IEC 62906-5-4

Edition 1.0 2018-01

INTERNATIONAL STANDARD

colour inside

Laser display devices –
Part 5-4: Optical measuring methods of colour speckle

IEC 62906-5-4:2018-01(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.260

ISBN 978-2-8322-5243-7

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- withdrawn,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

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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 (θ) or azimuth (φ) 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

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

$NU_{csu'}$, $NU_{csv'}$	Colour speckle variance non-uniformity
$NU_{csu'v'}$	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:

$$C_s = \frac{\sigma}{<E>_T} \tag{1}$$

where, E is the relative irradiance of spatial distribution for monochromatic speckle, $<E>_T$ is the total average in the probability density function shown later, and σ 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][1]:

$$p_{\mathrm{M}}(E) = \frac{M^{M} E^{M-1}}{\Gamma(M) < E >_{\mathrm{T}}^{M}} \exp\{-\frac{ME}{< E >_{\mathrm{T}}}\} \quad (2)$$

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 $< E >_{\mathrm{T}} /M = 1$ for the colour speckle estimation. The monochromatic speckle contrast given by Formula (1) is then expressed as follows:

$$C_{\mathrm{s}} = \frac{\sqrt{M}}{< E >_{\mathrm{T}}} = \frac{1}{\sqrt{M}} \quad (3)$$

Using Formula (3), the probability density function in Formula (2) is simply rewritten as a function of C_{s} instead of M.

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

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 $< E >_{\mathrm{T}} /M = 1$. 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 $S_{\mathrm{B,G,R}}(\lambda)$ ($\int S_{\mathrm{B,G,R}}(\lambda)\, d\lambda = 1$). To realize the target white point by mixing the BGR colours, the average power ratio, r_{B}, r_{G}, r_{R}, ($r_{\mathrm{B}} + r_{\mathrm{G}} + r_{\mathrm{R}} = 1$) 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 $E_{\mathrm{B,G,R}}$. In case of incoherence, $E_{\mathrm{B,G,R}} = 1$.

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

$$\begin{aligned}
X &= \int_{380}^{780} \bar{x}(\lambda) \cdot \{r_{\mathrm{B}} E_{\mathrm{B}} S_{\mathrm{B}}(\lambda) + r_{\mathrm{G}} E_{\mathrm{G}} S_{\mathrm{G}}(\lambda) + r_{\mathrm{R}} E_{\mathrm{R}} S_{\mathrm{R}}(\lambda)\} d\lambda \\
Y &= \int_{380}^{780} \bar{y}(\lambda) \cdot \{r_{\mathrm{B}} E_{\mathrm{B}} S_{\mathrm{B}}(\lambda) + r_{\mathrm{G}} E_{\mathrm{G}} S_{\mathrm{G}}(\lambda) + r_{\mathrm{R}} E_{\mathrm{R}} S_{\mathrm{R}}(\lambda)\} d\lambda \\
Z &= \int_{380}^{780} \bar{z}(\lambda) \cdot \{r_{\mathrm{B}} E_{\mathrm{B}} S_{\mathrm{B}}(\lambda) + r_{\mathrm{G}} E_{\mathrm{G}} S_{\mathrm{G}}(\lambda) + r_{\mathrm{R}} E_{\mathrm{R}} S_{\mathrm{R}}(\lambda)\} d\lambda
\end{aligned} \quad (5)$$

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

[1] Numbers in square brackets refer to the Bibliography.

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

$$x = \frac{X}{X+Y+Z}, \qquad y = \frac{Y}{X+Y+Z} \tag{6}$$

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

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

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, $S_{\mathrm{B,G,R}}(\lambda)$ 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, $r_{\mathrm{B}}E_{\mathrm{B}}S_{\mathrm{B}}(\lambda)$, $r_{\mathrm{G}}E_{\mathrm{G}}S_{\mathrm{G}}(\lambda)$, $r_{\mathrm{R}}E_{\mathrm{R}}S_{\mathrm{R}}(\lambda)$ 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 $C_{\mathrm{s\text{-}B}}$, $C_{\mathrm{s\text{-}G}}$, $C_{\mathrm{s\text{-}R}}$.

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:

a) target chromaticity (determine),

b) spectra of light sources (assumed or measure),

c) spectral power ratio of the BGR outputs (calculated to realize the target chromaticity),

d) 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.

1) Method superposing statistically-calculated spatial distribution of BGR monochromatic speckles using BGR speckle contrast values, $C_{\mathrm{s\text{-}B}}$, $C_{\mathrm{s\text{-}G}}$, $C_{\mathrm{s\text{-}R}}$.

2) 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.

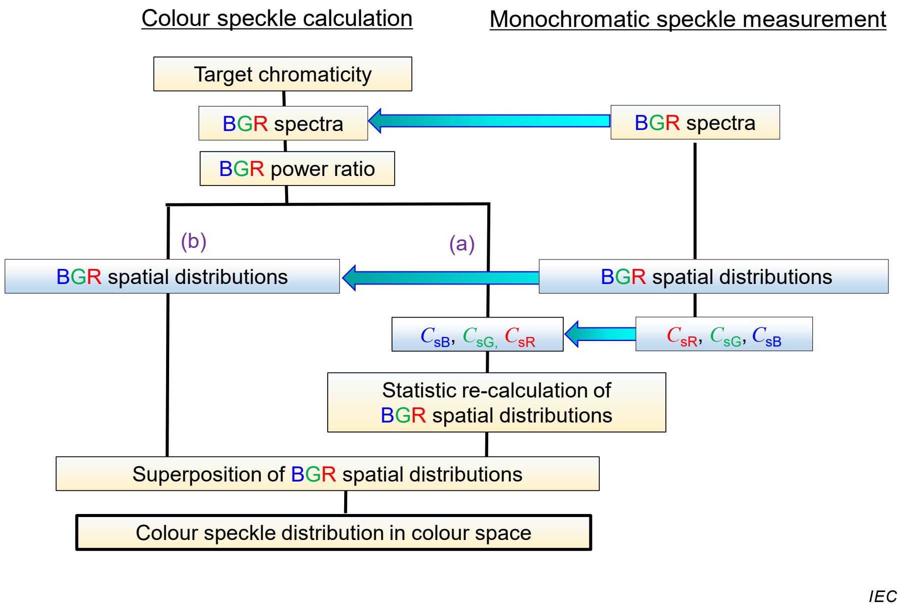

Figure 1 – Two speckle measuring methods and their flow charts

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.

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 $S_{\mathrm{B,G,R}}(\lambda)$ 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.

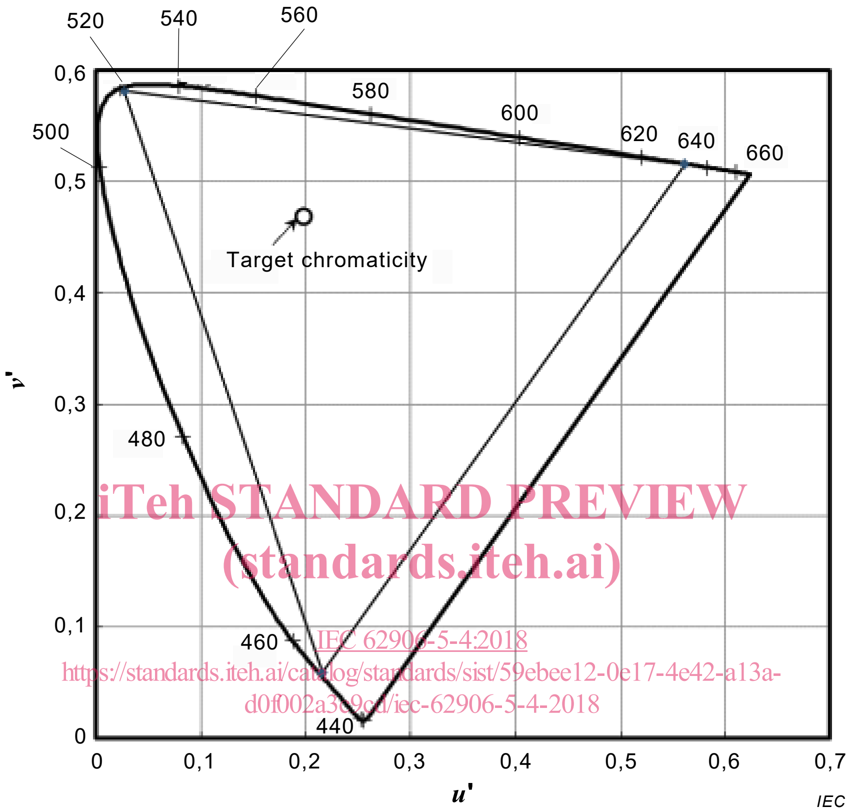

Figure 2 – Target chromaticity and colour gamut

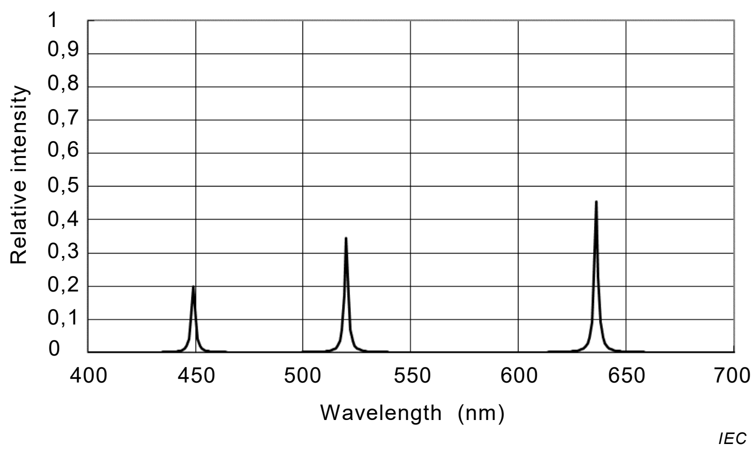

Figure 3 – $S_{\mathrm{B,G,R}}(\lambda)$ with an FWHM of 2 nm