INTERNATIONAL STANDARD

ISO 9241-305

First edition
2008-11-15

Ergonomics of human-system interaction —

Part 305:
Optical laboratory test methods for electronic visual displays

Ergonomie de l'interaction homme-système —

Partie 305: Méthodes d'essai de laboratoire optique pour écrans de visualisation électroniques

Reference number
ISO 9241-305:2008(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

COPYRIGHT PROTECTED DOCUMENT

© ISO 2008

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 ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9241-305 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

This first edition of ISO 9241-305, together with ISO 9241-302, cancels and replaces ISO 13406-1:1999 and ISO 9241-8:1997. Together with ISO 9241-302, ISO 9241-303 and ISO 9241-307, it also cancels and replaces ISO 9241-7:1998 and ISO 13406-2:2001, and partially replaces ISO 9241-3:1992. The following has been technically revised:

- terms and definitions related to electronic visual displays have been transferred to, and collected in, ISO 9241-302;
- while the areas previously covered in ISO 9241 and by ISO 13406 remain essentially unchanged, test methods and requirements have been updated to account for advances in science and technology;
- all generic ergonomic requirements have been incorporated into ISO 9241-303;
- the application of those requirements to different display technologies, application areas and environmental conditions — including test methods and pass/fail criteria — is specified in ISO 9241-307;
- methods for the laboratory testing of those requirements are specified in ISO 9241-305.

ISO 9241 consists of the following parts, under the general title *Ergonomic requirements for office work with visual display terminals (VDTs)*:

- *Part 1: General introduction*
- *Part 2: Guidance on task requirements*
- *Part 4: Keyboard requirements*
- *Part 5: Workstation layout and postural requirements*
- *Part 6: Guidance on the work environment*
- *Part 9: Requirements for non-keyboard input devices*

- *Part 11: Guidance on usability*
- *Part 12: Presentation of information*
- *Part 13: User guidance*
- *Part 14: Menu dialogues*
- *Part 15: Command dialogues*
- *Part 16: Direct manipulation dialogues*
- *Part 17: Form filling dialogues*

ISO 9241 also consists of the following parts, under the general title *Ergonomics of human-system interaction*:

- *Part 20: Accessibility guidelines for information/communication technology (ICT) equipment and services*
- *Part 110: Dialogue principles*
- *Part 151: Guidance on World Wide Web user interfaces*
- *Part 171: Guidance on software accessibility*
- *Part 300: Introduction to electronic visual display requirements*
- *Part 302: Terminology for electronic visual displays*
- *Part 303: Requirements for electronic visual displays*
- *Part 304: User performance test methods for electronic visual displays*
- *Part 305: Optical laboratory test methods for electronic visual displays*
- *Part 306: Field assessment methods for electronic visual displays*
- *Part 307: Analysis and compliance test methods for electronic visual displays*
- *Part 308: Surface-conduction electron-emitter displays (SED)* [Technical Report]
- *Part 309: Organic light-emitting diode (OLED) displays* [Technical Report]
- *Part 400: Principles and requirements for physical input devices*
- *Part 410: Design criteria for physical input devices*
- *Part 920: Guidance on tactile and haptic interactions*

For the other parts under preparation, see Annex A.

Introduction

This part of ISO 9241 was prepared with the support of the flat panel display measurements (FPDM) task group of VESA (Video Electronics Standards Association, USA). Contributions from its FPDM standard [10] are identified in Annex C.

The methods specified in this part of ISO 9241 are provided to assist test laboratories (either suppliers' facilities or test institutes) in deciding whether a specific electronic display conforms to the other relevant parts of ISO 9241, insofar as such a decision can be made in a laboratory setting. This part of ISO 9241 does not specify how to select display adjustment parameters or software for making a test representative of intended actual use. That judgement has to be made by the test laboratory and described in the test report.

ISO 9241 was originally developed as a seventeen-part International Standard on the ergonomics requirements for office work with visual display terminals. As part of the standards review process, a major restructuring of ISO 9241 was agreed to broaden its scope, to incorporate other relevant standards and to make it more usable. The general title of the revised ISO 9241, "Ergonomics of human-system interaction", reflects these changes and aligns the standard with the overall title and scope of Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*. The revised multipart standard is structured as series of standards numbered in the "hundreds": the 100 series deals with software interfaces, the 200 series with human centred design, the 300 series with visual displays, the 400 series with physical input devices, and so on.

See Annex A for an overview of the entire ISO 9241 series.

Ergonomics of human-system interaction —

Part 305:
Optical laboratory test methods for electronic visual displays

1 Scope

This part of ISO 9241 establishes optical test and expert observation methods for use in predicting the performance of a display vis-à-vis the ergonomics requirements given in ISO 9241-303.

2 Normative references

The following referenced documents are indispensable for the application 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.

ISO 9241-302, *Ergonomics of human-system interaction — Part 302: Terminology for electronic visual displays*

ISO 9241-303, *Ergonomics of human-system interaction — Part 303: Requirements for electronic visual displays*

ISO 9241-307, *Ergonomics of human-system interaction — Part 307: Analysis and compliance test methods for electronic visual displays*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9241-302 apply.

4 General

4.1 Measurements — Basic measurements and derived procedures

The collection of (optical) lab measurements necessary for the compliance evaluations given in this part of ISO 9241 are divided into *basic measurements* — identified by M and a measurement number — and *measurement procedures* — identified by P and a procedure number (and letter in the case of supplementary procedures) — briefly described below. Additional information, including decisions on developing the methods and their use for the definition of compliance procedures, can be found in Annex B.

4.1.1 Basic measurements (or evaluation) — Method M

Basic measurements should describe a fundamental method in as simple a form as possible. Most of the essential measurement parameters (such as screen location, viewing direction, test pattern) are not specified. The specified result is a physical quantity or some other directly measured property, and does not involve any processing of the collected data. These results are usually not directly used in a compliance procedure of the sort specified in ISO 9241-307. Rather, in a compound measurement procedure (see 4.1.2), a basic measurement will be used to achieve sets or collections of data.

These basic measurements define the types of meters acceptable for use, meter parameters, and any default parameters (“fixed measurement conditions”), and list the parameters that are to be varied by the compound measurement procedure (“configurable measurement conditions”). These latter parameters are often defined by the compliance procedure (see ISO 9241-307).

4.1.2 Compound measurement procedures — Procedure P

Compound measurement procedures are methods that collect and evaluate physical quantities that were measured using a basic method (see 4.1.1). These procedures reference basic measurements, and may specify the specific requirements for the “configurable measurement conditions”. They also include any special preparation procedures. The result of a procedure is a collection of basic quantities (e.g. area or angular distribution of luminance), or derived quantities (e.g. luminance contrast, colour difference). In many cases, the measurement procedures could have some of the configurable measurement conditions defined by the compliance procedure (see ISO 9241-307).

4.2 Structure

The measurement methods given in this part of ISO 9241 are structured as follows.

a) **Objective**: this describes the purpose and quantities measured.

b) **Applicability**: this describes the type of displays/applications in which the particular measurement is relevant.

c) **Preparation and set-up**: this describes fixed and configurable measurement conditions, optional accessory equipment, and any special preliminary requirements.

d) **Procedure**: this describes the measurement or references basic measurement method.

e) **Analysis**: this describes any analysis of the measured data.

f) **Reporting**: this describes the form of reporting, including the number of significant digits, where appropriate.

g) **Comments**: this describes any special concerns or relevant information not contained elsewhere.

4.3 Matrix of measurement conditions methods and procedures

A matrix of measurement conditions, methods and procedures comparing various source documents (including earlier International Standards) can be found in Annex C.

NOTE Many of the procedures in this document have been incorporated, in whole or in part, from ISO 9241-3:1992. See Annex C and the Bibliography for further references.

5 Measurement conditions

5.1 Preparations and procedures

5.1.1 CRT (cathode ray tube) monitor standard preparation

Allow sufficient time for the display luminance to stabilise, with a minimum of 20 min.

5.1.1.1 Technology dependent parameters

Manual degauss in measurement position (for colour displays only). This refers to externally applied degauss (not manual activation of an internal system).

5.1.1.2 Cleaning

Ensure that the display is clean.

5.1.1.3 Alignment

The display screen should be aligned such that a plane tangential to the screen centre is parallel to the axes of the measurement system(s).

Tilt: the active display area shall be aligned such that a horizontal line through the screen centre is parallel to the horizontal axis of the measurement instrument and/or of the measurement instrument travel.

5.1.1.4 Brightness and contrast control settings

Adjust the brightness control until the raster is at cut-off.

Adjustment should be performed under the lighting conditions for the specific compliance route as specified in ISO 9241-307.

After adjusting the display brightness to its default, adjust the centre-screen luminance to 100 cd/m^2 at 20 % screen loading. If this is not achievable, report the centre-screen luminance.

The controls shall remain at these settings for all measurements.

5.1.1.5 Image size

Use the factory setting or default, if available. Otherwise, adjust to a specified size.

5.1.1.6 Video drive levels

If the display uses an analogue interface, then the drive level(s) shall be specified for video signal lines.

Most applications drive the standard RGB interface with either 0,47 V or 0,7 V (corresponding to 2/3 video and full video respectively) and the use of one of these values is recommended. The value used should be specified.

5.1.2 LCD (liquid crystal display) monitor standard preparation

The flat panel display unit to be tested shall be physically prepared for testing.

5.1.2.1 Display warm-up

Allow sufficient time for the display luminance to stabilise, with a minimum of 20 min. When indicated by the manufacturer, the display shall be warmed up for the specified time (not to exceed 1 h).

5.1.2.2 Technology dependent parameters

Testing shall be conducted under normal user conditions for power supply. The bias settings (if any) of the display shall be set to those expected under typical use. Any reflection treatment or filter that is in place for the test specified in 6.5 shall be in place for every test.

One adjustment setting shall be used for each complete test sequence. If multiple settings are provided, this implies multiple complete test sequences.

5.1.2.3 Cleaning

Ensure that the display is clean.

5.1.2.4 Alignment

The display screen should be aligned such that a plane tangential to the screen centre is parallel to the axes of the measurement system(s).

Tilt: the active display area shall be aligned such that a horizontal line through the screen centre is parallel to the horizontal axis of the measurement instrument and/or of the measurement instrument travel.

5.1.2.5 Brightness and contrast control settings

The display shall be adjusted to its default or preset brightness and contrast. The controls shall remain at these settings for all measurements. Adjustment should be performed under the lighting conditions for the specific compliance route as specified in ISO 9241-307.

5.1.2.6 Image size

Use the factory setting or the default, if available. Otherwise, adjust to a specified size.

5.1.2.7 Video drive levels

If the display uses an analogue interface, then the drive level(s) shall be specified for video signal lines.

Most applications drive the standard RGB interface with either 0,47 V or 0,7 V (corresponding to 2/3 video and full video respectively) and the use of one of these values is recommended. The value used should be specified.

5.1.3 Front projection display standard preparation (fixed resolution systems)

5.1.3.1 Display warm-up

Measurements are carried out after 100 h operation of the projection lamp (burn-in time). After switching on, the minimum warm-up time shall be 1 h unless otherwise specified in ISO 9241-307.

5.1.3.2 Technology depending parameters

Testing shall be conducted under normal user conditions for power supply. The bias settings (if any) of the display shall be set to those expected under typical use. Any reflection treatment or filter that is in place for the test specified in 6.5 shall be in place for every test.

One adjustment setting shall be used for each complete test sequence. If multiple settings are provided, this implies multiple complete test sequences.

5.1.3.3 Cleaning

Ensure that the display screen is clean.

5.1.3.4 Alignment

All optics, convergence controls and focus shall be adjusted so that the projected image appears sharp over the largest percentage of the illuminated area. Front projection systems shall be positioned relative to the screen according to the manufacturer’s specifications for angle, height, and distance. Rear-projection systems shall be adjusted so that the image fills the screen completely (not overfill).

5.1.3.5 Brightness and contrast control settings

The control designed to adjust brightness shall be set to the point where the maximum number of signal level blocks on the top line, representing 0 %, 5 %, 10 % and 15 % signal levels, are visible and distinct from the adjacent signal level blocks.

The control designed to adjust contrast shall be advanced from minimum until the maximum number of signal level blocks in the lower line of the pattern (representing the 85 %, 90 %, 95 % and 100 % signal levels) are visible and distinct from the adjacent signal level blocks or until the picture no longer increases in brightness, as limited by automatic brightness circuitry.

The controls shall remain at these settings for all measurements. Adjustment should be performed under the lighting conditions for the specific compliance route as specified in ISO 9241-307.

5.1.3.6 Image size

Use the factory setting or the default, if available. Otherwise, adjust to a specified size.

5.1.3.7 Video drive levels

Connect the projector to a notebook computer or other signal generator. The signal generator shall offer a typical signal voltage on RGB of 0,7 V ± 0,07 V. Adjust the focus for the sharpest image.

5.1.4 PDP (plasma display panel) monitor standard preparation

Allow sufficient time for the display luminance to stabilise, with a minimum of 20 min.

5.1.4.1 Technology depending parameters

Testing shall be conducted under normal user conditions for power supply. The bias settings (if any) of the display shall be set to those expected under typical use. Any reflection treatment or filter that is in place for the test specified in 6.5 shall be in place for every test.

One adjustment setting shall be used for each complete test sequence. If multiple settings are provided, this implies multiple complete test sequences.

5.1.4.2 Cleaning

Ensure that the display is clean.

5.1.4.3 Alignment

The display screen should be aligned such that a plane tangential to the screen centre is parallel to the axes of the measurement system(s).

Tilt: the active display area shall be aligned such that a horizontal line through the screen centre is parallel to the horizontal axis of the measurement instrument and/or of the measurement instrument travel.

5.1.4.4 Brightness and contrast control settings

Adjust the brightness control until the raster is at cut-off. Adjustment should be performed under the lighting conditions for the specific compliance route as specified in ISO 9241-307.

After adjusting the display brightness to its default, adjust the centre-screen luminance to 100 cd/m^2 at 20 % screen loading. If this is not achievable, report the centre-screen luminance.

The controls shall remain at these settings for all measurements.

5.1.4.5 Image size

Use the factory setting or the default, if available. Otherwise, adjust to a specified size.

5.1.4.6 Video drive levels

If the display uses an analogue interface, then the drive level(s) shall be specified for video signal lines.

Most applications drive the standard RGB interface with either 0,47 V or 0,7 V (corresponding to 2/3 video and full video, respectively) and the use of one of these values is recommended. The value used should be specified.

5.1.5 Hand-held devices

The flat panel display unit to be tested shall be physically prepared for testing.

5.1.5.1 Display warm-up

Allow sufficient time for the display luminance to stabilise, with a minimum of 20 min. When indicated by the manufacturer, the display shall be warmed up for the specified time (not to exceed 1 h).

5.1.5.2 Technology depending parameters

Testing shall be conducted under normal user conditions for power supply. The bias settings (if any) of the display shall be set to those expected under typical use. Any reflection treatment or filter that is in place for the test specified in 6.5 shall be in place for every test.

One adjustment setting shall be used for each complete test sequence. If multiple settings are provided, this implies multiple complete test sequences.

5.1.5.3 Cleaning

Ensure that the display is clean.

5.1.5.4 Alignment

The display screen should be aligned such that a plane tangential to the screen centre is parallel to the axes of the measurement system(s).

Tilt: the active display area shall be aligned such that a horizontal line through the screen centre is parallel to the horizontal axis of the measurement instrument and/or of the measurement instrument travel.

5.1.5.5 Brightness and contrast control settings

The display shall be adjusted to its default or preset brightness and contrast. The controls shall remain at these settings for all measurements. Adjustment should be performed under the lighting conditions for the specific compliance route as specified in ISO 9241-307.

5.1.5.6 Image size

Use the factory setting or the default, if available. Otherwise, adjust to a specified size.

5.1.5.7 Video drive levels

If the display uses an analogue interface, then the drive level(s) shall be specified for video signal lines.

Most applications drive the standard RGB interface with either 0,47 V or 0,7 V (corresponding to 2/3 video and full video respectively) and the use of one of these values is recommended. The value used should be specified.

5.2 Test accessories

Several objects and devices are required or useful for carrying out the measurements described in this part of ISO 9241. Some are introduced here.

5.2.1 Mirror standard

Mirror standards are mainly used for checking the geometrical alignment and for redirecting light from a source into a light-measuring device (LMD).

Any flat and plane substrate with the front surface coated with, e.g. silver or aluminium, and protected by a thin layer of a transparent dielectric forms a surface mirror with a reflectance of 95 % or more. Standard mirrors with backside coating should not be used, since multiple reflections occur that make those mirrors unsuitable for most calibration purposes.

Another type of mirror that is particularly useful for display metrology is generally made from plane-polished black glass (i.e. highly absorbent glass). The specular reflectance of such a surface mirror without coating is given by the index of glass refraction as a function of the wavelength of light, and is in the range of 4 % to 5 % for normal incidence and increasing with angle of inclination.

Such mirrors are useful for measuring the reflectance properties of display devices, since the reflectance of a display device is rather in the range of some percent that in the range of 90 % and is thus in the same order of magnitude as the reflections of the EUT (equipment under test).

Calibration: in order to assure low uncertainties in the measurement, mirror standards should be calibrated explicitly for the task they will be used for (e.g. for the same angle of inclination).

IMPORTANT — It shall be assured that specular mirrors do not exhibit any directionality, i.e. they shall show the same specular reflectance for angles of rotation of the mirror about its surface normal. For the same reason, cleaning shall be done carefully and the result checked visually.

5.2.2 Haze standard

Characterisation and evaluation of the haze of display devices is strongly dependent on the geometry of illumination (e.g. angular extent of the light source) and of the receiver aperture. A haze standard is used to compare and correlate the measurements of different arrangements for measuring haze.

A haze standard is usually a flat surface that has been treated in order to scatter incident light around the specular direction. Haze standards are made by creating microstructures in the previously polished surface of e.g. a black glass mirror.

Commercial haze standards are usually calibrated in terms of gloss units. In order to make them useful for display measurements they have to be recalibrated, e.g. by the directional scattering for a specific arrangement of source and receiver.

NOTE Haze standards are extremely sensitive to surface contamination as applied by, e.g. fingerprints, and need to be treated with care and stored in a suitable container.

5.2.3 Diffuse reflectance standard

Ideal diffuse reflectance standards scatter all incident light equally into all directions (Lambertian characteristics); thus, they exhibit a constant luminance when viewed from different directions (under constant illumination). Diffuse reflectance standards are used to measure incident illumination (illuminance) via the luminance of the standard. The diffuse reflectance of a sample object can be determined by comparison with the calibrated standard.

Diffuse reflectance standards can be purchased with a wide range of reflectance values (from some percent to 99 %). Diffuse reflectance standards were formerly made from carefully refined $BaSO_4$ or MgO powder pressed into a tablet with plane surfaces. Such realisations, however, are very sensitive to ageing and to adsorption at their surfaces, making their use quite impractical. Modern diffuse reflectance standards are made from pressed PTFE powder and thus are quite robust with respect to handling and use.

Three aspects need to be considered pertaining to diffuse reflectance standards: the directional distribution of scattered light (ideally isotropic), the amount of light reflected by the standard (ideally 100 %) and the variation of reflectance with wavelength of light. Technical realisations of diffuse reflectance standards can reach high values of diffuse reflectance (99 %), but unfortunately they are far from being ideal scatterers.

Reflectance standards can be used for making illuminance from a luminance measurement of the standard ($E = \pi L_{\mathrm{STD}}/\beta_{\mathrm{STD}}$) only for the measurement geometry used to determine the standard's luminance factor, β, the geometry used for its calibration. If the reflectance (or diffuse reflectance) is associated with the standard — as the number 98 % or 99 % usually does refer to the reflectance — then that value can only be used for a uniform hemispherical illumination. If an isolated source is used at some angle, there is no reason to expect that the 99 % will be even close to the proper value of the luminance factor for that geometrical configuration. Measurement and calibration of the diffuse reflectance standard should therefore be carried out using the same geometry as will be used for the actual measurement (see 6.5.8).

NOTE Diffuse reflectance standards are sensitive to surface contamination as applied by e.g. fingerprints and need to be treated with care and stored in a suitable container. Some such standards can be carefully sanded (some require water with the sanding) or otherwise cleaned to refresh the surface back up to its maximum scattering, should the surface become soiled or contaminated (see supplier instructions).

5.2.4 Degaussing device

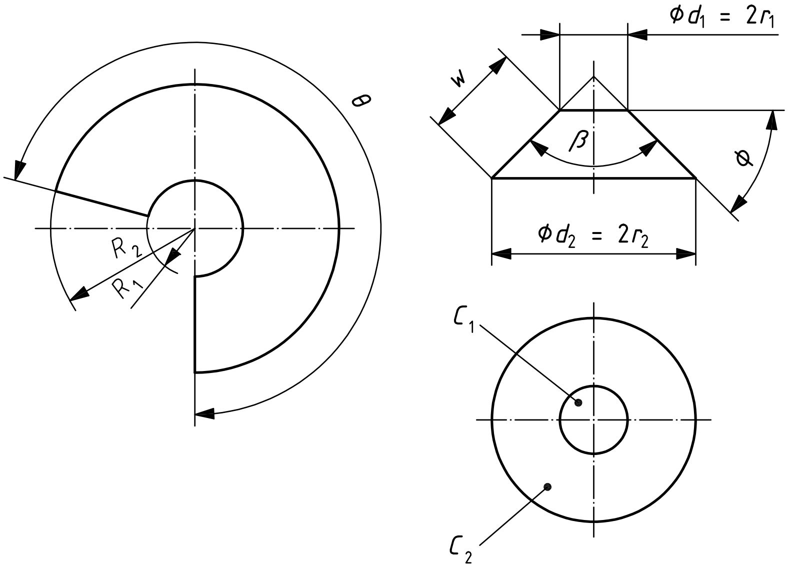
The colour appearance of a CRT monitor is affected by the static magnetic field of the earth. In particular, turning the CRT monitor when switched on can cause changes in the colour appearance. The CRT can be "zeroed" to its default state using a degaussing device. To improve repeatability of testing, it is good laboratory practice to degauss a CRT monitor under test using an external degaussing device, rather than the monitor's built-in degaussing device.

A degaussing device consists of a strong magnet that creates a static magnetic field. In manual degaussing, this magnet is moved circularly in front of the display and gradually moved away from the monitor. The circular movement resets the monitor appearance and the moving away from the monitor reduces the impact of the magnet on the CRT, resulting in an even colour appearance.

5.2.5 Veiling glare frustum

Previous work corroborates the effectiveness of frustums as a tool in reducing the amount of stray light corrupting light-output measurements of displays [13]. The frustums, or truncated cones, have apex angles of 90° and are constructed from 10 mm black vinyl plastic with a gloss surface on both sides, using the procedure shown in Figure 1.

The equations of Figure 1 relate the frustum apex angle and inner/outer diameters to a flat surface that can be easily cut using a mechanical compass with a sharpened edge for cutting the plastic. Place one point at the centre and rotate around the centre with the cutter until the material becomes separated. Alternatively, back and forth bending along a partial cut with a little stress can separate the material. Be sure to cut out the outer diameter first; otherwise the centre reference is lost.



$\beta = 2\phi =$ apex angle

$w = R_2 - R_1 = (r_1 - r_2)/\cos\phi$

$C_1 = 2\pi\, r_1 = R_1\theta$

$C_2 = 2\pi\, r_2 = R_2\theta$

$R_1 = r_1/\cos\phi$

$R_2 = r_2/\cos\phi$

$\theta = 2\,\pi\cos\phi$

For $\phi = 45°$, $\cos\phi = \frac{1}{\sqrt{2}}$:

$$R_1 = \sqrt{2} \times r_1$$

$$R_2 = \sqrt{2} \times r_2$$

$$\theta = \pi \times \sqrt{2}$$

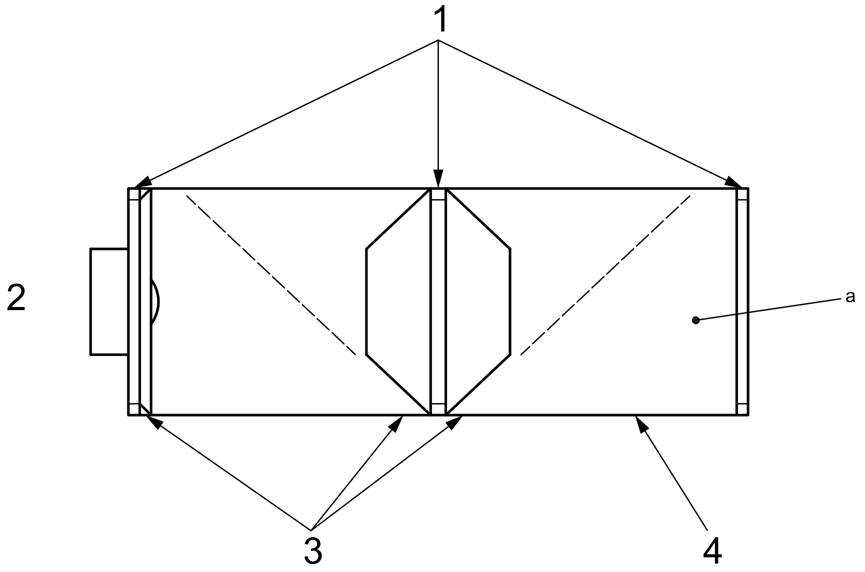
Figure 1 — Pattern for veiling glare frustum

5.2.6 Stray light elimination tube and projection masks

Stray light can result from veiling glare, ambient lighting conditions or light from the display reflecting off the room features and back onto the display surface. In most situations, this produces an undesirable effect as far as the performing of measurements is concerned and is especially significant when attempting to measure black level luminance or illuminance. Two options are presented here to reduce the stray light corruption: the stray-light elimination tube (SLET) and the projection mask.

The SLET consists of a long piece of plastic tubing as shown in Figure 2. Several frustums have been inserted to provide for the baffling and redirecting of stray light. The tube length and diameter, and the aperture of the frustums, are dependent upon measurement parameters, but are, typically, 9,5 cm for the inside diameter, 30,5 cm for the length, and 5 cm for the aperture. The entire tube shall be glossy black: the glossy surface provides for approximately 0,2 % diffuse (non-specular) reflection; whereas, flat black offers at best around 2 % to 3 % diffuse reflection. By careful positioning of the glossy black frustums, the SLET can be made to direct the specular reflections off the interior tube surface and away from the illuminance meter measurement head. The back plate needs to be thin enough so that reflections off its edge do not contribute to the illuminance measurement.

For performing small-area illuminance measurements for front-projection displays, a slit adapter can be used. The slit adapter shown in Figure 3 was built using black acetal plastic to mount the illuminance meter, so that various detector heads could be centred at the rear of the SLET. To accommodate the small measurement areas, a slit was devised, using razor blades painted in glossy black, to create an adjustable aperture. The blades are secured with setscrews to provide for adjustment. This allows the user to control the area of the projected image to be measured. Thus, measure contrast modulation could be measured by adjusting the aperture to allow only either the black or the white portion of the image to illuminate the detector head.

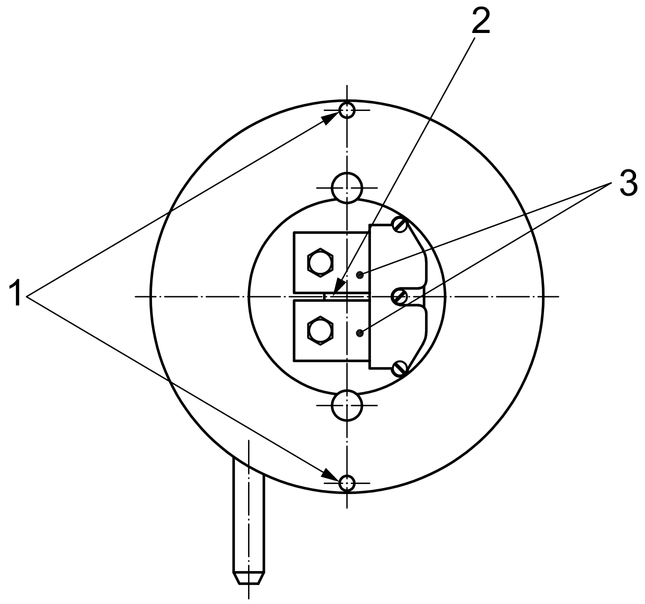


Key

1 rings
2 illuminance meter
3 glossy black frustums
4 glossy black tube

[a] From the projector.

Figure 2 — Stray light elimination tube



Key

1 SLET (stray-light elimination tube) mounting holes
2 LMD (light-measuring device) head
3 adjustable blade

Figure 3 — Slit mount for illuminance meter

5.2.7 Replica masks

Because the glossy black cone mask is not effective for measuring small-area black luminance, another mask can be utilised. This mask, called a replica mask, is a piece of black material that has the same dimension as the area that it is desired to measure. If the screen is rugged, the mask is placed on the display screen in close proximity to the pixel surface (see Figure 4). If it is assumed that the replica mask is absolutely black, then any luminance measured from this mask is the veiling glare contribution. This contribution can then be subtracted from the measured value of the display image to obtain a more accurate measurement of the true luminance. That is, for a given black pixel area, A_p, the corrected measured black luminance is

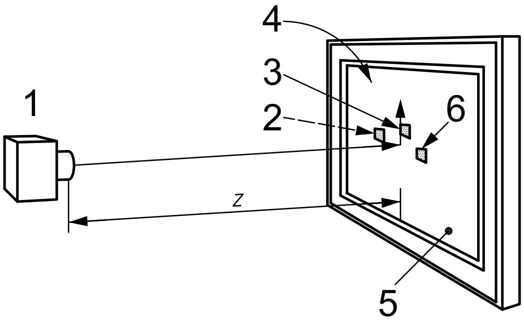
$$L'_\text{b} = L_\text{b} - L_\text{g} \tag{1}$$

where

L_b is the luminance of the black pattern (without glare correction);

L_g is the luminance contribution resulting from veiling glare (the measured replica luminance).

Figure 4 also shows a neutral density filter (NDF), which serves as a check of the replica mask measurements. The filter and replica mask shall be the same size as the black pixel area being measured. The square masks were cut from opaque glossy black plastic (approximately 0,25 mm thick), although other black material may be used. Glossy material was preferred due to its ability to reduce diffuse reflections from the surrounding environment. Care was taken to avoid any specular reflections off the glossy surface. The line replica mask can be created using black thread; nylon, human hair, horsehair, thin wire or pencil “lead” (graphite), or fine striping tape (darkened with a black marker if the material is not sufficiently black) can also be used.



Key

1 CCD (charge-coupled device) imaging system

2 replica mask

3 black pixels

4 white background

5 display surface

6 NDF (neutral density filter)

NOTE For z, see Table 1.

Figure 4 — Use of replica masks for veiling glare compensation

5.2.8 Data acquisition

LMD samples as a function of time are typically collected, stored, processed and displayed by a storage device such as a computer or storage oscilloscope.

5.2.9 Vibration-damped measurement bench

Both the display and the LMD could need to be seated on a vibration-damped aluminium-slab measurement bench. The motion of the test bench should be at least a factor of 10 times smaller than the jitter motion being measured.

5.2.10 Dimensional measurement devices

5.2.10.1 Reticle: a simple ruled magnifier marked with straight-line rules of known unit length, for the measurement of very small dimensions. The reticle is usually placed at the field stop within the eyepiece of a measuring microscope.

5.2.10.2 Ruler: Use of a steel ruler (mm resolution) or equivalent linear or digital micrometer can be used for small measurements. For large measurements, such as a steel tape measure (with mm resolution) can be used for determining large area dimensions, such as the size of a projected image.

5.2.10.3 Graduated scales: linear and rotational scales are recommended for achieving accurate alignment.

5.2.11 Uniform light source

An integrating sphere light source can be useful in providing

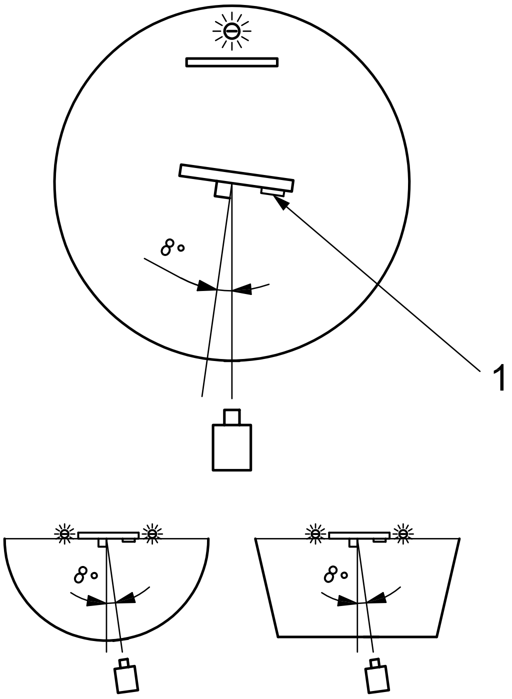
a) a source of calibrated luminance, if properly calibrated, and

b) a source of luminance that is uniform over the exit port.

An exit port diameter of 1/3 the sphere diameter or less will provide a ± 1 % to ± 2 % non-uniformity of luminance across the exit port if the interior of the integrating sphere is covered with a diffuse white reflectance material having a 96 % reflectance or greater. This source is very handy for many diagnostics [10]. If it is well designed, its stability over long periods of time can be impressive, and its uniformity can hardly be replicated with other sources.

5.2.12 Surrounds

Ideally, an integrating sphere is best to use for a surround. However, it may be possible to use a surround that is less than perfect (see Figure 5). The success of using a surround that is other than an integrating sphere depends upon how uniform the illumination is from all directions in front of the display. A white hemisphere that is evenly illuminated is preferred if an adequate integrating sphere is not available. If that is not possible, a box can be constructed and painted with the whitest matt paint available. A number of configurations can be used (even a hemisphere or integrating-sphere device smaller than the screen height or width), but it is most important that the surround have a relatively uniform luminance distribution over that part of it in the vicinity (± 30°) of the perpendicular of the display surface. The hole diameter should be larger than the diameter of the lens of the LMD — the entrance pupil of the LMD — by 20 % to 30 %. However, care shall be exercised to avoid any direct light from the sources or any bright reflections off any surface (other than the screen itself) from hitting the lens of the LMD, in order to minimise veiling glare contamination of the reflected luminance measurement. Since the hole is larger than the lens, the LMD should be moved back from the hole so that only a fraction of the screen is visible to the LMD. This will assure that there is no veiling-glare corruption in the measurement. Check for reflections off the inside diameter of the hole that can also contribute to glare corruption. The hole may have to be bevelled away from the lens.



Key

1 white standard

Figure 5 — Spherical and hemispherical surrounds

5.2.13 Magnification device

Jeweller's loupe: a magnification eyepiece that can be used to inspect pixels. A 10× magnification is standard and should suffice for most applications. Be aware of possible image distortions.

5.3 Test patterns

The test patterns that are used by the measurement procedures in Clause 6 are described below. The parameters for each pattern are defined by either the measurement procedure or the compliance procedure given in ISO 9241-307. These parameters include specification of foreground colour (colour of figure or text) and background colour. In these cases, the colour should be defined in terms of the display primaries; grey and colour levels will be expressed accordingly.

EXAMPLE 1 For RGB, red is R = 100 %, G = 0 %, B = 0 %.

EXAMPLE 2 50 % grey is R = 50 %, G = 50 %, B = 50 %.

NOTE Any pixel representations in the figures of the test patterns are shown for illustrative purposes only.

5.3.1 Character width target H

The parameters for this test pattern are foreground colour, background colour and font. The pattern consists of an unaccented upper case "H". See Figure 6.

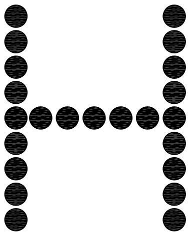


Figure 6 — Character width target H

5.3.2 Character width target block

The parameters for this test pattern are foreground colour, background colour, block size and block locations. This consists of a simple block of specified size.

5.3.3 Character height target E:

The parameters for this test pattern are foreground colour, background colour and font. The pattern consists of an unaccented upper case “E”. See Figure 7.

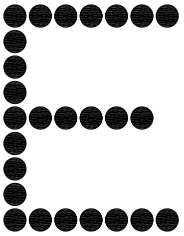


Figure 7 — Character height target E

5.3.4 Character height target block

The parameters for this test pattern are foreground colour, background colour, block size and block locations. This test pattern consists of a simple block of specified size.

5.3.5 Block

The parameters for this test pattern are foreground colour, background colour, block size and block locations. The pattern consists of a block on a specified background and location. This pattern can exhibit image-dependent luminance variation in some technologies. See Figure 8.

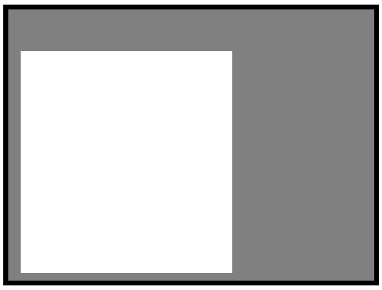


Figure 8 — Block

5.3.6 Character format

The parameters for this test pattern are foreground colour, background colour, font and matrix location. The pattern consists of a character matrix (width × height) based on the task requirements defined in ISO 9241-307.

5.3.7 Between-character spacing

The parameters for this test pattern are foreground colour, background colour, font and pattern location. The pattern consists of two adjacent “M” targets. See Figure 9.

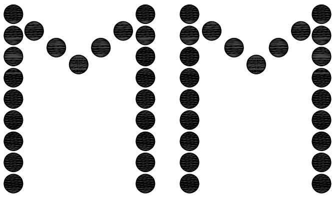


Figure 9 — Between-character spacing target

5.3.8 Between-word spacing

The parameters for this test pattern are foreground colour, background colour, font and pattern location. The pattern will consist of an unaccented upper case “H” unless the character font is designed as a representation of designed print fonts or proportional spacing is used. When simulating a print font, the spacing used in the font design may be used. The number of pixels in the width of the character “N” is recommended as between-word spacing for proportionally spaced fonts. See Figure 10.

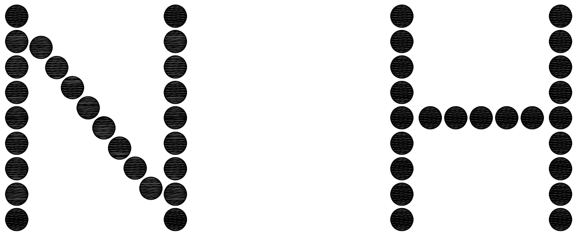


Figure 10 — Between-word spacing

5.3.9 Between-line spacing

The parameters for this test pattern are foreground colour, background colour, font and pattern location. The pattern consists of two “E” targets, each on a single line, one above the other. See Figure 11.

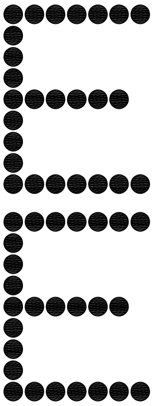
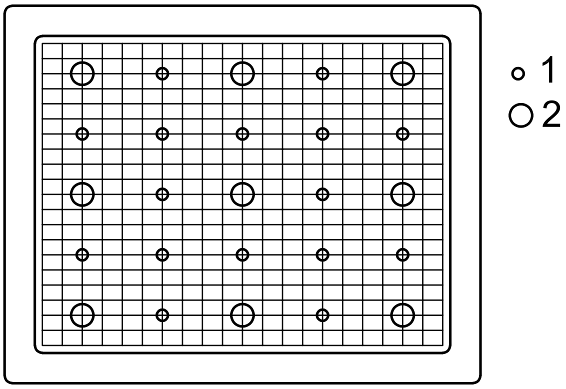


Figure 11 — Between-line spacing target

5.3.10 Grid pattern

The parameters for this test pattern are foreground colour, background colour, line width and measurement locations. See Figure 12.



Key

1 p-point locations

2 25-point locations

Figure 12 — Grid pattern (20 × 20 single-pixel-wide grid)

5.3.11 Screen full of H

The parameters for this test pattern are foreground colour, background colour, font and pattern location. An example of an unaccented upper case character “H” is shown in Figure 13.

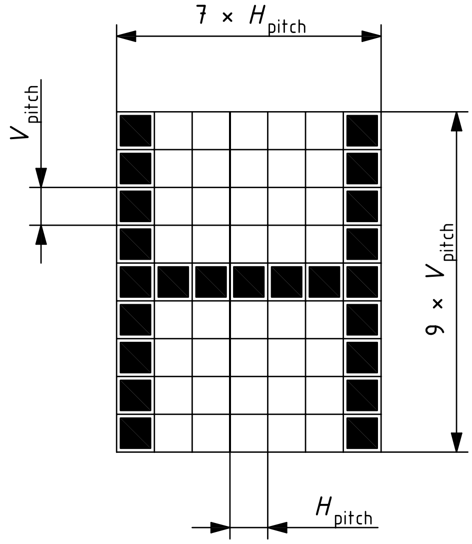


Figure 13 — Screen full of H

5.3.12 Orthogonality

The parameters for this test pattern are foreground colour, background colour, line locations.

EXAMPLE White lines on black background; vertical and horizontal lines along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centrelines (major and minor axes). See Figure 14.

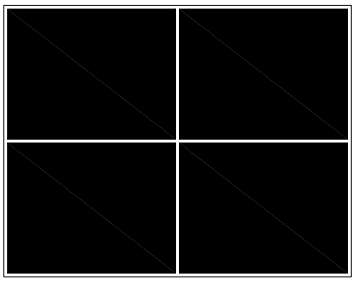


Figure 14 — Orthogonality test pattern

5.3.13 “eee” picture

The parameters for this test pattern are foreground colour, background colour, font and pattern location. The pattern consists of a screen full of “e” targets. See Figure 15.

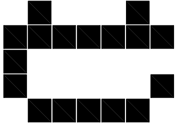


Figure 15 — “e” picture

5.3.14 “mmm” picture

The parameters for this test pattern are foreground colour, background colour, font, pattern location. The pattern consists of a screen full of “m” targets. See Figure 16.

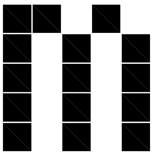


Figure 16 — “m” picture

5.3.15 Horizontal bars

The parameters for this test pattern are foreground colour, background colour, width 1, width 2 and pattern locations. Examples are shown in Figure 17.

5.3.16 Vertical bars

The parameters for this test pattern are foreground colour, background colour, width 1, width 2 and pattern locations. Examples are shown in Figure 17.

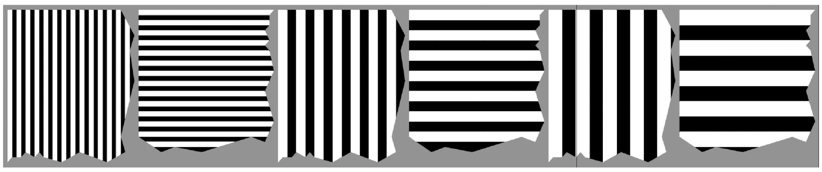


Figure 17 — Examples of horizontal and vertical bar patterns

5.3.17 Full-screen

The parameter for this test pattern is colour. The pattern fills the entire addressable area of the display with a single colour.

5.3.18 Dot

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. The pattern consists of a pixel dot at the specified measurement location.

5.3.19 Convergence test pattern

The parameter for this test pattern is the line locations. A test pattern (a white grid of intersecting lines) shall be displayed in the five screen locations described in 5.4.3. The test pattern should consist of a line that is three pixels wide, with the outside pixels 0,5 times the luminance of the centre pixel. If this pattern cannot be displayed, a single pixel line pattern, or a character approximation using the plus (“+”) character, may be used.

NOTE The use of this structure minimises the error that can occur from moiré luminance non-uniformity. It also minimises the differences that arise from different algorithms used for finding the centres of the three beams.

5.3.20 Dot raster

The parameters for this test pattern are foreground colour, background colour, dot size and dot locations. This bitmap pattern consists of a series of dots. Allow one blank column and row between each dot.

5.3.21 One-dot raster

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. This bitmap pattern consists of a single dot at the specified measurement locations.

5.3.22 Response time pattern

The shape, position, colour, intensity, size and blink rate of an appropriate test pattern depend on the display technology.

a) The test pattern should alternately switch between white, L_w, and black, L_b, luminance, unless otherwise noted. Some technologies exhibit fast response times for white–black transitions, but much slower response for grey-scale transitions. If a white–black (on–off) transition is not used, it shall be clearly specified to all interested parties.

b) The test pattern blink rate should be slow enough to ensure that both the leading and trailing edges of the recorded positive and negative electro-optical step response function (SRF) waveforms are flat, so that L_{100} (steady-state on) and L_0 (steady-state off) can be accurately determined. If this requirement cannot be met, L_{100} and L_0 may be measured separately, as long as they do not drift significantly during the SRF measurements.

c) In the event that the luminance asymptotically approaches the steady state value and thereby does not lend itself to a reasonable measurement of these response times, it is permissible to use a level line that is 5 % away from the steady-state level line as the 0 % or 100 % level line.

   As a criterion for implementing a 5 % shift, use the following: if the 10 % to 90 % response time is more than three times 20 % to 80 % response time, then the 5 % shifted level reference line may be used. Alternatively, the 20 % to 80 % response time may be employed as a replacement for the 10 % to 90 % response time. Such usage shall be noted in any reporting document.

d) The test pattern may be smaller than the detector image area if the filtered luminance contribution of the background (detector image area not covered by the test pattern) is constant. Alternatively, non-constant backgrounds may be removed using image-processing techniques.

e) In general, the test pattern should be as small as possible, since (ideally) the response of a single pixel is being measured. As a practical matter, LMD often produce larger signal-to-noise ratios and more repeatable measurements when larger targets are used. Larger targets may be used if the following applies.

   1) When multi-pixel test patterns are generated and displayed in a raster based display system, it is possible for the test pattern update to be occasionally split across two or more display refresh cycles. When this problem cannot be eliminated, it should be reduced as much as is practical (typically, by using targets with a small number of rows). Anomalous large measurements of the image formation time, T_f, caused by test pattern splitting should be discarded.

   2) Even within a single display refresh cycle, some time is typically required to electrically address/command the pixels in the test pattern from the on state to the off state. The test pattern update time, T_TPU, is the time between the first and last pixel updates in the selected test pattern. The size, shape and position of the test pattern should be selected so that $T_\mathrm{TPU} < 0{,}1T_\mathrm{f}$, where T_f is the image formation time.

      For most display technologies, the largest possible value for T_TPU is the refresh time, T_R. In this case, if $T_\mathrm{R} < 0{,}1T_\mathrm{f}$, the T_TPU requirement is met. The test pattern should not span the seam on dual-scanned displays or tiled displays, since this will cause T_TPU to equal $T_\mathrm{f.}$ Since T_TPU can be difficult to calculate or measure, the following diagnostic may be used instead of an actual T_TPU measurement/calculation.

— Measure T_f twice, once using the intended test pattern, and the second time using a very small test pattern (a single pixel if possible). If the two measurements agree within 5 %, then the T_{TPU} requirement is met.

5.3.23 Box patterns

The parameters for this test pattern are foreground colour, background colour and box size. Examples are shown in Figure 18.

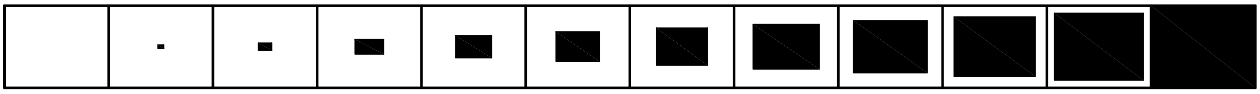


Figure 18 — Examples of box patterns

5.3.24 Checkerboard pattern

The parameters for this test pattern are colour 1, colour 2, number of vertical rectangles and number of horizontal rectangles. It is a checkerboard pattern of equal-sized rectangles, alternating colour 1 and colour 2. Note that for the 4 × 4 test pattern shown in Figure 19, the upper left rectangle is white.

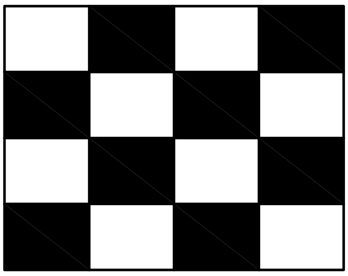


Figure 19 — Example of a checkerboard pattern

5.3.25 Latin characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 20.

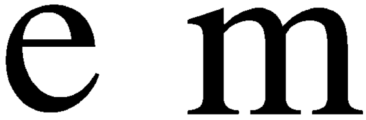


Figure 20 — Latin characters

5.3.26 Arabic characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 21.

Figure 21 — Arabic characters

5.3.27 Chinese characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 22.

Figure 22 — Chinese characters

5.3.28 Japanese characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. Because Japanese character patterns depend on the number of the character matrix elements, three (3) patterns, 11 × 11, 16 × 16, 72 × 72, should be used, as shown in Figure 23, which also shows representative hiragana and katakana characters.

Figure 23 — Japanese characters (11 × 11, 16 × 16, 72 × 72 points) and representative hiragana and katagana characters

5.3.29 Korean characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 24.

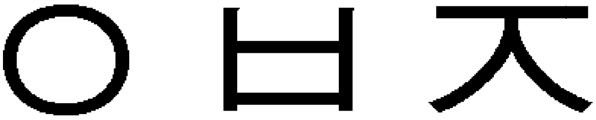


Figure 24 — Korean characters

5.3.30 Cyrillic characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 25.

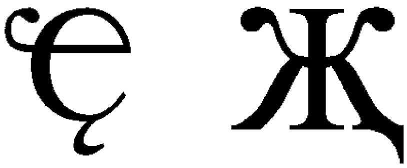


Figure 25 — Cyrillic characters

5.3.31 Greek characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 26.

Figure 26 — Greek characters

5.3.32 Thai characters

The parameters for this test pattern are foreground colour, background colour, size and pattern locations. Characters shall be adequate representatives of the character set, displaying horizontal and/or vertical strokes and curved lines as appropriate. See Figure 27.

Figure 27 — Thai characters

5.3.33 5 × 5 checkerboard pattern with crosses

The parameters for this test pattern are fixed. This pattern applies to goniometric measurements of non-stereoscopic displays that produce a virtual image. The test target consists of a 5 × 5 black-and-white checkerboard pattern with white corners. Four straight, thin lines are drawn through the centre of the image, connecting the midpoint of each side with the one opposite it, and each corner with the one opposite it. See Figure 28.

The centre and the endpoints of the crossing lines mark the standard nine measurement locations (see 5.4.5). The 5 × 5 checkerboard pattern is helpful in navigating across the screen, focusing the meter and determining image quality.

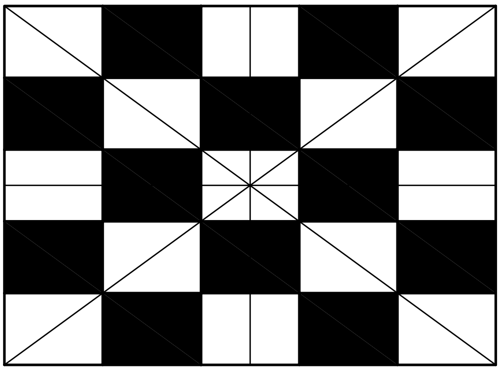


Figure 28 — 5 × 5 checkerboard pattern with crosses

5.3.34 Shadowing set-up

The parameters for this test pattern are foreground colour, background colour, size and grey levels. The pattern is a series of diagonal boxes of eight grey shades. See Figure 29.

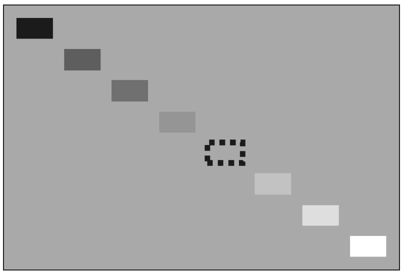


Figure 29 — Shadowing set-up pattern

5.3.35 Shadowing measurement

The pattern consists of a series of diagonal boxes of eight grey shades. There are a total of ten patterns used in this measurement: five single box patterns and five full-screen grey-level patterns interleaved. See Figure 30.

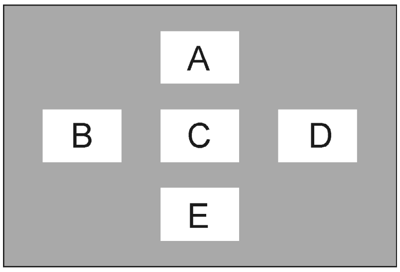


Figure 30 — Shadowing box pattern

As shown in Figure 30, the sequence of five box patterns has a box placed, sequentially, above (A), to the left of (B), to the right of (D), below (E) and at the centre (C) of the screen, with one box for each pattern. This, left-to-right, top-to-bottom, is the reading order in several languages. The edge boxes are centred along the closest side. The box sides are approximately 1/5 to 1/6 the width and height of the screen, and the box is separated from the edge of the screen by approximately half its width or height.

Placement of the boxes should be ± 5 % of the linear dimensions of the screen. The command level of the boxes is represented by G_s and the background command level by G_bkg. Each one-box pattern is separated in the sequence by a blank full screen of grey level G_bkg.

5.3.36 Projector set-up pattern

The parameters for this test pattern are foreground colour and background colour. This pattern is used for the set-up of projectors: The brightness control shall be set to the point where the maximum number of signal level blocks on the top line, representing 0 %, 5 %, 10 % and 15 % signal levels, are visible and distinct from the adjacent signal level blocks. See Figure 31.

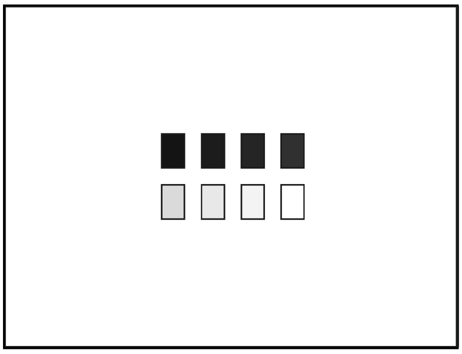


Figure 31 — Projector set-up pattern

5.3.37 Projector colour adjustment pattern

This colour bar pattern consists of the default 16 colours. See Figure 32.

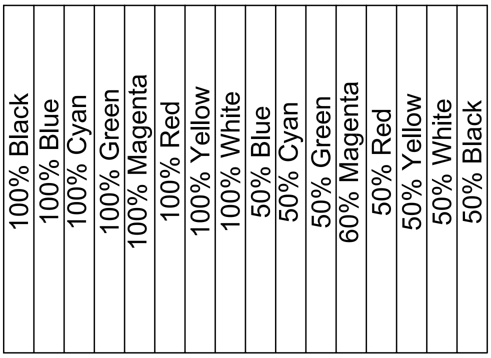


Figure 32 — Projector colour bar pattern

5.4 Alignment — Measurement location and meter position

5.4.1 Normal to display screen

LMD is aligned normal to the surface of the display screen.

5.4.2 Light source

To measure the light source, align the LMD normal to it. Focus on the exit port of the display, filling the measurement area of the LMD with as much of the exit port as possible.

5.4.3 Standard five locations

Five standard measurement locations are defined for making measurements of various types (see Figure 33). The locations are the following:

a) at the centre (i.e. at the intersection of the two diagonals of the addressable area);

b) at the locations on the diagonals that are 10 % of the diagonal length in from the corners of the addressable area of the display.

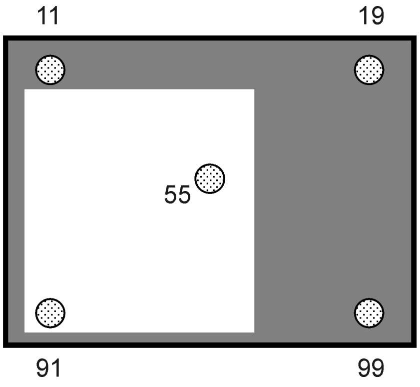


Figure 33 — Standard five locations

5.4.4 Standard 11 locations

Eleven standard measurement locations are defined for making measurements of various types (see Figure 34). The locations are the following:

a) nine points equally spread across the diagonal from the upper left corner of the display to the lower right of the display (of the addressable area of the display);

b) two points at the opposite corners of the addressable area of the display.

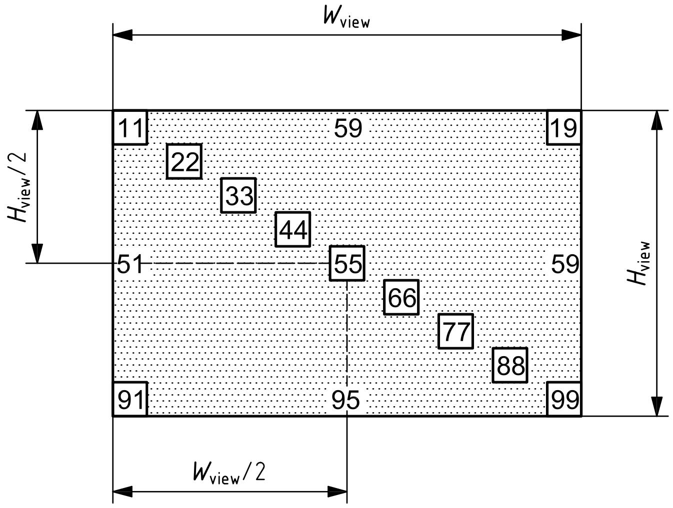


Figure 34 — Standard 11 locations

5.4.5 Standard nine locations

Nine standard measurement locations are defined (see Figure 34). The locations are the nine points equally spread across the diagonal from the upper left corner of the display to the lower right of the display (of the addressable area of the display). These are the same as the locations defined in 5.4.4, except for positions 19 and 91.

5.4.6 Projector: 16 locations

The measurement points are at the centre of each of the 16 rectangles in the 4 × 4 checkerboard pattern (see 5.3.24).

5.4.7 Projector: 13 locations

The screen is divided into nine equal-sized rectangles. Nine measurement points fall at the centre of each of the respective rectangles. The last four positions are at the corners of the screen, at a distance from the corner of 5 % of the diagonal of the screen. See Figure 35 — the circles are for positioning only and should be removed when measuring.

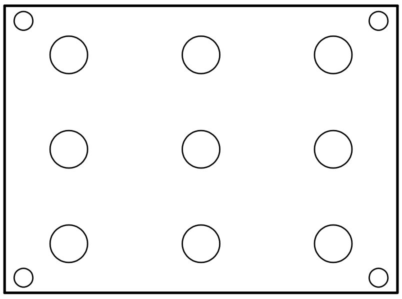


Figure 35 — Standard 13 locations

5.4.8 Centre-screen

The measurement location is at the centre of the display screen.

5.4.9 Visual determination

The determination of measurement test locations is based on visual observation.

5.4.10 Standard nine locations for virtual image displays

This applies to

- goniometric measurement of virtual image geometric distortions and QVS (qualitative vector space) in near-to-eye displays, and
- NED (dichoptic viewing with the non-dominant eye) types, both monocular and binocular, but not stereoscopic or two-eye monocular, devices.

The standard nine measurement locations of the virtual image are the image centre, and the corners and midpoints of each edge. See Figure 36.

See also 5.3.33 and 6.11.1.

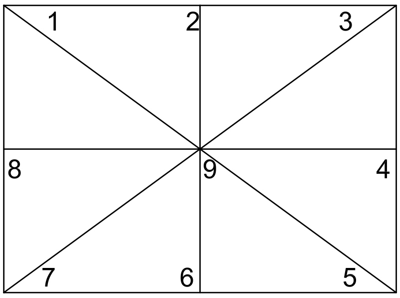


Figure 36 — Standard nine locations for virtual image displays

5.4.11 Alternative nine-point locations

An alternative set of nine standard measurement locations is defined by VESA (US Video Electronics Standards Association). See Figure 37 and Reference [10].

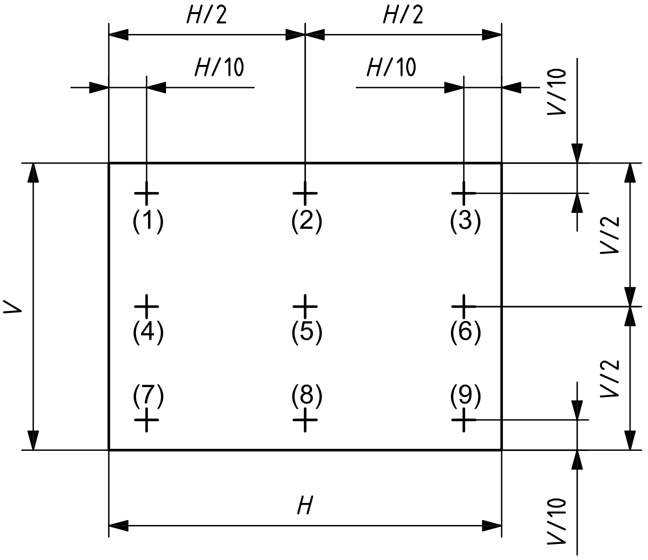


Figure 37 — Alternative nine-point locations (VESA)

5.5 Light measuring device (LMD)

Many factors contribute to the confidence that the measurements made actually reflect the value of the measurand. A complete description of all the factors that can affect measurement uncertainties is found in the GUM [6]. For a discussion of the propagation of errors and uncertainty estimation, see VESA-2005-5 [10], section A108 and, for terminology, section A221. Any uncertainty values are expressed using an expanded uncertainty with a coverage factor of $k = 2$ (a "two-standard-deviation" or "two-sigma" estimate).

The luminance relative expanded uncertainty of measurement with coverage factor of two shall be at least $u_{\text{LMD}} = \pm 5$ % of the luminance or less, and the luminance measurement repeatability shall be less than either a maximum of $\rho_{\text{LMD}} = \pm 0{,}5$ % of the luminance or the uncertainty introduced by any digitisation — whichever is larger — over a 5 min interval.

For colour, the expanded uncertainty of the measurement with coverage factor of two of chromaticity coordinates for tungsten-type CIE illuminant A above 10 cd/m^2 shall be at least ± 0,002.

For devices that use array photodetectors to provide spatially-resolved luminance measurements, in addition to the above requirements, such a system shall provide, either in hardware or after software processing, no more than a ± 2 % nonuniformity (1 − min./max.) for all detection elements employed in a measurement of luminance. If such LMD are used to resolve fine detail at the pixel level, then the array pixel shall measure no more than 1/10 the size of the smaller of the horizontal and vertical subpixel image pitch on the display, i.e. the smallest feature of interest should be rendered by at least ten detector pixels in the horizontal or vertical direction. The array shall be filtered to make it photopic (whenever luminance measurements are made). The CIE criterion for specifying the relative spectral responsivity from the human photopic response curve $V(\lambda)$, should be used so that $f_1' \leqslant 5$ % (see Reference [9]).

Ambient lighting shall be controlled to avoid errors caused by direct (instrumentation, room lighting, windows, and other sources) and indirect (walls, tables, equipment, lab personnel clothing, and other surfaces) reflections from the display screen. Additional errors can be contributed by lens flare or veiling glare from the rest of the screen. For screens that exhibit strong viewing-angle dependence, the glare contributions can be particularly significant. Measurement of front-projection display systems are also subject to corruption due to stray light from ambient lighting and back reflections from room surfaces. Stray light elimination techniques should be employed to minimise the impact, see References [13], [14], [15] and [16] and VESA-2005-5 [10], section A101, for a discussion of possible solutions.

This list of devices given in 5.5.1 to 5.5.6 is not exhaustive, and other devices exist that could be applicable to the particular measurement application. However, any LMD device shall meet the minimum above requirements.

5.5.1 Spot meter

The spot meter creates an image of the object on a photodetector using a lens, then sample part of that image to produce the measurement. Many of these LMD have a viewing port or viewfinder (either optical or video) such that the lens focuses the image of the object to be measured onto the detection aperture. It is always important to properly focus the device so that the image lies essentially in the plane of the measurement aperture.

NOTE Any instrument with a lens is sensitive to stray light and thus to methods taken to minimise any corruption.

5.5.2 Luminance microprofile meter

The effective width of the photometer measuring field should be no more than 1/8 the width of a pixel, for pixels of either continuous or discontinuous luminance distribution.

For pixels of continuous luminance distribution, a slit aperture or spot aperture measuring field may be used. If a spot aperture is used, the measurement path shall pass through the centre(s) of the pixel(s) to be measured.

For displays to which the provisions of 6.10.9 (M 21.10) may apply, a spot aperture should be used.

For pixels of discontinuous luminance distribution (especially multicolour shadow-mask CRT), a photometer with a slit aperture or an equivalent instrument shall be used. The length of the slit shall be at least four times the width of a single pixel. The slit shall be oriented parallel to the long axis of the features to be measured.

A special display-measuring device may be used. Measurements made with the device shall be equivalent to those defined for photometers.

5.5.3 Conoscopic light measuring device

Conoscopic LMD measure the directional distribution of light without goniometric directional scanning by the projection of a directions image on a two-dimensional detector array (e.g. electronic camera). These devices can be used for the measurement of luminance and colour stimuli, which can then be further evaluated for luminance contrast, transmittance, reflectance, chromaticity, colour difference, and other quantities.

NOTE Any instrument with a lens is sensitive to stray light and thus to methods taken to minimise any corruption.

5.5.4 Collimated optics system

LMD that employ collimated optics do not image the source. Instead, such devices place a detector at the position of the focal length of the lens (not at the focus of an image). The size of the detector and the focal length of the lens determine the angles of the rays of light that contribute to the measurement. Thus, the LMD may be placed close to the surface of the display, yet not accept light from a wide angle of view.

Because collimated optics systems does not require focusing, it may be used either close to the display (as in a goniometer), or farther from the display (to facilitate reflectance measurements), as long as the resulting measurement area is appropriate to the measurement.

5.5.5 Array devices

In addition to the general requirements already outlined for all LMD above, there are complications particular to the use of array detectors such as charge-coupled devices (CCD). Several sources of error are associated with array detector imaging systems. Note that the imaging system includes the lens. A calibrated CCD can have exactly the same response for each array pixel. But when it is put into a system with a lens, the entire imaging system likely no longer preserves that uniformity because of the performance of the lens, reflections, etc. Thus, there are several factors to consider when using an array photodetector including: 1) non-uniform response over the array, 2) non-uniform imaging from lens system, 3) glare, veiling glare and lens flare, 4) background subtraction, 5) flat-field corrections, 6) photopic response, 7) aliasing between the detector pixel and the display pixel, and 8) calibration in luminance. For a further description of these complications, see VESA-2005-5 [10], section A111.

5.5.6 Virtual image display goniometer

This LMD is used to measure monocular (single-eye) and binocular (both eyes with separate optics, identical image), near-to eye, displays that produce a virtual image. It is mounted on a five-axis positing system that simulates the movement of the eye: Cartesian coordinates (eye position) and rotational position (pitch and yaw, gaze angle). Requirements for this LMD are related to the performance of the human eye, and are specified in ISO 9241-302.

5.6 Measurement field

5.6.1 Many pixels

Measure a minimum of 500 pixels. If fewer pixels are used, it needs to be proven that any spatial non-uniformity is insignificant. Using the LMD, measure the luminance variation over an area of 500 pixels or the area of a box that is 10 % of the height and 10 % of the width of the display, at the desired measurement field. The area should centre around the measurement locations. If the variation is 1 % or better, then any spatial non-uniformity is insignificant, and the smaller measurement field can be used.

5.6.2 Within a pixel

For an array detector, there should be 10 or more detector pixels per display pixel.

For a spot meter, the diameter of the measurement spot should be less than 1/3 of the pixel area.

5.6.3 Exit port of light source

Always focus on the exit port of the light source, and measure normal to the exit port. The uniformity of the source can be determined using the procedure specified in 6.6.3 (P 17.3), measuring at five points. The non-uniformity should be 1 % or better. The temporal stability of the light source can be determined using the procedure specified in 6.4.8 (P 15.7), allowing the source to warm up for 1 h before taking data. The temporal stability should be better than 0,1 %.

5.6.4 Section of large illumination surface

For measuring the illuminance of a display projected onto an external screen, the minimum specified in 5.6.1 is not always practical. In this case, one should measure as many as feasible, but at minimum the meter head shall be filled with a 3×3 array of visually uniform pixels.

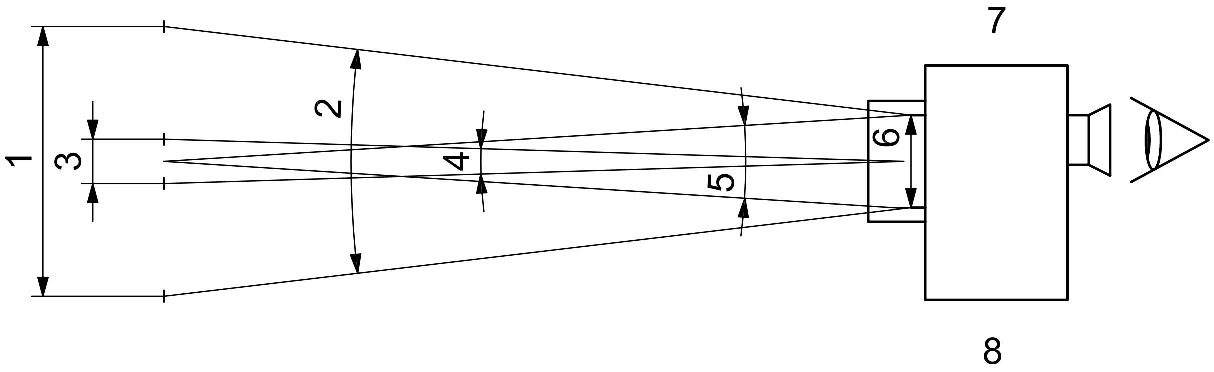
5.6.5 Luminance profile

For a scanning LMD, the averaging window width should be as close as possible to the pixel pitch.

5.7 Angular aperture

The angular aperture (see Figure 38) of the measurement instrument shall be 5° or less. Certain measurements may require the angular aperture to be 2° or less, unless it can be demonstrated that it is equivalent to measurements made at 2° or less.

If the detector head is used for illuminance measurements, it shall be fitted with a cosine-correcting accessory.



Key

1 field of view
2 angular field of view
3 measurement field
4 measurement field angle
5 angular aperture
6 acceptance area
7 luminance meter with view-port
8 focus on object being measured

Figure 38 — Measurement parameters

5.8 Meter time response

5.8.1 Fast response meter

The LMD shall have a response time of better than 1/10 the fastest part of the parameter under measurement, i.e. a signal bandwidth that is at least 10 times the highest frequency component. The rise time of the meter should be 1/10 the rise time of the measured signal to capture the signal with minimal rise time error. The LMD shall be capable of producing a linear response to rapid changes in luminance. Response time and sample time should be fast enough to avoid aliasing with the display.

5.8.2 Time-averaging meter

The measurement time interval shall be long enough so that the standard deviation of ten or more luminance measurements is no greater than 1 %. The instrument can be time-synchronised to trigger a measurement with the refresh rate of the display. Measurement interval should be a multiple ($n \geqslant 1$) of the refresh rate.

Be aware that some meters can provide erroneous results if the instantaneous power of the measurement area is significantly large. Such a problem could occur in flying-spot displays such as laser displays or some CRTs. This situation arises due to saturation of the detector, such as a PMT (photomultiplier tube) or clipping of the instrument amplifier.

5.9 Test illumination

5.9.1 Parameters and tolerances

The various parameters referenced in this section are listed in Table 1 for reference. The tightness of the tolerances will depend upon the characteristics of the display. The tolerances should be adequately set to provide a ± 5 % reproducibility of the particular measurement.

Table 1 — Detector and source parameters

Symbol	Description
Detector/LMD parameters	
θ_R	Inclination angle of detector from z-axis
z	Distance of centre of detector front surface (or lens) from centre (often z_d when detector on optical axis)
a	Diameter of source exit port (outer diameter of ring light source)
Source parameters	
d	Distance of centre of source exit port from centre of coordinate system
θ_S	Rotation angle of source from z-axis
θ_a	Subtense of entrance pupil of detector or angular aperture
θ_r	Angle from normal of ring light outer diameter

5.9.2 Darkroom

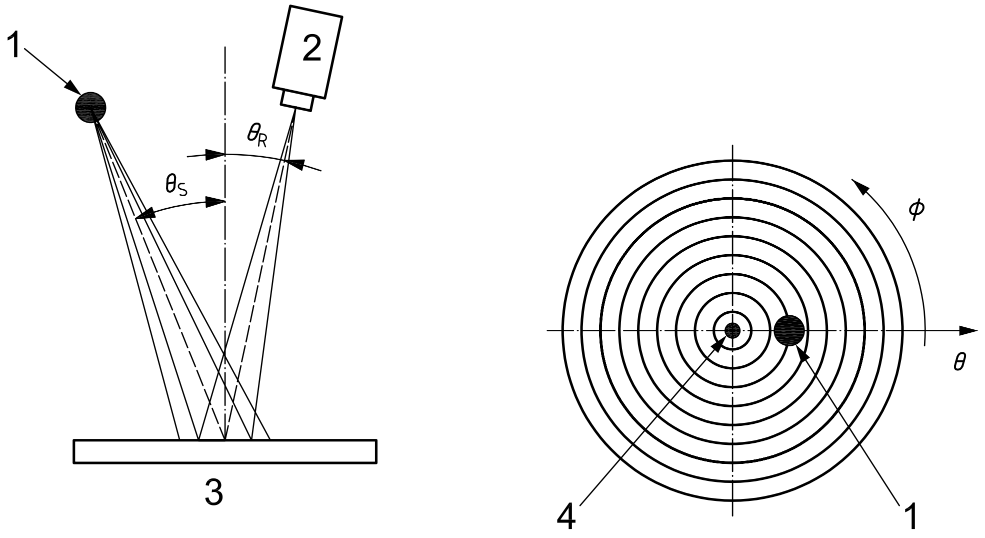
Ensure not only that all room lights are turned off, but that light from equipment in the room, and reflections from surrounding objects back to the screen are controlled such that they are at a negligible level. Illuminance, E, on the screen should be 1 lx or less ($E \leqslant 1$ lx). This is equivalent to stating that the luminance of a diffuse white surface at the position of the screen should have a luminance of less than 0,32 cd/m^2. However, there are cases where this specification is insufficient. In general, the goal is to avoid corruption of measured dark colours due to ambient light or reflections. Avoid measuring as screen luminance reflections off the screen from clothing and equipment lights. Ambient lighting — direct (instrumentation, room lighting, windows, and other sources) and indirect (walls, tables, equipment, lab personnel clothing, and other surfaces) — shall be controlled to avoid errors caused by reflections from the display screen. Additional errors can be contributed by lens flare or veiling glare from the rest of the screen. For screens that exhibit strong viewing-angle dependence, the glare contributions can be particularly significant.

For luminance measurements less than 3 cd/m^2, it is recommended that a diffuse white standard placed at the position of the screen have a reflected luminance of < 1/10 of the lowest luminance reading to be measured. This is equivalent to requiring the illuminance to be $E < 0{,}1\,\pi\,L$ for luminance values $L < 3$ cd/m^2.

"Best conditions" assume a room that is completely dark and filled only with dark objects. Reflections from light-emitting devices or from bright or reflective surfaces could reflect off the surface of the EUT, corrupting the measurement. This includes white clothing, lightly coloured objects in the room, lights on instruments, computer displays, bright spots or light leaks in distant areas, etc.

5.9.3 Directional illumination

A light-source with a small diameter (compared to the distance to the measurement field) is aligned to form an angle, θ_S, with respect to the surface-normal of the EUT. This light source illuminates the EUT to form a directional illumination for the measurement field. In the plane of light incidence, aligned at an angle θ_R with respect to the surface normal of the EUT is the LMD. The measurement field on the EUT is defined by the area element that is imaged on the detector of the LMD. The intensity across the cross-section of the beam shall be constant within 5 %. The angle between the axis and any ray of the illuminating beam shall not exceed ± 5°. See Figure 39.



Key

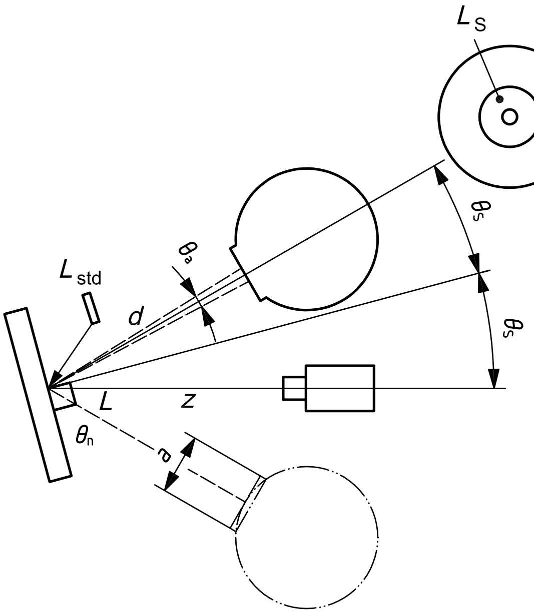
1	light source
2	LMD
3	EUT
4	ring light
θ	angle from normal
ϕ	azimuth angle in relation to θ

NOTE For the meaning of other symbols, see Table 1.

Figure 39 — Directional illumination[18]

5.9.4 Small aperture source

A single small-diameter light source (lamp) is required. Figure 40 shows the configuration with the display rotated 15° so that the angle between the normal of the screen and either the centre of the source or the LMD is 15°. Only one source is employed. A large-aperture source may be covered with an opaque black disk with a small hole at its centre to act as a small-diameter light source. A fibre-optic light source of the same diameter or other light sources can be used as well, provided they are adequately uniform and stable. The goal is that the small source subtend 1° as viewed from the centre of the screen.



θ_S= 15°

Key

L luminance of screen

L_S luminance of light source

L_{STD} luminance of standard

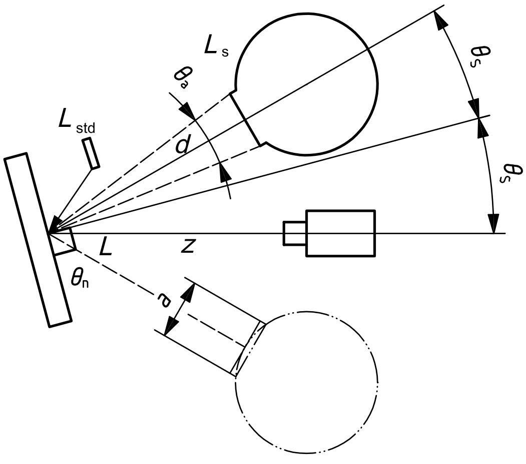
θ_n angle of LMD relative to normal

NOTE For the meaning of other symbols, see Table 1.

Figure 40 — Small aperture source configuration

5.9.5 Extended source, 5°

A single light source (lamp) is required. Figure 41 shows the general extended source configuration. For the specific case, the display is rotated 15° so that the angle between the normal of the screen and either the centre of the source or the LMD is 15°. The goal is that the source subtend 5° as viewed from the centre of the screen.



θ_S= 15°

Key

L	luminance of screen
L_S	luminance of light source
L_{STD}	luminance of standard
θ_n	angle of LMD relative to normal

NOTE For the meaning of other symbols, see Table 1.

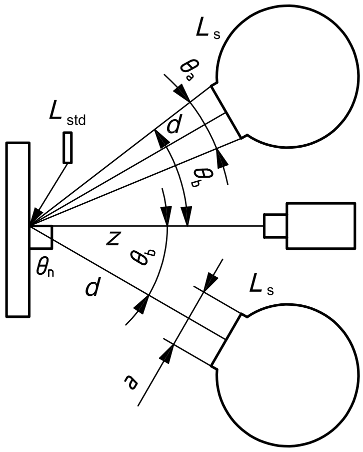
Figure 41 — Extended source — General configuration

5.9.6 Extended source 15° to 30°

A single light source (lamp) is required. Figure 42 shows the general extended source configuration. For the specific case, the display rotated 15° so that the angle between the normal of the screen and either the centre of the source and the LMD is 15°. Only one source is employed. The goal is that the source subtend 15° as viewed from the centre of the screen.

5.9.7 Two extended sources 15° to 30°

Figure 42 shows the configuration with the display rotated 15° so that the angle between the normal of the screen and either the centre of the source or the LMD is $\theta_b = 15°$. Two sources are employed. The goal is that the source subtend $\theta_a = 15°$ as viewed from the centre of the screen.



Key

L_S luminance of light source

L_{STD} luminance of standard

θ_n angle of LMD relative to normal

NOTE For the meaning of the other symbols, see Table 1.

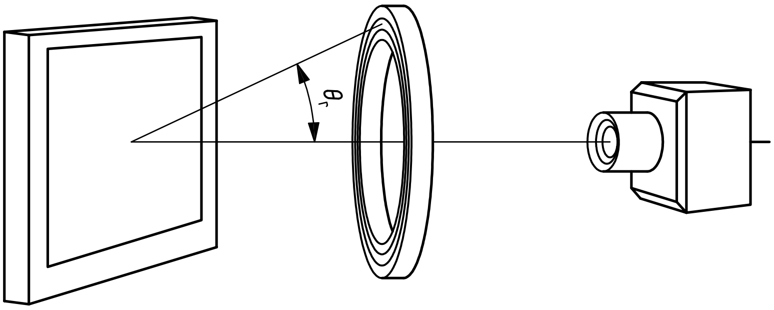
Figure 42 — Two extended light sources

5.9.8 Ring light

A usually diverging beam of white light is directed at the EUT from all azimuth angles in the range of 0° to 360°. Such an illumination scheme is also called *ring-light illumination*. The intensity of illumination as a function of the azimuth angle shall be constant within XY %. The inclination angle of light incidence has to be specified.

The measuring spot on the EUT as “seen” by the LMD shall be enclosed and centred in the illuminated spot on the EUT. The LMD shall not accept light with a deviation from the optical axis of more than ± 2,5°.

This set-up is used with the source fixed and the LMD can remain movable within the limits of the opening of the illuminating ring of light. See Figure 43.



Key

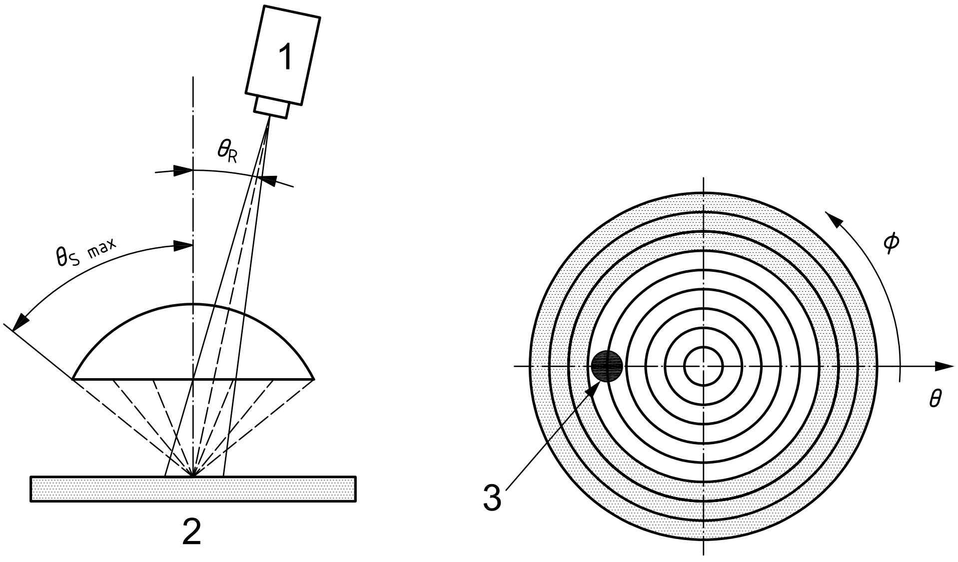
θ_r angle from normal to centre of ring's edge

Figure 43 — Ring light configuration

5.9.9 Conical source

A light-source centred about the surface normal of the EUT illuminates the EUT from a range of inclination angles, θ_S ($0° < \theta_S < \theta_{S\,max}$), for all azimuthal angles, $\phi_S = 0°$ to 360°. The LMD is aligned to form the angle, θ_R, with respect to the surface normal of the EUT. The measurement field on the EUT is defined by the area element that is imaged on the detector of the LMD.

The illumination is provided out of a solid angle, Ω_{SC}, with the apex of this solid angle fixed to the centre of the measuring spot on the EUT. The variation of the intensity of incident light with direction inside this solid angle shall be specified. The cone of illumination itself is specified by the direction of the axis of the cone and the maximum inclination with respect to the axis (i.e. cone angle). Figure 44 shows the side-view of the measuring setup (left) and its representation in a polar coordinate system (right) for an angle of LMD inclination, $\theta_R = 50°$ and a subtense of the source, $2 \times \theta_{S\,max} = 120°$.



Key

1 LMD

2 EUT

3 ring light

θ angle from normal

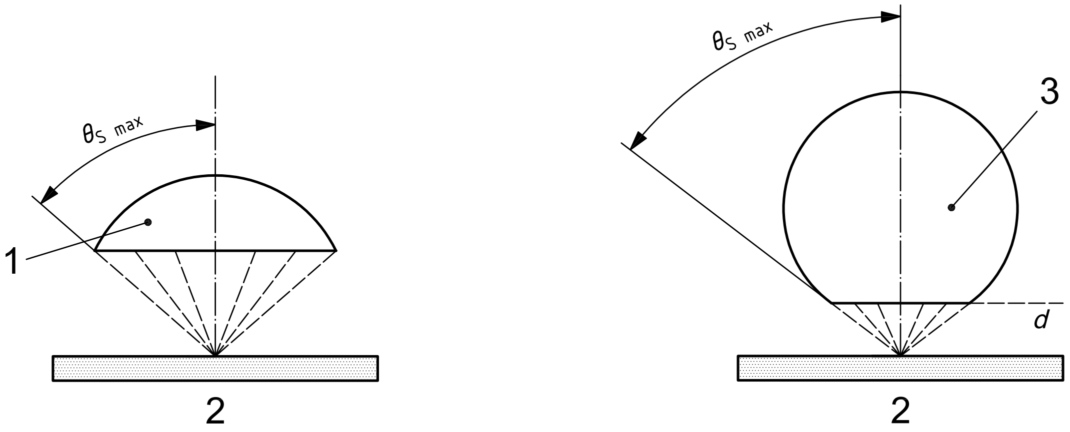
ϕ azimuth angle in relation to θ

NOTE For the meaning of the other symbols, see Table 1.

Figure 44 — Conical source configuration[18]

Conical illumination can be realised with three different geometries:

- the exit port of an integrating sphere at some distance to the measuring spot produces a conical illumination with constant intensity from all directions of light incidence (see Figure 45);
- a spherical dome (reflective or transmissive section of a sphere) produces conical illumination (up to angles of inclination of, for example, 80°), usually with variations of the intensity versus direction of light incidence (see Figure 45);
- a flat, Lambertian, luminance source parallel to the EUT surface produces an illumination of the measuring spot that drops with $\cos^4\theta$ (where θ is the angle of inclination of the direction of light incidence).



Key

1 spherical dome
2 EUT
3 integrating sphere with large aperture

Figure 45 — Realisation of conical illumination[18]

5.9.10 Hemispheric, specular included

A light source centred about the surface normal of the EUT illuminates the EUT from a range of inclination angles $0° \leqslant \theta_S \geqslant 60°$ for all azimuthal angles $\phi_S = 0°$ to 360°. The LMD is aligned to form an angle, $\theta_R < \theta_S$, with respect to the surface normal of the EUT. The measurement field on the EUT is defined by the area element that is imaged on the detector of the LMD.

Illumination is provided out of a solid angle, Ω_{SH}, with the apex of this solid angle fixed to the centre of the measuring spot on the EUT. In the hemispherical case, solid angle Ω_{SH} extends to an angle of inclination of 90°. For the purposes of this part of ISO 9241, the term *hemispherical illumination* is applicable when illumination is provided such that the intensity of illumination does not drop below 50 % of the maximum value at an angle of inclination of 85°. The variation of the intensity of incident light with direction inside Ω_{SH} shall be specified.

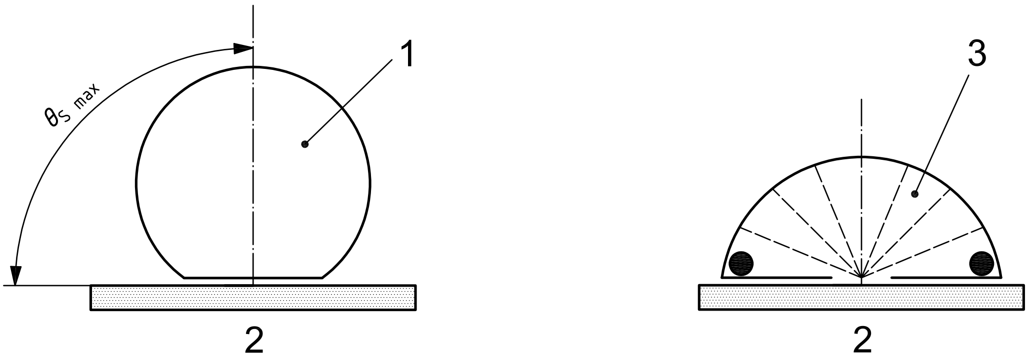
Good approximation of ideal hemispherical illumination (i.e. constant intensity from all directions up to 90°) can only be provided by integrating spheres with a small exit port diameter compared to the diameter of the sphere. The exit port shall be directly adjacent to the surface of the EUT in order to assure good hemispherical illumination (up to inclination angles of 90°).

Other approximations of hemispherical illumination may be realised by

a) diffusing hemispheres with diffuse reflective coatings, or

b) transmissive diffusing spheres and domes.

See Figure 46.



Key

1 integrating sphere

2 EUT

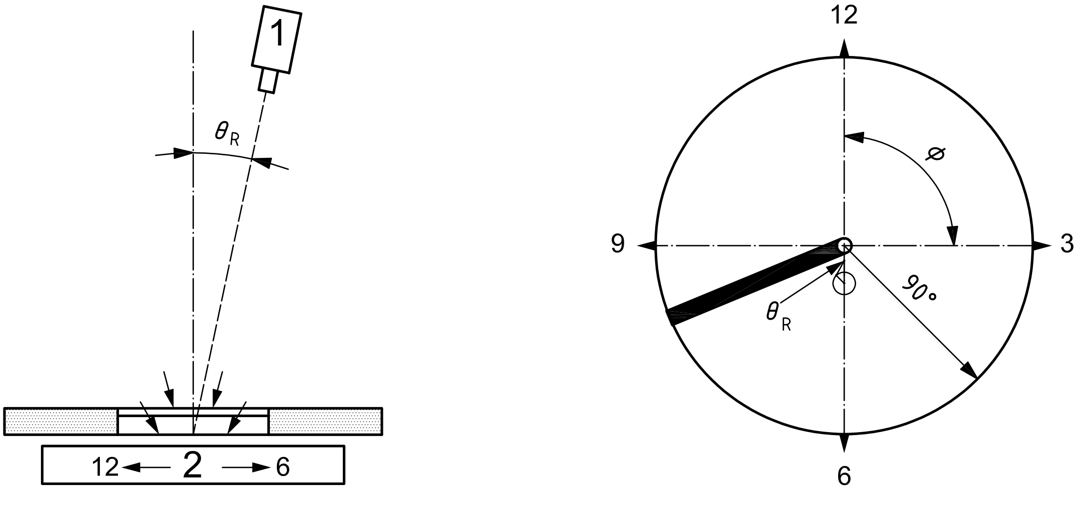
3 diffusing hemisphere

Figure 46 — Realisation of hemispherical illumination[18]

5.9.11 Hemispheric, specular excluded by hardware

This modification introduces a “shading slit” (gloss-trap) into the illumination system, as shown in Figure 47. The slit rotates together with the detector and is always parallel to the plane of incidence.

By excluding the mirror angle, a contrast number is achieved which is closer to real use conditions. The obtained LCD characteristics is also closer to the theoretical behaviour of LCD cells. With this method the optimum viewing angle and the usable viewing angle range can be easily measured and analysed. Recommended width of slit: not yet determined.



a) Side view

b) Configuration of light source on EUT

Key

1 photometer

2 EUT

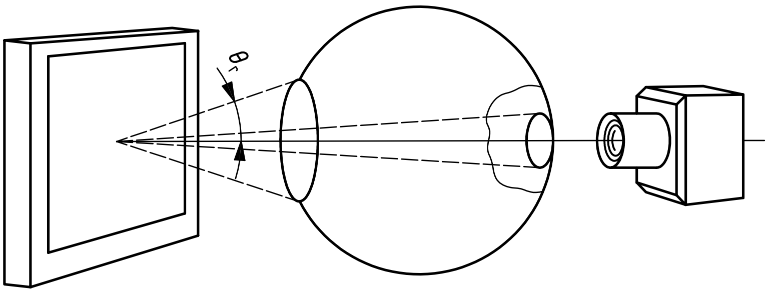
θ_R inclination angle of detector from z-axis

NOTE The numbers 12, 3, 6 and 9 refer to the cardinal directions on the face of a clock (“12 o’clock”, etc.)

Figure 47 — Hemispheric configuration

5.9.12 View port

Not a very robust configuration, except for simplest reflection properties (Lambertian and specular, but not haze). There is strong sensitive to geometry when haze is non-trivial because the view port image is in vicinity of the haze peak. See Figure 48.



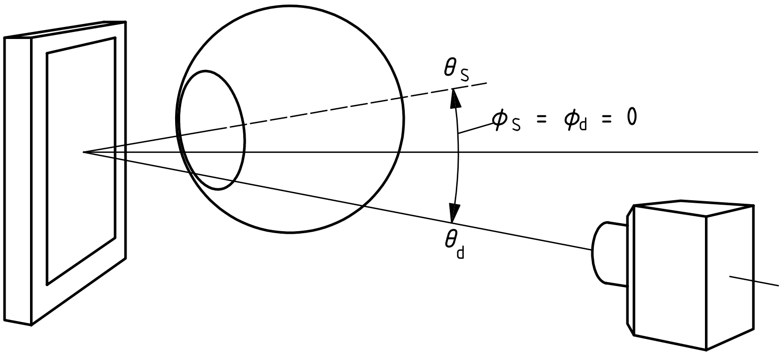
Key

θ_r angle from normal to centre of ring's edge

Figure 48 — View-port configuration

5.9.13 Proximal specular

The source is placed closely proximal to the display screen. In the standard position, it is placed so that the horizontal axis of the display surface and the normal of the display intersect it. This configuration is somewhat robust, but it combines much of any Lambertian component that might be present. However, if only making contrast measurements (or specular) it may be useful. See Figure 49.



$\theta_d = \theta_S$ (desired)

Key

ϕ_S azimuth angle of source

ϕ_d azimuth angle of detector

Figure 49 — Proximal specular configuration

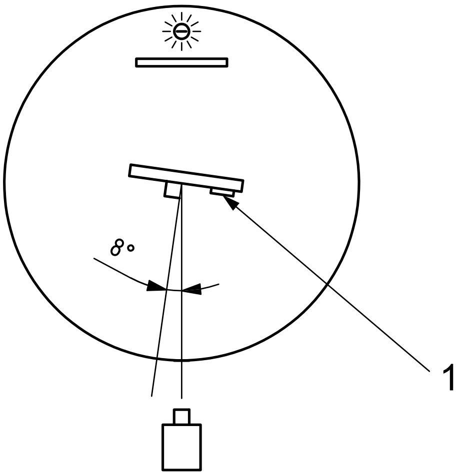
5.9.14 Inside diffuse sphere

A diffuse ambient light is provided to illuminate the screen from all directions as uniformly as is practical. The LMD is arranged such as to view the centre of the surface of the display through a hole in the surround from an angle of 8° (–0°, +2°) from the normal, or by rotating the display for an integrating sphere. The LMD is focused on the display surface.

Figure 50 shows the use of 8° — here, probably the safest angle to use, in order that the measurement hole will not affect the reflection — yet the measurement is made as close to the normal of the screen as possible.

The use of the 8° (–0°, +2°) angle can be important, depending upon the reflectance properties of the display and the uniformity of the illuminating surface. Ideally, it is desired to be infinitesimally small and located along the perpendicular of the centre of the screen, for the measurement to be made perfectly. Since the LMD has a finite size, the measurement cannot be made along the perpendicular, because the reflection of the LMD would interfere with the reflection (unless the screen was truly Lambertian). The problem with this measurement arises because of the haze term. If the display reflection were characterised by only Lambertian and (distinct-image) specular reflections (no haze), then simpler measurements could be used to characterise reflections. Which is the preferred angle? It is an angle that is as close to the perpendicular as possible but that will not interfere with the measurement of the reflection. If the angle is too great, say, 20° or more, then a good portion of the light hitting the display relative to the 20° viewpoint will come from angles greater than 90°, which is not representative of someone sitting in front of the display. Because of the haze, an error can be introduced in the measurement. Conversely, if less than 8° to 10° is used, then it might be found that the hole through which the measurement is taken starts to affect the measurement — again, because of the haze reflection. In many cases, 5° would probably work just as well; however, –8° is the safe choice.

The error in this measurement comes primarily from the error in the measured luminance, L, of the screen. It is not that the LMD is in error, but that unless an integrating sphere is used with care, the non-uniformity of the illumination can cause difficulties. If a hemisphere (or equivalent) is used, it can be a challenge to obtain an even illumination of the hemisphere. How well this method works depends upon the reflectance properties of the screen — and haze introduces much of the error — so that a measurement of the reflectance, ρ_H, can be expected to exhibit a reproducibility of ± 5 % at best.



Key

1 white standard

Figure 50 — Diffuse sphere configuration

5.10 Other ambient test conditions

5.10.1 Normal lab conditions

This assumes an environment similar to normal office conditions. If the EUT shall be operated beyond the conditions described, use the conditions recommended by the manufacturer and agreed upon by all interested parties. Report compliance with conditions. Any deviation from these limits shall be reported.

Temperature:	20 °C ± 5 °C.
Humidity:	25 % to 85 % relative humidity, non-condensing.
Barometric pressure:	86 kPa to 106 kPa (25 inHg to 31 inHg)[1] (approx. sea level to 1 400 m).

5.10.2 Multi-temperature testing

When testing at multiple temperatures, the settling time should be at least 20 min before measurements begin. Wait sufficient time until the temperature is stabilised by measuring the temperature (or, alternatively, the luminance) of the display. Temperatures should be monitored with thermistors at appropriate locations within the temperature chamber. Temperature gradients in the sampled area should be no more than ± 2° for 30 min unless otherwise specified.

5.10.3 CRT ambient magnetic field test

The ambient magnetic field should be limited to the lowest practical level.

There shall be no additional static magnetic field excepting that of the geomagnetic field. Effects of the geomagnetic field shall be eliminated by using a degaussing coil.

The power frequency magnetic field (at 50 Hz/60 Hz) shall be not more than 0,1 μT to 0,2 μT (100 nT to 200 nT) at the monitor position, when all other measuring equipment is switched on.

---

1) Inches of mercury.

6 Measurement methods

6.1 Basic light measurements

6.1.1 M 12.1 — Basic spot measurement

a) Objective: to measure the photometric and/or spectral properties of the display at the specified parameters.

b) Applicability: all direct view displays.

c) Preparation and set-up

   1) Auxiliary equipment: see 5.2.5 veiling glare frustum (optional).

   2) Fixed measurement conditions

      - Measurement field: see 5.6.1 many pixels.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions

      - test patterns;
      - measurement locations;
      - meter direction;
      - test illumination;
      - spectral characteristics.

d) Procedure

   1) Generate specified pattern on the screen of the EUT.

   2) Measure the luminance and/or the chromaticity coordinates and/or spectral power distribution for each of the specified measurement location(s) at the specified direction(s).

   3) Repeat for additional patterns if specified.

e) Analysis: none.

f) Reporting: report luminance in cd/m^2, chromaticity spectral power distribution in W/(sr·nm·m^2).

g) Comments: the measurement of the black luminance is particularly susceptible to errors caused by the room ambient lighting conditions. See 5.9.2 for more details.

6.1.2 M 12.2 — Reflection coefficient

a) Objective: to measure the reflection coefficient of the surface of a display.

b) Applicability: all direct view displays except for front-projection displays.

c) Preparation and set-up

1) Auxiliary equipment: see 5.2.3 diffuse reflectance standard.

   see 5.2.5 veiling glare frustum.

   see 5.2.11 uniform light source thermistors.

2) Test accessories: see 5.2.5 veiling glare frustum (optional).

3) Fixed measurement conditions

   — Measurement field: see 5.6.1 many pixels.

   — Meter angular aperture: see 5.7 angular aperture.

   — Meter response time: see 5.8.2 time-averaging meter.

4) Configurable measurement conditions

   — Test patterns: see 5.3.17 full-screen.

   — Measurement location: see 5.4.8 centre-screen unless otherwise specified.

   — Meter direction: see 5.4.1 normal to display screen/normal to display surface, unless otherwise specified.

   — Test illumination: see 5.9.2 darkroom.

   see 5.9.7 two extended sources — 15° to 30° — use ± 30 configuration.

d) Procedure

1) Configure the two extended sources 30° apart (15° from normal).

2) Measure the reflected panel luminance at each measurement location and direction. Perform these measurements with the EUT in low state and in high state. Focus is at the surface of the flat panel under test.

3) Measure the luminance of the reflectance standard placed in the plane of the EUT and with the light source in the same configuration as in 1), above.

4) Calculate the estimation of the reflected specular light using the following equations for each measurement location and direction:

$$\begin{aligned} L_{\mathrm{D,\,HS\text{-}OFF}} &= L_{\mathrm{d,HS}} - L_{\mathrm{dark,\,HS}} \\ L_{\mathrm{D,\,LS\text{-}OFF}} &= L_{\mathrm{d,\,LS}} - L_{\mathrm{dark,\,LS}} \end{aligned} \qquad (2)$$

where

$L_{\mathrm{D,HS\text{-}OFF}}$ is the reflected panel luminance in the high state with the diffuse illumination switched off;

$L_{\mathrm{D,HS}}$	is the reflected panel luminance in the high state under diffuse illumination;
$L_{\mathrm{dark,HS}}$	is the high-state reflected panel luminance under darkroom conditions;
$L_{\mathrm{D,LS\text{-}OFF}}$	is the low-state reflected panel luminance with the diffuse illumination switched off;
$L_{\mathrm{D,LS}}$	is the reflected panel luminance in the low state under diffuse illumination;
$L_{\mathrm{dark,LS}}$	is the reflected panel luminance in the low state under darkroom conditions.

5) For back-illuminated liquid crystal displays, where the illumination (e.g. backlight) can be switched off, but the state of the liquid crystals is still low-state and high-state (the case, for most notebook computers), measure the reflected panel luminance at 15°, with the flat panel switched on, in both low and high states, with the built in illumination of the flat panel switched off. Focus is at the surface of the flat panel under test.

e) Analysis: calculate the following reflectances.

$$\begin{aligned}
\rho_{\mathrm{D\,(HS\text{-}OFF)}} &= \rho_{\mathrm{D(STD)}} \times \frac{L_{\mathrm{D,\,HS\text{-}OFF}}}{L_{\mathrm{D,STD}}} \\
\rho_{\mathrm{D\,(LS\text{-}OFF)}} &= \rho_{\mathrm{D(STD)}} \times \frac{L_{\mathrm{D,LS\text{-}OFF}}}{L_{\mathrm{D,STD}}} \\
\rho_{\mathrm{D\,(HS\text{-}OFF)}} &= \rho_{\mathrm{D(STD)}} \times \frac{L_{\mathrm{D,HS\text{-}OFF}}}{L_{\mathrm{D,STD}}} \\
\rho_{\mathrm{D\,(LS\text{-}OFF)}} &= \rho_{\mathrm{D(STD)}} \times \frac{L_{\mathrm{D,LS\text{-}OFF}}}{L_{\mathrm{D,STD}}}
\end{aligned} \tag{3}$$

where

$\rho_{\mathrm{D(HS\text{-}OFF)}}$	is the high-state diffuse reflectance with the diffuse illumination switched off;
$\rho_{\mathrm{D(STD)}}$	is the diffuse reflectance of the standard;
$L_{\mathrm{D,HS\text{-}OFF}}$	is the high-state reflected panel luminance with the illumination switched off;
$L_{\mathrm{D,STD}}$	is the reflected panel luminance of the standard under diffuse illumination;
$\rho_{\mathrm{D(LS\text{-}OFF)}}$	is the low-state diffuse reflectance with the illumination switched off;
$L_{\mathrm{D,LS\text{-}OFF}}$	is the low-state reflected panel luminance with the diffuse illumination switched off.

Ensure that the value for $\rho_{\mathrm{D(STD)}}$ has been corrected for the proper orientation of the light sources. See 5.2.3.

f) Reporting: report the reflectances.

g) Comments: none.

6.1.3 M 12.9 — Basic illuminance measurement

a) Objective: to measure the illuminance of a front-projection system at the image plane at a specified location.

b) Applicability: front-projection display systems.

c) Preparation and set-up

   1) Auxiliary equipment: see 5.2.6 stray light elimination tube and projection masks.

   2) Fixed measurement conditions

      — Measurement field: see 5.6.4 section of large illumination surface.

      — Meter angular aperture: see 5.7 angular aperture.

      — Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions:

      — test patterns;

      — measurement locations;

      — meter direction;

      — test illumination;

      — spectral characteristics.

d) Procedure

   1) Place the detector in the image plane, normal to image plane.

   2) Measure the sampled illuminance, E_i, chromaticity coordinates and spectral response for each of the specified measurement.

   3) Repeat for additional patterns if specified.

e) Analysis: none.

f) Reporting: record the illuminance in lux and/or chromaticity in x,y and/or spectral response.

g) Comments

   1) See 6.1.1 (M 12.1), basic spot measurement.

   2) Measurement of front projection display systems are also subject to corruption due to stray light from ambient lighting and back reflections from room surfaces. Stray light elimination techniques may be employed to minimise the impact, see 5.2.6.

6.1.4 P 12.3 — Estimated approximate luminous flux

a) Objective: to measure the approximate estimated luminous flux of a front-projection system at the image plane by measuring the illuminance at nine specified measurement locations and determining the image area.

b) Applicability: front-projection display systems.

c) Preparation and set-up

   1) Preparation: see 5.1.3 front projection display standard preparation.

   2) Test accessories: see 5.2.6 stray light elimination tube and projection masks.

   3) Fixed measurement conditions

      — Measurement field: see 5.6.4 section of large illumination surface.

      — Meter angular aperture: see 5.7 angular aperture.

      — Meter response time: see 5.8.2 time-averaging meter.

   4) Configurable measurement conditions (use parameters as described unless otherwise specified)

      — Test pattern: see 5.3.17 full-screen — 100 % white.

      — Measurement location: see 5.4.7 projector — 13 locations.

      — Meter direction: see 5.4.1 normal to display screen/normal to display.

      — Test illumination: see 5.9.2 darkroom.

      — Spectral characteristics: illuminance.

d) Procedure

   1) Obtain the heights (h_1, h_2) and widths (w_1, w_2) of the projected image, in metres according to 6.9.11 (M 20.11).

   2) Measure the illuminance, E_i, at each of the specified measurement locations in accordance with 6.1.3 (M 12.9).

e) Analysis

   1) Calculate the area, A:

$$A = \frac{1}{2}\left(h_1 + h_2\right)\left(w_1 + w_2\right)$$

   2) Calculate the sampled flux, ϕ_W, for n positions:

$$\phi_\mathrm{W} = \frac{A}{n}\sum_{i=1}^{n=9} E_i$$

f) Reporting: record the estimated approximate luminous flux in lumens.

g) Comments: see 6.1.1 (M 12.1).

6.1.5 P 12.4 — Combined emitted and reflected light

a) Objective: to calculate the combined measurement for luminance and diffuse illumination.

b) Applicability: all direct view displays except for front-projection systems.

c) Preparation and set-up

1) Test accessories: 5.2.3 diffuse reflectance standard.
   5.2.5 veiling glare frustum.

2) Fixed measurement conditions
   - Measurement field: 5.6.1 many pixels.
   - Meter angular aperture: 5.7 angular aperture.
   - Meter response time: 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)
   - Test patterns: see 5.3.17 full-screen.
   - Measurement location: see 5.4.8 centre-screen unless otherwise specified.
   - Meter direction: see 5.4.1 normal to display screen/normal to display surface unless otherwise specified.
   - Test illumination: see 5.9.2 darkroom.
     see 5.9.7 two extended sources — 15 to 30° — use ± 30° configuration.

d) Procedure

1) Perform a luminance measurement, $L_{E_0}(\text{state}, n, \theta, \phi)$, at each specified location and angle for both the high and low states in darkroom conditions. See 6.1.1 (M 12.1).

2) Perform a reflectance coefficient measurement, $\rho(\text{state}, n, \theta, \phi)$, in the specified viewing directions and at the centre locations for both high and low states. See 6.1.2 (M 12.2).

e) Analysis:

$$L_{E_\text{S}}(\text{state}, n, \theta, \phi) = \frac{1}{2} \begin{bmatrix} L_{E_0}(\text{state}, n, \theta, \phi) + \rho(\text{state}, n, \theta, \phi) \times E_s \\ L_{E_0}(\text{state}, n, \theta, \phi) \times \dfrac{L_{E_0}(\text{state}, n, 0{,}0)}{L_{E_0}(\text{state}, \text{centre}, 0{,}0)} + \rho(\text{state}, \text{centre}, \theta, \phi) \times E \end{bmatrix} \quad (4)$$

for the centre measurement position.

f) Reporting: report the luminances, $L_{E_\text{S}}(\text{state}, n, \theta, \phi)$, in cd/m^2.

g) Comments

To reduce the number of measurements, it has been assumed that

$$L\left(\text{level,centre},\theta,\phi\right) = \alpha_n \times L\left(\text{level},n,\theta,\phi\right) \tag{5}$$

such that the screen tilt angle, α_n, at location n remains constant for all azimuth angles and inclination angles.

If this assumption is invalidated for a new technology, then

$$L_{E_0}\left(\text{state},n,\theta,\phi\right) + R\left(\text{state},n,\theta,\phi\right) \tag{6}$$

shall be calculated for all azimuth angles and inclination angles for each state.

For a uniform diffuse illumination (e.g. large integrating sphere) and a system insensitive to the azimuth angle between equipment under test and light meter (e.g. insensitive to polarisation of light), all values in the table remain constant for all values of n and need be measured for one azimuth angle only, e.g. CL-0.

For a good measurement system and diffuse reflectance standard, regardless of the uniformity of the diffuse illumination, $Y_{\text{DIFF,dSTD}(n)}$, remains constant for all values of n, and thus needs to be measured for one azimuth angle, only, e.g. CL-0.

6.1.6 P 12.5 — Site screening — Standard measurement locations

a) Objective: to measure the full-screen luminance at predefined positions based on screen size, and report the minimum, maximum, and centre-screen luminances. This procedure is based on 6.1.1 (M 12.1).

b) Applicability: all direct view displays.

c) Preparation and set-up

1) Test accessories: see 5.2.5 veiling glare frustum.

2) Fixed measurement conditions

- Measurement field: see 5.6.1 many pixels.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17, 5.3.23 full-screen — 100 % white or box patterns (1/5 to 1/6 the size of diagonal of display).

  NOTE The test pattern is set at 100 % white as the default. In the case of the display changing its luminance significantly in relation to the display area, the box luminance defined in 5.3.23 can be used instead of the full-screen luminance as the luminance value.

- Measurement location: see 5.4.4 standard 11 locations.
- Meter direction: see 5.4.1 normal to display screen — normal to display surface.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: only luminance required.

d) Procedure: perform a luminance measurement at each specified location. See 6.1.1 (M 12.1).

e) Analysis: none.

f) Reporting: report the maximum, minimum and centre-screen luminances along with their respective screen positions.

g) Comments: see 6.1.1 (M 12.1).

6.1.7 P 12.6 — Visual screening to find max. and min. locations

a) Objective: to measure the full-screen luminances at positions based on visual screening, and report the minimum, maximum, and centre-screen luminances.

b) Applicability: all direct view displays.

c) Preparation and set-up

   1) Test accessories: see 5.2.5 veiling glare frustum.

   2) Fixed measurement conditions

      — Measurement field: see 5.6.1 many pixels.

      — Meter angular aperture: see 5.7 angular aperture.

      — Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      — Test pattern: see 5.3.17 full-screen — 100 % white.

      — Measurement location see 5.4.9 visual determination.

      — Meter direction: see 5.4.1 normal to display screen/normal to surface.

      — Test illumination: see 5.9.2 darkroom.

      — Spectral characteristics: only luminance required.

d) Procedure

   1) Visually determine the areas of screen that appear brightest and dimmest and perform luminance measurements at these locations. See 6.1.1 (M 12.1).

   2) Perform a measurement at the centre-screen location.

e) Analysis: none.

f) Reporting: report the maximum, minimum and centre-screen luminances along with their respective screen positions.

g) Comments: see 6.1.1 (M 12.1).

6.2 Luminance profile measurements

6.2.1 M 13.1 — Luminance profile using green profile

a) Objective: to measure the luminance of single-pixel vertical and horizontal, attempting to correct for some of the veiling glare in the LMD.

b) Applicability: all direct view displays.

c) Preparation and set-up

1) Test accessories: see 5.2.7 replica masks.

2) Fixed measurement conditions

- Measurement field: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.15 horizontal bars — 100 % green, one pixel width, 100 % black, one pixel width, alternating;

  see 5.3.16 vertical bars — 100 % green, one pixel width, 100 % black, one pixel width, alternating.
- Measurement location: see 5.4.3 standard five locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: luminance only.

d) Procedure

1) With an array or scanning LMD (take special care for alignment, within 1°) obtain the luminance profile of the vertical line, S, as a function of distance. A correction for veiling glare, S_g, shall be made. Repeat for the horizontal line. Plot the measured luminance profile and connect the peaks for each single-colour response within each line.

2) Measure the average area luminance, according to 6.6.1 (P 17.1), of both white, L_w, and green, L_g, luminances.

e) Analysis

1) Plot the measured luminance profile and connect the peaks for each response within each line to determine the average.

2) Use a replica mask or line mask (see 5.2.7) to determine veiling glare correction, or include uncertainties of glare estimation.

3) Normalise (S_{cor}) the luminance profile to white using the following equation:

$$S_{cor} = S \times \frac{L_w}{L_g} S_g \qquad (7)$$

f) Reporting: report the line luminance to no more than three significant figures.

g) Comments

The measurement of the black luminance is particularly susceptible to errors caused by the room ambient lighting conditions. Ambient lighting shall be controlled in order to avoid errors caused by reflections off the display screen. Additional errors can be contributed by lens flare or veiling glare from the rest of the screen. For screens that exhibit strong viewing-angle dependence, the glare contributions can be particularly significant.

6.2.2 M 13.2 — Luminance profile with smoothing algorithm

a) Objective: to measure the luminance of single-pixel vertical and horizontal black lines and the luminance of its white background, attempting to correct for some of the veiling glare in the LMD.

b) Applicability: all direct view displays.

c) Preparation and set-up

1) Test accessories: see 5.2.7 replica masks.

2) Fixed measurement conditions

- Measurement field: see 5.6.2 within a pixel.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.15 horizontal bars — 100 % white, one pixel width, 100 % black one pixel width, alternating;

  see 5.3.16 vertical bars — 100 % white, one pixel width, 100 % black, one pixel width, alternating.
- Measurement location: see 5.4.3 standard five locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: luminance only.

d) Procedure

1) With an array or scanning LMD (taking special care to align to within 1°), obtain the luminance profile of the vertical line, S, as a function of distance with any background (inherent in the detector if a nonzero signal exists for no light input) subtracted.

A correction for veiling glare, S_{g}, shall be made.

2) Repeat for the horizontal line.

e) Analysis

   1) Perform a running window of the luminance profile where the averaging window width is as close as possible to the pixel pitch as rendered by the LMD. For an array detector, however, many detector array pixels are needed to cover one display pixel. There should be at least 10 or more detector pixels per display pixel, if possible.

   2) Use a replica mask or line mask (see 5.2.7*)* to determine veiling glare correction, or include uncertainties of glare estimation.

   3) From the resulting modulation curve, determine the net level of the line profile:

   $$S_{\text{cor}} = S - S_g$$

f) Reporting: report the line luminance to no more than three significant figures.

g) Comments

The measurement of the black luminance is particularly susceptible to errors caused by the room ambient lighting conditions. Ambient lighting shall be controlled to avoid errors caused by reflections from the display screen. Additional errors can be contributed by lens flare or veiling glare from the rest of the screen. For screens that exhibit strong viewing-angle dependence, the glare contributions can be particularly significant.

6.3 Directional light measurements

6.3.1 P 14.1 — Luminance angular distribution

a) Objective: to make full-screen luminance measurements made at the centre of the screen to determine luminance characteristics for a set number of viewing directions.

b) Applicability: all direct view displays.

c) Preparation and set-up

   1) Test accessories see 5.2.5 veiling glare frustum.

   2) Fixed measurement conditions

— Measurement field:	see 5.6.1	many pixels.
— Meter angular aperture:	see 5.7	angular aperture.
— Meter response time:	see 5.8.2	time-averaging meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen at specified colours.
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen — at specified values of θ and ϕ (10° steps or less within specified viewing region).
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		spectral distribution, luminance.

d) Procedure: make the required goniometric measurements of luminance $L_{\theta,\phi}$ and the chromaticity coordinates of the required patterns with the meter positioned at each of the appropriate viewing angles [see 6.1.1 (M 12.1)].

e) Analysis: none.

f) Reporting: data should be presented in tabular or graphic form, to no more than three significant figures.

g) Comments: see 6.1.1 (M 12.1).

6.3.2 P 14.2 — Luminance angular uniformity

a) Objective: to measure the full screen luminance uniformity for different angles at specified locations.

b) Applicability: all direct view displays.

c) Preparation and set-up

    1) Test accessories see 5.2.5 veiling glare frustum.

    2) Fixed measurement conditions

        — Measurement field: see 5.6.1 many pixels.

        — Meter angular aperture: see 5.7 angular aperture.

        — Meter response time: see 5.8.2 time-averaging meter.

    3) Configurable measurement conditions (use parameters as described unless otherwise specified).

        — Test pattern: see 5.3.17 full screen at specified colours.

        — Measurement location: see 5.4.3 standard five locations.

        — Meter direction: see 5.4.1 normal to display screen — at specified values of θ and ϕ (10° steps or less within specified viewing region.

        — Test illumination: see 5.9.2 darkroom.

        — Spectral characteristics: spectral distribution, luminance.

d) Procedure: see 6.3.1 (P 14.1).

e) Analysis: calculate the luminance uniformity, at each test position:

$$\text{uniformity} = 100\ \% \left(\frac{L_{\text{min}}}{L_{\text{max}}} \right)$$

where

L_{max} is the maximum measured display luminance of the sampled display luminance set, L_i, and where $i = 1, \dots, n$, for each test direction;

L_{min} is the minimum measured display luminance of the sampled display luminance set: L_i, and where $i = 1, \dots, n$, for each test direction.

f) Reporting: data should be presented in tabular form, to no more than three significant figures.

g) Comments: see 6.1.1 (M 12.1).

6.4 Temporal performance measurements

6.4.1 M 15.1 — Temporal luminance variation

a) Objective: to measure the variation of luminance as a function of time.

b) Applicability: all display technologies.

c) Preparation and set-up

   1) Test accessories: see 5.2.5 veiling glare frustum (optional).
      see 5.2.8 data acquisition.
      see 5.2.9 vibration-damped measurement bench (optional).

   2) Fixed measurement conditions
      - Measurement field: see 5.6.1 many pixels.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.1 fast response meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified):
      - test patterns;
      - measurement locations;
      - meter direction;
      - test illumination;
      - integration time;
      - sampling interval;
      - spectral characteristics.

d) Procedure:

   1) Display the selected test pattern.

   2) Take a series of test samples recording the luminance versus time, $L(t)$, for the specified sample period.

   3) Change the state of the test pattern, if appropriate, while continuing to take measurements.

6.4.2 P 15.2 — Image formation time

a) Objective: to measure the electro-optical step response function (SRF) resulting from pixel activation/deactivation, and report the pixel turn-on/turn-off (or high-level/low level) and image-formation times.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 5.2.5 veiling glare frustum (optional).

see 5.2.8 data acquisition.

see 5.2.9 vibration-damped measurement bench (optional).

2) Fixed measurement conditions

- Measurement field: see 5.6.1 many pixels.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.1 fast response meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.22 response time pattern 100% white and 100 % black.
- Measurement location: see 5.4.8 centre-screen.
- Meter direction: see 5.4.1 normal to display screen — normal to display surface.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: the LMD shall be photopically corrected if the colour of the test pattern changes between full white and full black.

d) Procedure

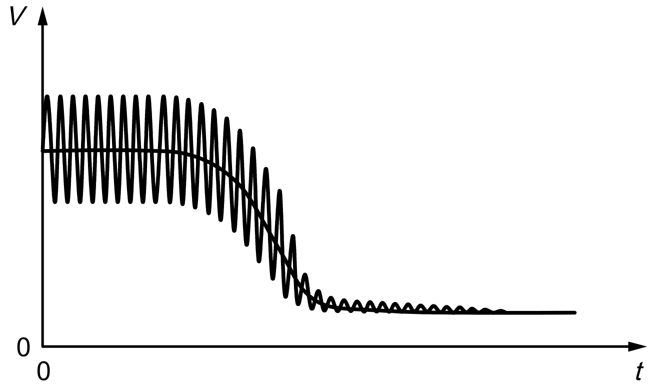
Follow the procedure given in 6.4.1 (M 15.1) with the following modifications.

- Change the test pattern from the low to the high state and measure the resulting positive electro-optical step response function, $L_{\mathrm{PSRF}}(t)$. This curve should include steady-state high (L_{high}) and low (L_{low}) reference levels.
- Change the test pattern from the high to the low state and measure the resulting negative electro-optical step response function, $L_{\mathrm{NSRF}}(t)$.

e) Analysis

1) Frame refresh, backlight modulation or other sources can superimpose a periodic ripple on top of the SRF curve (see Figure 51). If this ripple affects measurement repeatability, it may be controlled by a “tuned” moving window average filter (assuming a digitised output of the LMD). Let the ripple period be τ, the LMD sample rate be s, the raw time-dependent light measurements taken at intervals of $1/s$ be L_i, and ΔN be the number of light data points collected during the ripple period $\Delta N = \tau s$: the resultant moving-window-average-filtered signal, S_i, is given by

$$S_i = \frac{1}{\Delta N} \sum_{n=i}^{n=i+\Delta N-1} L_n \tag{8}$$



Key

V voltage

t time

Figure 51 — Step response function (SRF) curve with periodic ripple

2) Apply ripple filters as necessary.

3) Calculate $L_{\text{range}} = L_{\text{high}} - L_{\text{low}}$, $L_{10\ \%} = 0{,}1 L_{\text{range}} + L_{\text{low}}$ and $L_{90\ \%} = 0{,}9 L_{\text{range}} + L_{\text{low}}$,

where L_{high} and L_{low} are the luminances at the steady-state high and low reference levels, respectively, and L_{range} is the difference between the two.

4) Find the times, $T_{10\ \%}$, $T_{90\ \%}$, at which $L_{\text{PSRF}}(t)$ equals $L_{10\ \%}$, $L_{90\ \%}$ (using linear interpolation between the bounding data points) and record (pixel turn-on time) $T_{\text{on}} = T_{90\ \%} - T_{10\ \%}$.

5) Similarly, measure $L_{\text{NSRF}}(t)$ and record (pixel turn-off time) $T_{\text{off}} = T_{10\ \%} - T_{90\ \%}$.

f) Reporting

Report the test pattern used (position, size, colour, and blink on/off times), the LMD sample rate, the filtering used (if any), T_{high}, T_{low}, and the image formative time, T_{f}. Optionally, the raw and filtered SRF curves may be included with the reporting sheet. If multiple independent measurements are made, report the mean of the resulting values.

g) Comments: T_{high} and T_{low} are used only to measure the optical SRF curve — any delay between the electrical activation of a pixel and the start of the pixel's optical SRF is not measured.

6.4.3 P 15.2A — Image formation time between grey levels

a) Objective: to measure the electro-optical step response function (SRF) resulting switching between grey levels.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 5.2.5 veiling glare frustum (optional).

see 5.2.8 data acquisition.

see 5.2.9 vibration-damped measurement bench (optional).

2) Fixed measurement conditions

— Measurement field: see 5.6.1 many pixels.

— Meter angular aperture: see 5.7 angular aperture.

— Meter response time: see 5.8.1 fast response meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern: see 5.3.22 response time pattern (see Figure 52) — levels set as described in the procedure.

— Measurement location: see 5.4.8 centre-screen.

— Meter direction: see 5.4.1 normal to display screen/normal to display surface.

— Test illumination: see 5.9.2 darkroom.

— Spectral characteristics: the LMD shall be photo-optically corrected if the colour of the test pattern changes between grey levels.

d) Procedure

Follow the procedure given in 6.4.1 (M 15.1) with the following modifications.

— Use the input parameters (electrical driving) given in Tables 2 and 3 during the measurement.

Depending on the nature of the electro-optical effect used in the display to be measured (“normally white” or “normally black”), the transitions below/above the diagonal of the tables are all either driven by the electric field or are based on relaxation of the stared elastic energy, respectively, and vice versa.

If a certain application requires more measurements, there shall be no upper limit.

— For each transition, change the test pattern from the lower to the higher state and measure the resulting positive electro-optical step response function, $L_{\text{PSRF}}(t)$. This curve should include steady state high (L_{high}) and low (L_{low}) reference levels.

— For each transition, change the test pattern from the higher to the lower state and measure the resulting negative electro-optical step response function, $L_{\text{NSRF}}(t)$.

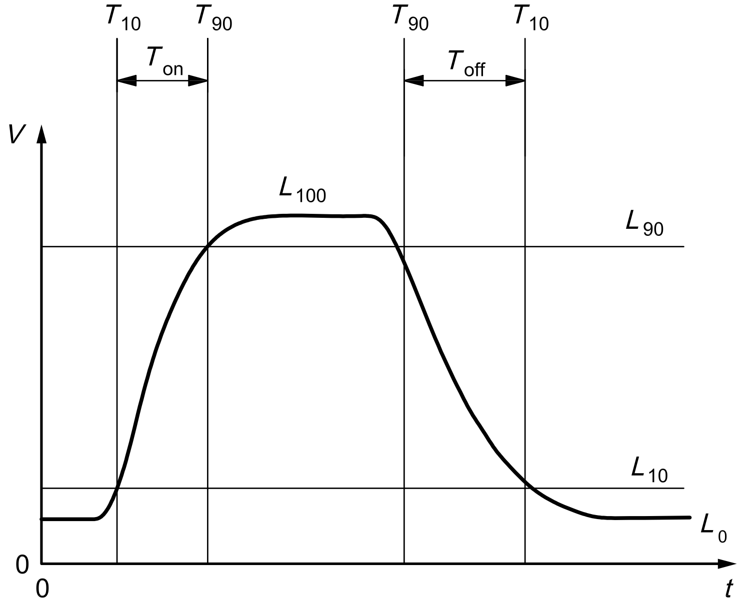


Figure 52 — Example of response times

Table 2 — Absolute minimum grey-level transitions (20 measurements)

Start level	End level				
	0	63	127	191	255
0	×				
63		×			
127			×		
191				×	
255					×

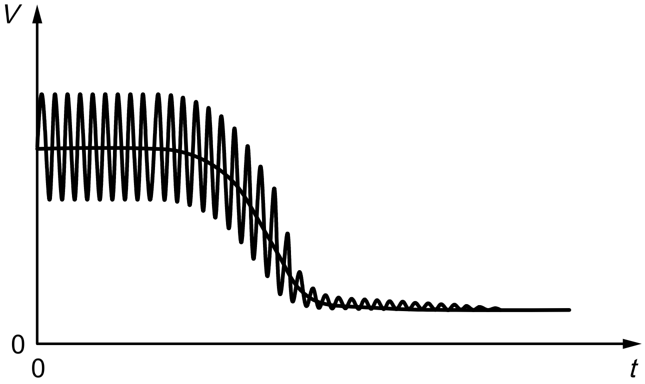
Table 3 — Standard grey-level transitions (72 measurements)

Start level	End level								
	0	31	63	95	127	159	191	232	255
0	×								
31		×							
63			×						
95				×					
127					×				
159						×			
191							×		
232								×	
255									×

e) Analysis

1) Frame refresh, backlight modulation or other sources can superimpose a periodic ripple on top of the SRF curve (see Figure 53). If this ripple affects measurement repeatability, it may be controlled by a "tuned" moving window average filter (assuming a digitised output of the LMD). Let the ripple period be τ, the LMD sample rate be s, the raw time-dependent light measurements taken at intervals of $1/s$ be L_i, and ΔN be the number of light data points collected during the ripple period $\Delta N = \tau s$: the resultant moving-window-average-filtered signal, S_i, is given by

$$S_i = \frac{1}{\Delta N} \sum_{n=i}^{n=i+\Delta N-1} L_n \tag{9}$$



Key

V voltage

t time

Figure 53 — Step response function (SRF) curve with periodic ripple

2) Apply ripple filters as necessary.

3) Calculate $L_{\text{range}} = L_{\text{high}} - L_{\text{low}}$, $L_{10\ \%} = 0{,}1L_{\text{range}} + L_{\text{low}}$ and $L_{90\ \%} = 0{,}9L_{\text{range}} + L_{\text{low}}$.

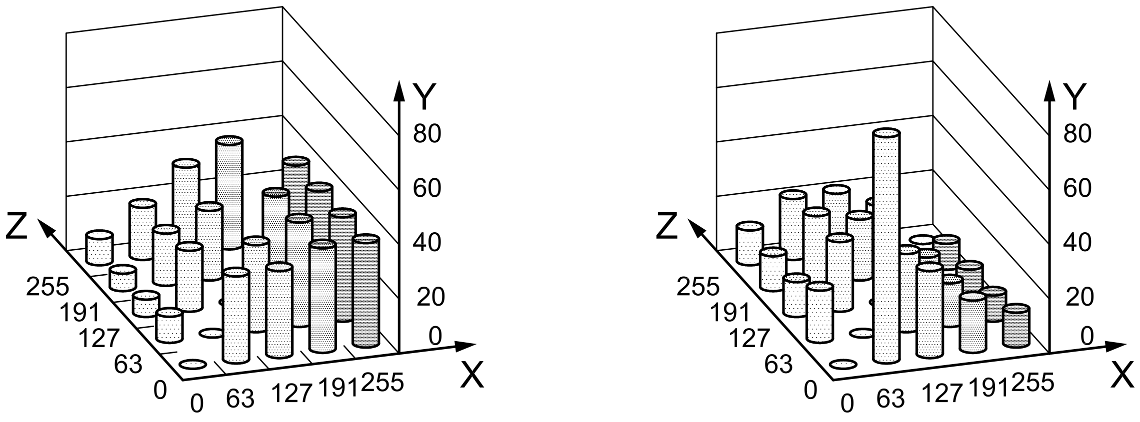
4) Find the times, $T_{10\ \%}$, T_{140}, at which $L_{\text{PSRF}}(t)$ equals $L_{10\ \%}$, $L_{90\ \%}$ (using linear interpolation between the bounding data points) and record $T_{\text{on}} = T_{90\ \%} - T_{10\ \%}$.

5) Similarly, measure $L_{\text{NSRF}}(t)$ and record $T_{\text{fall}} = T_{10\ \%} - T_{90\ \%}$.

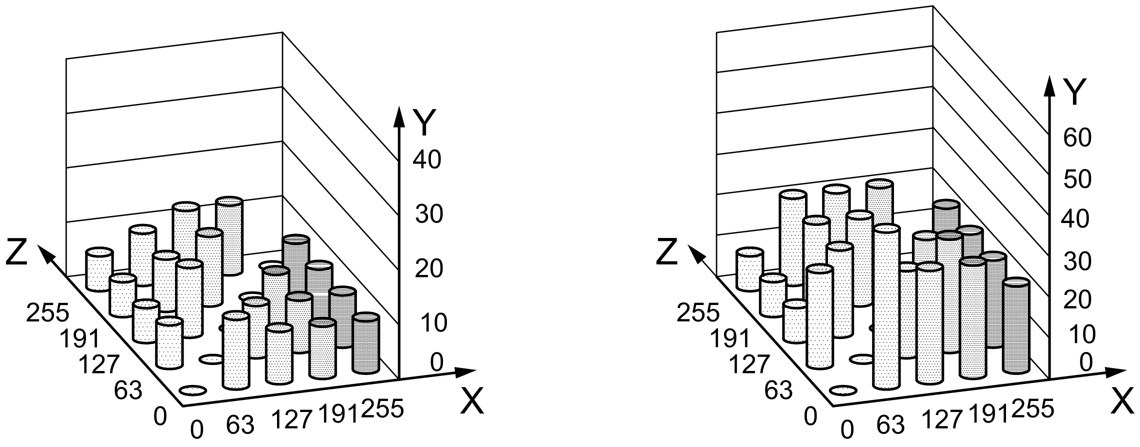
f) Reporting

Report the test pattern used (position, size, colour, and blink on/off times), the LMD sample rate, the filtering used (if any), T_{high}, T_{low}, and T_{f}. Optionally, the raw and filtered SRF curves may be included with the reporting sheet. If multiple independent measurements are made, report the mean of the resulting values.

See Figure 54: in such a graphical representation, the maximum value of all transition-times can easily be seen and distinguished.



a) TN mode **b) MVA mode**



c) TN-DCR **d) IPS mode**

Key

X end level

Y response time, ms

Z start level

Figure 54 — Graphical representation of image formation time between grey levels

g) Comments: T_{high} and T_{low} can only be used to measure the optical SRF curve — any delay between the electrical activation of a pixel and the start of the pixel's optical SRF is not measured.

6.4.4 P 15.3 — Flicker

a) Objective: to measure intensity as a function of time, then to use Fourier analysis to compute flicker intensity as a function of frequency, and finally to calculate flicker levels and report the frequency and flicker level of the highest flicker peak.

b) Applicability: on some display technologies, certain viewing angles, test patterns, colours, and/or drive levels can cause the display to appear to flicker, even though a constant test pattern is displayed.

c) Preparation and set-up

   1) Test accessories: see 5.2.5 veiling glare frustum (optional).

      see 5.2.8 data acquisition.

      see 5.2.9 vibration-damped measurement bench (optional).

   2) Fixed measurement conditions

      — Measurement field: see 5.6.1 many pixels.

      — Meter angular aperture: see 5.7 angular aperture.

      — Meter response time: see 5.8.1 fast response meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      — Test pattern: see 5.3.17 full-screen 100 % white.

      — Measurement location: see 5.4.8 centre-screen.

      — Meter direction: see 5.4.1 normal to display screen/normal to display surface.

      — Test illumination: see 5.9.2 darkroom.

      — Spectral characteristics: the LMD shall be photo-optically corrected unless it is known that there is no colour shift due to flicker or variations in test patterns.

      — Other parameters

      The LMD should be dark-field-corrected unless relative measurements are being performed.

      The LMD output should be low-pass filtered, with low with a cut-off frequency of 150 Hz (± 3dB), and −60 dB at the sample frequency. This filtering can be done in the LMD itself, or by filtering oversampled data using a digital filter such as a moving-window-average filter.

d) Procedure

   Follow the procedure given in 6.4.1 (M 15.1) with the following modification:

   — collect the array $f_{\text{raw}}(0 \ldots N_{\text{samples}} - 1)$ intensity data samples at the sample frequency, F_{sample}.

e) Analysis

   1) Calculate the FFT coefficients and the corresponding flicker levels. For each FFT frequency sample, the resulting coefficient is weighted determined by the corresponding scaling factor in Table 4. This weighting is performed to adjust the measured flicker levels to match the approximate temporal flicker sensitivity of the human eye, where flicker sensitivity decreases as the flicker frequency increases.

2) Validate the FFT algorithm as per the FFT validation section in the comments below.

3) Use $f_{\mathrm{raw}}[\ldots]$ to calculate $f_{\mathrm{fftc}}\ [0\ldots(N_{\mathrm{samples}}/2) - 1]$, the array of FFT coefficients, each representing the flicker intensity for a certain frequency range. Note that the centre frequency of $f_{\mathrm{fftc}}[n] = nF_{\mathrm{sample}}/N_{\mathrm{samples}}$. Also note that $f_{\mathrm{fftc}}[0]$ is the DC, or average, intensity.

4) Scale the $f_{\mathrm{fftc}}[\ldots]$ array by the human visual sensitivity factors in Table 4, using linear interpolation between the listed values, yielding the scaled FFT coefficient array $f_{\mathrm{sfftc}}[\ldots]$.

5) For each element in $f_{\mathrm{sfftc}}[\ldots]$, calculate the flicker level = $20\log10(2f_{\mathrm{sfftc}}[n]/f_{\mathrm{sfftc}}[0])$ dB. This is the equation for calculating number of decibels directly from the validated FFT coefficients. If the flicker level is to be calculated from “power spectrum” FFT coefficients, where each coefficient has been squared, either take the square root of each coefficient to yield the validated form, or use the alternative equation flicker level = 10log10(power[n]/power[0]dB. Here, the weighted flicker level at each frequency in decibels with respect to the mean luminance is being calculated.

f) Reporting: report any variations from standard setup/test pattern, $F_{\mathrm{repetition}}$, F_{sample}, and the frequency and value of the largest flicker level; optionally, report all flicker levels.

g) Comments: none.

Table 4 — Weighing factors

Frequency Hz	**Scaling** [a] dB	 Factor
20	0	1,00
30	− 3	0,708
40	− 6	0,501
50	− 12	0,251
⩾ 60	− 40	0,010

Use linear interpolation between the listed frequencies.

[a] “Scaling/dB” is equivalent to “Scaling/factor”.

6.4.5 P 15.3A — Extended flicker measurement

a) Objective: for different grey levels, to measure intensity as a function of time, then to use Fourier analysis to compute flicker intensity as a function of frequency, and finally to calculate flicker levels and report the frequency and flicker level of the highest flicker peak.

b) Applicability: on some display technologies, certain viewing angles, test patterns, colours, and/or drive levels can cause the display to appear to flicker, even though a constant test pattern is displayed.

c) Preparation and set-up

1) Test accessories: see 5.2.5 veiling glare frustum (optional).
   see 5.2.8 data acquisition.
   see 5.2.9 vibration-damped measurement bench (optional).

2) Fixed measurement conditions
   - Measurement field: see 5.6.1 many pixels.
   - Meter angular aperture: see 5.7 angular aperture.
   - Meter response time: see 5.8.1 fast response meter.

3) configurable measurement conditions (use parameters as described unless otherwise specified)
   - Test pattern: see 5.3.17 full-screen at specified grey levels.
   - Measurement location: see 5.4.8 centre-screen.
   - Meter direction: see 5.4.1 normal to display screen/normal to display surface.
   - Test illumination: see 5.9.2 darkroom.
   - Spectral characteristics: the LMD shall be photo-optically corrected unless it is known that there is no colour shift due to flicker or variations in test patterns.
   - Other parameters

     The LMD should be dark-field-corrected, unless relative measurements are being performed.

     The LMD output should be low-pass filtered, with low with a cut-off frequency of 150 Hz (± 3 dB), and –60 dB at the sample frequency. This filtering can be done in the LMD itself, or by filtering oversampled data using a digital filter such as a moving-window-average filter.

d) Procedure

Follow the procedure given in 6.4.3 (P 15.2A) with the following modification:

- collect the array $f_{\text{raw}}[0 \ldots N_{\text{samples}} - 1]$ intensity data samples at the sample frequency, F_{sample}.

e) Analysis

1) Calculate the FFT coefficients and the corresponding flicker levels. For each FFT frequency sample, the resulting coefficient is weighted determined by the corresponding scaling factor in Table 4. This weighting is performed to adjust the measured flicker levels to match the approximate temporal flicker sensitivity of the human eye, where flicker sensitivity decreases as the flicker frequency increases.

2) Validate the FFT algorithm as per the FFT validation section in the comments below.

3) Use $f_{\mathrm{raw}}[\ldots]$ to calculate $f_{\mathrm{fftc}}[0\ldots(N_{\mathrm{samples}}/2) - 1$, the array of FFT coefficients, each representing the flicker intensity for a certain frequency range. Note that the centre frequency of $f_{\mathrm{fftc}}[n] = nF_{\mathrm{sample}}/N_{\mathrm{samples}}$. Also note that $f_{\mathrm{fftc}}[0]$ is the d.c., or average, intensity.

4) Scale the $f_{\mathrm{fftc}}[\ldots]$ array by the human visual sensitivity factors in Table 4, using linear interpolation between the listed values, yielding the scaled FFT coefficient array, $f_{\mathrm{sfftc}}[\ldots]$.

5) For each element in $f_{\mathrm{sfftc}}[\ldots]$, calculate the flicker level = $20\log10(2f_{\mathrm{sfftc}}[n]/f_{\mathrm{sfftc}}[0])$ dB. This is the equation for calculating the number of decibels directly from the validated FFT coefficients. If the flicker level is to be calculated from “power spectrum” FFT coefficients, where each coefficient has been squared, either take the square root of each coefficient to yield the validated form, or use the alternate equation flicker level = 10log10(power[n]/power[0] dB. Here, the weighted flicker level at each frequency in decibels with respect to the mean luminance is being calculated.

f) Reporting: report any variations from standard set-up/test pattern, $F_{\mathrm{repetition}}$, F_{sample}, and the frequency and value of the largest flicker level; optionally, report all flicker levels.

g) Comments: none.

6.4.6 P 15.4 — Jitter

a) Objective: to measure the amplitude and frequency of variations in pixel position of the displayed image in display devices where the position of the pixel is not fixed in space (as with raster-scanned CRT, flying-spot laser displays, etc.) and to quantify the effects of perceptible time-varying distortions — jitter, swim, and drift.

NOTE The perceptibility of changes in the position of an image depends upon the amplitude and frequency of the motions that can be caused by imprecise control electronics or, in the case of CRT, external magnetic fields.

b) Applicability: variable-resolution displays.

c) Preparation and set-up

1) Test accessories: see 5.2.5 veiling glare frustum (optional).
see 5.2.8 data acquisition.
see 5.2.9 vibration-damped measurement bench (optional).

2) Fixed measurement conditions

— Measurement field: see 5.6.1 many pixels.

— Meter angular aperture: see 5.7 angular aperture.

— Meter response time: see 5.8.1 fast response meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern: see 5.3.15 horizontal bars — 100 % white, one pixel width lines, on black field, positioned at top, centre, and bottom (see Figure 55).
see 5.3.16 vertical bars —100 % white, one pixel width lines, on black field, positioned at left, centre, and right (see Figure 55).

— Measurement location:	see 5.4.3	standard five locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display surface.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		luminance only.

d) Procedure

Follow the procedure given in 6.4.1 (M 15.1) with the following modifications.

- At each measurement location, measure the change in position of the centroid of the line as a function of time. The measurement interval, Δt, shall be equal to a single field period in the case of an interlaced display, or the frame period for a progressive-scan display, for each pattern. Measure both $x(t)$ and $y(t)$ at all desired locations at times for Δt_T = 150 s (2,5 min).
- Tabulate horizontal motion as a function of time in the x-direction, $x(t)$, using the vertical-line pattern. (for raster-scanned displays such as CRT, corners typically exhibit more jitter than centre-screen.)
- Repeat for the vertical motion as a function of time in the y-direction, $y(t)$, using the horizontal-line pattern.

e) Analysis

1) Using index i to denote the position measurement at the start (i = 0 at t = 0) and at each interval, Δt, ($t = i\Delta t$), at any of the desired locations, the total number of measurements made on any line at each location is N + 1, where $N = \Delta t_\mathrm{T} / \Delta t$, and i = 0, 1, 2, … N. For each measurement location, determine the shift in position for horizontal and vertical motions:

$\delta x_i = x_{i+1} - x_i,\ \delta y_i = y_{i+1} - y_i$, for $i = 0, 1, 2, ..., N$,

2) Define the quantities Δx_k and Δy_k:

$$\Delta x_k = \frac{1}{N-k} \sum_{n=0}^{N-k} \frac{\left|\delta x_n + \delta x_{n+1} + \ldots + \delta x_{n+k}\right|}{k+1},\ \Delta y_k = \frac{1}{N-k} \sum_{n=0}^{N-k} \frac{\left|\delta y_n + \delta y_{n+1} + \ldots + \delta y_{n+k}\right|}{k+1} \quad (10)$$

This denotes the average amount of motion during k intervals of Δt for k = 0, 1, 2, … $\Delta t_\mathrm{T}/\Delta t$. These window intervals $\Delta t_k = k\Delta t$ are running window averages of increasing length (see VESA-2005-5 [10], section A218, for a rigorous discussion).

3) To define the jitter, swim and drift, we identify three temporal window intervals of interest:

- for jitter, 0,01 s $\leqslant \Delta t_k <$ 2 s,
- for swim, 2 s $\leqslant \Delta t_k <$ 60 s, and
- for drift 60 s $\leqslant \Delta t_k$.

Jitter, swim, and drift are the maximum average motion for those window intervals:

i) horizontal jitter is the maximum of Δx_k for intervals 0,01 s $\leqslant \Delta t_k <$ 2 s [or (0,01 s)/$\Delta t \leqslant k <$ (2 s)/Δt];

ii) horizontal swim is the maximum of Δx_k for intervals 2 s $\leqslant \Delta t_k <$ 60 s [or (2 s)/$\Delta t \leqslant k <$ (60 s)/Δt];

iii) horizontal drift is the maximum of Δx_k for intervals 60 s $\leqslant \Delta t_k$ [or (60 s)/$\Delta t \leqslant k$];

   - iv) vertical jitter is the maximum of Δy_k for intervals 0,01 s $\leqslant \Delta t_k <$ 2 s [or (0,01 s)/$\Delta t \leqslant k <$ (2 s)/Δt];
   - v) vertical swim is the maximum of Δy_k for intervals 2 s $\leqslant \Delta t_k <$ 60 s [or (2 s)/$\Delta t \leqslant k <$ (60 s)/Δt];
   - vi) vertical drift is the maximum of Δy_k for intervals 60 s $\leqslant \Delta t_k$ [or (60 s)/$\Delta t \leqslant k$].

f) Reporting: report the maximum jitter/swim/drift measured.

g) Comments

Motions are most noticeable below 5 Hz and are perceived as degraded focus above 25 Hz. The required measurement locations can be negotiated beyond the five (centre and corner) locations used in this procedure.

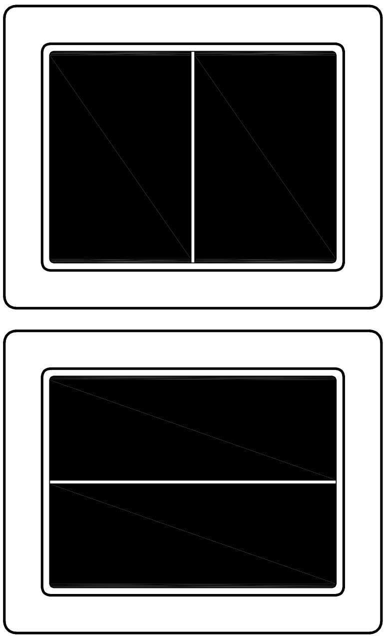


Figure 55 — Jitter patterns

6.4.7 P 15.5 — Blink coding

a) Objective: to measure the blink frequency and duty cycle for specific blink coding level.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories:

1) Test accessories:	see 5.2.5	veiling glare frustum (optional).
	see 5.2.8	data acquisition.
	see 5.2.9	vibration-damped measurement bench (optional).

2) Fixed measurement conditions

— Measurement field:	see 5.6.1	many pixels.
— Meter angular aperture:	see 5.7	angular aperture.
— Meter response time:	see 5.8.1	fast response meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.22 response time pattern — 100 % white and 100 % black.
- Measurement location: see 5.4.8 centre-screen.
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: the LMD shall be photo-optically corrected if the colour of the test pattern changes between full white and full black.

d) Procedure

Follow the procedure given in 6.4.1 (M 15.1) with the following modifications:

- When performing these measurements, alternate between the low state and the high state at the specified blink code rate.
- Measure the luminance over at least two cycles.

e) Analysis

1) Frame refresh, backlight modulation or other sources can superimpose a periodic ripple on top of the SRF curve (see Figure 51).

If this ripple affects measurement repeatability, it may be controlled by a “tuned” moving window average filter (assuming a digitised output of the LMD). Let the ripple period be τ, the LMD sample rate be s, the raw time-dependent light measurements taken at intervals of $1/s$ be L_i, and ΔN be the number of light data points collected during the ripple period $\Delta N = \tau s$. The resultant moving-window-average-filtered signal S_i is then given by

$$S_i = \frac{1}{\Delta N} \sum_{n=i}^{n=i+\Delta N-1} L_n \tag{11}$$

2) Apply ripple filters as necessary.

3) Calculate $L_{\text{range}} = L_{\text{high}} - L_{\text{low}}$ and $L_{90\,\%} = 0{,}9 L_{\text{range}} + L_{\text{low}}$ for two consecutive positive optical step functions.

4) Find the times, T_1, T_2, at which the first and second response function equals $L_{90\,\%}$ (using linear interpolation between the bounding data points).

5) Calculate the duty cycle:

$$\text{duty cycle} = \frac{T_1}{T_1 + T_2} \tag{12}$$

6) Calculate the blink frequency:

$$f = \frac{T_1}{T_1 + T_2} \tag{13}$$

f) Reporting: report the duty cycle in % and the frequency in Hz.

g) Comments

Where blink coding is used solely to attract attention, a single blink frequency of 1 Hz to 5 Hz, with a duty cycle of 50 %, is recommended. Where readability is required during blinking, a single blink rate of 1/3 to 1 Hz, with a duty cycle of 70 %, is recommended. Switching off the blinking of the cursor should be possible.

If blink coding is used, flat panel displays shall provide an image formation time of less than 55 ms, see 6.4.2 (P 15.2).

6.4.8 P 15.7 — Warm-up time

a) Objective: to measure the time to achieve luminance stability of the display

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 5.2.5 veiling glare frustum (optional).

   see 5.2.8 data acquisition.

   see 5.2.9 vibration-damped measurement bench (optional).

2) Fixed measurement conditions

   - Measurement field: see 5.6.1 many pixels.
   - Meter angular aperture: see 5.7 angular aperture.
   - Meter response time: see 5.8.1 fast response meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

   - Test pattern: see 5.3.22 response time pattern 100 % white and 100 % black.
   - Measurement location: see 5.4.8 centre-screen.
   - Meter direction: see 5.4.1 normal to display screen/normal to display surface.
   - Test illumination: see 5.9.2 darkroom.
   - Spectral characteristics: luminance.

   If the display was previously turned on, wait 3 h or longer with the display turned off before attempting a measurement of the warm-up time.

d) Procedure

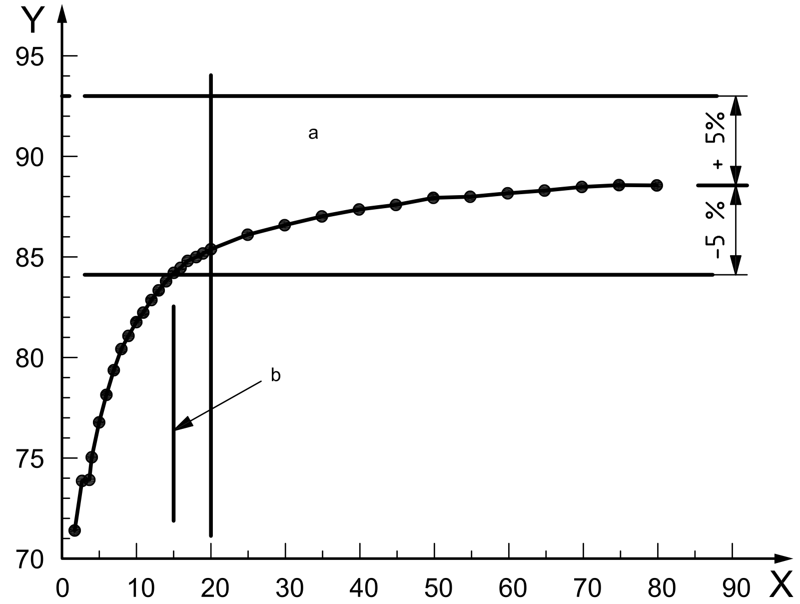
1) Turn on the display and begin recording the time, t_0.

2) Follow procedure given in 6.4.1 (M 15.1) for an interval of 10 min or less as soon as possible after the test pattern is displayed. Measure with an accuracy of 10 s or better. There is no objection to measuring as often as desired and the intervals do not have to be the same. The time of the beginning of the measurement is given as t_i.

3) As the luminance levels off to its stable value, look for the shortest time, t_s, when all the luminance values fall within ± 5 % of the final value for a duration Δt of 1 h.

e) Analysis: mathematically, t_s is the shortest time for which $L - \delta L \leqslant L_i \leqslant L + \delta L$ for all L_i within the time interval t_s to $t_\text{s} + \Delta t$, where L is the final value of L_i at the end of the same interval t_i to $t_\text{s} + \Delta t$ and δL = 0,05L (5 % of the average).

See Figure 56.



Key

X time, min

Y luminance, cd/m^2

[a] A nominal 20 min warm-up time is adequate.

[b] A 15 min warm-up time could be used for this display.

Figure 56 — Warm-up time

f) Reporting

Report the warm-up time, in minutes, to no more than two significant figures. If the warm-up time is measured to be less than 2 min, it is permissible to report the warm-up time in seconds.

g) Comments

Generally, the default 20 min warm-up time is adequate and will rarely have to be validated. However, there may be situations which require a warm-up time measurement: The recommended 20 min is an estimated adequate time for most displays; the tester may wish to more precisely determine the warm-up time needed for a specific display technology. Conversely, a longer warm-up time could be required to assure luminance stability. Once an adequate warm-up time has been established by the above method, if so desired, it may be considered to be the normal warm up time (instead of the default 20 min) for the technology and conditions under which it was determined.

6.4.9 M 15.8 — Motion artefacts

Test patterns consisting of moving patterns can create motion artefacts such as motion blur, smearing and colour bleeding in certain display technologies. Methodologies for measuring these effects had not yet been made available at the time of the publication of this part of ISO 9241. For information regarding metrology solutions for characterising motion artefacts in electronic displays, see Reference [10].

6.5 Reflection measurements

6.5.1 M 16.1 — Luminance specular reflectance

a) Objective: with the EUT off (assumed to be its darkest state), to measure the reflectance arising from a small source illumination and calculate a coefficient for small-source specular reflectance.

b) Units: none.

c) Symbol: ρ_{small}.

d) Applicability: all direct view displays except front-projection displays.

e) Preparation and set-up

1) Test accessories:

Test accessories:	see 5.2.3	diffuse reflectance standard.
	see 5.2.11	uniform light source — a single small-diameter light source that subtends 1° as viewed from the centre of the screen.

The specifications made upon the apparatus and the configuration presented below is especially important when the haze component of reflection is significant. If there is only a specular (mirror-like) and diffuse (Lambertian) component of reflection (i.e. the haze component is trivial), then all these constraints become much less important, e.g. the diffuse reflectance should be independent of the angles from the normal, sizes and distances of the lamps (if the surface is truly Lambertian) for a wide range of angles, sizes and distances. To accommodate these two possibilities, two specifications are offered — one for no haze component and the other for a non-trivial haze component. The tightening of the specifications is required whenever the haze component is significant, in order to assure reproducibility of the measurement. How closely these tolerances are met will determine how reproducible the measurement will be. The tolerances should be adequate to provide a ± 5 % reproducibility of the reflectance measurement result.

2) Fixed measurement conditions

— Measurement field:	see 5.6.1	many pixels.
— Meter angular aperture:	see 5.7	angular aperture.
— Meter response time:	see 5.8.2	time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:		N/A (not applicable).
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen; θ_S = 15° on one side of normal.
— Test illumination:	see 5.9.4	small — one small-diameter light source that subtends 1° as viewed from the centre of the screen.

Initially, the LMD is placed at a distance of $d + z$ away from the exit port of a lamp having a round exit port of 150 mm in diameter, and the lamp luminance L_S is measured. (It is probably wise to check the lamp luminance after the measurement to be sure it has not changed if the lamp is not monitored by other means.) A lamp luminance, L_S, of 2 000 cd/m^2 is preferred. The lamp should exhibit ± 1 % or smaller stability during the course of the measurements. After the direct measurement of the lamp luminance, the lamp is placed θ_S = 15° on one side of normal. The distance between the centre of the exit port and the centre of the screen is represented as d (nominally 500 mm). The nonuniformity $N = 1 - L_{\text{min}}/L_{\text{max}}$ over the exit port, and the tolerance of the other parameters in the configuration, depend upon the reflection properties of the screen. The LMD is placed θ_S = 15° on the other side of the normal, far enough away from the screen, z, that the surfaces of the LMD are not directly illuminated by the lamp.

f) Procedure

Measure the luminance of the lamp directly with the LMD at a distance of $d + z$ from the exit port of the lamp prior to configuring the apparatus. Measure at the centre of the small-source exit port. Then configure the reflection measurement apparatus and measure the luminance, L, of the centre of the screen with the EUT off (unpowered or darkest black) and the lamp on. Focus the LMD on the source (use a mirror if there is no specular reflection). Attempt to measure the centre of the virtual image of the source (whether distinct or fuzzy). There are two cases: case 1, where the specular (mirror-like) component dominates, and case 2, where the non-specular components are important.

1) Case 1: true specular reflection

Examine the appearance of the reflected light of the lamp from the position of the LMD. If the virtual image is distinct and there is very little luminance ($\leqslant$ 3 % of L) from reflections outside the boundaries of the virtual image of the source, then the reflection is principally specular (mirror-like).

Measure only the luminance, L, of the centre-screen at the centre of the virtual image. If there is a thick faceplate or separated reflecting surfaces, then two reflected virtual images (fuzzy or distinct) can be observed. If this happens for a CRT with a curved faceplate, then rotate the display about the centre of the screen until both virtual images are aligned as best as possible, and then measure L.

If two reflections are present using a FPD, then reduce the $\theta_S = 15°$ as much as the equipment will allow to overlap the reflections. If there is ambient illumination, also measure the luminance of the screen centre, L_a, with the lamp that is either off or completely obscured.

2) Case 2: non-specular components significant

Examine the appearance of the reflected light of the lamp from the position of the LMD. If the virtual image is present but there is substantial luminance ($\geqslant$ 3 % of L) from reflections outside the boundaries of the virtual image of the source, or no virtual image can be seen and only a “fuzzy ball of light” appears in the specular direction, measure the luminance, L, of the centre-screen, and then place a white diffuse standard, ρ_{STD}, of known reflectance at the position of the screen centre and measure its luminance, L_{STD}.

If there is a thick faceplate or separated reflecting surfaces, then two reflected virtual images (fuzzy or distinct) can be observed. If this happens for a CRT with a curved faceplate, then rotate the display about the centre of the screen until both virtual images are aligned as best as possible, and then measure L.

If there are two reflections using a FPD, then reduce $\theta_S = 15°$ as much as the equipment will allow to overlap the reflections. If there is ambient illumination, also measure the luminance of the screen centre, L_a, with the lamp either off or completely obscured.

Take care not to touch the surface of the screen if the screen is delicate.

g) Analysis

Analyse the two cases from f).

1) Case 1

If the examination of the appearance of the reflected light of the lamp from the position of the LMD has shown that the virtual image is distinct and there is very little luminance reflected outside the boundaries of the virtual image of the source, then calculate the small-source specular reflectance:

$$\rho_{small} = L/L_s$$

If ambient illumination is important, use the corrected form:

$\rho_{\text{small}} = (L - L_{\text{a}})/(L_{\text{s}} - L_{\text{a}})$

2) **Case 2**

If the examination of the appearance of the reflected light of the lamp from the position of the LMD showed that the virtual image is distinct but there is substantial luminance reflected beyond the virtual image of the source or no virtual image is observable except for a "fuzzy ball of light", then calculate the small-source specular reflectance, ρ_{small}, while attempting to subtract the diffuse background from the specular component using the luminance factor value, ρ_{d}, obtained from 6.5.6:

$\rho_{\text{small}} = (L - \rho_{\text{d}} L_{\text{STD}}/\rho_{\text{STD}})/(L_{\text{s}})$

If ambient lighting is important, use the corrected form:

$\rho_{\text{small}} = (L - L_{\text{a}} - \rho_{\text{D}} L_{\text{STD}}/\rho_{\text{STD}})/L_{\text{s}}$

h) Reporting: report the specular reflectance to no more than three significant figures.

i) Comments

Tungsten and fluorescent ac-powered lamps can exhibit an a.c. fluctuation that can increase the imprecision of the measurements.

Case 1 obeys the simple specular and simple diffuse (Lambertian) reflectance model.

Case 2 is an approximate attempt to account for the non-specular reflectance by subtracting it from the specular component. The method specified for case 2 is correct for reflective surfaces for which only a specular and diffuse (Lambertian) component of reflection exists. It does not properly subtract the haze contribution to the reflection. It is a naïve model and can generate confusing results, owing to the assumption by its users that they have the correct specular reflectance and can begin using the form $L = \rho_{\text{small}} L_{\text{s}}$ with impunity. The fact that this small-source measurement was invented to provide another type of specular reflectance proves this. The large-source specular reflectance will include a strong contribution from haze whenever haze is nontrivial. The small-source specular reflectance will minimise the contribution from haze.

6.5.2 M 16.1A — Reflectance with diffuse illumination

a) Objective: with the EUT off (assumed to be its darkest state), to measure the reflectance arising from uniform diffuse illumination and express it as a fraction of the reflectance from a perfect white diffuse reflector.

b) Applicability: all direct view displays except front-projection displays.

c) Preparation and set-up

1) Test accessories: see 5.2.3 diffuse reflectance standard.

   see 5.2.12 surround.

2) Fixed measurement conditions

   — Measurement field: see 5.6.1 many pixels.

   — Meter angular aperture: see 5.7 angular aperture.

   — Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

   — Test pattern: N/A.

   — Measurement location: see 5.4.8 centre-screen.

   — Meter direction: see 5.4.1 normal to display screen; –8° off normal.

   A diffuse-ambient light is provided to illuminate the screen from all directions as uniformly as is practical. The LMD is arranged so as to enable the viewing of the centre of the surface of the display through a hole in the surround from an angle of 8° (–0°+ 2°) from the normal (or rotate the display in an integrating sphere). See 5.9.14. The LMD is focused on the display surface. 8° is recommended so that the measurement hole will not affect the reflection, while the measurement is made as close to the normal of the screen as possible.

   — Test illumination: see 5.9.2 darkroom.

   see 5.9.14 inside diffuse sphere.

d) Procedure

1) Measure the reflected luminance, L, of the centre of the screen with the EUT off (unpowered or darkest black).

2) Place a white diffuse standard of known reflectance, ρ_{STD}, at the screen centre and measure its luminance, L_{STD}. Take care not to touch the surface of the screen unless the screen is made for rough handling.

e) Analysis

Calculate the reflectance, ρ, with diffuse illumination:

$$\rho = \rho_{\mathrm{std}} \times \frac{L}{L_{\mathrm{std}}} \tag{14}$$

f) Reporting: report the reflectance with diffuse illumination to no more than three significant figures.

g) Comments: tungsten and fluorescent a.c.-powered lamps can exhibit an a.c. fluctuation that could increase the imprecision of the measurements.

6.5.3 P 16.2 — BRDF and derived values

The proper treatment of reflection requires the use of the concept and measurement of the bidirectional reflectance distribution function (BRDF). Only then is the reflection properly characterised, and only then can a reflection model be developed which will provide the correct calculated reflected luminance from the screen in any lighting environment. Much of the trouble in the past with attempting to characterise reflection for displays has arisen from a failure to recognise and properly treat the diffuse-haze component.

NOTE No measurement is specified in the present edition for measuring the BRDF or its parametric representation. Research was underway at the time of its publication into whether a practical method based on BRDF measurements could be used as a normative evaluation means, the objective being a method both technically and practically superior to those given here. When the measurement has been sufficiently simplified such that it provides an adequate parameterisation of reflection, then it is intended that a procedure be added at a future revision of this part of ISO 9241.

See Annex D for additional information.

6.5.4 P 16.3 — Contrast of unwanted specular reflection

a) Objective: to calculate the contrast of unwanted specular reflections that competes with the text or other information generated by the display.

b) Applicability: all direct view displays except front-projection displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.
 see 6.5.1 luminance specular reflectance.
 see 6.5.2 reflectance with diffuse illumination.

2) Fixed measurement conditions: none.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

—	Test pattern:	see 5.3.17	full-screen — 100 % white and 100 % black.
—	Measurement location:	see 5.4.5	standard nine locations.
—	Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
—	Test illumination:		N/A.
—	Spectral characteristics:		only luminance required.

d) Procedure

1) Measure the following in accordance with 6.1.1 (M 12.1):

— L_{HS} = the emitted luminance component in the high state;

— L_{LS} = the emitted luminance component in the low state.

2) Measure, according to 6.5.2 (M 16.1A), the luminance component, L_{D}, reflected from diffuse illumination.

3) Measure, according to 6.5.1 (M 16.1), the luminance component, L_{S}, reflected from specular illumination.

e) Analysis

— For positive polarity screens or applications:

$$\frac{L_{HS} + L_D + L_S}{L_{HS} + L_D} \leqslant 1{,}25 \qquad (15)$$

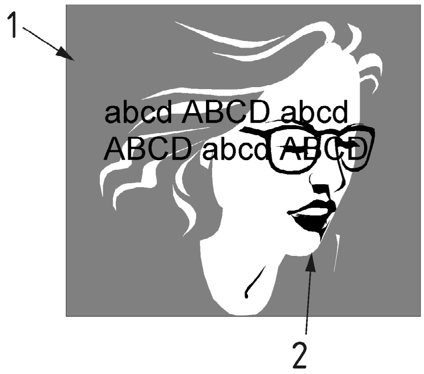
— For negative polarity screens or applications:

$$\frac{L_{HS} + L_D + L_S}{L_{HS} + L_D} \leqslant 1{,}25 + \frac{1}{15} \times \frac{L_{HS} + L_D}{L_{LS} + L_D} \qquad (16)$$

f) Reporting: report contrast, screen polarity, and viewing direction range.

g) Comments

The concept is not complex. The left-hand side of each inequality is the contrast ratio of the specular image (see, for example, the face shown in Figure 57) against the background. For positive polarity, the acceptability of an unwanted reflected image is independent of the contrast of the wanted information (hence the right-hand side is simply a number). In the case of a negative polarity screen, the contrast of the wanted negative image competes with the unwanted image (hence the luminance ratio on the right-hand side).



Key

1 background

2 unwanted image (specular reflection)

The display shows a text with two lines. The face of the user is unintentionally reflected in the display, creating an image that competes with the text. The objective is to keep the contrast of the reflected image low enough not to compete with the information on the display.

NOTE There are concerns for both large luminance sources, such as the cheek, and small ones such as the reflected edges from, for example, the eyeglasses.

Figure 57 — Example of unwanted specular reflections

6.5.5 P 16.4 — Ring light method

a) Objective: with the EUT off (assumed to be its darkest state), to measure the reflectance arising from illumination from a ring light and to express this as a fraction of the reflectance from a perfect white diffuse reflector.

b) Applicability: all direct view displays except front-projection displays.

c) Preparation and set-up

   1) Test accessories: see 5.2.3 diffuse reflectance standard.

   2) Fixed measurement conditions

      - Measurement field: see 5.6.1 many pixels.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test pattern: N/A.
      - Measurement location: see 5.4.8 centre-screen.
      - Meter direction: see 5.4.1 normal to display screen — 8° off normal, unless otherwise specified.
      - Test illumination: see 5.9.2 darkroom.
        see 5.9.8 ring light.

d) Procedure

   1) Place the ring light as described in 5.9.8, such that $\theta_R = 20°$ unless otherwise specified.

   2) Measure the reflected luminance, L, of the centre of the screen with the EUT off (unpowered or darkest black).

   3) Place a white diffuse standard, of known reflectance ρ_{STD}, at the position of screen centre and measure its luminance, L_{STD}. Take care not to touch the surface of the screen unless the screen is made for rough handling.

e) Analysis

   Calculate the reflectance with diffuse illumination:

$$\rho = \rho_{std} \times \frac{L}{L_{std}}$$

f) Reporting: report the reflectance with diffuse illumination to no more than three significant figures.

g) Comments: tungsten and fluorescent a.c.-powered lamps can exhibit an a.c. fluctuation that can increase the imprecision of the measurements.

6.5.6 P 16.5 — Extended source reflectance

a) Objective: to measure the diffuse (Lambertian) reflectance of the EUT in its powered-off state (assumed to be its darkest state).

b) Applicability: all direct view displays except front-projection displays.

c) Preparation and set-up

1) Test accessories:

Test accessories:	see 5.2.3	diffuse reflectance standard.
	see 5.2.11	uniform light source.

The specifications made upon the apparatus and the configuration presented below is especially important when the haze component of reflection is significant. If there is only a specular (mirror-like) and diffuse (Lambertian) component of reflection (i.e. the haze component is trivial), then all these constraints become much less important, e.g. the diffuse reflectance should be independent of the angles from the normal, sizes, and distances of the lamps (if the surface is truly Lambertian) for a wide range of angles, sizes and distances. To accommodate these two possibilities, two specifications are offered: one for no haze component and the other for a non-trivial haze component. The tightening of the specifications is required whenever the haze component is significant in order to assure reproducibility of the measurement. How closely these tolerances are met will determine how reproducible the measurement will be. The tolerances should be adequate to provide a ± 5 % reproducibility of the diffuse reflectance measurement result.

2) Fixed measurement conditions

— Measurement field:	see 5.6.1	many pixels.
— Meter angular aperture:	see 5.7	angular aperture.
— Meter response time:	see 5.8.2	time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:		N/A.
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen/normal to display surface.
— Test illumination:	see 5.9.2	darkroom.
	see 5.9.7	two extended sources 15° to 30° — use ± 30° configuration.

Two lamps are placed ± 30° ($\pm\theta_S$) on each side of normal having round exit ports of 150 mm in diameter. The distance between the centre of the exit port and the centre of the screen is d (nominally 500 mm). The nonuniformity $N = 1 - L_{\text{min}}/L_{\text{max}}$ over the exit ports as well as the tolerance of the other parameters in the configuration depend upon the reflection properties of the screen. Table 5 lists the tolerances for the extreme conditions. The LMD should be placed far enough away from the screen so that its surfaces are not directly illuminated by the lamps. A lamp luminance L_S of 2 000 cd/m^2 is preferred. The lamps should exhibit a ± 1 % or smaller stability during the course of the measurements. The LMD is placed along the normal a distance, z, (nominally 500 mm) away from the centre of the screen.

Table 5 — Diffuse reflectance measurement specifications

Symbol	Description	No haze	Significant haze
L	Luminance of screen, lamps on	Measured	
L_{STD}	Luminance of diffuse white standard, lamps on	Measured	
θ_{n}	Angle of LMD relative to normal	90° ± 5°	90° ± 0,3°
θ_{a}	Angle subtended by exit port of lamp	15° ± 5°	15° ± 0,3°
θ_{b}	Angle of lamp centre from normal	30° ± 5°	30° ± 0,3°
a	Diameter of exit port of lamp	Not critical	(150 ± 2) mm
z	Distance between LMD and screen centre	$\geqslant$ 500 mm	$\geqslant$ 500 mm
d	Distance between lamp centres and screen	(500 ± 50) mm	(570 ± 5) mm
θ_{F}	Angular field of view of LMD (∞ focus)	$\leqslant$ 5°	$\leqslant$ 1°
θ_{L}	Angle subtended by LMD lens (entrance pupil)	$\leqslant$ 5°	$\leqslant$ 1°
L_{a}	Ambient luminance of screen, lamps off	Measured	
$L_{\mathrm{a\text{-}STD}}$	Ambient luminance of diffuse white standard, lamps off	Measured	
$L_{\mathrm{a\text{-}ON}}$	Ambient luminance of diffuse white standard place above FPD, v-mask in place, lamps on	Measured	
$L_{\mathrm{a\text{-}OFF}}$	Ambient luminance of diffuse white standard place above FPD, v-mask in place, lamps off	Measured	
$\rho_{\mathrm{D}} = \rho_{\mathrm{STD}}\, L/L_{\mathrm{STD}}$	Luminance factor without ambient light corruption	Calculated	
ρ_{D}	Luminance factor with ambient light correction: $\rho_{\mathrm{D}} = \rho_{\mathrm{STD}} \left(\frac{L - L_{\mathrm{a}}}{L_{\mathrm{STD}} - L_{\mathrm{a\text{-}STD}}} \right)$	Calculated	
$q = \rho_{\mathrm{D}}/\pi$	Luminance coefficient	Calculated	
N	Nonuniformity of exit port of lamps ($1 - L_{\mathrm{min}}/L_{\mathrm{max}}$)	$\leqslant$ 50 %	$\leqslant$ 5 %
L_{s}	Luminance of lamps (not specifically measured in this procedure)	$\geqslant$ 2 000 cd/m^2 preferred Stability: ±1 % during measurement	
Any deviation from these specifications shall be clearly noted and clearly reported, and must be understood by all interested parties. Sometimes, for example, different angles between the sources and the normal could be specified. For comparison purposes, the above specifications should be maintained.			

d) Procedure

1) Measure the luminance, L, of the centre of the screen with the EUT off (unpowered or darkest black).

2) Then place a white diffuse standard, of known reflectance ρ_{STD}, at the position of screen centre and measure its luminance, L_{STD}. Take care not to touch the surface of the screen unless the screen is made for rough handling and is not delicate.

e) Analysis

Calculate the luminance factor:

$$\rho_{\mathrm{D}} = \rho_{\mathrm{STD}}\, L / L_{\mathrm{STD}} \tag{17}$$

f) Reporting: report the luminance factor, ρ_{D}, to no more than three significant figures.

g) Comments

The correct measurement of this reflectance assumes that the display surface exhibits a quasi-Lambertian diffuse reflectance away from the specular direction. If this is the case, the illuminance and luminance are related by $L = qE$, and $q = \rho_\mathrm{D} / \pi$, where ρ_D is the luminance factor. Applying this measurement to materials that have gain (i.e. that exhibit a haze component of reflection and are non-Lambertian) is, strictly speaking, incorrect. Not only are the results not simply interpreted by the true Lambertian reflectance model, $L = qE$, but the measurement can be subject to many errors from alignment of the components of the apparatus, and the placement and characteristics of the devices. Employing this diffuse reflectance measurement for surfaces that have a significant haze reflection component can create irreproducible results. All interested parties should be cognizant of any misapplication of this measurement.

See Annex D and the appropriate references in Annex E for further discussion of the components of reflection.

Tungsten and fluorescent a.c.-powered lamps can exhibit an a.c. fluctuation that can increase the imprecision of the measurements.

6.5.7 P 16.6 — Extended source specular reflectance

a) Objective: to measure the specular reflectance of the EUT in its powered-off state (assumed to be its darkest state).

b) Applicability: all direct view displays except front-projection displays.

c) Preparation and set-up

1) Test accessories: see 5.2.3 diffuse reflectance standard.

see 5.2.11 uniform light source.

The specifications made upon the apparatus and the configuration presented below are especially important when the haze component of reflection is significant. If there is only a specular (mirror-like) and diffuse (Lambertian) component of reflection (i.e. the haze component is trivial), then all these constraints become much less important, e.g. the diffuse reflectance should be independent of the angles from the normal, sizes and distances of the lamps (if the surface is truly Lambertian) for a wide range of angles, sizes and distances. To accommodate these two possibilities, two specifications are offered: one for no haze component and the other for a non-trivial haze component. The tightening of the specifications is required whenever the haze component is significant in order to assure reproducibility of the measurement. How closely these tolerances are met will determine how reproducible the measurement will be. The tolerances should be adequate to provide a ± 5 % reproducibility of the reflectance measurement result.

2) Fixed measurement conditions

- Measurement field: see 5.6.1 many pixels.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified).

— Test pattern:		none
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen — $\theta_S = 15°$ on one side of normal.
— Test illumination:	see 5.9.2	darkroom.
	see 5.9.5	extended source, 5°.

Initially, the LMD is placed at a distance of $d + z$ away from the exit port of a lamp having a round exit port of 150 mm in diameter, and the lamp luminance L_s is measured. (It is probably wise to check the lamp luminance after the measurement to be sure it has not changed if the lamp is not monitored by other means.) A lamp luminance, L_s, of 2 000 cd/m^2 is preferred. The lamp should exhibit a ± 1 % or smaller stability during the course of the measurements. After the direct measurement of the lamp luminance, the lamp is placed $\theta_S = 15°$ on one side of normal. The distance between the centre of the exit port and the centre of the screen is d (nominally 500 mm). The nonuniformity $N = 1 - L_{\text{min}}/L_{\text{max}}$ over the exit port as well as the tolerance of the other parameters in the configuration depend upon the reflection properties of the screen. The LMD is placed $\theta_S = 15°$ on the other side of the normal far enough away from the screen, z, so that its surfaces are not directly illuminated by the lamp.

d) Procedure

Measure the luminance of the lamp directly with the LMD a distance of $d + z$ from the exit port of the lamp prior to configuring the apparatus. Measure at the centre of the exit port to within ± 1°. Then configure the reflection measurement apparatus and measure the luminance, L, of the centre of the screen with the EUT off (unpowered or darkest black) and the lamp on. Attempt to measure the centre of the virtual image of the source (whether distinct or fuzzy) within ± 1°, i.e. focus the LMD on the source (use a mirror if there is no specular reflection). There are two cases: case 1, where the specular (mirror-like) component dominates, and case 2, where the non-specular components are important.

1) Case 1: true specular reflection

Examine the appearance of the reflected light of the lamp from the position of the LMD. If the virtual image is distinct and there is very little luminance ($\leqslant 3$ % of L) from reflections outside the boundaries of the virtual image of the source, then the reflection is principally specular (mirror-like). Measure only the luminance, L, of the centre-screen. If there is ambient illumination, also measure the luminance of the screen centre, L_a, with the lamp either off or completely obscured.

2) Case 2: non-specular components significant

Examine the appearance of the reflected light of the lamp from the position of the LMD. If the virtual image is present but there is substantial luminance ($\geqslant 3$ % of L) from reflections outside the boundaries of the virtual image of the source, or no virtual image can be seen and only a “fuzzy ball” of light appears in the specular direction, measure the luminance, L, of the centre-screen, and then place a white diffuse standard, of known reflectance ρ_{STD}, at the position of the screen centre and measure its luminance, L_{STD}. If there is ambient illumination, also measure the luminance of the screen centre, L_a, with the lamp either off or completely obscured. Take care not to touch the surface of the screen if the screen is delicate.

e) Analysis

Analyse the two cases from d).

1) **Case 1**

If the examination of the appearance of the reflected light of the lamp from the position of the LMD showed that the virtual image is distinct and there is very little luminance reflected outside the boundaries of the virtual image of the source, then calculate the large-source specular reflectance:

$\rho_\mathrm{s} = L/L_\mathrm{s}$

If ambient illumination is important, use the corrected form:

$\rho_\mathrm{s} = (L - L_\mathrm{a})/(L_\mathrm{s} - L_\mathrm{a})$

2) **Case 2**

If the examination of the appearance of the reflected light of the lamp from the position of the LMD showed that the virtual image is distinct but there is substantial luminance reflected beyond the virtual image of the source, or no virtual image is observable, only a “fuzzy ball of light”, then calculate the large-source specular reflectance, while attempting to subtract the diffuse background from the specular component using the luminance factor value, ρ_D, obtained from 6.5.6:

$\rho_\mathrm{s} = (L - \rho_\mathrm{D} L_\mathrm{STD}/\rho_\mathrm{STD})/(L_\mathrm{s})$

If ambient lighting is important, use the corrected form:

$\rho_\mathrm{s} = (L - L_\mathrm{a} - \rho_\mathrm{D} L_\mathrm{STD}/\rho_\mathrm{STD})/L_\mathrm{s}$

f) Reporting: report the luminance factor, ρ_D, to no more than three significant figures.

g) Comments

The correct measurement of this reflectance assumes that the display surface exhibits a specular component that produces a mirror-like distinct image where the reflected luminance, L, is related to the source luminance, L_s, by $L = \rho_\mathrm{s} L_\mathrm{s}$, where ρ_s is the specular reflectance. The surface is also assumed to have a Lambertian diffuse reflectance (away from the specular direction) where the illuminance and luminance are related by $L = qE$, and $q = \rho_\mathrm{D}/\pi$, where ρ_D is the luminance factor. Applying this measurement to materials that have gain (i.e. that exhibit a haze component of reflection) is, strictly speaking, incorrect. Not only are the results not simply interpreted by the above models, but also the measurement is subject to many errors from alignment of the components of the apparatus, the placement of the devices, and the characteristics of the devices. Employing this specular reflectance measurement for surfaces that have a significant haze reflection component can create irreproducible results. All interested parties should be cognizant of any misapplication of this measurement.

See Annex D and the appropriate references in the Bibliography for further discussion of the components of reflection.

Case 1 obeys the simple specular and simple diffuse (Lambertian) reflectance model. For such surfaces, the large-source and small-source specular reflectances should be approximately the same.

Case 2 is an approximate attempt to account for the non-specular reflectance by subtracting it from the specular component. The method specified for case 2 is correct for reflective surfaces for which only a specular and diffuse (Lambertian) component of reflection exists. It does not properly subtract the haze contribution to the reflection. It is a naïve model and can generate confusing results, owing to the assumption by its users that they have the correct specular reflectance and can begin using the form $L = \rho_\mathrm{s} L_\mathrm{s}$ with impunity. The fact that the small-source specular reflectance was invented to provide another type of specular reflectance proves this. The large-source specular reflectance will include a strong contribution from haze whenever haze is nontrivial. The small-source specular reflectance will minimise the contribution from haze. Both methods are non-rigorous characterisations of reflectance whenever haze is nontrivial.

Tungsten and fluorescent a.c.-powered lamps can exhibit an a.c. fluctuation that can increase the imprecision of the measurements.

6.5.8 P 16.7 — Calibration of diffuse reflectance sample

a) Objective: to calibrate a diffuse reflectance sample over a specified range of viewing directions.

b) Applicability: reflectance samples.

c) Preparation and set-up

   1) Auxiliary equipment see 5.2.3 diffuse reflectance standard.

   2) Fixed measurement conditions

      - Measurement field: see 5.6.1 many pixels.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions

      - Test pattern: N/A
      - Measurement locations: see 5.4.8 centre-screen.
      - Meter direction: θ and ϕ over the range of interest.
      - Test illumination: N/A.
      - Spectral characteristics: N/A.

d) Procedure

   1) Measure the luminance, $L_{\theta,\phi}$, of the reflectance light off the reflectance sample at the specified θ and ϕ.

   2) Repeat for additional patterns if specified.

e) Analysis

   Calculate the reflectance:

   $$\rho_{\theta,\phi} = \pi L_{\theta,\phi} / E_\text{s}$$

f) Reporting: report the reflectance over the range of interest.

g) Comments

   A diffuse reflectance standard shall be calibrated for the specific viewing angles. Do not rely on the manufacturer calibration, as that data does not apply to the applications used in this part of ISO 9241. See 5.2.3.

6.6 Luminance analysis

6.6.1 P 17.1 — Area average luminance

a) Objective: to measure the average of the display luminance at the defined locations of the screen.

b) Applicability: all direct view displays.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified in ISO 9241-307)

— Test pattern:	see 5.3.17 5.3.23	full-screen — 100 % white or box patterns (1/5 to 1/6 the size of diagonal of display). NOTE The test pattern is set at 100 % white as the default. In the case of the display changing its luminance significantly in relation to the display area, the box luminance defined in 5.3.23 can be used instead of the full-screen luminance as the luminance value.
— Measurement location:	see 5.4.5	standard nine locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		only luminance required.

d) Procedure: according to 6.1.1 (M 12.1).

e) Analysis

Calculate the average luminance of the display:

$$L_{\text{ave}} = \frac{1}{n} \sum_{i=1}^{n} L_i$$

where L_i is the luminance of the display at the i^{th} position, and n is the number of measurement locations.

f) Report: report the average luminance in cd/m^2.

g) Comments: if the test pattern specified in ISO 9241-307 is a box pattern, the resultant luminance should be referred to as *box luminance*.

6.6.2 P 17.2 — Lateral luminance uniformity

a) Objective: to ensure luminance and, optionally, the chromaticity coordinates of full-screen white at the dimmest (darkest) and the brightest areas (spots) — or the areas that exhibit the largest colour shift — and calculate the uniformity.

b) Applicability: all direct view displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17 full-screen — 100 % white.
- Measurement location: see 5.4.9 visual determination.
- Meter direction: see 5.4.1 normal to display screen/normal to display screen.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: only luminance required.

d) Procedure: according to 6.1.1 (M 12.1).

Measure the luminance of the centre of the brightest spot, L_{max}, and then of the centre of the darkest or dimmest spot, L_{min}, subject to above set-up conditions, or at the two spots that exhibit the largest colour difference. See 6.1.6 (P 12.5) for the maximum and minimum locations. The chromaticity can also be measured if the luminance uniformity is being characterised.

e) Analysis

Calculate the uniformity of the display:

$$\text{uniformity} = 100\ \% \left(\frac{L_{\text{min}}}{L_{\text{max}}} \right)$$

where L_{max} and L_{min} are the maximum and minimum measured display luminances.

Optionally, calculate the colour difference:

$$\Delta u'v' = \sqrt{\left(u'_1 - u'_2\right)^2 + \left(v'_1 - v'_2\right)}$$

f) Reporting: report the luminance uniformity in percent.

g) Comments

Anomalous nonuniformity is a measure of the worst-case nonuniformity for the standard measurement area of the LMD (500 pixels). It is particularly useful when the sampled uniformity measurement shows little nonuniformity, but there are obvious areas or spots between the sampled points that are clearly non-uniform. See Figure 58, in which two areas (spots) on a full white screen show an obvious nonuniformity that with the sampled uniformity measurements of five or nine sample points would be missed. One spot is brighter than most of the rest of the white screen, and the other spot is darker. (This is not always necessarily the case. The screen can have either a dark or a light spot that differs from most of the rest of the screen.) This measurement is for those anomalous “bad” regions that cover an area of 500 pixels or more — this is not a measurement of pixel defects in a small several-pixel-size region of the screen. If there are no obvious regions of nonuniformity, then this measurement might not be useful. Optionally, for colour there can be objectionable colour changes not on the sampled uniformity points that need to be documented.

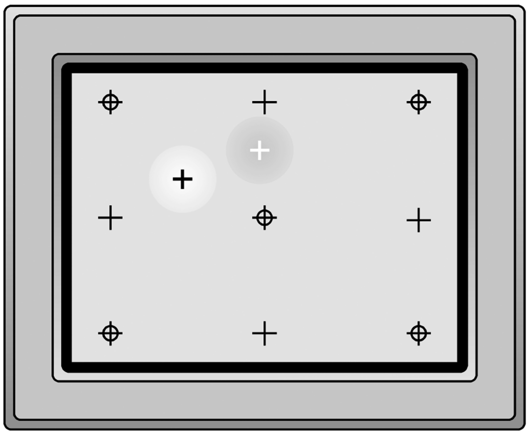


Figure 58 — Example of anomalous uniformity

6.6.3 P 17.3 — Luminance uniformity

a) Objective: to measure the uniformity of the display luminance at the defined locations of the screen.

b) Applicability: all direct view displays.

c) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen — 100 % white.
— Measurement location:	see 5.4.5	standard nine locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		only luminance required.

d) Procedure: according to 6.1.1 (M 12.1).

Measure the luminance at the specified measurement locations.

e) Analysis

Calculate the uniformity of the display:

$$\text{uniformity} = 100\ \% \left(\frac{L_{\min}}{L_{\max}} \right)$$

where L_{max} and L_{min} are the maximum and minimum measured display luminance of the sampled display luminance set, L_i, where $i = 1,\ldots, n$.

f) Reporting: report the luminance uniformity in percent.

g) Comments: none.

6.6.4 P 17.4 — Residual image

a) Objective: to measure the residual image of a high-contrast checkerboard.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full screen — 100 % white and 100 % black.
	see 5.3.24	5 × 5 checkerboard pattern — 100 % black and 100 % white rectangles of equal size and a black rectangle at centre.

— Measurement location:

Arrange to measure the display at three points: left of centre at a distance of the checkerboard box width; at centre; at right of centre at a distance of a box width. Depending upon how uniform the screen is, it could be necessary to measure at the exact same three locations throughout the procedure. This will require a reproducible positioning of the LMD relative to the screen.

— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
4) Spectral characteristics:		only luminance required.

d) Procedure

1) Initial measurements

Display a white full screen and measure the centre luminance, L_{WC}, and the luminance on each side (right and left) of centre, L_{WR} and L_{WL}, a distance of 20 % ($H/5$) of the screen horizontal width, H. Similarly, display a full black screen and measure the luminances, L_{BC}, L_{BR}, L_{BL}, at the same three locations.

2) Burn-in

Burn-in the checkerboard image by allowing it to remain displayed continuously for a certain number of hours, t, agreed to by all interested parties (t is to be reported). Near the end of the burn-in time, align the LMD to measure at the same three locations.

3) Final measurements

At the end of the burn-in time, switch the EUT directly from checkerboard to white full screen, after a time interval, t_R, upon which all interested parties agree, or as soon as possible, measure the luminance at the three locations (centre, right, left), K_{WC}, K_{WR}, K_{WL}. Then switch the display to a black full screen and measure the luminances at the three locations (centre, right, left) K_{BC}, K_{BR}, K_{BL}. These measurements should be made in as short a time as is easily possible.

e) Analysis

In the following, ratios of these luminance values are used to obtain contrasts. By using ratios, the effects of overall luminance degradation of the display from either an extended warm-up period or from aging are eliminated. Any non-uniformity inherent in the screen for the three measurement points also needs to be accounted for. The residual image factors are defined as follows:

$$R_W = \frac{\text{max.}\left[\left(K_{WR} + K_{WL}\right) L_{WC}, \left(L_{WL} + L_{WR}\right) K_{WC}\right]}{\text{min.}\left[\left(K_{WR} + K_{WL}\right) L_{WC}, \left(L_{WL} + L_{WR}\right) K_{WC}\right]}$$
$$R_B = \frac{\text{max.}\left[\left(K_{BR} + K_{BL}\right) L_{BC}, \left(L_{BL} + L_{BR}\right) K_{BC}\right]}{\text{min.}\left[\left(K_{BR} + K_{BL}\right) L_{BC}, \left(L_{BL} + L_{BR}\right) K_{BC}\right]} \quad (18)$$

These contain a compensation for non-uniformities inherent in the screen for the three measurement points for both black and white screens. R_W is the contrast in the residual image for the white screen and R_B is the contrast in the residual image for the black screen. (See comments below for a more detailed explanation.)

f) Reporting: report the burn-in time, t, in hours (the agreed-upon time interval, 5 h, in the examples is given as an illustration only), the measurement time after burn-in, t_R, and the measured residual image contrasts of white R_W and black R_B to no more than three significant figures.

g) Comments

IMPORTANT — This measurement can cause irreparable damage to the display.

This measurement, as described, does not account for sensitivity of residual images from colours or grey-scales. Be sure to use a measurement aperture small-enough to be completely contained within a checkerboard measurement box area. At least 20 % of the measured area should extend past the measurement aperture area on all sides. The luminances for the white and black screens at the centre and on each side of the centre shall be measured in the same time frame (within a few minutes). They cannot be measured before the end of the burn-in period. The residual image factors might not be uniform over the entire display area. Areas with the most pronounced amount of residual image should be assessed. If it appears to be generally uniform, then measuring at the centre of the screen and the adjacent boxes is preferred.

It will be noted that the residual image metrics (R_W and R_B) are insensitive to the algebraic sign of the change in the luminance from the burn-in. If that were not the case, then there could arise a technology dependence in the metric; for example, it would make FPD seem different from CRT, and hence be an obstacle to fairly comparing the two.

Equation (18) for R_W and R_B is a little more transparent if we assume a perfectly uniform screen for which L_W is the uniform white luminance of the unperturbed screen and where $L_{WR} = L_{WL} = L_{WC} = L_W$; let L_B be the luminance of the unperturbed black screen so that $L_{BR} = L_{BL} = L_{BC} = L_B$; let K_W be the burned-in luminance of white outside of centre so that $K_{WR} = K_{WL} = K_W$; and let K_B be the burned-in luminance of black outside the centre so that $K_{BL} = K_{BR} = K_B$. Then Equation (18) reduces to $R_W = \max(K_W, K_{WC})/\min(K_W, K_{WC})$ and $R_B = \max(K_B, K_{BC})/\min(K_B, K_{BC})$, and the residual image factors are seen to be contrasts (> 1) of the highest residual luminance to the lowest residual luminance for each of the black and white screens.

If deemed appropriate by all interested parties and provided any modifications are clearly stated in all reporting documentation:

1) other patterns may be used,

2) this measurement can be extended for use with points other than at the centre of the screen, and

3) colours other than black and white can also be important for certain applications.

There is no set way to recover from a residual image. Recovery procedures range from maintaining a full-screen white for a long period of time or displaying a changing series of images, to displaying the negative image of the image that originally produced the residual image. The manufacturer should be contacted for any possible recovery technique.

6.6.5 P 17.5 — Grey scale and gamma

a) Objective: to determine the electro-optic transfer function of a display and estimate its gamma.

b) Applicability: all display technologies.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      — Test pattern: see 5.3.17 full-screen or each specified grey level for white or other specified colour.

      — Measurement location: see 5.4.8 centre-screen.

      — Meter direction: see 5.4.1 normal to display screen/normal to display screen.

      — Test illumination: see 5.9.2 darkroom.

      — Spectral characteristics: only luminance required.

d) Procedure: perform measurements according to 6.1.1 (M 12.1) for specified grey levels.

e) Analysis

Plot the electro-optic transfer function and estimate gamma by fitting a curve to the luminance data using the model:

$$L = aV^{\gamma} + L_{\mathrm{b}}$$

Alternatively, express this in logarithmic terms as:

$$\log\left(L - L_{\mathrm{b}}\right) = \gamma \log\left(V\right) + \log\left(a\right)$$

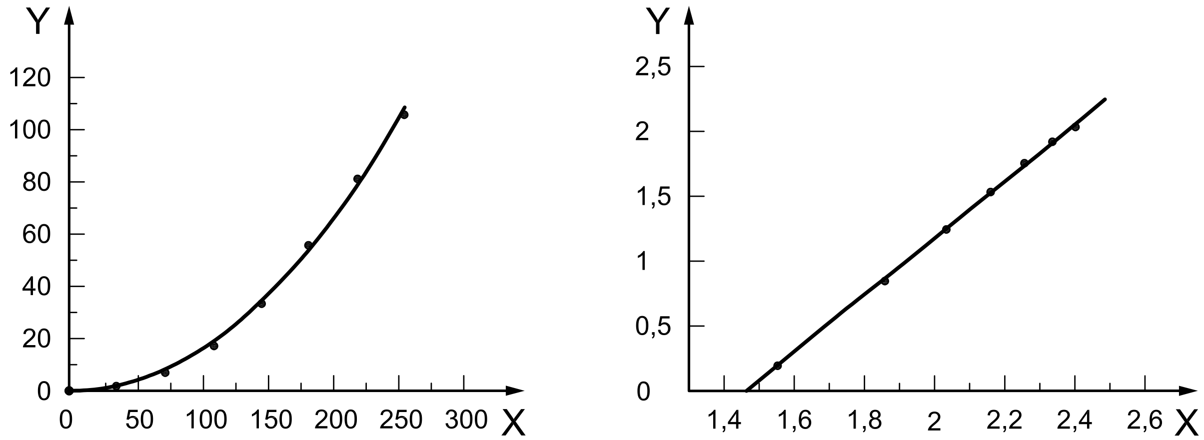
where a and γ relate the signal level, V, to the luminance, L, and L_{b} is the black-level luminance.

Use of least-squares fit on the data is recommended.

f) Reporting: together with any deviations from estimates, report grey scale illuminances and chromaticity in tabular format, the gamma estimate, and present a plot of electro-optic transfer function.

g) Comments: none.

See Figure 59 for an example.



Key

X command level value

Y luminance, in cd/m^2

Key

X log command-level value, $x = \log(V)$

Y log net Luminance, $y = \log(L - L_0)$

Linear regression: $\gamma x + b$

$b = \log(a) = -3{,}185 \pm 0{,}043$

$\gamma = 2{,}173 \pm 0{,}021$

$(r = 0{,}99978)$

a) Luminance vs. command-level value

b) Logarithmic view of a)

Figure 59 — Examples of grey-scale results

6.6.6 P 17.5A — Evaluation of grey-level reduction and inversion

a) Objective: to evaluate the electro-optic transfer function using this new method.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17 full-screen, or each specified grey level for white or other specified colour.
- Measurement location: see 5.4.5 standard nine locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display screen and all specified viewing directions.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: only luminance required.

d) Procedure: perform measurements according to 6.1.1 (M 12.1) for specified grey levels or colours, depending upon the compliance procedure, and in all specified viewing directions.

e) Reporting: report the grey level ranges and viewing directions in which reduction and inversion occurs.

If the measurements were performed with high angular resolution of the viewing direction (e.g. goniometric scans or conoscopic imaging), report the areas of the viewing cone where reduction and inversion occur.

f) Comments: none.

6.6.7 P 17.6 — Luminance coding

a) Objective: to measure the luminance code levels between two code levels.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17 full-screen, or each specified grey level for white or other specified colour.
- Measurement location: see 5.4.5 standard nine locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display screen.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: only luminance required.

d) Procedure: perform measurements according to 6.1.1 (M 12.1) for specified grey levels.

e) Analysis

   1) Determine maximum and minimum luminances L_{max} and L_{min} for each level.

   2) Calculate the critical ratio for each code level, $i = 1 \ldots n$:

$$\text{critical ratio} = \begin{cases} L_{i,\text{max}} & \text{for } i = 1 \\ \dfrac{L_i}{L_{i-1}} & \text{for } i > 1 \end{cases} \tag{19}$$

f) Reporting: report the critical ratios in tabular format.

g) Comments: none.

6.6.8 P 17.7 — Grey scale–JND relationship

a) Objective: to measure the mean number of discretely visible luminance levels [just-noticeable difference (JND) values] that can be displayed at the screen centre for each incremental input signal command level.

b) Applicability: all display technologies.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   Adjust the display using a manufacturer-specified JND-based set-up.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.23	box patterns (test pattern targets are square boxes) — approx. 10 % of the display area surrounded by a background luminance of 20 % of L_{W} (luminance of white).
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		only luminance required.

d) Procedure: measure the luminance of the centre target for all command levels according to 6.1.1 (M 12.1).

e) Analysis

Using a selected table of luminance vs. JND, and linear interpolation (to retrieve fractional JND values), find the number of JND between the luminance, L_n, at grey level $n > 0$ and the luminance, L_{K}, of the black box at grey level 0. Here $n = 0, 1, 2, \ldots, N$, and N (for example, $N = 255$) is the maximum grey level giving a white box. Each measured L_n will be between two luminance values in the JND table used: $K_{n>}$ (above), below $K_{n<}$ (below), associated with the respective JND levels, $J_{n>}$ and $J_{n<}$. Compute J_n associated with L_n [that is, $J_n = J(L_n)$] by linear interpolation:

$$J_n = J_{n<} + (J_{n>} - J_{n<})(L_n - K_{n<})/(K_{n>} - K_{n<})$$

Next, compute the JND change between adjacent levels by subtracting the n–1th JND level from the nth JND level for $n = 1, 2, \ldots, N$. Record the cumulative JND $J_n = J(L_n)$ and JND change per grey level $\Delta J_n = J_n - J_{n-1}$ for all measured grey levels above black, $n = 1, 2, \ldots, N$. If only every kth grey level is measured, be sure to divide each change in JND by the number of grey levels, k; in any event, at least 64 grey levels should be measured. Compute, as follows, the "effective bit depth" $\log_2(B)$, where B is the addressable number of perceptually distinct shades. Starting from $n = 0$ and $B = 0$, increment B by 1 at the next grey level whose luminance is at least 1 JND greater than the luminance at the current selected level; iterate until $n = N$.

f) Reporting: generate a table of JND and changes in JND per grey level.

g) Comments

Ideally, all grey levels should be evaluated and their associated grey shades measured, but if fewer levels are sampled, the samples should be incremented uniformly (e.g. every fourth level should be selected to test 64 levels out of a total of 256). A small standard deviation would imply that all grey level steps have the same perceptual salience for that JND model employed. The mean JND per command level is a measure of that salience. If there are more than three JND values between adjacent command levels, the change could be noticeable. If JND change is less than one per command level (observed with this example) the display is oversampling the command levels.

Avoid any possible veiling glare from the surrounding 20 % grey background when making luminance measurements of darker grey shades in the centred box.

6.7 Contrast analysis

6.7.1 P 18.1 — Box contrast

a) Objective: to calculate the box contrast.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen — 100 % black and 100 % white.
	see 5.3.23	box pattern — 100 % white box on 100 % black field — box should be centred on screen and be 1/5 to 1/6 the size of the diagonal of the display.
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		only luminance required.

d) Procedure: according to 6.1.1 (M 12.1).

e) Analysis

Calculate box contrast ratio:

$$C_{\mathrm{R}} = \frac{L_{\mathrm{W}}}{L_{\mathrm{K}}}$$

where L_{W} is the luminance of the white box and L_{K} is the centre-screen black level luminance for the full black field.

f) Reporting: report the darkroom box contrast ratio.

g) Comments: none.

6.7.2 P 18.2 — Contrast under ambient illumination

a) Objective: to calculate the contrast under diffuse illumination.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen 100 % black and 100 % white.
	see 5.3.23	box pattern — 100 % white box on 100 % black field — box should be centred on screen and be 1/5 to 1/6 the size of the diagonal of the display.
— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:		diffuse illumination.
— Spectral characteristics:		only luminance required.

d) Procedure:

1) Measure the following in accordance with 6.1.1 (M 12.1):

- the emitted luminance component in the high state, L_{HS};
- the emitted luminance component in the low state, L_{LS}.

2) Measure the luminance component reflected from diffuse illumination, L_{D}, in accordance with 6.5.6 (P.16.5).

e) Analysis

Calculate the contrast ratio:

$$C_R = \frac{L_{HS} + L_D}{L_{LS} + L_D} \quad (20)$$

f) Reporting: none.

g) Comments: none.

6.7.3 P 18.2A — Contrast under uniform diffuse illumination

a) Objective: to calculate the contrast under diffuse illumination.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen — 100 % black and 100 % white.
	see 5.3.23	box pattern — 100 % white box on 100 % black field — box should be centred on screen and be 1/5 to 1/6 the size of the diagonal of the display.
— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:		diffuse illumination.
— Spectral characteristics:		only luminance required.

d) Procedure

1) Measure the following in accordance with 6.1.1 (M 12.1):

   — the emitted luminance component in the high state, L_{HS};

   — the emitted luminance component in the low state, L_{LS}.

2) Measure, according to 6.5.2 (M.16.1A), the luminance component reflected from diffuse illumination for both high and low states:

   $L_D = \rho E/\pi$

e) Analysis

Calculate the contrast ratio:

$$C_R = \frac{L_{HS} + \rho_{HS} \times \frac{E}{\pi}}{L_{LS} + \rho_{LS} \times \frac{E}{\pi}} \quad (21)$$

f) Reporting: none.

g) Comment: the illumination due to the display inside the sphere shall be significantly less (by at least a factor of 10) than the illumination of the source.

6.7.4 P 18.3 — Contrast under ambient illumination and specular reflections

a) Objective: to calculate the contrast under diffuse illumination.

b) Applicability: all display technologies.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test pattern: see 5.3.17 full-screen — 100 % black and 100 % white.

        see 5.3.23 box pattern — 100 % white box on 100 % black field — box should be centred on screen and be 1/5 to 1/6 the size of the diagonal of the display.

      - Measurement location: see 5.4.8 centre-screen measurement location.

      - Meter direction: see 5.4.1 normal to display screen/normal to display screen.

      - Test illumination: diffuse and specular illumination.

      - Spectral characteristics: only luminance required.

d) Procedure

   1) Measure the following in accordance with 6.1.1 (M 12.1):

      - the emitted luminance component in the high state, L_{HS};

      - the emitted luminance component in the low state, L_{LS}.

   2) Measure the luminance component reflected from diffuse illumination, L_{D}, in accordance with 6.5.2 (M 16.1A).

   3) Measure the luminance component reflected from specular illumination, L_{S}, in accordance with 6.5.1 (M 16.1).

e) Analysis

   Calculate the contrast ratio:

$$C_{\mathrm{R}} = \frac{L_{\mathrm{HS}} + L_{\mathrm{D}} + L_{\mathrm{S}}}{L_{\mathrm{LS}} + L_{\mathrm{D}}} \tag{22}$$

f) Reporting: report contrast and viewing direction range.

g) Comments: none.

6.7.5 P 18.4 — Full-screen contrast

a) Objective: to calculate the contrast between a full-screen white image and a full-screen black image generated on a display.

b) Applicability: all display technologies.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test pattern: see 5.3.17 full-screen — 100 % black and 100 % white.
      - Measurement location: see 5.4.8 centre-screen measurement location.
      - Meter direction: see 5.4.1 normal to display screen/normal to display screen.
      - Test illumination: N/A.
      - Spectral characteristics: only luminance required.

d) Procedure: according to 6.1.1 (M 12.1), for both black and white patterns.

e) Analysis

   Calculate the full-screen contrast ratio:

$$C_\mathrm{R} = \frac{L_\mathrm{W}}{L_\mathrm{K}}$$

   where L_W is the luminance of the white screen and L_K is the luminance of the black screen.

f) Reporting: report the darkroom contrast.

g) Comments: sometimes referred to as “sequential contrast”.

6.7.6 P 18.5 — Contrast uniformity

a) Objective: to measure the variation of contrast across the display screen.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

   - Test pattern: see 5.3.17 full-screen — 100 % black and 100 % white.
   - Measurement location: see 5.4.5 standard nine locations.
   - Meter direction: see 5.4.1 normal to display screen/normal to display screen.
   - Test illumination: N/A.
   - Spectral characteristics: only luminance required.

d) Procedure

Use data from 6.1.5 (P 12.4) to perform a full-screen contrast for the specified test positions according to 6.7.5 (P 18.4).

Alternatively, data measured using 6.6.3 (P 17.3) may be used.

e) Analysis

Calculate the uniformity of contrast:

$$\text{ratio} = 100\ \% \left(\frac{C_{\text{min}}}{C_{\text{max}}} \right)$$

where C_{max} and C_{min} are the maximum and minimum contrasts of the sampled contrast set:

$$C_i = \frac{L_{\text{W}i}}{L_{\text{K}i}}$$

where $i = 1,\ldots, 9$.

f) Reporting: report the average sampled contrast and contrast uniformity.

g) Comments: none.

6.7.7 P 18.6 — Modulation depth

a) Objective: to measure the modulation depth of a display.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.2.2 line profile and contrast.

2) Fixed measurement conditions: see 6.2.2 line profile and contrast.

- Test patterns: see 5.3.15 horizontal bars

  100 % colour — one-row-on, one-row-off grille;

  100 % colour — two-rows-on, two-rows-off grille;

  100 % colour — three-rows-on, three-rows-off grille;

  see 5.3.16 vertical bars

  100 % colour — one-column-on, one-column-off grille;

  100 % colour — two-columns-on, two-columns-off grille;

  100 % colour — three-columns-on, three-columns-off grille.

- Measurement location: see 5.4.8 centre-screen.

- Meter direction: see 5.4.1 normal to display screen/normal to display surface.

- Test illumination: N/A.

- Spectral characteristics: luminance only.

d) Procedure: measure the 3D luminance distribution.

NOTE The accuracy of the measurement can be enhanced by means of a micro-stepping method (see Annex B).

e) Analysis

From the 3D luminance distribution of a horizontal line pattern, obtain a vertical 2D luminance distribution by means of integration. Likewise, from the 3D luminance distribution of a vertical line pattern, obtain a horizontal 2D luminance distribution. This is illustrated by Figure 60. The white lines indicate the area in which the 3D luminance distribution has to be integrated in the direction of the green arrow resulting in a 2D luminance distribution. These 2D luminance distributions are used to calculate the modulation depths for the horizontal and vertical line patterns.

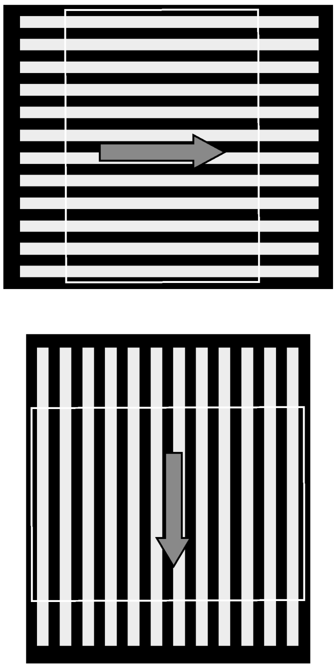


Figure 60 — Determination of luminance distribution

The 3D luminance distribution is on a number (between 1 and 10) of line pairs (light-dark) of adjacent horizontal lines or vertical lines. The 3D luminance distribution is then transformed into a 2D luminance distribution by means of integration. Then the amplitude, A, and average luminance value (L_{ave}) of the fundamental wave of the 2D luminance distributions is calculated by Fourier analysis.

Finally, the modulation depth, MD, is the ratio of amplitude, A, of the fundamental wave of the luminance distribution and the average luminance value, L_{ave}, of the fundamental wave of the 2D luminance distribution:

$$\text{MD} = A / L_{\text{ave}} \tag{23}$$

f) Reporting: report the modulation depth, MD.

g) Comments

The measurement of the black luminance is particularly susceptible to errors caused by the room ambient lighting conditions. Ambient lighting shall be controlled in order to avoid errors caused by reflections off the display screen. Additional errors can come from the contributions of lens flare or veiling glare from the rest of the screen. For screens that exhibit strong viewing-angle dependence, the glare contributions can be particularly significant.

6.7.8 P 18.7 — Contrast directional distribution

a) Objective: to make full-screen contrast measurements, at the centre of the screen, of luminance values for a set number of test positions.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Fixed test pattern: see 5.3.17 full-screen 100 % white, 100 % black.
- Fixed measurement location: see 5.4.8 centre-screen.
- Meter direction: see 5.4.1 normal to display screen — at specified values of θ and ϕ at 10° steps or less for the viewing region.
- Test illumination: N/A.
- Spectral characteristics: spectral response, luminance.

d) Procedure: perform, according to 6.1.1 (M 12.1), the required goniometric measurements of luminance, $L_{\theta,\phi}$, and the chromaticity coordinates of the required patterns, with the meter positioned at each of the appropriate off-normal viewing angles for black and white patterns.

e) Analysis

Calculate the contrast for each θ,ϕ:

$$C = \frac{L_{\mathrm{W}\theta,\phi}}{L_{\mathrm{K}\theta,\phi}} \tag{24}$$

f) Reporting: data should be presented in tabular form, to no more than three significant figures.

g) Comments: none.

6.7.9 P 18.8 — Contrast directional uniformity

a) Objective: To measure the full-screen contrast variation (at different angular alignments) from centre-screen.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Fixed test pattern: see 5.3.17 full-screen 100 % white, 100 % black.
- Fixed measurement location: see 5.4.5 standard nine locations.
- Meter direction: see 5.4.1 normal to display screen — at specified values of θ and ϕ at 10° steps or less for the viewing region.
- Test illumination: N/A.
- Spectral characteristics: spectral response, luminance.

d) Procedure: perform, according to 6.1.1 (M 12.1), the required goniometric measurements of luminance, $L_{\theta,\phi}$, and the chromaticity coordinates of the required patterns, with the meter positioned at each of the appropriate off-normal viewing angles for black and white patterns.

e) Analysis

1) Calculate the contrast for each θ,ϕ, for each test position:

$$C = \frac{L_{\mathrm{W}\theta,\phi}}{L_{\mathrm{K}\theta,\phi}}$$

2) Calculate the contrast uniformity at each test position:

$$\text{uniformity} = 100\ \% \left(\frac{C_{\theta,\phi}}{C_{\perp}} \right)$$

(check equation) where $C_{\theta,\phi}$ is the luminance at the test position and $C_{\perp}$ is the luminance at the centre position.

f) Reporting: data should be presented in tabular form, to no more than three significant figures.

g) Comments: none.

6.7.10 P 18.9 — Directional gamma

a) Objective: to determine the electro-optic transfer function of a display at different viewing angles and estimate its gamma.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen for each specified grey level for white or other specified colour.
— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen — at specified values of θ and ϕ at 10° steps or less for viewing region.
— Test illumination:		N/A.
— Spectral characteristic:		only luminance required.

d) Procedure: perform measurements in accordance with 6.1.1 (M 12.1) for specified grey levels.

e) Analysis

Plot the electro-optic transfer function and estimate gamma. Determine the gamma by fitting a curve to the luminance data using the model:

$$L = aV^{\gamma} + L_{\mathrm{b}}$$

Alternatively, express this in logarithmic terms as:

$$\log(L - L_\mathrm{b}) = \gamma \log(V) + \log(a)$$

where a and γ relate the signal level, V, to the luminance, L, and L_b is the black-level luminance.

Use of least-squares fit on the data is recommended.

f) Reporting: report grey scale illuminances and chromaticity in tabular format, the gamma estimate, and present a plot of electro-optic transfer function.

g) Comments: none.

See Figure 59 for an example.

6.7.11 P 18.10 — Directional gamma uniformity

a) Objective: to determine the electro-optic transfer function of a display at various locations on the screen and at different viewing angles.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen for each specified grey level for white or other specified colour.
— Measurement location:	see 5.4.5	standard nine locations.
— Meter direction:	see 5.4.1	normal to display screen — at specified values of θ and ϕ at 10° steps or less for viewing region.
— Test illumination:		N/A.
— Spectral characteristic:		only luminance required.

d) Procedure: perform measurements according to 6.1.1 (M 12.1) for specified grey levels at the specified screen locations and viewing directions.

e) Analysis

Plot the electro-optic transfer function and estimate gamma. Determine the gamma by fitting a curve to the luminance data using the model:

$$L = aV^{\gamma} + L_\mathrm{b}$$

Alternatively, express this in logarithmic terms as:

$$\log(L - L_\mathrm{b}) = \gamma \log(V) + \log(a)$$

where a and γ relate the signal level, V, to the luminance, L, and L_b is the black-level luminance.

Use of least-squares fit on the data is recommended.

f) Reporting: report grey scale illuminances and chromaticity in tabular format, the gamma estimate, and present a plot of electro-optic transfer function.

g) Comments: none.

See Figure 59 for an example.

6.8 Colour analysis

6.8.1 P 19.1 — Spectrally extreme colours

a) Objective: to check for spectrally extreme colours in order to avoid chromatic stereopsis.

b) Applicability: all colour displays.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test pattern: see 5.3.17 full-screen — 100 % colour at the specified colours.
      - Measurement location: see 5.4.8 centre-screen.
      - Meter direction: see 5.4.1 normal to display screen/normal to display screen.
      - Test illumination: N/A.
      - Spectral characteristics: luminance, chromaticity.

d) Procedure: measure the chromaticity for each colour at the specified measurement positions in accordance with 6.1.1 (M 12.1).

e) Analysis

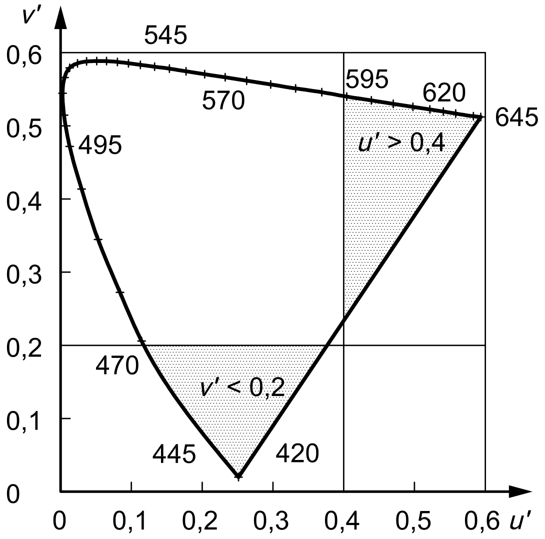
   Spectrally extreme colours are extreme blue, and extreme red. Extreme blue is any colour with $v' < 0{,}2$. Extreme red is any colour with $u' > 0{,}4$. The extreme regions are illustrated by Figure 61.

   Report the chromaticity of the extreme red and blue.

f) Comments

   Red ($u' > 0{,}4$) and blue ($v' < 0{,}2$) is the worst combination, but any pair of colours can, in principle, evoke false stereopsis.

   On flat panels, saturated red, green and blue, and also the pair-wise combinations, yellow, cyan and magenta, exhibit the minimum anisotropy. The appropriate use of these colours is an application issue and can be evaluated by reviewing the intended applications.



Key

u'	chromaticity coordinate, red
v'	chromaticity coordinate, blue

Figure 61 — Extreme red and extreme blue spectrally extreme colours

6.8.2 P 19.2 — Lateral chromaticity uniformity, $\Delta u',v'$

a) Objective: to measure the colour uniformity of the display at the defined locations of the screen.

b) Applicability: all colour displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen — 100 % colour at the specified colours.
— Measurement location:	see 5.4.5	standard nine locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		luminance.

d) Procedure: measure, according to 6.1.1 (M 12.1), the luminance and chromaticity for each colour at the specified measurement positions.

e) Analysis

1) Calculate the uniformity of the display:

$$\text{uniformity} = 100\ \% \left(\frac{L_{\text{min}}}{L_{\text{max}}} \right)$$

where L_{max} and L_{min} are the maximum and minimum measured display luminance of the sampled display luminance set, L_i, where $i = 1,\ldots, n$.

2) Determine the u',v' coordinates, either from direct measurement or from calculation using the x,y coordinates.

3) Determine the largest chromaticity difference between the pairs of sampled colours using the following:

$$u' = \frac{4X}{X + 15Y + 3Z} \left(= \frac{4x}{3 + 12y - 2x} \right) x = \frac{9u'}{6u' - 16v' + 12}$$
$$v' = \frac{9Y}{X + 15Y + 3Z} \left(= \frac{9y}{3 + 12y - 2x} \right) y = \frac{4v'}{6u' - 16v' + 12} \qquad (25)$$
$$\Delta u'v' = \sqrt{\left(u_1' - u_2'\right)} + \left(v_1' - v_2'\right)^2$$

f) Reporting: report the luminance uniformity and $\Delta u',v'$, as well as the maximum chromaticity difference and the chromaticity uniformity.

Data should be presented in tabular form, to no more than three significant figures.

g) Comments: none.

6.8.3 P 19.3 — Directional chromaticity uniformity

a) Objective: to measure the full-screen luminance variation (at different angular alignments) of different colours at specified locations on the screen.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17 full-screen — 100 % colour at the specified colours.
- Measurement location: N/A.
- Meter direction: see 5.4.1 normal to display screen — at specified values of θ and ϕ at 10° steps or less for the viewing region.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: spectral response, luminance.

d) Procedure: measure, according to 6.3.1 (P 14.1), the luminance and chromaticity for each colour specified.

e) Analysis

1) Calculate the uniformity at each test position:

$$\text{uniformity} = 100\ \% \left(\frac{L_{\theta,\phi}}{L_{\perp}} \right)$$

where $L_{\theta,\phi}$ is the luminance at the test position, and $L_{\perp}$ is the luminance at the centre position.

2) Determine the u′,v′ coordinates, either from direct measurement or from calculation using the x,y coordinates.

3) Determine the largest chromaticity difference between the pairs of sampled colours, using Equation (25).

f) Reporting: report the maximum chromaticity difference.

Data should be presented in tabular form, to no more than three significant figures.

g) Comments: see 6.1.1 (M 12.1).

6.8.4 P 19.4 — Colour difference, ΔE (CIELUV)

a) Objective: to determine the maximum colour difference of the display at the defined locations of the screen.

b) Applicability: all colour displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen 100 % colour at the specified colours.
— Measurement location:	see 5.4.5	standard nine locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		luminance, tristimulus, spectral.

d) Procedure

1) Measure, according to 6.1.1 (M 12.1), the luminance and chromaticity for each colour at the specified measurement positions.

2) Determine the display white point, see 6.8.8 (P 19.15).

e) Analysis

1) Determine the u',v' coordinates, either from direct measurement or from calculation using the x,y coordinates.

2) For each colour, calculate the colour difference, ΔE, based on the 1976 CIELUV model, as follows:

$$
\begin{aligned}
L^* &= 116\left(\frac{Y}{Y_\mathrm{w}}\right)^{1/3} - 16,\ \text{but } L^* = 903{,}3\,\frac{Y}{Y_\mathrm{w}},\ \text{for } \frac{Y}{Y_\mathrm{w}} \leqslant 0{,}008\,856.\\
u^* &= 13\,L^*\left(u' - u'_\mathrm{w}\right),\\
v^* &= 13\,L^*\left(v' - v'_\mathrm{w}\right).\\
\Delta E^*_\mathrm{uv} &= \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta u^*\right)^2 + \left(\Delta u^*\right)^2},\ \Delta L^* = L^*_1 - L^*_2,\ \Delta u^* = u^*_1 - u^*_2,\ \Delta v^* = v^*_1 - v^*_2
\end{aligned}
\qquad (26)
$$

where Y_w, u_w, and v_w are the luminance and chromaticity of the display white point.

f) Reporting: report the maximum colour difference for each colour.

g) Comments: none.

6.8.5 P 19.4A — Colour difference, ΔE (CIELAB)

a) Objective: to determine the maximum colour difference of the display at the defined locations of the screen.

b) Applicability: all colour displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17 full-screen — 100% colour at the specified colours.
- Measurement location: see 5.4.5 standard nine locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display screen.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: luminance, tristimulus, spectral.

d) Procedure

1) Measure, according to 6.1.1 (M 12.1), the luminance and chromaticity for each colour at the specified measurement positions.

2) Determine the display white point, see 6.8.8 (P 19.15).

e) Analysis

1) Determine the u',v' coordinates, either from direct measurement or from calculation using the x,y coordinates.

2) For each colour, calculate the colour difference, ΔE, based on the 1976 CIELUV model, as follows:

$$L^* = 116\left(\frac{Y}{Y_\mathrm{w}}\right)^{1/3} - 16,\ \text{but } L^* = 903{,}3\,\frac{Y}{Y_\mathrm{w}},\ \text{for } \frac{Y}{Y_\mathrm{w}} \leqslant 0{,}008\,856.$$

$$a^* = 500\left[\left(\frac{X}{X_\mathrm{w}}\right)^{1/3} - \left(\frac{Y}{Y_\mathrm{w}}\right)^{1/3}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_\mathrm{w}}\right)^{1/3} - \left(\frac{Z}{Z_\mathrm{w}}\right)^{1/3}\right] \tag{27}$$

$$\Delta E^*_\mathrm{ab} = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2}\ \text{where } \Delta L^* = L^*_1 - L^*_2, \Delta a^* = a^*_1 - a^*_2, \Delta b^* = b^*_1 - b^*_2$$

where Y_w, u_w, and v_w are the luminance and chromaticity of the display white point.

Modifications for low light levels:

for any tristimulus value $W = X, Y, Z$, in the above expressions for a^*, b^*,

replace $\left(\frac{W}{W_\mathrm{w}}\right)^{1/3}$ with $\left(7{,}787\,\frac{W}{W_\mathrm{w}} + \frac{16}{116}\right)$ whenever $\frac{W}{W_\mathrm{w}} \leqslant 0{,}008\,856$.

f) Reporting: report the maximum colour difference for each colour.

g) Comments: none.

6.8.6 P 19.6 — Chromaticity

a) Objective: to measure the chromaticity of a display.

b) Applicability: all displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen 100 % for each specified colour.
— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		luminance and chromaticity (x,y).

d) Procedure: perform measurements according to 6.1.1 (M 12.1) for the specified colours.

e) Analysis: none.

f) Reporting: for each specified colour, report the centre-screen luminance and chromaticity.

g) Comments: none.

6.8.7 P 19.7 — Colour gamut area

a) Objective: to calculate the total area of a display gamut as a percentage of the CIE u',v' colour space.

b) Applicability: all colour displays.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test pattern: see 5.3.17 full-screen 100 % for each primary colour.
- Measurement location: see 5.4.8 centre-screen measurement location.
- Meter direction: see 5.4.1 normal to display screen/normal to display screen.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: luminance and chromaticity (x,y).

d) Procedure

1) Perform measurements according to 6.1.5 (P 12.4) for each primary colour.

2) Perform measurements according to 6.1.1 (M 12.1) for the specified colours.

e) Analysis

Calculate the projector gamut as a percentage of colour space using centre-screen values:

$$A = 256{,}9 \left|\left(u'_{\gamma} - u'_{\mathrm{b}}\right)\left(v'_{\mathrm{g}} - v'_{\mathrm{b}}\right) - \left(u'_{\mathrm{g}} - u'_{\mathrm{b}}\right)\left(v'_{\gamma} - v'_{\mathrm{b}}\right)\right| \tag{28}$$

Convert Equation (28) to x,y.

f) Reporting: report the colour gamut area.

g) Comments: none.

6.8.8 P 19.15 — Colour temperature, white point, and white-point accuracy

a) Objective: to measure the chromaticity coordinates of white (white point), measure (or calculate) the CCT, and determine the distance of the white point from the daylight locus.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.17	full-screen 100 % white.
— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:	see 5.9.2	darkroom.
— Spectral characteristics:		luminance and chromaticity.

d) Procedure

1) Measure the white-point chromaticity (x_W, y_W) in accordance with 6.1.1 (M 12.1) and determine the colour-temperature limits, T_1 and T_2. Typically, T_1 is 6 500 K and T_2 is 9 300 K.

2) If the measurement instrument provides the CCT, then measure the CCT directly.

e) Analysis

1) If the measurement instrument does not provide the CCT directly, it may be calculated by using McCamy's formula [17]:

$$\text{CCT} = 437n^3 + 3061\, n^2 + 6\,861\, n + 5\,517$$

where $n = (x - 0{,}332\,0)/(0{,}1858 - y)$.

2) The following — taken from Reference [17], equations 5 (3.3.4) and 6 (3.3.4) — to compute the point (xd, yd) on the daylight locus that is associated with CCTTB. First, define g = 1 000/TB.

— If $T_B \leqslant 7\,000$ K, then $x_d = -4{,}607\,0g^3 + 2{,}967\,8g^2 + 0{,}099\,11g + 0{,}244\,063$.

— If $T_B > 7\,000$ K, then $x_d = -2{,}006\,4g^3 + 1{,}901\,8g^2 + 0{,}247\,48g + 0{,}237\,040$.

In either case, $y_d = 3{,}000\, x_d^2 + 2{,}870\, x_d - 0{,}275$.

3) Convert (x_W, y_W) and (x_d, y_d) to u',v' coordinates:

$(u'_W, v'_W) = (4\, x_W, 9\, y_W)/(3 + 12\, y_W - 2\, x_W)$

$(u'_d, v'_d) = (4\, x_d, 9\, y_d)/(3 + 12\, y_d - 2\, x_d)$

4) Evaluate the distance of the white point from the daylight locus, $\Delta u'v'$ between (u'W, v'W) and (u'_d, v'_d):

$$\Delta u',v' = \sqrt{\left(u'_w - u'_d\right)^2 + \left(v'_w - v'_d\right)^2} \qquad (29)$$

f) Reporting: report the CCT, chromaticity of white point, and white point accuracy.

g) Comments: none.

6.9 Dimensions and geometries

6.9.1 P 20.1 — Pixel size and pitch from luminance profile

a) Objective: to measure the pixel size and pixel pitch from the luminance profile.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 5.2.7 replica masks (optional).

2) Fixed measurement conditions

- Measurement field: see 5.6.2 within a pixel.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.15 horizontal bars — 100 % white or green, one pixel width, 100 % black, one pixel width, alternating.
  see 5.3.16 vertical bars — 100 % white or green, one pixel width, 100 % black, one pixel width, alternating.
- Measurement location: see 5.4.3 standard five locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: see 5.9.2 darkroom.
- Spectral characteristics: luminance only.

4) Pixels shall be fully on (all subpixels on).

d) Procedure: measure the luminance profile for both the vertical and horizontal lines in accordance with 6.2.2 (M 13.2).

e) Analysis

1) The pixel width is the distance between the 50 % contours of luminance difference between the body of the horizontal grill and the background.

2) The pixel height is the distance between the 50 % contours of luminance difference between the body of the vertical grill and the background.

3) The 50 % luminance difference contours are determined from the luminance profile.

4) The distance shall be measured along lines that pass horizontally through the centre, or centres, of the pixels that define the vertical line, and vertically through the centre(s) of the pixels that define the horizontal line.

5) The character size will be the average pixel dimensions measured in the five measurement positions.

f) Reporting: none.

g) Comments: none.

6.9.2 M 20.2 — Pixel size and pitch from artwork

a) Objective: to measure the pixel size and pixel pitch from the display artwork.

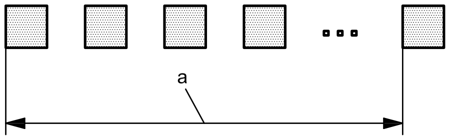
b) Applicability: all display technologies.

c) Preparation and set-up

Test accessories: see 5.2.10 dimensional measurement devices.

d) Procedure

Measure the vertical pitch, V_{pitch}, and the horizontal pitch, H_{pitch}. For accuracy, measure from the leading edge (or other convenient point) of one pixel to the same point many pixels away and dividing by that number. See Figure 62 for an example — if the panel had 480 lines of pixels, measure from the first pixel the same point on the last pixel (479 pixels away) and divide by 479.



[a] Measurement: $H_{\text{pitch}} = \dfrac{\text{measurement}}{479}$

Figure 62 — Measurement of pitch from artwork

e) Analysis: none.

f) Reporting: report the vertical and horizontal pitches.

g) Comments

These measurements are used in character design, as well as for each specified character font and in spacing design, without additional measurement. Sometimes, the font specified is the result of a complex algorithm and a design document is not available, in which case the pixel arrangement may be observed on the screen using a jeweller's loupe or equivalent.

6.9.3 P 20.3 — Pixel size for projector displays

a) Objective: to measure the pixel size.

b) Applicability: projection displays.

c) Preparation and set-up

   1) Test accessories see 5.2.10 dimensional measurement devices.

   2) Fixed measurement conditions: none.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      Test patterns: see 5.3.12 orthogonality.

d) Procedure

   1) Measure the width and height of the projected image in accordance with 6.9.11 (M 20.11).

   2) Measure the vertical and horizontal addressable resolution in accordance with 6.9.9 (M 20.9).

e) Analysis

   Calculate the following the vertical and horizontal pitches:

   V_{pitch} = height/vertical resolution

   H_{pitch} = width/horizontal resolution

f) Reporting: report vertical and horizontal pitch.

g) Comments

   These measurements are used in character design, as well as for each specified character font and in spacing design, without additional measurement. Sometimes, the font specified is the result of a complex algorithm and a design document is not available, in which case the pixel arrangement may be observed on the screen using a jeweller's loupe or equivalent.

6.9.4 P 20.4 — Character dimensions for CRT

a) Objective: to measure the character height and width for a particular character font displayed on a CRT.

b) Applicability: CRT-based displays.

c) Preparation and set-up

   1) Test accessories: see 5.2.7 replica masks (optional).

   2) Fixed measurement conditions

      - Measurement field: see 5.6.2 within a pixel.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns:	see 5.3.1	character width target “H” or equivalent.
— Measurement location:	see 5.4.3	standard five locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display surface.
— Test illumination:		N/A.
— Spectral characteristics:		luminance only.

d) Procedure: for all measurement locations, measure the luminance profile of the character, in both the vertical and horizontal directions, in accordance with either 6.2.1 (M 13.1) or 6.2.2 (M 13.2).

e) Analysis

1) Determine the character height and width for each character using the measured luminance profiles. The character edge is defined as extending to the 50 % of luminance difference between the character and the background.

2) Character height and width shall be the mean dimensions of the character “M” or of an equivalent test object presented in the five test locations.

f) Reporting: report character height and width.

g) Comments

Character height and width for a particular character font are the distance between the appropriate parallel edges of a non-accented capital letter (see Figures 6 and 7). For the purposes of this procedure, the capital letter “H” shall be used to define the character height and width. However, “H” may be unsuitable for measurement of character height. Therefore, a test object having the same number of pixels between its measured features as a capital “H” may be used for character height and width measurements.

6.9.5 P 20.5 — Character dimensions for LCD

a) Objective: to measure the character height and width for a particular character font displayed on an LCD.

b) Applicability: LCD-based displays.

c) Preparation and set-up

1) Test accessories:	see 5.2.10	dimensional measurement devices.

2) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns:	see 5.3.11	screen full of H.
— Measurement location:	see 5.4.3	standard five locations.
— Spectral characteristics:		none.

d) Procedure

1) For all measurement locations, measure the horizontal and vertical pixel pitch in accordance with 6.9.2 (M 20.2), using the appropriate character in the pattern.

2) Measure the character height, $N_{\mathrm{H,Height}}$, and character width, $N_{\mathrm{H,Width}}$, by counting the appropriate number of pixels in the letter “H”.

e) Analysis

Determine the character height, Ψ, as follows:

$$\Psi = \frac{180 \times 60 \times V_{\mathrm{pitch}} \times N_{\mathrm{H,Height}}}{\pi \times D_{\mathrm{view}}} \tag{30}$$

f) Reporting: report character height and width in pixels.

g) Comments: none.

6.9.6 P 20.6 — Character stroke width for CRT

a) Objective: to measure the character stroke from the luminance profile.

b) Applicability: CRT-based displays and PDP.

c) Preparation and set-up

1) Test accessories: see 5.2.7 replica masks (optional).

2) Fixed measurement conditions

— Measurement field: see 5.6.2 within a pixel.

— Meter angular aperture: see 5.7 angular aperture.

— Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns: see 5.3.1 character width target “H” or equivalent.

see 5.3.11 screen full of H or equivalent.

— Measurement location: see 5.4.3 standard five locations.

— Meter direction: see 5.4.1 normal to display screen/normal to display surface.

— Test illumination: N/A.

— Spectral characteristics: luminance only.

d) Procedure: for all measurement locations, measure the luminance profile of the character stroke, in both vertical and horizontal directions, in accordance with either 6.2.1 (M 13.1) or 6.2.2 (M 13.2).

e) Analysis

1) The stroke width of a character set is the distance between the 50 % contours of luminance difference between the body of a stroke used to define a character, and the background.

2) The 50 % luminance difference contours are determined from the luminance profile.

3) The distance shall be measured along lines that pass horizontally through the centre, or centres, of the pixels that define vertical strokes, and vertically through the centre(s) of pixels that define horizontal strokes. Serifs shall not be included in these measurements.

4) Stroke width for a character set will be the average stroke width for horizontal and vertical strokes presented in the five measurement positions.

5) The capital letter “M” shall be used to define vertical stroke width. The capital letter “H” shall be used to define horizontal stroke width.

f) Reporting: none.

g) Comments: none.

6.9.7 P 20.7 — Character stroke width for regular addressed pixels

a) Objective: Measure the character stroke width for a particular character font displayed on an LCD.

b) Applicability: LCD-based displays, projection displays, and hand-held devices.

c) Preparation and set-up

1) Test accessories: see 5.2.10 dimensional measurement devices.

2) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.11 screen full of H or equivalent.
- Measurement location: see 5.4.3 standard five locations.
- Spectral characteristics: none.

d) Procedure

Perform the procedure according to 6.9.2 (M 20.2), using the appropriate character in the pattern. Measure the horizontal stroke width, $N_{\mathrm{H,hz\_stroke}}$, and the vertical stroke width, $N_{\mathrm{H,vt,\_stroke}}$, by counting the appropriate number of pixels in the “H” for all measurement locations.

e) Analysis: the character stroke width is the average of the horizontal and vertical stroke widths for all measurement positions.

f) Reporting: report character stroke width in number of pixels.

g) Comments: none.

6.9.8 P 20.8 — Character width-to-height ratio

a) Objective: to measure the character width-to-height ratio for a particular character font displayed on a CRT.

b) Applicability: CRT-based displays and PDP.

c) Preparation and set-up

1) Test accessories see 5.2.7 replica masks (optional).

2) Fixed measurement conditions

- Measurement field: see 5.6.2 within a pixel.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.1 character width target “H” or equivalent.
- Measurement location: see 5.4.3 standard five locations
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: N/A.
- Spectral characteristics: luminance only.

d) Procedure: for all measurement locations, measure the luminance profile of the character, in both vertical and horizontal directions, according to either 6.2.1 (M 13.1) or 6.2.2 (M 13.2).

e) Analysis

1) Determine character height and width for each character using the measured luminance profiles. The character edge is defined as extending to the 50 % of luminance difference between the character and the background.

2) Character height and width shall be the mean dimensions of the character “M” or of an equivalent test object presented in the five test locations.

3) The width-to-height ratio of a particular font is the ratio of the character width to the character height.

f) Reporting: report character height and width.

g) Comments

Character height and width for a particular character font are the distance between the appropriate parallel edges of a non-accented capital letter (see Figures 6 and 7). For the purposes of this procedure, the capital letter “H” shall be used to define the character height and width. However, “H” may be unsuitable for measurement of character height. Therefore, a test object having the same number of pixels between its measured features as a capital “H” may be used for character height and width measurements.

6.9.9 M 20.9 — Resolution addressable

a) Objective: to describe the number of addressable physical full picture elements.

b) Applicability: all display technologies.

c) Preparation and set-up: none.

d) Procedure

The addressable resolution, or addressability, is the number of pixels in the horizontal and the vertical directions that can have their luminance changed, which is usually expressed as the number of horizontal pixels multiplied by the number of vertical pixels, $N_H \times N_V$. This term should *not* be used synonymously with *visible resolution* (see 6.9.10). However, for most purposes, it is the same as the pixel array.

e) Analysis: none.

f) Reporting: report the addressable resolution in number of horizontal pixels by the number of vertical pixels.

g) Comments: there are cases where the display could use a pixel array different from its addressability.

6.9.10 P 20.10 — Resolution, visible

a) Objective: to calculate the resolution.

b) Applicability: all display technologies.

c) Preparation and set-up

1) Test accessories: see 6.2.2 luminance profile with smoothing algorithm.

2) Fixed measurement conditions: see 6.2.2 luminance profile with smoothing algorithm.

— Test patterns: see 5.3.15 horizontal bars — 100 % white on black —

1 × 1 horizontal grille (one row on, one row off);

2 × 2 horizontal grille;

3 × 3 horizontal grille;

4 × 4 horizontal grille;

5 × 5 horizontal grille;

see 5.3.16 vertical bars — 100 % white on black —

1 × 1 vertical grille (one column on, one column off);

2 × 2 vertical grille;

3 × 3 vertical grille;

4 × 4 vertical grille;

5 × 5 vertical grille.

— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen/normal to display surface.
— Test illumination:	see 5.9.2	darkroom or specified ambient illumination.
— Spectral characteristics:		luminance only.

d) Procedure

Perform measurements according to 6.2.2 (M 13.2) for each pattern, for both the white and black lines. Take an average of at least three lines for black and white respectively. The results from 6.7.7 (P 18.6) may also be used.

e) Analysis

1) Calculate the contrast modulation, C_m, for each pattern:

$$C_\mathrm{m} = \frac{L_\mathrm{w} - L_\mathrm{k}}{L_\mathrm{w} + L_\mathrm{k}}$$

where L_W and L_K are the average white and black luminances.

2) Calculate the grille line width, n_r, in pixels, for which C_m is estimated to be equal to the contrast modulation threshold, C_T (see comment):

$$n_\mathrm{r} = n + \frac{C_\mathrm{T} - C_n(n)}{C_\mathrm{m}(n+1) - C_\mathrm{m}(n)} \; for \; C_\mathrm{m}(n) < C_\mathrm{T} < C_\mathrm{m}(n+1) \tag{31}$$

3) Calculate the resolution (in number of resolvable pixels) by dividing the number of addressable lines by n_r, for both horizontal and vertical directions. Add this analysis to modulation depth.

f) Reporting: report addressability and resolution, and show the contrast modulation plots. See Figure 63.

g) Comments

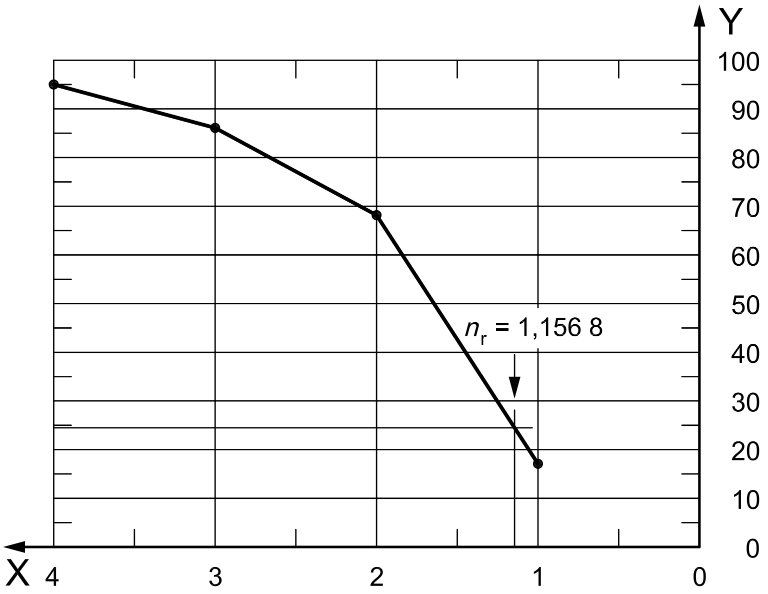
C_m is estimated to be equal to the contrast modulation threshold, C_T = 33 %[2] or C_T = 25 %[3].

The measurement of the black luminance is particularly susceptible to errors caused by the room ambient lighting conditions. Ambient lighting shall be controlled to avoid errors caused by reflections from the display screen. Additional errors can be contributed by lens flare or veiling glare from the rest of the screen. For screens that exhibit strong viewing-angle dependence, the glare contributions can be particularly significant.

---

[2] ANSI (American National Standards Institute) value.

[3] VESA (Video Electronics Standards Association, USA) value.



Key

X grille line width, pixels

Y contrast modulation (C_m), %

Figure 63 — Reporting for P 20.10 — Resolution, visible

6.9.11 M 20.11 — Aspect ratio

a) Objective: to calculate the screen aspect ratio.

b) Applicability: all display technologies.

c) Preparation and set-up

  1) Test accessories: N/A.

  2) Fixed measurement conditions: N/A.

  3) Configurable measurement conditions (use parameters as described unless otherwise specified)

  Test patterns: see 5.3.12 orthogonality.

d) Procedure

  1) Place the orthogonality pattern on the screen.

  2) Measure the horizontal distance, H, across the centre, in metres or millimetres, as appropriate.

  3) Measure vertical distance across centre, V, in metres or millimetres, as appropriate.

e) Analysis

  1) Calculate aspect ratio:

$$\alpha = \frac{H}{V}$$

  2) Convert the decimal aspect ratio to the nearest integer aspect ratio.

f) Reporting: report aspect ratio.

g) Comments: CRT have parallax.

6.9.12 P20.12 — Between-character spacing

a) Objective: to determine whether or not the between-character spacing is within the required specification.

b) Applicability: all displays.

c) Preparation and set-up.

   1) Test accessories: see 5.2.7 replica masks (optional).

   2) Fixed measurement conditions

      - Measurement field: see 5.6.2 within a pixel.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test patterns: see 5.3.7 between-character spacing.
      - Measurement location: see 5.4.3 standard five locations.
      - Meter direction: see 5.4.1 normal to display screen/normal to display surface.
      - Test illumination: N/A.
      - Spectral characteristics: luminance only.

d) Procedure

   1) For variable-resolution displays: for all measurement locations, measure the luminance profile of the space between the characters, in accordance with either 6.2.1 (M 13.1) or 6.2.2 (M 13.2).

   2) For CRT displays, determine the character stroke width according to 6.9.6 (P 20.6).

   3) For fixed-resolution displays

      i) For all measurement locations, perform the procedure in accordance with 6.9.2 (M 20.2), using the appropriate character in the pattern.

      ii) Determine character stroke width according to 6.9.7 (P 20.7).

e) Analysis

   1) For variable-resolution displays, compare the width of the luminance profile with the character stroke width to determine whether or not it meets the specifications.

   2) For fixed-resolution displays, compare the number of pixels between the characters and the character stroke width to determine whether or not it meets the specifications.

f) Reporting

   1) For variable-resolution displays, report the luminance profile width.

   2) For fixed-resolution displays, report the number of pixels.

g) Comments

   For character fonts without serifs, the number of between-character pixels shall be a minimum of the stroke width count or one pixel. If characters have serifs, the between-character spacing shall be a minimum of one pixel between the serifs of adjacent characters.

6.9.13 P 20.13 — Between-word spacing

a) Objective: to determine that the between-word spacing is within the required specification.

b) Applicability: all displays.

c) Preparation and set-up

   1) Test accessories see 5.2.7 replica masks (optional).

   2) Fixed measurement conditions

      - Measurement field: see 5.6.2 within a pixel.
      - Meter angular aperture: see 5.7 angular aperture.
      - Meter response time: see 5.8.2 time-averaging meter.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test patterns: see 5.3.8 between-word spacing.
      - Measurement location: see 5.4.3 standard five locations.
      - Meter direction: see 5.4.1 normal to display screen/normal to display surface.
      - Test illumination: N/A.
      - Spectral characteristics: luminance only.

d) Procedure

   1) For variable-resolution displays

      i) For all measurement locations, measure the luminance profile of the character in the horizontal direction in accordance with either 6.2.1 (M 13.1) 6.2.2 (M 13.2).

      ii) Using the same procedure, measure the luminance profile of the between-word spacing for all measurement locations.

   2) For fixed-resolution displays

      i) For all measurement locations, measure the character width in accordance with 6.9.2 (M 20.2), using the appropriate character in the pattern.

      ii) Using the same procedure, measure the between-word spacing for all measurement locations.

e) Analysis

Character width shall be the mean dimensions of the character “N” or of the equivalent test object presented in the five test locations.

1) For variable-resolution displays

i) Determine character width for each character using the measured luminance profiles. The character edge is defined as extending to the 50 % of luminance difference between the character and the background.

ii) Compare the width of the luminance profile with the character stroke width to determine whether or not it meets the specifications.

2) For fixed-resolution displays: compare the number of pixels between the characters with the character stroke width to determine whether or not it meets the specifications.

f) Reporting

1) For variable-resolution displays, report the between-word spacing luminance profile width.

2) For fixed-resolution displays, report the number of pixels in the between-word spacing.

g) Comments

For variable-resolution displays, a minimum of one character width (capital “N” for proportional spacing) shall be used between words.

For fixed-resolution displays, the minimum number of pixels between words shall be the number of pixels in the width of an unaccented upper case “H”, unless the character font is designed as a representation of designed print fonts or proportional spacing is used. When simulating a print font, the spacing used in the design may be used. The number of pixels in the width of the “N” is recommended for proportionally spaced fonts.

6.9.14 P 20.14 — Between-line spacing

a) Objective: to determine whether or not the between-line spacing is within the required specification.

b) Applicability: all displays.

c) Preparation and set-up

1) Test accessories see 5.2.7 replica masks (optional).

2) Fixed measurement conditions

— Measurement field:	see 5.6.2	within a pixel.
— Meter angular aperture:	see 5.7	angular aperture.
— Meter response time:	see 5.8.2	time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns:	see 5.3.9	between-line spacing.
— Measurement location:	see 5.4.3	standard five locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display surface
— Test illumination:		N/A.
— Spectral characteristics:		luminance only.

d) Procedure

1) For variable-resolution displays

   i) For all measurement locations, measure the luminance profile of the between-line spacing in the vertical direction, in accordance with either 6.2.1 (M 13.1) or 6.2.2 (M 13.2).

   ii) For CRT displays, determine the character stroke width in the vertical direction according to 6.9.6 (P 20.6).

2) For fixed-resolution displays: for all measurement locations, measure the between-line spacing in accordance with 6.9.2 (M 20.2), using the appropriate character in the pattern.

e) Analysis

1) Between-line spacing shall be the mean dimensions measured in the five test locations.

2) A minimum of one pixel shall be used for spacing between lines of text. This area may not contain parts of characters or diacritics, but may contain underscores.

f) Reporting

1) For variable-resolution displays, report the between-line spacing luminance profile width.

2) For fixed-resolution displays, report the number of pixels in the between-line spacing.

g) Comments

A minimum of one pixel shall be used for spacing between lines of text. This area may not contain parts of characters or diacritics, but may contain underscores.

6.10 Geometrics and defects

6.10.1 M 21.1 — Linearity

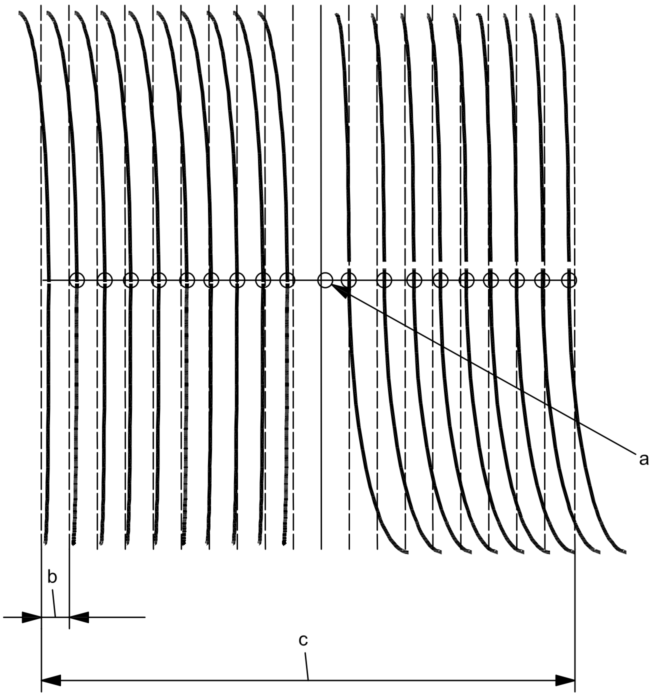
a) Objective: to measure the relation between the actual measured position of a pixel compared to the intended position in order to quantify effects of non-linearity.

b) Applicability: all display technologies.

c) Preparation and set-up

Display vertical or horizontal lines spaced no more than 5 % of the addressable screen, and arrange the spatial luminance meter to measure the position of the centroid of each line luminance profile: see Figure 64. Positioning uncertainty need only be ± 0,1 pixels; the normal direction should be maintained.

For optical measurements of the positions of the lines shown in Figure 64, use V-grille and H-grille video patterns consisting of vertical and horizontal lines each 1 pixel wide, equally spaced (in pixel units) by no more than 5 % of the addressable screen.



[a] Centre of screen ($x = 0$, $y = 0$).

[b] 5 % of total addressable width.

[c] Total width of addressable screen.

Figure 64 — Setup for linearity measurement

d) Procedure

Use an array detector to locate centre of line profiles in conjunction with an x,y translation stage to measure screen x,y coordinates of points where video pattern vertical lines intersect the horizontal centreline, and where horizontal lines intersect the vertical centreline, of the display screen. Tabulate x,y positions (in mm or pixels) of equally spaced lines (nominally 5 % addressable screen apart) along major (horizontal or longest centreline) and minor (vertical or shortest centreline) axes of the screen.

e) Analysis

Non-linearity is the difference between the spacing measured between each pair of adjacent lines minus the average of all the measured spacing, expressed as a percentage of average spacing.

If both scans are truly linear, the differences in the positions of adjacent lines will be constant. The departures of these differences is the non-linearity. The linearity of the horizontal scan is determined from measured x-positions, x_i for $i = 0, 1, 2, \ldots 10$, of equally indexed vertical lines on the screen, with such lines being equally spaced by pixel count. The linearity of the vertical scan is similarly determined using the y positions, y_i for $i = 0, 1, 2, \ldots 10$, of horizontal lines. The spacing between adjacent lines is computed as the difference in x-positions, $\Delta x = x_{i+1} - x_i$ for $i = 0, 1, 2, \ldots 9$, of vertical lines. The line spacings are used to determine the horizontal non-linearity characteristic. Similarly, differences in y-positions, $\Delta y = y_{i+1} - y_i$ for $i = 0, 1, 2, \ldots 9$, of horizontal lines are calculated to determine vertical non-linearity characteristic. For each adjacent pair of lines, a non-linearity value is computed and plotted:

Horizontal non-linearity $= 100\ \% \times (\Delta x_i - \Delta x_{\text{avg}})/\Delta x_{\text{avg}}$, for $i = 0, 1, 2, \ldots 10$

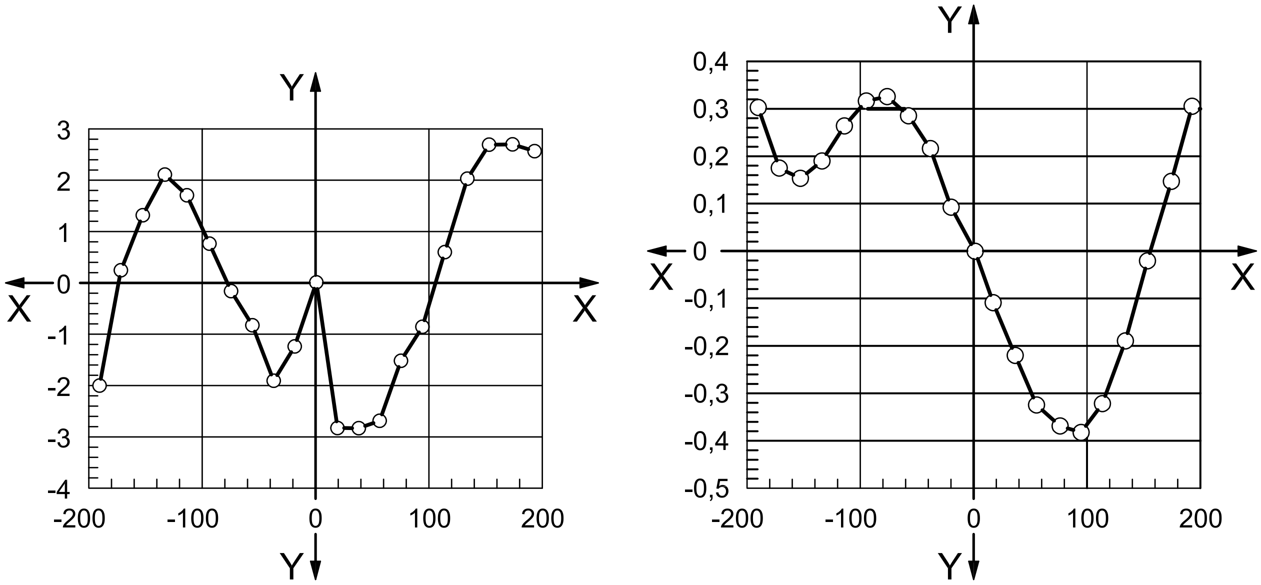
Vertical non-linearity $= 100\ \% \times (\Delta y_i - \Delta y_{\text{avg}})/\Delta y_{\text{avg}}$, for $i = 0, 1, 2, \ldots 10$

Optionally*, pixel position error* can be computed and plotted from the measured positions of the lines if one chooses the average line spacing to be the reference. Then a linear reference grid, $(x_{i\text{ref}}, y_{i\text{ref}})$ for $i = 0, 1, 2, \ldots 10$, can be numerically constructed. The measured positions of lines are then compared to the reference grid. Differences between actual measured positions of lines and the corresponding reference position of that line is expressed as a percentage of the total screen size in that direction to provide pixel position errors:

horizontal pixel position error $= 100\ \% \times (x_i - x_{i\text{ref}})/H$, for $i = 0, 1, 2, \ldots 10$;

vertical pixel position error $= 100\ \% \times (y_i - y_{i\text{ref}})/V$, for $i = 0, 1, 2, \ldots 10$.

See Figure 65.



a) Horizontal linearity **b) Horizontal pixel position error**

Key

X pixel position from centre in millimetres, mm

Y deviation, in percent of average line spacing, %

Figure 65 — Linearity and pixel position error (sample data only)

f) Reporting

Report the four maximum non-linearity values for: 1) the top half, 2) the bottom half, 3) the left side and 4) the right side of the screen, to no more than three significant figures. Optionally, report the four maximum pixel position errors for 1) the top half, 2) the bottom half, 3) the left side and 4) the right side of the screen, to no more than three significant figures.

g) Comments: accuracy of the *x,y* translation stage should be better than 0,1 % of display screen linear dimension for raster distortion (linearity, waviness) measurements.

6.10.2 P 21.2 — Linearity, short distance line distortion

a) Objective: to measure the pixel position on the displayed target in order to determine character distortion or small area geometric distortion.

b) Applicability: within small areas of the display, distortions can occur in what ought nominally to be straight features in images, characters and symbols — this measurement characterises the deviations from straightness for small areas. See Figure 66.

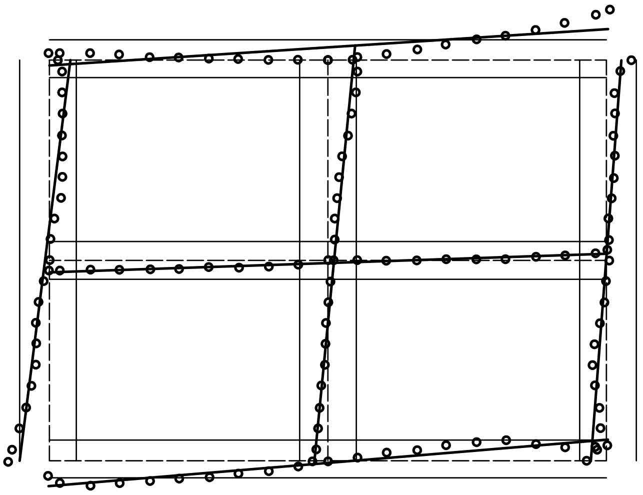
c) Preparation and set-up: in accordance with 6.10.3 (M 21.3).

d) Procedure: in accordance with 6.10.3 (M 21.3).

e) Analysis: determine the largest change between two adjacent points in both the horizontal and vertical directions.

f) Reporting: report the largest adjacent point deviation, both horizontally and vertically, to no more than three significant figures, and their respective locations.

g) Comments: accuracy of the *x,y* translation stage should be better than 0,1 % of display screen linear dimension for raster distortion (linearity, waviness) measurements.



Error bars are ± 0,1 % of screen size.

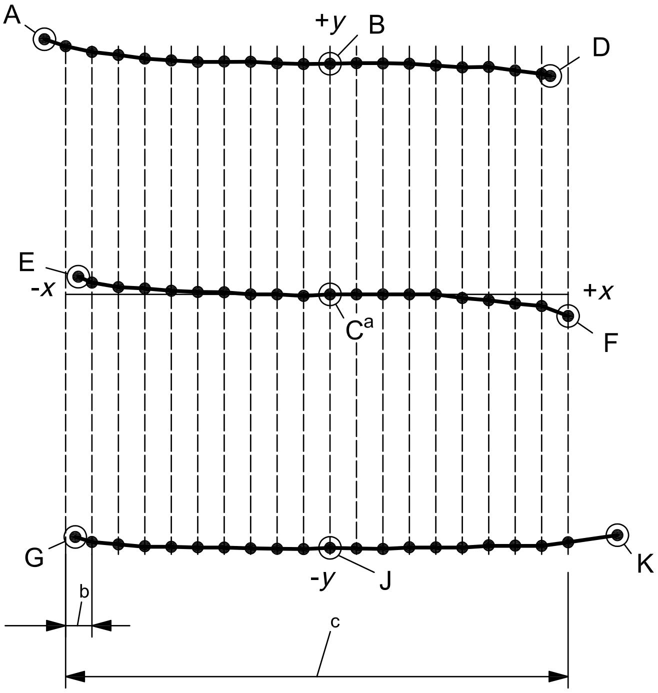
Figure 66 — Waviness errors (magnified 50× for clarity)

6.10.3 M 21.3 — Waviness

a) Objective: to measure the pixel position on the displayed target to characterise distortions that bend what should be straight lines.

b) Applicability: within small areas of the display, distortions can occur in what ought nominally to be straight features in images, characters and symbols. This measurement characterises the deviations from straightness. See Figure 66.

c) Preparation and set-up: display vertical and horizontal lines along the top, bottom and side edges of the addressable screen, as well as along both the vertical and horizontal centrelines (major and minor axes), and arrange a spatially resolved luminance meter to measure the position of the centroid of each line luminance profile. See Figure 67.



A, B, C, D, E, F, G, J and K are standard test locations.

[a] Centre-screen (x = 0, y = 0).

[b] 5 % of total ideal width of addressable screen.

[c] Total ideal width of addressable screen.

Figure 67 — Waviness measurement

For optical measurement at the standard test locations shown up to Figure 67, use vertical and horizontal lines, each 1 pixel wide. Display the lines in test pattern at 100 % grey level (white), positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centrelines (major and minor axes). It is permissible to use green instead of white lines to improve measurement repeatability and to avoid complications that can arise from large convergence errors.

d) Procedure

Use an array detector to locate the centre of line profiles in conjunction with the x,y translation stage to measure screen x,y coordinates of points along video pattern vertical and horizontal lines. Tabulate x,y positions (in mm) at equally spaced intervals (nominally 5 % addressable screen apart) along each line. In addition, include the x,y coordinates of the extreme endpoints of each line.

e) Analysis

Use linear regression to numerically fit a straight line through the measured coordinates of each line. For the horizontal lines at the top, centre and bottom of horizontal lengths, H_T, H_C, H_B, respectively, the x-axis is considered to be an independent axis, with data taken at locations, x_i, and the vertical position (the dependent variable) is fit according to $y = mx + s$. For the vertical lines at the left, centre and right of vertical lengths, V_L, V_C, V_R, respectively, the y-axis is considered to be the independent axis, with data taken at vertical locations, y_i, and the horizontal position (the dependent variable) is fit according to $x = my + s$. The following applies for all six lines.

- Top: $y_{\text{T}i}$ fit to H_T: $y_{\text{T}i} = m_\text{T} x_i + s_\text{T}$ — Left: $x_{\text{L}i}$ fit to V_L: $x_{\text{L}i} = m_\text{L} y_i + s_\text{L}$
- Centre: $y_{\text{C}i}$ fit to H_C: $y_{\text{C}i} = m_\text{CH} x_i + s_\text{CH}$ — Centre: $x_{\text{C}i}$ fit to V_C: $x_{\text{C}i} = m_\text{CV} y_i + s_\text{CV}$
- Bottom: $y_{\text{B}i}$ fit to H_B: $y_{\text{B}i} = m_\text{B} x_i + s_\text{B}$ — Right: $x_{\text{R}i}$ fit to V_R: $x_{\text{R}i} = m_\text{R} y_i + s_\text{R}$

The waviness of each line is computed as the peak-to-peak (PTP) deviation of the measured coordinates from the corresponding points along the fitted line: in the vertical direction for horizontal lines and in the horizontal direction for the vertical lines (i.e. in a direction approximately orthogonal to the line). For vertical lines, the waviness error is expressed as a percentage of the average horizontal width, H, between the vertical lines used. Similarly, for horizontal lines, the waviness error is expressed as a percentage of the average vertical height, V, between the horizontal lines used.

Vertical waviness of horizontal lines	**Horizontal waviness of vertical lines**
$V = \text{average}\ (y_{\text{T}i} - y_{\text{B}i})$	$H = \text{average}\ (x_{\text{R}i} - x_{\text{L}i})$
Top: H_T: $e = [\max(y_i - y_{\text{T}i}) - \min(y_i - y_{\text{T}i})]/V$	Left: V_L: $e = [\max(x_i - x_{\text{L}i}) - \min(x_i - x_{\text{L}i})]/H$
Centre: H_C: $e = [\max(y_i - y_{\text{C}i}) - \min(y_i - y_{\text{C}i})]/V$	Centre: V_C: $e = [\max(x_i - x_{\text{C}i}) - \min(x_i - x_{\text{C}i})]/H$
Bottom: H_B: $e = [\max(y_i - y_{\text{B}i}) - \min(y_i - y_{\text{B}i})]/V$	Right: V_R: $e = [\max(x_i - x_{\text{R}i}) - \min(x_i - x_{\text{R}i})]/H$

f) Reporting: report the peak-to-peak waviness error as a percentage of linear screen dimension, as well as large area distortions, to no more than three significant figures.

g) Comments: accuracy of the x,y translation stage should be better than 0,1 % of display screen linear dimension.

6.10.4 M 21.4 — Orthogonality

a) Objective: to use measured pixel positions from a displayed target to characterise common distortions known as trapezium (trapezoid or keystone), rotation, orthogonality and pincushion.

b) Applicability: all display technologies.

c) Preparation and set-up

Display vertical and horizontal lines along the top, bottom and side edges of the addressable screen, as well as along both the vertical and horizontal centrelines (major and minor axes), and arrange a spatially resolved luminance meter to measure the position of the centroid of each line luminance profile.

For optical measurement at the standard test locations, as shown in Figure 66, use vertical and horizontal lines, each 1 pixel wide. Display the lines in test pattern at 100 % grey level (white), positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centrelines (major and minor axes). It is permissible to use green instead of white lines to improve measurement repeatability and to avoid complications that may arise from large convergence errors.

d) Procedure

Use an array detector to locate the centre of line profiles in conjunction with the *x,y* translation stage to measure screen *x,y* coordinates of points along video pattern vertical and horizontal lines. Tabulate *x,y* positions (in mm) at equally spaced intervals (nominally 5 % addressable screen apart) along each line. In addition, include the *x,y* coordinates of the extreme endpoints of each line.

e) Analysis: characterise the two types of large-area distortions — the linear distortions known as trapezium, rotation and orthogonality, and the quadratic distortion known as pincushion (or barrel).

Linear distortions

Use the linear regression results of the previous measurement, according to 6.10.3, to establish the locations of the cardinal points, p, as shown in the figures up to Figure 66, where p can be A, B, D, E, C, F, G, J and K, associated with the intersections of the linear-fit lines at locations x_p, y_p, where:

$$x_p = \frac{m_h\ m_v + s_h}{1 - m_h\ m_v}, \quad y_p = \frac{m_v\ sh + m_v}{1 - m_h\ m_v} \tag{32}$$

and where, for each p, the horizontal lines, h, and vertical lines, v, have subscripts according to Table 6.

Table 6 — Subscript notation for line distortions

Subscript notation: T = top, C = centre, B = bottom, L = left, R = right									
p =	A	B	D	E	C	F	G	J	K
h =	T	T	T	CH	CH	CH	B	B	B
v =	L	CV	R	L	CV	R	L	CV	R

See Figure 68.

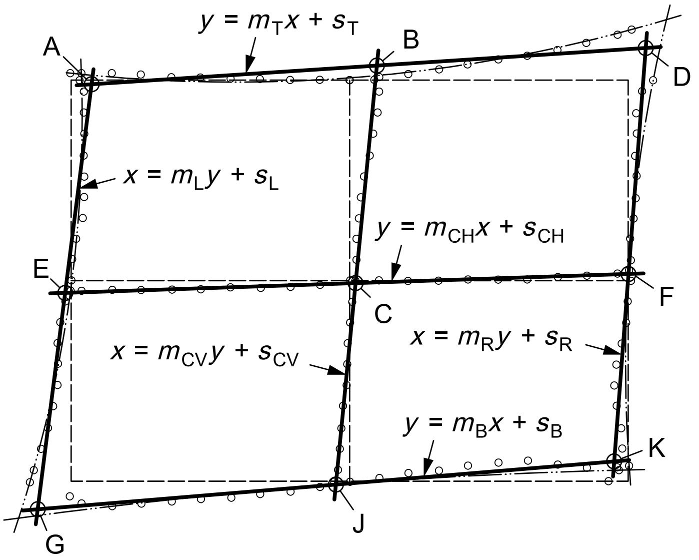


Figure 68 — Line distortion test locations and analysis

Trapezium, rotation, and orthogonality measurements are based upon the linear fits to the data as follows.

— Horizontal trapezium (or trapezoid), δ_{TH}, characterises any linear picture height change in the horizontal direction:

$$\delta_{\mathrm{TH}} = 2\,\frac{\left(\overline{AG} - \overline{DK}\right)}{\left(\overline{AG} + \overline{DK}\right)} \times 100\ \% \tag{33}$$

$$\text{where } \overline{AG} = \sqrt{\left(x_A - x_G\right)^2 + \left(y_A - y_G\right)^2} \tag{34}$$

$$\text{and } \overline{DK} = \sqrt{\left(x_D - x_K\right)^2 + \left(y_D - y_K\right)^2} \tag{35}$$

— Vertical trapezium (or trapezoid) δ_{TV}, characterises any linear picture width change in the vertical direction:

$$\delta_{\mathrm{TV}} = 2\,\frac{\left(\overline{AD} - \overline{GK}\right)}{\left(\overline{AD} + \overline{GK}\right)} \times 100\ \% \tag{36}$$

$$\text{where } \overline{AD} = \sqrt{\left(x_A - x_D\right)^2 + \left(y_A - y_D\right)^2} \tag{37}$$

$$\text{and } \overline{GK} = \sqrt{\left(x_G - x_K\right)^2 + \left(y_G - y_K\right)^2} \tag{38}$$

— Each major and minor axis can have a different rotation from the horizontal and vertical — the rotation of horizontal axis (major axis for a landscape display) is θ_{RH}, while the rotation of the vertical axis (minor axis for a landscape display) is θ_{RV}:

$$\Theta_{\mathrm{RH}} = \arctan\left(\frac{y_{\mathrm{F}} - y_{\mathrm{E}}}{x_{\mathrm{F}} - x_{\mathrm{E}}}\right) \text{ and } \Theta_{\mathrm{RV}} = \arctan\left(\frac{y_{\mathrm{B}} - y_{\mathrm{J}}}{x_{\mathrm{B}} - x_{\mathrm{J}}}\right) \tag{39}$$

with x_p and y_p being the intersection points of the linear-fit lines, where p = A,B…K, and where (x_{E},y_{E}) and (x_{F},y_{F}) are the intersection points at p = E and p = F, respectively.

— For orthogonality, a measure of how much the screen looks like a parallelogram (an alternative name for this distortion) is given by:

$$\delta_{\mathrm{O}} = 2\,\frac{\left(\overline{AK} - \overline{DG}\right)}{\left(\overline{AK} + \overline{DG}\right)} \times 100\ \% \tag{40}$$

$$\text{where } \overline{AK} = \sqrt{\left(x_A - x_K\right)^2 + \left(y_A - y_K\right)^2}$$

$$\text{and } \overline{DG} = \sqrt{\left(x_D - x_G\right)^2 + \left(y_D - y_G\right)^2}$$

Pincushion (quadratic) distortions

Fit a second-order polynomial curve to each of the six lines, three vertical and three horizontal. Determine the new locations of the cardinal points A′, B′, D′, E′, C′, F′, G′, J′, and K′ associated with the intersections of the quadratic-fit lines (see Figure 69). The closed-form solutions to the intersection locations (x_p, y_p) are the roots of fourth-order polynomials and are particularly ugly. Usually, numerical methods are used rather than attempting to fill the page with the analytical solution. Probably the crudest way to solve for the intersections is to use a spreadsheet: select an x_H value along a horizontal line near an intersection; determine the corresponding y value for the horizontal line $y = a_\text{H}x_\text{H}{}^2 + b_\text{H}x_\text{H} + c_\text{H}$, and put this y back into the equation for the vertical intersecting line $x_\text{V} = a_\text{V}y^2 + b_\text{V}y + c_\text{V}$; then find the x_H that gives the same x_V, then $x_p = x_\text{H} = x_\text{V}$ and $y_p = y$.

$$\delta_\text{PT} = 2\,\frac{(y_A + y_D) - y_B}{\left(\overline{A'G'} + \overline{D'K'}\right)} \times 100\ \% \tag{41}$$

$$\delta_\text{PB} = 2\,\frac{(y_G + y_K) - y_J}{\left(\overline{A'\,G'} + \overline{D'K'}\right)} \times 100\ \% \tag{42}$$

$$\delta_\text{PL} = 2\,\frac{(x_A + x_G) - y_E}{\left(\overline{A'D'} + \overline{G'K'}\right)} \times 100\ \% \tag{43}$$

$$\delta_\text{PR} = 2\,\frac{(x_D + x_K) - x_F}{\left(\overline{A'\,D'} + \overline{G'K'}\right)} \times 100\ \% \tag{44}$$

where $$\overline{A'G'} = \sqrt{(x_{A'} - x_{G'})^2 + (y_{A'} - y_{G'})^2} \tag{45}$$

$$\overline{D'K'} = \sqrt{(x_{D'} - x_{K'})^2 + (y_{D'} - y_{K'})^2} \tag{46}$$

$$\overline{A'D'} = \sqrt{(x_{A'} - x_{D'})^2 + (y_{A'} - y_{D'})^2} \tag{47}$$

and $$\overline{G'K'} = \sqrt{(x_{G'} - x_{K'})^2 + (y_{G'} - y_{K'})^2} \tag{48}$$

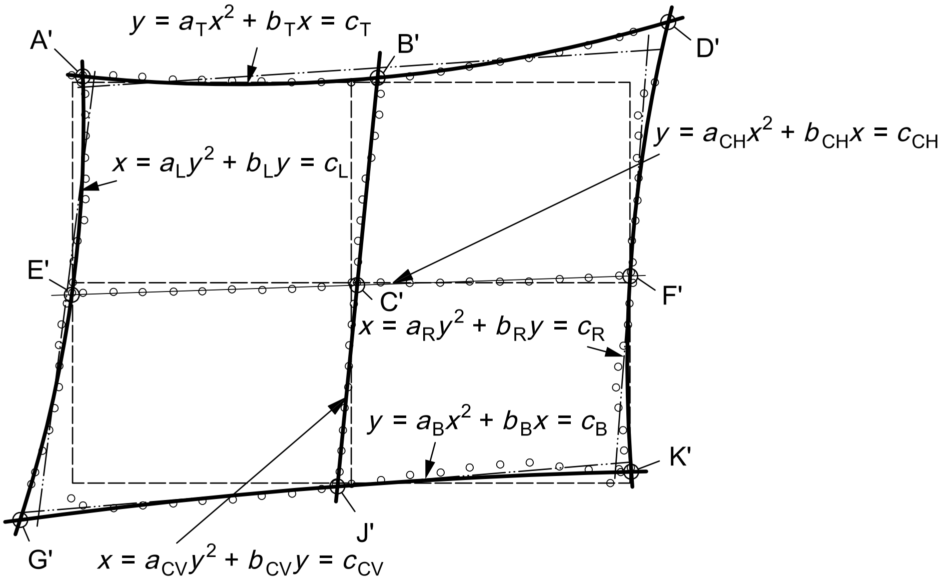


Figure 69 — Pincushion distortion analysis

f) Reporting: report large area distortions to no more than three significant figures.

g) Comments

Accuracy of the x,y translation stage should be better than 0,1 % of display screen linear dimension for raster distortion (linearity, waviness) measurements. If an accurate grid can be obtained (either a transparent mask that covers a direct-view display or a grid on a projection screen), it may be possible to obtain the location of the cardinal points from a direct measurement using the grid without the use of a positioning system. This is particularly true for well-behaved displays where these distortions are small. In such a case, the locations of the cardinal points are determined using a pattern where single-pixel white lines mark the centrelines (or nearly centre) and the edges, or where even single white pixels can be placed at the cardinal points.

6.10.5 P 21.5 — Symbol distortion

a) Objective: to measure the variation of character height and width for a particular character font displayed at various locations on the screen.

b) Applicability: CRT-based displays.

c) Preparation and set-up

1) Test accessories: see 5.2.7 replica masks (optional).

2) Fixed measurement conditions

- Measurement field: see 5.6.2 within a pixel.
- Meter angular aperture: see 5.7 angular aperture.
- Meter response time: see 5.8.2 time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.1 character width target “H” or equivalent.
- Measurement location: see 5.4.3 standard five locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: N/A.
- Spectral characteristics: luminance only.

d) Procedure: for all measurement locations, measure the luminance profile of the character, in both vertical and horizontal directions, according to either 6.2.1 (M 13.1) or 6.2.2 (M 13.2).

e) Analysis

1) Determine character height and width for each character using the measured luminance profiles. The character edge is defined as extending to the 50 % of luminance difference between the character and the background.

2) Character height and width shall be the mean dimensions of the character “H” or of an equivalent test object presented in the five test locations.

3) Calculate variations from the mean dimensions for each measurement location.

f) Reporting: report variation in character height and width for each location.

g) Comments

Character height and width for a particular character font are the distance between the appropriate parallel edges of a non-accented capital letter (see Figures 6 and 7). For the purposes of this procedure, the capital letter “H” shall be used to define the character height and width. However, “H” may be unsuitable for measurement of character height. Therefore, a test object having the same number of pixels between its measured features as a capital “H” may be used for character height and width measurements.

6.10.6 M 21.7 — Cosmetic defects including face plate defects

a) Objective: to observe and record any unacceptable cosmetic defects on the display surface or its housing.

b) Applicability: all display technologies.

c) Preparation and set-up: none.

d) Procedure: display, alternately, a white then black full-screen pattern, then inspect the display for imperfections of the display surface that are visible and detract from the display’s functionality.

e) Analysis: none.

f) Reporting: report any cosmetic defect, together with its type, size, shape and location.

g) Comments: cosmetic defects include cuts, gouges, pullouts, misalignment of parts, dents, scratches, cracks, stains on components, smears, bubbles, bumps, and other imperfections; they do not include pixel defects or non-uniformities on the display surface [see 6.6.2 (P 17.2)].

6.10.7 M 21.8 — Colour effects based on misconvergence

a) Objective: to measure the separation or convergence errors between primaries of the colour display.

Convergence is measured at nine (or 25) specified points on the screen and reported as the maximum distance between any two primary colours.

b) Applicability: all colour display technologies.

c) Preparation and set-up

Display a full-screen crosshatch test pattern, and arrange the spatial luminance meter so as to measure the line luminance profiles at nine (or 25) positions. See Figure 12. The corner points are 1/10 the screen height and 1/10 the screen width from the edge of the image displaying surface. Positioning uncertainty need only be ± 0,1 pixels, and the normal direction should be maintained. See 5.1 for any standard set-up details.

1) Test accessories

2) Fixed measurement conditions

— Measurement field:	see 5.6.2	within a pixel.
— Meter angular aperture:	see 5.7	angular aperture.
— Meter response time:	see 5.8.2	time-averaging meter.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

- Test patterns: see 5.3.15 horizontal bars — 100 % colour varying pixel width, 100 % black, one pixel width, alternating.

  see 5.3.16 vertical bars — 100 % colour varying pixel width, 100 % black, one pixel width, alternating.
- Measurement locations: see 5.4.3 standard five locations.
- Meter direction: see 5.4.1 normal to display screen/normal to display surface.
- Test illumination: N/A.
- Spectral characteristics: N/A.

d) Procedure

1) Visually examine the crosshatch pattern for overall convergence performance. Record measurements at any screen location where significant misconvergence is apparent but not able to be characterised at the standard screen test locations. Separately measure vertical and horizontal misconvergence at the standard screen test points, using appropriate horizontal and vertical grille test patterns of lines from 1 pixel to 5 pixels wide for each primary, e.g. R, G, B.

2) Use a spatially-calibrated array detector or luminance microprofile meter to measure the luminance profiles of the lines at each measurement location and determine the horizontal x_R, x_G, x_B, and vertical position y_R, y_G, y_B of the centroid of each horizontal and vertical luminance profile in units of mm or pixels, $(x_R, y_R)_i$, $(x_G, y_G)_i$, $(x_B, y_B)_i$, for $i = 1, 2, \ldots n$ at each measurement location. It is sometimes helpful to average a number of luminance profiles to provide a more reproducible measurement of the centroids of the line profiles. See 6.2.2 (M 13.2).

e) Analysis

1) From the collected centroid data, determine the line separations $(\Delta x_{BR}, \Delta y_{BR})_i$ between the blue and red line centroids at each of the measurement locations [optionally, determine the green-with-respect-to-red line centroid separation $(\Delta x_{GR}, \Delta y_{GR})_i$], where

$$\left(\Delta x_{BR} = x_B - x_R\right)_i, \quad \left(\Delta y_{BR} = y_B - y_R\right)_i \tag{49}$$

and, optionally,

$$\left(\Delta x_{GR} = x_G - x_R\right)_i, \quad \left(\Delta y_{GR} = y_G - y_R\right)_i \tag{50}$$

2) Determine the maximum horizontal and vertical separations for blue with-respect-to-red lines and, optionally, for green-with-respect-to-red lines.

f) Reporting

Report the number of samples used along with their average value. Report $(\Delta x_{BR}\ \Delta y_{BR})_i$ for all measurement locations to no more than three significant figures. Report the maximum line separations as the convergence error in mm or pixels. If a number of luminance profiles are averaged to provide the centroid measurement, the number of profiles that are averaged should be reported.

g) Comments

For colour CRT, measurements of centroids can be subject to large errors depending on the detector sampling and the aliasing between the beam and the shadowmask. Repeat measurements of luminance profiles at slightly different screen positions, offset by subpixel distances if possible, in order to randomise the sampling pattern of the luminance profile. Ensure that the number of measurement samples is adequate. Acceptable results have been obtained using at least seven samples. Each sample is offset from the specified pixel position by ± 1, ± 2, and ± 3 pixel spacings for a total of seven measurements, including the starting location. It is important to report whether the convergence measurements are made sequentially or simultaneously, e.g. for white. In CRT, space-charge repulsion forces between electron beams can significantly impact the convergence of the beams at the screen.

6.10.8 P 21.9 — Raster modulation

a) Objective: to determine the raster modulation.

b) Applicability: all variable-resolution displays.

c) Preparation and set-up

1) Test accessories:	see 6.2.1	luminance profile using green profile.
	see 6.2.2	luminance profile with smoothing algorithm.
2) Fixed measurement conditions:	see 6.2.1	luminance profile using green profile.
	see 6.2.2	luminance profile with smoothing algorithm.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns:	see 5.3.15	horizontal bars — 100 % green, one pixel width, 100 % black, one pixel width, alternating.
	see 5.3.16	vertical bars — 100 % green, one pixel width, 100 % black, one pixel width, alternating.
— Measurement location:	see 5.4.5	standard nine locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:		N/A.
— Spectral characteristics:		only luminance required.

d) Procedure: measure the raster modulation, in accordance 6.2.1 (M 13.1) 6.2.2 (M 13.2) — either method may be used — by obtaining a luminance profile along a line passing through adjacent raster lines.

e) Analysis: the raster modulation is the modulation between the mean of the maxima and the mean of the minima along a profile that, for multicolour displays, should include at least nine lines.

f) Reporting: report the raster modulation between and the actual resolution of the luminance profile for the worst location.

g) Comments: none.

6.10.9 M 21.10 — Fill Factor

a) Objective: to measure the pixel fill factor using an area LMD or to calculate it based on design parameters.

The pixel fill factor is the amount of the area producing useful luminance compared to the amount of the area allocated to the pixel.

b) Applicability: all fixed-resolution displays.

Some displays have well-defined pixels because of a known black matrix. In such cases, the pixel fill factor may be calculated from geometry.

NOTE For the purposes of this measurement, *subpixels* are referred to for the case of colour displays. For measuring monochrome displays, read “pixel” for “subpixel.”

c) Preparation and set-up: N/A.

d) Procedure/analysis

1) Well-defined subpixels

For many display technologies, the subpixel matrix mask and resulting pixels are well-defined and relatively uniform (say, ± 20 % of the average luminance). In such cases, the fill factor, f, may be calculated from geometry if the design spatial parameters are known, or it may be calculated by measuring the sizes of the subpixels:

i) sum up the area of the subpixels, $s = s_{\mathrm{red}} + s_{\mathrm{grn}} + s_{\mathrm{blu}}$, and divide by the area, a, allocated to the pixel, $a = P_{\mathrm{H}} P_{\mathrm{V}}$, where s_i is the area of each subpixel, P_{H} is the pixel pitch in the horizontal direction, and P_{V} is the pixel pitch in the vertical direction;

ii) the fill factor is $f = s/a$.

2) Non-uniform subpixels

With other technologies where the subpixel is not uniform in its cross-section as viewed, use a spatially resolved LMD to measure the luminance distribution of each subpixel. The LMD need not be calibrated in units of luminance, but it should be linear over the range of luminances measured.

i) Using a white screen, select one pixel near the centre of the screen that appears to be typical (± 10 % of average in the centre region). For each subpixel, i, within that pixel, determine the peak subpixel level, S_i.

ii) Locate the darkest detector pixel in the near vicinity of the selected pixel (such as within the black matrix mask that separates the subpixels or within some other available structure that is black), then determine the minimum of the black area (its dimness), S_{d}. This dimness value includes the true black value, S_{b}, and any additional glare, S_{g}, so that $S_{\mathrm{d}} = S_{\mathrm{b}} + S_{\mathrm{g}}$.

iii) Call the measured luminance of any detector pixel within the subpixel, $S_i(x,y)$, where x,y denotes the location of the detector pixel. The net luminance of each detector pixel within any subpixel is then the measured luminance with the true black value and the glare subtracted $K_i(x,y) = S_i(x,y) S_{\mathrm{g}} S_{\mathrm{b}} = S_i(x,y) S_{\mathrm{d}}$.

iv) The net maximum luminance is given by $S_i - S_{\mathrm{g}} - S_{\mathrm{b}}$.

v) Now, determine the area, s_i (in number of detector pixels), of each subpixel for which the net luminance of that subpixel $K_i(x,y)$ is not less than a certain threshold fraction, τ, of the net maximum luminance: $K_i(x,y) \geqslant \tau\,(S_i - S_{\mathrm{g}} - S_{\mathrm{b}})$ or $K_i(x,y) \geqslant \tau\,(S_i - S_{\mathrm{d}})$. This can be rewritten in terms of the measured quantities $S_i(x,y) \geqslant S_{\mathrm{d}} + \tau\,(S_i\, S_{\mathrm{d}}) = \tau S_i + (1\ \tau) S_{\mathrm{d}}$, which probably could have been written down directly.

vi) The threshold fraction, τ, used should be reported. Either 5 % ($\tau = 0{,}05$) or 10 % ($\tau = 0{,}1$) is recommended.

vii) The fill factor is then defined as $f = s/a$, where $s = \Sigma s_i$ is the area (in detector pixels) of all subpixels brighter than the threshold relative to each subpixel, and $a = P_\mathrm{H} P_\mathrm{V}$ is the area allocated to the entire pixel.

NOTE 1 Some documents use a 50 % threshold. However, the eye perceives the size closer to the 5 % or 10 % threshold. In fact, a 50 % level to the eye is an L^* of 0,5, whereby $L^* = (L/L_\mathrm{W})^{(1/3)}$ gives a luminance for 50 % perception of $L = 0{,}125\ L_\mathrm{W}$. This underscores the reasonableness of the 5 % or 10 % value for the threshold.)

NOTE 2 The veiling glare does not ultimately have to be measured explicitly, since it is implicitly contained within S_d.

It is recommended that the magnification of the optical system be sufficiently high such that the smallest horizontal or vertical dimension of each subpixel can be resolved and quantified by at least 10 detector pixels (preferably more) assuming an array detector is used. Use a calibrated ruler such as a graticule scale for a measuring loupe or a microscope calibration ruler in order to determine the size associated with each array detection pixel should their areas need to be measured. Then, simply count the number of array detection pixels that have a luminance greater than or equal to the threshold, $S_\mathrm{d} + \tau (S_i - S_\mathrm{d})$, for each display subpixel within a pixel.

It needs to be kept in mind that if an optical system is used such as a microscope or a system where the lens of the LMD subtends a significant angle (large θ_L), the uncertainty in the measurement increases. The lens subtense limit specified in this document is 2° and is difficult to maintain in producing high-magnification images unless a long-distance microscope is used. Tests may have to be done to assure that too wide a lens subtense angle will not perturb the measurements; see VESA-2005-5 [10], section A101, under “Diagnostic — Verification of Subtense Angle Suitability of the LMD”. Most users will be faced with using a lens system that exceeds the 2° limit. If that is the case, a note of the optical arrangement should be made in the reporting document. In all cases, report the fill factor and the threshold fraction employed.

e) Reporting: report the threshold (if used), the area of the display pixel, the area of the display subpixels above the threshold (if used), and the fill factor — the latter to no more than three significant figures — and when reporting in percent, round off to the nearest integer percent.

f) Comments: none.

6.10.10 M 21.11 — Whole screen visual screening to find geometric distortions and artefacts

a) Objective: to visually determine the locations of the worst geometric distortions and artefacts from a specified distance and under a specified illumination.

b) Applicability: CRT-based displays.

c) Preparation and set-up

1) Test accessories: none.

2) Fixed measurement conditions: none.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns:	see 5.3.10	grid pattern.
— Measurement location:	see 5.4.9	visual determination.
— Test illumination:		N/A.

d) Procedure: visually determine locations on screen where the worst geometric distortions and artefacts can be observed.

e) Analysis: none.

f) Reporting: report locations and description of worst-case geometric distortions and artefacts.

g) Comments: none.

6.10.11 P 21.12 — Display loading

a) Objective: to measure the luminance of a white box with a black background as the size of the box is adjusted from a small fraction of the screen to full-screen.

b) Applicability: Luminance loading is said to occur when the luminance of a white area on a screen changes as the white area changes its size. In some cases this can be a desirable effect, in other cases it can be objectionable. This method is a way to characterise the effect luminance loading.

c) Preparation and set-up

1) Test accessories: see 6.1.1 basic spot measurement.

2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.23	box patterns — use a sequence of centred white boxes on a black back ground with the size of the boxes being $kh \times kv$, where $k =$ 0,05; 0,1; 0,2; ...; 0,9; 1,0.
— Measurement location:	see 5.4.8	centre-screen measurement location.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:		N/A.
— Spectral characteristics:		luminance only.

d) Procedure: measure the test patterns with in accordance with 6.1.1 (M 12.1).

e) Analysis

1) Calculate the ratio of the difference in percent of the extreme value from L_{EXT} and L_{W}, with a luminance loading of 100 %($L_{\text{EXT}} - L_{\text{W}})/L_{\text{W}}$, where L_{W} is the full screen white luminance and L_{EXT} is the screen luminance furthest in value from L_{W}.

2) Plot the luminance of the box vs. the area of the box (HVk^2) or the luminance of the box vs. the k factor (in percent or as a decimal).

f) Reporting: report the full-screen white and black luminances, the minimum box size used, the maximum box luminance and the resulting loading.

g) Comments

If the smaller boxes are less than 110 % of the minimum measurement FOV, a veiling glare frustum can be necessary. Arrange the frustum over the screen with a hole of diameter 0,045 times the lesser of H or V, and make all measurements with the mask and LMD rigidly fixed in place.

6.10.12 P 21.13 — Checkerboard contrast

a) Objective: to measure the checkerboard contrast.

b) Applicability: all display technologies.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

   3) Configurable measurement conditions (use parameters as described unless otherwise specified)

      - Test pattern: see 5.3.24 checkerboard pattern — use 4 × 4 checkerboard.
      - Measurement location: see 5.4.6 projector — 16 locations.
      - Meter direction: see 5.4.1 normal to display screen/normal to display screen.
      - Test illumination: N/A.
      - Spectral characteristics: luminance only.

d) Procedure: measure all checkerboard rectangles in accordance with see 6.1.1 (M.12.1).

e) Analysis

   Calculate the average checkerboard contrast:

$$C_{\mathrm{Cave}} = \frac{1}{n} \sum_{i=E}^{n} \frac{L_{\mathrm{w}}}{L_{\mathrm{b}}}$$

   where, n, the number of black and white checkerboard pairs, is equal to 8, and L_{w} and L_{b} are the full-screen white and full-screen black luminances.

f) Reporting: report the checkerboard contrast ratio.

g) Comments: none.

6.10.13 P 21.14 — Halation

a) Objective: to measure the luminance of a black box with a white background as the size of the box is adjusted from a small fraction of the screen to full-screen.

b) Applicability: halation is said to occur when light from surrounding white areas corrupts a black area on the screen, and this measurement is a means of characterising the amount of halation for a black box at the centre of a white screen.

c) Preparation and set-up

   1) Test accessories: see 6.1.1 basic spot measurement.

   2) Fixed measurement conditions: see 6.1.1 basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern:	see 5.3.23	box patterns — use a sequence of centred black boxes on a white background with the size of the boxes being $kh \times kv$, where $k = 0{,}05; 0{,}1; 0{,}2; ...; 0{,}9; 1{,}0$.
— Measurement location:	see 5.4.8	centre-screen.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:		N/A.
— Spectral characteristics:		luminance only.

d) Procedure: measure the test patterns in accordance with 6.1.1 (M 12.1).

e) Analysis

1) Calculate the ratio of the difference between the maximum box luminance, L_{max}, and the full-screen black luminance, L_{b}, to the full-screen white luminance, L_{w}, as the halation in percent, $100\ \%(L_{\text{max}} - L_{\text{b}})/L_{\text{w}}$.

2) Plot the luminance of the box vs. the area of the box (HVk^2), or the luminance of the box vs. the k factor (in percent or as a decimal).

f) Reporting: report the full-screen white and black luminances, the minimum box size used, the maximum box luminance and the resulting halation.

g) Comments: if the smaller boxes are less than 110 % of the minimum measurement FOV, arrange a frustum mask over the screen with a hole of diameter 0,045 times the lesser of the H or V, and make all measurements using the mask.

6.10.14 M 21.16 — Shadowing

a) Objective: to measure the worst-case shadowing in eight-levels of grey.

b) Units: percentage perturbation of the luminance of the grey shade.

c) Symbol: none.

d) Applicability: all display technologies.

e) Preparation and set-up

1) Test accessories:	see 6.1.1	basic spot measurement.
2) Fixed measurement conditions:	see 6.1.1	basic spot measurement.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test patterns:	see 5.3.34	shadowing set-up.
	see 5.3.35	shadowing measurement.
— Measurement location:	see 5.4.3	standard five locations.
— Meter direction:	see 5.4.1	normal to display screen/normal to display screen.
— Test illumination:		N/A.
— Spectral characteristics:		luminance.

f) Procedure

1) Using a series of diagonal boxes of eight grey shades, change the background grey shade over all eight grey shades (other patterns are acceptable so long as the entire combination of the eight grey shades is examined for shadowing). Look for the worst case of shadowing. It could be necessary to quickly measure the shadowing: if L_s is the perturbed luminance of the background and L_{bkg} is the background luminance without perturbation, then the shadowing measure is $|L_s - L_{bkg}|/L_{bkg}$. Once the worst-case shadowing grey shades, G_{bkg} and G_s, have been determined, proceed to the next step.

2) There are a total of ten patterns used in this measurement: five single box patterns and five full-screen grey-level patterns, interleaved. As shown in Figure 70 (see under “Measuring areas”), the sequence of five box patterns has a box placed, sequentially, above (A), to the left of (B), to the right of (D), below (E) and at the centre (C) of the screen, with one box for each pattern. This, left-to-right, top-to-bottom, is the reading order in several languages. The edge boxes are centred along the closest side. The box sides are approximately 1/5 to 1/6 the width and height of the screen, and the box is separated from the edge of the screen by approximately half its width or height. Placement of the boxes should be ± 5 % of the linear dimensions of the screen. The command level of the boxes is G_s and the background command level is G_{bkg}. Each one-box pattern is separated in the sequence by a blank full screen of grey level, G_{bkg}.

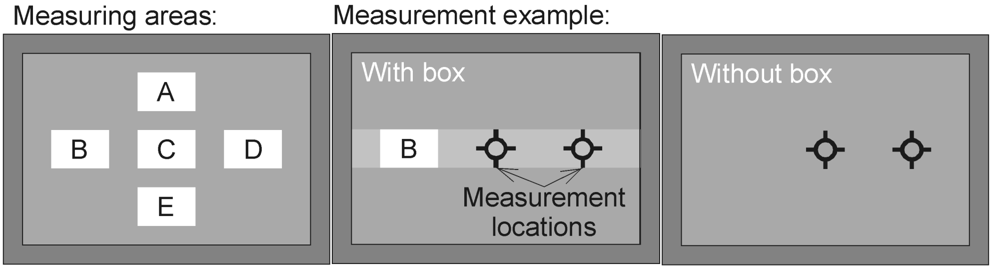


Figure 70 — Shadow measurement — Box pattern with example of procedure

3) After having selected the worst-case shadowing during the initial set-up, start with an edge box, for example, at the B position, as shown in Figure 70 (see under “Measurement example”). Measure the luminance at centre and at the position opposite to the box (D). Go to the next pattern without the box and measure at position C, at the centre. Repeat this procedure for the other edge boxes (at A, D, and E). When the box is at centre position C, measure at each of the other box positions A, B, D and E (not at the centre, obviously). The exact position of the area at which the measurement is made does not need to be precise — to within ± 5 % of the linear dimensions of the screen is sufficient. Determine the worst-case shadowing configuration (i.e. showing the greatest change in luminance with and without the box present). Select the worst-case shadowing box position from all the measurements made and secure the LMD in the position to repeat the measurement of the worst-case configuration. With the LMD in a secure position so it will not move relative to the screen, measure the luminances, Ls, with the box present, and Lbkg, without the box present. Critical alignment of the LMD is not necessary; but when the final measurement is made it is important that the LMD not move relative to the screen.

g) Analysis: Express the shadowing as a percentage: $S = 100\ \%\ |L_s - L_{bkg}|/L_{bkg}$.

h) Reporting

Report the following:

1) the maximum shadowing in percent, and where the measurement was made;

2) the background grey shade as a percentage of white (white being 100 % and black, x %, the fraction that black is of white) and/or level (7 = white, 0 = black);

3) the box grey shade (reported in the same format as the background);

4) the position of the box used (A-D) to produce the shadowing.

In the report sample below, B refers to luminance taken with the box present, and N to the luminance taken with no box present.

Shadowing = 100%$\|B - N\|$/N ``(303–4)			
Box at (A–D)	C	L (cd/m^2)	
Box (0–7)	0	$B =$ box	95
Bkg. (0–7)	7	$=$ no box	103
Shadowing, %:		7,8 %	

i) Comments

Depending upon the technology, there could be some dependencies on grey scale (addressed in this procedure) and colour (not directly addressed herein). Sixteen grey levels can optionally be used if desired. The worst case is generally display-dependent, in which case both the luminance level of the offending box and the background should be determined. Be careful of changing positions when taking the final luminance measurements because of the non-uniformity that may be inherent in the screen. If a stable mount cannot be provided, as when using a hand-held meter, consider using an alignment mask (an opaque card with appropriately placed holes through which the screen is measured).

Adaptation of the method to include colours is straightforward. After determining the two-colour combination that produces the most offensive shadowing, follow the same procedure as above, but also measure the chromaticity coordinates (x,y). Instead of calculating a percent fractional change in luminance, compute a colour change metric such as $\Delta u'v'$ for only colour changes, or ΔE to include the effects of luminance changes as well.

6.11 Alignment of virtual image displays

6.11.1 M 23.1 — Goniometric measurements of virtual images

a) Objective: to measure various goniometric quantities of the virtual image(s) produced by a near-to-eye display — quantities that can then be used to assess the general quality of the NED optics, and determine whether or not they meet the ergonomic requirements for such devices.

b) Applicability: monocular (single eye) and biocular (both eyes, separate optics, identical images) near-to-eye displays, which produce a virtual image.

This procedure does not apply to stereoscopic vision (different image for each eye) or two-eye monocular (one large optics for both eyes) devices.

c) Preparation and set-up

1) Test accessories: see 5.5.6 virtual image display goniometer.

2) Fixed measurement conditions: see 5.5.6 virtual image display goniometer.

3) Configurable measurement conditions (use parameters as described unless otherwise specified)

— Test pattern: see 5.3.33 5 × 5 checkerboard pattern with crosses.

— Measurement location: see 5.4.5 standard nine locations.

NOTE The standard nine locations are referred to as the image centre, edges and corners in the following.

- **Preparation**
  - i) Attach the EUT (equipment under test) firmly into the meter, keeping the EUT as level as possible (i.e. attempt to maintain the interocular line of the theoretical user parallel to the Y-axis).
  - ii) Display the test pattern in the EUT.
  - iii) Visually estimate the location of the EUT optical axis. Look through the ocular from a distance of 20 to 30 cm: a small portion of the test pattern can be seen — now find the centre.
  - iv) Place the moving telescope (or camera head with optics) on the optical axis, allowing an eye-relief of a few millimetres, but not more — the telescope should be well within the QVS (qualified viewing space) so that the entire virtual screen is clearly visible from this one spot only by turning the telescope.
  - v) Point the telescope toward the pattern centre and verify that the image can clearly be seen. Adjust for focus, re-adjust for position if necessary. Then turn the telescope and verify that the image edges can also be seen clearly. If they cannot, then the telescope is probably outside the QVS. Adjust for position as necessary.
  - vi) Point the telescope toward the left edge of the image, then move left until the image is no longer visible.
  - vii) Verify that no moving part of the meter has come into physical contact with the EUT, including the frame. If it did, adjust the set-up accordingly and start again from step i).
  - viii) Return the telescope to the centre.
  - ix) Repeat steps vi) to viii) for each edge and corner of the ocular.
  - x) Repeat steps iii) to ix) for the other ocular, if applicable (binocular devices).
  - xi) Finally, leave the telescope on the centreline.

The preparatory check-up can sometimes be a long and tedious process — the fastest way to do it is correctly the first time.

d) Procedure

See 6.11.2 and 6.11.3 for criteria for locating the edge of the QVS.

Refining the location of the optical centre axis

1) Initially, the telescope is on the (initially estimated) optical centreline. Record the location and the gaze angle values.
2) Point the telescope toward the image left edge and move left until the edge of the QVS is met.
3) Record the distance moved. (It is advisable, however, to always record all five readings.)
4) Return to the starting point and repeat steps 2) and 3) for the right edge.
5) Calculate the midpoint between the recorded QVS edges and move the telescope there.
6) Repeat steps 2) to 5) for the upper and lower image edges.
7) Record the new centreline position (including angles). This is the *base position* at which to begin and return to after each measurement. (It can be advisable to set the base position as the new origin for the X,Y and Z coordinates. The base position will be referred to as the origin later on.)
8) Measure the eye relief — the distance from the aperture stop of the telescope to the first surface of the EUT along the optical centre axis.

If one or more of the following three measurements is not required, the corresponding part may be omitted in the procedure. Normally, all three will be performed.

Measuring distortion

1) Record the image centre position. (This is done throughout the process at regular intervals in order to estimate the accuracy of the measurement and to make sure the EUT has not moved during the measurement.)

2) Point the telescope at the left edge and record the coordinates. (X,Y and Z need not be re-written, as the telescope has not moved.)

3) Repeat step 2) for the remaining seven measurement locations (edges and corners). Re-record the centre coordinates after every two or three measurements.

Measuring focal distance

1) Point the telescope at the image centre and adjust for best focus.

2) Record the focal length either by direct read-out of a calibrated scale (if available), or by pointing the telescope away from the EUT and using a test target and a measure to find it out experimentally.

3) Repeat for the remaining eight positions.

NOTE 1 The focal distance measurement can be problematic, if the QVS of the EUT is small. A narrow aperture stop will keep the image clearer, but will also result in large depth of focus and therefore low accuracy. Increasing the aperture width makes the depth of focus shorter, but will often blur the image to such an extent that finding the best focus is extremely difficult. It might be necessary to experiment with several aperture sizes.

NOTE 2 Slight adjustments in the telescope position can also be tried. If a certain location cannot be brought to a focus, the telescope can be moved a couple of millimetres in the opposite direction in the Y-Z plane. This will place the aperture better within the QVS for that location (at the expense of losing sight of the other edge of the virtual image).

NOTE 3 If nothing else helps, back off slightly from the edges/corners toward the centre of the image, until the measurement can be performed.

NOTE 4 Often, the telescope can’t be brought to a sharp focus at all. The most likely reason for this is astigmatism. To measure astigmatism, replace the round aperture of the telescope by a narrow slit. Orient it vertically, measure as usual, then re-orient it horizontally and measure again.

QVS measurement

1) Point the telescope toward the image left edge and move left until the edge of the QVS is met. Adjust focus if necessary. See 6.11.2 and 6.11.3 for criteria for locating the edge of the QVS. Other test patterns might need to be displayed in the EUT to determine the correct location.

2) Record all coordinates.

3) Return to the centre and (re-)record the image centre coordinates.

4) Repeat steps 1) to 3) for the remaining seven positions. Note that when approaching the corners, the movement of the telescope also needs to be diagonal.

Repeat the entire process for the other ocular, if applicable. Be sure to record the distance (delta X,Y and Z) between the base positions of the two oculars.

Finally, always make note of the case where the EUT has been accidentally touched during the process. Such an incident is almost certain to be visible in the results, too. Fortunately, the centre coordinates have been carefully recorded and re-recorded, small amounts of EUT movement might be able to be removed from the data in the analysis phase.

e) Analysis

Many quantities can be calculated from the data obtained herein. The analysis procedures are explained separately for each quantity in 6.11.4 to 6.11.9. The common-to-all components are as follows:

1) Verification of measurement accuracy

For each ocular, plot all the measurements made of the image centre in the same graph (theta vs. phi = yaw vs. pitch) and label them in chronological order. This will provide a rough idea of the random component of the measurement error in the gaze angle. It will also expose any accidental EUT movement or other mistakes that may have occurred during the measurement.

Excluding the QVS measurement, accuracy of the X,Y and Z measurements essentially depends on the hardware. As micrometer class accuracy is easily achieved with modern electric actuators, the angle measurement is likely to be a greater source of error of the two.

In measuring the QVS, the greatest errors are likely to be introduced in determining the precise location of the edge of the QVS (rather than measuring its location, once it has been found). The QVS criteria are set by the ergonomic requirements of the user. Unfortunately, there is no single, simple measurable quantity that would enable the judgement to be made.

2) Optical axis

An average value of the image centre measurements is used as the optical centre axis. It is used as an origin of reference in calculating some of the quantities. As always, the operator should check the data for clearly faulty measurements and remove them by hand.

f) Reporting

After the measurement, the following set of data should have been gathered [each measurement defines a straight line (and an equation for it) in 3-D space]:

1) optical centre axis (several measurements);

2) each edge and corner, viewed from the base position on the centreline;

3) each edge and corner, viewed along the edge of the QVS (just inside).

In addition, the following should be reported:

4) focal distances for each nine measurement locations;

5) optionally, the equivalent focal distances measured using horizontal and vertical slits;

6) an estimate of the achieved measurement accuracy;

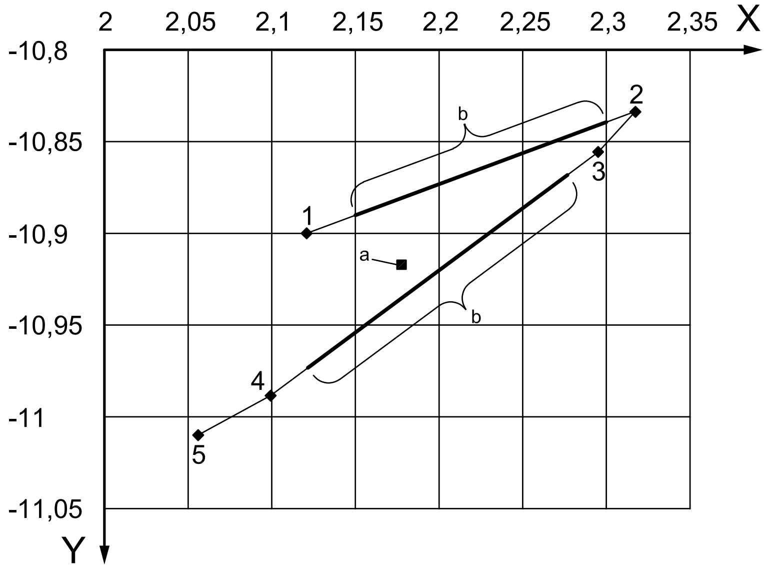
7) A reference axis (the centre axis) for each ocular, averaged from several measurements.

Report the (current) measurement accuracy.

g) Comments

A common error in this type of measurement is that the EUT is accidentally touched during the measurement — unless the entire measurement system is fully remote controlled (and even then, the moving parts can come into contact with the EUT). This arises from the fact that NED are designed to be worn by a human being, rather than to maintain alignment in an optical test bench.

In particular, the gaze angle values are sensitive to such seemingly minuscule incidents. Figure 71 shows an example of an "unlucky" measurement: five consecutive measurements of the centre axis, with two accidental contacts between. The "natural" random error in this measurement is less than 0,1°. The contacts spread it out to at least three times that much. Clearly, the average of this set of data has no physical meaning. If the measurement cannot be repeated, three separate reference points should be used to account for the contacts. (This is analogous to testing for and removing the "zero level drift" present in many commonly used electronic sensors.)



Key

X yaw (θ), degrees

Y pitch (ϕ), degrees

1–5 measurements

[a] Average.

[b] Contact.

Figure 71 — "Unlucky" set of measurement data

6.11.2 P 23.2M — QVS — Subjective judgement

The qualified viewing space measurement (QVS) is essentially an ergonomics concept. It is that volume in 3-D space, in relation to the NED, within which the user needs to place his/her eye, in order to be able to properly see the entire virtual image display screen without moving his/her head or making any other adjustments (other than the natural rolling movement of the eye).

"To be able to properly see" means not only that the user has a visual contact, but also that the image remains sufficiently sharp, has a high enough contrast ratio, is bright enough, is not distorted too much, etc.

It can also be taken to mean that no two locations on the screen should differ too much from one another (e.g. focal distance, brightness, contrast, colour balance). Such differences would strain the eye by forcing it to constantly readjust for new conditions.

Due to the complexity of the phenomenon, no single, easy, quantitative measurement can reliably be used as a criteria for the QVS. If the available resources do not allow for a more thorough analysis, a subjective measurement can be made in the following way. This method uses the measurer's own eye and impression as the criteria. The results are thus not only subjective, but also dependent on the measurement hardware (as the user has to view the target through the device).

While repeatability cannot be claimed, the results should nevertheless be indicative — and better than no results at all.

First, look at the image centre along the optical centreline through the viewing device of the meter and adjust for focus. Get the best possible image quality possible, and then take note of the achieved sharpness of the image. Typically, individual pixels should be clearly resolvable, though sometimes this might not be the case. If the meter optics cannot perfectly emulate the human eye, the virtual image quality can appear poorer than it is in reality.

The edge of the QVS is met when the apparent image quality is “significantly worse” than at the image centre. The operator should judge when the image is blurred to such an extent that the performance drops significantly below the resolving power of the eye.

Typically, the apparent size of a single pixel is roughly matched to the resolving power of the eye. Therefore, when individual pixels can no longer be told apart, and reading of text (with a small font) becomes impossible, the edge has been reached. The font size should be the smallest which is intended to be used in the EUT.

6.11.3 P 23.3M — QVS — Calculated judgement

The qualified viewing space measurement (QVS) is essentially an ergonomics concept. It is that volume in 3-D space, in relation to the NED, within which the user needs to place his/her eye, in order to be able to properly see the entire virtual image display screen without moving his/her head or making any other adjustments (other than the natural rolling movement of the eye).

The location of the eye is in this context taken to mean the location of the effective centre of rotation of the eyeball.

“To be able to properly see” in the context of this procedure is taken to mean that the display shall fulfil all the ergonomic requirements set to such devices according to ISO 9241-303. If it does, that particular location is within the QVS, otherwise it is not.

6.11.4 P 23.6 — Geometric distortion

a) Objective: to quantify the optical geometric distortion present in the image(s) of a near-to-eye display.

b) Applicability: see 6.11.1 b).

c) Preparation and set-up: N/A.

d) Procedure: perform the procedure for measuring distortion specified in 6.11.1 (M 23.1) d).

e) Analysis

    1) Basic analysis

    The following directions apply for the angular coordinates only. (X,Y and Z values are all the same, as the entire measurement was done in the base position.)

    i) Perform a coordinate transformation by subtracting the origin (image centre) coordinates from each coordinate value. This will make the image centre the new origin.

    ii) De-rotate the image about the centre axis, so that the measured image appears to be “level” (aligned with the horizontal and vertical axes). Required accuracy: About 0,1° would be sufficient in most cases.

    To accomplish this, an optimisation algorithm will likely need to be constructed in the computer. Use all the eight measured screen points and exploit the symmetry of the target pattern to make the judgment. Often, the Phi axis is an axis of symmetry, but this will need to be verified every time (depending on the optics of the EUT). Check the data for obvious mistakes before running the algorithm.

Then, using the derotated data, perform the following steps.

iii) Calculate the average width, height and semi-diagonal of the image (in angular units). The width and height are also the horizontal and vertical fields of view (HFOV and VFOV) of the device/ocular.

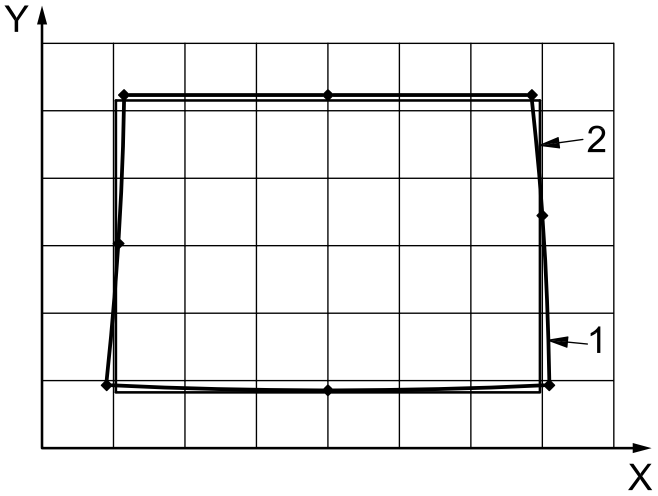
iv) Calculate the ideal image coordinates: Angular values for the nine standard locations, assuming that the image centre is at the origin and the width and height of the image correspond to the measured average values.

v) Compare measured (derotated) points to the ideal values at the standard nine locations. (The error is by definition zero at the centre).

vi) Report distortions as percentages: distance between the measured and ideal points, divided by the semi-diagonal (multiplied by 100 %). The vertical and horizontal deviations may also be reported separately.

Figure 72 is an example visualisation of actual measurement data. The eight measured points are shown (after de-rotation) in comparison with a box showing the outline of the ideal, undistorted image. The origin is at the centre.

vii) Repeat for the other ocular (if applicable).



Key

X Theta, θ

Y Phi, ϕ

1 measured

2 ideal

There is one measurement error in the data: The Phi value of the right centre point has probably been read incorrectly. This point was excluded from the analysis.

The Phi axis ($\theta = 0$) appears to be an axis of symmetry. This was exploited in the de-rotation process.

Figure 72 — Geometric image distortion of few percent

2) Comparing distortion data for binocular devices

While the eye is relatively tolerant of slight geometric distortion, the matter becomes much more serious in the case of the binocular display. If the corresponding pixels of the two images do not appear to be located in the same spot in 3-D space, the human brain does not know how to interpret the data. Typically, the user experiences abnormal stress in his/her eyes, which develops into a headache after a while.

Interocular geometric distortion (i.e. difference in image geometry between the two oculars)

i) Take the coordinate-shifted but *non-derotated* measurement data for each ocular.

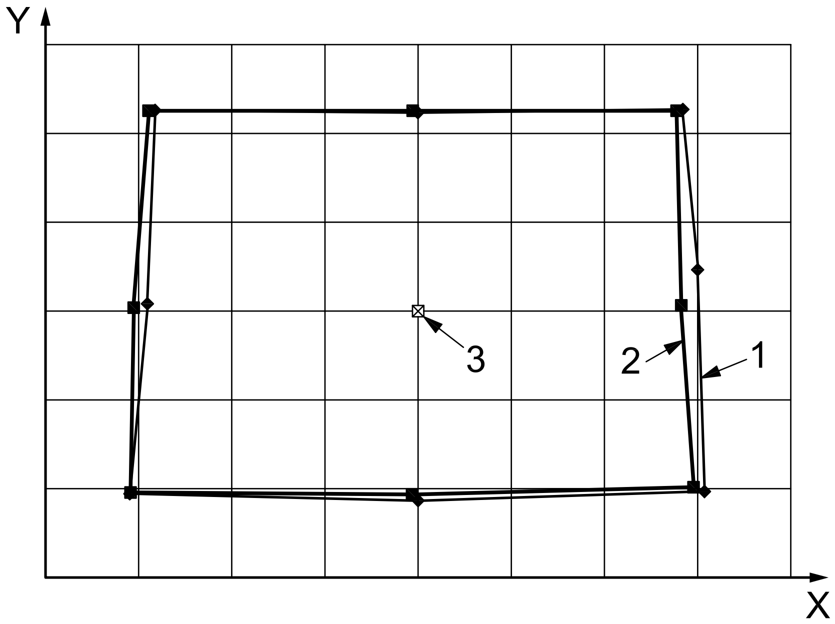
ii) Find the angular distance between each corresponding pair of points: subtract the coordinates from each other and apply the Pythagorean Theorem:

$$d = \sqrt{\Delta\rho^2 + \Delta\theta^2}$$

Here, distance, d, at the centre is zero by definition — see 6.11.8 (P.23.10) for further discussion.

iii) Report the distances for the eight pairs of points as percentages of the average semi-diagonal.

iv) To plot, place the distortion graphs of the left and right images on top of each other, as shown in Figure 73.



Key

X Theta, θ

Y Phi, ϕ

1 right

2 left

3 centre

Figure 73 — Distortion graphs of left and right images overlaid

f) Reporting: report geometric distortion percentages for each ocular and all measurement locations (except the image centre), and interocular geometric distortion percentages for all measurement locations (except the image centre), while plotting distortion graphs for each ocular and the interocular difference.

g) Comments: none.

6.11.5 P 23.7 — Field of view

a) Objective: to measure the horizontal and vertical fields of view (HFOV, VFOV) of a near-to-eye display in angular units.

b) Applicability: see 6.11.1 b).

c) Preparation and set-up: N/A.

d) Procedure: perform the procedure for measuring distortion specified in 6.11.1 (M 23.1) d).

e) Analysis: see 6.11.4 (P 23.6)

   For binocular devices, also calculate the average HFOV and VFOV values and differences as percentages:

   HFOV difference % = (HFOV_right – HFOV_left) × 100 % / HFOV_left

   VFOV difference % = (VFOV_right – VFOV_left) × 100 % / VFOV_left

f) Reporting

   Report the horizontal and vertical fields of view for each ocular in angular units.

   For binocular NED, also report the HFOV and VFOF average values and difference percentages.

g) Comments: none.

6.11.6 P 23.8 — Focal distance

a) Objective: to measure the focal distance at various points on the virtual image.

b) Applicability: see 6.11.1 b).

c) Preparation and set-up: N/A.

d) Procedure: perform the procedure for measuring focal distance specified in 6.11.1 (M 23.1) d).

e) Analysis: none.

f) Reporting: report the focal distance for each measured location.

g) Comments

   Compare with 6.11.9. Ideally, these two measurements should give just one result, constant throughout the image.

   This measurement may be difficult to carry out, if the EUT optics is of lesser quality. There are two typical explanations for this. If the QVS of the EUT is (too) narrow, it may be impossible to find a single location, where the input aperture of the measurement device (which should emulate the human pupil) can be kept fully within the QVS at all times. A smaller aperture will usually improve the sharpness of the image, but as it will also increase the measuring optics' focal depth, determining the correct focal distance becomes increasingly difficult.

You may attempt to work around this problem by allowing the meter head to move slightly away from the base position: For example, when measuring the left edge of the image, move the telescope a couple of millimetres in the right direction (along the Y axis) and try again. This will enable a better view of the image left side – at the expense of losing sight of the right edge.

The other explanation is the presence of astigmatism (an optical aberration which causes sagittal and tangential rays of light to be focused at different distances). If an astigmatic system is viewed through conventional optics (which does not differentiate between sagittal and tangential rays), the image cannot be brought to focus. One can only look for the least blurry position.

If the EUT is suspected to be heavily astigmatic, it may be advantageous to measure the sagittal and tangential focal distances separately: Replace the round aperture with a narrow slit. Orient it vertically, measure the focal distance as usual, then re-orient the slit horizontally and measure again. If astigmatism is the dominant aberration, good focus should be much easier to locate.

6.11.7 P 23.9 — Interocular distance

a) Objective: to measure the interocular distance of a binocular near-to-eye display.

b) Applicability: binocular near-to-eye displays. (See also 6.11.1.)

c) Preparation and set-up: N/A.

d) Procedure: see 6.11.1 (M 23.1). Refine the location of the optical centre axis for both oculars. Use the X-Y-Z coordinates of the two base positions.

e) Analysis: calculate the physical distance between the two “base positions” by applying the Pythagoras’ Theorem:

$$\text{Interocular distance} = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \qquad (51)$$

where ΔX is the difference between the X coordinate values of the left and right base positions, and so on.

f) Reporting: report the interocular distance (in millimetres).

g) Comments: none.

6.11.8 P 23.10 — Convergence angle

a) Objective: measure the horizontal convergence angle of a binocular near-to-eye display.

b) Applicability: binocular near-to-eye displays [see also 6.11.1 (M 23.1)].

c) Preparation and set-up: N/A.

d) Procedure: perform the procedure for making goniometric measurements of virtual images specified in 6.11.1 (M 23.1). Measure the distortion. Use the measured theta values (yaw, rotation around the Z axis) for each ocular and measured location (2 × 9 values).

e) Analysis

For each of the nine measurement locations, take the measured theta values for the left and right oculars and subtract the left value from the right one.

Sign convention check: the convergence angle is positive when the measured gaze angles are mutually convergent.

f) Reporting: report the convergence angles for each measurement location.

g) Comments: possible divergence caused by vertical misalignment is ignored in this calculation.

6.11.9 P 23.11 — Convergence distance

a) Objective: determine the horizontal convergence distance of a binocular near-to-eye display.

b) Applicability: —.

c) Preparation and set-up: N/A.

d) Procedure: perform the procedures for measuring the interocular distance and convergence angle, 6.11.7 (P 23.9) and 6.11.8 (P 23.10). Needed is the interocular distance and convergence angles for each measurement location.

e) Analysis: the convergence distance is given by the following formula:

$$C = \cos\left(\theta\right) \times \tan\left(\frac{\alpha}{2}\right) \times \frac{D}{2} \qquad (52)$$

where

D is the interocular distance;

α is the convergence angle;

θ is the (average) horizontal gaze angle, defined as zero when looking straight ahead, or normal to the interocular line.

The first cosine term is used to account for the shortening of the effective interocular distance, when looking sideways. With small horizontal field-of-view devices (± 10°), this term may safely be omitted.

f) Reporting: report the convergence distances for each measurement location.

g) Comments: sometimes a device with a negative convergence angle can even be encountered. The convergence distance is then also negative. Having the virtual screen behind the head is, of course, an awkward condition physically.

6.11.10 P 23.12 — Vertical misalignment

a) Objective: to measure the vertical misalignment of a binocular near-to-eye display.

b) Applicability: binocular near-to-eye displays (see also 6.11.1).

c) Preparation and set-up

d) Procedure: perform the procedure for measuring distortion specified in 6.11.1 (M 23.1) d).

You will need the measured Phi values (pitch, rotation around the Y axis) for each ocular and measured location (2 x 9 values).

e) Analysis

For each of the nine measurement locations, take the measured Phi values for the left and right oculars and subtract the left value from the right one.

When reporting the values, the sign may be omitted, as any deviation from zero is always bad news.

f) Reporting: report the vertical misalignment for each measurement location.

g) Comments: retaining the sign only makes sense when adjusting or designing a new NED. A change of sign in the vertical misalignment indicates a difference in magnification, rotational misalignment or other such unwanted effect. These effects are, however, much easier to spot directly in the distortion measurement results (the interocular comparison graph in particular).

6.11.11 P 23.13 — Qualified viewing space (QVS), maximum eye relief and exit pupil size

a) Objective: to determine the QVS, maximum eye relief and exit pupil size parameters of a near-to-eye display.

The ocular of a NED can be interpreted as a window, which allows us to see the virtual space (housing a virtual screen) that lies within the device to be seen. The above three quantities are helpful in determining whether the NED window is physically big enough for the user to see the virtual screen comfortably, without straining or having to constantly re-adjust his/her headset.

b) Applicability: —.

c) Preparation and set-up: N/A.

d) Procedure: perform the procedure for measuring QVS specified in 6.11.1 (M 23.1) d).

e) Analysis

1) Qualified Viewing Space (QVS)

The QVS (one for each ocular) is defined here as that physical, 3-dimensional volume within which the centre of rotation of the eye must be placed in order to be able to observe the entire virtual image by only rotating the eyeball.

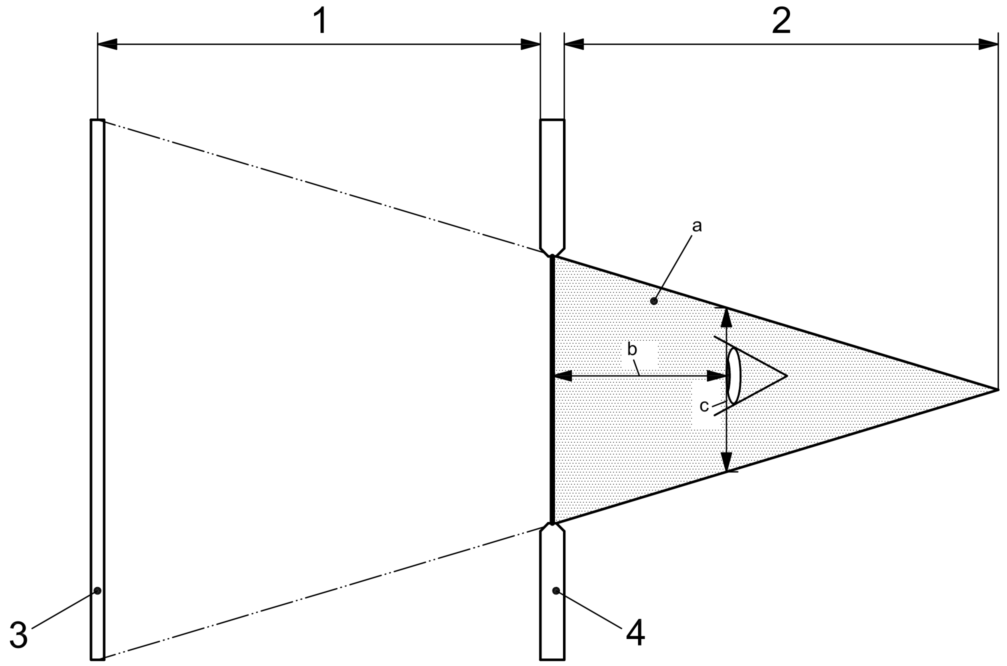
Let us imagine a large box, about a metre in every direction. Someone has plastered a poster inside, on one of the walls. The box is opaque, but there is a small peephole, a couple of centimetres wide, on the wall opposite the poster (we will also assume a source of light somewhere).

An observer wishes to see the poster, but cannot open the box. He/she uses the peephole instead. The question is: where should the observer place his/her eye in order to see it all at once?

Clearly, there are limitations. The best place is obviously near the centre of the hole, close to it but not so close to it as to bring, say, his/her eyewear into contact with the box. If he/she moves too much to either side, the wall blocks part of the poster. If he/she is too far away, the small peephole only allows him/her to see a part of the poster.

The situation is analogous with a near-to-eye display. The user does not care about the complex optics inside. For him/her, there is only a “peephole”, the ocular, and a “box” with a screen inside.

As seen in Figure 74, the size and shape of the virtual screen and the ocular (the exit pupil of the optics of the ocular, to be precise) determine, in turn, the size and shape of the “region of good visibility”, the QVS (the grey triangle in the picture). As the virtual screen is always bigger than the ocular, the QVS is roughly conical in shape. The tip of the cone should ideally extend a few centimetres outside the first surface of the ocular (which is not always the case).



Key

1 virtual space

2 real space

3 virtual screen

4 NED ocular (first surface)

[a] Qualified vector space (QVS).

[b] Eye relief (ER).

[c] Exit pupil size (EPS).

Figure 74 — QVS, eye relief and exit pupil size

The first task is to determine two parameters: one, the height of the tip (along the optical centre axis) and two, the cross-section (width and height) of the QVS at an arbitrary distance of interest from the ocular, along and normal to the optical centre axis. In NED literature, the QVS cross-section is called the exit pupil size, and the distance from the ocular is the eye relief (as in the figure).

As a result of the measurement campaign described in 6.11.1, we now have a set of eight lines in 3-D space. Each line touches both the edge of the virtual screen and the edge of the NED ocular (exit pupil of the optics). The lines are spread evenly around the “cone”, outlining the shape of the QVS.

For the purpose of the analysis, this loose “cage” of lines shall be turned into a mathematically well-defined solid wall that surrounds the QVS from all sides. Once this is done, the height of the tip and the cross-section are mathematically well defined. That is, they have a unique numerical value, which can be solved from the equations.

The easiest way to create a wall from a set of lines is to extend each line into a plane, tangential to the edge of the QVS. The optical centre axis is conveniently in the centre (and thus normal to the tangent), so we will pick a reference point along the centreline. In order to reduce numerical uncertainty, be sure to have the reference point sufficiently far in the virtual space region. A metre or two from the base position (the X-Y-Z origin, also along the centre axis) would place the spot roughly at the centre of the virtual screen, which is fine for our purposes.

Now, create a projection from the reference point to each line. By asserting that the projection be normal to the line, there is now enough information to work out the equation of the plane. Repeat for all the eight lines.

To find out the height of the QVS tip from the base position, simply work out the crossing coordinates of the centreline and each of the eight planes. Pick the one that is closest along the centreline, and add the distance from the origin to the first optical surface of the NED. It should be entered in a measurement diary: the telescope eye relief + distance to its centre of rotation.

Due to random error in the measurement data, the highest point of the QVS cone is not always precisely at the centreline. It is therefore advisable to numerically shift the centreline in the Y-Z plane and iteratively look for the highest point in the immediate vicinity of the original location.

To summarise the procedure so far:

i) Transform the measurement data (nine times X, Y, Z, Theta and Phi) into nine equations of straight lines (an equation pair of the form $Y = a X$ and $Z = b X$).

ii) Choose a reference point along the centre axis, about a metre or two toward the virtual screen, measured from the origin (the base position). Work out its X-Y-Z coordinates.

iii) Project the reference spot to each line in turn. That is, find out the equation for that straight line, which is normal to the original one and passes through the reference point. (Hint: the dot product is zero at right angles.)

iv) Work out the equation of the tangential plane for each line: require that the original line is in the plane (the line equation fulfils the plane equation everywhere) and that the projection is normal to the plane.

v) Solve the crossing coordinates of the centreline and each of the planes. Calculate the distance from the origin to each of the crossings. Choose the smallest one; this is our first hypothetical value for the height of the QVS cone.

vi) Refine the location of the tip by iteratively shifting the centreline in Y-Z plane in the immediate vicinity of the original location and repeating step v). (This is necessary due to the presence of random error in the measurement results.) Choose the highest value.

vii) The height of the QVS cone is: the eye relief value used during the measurements + distance from the front of the telescope to its centre of rotation + distance from origin to the tip of the QVS cone.

2) Maximum eye-relief and exit pupil size

Eye relief is defined as the instantaneous distance from the first optical surface of the eye (the cornea) to the first optical surface of the ocular, along the optical centre axis. The eye relief is not a property of the display device, as it depends on the user. Each NED does, however, have a certain maximum allowed value for the eye relief. The user shall stay within this distance, in order to be able to see the virtual screen properly. The maximum eye-relief is a property of the display device, and can be measured.

Maximum eye relief is: the height of the QVS cone, as calculated above, minus 13 mm. Thirteen millimetres is the average distance from the cornea to the eyeball centre of rotation.

The maximum eye relief value does not have much physical significance, as it really is only the theoretical maximum. The slightest sideways deviation of the eyeball will bring it outside the QVS.

Reporting eye-relief values does, however, make a great deal of sense when reported in conjunction with the corresponding exit pupil size. The exit pupil size is the cross-section (which can be taken to mean the width and height) of the QVS cone at a certain, arbitrarily chosen, value of eye relief.

The width and height of the exit pupil can be worked out in similar fashion to the height of the QVS cone.

i) Choose a suitable value of eye relief. Solve for the coordinates of a corresponding point on the optical centreline.

ii) Find out the equation for a straight line that goes via the chosen point, is normal to the centreline and goes in the required direction — for “width”, parallel to the interocular line (or Y-axis); for “height”, normal to it. (Note that it cannot be assumed that the interocular line would be exactly normal to the centreline. Project the interocular line on a plane normal to the centreline to be on the safe side.)

iii) Similarly to step v) in the previous process description, calculate the crossing coordinates of the line and each of the eight QVS cover planes. Choose the two that are closest to the centreline on each side of it.

iv) Add the distances to obtain the “width”, and then repeat from step 2 ii) for “height” (diagonal directions can sometimes be of interest too.)

f) Reporting

Report the theoretical maximum eye relief and the exit pupil width and height at that value.

The exit pupil width and height may also be reported at other suitable values of eye relief (25 mm would be a good choice, for example).

g) Comments: the QVS is, in general, not reported, as it is a complex shape rather than a single number.

7 Conformance

Conformance with this part of ISO 9241 may be claimed based on compliance with its requirements only if an applicable analysis and compliance method as defined in ISO 9241-307 has been used.

Annex A
(informative)

Overview of the ISO 9241 series

This annex presents an overview of ISO 9241: its structure, subject areas and the current status of both published and projected parts, at the time of publication of this part of ISO 9241. For the latest information on the series, see: http://isotc.iso.org/livelink/livelink?func=ll&objId=651393&objAction=browse&sort=name.

Part no.	Subject/title	Current status
1	General introduction	International Standard (intended to be replaced by ISO/TR 9241-1 and ISO 9241-130)
2	Guidance on task requirements	International Standard
3	Visual display requirements	Replaced by the ISO 9241 “300” subseries
4	Keyboard requirements	International Standard (intended to be replaced by the ISO 9241-“400” subseries)
5	Workstation layout and postural requirements	International Standard (intended to be replaced by ISO 9241-500)
6	Guidance on the work environment	International Standard (intended to be replaced by ISO 9241-600)
7	Requirements for display with reflections	Replaced by the ISO 9241 “300” subseries
8	Requirements for displayed colours	Replaced by the ISO 9241 “300” subseries
9	Requirements for non-keyboard input devices	International Standard (intended to be replaced by the ISO 9241-“400” subseries)
11	Guidance on usability	International Standard
12	Presentation of information	International Standard (intended to be replaced by ISO 9241-111 and ISO 9241-141)
13	User guidance	International Standard (intended to be replaced by ISO 9241-124)
14	Menu dialogues	International Standard (intended to be replaced by ISO 9241-131)
15	Command dialogues	International Standard (intended to be replaced by ISO 9241-132)
16	Direct-manipulation dialogues	International Standard (intended to be replaced by ISO 9241-133)

Part no.	Subject/title	Current status
17	Form filling dialogues	International Standard (intended to be replaced by ISO 9241-134)
20	Accessibility guidelines for information/communication technology (ICT) equipment and services	International Standard
Introduction		
100	Introduction to software ergonomics	Planned
General principles and framework		
110	Dialogue principles	International Standard
111	Presentation principles	Planned to partially revise and replace ISO 9241-12
112	Multimedia principles	Planned to revise and replace ISO 14915-1
113	GUI and controls principles	Planned
Presentation and support to users		
121	Presentation of information	Planned
122	Media selection and combination	Planned to revise and replace ISO 14915-3
123	Navigation	Planned to partially revise and replace ISO 14915-2
124	User guidance	Planned to revise and replace ISO 9241-13
129	Individualization	Planned
Dialogue techniques		
130	Selection and combination of dialogue techniques	Planned to incorporate and replace ISO 9241-1:1997/Amd 1:2001
131	Menu dialogues	Planned to replace ISO 9241-14
132	Command dialogues	Planned to replace ISO 9241-15
133	Direct-manipulation dialogues	Planned to replace ISO 9241-16
134	Form-based dialogues	Planned to replace ISO 9241-17
135	Natural language dialogues	Planned
Interface control components		
141	Controlling groups of information (including windows)	Planned to partially replace 9241-12
142	Lists	Planned
143	Media controls	Planned to partially revise and replace ISO 14915-2

Part no.	Subject/title	Current status
Domain-specific guidance		
151	Guidance on World Wide Web user interfaces	International Standard
152	Interpersonal communication	Planned
153	Virtual reality	Planned
Accessibility		
171	Guidance on software accessibility	Under preparation
Human-centred design		
200	Introduction to human-centred design standards	Planned
210	Human-centred design of interactive systems	Planned to revise and replace ISO 13407
Process reference models		
220	Human-centred lifecycle processes	Planned to revise and replace ISO/PAS 18152
Methods		
230	Human-centred design methods	Planned to revise and replace ISO/TR 16982
Ergonomic requirements and measurement techniques for electronic visual displays		
300	Introduction to electronic visual display requirements	International Standard
302	Terminology for electronic visual displays	International Standard
303	Requirements for electronic visual displays	International Standard
304	User performance test methods	International Standard
305	Optical laboratory test methods for electronic visual displays	International Standard
306	Field assessment methods for electronic visual displays	International Standard
307	Analysis and compliance test methods for electronic visual displays	International Standard
308	Surface conduction electron-emitter displays (SED)	Technical Report
309	Organic light emitting diode (OLED) displays	Technical Report
Physical input devices		
400	Principles and requirements for physical input devices	International Standard
410	Design criteria for physical input devices	International Standard
411	Laboratory test and evaluation methods for the design of physical input devices	Planned

Part no.	Subject/title	Current status
420	Selection procedures for physical input devices	Under preparation
421	Workplace test and evaluation methods for the use of physical input devices	Planned
Workstation		
500	Workstation layout and postural requirements	Planned to revise and replace ISO 9241-5
Work environment		
600	Guidance on the work environment	Planned to revise and replace ISO 9241-6
Application domains		
710	Introduction to ergonomic design of control centres	Planned
711	Principles for the design of control centres	Planned to revise and replace ISO 11064-1
712	Principles for the arrangement of control suites	Planned to revise and replace ISO 11064-2
713	Control room layout	Planned to revise and replace ISO 11064-3
714	Layout and dimensions of control centre workstations	Planned to revise and replace ISO 11064-4
715	Control centre displays and controls	Planned to revise and replace ISO 11064-5
716	Control room environmental requirements	Planned to revise and replace ISO 11064-6
717	Principles for the evaluation of control centres	Planned to revise and replace ISO 11064-7
Tactile and haptic interactions		
900	Introduction to tactile and haptic interactions	Planned
910	Framework for tactile and haptic interactions	Under preparation
920	Guidance on tactile and haptic interactions	Under preparation
930	Haptic and tactile interactions in multimodal environments	Planned
940	Evaluation of tactile and haptic Interactions	Planned
971	Haptic and tactile interfaces to publicly available devices	Planned

Annex B
(informative)

Guidelines for measurement method types

B.1 General

The collections of (optical) laboratory measurements, that are necessary for the compliance evaluations, are defined in ISO 9241-5. These measurements are divided into “basic measurements” and “measurement procedures”. The following sections define the two items, the decision about the type during the drafting of this standard, and their use for the definition of compliance procedures.

See Figure B.1.

B.2 Basic measurement (or evaluation) method — “Basic measurement” M

Should describe a generic measurement, i.e. it cannot be applied directly without fixing the configurable measurement conditions.

Rule: Non-generic basic measurements should be avoided.

EXAMPLE Large area luminance, with configurable measurement conditions like direction, location, displayed pattern, etc.

- Result is a physical quantity or comparable (luminance; number of pixels, etc.)
- Usually does not yield final quantities that are directly used by a compliance procedure.
- Can be used by a procedure to achieve sets or collections of data.
- Defines types of meter, meter parameters and default parameters ("standard settings") (field of view, timing, …).
- Specifies configurable measurement conditions that are varied by the procedures (location, direction,...).

B.3 Test procedure — “Procedure” P

- Collects and evaluates physical quantities that were measured using a basic method.
- Procedure references to basic measurements, preparation procedures, test patterns, etc.
- Result is a collection of basic quantities (e.g. area or angular distribution of luminance), or derived quantities (e.g. luminance contrast, colour difference).
- Procedures could (still) be generic, if they have free parameters. In that case, the compliance procedure defines the final parameters.

Rule: Generic procedures should be avoided.

EXAMPLE Angular dependence of contrast on reflection. With different technologies, the definition of the viewing directions might vary, e.g. the number of directions, the determination of directions from display and observation geometry, etc.

- A procedure should be created, if a compliance assessment needs a measure for a decision.
- Interaction with compliance procedures: The compliance procedure can either directly define criteria using measurements from a procedure, or derive secondary quantities and define the criteria based on these values.

EXAMPLE 1 Procedure yields average contrast ratio: "The average contrast ratio at normal viewing direction according to Pixels.y shall be greater than 3."

EXAMPLE 2 Procedure yields primary quantity, the final quantity is calculated in the compliance procedure: "Measure the luminances at all defined locations. The standard deviation shall be lower than 5." (Procedure yields luminances, the standard deviation is calculated.)

- Definition: If a two-level hierarchy of basic measurement and procedure is not necessary, the resulting description is a procedure. Only procedures yield concrete results.

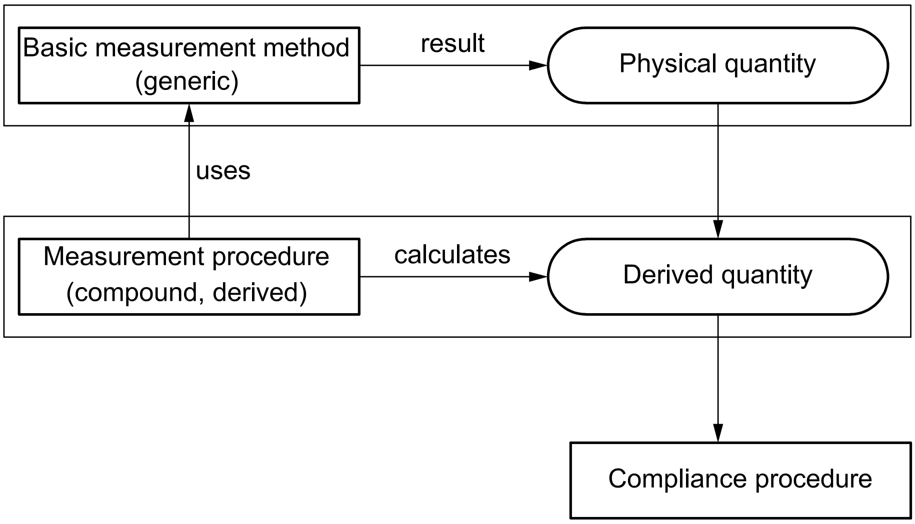


Figure B.1 — Relationship of methods, measurement procedures and compliance procedures

Annex C
(informative)

Matrix of measurement procedures and their sources

Table C.1 contains a matrix linking the procedures specified in this part of ISO 9241 with source material used in its development. Not all procedures have source material referenced; neither should the information in this matrix be considered exhaustive. These references are for information only. See also the Bibliography.

Table C.1 — Matrix of measurement procedures and their sources

Measurement procedure	Source material
6.1 Basic light measurements	
6.1.1 M 12.1 Basic spot measurement	ISO 13406-2:2001 8.7.14 Display luminance VESA FPDM Ver 2.0 (2001) 302-1 Luminance and Colour of Full-Screen White 302-2 Luminance and Colour of Full-Screen Black 304 Box-Pattern Measurements
6.1.2 M 12.2 Reflection coefficient	ISO 13406-2:2001
6.1.3 M 12.9 Basic illuminance measurement	
6.1.4 P 12.3 Estimated approximate luminous flux	
6.1.5 P 12.4 Combined emitted and reflected light	ISO 13406-2:2001
6.1.6 P 12.5 Site screening — Standard measurement locations	
6.1.7 P 12.6 Visual screening to find max. and min. locations	
6.2 Luminance profile measurements	
6.2.1 M 13.1 Luminance profile using green profile	
6.2.2 M 13.2 Luminance profile with smoothing algorithm	
6.3 Directional light measurements	
6.3.1 P 14.1 Luminance angular distribution	
6.3.2 P 14.2 Luminance angular uniformity	

Table C.1 *(continued)*

Measurement procedure		Source material
6.4	**Temporal performance measurements**	
6.4.1	M 15.1 Temporal luminance variation	
6.4.2	P 15.2 Image formation time	ISO 13406-2:2001 8.7.21 Image formation time VESA FPDM Ver. 2.0 (2001) 305-1 Response Time
6.4.3	P 15.2A Image formation time between grey-levels	
6.4.4	P 15.3 Flicker	ISO 13406-2:2001 8.7.24 Temporal instability (flicker) VESA FPDM Ver. 2.0 (2001) 305-4 Dominant Flicker Component (EIAJ flicker level, ISO flicker)
6.4.5	P 15.3A Extended flicker measurement	
6.4.6	P 15.4 Jitter	ISO 9241-3:1992 6.6.14 Spatial instability (jitter) VESA FPDM Ver. 2.0 (2001) 305-6 Jitter
6.4.7	P 15.5 Blink coding	
6.4.8	P 15.7 Warm-up time	VESA FPDM Ver. 2.0 (2001) 305-3 Warm-Up-Time Measurement
6.5	**Reflection measurements**	
6.5.1	M 16.1 Luminance specular reflectance	VESA FPDM Ver. 2.0 (2001) 308-5 Small-Source Specular Reflectance
6.5.2	M 16.1A Reflectance with diffuse illumination	VESA FPDM Ver. 2.0 (2001) 308-1 Reflectance With Diffuse Illumination
6.5.3	P 16.2 BRDF and derived values	VESA FPDM Ver. 2.0 (2001) A217 Reflection Models and Terminology
6.5.4	P 16.3 Contrast of unwanted specular reflection	ISO 13406-2:2001 7.17.2 Contrast of unwanted reflections
6.5.5	P 16.4 Ring Light Method	
6.5.6	P 16.5 Extended source reflectance	VESA FPDM Ver. 2.0 (2001) 308-3 Large-Source Diffuse Reflectance

Table C.1 *(continued)*

Measurement procedure	Source material
6.5.7 P 16.6 Extended source specular reflectance	VESA FPDM Ver. 2.0 (2001) 308-4 Large-Source Specular Reflectance
6.5.8 P 16.7 Calibration of diffuse reflectance sample	
6.6 Luminance analysis	
6.6.1 P 17.1 Area average luminance	IEC 61947-1:2002 4 Light output measurement and specification 4.2 Light uniformity IEC 61947-2:2001 4.1 Light output measurements 5.1 Light output specifications 5.2 Light output uniformity VESA FPDM Ver. 2.0 (2001) 306-1 Sampled Uniformity & Colour of White 306-2 Sampled Uniformity of Black
6.6.2 P 17.2 Lateral luminance uniformity	VESA FPDM Ver. 2.0 (2001) 306-6 Anomalous Nonuniformity
6.6.3 P 17.3 Luminance Uniformity	IEC 61947-1:2002 4 Light output measurement and specification 4.2 Light uniformity IEC 61947-2:2001 4.1 Light output measurements 5.1 Light output specifications 5.2 Light output uniformity VESA FPDM Ver. 2.0 (2001) 306-1 Sampled Uniformity & Colour of White 306-2 Sampled Uniformity of Black
6.6.4 P 17.4 Residual Image	VESA FPDM Ver. 2.0 (2001) 305-2 Residual Image
6.6.5 P 17.5 Grey Scale and gamma	VESA FPDM Ver. 2.0 (2001) 302-5 Grey Scale of Full Screen 302-5a Determination of “Gamma”

Table C.1 *(continued)*

Measurement procedure	Source material
6.6.6 P 17.5A Evaluation of grey-level reduction and inversion	
6.6.7 P 17.6 Luminance coding	VESA FPDM Ver. 2.0 (2001) 302-5 Grey Scale of Full Screen 302-5a Determination of "Gamma"
6.6.8 P 17.7 Greyscale-JND relationship	VESA FPDM Ver. 2.0 (2001) 304-11 Greyscale-JND Relationship
6.7 Contrast analysis	
6.7.1 P 18.1 Box contrast	
6.7.2 P 18.2 Contrast under ambient illumination	
6.7.4 P 18.3 Contrast under ambient illumination and specular reflections	
6.7.5 P 18.4 Full screen contrast	IEC 61947-1:2002 4.3 Contrast ratio IEC 61947-2:2001 5.3 Contrast ratio VESA FPDM Ver. 2.0 (2001) 302-3 Darkroom Contrast Ratio of Full Screen 306-3 Sampled Uniformity of Contrast Ratio
6.7.6 P 18.5 Contrast uniformity	IEC 61947-1:2002 4.3 Contrast ratio IEC 61947-2:2001 5.3 Contrast ratio VESA FPDM Ver. 2.0 (2001) 306-3 Sampled Uniformity of Contrast Ratio
6.7.7 P 18.6 Modulation depth	
6.7.8 P 18.7 Contrast directional distribution	ISO 13406-2:2001 VESA FPDM Ver: 2.0 (2001) 307 Viewing Angle Performance
6.7.9 P 18.8 Contrast directional uniformity	

Table C.1 *(continued)*

Measurement procedure	Source material
6.7.10 P 18.9 Directional gamma	VESA FPDM Ver: 2.0 (2001) 302-5 Grey Scale of Full Screen 302-5a Determination of “Gamma”
6.7.11 P 18.10 Directional gamma uniformity	VESA FPDM Ver: 2.0 (2001) 302-5 Grey Scale of Full Screen 302-5a Determination of “Gamma”
6.8 Colour analysis	
6.8.1 P 19.1 Spectrally extreme colours	ISO 13406-2:2001 8.7.28 Spectrally extreme colours
6.8.2 P 19.2 Lateral chromaticity uniformity ($\Delta u'v'$)	IEC 61947-1:2002 4 Light output measurement and specification 4.2 Light uniformity IEC 61947-2:2001 4.1 Light output measurements 5.1 Light output specifications 5.2 Light output uniformity VESA FPDM Ver. 2.0 (2001) 306-1 Sampled Uniformity & Colour of White 306-2 Sampled Uniformity of Black
6.8.3 P 19.3 Directional chromaticity uniformity	ISO 13406-2:2001 8.7.19 VESA FPDM Ver.: 2.0 (2001) 307 Viewing Angle Performance
6.8.4 P 19.4 Colour difference, ΔE (CIELuv)	IEC 61947-1:2002 4 Light output measurement and specification 4.2 Light uniformity IEC 61947-2:2001 4.1 Light output measurements 5.1 Light output specifications 5.2 Light output uniformity VESA FPDM Ver: 2.0 (2001) 306-1 Sampled Uniformity & Colour of White 306-2 Sampled Uniformity of Black

Table C.1 *(continued)*

Measurement procedure	Source material
6.8.5 P 19.4A Colour difference, ΔE (CIELab)	IEC 61947-1:2002 4 Light output measurement and specification 4.2 Light uniformity IEC 61947-2:2001 4.1 Light output measurements 5.1 Light output specifications 5.2 Light output uniformity VESA FPDM Ver: 2.0 (2001) 306-1 Sampled Uniformity & Colour of White 306-2 Sampled Uniformity of Black
6.8.6 P 19.6 Chromaticity	IEC 61947-1:2002 5.51 Colour chromatically 5.52 Colour uniformity IEC 61947-2:2001 6.6.1 Colour chromaticity 6.6.2 Colour uniformity VESA FPDM Ver: 2.0 (2001) 302-4 Gamut and Colour of Full Screen
6.8.7 P 19.7 Colour gamut area	IEC 61947-1:2002 5.51 Colour chromatically 5.52 Colour uniformity IEC 61947-2:2001 6.6.1 Colour chromaticity 6.6.2 Colour uniformity VESA FPDM Ver: 2.0 (2001) 302-4 Gamut and Colour of Full Screen 302-4A Gamut-Area Metric
6.8.8 P 19.15 Colour temperature, white point, and white-point accuracy	IEC 61947-1:2002 5.5 Colour measurements IEC 61947-2:2001 6.6 Colour measurements VESA FPDM Ver: 2.0 (2001) 302-1 Luminance and Colour of Full-Screen White 302-6A White-point accuracy

Table C.1 *(continued)*

Measurement procedure	Source material
6.9 Dimensions and geometries	
6.9.1 P 20.1 Pixel size and pitch from luminance profile	
6.9.2 M 20.2 Pixel size and pitch from artwork	
6.9.3 P 20.3 Pixel size for projector displays	
6.9.4 P 20.4 Character dimensions for CRT	
6.9.5 P 20.5 Character dimensions for LCD	
6.9.6 P 20.6 Character stroke width for CRT	ISO 9241-3:1992 6.6.3 Character stroke width
6.9.7 P 20.7 Character stroke width for regular addressed pixels	ISO 13406-2:2001 8.7.7 Stroke width
6.9.8 P 20.8 Character width-to-height ratio	ISO 13406-2:2001 8.7.8 Character width-to-height ratio ISO 9241-3 6.6.2 Character width-to-height ratio
6.9.9 M 20.9 Resolution addressable	
6.9.10 P 20.10 Resolution, visible	IEC 61947-1:2002 4.4 Small area contrast ratio for alternating black and white pixels 5.1 Displayable format (ANSI Resolution) IEC 61947-2:2001 6.1 Variable resolution measurement and specification Annex H Alternative method for measuring resolution using the NIDL grille contrast method VESA FPDM Ver: 2.0 (2001) 303-2 N × N Grille Luminance and Contrast 303-7 Resolution from Contrast Modulation

Table C.1 *(continued)*

Measurement procedure		Source material
6.9.11	M 20.11 Aspect ratio	IEC 61947-1:2002 5.2 Aspect ratio VESA FPDM Ver. 2.0 (2001) 501-2 Aspect ratio
6.9.12	P 20.12 Between-character spacing	ISO 13406-2:2001 8.7.11 Between-character spacing ISO 9241-3:1992 6.6.7 Between-character spacing
6.9.13	P 20.13 Between-word spacing	ISO 13406-2:2001 8.7.12 Between-word spacing
6.9.14	P 20.14 Between-line spacing	ISO 13406-2:2001 8.7.13 Between-line spacing
6.10	**Geometrics and defects**	
6.10.1	M 21.1 Linearity	
6.10.2	P 21.2 Linearity, short distance line distortion	VESA FPDM Ver. 2.0 (2001) 503-3 Waviness
6.10.3	M 21.3 Waviness	VESA FPDM Ver. 2.0 (2001) 503-3 Waviness
6.10.4	M 21.4 Orthogonality	
6.10.5	P 21.5 Symbol distortion	
6.10.6	M 21.7 Cosmetic defects including face plate defects	VESA FPDM Ver: 2.0 (2001) 301-3c Cosmetic Defects
6.10.7	M 21.8 Colour effects based on misconvergence	ISO 9241-8:1997 7.2.4 Colour misconvergence measurement VESA FPDM ver. 2.0 (2001) 503-1 Convergence
6.10.8	P 21.9 Raster modulation	ISO 9241-3:1992 6.6.4 Raster Modulation
6.10.9	M 21.10 Fill Factor	VESA FPDM Ver: 2.0 (2001) 303-3 Pixel Fill Factor
6.10.10	M 21.11 Whole screen visual screening to find geometric distortions and artefacts	

Table C.1 *(continued)*

Measurement procedure	Source material
6.10.11 P 21.12 Display loading	VESA FPDM Ver: 2.0 (2001) 304.8 Luminance Loading
6.10.12 P 21.13 Checkerboard contrast	IEC 61947-1:2002 4.3 Contrast ratio IEC 61947-2:2001 5.3 Contrast ratio VESA FPDM Ver: 2.0 (2001) 302-3 Darkroom Contrast Ratio of Full Screen 306-3 Sampled Uniformity of Contrast Ratio 304-9 Checkerboard Luminance and Contrast (n×m)
6.10.13 P 21.14 Halation	VESA FPDM Ver: 2.0 (2001) 304.7 Halation
6.10.14 M 21.16 Shadowing	VESA FPDM Ver: 2.0 (2001) 308-4 Shadowing (Grey-Scale Artefacts)
Annex D: Bidirectional Reflectance Distribution Function (BRDF)	
D.2 Significance and use	VESA FPDM Ver: 2.0 (2001) A217 Reflection Models ISO 13406-2:2001 Annex D: Bidirectional Reflectance Distribution Function (BRDF)
	ISO 13406-2:2001 Annex D: Bidirectional Reflectance Distribution Function (BRDF)
Annex E: Uncertainty analysis guidelines	
E.1 Expression of uncertainty	ISO Guide to the Expression of Uncertainty in Measurement (1995) VESA FPDM Ver. 2.0 (2001) A108 Uncertainty Evaluations A221 Statements of Uncertainty

Annex D
(informative)

Bidirectional reflectance distribution function (BRDF)

D.1 General

Reflection characteristics are still under study. Overly simplistic models do not adequately characterise reflection for modern displays. This annex presents an introduction to a more rigorous model of reflection and determination of the amount, and the angular distribution of optical scatter from a display device — the bidirectional reflectance distribution function (BRDF).

No measurement is currently specified in this part of ISO 9241 for measuring the BRDF or its parametric representation. Research is underway to learn if a practical method based on BRDF measurements can be used as a normative evaluation means. The objective is a method that is both technically and practically superior to those given in 6.5. When the measurement is simplified, such that it is sufficient to provide an adequate parameterisation of reflection, it is intended that a procedure be added at a future revision of this part of ISO 9241.

D.2 Significance and use

Optical scatter from a visual display originates from the surface topography (due to antiglare treatments) and from microstructures below the surface (technology-dependent). In the most general case — neglecting any wavelength and polarisation dependence — the BRDF is a function of two directions: that of the source (incident light), $(\theta_\mathrm{i},\phi_\mathrm{i})$, and the direction of the receiver (eye or photometer), $(\theta_\mathrm{r},\phi_\mathrm{r})$. The BRDF is a four-dimensional function that relates how the incident illuminance, $\mathrm{d}E_\mathrm{i}$ from direction $(\theta_\mathrm{i},\phi_\mathrm{i})$ contributes a quantity of luminance $\mathrm{d}L_\mathrm{r}$ to the observed or measured reflected luminance:

$$\mathrm{d}L_\mathrm{r}\left(\theta_\mathrm{r},\phi_\mathrm{r}\right)=B\left(\theta_\mathrm{i},\phi_\mathrm{i},\theta_\mathrm{r},\phi_\mathrm{r}\right)\mathrm{d}E_\mathrm{i}\left(\theta_\mathrm{i},\phi_\mathrm{i}\right) \tag{D.1}$$

where $B(\theta_\mathrm{i},\phi_\mathrm{i},\theta_\mathrm{r},\phi_\mathrm{r})$ is the BRDF.

For display purposes, it is anticipated that all the angular information for a complete BRDF will not be needed, and the data requirements can be minimised to information in one to three planes. The luminance observed from the reflection angle is given by the integral over all the directions of incident illuminance:

$$L_\mathrm{r}\left(\theta_\mathrm{r},\phi_\mathrm{r}\right)=\int_0^{2\pi}\int_0^{\pi/2}B\left(\theta_\mathrm{i},\phi_\mathrm{i},\theta_\mathrm{r},\phi_\mathrm{r}\right)\mathrm{d}E_\mathrm{i}\left(\theta_\mathrm{i},\phi_\mathrm{i}\right) \tag{D.2}$$

Suppose we have a distribution of luminance sources in the ambient that gives rise to the incident illuminance distribution, $\mathrm{d}E_i$. For each element of solid angle $\mathrm{d}\Omega=\sin(\theta_\mathrm{i})\,\mathrm{d}\theta_\mathrm{i}\,\mathrm{d}\phi_\mathrm{i}$ measured from the screen, there is an associated source luminance in the room $L_\mathrm{S}(\theta_\mathrm{i},\ \phi_\mathrm{i})$. The illuminance arising from that source is then $L_\mathrm{S}\cos(\theta_\mathrm{i})\,\mathrm{d}\Omega$, where the cosine-term accounts for the light being spread out more at larger angles from the normal. In terms of luminance sources in the surround of the display, the observed reflected luminance then becomes:

$$\mathrm{d}E_\mathrm{i}=L_\mathrm{i}\left(\theta_\mathrm{i},\phi_\mathrm{i}\right)\cos\theta_\mathrm{i}\,\mathrm{d}\Omega=L_\mathrm{i}\left(\theta_\mathrm{i},\phi_\mathrm{i}\right)\cos\theta_\mathrm{i}\,\sin\theta_\mathrm{i},\mathrm{d}\theta\,\mathrm{d}\phi \tag{D.3}$$

Specular reflection is characterised in terms of the luminance of the source, L_S, and the specular reflectance, ρ_S, so that the reflected luminance is given by $L=\rho_\mathrm{S}L_\mathrm{S}$. This is the specular reflection that produces a distinct image as does a mirror: the component of reflection that produces a distinct mirror-like image without diffusion.

Diffuse reflection refers to light energy that is scattered out of the specular direction. Often we think of diffuse as being Lambertian-like. The diffuse reflection model for a Lambertian surface relates the reflected luminance to the total illuminance by

$$L = qE \tag{D.4}$$

where $q = \beta/\pi$ is the luminance coefficient, and β is the luminance factor.

However, diffuse-Lambertian and specular reflections alone are not adequate to characterise the reflective properties of typical display devices. There is a second type of diffuse reflection that we will call *diffuse-haze*, which is the non-specular, non-Lambertian component. This haze component is responsible for many measurement inconsistencies when the reflection is treated with the diffuse-Lambertian and the specular models only.

All components need not exist simultaneously. At least one component exists: to have light reflected from the sample. There are displays that have entirely diffuse-Lambertian surface treatments (e.g. a sheet of writing paper). There are displays that do not have a specular component (distinct reflected images of any light sources cannot be seen) and sometimes displays have only a diffuse-haze component with a negligible diffuse component. There are also displays that do not have a substantial haze component and only exhibit specular and diffuse reflections.

The BRDF can be expressed in terms of the three additive components, diffuse-Lambertian (D_L), specular (S) and diffuse-haze (D_H):

$$B = S + D_\mathrm{L} + D_\mathrm{H} \tag{D.5}$$

where

$$S = 2\rho_\mathrm{s}\, \delta\left(\sin^2 \theta_\mathrm{r} - \sin^2 \theta_\mathrm{i}\right) \delta\left(\phi_\mathrm{r} - \phi_\mathrm{i} \pm \pi\right) \tag{D.6}$$

$$D_\mathrm{L} = q = \beta / \pi \tag{D.7}$$

$$D_\mathrm{H} = H\left(\theta_\mathrm{i}, \phi_\mathrm{i}, \theta_\mathrm{r}, \phi_\mathrm{r}\right) \tag{D.8}$$

The specular component characterises the distinctness of image. The delta functions ensure that the specular contribution only comes from whatever source is located in the specular direction of reflection. When this three-component BRDF is integrated over all incident illumination directions, the more familiar result is:

$$L_\mathrm{r}\left(\theta_\mathrm{r}, \phi_\mathrm{r}\right) = qE + \rho_\mathrm{s} L_\mathrm{s}\left(\theta_\mathrm{r}, \phi_\mathrm{r} \pm \pi\right) + \int_0^{2\pi} \int_0^{\pi/2} H\left(\theta_\mathrm{i}, \phi_\mathrm{i}, \theta_\mathrm{r}, \phi_\mathrm{r}\right) L_\mathrm{i}\left(\theta_\mathrm{i}, \phi_\mathrm{i}\right) \cos\left(\theta_\mathrm{i}\right) \mathrm{d}\Omega \tag{D.9}$$

The first two terms are the diffuse-Lambertian and the specular contributions in their familiar form. The $(\phi_\mathrm{r} \pm \pi)$ term in the specular component simply selects the light from the direction reflected about the normal, i.e. the usual specular configuration. The last term is the diffuse-haze contribution.

The haze function is peaked about the specular direction. Sometimes, the function can cover three or four orders of magnitude (very matt-black screens). To see substantial width of the function in such a case, it is necessary to use a logarithmic scale.

When this work is complete, it is anticipated that a parametric form of this function will be available that will adequately characterise the haze for use in calculations of display reflections. The authors anticipate that the haze height, h, its full-width at half maximum, w (perhaps 5 % or 10 % width), and some shape factor, f, are possibly required to specify the haze function. It is to be hoped that the shape factor will not be required. This would yield a complete characterisation of the reflection with four or five parameters, q, β, h, w, and possibly f. With such formalism, we should be able to calculate how a display will perform in any specified luminance surround without having to create that luminance distribution in the laboratory and measure the reflected luminance.

Annex E
(informative)

Uncertainty analysis guidelines

E.1 Expression of uncertainty

For information concerning the expression of the uncertainty in the measurements described in this part of ISO 9241, refer to the GUM [6].

E.2 Analysis of uncertainty

E.2.1 Summary of error propagation

A summary of error propagation is presented and then applied to several specific measurements in this part of ISO 9241. For more detail, see extensive literature covering this subject. For a discussion of the proper terminology to be used with statements of uncertainty, see the GUM.

In general, every quantity, Q, that we attempt to measure is a function of other variables or parameters in the experiment, so that we can write: $Q = Q(p_1, p_2, p_3, \ldots, p_n)$. Each parameter, p_i, has an uncertainty, Δp_i associated with it. If we want to ask how Q is affected by small changes in the parameters, p_i, we could set up an experiment where we change each parameter by its estimated uncertainty (in either the positive or negative direction) and re-measure Q for each change. The change in Q can be expressed in terms of its partial derivatives:

$$\Delta Q = \sum_{i=1}^{n} \frac{\delta Q}{\delta p_i} \Delta p_i \qquad \text{(E.1)}$$

where Δp_i represents the changes in the parameters and ΔQ is the resultant change in Q.

To take an average of a number, N, of the ΔQ should result in zero, since the changes can, in general, be negative or positive. A better measure of the error would be the square-root of the average of the squares of the ΔQ. So, for $k = 1, 2, \ldots N$, in such experiments we have as the average uncertainty in ΔQ expressed as:

$$(\Delta Q)^2 = \frac{1}{N}\sum_{k-1}^{N}\left(\sum_{i=1}^{n}\frac{\delta Q}{\delta p_i}\Delta p_i\right)_k^2 = \frac{1}{N}\sum_{k-1}^{N}\left(\sum_{i=1}^{n}\left(\frac{\delta Q}{\delta p_i}\Delta p_i\right)^2\right)_k + \frac{1}{N}\sum_{k-1}^{N}\left(\sum_{\substack{i=1,\, j=1\\ i\neq j}}^{n}\frac{\delta Q}{\delta p_i}\frac{\delta Q}{\delta p_j}\Delta p_i\,\Delta p_j\right)_k \qquad \text{(E.2)}$$

Over a large number of such experiments, the second term on the right — the cross-terms — will eventually average to zero, since both positive and negative changes in the parameters are allowed. An estimate of the anticipated change in Q will result when the parameters are all changed by their anticipated uncertainties. Since the changes in the parameters are squared in the first term, their respective signs are not important; dropping the cross-terms, Equation E.2 reduces to

$$(\Delta Q)^2 = \sum_{i=1}^{n}\left(\frac{\delta Q}{\delta p_i}\Delta p_i\right)^2 \qquad \text{(E.3)}$$

Another useful expression is the relative uncertainty where we divide Equation E.3 by Q^2 to obtain:

$$\left(\frac{\Delta Q}{Q}\right)^2 = \sum_{i=1}^{n}\left(\frac{1}{Q}\frac{\delta Q}{\delta p_i}\Delta p_i\right)^2 \tag{E.4}$$

This often results in an algebraic simplification of the uncertainty expression. The uncertainty, ΔQ, or relative uncertainty, $\Delta Q/Q$, is the square-root of the sum on the right side of the equation.

Equation (E.3) is a statement of the propagation of errors from the parameters that contribute to the resulting measurement. If any one of the parameters, p, were dependent upon other variables, r_j, then a similar expression would be used to estimate the anticipated error in Δp in terms of the uncertainties, Δr_j, and the partial derivatives, $\partial p/\partial r_j$, just as expressed in Equation (E.3). Then that Δp value would be used in the expression for ΔQ — a compounding of errors, a propagation of errors. There are certain circumstances when Equation (E.3) becomes rather simple. Suppose Q depends upon a multiplication of the powers (positive or negative) of the parameters, such as:

$$Q = \prod_{i=1}^{n} p_i^{s_i}$$

where the s_i are positive or negative real numbers, for example, $Q = A^n B^m C^r D^s$. If we calculate ΔQ by Equation (E.3) and divide by Q^2 we obtain the relative uncertainty of Q that has a particularly simple form:

$$\text{for } Q = \prod_{i=1}^{n} p_i^{s_i} \text{ then} \left(\frac{\Delta Q}{Q}\right)^2 = \sum_{i=1}^{n}\left(s_i \frac{\Delta p_i}{p_i}\right)^2 \tag{E.5}$$

$$\text{e.g. for } Q = A^n\ B^m\ C^r\ D^s, \quad \text{then} \left(\frac{\Delta Q}{Q}\right)^2 = \left(n\frac{\Delta A}{A}\right)^2 + \left(m\frac{\Delta B}{B}\right)^2 + \left(r\frac{\Delta C}{C}\right)^2 + \left(s\frac{\Delta D}{D}\right)^2 \tag{E.6}$$

Here, the s_i as well as n, m, r, s, can be any positive or negative real number.

Another case of interest is the situation where Q is a sum of other quantities: $Q = p_1 + p_2 + p_3 \ldots + p_n$. Equation (E.3), of course, still valid. When we have such a sum, we often have that the p_i are similar in size, $p_i = p$, and each has approximately the same uncertainty, Δp. Should this be the case, then some simplification occurs:

$$(\Delta Q)^2 = \sum_{i=1}^{n}(\Delta p_t)^2 \approx n\Delta p^2$$

and with $Q \cong np$ we can estimate (E.7)

$$\left(\frac{\Delta Q}{Q}\right)^2 \approx \frac{1}{n}\left(\frac{\Delta p}{p}\right)^2 \quad \text{or} \quad \left|\frac{\Delta Q}{Q}\right| \approx \frac{1}{\sqrt{n}}\left|\frac{\Delta p}{p}\right|$$

Thus, the relative uncertainty in such a sum decreases inversely as the square-root of the number of terms in the sum.

When a measurement instrument, such as a luminance meter, is purchased, the manufacturer provides a statement of uncertainty, U_m, that is usually an expanded uncertainty with a coverage factor of $k = 2$ — this should always be checked with the manufacturer. The associated combined standard uncertainty, $u_\text{m} = U_\text{m}/2$, is likely a root-sum-of-squares of the calibration uncertainty of the manufacturer's transfer standard (traceable to the appropriate national laboratory), u_c, the repeatability of the measurement of that standard, s_m, and various other factors such as drift, temperature effects, focus and distance. With luminance meters, since the repeatability is often much smaller than the uncertainty, the manufacturer could quote the repeatability, s_m, of that instrument in order to give the purchaser an idea of how well the instrument can make relative measurements in a short time period. Such an uncertainty statement and its related repeatability are often made in connection with a particular, CIE illuminant A, for example. How well the instrument performs for other colours and sources might not be stated. Furthermore, the stated uncertainty might only apply to luminances above a certain threshold. Thus, without clear specifications from the manufacturer, it might not be appropriate to apply the stated uncertainty of a luminance meter to low-light level readings.

E.2.2 Example — Luminance measurement uncertainties

The manufacturer claims that his instrument has a relative uncertainty of $U_\mathrm{m}/L = 4$ % and a relative repeatability of $s_\mathrm{m}/L = 0{,}2$ %. We will assume that this U_m is an expanded uncertainty with a coverage factor of $k = 2$. When we make a single measurement, the uncertainty of our measurement result would be U_m , i.e. we will assume the repeatability has already been folded into the uncertainty. If we were to make several measurements of an absolutely stable light source in a short period of time, we would expect that the standard deviation of that set of results would be approximately the repeatability, s_m.

Suppose we make several measurements of the luminance, L_i, $i = 1,2,3,\ldots,n$, and determine the mean, L_ave, and standard deviation, s_L, of the resulting set. Then we find that the standard deviation is significantly larger than the repeatability of the instrument, $s_\mathrm{L} > s_\mathrm{m}$. What do we then use for the uncertainty? Obviously, there is some instability somewhere. If we cannot improve the apparatus to eliminate the increased uncertainty, then we incorporate it into the uncertainty estimate that we would provide to characterise our measurement capability. The combined standard uncertainty is the root-sum-of-squares of the component uncertainties. Assuming the uncertainty of the light-measuring device includes a $k = 2$ coverage factor, U_m would not be used as a component of uncertainty, but the coverage factor would have to be eliminated, thereby using $U_\mathrm{m}/k = U_\mathrm{m}/2 = u_\mathrm{m}$ as the component of uncertainty that is associated with the instrument. The combined standard uncertainty for the luminance measurement would be:

$$u_\mathrm{L} = \sqrt{\left(\frac{U_\mathrm{m}}{k}\right)^2 + s_\mathrm{L}^2} = \sqrt{\frac{U_\mathrm{m}^2}{4} + s_\mathrm{L}^2} \tag{E.8}$$

Finally, we reintroduce a $k = 2$ coverage factor to obtain $U_\mathrm{L} = 2u_\mathrm{L}$, which is properly called the *expanded uncertainty* with a coverage factor of $k = 2$. It is U_L that we would use in quoting the final uncertainty of the luminance measurement.

With the above example of $U_\mathrm{m} = 4$ %, we will assume that the manufacturer used a $k = 2$ coverage factor in establishing the measurement uncertainty of the LMD. Further, let us assume that the relative standard deviation of the set of measurements with respect to the average, L_ave, is $s_\mathrm{L}/L_\mathrm{ave} = 1{,}2$ %. Using Equation (E.8), we would obtain $u_\mathrm{L}/L_\mathrm{ave} = 2{,}3$ %, and the relative expanded uncertainty with a coverage factor of $k = 2$ would be $U_\mathrm{L}/L_\mathrm{ave} = 4{,}6$ %.

E.2.3 Example — Chromaticity coordinate measurement uncertainties

This is a similar situation to E.2.2, except that the repeatability of the chromaticity measurement is not necessarily much smaller than the uncertainty of measurement of the instrument. For a single measurement, we would be inclined to accept the manufacturer's uncertainty statement of U_m. Thus, when making single measurements, there is the possibility of an increased uncertainty from type A effects than might be found with the luminance measurement.

Let c be any one of the chromaticity coordinates. Suppose the uncertainty of measurement of the instrument is $U_\mathrm{m} = 0{,}002\,4$ and the repeatability is $s_\mathrm{m} = 0{,}000\,5$. Also, suppose we take a series of measurements of the chromaticity coordinates of some source and find that the standard deviation (s_c) is $s_\mathrm{c} = 0{,}001\,5$ of those measurements. Since the standard deviation of the set is in excess of the repeatability, then we will want to account for it as another component of uncertainty. Assuming that the manufacturer uncertainty estimate, U_m, is an expanded uncertainty with a coverage factor of $k = 2$, then the combined standard uncertainty of any chromaticity measurement would be

$$u_\mathrm{c} = \sqrt{\left(\frac{U_\mathrm{m}}{k}\right)^2 + s_\mathrm{c}^2} = \sqrt{\frac{U_\mathrm{m}^2}{4} + s_\mathrm{c}^2} \tag{E.9}$$

or u_c = 0,001 4. We would quote an expanded uncertainty of $U_\mathrm{c} = 2u_\mathrm{c}$ = 0,002 8 with a coverage factor of k = 2.

E.2.4 Example — Contrast measurement uncertainties

The error in the contrast $C = L_\mathrm{w}/L_\mathrm{b}$ is based on a luminance measurement of white, L_w, and black, L_b. The relative uncertainty in the contrast measurement is, from Equation (E.6):

$$\left(\frac{u_\mathrm{c}}{C}\right)^2 = \left(\frac{\mathrm{d}C}{C}\right)^2 = \left(\frac{\mathrm{d}L_\mathrm{w}}{L_\mathrm{w}}\right)^2 + \left(\frac{\mathrm{d}L_\mathrm{b}}{L_\mathrm{b}}\right)^2 = \left(\frac{u_\mathrm{w}}{L_\mathrm{w}}\right)^2 + \left(\frac{u_\mathrm{b}}{L_\mathrm{b}}\right)^2 \tag{E.10}$$

where, u_c, u_w, and u_b are the combined standard uncertainties associated with the contrast, the white, and the black measurement, respectively.

EXAMPLE The manufacturer quotes a relative uncertainty of measurement of $R_\mathrm{m} = U_\mathrm{m}/L$ = 4 % for the luminance L of a CIE illuminant A at 100 cd/m^2, which we will assume is an expanded uncertainty with a coverage factor of $k = 2$. He then claims that the relative repeatability at this luminance level is $r_\mathrm{m} = s_\mathrm{m}/L$ = 0,1 %. Suppose also that the lowest the meter can read is 0,01 cd/m^2 and that the readout error is roughly δL = 0,01 cd/m^2 because of the uncertainties associated with that last digit. We assume that the white luminance is L_w = 130 cd/m^2. Suppose the black luminance measures L_b = 0,51 cd/m^2. The contrast is $L_\mathrm{w}/L_\mathrm{b}$ = 255, but what is the uncertainty in that contrast measurement?

If we only made a white luminance measurement, the uncertainty would be $R_\mathrm{m}L_\mathrm{w}$, that is, 4 % of L_w. But when measuring contrast, the uncertainties of the white and black measurements will be combined. For this calculation, the standard uncertainty in the white luminance measurement is $u_\mathrm{w} = (R_\mathrm{m}/2)L_\mathrm{w}$ =2,6 cd/m^2, where the factor of two is from removing the effects of the k = 2 coverage factor. (Once we have calculated the combined standard uncertainty of the contrast, then we will use a $k = 2$ coverage factor to obtain the final expanded uncertainty of contrast.) For the white measurement, the readout error is ignorable.

Naïvely speaking, the uncertainty in the black arises from the component of uncertainty associated with the instrument's calibration $R_\mathrm{m}L_\mathrm{b}$ and the component of uncertainty associated with the readout δL = 0,01 cd/m^2, which for black is not longer able to be ignored. If that were true — that the relative uncertainty R_m stays unchanged for low-light level reading — then the standard uncertainty in the black measurement would be given by:

$$u_\mathrm{b} = \sqrt{\left(\frac{R_\mathrm{m}}{2}L_\mathrm{b}\right)^2 + (\delta L)^2} \tag{E.11}$$

or u_b = 0,014 cd/m^2. In doing this we have made the assumption that the repeatability is not a factor with which we have to be separately concerned, i.e. we have assumed that u_b adequately accounts for repeatability. Now, from Equation (E.8) the relative combined standard uncertainty (u_c/C) in the contrast is, naïvely:

$$\left(\frac{u_\mathrm{c}}{C}\right)^2 = \left(\frac{\mathrm{d}C}{C}\right)^2 = \left(\frac{u_\mathrm{w}}{L_\mathrm{w}}\right)^2 + \left(\frac{u_\mathrm{b}}{L_\mathrm{b}}\right)^2 = (0{,}020)^2 + (0{,}027)^2 \text{, or } u_\mathrm{c}/C = 3{,}4\ \% \tag{E.12}$$

We should use a coverage factor of $k = 2$ so that the relative expanded uncertainty of the contrast measurement is $R_\mathrm{c} = U_\mathrm{c}/C$ = 6,8 %. This calculation may seem adequate, but it probably is not. The reason why it is probably not, is that this naïve calculation hinges on the assumption that the R_m = 4 % relative uncertainty of measurement of the instrument and its 0,1 % relative repeatability remains the same for dark measurements as for the brighter measurements (such as its calibration point of the CIE illuminant A). That is not necessarily true — in fact, probably not. Unless the manufacturer can assure that fact or provide the user with more uncertainty information covering the lower-luminance levels, some attempt needs to be made to characterise the luminance meter for low light levels.

For example, suppose the detector has a noise of $s_\mathrm{n} = 0{,}1\ \mathrm{cd/m}^2$ about the zero signal, but any negative results would always be truncated to zero in the output of the instrument. For measurements of luminances of $100\ \mathrm{cd/m}^2$ and above, that will permit a relative repeatability of 0,1 % as stated in the specifications. The uncertainty in the white measurement is not affected by such noise, but the black is definitely affected. The combined standard uncertainty of black will add another component to account for this noise s_n. This is equivalent to including the measured repeatability of black as a component of the uncertainty in the result of a measurement:

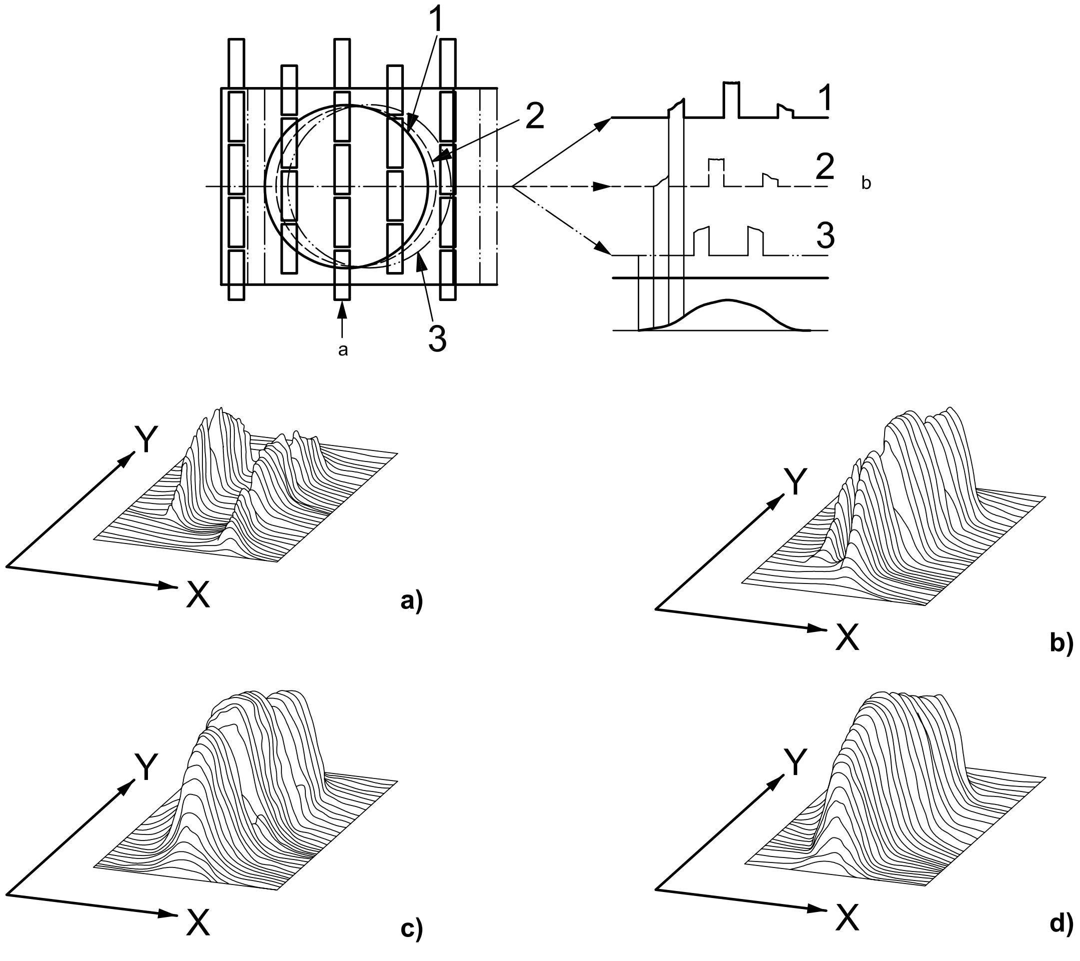
$$u_\mathrm{b} = \sqrt{\left(\frac{R_\mathrm{m}}{2} L_\mathrm{b}\right)^2 + \left(\delta L\right)^2 + s_\mathrm{n}^2} \tag{E.13}$$

or $u_\mathrm{b} = 0{,}10\ \mathrm{cd/m}^2$ and the relative contribution to the contrast uncertainty is $u_\mathrm{b}/L_\mathrm{b} = 0{,}20$. The noise in the black measurement now becomes the dominant source of uncertainty in the contrast result. The uncertainty in the white measurement becomes ignorable by comparison ($u_\mathrm{b}/L_\mathrm{w} = 0{,}020$), and essentially all of the uncertainty in the contrast measurement comes from the black measurement: with a coverage factor of $k = 2$, the relative expanded uncertainty in the contrast measurement result becomes 40 %. This shows how important it is to understand the instrument's capabilities in making black measurements. However, there are further problems. In evaluating Equation (E.10), it had been assumed that the relative uncertainty R_m does not change as the luminance decreases. Usually, the uncertainty of an instrument decreases with the level of the signal measured — this is in addition to any readout errors encountered for low-level measurements (δL). Thus, before an uncertainty in a contrast measurement can be evaluated, the performance of the instrument in measuring low-level luminances needs to be provided or determined.

Annex F
(informative)

Reconstruction of luminance distribution by microstepping

See Figure F.1 (in this case a dot). The dot is scanned behind the mask with microstepping. Each step corresponds to the size of n-pixels in the camera pick-up area. The pick-up area of the camera is virtually moved with the same stepsize. Doing this, the mask is virtually moved between spot and camera. To construct this distribution, the "maximum luminance" algorithm is used. Procedure: take image 1; apply one microstep, take image 2; compare these two images; of each corresponding pixel take the highest luminance and store; apply microstep, etc.



a)

b)

c)

d)

Key

1 measurement 1

2 measurement 2

3 measurement 3

a) to d) shows luminance distribution reconstruction in four steps.

[a] Mask hole.

[b] Middle video line of the measurement 1-2-3 and combination.

Figure F.1 — Reconstruction of luminance distribution

Bibliography

[1] ISO 9241-3:1992, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 3: Visual display requirements*

[2] ISO 9241-7, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 7: Requirements for display with reflections*

[3] ISO 9241-8, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 8: Requirements for displayed colours*

[4] ISO 13406-1:1999, *Ergonomic requirements for work with visual displays based on flat panels — Part 1: Introduction*

[5] ISO 13406-2:2001, *Ergonomic requirements for work with visual displays based on flat panels — Part 2: Ergonomic requirements for flat panel displays*

[6] *Guide to the Expression of Uncertainty in Measurement (GUM)*. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition, 1993, corrected and reprinted in 1995

[7] IEC 61947-1:2002, *Electronic projection — Measurement and documentation of key performance criteria — Part 1: Fixed resolution projectors*

[8] IEC 61947-2:2001, *Electronic projection — Measurement and documentation of key performance criteria — Part 2: Variable resolution projectors*

[9] CIE Publication No. 69, *Methods of Characterizing Illuminance Meters and Luminance Meters,* 1987

[10] VESA-2005-5, *Flat Panel Display Measurements*, FPDM2, Version 2.0 [4)]

[11] KELLEY, E.F., JONES, G.R., GERMER, T.A. *Display Reflectance Model Based on the BRDF, Displays,* Vol. 19, No. 1, pp. 27-34, June 30, 1998

[12] KELLEY, E.F. *Sensitivity of Display Reflection Measurements to Apparatus Geometry.* Information Display International Symposium Digest of Technical Papers, Vol. XXXIII, Boston, MA, pp. 140-143, May 2002

[13] BOYNTON, P.A., KELLEY, E.F. *Accurate Contrast Ratio Measurements Using a Cone Mask.* Society for Information Display International Symposium Digest of Technical Papers, Boston, MA, May 11-16, 1997, Vol. XXVIII, pp. 823-826, May 1997

[14] BOYNTON, P.A., KELLEY, E.F. *NIST Stray Light Elimination Tube Prototype.* National Institute of Standards and Technology Interagency Report NIST IR 6851, March 2002

[15] BOYNTON, P.A., KELLEY, E.F. *Small-Area Black Luminance Measurements on White Screen Using Replica Masks.* Society for Information Display International Symposium Digest of Technical Papers, Anaheim, CA, May 17-22, 1998, vol. XXIX, pp. 941-944, May 1998

[16] BOYNTON, P.A., KELLEY, E.F. *Comparing Methodologies for Determining Resolution from Contrast in Projection Display Systems. Projection Displays XI,* Proceedings of the SPIE, January 2005

[17] MCCAMY, *Color Res. Appl.* 17 (1992), pp. 142-144 with erratum in *Color Res. Appl.* 18, 1993, p. 150

[18] BECKER, M. Standards and Metrology for Reflective LCDs. *SID 2002 Digest*, pp. 136-139

---

4) US Video Electronics Standards Association standard.

ICS 13.180; 35.180

Price based on 183 pages