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Edition 1.0 2018-09

TECHNICAL REPORT

colour inside

Eyewear display –
Part 1-1: Generic introduction

IEC TR 63145-1-1:2018-09(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC TR 63145-1-1, which is a Technical Report, has been prepared by IEC technical committee 110: Electronic display devices.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
110/966/DTR	110/982A/RVDTR

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

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

A list of all parts in the IEC 63145 series, published under the general title *Eyewear display*, can be found on the IEC website.

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

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- withdrawn,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

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

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INTRODUCTION

This document intends to gather technical information on eyewear displays, and to clarify the relationship to normative aspects of the standardization in this technology area.

EYEWEAR DISPLAY –

Part 1-1: Generic introduction

1 Scope

This part of IEC 63145, which is a Technical Report, provides general information for the standardization of eyewear displays. This document includes an overview of the technology, critical performance characteristics, issues of optical measurements, and other information.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

3.1.1
eyewear display
display worn on the user's eye or worn close to the eye in order to provide information to the user

Note 1 to entry: See 4.1.

3.1.2
pupil forming
virtual image optics that are equipped with a magnifier and the optical elements which act as an aperture stop, and where the magnifier forms a real image of the aperture stop

3.1.3
non-pupil forming
virtual image optics where the magnifier does not form a real image of the aperture stop

Note 1 to entry: See 3.1.2.

3.2 Abbreviatied terms

AR	augmented reality
CAVE	cave automatic virtual environment
CRT	cathode ray tube
FOV	field of view
FPD	flat panel display
HMD	head mounted display

HUD	head up display
IPD	interpupillary distance
LMD	light measuring device
MR	mixed reality
QVS	qualified viewing space
VR	virtual reality
WFOV	wide field of view
2-D	two-dimensional

4 Eyewear display technologies

4.1 General

The advancement of display technology has enabled the creation of compact displays that can be placed close to or on a viewer's eye. This miniaturization enables the user to wear the display in a comfortable form factor (such as eye glasses), and allows an individual to render information of interest for their personal use. Some of the benefits of this display technology include:

- good portability, such as hands-free, like eye glasses;
- large perceived image size, despite small structure; and
- link with user's behaviour or external world, for virtual reality/augmented reality/mixed reality.

There have been several designs proposed for wearing the display:

- head mount;
- helmet mount;
- headset;
- glasses mount;
- goggle;
- visor;
- contact lens.

The term "eyewear" is defined as follows in several sources:

a) things worn on the eyes, such as spectacles and contact lenses [1][1]; and

b) devices worn to protect the eyes or improve the vision, such as eyeglasses, sunglasses, safety goggles, etc. [2].

The eyewear includes things to cover the user's eye, and contact lenses are also included.

How the display is mounted near the eye affects the display optics, the performance, and how it is measured. There are other kinds of displays which do not have a mount structure or do not attach to the eye:

- electronic view finder;
- telescope;
- microscope;

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

- binoculars;
- opera glasses; and
- ophthalmic instruments, such as an auto-refractometer.

These cover the user’s eye, but are not included in the eyewear display because they are not worn.

The term “near-eye display” is often used because, compared to an ordinary display, such as a TV or PC monitor, the display is positioned closer to the user’s eye. In ISO 9241-302:2008 [3], Figure 11, “NTE (near to the eye) display” is used to explain the term "virtual image display". In ISO 9241-305:2008 [4], 6.11.1, the terms “near-to-eye display” and “NED” are used. These four terms are slightly different, but are considered to have the same meaning. For near-eye displays, the proximity of the display to the eye makes it difficult to focus on the display directly. Therefore, it is necessary to include optics between the display and eye for the viewer to focus on the display image. Generally, the optics forming a virtual image are used.

Eyewear displays are typically used in virtual reality (VR) and augmented reality (AR) applications. When the application of displays is considered, “VR” or “AR” is frequently used in academic conferences and even in newspapers to describe them. Mixed reality (MR) is also used when physical and digital (visual) objects co-exist and interact in real time. Some common dictionary definitions of VR are:

- the computer-generated simulation of three-dimensional images of an environment or sequence of events that someone using special electronic equipment may view, as on a video screen, and interact with in a seemingly physical way [2]; and
- a computer-generated environment that, to the person experiencing it, closely resembles reality [5].

It is noted that VR is not limited to eyewear displays. There are other ways to implement VR, such as a multi-screen CAVE (cave automatic virtual environment) [6][7] using image projection. Compared with these VR displays, where the user directly observes the images shown on the display screen, VR eyewear displays are worn and need special optics to see an image. Without the optics, it is difficult for the human eye to focus on the displayed image, or the observed image is too small. The use of eyewear displays for VR has become very popular, with many companies offering non-see-through goggles in the marketplace.

Compared to VR, AR is a relatively new term and technology. AR allows for a live direct or indirect view of a physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data. It is related to a more general concept called mediated reality, in which a view of reality is modified (possibly even diminished rather than augmented) by a computer. As a result, the technology functions by enhancing one’s current perception of reality. In contrast, virtual reality replaces the real world with a simulated one. Many AR displays are designed in the form of eye glasses or visors. It is important that the AR/VR term be used with the form factor, such as “VR goggles” and “AR glasses”, otherwise AR/VR just identifies the application, not the device type.

The popular use of the term “virtual” has caused some confusion in how it is used for AR/VR applications. In the technical field of optics, the term “virtual”, such as “virtual image”, has a specific meaning [8]. In optics, the virtual image is defined as an image formed when the outgoing rays from a point on an object always diverge. Therefore, it is more precise to use the term “virtual” in combination with other attributes, such as “virtual reality”, “VR”, or “virtual image”. In ISO 9241-302:2008 [3], 3.4.52, “virtual-image display” is defined as a device that optically or holographically forms a virtual image. Instead of “virtual-image display”, “virtual display” is used in ISO 9241-303:2011 [9], Annex E, and “virtual image display” appears in ISO 9241-305:2008 [4], 6.11. These terms are considered to have the same meaning, that is, a display with optics that creates a virtual image. However, the term "virtual display" is confusing, and should be avoided. For example, a projection display with a cave shape screen is often called a “virtual display” because it can produce a virtual reality scene, but it does not use virtual-image optics.

A “head up display (HUD)” is considered as one type of virtual image display, but it is not considered as an eyewear display because it is not worn close to the eye.

To establish the classification of eyewear displays, the above-mentioned points need to be considered.

4.2 Classification

To classify the eyewear displays, as shown in Figure 1, there are some key points to consider as follows:

- virtual image optics, or retina direct projection;
- optical see-through or video see-through (optical non-see-through);
- monocular or binocular;
- near or contact.

AR video see-through is also possible.

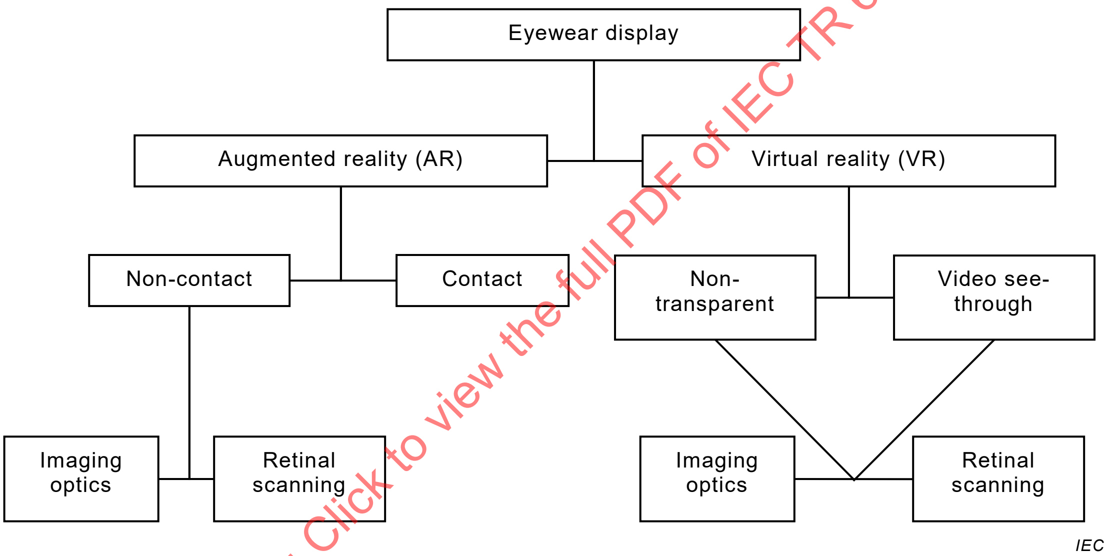


Figure 1 – Eyewear display classification

When application, interface, and design are considered, an alternative classification can be considered as shown in Figure 2. In this classification, the key points are as follows:

– see-through or non-see-through from an application stand point;
– mounting method base by human physical interface;
– monocular, bi-ocular or binocular for human optical interface;
– pupil forming or non-pupil forming from an optical design stand point;
– display source driving method.

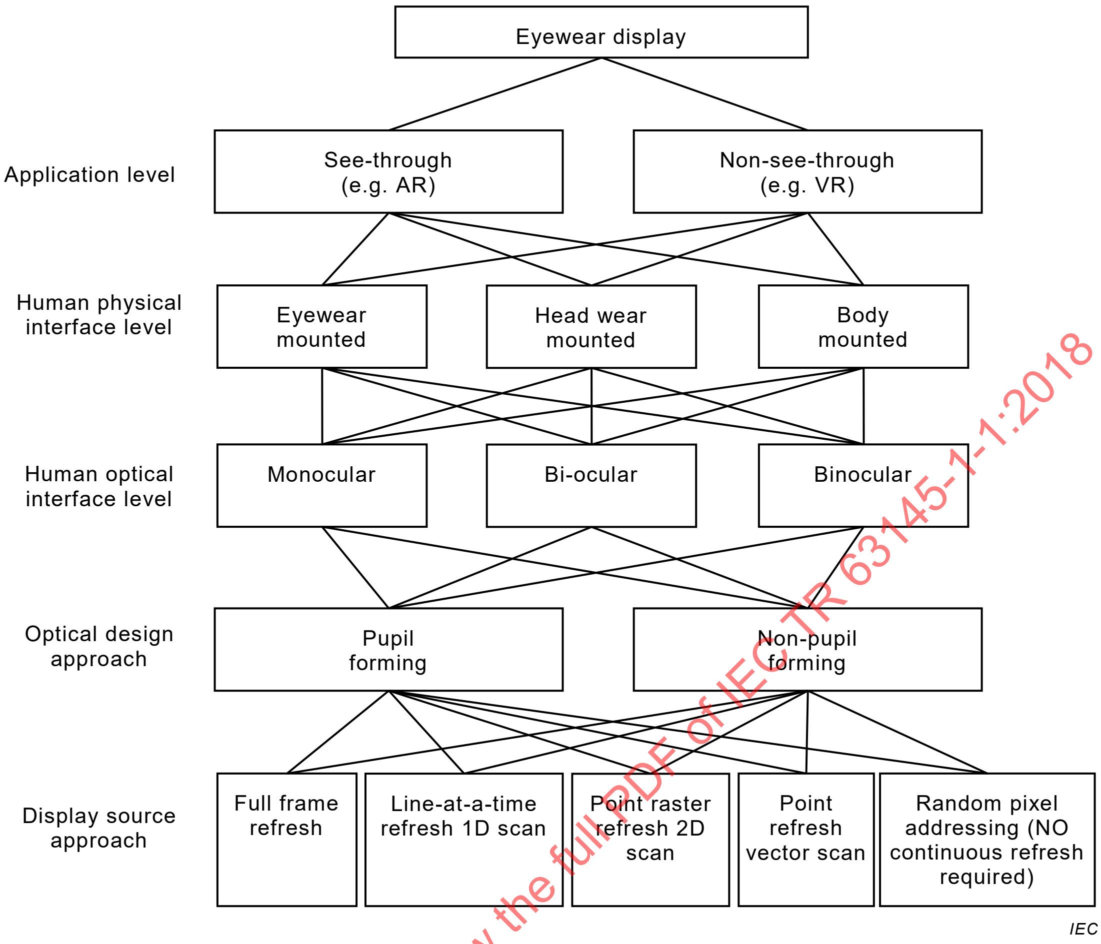


Figure 2 – Alternative classification

The use of eyewear displays with binocular vision and video see-through capability is very popular. Monocular and binocular optical see-through eyewear displays have also recently been developed. Therefore, considering the current market situation, the following two types of devices are needed for standardization:

1) non see-through type using virtual image optics;

2) see-through type using virtual image optics.

The essential performance of eyewear displays can be characterized by measuring the left or right eyepiece separately. When the users use a binocular system, there can be a difference between the left and right images for various reasons. This difference can be intentionally generated to induce the perception of binocular depth. It can also be affected by the difference between the interpupillary distance (IPD) of the user and the distance between the virtual image optics of the user's eyes. When this difference is large it can induce visual discomfort. More advanced measurements can then be conducted for binocular vision. This will be important for conformity purposes.

In the case of "retina direct projection", laser optics are used to implement the Maxwellian view principle. Its standardization can be addressed separately from that of virtual image optics devices.

4.3 Principles

4.3.1 Virtual image optics

Figure 3 shows the principle of virtual image optics, which contain an optical component, such as a convex lens or a concave mirror, located between an imager (i.e., a small size display) and a user's eye. For example, in this convex lens case, the lens magnifies the image shown on the imager like an eye loupe. The imager is located nearer than the front focal distance of the lens, and therefore after going through the lens the light rays from each pixel diverge, as if originating from a (virtual) source far in front of the lens. The light rays do not converge without an additional lens, which means that a real image cannot be projected onto a screen directly. Instead, when these light rays enter into the human eye, the lens of the eye focuses the light rays on the retina, and as a result, the virtual images can be perceived.

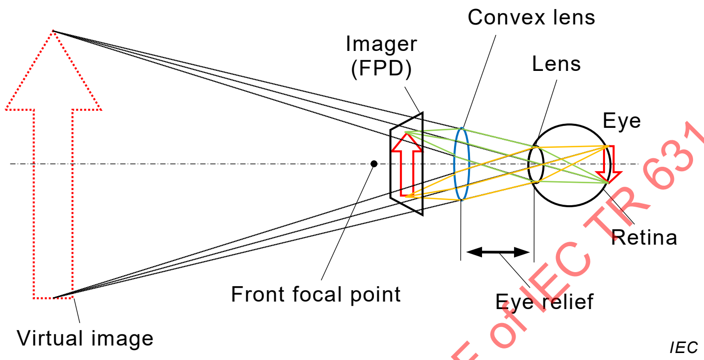


Figure 3 – Principle of virtual image optics

In the actual implementation of eyewear displays, this optical configuration is designed so that an eye is located at a specific eye-position, called "eye point". This means that the eye point is the centre position of the eyewear display's exit pupil and is aligned with the viewer's pupil position. Instead of the eye pupil, the centre of the cornea is sometimes used, but these are not the same. There is difference of a few millimetres (i.e., 3 mm) between these positions, as shown in Figure 4. This difference is important when evaluating optical performance. It is noted that the eye point is the origin for most optical measurements and is generally defined by the manufacturer or supplier. A suitable eye point (eye position) is very much dependent on the display configuration and system design. If the manufacturer does not specify the eye point, experimentally finding the eye point can be ambiguous and difficult to determine without proper metrology [10][11].

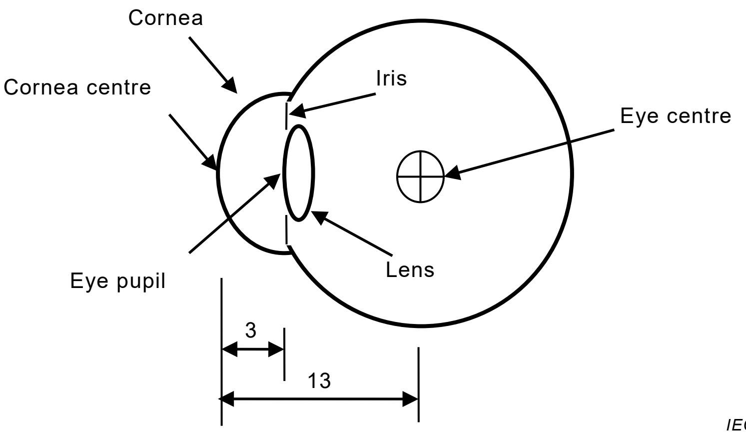


Figure 4 – Dimensions of a typical adult eye

“Eye relief” is generally the distance from the exit pupil of the eyewear display to the nearest physical surface (the reference point) of the virtual image optics. The reference point is sometimes specified by the manufacturer or supplier to be at a different position.

The eye-box is shown as the three-dimensional size of the eyewear display’s exit pupil. The eye-box size is generally restricted due to the limitations of the optical design. If the eye is not positioned within the eye-box, some or all of the displayed images can be degraded below a predetermined set of performance characteristics that can include, but not necessarily be limited to, luminance, field of view, resolution or distortion.

In the eyewear display, the field of view (FOV) is the angular size of the virtual image projected by the eyewear display to the human retina. The width and height of the virtual image are normally described in terms of their horizontal and vertical FOV. However, some recent head mounted displays (HMDs) do not have rectangular screens. In those cases, the new FOV specifications need to be considered.

Eyewear display designs can often be described as either pupil forming or non-pupil forming. A pupil forming optical magnifier is a magnifier in which a physical aperture stop exists within the optical design, and the optical elements that are between the aperture stop and the user form a real image of the aperture stop at a defined plane. The aperture stop in this system limits only the numerical aperture of the magnifier but not the field of view. The eye-box of this system has its maximum two-dimensional area at the plane of the real image of the aperture stop and the two-dimensional area of the eye-box decreases in size on either side of this aperture image plane.

A non-pupil forming optical magnifier or “simple magnifier” is a magnifier in which a) the image of the aperture stop is virtual, or b) the magnifier has no clearly defined aperture stop within the optical design. Sometimes, the aperture stop is outside the system, or there is no “real” image conjugate.

ISO 9241-302:2008 [3], 3.5, explains several aspects of virtual-image displays. The topics include the operating principle, visual ergonomics, performance characteristics, and so on, which are especially important for designing HMDs. The operating principle part in 3.5 of ISO 9241-302:2008 [3] (and Figure 11) is particularly valuable when considering the standardization of virtual image optics. In Figure 11 of ISO 9241-302:2008 [3], five key elements are mentioned: field of view, micro display as the imager, imaging optics (a convex lens in the figure), exit pupil, and eye relief. The concepts described in that document are almost the same, except for the exit pupil. Figure 11 shows the exit pupil as the width of light across a section, while in 3.5.20 it is defined as the “vertical/horizontal dimension of the QVS (qualified viewing space)". The exit pupil of Figure 11 is shown as “minimum exit pupil size needed” in Figure 13 of ISO 9241-302:2008 [3]. The definition seems to be ambiguous, and needs to be clarified.

In ISO 9241-302:2008 [3], 3.5.42, QVS is defined as the “space (volume, centre of volume) from where the image is perceived at an acceptable level”. But the details are not shown in ISO 9241-302 [3] and ISO 9241-303 [9]. Instead, the details are shown in ISO 9241-305:2008 [4], 6.11.11. In ISO 9241-305:2008 [4], 6.11.11, the QVS is defined as the “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”. In ISO 9241-305:2008 [4], Figure 74 shows the QVS represented by a triangular shape. Generally, the QVS corresponds to the eye-box, which was already mentioned in the above explanation, but the shape of the eye-box is more complex. It is not always correct that the closer the user comes to the display, the wider the eye-box cross-section. Further work is needed to better understand how to characterize the eye-box [12].

In the QVS definition of ISO 9241-305:2008 [4], 6.11.11, the inclusion of the phrase “by only rotating the eyeball” introduces greater complexity into the QVS evaluation. When the FOV is wider, this point becomes important because when the eyeball is rotated, the position of the entrance pupil is also changed. This impacts the measurement equipment configuration [10][11], though this has not been discussed yet. What needs to be discussed is how to treat the centre of the eyeball rotation.

In ISO 9241-303:2011 [9], Clause E.2 indicates that “to accommodate spectacles, the eye relief should be at least 25 mm”. However, recently some eyewear displays have included a vision correction function, and therefore such a large value is not always necessary.

4.3.2 Transparency

In the case of a virtual image display, when the transparent combiner (e.g., half mirror) is added to the virtual image optics, virtual image information can be overlapped on real scenes (Figure 5). Therefore, in addition to on-screen performance, the see-through performance needs to be considered. In ISO 9241-302:2008 [3], 3.5.45, the term “see-through” is defined as “superimposition of an image or images onto the user’s field of view”. But the details are not described. Therefore, this definition needs to be further developed.

The see-through performance of virtual displays appears to have some similarity to direct-view-type transparent displays. Given that similarity, the transparency characterization methods in transparent display standards are considered when developing methods for virtual displays. IEC TC 110 is developing several documents on these issues [13][14][15][16]. However, the optical instruments used for eyewear displays need special optics (e.g. small entrance pupil).

In contrast to the direct-view type transparent display, the see-through characteristics of an eyewear display can be complicated by factors such as a stray light and optical distortion effects. These can be introduced by special optics, like holographic films or micro mirror optics. Figure 6 shows three typical types of transparent optics: front optics, rear optics, and internal optics [17]. The front type uses optics provided in front of the eyeglass lens, while the rear type uses optics provided behind the eyeglass lens. In the internal type, the optics are located within the eyeglass lens.

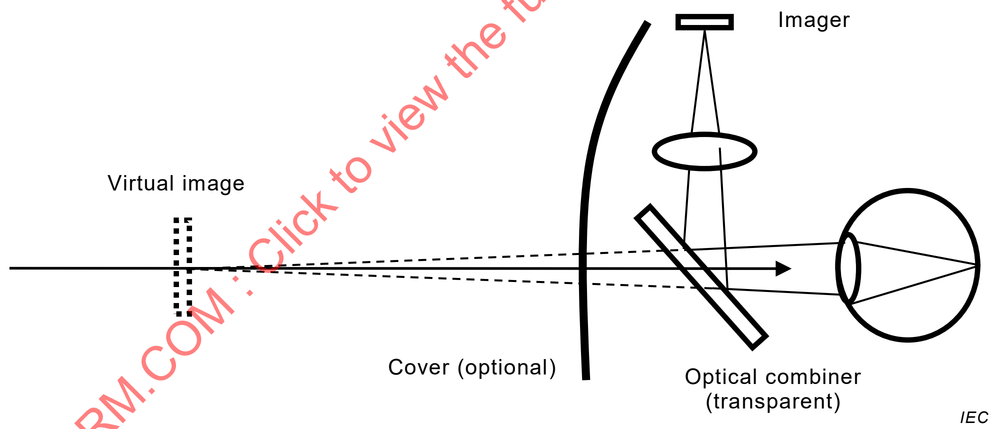


Figure 5 – Principle of transparency

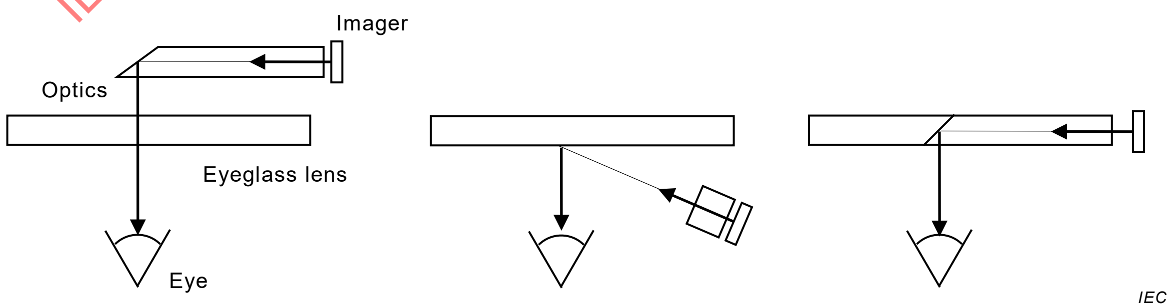


Figure 6 – Three types of transparent optics

4.3.3 Monocular/binocular optics

Monocular optics provide the fundamental functionality of the display. Binocular optics consist of two sets of monocular optics. In both cases, the geometrical and optical relations between the user's eye and the optics are important. For binocular optics, the relationship between the two monocular optics is critical (e.g. binocular difference, misalignment, convergence, etc.). In the simple binocular case, the right and left displays can show the same image. However, if parallax is introduced between the right and left image, stereoscopic perception can be observed. This means that binocular optics type can generate stereoscopy, but this is just one of the possible functions. Many binocular characteristics are described in ISO 92401-302 [3], ISO 92401-303 [9], and ISO 92401-305 [4]. For the purpose of display measurements, initially evaluating the right and left eye performance separately is of primary importance. It is not always necessary to consider the combined effects from both eyes.

5 Performance characteristics and specifications

5.1 General

The performance characteristics and specifications of eyewear displays include not only optical performance, but also mechanical and electrical performance, as shown in Annex A. This document mainly focuses on the optical performance.

5.2 Optical performance

5.2.1 Virtual image optics properties

In order to evaluate the virtual image optics properties, the following characteristics need to be measured:

- FOV as well as eye-box,
- luminance, chromaticity, and contrast (including uniformity),
- distortion, resolution (Michelson contrast), colour registration error (chromatic aberration), and virtual image distance.

As shown in Figure 7 and Figure 8, the FOV is closely related with the eye-box. If the user's eye is rotated so that part of the entrance pupil is outside the eye-box, the virtual image brightness lowers, and the FOV might become smaller. In other words, if a smaller FOV image is used, the eye-box will be longer. Therefore, unless stated otherwise, the largest addressable virtual image possible can be used to assess the FOV. As the FOV of eyewear displays becomes larger, the significance and complexity of this measurement will also grow.

The FOV can be expressed in several ways. For example, in conventional flat panel displays (FPDs), such as a TV or PC monitor, the FOV corresponds to the viewing direction range. Historically, the viewing direction range has been defined by the contrast ratio. But defining the FOV in terms of colour difference based range has also been recently proposed. However, the most basic definition of FOV is in terms of luminance. It is often checked whether the displayed grid test pattern can be observed. To establish more quantitative evaluation methods, the luminance, chromaticity, and contrast measurement are important.

The interrelationship between the eye-box, FOV, and contrast can be visually represented by the example shown in Figure 9. This visualization provides an example of how the left and right eye-box can vary based on the following criteria: the design pupil, and the boundary where at least 95% of the luminance FOV can be observed, and at least 25 % of Michelson contrast $(L_{max} - L_{min}) / (L_{max} + L_{min})$ can be observed with a 1 x 1 grille pattern. If these parameters are measured at different points on the FOV, then the shape of these contours can change.

The distortion, Michelson contrast, and colour registration error are characteristics of the eyewear display image quality. These characteristics are closely related with the FOV, and it can be discussed whether these characteristics determine the FOV. However, generally, the FOV is determined by the luminance, and these characteristics are measured within this luminance-based FOV.

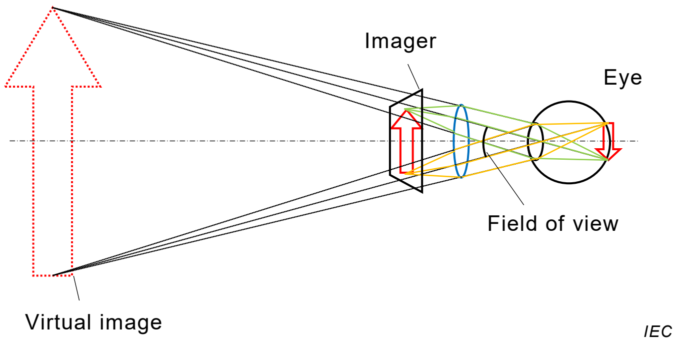


Figure 7 – Field of view

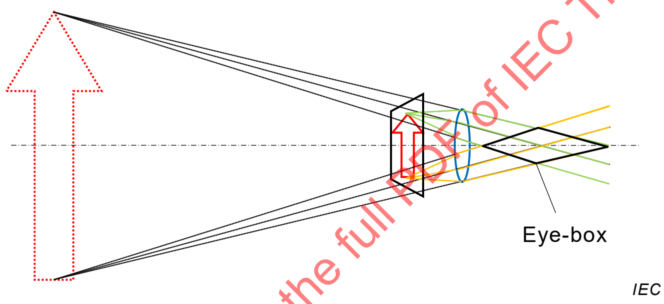


Figure 8 – Eye-box

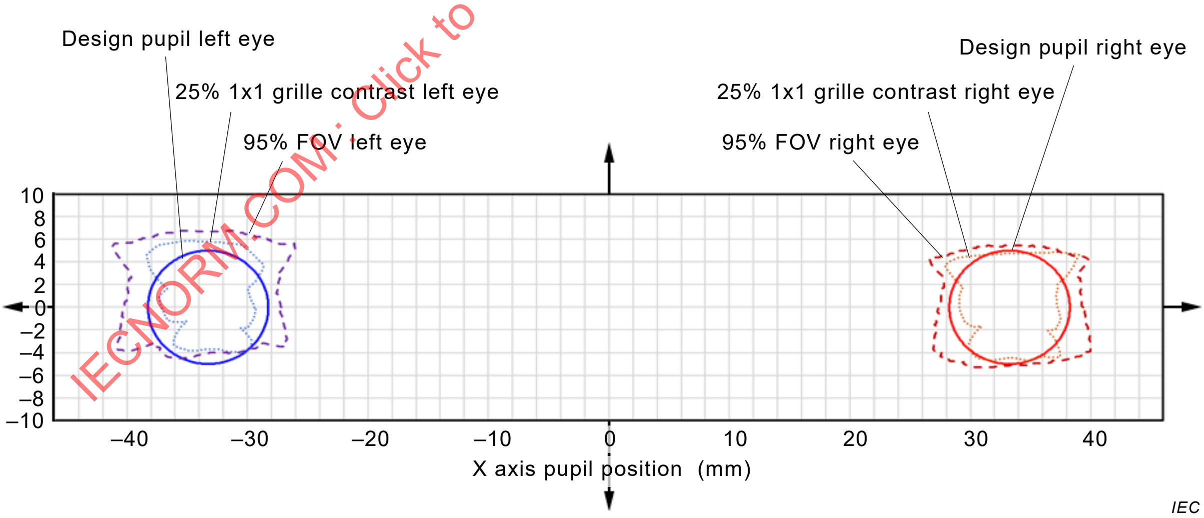


Figure 9 – Example of binocular eye-box

5.2.2 Transparent property

For direct-view transparent displays, the performance characteristics are described in IEC TR 62977-2-4 [13], IEC TR 62977-2-5 [14], IEC 61747-30-5 [15], and IEC 61234-6-4 [16]. Based on these documents, the following characteristics are significant for see-through eyewear displays:

- Measuring methods of transmission performance:
  - hemispherical transmittance factor with specular included;
  - transmitted haze under hemispherical illumination;
  - directional transmittance factor (including stray light);
  - measurement method of purity;
  - colour variation caused by a transparent display.
- Measuring methods of reflection properties:
  - hemispherical reflectance factor with specular included;
  - directional reflectance factor.

The measurements of the reflection properties mentioned above seem difficult, and measurement equipment needs to be developed.

These characteristics are based on transparent FPDs, and therefore additional aspects of a transparent screen or transparent optics are necessary, such as stray light and see-through distortion.

5.2.3 Binocular properties

ISO 9241-303:2011 [9], Annex E, describes requirements for the following binocular characteristics:

1) convergence demand,
2) horizontal disparity,
3) vertical misalignment of the displays,
4) interocular rotation difference,
5) interocular magnification difference,
6) interocular vertical magnification difference,
7) interocular horizontal magnification difference,
8) interocular luminance difference,
9) interocular focus difference,
10) temporal asynchrony,
11) interocular distance,
12) field curvature difference.

The binocular characteristics can be grouped in terms of their horizontal and vertical misalignment, and the vergence difference variations in the virtual image:

- horizontal misalignment versus field position (divergence): 1), 2), 4), 5) and 7)
- vertical misalignment versus field position (divergence): 3) to 6)
- vergence difference versus field position: 9) and 12)

ISO 9241-303:2011 [9], Annex E, also includes other characteristics, such as focal distance and eye relief, which are important virtual image optics properties.

5.3 Mechanical performance

The weight, weight balance, dimensional size, etc., can be specified and measured. The mounting structure can affect the performance in general.

5.4 Electro-optical performance

The electrical power consumption of the display device is one of those performances. In addition, this includes frame rate, refresh rate, latency, addressing scheme, and so on.

6 Optical measurement methods

6.1 General

In order to establish the optical measurement methods for eyewear displays, the following items are considered:

- measurement equipment and setting (layout), including the sample stage,
- environmental conditions,
- coordinate system,
- test patterns,
- measurement items.

6.2 Optical measurement equipment

6.2.1 Goniometer

A goniometer is needed (see Figure 10) to align the optical measurement equipment to the eyewear display. The number of axes needed for the goniometer will depend on the measurement to be made. The position accuracy of the goniometer is also important.

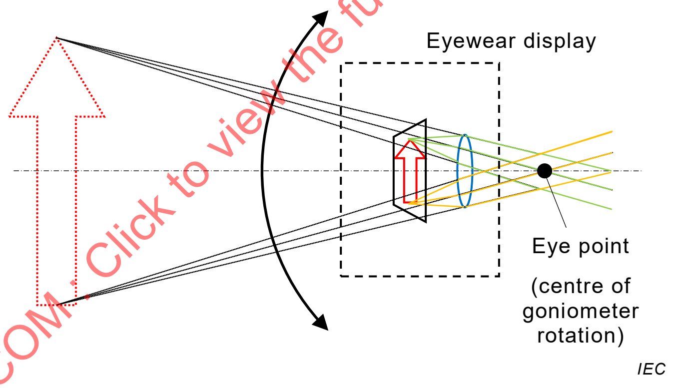


Figure 10 – Goniometer rotation and eye point

When rotating the optical measurement equipment with respect to the display, the centre of the rotation point needs to be discussed. There are two options: one is to rotate about the cornea or iris of the eye, and the other is to rotate about the centre of the eyeball. Generally, when the FOV is small, the eye is not rotated, and the first candidate can be applied. However, when the FOV is large, eye rotation can occur, and there are some eyewear display designs which take into account this situation. For the latter case, it is preferable for the supplier to specify the design eye point at which the rotation is applied.

ISO 9241-305:2008 [4], 5.5.6, specifies the requirement for a goniometer. It describes a five-axis positioning system, which includes a two-axis translation for eye position and rotation for pitch, yaw, and gaze angle, in order to simulate the movement of the eye.

6.2.2 Spot LMD

When a spot LMD is applied to measure eyewear displays, the configuration of the LMD lens system needs to be considered. Unlike a conventional direct-view type display, eyewear displays produce nearly parallel light rays. If the entrance pupil size of the spot LMD is larger than that of the light ray cross-section, the measured luminance will be lower, and a scan of the eye-box will be broader [18]. This is a consequence of the optical design, and of how the LMD is calibrated [19]. Most LMDs have relatively large entrance pupils for better light collection, and are calibrated with large area light sources which have diverging rays. However, the situation is different for most eyewear displays. It is necessary that the entrance pupil size of the spot LMD be smaller than the width of the eye-box of the eyewear display. Since the human eye has an entrance pupil diameter from about 2 mm to 5 mm, depending on the environmental illuminance, it is best to use an LMD entrance pupil size in that range. The most representative results will be obtained when the LMD entrance pupil size is similar to the human eye's entrance pupil at the luminance of the intended application.

It is possible to add a smaller aperture to a conventional spot spectroradiometer which has a large entrance pupil size. However, it needs careful calibration at the specific configuration (measurement field angle, lens position) as it is intended to measure the eyewear display.

The existing document, ISO 9241-305 [4], does not describe any specific requirements for LMDs.

6.2.3 2-D LMD

A 2-D LMD (also called an imaging LMD) is effective for measuring characteristics such as the luminance distribution. It is also important for measuring resolution (Michelson contrast) or virtual image distance. In case a 2-D LMD is used for measuring distortion and resolution, the impact from the lens used in the 2-D LMD needs to be well verified. In the same manner as the spot LMD, the entrance pupil size of the 2-D LMD needs to be equal to or smaller than the width of the light ray bundle from the eyewear display. Since the size of the 2-D LMD entrance pupil can determine the resolution measurement capability of the LMD, it is particularly important that it be similar to the size of the eye for the luminance used in the intended application. However, it is difficult to reduce the entrance pupil size of the 2-D LMD in general [20]. If a smaller aperture is added in front of the existing entrance pupil or the outer lens of the 2-D LMD, the measurement field angle will be greatly limited, because the incident light rays from higher angles cannot pass through. As with the spot LMD, the entrance pupil of the 2-D LMD should be placed at the eye point. However, it should be noted that the location of the LMD entrance pupil can be difficult to determine unless it is identified by the manufacturer, since the entrance pupil is at a virtual plane created by the image of the aperture stop for rays entering the LMD (see Figure 11). Therefore, the eye point may not be always located at the front of the lens. In addition, the rays for the eyewear display can be vignetted if the lens of the LMD cannot be placed close enough for the entrance pupil to be located at the eye point. This issue is common to all conventional 2-D LMDs, and the use of a 2-D LMD will be limited to the following conditions:

- the width of the light ray bundle from the eyewear display (i.e., the exit pupil) is sufficiently larger than the 2-D LMD entrance pupil,
- the measurement field of the 2-D LMD is limited to around the centre of the virtual image, and for corner measurements, the relative angle of 2-D LMD can be rotated like a spot LMD.

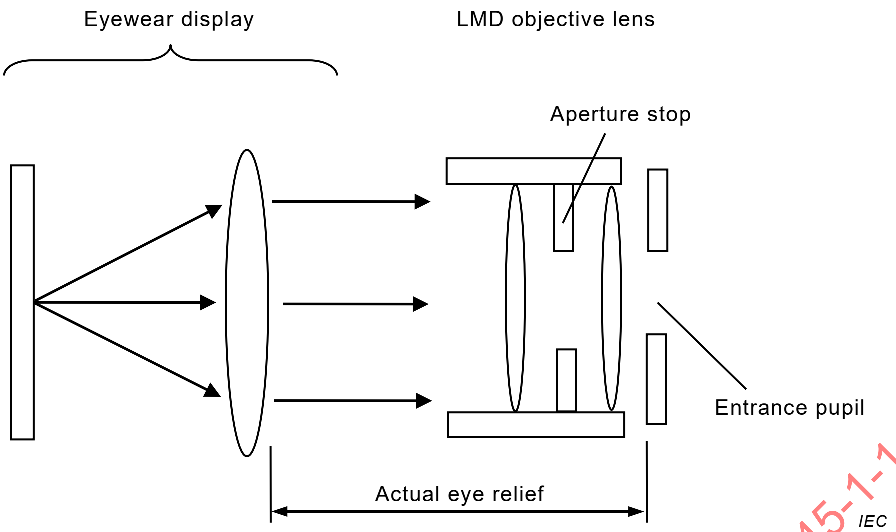
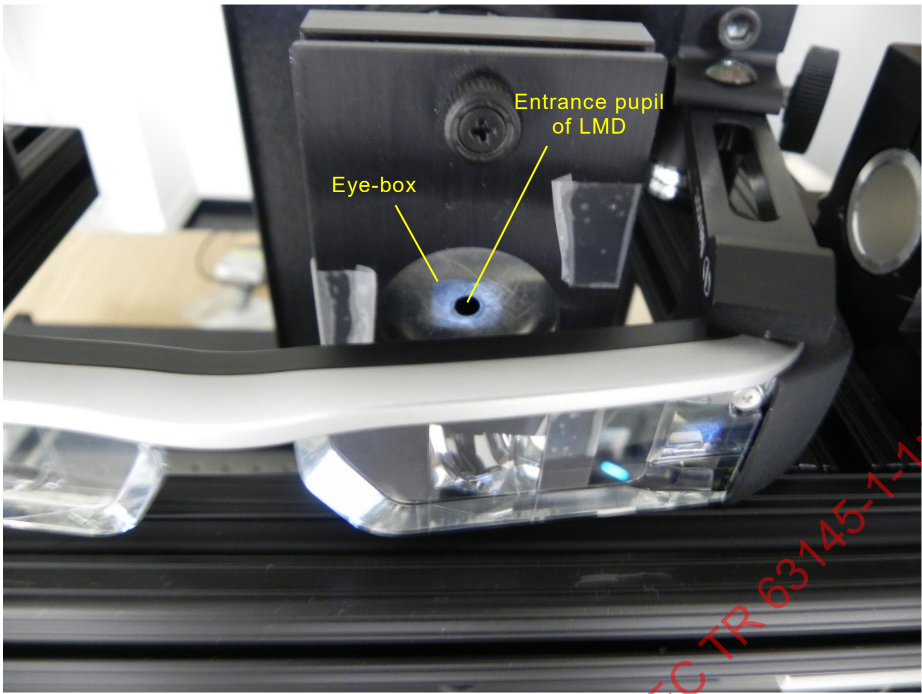


Figure 11 – Proper positioning of LMD entrance pupil to eye point

6.3 Optical measurement conditions

In setting up the measurement, the measurement layout is critical to obtain reproducible results. In general, the measurement instrument will be centred on the optical axis of the eyewear display. For displays that have a well-defined eye-box (see Figure 12), the entrance pupil of the measurement instrument will be centred within the eye-box. If the eye-box is not well defined, then the lateral centre of the eye-box can be determined by performing a two-dimensional lateral luminance scan with a full white image. Using an alignment pattern with centre crosshairs, the measurement instrument (or eyewear display) can be pivoted about the entrance pupil until the instrument measurement field is centred on the crosshairs. The eye relief along the optical axis can be defined by the manufacturer, or otherwise can be between 15 mm to 30 mm. This simplified alignment procedure is similar to the more detailed procedure given in ISO 9241-305:2008 [4], 6.11. As new eyewear displays become more complex, more careful consideration will be necessary. The alignment could be simplified if the supplier or manufacturer specifies the optical axis of the eyewear display.

To produce an accurate measurement, the measurement layout is significant in order to obtain reproducible results. In ISO 9241-305:2008 [4], 6.11, the detailed procedure is defined, but it is not sufficient. For example, in this procedure, after showing the test pattern, it is indicated to “visually estimate the location of the EUT optical axis” by looking through the ocular from a distance of 20 cm to 30 cm, and find the centre. When this alignment method is applied, the difference between position misalignment and angular misalignment needs to be considered, because they can easily be confused. However, if some parameters, such as the optical axis, are provided from the supplier or the manufacturer, this will be effective for measurements. Recently, some eyewear displays have had more complex optics, and in such a case more details will be considered. This method seems to be applied to some limited HMDs, which have a wider eye-box and a narrower FOV.



IEC

Figure 12 – Example of alignment of entrance pupil within the eye-box

6.4 Virtual image optics properties

6.4.1 Eye point

The eye point is the nominal centre position of the eyewear display's exit pupil. It is designed to be aligned with the centre of the iris or cornea. If the eye point is in the centre of the eye-box, scanning the extent of the eye-box can estimate the eye point. However, finding the eye point is difficult. Not only luminance but other characteristics will affect the location of the eye-point. Sometimes the manufacturer or supplier uses an eye point that is not centred in the eye-box, which can be difficult to locate. Therefore, it is best if the manufacturer or supplier defines the location of the eye point.

6.4.2 Eye relief

The eye relief is the distance between the eye point to the nearest surface of the virtual image optics (or reference point) of the eyewear display. The reference point needs to be specified by the manufacturer or supplier. Generally, the eye relief cannot be easily measured, so it needs to be provided by the manufacturer or supplier.

6.4.3 FOV

There are two main methods for measuring the FOV: the camera method [21] and the goniometer method [9]. The camera-based method uses an imaging sensor and imaging optics, and has the same issues as described for the 2-D LMD. If the eye-box size is sufficiently larger than the entrance pupil size of the 2-D LMD, it can be applicable, but the quantitative influence is still unclear. The goniometer method can use the spot LMD, which can use the same entrance pupil size as the human eye, and seems to have no issues. This method can best serve as the basis for a FOV measurement.

As the FOV of eyewear displays gets larger, the boundary of the virtual image can sometimes be unclear. In this case, the FOV is best measured quantitatively using an LMD. If the virtual image boundary is clear, then a camera, finder or telescope can be used by subjective judgement.

The FOV measurement is closely related with the distortion measurement [4]. The calculation methods are not the same, but the measurement methods are similar. Therefore, both characteristics can be measured at the same time. See ISO 9241-305:2008 [4] 6.11.1 and 6.11.4.

The FOV measurement results depend on the position of the LMD, with the maximum FOV presumably at the eye point. In that case, the eye point FOV is then used as a reference for determining the extent of the eye-box.

Traditionally, the FOV was expressed by its horizontal and vertical angular range. However, some new eyewear displays are not limited to the rectangular shape, and will need to be characterized by different criteria.

For binocular applications, the overlap of the left and right monocular FOV will be important. Figure 13 shows an example of the binocular FOV of an eyewear display relative to the eye point of each eye at three different interpupillary distances (IPDs): nominal, wide, and narrow.

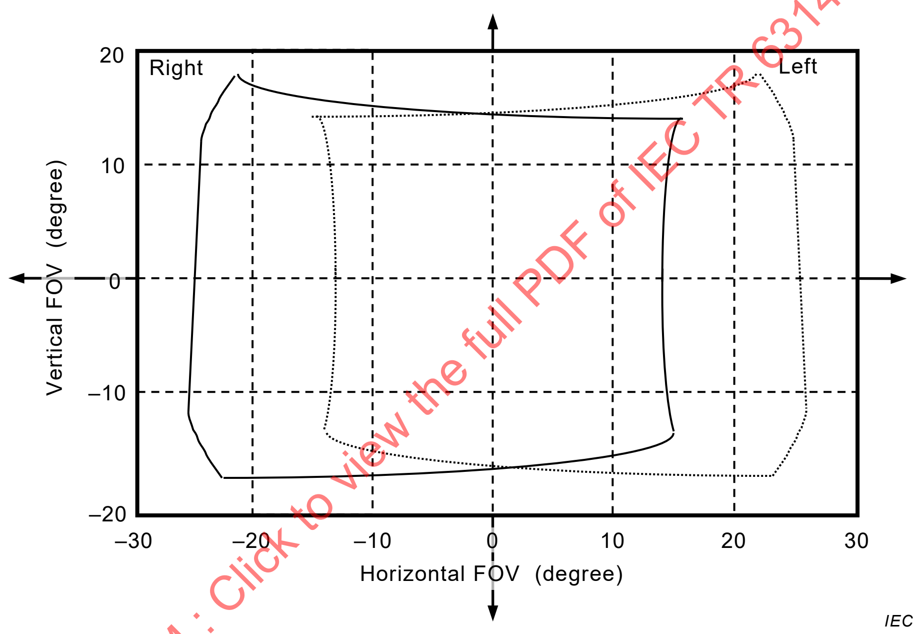


Figure 13 – Example of binocular FOV

6.4.4 Distortion of virtual image

As with the FOV measurement, there are two main methods for measuring the distortion of the virtual image. The goniometer method is defined in ISO 9241-305:2008 [4], 6.11.4. In this method, the vertical and horizontal deviations of the virtual image edges are measured. This method focuses on the deformation of the image edge (edge distortion), because this is based on the premise that if the edge distortion is sufficiently small, all portions of the virtual image are not distorted. If the optical system of eyewear displays is simple, this will be applicable. However, more recent optical designs have become quite complex, so it can be important to check not only the edges, but also the inside part of the virtual image. The goniometric method can be extended by using a grid test pattern with more measurement points. In addition, other standards for cameras [22][23] or CRTs [24] can be referenced. The 2-D LMD with the WFOV lens measurement method is an alternative method. In this measurement lens distortion calibration used in 2-D LMDs is important.

For binocular eyewear displays, it is important that the two eyes have distortions that do not create unacceptable divergence or divergence between the two eyes when looking at the same point on the display.

Sometimes the distortion is artificially added in order to make the image look more realistic.

6.4.5 Colour registration error (chromatic aberration)

Colour registration error, which is also called chromatic aberration, can be measured using the same method as the distortion measurement. However, suitable test patterns need to be defined.

6.4.6 Eye-box

ISO 9241-305:2008 [4] defines the eye-box measurement method in 6.11.11. In this document, two major characteristics, the maximum eye relief and the exit pupil size, represent the eye-box characteristics. The maximum eye relief is defined as the effective range on the optical axis direction, while the exit pupil size gives the width and height of the eye-box at a "suitable value" of eye relief. In both measurements, the procedure confirms that the full screen virtual image is still visible. However, the criteria for visibility of the full screen are ambiguous. Some threshold requirements need to be established. The eye-box can also be defined in terms of resolution, distortion, etc. The definition of the eye-box for the eyewear display needs to be discussed.

Although the eye-box has a three-dimensional shape, general agreement is still needed on how to measure and characterize this three-dimensional shape. Some new eyewear displays can have complex shapes, which will require further consideration of these issues. However, at least measuring the two-dimensional shape on the eye point will be essential.

6.4.7 Luminance, contrast, and chromaticity

Conventional LMDs may not be suitable for eyewear displays. The LMD often needs to have a relatively small entrance pupil, but similar measurement methods as used for other FPDs can be applied. As explained earlier, the shape of the virtual image is not limited to a rectangle, thus the measurement points need to be clarified. The full screen characteristics (i.e., the full screen white luminance, and the full screen contrast) are often a common starting point, but natural test patterns can provide more realistic characteristics of the device performance. For safety reasons, the discussion about maximum luminance criteria needs to be considered. The ambient conditions of the measurement also need to be discussed, especially for AR displays.

6.4.8 Michelson contrast and contrast modulation (virtual image resolution)

The Michelson contrast, which is also called contrast modulation, is often used to represent the virtual image resolution. It is affected by the imager resolution, the virtual image optics, image processing, and other factors. Some optical designs can cause image artefacts, such as a ghost, haze, and flare. These artefacts affect the measurement. It will be difficult to determine the Michelson contrast when these artefacts are contained in the measured image. For some artefacts, the same measurement method as used for other FPDs can be applied. Refer to IEC 62341-6-3:2017 [25], 5.1.4, for the static image resolution measurement. However, for other artefacts, a more simplified method using a checkerboard pattern or stripe pattern can be a good candidate.

In order to evaluate the influence of aberrations, such as field curvature, astigmatism, chromatic aberration, and others, the Michelson contrast needs to be measured not only on the centre point of the virtual image, but also on points near the corners and edges.