on blue lights). CIE Technical Report 107-1994 [5] also recommends a truncated blue region for blue lights intending to be viewed at low illuminance.

3 IALA Recommended Chromaticity Regions for Lights

3.1CIE 1931 Colour Chart

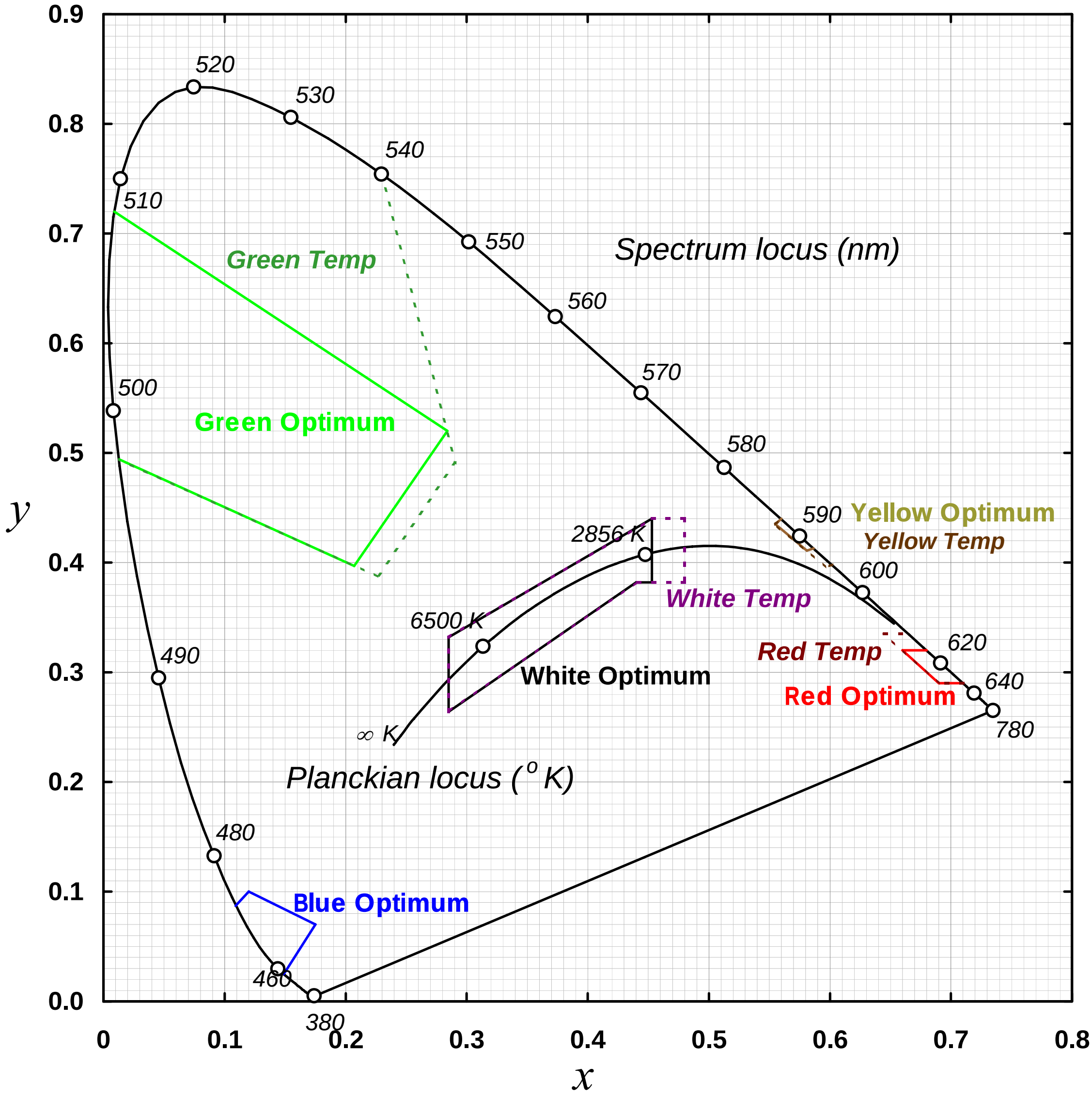


Figure 1.1
Showing the chromaticity regions of the recommended IALA colours for lights in terms of the CIE 1931 Standard Colorimetric System.
IALA Optimum boundaries in solid lines, IALA Temporary boundaries in dashed lines.

3.2 Chromaticity Corner Coordinates of IALA Optimum Regions

Colour	1		2		3		4		5	
	x	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*
Red	0.71	0.29	0.69	0.29	0.66	0.32	0.68	0.32		
Yellow	0.5865	0.413	0.581	0.411	0.555	0.435	0.56	0.44		
Green	0.009	0.720	0.284	0.520	0.207	0.397	0.013	0.494		
White	0.44	0.382	0.285	0.264	0.285	0.332	0.453	0.44	0.453	0.382
Blue	0.109	0.087	0.12	0.1	0.175	0.07	0.149	0.025		

3.3 Chromaticity Corner Coordinates of IALA Temporary Regions

Colour	1		2		3		4		5		6	
	x	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*
Red	0.71	0.29	0.69	0.29	0.645	0.335	0.665	0.335				
Yellow	0.602	0.398	0.596	0.396	0.555	0.435	0.56	0.44				
Green	0.2296	0.7543	0.2908	0.4907	0.2260	0.3872	0.0130	0.4940				
White	0.48	0.382	0.44	0.382	0.285	0.264	0.285	0.332	0.453	0.44	0.48	0.44

3.4 Expanded Charts showing Individual Regions

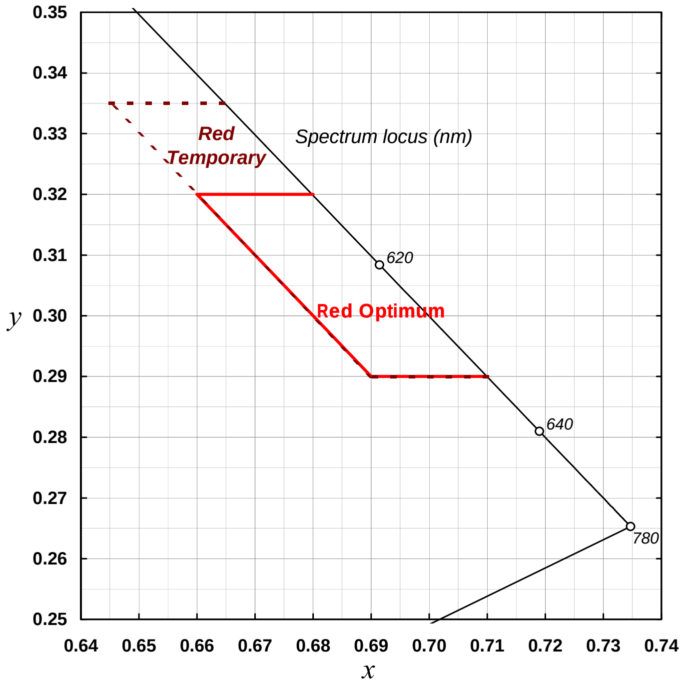


Figure 1.2 Expanded Chart showing Red Region

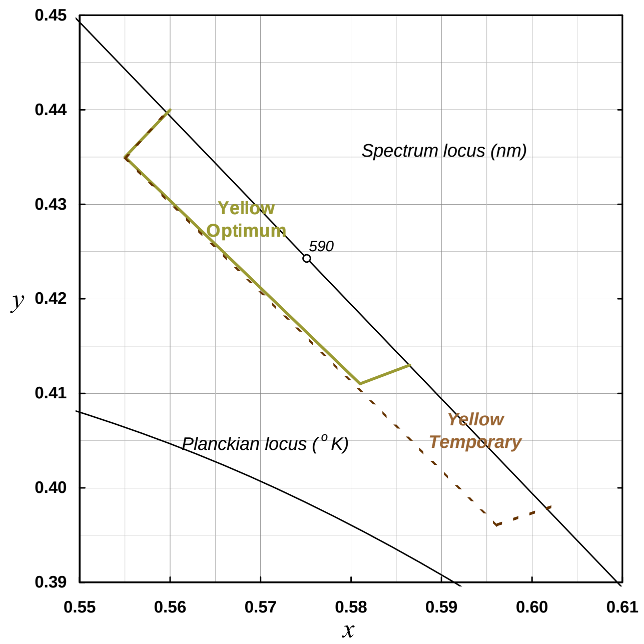


Figure 1.3 Expanded Chart showing Yellow Region

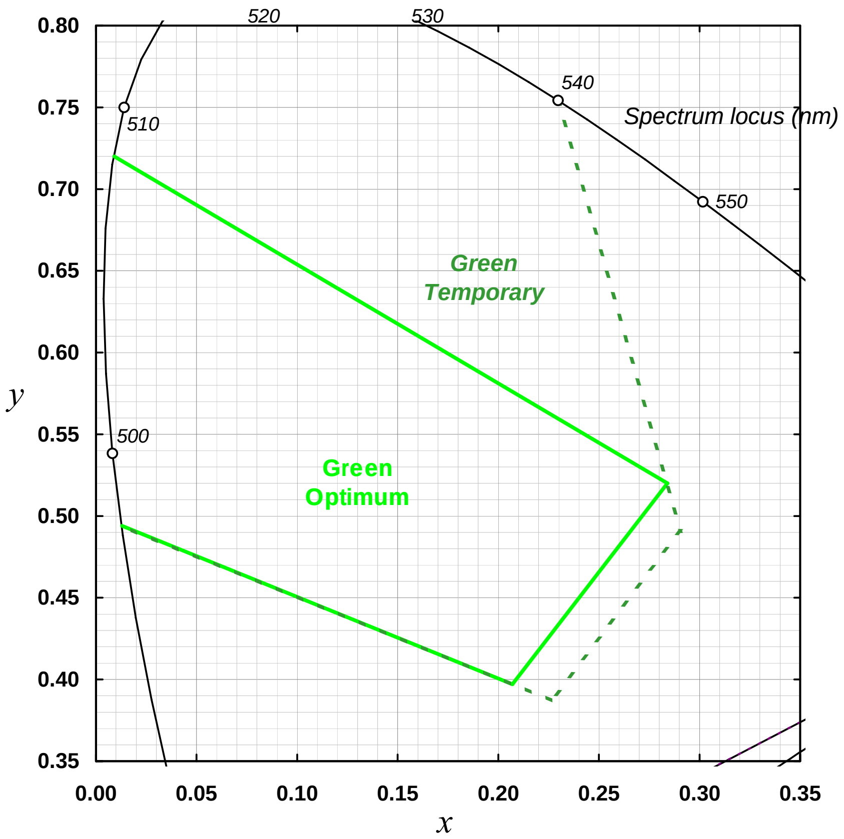


Figure 1.4 Expanded Chart showing Green Region

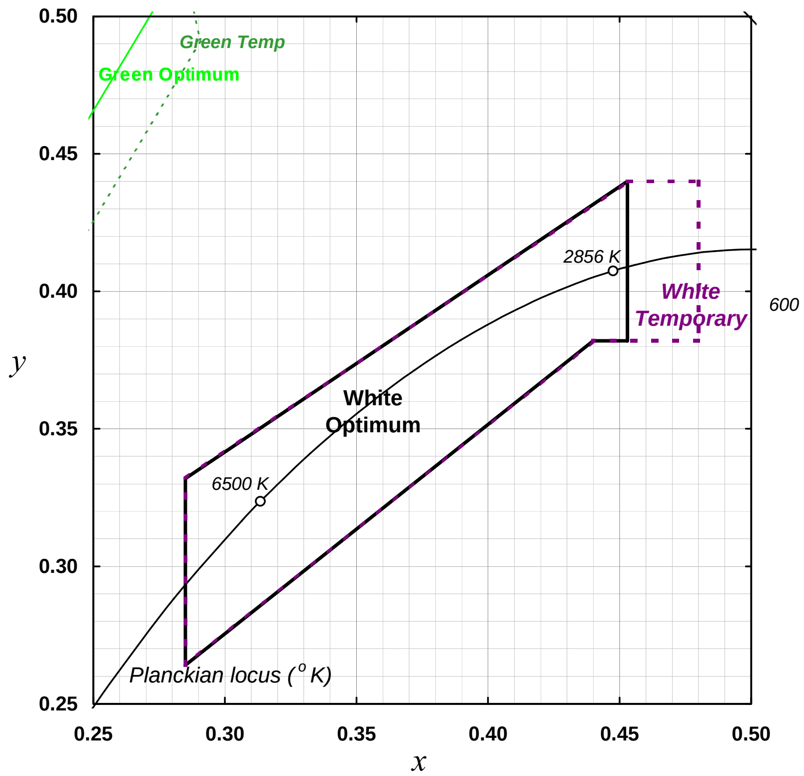


Figure 1.5 Expanded Chart showing White Region

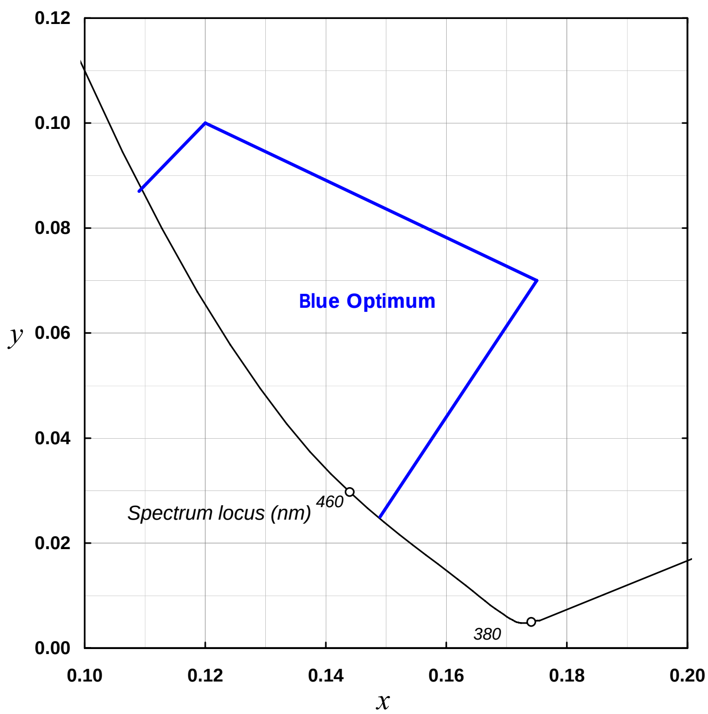


Figure 1.6 Expanded Chart showing Blue Region

4 Measurement of Colour of Signal Lights

4.1 Method used for Colour Measurements

Whatever the system of colour measurement used to find the *x, y* values of chromaticity, it should be validated by appropriate colour measurement (see E200-3, “Measurement”).

5 Considerations for LED Technology

LEDs emit light with a narrow spectral distribution. The junction temperature has a significant effect on the radiant intensity and dominant wavelength of light emitted. A temperature increase causes a decrease in radiant intensity and wavelength. Lower than nominal values of junction current can also affect the spectral distribution of an LED, typically causing an increase in dominant wavelength.

White phosphor-conversion LEDs rely on two components for their broadband spectral distribution, these being an LED chip (usually blue) and a phosphor that converts some of the blue light to yellow light. Thus the light emitted from the device is a mixture of blue and yellow that the eye percieves as white. However, the amount of blue and yellow light may vary independently with angle of emission, thereby causing colour variation over viewing angle.

6 References

[1] IALA, December 1977 - “Recommendations for the colours of signal lights on aids-to-navigation”

[2] Commission Internationale de l’Eclairage (CIE), S004/E-2001 - “Colours of Light Signals”

[3] Soon & Cole, 1999 - “Critical Test of the CIE Domains for Signal Colours”

[4] GLA R&D Department, Technical Report No. 31/IT/2004, “Recommendation E-200-1 – Colours Proposed New Colour Boundaries for IALA Light Signals”

[5] Commission Internationale de l’Eclairage (CIE), Technical Report 107-1994 - “Review of the Official Recommendations of the CIE for the Colours of Signal Lights”

[6] Commission Internationale de l’Eclairage (CIE), Technical Report 2.2-1975 - “Colours of Light Signals”

[7] Chapman and Hall, London 1968 - “Light, Colour and Vision”.

[8] European Committee for Standardisation EN 14744, August 2005, “Inland Navigation Vessels and Sea-going Vessels – Navigation Light”.

Annex 2 – Blue Lights

IALA Recommendation E-200-1
Marine Signal Lights
Part 1 – Colours

Luminous Range of Blue Lights

When visibility is moderate to good, blue light is preferentially scattered by the atmosphere (due to aerosol scattering). Therefore, the luminous range of a blue light under these conditions will be less than for that of a red light of the same intensity (see IALA E-200/2). Therefore, if a blue light is to be used at ranges of more than five nautical-miles (5M), it is recommended that the published range be reduced by one nautical-mile in order to provide reliable detection over this distance.

Filtered blue light - Effects of Scattering on Perceived Colour

The use of blue lights consisting of a white light source and a blue filter may cause confusion when viewed at a distance because of the significant red content present in most filtered blue lights (see figure 2.1).

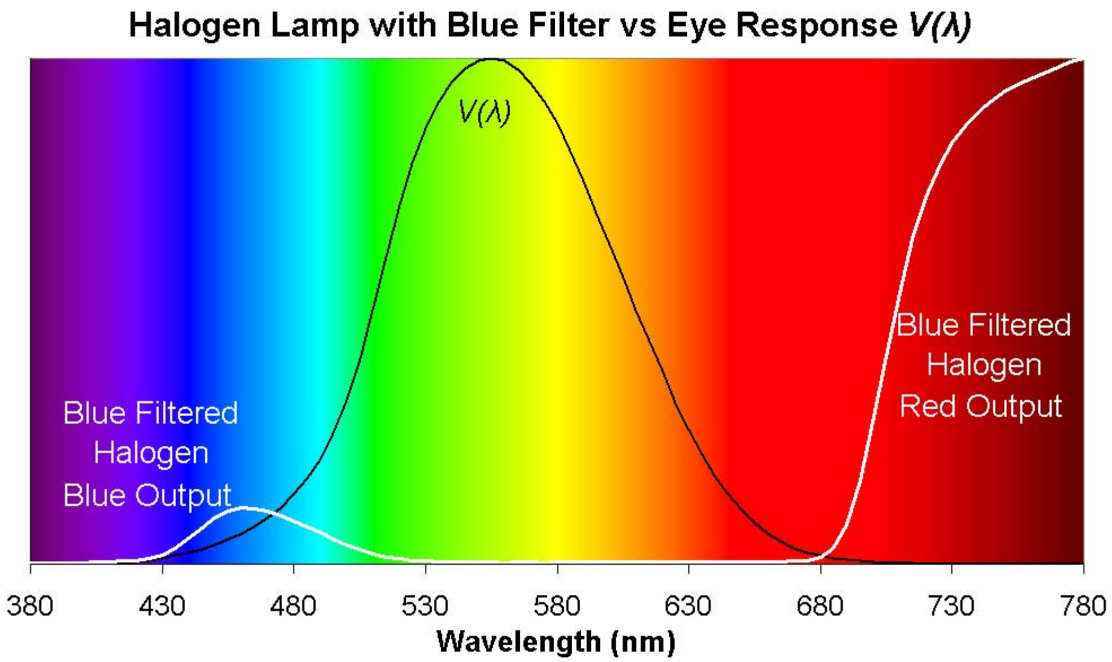


Figure 2.1
Showing the significant red content of a halogen lamp with a blue filter - the white line shows a spectral plot of the blue-filtered incandescent light.

Over distances of a few miles, the blue content of the light will be scattered more than the red. Therefore, when in close proximity the light will appear blue, but at a distance it will appear as a red or purple light with a blue halo. Thus the effects of scattering can cause a blue filtered white light to appear red at distances of a few miles. This is highly undesirable.

The colour confusion caused by this preferential scattering can be reduced by ensuring that the red content of the blue light is suppressed to less than 1.5% of the total visible light emitted. This can be done by selecting light sources with low emission in the red spectrum or by careful filter selection, including secondary filtering if necessary.

Accordingly, it is recommended that the red emission conforms to the following formula [6]:

$$\frac{\int_{650}^{830} S(\lambda).\tau(\lambda).V(\lambda)\,d\lambda}{\int_{380}^{830} S(\lambda).\tau(\lambda).V(\lambda)\,d\lambda} \leq 0.015$$

where: $S(\lambda)$ is the relative spectral power distribution of the illuminant
$\tau(\lambda)$ is the spectral transmittance of the filter
$V(\lambda)$ is the photopic luminous efficiency function

Possible Confusion with Blue Lights in Emergency Services

Most people associate flashing blue lights with emergency service vehicles and vessels. In order to ensure that blue marine AtoN signal lights are not confused with emergency services warning beacons, they should where possible, be exhibited as a continuous light and not flashed. Where flashing blue lights are to be used as marine AtoN's, they should be used only in an emergency and their rhythmic character should be restricted to 'on' periods of one second or greater.

Advantages of New Light Sources

Light Emitting Diode (LED) technology is emerging as a preferred option for the provision of AtoN signal lights of low to medium intensity. Coloured LED sources have the advantage of a narrow spectral distribution resulting in colour of high purity that does not requiring filtering. Colour confusion is less likely between two lights of high colour purity. Furthermore, although the effects of scattering cannot be ignored, the colour of near-monochromatic light does not change over distance.

Further Notes on Blue Light

- At low illuminances and small angular subtense, the eye tends towards tritanopic myopia (short-sightedness to blue light) and this causes the light to appear blurred.
- Older observers typically suffer from a yellowing of the cornea so that blue may appear less bright than to a younger observer, it may also be more easily confused with green, white and yellow.
- Peripheral vision is more sensitive to blue light, especially when viewed with a dark-adapted eye. A blue light may therefore be more noticeable than other colours when viewed not directly but a few degrees peripherally.
- The blue region recommended is designed to enhance reliable recognition of blue at low illuminance levels but this may preclude many light sources, including some blue LEDs. A small shift in LED wavelength, for example as a result of

junction temperature increase, may be enough to cause the chromaticity of some 470nm blue LEDs to cross the long-wavelength boundary (towards the green). Recommendations given in CIE documents [2][5] suggest restricting the blue region to below a y value of 0.06 ($y < 0.06$). However, it may be difficult to reliably maintain any light source within this small chromaticity triangle.

- The Ishihara plate test, commonly used to test mariners, is not a suitable test for blue colour vision deficiency.

Annex 3 – Colour Deficient Observers

IALA Recommendation E-200-1
Marine Signal Lights
Part 1 – Colours

Percentages of Colour Vision Deficient Observers [7]

Type of Deficiency		% males	% females
Overall		~8%	~0.5%
Anomalous trichromasy	Protanomaly	1%	0.01%
	Deutanomaly	5%	0.4%
	Tritanomaly	rare	rare
Dichromasy	Protanopia	1%	0.01%
	Deuteranopia	1.5%	0.01%
	Tritanopia	0.008%	0.008%

Description of Different Types of Colour Vision Deficiency [7]

Protan	Protanope	Dichromat	missing longer wavelength (red) cone pigment
	Protanomal	Anomalous Trichomat	anomalous (misaligned) longer wavelength cone pigment
Deutan	Deuteranope	Dichromat	missing middle wavelength (green) cone pigment
	Deuteranomal	Anomalous Trichomat	anomalous (misaligned) middle wavelength cone pigment
Tritan	Tritanope	Dichromat	missing shorter wavelength (blue) cone pigment
	Tritanomal	Anomalous Trichomat	anomalous (misaligned) shorter wavelength cone pigment

Lines of Colour Confusion for Colour Deficient Observers [7]

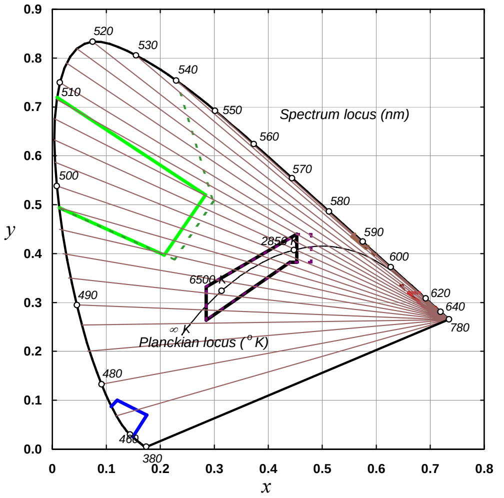


Figure 3.1 Protanope

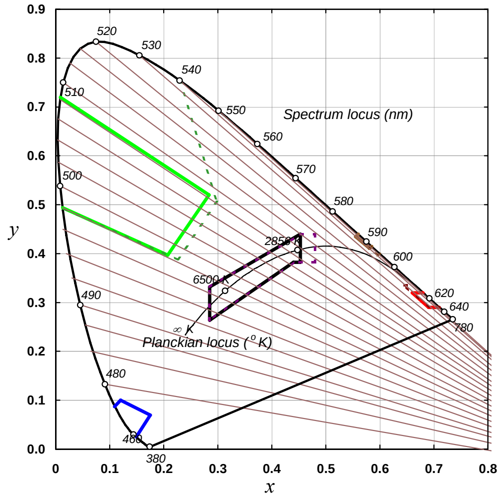


Figure 3.2 Deuteranope

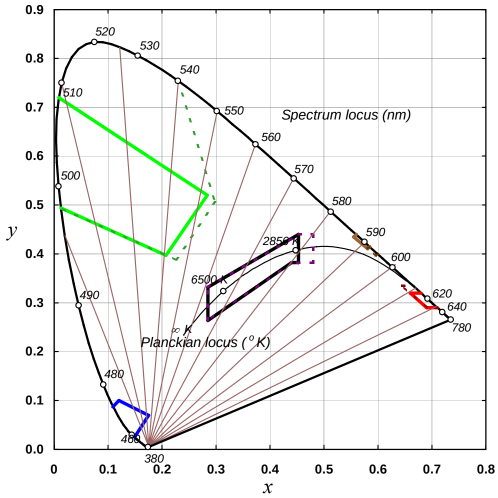


Figure 3.3 Tritanope

AISM Association of Internationale de Signalisation Maritime IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

DRAFT
IALA Recommendation E200-2

On

Marine Signal Lights

Part 2 - Notation of Luminous Intensity and Range

Edition 1.0beta

20ter, rue Schnapper, 78100
Saint Germain en Laye, France
Telephone +33 1 34 51 70 0 Telefax +33 1 34 51 82 05
E-mail - iala-aism@wanadoo.fr Internet - http://iala-aism.org

IALA Recommendation E-200-2
Marine Signal Lights
Part 2 - Notation of Luminous Intensity and Range

IALA Recommendation E-200-2, January 2008

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 [to be reviewed by Secretariat - for example - IMO has concluded that AIS will improve the safety of navigation and the protection of the environment];

RECOGNISING ALSO that [to be reviewed by Secretariat - for example - there is a mandatory carriage requirement for AIS equipment on SOLAS Convention vessels that entered into force on 1 July 2002 and will be complete by [2008]];

RECOGNISING FURTHER that [to be reviewed by Secretariat - for example - documentation of IMO, ITU and IEC refer to the provision of an AIS shore infrastructure as part of the overall operational system];

NOTING the [as above];

NOTING ALSO that;

NOTING FURTHER that;

CONSIDERING that to be reviewed by Secretariat - for example.

ADOPTS the [name of document] in the annex of this recommendation; and,

RECOMMENDS that National Members and other appropriate Authorities providing marine aids to navigation services [action to be taken].

* * *

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
January 2008 [example only]		

Table of Contents

IALA Recommendation E-200-2
Marine Signal Lights
Part 2 - Notation of Luminous Intensity and Range

Annex

1 Introduction

1.1 Scope / Purpose

The scope of this recommendation is to permit providers and manufacturers of marine AtoN lights, as well as mariners, to determine the luminous range of lights as a function of their intensity and of the meteorological visibility. This recommendation provides a link between the physical and photometric features of marine AtoN lights and the luminous range information given to the mariner.

For providers of marine AtoN lights, this recommendation should be used to estimate the required luminous intensity when designing lights.

Manufacturers of marine AtoN lights should quote the nominal luminous range of their lights in accordance with this recommendation.

1.2 Background / History

The IALA definition of the luminous range of lights was first introduced by a Recommendation in 1966 [1]. For many years this definition has been an important basis for the description of marine AtoN lights.

However, since 1966 several additions have been made to the definition of luminous range. These additions were spread over five IALA documents ([2], [3], [4], [5], [6]).

To avoid confusion the information from these six documents has been collated into a single document for the calculation, definition and notation of luminous range of lights, which helps to distinguish between the different values for the required illuminance and their application.

The two basic recommendations [1] and [3] included nomograms for luminous range estimation. These nomograms are still supported. However, the wide-spread use of computer modelling makes it feasible to base the estimation of luminous range on formulae. Therefore, these have been provided in this recommendation.

Previous IALA Recommendations and the IALA Dictionary use the “sea mile” as the unit of measure for luminous range, nominal luminous range, and meteorological visibility. This document replaces the sea mile with the nautical mile as the preferred unit of measure and as the unit of measure used in definitions. The difference between a sea mile (about 1853.2 m) and a nautical mile (1852 m) is small, and of no practical consequence for these calculations. The nautical mile has been chosen as the unit of measure because it is used more widely than the sea mile.

For many countries the use of SI-units is obligatory. The 'nautical mile' and the units derived from it are outside this International System of Units. One aim of this recommendation is to give the reader the necessary formulae to convert between the SI-units and the units used in navigation.

2 Physical basics – Allard’s Law

The illuminance of a signal light at the observer’s eye can be calculated by a physical law called Allard’s law.

2.1 Allard’s law

Allard’s law allows the calculation of the illuminance E as a function of distance d, luminous intensity I and an exponential factor z.

$$E(d) = I\,\frac{e^{-zd}}{d^2} \qquad \text{(Equation 1)}$$

The exponential factor z describes the atmospheric absorption and scattering (extinction). In practice, there are alternative ways of characterizing the prevailing atmosphere as follows.

2.2 Allard's law using the atmospheric transmissivity T

Atmospheric transmissivity (T) is defined as the ratio of the luminous flux transmitted by the atmosphere over a unit distance to the luminous flux which would be transmitted along the same path in a vacuum.

$$\mathrm{T} = \frac{\Phi(\mathrm{d_U})}{\Phi_{\mathrm{vacuum}}(\mathrm{d_U})} \qquad \text{(Equation 2)}$$

Where:

T is the atmospheric transmissivity (dimensionless)
$\Phi(d_U)$ is the luminous flux at the unit distance after passing through the atmosphere
$\Phi_{vacuum}(d_U)$ is the theoretical luminous flux at the unit distance after passing through a vacuum
d_U is the unit distance

Because the ratio of the luminous fluxes in equation 2 is the same as the ratio of the corresponding illuminance values, equation 2 can be rewritten as

$$\mathrm{T} = \frac{\mathrm{E}(\mathrm{d_U})}{\mathrm{E_{vacuum}}(\mathrm{d_U})} \qquad \text{(Equation 3)}$$

Where:

$E(d_U)$ is the illuminance at the unit distance after passing through the atmosphere
$E_{vacuum}(d_U)$ is the theoretical illuminance at the unit distance after passing through a vacuum

Inserting expressions for $E(d_U)$ and $E_{vacuum}(d_U)$ from equation 1 into equation 3, and noting that for $E_{vacuum}(d_U)$ z = 0, equation 3 becomes

$$T = e^{-zd_U} \qquad \text{(Equation 4)}$$

Combining equation 1 and 4 yields

$$E(d) = I\,\frac{T^{d/d_U}}{d^2} \qquad \text{(Equation 5)}$$

2.3 Allard's law using the transmissivity T_M for 1 nautical mile

The unit distance for transmissitity is chosen to be one nautical mile. Expressed in all metric units equation 5 takes the form

$$E(d) = I\,\frac{T_M{}^{d/d_U}}{d^2} \qquad \text{(Equation 6)}$$

Where:

E(d) is the illuminance at distance d in metres
I is the luminous intensity in candela
T_M is the atmospheric transmissivity [dimensionless] for 1 nautical mile
d is the distance in metres
d_U is the unit distance that corresponds to the transmissivity [1852 m]

In practice the distance d is expressed in nautical miles. Using the fact that one nautical mile equals 1852 metres and suppressing the unit distance in the exponent equation 6 can be written as

$$E(d) = I\,\frac{T_M{}^d}{\left(1852\,\dfrac{metres}{nautical\ mile}\times d\right)^2} \qquad \text{(Equation 7)}$$

where d is the distance in nautical miles.

Simplifying and suppressing all units yields

$$E(d) = \frac{I}{(3.43 \times 10^6)} \frac{T_M{}^d}{d^2} \qquad \text{(Equation 8)}$$

Where:

E(d) is the illuminance at the eye of the observer in lm/m^2 [lx]
I is the luminous intensity of the light [cd]
T_M is the transmissivity for one nautical mile of the atmosphere
d is the numerical value of the distance in nautical miles

2.4 Meteorological Visibility

The meteorological visibility is an alternative way to describe the extinction of the atmosphere, which in the development above is quantitatively characterised by the atmospheric transmissivity.

Meteorological visibility is the greatest distance at which a black object of suitable dimensions can be seen and recognized by day against the horizon sky, or, in the case of night observations, could be seen and recognized if the general illumination were raised to daylight level.

By definition the relationship between the meteorological visibility (V) and the transmissivity is

$$V = \frac{\ln 0.05}{\ln T_M} \times d_U \qquad \text{(Equation 9)}$$

Where:

V is the meteorological visibility in nautical miles
T_M is the transmissivity [dimensionless] for one nautical mile
d_U is the unit distance of 1 nautical mile

Suppressing the units and suppressing the unit distance yields:

$$\mathrm{V} = \frac{\ln 0.05}{\ln \mathrm{T_M}} \qquad \text{(Equation 10)}$$

2.5 Allard’s Law based on Meteorological Visibility

It is recommended in the IALA dictionary that the atmospheric extinction be described by using meteorological visibility V rather than the transmissivity T_M.

Allard's law can be expressed using meteorological visibility V by combining equations 8 and 10.

$$E(d) = \frac{I}{(3.43 \times 10^6)} \frac{0.05^{\frac{d}{V}}}{d^2} \qquad \text{(Equation 11)}$$

Where:

E(d) is the illuminance at the eye of the observer [lx]
I is the luminous intensity of the light [cd]
d is the distance in nautical miles
V is the meteorological visibility in nautical miles
the units (not shown) associated with (3.43×10^6) are m^2/M^2

3 Luminous Range

In the case of a light that appears as a point source, the **luminous range D** is defined as the maximum distance at which a light can be seen, as determined by the luminous intensity I of the light, the meteorological visibility V and the required illuminance E_r at the eye of the observer. At this distance, the illuminance E at the observer’s eye is reduced to the value E_r.

Inserting these parameters into equation 11 and rearranging yields:

$$I = (3.43 \times 10^6) E_r D^2 (0.05)^{-\frac{D}{V}} \qquad \text{(Equation 12)}$$

Equation 12 is recommended for the calculation of the luminous range of signal lights. Due to the numerical character of equation 12, numerical iteration is necessary in order to calculate the luminous range D. A rough estimation of D can be derived from the nomograms provided in this recommendation.

4 Nominal Luminous Range

4.1 Definition of the nominal luminous range of lights intended for the guidance of shipping

IALA recommends that the nominal luminous range of maritime signal lights intended for the guidance of shipping should be defined as follows:

The nominal luminous range of a maritime signal light is the distance in nautical miles at which this light produces an illumination at the eye of the observer:

- *of* 2×10^{-7} *lx for night time range*
- *of* 1×10^{-3} *lx for day time range*

It should be assumed that meteorological visibility V equals 10 nautical miles ($T_M = 0.7411$) *and that the atmosphere is homogenous.*

The value 2×10^{-7} lx, agreed upon at the International Technical Conference of Lighthouse Authorities in Paris 1933, is the internationally accepted value of the illuminance required for observation of a light at night under typical maritime conditions.

It is important to note that a leading light, like any other night-time light, will have a nominal luminous range that corresponds to the distance at which the illumination at the eye of the observer is 2×10^{-7} lx. However, per IALA recommendation for leading lights [5] the illumination required for an observer to use the leading lights for alignment must be at least 1×10^{-6} lx. Because the illumination level that corresponds to nominal luminous range is 5 times less than the level needed to align the lights, the concept of nominal range for a leading light is not typically used.

4.2 Notation of the nominal luminous range of lights intended for the guidance of shipping

IALA recommends that the nominal range of lights intended for the guidance of shipping should be published in the "Lists of Lights".

The following information should be published in the "Lists of Lights":

- *The nominal range of lights intended for the guidance of shipping by night;*
- *Where applicable, the nominal range of lights intended for the guidance of shipping by day;*
- *Nomograms permitting mariners to estimate the luminous range of lights intended for the guidance of shipping by day or by night as a function of their nominal range, the prevailing meteorological visibility and, where applicable, the sky luminance in the direction of observation.*

Note:

The nominal range of leading lights is typically omitted for reasons as described in Section 4.1.

The published nominal luminous range of a light should include a reference to the value of illuminance used.

Appendix 1
Further Considerations

A1.1: Estimation of the Required Illuminance for Daytime Range

The mariners should be able to estimate the luminous range of lights by day for different sky luminances. However, the required illuminance E_r in lx, produced by a light, depends on the luminance L of the sky in candelas per square metre, in the direction of observation according to the formula:

$$E_r = (0.242 \times 10^{-6})) \times \left(1 + \sqrt{0.4L}\right)^2 \qquad \text{(equation 13)}$$

Where:

E_r is the required illuminance at the observer's eye in lm/m^2 [lx]

L is the sky (background) luminance in cd/m^2

The illuminance E_r of 1×10^{-3} lx thus corresponds to a sky luminance of 10,000 candelas per square meter. The calculated illuminance E_r should be inserted in equation 12

A1.2: Service Condition Factor

In practical installations, the degradation of luminous intensity under service conditions should be taken into consideration. It is recommended that the intensity used to calculate the nominal range for publication should include a service factor. It is recommended that this service factor be taken as 0.75 (corresponding to a reduction in intensity of 25%).

A1.3: Some Important Factors in the Design of Marine Signal Lights

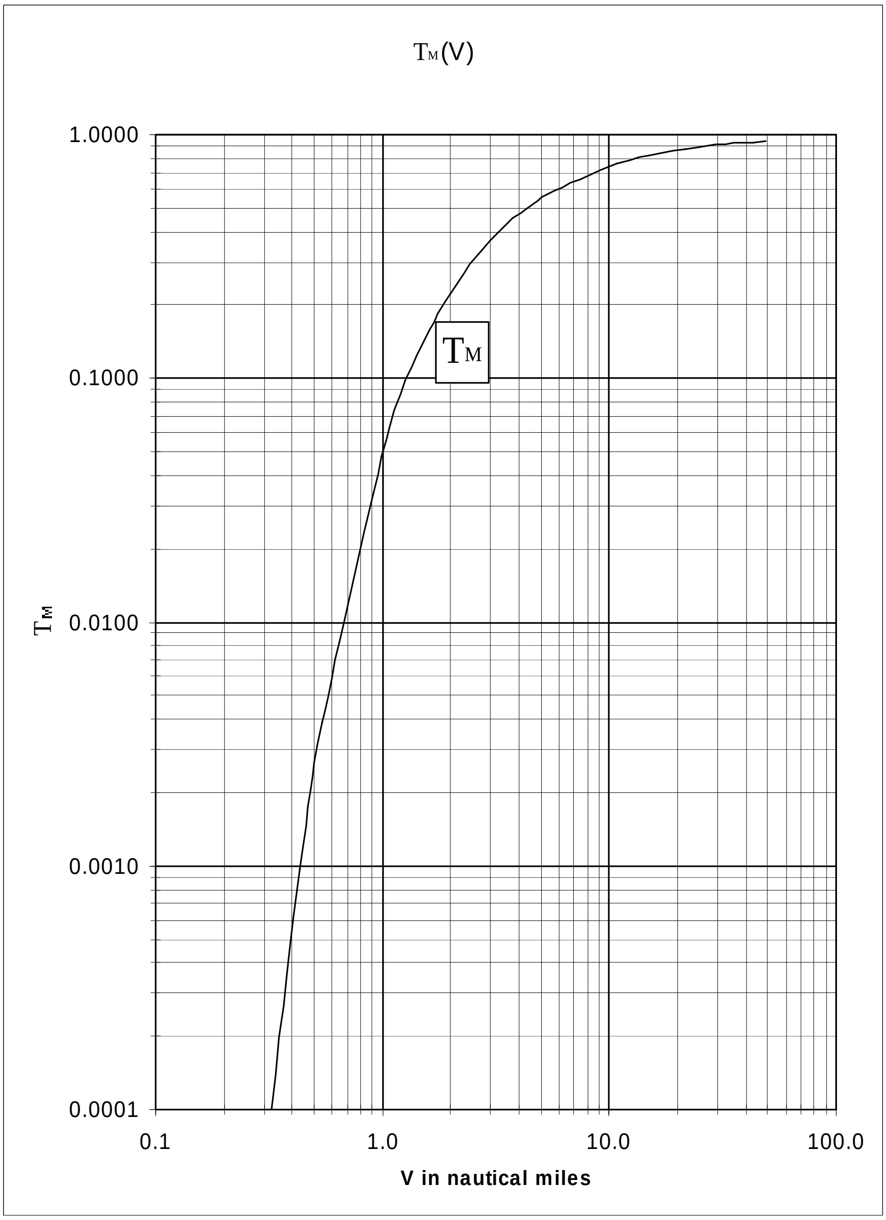
The following important factors should be taken into account when selecting marine AtoN signal lights for installation:

- The prevailing visibility conditions will vary over different geographical locations. Therefore, when selecting a light, this should be taken into account. Selection should be based on a practical luminous range value and not on nominal range;
- the required range may vary over the zone of utilization of the light;
- different levels of background luminance leading to different values of the required illuminance values;

As a result, a different luminous intensity may be required to achieve the required range.

Appendix 2
Diagrams and Tables

A2.1 Meteorological Visibility and Transmissivity



$$V = \frac{\ln 0.05}{\ln T_M} * d_U = -\frac{3\ M}{\ln T_M}$$

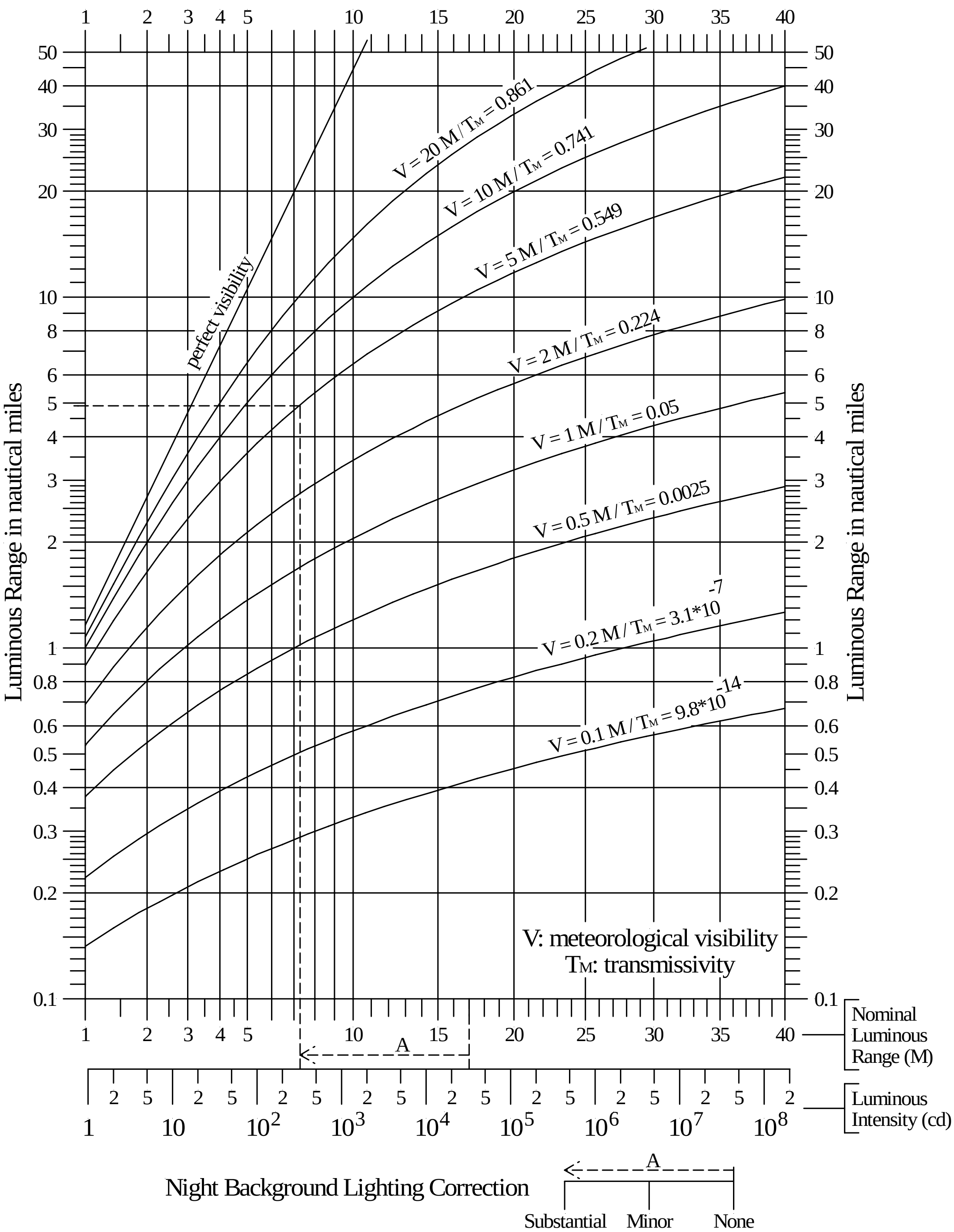
$$T_M = 0.05^{\frac{d_U}{V}} = 0.05^{\frac{1M}{V}}$$

A2.2 Luminous range for night time

A2.2.1 Diagram Luminous Range

Required illuminance $\boxed{\mathbf{E_r = 2\times10^{-7}\ lx}}$

$I = 0.686\ D^2\ (0.05)^{-D/V}$ where I is in candela, and D & V are numerical values in M



A2.2.2 Table (nightime)

Table to be used to determine the nominal range
rounded off to the nearest nautical mile

Luminous intensity	Nominal range (rounded)	Luminous intensity	Nominal range (rounded)	Luminous intensity	Nominal range (rounded)
candelas	nautical miles	kilocandelas (10^3 cd)	nautical miles	Megacandelas (10^6 cd)	nautical miles
1 - 2	1	0.633 – 1.06	9	0.927 – 1.35	26
3 - 9	2	1.07 – 1.75	10	1.36 – 1.96	27
10 - 23	3	1.76 – 2.84	11	1.97 – 2.84	28
24 - 53	4	2.85 – 4.53	12	2.85 – 4.11	29
54 - 107	5	4.54 – 7.13	13	4.12 – 5.93	30
108 - 203	6	7.14 – 11.1	14	5.94 – 8.53	31
204 - 364	7	11.2 – 17.1	15	8.54 – 12.2	32
365 - 632	8	17.2 – 26.1	16	12.3 – 17.5	33
		26.2 - 39.7	17	17.6 – 25.1	34
		39.8 – 59.9	18	25.2 – 35.9	35
		60.0 – 89.8	19	36.0 – 51.2	36
		89.9 - 133	20	51.3 – 72.9	37
		134 -198	21	73.0 - 103	38
		199 - 293	22	104 -147	39
		294 - 432	23	148 - 209	40
		433 - 634	24		
		635 - 926	25		

Required illuminance $\boxed{\mathbf{E_r = 2 \times 10^{-7}\ lx}}$

A2.2.3 Compensation for Background Lighting (night time)

The illuminance of 2×10^{-7} lx corresponds to a situation with no background lighting. In most real situations the lights are viewed against a background that does have lights. This will reduce the luminous range.

The recommended method for compensating for background lighting is to use different values for the required illuminance.
Two different values should be used:

minor background lighting:	2×10^{-6} lx	factor 10 ×
considerable background lighting:	2×10^{-5} lx	factor 100 ×

According to equation 12 of the recommendation, background lighting will increase the required intensity by the factor above when the luminous range is fixed.

Regarding a light with a fixed intensity the consideration of background lighting will reduce the luminous range.
The graph in A2.2.1 has been drawn for an illuminance of 2×10^{-7} lx. For the other values (minor and substantial background lighting) mark off along the scale of abscissae the distance between 'No Background lighting (NONE)' and that under consideration as it appears on the auxiliary scale.

Example:

Suppose that it is required to find the luminous range of a light with a nominal luminous range of 17 M and a luminous intensity of 32,300 cd for substantial background lighting and a visibility of 5 M.

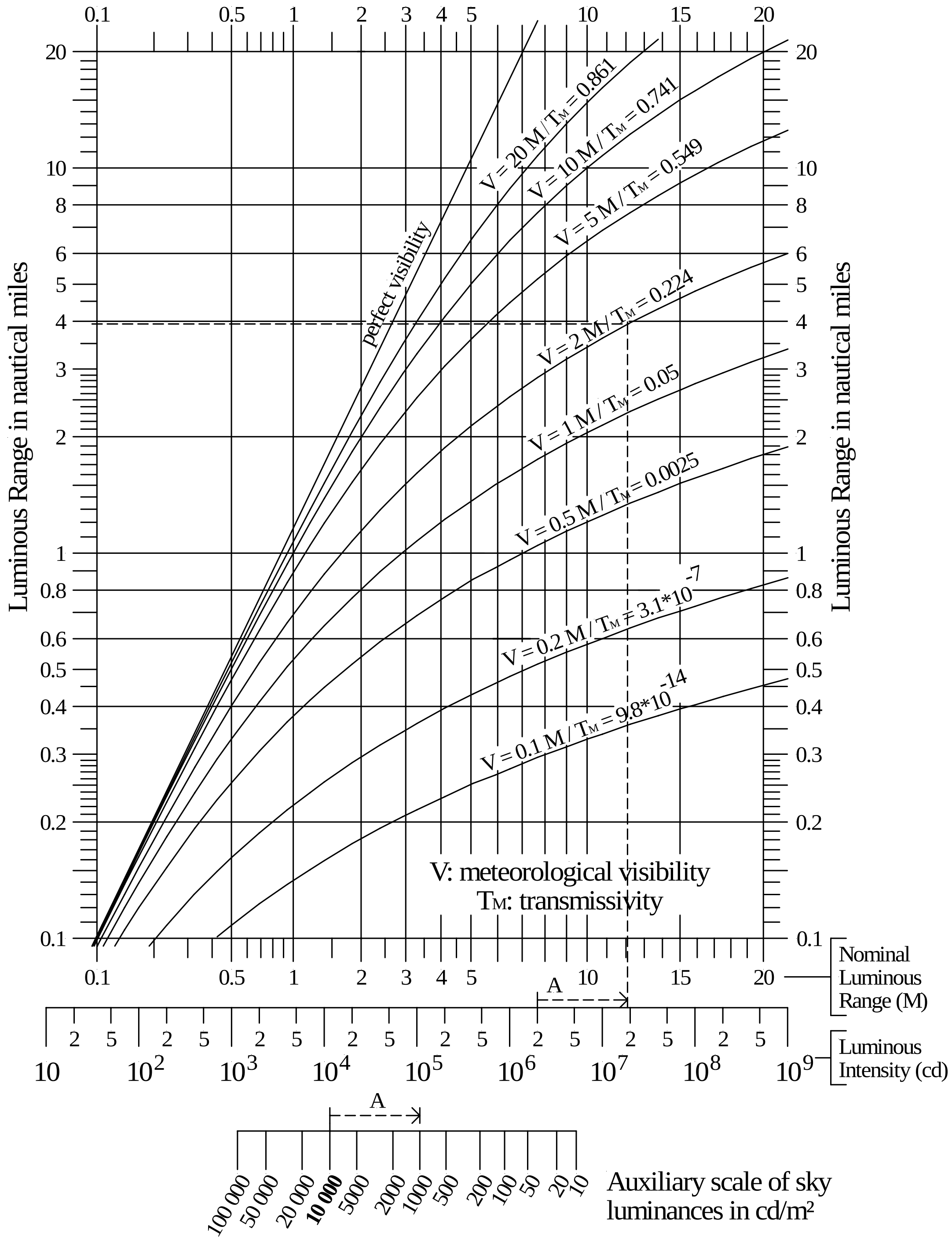
Measure the distance A separating 'no background lighting (NONE)' and 'substantial background lighting (SUBSTANTIAL)'. Transfer this distance to the scale of abscissae from graduation to 17 M (32,300 cd) in the same sense. A point slightly to the right of graduation corresponding to 7 nautical miles is obtained. Erect from this point a parallel to the axis of ordinates to meet the curve for 5 nautical miles visibilty. Read off the luminous range on the vertical scale against the point so obtained. We read approx. 5 nautical miles.

A2.3 Luminous range for daytime

A2.3.1 Diagram Luminous Range

Required illuminance $\boxed{\mathbf{E_r = 1 \times 10^{-3}\ lx}}$

$I = 3430\ D^2\ (0.05)^{-D/V}$ where I is in candela, and D & V are numerical values in M



A2.3.2 Explanation of daytime diagram

Calculation of the required illuminance at day

$$E_r = (0.242 \times 10^{-6}\ \text{lx}) \times \left(1 + \sqrt{0.4 \times L/(\text{cd}/\text{m}^2)}\right)^2$$

E_r : required illuminance

L : luminance of sky in the direction of observation

Meteorological condition	Luminance L in cd/m²	Illuminance E_r in 10^{-3} lx
Very dark overcast sky	100	0.013
Dark overcast sky	200	0.024
Ordinary overcast sky	1 000	0.107
Bright overcast sky or clear sky away from the direction of the sun	5 000	0.506
Bright cloud or clear sky close to the direction of the sun	10 000	1
Very bright cloud	20 000	1.98
Glaring cloud	50 000	4.91

Use of the graph (A2.3.1):

The graph has been drawn for a sky luminance of 10 000 cd/m². For other values of sky luminance mark off along the scale of abscissae the distance between the luminance of 10 000 cd/m² and that under consideration as it appears on the auxilliary scale.

Example:

Suppose that it is required to calculate the luminous range of a light of 2 000 000 cd for a meteorological visibility of 2 nautical miles under an ordinary overcast sky (luminance 1 000 cd/m²).

Measure the distance A separating graduations 10 000 cd and 1 000 cd on the auxiliary scale. Transfer this distance to the scale of abscissae from graduation corresponding to 2 000 000 cd (2×10^6 cd) in the same sense. A point slightly to the right of graduation corresponding to 12 nautical miles is obtained. Erect from this point a parallel to the axis of ordinates to meet the curve for 2 nautical miles visibility. Read off the luminous range on the vertical scale against the point so obtained. We read approx. 4 nautical miles.

A2.3.3 Table (daytime)

Table to be used to determine the nominal range
rounded off to the nearest nautical mile

Luminous intensity	Nominal range (rounded)	Luminous intensity	Nominal range (rounded)
kilocandelas (10^3 cd)	nautical miles	Megacandelas (10^6 cd)	nautical miles
1 – 12.0	1	1.02 – 1.82	7
12.1 – 45.3	2	1.83 – 3.16	8
45.4 – 119	3	3.17 – 5.32	9
120 – 267	4	5.33 – 8.78	10
268 – 538	5	8.79 – 14.2	11
539 – 1010	6	14.3 – 22.6	12
		22.7 – 35.6	13
		35.7 – 55.5	14
		55.6 – 85.6	15
		85.7 – 130	16
		131 – 198	17
		199 – 299	18
		300 – 449	19
		450 – 669	20
		670 – 993	21
		994 – 1460	22

Required illuminance $\boxed{\mathbf{E_r = 1 \times 10^{-3} lx}}$

References

[1] Recommendation for the notation of luminous intensity and range of lights.
(IALA, November 1966)

[2] International Dictionary of Aids to Marine Navigation, Chapter 2, Visual Aids 2-1-265 to 2-1-285
(IALA 1970)

[3] Recommendation for a definition of the nominal daytime range of marine signal lights intended for the guidance of shipping by day
(IALA 1974)

[4] Recommendations on the determination of the luminous intensity of a marine aid-to-navigation light
(IALA 1977)

[5] Recommendation for leading lights
(IALA, E-112, May 1998)

[6] Recommendation on the photometry of marine aids to navigation Signal lights
(IALA, E-122, June 2001)

AISM Association of Internationale de Signalisation Maritime IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

DRAFT

IALA Recommendation E-200-3

On

Marine Signal Lights

Part 3 - Measurement

Edition 0.32

February 2008

20ter, rue Schnapper, 78100
Saint Germain en Laye, France
Telephone +33 1 34 51 70 01 Telefax +33 1 34 51 82 05

Recommendation on Marine Signal Lights

Part 3 - Measurement

(Recommendation E-200-3)

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…;

RECOGNISING ALSO that …;

RECOGNISING FURTHER that …..;

NOTING the …;

NOTING ALSO that;

NOTING FURTHER that;

CONSIDERING that to be reviewed by Secretariat - for example.

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

RECOMMENDS that National Members and other appropriate Authorities providing marine aids to navigation services [action to be taken].

* * *

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
22.01.08	• changes highlighted in yellow • 4.20 Spectral Correction removed • annex on spectroradiometric measurement inserted • reformatted • discussion items in purple highlight	Review and preparation for meeting in Koblenz
08.02.09	Draft Edition 0.3	Changes after discussions in Koblenz meeting
26.02.2008	Draft Edition 0.32	Amended to include input from Frank Hermann and updated after review at Koblenz. Note: Example Test Report requires updating.

Table of Contents

Index of Figures

IALA Recommendation E-200-3
Marine Signal Lights
Part 3 – Measurement

Annex 1 – Measurement (no body of part 3 – only annexes?)

Kommentar [i1]: Page: 7
Up for discussion - the recommendation states, "in the annex of this recommendation". We could change this to "annexes"???

1 Introduction

This document is one of several parts dealing with aid-to-navigation signal lights and concerns their measurement, both photometric and colorimetric. Before bringing into service a new type of aid-to-navigation light, at least one equipment of each type shall be subjected to appropriate photometric and colorimetric measurements. These measurements shall provide information on the luminous intensity and colour of the light for substantially all directions within its zone of utilization. Measurements on flashing lights shall provide information on the variations of luminous intensity with time. The collated information from all measurements shall be used to assign the following for the equipment when deployed as an AtoN signal light:

rhythmic character (as described in E-110);

colour (as described in E-200-1);

nominal luminous range (as described in E-200-2).

effective intensity (as described in E-200-4).

Manufacturers of marine signal lights may use the results of such measurements to provide a specification of product performance. Measurements may be carried out on equipment already in service to ensure continued quality of performance, both to the AtoN provider and the mariner.

In each country, the competent technical authority shall determine the appropriate measurements to be made for each type of aid-to-navigation light. Photometric and colorimetric methods shall be determined by the laboratory to which the task is assigned but, as an indication of the general principles to be followed, reference should be made to this document.

If possible, the photometric measurements should be made on a complete aid-to-navigation light as installed, including protective housing enclosing the optical system. To this end, measurements "in situ" may be desirable. Measurements may also be made at suitable test sites, on a complete equipment, or on a source-optic combination without protective housing, and possibly also without colour filters intended for use in service. Such measurements, after correction for the effects of protective housing and of colour filters (where used), shall be applied to the actual equipment intended for subsequent installation, or to a light consisting of an identical source and operated under identical conditions to those of the aid-to-navigation light in question. The deduced effective intensity and luminous range may be taken as those of the installed aid.

The measurement of light is a complex subject and there is a danger that uninformed practitioners could achieve measurement results containing large errors of which they are unaware. Even when such errors are corrected or accounted for, the measurement result may still have a measurement uncertainty of several percent and in some cases tens of percent. Sometimes, such high uncertainties are unavoidable.

However, whatever measurement method is used, and whatever errors and uncertainties attained, it is important to properly evaluate them. The best way of doing this is by the use of an uncertainty budget. Properly used, this budget can be used, not only to determine uncertainty, but also to refine the measurement method by addressing dominant uncertainties. It should be remembered that no measurement result is complete without a statement of uncertainty and confidence.

2 Scope

This recommendation applies to the photometric measurement and characterisation of all marine aids-to-navigation signal lights. In general, the emissions provided by these signal lights may be categorized as “pencil beams” or “fan” beams.

Equipments used to generate pencil beams include searchlight-style or projector beacons, with single or multiple optics, and assemblies of “bulls-eye” lenses rotating about a common focal point. The peak fixed intensities provided by these beacons range from a few thousand to several million candelas, with beam spreads (as measured between the 50% intensity points) typically less than ten degrees in any cross section. Searchlight-style beacons may be fixed in position, to provide a *leading light* for marking a navigational channel, or may be rotated about a vertical axis to sweep the horizon and provide the appearance of a flashed light when viewed from a distance.

Anamorphic cylindrical lenses are typically used to generate fan beams. These lenses are usually made from Fresnel sections and can be drum or ‘beehive’ in shape. Such optics may be used to produce a uniform light signal about the horizontal plane (an omnidirectional signal). The signal may be blanked or coloured in one or more sections around the horizon, or may exhibit one or more areas of increased intensity by the use of condensing panels. The peak fixed intensities provided by these beacons range from a few tens of candelas to tens of thousands of candelas.

Light sources used in marine aids-to-navigation signal lights are typically incandescent lamps or discharge lamps. Light emitting diodes (LEDs) are increasingly being used, while acetylene open flame or gas-mantle light sources are becoming increasingly rare.

3 Objective

The objective of this recommendation is to provide an approved methodology to promote uniformity in determining and reporting the optical performance of a diverse group of marine aids-to-navigation signal lights. Marine aids-to-navigation signal lights encompass projection-type equipment, using various light sources, lenses and mirrors, singly or in combination, and Fresnel-type drum lenses.

4 Definitions

The definitions in this section are not all encompassing. More complete and further definitions can be found in relevant CIE Publications [5], [6], [10], [14], [16], [17], [18], [19], [21], [24], [26], [27], [30], [31], [32], [33], [34], [35] and [36].

4.1 Photometry

Photometry is the measurement of electromagnetic radiation detectable by the human eye (visible light). The units of photometry can be derived from radiometric quantities (e.g. Watts) weighted by the luminous efficiency function of the human observer. The wavelength range of the spectrum concerned is typically taken between 380nm and 780nm.

The word **photometry** is derived from Greek: *phōtos* = light and *metron* = measure. It is the measurement of the visual aspect of radiant energy (visible light). As such, it is distinguished from radiometry in that photometry takes into account the varying sensitivity of the eye to different wavelengths of light. The units of photometry are luminous quantities that include luminous intensity, luminous flux, luminance and illuminance (see Definitions).

Wavelengths of light energy that can cause human visual sensation are typically from 380nm to 780nm. Wavelengths outside this range do very little to stimulate the human eye.

The eye itself, although a very sensitive and versatile receptor, is not a reliable indicator of luminous quantity. Therefore, in order to quantify the visible light seen by a human observer, it is necessary to carry out some form of measurement. This can be done by replacing the human observer with an instrument called a photometer (see 7.1). Although the spectral response of a photometer mimics that of the eye, it is colour-blind. So a photometer can quantify the amount of visible light but cannot indicate its colour.

4.2 Colorimetry

Colorimetry is the science of measuring colours. This could be the colour of a light source or the colour of a surface (e.g. red paint). The colorimetry of surface colours depends upon the illuminating light source, its angle of incidence, the viewing angle, surface texture and other variables. Only colours of light sources are dealt with in this document.

The word **colorimetry** is derived from Latin: *color* = colour and Greek: *metron* = measure. It is the science of measuring colour. There are broadly two types of colorimetry, the measurement of surface colours, such as painted metal, that are illuminated by incident light; and the measurement of light emitting objects, such as lamps.

The main focus of surface colorimetry has been the development of methods for predicting visual colour matching on the basis of physical measurements. The colorimetry of surface colours is not covered by this document.

The colorimetry of light sources is usually confined to describing colours as a series of numbers, typically as chromaticity coordinates giving the location of a point within a model of two-dimensional colour space (see 6.5). The resultant colour coordinates describe a colour, but not how bright the light is.

4.3 Luminous Flux (lumen)

Luminous flux is photometrically weighted radiant flux (power).

At a frequency of 540 x 10^{12} Hertz, it is defined as 1 lm/683 watts of radiant flux.

If a uniform point light source of one candela luminous intensity is positioned at the centre of a sphere of one metre radius, then every area of one square metre on the inside of that sphere will receive a luminous flux of one lumen (1 lm).

Since the surface area of a full sphere is 4π times the square of the radius, a uniform point light source of 1 cd therefore produces a **total** 12.57 lm of luminous flux. This **Total Luminous Flux** figure is often quoted by lamp manufacturers in their specifications. However, it should be remembered that most light sources are not uniform in their spatial distribution of light.

Standard unit of luminous flux is **Lumen (lm).**

4.4 Solid Angle (steradian)

A **solid angle** is the angle that, seen from the centre of a sphere, includes a given area on the surface of that sphere. The value of the solid angle is numerically equal to the size of that area divided by the square of the radius of the sphere. For example, in a sphere of one metre radius, a solid angle will describe an area of one square metre on the sphere's surface.

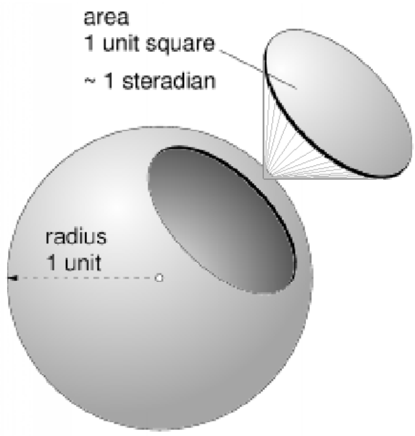


Figure 1 Solid Angle Geometry

Using the example of one candela at one metre distant, imagine a sphere of one metre radius with a point source of one candela at its centre. The illuminated surface area of the sphere over a solid angle of one steradian is one square metre. The luminous flux within that solid angle is one lumen. The illuminance incident on that surface is one lumen per metre squared or one lux.

4.5 Luminous Intensity (candela)

The **luminous intensity** is the luminous flux emitted from a point per unit solid angle into a particular direction.

Luminous intensity is the base unit for photometry and is defined as follows:

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 1012 hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. [32]

Standard unit of luminous intensity is **candela (cd)**,
also expressed as *lumen* per *steradian* (lm/sr)

4.5.1 Angular luminous intensity distribution

The **angular luminous intensity distribution** is a function of the intensity depending on the direction. In general the direction is described by two angles (e.g. Θ and Φ). The intensity distribution becomes $I = I(\Theta, \Phi)$.

For many applications the intensity is restricted to a plane. The intensity distribution is then a function of one angle only $I = I(\Phi)$.

Maximum, average and 10th Percentile intensities can be read from an angular intensity distribution, as well as beam divergence angles.

4.5.2 Time dependent luminous intensity distribution

If the intensity I in a certain direction varies with time t the function I(t) is called **time dependent luminous intensity distribution**.

Peak Intensity, integrated intensity and effective intensity can be read or calculated from a time dependent intensity distribution.

4.5.3 Continuous Intensity (I_{cont})

The intensity of a continuously burning light.

4.5.4 Fixed Intensity

Same as 4.5.3

4.5.5 Maximum Intensity (I_{max})

The maximum intensity in any given angular plot.

4.5.6 Peak Intensity (I_o)

The maximum value of instantaneous intensity reached within the time duration of a flash of light.

4.5.7 10th Percentile Intensity

The intensity exceeded by 90% of all intensity measurements within a given plot. The 10^{th} percentile line is that which divides the lowest 10% and the highest 90% in any given population.

The 10th percentile intensity is used to describe the horizontal intensity distribution of an omnidirectional horizontal light (fan beam).

4.5.8 Integrated Intensity (I_{int})

This is the integral of instantaneous intensity with respect to time within a flash of light. With units of candela.seconds, this relates to a photometric quantity of energy:

$$I_{\text{int}} = \int I(t)dt$$

Equation 1

4.5.9 Effective Intensity (I_e)

This is the intensity of a continuous light that gives the equivalent perception as that of a flash of light when viewed at the achromatic threshold of visual detection.

4.6 Luminance (L)

note: Photometric brightness is a deprecated term for luminance.

Luminous intensity per unit projected area of any surface, as measured from a specific direction. It is the physical measure of brightness.

Luminance (usually 'L' in formulas) is the amount of visible light leaving a point on a surface in a given direction. This "surface" can be a physical surface or an imaginary plane, and the light leaving the surface can be due to reflection, transmission, and/or emission

Standard unit of luminance is **candela per square meter (cd/m^2)**.
(also called **Nits** in the USA, from Latin "nitere" = "to shine").

There are several older units of luminance:

Apostilb (deprecated)	1 asb	=	1/π cd/m^2
Blondel (deprecated)	1 blondel	=	1/π cd/m^2
Candela per square foot	1 cd/ft^2	=	10.764 cd/m^2
Candela per square inch	1 cd/in^2	=	1550 cd/m^2
Footlambert (deprecated)	1 fL	=	3.426 cd/m^2
Lambert (deprecated)	1 L	=	10^4/π cd/m^2
Nit	1 nit	=	1 cd/m^2
Skot (deprecated)	1 skot	=	10^{-3}/π cd/m^2
Stilb (deprecated)	1 sb	=	10^4 cd/m^2

4.7 Luminous Flux Density or Illuminance (lumen/m2 or lux) [32]

note: Illumination is a deprecated term for Illuminance.

Luminous flux density is photometrically weighted radiant flux density, which means luminous flux per unit area at a point on a surface, where the surface can be real or imaginary.

Illuminance (usually 'E' in formulas) is the total amount of visible light illuminating, or incident upon, a point on a surface from all directions above the surface. This "surface" can be a physical surface or an imaginary plane. Illuminance is equivalent to *irradiance* weighted with the response curve of the human eye.

Standard unit for illuminance is **Lux (lx),** or lumens per square meter (lm/m^2).

There are several older units of illuminance:

footcandle	1 fc = 10.764 lx.
dalx (in Canadian safety regulations)	1 dalx = 10.764 lx.
phot	1 ph = 10,000 lx

A surface will receive 1 lx of illuminance from a point light source that emits 1 cd of *luminous intensity* in its direction from a distance of 1 m.
When using the non-standard US units, this translates into 1 fc received from a 1 cd source 1 ft away.

4.8 Beam Divergence

Beam Divergence (sometimes called beam spread) describes the angle between the two directions opposed to each other over the beam axis. Limits of divergence are set where the luminous intensity falls to a certain fraction of that of the maximum intensity within the beam. For aid-to-navigation beacons, horizontal and vertical divergences are usually quoted.

When used to describe the **vertical** spread of a beam, the vertical divergence is usually given two angles, upper and lower. These are given plus and minus figures respectively in accordance with measurement geometry (see 11.1.1)

It is normal practice to quote the angle between the two directions opposed to each other over the *beam axis* for which the *luminous intensity* is half that (50%) of the maximum luminous intensity (sometimes referred to as the *Beam Angle*). The angle between these 50% points is some times called full-width at half maximum—FWHM. It is recommended that FWHM is used when quoting beam divergence

Sometimes, the angle between the two directions opposed to each other over the *beam axis* for which the *luminous intensity* is one-tenth that (10%) of the maximum luminous intensity (sometimes referred to as the *Field Angle*) is quoted. The angle between these 10% points is some times called full-width at tenth maximum—FWTM. When FWTM is used instead of FWHM, it should be clearly stated.

When the luminous intensity points are other than half of maximum, the fraction or percentage of maximum should be quoted.

4.9 Flicker Fusion Frequency or Critical Flicker Frequency

This is the frequency above which the human eye perceives a flickering light source to be steady. Humans have a flicker fusion frequency of only 60Hz in bright light and 24Hz in low light.

4.10 Crossover Distance

This is the distance at which a beam of light is fully developed; where the divergent rays from the extremities of the optical aperture meet (see figure 19). At this distance, the image of the light source will fully fill the aperture of the optical apparatus.

4.11 Minimum Photometric Distance

The minimum photometric distance is the minimum distance between the beacon and the photoreceptor needed to ensure a certain accuracy for the measurement.

The minimum photometric distance depends on the required accuracy, the beacon and the photometer. In many cases an exact definition cannot be stated.

In some cases the crossover distance can be used as the minimum photometric distance (see 9.8).

4.12 RMS

The root mean square or rms is a statistical measure of the magnitude of a varying quantity. It can be calculated for a series of discrete values f_i or for a continuously varying function f(t). The name comes from the fact that it is the square root of the mean of the squares of the values.

When f(t) is a function of time then the root mean square for a time interval $[t_1, t_2]$ is

$$RMS = \sqrt{\frac{1}{(t_2 - t_1)} \times \int_{t_1}^{t_2} f^2(t)\, dt}$$

Equation 2

When f(t) is a discrete function f_i for equally spaced times t_i = i*)t then the integral can be replaced by a sum

$$RMS = \sqrt{\frac{1}{N} \times \sum_{i=0\ to\ N} f_i^2}$$

Equation 3

where N *)t = t_2 - t_1

It is recommended to use the RMS-value for electrical voltage, current and power, when a beacon has AC power supply.

4.13 Goniometer, Goniophotometer [19]

A goniometer is an instrument used for measuring geometric angles. When such an instrument is combined with a photometer to measure luminous intensity against a geometric angle, the device is called a *goniophotometer*. The practice of measuring luminous values with reference to geometric angle is called *goniophotometry*.

4.14 Chromaticity [24]

Chromaticity is the aspect of colour that includes consideration of its dominant or complementary wavelength and purity taken together. It is usually quantified by plotting a point, given as two coordinates, in a two-dimensional colour model space. An example is a chromaticity chart or diagram (see 6.5).

4.15 Spectral Distribution [14]

Spectral distribution is the way in which the relative radiometric value of electromagnetic radiation varies with wavelength.

4.16 Spectral Power Distribution [14]

A spectral power distribution (SPD) curve shows the radiant power emitted by a light source at each wavelength or band of wavelengths over the electromagnetic spectrum. For colorimetry and photometry the limits of the spectrum are typically 380 to 780 nm (visible light). The SPD may be weighted by $\bar{x}$, $\bar{y}$ and $\bar{z}$ colour functions to obtain tristimulus (X, Y and Z) colour values (see 6.4). The resultant X, Y, Z values can be further reduced to two x, y values and used as coordinates on a two-dimensional colour chart, or they may be weighted by the $V(\lambda)$ function to obtain a photometric value of luminous flux or luminous intensity.

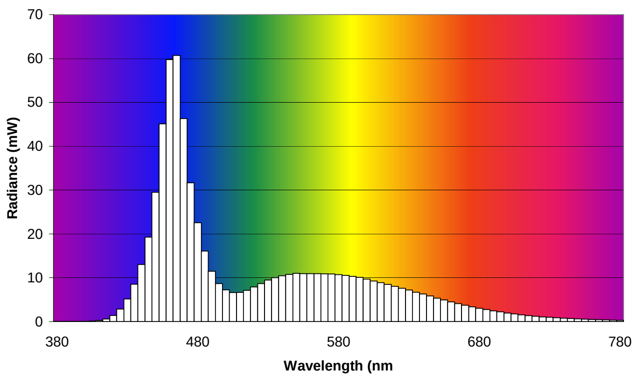


Figure 2 Spectral Power Distribution of White LED (5nm intervals)

4.17 Hue

The property of a colour by which it can be perceived as determined by the dominant wavelength of the light.

4.18 Colour Saturation

This is defined as chromatic purity, freedom from whiteness hence vividness of colour. A saturated colour will have a narrow spectral distribution and its chromaticity coordinate will lie close to the spectral locus of the chromaticity diagram (see 6.5).

4.19 Chroma

Short for "chrominance", it describes the attributes of a colour, which include its hue (wavelength) and saturation (lack of whiteness).

4.20 Slew Rate

The term is used to define the maximum rate of change of an amplifier's output voltage with respect to its input voltage. In essence, slew rate is a measure of an amplifier's ability to faithfully follow its input signal. Typically quoted as the time it takes the amplifier output to rise from 10% to 90% of its maximum output amplitude.

When considering the amplifier used in conjunction with a photometric detector, the ability of the amplifier to faithfully reproduce variations in intensity is important. Therefore, when measuring flashing lights where the instantaneous intensity varies quickly with time, the slew rate of the amplifier should be faster than the rise-time or fall-time of the flash profile.

Slew rate can be relevant for goniometers when intensity measurements are carried out whilst the goniometer is moving. It relates to the time interval between the angular steps, in other words, how long it takes the goniometer to move from one angular position to the next. The relationship between the time taken to carry out an intensity measurement and the speed of rotation of the goniometer can give an angular error.

Kommentar [i2]: Page: 16
Frank, is this OK?? Ian

4.21 Spectral Mismatch Errors and Correction [6]

Errors may occur when measuring a light source of different spectral distribution to the one used to calibrate the photometer because of differences between the spectral response of the photometer and the response of the standard photometric observer *V(λ)*. Such errors are called ‘spectral mismatch errors’ and can be quite large at certain wavelengths, typically in the red and blue regions where the photometer is least sensitive. Light sources with a narrow spectral distribution (e.g. coloured LED’s) are more likely to produce large errors than broad-spectrum white light sources.

Spectral mismatch correction is an adjustment, carried out on the results of a photometric measurement, to correct any errors in the photometer spectral response.

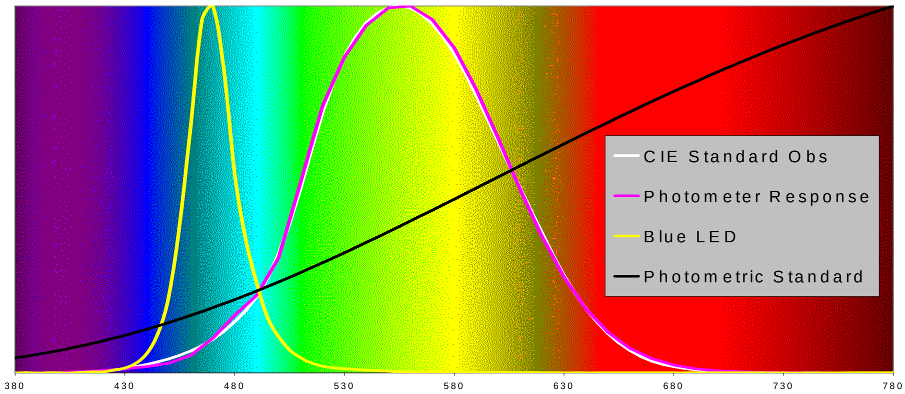


Figure 3 Spectral Plot showing Differences between Typical Photometer Response and *V(λ)* -Example

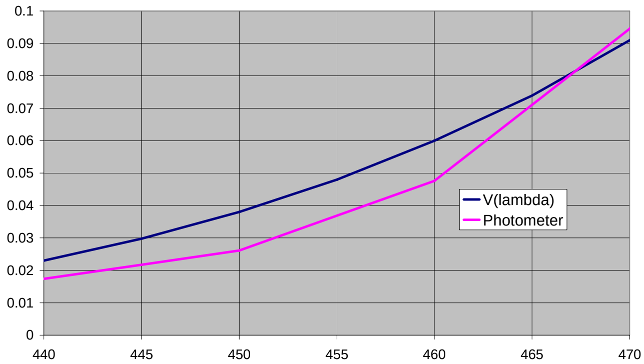


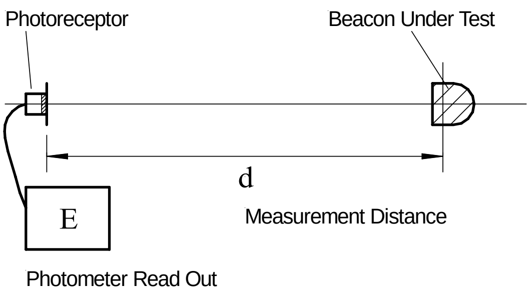
Figure 4 Expanded Section of Spectrum Highlighting Photometric Error in figure 3 - Example

5 Measurement Principles

5.1 Photometric Distance Law

The measurement of luminous intensity is carried out by measuring the illuminance produced by a beacon a distance d apart.

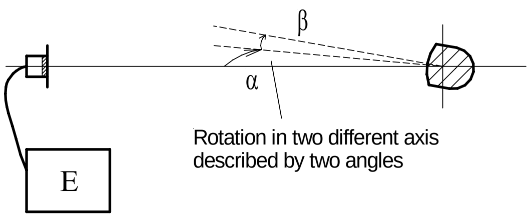
The luminous intensity is calculated by the Photometric Distance Law $I = d^2 E$.



The arrangement above can be modified by introducing a folding mirror or by using Zero-Length Photometry (see Annex 2).

5.2 Measurement of Angular Luminous Intensity Distribution

For signal lights the measurement of angular distributions can be carried out by rotating the beacon about two different axis. The intensity is a function of two angles $I = I(\alpha,\beta)$.



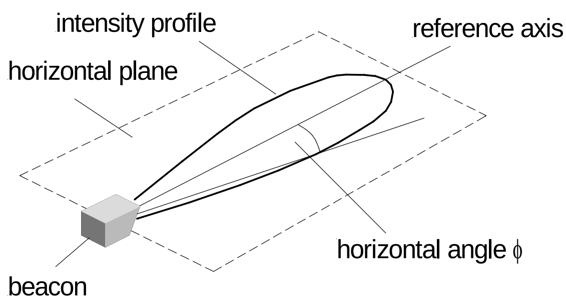
5.3 Recommended Measuring Planes

The measurement of the intensity distribution is often reduced to a number of planes. Within these planes the intensity distribution depends on one angle only. For Signal Lights, the recommended planes are horizontal and vertical planes.

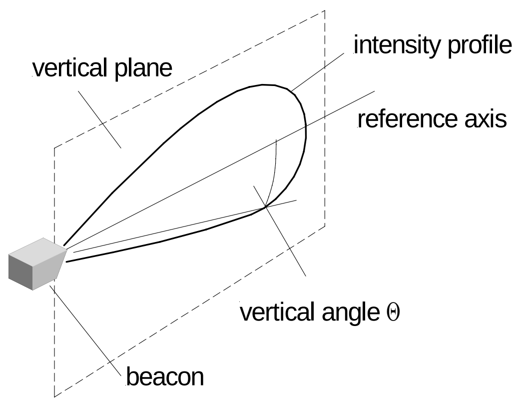
5.3.1 'Pencil beams'

The axis of the beacon should be in or near the direction with highest intensity. The horizontal and vertical planes should include the reference axis (datum). All angles should be referenced to this axis.

- Horizontal plane:



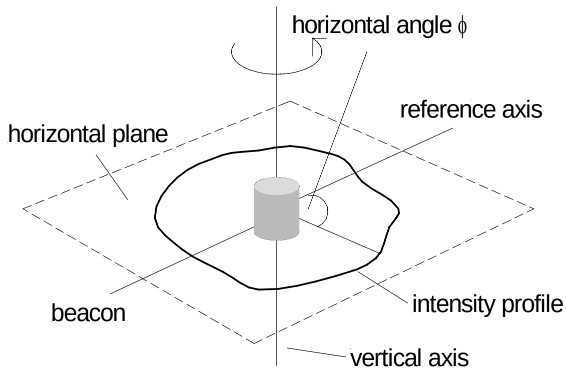
- Vertical plane:



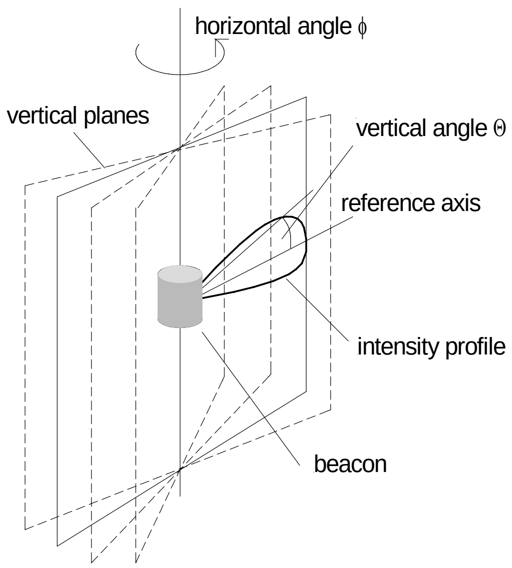
5.3.2 'Fan Beams'

- Horizontal plane:

In the horizontal plane a reference axis (datum) has to be defined. The selection of this axis is arbitrary because there is no preferred direction for the intensity. All angles are referenced to the axis defined.



- Vertical plane



It is recommended to use more than one vertical plane. Each vertical plane is named by its horizontal angle from the horizontal reference axis.

For omnidirectional lights with one colour only, at least three planes should be measured (e.g. with horizontal angle ϕ = -120°, ϕ = 0°, ϕ = +120°).

For lights with coloured sectors measurements should be taken in at least one vertical plane per sector.

5.4 Colorimetry [24]

The colour of a signal light is described by chromaticity coordinates in accordance with CIE 1931 Standard Colorimetric Observer.

There are two main methods for the determination of chromaticity coordinates.

5.4.1 Tristimulus measurement

The light is passed through 3 different optical filters. Behind each filter a receptor measures the amount of light. Three different values are obtained. From these values the chromaticity coordinates can be calculated.

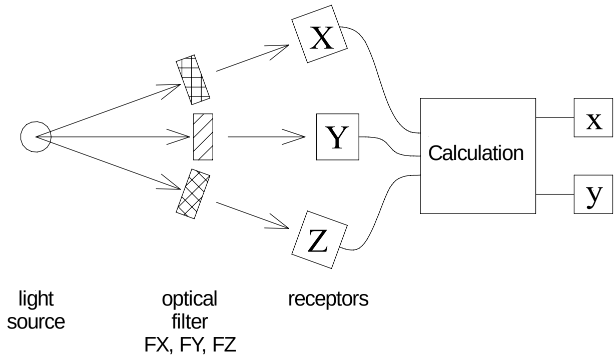


Figure 5 Tristimulus Principle

5.4.2 Spectral measurement

The light is split into different wavelengths. The amount of light for each wavelength or wavelength interval is measured by a receptor. The spectral values are used to calculate the chromaticity coordinates. If the splitting device is rotated the measurement can be done with a single receptor. The spectral values then are produced in temporal steps.

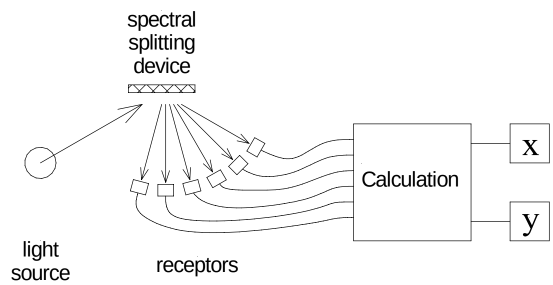


Figure 6 Spectral measurement

6 Models and Functions

6.1 Photopic Luminous Efficiency Function of the Standard Observer *V(λ)* [16]

This is the spectral response of the average human eye in bright light using foveal vision (i.e. looking directly at an object). Developed by CIE in 1924 [5][16], it is sometimes called the CIE 2° standard photometric observer. It has a roughly Gaussian distribution with a peak wavelength of 555nm.

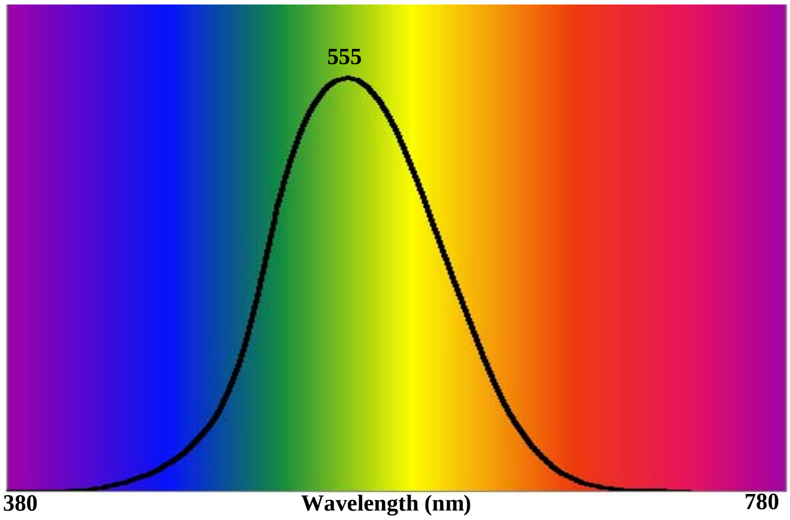


Figure 7 Photopic Luminous Efficiency Function *V(λ)*

Kommentar [I3]: Page: 22
Insert wavelength values on X axis

It should be noted that the *V(λ)* function should be used for the photometry of marine signal lights. If another visual scale, such as scotopic or mesopic, is used, this should be clearly stated.

6.2 Scotopic Luminous Efficiency Function *V'(λ)* [16]

This is the spectral response of the average human eye with dark-adapted vision (below a luminance value of 0.034 lm/m^2). *V'(λ)* has a similarly shaped response to *V(λ)* but is shifted towards the shorter wavelengths, peaking at 505nm.

Scotopic vision means that there is no colour recognition.

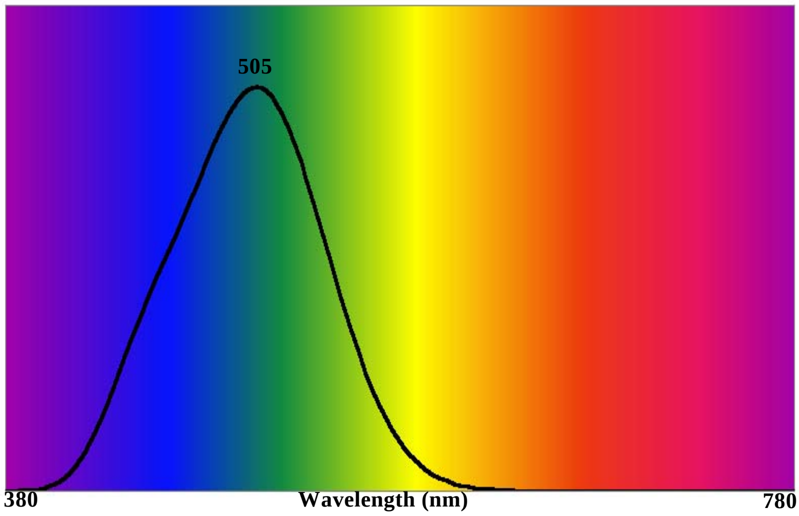


Figure 8 Scotopic Luminous Efficiency Function *V'(λ)*

6.3 Talbot-Plateau Law

The Talbot-Plateau Law states that if a light source is flashed or pulsed at a rate above the critical flicker frequency or flicker fusion frequency, such that it appears as a continuous light, the luminance of the source will be equal to that of a steady light that has the same time-average luminance [4].

When using high precision photometers, which typically have a low amplifier slew rate, to measure the continuous intensity of a light flickering or pulsing above the flicker fusion frequency, the Talbot-Plateau Law should be obeyed.

6.4 Standard Colorimetric Observer [30]

In 1931, the CIE developed three colour matching functions labelled $\bar{x}$, $\bar{y}$ and $\bar{z}$. These functions can be used to weight the spectral power distribution (SPD – see 4.16) of a light source in order quantify its colour.

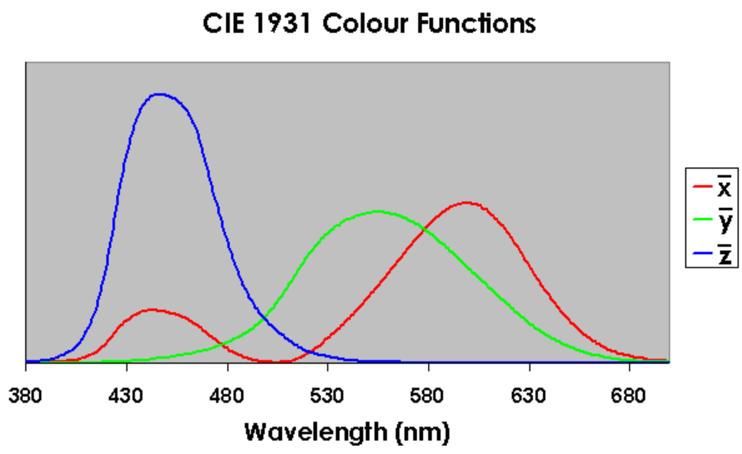


Figure 9 The CIE 1931 Standard Colour Observer

6.5 Chromaticity [24]

The resultant integrated quantities of a given SPD, when weighted by $\bar{x}$, $\bar{y}$ and $\bar{z}$, are called X, Y and Z respectively. They can be reduced to two values in order to plot the colour of the light source on a two-dimensional x, y chromaticity chart, where:

$$x = \frac{X}{X+Y+Z}$$

Equation 4

$$y = \frac{Y}{X+Y+Z}$$

Equation 5

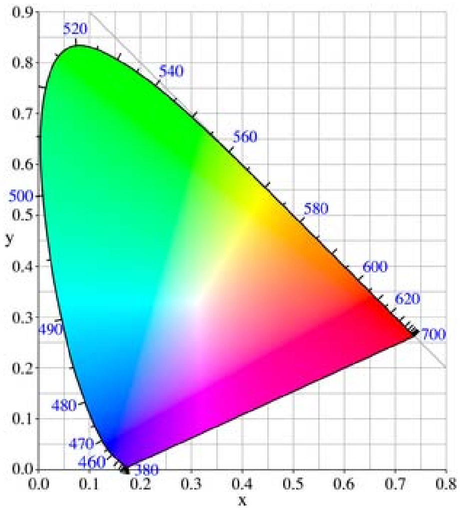


Figure 10 CIE 1931 Chromaticity Chart

The colour space is bounded by the spectral locus where monochromatic wavelengths are shown in units of nanometres (blue numbers). The CIE 1931 x, y chromaticity chart is the most commonly used for plotting the colour of light sources.

6.6 Colour Temperature and Correlated Colour Temperature [24]

The colour temperature of a traditional incandescent light source is determined by comparing its hue with a theoretical, heated black-body radiator. The lamp's colour temperature is the temperature in degrees Kelvin at which the heated black-body radiator matches the hue of the lamp.

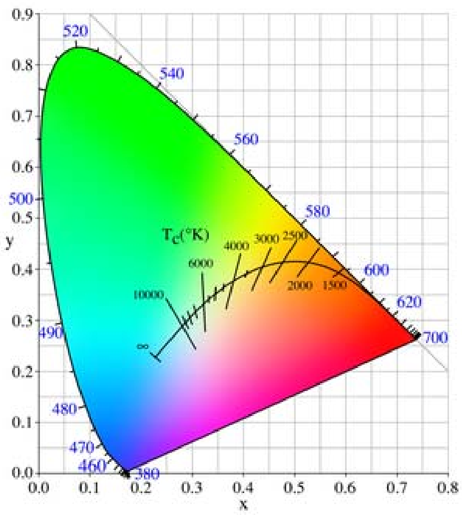


Figure 11 CIE x, y Chromaticity Diagram showing the Planckian Locus

The Planckian locus is the path that a black body colour takes through the chromaticity diagram as the black body temperature changes. Lines crossing the locus indicate lines of constant ‘correlated colour temperature’ (CCT).

6.7 CIE Illuminant A [21]

Illuminant A is often used as a reference light source to calibrate photometers. It has a spectral distribution of that of a theoretical black body at 2856ºK. A tungsten filament lamp, run under the correct conditions, has a similar spectral distribution to that of Illuminant A.

7 Measurement Equipment

7.1 Photometer

Photometry, which is the measurement of visible light, is usually carried out with a measuring instrument capable of detecting light, usually by means of a photodetector, which converts incident photons to a proportionate electrical current. The electrical output of the photodetector is amplified to provide a readout that may be calibrated in a luminous value. Such a device is called a photometer.

A photometer may be calibrated in lumens per metre squared (lux) to measure the amount of light falling onto the surface of the photodetector (illuminance). Such a device is sometimes called a luxmeter.

The luxmeter is most commonly used for measurement on signal lights to determine the luminous intensity via photometric distance law.

$$I = d^2 E$$

Equation 6

The output of a photometer may be calibrated to provide a readout in candelas using a known measurement distance and the above formula.

If the output aperture of the light-emitting device is restricted to a given area A_{emit}, the output of the photometer may be calibrated to provide a readout in candelas per metre squared (luminance). Such devices are called luminance meters and are useful for measuring the brightness of an emitting surface.

$$L = {}^{I}\!/\!_{A_{emit}}$$

Equation 7

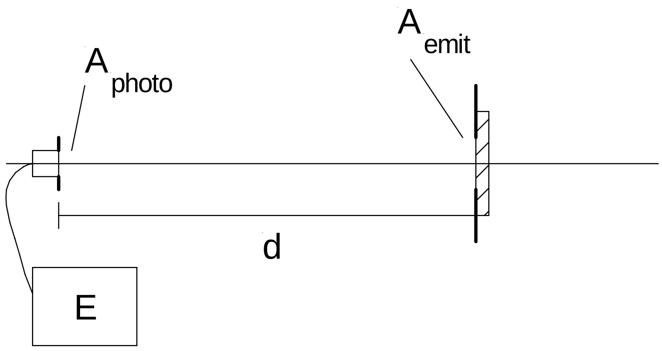


Figure 12 Measurement of Luminance

Use of a calibrated photometer is recommended. It would typically comprise a silicon photodiode, a *V(λ)*-correction filter, and a precision aperture. Use of a calibrated detector, within the limits of the rated output, may eliminate the requirement to maintain calibrated sources. The light source reference for photometer calibration should be CIE Illuminant A.

A photometer used to measure flashing lights should have a temporal response fast enough to faithfully follow the temporal intensity profile. When analogue to digital (A/D) techniques are used to plot the time profile of a flash, the temporal response or integration time of the photometer should be similar to the sampling period to ensure that no gaps occur in recorded data.

The spectral response of the photometric system should closely approximate the spectral luminous efficiency curve *V(λ)* for the CIE standard photometric observer in photopic vision (see 6.1). The calibration documentation for the photometric system should include the spectral response values of the photometric detector from 380 to 780 nm, in increments no greater than 10nm. Most photometers are calibrated using Illuminant A (see 6.7), therefore when using a photometer to measure lights with spectral distributions different to Illuminant A (e.g. coloured lights or discharge lamps) care must be taken to avoid errors due to spectral mismatch (see 9.4).

7.2 Goniometer Type 1

In the interests of commonality, a type 1 goniometer is recommended for the angular measurement of marine signal lights. With a type 1 goniometer the source is tilted about a fixed horizontal axis and also turned about an axis which, in the position of rest, is vertical, and upon rotation follows the movement of the horizontal axis. Figure 13 illustrates a typical type 1 goniometer, and the loci traced by the goniometer in relation to the photocell. The related coordinate system to be used with the type 1 goniometer is described in CIE Publication No. 121 of 1996 [19]. If a goniometer of a type other than type 1 is employed, geometric reference should be made to Figure 13.

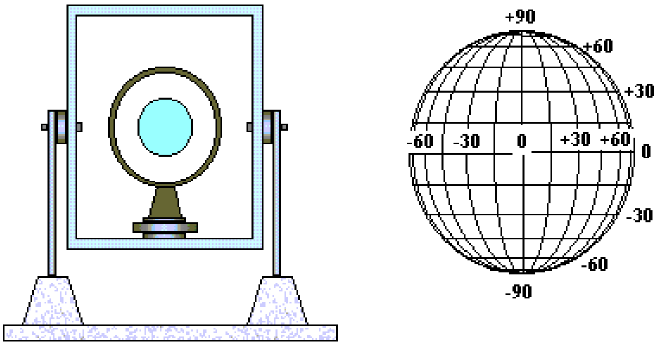


Figure 13 Type 1 Goniometer and Coordinate System.

A method of determining the uncertainty in the positioning mechanisms of the goniometer should be documented, and the stated uncertainty in angular displacement evaluated. It should be noted that when the goniometer table is tilted, the measurement distance from the top and bottom of the item under test changes and this can lead to a measurement error. This error may be corrected or treated as an additional uncertainty (see 8.14).

7.3 “Folding” Mirror

When the minimum photometric distance (see 4.11) exceeds the length of the measurement light path, a flat mirror, sufficiently large as to generate a full image of the item under test, may be placed at the end of the light path. The photometer may be used to measure the light signal reflected from the mirror.

It is recommended to use a front-surfaced mirror with a very accurate flat surface, high reflectance and flat spectral reflectance to minimize losses and geometrical distortion of the reflected image.

However the use of a mirror may result in a change to the spectral correction factor, SCF (see 9.4). Measurement of a reference source, directly and over the folded path, of similar spectral output to the item under test, may be used to determine overall losses and spectral distortion produced by the mirror. If the minimum measurement distance still exceeds the folded measurement length, measurements should be made using one of the two methods described in Annexes 2 and 3.

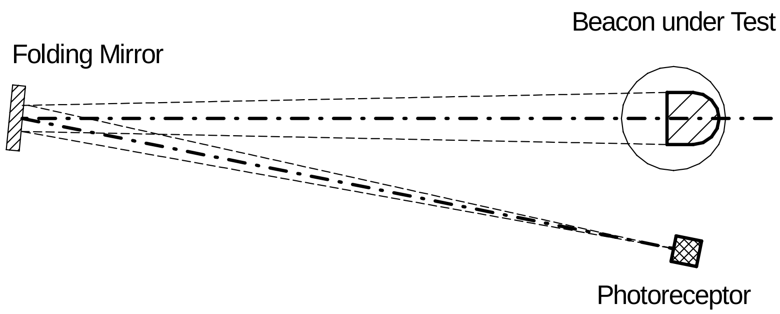


Figure 14 Folding Mirror Schematic

It is recommended that the photoreceptor be close to the beacon under test. For this the reflecting angle of the mirror is very small and the path between beacon and mirror equals approximately the path between the mirror and the photoreceptor.

Care must be taken to avoid stray light because the volume between mirror and beacon is strongly illuminated.

If the diameter of light output area of the beacon is DB and the diameter of the light input area of the photoreceptor is DP than the diameter of the folding mirror DM should be:

$$DM > \frac{1}{2}(DB + DP)$$

Equation 8

7.4 Tristimulus Colorimeter [33]

A tristimulus colorimeter may be used to measure the colour of a light source. The device consists of three photodetectors, each with a filter that approximates one of the three colour functions $\bar{x}$, $\bar{y}$ and $\bar{z}$. The three outputs are then arranged to give X, Y and Z values, or computed to give x, y chromaticity. Additionally, because the Y function is the same as *V(λ)*, the Y output may be calibrated to give a luminous value (e.g. lux). Colorimeters are sometimes combined with a luminance meter aperture, often with input optics.

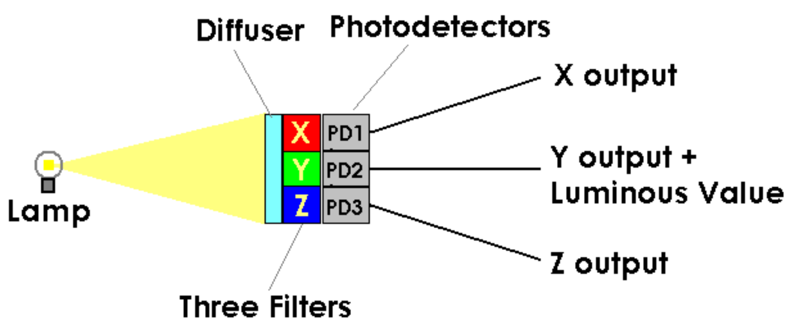


Figure 15 Schematic of a simple Tristimulus Colorimeter

Tristimulus colorimeters have the advantage that a relatively fast measurement can be made of colour. However, cheaper models may yield significant errors because the filters do not faithfully follow the colour functions. Such errors are more noticeable when measuring light sources with a narrow spectral distribution. A relative spectral calibration of the colorimeter, showing the function of each filter, may help identify errors.

A method for carrying out a colour measurement using a tristimulus colorimeter is given in Annex 4.

7.5 Monochromator [14]

A monochromator is a device that can select narrow bands of light (near-monochromatic) from a given light input. It employs an entrance slit, some means of splitting the light into component wavelengths (e.g. a diffraction grating or prism) and an exit slit. The bandwidth of the output monochromatic light is dependant on the spacing of lines in the grating together with the slit width. The diffraction grating may be rotated to select different wavelengths of light.

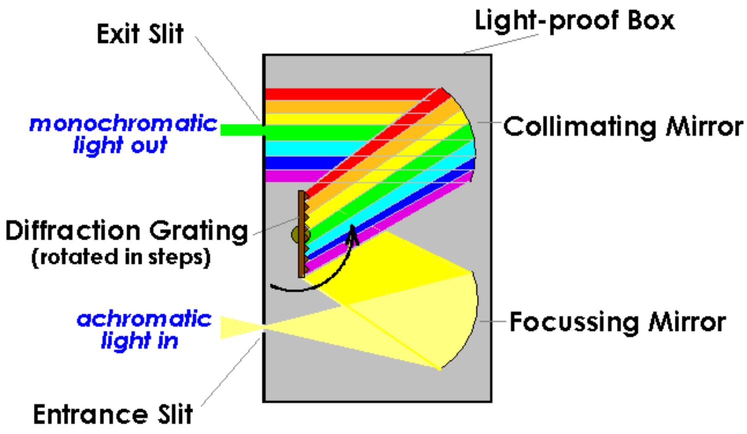


Figure 16 Schematic of Czerny-Turner Stepping Monochromator

7.6 Spectroscope, Spectrometer, Spectroradiometer

- A spectroscope is a device used to observe the spectrum.
- A spectrometer is a spectroscope equipped with the ability to measure wavelengths.
- A spectroradiometer is a device for determining the radiant-energy distribution in a spectrum.

7.6.1 Scanning or Stepping Spectroradiometer

A scanning spectroradiometer is a monochromator, such as the Czerny-Turner in figure 16, with a radiometer head (typically a photodiode or photomultiplier) coupled to the output slit. The radiometric power may then be measured for each component wavelength or waveband on the light shone into the input slit.

Typically, the diffraction grating is turned in increments and a radiometric measurement taken at each incremented step. Such devices are quite slow and may not be suitable for flashing light sources. They are however, capable of great accuracy but can be prone to mechanical instability and need frequent calibration.

7.6.2 Array-based Spectroradiometer

An array-based spectroradiometer uses a monochromator that is fixed and where the output slit is replaced by an array of charge-coupled devices (CCDs) that act as individual radiometric receptors for each waveband. CCDs record the amount of charge, which is dependent on the exposure time to the light being measured. This exposure time is commonly known as integration time, which can be varied to accommodate varying levels of light input.

7.7 Calibrated Light Sources [31]

Calibrated sources, while not required when a calibrated photometer is used, are useful for making comparative measurements [21]. The comparative method of measurement is sometimes known as 'measurement by substitution', where the item under test is substituted for the calibrated light source and measured over the same measurement path. Sources calibrated at a national standards laboratory, and traceable to the national standard, are sometimes known as 'standard lamps', 'standard reference lamps' or 'transfer standards'. Such lamps require carefully regulated power supplies and also require their voltage and current to be measured with low uncertainty. The equipment used to measure their voltage and current should also be traceable to national standards; otherwise the 'transfer standard' becomes meaningless.

Transfer standards may be calibrated for luminous intensity, colour temperature or spectral radiance or irradiance. A calibrated selective emitter, such as an LED source, may also be used as an alternative to spectral correction when the relative spectral responsivity of the photometer is not available.

Measurement by substitution is useful when the spectral transmittance of the measurement path is not linear; for instance, when measuring over a large distance, or when using adaptive optics such as a folding mirror or a collecting lens on the photometer. For scanning spectroradiometers, that can suffer considerable short-term calibration drift, it is recommended that a spectral irradiance standard reference lamp be used to calibrate the instrument before every measurement session.

8 General Laboratory Procedures

Testing facilities should establish and maintain a quality system appropriate to the type, range and volume of calibration and testing activities it undertakes. All procedures for conducting calibrations and photometric measurements should be documented as part of the quality system.

8.1 Written Procedures and Documentation

It is recommended that guidelines on laboratory equipment given in ISO 17025 be followed [20].

8.2 Test Equipment Identification

A list of all test equipment used in the measurement, including model numbers, serial numbers and calibration details, should be included in the test results and any documentation produced from those results.

8.3 Calibration and Traceability

All test equipment should be calibrated at an accredited test house and the calibration traceable to a national standard. Test equipment should be calibrated at regular intervals and, if calibrated in house, should be calibrated using equipment traceable to national standards. When a replacement calibration certificate is issued, the calibration notes should be checked for any undue variations from the previous calibration. Large changes to calibrated values may affect the uncertainty budget of prior measurements.

All items of test equipment should be uniquely identified. Details of all test equipment should be logged in a register stating manufacturer, model number and serial number. The register should also show calibration due dates for each separate item of test equipment, to ensure that calibration is maintained at correct intervals. Calibration labels, identified with the calibration certificate serial number, equipment serial number and next due date of calibration, should be firmly fixed to the test equipment by the test house upon completion of calibration. Any obsolete calibration labels should be removed from the test equipment by the test house.

8.4 Identification of Test Items

Each item under test should be described and uniquely identified. If there is no manufacturer's label, or if the label contains insufficient information to enable the item to be identified uniquely, a label should be attached giving a unique identification for test purposes. The information given on the label should be included in the test results and any documentation produced from those results.

8.5 Items Under Test

The item to be tested or measured should be checked to ensure that it is in good operating condition. Its optical system should be outfitted with the appropriate light source, which may be supplied by the manufacturer or be a standard laboratory test lamp, and focused (if required) in accordance with the manufacturer's instructions or standard laboratory procedure.

Laboratory test lamps should be selected for close conformance to design dimensions, rated power consumption, and rated lumen output. Manufacturing tolerances between individual lamps of the same manufacturer's specification may be very large causing a correspondingly large variation in the intensity of a beacon. Parameters such as filament coil spacing and size also impact greatly on the intensity distribution, therefore close inspection and selection is recommended. A test procedure should be written to ensure conformance of laboratory test lamp properties within 3% of the manufacturer's specification [11].

When a lampchanger is included as part of the test item, lamps should be installed in all positions of the lampchanger where they might impact on the photometric output of the item under test. Lamps should be seasoned by running them for a few tens of hours prior to initial use [11]. Note that all light sources, particularly LEDs and discharge lamps, may require several hundred hours of operation (ageing) prior to being used for measurement purposes.

Marine aid-to-navigation light signals should be tested at rated voltage, rather than current or power. The voltage should be monitored, with sense leads attached as close as practical to the lamp inputs or controlling circuitry inputs, and kept constant throughout the measurement process. Current should also be monitored and recorded, to detect any changes in the input power during measurements and allow for correction of measured photometric output (see 8.11).

In the case of LED light sources with conditioning circuitry, both the input voltage and current to that circuitry should be monitored. Stand alone LED's are normally rated at a given current rather than voltage because dI/dV is very large at the operating point therefore, in the absence of conditioning circuitry, current should be controlled and monitored rather than voltage. LED aging should be taken into account when carrying out measurements on new beacons and those that have been in service for several years.

8.6 Environmental Conditions

Ambient conditions for indoor measurements should be stabilized at 25(+5/-10)^{o}C and 60(±10)% relative humidity. In the case of outdoor measurements, the temperature and relative humidity should be noted at the time of the measurement. Any significant changes in ambient conditions during the course of the measurement should be recorded.

8.7 Power/Electrical Conditions

For tests involving equipment powered by a dc power supply, the output voltage and/or current should be maintained within ± 0.1% or better, unless otherwise specified by the person requesting the measurement. When output voltage is controlled, the voltage should be monitored as close to the light source as possible. Ripple voltage should not exceed 0.4% of the dc output voltage.

For tests involving equipment powered by an external ac power supply, the output rms voltage or current should be maintained within ± 0.5%. The rms summation of the harmonic components, caused by departures from a true sinusoidal waveform, should not exceed 3% of the rms value of the fundamental frequency. Readjustment of the output voltage may be required during measurements if adequate stabilization is not achieved.

8.8 Equipment Warm-up

All test equipment requiring electrical power should be switched on and allowed to warm up in accordance with the manufacturers' operating instructions or calibration certificates before commencement of any tests or measurements. In the absence of such guidance, the measurement facility should evaluate the performance of test equipment to determine the required warm up period to prevent drift for each piece of equipment.

Items under test should be run at rated power for a sufficient period of time to ensure stability. The warm-up time selected for any type of light source should be documented in the laboratory procedures, and used consistently.

8.9 Stray and Ambient Light Control

Stray light control includes eliminating reflected light of the item under test, from walls, floors, and other surfaces, from reaching the photodetector. Ambient light control includes eliminating or reducing the amount of light from sources other than the item under test. The impact of ambient light may be determined by removing power to the item under test and recording the output of the photodetector. The impact of both elements may be determined by taking measurements with the item under test on, but with the direct light path occluded by a screen just larger than the light source aperture.

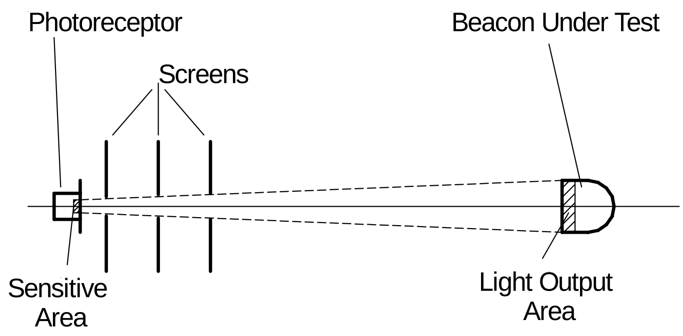


Figure 17 Stray light reduction by absorbing screens

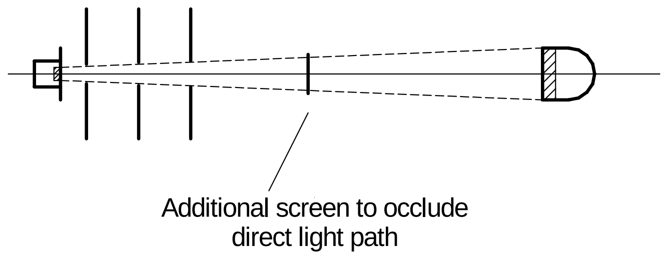


Figure 18 Arrangement to determine ambient and stray light

8.10 Source/Data Identification

The "raw" or "source" measurement data should be clearly identified and stored in accordance with [20]. The use of this data in any subsequent report or test sheet should be made fully auditable, so that the original measurement data can be referred to without ambiguity.

8.11 Power Monitoring of Item under Test

The power consumption of the item under test should be measured and recorded at the time of the photometric measurement. For electrical systems, power monitoring should be conducted throughout the measurement process. For other systems, such as gas or liquid fuel, monitoring of fuel consumption rate should be carried out, as a minimum, at the beginning and end of the measurement process or as an average over the time taken to carry out the measurement.

8.12 Recording System

All relevant measurement information should be recorded. The recording medium may be manually operated pen and paper, automatic chart plotter or electronic storage such as a computer. The recording system in use should have a response time fast enough to faithfully record all relevant data output from the measuring system.

8.13 Software

Details of all software used in any measurement process should be recorded. Custom software used in data acquisition, analysis, and/or presentation of results should be documented, and a printed copy maintained with other test procedure documentation. Algorithms used to manipulate data should be documented.

8.14 Errors, Uncertainty and Confidence

An expression of the result of a measurement is incomplete unless it includes a statement of the associated uncertainty. The results of all measurements should state the range, within which the measured value is estimated to lie, for a stated level of confidence. All type A and type B uncertainties associated with the measurement process should be evaluated in accordance with ISO Publication N^{o}. 2, Guide to the Expression of Uncertainty in Measurement, 1993 [9]. A suitable uncertainty budget should be produced for each measurement process undertaken.

Type A evaluation of uncertainty is made by statistical analysis of a series of observations. Type B evaluation of uncertainty is made by means other than the statistical analysis of the observations; for example, the uncertainty quoted on the calibration certificate of an item of test equipment.

8.14.1 Systematic Errors (Characterisation)

Any fixed errors within the measuring system should be evaluated and, where possible, corrected by the use of an appropriate correction factor. These errors and corrections should be recorded but not necessarily given with the measurement results. Appropriate uncertainty and confidence figures associated with error correction should be included in the uncertainty budget.

8.14.2 Combined Standard Uncertainty

The combined standard uncertainty is calculated by combining the individual uncertainties that comprise the uncertainty budget using the square root of the sum of the squares of the individual uncertainties.

8.14.3 Expanded Uncertainty

The expanded uncertainty is obtained by multiplying the combined standard uncertainty by a coverage factor, *k*. Unless otherwise determined, it may be assumed that the probability distribution of a measurement result and the combined standard uncertainty is approximately normal. The combined standard uncertainty is equivalent to the standard deviation of the Gaussian distribution. An appropriate coverage factor should be determined in order to provide a confidence level of 95%.

8.14.4 Sampling Guidelines

Sampling consists of taking a sufficient number of measurements for a given condition to minimize the impact of minor random fluctuations in the measurement process. A coverage factor between 2 and 3 should be achieved, consistent with the evaluation of uncertainty figures and confidence levels [9]. Sampling procedures should be documented as part of the standard laboratory procedures. Exceptions to standard sampling procedures should be discussed in any test results.

8.15 Notes/Comments

A copy of all information relevant to the measurement, including observations, modifications, statement of requirements and item under test manufacturer's instructions, should be retained with the recorded data.

8.16 Authorised Signatories

The person or persons carrying out the measurement should be authorised to do so by the facility or laboratory undertaking the work. A record of the person carrying out the measurement, along with the date when the signature was written and the place where the measurement was carried out, should be kept with the recorded test results and on any ensuing publication.

8.17 Retention of Data

Retention of data should be in accordance with local laboratory procedure.

9 Photometry Methods and Requirements

9.1 Standard Laboratory Photometry

The measurement of the luminous intensity of a light source in the laboratory is usually carried out by taking an illuminance reading, in lumens per metre squared (lux), of the light source at a measured distance, in metres. The luminous intensity in candelas may then be calculated by multiplying the illuminance by the square of the distance, this is known as the Photometric Distance Law [5] (see 5.1). The transmissivity of the atmosphere over short distances in the laboratory may be taken as unity. The light source and photometric receptors are usually mounted on an optical bench or table to reduce the uncertainty of distance measurement. To ascertain the luminous intensity of the light source in more than one direction, the light source may be rotated about its light centre and several illuminance readings taken at different orientations. To ascertain the total luminous flux emitted by a light source, an integrating sphere may be used. Photometers, used for measuring illuminance, have a photopic spectral response that approximates the standard human observer, $V(\lambda)$ [6].

Provided the measuring distance is relatively large compared to the size of the light source (greater than fifteen times as a rule of thumb), this method is simple and accurate for unfocussed light sources. However, when measuring light beam projection apparatus, such as a light source and lens or mirror system, much greater measuring distances are required to ensure an error free result when using this method. At these greater distances several problems arise, such as the effects of atmospheric transmissivity and disturbance, and the difficulty in measuring much lower levels of illuminance. The projection apparatus may be rotated through different angles and illuminance readings taken to determine the shape of the projected beam. A goniometer is usually employed to facilitate the measurement of intensity against angle.

Further guidance on basic photometry can be obtained from CIE publications [5], [8], [19] and [32].

9.2 Alignment

A datum point should be identified on the perimeter of the item under test such that it clearly defines a direction of radiation towards the horizon. This may be a manufacturer's mark or one put there by the testing laboratory. Items under test should be installed on the goniometer and aligned with the measurement system such that the datum point is in line with the measurement direction. Where possible, the height of the goniometer table should be adjustable so that both the horizontal and vertical axes of the optic may be aligned with the rotational axes of the goniometer. If this is not possible, due to the design constraints of the goniometer table, the errors in measurement distance caused by tilting the table should be corrected or included in the uncertainty budget. The centre of the photodetector aperture should lie along the line normal to the rotational axes of the goniometer. The alignment process and its associated uncertainty should be part of the documented laboratory procedure. Since the angle of incidence is always close to zero, there is no need to carry out cosine correction.

When a flat folding mirror is used, the distance from the item under test to the mirror should be as close as possible to the distance from the mirror to the photometer. The reflection angle of the light path should be minimised. The normal of the mirror surface should lie on the plane described by the optical axis of the item under test and the reference plane of the goniometer [19].

For all measurement procedures, the measurement distance and measurement angle should be known and reported.

9.3 Photometric System Response; $V(\lambda)$ and $f1'$

The overall spectral response of the photometric system used should approximate closely the spectral luminous efficiency function $V(\lambda)$ for the CIE standard photometric observer in photopic vision (see 6.1). For broadband emitters, such as incandescent lamps, a single value measurement of the spectral response, the closeness of fit (f_1') [6] figure of the system, may be used to determine measurement uncertainty. For light sources with narrow or rapidly varying spectral distribution, such as LEDs or metal-halide lamps, the deviation of the response of the photometric system from $V(\lambda)$ for specific wavelengths may have to be accounted for by use of spectral correction (see 9.4).

9.4 Spectral Correction

Even photometric systems with low f_1' figures can exhibit significant errors at extremes of the visible spectrum. If the light source being measured has a spectral power distribution that is significantly different from the calibrating light source, especially if it has a narrow band of distribution (such as LED sources), spectral correction should be undertaken. An accepted method of correction is by use of a spectral correction factor (SCF) [6], as given by:

$$SCF = \frac{\int_{\lambda} S_A(\lambda) S_{rel}(\lambda) d\lambda \int_{\lambda} S_t(\lambda) V(\lambda) d\lambda}{\int_{\lambda} S_A(\lambda) V(\lambda) d\lambda \int_{\lambda} S_t(\lambda) s_{rel}(\lambda) d\lambda}$$

Equation 9

where: $S_t(\lambda)$ is the spectral power distribution of the test lamp;

$S_A(\lambda)$ is the spectral data of the CIE Illuminant A;

$S_{rel}(\lambda)$ is the relative spectral responsivity of the photometer.

Using this equation, the correction factor can be obtained for any light source of known spectral power distribution (see 4.16). If a calibrated light source is being used as a reference, its spectral power distribution $S_R(\lambda)$ may be substituted for $S_A(\lambda)$.

The correction factor will have an associated uncertainty derived from the spectral measurement process and the pertinent calibration details of equipment used in the measurement.

A second method of spectral correction is by use of a calibrated light source with the same spectral power distribution as that of the test lamp. Measurement of the calibrated light source will establish a scaling factor that may be used to correct the measured illuminance of the item under test.

9.5 Measurement of Angular Dependency of Luminous Intensity [18]

The measurement of angular dependency, sometimes called the angular distribution, of luminous intensity (see Definitions) is usually carried out by using a goniophotometer. A goniophotometer consists of a goniometer (tilt and turn) table, on which the item under test is mounted, and a distant photometer that measures the light emanating from the item. As the goniometer is moved or stepped through various angular positions, the photometer records the luminous intensity at each angle. There is an important relationship between the angular resolution of the goniometer and the measurement angle of the photometer (see 9.9).

In order to carry out angular measurements using the goniometer it is usually necessary to make the item under test exhibit a fixed light. For rotating beacons, this can be achieved by disabling the rotation mechanism and locking the mechanism in one position. If the item under test emits more than one beam, each beam axis or surface should be identified with the datum clearly defined. Separate vertical and horizontal plots should be carried out for each beam axis.

If the light source within a rotating beacon is non-uniform and the measurement is to be carried out by rotating the whole beacon, including the light source, on the goniometer, additional output data for the bare light source, for example a lamp polar plot, should be obtained. If the measurement is to be carried out with the lamp in a fixed position and not rotated with the goniometer, measurements of all emitted beams should be carried out with the light source in two different positions, those that give maximum and minimum intensity.

For omnidirectional beacons with a flashing light source, the light source should be made to light continuously by following instructions in the manufacturer's handbook. If no instructions are available, advice from the manufacturer or supplier should be sought. It should be noted that the continuous intensity of a beacon exhibiting a fixed light may be different to the peak intensity of the same beacon when it exhibits a flashing light (see 11.4)

9.6 Minimum Requirements for Angular Resolution

The following are minimum requirements for the two main types of marine aids-to-navigation optical systems:

9.6.1 Omnidirectional lantern—(fan beams)

- horizontal profile, 360 degree plot, readings every 1.0 degrees or less;
- vertical profile to the 1% intensity points (or the lowest possible reading), readings every 0.1 degrees or less.

A minimum of three equidistant vertical profiles should be recorded, one of which should be taken at a position where the on-axis intensity is close to the 10^{th} percentile value for the horizontal profile. Additional vertical profiles may be necessary to adequately investigate irregularities in the horizontal profile.

9.6.2 Directional and rotating beacons and precision projectors

- horizontal profile to 1% intensity points (or the lowest possible reading), readings every 0.1 degrees or less;
- vertical profile to 1% intensity points (or the lowest possible reading), readings every 0.1 degrees or less.

9.7 Measurement of Time Dependency of Luminous Intensity

In order to determine the effective intensity of a flashing omnidirectional aid-to-navigation light operating at a chosen character, the time-dependent luminous intensity profile should be measured. The absolute values of the instantaneous luminous intensity do not have to be measured, as long as the peak intensity during a flash is equal to the intensity measured when the item under test provides a fixed light. This requires that the time duration of a flash generated by a contact-closure (such as a tungsten-incandescent lamp that is switched on and off) be of sufficient length to ensure that full output of the light source is achieved. Examples of types of illuminant that may exhibit different values of instantaneous peak intensity and continuous intensity are:

- A tungsten filament lamp whose time to reach full incandescence is greater than the contact-closure time (CCT) of the device controlling the lamp supply; [2]
- An LED whose luminous intensity reduces with time when supplied with constant current, this being the result of an increase in junction temperature of the LED.

Care should therefore be taken to ensure that such devices either reach full incandescence during the measurement of the flash profile or that the relationship between instantaneous peak intensity and continuous intensity is known. The latter may be treated as an error to which a correction factor is applied with an associated correction uncertainty.

For rotating beacons, the instantaneous luminous intensity may be plotted against time by allowing the beacon to rotate under its own power and recording each beam as it passes the measuring instrument. With this method, the light source does not usually rotate. If the light source is non-uniform, measurements of all emitted beams will be carried out with the light source in two different positions, those that give maximum and minimum intensity.

9.8 Minimum Photometric Distance

Before commencing a measurement, the minimum photometric distance of the item under test should be estimated. This involves calculating the crossover distance for a projection apparatus such as a marine aid-to-navigation light. John W. T. Walsh described a method for determining crossover distance in his book on Photometry [8] as follows:

$$d = \frac{R^2}{4f} + \frac{R}{r}\left(f + \frac{R^2}{4f}\right)$$

Equation 10

where: d = crossover distance
f = focal length of optical system
R = radius of optic aperture
r = radius of light source

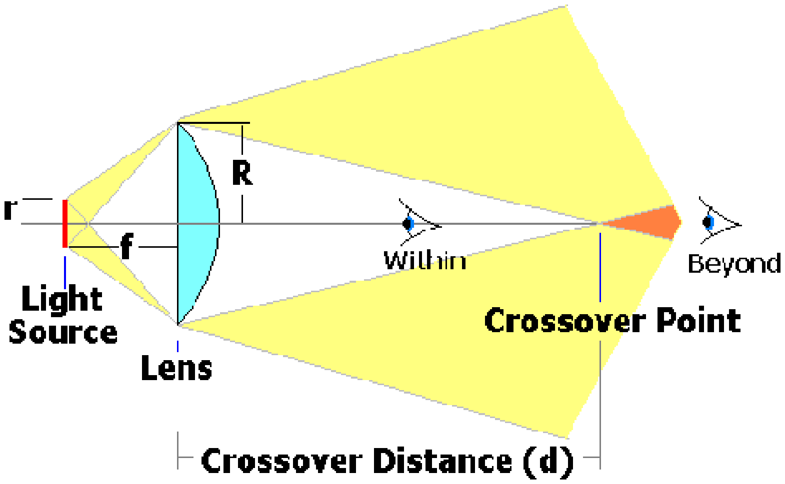


Figure 19 Crossover Distance

An approximation of crossover distance can be obtained by the formula:

$$d = 2\frac{fR}{r}$$

Equation 11

The approximation only holds good for an optical lens system with a collection angle of approximately 63°. If the collection angle is markedly different, the full formula, as prescribed by Walsh, should be used.

Equation 11 is good for circular optical apparatus with a spherical light source but when the optical system is larger in one dimension than another; for example, a rectangular lens with a cylindrical light source, the vertical and horizontal crossover distance will be different. In this case the formula can be expressed as follows:

$$d = 2\frac{fH}{h}$$

Equation 12

where: d = crossover distance
f = focal length of optical system
H = height of optic aperture
h = height of light source

or:

$$d = 2\frac{fW}{w}$$

Equation 13

where: d = crossover distance
f = focal length of optical system
W = width of optic aperture
w = width of light source

Both the crossover distances of height and width should be calculated and the greater of the two used. For an omnidirectional beacon, only the vertical crossover is relevant, therefore only equation 12 is relevant.

For a precision sector projector, the crossover distance may be expressed as follows [28]:

$$d = 2\frac{R}{\alpha}$$

Equation 14

where: d = crossover distance
R = radius of optic aperture
α = requested angular resolution

The minimum photometric distance may be taken as twice the calculated crossover distance.

In cases where the sizes of optical components are unknown, the minimum photometric distance may be determined by measuring the intensity at several different distances from the beacon, always on the same radial coordinate, and assessing the distance beyond which the resultant measured intensity is consistent [29]. In practice this will be restricted to small sealed beacons, whose component parts are not measurable.

9.9 Measurement Aperture and Measurement Angle

The measurement aperture is the physical size of the photoreceptor active surface, i.e. that area receiving light being measured. It is sometimes quoted as an area or, if the aperture is circular, a radius or diameter.

The measurement angle is described by the aperture over the measurement distance and usually refers to a point source of measurement. The measurement angle is important when carrying out goniophotometry, where a graph of intensity against angle is being plotted. The measurement angle describes the integral angle over which each incremented measurement is carried out, and should therefore approximate the goniometer incremented angle.

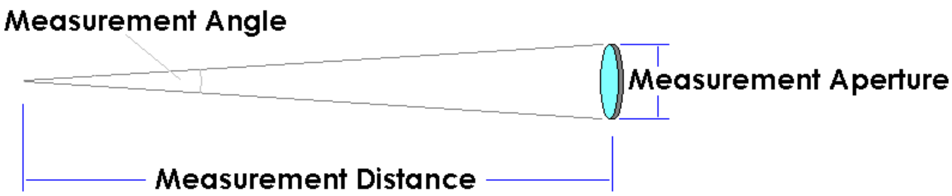


Figure 20 Measurement Angle

Providing a<<d, the measurement angle may be calculated as follows:

$$\theta = 2\times\arctan\frac{a}{2d} \approx \arctan\frac{a}{d} \approx \frac{a}{d}[radians]$$

Equation 15

or providing r<<d:

$$\theta = 2\times\arctan\frac{r}{d} \approx \frac{2*r}{d}[radians]$$

Equation 16

where: θ is the measurement angle

a is the diameter of the measurement aperture

r is the radius of the measurement aperture

d is the measurement distance

9.10 Detailed Measurement Methods

In addition to these general measurement methods and requirements, two detailed methods, for the photometry of projection apparatus such as aid-to-navigation signal lights, have been reviewed and approved for inclusion in this document: Zero-Length Photometry (Annex 2) and Outdoor Telephotometry (Annex 3). Much of the equipment and measurement procedures are the same for all methods. Unique requirements for both methods are discussed in their respective sections.

These detailed methods have been reviewed and accepted as providing equivalent results, within stated uncertainties. Other methods of measurement are not excluded, but should meet the same criteria for traceability and evaluation of uncertainty described in this recommendation.

10 Colorimetry Methods and Requirements

10.1 Standard Laboratory Colorimetry

The measurement of the colour of a light source in the laboratory is carried out by one of two methods; either by use of a tristimulus colorimeter (see 7.4), or a spectroradiometer (see 7.5 and 7.6). The results from either method should be reduced to x, y coordinates that enable a colour point to be plotted on a CIE 1931 chromaticity diagram (see 6.5) [24]. The transmissivity of the atmosphere over short distances in the laboratory may be taken as unity. The light source is usually mounted on an optical bench or table to reduce the uncertainty of distance measurement. To ascertain the colour of the light source in more than one direction, the light source may be rotated about its light centre and several measurements carried out at different orientations. To ensure that a light source fully and evenly illuminates the measurement aperture, a diffuser or integrating sphere may be used.

Provided the measuring distance is relatively large compared to the size of the light source (greater than fifteen times as a rule of thumb), this method is simple and accurate for unfocussed light sources where the measurement angle is unimportant. However, when measuring light beam projection apparatus, such as a light source and lens or mirror system, the measurement angle may be important, especially when different coloured sectors are being measured. It is also important when considering the observed colour of a beacon comprising a cluster or array of LEDs that may exhibit different individual colours. If the measurement angle needs to be small, then either the measurement distance should be increased or the measurement aperture should be decreased. At greater measurement distances, the lower levels of illuminance at the measurement aperture may increase measurement uncertainty considerably due to instrument noise. A goniometer may be employed to facilitate the measurement of colour against angle.

When measuring the overall colour of a light, the measurement may be carried out by placing the beacon in an integrating sphere. However, if the angular dependence of colour is being measured, a minimum colorimetric distance should be employed. The distance defined in 9.8 may be used for this purpose.

Further guidance on basic colorimetry can be obtained from CIE publications [14], [24], [31], [34], [35].

10.2 Alignment

The datum point identified in 9.2 for photometric measurement should be the same, where possible, for colorimetry. The measurement distance and measurement angle (see 9.9) should be reported.

10.3 Measurement System Spectral Response

Tristimulus colorimeters have a spectral response that approximates the standard colorimetric observer (see 6.4) [24]. However, as with photometers, the three filters used to obtain the response inevitably introduce errors. Because the measurement process involves a combination of the responses of three filters, spectral mismatch correction is more difficult for tristimulus colorimeters than for photometers. Errors are more likely when measuring light sources with narrow spectral distribution (e.g. LEDs) and when that distribution is concentrated in a less sensitive part of the visible spectrum.

Spectroradiometers should ideally have a radiometrically flat response over the visible spectrum but this is never the case in practice. Calibration of the spectroradiometer with a lamp of known SPD (see 7.7) is usually carried out before and after each measurement session. Correction of the spectral response of the system is achieved by comparing the data obtained from the measurement of the standard lamp and the data from the standard lamp calibration sheet.

10.4 Illumination of the Measurement Aperture

When measuring colour it is important that the light to be measured fully and evenly illuminates the input aperture of the measuring instrument. This can be achieved by inserting a diffuser or integrating sphere between the light source and the measurement aperture. However, such devices can greatly attenuate the light input to the instrument.

10.5 Considerations of Rapid Intensity Fluctuation of the Light Source

As with photometers, the rapid fluctuation of light source radiant intensity can cause measurement errors. The temporal response of the measuring instrument should either be fast enough to follow the fluctuation or should be slow enough to give an average.

10.6 Minimum Measurement Distance

With aid-to-navigation beacons, the area of lit beacon seen by the observer should be considered when carrying out colour measurements. With bare or filtered incandescent lamps, the colour changes very little when viewed at different angles. However, this is not necessarily the case with clusters or arrays of LEDs, where a change of viewing angle will reveal a different group of light sources.

Often, the measurement distance will be limited by the sensitivity of the measuring instrument. Sometimes, optical gain can be employed to increase the light input to the measurement aperture. A “zero-length” measurement system, such as that described in Annex 2 for photometry, may also be used with good effect for colorimetry. However, the use of optical apparatus in the measurement path will introduce spectral distortion and such errors should be corrected. The use of a spectral standard lamp (e.g. measurement by substitution) can help eliminate such errors.

10.7 Detailed Measurement Methods

In addition to these general measurement methods and requirements, two detailed methods, for the colorimetry of projection apparatus such as aid-to-navigation signal lights, have been reviewed and approved for inclusion in this document: Tristimulus Colorimeter (Annex 4) and Spectroradiometry (Annex 5). Measurement uncertainties for both methods are currently under review.

11 Presentation of Results

A test report should be prepared containing all relevant results annotated to clearly identify the item under test, including the optical assembly and the light source (if separable). The testing procedures (standard laboratory photometry, zero-length photometry, or outdoor telephotometry) should be identified. Test conditions, including voltage settings, current consumption of the item under test and/or the light source (if independently powered) should be listed. Results of measurements of any laboratory test lamp used should be presented with results of the item under test.

Units of the measured results should be as follows:

time	seconds (s)
luminous intensity	candelas (cd)
angle	degrees (º)
luminous range	nautical miles (M)
chromaticity	values of x and y according to CIE 1931 diagram.

11.1 Luminous Intensity versus Angle

Results of the angular dependence of the luminous intensity should be graphically presented to clearly illustrate the performance of the lantern. Graphs should be linear and annotated to identify causes of irregularities in the intensity measurements, such as shadowing due to filament supports, effects of lens seams, etc. For beacons or projectors with coloured sectors, the angle of indecision between sectors may be defined by visual observation, not by photometric measurement.

11.1.1 Main Values of a Symmetric Intensity Distribution

An intensity distribution in a plane, which is symmetric about a reference axis (datum) can be characterised by three values:

- maximum intensity at reference axis: I_{max}
- full width half maximum: FWHM
- full width tenth maximum: FWTM

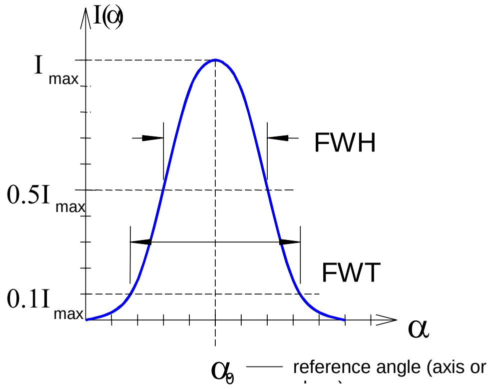


Figure 21 Symmetrical Intensity Distribution

In practice the distributions are not exactly symmetric and there may be minor maxima.

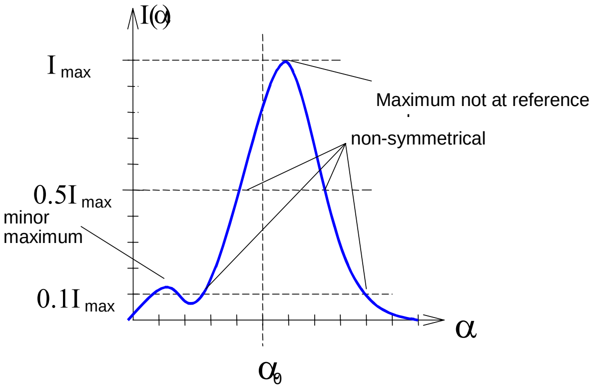


Figure 22 Asymmetrical Intensity Distribution

The I_{max} figure reported should be the intensity at the reference axis. If an I_{max} figure is reported that is not on the reference axis, the intensity value and the angle at which it was measured should be clearly stated.

The FWHM values reported should correspond to the angles either side of the reference axis where the intensity first falls to 50% of I_{max}. An overall value of FWHM may be reported in addition but this should be clearly marked "overall FWHM" or "overall 50% divergence".

The FWTM values reported should correspond to the angles either side of the reference axis where the intensity first falls to 10% of I_{max}. An overall value of FWTM may be reported in addition but this should be clearly marked "overall FWTM" or "overall 10% divergence".

11.1.2 Reduced Values for Type Testing or Type Approval

For type approval testing, where a symmetrical distribution is specified or expected but measured results show an asymmetrical distribution, the values reported should be characterised by the intensity at reference axis I_0, and the reduced overall angles:

$FWHM_{red} = 2 \text{ x } \min\{\Delta_{H1}, \Delta_{H2}\}$

$FWTM_{red} = 2 \text{ x } \min\{\Delta_{T1}, \Delta_{T2}\}$

This is so that the unexpected performance of a beacon is reflected in lower reported values for intensity and divergence angles.

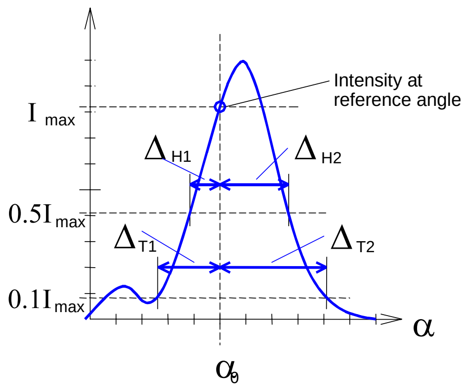


Figure 23 Asymmetrical Intensity Distribution showing Reduced Values

11.1.3 Main values for Omnidirectional Beacons (fan beams)

- Horizontal Profile

Graphs of the horizontal profiles should be plotted over ±180º from the vertical reference plane. The following main values of the luminous intensity should be reported for the horizontal profile for an omnidirectional light signal, preferably annotated on the graph:

- maximum intensity: I_{max}
- minimum intensity: I_{min}
- mean intensity: I_{mean}
- 10^{th} percentile intensity: $I_{10\%ile}$

The 10^{th} percentile value, equalled or exceeded by 90% of the individual measurements of the luminous intensity in the horizontal plane, will be the value used to define the fixed (continuous) intensity of the beacon.

Note:

The luminous intensity of LED light sources under test may vary considerably with LED junction temperature and this can be a consequence of duty cycle of operation, for instance flash character. It is important therefore, to ensure that the peak intensity (I_0) in flashing mode is measured at the character specified and clearly labelled so as not to be confused with the fixed (continuous) intensity.

- Vertical Profiles

Measurements in three vertical planes, preferably including and equidistant from the reference vertical plane, should result in graphs of the vertical profiles plotted between the points where the intensity falls below 1% of maximum. Each graph should preferably be annotated with the main values Imax, FWHM and FWTM.

The average of all three FWHM and FWTM results, above and below the horizontal reference plane, should then be reported (e.g. -3.1, +4.2 degrees).

For type approval testing, where the profile is expected to be symmetric about the datum, an asymmetric distribution shows deficiency in quality. Therefore, it is recommended to use the reduced overall values for FWHM and FWTM as described in 11.1.1.

11.1.4 Rotating Beacons (pencil beams)

Graphs of the vertical and horizontal profiles should be plotted between the points where the intensity falls below 5% of maximum. The main values I_{max}, FWHM and FWTM should be reported and preferably annotated on each graph. The horizontal angular intensity variation may be converted to a time-dependent profile at specific rotation rates for calculation of the effective intensity and flash duration. For rotating beacons with more than one emitted light beam, the results of all beams will be shown. The beam of least effective intensity shall be used to calculate the nominal range of the beacon.

If the light source within the beacon is non-uniform and the measurement was carried out by rotating the whole beacon, including the light source, on the goniometer table, additional output data for a bare lamp, e.g. a polar plot, should be presented. If the measurement was carried out with a non-uniform lamp in a fixed position and not rotated with the goniometer table, measurement results of all emitted beams will be presented for positions of the light source that give maximum and minimum intensity.

11.1.5 Directional Beacons

Graphs of the vertical and horizontal profiles should be plotted over the intended arc of utilisation of the beacon or to the horizontal angles where the intensity falls below 1% of maximum, whichever is the greater. Where applicable, the intended arc of utilisation should also be shown on the graph. The main values of Imax, FWHM and FWTM should be reported for both horizontal and vertical graphs, and preferably annotated on each graph. The 50% points will be used to define the vertical and horizontal divergences of the beam and should be given as minus and plus angles relative to the vertical reference plane. The 10% points should be shown on the graph but need not be quoted.

11.2 Luminous Intensity versus Time

For aid-to-navigation light signals that are flashed by eclipsing or switching the light source, the instantaneous luminous intensity profile versus time (flash profile) should be plotted with the luminous intensity as the dependent variable (ordinate) and time as the independent variable (abscissa). The plot should be linear and include the entire cycle of the flash character, illustrating both the on and off periods. Secondary plots may be used to illustrate any short-duration fluctuations of the instantaneous luminous intensity.

For rotating beacons where the instantaneous luminous intensity is plotted against time by allowing the beacon to rotate under its own power, plots should be linear and show the luminous intensity profile against time for one complete revolution of the beacon. Secondary plots should also be used to illustrate individual emitted beams in greater detail. If the light source spatial distribution is non-uniform, measurement results of all emitted beams will be presented for positions of the light source that give maximum and minimum intensity. The periods between the times where the intensity falls or rises through 50% of peak intensity (I_0) shall be used to determine the rhythmic character of the light.

11.3 Flash Duration

The reporting of the duration of a flash of light should be in accordance with IALA E-200-4.

11.4 Effective Intensity

The effective intensity of a marine aid-to-navigation light shall be presented in the final results having been calculated using the method outlined in IALA E-200-4. In the case of an omnidirectional beacon, the 10th percentile value of the horizontal plot should be used to scale the calculated effective intensity. It should be noted that a function to calculate a percentile value is available in many computer spreadsheet packages.

Note that some light sources have different intensities for continuous and flashed modes (e.g. LED's). Therefore, when the measurement of luminous intensity against angle is carried out with a continuous light source, the intensity measured for a given angle will be different than when the light source is flashing. In this case, intensity against time may be measured in both modes, ensuring the light source reaches stability in each mode, at the same angular reference (e.g. datum). The ratio of continuous intensity to flashing (peak or effective) intensity may be calculated and used to scale the 10th percentile figure. The rhythmic character used during the measurement of intensity against time should be reported with the effective intensity value.

11.5 Spectral Correction

Where the photometric result has been corrected by applying a spectral correction factor, the value of the factor, and how it was applied, should be clearly stated.

11.6 Service Conditions Allowance

Where applicable, a service conditions allowance may be applied to the measured intensity. This allowance accounts for the reduction in intensity through equipment degradation over the lifetime and service period of the equipment when it enters service. The details of such an allowance, and how it was applied, should be clearly reported.

11.7 Light Colour

The measured colour of the light should be reported in x, y coordinates according to the CIE 1931 chromaticity chart (see 6.5). Compliance with the appropriate IALA colour region should also be reported with reference to IALA E-200-1. At least three colour measurements should be taken at different points within the arc of utilisation.

If the colour of the light emitted by the equipment being tested varies with angle, for example a sector light with white, red and green sectors, the colour should be tested in at least three points within each coloured sector. The results of all measurements should be reported.

If the angle or sector of uncertainty (sometimes called the angle of indecision) at the boundary between two different coloured sectors needs to be defined, colour measurements can be taken at angular intervals across the boundary. The angle of uncertainty is defined as the angle distance from the point the colour departs from the IALA region of the first sector colour to the point the colour enters the IALA region of the second colour. It is important to ensure that the angular increments are similar to the measurement angle of the instrument (9.9); otherwise sharp transitions in colour will be reported incorrectly (see IALA Guideline 1041 on Sector Lights). Figure 24 shows a Cartesian plot of chromaticity x, y coordinates against horizontal angle for a white omnidirectional beacon with a red sector. The vertical yellow line shows where the colour of the light leaves the red IALA Class A region and the vertical blue line shows where it enters the white IALA Class A region. The angle of uncertainty covers 0.8º from -56.6º to -55.8º.

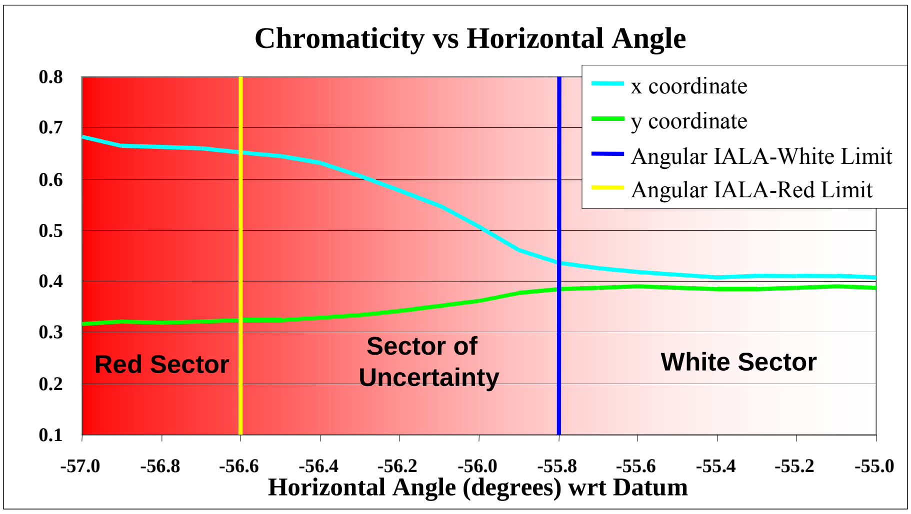


Figure 24 Plot of chromaticity across the boundary between red and white sectors

The same plot is shown in figure 25 but this time shown on a CIE 1931 chromaticity diagram.

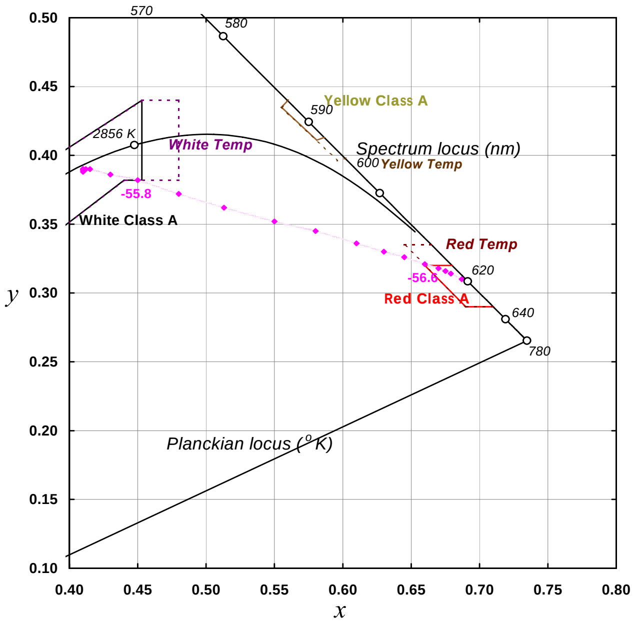


Figure 25 As Figure 24 but plotted on a partial CIE 1931 Chromaticity Diagram

The sector information and angle or sector of uncertainty may also be annotated on a plot of intensity against horizontal angle.

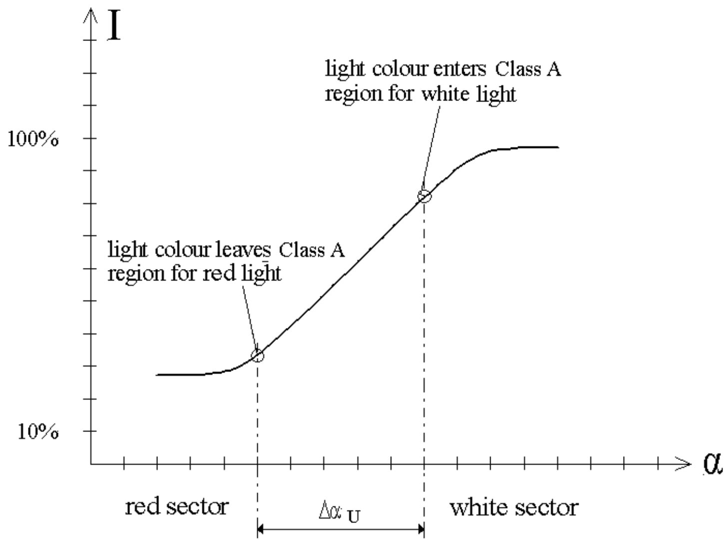


Figure 26 Method of Plotting Sector of Uncertainty on Intensity Graph

If the equipment comprises more than one light source, an LED array for example, there are likely to be variations from one light source to the next. Furthermore, the colour of some types of LEDs, white phosphor-conversion types in particular, varies with angle of view. It is important for such devices that colour is measured at as many angles as possible within the zone of utilisation. If all points lie within the recommended boundary, results may be shown as a scatter plot on a chromaticity chart. However, if there are deviations in colour from the recommended regions, a Cartesian plot of x, y chromaticity against angle is preferable because the angles at which deviations occur can be seen.

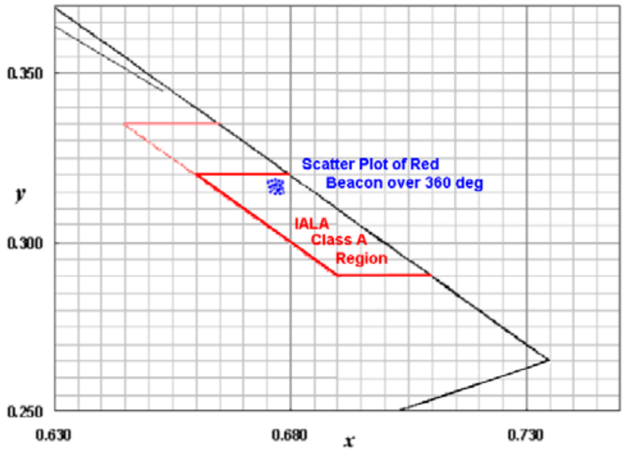


Figure 27 Scatter plot of red LED beacon over 360°

11.8 Spectral Power Distribution

The graph of SPD of a spectroradiometric measurement may be presented. Units of wavelength of the visible spectrum should be plotted on the independent variable (abscissa) and power (either relative or in Watts) should be plotted as the dependent variable (ordinate).

11.9 Nominal Luminous Range

The nominal range of the lowest resultant effective intensity of all flashes within the rhythmic character or lowest resultant effective intensity of all panels within a rotating optical system should be calculated according to E-200-2 and reported.

11.10 Uncertainty & Confidence

The results of all measurements should be presented with a statement of uncertainty and confidence level as outlined in 8.14 (also see Annex 7).

12 References

[1] International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), "Recommendations for the Colours of Light Signals on Aids to Navigation," December 1977.

[2] IALA, "Recommendations on the Determination of the Luminous Intensity of a Marine Aid-to-Navigation Light," December 1977.

[3] Schmidt-Clausen, H.J., "Über das Wahrnehmen verschiedenartiger Lichtimpulse bei veränderlichen Umfeldleuchtdichten" (Concerning the perception of various light flashes with varying surrounding luminances, Darmstadt Dissertation D17, Darmstadt University of Technology, 1968.

[4] Graham, C.H., ed. "Vision and Visual Perception", John Wiley & Sons, Inc., New York, 1965.

[5] International Commission on Illumination (CIE), Publication No. 18.2, "The Basis of Physical Photometry," 1983.

[6] CIE Publication No. 69, "Methods of Characterising Illuminance Meters and Luminance Meters," 1987.

[7] National Institute of Standards and Technology (NIST), Special Publication 250-37, "Photometric Calibrations", U.S. Department of Commerce, July 1997.

[8] John W. T. Walsh, "Photometry," Dover Publications, 1965.

[9] ISO Publication No. 2, "Guide to the Expression of Uncertainty in Measurement", 1993.

[10] CIE Publication No. 43, "Photometry of Floodlights" (Appendix C.2), 1979.

[11] Illuminating Engineering Society (IES), Publication LM-54-1991, "IES Guide to Lamp Seasoning", 1991.

[12] J. Johnson, "Zero-Length Searchlight Photometry System," Illuminating Engineering, Vol 57, No. 3, March 1962, p. 187.

[13] IES, Publication LM-11-84, "IES Guide for Photometric Testing of Searchlights", July 1984.

[14] CIE Publication No. 63, "The Spectroradiometric Measurement of Light Sources", 1984.

[15] IALA Recommendation E-110 "on the Rhythmic Characters of Lights on Aids-to-Navigation", May 1998.

[16] CIE Publication No. 86, "CIE 1988 2° Spectral Luminous Efficiency Function for Photopic Vision", 1990.

[17] CIE Publication No. 127, "Measurement of LEDs" (Technical Report), 1997.

[18] CIE Publication No. 70, "The Measurement of Absolute Luminous Intensity Distributions", 1987.

[19] CIE Publication No. 121, "The Photometry and Goniophotometry of Luminaires", 1996.

[20] ISO/IEC 17025, "General Requirements for the Competence of Testing and Calibration Laboratories", 1999.

[21] CIE Standard 149-2002 "Use of Tungsten Filament Lamps as Secondary Standard Sources".

[22] "Modified Allard Method for Effective Intensity of Flashing Lights" Yoshi Ohno and Dennis Couzin, CIE Symposium 2002.

[23] Aerospace Recommended Practice, SAE ARP 5029 "Measurement Procedures for Strobe Anti-collision Lights".

[24] CIE Publication No. 15, "Colorimetry 3rd Edition", 2004.

[25] http://en.wikipedia.org

[26] CIE Publication No. 84, "Measurement of Luminous Flux," 1989.

[27] CIE Publication No. 102, "Recommended file format for electronic transfer of luminaire photometric data ," 1993.

[28] German Federal Waterways, "Minimum Photometric Distance", 2006-01-31.

[29] German Federal Waterways, "Determination of Photometric Distance", 2006-01-31.

[30] CIE S 014-1/E:2006, "CIE Standard Colorimetric Observers"

[31] CIE S 014-2/E:2006, "CIE Standard Illuminants for Colorimetry"

[32] CIE S 010/E:2004, "Photometry - The CIE System of Physical Photometry"

[33] CIE Publication No. 179, "Methods for Characterizing Tristimulus Colorimeters for Measuring the Colour of Light", 2007.

[34] CIE Publication No. 53, "Methods of characterizing the performance of radiometers and photometers",

1982

[35] CIE Publication No. 10527(E), “Colorimetric observers”, 1991 (S002, 1986)

[36] CIE Publication No. 17.4, “International Lighting Vocabulary”, 1987

Annex 2 – Detailed Measurement Method
Zero-Length Photometry

1 Introduction

Zero-Length Photometry is a methodology for approximating far-field conditions in a short distance. The principal technique of Zero-Length Photometry is the use of a paraboloidal mirror to optically place the detector at an infinite distance from the source and thus out of the near field. An incoming plane wave, incident upon a concave paraboloidal mirror is converted to a converging spherical wave. The resulting image is measured by a detector at the focal point of the mirror [12]. The Illuminating Engineering Society (IES) has presented this as an alternative method for photometric measurement of searchlights [13]. Figure 28 illustrates a Zero-Length Photometry system.

The mirror should be able to focus collimated rays from all sections of the mirror face to a spot no greater than the aperture of the photometer, while excluding off-axis rays. The diameter of the mirror should be greater than the largest dimension of the optical components of the item under test. A front-surfaced mirror is recommended to minimize losses. As with a folding mirror, the relative spectral reflectivity of the mirror should be measured and used in the calculation of the spectral mismatch correction factor.

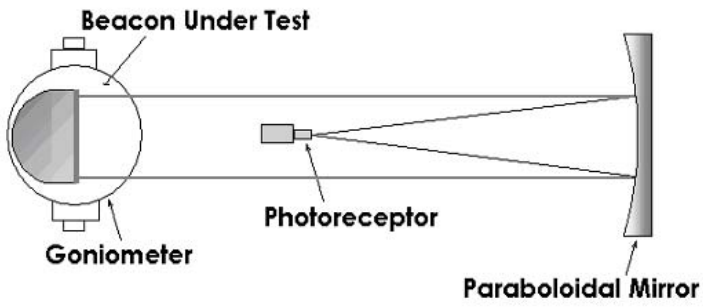


Figure 28 Zero-Length Photometry System.

The angular resolution depends on the focal length f and the size of the measurement aperture of the photometer head (see figure 29).

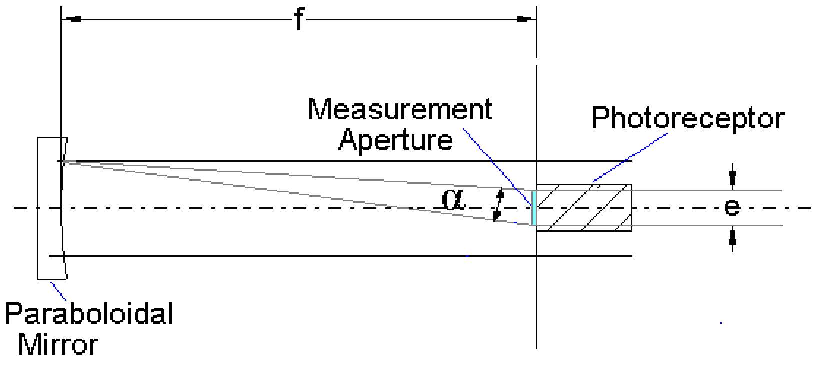


Figure 29 Zero-Length Geometry showing Angular Resolution

As an approximation the angular resolution can be expressed as follows:

$$\tan\alpha \approx \alpha \approx \frac{e}{f}$$

Equation 17

2 Off-axis Zero-Length Photometry

The photoreceptor may be removed from the direct path of the light signal from the item under test by use of an off-axis paraboloidal mirror. This is especially important when measuring smaller optics, where the amount of obscuration may be a substantial proportion of the light signal. Tilting a centred system will achieve the same result, albeit with an increase in measurement uncertainty.

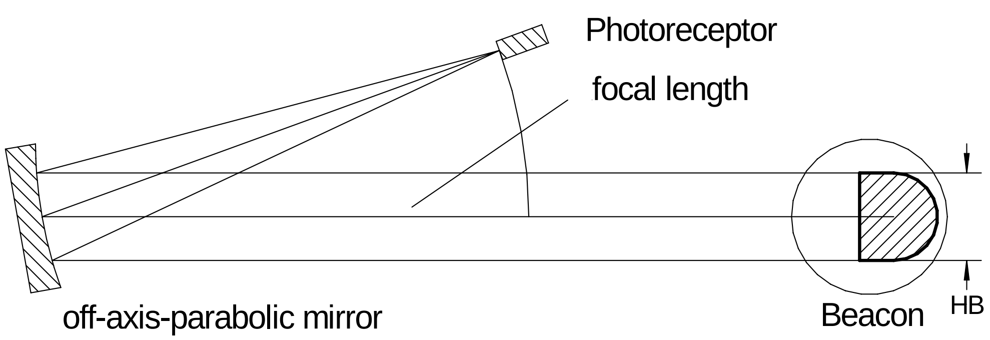


Figure 30 Off-Axis Zero-Length Geometry

3 Calibrating or Characterising the Zero-Length System

Kommentar [i4]: Page: 57 ' Determining Uncertainty of' removed and replaced with 'calibrating or characterising'

Theoretically, all of the on-axis, collimated rays striking the paraboloidal mirror will be gathered at the focal point of the mirror. In actuality, there will be losses due to the overall spectral reflectivity of the mirror, non-uniformity of the mirror's reflective coating, and aberrations in the curvature of the mirror. The following method may be used to determine the losses through the zero-length setup. Measure the illuminance from a stable light source at various distances from the photometer. Placing the source in a light box with a variable aperture will allow for generation of a very small source, so that the illuminance may be found to follow the photometric distance law within the limits of the measurement path. Precise alignment of the light box with the detector is required. The lamp current should be monitored and controlled. Make a series of measurements at distances beyond the minimum distance required for the photometric distance law to apply. Determine the intensity of the source and variance from the series of measurements. Move the light box to the goniometer and align with the mirror and the photometer. Monitor and control the lamp current as the illuminance (E_{meas}) is measured through the zero-length system. Using the intensity determined from the direct measurements (I_{direct}), calculate the "corrected" length of the light path,

$$r_{corr} = \sqrt{\frac{I_{direct}}{E_{meas}}}$$

Equation 18

where: I direct is in candelas

E is in lux

R_{corr} is in metres

The corrected light path length of the zero-length setup, r_{corr}, is then used to calculate the luminous intensity of the item(s) under test. Determination of the corrected light path length of the zero-length setup should be carried out whenever new data are to be recorded. Changes to the corrected length that cannot be accounted for in the uncertainty budget should be examined to determine if they are caused by some systematic error or equipment malfunction.

The variance recorded during the series of direct measurements of the light box includes the effects of a significant proportion of the elements that comprise the total uncertainty budget of the zero-length photometry setup. The variance may be used as the unexpanded uncertainty for those elements.

Annex 3 – Detailed Measurement Method Outdoor Telephotometry

1 Introduction

Because some aid to navigation lights are projection systems, with minimum photometric distances in excess of 100 metres, all or part of the light range path may be situated outdoors. IALA Recommendations on the Determination of the Luminous Intensity of a Marine Aid-to-Navigation Light, 1977 [2], provides an overall recommendation for this type of measurement. Advantages are that a large building is not required and stray light bouncing off walls will not distort the measurement result. A further advantage is that this method allows for photometric measurements of lighthouses “in situ”. Disadvantages of outdoor telephotometry are that ambient light levels, such as daylight, may be high and/or variable and that the state of the weather may affect the light path. The timing of the measurement may therefore be important, and testing may be limited to periods of fine weather or at night.

A further problem with long distance photometric measurements is that the photometer may not be sensitive enough to measure illuminance from a light source several hundred metres away. One solution to this is to use a sensitive photometer receptor (e.g. photomultiplier); another is to use optical magnification (e.g. telephoto lens or telescope) in front of the receptor. At extreme distance both options may be required.

Outdoor measurements may be divided into two types:

- Those carried out on an outdoor light range, where the item under test is mounted on a goniometer table and its intensity is measured against angular displacement; and
- Those of a lighthouse “in situ” where no goniometer is used, the character of the light is measured against time and shallow prisms are used to obtain a plot of the vertical beam profile

Just as for standard laboratory photometry, the path length used in outdoor telephotometry should be greater than the crossover distance of the item under test. A flat folding mirror may be used to double the path length of the light range. The photometer should be shielded from stray light emitted by the item under test when folding the light path.

2 Additional Equipment Required for Outdoor Telephotometry

2.1 Telephotometer

The low values of illuminance that may be incurred when using an outdoor light range may result in the need to couple the photometer to a collecting telescope. The telescope should be capable of collecting light from the item under test and any reference source that might be used. It should also incorporate an iris so that the acceptance angle may be adjusted to exclude unwanted background light. The use of a telescope, or any such device in the optical measurement path, may alter the spectral correction factor, SCF.

2.2 Reference Light

To overcome uncertainties caused by varying atmospheric transmissivity over a longer measurement path, a reference light should be used. This is a light source of known intensity, preferably one calibrated to national standards, with a controlled supply voltage and current.

In practice two measurements are made, one of the item under test and one of the reference light, which is placed in the same (or equivalent) physical position as the item under test. The two readings are then compared. This method does not rely on accurate measurements of distance nor does it require the photometer to be calibrated in absolute units. However, the photometer output should be directly proportional to the illuminance input. Any non-linearity should be accounted for in the uncertainty budget. The measurement path from the reference light to the receptor should, as far as possible, be the same as that from the item under test to the receptor.

3 Calibration procedures

The use of a reference light as the comparator eliminates the need for absolute calibration of the light measurement system. However, calibration is required of the reference light itself, and the test equipment. The uncertainty in measurements due to the geometric relationships between the reference light, the item under test, and the photometer should also be evaluated and quantified.

4 Atmospheric Conditions and Ambient Light

One of the greatest uncertainties in outdoor photometry is that caused by changing atmospheric conditions during measurements. Those contributing most to the uncertainty figure are changing visibility and scintillation.

A sizable error may result when visibility varies between the time of measurement of the item under test and the time of measurement of the reference light. If visibility is varying considerably, due to fog or rain, measurements should not be undertaken.

Variation of received light due to scintillation can increase the uncertainty of the resulting intensity figure in the same way as noise. This variation can be reduced by increasing the response time of the photometer or by using some averaging of the photometer output. However, care should be exercised when measuring flashing lights. Increasing the response time of the photometer may cause distortion of the measured flash profile. The response time used should be less than one tenth of the expected duration between the 50% intensity points of the flash. Several measurements should be made and an average of each flash profile can then be calculated.

Variation in ambient light, for instance when the measurement is being undertaken in daylight, can produce an error similar to a zeroing error. Care should be taken to ensure that readings taken from the photometer under ambient light conditions, i.e. with the item under test and reference light switched off, do not vary significantly.

5 Recording Environmental Conditions

A record should be made at the time of the measurement of the following environmental conditions:

- general weather;
- visibility;
- temperature; and
- relative humidity.

These data should be saved with the light range measurement data for the item under test. Visibility meters placed in the optical measurement path can be useful indicators during the hours of darkness.

6 Aligning the Telephotometer

Using a viewing sight, or similar apparatus, look into the optical path of the telescope and adjust the telescope alignment and focus until the item under test can be seen clearly in the centre of the eyepiece. The output aperture should then be adjusted so that only the item under test is visible.

The item under test should then be lit and allowed to come to full brightness. When viewed once more through the eyepiece care should be taken to avoid excessive glare to the eye. A filter may be inserted at the eyepiece to facilitate comfortable viewing. The goniometer table should then be turned through the desired angles of measurement to ensure that there is no obscuration of the light emitting surfaces by components in the optical path. When the image is satisfactory in all positions, the optical path output from the telescope should be directed to the photometer receptor.

7 Measurement Procedures for Outdoor Telephotometry

Ensure the photometer is switched on and warmed up. The received light from the item under test falling upon the receptor should be measurable on the photometer readout. The gain of the photometer may need adjusting until a satisfactory reading is obtained. To ensure that the reading obtained is caused by received light, the light path can be interrupted and the effect on the reading observed.

The item under test should then be extinguished and the photometer reading observed. If the reading is not zero, due to ambient light, a zero offset may be used to reduce the photometer readout in ambient light conditions. Care should be taken however, when ambient conditions are variable, not to allow the reading to go below zero unless the recording system is suitable.

Complete measurements of the angular and time dependency of the luminous intensity of the item under test, as outlined in 9.7.

Following measurement of the item under test, mount the reference light on the goniometer table, and ensure that it is in the same position relative to the photometer as was the item under test. Allow the output of the reference light to stabilise, in compliance with the reference lamp calibration data. Take at least two measurements of the luminous intensity of the reference light as soon after the measurement of the item under test as is possible.

The reference light should then be powered down (or baffled, depending on the calibration conditions) and further photometer readings of the ambient light (or ambient plus stray light) recorded. The resultant average value of the reference light minus ambient light (or ambient plus stray light) and associated uncertainties should be calculated and recorded.

A minimum of three complete measurements should be carried to obtain average and uncertainty values.

8 Additional Equipment for “In Situ” Measurement

8.1 Prisms and Prism Frame

For in situ measurements of large optical systems, a lighthouse lantern for example, it may not be feasible to mount the item under test on a goniometer table; nor may it be feasible to tilt the item. In these cases, the vertical beam profile may be measured by placing prismatic sheets on the focal plane of the item under test, to “tilt” the beam by refraction. Two sets of such prisms, each providing 0.5^o and 1.5^o deviation, enable measurements to be taken over $\pm 2^o$ in 0.5^o steps; a total of nine points on the vertical beam plot. A further step at $\pm 3^o$ is possible by the provision of a second set of 1.5^o prisms; for a total of 11 points. The relative spectral transmissivity of the prisms, singly and in combination, should be determined and recorded (see figure 31).

8.2 Reference Projector

For long-range measurements of high intensity beacons, a calibrated, high-intensity reference projector should be used as the reference light. The reference projector should be of comparable intensity, within two orders of magnitude, to the item under test.

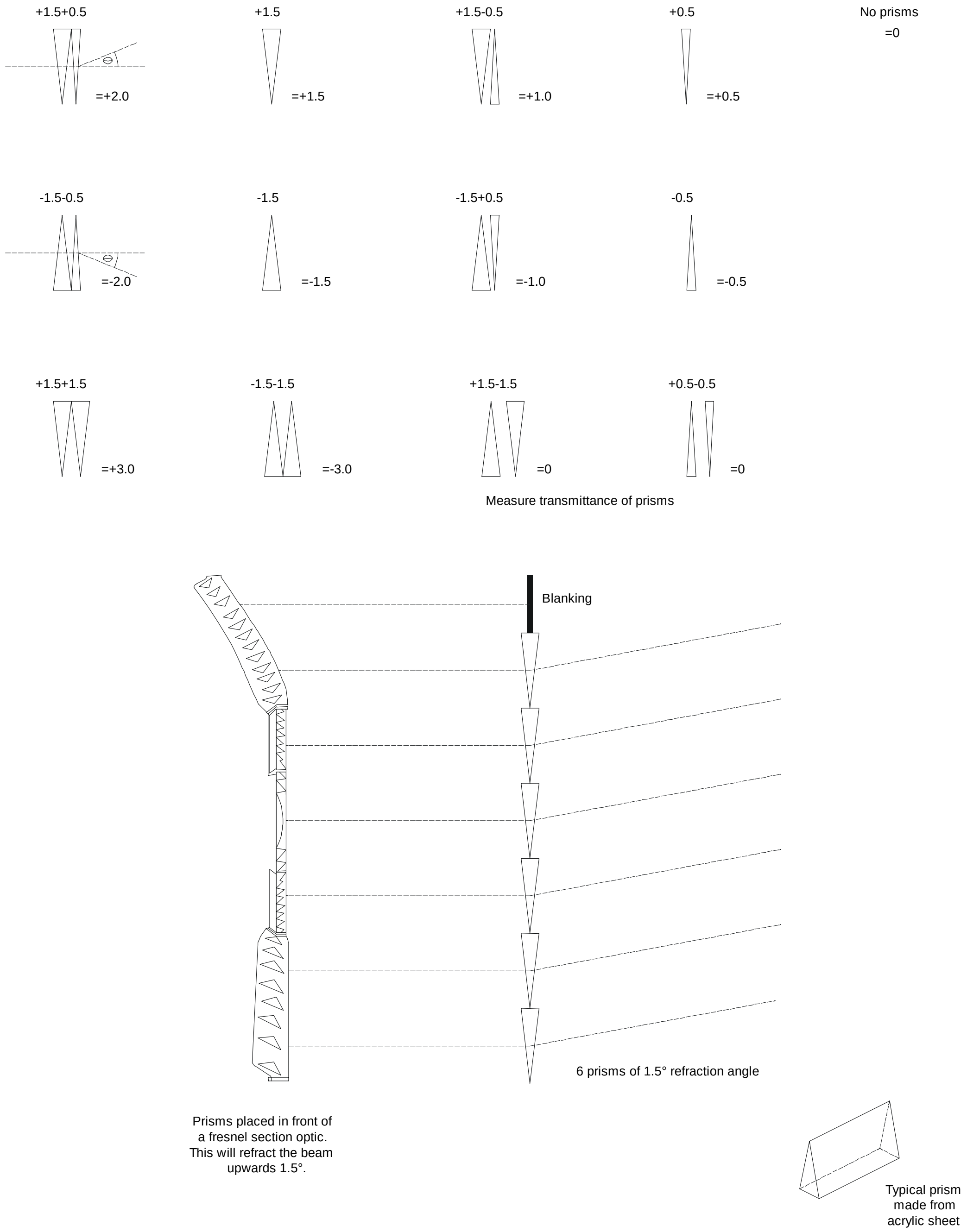


Figure 31 The use of Prisms to Divert a Beam through a Vertical Angle

9 Additional Procedures for “In Situ” Measurement

In situ measurements are generally conducted on existing lighthouse optics. Because measurement sites using telephotometry should be situated on land, it should be remembered that in situ measurements are usually only feasible in one or two directions within the zone of utilisation of the light. During the course of the measurements, the operational availability of the lighthouse may be affected. Appropriate navigational warnings should be raised.

9.1 Choice of Measurement Site

The first requirement when carrying out a field light measurement is to find a suitable measurement site. This should be a site where stable mounting of the photometric equipment is possible, preferably away from any adverse conditions of weather or unwanted interference from extraneous light sources. The whole of the optic to be measured should be clearly visible from the measurement site.

Calculations of the crossover distance of the optic being measured should be made to establish the minimum photometric distance. Once this minimum is established, a measurement site should be sought which is beyond the minimum photometric distance, and within plus or minus one degree of a line between the optic centre and the horizon. This vertical tolerance of two degrees is approximate and depends on the vertical beam profile of the light to be measured. The closer the measurement site is to the nominal beam centre, the less the measurement uncertainty.

9.2 Setting Up the Telephotometer

The iris of the telephotometer should be set to accept light from the optic being measured and the reference light. The field outside that of interest should be stopped. Daytime is the best time to set up the equipment because the field of view can be easily seen and any potential obstructions accounted for.

9.3 Setting Up the Lighthouse Optic

The lighthouse optic to be measured should be inspected and cleaned. The optic type and dimensions plus any manufacturer’s details should be noted, as should any faults or defects in its operation.

The optic should be outfitted with lamps that conform to design dimensions, rated power consumption, and rated lumen output. The light source should be positioned in the optic in accordance with the procedures established by the optic manufacturer and the Lighthouse Authority.

If the optic is a rotating type, with several light emitting axes, each one should be identified and numbered if not already done so by the manufacturer. This may be done by identifying a unique mark on the rotating part of the item under test (e.g. datum mark or optic door hinge) and numbering each beam or axis from there in the direction opposite to the direction of rotation.

9.4 Setting Up the Prism Frame and Prisms

Install the prism frame between the optic and the measurement site so as to include the maximum area of the lens (or lenses) as possible. Any remaining area of the emitting surface(s) should be screened to prevent light from the optic going past the outside of the frame in the direction of the measurement site (see figure 31). It should be noted that any blanked area would increase uncertainty of beam profile measurement as upper and lower reflectors/refractors may affect the beam shape.

9.5 Setting Up the Reference Projector

A reference projector should be installed on the outside of the lantern, e.g. on the gallery handrail, as close as possible to the optic and directed towards the measurement site. The path between the reference projector and the measurement site should be free from obstructions.

9.6 Carrying Out the Measurement

Measurements may commence as soon as conditions allow. Bear in mind that zero conditions are those of ambient light, if the ambient light level is varying significantly, e.g. because of clouds passing in front of the sun, measurement uncertainties will be increased. Most field light measurements will need to be carried out at night and in good weather.

On commencement, the reference projector should first be aligned so that its beam centre is directed towards the measurement site. The amount of variation in the reference light reading will give a good indication of the suitability of conditions.

Measurements with different prisms should then be carried out to ascertain the vertical beam profile. Each set of prisms is inserted and the flash profile(s) from the optic recorded. Each measurement set should contain a sample of reference light and ambient light. The range setting on the telephotometer should be recorded.

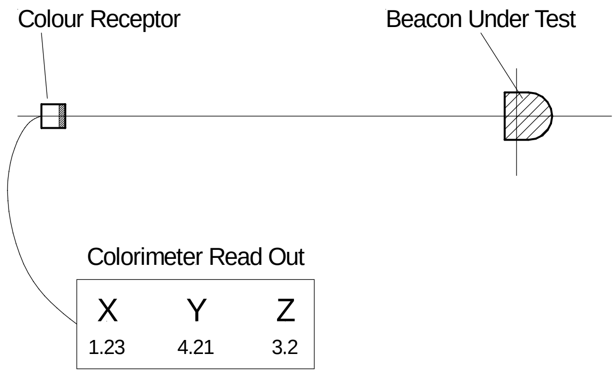
When all relevant prism positions have been recorded, the prisms, prism frame and screening should be removed. Flashes from the unobstructed optic should then be recorded along with reference light, ambient light and photometer settings. At least three recordings of each flash profile should be taken.

A minimum of three complete measurements should be carried out for each complete character to obtain average and uncertainty values. Dominant measurement uncertainties are likely to be due to variation in light path conditions and reference light alignment. Extreme measurement distance requires a large number of repeated measurements to reduce uncertainty.

Annex 4 – Detailed Measurement Method Tristimulus Colorimetry

1 Measurement Geometry

The standard arrangement for tristimulus colorimetry is exactly the same as for photometry except that the photometric receptor is replaced by a colorimetric receptor.



For light sources with a narrow intensity distribution the distance between the beacon and the colorimeter has to be increased to ensure the required high uniformity. For the optical input at the receptor, diffusers are necessary so that the light to be measured is spread over the three photodetectors with high uniformity.

To test the correct arrangement the colorimeter should be rotated in the axis. The output should not change during the rotation.

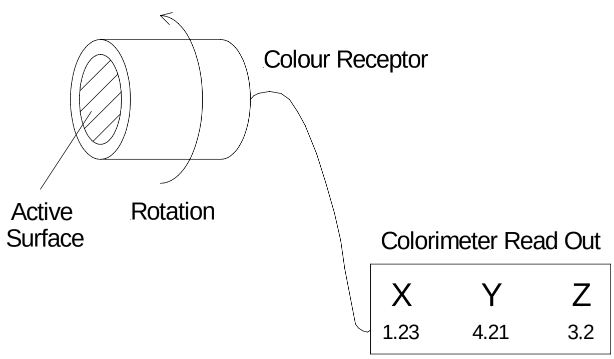


Figure 32 Simple Test for Setting Up Colorimeter

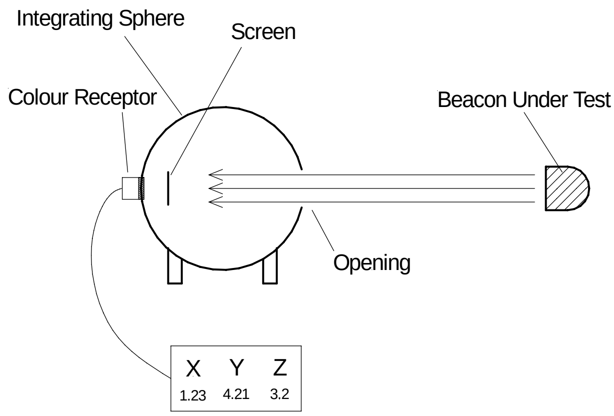
Because of the size of the area to be illuminated and the need for high uniformity, the use of a diffuser requires a relatively large measurement distance. However, most tristimulus colorimeters are fairly insensitive and the requirement for a large measurement distance precludes their use for lights with low intensities. To improve the performance of a tristimulus colorimeter, an integrating sphere may be used. The inside of the sphere should be spectrally neutral.

Whatever method is used for obtaining a high uniformity of illuminance at the input to the colorimeter, care must be taken to ensure that any spectral distortion is accounted for.

1 Application 1

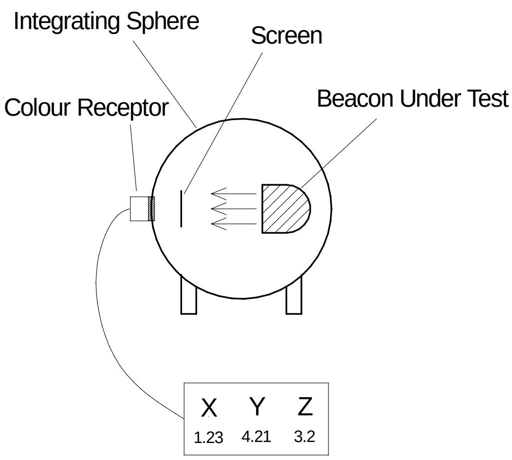
In application 1 a small integrating sphere with an aperture is used.

The light beam that reaches the aperture is measured. The integrating sphere acts as a diffuser for the light. A baffle is necessary to avoid direct light on the colorimeter. A calibration for illuminance and the calculation of luminous intensity is possible (the aperture acts as a photodetector).



2 Application 2

The second application requires a large integrating sphere and the lantern in test is positioned inside the sphere. The average of all light is used for measurement of the colour functions. A baffle is necessary to avoid direct light on the colorimeter. A calibration for luminous flux is possible.



3 Spectrum

The spectral response of each photodetector should approximate the colour matching functions x, y, z. The residual error between the spectral response (x_C, y_C, z_C) and the colour matching functions (x, y, z) should be published in relative values for the range 380 nm to 780 nm in intervals of 10 nm:

$$r_x = \frac{\bar{x}_C - \bar{x}}{\bar{x}} \qquad r_y = \frac{\bar{y}_C - \bar{y}}{\bar{y}} \qquad r_z = \frac{\bar{z}_C - \bar{z}}{\bar{z}}$$

The ultraviolet ($\lambda < 380$ nm) and infrared ($\lambda > 780$ nm) spectrum has to be suppressed to avoid errors.

In general it can be stated that the error increases when the light is near the infrared or ultraviolet. For many tristimulus colorimeter it is useful to reduce the nominal spectral range when the errors get to high.

Annex 5 – Detailed Measurement Method
Spectroradiometry

1 Measurement Geometry

For the optical input, diffusers are necessary so that the light to be measured is spread over the input aperture with high uniformity. For light sources with a narrow intensity distribution the distance between the source and the spectroradiometer has to be adequate to ensure the required uniformity.

To test the correct arrangement the input aperture or the light under test should be rotated in the axis. The spectroradiometer output should not change as a result of the rotation.

The use of a fibre-optic bundle to couple light from the input aperture to the spectroradiometer is common.

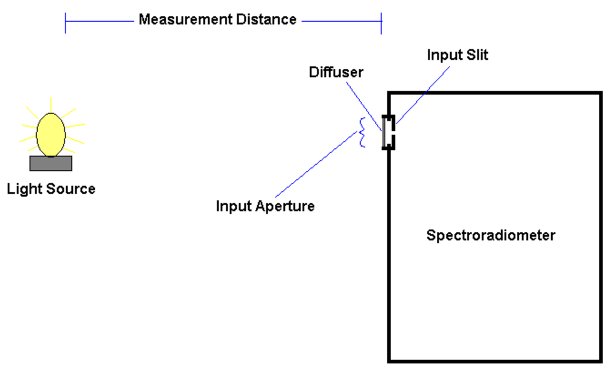


Figure 33 Spectroradiometer Measurement Geometry

2 Calibration / Characterisation

In order to calibrate or characterise the spectroradiometer system, it is usually necessary to use a spectral radiance or irradiance standard lamp. This is a lamp that has been calibrated throughout the spectrum being used usually in milliwatts of power per nanometre of wavelength. The calibration file of such a lamp is usually arranged as two columns of data, wavelength and radiant power (or irradiant power per area). It is important that the resolution of the lamp calibration matches that of the measurement to be taken. Therefore, if a measurement is to be taken of a light source from 380nm to 780nm in 10nm intervals, the standard lamp should also be calibrated over that range at that interval.

The standard lamp should be placed at a distance from the measurement aperture, as specified in the lamp calibration certificate. Power should be applied as specified in the lamp calibration certificate. Then, after allowing the lamp to stabilise, a reading taken with the spectrometer. If a spectroradiometer uses charge-couple devices (CCD array) as the final detector, a note should be made of the integration period over which the spectroradiometer is taking measurements.

Once the results of the measurement are obtained, it should be compared to the similar array of data given in the standard lamp calibration certificate. By dividing the calibration figure at each wavelength with the figure obtained for that wavelength in the measurement, a correction file can be obtained. This correction file can be used to correct measurements of other light sources. If the spectroradiometer uses a CCD array, the calibration factor should include the integration time as a divisor, thereby normalising the value to one second.

Wavelength (nm)	Calibration Radiance (mW/nm)	Measured Radiance (raw)	Calibration Correction Factor
380	2.317801	1.3450	1.723272119
390	2.789061	1.8290	1.524910334
400	3.306898	1.1954	2.766352685
---------------------	---------------------	---------------------	---------------------
750	28.443800	34.5560	0.823121889
760	28.814490	33.2240	0.867279376
770	29.052000	31.5550	0.920678181
780	29.287460	30.3000	0.966582838

Figure 34 Example of a Spectroradiometer Correction File

Some spectroradiometer systems have the ability to carry out corrections automatically, so that the results of the measurement show the corrected radiance or irradiance figures.

3 Carrying Out the Measurement

Once the system is calibrated or characterised, the light source under test should be placed at the same distance away from the measurement aperture as the standard lamp. If, due to size constraints, the distance needs to exceed that of the standard lamp, the distance should be recorded and used to factor the measurement results using the inverse square law. However, if the measurement results are only going to be used to determine the colour of the light, no distance factoring is necessary and a relative irradiance will suffice.

The light source under test should then be lit and allowed to stabilise. Once stabilised, a measurement of the spectrum can take place recording the radiance or irradiance at each wavelength. The resultant measurement data can then be corrected using the spectroradiometer correction file. For instrument using a CCD array, normalisation of the integration time to one second should be carried out.

4 Results

In order to obtain a spectral power distribution, further corrections may be necessary to correct differences in measurement distance. If an irradiance standard was used, it will be necessary to convert irradiance to radiance by multiplying the irradiance figures by the square of the measurement distance in metres. It may also be necessary to factor for wavelength if the units quoted in the standard lamp calibration certificate are different to the wavelength interval sampled during the measurement. For instance, if the standard lamp is reported in units of mW/nm, the amount of power in a measurement sample 10nm wide would be ten times that. The following formula may be used:

$$Rad = Irr \times d^2 \times WLres$$

Equation 19

where: *Rad* is the Radiance in Watts (W);
Irr is the irradiance in Watts per cm2 per nanometre (W/cm2/nm);
d is the measurement distance in metres (m); and
WLres is the wavelength resolution or bandwidth of the each sample.

For example, the 29.28746 mW/cm^2/nm shown in figure 34 relates to a standard lamp measured at 0.5 metres with a spectral resolution of 10nm. Therefore, the amount of power per 10nm would be:

$$29.28746 \times 0.5^2 \times 10 = 73.21865 mW \,;$$

this being the amount of radiant power in the 10nm sample between 770nm and 780nm.

5 Converting Spectral Data to Colour and Chromaticity

The resultant SPD, whether in absolute or relative power, can be converted to colour values of X, Y and Z (see 6.4) by multiplying the power data array by the standard colorimetric observer colour functions $\bar{x}$, $\bar{y}$ and $\bar{z}$. The resultant arrays should then each be summed to give three single values of X, Y and Z.

Wavelength (nm)	Lamp SPD	Standard Colorimetric Observer			xbar*lamp	ybar*lamp	zbar*lamp
		xbar	ybar	zbar			
380	1.57846000	0.00136800	0.00003900	0.00645000	0.00215933	0.00006156	0.01018107
385	1.73321000	0.00223600	0.00006400	0.01054999	0.00387546	0.00011093	0.01828535
390	1.89965000	0.00424300	0.00012000	0.02005001	0.00806021	0.00022796	0.03808800
395	2.07293000	0.00765000	0.00021700	0.03621000	0.01585791	0.00044983	0.07506080
400	2.25985000	0.01431000	0.00039600	0.06785001	0.03233845	0.00089490	0.15333085
-------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------
740	22.47410000	0.00069008	0.00024920	0	0.015508895	0.005600546	0
745	22.69190000	0.00047602	0.00017190	0	0.010801828	0.003900738	0
750	22.87750000	0.00033230	0.00012000	0	0.007602218	0.0027453	0
755	23.06570000	0.00023483	0.00008480	0	0.005416428	0.001955971	0
760	23.19950000	0.00016615	0.00006000	0	0.003854609	0.00139197	0
765	23.38130000	0.00011741	0.00004240	0	0.002745269	0.000991367	0
770	23.52330000	0.00008308	0.00003000	0	0.001954204	0.000705699	0
775	23.69320000	0.00005871	0.00002120	0	0.001390945	0.000502296	0
780	23.80550000	0.00004151	0.00001499	0	0.000988165	0.000356844	0
					X	Y	Z
				Sum	273.1761517	254.6582997	105.3921376

Figure 35 Table of Results showing Conversion from SPD to X, Y, Z colour

To convert the X, Y and Z colour values to conform to the CIE 1931 chromaticity diagram, equations 4 and 5 (see 6.4 above) should be used:

$$x = \frac{X}{X+Y+Z} \quad \text{and} \quad y = \frac{Y}{X+Y+Z}$$

Using the X, Y, Z results from figure 35, the resultant values of x and y are 0.4314 and 0.4022 respectively, when rounded off to four decimal places. This is in the IALA white preferred region.

6 Converting Spectral Data to Luminous Intensity

The measured SPD can be converted to luminous intensity by applying the standard photopic observer function *V(λ)* to the measured data and summing the result. A lumen per Watt factor of 683 is then applied to achieve a luminous intensity value.

Wavelength (nm)	**Lamp SPD (mW)**	**Standard Photopic Observer *V(λ)***	**Combined Value**
380	1.57846000	0.000039	0.00006156
385	1.73321000	0.000064	0.00011093
390	1.89965000	0.00012	0.00022796
395	2.07293000	0.000217	0.00044983
400	2.25985000	0.000396	0.00089490
-------------	-------------	-------------	-------------
740	22.47410000	0.0002492	0.005600546
745	22.69190000	0.0001719	0.003900738
750	22.87750000	0.00012	0.0027453
755	23.06570000	0.0000848	0.001955971
760	23.19950000	0.00006	0.00139197
765	23.38130000	0.0000424	0.000991367
770	23.52330000	0.00003	0.000705699
775	23.69320000	0.0000212	0.000502296
780	23.80550000	0.00001499	0.000356844
		Sum	273.1761517
		Factor mW to cd	683/1000
		Luminous Intensity (cd)	**186.6**

Figure 36 Table of Results showing Conversion from SPD to Luminous Intensity

Annex 6 – Example of a Test Report

In this example, a typical indoor light measurement is featured. The contents and layout are only for guidance, for other types of measurement contents may differ. For instance, an outdoor light measurement may include environmental conditions for each test carried out if they were outside the quoted indoor range of temperature, relative humidity etc. There may also be the need to include further information if it is specifically requested, such as the measured average power consumption when exhibiting a certain flash character. On the other hand, minimal information, such as the nominal range at a certain character, may be all that is required by the person requesting the measurement. Whatever the form of the test report issued or published, it is important to give sufficient information for the results to be fully understood and not taken out of context.

The names and general information quoted in this example are fictitious and do not knowingly refer to any person or entity.

LABORATORY PHOTOMETRY TEST REPORT

Test Report No: 248 **Prepared by:** J. Bloggs

Date of Issue: 19 February 2001 **Approved by:** H. Houdini

Commercial in Confidence Statement (if required)

INTRODUCTION

The Acme Buoy Company of Newtown, Westshire requested the Laboratory to carry out tests on its prototype buoy beacon type ABB1. Assessment of omnidirectional light output and colour conformance were required as well as the flash profile of a specified character. These tests were carried out in accordance with the IALA Recommendation for the Photometry of Marine Aids-to-Navigation.

EQUIPMENT UNDER TEST

The equipment under test was an Acme Buoy Beacon type ABB1, serial number 0001 received on the 18th February 2001. The beacon, an omnidirectional marine aids-to-navigation signal light coloured red, was a prototype device not yet in final production. The light source was a cylindrical array of LEDs powered by an integral Acme LED power and flasher unit. The supply voltage range of the equipment was 11 - 16VDC with a maximum current requirement of 2A. The beacon was hermetically sealed with supply connections via an integral two-metre cable. Selection of the flash character was carried out via a remote infra-red controller, type ABC1, supplied with the beacon.

OBJECT

The object was to measure the horizontal and vertical profiles of the Acme Buoy Beacon type ABB1 supplied together with a flash profile of the character Iso 1s. A measurement of chromaticity was also required to ensure conformance of the beacon to the correct IALA colour region.

TEST CONDITIONS

Photometric tests on this beacon were carried out using standard laboratory photometry in the darkened goniophotometer room of the Sodor Laboratory where ambient conditions of 20°C temperature and 61% relative humidity prevailed. The light path was folded by a one metre square front silvered flat mirror. The overall folded light path length for goniophotometry and flash photometry was 20m. Established written procedures for light range measurement were followed. Spectroradiometric tests were carried out over a light path of 0.5m in a direction 180 degrees from the photometric light path.

TEST METHOD

The beacon was inspected and found to be in good condition. It was placed in the centre of the goniometer table, with its light centre on the tilt axis and the datum mark aligned with the direction of measurement. The goniometer table was set to level and the beacon was set to level on the table by means of its integral bubble level. The beacon was firmly secured in this position by means of the integral mounting lugs and supplied with 12.00VDC from a stabilized linear power supply. The controller was utilized to force the beacon to exhibit a fixed light and, when this condition was attained, the beacon was left to stabilise for twenty minutes. Supply voltage and current was continuously monitored at the input to the supply cable.

Goniophotometry

The goniometer table was rotated about its vertical axis clockwise from the datum to an x value of -180^o. A plot was then carried out of the horizontal plane from $x = -180^o$ to $x = +180^o$ by rotating the table in an anticlockwise direction and recording the photometer reading every 0.5^o. This plot was carried out with the table level, i.e. at $y = 0^o$.

The table was returned to datum and tilted to a position of $y = -10^o$. A plot was then carried out of the vertical beam profile through the datum (at $x = 0^o$) from -10^o to $+10^o$ by tilting the table about its horizontal axis and recording the photometer reading every 0.1^o. This process of plotting the vertical beam profile was repeated at $x = +120^o$ and $x = -120^o$.

Spectroradiometry (at x = 180, y = 0)

Upon completion of goniophotometric tests, whilst the beacon was in the datum position on the goniometer table and exhibiting a fixed light, a plot of the spectral output of the beacon was carried out using a monochromator type spectroradiometer. The slit aperture was placed 0.5m away from the beacon, level with the light centre, at $x = 180^o$. An average plot of the visible spectrum between 380nm and 780nm at 1nm intervals was obtained.

Flash Photometry (at Datum x = 0, y = 0)

The beacon controller was used to change the character exhibited by the beacon from fixed to Iso 1.0s (a contact closure of 0.5 seconds followed by a contact opening of 0.5 seconds). At that character, the beacon was allowed to stabilise for twenty minutes. The output of the photometer was then input to the event logger and a plot of luminous intensity vs time was carried out for ten consecutive flashes of the beacon. Averages of five alternate flashes were taken to obtain the plot shown in the graph.

TEST EQUIPMENT

Instrument	Maker	Type	Serial No	Last Cal Date
Photometer	Lite Lab	LLP042	C308-3	03.09.00
Reference Lamp	Althorpe	12.75V 25.00A	R21A79 443.4cd	09.12.00
Voltmeter	Meterex	2001	50518866	23.04.00
Ammeter	Meterex	2002	50518867	23.04.00
Power Supply	Powerlab	SP 060	C309A	14.06.00
Goniometer	Sodor Laboratory	Drawing No. 4321 version 02	N/A	01.02.01
Event Logger	Time systems	Maxi Log 2	368195	01.02.01
Spectroradiometer	SpecPal	SP6	S345981	31.05.00

RESULTS

The overall results of the measurements are shown below, plots of goniometry, spectroradiometry and flash photometry are shown on following pages.

Overall Results

Acme Buoy Beacon type ABB1, serial number 0001

Measurement Quantity	10th Percentile Fixed Intensity (cd)	Effective Intensity at Iso 1.0s (cd)	Vertical Divergence (degrees)	Flash Duration Δt (seconds)	Chromaticity by CIE 1931 Method		IALA 1977 Colour Region
					x	y	
Value	326	234	-4.5 +5.2	0.499	0.692	0.307	Red Preferred
Uncertainty	±19	±15	±0.05	±0.001	±0.002	±0.002	

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the appropriate coverage factor k, which corresponds to a coverage probability of approximately 95%. The standard uncertainty has been determined in accordance with the “Guide to expression of uncertainty in measurement”[9].

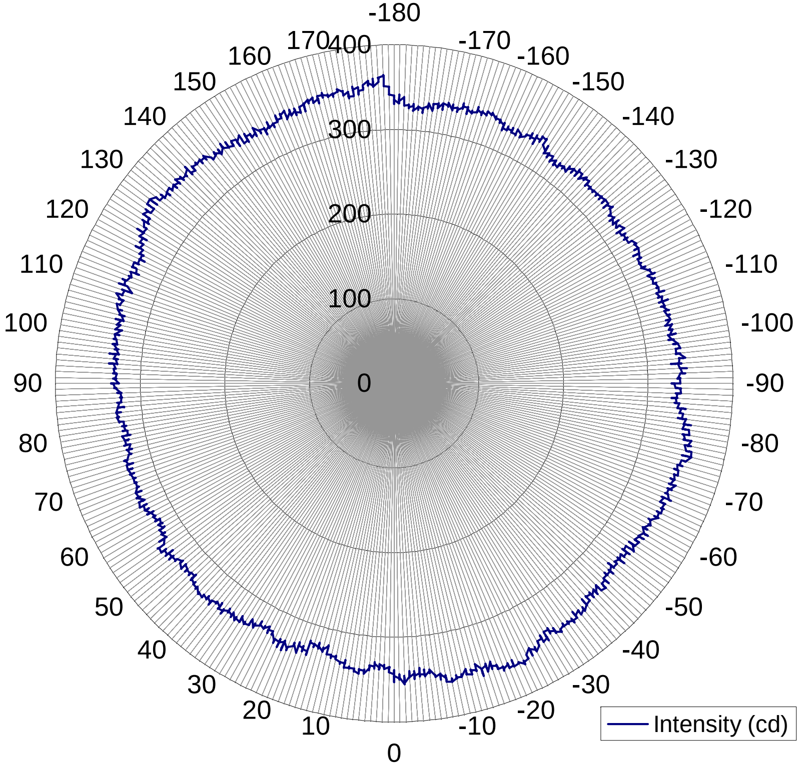
COMMENTS

1. When the beacon exhibited a fixed light with a supply voltage of 12.00VDC, the measured supply current was 1.91A ± 0.01A throughout the course of the measurement.
2. The flash profile is almost rectangular but the plot shows that intensity decreases slightly over the duration of the flash. However, the difference between the initial intensity of the flash, (345cd) and the fixed intensity plotted at x = 0 (329cd) is not great and lies within the uncertainty limits quoted.

SODOR LABORATORY TEST REPORT

Goniophotometry

Acme Buoy Beacon Type ABB1 s/n 0001



Polar Plot of Intensity vs Angle x

Operator Name:	J. Bloggs
Date of Measurement:	19.02.01
Time of Measurement:	14.20.20
Measurement Site:	Sodor Laboratory - Room 101

Results

	Value	Uncertainty +/-
Maximum Intensity (cd)	366	19
Minimum Intensity (cd)	317	19
10th Percentile Intensity (cd)	326	19

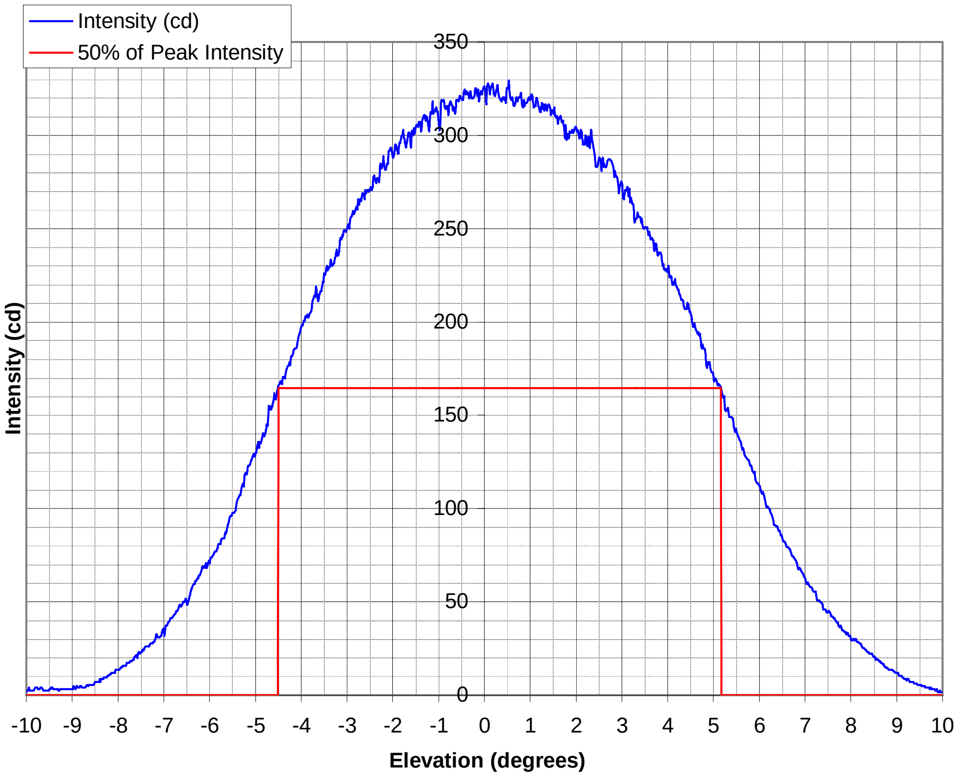
The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2.65 which corresponds to a coverage probability of approximately 95%.
The standard uncertainty has been determined in accordance with the "Guide to expression of uncertainty in measurement". For this goniophotometric measurement, uncertainty quoted is the largest of all the plotted data points.

Results of Azimuth Plot from x = - 180 to x = +180 at y = 0

SODOR LABORATORY TEST REPORT

Goniophotometry

Acme Buoy Beacon Type ABB1 s/n 0001



Operator Name:	J. Bloggs
Date of Measurement:	19.02.01
Time of Measurement:	14.22.09
Measurement Site:	Sodor Laboratory - Room 101

Results	Value	Uncertainty +/-
Peak Intensity (cd)	329	21
Divergence at 50% (degrees)	9.7	0.05

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2.65 which corresponds to a coverage probability of approximately 95%.
The standard uncertainty has been determined in accordance with the "Guide to expression of uncertainty in measurement". For this goniophotometric measurement, uncertainty quoted is the largest of all the plotted data points.

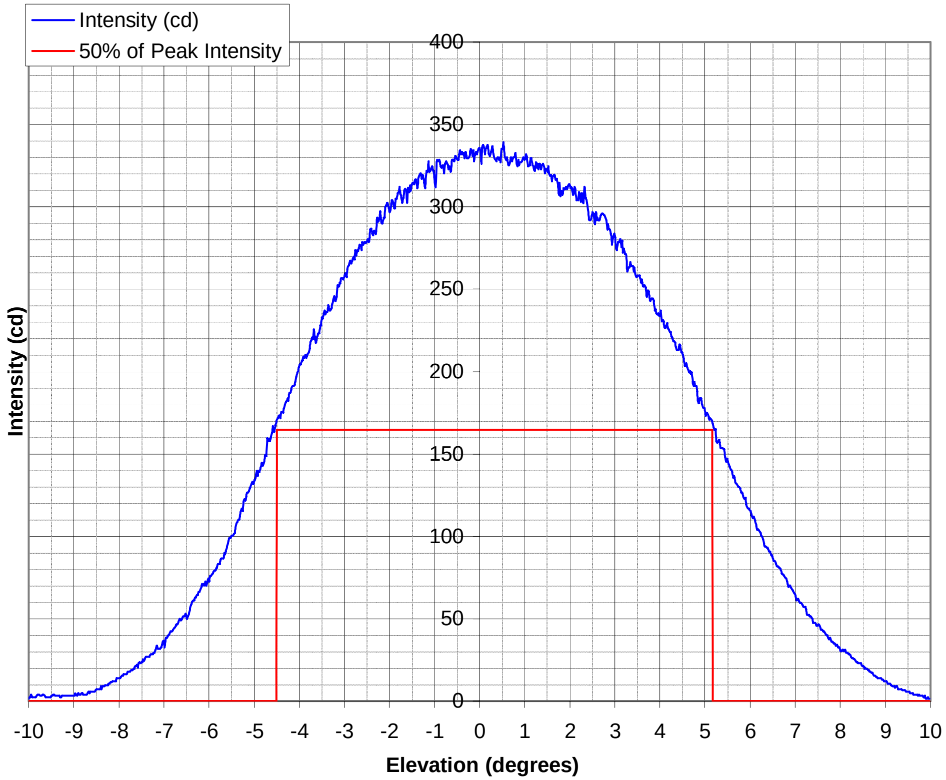
Cartesian Plot of Intensity vs Angle

Results of Elevation Plot from y = - 10 to y = +10 at x = 0

SODOR LABORATORY TEST REPORT

Goniophotometry

Acme Buoy Beacon Type ABB1 s/n 0001



Operator Name:	J. Bloggs
Date of Measurement:	19.02.01
Time of Measurement:	14.24.14
Measurement Site:	Sodor Laboratory - Room 101

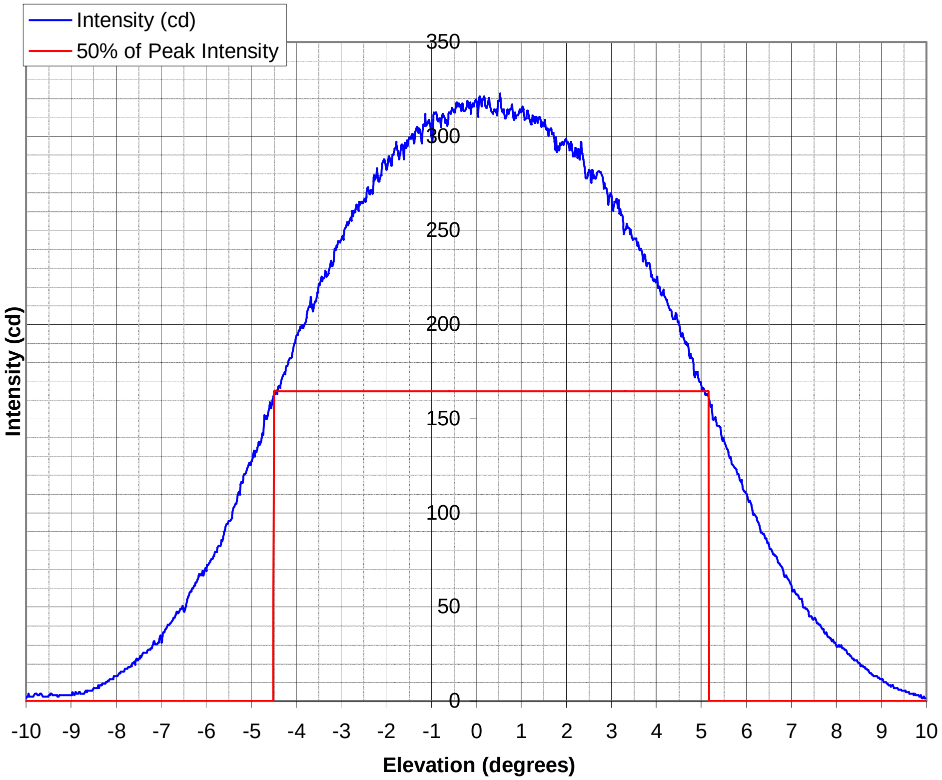
Results	Value	Uncertainty +/-
Peak Intensity (cd)	339	18
Divergence at 50% (degrees)	9.7	0.05

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2.65 which corresponds to a coverage probability of approximately 95%. The standard uncertainty has been determined in accordance with the "Guide to expression of uncertainty in measurement". For this goniophotometric measurement, uncertainty quoted is the largest of all the plotted data points.

Cartesian Plot of Intensity vs Angle

Results of Elevation Plot from y = - 10 to y = +10 at x = +120

SODOR LABORATORY TEST REPORT
Goniophotometry
Acme Buoy Beacon Type ABB1 s/n 0001



Operator Name:	J. Bloggs
Date of Measurement:	19.02.01
Time of Measurement:	14.26.53
Measurement Site:	Sodor Laboratory - Room 101

Results	Value	Uncertainty +/-
Peak Intensity (cd)	323	19
Divergence at 50% (degrees)	9.7	0.05

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2.65 which corresponds to a coverage probability of approximately 95%.
The standard uncertainty has been determined in accordance with the "Guide to expression of uncertainty in measurement". For this goniophotometric measurement, uncertainty quoted is the largest of all the plotted data points.

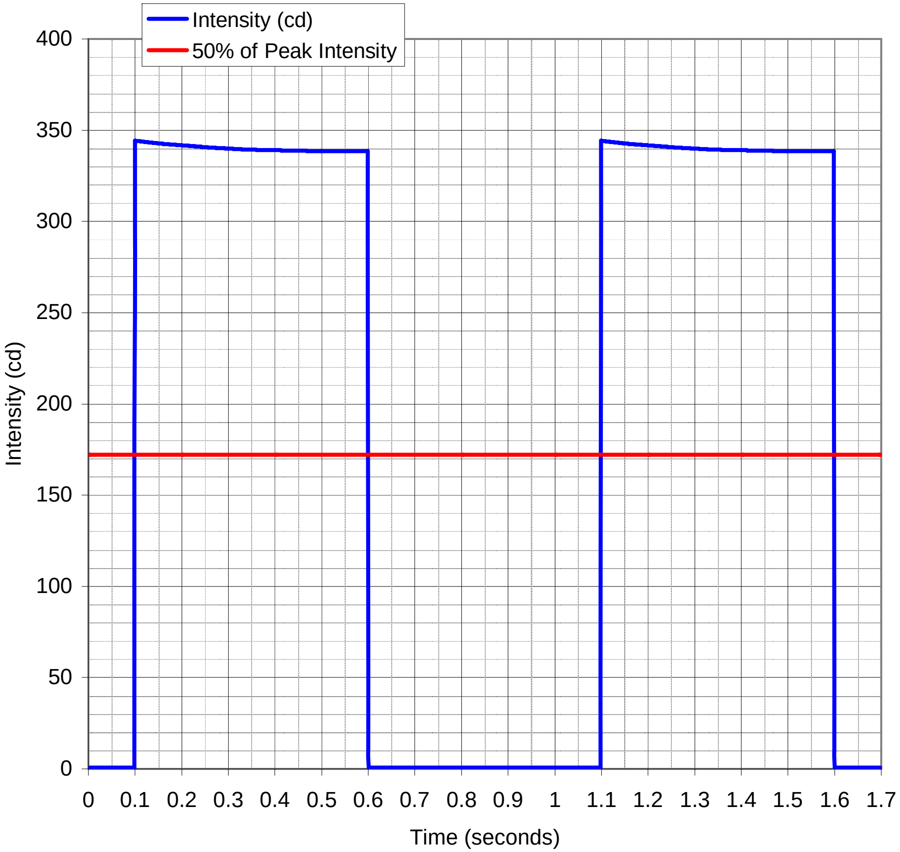
Cartesian Plot of Intensity vs Angle

Results of Elevation Plot from y = - 10 to y = +10 at x = -120

SODOR LABORATORY TEST REPORT

Flash Photometry

Acme Buoy Beacon Type ABB1 s/n 0001



Operator Name:	J. Bloggs
Date of Measurement:	19.02.01
Time of Measurement:	14.31.25
Measurement Site:	Sodor Laboratory - Room 101

Results

	Value	Uncertainty +/-
Peak Intensity (cd)	344	15
Effective Intensity	245	15
Flash Duration (seconds) (measured to 50% of peak)	0.499	0.001
Night-time Nominal Range (M) (as per IALA 1966)	7	

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2 which corresponds to a coverage probability of approximately 95%. The standard uncertainty has been determined in accordance with the "Guide to expression of uncertainty in measurement".

Cartesian Plot of Intensity vs Time

Results of Time Dependent Plot at x = 0, y = 0

Annex 7 – Example of a Condensed Test Report

(for intercomparison tests)

Report Number	**815**
Organisation	RDANH
Operator Name	Jørgen Royal Petersen
Measurement Site	Lightrange of RDANH, Korsoer
Date of Measurement	04-Oct-04
Equipment under test	Acme Buoy Beacon type ABB3
Light Source	12V 1.5W CC8
Lamp Changer	Acme 6-pos
Flasher type	Acme F3
Temperature (°C)	23
Relative Humidity (%)	65
Datum of the equipment under test	centre of photocell – beacon level
Supply Voltage (V)	12.4
Lamp Voltage (V)	11.95
Current Load (A)	0.12
Consumption of Energy (W)	1.44
Burn-in time before measurements (h)	0.3
Measurement Distance (m)	12
Scale Photometer	10
Type of Plot	Vertical (Elevation)
Comments	none
Measured values (divided by comma)	deg, cd
1	-10,17.712
2	-9.9,17.856
3	etc.

Annex 8 – Example of a Photometry Uncertainty Budget

This example of an uncertainty budget is meant for guidance only. It has been compiled in accordance with ISO Guide No. 2 [9] and incorporates current methodologies. The model used is a simple one incorporating those inputs thought to have a significant effect on uncertainty. The model may change depending on the particular measurement method, measurement equipment or item being measured. For instance, if the same method and equipment shown in the example were used to measure a beacon with a tungsten filament lamp with a similar spectral output to that of the reference lamp, no spectral correction would be necessary. Furthermore, it can be seen from the uncertainty contributions shown in the example that the uncertainty of photometer gain has little influence on uncertainty and could possibly be excluded from the budget.

A separate uncertainty budget for each individual measurement process should be compiled if there is insufficient knowledge of the uncertainty of the result. For example, the spectroradiometer plot shown in the test report would have its own uncertainty budget for the evaluation of the spectral correction factor (SCF). This would include, as the model, the equation for determining SCF (see 4.21).

In general, if there is any doubt as to the significance of an uncertainty contribution, it should be evaluated, used if necessary or discarded if insignificant. A reduction in uncertainty should always be strived for and unnecessary sources of uncertainty should, wherever possible, be eliminated. Significant types of uncertainty and other limiting factors for two measurement methods are as follows:

Outdoor Photometry

Uncertainties:

- establishing and measuring beyond the minimum photometric distance
- stray and ambient light
- photometer calibration
- colour correction of photometer for red and green colours
- environmental conditions

Limiting factors:

- finding suitable dark real estate
- obtaining sufficient meter sensitivity at the minimum photometric distance

Zero-Length Photometry

Uncertainties:

- shape, accuracy and reflectance of parabolic mirror
- alignment and calibration of system
- stray and ambient light
- photometer calibration
- colour correction of photometer (plus mirror) for red and green colours

Limiting factors:

- cost and accuracy of parabolic mirror
- size of specimen optic is limited to size of mirror

Light Measurement Uncertainty

Example

Determination of luminous intensity of a light beacon by measurement of illuminance at a measured distance.

Procedure

A beacon is positioned such that its beam is projected onto the acceptance area of an illuminance meter (luxmeter) placed at a measured distance from the beacon. Five illuminance readings are taken of the beacon under test ($E_{x1\,-\,5}$). Ambient and stray light conditions are accounted for by occluding the direct light path between the beacon and the illuminance meter and taking further five readings ($E_{z1\,-\,5}$). These further readings are used as the baseline for the measurement such that E_x - E_z = $E_,$ where E is directly proportional to the luminous intensity of the beacon. Three measurements are taken of the distance between the beacon and the illuminance meter ($D_{1\,-\,3}$). When measuring luminous intensity against angular displacement, the beacon will be installed on a goniometer and five readings will be recorded for each incremented angular (goniophotometric) position. Five illuminance readings of ambient and stray light will be recorded before the goniophotometric process commences.

The illuminance meter spectral response does not exactly follow V(λ) and this can lead to a measurement error if the spectral output distribution of the beacon being measured and the light source used to calibrate the illuminance meter are different. If the spectra are different, a spectral correction factor (SCF) and its uncertainty should be determined separately and applied. If the spectra are similar, the V(λ) closeness of fit figure (f1') for the illuminance meter can be used as the measurement uncertainty associated with SCF, SCF itself being unity.

Measurement Model

$$\mathbf{I = (E_x - E_z).\ \ SCF\ .\ \ D^2}$$

Measurement Quantities

Output Quantity - Mean value of $I_,$ and uncertainty *u* (I), is the output quantity of the luminous intensity, in candelas, of the beacon under test.

Input Quantity 1 - Mean value of $E_{x,}$ and uncertainty *u* (E_x), is the input quantity of the illuminance meter reading in lux proportional to the beacon light output plus stray and ambient light.

Input Quantity 1 - Mean value of $E_{z,}$ and uncertainty *u* (E_z), is the input quantity of the illuminance meter reading in lux proportional to the stray and ambient light.

Input Quantity 2 - SCF, and uncertainty *u* (SCF), is the input quantity of the spectral correction factor determined separately.

Input Quantity 3 - D, and uncertainty *u* (D), is the input quantity of the measured distance between the beacon under test and the acceptance plane of the illuminance meter

Measurement Input Data

Inputs	Description	Readings	Data Handling	Value	Standard Uncertainty	Notes
E_{x1} Lux	Five raw illuminance meter readings of beacon (in lux - inc. stray and ambient)	8.44	Example result of five measurements Mean $E_x = (E_{x1} + E_{x2} + E_{x3} + E_{x4} + E_{x5})/5$ +/- $u\,(E_x)$ Lux	8.38	0.0214	Type A - normal distribution - standard uncertainty taken from 5 readings
E_{x2} Lux		8.36				
E_{x3} Lux		8.38				
E_{x4} Lux		8.32				
E_{x5} Lux		8.42				
E_{z1} Lux	Five raw illuminance meter readings of stray and ambient light (in lux - direct light path occluded)	0.10	Example result of five measurements Mean $E_z = (E_{z1} + E_{z2} + E_{z3} + E_{z4} + E_{z5})/5$ +/- $u\,(E_z)$ Lux	0.15	0.0245	Type A - normal distribution - standard uncertainty taken from 5 readings
E_{z2} Lux		0.20				
E_{z3} Lux		0.10				
E_{z4} Lux		0.20				
E_{z5} Lux		0.10				
E +/- 2.00%	Illuminance meter uncertainty quoted on calibration certificate				1.00%	Type B - normal distribution - expanded uncertainty from calibration certificate divided by the coverage factor (e.g. k = 2)
SCF = 1 +/- 0.03	Spectral correction factor - for illuminance meter		SCF +/- u (SCF) the standard uncertainty from separate measurement of spectral distributions (see BS667:1996)	1	1.50%	Type B - normal distribution - *Note: Provided the spectral output of beacon and illuminance meter reference are similar, u(SCF) can be the f1' figure and SCF made unity.*
D_1 metres	Three measurements of distance between beacon and illuminance meter	25.005	Example result of three measurements Mean $D = (D_1 + D_2 + D_3)/3$ +/- $u\,(D)$ metres	25.000667	0.002603	Type A - normal distribution - standard uncertainty taken from 3 readings
D_2 metres		25.001				
D_3 metres		24.996				
D +/- 2mm	Measuring device uncertainty quoted on calibration certificate or minimum resolution (e.g. 2mm)				0.001155	Type B - rectangular distribution - resolution of measuring device divided by *?3*

Sensitivity Coefficient (output : input)

Input No.	Derivation	Formula	Coefficient
c1	I/E_x	$= SCF\ D^2$	625.0333338
c2	I/E_z	$= SCF\ D^2$	625.0333338
c3	I/SCF	$= E\ D^2$	5234.65417
c4	I/D	= E SCF D	209.3805833

Uncertainty Budget

Input Quantity	Quantity Name	Symbol	Quantity Value	Standard Uncertainty $u_{\text{(input)}}$	Type of Evaluation	Degrees of Freedom $v_{\text{(input)}}$	Sensitivity Coefficient $c_{\text{(input)}}$	Uncertainty Contribution $u_{I(output)}$ cd
1	Beacon Illuminance	E_x	8.38	0.021354	A	4	625.0333	13.347060
				0.001194	B	infinity	625.0333	0.746308
2	Ambient & Stray Illuminance	E_z	0.15	0.024495	A	4	625.0333	15.310127
				0.001194	B	infinity	625.0333	0.746308
3	Spectral Correction Factor	SCF	1.00	0.015000	B	infinity	5234.65417	78.519813
4	Distance	D	25.0006667	0.002603	A	2	209.38058	0.545105
				0.001155	B	infinity	209.38058	0.241772
Outputs	**Beacon Intensity**	**I**	**5140.89917**		v_{eff}	**1891**	**Combined Uncertainty $u_{c(output)}$**	**80.0042**

Degrees of Freedom (ν_{eff}) and Coverage Factor (k)

ν_{eff} =	1891	from Welch-Satterthwaite	**note: should be >100 for coverage factor of 2**
k =	2	this is the coverage factor for 95% confidence from *t*- distribution chart	

Expanded Uncertainty

$U_{(output)} = k \cdot u_{(output)} =$ 2 x 80.0042 = 160.01 cd

Reported Result

Luminous Intensity of Beacon (I) = 5141 +/-160 cd

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k which corresponds to a coverage probability, or confidence, of approximately 95%. The standard uncertainty has been determined, as far as practicable, in accordance with ISO Publication No. 2 1993 "Guide to expression of uncertainty in measurement".

Comments

The following uncertainties have not been considered in this measurement process but may be considered if thought to give a significant contribution:

1. Effects of angular alignment (usually cosine related)
2. Effects of temperature on measurement of distance and illuminance meter performance (from calibration certificate)
3. Effects of long term drift (over time, the calibration certificates and measurement data can be used to provide an assessment)

References

1. IALA E-122: "Recommendation for the Photometry of Marine AtoN Lights", 2001
2. SIRA: "Practical Approach to Uncertainties in Measurement", 2002
3. CIE TC 2-43: "Determination of Measurement Uncertainties in Photometry", Expert Symposium 2001
4. ISO Publication No. 2: "Guide to the Expression of Uncertainty in Measurement", 1993

AISM Association of Internationale de Signalisation Maritime IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

DRAFT

IALA Recommendation E-200-4

On

Marine Signal Lights

Part 4- Determination and Calculation of Effective Intensity

Edition 0.1

December 2005

20ter, rue Schnapper, 78100
Saint Germain en Laye, France
Telephone +33 1 34 51 70 0 Telefax +33 1 34 51 82 05
E-mail - iala-aism@wanadoo.fr Internet - http://iala-aism.org

Recommendation on XXX [Title Here]

(Recommendation [leave number blank, to be filled by IALA Secretariat])

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 [to be reviwed by Secretariat - for example -];

RECOGNISING ALSO that [to be reviewed by Secretariat - for example];

RECOGNISING FURTHER that [to be reviewed by Secretariat - for example -];

NOTING the [as above];

NOTING ALSO that;

NOTING FURTHER that;

CONSIDERING that to be reviewed by Secretariat - for example.

ADOPTS the [name of document] in the annex of this recommendation; and,

RECOMMENDS that National Members and other appropriate Authorities providing marine aids to navigation services [action to be taken].

* * *

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
August 2005 [example only]	Section 3.4; Tables 1-4;	

Annex

Title of document [Ariel 16, centred, bold, 9 pts before, 3 pts after]

1 INTRODUCTION [Heading 1 Ariel, 14, bold, capitals, spacing 12 pt before, 6 pt after, automatic outline numbering]

[anchor the document in regulations / documentation]

1.1 Background

[provide any background information required to ensure complete understanding of the document]

The recommended way of determining the intensity of the beam is by direct photometric measurement on a suitable measuring range as referred to in E200-3.

Methods of calculating the "effective intensity" of a light from data on the variation of instantaneous luminous intensity with time, as measured by the methods described in E200-3.

2 Scope / Purpose

The Scope/Purpose of the Recommendation is to describe how to determine or calculate . For flashing lights exhibiting flashes* of short duration, an effective luminous intensity, less than the maximum of measured intensity during the flash, is to be derived, using knowledge of the response of the human eye to short flashes. This effective intensity is to be used in the calculation of luminous range.

3 Definitions

Definitions are referenced to the IALA Dictionary and are listed in Appendix II.

The International Association of Lighthouse Authorities makes the following recommendations for the calculation of the effective intensity of a rhythmic light:

(i) For rhythmic lights in which flashes are exhibited at any rate up to 300 flashes per minute, the effective intensity of a flash is to be calculated using the method of Schmidt-Clausen.

(ii) 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.

(iii) If, and only if, it is impossible to measure the variation of instantaneous intensity with time, the effective intensity may be calculate from

$$I_e = \frac{I_0 \tau}{a + \tau}$$

where
I_0 is the peak instantaneous intensity during the flash
τ is the duration of the flash calculated as described in Ref.1, Section A.6
a is obtained from the following table:

	For observation by night	For observation by day
For flashes produced by blanking or switching	a = 0.2	a = 0.1
For flashes produced by rotating optical apparatus	a = 0.3	a = 0.15

The limitations that apply to effective intensities so obtained are reprinted below from Ref.1:
In these circumstances, the figure of intensity shall not be published but shall be applied to the table of Appendix IV of the IALA publication "Recommendation for the notation of luminous intensity and range of lights"[3]*. 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, the table of Appendix IV of the IALA publication "Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day"[4] *may be used in a similar way.*

(iv) For repeated flashes at a rate above the fusion frequency, intended to simulate continuous light, the steady-state effective intensity is to be determined by the application of Talbot's Law.

Note. For groups of flashes of group duration less than about 0.5 s, Talbot's Law is likely to over-estimate the effective intensity.

SECTION C

THE EFFECTIVE INTENSITY OF A RHYTHMIC LIGHT

1. INTRODUCTION

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 in assessing the apparent luminosity of the 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 threshold*. In the present Section, 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 lighthouse engineering, 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:

(a) Young observer with normal vision.
(b) The light seen in foveal vision and at chromatic threshold.
(c) Subtense angle of light source at the eye of the observer ≤ 1′.
(d) 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 an seasonal effects and on weather conditions. For the effect of such variations on the threshold of illuminance for vision of steady lights, see Ref. [2].

The effective intensity deduced may be applied to determine the luminous range of the light, using the methods laid down in Ref. [1], and in particular may be used to determine the nominal range of the 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 Method I, by A in the Method II and by *a* in the Method III. (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 [21] for the effective intensity I_e of flashes of rectangular form, viz $\frac{I_e}{I_O} = \frac{\tau^{m}}{a + \tau}$ where I_0 is the intensity of the flash at maximum and τ 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 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.*

2. THE CONCEPT OF EFFECTIVE INTENSITY OF A FLASH

In the case of a fixed light*, the measurements of E200-3 can supply all the information required for the prediction of performance. If, however, the light source is flashing or occulting*, or if the 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 which must be used when calculating the range of the light in any given atmospheric conditions.

3. THE EVALUATION OF EFFFECTIVE 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 E200-3, 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 [21]. 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 [22] into the Method III described below. The Blondel-Rey-Douglas formula has been widely used and has given satisfactory results in practice. In Ref. [23] it is shown that results obtained by the three 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 national authorities should determine which of the methods they will apply; that each should apply; only one method consistently; and that the method applied should be clearly stated.*

> *The differences of result by the three methods, for certain specific flash forms approximating forms commonly encountered in practice, can be seen in Tables 1 and 2 (pages 46-48). Rectangles and trapezia approximately represent the flashes from eclipsed lights; sine-squared and Gaussian curves approximately represent the flashes from rotating beams; the curves of Table 2 approximately represent the flashes from switched electric lights on from mantle burners*. For further tables extending to other flash forms, as well as for tables of explicit solutions for effective intensity for simple flash forms, see Ref [23].*

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_0). Accurate measurements of I_o for flashes of about one millisecond or less in duration present problems, as discussed in E200-3.

3.1. METHOD I — THE METHOD OF SCHMIDT CLAUSEN [24, 25, 26]

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

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

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

$$I_e = \frac{J}{C + \frac{J}{I_o}} \quad (1)$$

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.*

In this form the method is convenient for use in evaluation of the effective intensity of short flashes produced by electronic flash tubes*, for which J can be measured directly. It is to be noted, however, that the peak intensity during the flash, I_o, has also to be measured.
For longer flashes, such as those produced by revolving beams, it may be more convenient to express effective intensity in the following form:

$$I_e = \frac{I_o \tau}{\frac{C}{F} + \tau} \qquad (2)$$

where τ = total duration of the flash

F = the Schmidt-Clausen form-factor defined by

$$F = \frac{\int_{t_1}^{t_2} I(t).dt}{I_0(t_2 - t_1)} \qquad (3)$$

where t_1 = time of commencement of the flash
t_2 = time of cessation of the flash
so that

$$\tau = t_2 — t_1$$

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 (Fig. 2).

Fig 6
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, τ becomes negligible in comparison with C/F and equation (1) becomes

$$I_e = \frac{J}{C} \qquad (4)$$

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).
The expression (2) above can be readily represented by a simple electrical resistance circuit analogue. Certain countries have found it useful to develop additional circuit elements so that effective intensity may be derived for a wide range of values of background luminance and regular size of light source [27]. The variations of these parameters are outside the scope of the present document.
Specially-constructed "slide-rules" have also been developed for these calculations.
The use of a digital computer makes the calculations very simple. Generally it is convenient to evaluate J from the measured values of I (t), using any convenient standard integration programme. I_e is then calculated from equation (1) above.

1. THE PROBLEM OF REPEATED FLASHES

The method of Schmidt-Clausen can be applied only to single flashes. Although adequate experimental evidence is lacking, it is generally accepted that rapidly-repeated flashes may produce an effective intensity somewhat higher than that of a single flash of the same kind.

In the "Recommendations for the rhythmic characters of lights on aids to marine navigation", May 1979[2], 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. It is

considered that, for rates up to 300 flashes per minute, the calculation of effective intensity by the application of the Schmidt-Clausen method to a single flash will be adequate.
It is recognized, however, that steady lights or long flashes may be simulated by rapidly-repeated flashes of very short duration recurring at rates in excess of the fusion frequency. For these, the intervals of darkness between flashes are not perceived and the effective intensity is obtained by the application of Talbot's Law (see below).

2. TALBOT'S LAW FOR RAPIDLY REPEATED FLASHES

The effective intensity of a train of identical flashes of any form repeated at a rate exceeding the fusion frequency is the average intensity taken over one or more complete periods. If the integrated intensity of the flash is

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

as previously, and the period of repetition is T, the effective intensity is

$$I_e = J/T$$

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.

3.2 METHOD II — THE METHOD OF ALLARD [28]

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

$$\frac{di}{dt} = \frac{I(t) - i(t)}{A} \qquad (5)$$

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".

Fig 7
For practical calculations under the reference conditions of night-time observation, A is to be taken as 0.2 second.
Solutions of equation (5) yield values of I (t) at each instant during and after the course of a flash (see Fig. 3). 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 (5) 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 adapted to surrounding light on the bridge of a vessel.

The effective intensity I_e is the maximum value of i (t) during the duration of the flash.
An explicit solution of equation (5) may be obtained in integral form ([1]). From this it may be seen that, for flashes of very short duration, the effective intensity becomes:

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

where J = integrated intensity, as defined in Section C.3.1. 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 (5) 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. It is not considered, however,

that an analogue circuit of this type can be readily constructed in practice to give results of sufficient accuracy. The use of a digital computer is therefore recommended. The problem is then one of finding the function i (t) as a solution of the differential equation given

([1]) The explicit solution of equation (5) is

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

where t_1 is a time before which there is no light exhibited.
For rotating optical systems and other apparatus producing flashes which 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.
as equation (5) above, for any programmed or entered values of the function I (t). Any standard computer programme for the solution of first-order linear differential equations may be used. 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 [23]. Results thus obtained are given in Table 3 for trains of 1 to 10 flashes, for two ratios of flash duration to period. The limiting values for infinite trains of pulses are also indicated. For rapidly repeating pulses these agree closely with Talbot's Law.

3.3 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 [21] would assume the form

$$I_e = \frac{\int_{t_1}^{t_2} I(t).dt}{a + t_2 - t_1} \qquad (6)$$

in which
I (t) describes the variation of instantaneous luminous intensity I with time t
a is the Blondel-Rey visual time-constant (see Section B.1)
t_1 and t_2 are the initial and final instants of time, the determination of which remained ambiguous.
Douglas [22] 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

$$a\,I_e = \int_{t_1}^{t_2} [I(t) - I_e].dt \qquad (7)$$

in which 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 (7), I_e is a function of t_1 and t_2, iterative methods of solution have normally to be used to determine I_e. Fig. 4 shows a graphical representation of equation (7) 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 (7) 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.

Fig 8

3.4 METHOD IV MODIFIED ALLARD

(NEW SECTION TO BE WRITTEN)

Calculation of Nominal Range

The luminous range of a light is defined as the maximum distance at which a light can be seen, as determined by the luminous intensity of the light, the meteorological visibility, and the threshold of illuminance at the eye of an observer. The IALA Recommendation for the Notation of Luminous Intensity and Range of Lights, November 1966, states that the "nominal" range is the luminous range of a light when the meteorological visibility is 10 nautical miles, and a threshold of illuminance of 0.2 microlux is used for nighttime observation. Calculation of the "nominal" range is made using Allard's Law [14]:

$$E = \frac{I * T^{D}}{D^{2}}$$ Equation 6.

where: E = illuminance at the eye of the observer (lux)
I = luminous intensity of the light (candelas)
T = the transmissivity of the atmosphere, defined as the ratio of the amount of light that exits a unit length of atmosphere to the amount of light that entered the unit length of atmosphere
D = the distance between the observer and the light (metres)

Meteorological visibility is defined as the distance required for the atmosphere to reduce the contrast of a black object against its background to 5% of the original contrast value at zero distance. The relationship between transmissivity and meteorological visibility is given as:

$$T^{V} = 0.05$$ Equation 7.

where: V = is the meteorological visibility (metres).
Allard's Law may be rearranged to solve for the required intensity of a light signal to produce a given value of illuminance at some distance under specific conditions of visibility, thus:

$$I = \frac{E * D^{2}}{(0.05)^{\frac{D}{V}}}$$ Equation 8.

The resultant nominal range should be calculated in metres, converted to nautical miles and rounded off to the nearest nautical mile [14].

4 Conclusions

[ties document together – do not introduce any new concepts in the conclusions. Conclusions should reflect the 'Recommendation' text in some manner]

5 References

Add in all refs from 1977 + Appendix I,II.

REFERENCES

[1] International Association of Lighthouse Authorities (I.A.L.A.), "Recommendation for the notation of luminous intensity and range of lights", 16th November 1966.

[2] International Association of Lighthouse Authorities (I.A.L.A.), “Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day”, April 1974.
[3] Walsh J. W. T., “Photometry”, 3rd. edition, 1958 Dover Publications Inc., New York, U.S.A., Constable and Co., London, England.
[4] Reeb O., “Grundlagen der Photometrie”. G. Braun Verlag, Karlsruhe, 1962.
[5] Blondel A., “Théorie photométrique des projecteurs”, *L’Industrie Electrique*, n° 46, 25 novembre 1893, pp. 517-520 et n° 47, 10 décembre 1893, pp. 541-546.
[6] Chernoff L., “Photometry of projectors at the National Bureau of Standards”, National Bureau of Standards Technical Note 198, December 17th 1963. U.S. Govt. Printing Office, Washington D.C., U.S.A.
[7] Waldram J.M., “The photometry of projected light”, *Transactions of the Illuminating Engineering Society*, London. Volume XVI, No. 8, 1951, pp. 187-207.
[8] Blaise P., “The photometry of projectors”, Report No. 5-3-5 to the VIIIth International Conference on Lighthouses and other Aids to Navigation, Stockholm, 1970.
[9] Douglas C. A., “Review of elementary theory of the photometry of projection apparatus”, *Illuminating Engineering*, N.Y., Vol. LXII, No. 4, April 1967, pp. 246-253.
[10] International Commission on Illumination (C.I.E.), “International Lighting Vocabulary”, Publication No. 17 (E.1.1.), 3rd edition 1970. (See definition 45-10-015 and Table I, p. 51.)
[11] Wall A. C., “The photometry of coloured light” *Illuminating Engineering*, N. Y., Vol. LXII, No. 4, April 1967, pp. 239-242.
[12] Crawford B. H., “Physical photometry”, National Physical Laboratory Notes on Applied Science, No. 29, H.M.S.O., London, 1962.
[13] Gueydan M., “Heterochromatic photometry in maritime signalling”, Report No. 5-4-8 to the IXth International Conference on Lighthouses and other Aids to Navigation, Ottawa, 1975.
[14] Geutler G., Krochmann J., Ozver Z. and Röhricht W., “Uber die Kennzeichnung der Güte des Angleichs der relativen spektralen Empfindlichkeit lichtempfindlicher Empfänger an die V (λ)-Funktion”. *Optik*, Vol. 43, No. 5, 1975, pp. 453-469.
[15] Douglas C. A., “Photometer for measurement of effective intensity of condenser – discharge lights”, *Illuminating Engineering*, N. Y., Vol. LIII, No.4, April 1958, pp. 205-208.
[16] Blaise P., “Colour and colorimetry”, *I.A.L.A. Bulletin*, No. 35, January 1968, pp. 10-25.
[17] Projector T. H., “The use of zonal constants in the calculation of beam flux”, *Illuminating Engineering,* N.Y., Vol. XLVIII, No. 4, April 1953, pp. 189-191.
[18] Projector T. H., “Versatile goniometer for projection photometry”, *Illuminating Engineering*, N. Y., Vo. XLVIII, No. 4, April 1953, pp. 192-196.
[19] Blaise P., “Appareil d’orientation pour la photométrie des projecteurs” (Directing device used in the photometry of projectors), Rapport n° 5-4-2 à la IXe Conférence Internationale des Services de Signalisation Maritime, Ottawa, 1975.
[20] Gueydan M., “Mesures des intensités lumineuses des phares en service” (Field measurements of luminous intensities of lights), *Bulletin de l’A.I.S.M. – I.A.L.A. Bulletin*, n° 37, juillet – July 1968, pp. 7-12.
[21] Blondel A. et Rey J., “Sur la perception des lumières brèves à la limite de leur portée” *Journal de Physique*, juillet et août 1911. Comptes rendus de l’Académie des Sciences, Paris, vol. CLIII, 3 juillet 1911, p. 54.
[22] Douglas C. A., “Computation of the effective intensity of flashing lights”. *Illuminating Engineering*, N. Y., Vol. LII, No. 12, December 1957, pp. 641-646.

APPENDIX I
SYMBOLS

Symbol	*Meaning*	*Unit*
A	Time-constant in Allard's formula for effective intensity	s
a_1, a_2, etc.	Area of part of projection apparatus	m^2
a	Time constant in Blondel-Rey formula for effective intensity	s
C	Time constant in form-factor method for effective intensity	s
c_1, c_2, etc.	Constants in calculation of intensity for pencil beams and auxiliary beams	—
d	Dimension of light source	m
E	Illuminance at eye of an observer	lx
f	Focal distance of projection apparatus	m
h_1, h_2, etc.	Height of optical panel	m
i	Instantaneous effective 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
k_1, k_2, etc.	Constants in calculation of intensity for fan beams	—
L	Luminance of a light source	cd/m2
N	Rotation rate of a rotating optical apparatus	rev/s
n	Number of changes of direction of a diverted beam	—
P^f	Additional factor characterising filament shape, in calculation of intensity for pencil beams	—
S	Area of luminous surface	m^2
t	Time variable	s
τ	Duration of flash	s
α	Plane angle of divergence of a beam	rad
θ	Angle between normal to surface and direction of light	rad
Φ	Luminous flux	lm
Ω	Solid angle	Sr

APPENDIX II

TERMS DEFINED IN CHAPTER 2
OF THE I.A.L.A. "INTERNATIONAL DICTIONARY OF AIDS TO MARINE NAVIGATION"

International Association of Marine Aids to Navigation and Lighthouse Authorities

IALA

...tion of Internationale de Signalisation Maritime

DRAFT

IALA Recommendation E-200-5

On

Marine Signal Lights

Part 5- Calculation of the Performance of Optical Apparatus

Edition 0.4

February 2008

Recommendation on XXX [Title Here]

(Recommendation [leave number blank, to be filled by IALA Secretariat])

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 [to be reviwed by Secretariat - for example -];

RECOGNISING ALSO that [to be reviewed by Secretariat - for example];

RECOGNISING FURTHER that [to be reviewed by Secretariat - for example -];

NOTING the [as above];

NOTING ALSO that;

NOTING FURTHER that;

CONSIDERING that to be reviewed by Secretariat - for example.

ADOPTS the [name of document] in the annex of this recommendation; and,

RECOMMENDS that National Members and other appropriate Authorities providing marine aids to navigation services [action to be taken].

* * *

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
August 2005 [example only]	Section 3.4; Tables 1-4;	

Annex

Calculation of the Performance of Optical Apparatus

1 INTRODUCTION

This recommendation is divided into two Sections A and B.

The recommended way of determining the intensity of the beam is by direct photometric measurement on a suitable measuring range as referred to in E200-3.

Section A gives details of a method for the approximate calculation of the peak luminous intensity of a beam from an aid-to-navigation light, i.e. the intensity at a maximum of its distribution in space, usually in the direction of the optical axis of the beam projection system.

This type of calculation is intended for use when direct photometric measurement is impossible and when the data required for the methods of *Section B* are not available.

Section B describes methods by which it is possible to obtain better estimates of luminous intensity for a given source-optic combination, than those obtainable by the methods of *Section A*, provided that measured data are available for an identical optic with other sources or for an identical source with other optics.

This type of calculation is preferred to that of *Section A*, where possible.

2 PURPOSE

The purpose of this recommendation is to describe how to determine or to calculate one or more figures of luminous intensity to provide meaningful descriptors of the performance of a light when it is used at an installation. It will rarely be possible to make the necessary measurements on the installed light in situ, but for the majority of lights it should be possible to measure the spatial distribution of luminous intensity of the beam or beams of light emitted, e.g. by a fixed lens or by a number of prismatic lens panels, either on the actual equipment to be installed or on an exactly similar one. The measurements will usually be made at a photometric test site set up for this purpose. As far as possible, the equipment measured at the site should be identical in all particulars with that of the installation, including both colour filters and lantern glazing where applicable. In cases where these cannot be included in the measuring set-up, corrections for colour filter transmission factors may be derived from separate measurements and allowance for losses in lantern glazing may be made.

3 DEFINITIONS

Definitions are referenced to the IALA Dictionary and are listed in Appendix II.

SECTION A

METHODS OF APPROXIMATE CALCULATION

OF THE PEAK LUMINOUS INTENSITY OF THE BEAM FROM AN AID-TO-NAVIGATION LIGHT

1. PURPOSE

As stated in the Introduction, the formulae given in this Section are intended only for use as a means of approximate estimation of the luminous intensity in the axial direction when it is impossible to make photometric measurements. The accuracy is likely to be no better than ± 20% for sources approximating to spheres of uniform luminance and will usually be significantly lower for filament and compact source arc discharge lamps.

The formulae may also be used in the design stage of a new lighted aid, when they may be very useful as a guide to the size of panel, luminance of source, etc, required to meet a given operational need.

2. TYPES OF BEAM PROJECTION APPARATUS

The formulae of this Section apply to the following types of beam projection apparatus.

(a) *Catoptric systems, including paraboloidal and parabolic cylindrical reflectors.*
(b) *Prismatic lens systems* (with dioptric and/or catadioptric elements).
(c) *Auxiliary Systems*
  (i) Diverting prisms
  (ii) Reinforcing mirrors, e.g. spherical reflectors of either catoptric or catadioptric type.

The calculations have been made for systems having a Fresnel profile. It can be shown that the results are not very dependent on the shapes of the prisms, and the calculations may be applied with reasonable accuracy to other profiles, e.g. equi-angular. When the Fresnel profile includes catadioptric elements, these may be arranged to recede at high angles, or to remain in one plane. In the latter case, dark spaces occur between the prisms. Two separate sets of formulae are given, applicable respectively to optical panels and to drum lenses.

3. TYPES OF LIGHT SOURCE

The formulae apply strictly to sources having the form of spheres of uniform luminance. They are therefore capable of giving reasonably accurate results for sources which approximate to this form, such as mantle burners with large single incandescent mantles.

Additional correction factors are tabulated to permit approximate calculations for the following common types of incandescent electric lamp filaments:

(a) Grid
(b) Cylindrical
(c) Cruciform
(d) Compact coiled-coil

The application of the formulae to other forms of filament and other light sources such as open-flame burners, carbon arc lamps and high pressure arc discharge lamps is subject to great reserve in respect of accuracy. NEED MORE MODERN DATA

4. LUMINANCE OF LIGHT SOURCES

For accuracy in use of the formulae, the light source must be a uniformly bright sphere. Large light sources of other shapes having nearly uniform surface luminance may also be expected to give beam intensity fairly close to the calculated values.
In a fixed directional optical system, the luminance(L) which is to be entered in the formulae of Section A.5 is the mean luminance in the direction of the axis of the optical system. In the case of rotating optical panels the axis rotates in the horizontal plane, while in the case of drum lenses there is no defined axis in the horizontal plane. In these cases it is necessary to consider possible variations in light intensity with bearing or to take a mean of effective source luminance at various bearings.
The luminance for any given direction is given by:

$$L = \frac{I}{S}$$

where L = Mean luminance of the source, in cd/m²
I = Luminous intensity of light source, in the given direction, in candelas
S = Projected area of light source, in m², on a plane surface normal to the given direction. (This direction will usually be the optical axis.)

In general, for complex filament structures, arc discharges of non-uniform luminance, etc., the best that can be done is to take S as the whole area within the smallest convex contour circumscribing the luminous element, even though this area may contain dark spaces within it. PROVIDE DIAGRAM AS AN EXAMPLE

The above method derives the mean luminance, for use in the formulae of Section A.5, from a measurement of the luminous intensity of the source. Such a measurement is subject to the general requirements of short-range photometric measurements described in E200-3 but is usually possible even when measurement on the complete optical system is not possible. In the case of non-uniform light sources, it may be preferable to place the source at the focus of a lens of photographic quality and to make a number of measurements in the beam at various directions close to the optical axis in order to determine the average value of the peak beam intensity. The formulae of Section A.5 below may then be used to calculate the mean luminance L. This method is essentially an application of the "ratio-ing" techniques described in Section B.

Kommentar [M1]: Page: 6
This section reads OK, but needs updating to reflect up to date practices.

If this method is used, it is necessary to ensure that the aperture of the lens is fully and reasonably uniformly illuminated. If the light source dimensions are very much less than 1/20 of the focal length of the lens, this may not be possible and the derivation of the mean luminance from measurements on the source alone may be preferable.

When luminous elements of small dimensions are enclosed within a large glass or quartz envelope, there may be difficulty in determining the projected area S. In some cases the linear dimensions may be measured accurately by the use of a traveling microscope having an objective lens of sufficiently great object distance to permit focusing on the luminous element when the objective is outside the envelope. In the case of arc discharge lamps, it is customary for manufacturers to supply a typical contour diagram of luminance within the discharge. Inspection of this, and of the regions of rapid decrease of luminance with position, may enable a reasonable value of S to be assessed for the discharge. When information of this type is not available, a convenient method of estimation of S may be to use a projection lens of photographic quality to project a focused image of the luminous element on a screen at a convenient finite distance. The measured dimensions of the bright image may be reduced to the corresponding dimensions of the luminous element by multiplying by the ratio of object distance to image distance from the lens. By applying an illumination photometer to the image, information may also be obtained on non-uniform distributions of luminance of the luminous element. In particular, a discharge or a filament may display a useful length (characterized by high luminance) somewhat less than its actual length obtained by direct measurements. EXPAND

Kommentar [M2]: Page: 7
Again this section reads OK, but could be more specific. i.e. a projection lens of photographic quality.

5. FORMULAE FOR CALCULATION OF PEAK BEAM INTENSITY

The luminous intensity (I_o) at the peak of the beam from a beam projection apparatus which is exhibiting a fixed white light may be calculated from the following formulae in which

(a) The term "net" shall be taken as including only that portion (height or area) of the projection apparatus which is actually illuminated on its emergent face (excepting the bases of the prisms, which are to be included although they will generally be only weakly illuminated). It shall exclude any portion unilluminated because of the intervention of framework or other obstruction, whether between light source and optic or between optic and observer. It shall also exclude dark spaces or areas due to openings in a catoptric or to the separation of the prisms in a catadioptric apparatus.

(b) The term "vertical surface" shall be taken as a plane surface normal to the optical axis through the focal point of the beam projection apparatus. In general, lighthouse beams are depressed through a very small angle towards the horizon, but the difference is insufficient to require other terminology.

5.1 Projection Apparatus for a Fan Beam (generated around a vertical axis)

5.1.1 Catoptric

$$I_o = h_1 d L k_1 c_1$$

Where **h_1** = net height of reflectors, in m, projected on to a vertical surface, less the height similarly projected, of any obstruction other than the light source itself, unless it also is obscured.

d = horizontal width of light source, in m

L = luminance of light source, in cd/m²

k_1 = correction factor depending on the vertical sub-tense angles θ_1 and θ_2 of the mirror, taken from Fig. 1. Where there is no obstruction to the beam such as an electric lamp bulb or burner, θ_1 equals zero.

c_1 = effective reflection factor which for the purpose of this formula shall be taken as:

0.9	for vaporized silver or aluminium
0.8	for silvered glass mirror
0.75	for lacquered surface-silvered metallic mirrors and anodized aluminium electrolytically brightened mirrors
0.7	for tin, chromium and rhodium surface-plated mirrors
0.6	for nickel surface-plated mirrors

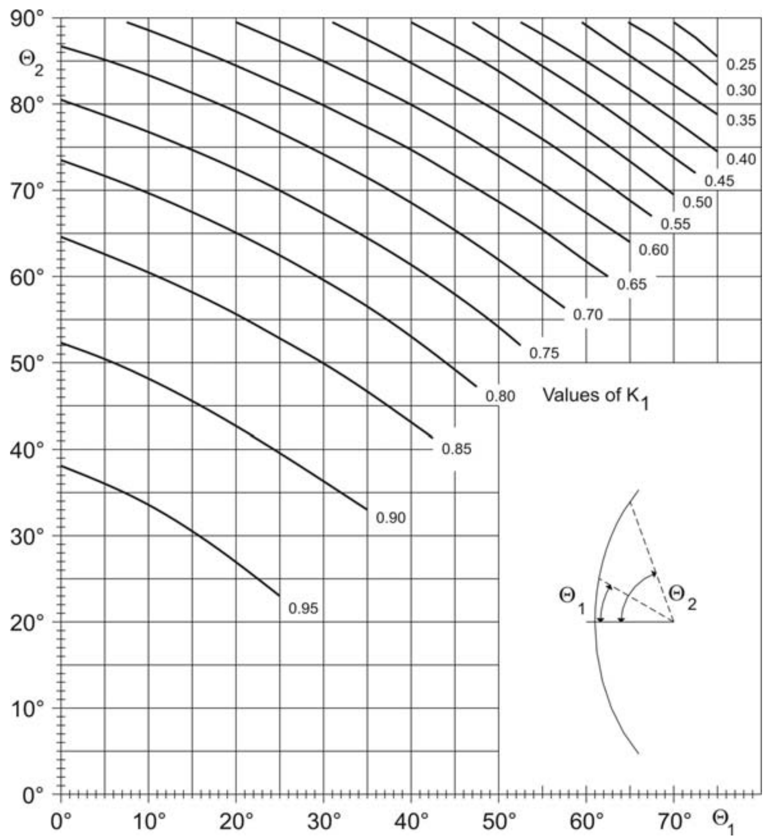


Figure 1

5.1.2 Dioptric and Catadioptric

$$\mathbf{I_o = h_2dLk_2 + h_3dLk_3 + h_4dLk_4}$$

Where **h_2** = net glass height of refractors, in m, projected on to a vertical surface

h_3 = net glass height of upper reflectors, in m, projected on to a vertical surface

h_4 = net glass height of lower reflectors, in m, projected on to a vertical surface

d = horizontal width of light source, in m

L = luminance of light source, in cd/m²

k_2 = correction factor depending upon the subtense angle of refractors taken from Fig. 2

k_3 = average correction factor depending upon the appropriate angular limits θ_1 and θ_2 of the upper reflectors calculated from Fig. 3

k_4 = average correction factor depending upon the appropriate angular limits θ_3 and θ_4 of the lower reflectors calculated from Fig. 3

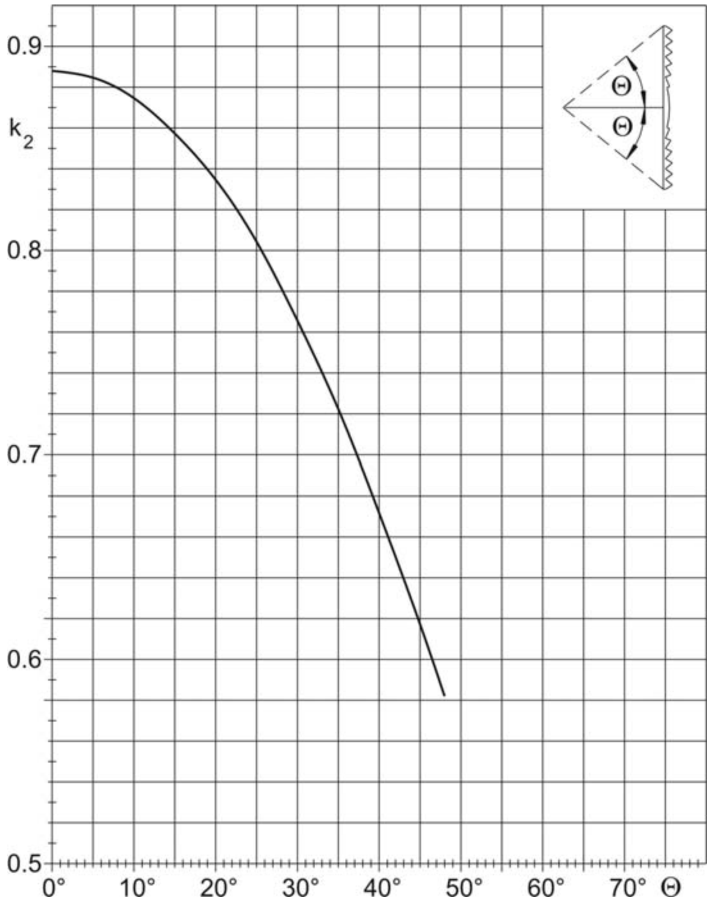


Figure 2

Note (1): In the correction factors $\mathbf{k_1}$ to $\mathbf{k_4}$ inclusive, allowance has been made for the variations of the width of the flashed area due to the change of focal distance across the apparatus.

Note (2): The above formula is to be used for drum lenses having receding catadioptric rings. For drum lenses having a profile in which the lower catadioptric sections are arranged vertically over one another, the value of $\mathbf{k_4}$ should be reduced by 20%.

Note (3): For smaller drum lenses (dioptric only, and **o**[f] focal distance 250 mm or less), the following values of $\mathbf{k_2}$ should be used:

0.45	Pressed glass drum lens
0.55	Cut glass drum lens
0.6	Moulded acrylic

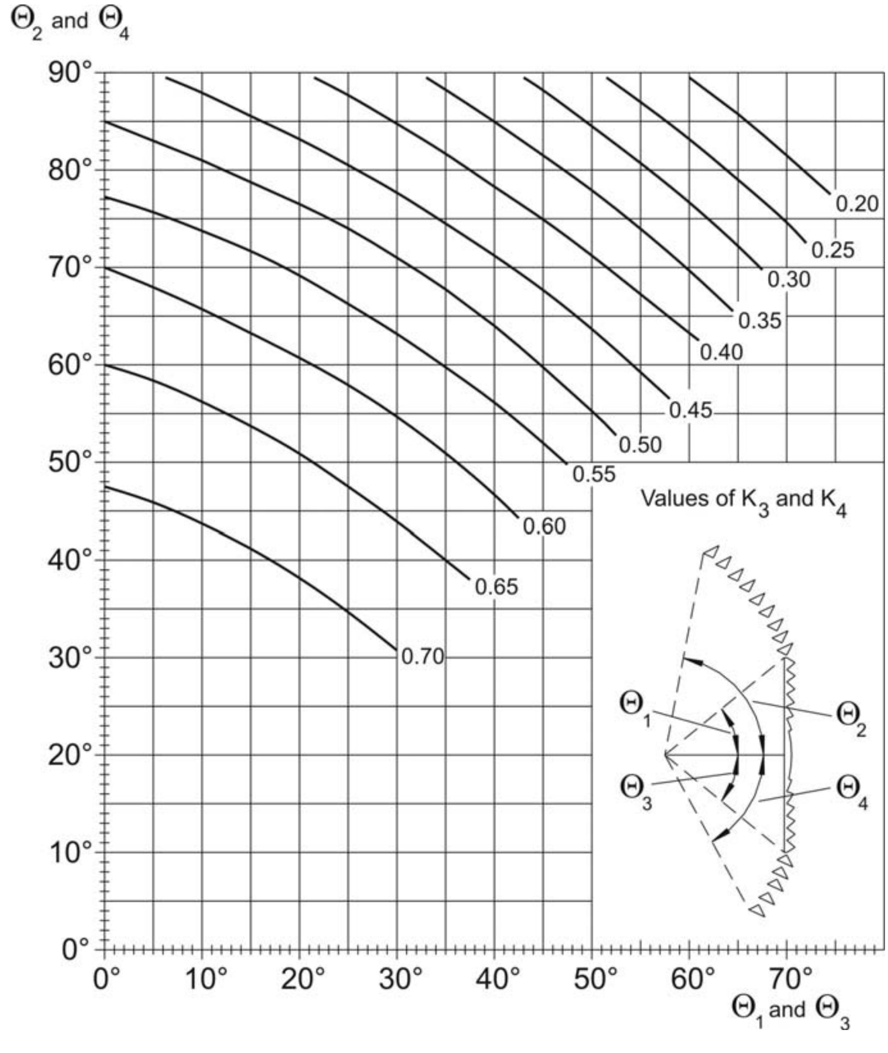


Figure 3

5.2 Projection Apparatus for a Pencil Beam

5.2.1 Catoptric

$$I_o = a_1 L c_1$$

Where **a_1** = net area of mirror, in m², projected on to a plane normal to the direction of concentration, less the area, similarly projected, of any obstruction other than the light source itself unless it also is obscured

L = luminance of light source, in cd/m²

c_1 = effective reflection factor which, for the purpose of this formula, shall be as given in Section C.5.1.1.

5.2.2 Dioptric and Catadioptric

$$I_o = a_2 L c_2 + a_3 L c_3$$

Where **a_2** = net glass area of refractors, in m², projected on to a plane normal to the direction of concentration

a_3 = net glass area of reflectors, in m2, projected on to a plane normal to the direction of concentration

L = luminance of light source, in cd/m²

c_2 = correction factor depending on the subtense angle of refractors taken from Fig. 4.

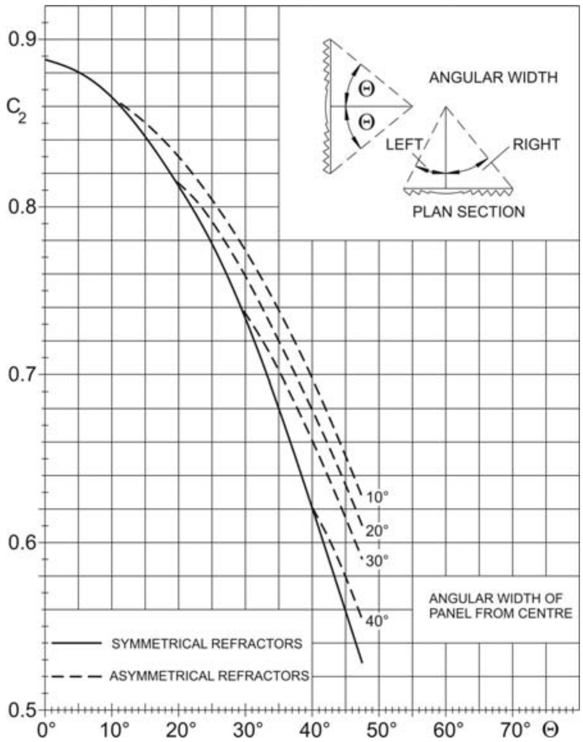


Figure 4

Where the panel is asymmetric the right and left portions of the refractors have to be considered separately and the area of each portion multiplied by the appropriate value of c_2. The sum of these two quantities when multiplied by L corresponds to the first term on the right hand of the equation.

$$c_3 = \begin{cases} 0.85 \text{ for receding catadioptric elements} \\ 0.70 \text{ for vertically stacked catadioptric elements} \end{cases}$$

Note: The above formulae apply with reasonable accuracy to uniform spherical light sources and to large mantle burners. For use with certain types of filament lamp in common use in lighthouse apparatus, the additional correction factors listed below should be applied. These factors are multipliers for that part of the intensity contributed by the catadioptric elements, and make allowance for the reduction in source luminous intensity in the direction of these elements.

The formula becomes

$$\mathbf{I_o = a_2\, Lc_2 \div a_3 p_f\, Lc_3}$$

where

$$p_f = \begin{cases} 0.9 \text{ for compact coiled-coil filaments} \\ 0.8 \text{ for plane grid filaments} \\ 0.7 \text{ for cylindrical, bunch* and cruciform} \\ \quad \text{filaments.} \end{cases}$$

For all other sources, including linear coiled-coil filament, filament structures of greater complexity and all discharge lamps, a value of p_f = 0.5 should be assumed.

Note: By "compact coiled-coil filament" is meant a filament structure consisting of a closely wound coil which is itself wound into a helix of small radius, presenting a compact structure of approximately cylindrical form.

5.3 AUXILIARY BEAMS

The luminous intensity of a converged, (or diverged) beam may be derived from that of the initial beam by multiplication by two factors.
One factor is the quotient of the angle of divergence of the beam *before* convergence (or divergence) by that of the converged (or diverged) beam; the other factor may be taken as 0.9 in the case of auxiliary optical systems made of glass and 0.92 for those made in plastics, to allow for reflection and transmission losses.
The luminous intensity of a diverted beam, changed in direction without change in angle of divergence, is derived from that of the initial beam by multiplying by $(0.9)^n$ for glass systems or $(0.92)^n$ for plastics systems, where n is the number of diverting

prisms traversed.

5.4 REINFORCING MIRRORS

5.4.1 Centred Reinforcing Mirrors

When a reinforcing mirror is employed in conjunction with any of the above beam projection apparatus, the intensity of the beam from the reinforced portion of the aparatus is increased and the intensity previously found should be multiplied by the appropriate factor from the following table:

Type of mirror	*Factor*
(i) *Catoptric* Vaporized silver, silvered glass, or aluminium, anodized aluminium, lacquered silver on metal	1.4
Rhodium or tin surface-plated	1.3
Chromium or nickel surface-plated	1.2
(ii) *Catadioptric*	1.2

5.4.2 De-centred Reinforcing Mirrors

By employing de-centred reinforcing mirrors with a fan beam it is possible to increase the effective width of the light source over a given arc by forming an image or images to one side of it and so increasing the intensity of the beam over that arc. The increased intensity is given by multiplying the fixed intensity as calculated from Section A.5.1.3 above by:

$$1.0 \div 0.7\, c_1 m$$

where m = number of supplementary images (number of de-centred auxiliary mirrors)

c_1 = reflection factor in Section A.5.1.1 above.

6. LIGHT DURATION OF RHYTHMIC BEAMS

6.1 ROTATING APPARATUS

When the beam projection apparatus rotates, the duration of each appearance of light is dependent upon the angle of divergence of the beam and the speed of revolution of the apparatus. If the beam divergence cannot be measured directly, its approximate value may be calculated from the formula:

$$\alpha = \frac{d}{f} \text{ radians or } \frac{180\mathrm{d}}{\pi \mathrm{f}} \text{ degrees}$$

where α = angle of divergence

d = width of light source in the case of horizontal divergence, or height of light source in the case of vertical divergence

f = focal length of the system

Consistent units of length must be used.

The width of the light source may be determined as described in Section A.4 to above. In the case of a light source with diffused edges (e.g. a frosted lamp* or an arc discharge*), the width should be taken as that between points at which the intensity falls to 50% of the peak value. If any other percentage is used, due to previous custom, this should be stated.

The duration of an appearance of light is given by

$$t = \frac{\alpha}{2\pi N} = \frac{d}{2\pi N f}$$

where t = duration of the appearance of light

α = angle of divergence in the horizontal plane, in radians

N = rate of rotation (number of revolutions per second) of the apparatus.

6.2 BLANKING* SYSTEMS

For a flashing light produced by blanking the light source by the use of an occulting hood, shutter, revolving screen or other mechanical device, the flash duration may be taken as the time interval between the passage of the screen or shutter through its mean position when exhibiting and eclipsing the light respectively. If the time variation of intensity can be measured, the time interval should be taken as that between the instants at which the intensity is 50% of the peak intensity.

6.3 EXTINCTION SYSTEMS

6.3.1 Acetylene and other Gas Flames, and Discharge Lamps

When the beam is eclipsed by a flasher or coder mechanism which interrupts the supply of gas or electricity, the duration of each appearance of light is approximately the duration of the “on” time of the supply. When it is possible to measure the variation of luminous intensity with time directly, the duration of the appearance of light may be taken as the interval between the instants at which the intensity is 50% of the peak intensity.

6.3.2 Incandescent Lamps and Mantle Burners

Owing to the relatively slow thermal response of the filament or mantle, there is a delay in the time course of the luminance of the luminous element with respect to the time of “on” or “off” operation of the flasher or coder mechanism.
Figure 9 shows, *for the case of an incandescent filament*, the difference between the incandescence time and the nigrescence time, as a function of steady-state filament current. Two curves are given, defined for levels of 90% and 50% of the steady luminous intensity respectively.
The time during which the luminous intensity from the filament exceeds respectively 90% and 50% of steady luminous intensity is given by the contact closure time (i.e. the time during which the supply current is switched on) less the time read from the appropriate curve of Figure 9. If the contact closure time is less than the corresponding time from Figure 9 for 90% level, no guidance can be obtained from the figure, and it is recommended that such short closure times should not be used. If the contact closure time is greater than the time from Figure 9 for 90% level, the flash duration may be taken as contact closure time less the time from Figure 9 for 50% level. This duration may be used in the approximate calculation of effective intensity as in Section A.7 below.
Note: Figure 9 corresponds to the behaviour of lamps operated at rated voltage and with effectively zero circuit resistance.
Underrunning a lamp increases both incandescence and nigrescence times, but the net effect on the correction in Figure 9 is to increase it. If the reduction is of only a few per cent, then in general the effect on the correction will not be important.
The use of Figure 2 may be extended to tungsten-halogen lamps operating at filament temperatures above 3 000 K. The difference of the incandescence and nigrescence times of these lamps from those of ordinary filament lamps is unlikely to be significantly greater than the spread of values of these quantities from lamp to lamp.
The use of a series resistance in the external circuit will increase incandescence time, as shown in Figure 11 of B.S. 942: 1949 [29]. The correction in Figure 9 is thereby also increased.
The use of a shunt resistance across the circuit switch, to produce a simmering current, will reduce incandescence time and increase nigrescence time. The correction in Figure 9 is thereby decreased. For a simmering current of not more than one quarter of rated current, the correction will not in general be decreased by more than 20%.
In the case of doubt as to the magnitude of the correction, it is recommended to measure the time variation of intensity of the switched light source; the optical system need not be used.
From the measured curve, the duration of the appearance of light should be taken as that between the instants at which the intensity is 50% of peak intensity. If any other percentage is used, due to previous custom, this should be stated.

Fig 5

7. USE OF COLOUR FILTERS

The luminous intensity of a coloured light obtained by the use of a colour filter may be calculated approximately by applying the above methods to derive the luminous intensity of the white light obtained from the optical system in the absence of the filter, and then applying to it the transmission factor of the appropriate filter, which may be separately measured.If transmission factor measurements on the colour filter to be used in an installed light are not available, approximate luminous intensity may be found by the use of the appropriate value from the table below, which shows typical average values of percentage transmission factor of colour filters made in glass or dyed plastics.

TRANSMISSION FACTORS OF COLOUR FILTERS (IN%)

		Colour of Filter					
Colour Temperature or Correlated Colour Temperature	*Light Source*	*Red*	*Green*		*Yellow*	*Blue*	
		Glass & Plastics	*Glass*	*Plastics*	*Glass & Plastics*	*Glass*	*Plastics*
1 900-2 200 K	Oil Flame	30	8	10	70	__	__
2 200-2 500 K	Vacuum lamp	25	10	15	60	__	__
2 500-3 200 K	Acetylene flame \ Gas-filled lamp / Incandescent mantle	20	12	20	50	1	2
5 000-7 000 K	Xenon discharge	13	15	23	__	2	3

It should be noted that with some colour filters, particularly those which give greater certainty of colour recognition, transmission factors may be significantly lower than those given in the table. It is therefore recommended that, as far as possible, values of transmission factor of colour filters should be measured.

8. EFFECT OF LANTERN GLAZING AND SERVICE CONDITIONS

The formulae given above give approximate beam luminous intensities at emergence from the beam projection apparatus. When such apparatus is housed in a lantern, calculated intensities should be reduced by a factor. It is recommended that the factor be taken as 0.85 (15%) for a system in clean condition. The factor to cover practical service conditions, may also be applied. It is recommended that this factor be taken as 0.75 (25%), this should be stated clearly in any calculation.

9. LIMITATIONS OF THE CALCULATIONS

The accuracy of the results obtained from the above calculations is very limited, being of the order of ± 20% for a uniform spherical light source (approximated by a mantle burner). For light sources of other shapes, particularly planar filaments and discharge lamps, the accuracy becomes very much lower in an unpredictable way. The calculations are intended only for use when no other method of estimating beam intensity is available.

When it is required to estimate the beam intensity for a given source-optic combination on which direct measurements cannot be made, it may be that measured data are available for the same optic with other sources, or for the same source with other optics. In such cases, a better estimate of beam intensity may possibly be obtained by methods described in Section B.

10. EXAMPLE (By Kind Permission of NLB)

CALCULATIONS OF ST CATHERINE'S POINT (ISLE OF WIGHT) SECOND ORDER OPTIC

Exercise	To calculate the peak intensity, effective intensity, flash duration and character of St Catherine's Point rotating optic with a GE 400W MBI clear envelope lamp as the light source.
Rotation	3 RPM
No. of panels	4
Formulae	1. Luminance of Light Sources - p. 27javascript:self.close();

$L = I/S$ ($I \approx \Phi/10$)

2. Projection Apparatus for Pencil Beam - p. 31
   $Io = a_2\, Lc_2 + a_3\, p_f\, Lc_3$
   (use $p_f = 0.5$, c_2 from p. 55 and $c_3 = 0.8$)
3. Glazing losses - p. 19 (15%)
4. Light Duration - p. 33
   $t = d / 2\pi N f$ (note N = revs per *second*)
5. Effective Intensity by Schmidt-Clausen - pp. 23 & 35
   $Ie = \dfrac{Io\,\tau}{C/F + \tau}$ use C/F = 0.3

A ROUGH METHOD OF CALCULATION

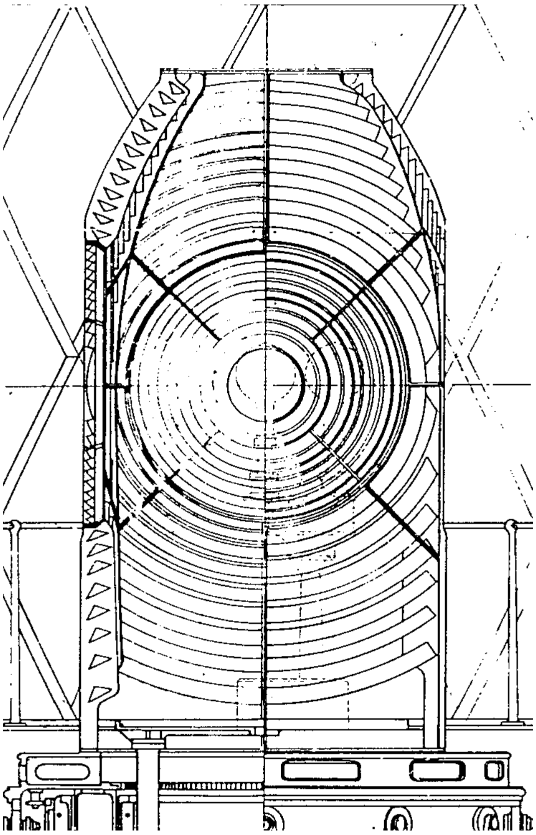
Using the Cordell Method:

Io = Lens area x Luminance of lamp x 0.6 x 0.6 x 0.85

(The factors of 0.6 are for lens collection angle losses and losses due to using a small light source in a lens designed for a larger one. The 0.85 factor is for glazing and astragal losses)

t = dP / 2πf where d is light source width in mm
P is rotational period in seconds
f is focal distance in mm
(note: calculated t is approximately the 50% or half peak flash duration)

Ie = Io t / (0.2 + t) (this assumes a *triangular* flash shape in that J = half base x height)



SECTION B

ESTIMATION OF BEAM INTENSITY BY RATIO-ING TECHNIQUES [30]

1. PURPOSE

This section is intended as a guide to estimation of the luminous intensity and angle of divergence of the beam from various types of beam projection apparatus when data can be obtained by direct measurement on similar but not identical combinations of light source and optical system. The methods described are referred to as comparison or "ratio-ing" techniques.
Accuracy of results obtained by using ratio-ing techniques is only as good as the first-order geometrical relations which they represent. The precision of the results is limited by inaccuracies in the assumptions made. However, the ratio-ing technique is to be preferred to that of direct computation, of the type given in Section A. There is less liklihood of error in an estimation of optical performance based on comparisons between source/optic combinations of similar design where measurements are available for one such design, than in estimation of performance for a new combination.
Similar optical systems can be scaled, within reasonable limits, to predict performance with more confidence than can be placed in the use of the formulae given in Section A.

2. EXAMPLES OF ESTIMATION OF LUMINOUS INTENSITY

2.1 FIXED LENSES

2.1.1 Change of Source

It is required to find the luminous intensity of the fan beam produced by a fixed lens when used with a light source of luminance L and width d. The luminous intensity is assumed to have been measured for an identical fixed lens with a light source of luminance L´ and width d´, and has been found to be I´.

From SectionA.5.1.2

$$I' = h_2\, d'L'\, k_2 + h_3\, d'L'\, k_3 + h_4\, d'L'\, k_4$$

and the required intensity is

$I = h_2\, dLk_2 + h_3\, dLk_3 + h_4\, dLk_4$

Hence $\frac{I}{I'}$ is given by $\frac{dL}{d'L'}$

2.1.2 CHANGE OF FIXED LENS SIZE

In this case the intensity is assumed to have been measured for an identical light source in a fixed lens of different focal length and dimensions but with the same, or nearly the same, relative areas and angular subtenses of dioptric, upper and lower catadioptric portions. Thus the coefficients k_2, k_3, and k_4 are virtually unaltered, and the heights of the various portions of the unknown system may be taken as a constant (say p) times the corresponding heights of the measured system.

From Section A.5.1.2

$$\frac{I}{I^{'}} = \frac{h_2 dLk_2 + h_3 dLk_3 + h_4 dLk_4}{h_2^{'} dLk_2 + h_3^{'} dLk_3 + h_4^{'} dLk_4} = p$$

so that the intensity is scaled directly as the linear dimensions of the fixed lens.

2.2 OPTICAL PANELS

2.2.1 Change of Source

In this case, from Section A.5.2.2

$I' = a_2\, L'c_2 + a_3\, L'c_3$

and the required intensity is

$I = a_2\, Lc_2 + a_3\, Lc_3$

so that

$$\frac{I}{I'} = \frac{L}{L'}$$

and the intensity is scaled directly as the luminance of the source.

2.2.2 Change of Optical Panel Size

In this case, measurements of intensity are assumed to have been made on a combination consisting of an identical source with an optical panel of different dimensions but having approximately the same relative areas and angular subtense angles for the various dioptric and catadioptric portions. (This will apply to panels of different focal length with all dimensions scaled

porportionally, or to panels of similar section but extended over different ranges of azimuth angle.)
The coefficients c_2 and c_3 are thus virtually unchanges, and the areas of the various portions of the unknown panel may be taken as a constant (say q) times the corresponding areas of the measured panel.

From Section A.5.2.2

$$\frac{I}{I'} = \frac{a_2 L_{c2} + a_3 L_{c_3}}{a_2' L_{c_2} + a_3' L_{c_3}} = q$$

so that the intensity is scaled directly as the area of the optical panel.

Note 1: The beam intensities referred to in the above calculations are *uncorrected beam intensities* corresponding to steady light intensities measured for the source/optic combination alone, at rated lamp voltage.
They make no allowance for glazing losses, effects of supply voltage variation or visual effects of flashing lights.

Note 2: Application of the ratio-ing technique to optical systems of somewhat different shape, so that the constants k and c are not unchanged, is possible within limits, provided that care is exercised to avoid unduly gross approximations.

3. EXAMPLES OF ESTIMATION OF BEAM DIVERGENCE

According to Section A.6.1, the beam divergence in radians may be calculated as

$$\alpha = \frac{d}{f}.$$

The uncertainties in estimating the proper value for the source dimension d make the ratio-ing technique the preferred method of estimation of divergence when photometric data is available for an identical light source in a similar optical system of different focal length.
If, for this second system, the divergence has been found to be α', and the focal length of the system is f´, then from Section A.6.1

$$\alpha' = \frac{d}{f}$$

The required divergence is therefore obtainable from

$$\frac{\alpha}{\alpha'} = \frac{f'}{f}$$

The use of this technique often gives significantly better agreement with measured values than does the method of direct calculation.

3.1 SCALING OF FLASH DURATION

For a rotating optic at a rotation speed N rev/s, the divergence α is related to the flash duration τ by

$$\tau = \frac{\alpha}{2\pi N}$$

Suppose that it is required to find the flash duration for an optic of focal length f and rotation speed N. It has been found that a similar optic of focal length f´ and rotation speed N´ gives a flash duration τ'. Then the required flash duration τ is obtained from.

$$\tau = \frac{f'N'}{fN}\,\tau'$$

For rotating optical systems with fairly large light sources giving smooth distributions of intensity, changes in rotation speed or focal length result in changes of flash duration without change in flash shape. By the use of the above expression, measured data for one such system may be scaled to yield flash durations for a wide range of similar optical systems of different focal lengths and/or rotation speeds. By application of the methods of Section C, tables or graphs of the ratio of effective intensity to peak intensity can be deduced over the whole range.

4 Conclusions

[ties document together – do not introduce any new concepts in the conclusions. Conclusions should reflect the 'Recommendation' text in some manner]

5 References

Add in all refs from 1977 + Appendix I,II.

REFERENCES

[1] International Association of Lighthouse Authorities (I.A.L.A.), "Recommendation for the notation of luminous intensity and range of lights", 16th November 1966.

[2] International Association of Lighthouse Authorities (I.A.L.A.), "Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day", April 1974.

[3] Walsh J. W. T., "Photometry", 3rd. edition, 1958 Dover Publications Inc., New York, U.S.A., Constable and Co., London, England.

[4] Reeb O., “Grundlagen der Photometrie”. G. Braun Verlag, Karlsruhe, 1962.
[5] Blondel A., “Théorie photométrique des projecteurs”, *L’Industrie Electrique*, n° 46, 25 novembre 1893, pp. 517-520 et n° 47, 10 décembre 1893, pp. 541-546.
[6] Chernoff L., “Photometry of projectors at the National Bureau of Standards”, National Bureau of Standards Technical Note 198, December 17th 1963. U.S. Govt. Printing Office, Washington D.C., U.S.A.
[7] Waldram J.M., “The photometry of projected light”, *Transactions of the Illuminating Engineering Society*, London. Volume XVI, No. 8, 1951, pp. 187-207.
[8] Blaise P., “The photometry of projectors”, Report No. 5-3-5 to the VIIIth International Conference on Lighthouses and other Aids to Navigation, Stockholm, 1970.
[9] Douglas C. A., “Review of elementary theory of the photometry of projection apparatus”, *Illuminating Engineering*, N.Y., Vol. LXII, No. 4, April 1967, pp. 246-253.
[10] International Commission on Illumination (C.I.E.), “International Lighting Vocabulary”, Publication No. 17 (E.1.1.), 3rd edition 1970. (See definition 45-10-015 and Table I, p. 51.)
[11] Wall A. C., “The photometry of coloured light” *Illuminating Engineering*, N. Y., Vol. LXII, No. 4, April 1967, pp. 239-242.
[12] Crawford B. H., “Physical photometry”, National Physical Laboratory Notes on Applied Science, No. 29, H.M.S.O., London, 1962.
[13] Gueydan M., “Heterochromatic photometry in maritime signalling”, Report No. 5-4-8 to the IXth International Conference on Lighthouses and other Aids to Navigation, Ottawa, 1975.
[14] Geutler G., Krochmann J., Ozver Z. and Röhricht W., “Uber die Kennzeichnung der Güte des Angleichs der relativen spektralen Empfindlichkeit lichtempfindlicher Empfänger an die V (λ)-Funktion”. *Optik*, Vol. 43, No. 5, 1975, pp. 453-469.
[15] Douglas C. A., “Photometer for measurement of effective intensity of condenser – discharge lights”, *Illuminating Engineering*, N. Y., Vol. LIII, No.4, April 1958, pp. 205-208.
[16] Blaise P., “Colour and colorimetry”, *I.A.L.A. Bulletin*, No. 35, January 1968, pp. 10-25.
[17] Projector T. H., “The use of zonal constants in the calculation of beam flux”, *Illuminating Engineering,* N.Y., Vol. XLVIII, No. 4, April 1953, pp. 189-191.
[18] Projector T. H., “Versatile goniometer for projection photometry”, *Illuminating Engineering*, N. Y., Vo. XLVIII, No. 4, April 1953, pp. 192-196.
[19] Blaise P., “Appareil d’orientation pour la photométrie des projecteurs” (Directing device used in the photometry of projectors), Rapport n° 5-4-2 à la IXe Conférence Internationale des Services de Signalisation Maritime, Ottawa, 1975.
[20] Gueydan M., “Mesures des intensités lumineuses des phares en service” (Field measurements of luminous intensities of lights), *Bulletin de l’A.I.S.M. – I.A.L.A. Bulletin*, n° 37, juillet – July 1968, pp. 7-12.
[21] Blondel A. et Rey J., “Sur la perception des lumières brèves à la limite de leur portée” *Journal de Physique*, juillet et août 1911. Comptes rendus de l’Académie des Sciences, Paris, vol. CLIII, 3 juillet 1911, p. 54.
[22] Douglas C. A., “Computation of the effective intensity of flashing lights”. *Illuminating Engineering*, N. Y., Vol. LII, No. 12, December 1957, pp. 641-646.

APPENDIX I
SYMBOLS

Symbol	*Meaning*	*Unit*
A	Time-constant in Allard’s formula for effective intensity	s

a_1, a_2, etc.	Area of part of projection apparatus	m^2
a	Time constant in Blondel-Rey formula for effective intensity	s
C	Time constant in form-factor method for effective intensity	s
c_1, c_2, etc.	Constants in calculation of intensity for pencil beams and auxiliary beams	—
d	Dimension of light source	m
E	Illuminance at eye of an observer	lx
f	Focal distance of projection apparatus	m
h_1, h_2, etc.	Height of optical panel	m
i	Instantaneous effective 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
k_1, k_2, etc.	Constants in calculation of intensity for fan beams	—
L	Luminance of a light source	cd/m2
N	Rotation rate of a rotating optical apparatus	rev/s
n	Number of changes of direction of a diverted beam	—
P^f	Additional factor characterising filament shape, in calculation of intensity for pencil beams	—
S	Area of luminous surface	m^2
t	Time variable	s
τ	Duration of flash	s
α	Plane angle of divergence of a beam	rad
θ	Angle between normal to surface and direction of light	rad
Φ	Luminous flux	lm
Ω	Solid angle	Sr

APPENDIX II

TERMS DEFINED IN CHAPTER 2
OF THE I.A.L.A. "INTERNATIONAL DICTIONARY OF AIDS TO MARINE NAVIGATION"

Term	*Term number*	*Term*	*Term number*
Allard's Law	2-1-265	Incandescent mantle	2-3-025
Angle of divergence	2-1-100	Incandescence time	2-3-275
Appearance of light	2-5-125	Inverse square law	2-1-065
Arc discharge	2-3-385	Landfall mark (or buoy)	2-6-095
Astragal	2-4-015	Landfall light	2-5-050
Beam (Luminous)	2-1-085	Lantern	2-4-000
Blanking screen	2-4-105	Lantern glazing	2-4-005
Bunch filament	2-3-220	Luminance	2-1-045
Candela	2-1-040	Luminosity	2-1-365
Candela per square metre (cd/m^2)	2-1-050	Luminous efficiency, Spectral	2-1-015
Carbon arc lamp	2-3-400	Luminous intensity	2-1-035
Catadioptric	2-2-070	Luminous range	2-1-250
Catoptric	2-2-065	Lux	2-1-060
Coiled-coil lamp	2-3-185	Mantle burner	2-3-030
Colour filter	2-2-200	Meteorogical visibility	2-1-280
Compact source arc discharge lamp	2-3-420 N	Moulded glass (or plastic)	2-2-240
Converged beam	2-2-215	Neutral density filter	2-2-205
Cruciform filament	2-3-205	Nigrescence time	2-3-280
Cut glass	2-2-245	Nominal range	2-1-255
Cylindrical filament	2-3-210	Occultation	2-5-140
Dioptric	2-2-060	Occulting hood	2-4-110
Discharge lamp	2-3-310	Occulting light	2-5-170
Diverged beam	2-2-220	Optical axis	2-2-110
Diverted beam	2-2-225	Optical panel	2-2-175
Divergence	2-1-100 N	Order (of an optic)	2-2-260
Diverting prism	2-2-210	Pencil beam	2-1-095
Drum lens	2-2-100	Photometer	2-1-535
Effective intensity	2-1-400	Physical photometer	2-1-545
Electric lamp, Incandescent	2-3-080	Pressed glass	2-2-240
Equi-angular profile	2-2-145	Prismatic lens	2-2-085
Fan beam	2-1-090	Projector	2-2-005
Filament	2-3-090	Reflection factor	2-1-150
Fixed lens	2-2-090	Reflector	2-1-130
Fixed light	2-5-105	Refractor	2-1-235
Flash	2-5-130	Reinforcing mirror	2-2-040
Flasher	2-4-100	Revolving screen	2-4-120
Flashing light	2-5-145	Rhythmic light	2-5-110
Flash tube	2-3-435	Screen	2-4-105
Flicker photometer	2-1-555	Sealed beam lamp	2-3-245
Flourescent lamp	2-3-340	Shutter	2-4-115
Focal length	2-2-160	Simmering current	2-3-270
Focus	2-1-125	Spherical reflector	2-2-045
Fresnel profile	2-2-135	Stray light	2-2-265
Frosted lamp	2-3-230	Threshold of illuminance	2-1-390
Geographical range	2-1-245	Transmittance	2-1-185
Grid filament	2-3-195	Transmission factor	2-1-185
High pressure arc discharge lamp	2-3-415	Tungsten-halogen lamp	2-3-160