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Laser display devices –
Part 5-2: Optical measuring methods of speckle contrast

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INTERNATIONAL
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LASER DISPLAY DEVICES –

Part 5-2: Optical measuring methods of speckle contrast

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The text of this standard is based on the following documents:

FDIS	Report on voting
110/760/FDIS	110/768/RVD

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

This publication 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 publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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

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LASER DISPLAY DEVICES –

Part 5-2: Optical measuring methods of speckle contrast

1 Scope

This part of IEC 62906 specifies the standard measurement conditions and measurement methods for determining the monochromatic speckle contrast of laser display devices (LDDs). The LDDs may include hybrid types using both a laser or lasers, and spontaneous emission-based light sources, such as LEDs.

NOTE The monochromatic speckle contrast measurements do not include image quality issues.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 62906-1-2:2015, *Laser display devices – Part 1-2: Vocabulary and letter symbols*

3 Terms, definitions and abbreviations

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

3.1 Terms and definitions

3.1.1
fully developed speckle
FDS
speckle when the speckle contrast ratio is equal to one (C_s = 1)

[SOURCE: Goodman:2006] [1][1]

3.2 Abbreviations

DN digital number

DUT device under test

LD laser diode

LMD light measuring device

MTF modulation transfer function

NA numerical aperture

PPUT projection plane under test

PSF point spread function

1 Numbers square brackets refer to the bibliography.

SNR signal to noise ratio

4 Standard measuring conditions

4.1 General

An LDD is featured by using coherent or partially-coherent light sources. Speckle is created particularly by coherence of the light sources. Therefore, measuring methods and equipment particularly designed for speckle are necessary.

When carrying out optical measurements of LDD, the measuring environment, equipment and methods shall be compliant with IEC 60825-1 for human safety.

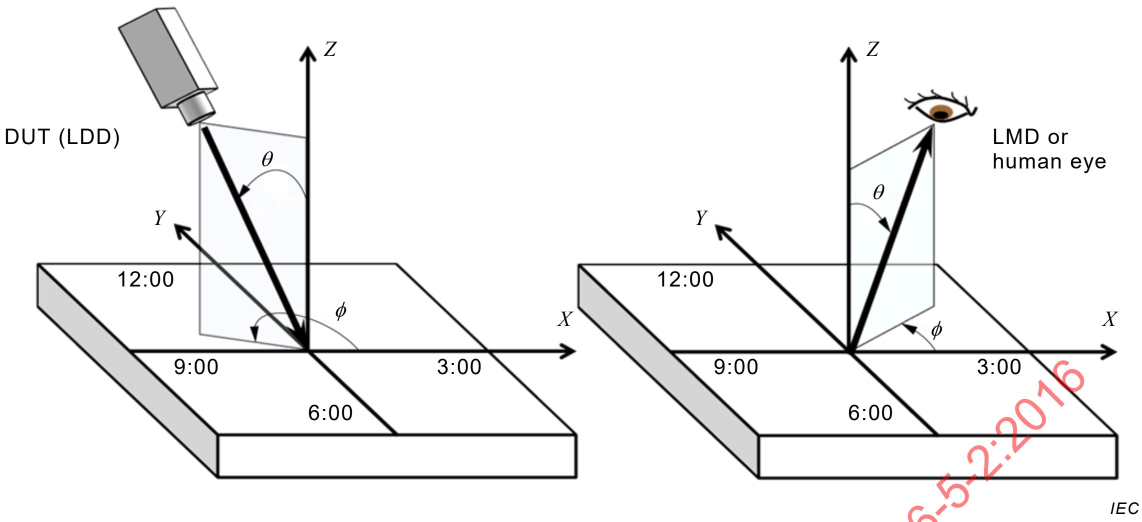
4.2 Standard measuring environmental conditions

Optical measurements related to speckle shall be carried out under the standard environmental conditions, at a temperature of 25 °C ± 3 °C, a relative humidity of 25 % to 85 %, and pressure of 86 kPa to 106 kPa. When different environmental conditions are used, they shall be noted in the report.

4.3 Measurement coordinate system

The projection direction is the direction of a beam coming from the LDD to the projection plane under test (PPUT). The projection direction is defined by two angles: the angle of inclination θ (relative to the surface normal of the PPUT) and the angle of rotation ϕ (also called azimuth angle) as illustrated in Figure 1 a). Although the azimuth angle is measured in the counter-clockwise direction, it is related to the directions on a clock face as follows: $\phi = 0°$ is the 3 o'clock direction ("right"), $\phi = 90°$ the 12 o'clock direction ("top"), $\phi = 180°$ the 9 o'clock direction ("left") and $\phi = 270°$ the 6 o'clock direction ("bottom").

The viewing direction is the direction under which the observer looks at the point of interest on the device under test (DUT), including the projection plane under test (PPUT). During the measurement, the light-measuring device (LMD) simulates the observer, by aiming the LMD at the point of interest on the DUT from the viewing direction. The viewing direction is defined by two angles: the angle of inclination θ (relative to the surface normal of the DUT) and the angle of rotation ϕ (also called azimuth angle) as illustrated in Figure 1. Although the azimuth angle is measured in the counter-clockwise direction, it is related to the directions on a clock face as follows: $\phi = 0°$ is the 3 o'clock direction ("right"), $\phi = 90°$ the 12 o'clock direction ("top"), $\phi = 180°$ the 9 o'clock direction ("left") and $\phi = 270°$ the 6 o'clock direction ("bottom").



a) PPUT (screen) for front projection

b) PPUT (screen) for front projection, or DUT (LDD) for rear projection

Figure 1 – Coordinate system for projection direction and viewing direction

4.4 Darkroom conditions

The LDD should be measured under controlled lighting conditions. Unwanted background illumination except the light generated by the LDD itself shall be minimized, typically by illuminating the display in a darkroom. The darkroom luminance contribution from the background illumination, which is the measurement illumination reflected off the DUT, shall be ≤ 1/20 of the lowest black level of the display. If this condition is not satisfied, then background subtraction is required and it shall be noted in the report. It is recommended that the background for each pixel of the imaging device be subtracted. In addition, if the sensitivity of the LMD is inadequate to measure at these low levels, then the lower limit of the LMD shall be noted in the report.

Unless stated otherwise, the standard background lighting conditions shall be the darkroom conditions.

4.5 Standard conditions of measuring equipment

4.5.1 General

It is assumed that all measurements are performed by personnel skilled in the general art of radiometric and electrical measurements as the purpose of this standard is not to give a detailed account of good practice in electrical and optical experimental physics. Furthermore, it is necessary to ensure that all equipment is suitably calibrated as is known to skilled personnel and that records of the calibration data and traceability are kept.

It is assumed that all measurements are performed under normal operation conditions as used in the finished product by the end user unless requested otherwise.

Standard equipment conditions are given below. Any deviations from these conditions shall be noted in the report.

Measurements shall be started after the LDD, the light source, and measuring instruments achieve stability.

If the measurement is not carried out under the darkroom conditions, depending on the application, the illumination/detection geometry and the light source spectral behaviour shall be reported.

4.5.2 Adjustment of LDD

The LDD shall be measured at the factory default mode. The LDD may be also measured at additional modes (e.g. bright or movie mode).

4.5.3 Conditions of measuring equipment

The speckle contrast created by the LDD shall be measured using the standard measurement conditions given in 4.2.

The following conditions of the speckle contrast measuring equipment shall be noted in the record:

a) LDD operation mode,
b) distance from projection plane to LDD (except rear projection),
c) distance from projection plane to LMD,
d) projection direction as given in 4.3,
e) viewing direction as given in 4.3,
f) polarization conditions if not operating in the factory default mode,
g) centre wavelength of the LDD,
h) spectrum of the LDD if not operating in the default monochromatic mode,
i) optical system parameters of LMD,
   1) imaging lens F-number
   2) iris diameter
   3) spectral characteristics of the optical filter of the LMD (when they were applied)
j) specifications of two-dimensional imaging device,
   1) pixel size
   2) bit depth
   3) spectral sensitivity
   4) dynamic range
   5) linearity of input signal to DN
   6) exposure time

The speckle of each primary colour generally shall be measured in terms of the spectrum of the LDs which line-width is much narrower than LEDs either in the case of single longitudinal or in the case of multi-longitudinal mode operation (see Annex A). Spectral measurement of such a narrow line-width requires much higher resolution: a spectrometer, or a spectrum analyser may be used.

The measurement shall be performed considering the following aspects.

- A spectrometer or a spectrum analyser shall be capable of covering a wavelength range of at least 380 nm to 780 nm and shall have polarization sensitivity less than 2 %.
- Care shall be taken to ensure that the LMD has enough sensitivity and dynamic range to perform the required task.
- The relative uncertainty and repeatability of all the measuring devices shall be maintained by following the recommended calibration schedule instructed by the instrument supplier.
- The DUT shall be operated at its intended image refresh rate.

4.6 Screen conditions

4.6.1 General

The screen is an important component of the LDD in the measurement of speckle. If the DUT contains a screen as one of the components of the product, the measurement shall be carried out using the screen.

4.6.2 Report

The following specifications related to screen gain shall be noted in the report:

- viewing angle characteristic,
- peak gain,
- half-gain angle.

NOTE 1 The definitions and measurement methods of these parameters are shown in the ICDM information display measurements standard, 2012, Appendix B17 [3].

The screen should be held rigidly or the measurement results might be affected, particularly for long exposure times.

NOTE 2 The ICDM document [3] in the bibliography is referred because there is no other appropriate reference source for the screen gain for this document, but in the future, more appropriate document will be referred.

5 Measuring methods of speckle contrast

5.1 Speckle contrast measurement of still image

5.1.1 Purpose

The purpose of this method is to determine the speckle contrast of an LDD. The main focus of this measuring method is to measure the screen speckle contrast.

5.1.2 Measuring conditions

The apparatus consists of the following:

- a driving power source,
- a driving signal equipment,
- an imaging device,
- an imaging lens and iris,
- a screen for front projection display.

An LMD consisting of an imaging lens, iris and imaging device should be based on the MTF or the PSF of the human eye perception. [2] The imaging device such as a CCD or a CMOS output signal should have a linear response to the incident light above the dark current noise level. Full well capacity should be large enough for the measurement not to be affected by shot noise. The SNR is more than 10 and the dark current noise is less than 0,1 electrons. The imaging device should have enough resolution to resolve the minimum subjective speckle grain size caused by the iris (see Annex B).

NOTE For the noise of the imaging sensor, refer to Chapter 3: Photon Transfer Noise Sources in [4]. For the characteristics of the imaging sensor, refer to Annex D.

5.1.3 Measuring the monochromatic speckle contrast of front projection

The measurement shall be performed as follows:

a) Place the DUT in front of the screen. The projection distance should be the same as the nominal product design values.

b) Place the LMD as indicated in Figure 2. The measurement distance should be the same as the intended audience viewing distance.

The measurement distance strongly depends on the DUT. For example, a measurement distance of three times the image height is recommended for a full HD projector. A measurement distance of 5 m is recommended for a cinema projector.

The imaging device shall be placed at the conjugate focal plane of the screen.

c) The projection image of the DUT is a spatially uniform pattern (typically a primary colour R, G or B). The speckle should be measured for all primaries, when multi-primary systems are measured. The image size shall be larger than the field of view of the LMD.

d) Set the colour filter if necessary, for example avoiding an unnecessary optical signal. The filter should transmit the primary colour channel of the projected image. It is recommended to apply the optical filter that transmits the primary colour separately to measure the speckle contrast of each light source.

e) Focus the LMD to the projected image on the screen.

f) It is recommended to align the DUT and LMD at an appropriate angle to avoid specular reflection to the LMD. Focus the LMD on the screen.

g) Capture the image. The exposure time shall be determined so as not to saturate the imaging device.

h) Calculate the speckle contrast C_s using the following equation:

$$C_s = \frac{\sigma}{\bar{I}} \quad (1)$$

where σ is the standard deviation of the speckle pattern and $\bar{I}$ $\bar{I}$ is the average of the speckle pattern.

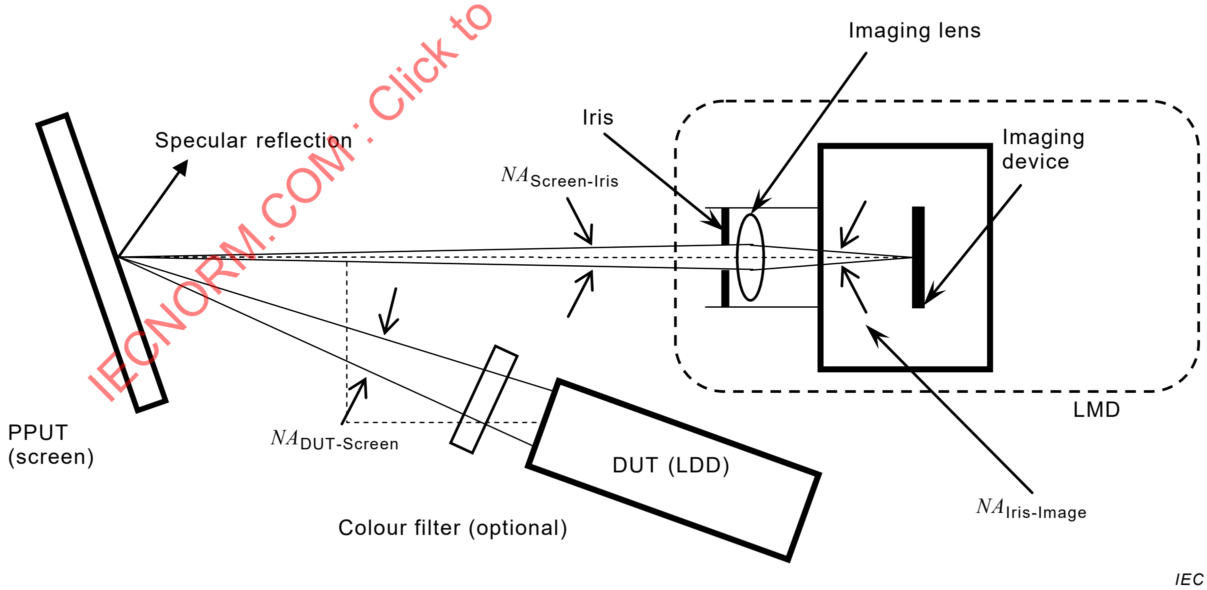


Figure 2 – Example of measurement geometries for monochromatic speckle contrast of front projection

NOTE 1 The colour filter set in front of the DUT has a bandpass property for extracting only the very narrow “monochromatic” bandwidth of lasers generating speckle (see Annex A). It is optional particularly when the other light sources affect the speckle contrast (see IEC 62906-1-2:2015, 2.3.5). The crosstalk involving the other light sources is eliminated during the measurement.

NOTE 2 For applications using specific eyepieces, such as 3D glasses which have different optical properties (polarization or wavelength-band, etc.) between the right and left eyes, appropriate optics which have the same optical properties as the eyepieces is set in front of LMD.

5.1.4 Measuring the monochromatic speckle contrast of rear projection

It is assumed that a screen is a component part of the rear projector.

a) Place the DUT and the LMD as indicated in Figure 3. The measurement distance should be the same as the intended audience viewing distance.

b) The projection image of the DUT is a spatially uniform pattern (typically a primary colour R, G or B). The image size shall be larger than the field of view of the LMD.

c) Set the colour filter if necessary, for example avoiding an unnecessary optical signal. The filter should transmit only the primary colour channel of the projected colour. It is recommended to apply the optical filter that transmits the primary colour separately to measure the speckle contrast of each light source.

d) Focus the LMD on the screen.

e) Capture the image. The exposure time shall be determined so as not to saturate the imaging device.

f) Calculate the speckle contrast C_s in the same manner as in 5.1.3 g).

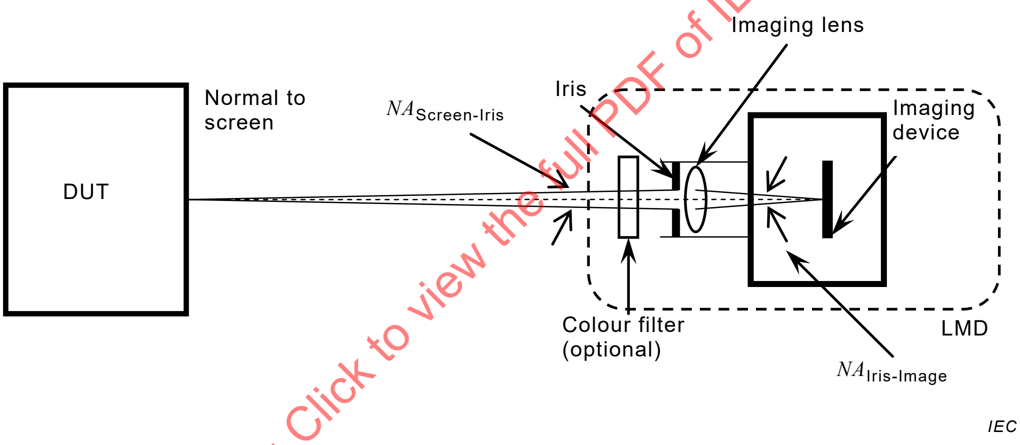


Figure 3 – Example of measurement geometries for monochromatic speckle contrast of rear projection

5.2 Calibration and diagnosis of the LMD

5.2.1 General

To achieve an accurate and repeatable C_s measurement, calibration and diagnosis of the LMD are important. The scheduled calibration and diagnosis are recommended.

The entire calibration shall be carried out by front projection, not by rear projection.

The apparatus consists of the following:

- a continuous-wave, narrow-bandwidth and linearly-polarised coherent light source stabilised in a single longitudinal and transverse mode such as a stabilised He/Ne laser with a frequency bandwidth less than 20 MHz for high C_s calibration;
- a polariser;
- an incoherent light such as incandescent lamp for low C_s;
- a projection lens;

- a diffuse reflectance standard screen which has an approximate Lambertian scattering property.

NOTE The surface texture of reflectance standards may vary and affect the absolute speckle contrast value. A single reflectance standard sample is designated as the reference when comparing results.

5.2.2 Calibration procedure and diagnosis for the highest C_s

The measurable highest value of C_s obtained from an almost perfect coherent light source as specified in 5.2.1 shall be used for the highest C_s calibration as the C_s value closest to that for a fully developed speckle (FDS; C_s = 1, see 3.1).

a) Place the LMD as indicated in Figure 4.
b) Set the coherent light source at the position of the “light source” in Figure 4.
c) The projection beam shall be collimated and the projected area shall be large enough to overfill the measurement area.
d) Set a screen and align the DUT and LMD at an appropriate angle to avoid specular reflection to the LMD.
e) Set a polariser in front of the imaging lens.
f) Align the polarization plane of the polariser in the same direction as that of the coherent light source.
g) Focus the LMD on the screen.
h) Capture the image. The exposure time shall be determined so as not to saturate the imaging device.
i) Calculate the speckle contrast C_s in the same manner as in 5.1.3 g).
j) Report the obtained speckle contrast C_s

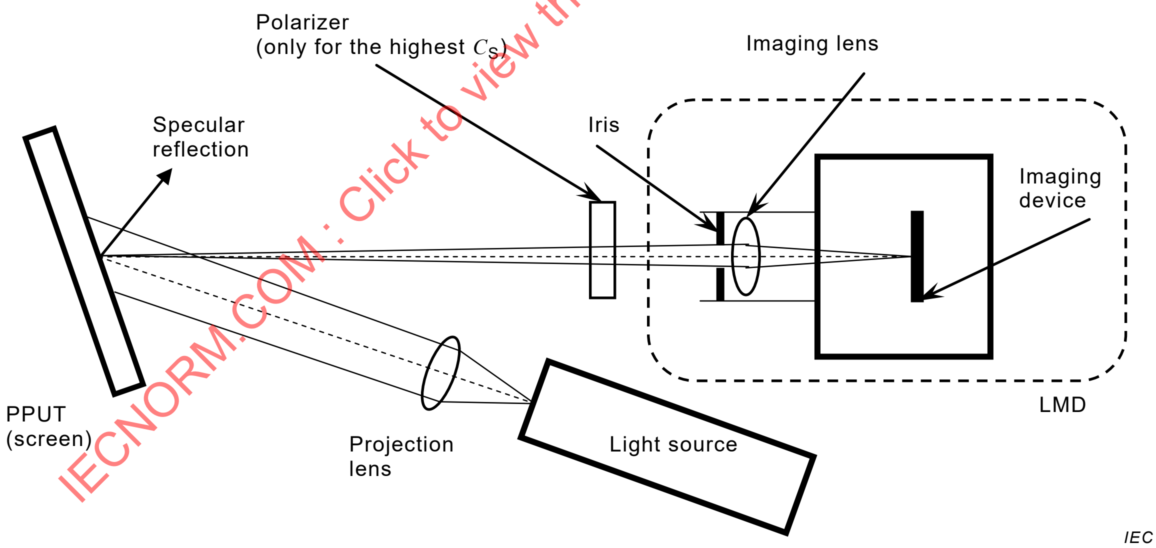


Figure 4 – Example of measurement geometries for C_s calibration

The measured highest C_s value shall be larger than 0,97. Otherwise, the LMD shall be adjusted to be larger than 0,97.

5.2.3 Calibration procedure and diagnosis for the lowest C_s

The measurable lowest value of C_s obtained from an incoherent light source such as an incandescent lamp or a white LED with uniform illumination shall be used for the lowest C_s calibration as the C_s value closest to that for the perfectly incoherent case of C_s = 0.

a) Place the LMD as indicated in Figure 4 (without the polariser).

b) Set the incoherent light source at the position of the “light source” in Figure 4.

c) The projection beam shall be collimated and the projected area shall be large enough to overfill the measurement area.

d) Align the DUT and LMD at an appropriate angle to avoid specular reflection to the LMD.

e) Focus the LMD on the screen.

f) Capture the image. The exposure time shall be determined so as not to saturate the imaging device.

g) Calculate the speckle contrast C_s in the same manner as in 5.1.3 g).

h) Report the obtained speckle contrast C_s.

The measured lowest C_s value shall be smaller than 0,02. Otherwise, the LMD shall be adjusted to be smaller than 0,02.

Annex A
(informative)

Spectral behaviour of the LD

A.1 Spectral behaviour of a single-longitudinal mode LD

A single-longitudinal mode LD usually operates with a very narrow single spectral line (longitudinal mode) as in Figure A.1. The relationship to speckle contrast is described in detail by Goodman [1].

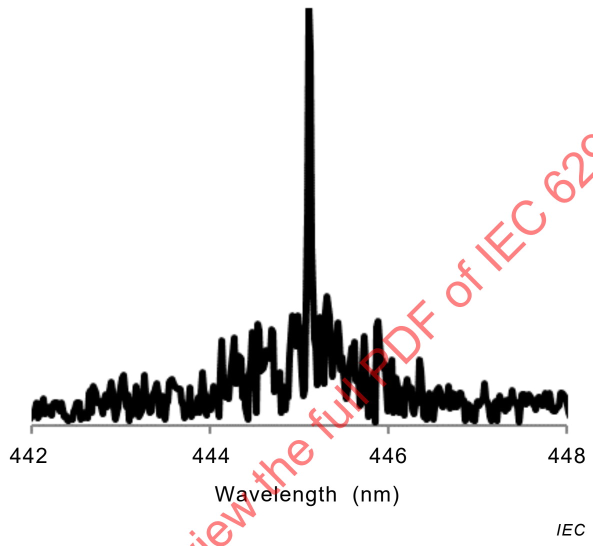


Figure A.1 – Example of spectral behaviour of a single-longitudinal mode LD

A.2 Spectral behaviour of a multi-longitudinal mode LD

A multi-longitudinal mode LD usually operates with a bunch of many spectral lines as in Figure A.2. The relationship to speckle contrast is described in detail by Goodman [1].

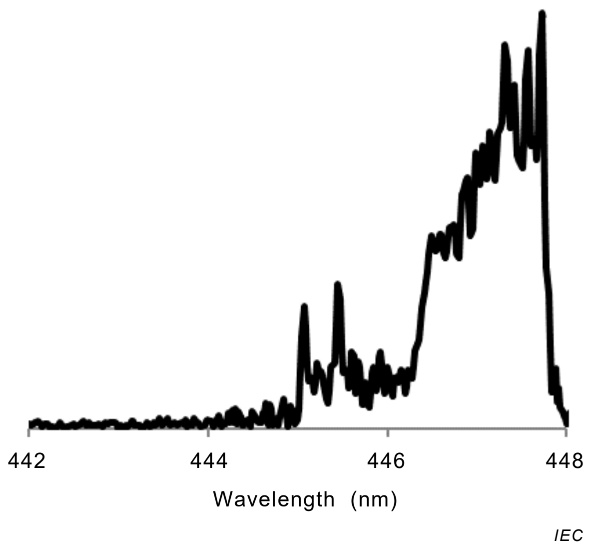


Figure A.2 – Example of spectral behaviour of a multi-longitudinal mode LD

Annex B
(informative)

Recommendation on imaging sensor pixel size

The minimum subjective speckle grain size, s_{subj} is given as follows:

$$s_{subj} = \frac{\lambda}{2\sin\theta_{subj}} \quad \text{(B.1)}$$

where λ is the wavelength of coherent beam and θ_{subj} is the half-angle between two coherent beams from opposite edges of the effective diameter of the imaging lens at the image space. θ_{subj} can be given by:

$$\theta_{subj} = \arctan(\frac{D}{2f}) \quad \text{(B.2)}$$

where D is the iris diameter and f is the focal length of the lens. Assuming that f is 50 mm and λ is 532 nm, s_{subj} at various D values is given in Table B.1. Also s_{subj} is potted as a function of the F-number (f/D) in Table B.1 and Figure B.1.

Table B.1 – Example of s_{subj}

D (mm)	s_{subj} (µm)
0,4	66,5
0,8	33,3
1,2	22,2
1,6	16,6
2,0	13,3
2,4	11,1
2,8	9,5
3,2	8,3
3,6	7,4
4,0	6,7

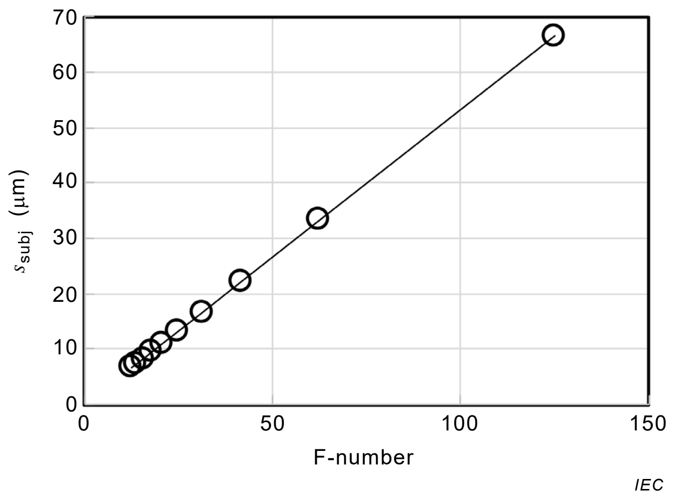


Figure B.1 – Minimum subjective speckle grain size as a function of the F-number

To resolve the speckle, the CCD pixel size is required to be at least half the size of s_{subj} according to the sampling theory [8].

Annex C
(informative)

Fundamental formulation of speckle contrast and the effects of measurement variables

C.1 Fundamental formulation

The formulation of speckle contrast is given by Goodman [1]. The speckle contrast, C_s, is basically expressed as follows:

$$C_s = \sqrt{\frac{M+K\pm 1}{MK}} \quad C_s = \sqrt{\frac{M+K\pm 1}{MK}} \tag{C.1}$$

where, M is the temporal diversity, and K is the spatial diversity. In the case of $M \gg K \gg 1$, Equation (C.1) can be approximated by the following equation:

$$C_s \approx \frac{1}{\sqrt{K}} \approx \frac{NA_{\text{Screen−Iris}}}{NA_{\text{DUT−Screen}}} \quad C_s \approx 1/\sqrt{K} \approx \frac{NA_{\text{Screen−Iris}}}{NA_{\text{DUT−Screen}}} \tag{C.2}$$

where, $NA_{\text{DUT-Screen}}$ is the numerical aperture of the projector illumination lens, and $NA_{\text{Screen-Iris}}$ is that of the imaging lens (see Figure 2). Equation (C.2) implies that C_s depends on the projection distance, the observation distance, and other measurement variables. Therefore, such variables should be carefully chosen when C_s is measured.

An example of the effects of such variables is shown in Clause C.2.

C.2 Effect of observation distance and iris radius

$NA_{\text{Screen-Iris}}$ is redefined, using the iris diameter D and the observation distance L_{obs} as follows:

$$NA_{\text{screen−Iris}} = \frac{D/2}{L_{\text{obs}}} \tag{C.3}$$

Figure C.1 shows an example of measurement results of C_s for a laser projector. C_s is plotted by changing the iris radius and observation distance [9]. The horizontal axis is the normalized $NA_{\text{Screen-Iris}}$ redefined as Equation (C.3).