

# INTERNATIONAL STANDARD



Laser display devices – **STANDARD PREVIEW**  
Part 5-4: Optical measuring methods of colour speckle  
(standards.iteh.ai)

[IEC 62906-5-4:2018](https://standards.iteh.ai/catalog/standards/sist/59ebee12-0e17-4e42-a13a-d0f002a3c9cd/iec-62906-5-4-2018)

<https://standards.iteh.ai/catalog/standards/sist/59ebee12-0e17-4e42-a13a-d0f002a3c9cd/iec-62906-5-4-2018>



## THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2018 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://www.iec.ch)

### About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

### About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

#### IEC Catalogue - [webstore.iec.ch/catalogue](http://webstore.iec.ch/catalogue)

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

#### IEC publications search - [webstore.iec.ch/advsearchform](http://webstore.iec.ch/advsearchform)

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

#### IEC Just Published - [webstore.iec.ch/justpublished](http://webstore.iec.ch/justpublished)

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

#### Electropedia - [www.electropedia.org](http://www.electropedia.org)

The world's leading online dictionary of electronic and electrical terms containing 21 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

#### IEC Glossary - [std.iec.ch/glossary](http://std.iec.ch/glossary)

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

#### IEC Customer Service Centre - [webstore.iec.ch/csc](http://webstore.iec.ch/csc)

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: [sales@iec.ch](mailto:sales@iec.ch).

IEC STANDARD PREVIEW  
(standards.iteh.ai)

IEC 62906-1-4:2018  
IEC STANDARD PREVIEW  
(standards.iteh.ai)

https://standards.iteh.ai/catalog/standards/iec-62906-1-4:2018  
d0f002a3c9cd/iec-62906-1-4:2018

# INTERNATIONAL STANDARD



---

**Laser display devices –** **STANDARD PREVIEW**  
**Part 5-4: Optical measuring methods of colour speckle**  
(standards.iteh.ai)

[IEC 62906-5-4:2018](https://standards.iteh.ai/catalog/standards/sist/59ebee12-0e17-4e42-a13a-d0f002a3c9cd/iec-62906-5-4-2018)

<https://standards.iteh.ai/catalog/standards/sist/59ebee12-0e17-4e42-a13a-d0f002a3c9cd/iec-62906-5-4-2018>

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 31.260

ISBN 978-2-8322-5243-7

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD.....	5
1 Scope.....	7
2 Normative references .....	7
3 Terms, definitions, letter symbols and abbreviated terms.....	7
3.1 Fundamental terms.....	7
3.2 Terms related to colour speckle distribution .....	7
3.3 Terms related to spatial variation .....	8
3.4 Letter symbols .....	8
3.5 Abbreviated terms.....	9
4 Theory of colour speckle.....	9
4.1 General.....	9
4.2 Mechanism for generating colour speckle .....	9
5 Calculation methods of colour speckle .....	11
5.1 General.....	11
5.2 Measuring method of spectral behaviour of BGR light sources.....	12
5.3 Target chromaticity .....	12
5.4 Adjustment of BGR power ratio .....	14
5.5 Calculation method (a) using BGR speckle contrast $C_{s-B}$ , $C_{s-G}$ , $C_{s-R}$ .....	15
5.5.1 General .....	15
5.5.2 Examples of measured distributions.....	16
5.6 Evaluation metrics .....	20
5.7 Calculation method (b) using the measured spatial distribution of BGR monochromatic speckles.....	21
5.7.1 General .....	21
5.7.2 Examples of measured distributions.....	21
5.7.3 Comparison between methods (a) and (b) .....	23
5.7.4 Elimination of the background effects .....	25
5.8 Error analysis based on data size .....	28
6 Direct measuring methods of colour speckle.....	32
6.1 General.....	32
6.2 Fundamental design of LMD for colour speckle measurement.....	33
6.3 Colour speckle measuring method using LMD with XYZ filters .....	34
6.4 Colour speckle measuring method using LMD with BGR filters.....	35
7 Measuring methods related to spatial variation .....	36
7.1 General.....	36
7.2 Angular colour speckle variation .....	36
7.3 Photometric speckle contrast uniformity/non-uniformity.....	37
7.4 Colour speckle variance/covariance non-uniformity.....	38
Annex A (informative) Complementary explanation of colour speckle.....	39
Annex B (informative) Examples of colour speckle distributions .....	40
B.1 Colour speckle distributions (one of the BGR: 90 %, the others: 1 %) .....	40
B.2 Colour speckle distributions (two of the BGR: 90 %, the other: 1 %).....	43
Annex C (informative) Calibration of XYZ errors .....	48
C.1 General.....	48
C.2 Formulation of XYZ mismatches .....	48

C.3	Calibration of the mismatched XYZ errors using the true BGR chromaticity values .....	50
	Bibliography.....	51
	Figure 1 – Two speckle measuring methods and their flow charts .....	12
	Figure 2 – Target chromaticity and colour gamut.....	13
	Figure 3 – $S_{B,G,R}(\lambda)$ with an FWHM of 2 nm.....	13
	Figure 4 – Adjustment method of BGR power ratio.....	15
	Figure 5 – Colour speckle distribution for $C_{S-B} = 100\%$ , $C_{S-G} = 100\%$ , $C_{S-R} = 100\%$ .....	16
	Figure 6 – Photometric speckle distribution for $C_{S-B} = 100\%$ , $C_{S-G} = 100\%$ , $C_{S-R} = 100\%$ .....	17
	Figure 7 – Colour speckle distribution for $C_{S-B} = 50\%$ , $C_{S-G} = 50\%$ , $C_{S-R} = 50\%$ .....	18
	Figure 8 – Photometric speckle distribution for $C_{S-B} = 50\%$ , $C_{S-G} = 50\%$ , $C_{S-R} = 50\%$ .....	18
	Figure 9 – Colour speckle distribution for $C_{S-B} = 10\%$ , $C_{S-G} = 10\%$ , $C_{S-R} = 10\%$ .....	19
	Figure 10 – Photometric speckle distribution for $C_{S-B} = 10\%$ , $C_{S-G} = 10\%$ , $C_{S-R} = 10\%$ ....	20
	Figure 11 – Colour speckle distribution for $C_{S-B} = 9,2\%$ , $C_{S-G} = 9,7\%$ , $C_{S-R} = 9,2\%$ obtained by method (b) .....	22
	Figure 12 – Colour speckle distribution for $C_{S-B} = 9,2\%$ , $C_{S-G} = 19,2\%$ , $C_{S-R} = 23,2\%$ obtained by method (b) .....	23
	Figure 13 – Colour speckle distribution for $C_{S-B} = 9,2\%$ , $C_{S-G} = 9,7\%$ , $C_{S-R} = 9,2\%$ obtained by method (a) .....	24
	Figure 14 – Colour speckle distribution for $C_{S-B} = 9,2\%$ , $C_{S-G} = 19,2\%$ , $C_{S-R} = 23,2\%$ obtained by method (a) .....	24
	Figure 15 – Raw data of BGR speckle distributions (upper row) and post-processed data (lower row) for BGR monochromatic speckles (left: B, centre: G, right: R).....	26
	Figure 16 – Colour speckle distribution directly using the raw data in Figure 15 .....	26
	Figure 17 – Colour speckle distribution for $C_{S-B} = 16,2\%$ , $C_{S-G} = 17,4\%$ , $C_{S-R} = 17,3\%$ obtained by indirect measuring method (a).....	27
	Figure 18 – Calculated average chromaticity values of the colour speckle distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 80\%$ .....	28
	Figure 19 – Calculated average values of the normalized speckle illuminance speckle distribution and the normalized monochromatic speckle intensity distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 80\%$ .....	29
	Figure 20 – Calculated average chromaticity values of the colour speckle distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 60\%$ .....	29
	Figure 21 – Calculated average values of the normalized speckle illuminance speckle distribution and the normalized monochromatic speckle intensity distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 60\%$ .....	30
	Figure 22 – Calculated average chromaticity values of the colour speckle distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 40\%$ .....	30
	Figure 23 – Calculated average values of the normalized speckle illuminance speckle distribution and the normalized monochromatic speckle intensity distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 40\%$ .....	31
	Figure 24 – Calculated average chromaticity values of the colour speckle distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 20\%$ .....	31
	Figure 25 – Calculated average values of the normalized speckle illuminance speckle distribution and the normalized monochromatic speckle intensity distribution with respect to data size for $C_{S-B} = C_{S-G} = C_{S-R} = 20\%$ .....	32
	Figure 26 – Example of LMDs using XYZ filters for colour speckle measurement .....	33

Figure 27 – Example of LMDs using BGR filters for colour speckle measurement .....	34
Figure 28 – Example of measurement geometries for colour speckle using an LMD with XYZ filters.....	35
Figure 29 – Example of measurement geometries for colour speckle using an LMD with BGR filters .....	36
Figure 30 – Representation of the viewing direction, or direction of measurement, defined by the angle of inclination $\theta$ , and the angle of rotation (azimuth angle $\varphi$ ) in a polar coordinate system .....	37
Figure A.1 – Photograph of colour speckle.....	39
Figure B.1 – Colour speckle distribution for $C_{S-B} = 90\%$ , $C_{S-G} = 1\%$ , $C_{S-R} = 1\%$ .....	40
Figure B.2 – Photometric speckle distribution for $C_{S-B} = 90\%$ , $C_{S-G} = 1\%$ , $C_{S-R} = 1\%$ .....	41
Figure B.3 – Colour speckle distribution for $C_{S-B} = 1\%$ , $C_{S-G} = 90\%$ , $C_{S-R} = 1\%$ .....	42
Figure B.4 – Photometric speckle distribution for $C_{S-B} = 1\%$ , $C_{S-G} = 90\%$ , $C_{S-R} = 1\%$ .....	42
Figure B.5 – Colour speckle distribution for $C_{S-B} = 1\%$ , $C_{S-G} = 1\%$ , $C_{S-R} = 90\%$ .....	43
Figure B.6 – Photometric speckle distribution for $C_{S-B} = 1\%$ , $C_{S-G} = 1\%$ , $C_{S-R} = 90\%$ .....	43
Figure B.7 – Colour speckle distribution for $C_{S-B} = 90\%$ , $C_{S-G} = 1\%$ , $C_{S-R} = 90\%$ .....	44
Figure B.8 – Photometric speckle distribution for $C_{S-B} = 90\%$ , $C_{S-G} = 1\%$ , $C_{S-R} = 90\%$ .....	45
Figure B.9 – Colour speckle distribution for $C_{S-B} = 1\%$ , $C_{S-G} = 90\%$ , $C_{S-R} = 90\%$ .....	45
Figure B.10 – Photometric speckle distribution for $C_{S-B} = 1\%$ , $C_{S-G} = 90\%$ , $C_{S-R} = 90\%$ .....	46
Figure B.11 – Colour speckle distribution for $C_{S-B} = 90\%$ , $C_{S-G} = 90\%$ , $C_{S-R} = 1\%$ .....	46
Figure B.12 – Photometric speckle distribution for $C_{S-B} = 90\%$ , $C_{S-G} = 90\%$ , $C_{S-R} = 1\%$ .....	47
Figure C.1 – Deviated values (marker points) and ideal colour matching functions.....	49
Figure C.2 – Correct plot by spectral measurements and plot with XYZ errors .....	49
Table 1 – Values of measurement metrics for the calculated examples .....	21
Table 2 – Values of measurement metrics for the examples in Figure 11 to Figure 14.....	25
Table 3 – Values of measurement indices for the examples in Figure 16 and Figure 17 .....	27
Table C.1 – Mismatch coefficients.....	49

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## LASER DISPLAY DEVICES –

## Part 5-4: Optical measuring methods of colour speckle

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.  
<https://standards.iteh.org/catalog/standards/sii/59b9ed3-0e17-4ed3-a13a-3e2a2c991c06/iec-62906-5-4-2018>
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62906-5-4 has been prepared by IEC technical committee TC 110: Electronic display devices.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
110/926/FDIS	110/938/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62906 series, published under the general title *Laser display devices*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

**IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

## **iTeh STANDARD PREVIEW (standards.iteh.ai)**

[IEC 62906-5-4:2018](https://standards.iteh.ai/catalog/standards/sist/59ebee12-0e17-4e42-a13a-d0f002a3c9cd/iec-62906-5-4-2018)

<https://standards.iteh.ai/catalog/standards/sist/59ebee12-0e17-4e42-a13a-d0f002a3c9cd/iec-62906-5-4-2018>

## LASER DISPLAY DEVICES –

### Part 5-4: Optical measuring methods of colour speckle

#### 1 Scope

This part of IEC 62906 specifies the fundamental colour speckle distribution in CIE colour systems and the measuring methods of the colour speckle of laser display devices (LDDs).

#### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62906-1-2, *Laser display devices – Part 1-2: Vocabulary and letter symbols*

IEC 62906-5-2:2016, *Laser display devices – Part 5-2: Optical measuring methods of speckle contrast*

CIE publication 15:2004, *Colorimetry*

#### 3 Terms, definitions, letter symbols and abbreviated terms

For the purposes of this document, the following terms and definitions given in IEC 62906-1-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

##### 3.1 Fundamental terms

###### 3.1.1

###### colour speckle distribution

colour distribution in a specified colour space of the speckle patterns which are generated by colour mixing of monochromatic screen speckles

###### 3.1.2

###### photometric speckle distribution

distribution of photometric variables such as illuminance, luminance or luminous flux of a colour speckle pattern which are generated by colour mixing of monochromatic screen speckles

##### 3.2 Terms related to colour speckle distribution

###### 3.2.1

###### colour speckle variance

variance for either of the chromaticity coordinates of colour speckle distribution data, used as one of the metrics of colour speckle distribution

### 3.2.2

#### colour speckle covariance

covariance between chromaticity coordinates of colour speckle distribution data, used as one of the metrics of colour speckle distribution

### 3.2.3

#### photometric speckle contrast

#### photometric speckle contrast ratio

ratio of the standard deviation to the average of the photometric distribution, such as illuminance, luminance, or luminous flux

### 3.2.4

#### colour difference variance

variance of distribution of colour difference of colour speckle between the target chromaticity in an appropriate colour space

Note 1 to entry: See Annex B.

## 3.3 Terms related to spatial variation

### 3.3.1

#### angular colour speckle variation

variation of colour speckle contrast and variance/covariance with zenith ( $\theta$ ) or azimuth ( $\varphi$ ) angles on a point of the projection plane (screen)

### 3.3.2

#### photometric speckle contrast uniformity/non-uniformity

uniformity or non-uniformity of photometric speckle contrast on the predefined points of the projection plane (screen)

### 3.3.3

#### colour speckle variance/covariance non-uniformity

non-uniformity of colour speckle variance/covariance on the predefined points of the projection plane (screen)

## 3.4 Letter symbols

$\bar{x}(\lambda)$ , $\lambda$ , $\lambda$ , $\bar{y}(\lambda)$ , $\bar{z}(\lambda)$	Colour matching functions
$X$ , $Y$ , $Z$	Tristimulus values
$S_{B,G,R}(\lambda)$	Spectral power distribution for each B, G, R (normalized as unity)
$r_B$ , $r_G$ , $r_R$	Average power ratio for each B, G, R ( $r_B + r_G + r_R = 1$ )
$E$	Monochromatic speckle (relative illuminance) distributions
$E_{B,G,R}$	Monochromatic speckle distributions for each B, G, R
$M$	Number of independent coherent light sources
$C_s$	Monochromatic speckle contrast
$C_{s-B,G,R}$	Monochromatic speckle contrast for each B, G, R
$C_{ps}$	Photometric speckle contrast
$\sigma$	Standard deviation of monochromatic spatial speckle distribution
$\sigma_u^2$ , $\sigma_v^2$	Colour speckle variance (CIE 1976)
$\mu_{u'v'}$	Colour speckle covariance (CIE 1976)
$NU_{ps}$	Photometric speckle contrast non-uniformity

$NU_{\text{csu}'}, NU_{\text{csv}'}$	Colour speckle variance non-uniformity
$NU_{\text{csu}'v'}$	Colour speckle covariance non-uniformity

### 3.5 Abbreviated terms

B,G,R (BGR)	Blue, green, red
DUT	Device under test
FDS	Fully developed speckle
FWHM	Full width at half maximum
LD	Laser diode
LDD	Laser display device
LMD	Light measuring device
MTF	Modulation transfer function

## 4 Theory of colour speckle

### 4.1 General

The colour speckle of laser display devices (LDDs) is defined as speckle when the light source is multi-coloured (see IEC 62906-1-2). It is recognized as fine colour patterns different from the colour intended to be displayed (see Annex A).

The colour speckle of the LDDs using coherent or partially coherent light sources emitting at different wavelengths is created by spatially superposing their monochromatic speckle patterns. Particularly for hybrid LDDs, the colour speckle is also created by superposing such monochromatic speckle patterns on speckle-less colour patterns generated by incoherent light sources.

The colour speckle is theoretically obtained as distribution in CIE colour spaces (see CIE publication 15:2004) using the measured data of monochromatic speckles created by coherent or partially coherent light sources.

Clause 4 specifies the colour speckle creation mechanism, examples of colour speckle distribution in CIE 1976 chromaticity diagram and the evaluation indices.

### 4.2 Mechanism for generating colour speckle

Subclause 4.2 specifies the mechanism for generating colour speckle.

Monochromatic speckle contrast  $C_s$  is expressed as follows:

$$C_s = \frac{\sigma}{\langle E \rangle_T} \quad (1)$$

where,  $E$  is the relative irradiance of spatial distribution for monochromatic speckle,  $\langle E \rangle_T$  is the total average in the probability density function shown later, and  $\sigma$  is the standard deviation. Speckle is recognized as an interference pattern projected on human retina. Therefore, illuminance  $E$  on the retina is used here. This is the same definition as in IEC 62906-5-2.

The number of independent coherent light sources is defined as  $M$ . Therefore, the probability density function of speckle is given by the gamma distribution as follows [1], [3]<sup>1</sup>:

$$p_M(E) = \frac{M^M E^{M-1}}{\Gamma(M) \langle E \rangle_T^M} \exp\left\{-\frac{ME}{\langle E \rangle_T}\right\} \quad (2)$$

where,  $\Gamma(M)$  is the gamma function. The number  $M$  is usually an integer. However,  $M$  can be used as a decimal number.

Formula (2) is normalized as  $\langle E \rangle_T / M = 1$  for the colour speckle estimation. The monochromatic speckle contrast given by Formula (1) is then expressed as follows:

$$C_s = \frac{\sqrt{M}}{\langle E \rangle_T} = \frac{1}{\sqrt{M}} \quad (3)$$

Using Formula (3), the probability density function in Formula (2) is simply rewritten as a function of  $C_s$  instead of  $M$ .

$$p(E) = \frac{E C_s^{-2} - 1}{\Gamma(C_s^2)} \exp(-E) \quad (4)$$

**iTeh STANDARD PREVIEW**  
(standards.iteh.ai)

The illuminance values  $E$  at a given  $C_s$  value can be obtained statistically by generating random numbers for the inverse function of Formula (4). However, it should be noted that  $E$  shall be scaled down as  $E/M$  because it has already been normalized as  $\langle E \rangle_T / M = 1$ . This statistical speckle formulation is based on radiometry.

To apply the above radiometric formulation to colour speckle, it is necessary to couple it with colourimetry. For BGR laser light sources, the normalized spectral power distribution is expressed as  $S_{B,G,R}(\lambda)$  ( $\int S_{B,G,R}(\lambda) d\lambda = 1$ ). To realize the target white point by mixing the BGR colours, the average power ratio,  $r_B, r_G, r_R$ , ( $r_B + r_G + r_R = 1$ ) shall be determined. The target white point is not affected by monochromatic speckles. In actual measurements, it is obtained by averaging the spatial distribution of each monochromatic speckle. The monochromatic speckle distributions for each colour are expressed as  $E_{B,G,R}$ . In case of incoherence,  $E_{B,G,R} = 1$ .

Therefore, the tristimulus values,  $X, Y,$  and  $Z$  are given by

$$\begin{aligned} X &= \int_{380}^{780} \bar{x}(\lambda) \cdot \{r_B E_B S_B(\lambda) + r_G E_G S_G(\lambda) + r_R E_R S_R(\lambda)\} d\lambda \\ Y &= \int_{380}^{780} \bar{y}(\lambda) \cdot \{r_B E_B S_B(\lambda) + r_G E_G S_G(\lambda) + r_R E_R S_R(\lambda)\} d\lambda \\ Z &= \int_{380}^{780} \bar{z}(\lambda) \cdot \{r_B E_B S_B(\lambda) + r_G E_G S_G(\lambda) + r_R E_R S_R(\lambda)\} d\lambda \end{aligned} \quad (5)$$

where,  $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$  are the colour matching functions.

<sup>1</sup> Numbers in square brackets refer to the Bibliography.

The CIE 1931 chromaticity coordinates,  $x$ ,  $y$ , are given by

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z} \quad (6)$$

The CIE 1976 chromaticity coordinates,  $u'$ ,  $v'$  are thus given by

$$u' = \frac{4x}{-2x+12y+3} = \frac{4X}{X+15Y+3Z}, \quad v' = \frac{9y}{-2x+12y+3} = \frac{9Y}{X+15Y+3Z} \quad (7)$$

The above formulation can be applied in this document not only to the case of a narrow spectral linewidth of BGR LDs but also to the much wider spectra of an incoherent light source such as phosphor emission.

In the theoretical analysis of the colour speckle distribution,  $S_{B,G,R}(\lambda)$  shall be given first. Then the target chromaticity point is determined. Next, the power ratio  $r_B$ ,  $r_G$ ,  $r_R$  shall be calculated to realize the target chromaticity. After that, the monochromatic speckles,  $r_B E_B S_B(\lambda)$ ,  $r_G E_G S_G(\lambda)$ ,  $r_R E_R S_R(\lambda)$  are calculated by generating a random number using Formula (4) at the given  $C_s$  values for each B, G, R colour, which are denoted as  $C_{s-B}$ ,  $C_{s-G}$ ,  $C_{s-R}$ .

Repeating the above procedure, the colour speckle distribution  $x$ ,  $y$  can be obtained in the CIE 1931 chromaticity diagram using Formula (6), or  $u'$ ,  $v'$  in the CIE 1976 chromaticity diagram using Formula (7).

If  $Y$  only is used, the distribution of the relative illuminance, luminance or luminous flux, as photometric speckle distribution, can be obtained.

## 5 Calculation methods of colour speckle

### 5.1 General

For the calculation of colour speckle, it is necessary to determine the following physical parameters on the imaging plane:

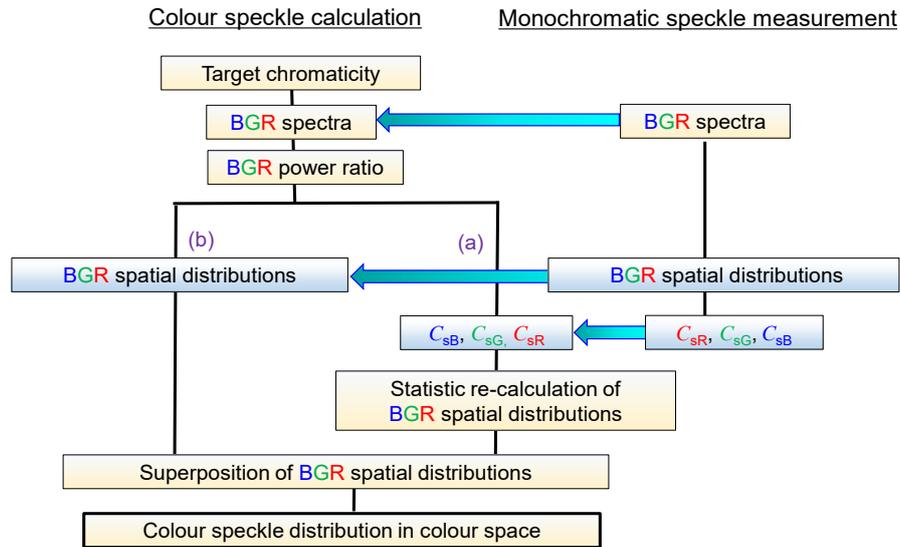
- target chromaticity (determine),
- spectra of light sources (assumed or measure),
- spectral power ratio of the BGR outputs (calculated to realize the target chromaticity),
- speckle contrast of the BGR outputs (assume or measure).

The flow charts of the calculation methods of colour speckle are illustrated in Figure 1.

Two calculation methods of colour speckle are given as follows.

- Method superposing statistically-calculated spatial distribution of BGR monochromatic speckles using BGR speckle contrast values,  $C_{s-B}$ ,  $C_{s-G}$ ,  $C_{s-R}$ .
- Method superposing the measured spatial distribution of BGR monochromatic speckles.

The above two methods theoretically reach the same results within the statistical errors based on the law of large numbers.



IEC

Figure 1 – Two speckle measuring methods and their flow charts

5.2 Measuring method of spectral behaviour of BGR light sources

The normalized spectral power distribution  $S_{B,G,R}(\lambda)$  ( $\int S_{B,G,R}(\lambda)d\lambda = 1$ ) shall be obtained to calculate colour speckle distribution because it is necessary for calculating tristimulus values, X, Y, and Z, as in 4.2.

IEC 62906-5-4:2018

The spectral measurements should be carried out at the driving currents of the BGR LDs for the light output powers of each BGR LD realizing the target chromaticity of the measurement. This is because  $S_{B,G,R}(\lambda)$  usually varies with the driving currents or modulation method of the LDs.

The spectral measurement of coherent light sources such as RGB LDs (laser diodes) of which linewidth is much narrower than LEDs requires an LMD with higher resolution of wavelength, such as a spectrometer, or a spectrum analyser (see IEC 62906-5-2:2016, 4.5.3; examples of LD spectra are shown in IEC 62906-5-2:2016, Annex A). The accuracy of  $S_{B,G,R}(\lambda)$  measurement affects the calculation accuracy of colour gamut and/or chromaticity coordinates.

The spectral measurement of incoherent light sources with a broad spectrum can be carried out by the conventional methods.

If the LDD (DUT) uses BGR colour filters,  $S_{B,G,R}(\lambda)$  shall be measured or calculated through the colour filters.

5.3 Target chromaticity

The target chromaticity shall be determined for the colour speckle measurement. The target chromaticity can be chosen at any point within the colour gamut created by the BGR spectral power distribution  $S_{B,G,R}(\lambda)$ . It should be chosen at a white point because it is easier to observe an effect of each of the BGR colours on colour speckle distribution.

It should be noted that the target chromaticity is theoretically equal to the average chromaticity of the colour speckle distribution.

Figure 2 illustrates an example of the chromaticity diagram plotting the colour gamut triangle for BT.2020 (Recommendation ITU-R BT.2020-2 [6]). The target chromaticity,  $u' = 0,198$ ,  $v' = 0,468$  corresponds to the BT.2020 reference white point. The BGR points are plotted slightly inside the wavelength rim because  $S_{B,G,R}(\lambda)$  is assumed to have a Lorentzian spectral profile with an FWHM of 2 nm as in Figure 3. This profile is approximately equal to actual high-power BGR LDs. It should be noted that the peak wavelengths are 449 nm, 520 nm, and 636 nm, which are not perfectly in accordance with BT.2020 parameter values. They are chosen for comparison with the measured results shown in 5.7, considering availability of LDs.

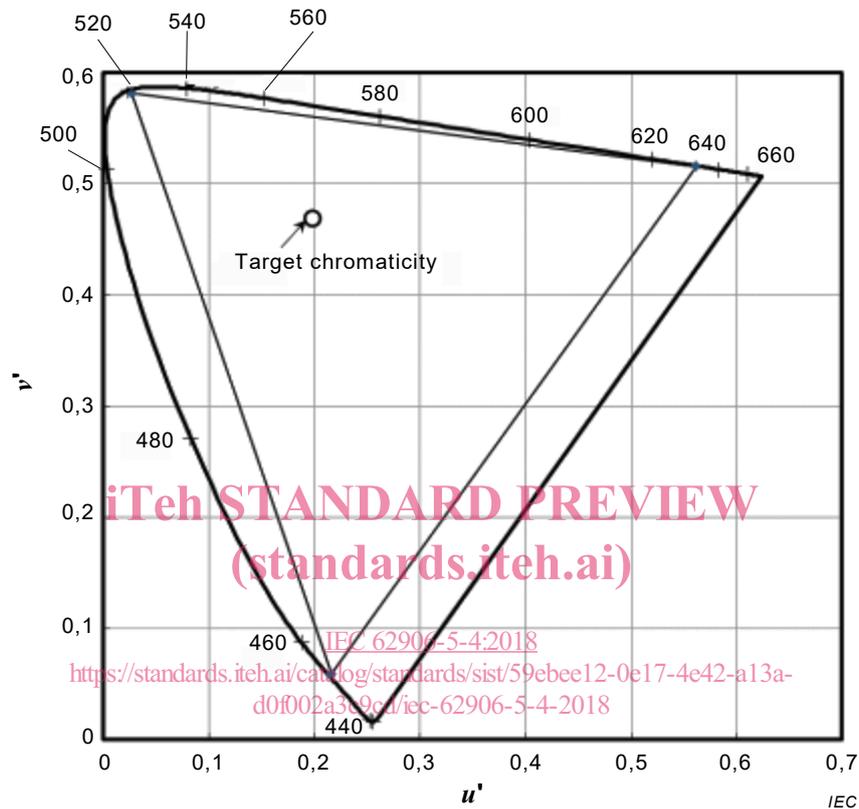


Figure 2 – Target chromaticity and colour gamut

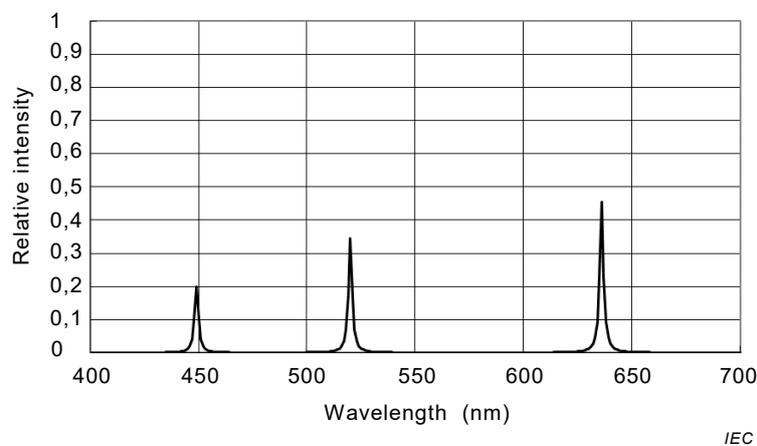


Figure 3 –  $S_{B,G,R}(\lambda)$  with an FWHM of 2 nm