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Road vehicles — Ergonomic and performance aspects of Camera Monitor Systems — Requirements and test procedures

National foreword

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Road vehicles — Ergonomic and performance aspects of Camera Monitor Systems — Requirements and test procedures

Véhicules routiers — Aspects ergonomiques et de performance des caméras embarquées — Exigences et procédures d'essai

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 35, *Lighting and visibility*.

Introduction

The purpose of this International Standard is to give minimum safety, ergonomic, and performance requirements and test methods for Camera Monitor Systems (CMS) to replace mandatory inside and outside rearview mirrors for road vehicles (e.g. classes I to IV as defined in UN REGULATION NO. 46). This International Standard can follow updates of referred national regulations that influence the included contents.

Where possible, the requirements established for a CMS providing a specific legally prescribed field of view are based on the properties of conventional state of the art mirror systems providing that field of view.

The CMS is treated as a functional system in regards to requirement definitions and performance tests.

This International Standard outlines general requirements and test methods regarding the basic aspects of CMS; e.g. intended use, operating readiness, field of view, magnification, etc.

Furthermore, this International Standard outlines requirements and test methods regarding the necessary object size and resolution provided by the CMS. Besides the properties of the mirror system to be replaced, those requirements are also based on physical aspects of the human operator (e.g. visual acuity).

The given requirements follow the assumption, that the CMS provides an ideal mapping of the real world scene. To correspond to reality, this International Standard also provides requirements and test methods for all relevant parameters that worsen the ideal mapping (e.g. isotropy or artefacts).

Finally, this International Standard gives requirements and test methods regarding the aspects of time behaviour and failure behaviour.

All requirements are established to be as generic as possible, i.e. that these are possible to apply to any of the covered rearview mirrors. If additional or specific information is required for certain mirrors, these are provided in separate annexes.

This International Standard declares that CMS replacing legally prescribed mirrors have to be considered as safety-relevant systems and therefore, relevant safety standards (e.g. ISO 26262) have to be considered.

Road vehicles — Ergonomic and performance aspects of Camera Monitor Systems — Requirements and test procedures

1 Scope

This International Standard gives minimum safety, ergonomic, and performance requirements for Camera Monitor Systems to replace mandatory inside and outside rearview mirrors for road vehicles (e.g. classes I to IV as defined in UN REGULATION NO. 46). It addresses Camera Monitor Systems (CMS) that will be used in road vehicles to present the required outside information of a specific field of view inside the vehicle. These specifications are intended to be independent of different camera and display technologies unless otherwise stated explicitly. ADAS Systems (such as parking aid) are not part of this International Standard.

NOTE 1 Mirror classes V and VI (as defined in UN REGULATION NO. 46) are not in scope of this International Standard since the requirements are already defined in UN REGULATION NO. 46.

NOTE 2 The definitions and requirements in this International Standard are formulated with regard to a system structure, where one camera captures one legally prescribed field of view and one monitor displays one legally prescribed field of view. Of course, also other system structures (e. g. with one monitor displaying two legally prescribed fields of view) are within the scope of this International Standard. For those systems, either the system supplier or the vehicle manufacturer has to prove that the resulting system fulfils the requirements given in Clause 6.

NOTE 3 Whenever the phrases “field of view” or “field of vision” are used, then both have the same meaning and are to be used in parallel.

2 Normative references

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

ISO 2813, *Paints and varnishes — Determination of gloss value at 20 degrees, 60 degrees and 85 degrees*

ISO 9241-302:2008, *Ergonomics of human-system interaction — Part 302: Terminology for electronic visual displays*

ISO 9241-305:2008, *Ergonomics of human-system interaction — Part 305: Optical laboratory test methods for electronic visual displays*

ISO 9241-307:2008, *Ergonomics of human-system interaction — Part 307: Analysis and compliance test methods for electronic visual displays*

ISO 12233:2014, *Photography — Electronic still picture imaging — Resolution and spatial frequency responses*

UN REGULATION NO. 46, *Uniform provisions concerning the approval of devices for indirect vision and of motor vehicles with regards to the installation of these devices (ECE homologation)*

3 Terms and definitions

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

3.1 Vehicle related terms and definitions

3.1.1
vehicle
vehicle with a combustion engine and/or electric driving motor, intended for use on the road, with or without external body components added, having a permissible maximum mass of at least 400 kg and a maximum design speed equal to or exceeding 50 km/h

Note 1 to entry: Vehicles of categories M1, M2, M3, N1, N2 and N3 (see UN-ECE REGULATION NO. 46).

[SOURCE: ISO 13043, definition 3.1]

3.1.2
vehicle coordinate system
positive x-axis pointing into the opposite of the forward movement direction of the vehicle, the z-axis being orthogonal to the ground plane pointing upwards and the y-axis pointing to the right seen in forward movement direction thus forming a right handed coordinate system

3.1.3
driver's ocular points
points that are uniquely defined for each vehicle

Note 1 to entry: See Figure 1.

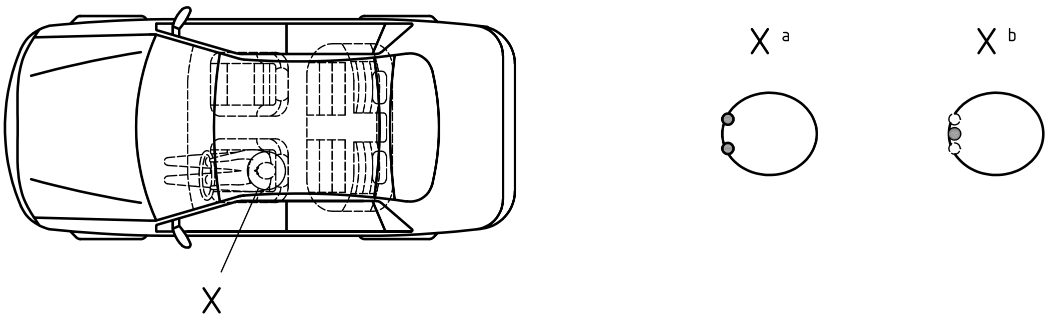
Note 2 to entry: These points are related to data given by the vehicle manufacturer following definitions of the responsible national body.

EXAMPLE "The driver's ocular points" means two points 65 mm apart and 635 mm vertically above point *R* of the driver's seat as defined in Annex 8. The straight line joining these points runs perpendicular to the vertical longitudinal median plane of the vehicle. The centre of the segment joining the two ocular points is in a vertical longitudinal plane which has to pass through the centre of the driver's designated seating position, as specified by the vehicle manufacturer."

3.1.4
driver's ocular reference point
middle point between the two ocular points of the driver

Note 1 to entry: See Figure 1.

Note 2 to entry: The abbreviation ORP can be used for this point.



Key

a ocular points

b ocular reference point

Figure 1 — Driver's ocular reference point

EXAMPLE The two ocular points of the driver uses 635 mm vertically above point *R* as shown in the example given in 3.1.3.

3.2 Mirror related terms and definitions

3.2.1
mirror
device with a reflective surface mounted to the bodywork of a vehicle

Note 1 to entry: It is used to see the required outside information of a specific field of view by indirect vision.

Note 2 to entry: The definitions in the subclauses from 3.2.2 to 3.2.28 assume an ideal mirror and do not deal with artefacts like low quality surface, dirt, etc.

3.2.2
mirror distance to driver ocular reference point
distance from the driver's ocular reference point to the centre of the mirror

Note 1 to entry: See Figure 2.

Note 2 to entry: It is denoted as a_{mirror} and is measured in metres.

Note 3 to entry: The mirror distance to driver ocular reference point influences the resolution and the magnification requirements for a CMS replacing a mirror. The designed resolution and magnification of a CMS should take into account that this distance is usually lower than the maximum values given in the following subclauses.

3.2.3
maximum mirror distance to driver ocular reference point (driver side)
maximum value for a_{mirror} as found in existing homologated vehicles for the given mirror class on the driver side

Note 1 to entry: It is denoted as $a_{mirror/driver/max}$ and is measured in metres:

— for class I UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/driver/max}$ = 1,05 m;

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/driver/max}$ = 1,7 m;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/driver/max}$ = 1,2 m;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/driver/max}$ = 1,7 m.

Note 2 to entry: The above values represent the maximum distances for MY 2013 mass produced vehicles (based upon 2013 survey).

Note 3 to entry: See B.6.2 for more information on the values for class II and class IV mirrors.

3.2.4
maximum mirror distance to driver ocular reference point (passenger side)
maximum value for a_{mirror} as found in existing homologated vehicles for the given mirror class on the passenger side

Note 1 to entry: It is denoted as $a_{mirror/passenger/max}$ and is measured in metres:

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/passenger/max}$ = 2,6 m;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/passenger/max}$ = 1,9 m;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $a_{mirror/passenger/max}$ = 2,6 m;

— for main mirrors on cab-over-engine type trucks according to Japanese REGULATION NO. 44, this value is defined as $a_{mirror/passenger/max}$ = 2,5 m;

— for main mirrors on motor vehicles with a passenger capacity of 11 persons or more according to the Japanese REGULATION NO. 44, this value is defined as $a_{mirror/passenger/max}$ = 2,5 m.

— for vehicle category of Japanese REGULATION refer to Japanese REGULATION NO. 44.

Note 2 to entry: The above values represent the maximum distances for MY 2013 mass produced vehicles (based upon 2013 survey).

Note 3 to entry: See B.6.3 for more information on the values for class II and class IV mirrors.

Note 4 to entry: Japanese REGULATION main mirror means "Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle".

3.2.5
mirror viewing angle
total angle between the ray leaving the eye-point and reaching an object after being reflected from the mirror surface, i.e. two times the angle between the driver's line of sight and the surface normal of the mirror

Note 1 to entry: See Figure 3.

Note 2 to entry: It is denoted as β_{mirror} and is measured in degrees.

3.2.6
minimum mirror viewing angle (driver side)
minimum value for β_{mirror} as found in existing homologated vehicles for the given mirror class on the driver side

Note 1 to entry: It is denoted as $\beta_{mirror/driver/min}$ and is measured in degrees:

— for class I UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/min}$ = 20 °;

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/min}$ = 55 °;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/min}$ = 30 °;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/min}$ = 55 °.

Note 2 to entry: The above values represent the minimum angles for MY 2013 mass produced vehicles (based upon 2013 survey) regarding the required field of view.

3.2.7
maximum mirror viewing angle (driver side)
maximum value for β_{mirror} as found in existing homologated vehicles for the given mirror class on the driver side

Note 1 to entry: It is denoted as $\beta_{mirror/driver/max}$ and is measured in degrees:

— for class I UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/max}$ = 65 °;

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/max}$ = 75 °;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/max}$ = 65 °;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/driver/max}$ = 125 °.

Note 2 to entry: The above values represent the maximum angles for today's vehicles in the market based on the required field of view.

3.2.8
minimum mirror viewing angle (passenger side)
minimum value for β_{mirror} as found in existing homologated vehicles for the given mirror class on the passenger side

Note 1 to entry: It is denoted as $\beta_{mirror/passenger/min}$ and is measured in degrees:

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/passenger/min}$ = 80 °;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/passenger/min}$ = 55 °;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/passenger/min}$ = 80 °;

— for main mirrors on cab-over-engine type trucks according to Japanese REGULATION NO. 44, this value is defined as $\beta_{mirror/passenger/min}$ = 54 °;

— for main mirrors on motor vehicles with a passenger capacity of 11 persons or more according to Japanese REGULATION NO. 44, this value is defined as $\beta_{mirror/passenger/min}$ = 50,5 °.

— for vehicle category of Japanese REGULATION refer to Japanese REGULATION NO. 44.

Note 2 to entry: The above values represent the minimum angles for MY 2013 mass produced vehicles (based upon 2013 survey) regarding the required field of view.

Note 3 to entry: Japanese REGULATION main mirror means "Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle".

3.2.9
maximum mirror viewing angle (passenger side)
maximum value for β_{mirror} as found in existing homologated vehicles for the given mirror class on the passenger side

Note 1 to entry: It is denoted as $\beta_{mirror/passenger/max}$ and is measured in degrees:

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/passenger/max}$ = 95 °;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/passenger/max}$ = 85 °;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $\beta_{mirror/passenger/max}$ = 150 °;

— for main mirrors on cab-over-engine type trucks according to Japanese REGULATION NO. 44, this value is defined as $\beta_{mirror/passenger/max}$ = 111 °;

— for main mirrors on motor vehicles with a passenger capacity of 11 persons or more according to Japanese REGULATION NO. 44, this value is defined as $\beta_{mirror/passenger/max}$ = 64 °.

— for vehicle category of Japanese REGULATION refer to Japanese REGULATION NO. 44.

Note 2 to entry: The above values represent the maximum angles for MY 2013 mass produced vehicles (based upon 2013 survey) regarding the required field of view.

Note 3 to entry: Japanese REGULATION main mirror means "Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle".

3.2.10
distance from mirror to object
distance from the mirror to an object being viewed by the driver

Note 1 to entry: See Figure B.14.

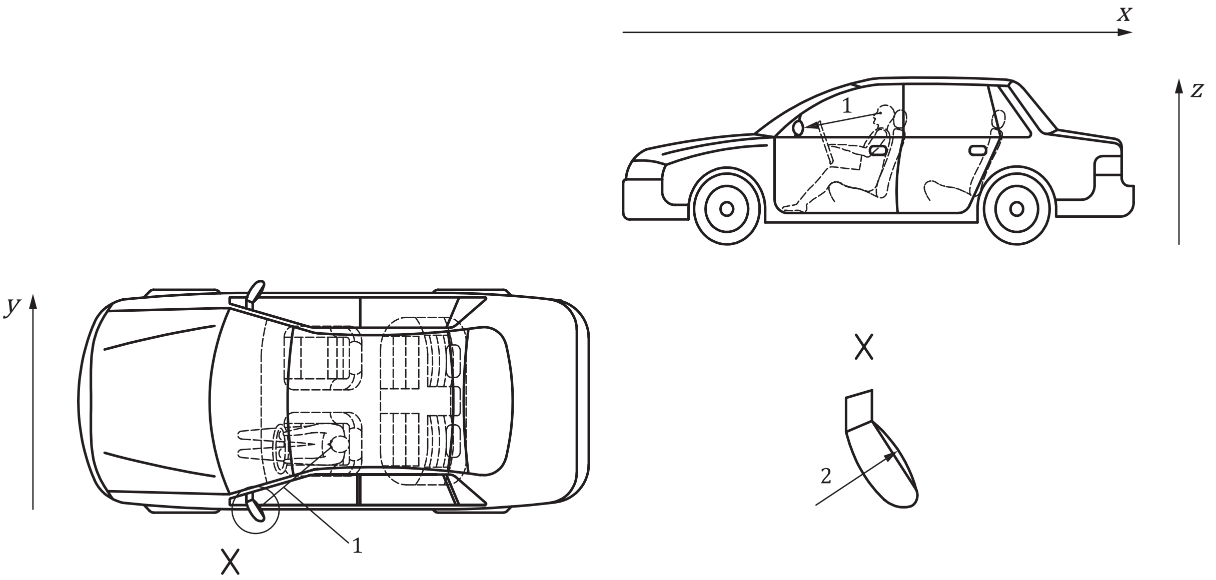
Note 2 to entry: It is denoted as d_{object} and is measured in meters.

3.2.11
mirror radius of curvature
radius of the sphere that specifies the shape of a spherical mirror surface

Note 1 to entry: See Figure 2.

Note 2 to entry: For convex spherical mirrors with the reflective layer on the convex surface, this value is positive.

Note 3 to entry: It is denoted as r_{mirror} and is measured in metres.



Key

1 a_{mirror}

2 r_{mirror}

Figure 2 — Mirror radius of curvature

3.2.12
mirror minimum allowed radius of curvature
minimum allowed value for r_{mirror} as defined by the responsible national body

Note 1 to entry: It is denoted as $r_{mirror/min}$ and is measured in metres.

Note 2 to entry: The values given below are examples:

— for class I UN REGULATION NO. 46 spherical convex mirrors, this value is defined as $r_{mirror/min}$ = 1,2 m;

— for class II UN REGULATION NO. 46 spherical convex mirrors, this value is defined as $r_{mirror/min}$ = 1,2 m;

— for class III UN REGULATION NO. 46 spherical convex mirrors, this value is defined as $r_{mirror/min}$ = 1,2 m;

— for class IV UN REGULATION NO. 46 spherical convex mirrors, this value is defined as $r_{mirror/min}$ = 0,3 m;

— for main mirrors on cab-over-engine type trucks according to Japanese REGULATION NO. 44, this value is defined as $r_{mirror/min}$ = 0,6 m;

— for main mirrors on motor vehicles with a passenger capacity of 11 persons or more according to Japanese REGULATION NO. 44, this value is defined as $r_{mirror/min}$ = 0,6 m;

— for vehicle category of Japanese REGULATION refer to Japanese REGULATION NO. 44;

— FMVSS 111 only allows for plane mirrors where $r_{mirror/min}$ is infinite on the driver side; however, on the passenger side of the vehicle, FMVSS 111 defines a spherical convex mirror with a minimum radius of $r_{mirror/min}$ = 0,889 m.

Note 3 to entry: Japanese REGULATION main mirror means “Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle”.

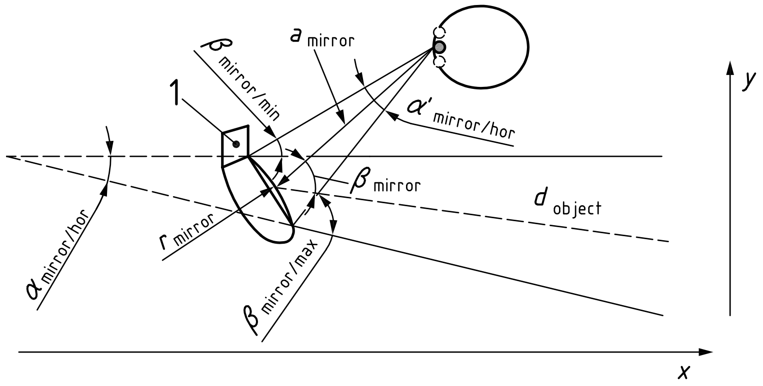
3.2.13
mirror angular size
angle under which the driver perceives the mirror

Note 1 to entry: See 3.2.14 and 3.2.15 for details and differentiation between horizontal and vertical direction.

3.2.14
mirror horizontal angular size
angle between the lines from the ORP to the left and right edge (in y-direction) of the reflective mirror surface

Note 1 to entry: See Figure 3.

Note 2 to entry: It is denoted as $\alpha'_{mirror/hor}$ and is measured in degrees.



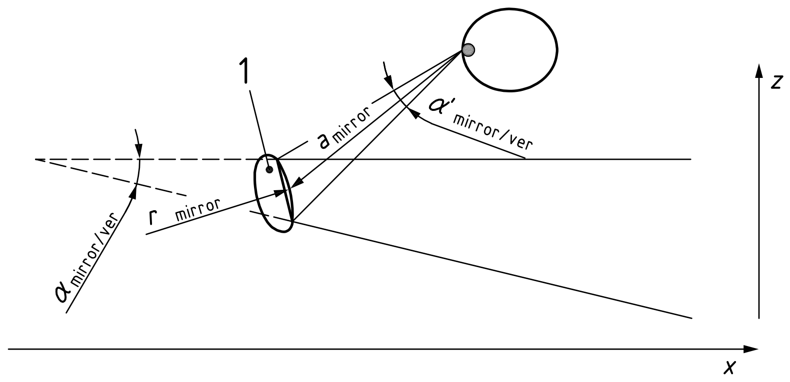
Key
1 mirror

Figure 3 — Mirror horizontal angular size (bird's eye view)

3.2.15
mirror vertical angular size
angle between the lines from the ORP to the top and bottom edge in (z-direction) of the reflective mirror surface

Note 1 to entry: See Figure 4.

Note 2 to entry: It is denoted as $\alpha'_{mirror/ver}$ and is measured in degrees.



Key
1 mirror

Figure 4 — Mirror vertical angular size (side view)

3.2.16
field of view
space defined by all rays of light (lines from object points to the reflective mirror surface) that are still reflected into the driver's imaginary monocular eye point at the ORP

Note 1 to entry: This space can be approximated by a pyramid with its base lying in the y-z-plane.

3.2.17
horizontal field of view
angle between the leftmost and the rightmost ray of the field of view projected to the x-y-plane

Note 1 to entry: It is denoted as $\alpha_{mirror/hor}$ and is measured in degrees.

3.2.18
minimum horizontal field of view
minimum allowed value for $\alpha_{mirror/hor}$ as defined by the responsible national body

Note 1 to entry: It is denoted as $\alpha_{mirror/hor/min}$ and is measured in degrees.

Note 2 to entry: Information on $\alpha_{mirror/hor/min}$ for different mirror classes is given in B.2.1.

3.2.19
vertical field of view
angle between the topmost and the bottommost ray of the field of view projected to the x-z-plane

Note 1 to entry: It is denoted as $\alpha_{mirror/ver}$ and is measured in degrees.

3.2.20
minimum vertical field of view
minimum allowed value for $\alpha_{mirror/ver}$ as defined by the responsible national body

Note 1 to entry: It is denoted as $\alpha_{mirror/ver/min}$ and is measured in degrees.

Note 2 to entry: Information on $\alpha_{mirror/ver/min}$ for different mirror classes is given in B.2.2.

3.2.21
mirror magnification factor
relationship between the correct size of an object and its perceived size when seen through the mirror

Note 1 to entry: It is dependent on the distance from the ORP to the mirror a_{mirror} (see 3.2.2), the radius of the mirror r_{mirror} (see 3.2.11), the distance to the object d_{object} (see 3.2.10), and the mirror viewing angle β_{mirror} (see 3.2.5). It is denoted as $M_{mirror.}$

Note 2 to entry: For convex spherical rearview mirrors, the magnification factor is below 1, i.e. objects in a rearview mirror appear smaller than they really are. For plane mirrors with unit magnification, the magnification factor is equal to 1, i.e. there is no magnification.

Note 3 to entry: For a formula describing the magnification factor variation over the mirror, refer to B.3.

3.2.22
mirror average magnification factor
average value for the magnification based on a mirror with minimum radius $r_{mirror/min}$ and maximum distance to the ORP $a_{mirror/max}$

Note 1 to entry: It is denoted as $M_{mirror/avg}$.

Note 2 to entry: It is derived as the average over the relevant range of viewing angles β_{mirror} at the horizontal centre line of the mirror and distances d_{object}.

Note 3 to entry: See 3.2.23 and 3.2.24 for details and differentiation between driver and passenger side.

3.2.23
mirror average magnification factor (driver side)
average magnification factor for M_{mirror} as found in existing homologated vehicles for the given mirror class on the driver side

Note 1 to entry: It is denoted as $M_{mirror/driver/avg}$:

— for class I UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/avg}$ = 0,33;

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/avg}$ = 0,23;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/avg}$ = 0,31;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/avg}$ = 0,065;

— for an FMVSS 111 plane driver mirror, this value is $M_{mirror/driver/avg}$ = 1.

Note 2 to entry: The above values were derived from MY 2013 mass produced vehicles (based upon 2013 survey).

Note 3 to entry: For detailed information how these values were derived, refer to B.3.

Note 4 to entry: For additional recommendations concerning commercial vehicles, refer to A.3.3.

3.2.24
mirror average magnification factor (passenger side)
average magnification factor for M_{mirror} as found in existing homologated vehicles for the given class on the passenger side

Note 1 to entry: It is denoted as $M_{mirror/passenger/avg}$:

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/passenger/avg}$ = 0,15;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/passenger/avg}$ = 0,20;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/passenger/avg}$ = 0,036;

— for an FMVSS 111 passenger mirror, this value is defined as $M_{mirror/passenger/avg}$ = 0,17;

— for main mirrors on cab-over-engine type trucks according to Japanese REGULATION NO. 44, this value is $M_{mirror/passenger/avg}$ = 0,088;

— for main mirrors on motor vehicles with a passenger capacity of 11 persons or more according to Japanese REGULATION NO. 44, this value is $M_{mirror/passenger/avg}$ = 0,10;

— for vehicle category of Japanese REGULATION refer to Japanese REGULATION NO. 44.

Note 2 to entry: The above values were derived from MY 2013 mass produced vehicles (based upon 2013 survey).

Note 3 to entry: For detailed information how these values were derived, refer to B.3.

Note 4 to entry: For additional recommendations concerning commercial vehicles, refer to A.3.3.

Note 5 to entry: Japanese REGULATION main mirror means “Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle”.

3.2.25
mirror minimum magnification factor
minimum value for the magnification based on a mirror with minimum radius $r_{mirror/min}$ and maximum distance to the ORP $a_{mirror/max}$; it is derived from the maximum viewing angle $\beta_{mirror/max}$ at the horizontal centre line of the mirror within the relevant range and the distance $d_{object} = \infty$

Note 1 to entry: It is denoted as $M_{mirror/min}$.

Note 2 to entry: See 3.2.26 and 3.2.27 for details and differentiation between driver and passenger side.

3.2.26
mirror minimum magnification factor (driver side)
minimum magnification factor for M_{mirror} as found in existing homologated vehicles for the given class on the driver side

Note 1 to entry: It is denoted as $M_{mirror/driver/min}$:

— for class I UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/min}$ = 0,31;

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/min}$ = 0,21;

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/min}$ = 0,29;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/driver/min}$ = 0,037;

— for an FMVSS 111 plane driver mirror, this value is $M_{mirror/driver/min}$ = 1.

Note 2 to entry: The above values were derived from MY 2013 mass produced vehicles (based upon 2013 survey).

Note 3 to entry: For detailed information how these values were derived, refer to B.3.

Note 4 to entry: For additional recommendations concerning commercial vehicles, refer to A.3.3.2.

3.2.27
mirror minimum magnification factor (passenger side)
minimum magnification factor for M_{mirror} as found in existing homologated vehicles for the given class on the passenger side

Note 1 to entry: It is denoted as $M_{mirror/passenger/min}$:

— for class II UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/passenger/min}$ = 0,13,

— for class III UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/passenger/min}$ = 0,19;

— for class IV UN REGULATION NO. 46 mirrors, this value is defined as $M_{mirror/passenger/min}$ = 0,014;

— for an FMVSS 111 passenger mirror, this value is defined as $M_{mirror/passenger/min}$ = 0,17;

— for main mirrors on cab-over-engine type trucks according to Japanese REGULATION NO. 44, this value is $M_{mirror/passenger/min}$ = 0,061;

— for main mirrors on motor vehicles with a passenger capacity of 11 persons or more according to Japanese REGULATION NO. 44, this value is $M_{mirror/passenger/min}$ = 0,094.

Note 2 to entry: The above values were derived from MY 2013 mass produced vehicles (based upon 2013 survey).

Note 3 to entry: For detailed information how these values were derived, refer to B.3.

Note 4 to entry: For additional recommendations concerning commercial vehicles, refer to A.3.3.2.

Note 5 to entry: Japanese REGULATION main mirror means "Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle".

3.2.28
mirror angular resolution
parameter that describes the ability of a mirror to resolve small details in a reflected scene

Note 1 to entry: In principle, a mirror can resolve an unlimited amount of detail. Nevertheless, in combination with the human eye, the angular resolution of a driver seeing through the rear view mirror of a vehicle is limited by the angular resolution of the human eye. The smaller the angular resolution of the human eye, the smaller the details can be that are still resolved by the driver, i.e. in contrast to the pixel resolution of cameras smaller values for the angular resolution indicate a higher quality vision.

3.2.29
visual acuity of the human eye
ability of the human eye and human visual system to resolve small details; it is different for each person and usually degrades with increasing age of the person

Note 1 to entry: It is measured using a Landolt C test (see ISO 8596:2009) at an optician, denoted as V_{eye} and measured in [1/arcmin].

Note 2 to entry: Usually, national bodies define a minimum visual acuity for acquiring a driver's license. A visual acuity of 1 is reached if a test person has correctly identified the direction of 60 % of the Landolt C openings, assuming that the Landolt C openings are of a size such that the openings are visible (from the test person's eye position) under an angle of 1 arcmin (see Figure 5).

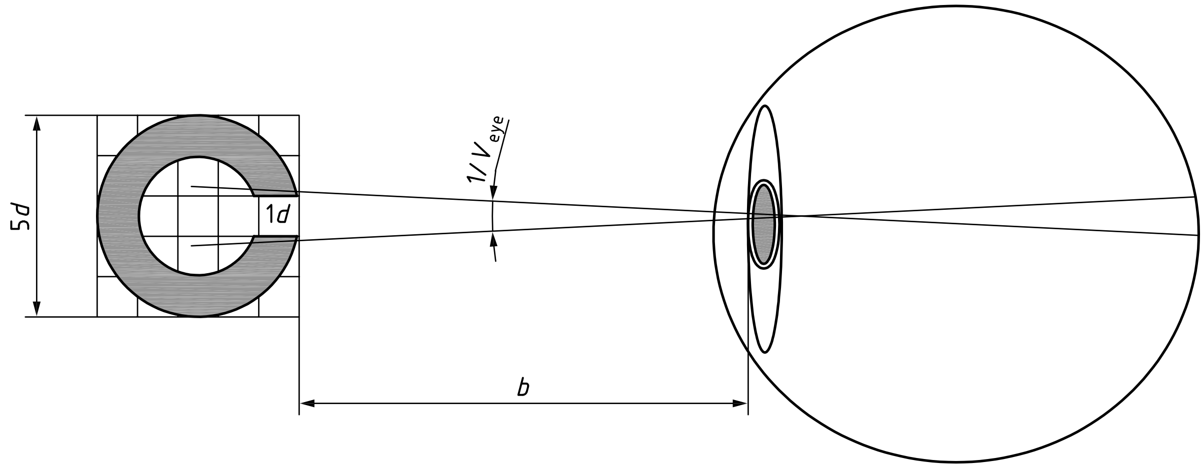


Figure 5 — Visual acuity of the human eye, e.g. tested with Landolt C ring

3.2.30
minimum visual acuity of the human eye
minimum value of V_{eye}

Note 1 to entry: It is denoted as $V_{eye/min}$:

— for UN REGULATION NO. 46 class I mirrors, this value is defined as $V_{eye/min}$ = 0,7;

— for UN REGULATION NO. 46 class II mirrors, this value is defined as $V_{eye/min}$ = 0,8;

— for UN REGULATION NO. 46 class III mirrors, this value is defined as $V_{eye/min}$ = 0,7;

— for UN REGULATION NO. 46 class IV mirrors, this value is defined as $V_{eye/min}$ = 0,8.

Note 2 to entry: FeV, the German requirements for acquiring drivers licenses for passenger vehicles, Appendix 6 §1.1 defines a minimum visual acuity of 0,7. Japan defines 0,7, Netherlands defines 0,5, and Sweden defines 0,5.

Note 3 to entry: In Sweden, Germany, Japan, and Netherlands, driving licenses for C/CE (heavy truck/heavy truck with trailer), D/DE (heavy bus/heavy bus with trailer) type of vehicles, as well as for taxis; minimum 0,8 in binocular acuity is required. Glasses or contact lenses may be used to achieve this acuity.

Note 4 to entry: There may be differences depending on the market where the vehicle is to be driven.

3.3 Camera related terms and definitions

3.3.1
camera
device used to capture colour images of a specific field of view; it mainly consists of two relevant items: imager and lens

Note 1 to entry: The following definitions assume an ideal camera and do not deal with artefacts like image blur, wrong focus, lens distortion, etc. The tests defined in 7.8 make sure that these artefacts are reduced to a minimum.

3.3.2
camera optical axis
virtual line that defines the path along which light propagates through the system; for a system composed of simple lenses, the axis passes through the centre of curvature of each surface, and coincides with the axis of rotational symmetry

3.3.3
camera reference orientation
the orientation of a camera of a CMS where the optical axis of the camera is pointing along the positive x-axis of the vehicle [the camera is looking backwards with the imager (see 3.3.7) lying in the y-z-plane] and the camera's upper side normal is parallel to the positive z-axis of the vehicle

Note 1 to entry: It helps to simplify the definition of further parameters of the camera (see Figure 6). See also 3.1.2 for coordinate convention used.

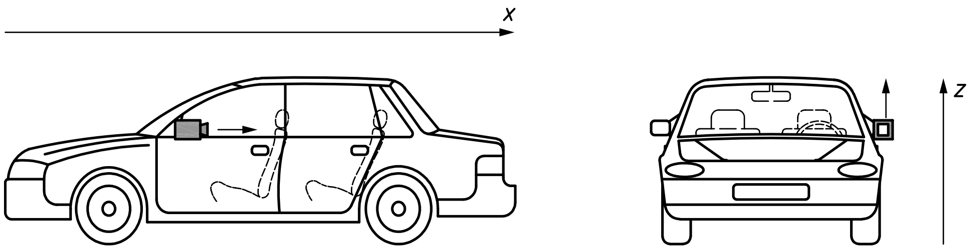


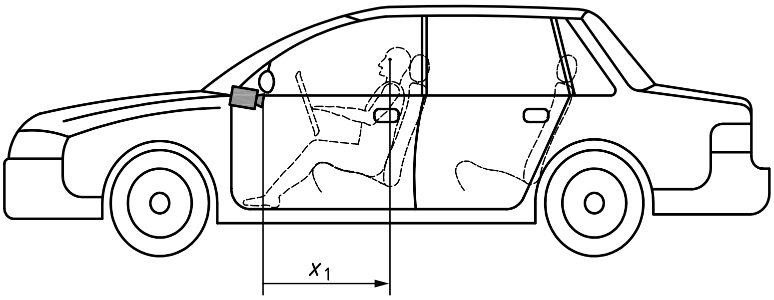
Figure 6 — Camera reference orientation

3.3.4
camera distance to driver ocular reference point in x-direction
distance from the centre of the *entrance pupil of the camera* (3.3.13) to the *driver's ocular reference point* (3.1.4) in x-direction when mounted to the vehicle; it is specific for each vehicle, even if the camera itself is the same for each vehicle

Note 1 to entry: See Figure 7.

Note 2 to entry: It is denoted as x_{camera} and is measured in metres.

Note 3 to entry: For camera positions forward of the ORP, x_{camera} has to be a positive value while for camera positions rear of the ORP, x_{camera} has to be a negative value.



Key

X_1 x_{camera}

Figure 7 — Distance to driver ocular reference point in x-direction

3.3.5
camera distances in y-direction

displacement from the outermost point of the same side of the vehicle to the entrance pupil of a camera replacing side mirrors in y-direction is denoted as y_{camera}, and displacement from the longitudinal centre x-z-plane to the entrance pupil of a camera replacing the interior centre mirror in y-direction is denoted as y'_{camera}

Note 1 to entry: Distances are measured in metres (see Figure 8).

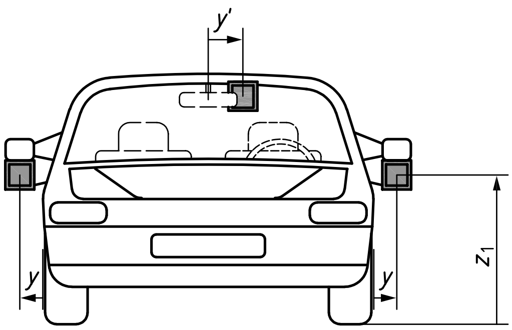
Note 2 to entry: For camera positions located outboard of the outermost point of the vehicle, y_{camera} has to be a positive value while for camera positions located inboard of the outermost point of the vehicle, y_{camera} has to be a negative value.

Note 3 to entry: For camera positions located in positive y-direction, y'_{camera} has to be a positive value while for camera positions located in negative y-direction, y'_{camera} has to be a negative value.

3.3.6
camera height above road surface

distance from the road surface to the centre of the *entrance pupil of the camera* (3.3.13) in z-direction when mounted to the vehicle; it is specific for each vehicle, even if the camera itself is the same for each vehicle

Note 1 to entry: It is denoted as z_{camera} and is measured in metres.



Key

y y_{camera}

y' y'_{camera}

Z_1 z_{camera}

Figure 8 — Height above road surface

Note 2 to entry: For some vehicles (e.g. heavy trucks), different chassis variants and/or wheel dimensions are common depending on what type of transport the vehicle is intended for. It is important to be aware of this as the actual height above road surface will influence the requirement fulfilment by the CMS. Often, there will be worst case variants to consider.

3.3.7
camera imager
rectangular device that transforms electromagnetic radiation (irradiance) mostly of visible wavelength into electric currents; it is subdivided into a matrix of smaller (usually squared) active areas

3.3.8
camera pixel
smallest active area in a matrix of several active areas forming an imager

Note 1 to entry: It is an abbreviated term for picture element.

EXAMPLE For a Bayer pattern imager, it is either the green, blue, or red filtered pixel.

3.3.9
camera resolution
measure of the ability of a camera system to depict picture detail

Note 1 to entry: The specification hereinafter will assume a camera orientation where the imager axes are parallel to the coordinate axes when CMS camera is fixed to the body of the vehicle. For all other CMS systems composed of a different configuration, those specifications shall meet the same or increased perceptibility to the specification cited herein, under above consideration.

3.3.10
camera horizontal pixel resolution
number of pixels of the imager in y-direction for a *camera in reference orientation* (3.3.3)

Note 1 to entry: It is denoted as $N_{camera/hor}$; this is not necessarily the scanning direction of the imager.

3.3.11
camera vertical pixel resolution
number of pixels of the imager in z-direction for a *camera in reference orientation* (3.3.3)

Note 1 to entry: It is denoted as $N_{camera/ver}$.

3.3.12
camera lens
optical device of one or more optical elements that collects the incident light reflected or emitted from the scene and focuses the target scene image on to the surface of the imager

3.3.13
camera entrance pupil
optical image of the physical aperture stop seen through the front lens of the system; it is also defined as the vertex of the camera's field of view; it is influenced by the lens and is also sometimes called the "projection centre" or "centre of projection"; for simplicity, it is approximated by the centre of the outermost lens surface

Note 1 to entry: It is denoted as EP_{camera} and is a coordinate triplet given in metres.

3.3.14
camera field of view
space defined by all rays of light (lines from the centre of the entrance pupil of a camera to object points) that are projected onto the imager; for a camera fulfilling the recommendation of minimum geometric distortion, this space can be approximated by a pyramid with its apex lying in the centre of the entrance pupil and its base lying in the y-z-plane for a *camera in reference orientation* (3.3.3)

Note 1 to entry: See 6.9.6.

3.3.15
camera horizontal field of view
angle between the leftmost and the rightmost ray of the field of view projected to the x-y-plane for a *camera in reference orientation* (3.3.3)

Note 1 to entry: See Figure 9.

Note 2 to entry: It is denoted as $\alpha_{camera/hor}$ and measured in degrees. It is sometimes also called the horizontal opening angle of a camera.

3.3.16
camera vertical field of view
angle between the topmost and the bottommost ray of the field of view projected to the x-z-plane for a *camera in reference orientation* (3.3.3)

Note 1 to entry: See Figure 9.

Note 2 to entry: It is denoted as $\alpha_{camera/ver}$ and measured in degrees. It is sometimes also called the vertical opening angle of a camera.

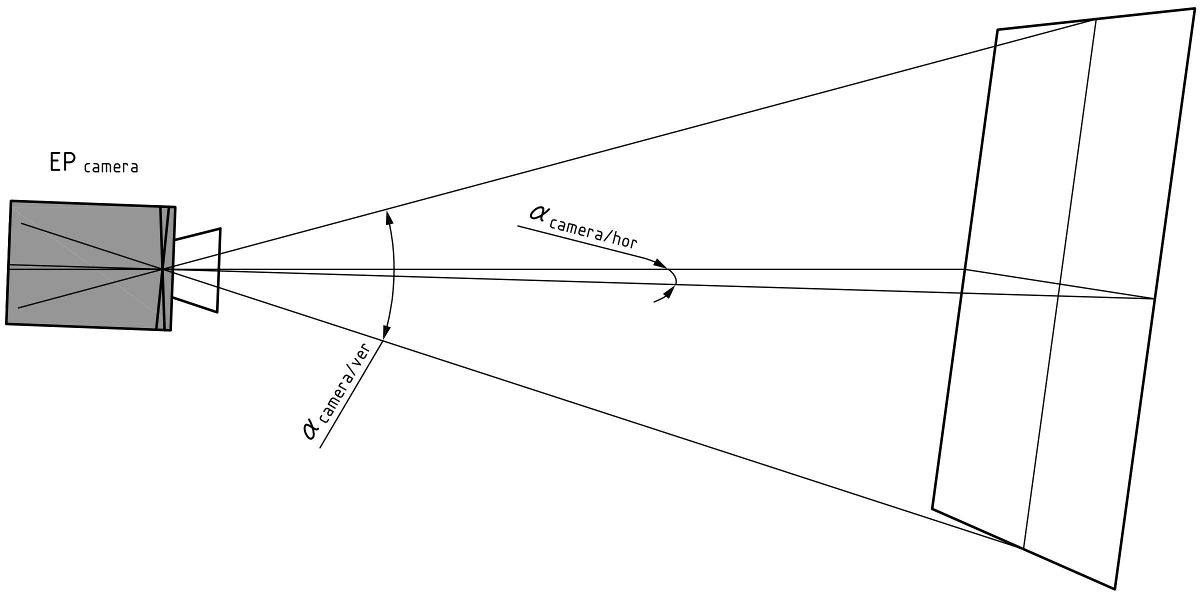


Figure 9 — Horizontal and vertical camera field of view

3.3.17
camera angular resolution
parameter describing the ability of a camera to resolve small details in a captured scene; it does not only take into account the mere resolution of the imager but also relating it to the field of view that the camera is capturing; the smaller the angular resolution of a camera, the smaller the details that can be resolved by the camera, i.e. in contrast to the pixel resolution, smaller values for the angular resolution indicate a more detailed camera image

3.4 Monitor related terms and definitions

3.4.1
monitor
device for displaying images; it either consists of a matrix of active areas that radiate light of different wavelengths or is a (usually diffuse) reflector that is illuminated in different wavelengths and in a matrix of specific points by a projector

Note 1 to entry: The following definitions assume an ideal monitor and do not deal with artefacts like pixel defects etc. The tests defined in Clause 7 ensure that these artefacts are kept to a minimum.

3.4.2
monitor coordinate system
spherical coordinate system ($a_{monitor}$, $\Theta_{monitor}$, $\Phi_{monitor}$) of the monitor; it is mainly used for evaluation of the viewing angle dependent visual performance of the monitor; the origin of the spherical coordinate system is placed in the centre of the active area of the monitor

[SOURCE: ISO 9241-302:2008, 3.3.19, modified]

Note 1 to entry: See Figure 10.

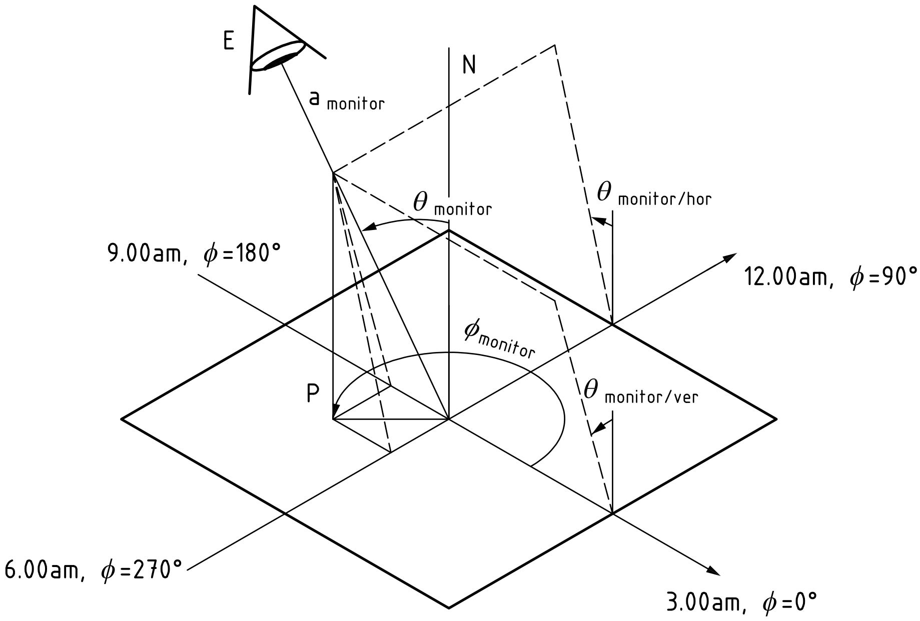


Figure 10 — Monitor spherical coordinate system

3.4.3
monitor viewing direction
direction from which the monitor is viewed; it is a line from the mid-eye point of the viewer to the centre of the monitor coordinate system

Note 1 to entry: The mid-eye point is the actual middle point between the driver's eyes. This point varies with the driver's head movement.

3.4.4
monitor viewing distance
distance of the mid-eye point of the viewer to the centre of the monitor coordinate system

Note 1 to entry: It is denoted as $a_{monitor}$ and is measured in metres.

3.4.5
monitor viewing inclination angle
inclination angle of the monitor viewing direction in monitor coordinates

Note 1 to entry: It is denoted as $\Theta_{monitor}$ and is measured in degrees.

Note 2 to entry: See Figure 10.

Note 3 to entry: From the monitor horizontal viewing angle (see 3.4.7) and the monitor vertical viewing angle (see 3.4.8), this value can be derived as:

$$\Theta_{monitor} = \arctan\sqrt{\tan^2\theta_{monitor/hor} + \tan^2\theta_{monitor/ver}} \quad (1)$$

3.4.6
monitor viewing azimuthal angle
azimuthal angle of the monitor viewing direction in monitor coordinates; it is measured counterclockwise and starting at 3 o'clock. 3 o'clock is the right edge and 12 o'clock is the upper edge of the monitor as seen from the driver

Note 1 to entry: It is denoted as $\Phi_{monitor}$ and is measured in degrees.

Note 2 to entry: See Figure 10.

Note 3 to entry: From the monitor horizontal viewing angle (see 3.4.7) and the monitor vertical viewing angle (see 3.4.8), this value can be derived as:

$$\Phi_{monitor} = \arctan\left(\frac{\tan\theta_{monitor/ver}}{\tan\theta_{monitor/hor}}\right) \quad (2)$$

3.4.7
monitor horizontal viewing angle
monitor viewing inclination angle projected onto the plane defined by the monitor surface normal and the 12 o'clock direction

Note 1 to entry: It is denoted as $\theta_{monitor/hor}$ and is measured in degrees:

$$\theta_{monitor/hor} = \arctan\left(\tan\left(\Theta_{monitor}\right)\cdot\cos\left(\Phi_{monitor}\right)\right) \quad (3)$$

Note 2 to entry: See Figure 10.

3.4.8
monitor vertical viewing angle
monitor viewing inclination angle projected onto the plane defined by the monitor surface normal and the 3 o'clock direction

Note 1 to entry: It is denoted as $\theta_{monitor/ver}$ and is measured in degrees:

$$\theta_{monitor/ver} = \arctan\left(\tan\left(\Theta_{monitor}\right)\cdot\sin\left(\Phi_{monitor}\right)\right) \quad (4)$$

Note 2 to entry: See Figure 10.

3.4.9
monitor design viewing direction
specific monitor viewing direction allocated to the ORP and the specific vehicle design (i.e. monitor placement and rotation) indicated by the index "D"

3.4.10
monitor design viewing distance
distance of the ORP to the centre of the monitor coordinate system

Note 1 to entry: It is denoted as $a_{monitor/D}$ and is measured in metres.

3.4.11
monitor design viewing inclination angle
monitor viewing inclination angle derived from the monitor design viewing direction

Note 1 to entry: It is denoted as $\Theta_{monitor/D}$ and is measured in degrees.

3.4.12
monitor design viewing azimuthal angle
monitor viewing azimuthal angle derived from the monitor design viewing direction

Note 1 to entry: It is denoted as $\Phi_{monitor/D}$ and is measured in degrees.

3.4.13
monitor design horizontal viewing angle
monitor horizontal viewing angle derived from the monitor design viewing direction

Note 1 to entry: It is denoted as $\theta_{monitor/hor/D}$ and is measured in degrees.

3.4.14
monitor design vertical viewing angle
monitor vertical viewing angle derived from the monitor design viewing direction

Note 1 to entry: It is denoted as $\theta_{monitor/ver/D}$ and is measured in degrees.

3.4.15
monitor pixel
smallest distinct able area on the monitor displaying a specific colour usually by additive mixing of the three primary colours (red, green, and blue) in different intensities

3.4.16
monitor defined size
portion of the monitor active area displaying at least the required field of view

Note 1 to entry: The monitor active area, as well as the displayed camera image, may extend beyond this area.

Note 2 to entry: The monitor defined size is defined by the system manufacturer.

Note 3 to entry: See 3.4.17 and 3.4.18 for details and differentiation between horizontal and vertical size.

3.4.17
monitor defined horizontal size
portion of the monitor active area displaying at least the required horizontal field of view along the axis from 9 o'clock to 3 o'clock according to Figure 11

Note 1 to entry: It is denoted as $W_{monitor/hor}$ and is measured in metres.

3.4.18
monitor defined vertical size
portion of the monitor active area displaying at least the required vertical field of view along the axis from 6 o'clock to 12 o'clock according to Figure 11

Note 1 to entry: It is denoted as $H_{monitor/ver}$ and is measured in metres.

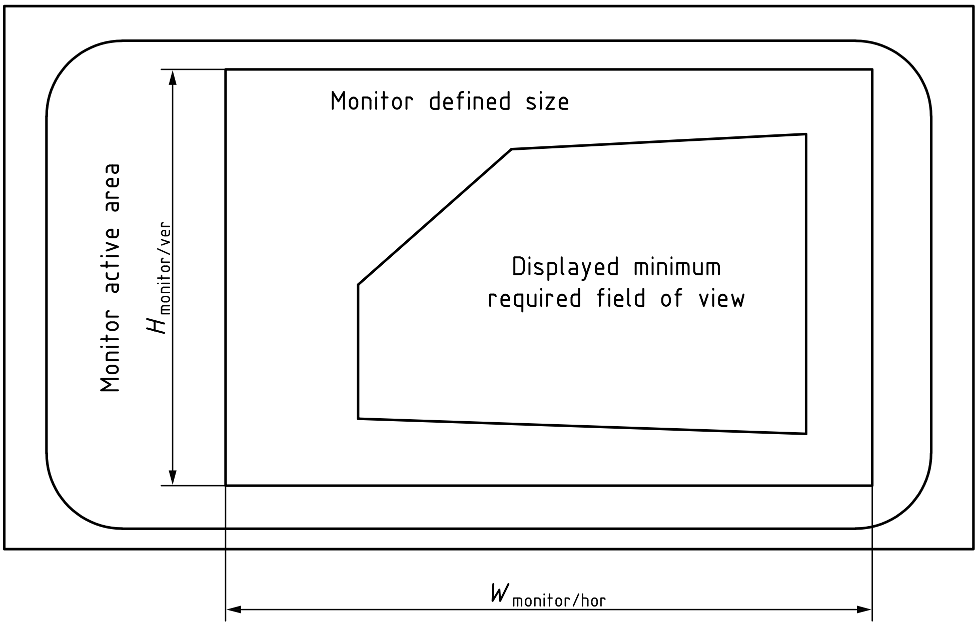


Figure 11 — Example of monitor defined size

3.4.19
monitor angular size
angle under which the driver would perceive the monitor defined size for $\Theta_{monitor} = 0°$ and $a_{monitor} = a_{monitor/D}$

Note 1 to entry: See 3.4.20 and 3.4.21 for details and differentiation between horizontal and vertical angular size.

3.4.20
monitor horizontal angular size
angle between the lines from the ORP to the left and right edge of the monitor defined horizontal size for $\Theta_{monitor} = 0°$ and $a_{monitor} = a_{monitor/D}$

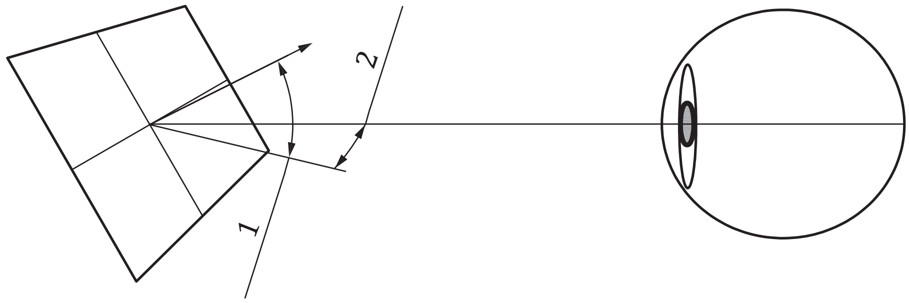
$$\alpha'_{monitor/hor} = 2\arctan\left(\frac{W_{monitor/hor}}{2a_{monitor/D}}\right) \quad (5)$$

3.4.21
monitor vertical angular size
angle between the lines from the ORP to the top and bottom edge of the monitor defined vertical size for $\Theta_{monitor} = 0$ and $a_{monitor} = a_{monitor/D}$

$$\alpha'_{monitor/ver} = 2\arctan\left(\frac{H_{monitor/ver}}{2a_{monitor/D}}\right) \quad (6)$$

3.4.22
monitor design angular size
actual angular size of the monitor defined size as perceived from the driver in the specific vehicle design (i.e. seen from the monitor design viewing direction $\Theta_{monitor} = \Theta_{monitor/D}$, $\Phi_{monitor} = \Phi_{monitor/D}$, and $a_{monitor} = a_{monitor/D}$)

Note 1 to entry: See 3.4.23 and 3.4.24 for details and differentiation between horizontal and vertical angular size.



Key

1 $\theta_{monitor/ver}$

2 $\theta_{monitor/hor}$

Figure 12 — Perspective view of horizontal and vertical viewing angle

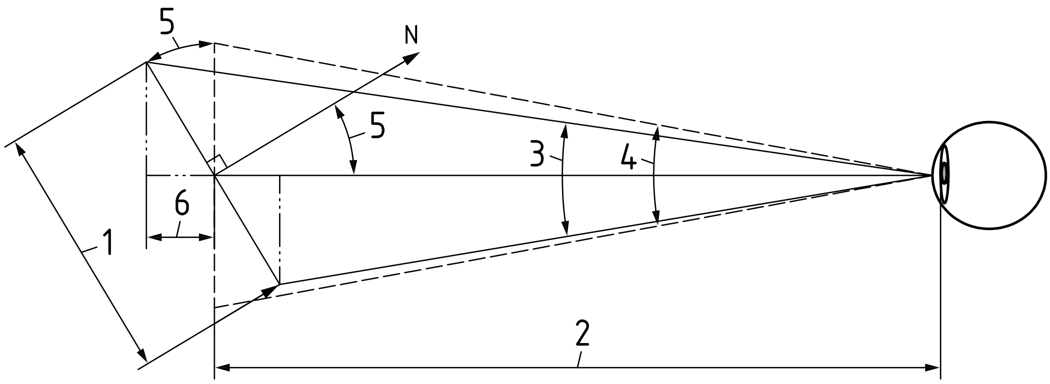
3.4.23
monitor design horizontal angular size

actual angular size of the monitor defined size as perceived from the driver in the specific vehicle design measured in the direction of the horizontal extent of the monitor

$$\alpha'_{monitor/hor/D} = \arctan\left(\frac{\frac{1}{2}\cdot W_{monitor/hor}\cdot\cos\left(\theta_{monitor/hor/D}\right)}{a_{monitor/D}+\left(\frac{1}{2}\cdot W_{monitor/hor}\cdot\sin\left(\theta_{monitor/hor/D}\right)\right)}\right) + \arctan\left(\frac{\frac{1}{2}\cdot W_{monitor/hor}\cdot\cos\left(\theta_{monitor/hor/D}\right)}{a_{monitor/D}-\left(\frac{1}{2}\cdot W_{monitor/hor}\cdot\sin\left(\theta_{monitor/hor/D}\right)\right)}\right) \quad (7)$$

Note 1 to entry: See Figure 13.

Note 2 to entry: For $W_{monitor/hor} << a_{monitor/D}$, Formula (7) can be simplified to $\alpha'_{monitor/hor/D} = \cos\left(\theta_{monitor/hor/D}\right)\cdot\alpha'_{monitor/hor}$.



Key

1 $W_{monitor/hor}$, horizontal size of the monitor, tilted at centre

2 $a_{monitor/D}$

3 $\alpha'_{monitor/hor/D}$

4 $\alpha'_{monitor/hor}$, horizontal angular size of the monitor as seen from $\theta_{monitor/hor} = 0$

5 $\theta_{monitor/hor/D}$

6 $\frac{1}{2} W_{monitor/hor} * \sin\left(\theta_{monitor/hor/D}\right)$

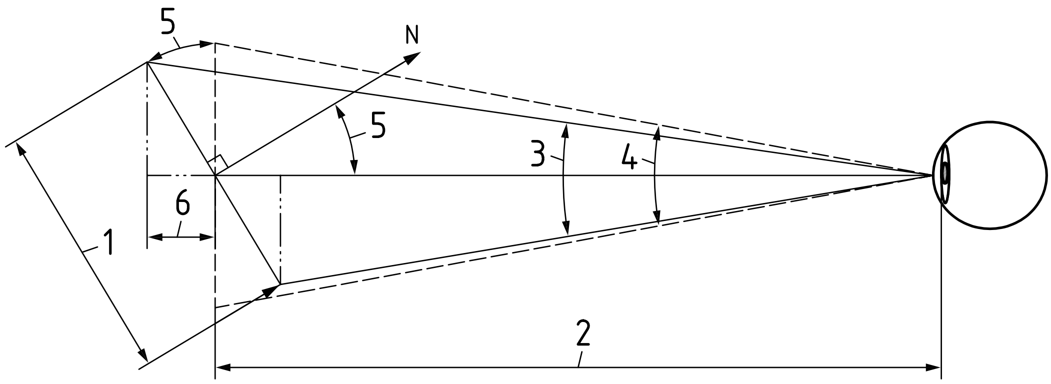
Figure 13 — Monitor design horizontal angular size

3.4.24
monitor design vertical angular size

actual angular size of the monitor defined size as perceived from the driver in the specific vehicle design measured in direction of the vertical extent of the monitor

$$\alpha'_{monitor/ver/D} = \arctan\left(\frac{\frac{1}{2} \cdot H_{monitor/ver} \cdot \cos\left(\theta_{monitor/ver/D}\right)}{a_{monitor/D} + \left(\frac{1}{2} \cdot H_{monitor/ver} \cdot \sin\left(\theta_{monitor/ver/D}\right)\right)}\right) + \arctan\left(\frac{\frac{1}{2} \cdot H_{monitor/ver} \cdot \cos\left(\theta_{monitor/ver/D}\right)}{a_{monitor/D} - \left(\frac{1}{2} \cdot H_{monitor/ver} \cdot \sin\left(\theta_{monitor/ver/D}\right)\right)}\right) \quad (8)$$

Note 1 to entry: For $H_{monitor/ver} << a_{monitor/D}$ Formula (8) can be simplified to $\alpha'_{monitor/ver/D} = \cos\left(\theta_{monitor/ver/D}\right) \cdot \alpha'_{monitor/hor}$



Key

1 $H_{monitor/ver}$, vertical size of the monitor, tilted at centre

2 $a_{monitor/D}$

3 $\alpha'_{monitor/ver/D}$

4 $\alpha'_{monitor/ver}$, vertical angular size of the monitor as seen from $\theta_{monitor/ver} = 0$

5 $\theta_{monitor/ver/D}$

6 $\frac{1}{2} H_{monitor/ver} * \sin(\theta_{monitor/ver/D})$

Figure 14 — Monitor design vertical angular size

3.4.25
monitor displayed field of view
portion of the camera's field of view that is actually displayed on the monitor defined size

3.4.26
monitor horizontal percentage of displayed camera field of view
percentage of the camera's horizontal field of view that is actually visible on the monitor defined horizontal size

Note 1 to entry: It is denoted as $p_{camera/hor}$ and is given in percent.

3.4.27
monitor vertical percentage of displayed camera field of view
percentage of the camera's vertical field of view that is actually visible on the monitor defined vertical size

Note 1 to entry: It is denoted as $p_{camera/ver}$ and is given in percent.

3.4.28
field of view displayed in the monitor defined horizontal size
portion of the camera's field of view that is actually displayed on the monitor defined horizontal size

$$\alpha_{monitor/hor} = \alpha_{camera/hor} * p_{camera/hor} \quad (9)$$

3.4.29
field of view displayed in the monitor defined vertical size
portion of the camera's field of view that is actually displayed on the monitor defined vertical size

$$\alpha_{monitor/ver} = \alpha_{camera/ver} * p_{camera/ver} \quad (10)$$

3.4.30
monitor displayed angular resolution
parameter that describes the ability of the monitor to resolve small details in the displayed scene

Note 1 to entry: It considers the mere resolution of the monitor and its relation to the field of view, the monitor is displaying.

Note 2 to entry: The smaller the angular resolution of a monitor, the smaller the details can be that are still resolved by the monitor.

3.4.31
monitor standard isotropy range
specific vertical range of 6 ° up and 6 ° down from the monitor design vertical viewing angle as defined in 3.4.14, and specific horizontal range of 7 ° right and 7 ° left from the monitor design horizontal viewing angle as defined in 3.4.13

Note 1 to entry: The value is derived from the eye ellipse definition given in ISO 4513:2010, Table 2, with $a_{monitor}$ equals 60 cm.

3.4.32
monitor extended isotropy range
additional 5 ° from the standard isotropy range in the vertical and horizontal directions

Note 1 to entry: This additional range covers head movements.

3.4.33
image formation time
summation of the rise time and the fall time as defined in ISO 9241-302:2008, 3.4.14

3.5 Camera Monitor System based terms and definitions

3.5.1
Camera Monitor System
CMS
entity used in vehicles that presents the required outside information of a specific field of view to the driver of the vehicle, replacing conventional mirror system by means of electronic image capture and display devices

Note 1 to entry: It consists of a camera following the definition given in 3.3.1 that is usually installed at the bodywork of a vehicle and a monitor following the definition given in 3.4.1 that is usually placed inside the vehicle.

3.5.2
CMS system overview
scheme that comprises the black box of a functional system and its interfaces

Note 1 to entry: See Figure 15.

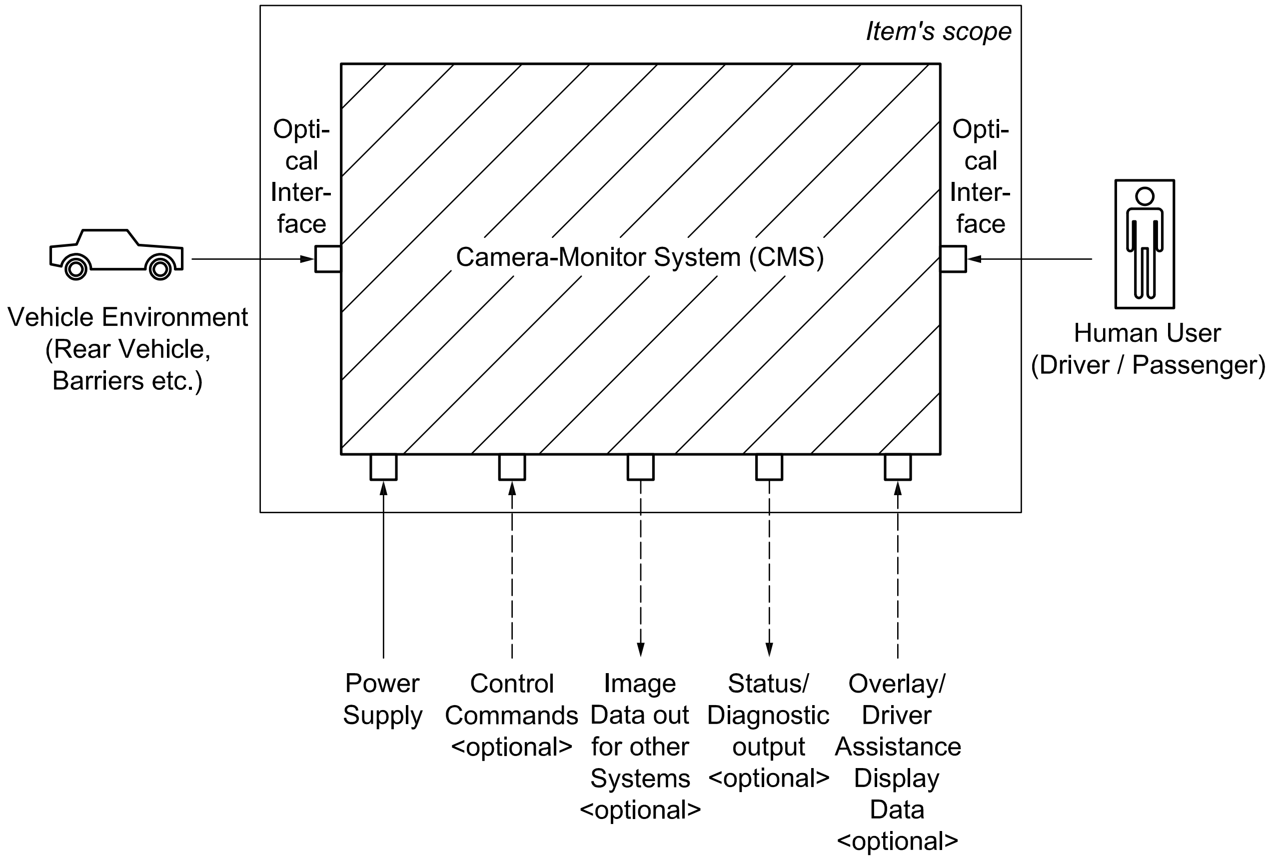


Figure 15 — System block diagram

Note 2 to entry: The external interfaces of the CMS are the following:

— captured optical signal from the vehicle's surrounding environment (technical realization: e.g. camera);

— optical image shown to the driver or a passenger (technical realization: e.g. display);

— power supply;

— control commands, e.g. on/off command (unless technically linked to the toggling of the power supply), and optionally choice of the image zoom factor, viewing area, contrast, brightness, etc.;

— optionally, image data output for other ADAS, which are not the scope of this International Standard;

— optionally, status/diagnostic output signal (e.g. to activate warning lamp in the instrument cluster);

— optionally, overlay information or driver assistance display data from other ADAS, which are not in the scope of this International Standard.

Note 3 to entry: The following entities are usually interacting with the CMS:

— vehicle on-board network (e.g. CAN, FlexRay, LIN, etc.);

— optionally, control elements (e.g. switches, buttons, joystick, menu entries, etc.);

— optionally, ADAS, which provide additional information on the display graphically or use images captured by the camera for their purposes.

3.5.3
CMS functional structure
system that is functionally divided in its essential parts

Note 1 to entry: See Figure 16.

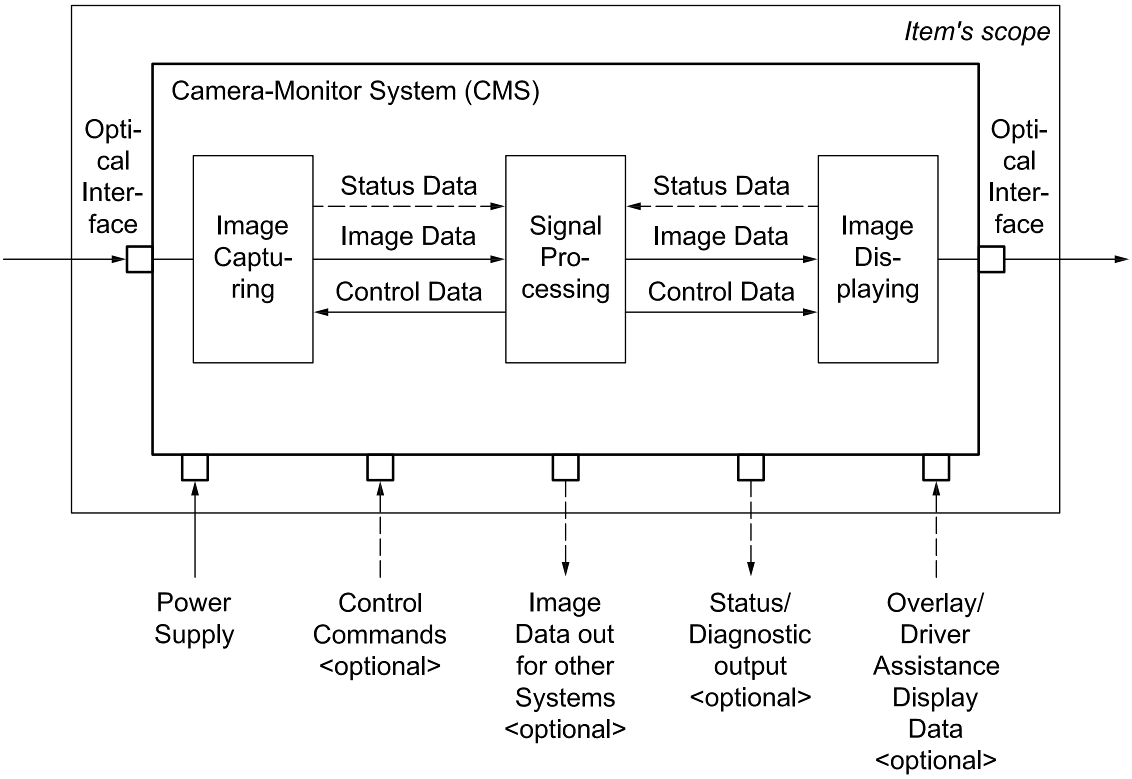


Figure 16 — CMS as white box

Note 2 to entry: A CMS is functionally divided in three essential parts:

— image capturing;

— image processing;

— image displaying, independent of different display technologies (e.g. flat screen, projection).

Note 3 to entry: The main task of the image capturing is to capture the visual surrounding field of the vehicle. It is realized by a camera, without regard to its implementation technologies.

Note 4 to entry: The image processing processes the image captured to realize display characteristics on the display unit, e.g. brightness or contrast adaptation, filtering, etc. It can be realized in hardware or software, either as a separate device, or integrated directly into the camera or in the display unit. Besides, the image processing part computes necessary controls of the camera (e.g. zoom) or display unit and also processes user inputs, if available, and optionally interface data from/to external ADAS.

Note 5 to entry: The image displaying represents the actual computed image in the vehicle on a screen or display at an appropriate viewing position for the driver. It can be realized for example by flat screen, projection, etc.

3.5.4
CMS field of view
field of view that a driver using the CMS is really able to observe; it is equal with the displayed field of view; for CMS with one camera and one monitor, this value is always less or equal to the camera field of view

3.5.5
CMS horizontal field of view
field of view that a driver using the CMS is really able to observe along the monitor defined horizontal size

Note 1 to entry: It is equal with the field of view displayed in the monitor horizontal size.

$$\alpha_{system/hor} = \alpha_{monitor/hor} \quad (11)$$

3.5.6
CMS vertical field of view

field of view that a driver using the CMS is really able to observe along the monitor defined vertical size

Note 1 to entry: It is equal with the field of view displayed in the monitor vertical size.

$$\alpha_{system/ver} = \alpha_{monitor/ver} \quad (12)$$

3.5.7
CMS magnification factor

defines the relationship between the angular size of an object as seen by the camera and the angular size as it is perceived by the driver on the monitor of the CMS

Note 1 to entry: It is denoted as M_{system}.

3.5.8
CMS average magnification factor

average value for the magnification of the CMS based on the relationship between $\alpha_{monitor}$, i.e. the displayed field of view, and $\alpha'_{monitor/D}$, i.e. the monitor design angular size

Note 1 to entry: It is denoted as $M_{system/avg}$.

3.5.9
CMS horizontal average magnification factor

horizontal average magnification of the scene observed through the CMS is given by:

$$M_{system/hor/avg} = \frac{\alpha'_{monitor/hor/D}}{\alpha_{monitor/hor}} \approx \cos\left(\theta_{monitor/hor/D}\right) * \left\{ \frac{2\arctan\left(\frac{W_{monitor/hor}}{2a_{monitor/D}}\right)}{\alpha_{camera/hor} * p_{camera/hor}} \right\} \quad (13)$$

where

$\theta_{monitor/hor/D}$	is the *monitor's design horizontal viewing angle* (3.4.13);
$a_{monitor/D}$	is the distance of the ORP to the centre of the monitor coordinate system (see 3.4.10);
$W_{monitor/hor}$	is the *monitor defined horizontal size* (3.4.17);
$\alpha_{camera/hor}$	is the *camera's horizontal field of view* (3.3.15);
$p_{camera/hor}$	is the percentage of the camera's field of view as displayed on the monitor (see 3.4.26).

3.5.10
CMS vertical average magnification factor

vertical average magnification of the scene observed through the CMS is given by:

$$M_{system/ver/avg} = \frac{\alpha'_{monitor/ver/D}}{\alpha_{monitor/ver}} \approx \cos\left(\theta_{monitor/ver/D}\right) * \left\{ \frac{2\arctan\left(\frac{H_{monitor/ver}}{2a_{monitor/D}}\right)}{\alpha_{camera/ver} * p_{camera/ver}} \right\} \quad (14)$$

where

$\theta_{monitor/ver/D}$	is the *monitor's design vertical viewing angle* (3.4.14);
$a_{monitor/D}$	is the design distance of the monitor to the ORP (3.4.10);
$H_{monitor/ver}$	is the *monitor defined vertical size* (3.4.18);
$\alpha_{camera/ver}$	is the *camera's vertical field of view* (3.3.16);
$p_{camera/ver}$	percentage of the camera's field of view as displayed on the monitor (3.4.27).

3.5.11
CMS minimum magnification factor
minimum value for the magnification the CMS shows in the required field of view as defined in 6.5

Note 1 to entry: It is denoted as $M_{system/hor/min}$ for horizontal direction and $M_{system/ver/min}$ for vertical direction.

3.5.12
CMS angular resolution
combination of the camera's angular resolution according to 3.3.17 and the displayed angular resolution on the monitor according to 3.4.30; it describes the ability of the CMS as a whole to resolve small details in the displayed scene and is defined as the maximum of both values

Note 1 to entry: If the camera is not capturing a certain detail (i.e. it does not have a sufficient angular resolution), the monitor will not be able to display it, so the camera limits the angular resolution of the CMS. On the other hand, in case the monitor is displaying the camera image (i.e. the captured field of view) with less pixel resolution, it is the monitor that limits the angular resolution of the CMS, as details that are present in the camera image cannot be displayed and, thus, are not observable by the user. It has to be the maximum of both values, as smaller values for the angular resolution indicate a higher quality for the displayed scene.

3.5.13
CMS overlay
any driving-related visual information added to the original image (such as icons, labels, coloured areas, etc.) that modifies it in a way that part of the original information is hidden; overlays can be partially transparent or totally opaque and can be displayed temporary or permanently

3.6
signal to noise ratio
SNR
ratio of the usable wanted optical signal to unwanted noise

3.7
point light source
light source of very small angular extend of about 2 arcmin and has a luminance of more than 300 cd/m^2

EXAMPLE Low beam headlights with a dimension of about 20 cm width in 350 m distance.

3.8
glare
condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance or by extreme contrasts

3.9
glare source
very bright light source like the sun or the headlights of a vehicle

Note 1 to entry: Table 1 below shows some typical luminance values that are relevant for the case of a camera-monitor-system observing a road scene.

Table 1 — Typical luminance values relevant for camera monitor systems in road vehicles

Object	Luminance
Clear sky	8 000 cd/m^2
Night sky at full moon	0,1 cd/m^2
60 W light bulb	120 × 10^3 cd/m^2
TFT white	500 cd/m^2
TFT black	0,8 cd/m^2
White LED	50 × 10^6 cd/m^2
Sun (clear day at noon)	1,6 × 10^9 cd/m^2

3.10
glare scenario
situation where a glare source is shining directly into the imaging system

3.11
parking situation
driving situation that includes all low speed manoeuvring with a vehicle or vehicle combination where it is important to precisely manoeuvre to the right spot ending at a certain vehicle orientation without colliding or interfering with surrounding objects

3.12
modulation transfer function
MTF
quantitative means to measure the spatial frequency capability as a modulus of the signal amplitude at which the individual black and white lines (or also described as line and space) of a test pattern are captured and transferred as output signal and reproduced on a display

Note 1 to entry: An MTF plot is obtained as signal amplitude response to the spatial frequency of the elements J1-J2, K1-K2, JS1-JS2, and KS1-KS2 of the chart shown in ISO 12233:2014, Figure I.2.

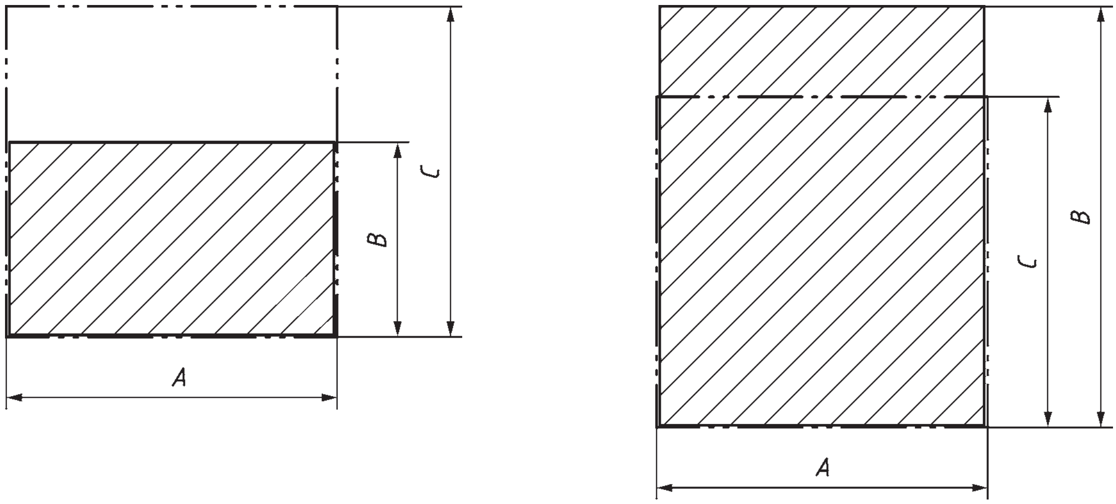
Note 2 to entry: An MTF plot can also be obtained by the discrete Fourier transform of the line-spread function, also known as SFR (spatial frequency response), if the camera signal is not submitted to nonlinear gamma correction and/or image edge enhancement and/or image smoothing process. As this might not apply to most CMS, this method should only be used as a practical method for depth of field measurement.

3.13
MTF10
spatial frequency of the modulation transfer function as defined in 3.12, where an average modulation value is equal to 10 % of the modulation of its black and white reference level, given in [LW/PH] or line widths per picture height

Note 1 to entry: The modulation is the difference between the black and white signal level divided by the sum of these levels. The result shows the limit visual resolution, to perceive fine details of the observed scene through the CMS. For the purpose of fast recognition of the scene, a signal drop limit of 10 % is used, instead of commonly used 5 % which is described as an example of limiting resolution in ISO 12233. The higher the frequency, the higher is the capability of the CMS system to reproduce fine details of the scene.

3.14
MTF10$_{(1:1)/hor}$
is the horizontal spatial frequency of the CMS as measured and converted to an assumed monitor vertical size $H'_{monitor/ver} = W_{monitor/hor}$ resulting in a horizontal versus vertical output aspect ratio of 1:1 using the test procedure given in 7.5.3

Note 1 to entry: See Figure 15.



a) **Landscape monitor** b) **Portrait monitor**

Key

A $W_{monitor/hor}$

B $H_{monitor/ver}$

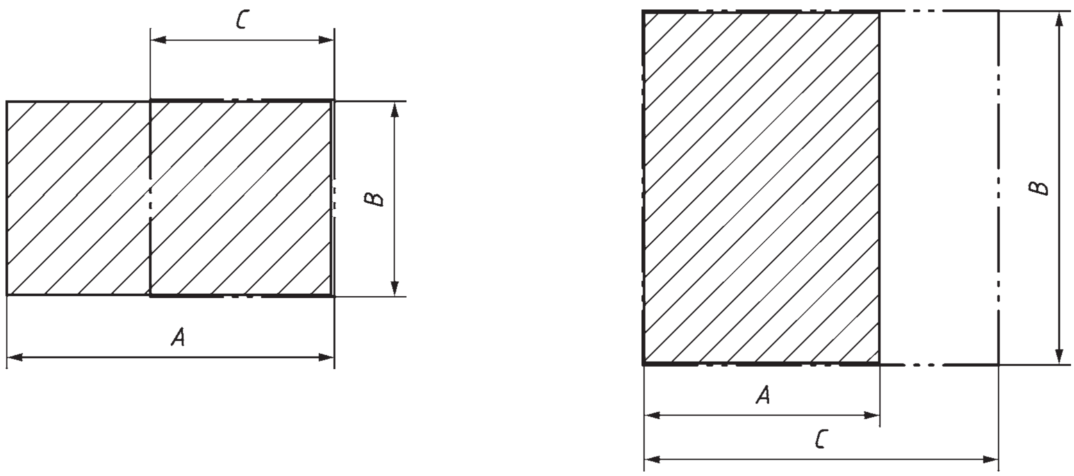
C $H'_{monitor/ver}$

Figure 17 — Illustration of the assumed monitor dimensions of MTF10$_{(1:1)/hor}$

3.15
MTF10$_{(1:1)/ver}$

vertical spatial frequency of the CMS as measured and converted to an assumed monitor horizontal size $W'_{monitor/hor} = H_{monitor/ver}$ resulting in a horizontal versus vertical output aspect ratio of 1:1 using the test procedure given in 7.5.3

Note 1 to entry: See Figure 16.



a) **Landscape monitor** b) **Portrait monitor**

Key

A $W_{monitor/hor}$

B $H_{monitor/ver}$

C $W'_{monitor/hor}$

Figure 18 — Illustration of the assumed monitor dimensions of MTF10$_{(1:1)/ver}$

3.16
MTF10$_{MIN(1:1)/hor}$

definition of horizontal spatial frequency requirement of resolution (MTF)

Note 1 to entry: It is denoted as MTF10$_{MIN(1:1)/hor}$ and it is measured in line widths per picture height [LW/PH] of an assumed monitor defined size $H'_{monitor/ver} = W_{monitor/hor}$, resulting in a horizontal versus vertical output aspect ratio of 1:1; the requirement is given as observable number of lines along this assumed monitor defined size $H'_{monitor/ver} = W_{monitor/hor}$ and it is calculated as:

$$MTF10_{MIN(1:1)/hor} = \left(\frac{W_{monitor/hor}}{W_{monitor/hor/\min}}\right) * M_{mirror/avg} * \alpha_{mirror/hor/\min} * V_{eye/\min} * 60 \frac{\text{arcmin}}{\circ} \quad (15)$$

Note 2 to entry: The spatial frequency requirement is derived from the number of observable lines in the required field of view of a traditional mirror which is given by: $M_{mirror/avg} * \alpha_{mirror/hor/\min} * V_{eye/\min} * 60 \frac{\text{arcmin}}{\circ}$. The factor $\left(\frac{W_{monitor/hor}}{W_{monitor/hor/\min}}\right)$ in Formula (15) reflects the size correction, as the ratio of the monitor horizontal defined size $\left(W_{monitor/hor}\right)$ versus the monitor horizontal size displaying the required field of view $\left(W_{monitor/hor/\min}\right)$, compensating for the different size in the monitor defined size measurement.

In a distortion free CMS with a constant magnification throughout the entire monitor defined size, the following approximation applies $\left(\frac{W_{monitor/hor}}{W_{monitor/hor/\min}}\right) \approx \left(\frac{\alpha_{monitor/hor}}{\alpha_{mirror/hor/\min}}\right)$. For such a system, the calculation formula of the measurable value MTF10$_{MIN(1:1)/hor}$ can be simplified as:

$$MTF10_{MIN(1:1)/hor} = M_{mirror/avg} * \alpha_{monitor/hor} * V_{eye/\min} * 60 \frac{\text{arcmin}}{\circ}$$

Note 3 to entry: For the adaptation of resolution measurement according to ISO 12233, the measurable value given for a squared aspect ratio 1:1 with length equal to monitor defined size, has to be corrected to take into account the actual measuring monitor size, according to different aspect ratio or to wider measuring field of view. For details of measurement using the monitor defined size, see D.3, or see D.4 for measurement using a partially cropped square image.

Note 4 to entry: Concerning the resolution MTF requirements, $M_{mirror/avg}$ has to be 0,33 for the FMVSS 111 interior mirror and 0,31 for the driver side exterior mirror.

3.17
MTF10$_{MIN(1:1)/ver}$

definition of vertical spatial frequency requirement of resolution (MTF)

Note 1 to entry: It is denoted as MTF10$_{MIN(1:1)/ver}$ and it is measured in line widths per picture height [LW/PH] of an assumed monitor defined size $W'_{monitor/hor} = H_{monitor/ver}$, resulting in a horizontal versus vertical output aspect ratio of 1:1; the requirement is given as observable number of lines along this assumed monitor defined size $W'_{monitor/hor} = H_{monitor/ver}$ and it is calculated as:

$$MTF10_{MIN(1:1)/ver} = \left(\frac{H_{monitor/ver}}{H_{monitor/ver/\min}}\right) * M_{mirror/avg} * \alpha_{mirror/ver/\min} * V_{eye/\min} * 60 \frac{\text{arcmin}}{\circ} \quad (16)$$

Note 2 to entry: The spatial frequency requirement is derived from the number of observable lines in the required field of view of a traditional mirror which is given by $M_{mirror/avg} * \alpha_{mirror/ver/\min} * V_{eye/\min} * 60 \frac{\text{arcmin}}{\circ}$. The factor $\left(\frac{H_{monitor/ver}}{H_{monitor/ver/\min}} \right)$ in Formula (16) reflects the size correction, as the ratio of the monitor vertical defined size $\left(H_{monitor/ver} \right)$ versus the monitor vertical size displaying the required field of view $\left(H_{monitor/ver/\min} \right)$, compensating for the different size in the monitor defined size measurement. In a distortion free CMS with a constant magnification throughout the entire monitor defined size, the following approximation applies $\left(\frac{H_{monitor/ver}}{H_{monitor/ver/\min}} \right) \approx \left(\frac{\alpha_{monitor/ver}}{\alpha_{mirror/ver/\min}} \right)$. For such a system, the calculation formula of the measurable value $\text{MTF10}_{\text{MIN(1:1)/ver}}$ can be simplified as $MTF10_{MIN(1:1)/ver} = M_{mirror/avg} * \alpha_{monitor/ver} * V_{eye/\min} * 60 \frac{\text{arcmin}}{\circ}$.

3.18
$\text{MTF50}_{\text{MIN(1:1)}}$
spatial frequency of the modulation transfer function as defined in 3.12, where an average modulation value equal to 50 % of the modulation of its black and white reference level, where the monitor displayed field of view is shown in the monitor defined size, with horizontal versus vertical output aspect ratio of 1:1

Note 1 to entry: Adaptation of measurable value to specific CMS with different aspect ratio or to different measured field of view has to be done accordingly as it is done for $\text{MTF10}_{\text{MIN(1:1)}}$. For more details of unit conversion and measurement, see information given in D.3, D.4 or D.5. Lower frequency of this value results in lower contrast of the scene observed through the CMS and the value is used to characterize the sharpness performance of the CMS.

3.19
luminance white level
luminance of the monitor when driven with an artificial 70 % grey-scale image measured from a specific viewing direction (Θ,Φ)

Note 1 to entry: It is denoted as $L_{monitor/white}(\Theta,\Phi)$ and measured in cd/m^2.

Note 2 to entry: This luminance is representing the white level output of the camera.

3.20
luminance of region white at contrast chart
luminance of a high reflective part of a contrast chart reproducing a contrast ratio CR of at least 20:1; the luminance value is measured with an area luminance photometer in cd/m^2 from the CMS cameras point of view

Note 1 to entry: It is denoted as $L_{chart/white}$.

3.21
luminance of region black at contrast chart
luminance of a low reflective part of a contrast chart reproducing a contrast ratio CR of at least 20:1; the luminance value is measured with an area luminance photometer in cd/m^2 from the CMS cameras point of view

Note 1 to entry: It is denoted as $L_{chart/black}$.

3.22
luminance of region white at contrast chart reproduced from the monitor
luminance of the high reflective part of a contrast chart (min CR = 20:1) displayed on the CMS monitor; the luminance value is measured at darkroom conditions with an area luminance photometer in cd/m^2 from the design viewing direction

Note 1 to entry: It is denoted as $L_{monitor/chart/white}$.

3.23
luminance of region black at contrast chart reproduced from the monitor
luminance of the low reflective part of a contrast chart (min CR = 20:1) displayed on the CMS monitor; the luminance value is measured with an area luminance photometer in cd/m² from the design viewing direction

Note 1 to entry: It is denoted as $L_{monitor/chart/black}$.

3.24
luminance of region white at contrast chart reproduced from the monitor under ambient light
luminance of the high reflective part of a contrast chart (min CR = 20:1) displayed on the CMS monitor; the luminance value is measured at test conditions with ambient light with an area luminance photometer in cd/m² from the design viewing direction

Note 1 to entry: It is denoted as $L_{monitor/chart/white/ambient}$.

3.25
luminance of region black at contrast chart reproduced from the monitor under ambient light
luminance of the low reflective part of a contrast chart (min CR = 20:1) displayed on the CMS monitor; the luminance value is measured at test conditions with ambient light with an area luminance photometer in cd/m² from the design viewing direction

Note 1 to entry: It is denoted as $L_{monitor/chart/black/ambient}$.

3.26
reflected luminance from ambient light at monitor displaying a bright scene
luminance of the reflected ambient light measured at an area of the monitor displaying a bright part of a contrast chart (min CR = 20:1)

Note 1 to entry: The luminance value is denoted as $L_{r/white}$ and is calculated from measured values with an area luminance photometer in cd/m² from the design viewing direction using the following formula:

$$L_{r/white} = L_{monitor/chart/white}\left(ambient\ light\ on\right) - L_{monitor/chart/white}\left(ambient\ light\ off\right) \quad (17)$$

3.27
reflected luminance from ambient light at monitor displaying a dark scene
luminance of the reflected ambient light measured at an area of the monitor displaying a dark part of a contrast chart (min CR = 20:1)

Note 1 to entry: The luminance value is denoted as $L_{r/black}$ and is calculated from measured values with an area luminance photometer in cd/m² from the design viewing direction using the following formula:

$$L_{r/black} = L_{monitor/chart/black}\left(ambient\ light\ on\right) - L_{monitor/chart/black}\left(ambient\ light\ off\right) \quad (18)$$

3.28
background luminance
luminance of the monitor displaying the image of a completely dark scene (e. g. the camera covered with opaque tissue), measured in a dark environment

4 Symbols and abbreviated terms

$\alpha_{mirror/hor}$	horizontal field of view of a mirror (see 3.2.17)
$\alpha_{mirror/ver}$	vertical field of view of a mirror (see 3.2.19)
$\alpha_{mirror/hor/min}$	minimum horizontal field of view of a mirror (see 3.2.18)
$\alpha_{mirror/ver/min}$	minimum vertical field of view of a mirror (see 3.2.20)

$\alpha_{camera/hor}$	horizontal field of view of a camera (see 3.3.15)
$\alpha_{camera/ver}$	vertical field of view of a camera (see 3.3.16)
$\alpha_{monitor/hor}$	horizontal displayed field of view on the monitor defined horizontal size (see 3.4.28)
$\alpha_{monitor/ver}$	vertical displayed field of view on the monitor defined vertical size (see 3.4.29)
$\alpha_{system/hor}$	horizontal field of view of the CMS (see 3.5.5)
$\alpha_{system/ver}$	vertical field of view of the CMS (see 3.5.6)
$\alpha'_{mirror/hor}$	horizontal angular size of a mirror (see 3.2.14)
$\alpha'_{mirror/ver}$	vertical angular size of a mirror (see 3.2.15)
$\alpha'_{monitor/hor}$	horizontal angular size of the monitor (see 3.4.20)
$\alpha'_{monitor/ver}$	vertical angular size of the monitor (see 3.4.21)
$\alpha'_{monitor/hor/D}$	horizontal angular size of the monitor defined horizontal size derived from the monitor design viewing direction (see 3.4.23)
$\alpha'_{monitor/ver/D}$	vertical angular size of the monitor defined vertical size derived from the monitor design viewing direction (see 3.4.24)
β_{mirror}	mirror viewing angle (see 3.2.5)
$\beta_{mirror/driver/min}$	minimum mirror viewing angle on the driver side (see 3.2.6)
$\beta_{mirror/driver/max}$	maximum mirror viewing angle on the driver side (see 3.2.7)
$\beta_{mirror/passenger/min}$	minimum mirror viewing angle on the passenger side (see 3.2.8)
$\beta_{mirror/passenger/max}$	maximum mirror viewing angle on the passenger side (see 3.2.9)
$\theta_{monitor/hor}$	horizontal viewing angle onto the monitor (see 3.4.7)
$\theta_{monitor/ver}$	vertical viewing angle onto the monitor (see 3.4.8)
$\theta_{monitor/hor/D}$	horizontal viewing angle onto the monitor derived from the monitor design viewing direction (see 3.4.13)
$\theta_{monitor/ver/D}$	vertical viewing angle onto the monitor derived from the monitor design viewing direction (see 3.4.14)
$\Theta_{monitor}$	inclination viewing angle onto the monitor in spherical coordinates (see 3.4.5)
$\Phi_{monitor}$	azimuthal viewing angle onto the monitor in spherical coordinates (see 3.4.6)
$\Theta_{monitor/D}$	inclination viewing angle onto the monitor derived from the monitor design viewing direction (see 3.4.11)
$\Phi_{monitor/D}$	azimuthal viewing angle onto the monitor derived from the monitor design viewing direction (see 3.4.12)

a_{mirror}	distance from the ocular reference point to the centre of the mirror (see 3.2.2)
$a_{mirror/driver/max}$	maximum distance from the ocular reference point to the centre of the mirror on the driver side (see 3.2.3)
$a_{mirror/passenger/max}$	maximum distance from the ocular reference point to the centre of the mirror on the passenger side (see 3.2.4)
$a_{monitor}$	distance of the mid-eye point of the viewer to the centre of the monitor coordinate system (see 3.4.4)
$a_{monitor/D}$	distance of the ORP to the centre of the monitor coordinate system (see 3.4.10)
d_{object}	distance from the mirror to an object being viewed by the driver (see 3.2.10)
EP_{camera}	entrance pupil of a camera (see 3.3.13)
$H_{monitor/ver}$	monitor defined vertical size (see 3.4.18)
$H_{monitor/ver/min}$	vertical height of the minimum (required) vertical field of view (see 3.2.19 and Figure D.7) as displayed on the monitor
$L_{chart/white}$	luminance of region white at contrast chart (see 3.20)
$L_{chart/black}$	luminance of region black at contrast chart (see 3.21)
$L_{monitor/chart/white}$	luminance of region white at contrast chart reproduced from the monitor (see 3.22)
$L_{monitor/chart/black}$	lLuminance of region black at contrast chart reproduced from the monitor (see 3.23)
$L_{monitor/chart/white/ambient}$	luminance of region white at contrast chart reproduced from the monitor under ambient light (see 3.24)
$L_{monitor/chart/black/ambient}$	luminance of region black at contrast chart reproduced from the monitor under ambient light (see 3.25)
$L_{monitor/white}(\Theta, \Phi)$	luminance of the monitor when driven with an artificial 70 % grayscale image, measured from a specific viewing direction (Θ,Φ) (see 3.19)
$L_{r/white}$	reflected luminance from ambient light at monitor displaying a bright scene (see 3.26)
$L_{r/black}$	reflected luminance from ambient light at monitor displaying a dark scene (see 3.27)
M_{mirror}	magnification factor of a mirror (see 3.2.21)
$M_{mirror/avg}$	average magnification factor of a mirror (see 3.2.22)
$M_{mirror/driver/avg}$	average magnification factor of a mirror on the driver side (see 3.2.23)
$M_{mirror/passenger/avg}$	average magnification factor of a mirror on the passenger side (see 3.2.24)
$M_{mirror/min}$	minimum magnification factor of a mirror (see 3.2.25)

$M_{mirror/driver/min}$	minimum magnification factor of a mirror on the driver side (see 3.2.26)
$M_{mirror/passenger/avg}$	minimum magnification factor of a mirror on the passenger side (see 3.2.27)
$M_{mirror/0}$	ideal magnification when viewing an object at a large distance straight from front, i.e. at viewing angle β_{mirror} = 0 and d_{object} approaching infinity
M_{system}	magnification factor of the CMS (see 3.5.7)
$M_{system/avg}$	average magnification factor of the CMS (see 3.5.8)
$M_{system/hor/avg}$	horizontal average magnification factor of a CMS (see 3.5.9)
$M_{system/avg/ver/avg}$	vertical average magnification factor of a CMS (see 3.5.10)
$M_{system/hor/min}$	horizontal minimum magnification factor of a CMS (see 3.5.11)
$M_{system/ver/min}$	vertical minimum magnification factor of a CMS (see 3.5.11)
MTF10	spatial frequency of the MTF, where the modulation has dropped to 10 % of the modulation of its reference black and white signal level (see 3.13)
$\mathrm{MTF10}_{(1:1)/\mathrm{hor}}$	spatial frequency of the CMS as measured and converted to an assumed monitor aspect ratio of (1:1) using the test procedure given in 7.5.3 (see 3.14)
$\mathrm{MTF10}_{(1:1)/\mathrm{ver}}$	spatial frequency of the CMS as measured and converted to an assumed monitor aspect ratio of (1:1) using the test procedure given in 7.5.3 (see 3.15)
$\mathrm{MTF10}_{\mathrm{MIN}(1:1)/\mathrm{hor}}$	MTF10 displaying the minimum horizontal field of view assuming a monitor with 1:1 aspect ratio (see 3.16)
$\mathrm{MTF10}_{\mathrm{MIN}(1:1)/\mathrm{ver}}$	MTF10 displaying the minimum vertical field of view assuming a monitor with 1:1 aspect ratio (see 3.17)
$\mathrm{MTF50}_{(1:1)}$	spatial frequency of the MTF, where the modulation has dropped to 50 % of the modulation of its reference black and white signal level (see 3.18)
$N_{camera/hor}$	horizontal resolution of a camera (see 3.3.10)
$N_{camera/ver}$	vertical resolution of a camera (see 3.3.11)
$p_{camera/hor}$	percentage of camera horizontal field of view displayed on the monitor defined horizontal size (see 3.4.26)
$p_{camera/ver}$	percentage of camera vertical field of view displayed on the monitor defined vertical size (see 3.4.27)
r_{mirror}	radius of curvature of a mirror (see 3.2.11)
$r_{mirror/min}$	minimum allowed radius of curvature (see 3.2.12)
V_{eye}	visual acuity of the human eye (see 3.2.29)
$V_{eye/min}$	minimum allowed visual acuity (see 3.2.30)
$W_{monitor/hor}$	monitor defined horizontal size (see 3.4.17)

$W_{monitor/hor/min}$	horizontal width of the minimum (required) horizontal field of view (see 3.2.18 and Figure D.7 in D.5) as displayed on the monitor
x_{camera}	distance of the camera to the ocular reference point in x-direction (see 3.3.4)
y_{camera}	distance from the outermost point of the same side of the vehicle to the entrance pupil of a camera replacing side mirrors in y-direction (see 3.3.5)
y'_{camera}	distance from the longitudinal centre x-z-plane to the entrance pupil of a camera replacing the interior centre mirror in y-direction (see 3.3.5)
z_{camera}	distance from the road surface to the centre of the entrance pupil of the camera (see 3.3.6)
ADAS	advanced driver assistance systems
CMS	Camera Monitor System (s)
FOV	field of view
GVW	gross vehicle weight
HMI	human machine interface
LCD	liquid crystal display
MTF	modulation transfer function (see 3.12)
ORP	driver's ocular reference point (see 3.1.4)
SFR	spatial frequency response (see 3.12)
SNR	signal to noise ratio (see 3.6)

5 General information and use case definitions

The main content of the displayed image on the monitor is “reality information” (according to ISO 9241-307) that is the imaging of objects and scenes that do have existing originals in our world — e.g. faces, people, landscapes, etc. — in colour presentation.

The perception is summarized as follows:

— view of the field of vision of the intended mirror class;

— observation of traffic situations;

— observation of the near and far environment around the vehicle;

— perception of objects (e.g. vehicles, cyclists, pedestrian, traffic signs, signal lights, etc.);

— perception of location, distance and velocity of objects.

The use cases serve as an orientation for the derivation of system requirements. In addition, they may be used for practical evaluation of a CMS during road tests.

A use case identifies a single traffic situation in which a CMS is used together with its specific task to be performed by the driver as well as its associated potential critical situations and metrics.

Table 2 is the list of possible use cases applicable for CMS.

Table 2 — List of possible use cases applicable for CMS

Title	Task description	Critical situation	Critical metric	Justification
Roundabout	Monitoring traffic when whole image content rapidly changes (e.g. roundabout with multiple lanes)	Night time	Frame rate and controlling the driver side field of view	Night time is critical because of higher exposure time for the camera
Merge lane	Vehicle is entering a freeway	Inability to merge into freeway traffic	Limited field of view	Inability to expand the field of view similar to head movement using conventional mirror
Lane change (1)	Object are next to vehicle when a lane change is intended	Object in blind spot	Limited field of view	According to UN REGULATION NO. 46, conventional mirrors can have aspheric extension for covering the blind spot
Lane change (2)	Objects approaching from behind at a high relative speed	Day time and night time	Distance and speed estimation	Different cues for estimating distance and speed during day and night time
Tunnel	Drive into/out of tunnel at high speed	Significant and fast ambient light change	Camera and monitor parameters	Change in overall lighting on bright days require a fast adjustment of camera and monitor parameters
Direct light in the display	Ambient light reflection on display surface	Direct sunlight	Legibility of information	Ambient light could affect contrast ratio
Direct light in the camera	High dynamic ambient light	Reflections, low sun, headlamps, etc.	Legibility of information	Ambient light could affect contrast ratio
Cold start	Start driving immediately after a cold start	Cold temperature	Start-up, boot time	System requires initialization
Reverse driving (1)	Detect relevant objects while backing up	N/A	Field of view	Fixed versus dynamic field of view
Reverse driving (2)	Estimate distance to relevant objects while backing up	N/A	Distance estimation	Lack of stereoscopic vision while using two dimensional monitor and camera
Vehicle in garage situation	Detect relevant objects while backing up	Daylight versus dark environment	Legibility	Camera and monitor in different modes (day versus night)
Engine stop	Detect relevant objects when engine is stopped	N/A	Availability of the system	Observation of traffic is necessary even engine is stopped
City drive	Concentrate on relevant critical objects	Day and night time	Distance estimation and spatial relation	Distraction, depth of field is usually static with CMS while a driver can adjust the focal plane using a conventional mirror
Long-time drive (1)	Monotonous drive of longer distances most likely on freeways	Day time	Ergonomic factors	Possible fatigue of the driver due to frequent changes of accommodation
Long-time drive (2)	Monotonous drive of longer distances most likely on freeways	Night time	Ergonomic factors	Possible annoyance due to nonblack display

Table 2 *(continued)*

Title	Task description	Critical situation	Critical metric	Justification
Elderly driver	Presbyope wear special eye glasses (bifocal or progressive lens)	N/A	Position of the display	Focus on near objects limited to angular sizes beneath the Frankfort plane
Turning	Percept critical objects while turning	Persons, children, bicycles, etc.	Field of view	Inability to expand the field of view similar to head movement using conventional mirror
Signal lamps	Percept an emergency vehicle in action, percept turn signals, etc.	Night time	Colour rendering index; frame rate	Recognize colour of signal lamps
Static evaluation	Precise measurement of the field of view	N/A	Field of view	Check accordance with legal requirements
Display arrangements for natural driving behaviour	Monitoring a complex situation where the display position should come natural in relation to other vision means	Complex traffic situations or tricky manoeuvring where adjacent or approaching objects are to be detected	Safety and driver acceptance	Arrangements of displays and how field of views are presented in relation to other vision means could be dangerous and cause incidents or even accidents
Round-about with trailer	Monitoring vehicle, trailer and rear end of trailer, but also road side, lines, and other road users	Day time and night time when passing through a round-about	Field of view (increase from head movements not available as with a conventional mirror system)	Without considering the increased field of view from head movements, a CMS will provide too little and become unsafe/hard to implement
Monitor reflections into window surfaces	Viewing objects through lower side-windows or windscreen either with direct vision or via external indirect vision devices gets disturbed by monitor reflections onto the window surfaces	Night time	Geometrical relations between monitor and windows as well as monitor luminance level	Reflections that prevent direct or indirect vision of objects around the vehicle form a safety risk
Light and shadow in the same view	Viewing and understanding the near surroundings around the vehicle gets difficult when different parts of the surroundings have very different light conditions (e.g. direct sunlight and complete shadow)	Objects in direct sun light versus complete shadow can be missed if not displayed in a discernible way	Legibility (brightness and contrast control by camera and display)	Camera and monitor needs to process areas with different light conditions differently to secure that the driver can see critical objects properly
Light and shadow in different views	Viewing what happens around the vehicle when each camera view covers surroundings with very different light conditions	Camera views with better light conditions get more attention than camera views with poor conditions where something critical actually takes place	Legibility (brightness and contrast)	Camera views need to be processed so they can be presented for the driver in a balanced way securing that critical objects are brought to the driver's attention

Table 2 *(continued)*

Title	Task description	Critical situation	Critical metric	Justification
Reversing with trailer	Monitoring vehicle, trailer and rear end of trailer. It is also important to see the object that you are reversing towards and any obstacles along the way.	Day time and night time when reversing	Field of view (increase from head movements not available as with a conventional mirror system)	Without considering the increased field of view from head movements, a CMS will provide too little and become unsafe/hard to implement.
Extreme driver sizes	An extreme driver size (e.g. very short, very tall or with unusual anthropometric proportions) gets an awkward relation between eye locations and the monitor arrangement.	Display gets hard to view due to distance, viewing angle and/or large required head rotation	Ergonomic factors	Potential safety risks compared to a conventional adjustable mirror designed to take most driver sizes into account
Turning with trailer	Monitoring vehicle and trailer as well as more of the road to understand how the vehicle combination is located in relation to surroundings	Day time and night time when turning left or right	Field of view (increase from head movements not available as with a conventional mirror system)	Without considering the increased field of view from head movements, a CMS will provide too little and become unsafe/hard to implement
Exiting after temporary standstill	Indirect vision is needed in order to see if it is safe to exit the vehicle	Another vehicle is coming close to the vehicle when the driver and/or passengers intend to exit	CMS availability; thanks to the wise use of conditions for keeping the system active	Dangerous situations need to be avoided compared to the functionality that conventional mirrors provide
Exiting after longer period of resting in the vehicle	Indirect vision is needed in order to see if it is safe to exit the vehicle	Another vehicle is coming close to the vehicle when the driver and/or passengers intend to exit	CMS availability despite fewer conditions that could trigger system initiation	Dangerous situations need to be avoided compared to the functionality that conventional mirrors provide
Normal entrance and take-off procedure	Viewing what is behind before taking off as with a conventional mirror system	Another vehicle is coming from behind and shall be shown in time for the driver before entering the traffic	CMS availability; thanks to the wise use of conditions to trigger system initiation	Dangerous situations need to be avoided compared to the functionality that conventional mirrors provide
Take-off after longer period of resting in the vehicle	Viewing what is behind before taking off as with a conventional mirror system	Another vehicle is coming from behind and shall be shown in time for the driver before entering the traffic	CMS availability despite fewer conditions that could trigger system initiation	Dangerous situations need to be avoided compared to the functionality that conventional mirrors provide
Driving in LHS and RHS markets with the same vehicle	Monitoring surroundings as appropriate to driving on the “right”, as well as on the “wrong” side of the road	Surrounding vehicles and/or objects are hard to see due to the provided field of view(s)	Field of view adjustability	To secure safe driving, it is necessary to provide some adjustability of provided field of views in order to adapt the vehicle to the different driving conditions in LHS and RHS markets
Driving with different superstructure or trailer widths	Monitoring field of view based on the current width of the vehicle	Surrounding vehicles and/or objects are not shown as the field of view is adapted to a narrower vehicle condition.	Field of view adaptation to actual vehicle width	To secure safe driving and to remain legal, it is necessary to adapt the field of view to the current width of replaceable superstructures or trailers

Table 2 *(continued)*

Title	Task description	Critical situation	Critical metric	Justification
Motorway	Observation of the traffic behind. Make a decision on how many vehicles are in behind and on which lane does they drive.	Night time	Rendering of point light sources (e.g. low beam headlights)	Rendering of point light sources (e.g. low beam headlights) can lead to blooming, that means that e.g. the two low beam headlights of a vehicle are not separated and are rendered as a more or less large “light cloud” on the monitor. This “light cloud” increases as more vehicles drive in behind at small distances. In such a situation, it is not possible to decide on the number of vehicles in behind and on their location.

6 Requirements

6.1 Intended use

The intended use shall be mentioned within the operator’s manual.

6.1.1 Default view

The default view shall enable the driver to observe the surroundings in most driving situations. The CMS shall support a default view at least for homologation. In default view the CMS shall show the FOV at least as defined in 6.4, with at least the minimum magnification, average magnification, and resolution as defined in 6.5.

6.1.2 Adjusted default view

The CMS may allow the user to change the field of view to his required setup in normal driving situations as it is possible today with conventional mirror systems. In the adjusted default view, the requirement of 6.4 might not be fulfilled; however, all other requirements still apply. This user adjusted default view may be restored for the next trip.

6.1.3 Temporary modified view

The CMS may allow a temporary modification of the default view or the adjusted default view regarding the field of view and/or magnification and shall enable the driver to observe the surroundings in special driving situations such as merging, parking manoeuvre, etc. The temporary modification shall be indicated to the driver. The operator’s manual shall inform the driver as well.

NOTE 1 The temporary modification can be activated automatically or manually.

NOTE 2 For requirements and recommendations regarding the modified view in commercial vehicles, refer to A.3.1.1

NOTE 3 See 6.2.3.1 and 6.2.3.2 for examples of temporary modified views.

6.1.3.1 Example of temporary changed field of view

The CMS may allow the user to select or automatically activate a temporary changed field of view so that the requirement of 6.4 may not be fulfilled (e.g. driver turning head while merging), to be able to observe the relevant traffic in special situations as shown for example in Figure 19, where the driver needs to pull out in a shallow angle (higher than 0 ° but still not enough to observe the relevant traffic by turning the head.

Figure 19 — Special situation where field of view is usually changed by the driver moving its head to achieve a different incident angle to the mirror

6.1.3.2 Example of temporary changed magnification factor

The CMS may allow the user to select or automatically activate a temporary changed magnification factor so that the requirements in 6.5.1 and 6.5.3 may not be fulfilled to be able to better observe the relevant traffic in special situations for example parking.

6.1.4 Luminance and contrast adjustment

It shall be possible to adjust the average luminance of the monitor either manually or automatically to the ambient conditions. Changing the CMS contrast should be allowed either manually or automatically. If manual adjustment is provided, the operator's manual shall give advice on how to change the luminance/contrast.

6.1.5 Overlays

Overlays, according to 3.5.13, are generally allowed. Within the required field of vision only temporary transparent overlays are allowed.

6.2 Operating readiness (system availability)

The CMS should be operational as soon as the driver is ready to drive. If the system is not operational, the driver shall be informed (i.e. warning indication, display information, etc.), see also 6.10. The operator's manual shall explain the information to be indicated to the driver.

In order to enable the availability in a reasonable timeframe the switch-on-time for a cold start of the CMS t_{ON} is specified to be $t_{ON} \leq 7$ s.

NOTE The switch-on-time for a cold start of the CMS t_{ON} corresponds to the time-behaviour of folding mirrors.

In the interest of reducing power consumption, the CMS may suspend operation when the vehicle is temporarily stopped (e.g. at red traffic light, traffic jam, etc.), but shall be fully reactivated in $t_{RESTART} \leq 1$ s so that the driver can scan the surrounding.

6.3 Field of view

The system field of view of the CMS following 3.5.4 shall cover the field of view at least that is required by the national body for conventional mirrors of the same class, both in horizontal and vertical direction. The CMS camera orientation shall be such that the CMS required field of view is properly secured when integrated into the vehicle.

RATIONALE: Following this definition, the minimum required field of view for a CMS is identical to the minimum field of view of a conventional mirror (see 3.2.18 and 3.2.20).

NOTE The field of view is dependent of the superstructure (e.g. trailer, load, etc.) that is carried.

Examples for different mirror classes are given in B.2.

6.4 Magnification and resolution

6.4.1 Average magnification factor

The average magnification factor of the CMS following 3.5.8 in both horizontal and vertical direction shall not be lower than the average allowed magnification factor of a mirror following definitions in 3.2.23 (driver side) and 3.2.24 (passenger side).

6.4.1.1 Average magnification factor (driver side)

The following requirement applies:

$$M_{system/hor/avg} \geq M_{mirror/driver/avg} \quad (19)$$

$$M_{system/ver/avg} \geq M_{mirror/driver/avg} \quad (20)$$

The values of $M_{mirror/driver/avg}$ for different mirror classes are given in 3.2.23.

6.4.1.2 Average magnification factor (passenger side)

The following requirement applies:

$$M_{system/hor/avg} \geq M_{mirror/passenger/avg} \quad (21)$$

$$M_{system/ver/avg} \geq M_{mirror/passenger/avg} \quad (22)$$

The values of $M_{mirror/passenger/avg}$ for different mirror classes are given in 3.2.24.

6.4.2 Minimum magnification factor

The minimum magnification factor of the CMS following 3.5.11 in both horizontal and vertical direction shall not be lower than the minimum allowed magnification factor of a mirror following definitions in 3.2.26 (driver side) and 3.2.27 (passenger side).

6.4.2.1 Minimum magnification factor (driver side)

The following requirement applies:

$$M_{system/hor/\min} \geq M_{mirror/driver/\min} \quad (23)$$

$$M_{system/ver/\min} \geq M_{mirror/driver/\min} \quad (24)$$

The values of $M_{mirror/driver/min}$ for different mirror classes are given in 3.2.26.

6.4.2.2 Minimum magnification factor (passenger side)

The following requirement applies:

$$M_{system/hor/\min} \geq M_{mirror/passenger/\min} \quad (25)$$

$$M_{system/ver/\min} \geq M_{mirror/passenger/\min} \quad (26)$$

The values of $M_{mirror/passenger/min}$ for different mirror classes are given in 3.2.27.

6.4.3 Resolution (MTF)

The resolution (MTF) defines the minimum distinguishable details observable in an image and it is represented by the MTF10 as described in 3.13. For reasons of simplicity the requirement is defined assuming an aspect ratio of 1:1. The correction factor for other aspect ratios can be found in Annex D.

NOTE 1 Refer to Annex D for more information on the assumed aspect ratio of 1:1.

Resolution MTF10, at the centre of the monitor defined size shall fulfil the following requirements:

— $MTF10_{(1:1)/hor} \geq MTF10_{MIN(1:1)/hor}$, in horizontal direction;

— $MTF10_{(1:1)/ver} \geq MTF10_{MIN(1:1)/ver}$, in vertical direction.

Resolution MTF10, at the corner measurement points as illustrated in Figure 20 shall fulfil the following requirements:

— $MTF10_{(1:1)/hor} \geq \frac{1}{2} MTF10_{MIN(1:1)/hor}$, in horizontal direction;

— $MTF10_{(1:1)/ver} \geq \frac{1}{2} MTF10_{MIN(1:1)/ver}$, in vertical direction.

NOTE 2 The corner measurement points as illustrated in Figure 20 are representative points to evaluate the performance of the CMS in the whole relevant displayed range.

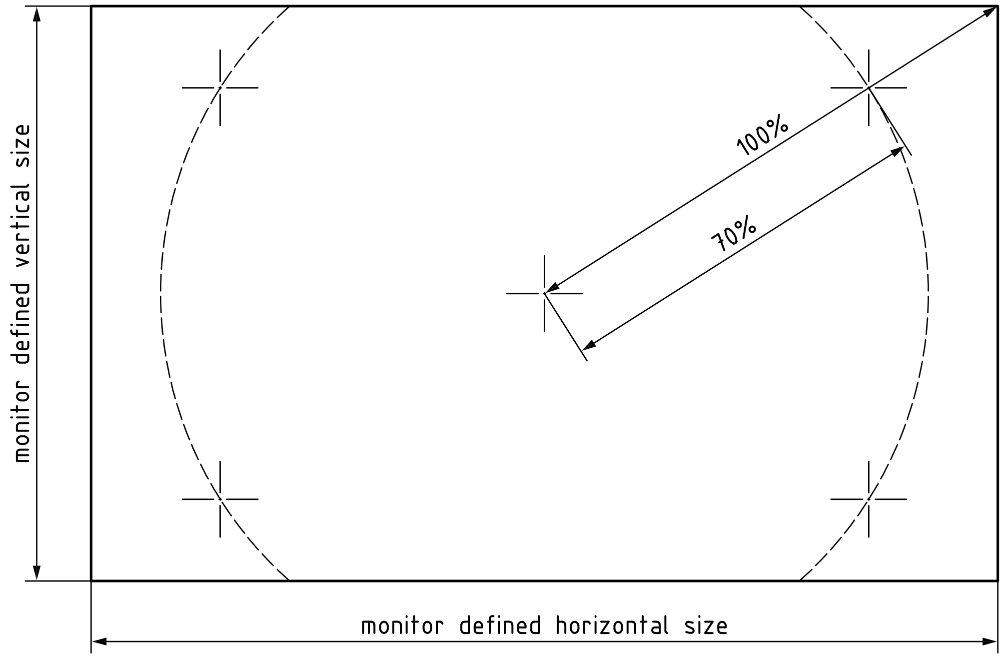


Figure 20 — Illustration of the corner measurement points for measuring the MTF10

6.5 Magnification aspect ratio

In the required field of view, the difference between the average magnification factor for horizontal and vertical direction of a CMS shall satisfy the following formulae depending on the individual mirror classes. For more information, see B.3.4. The preferable average magnification should be the same for horizontal and vertical direction.

For UN REGULATION NO. 46 class I CMS, the acceptable range shall be:

$$-0{,}34 \le 1 - \frac{M_{system/hor/avg}}{M_{system/ver/avg}} \le 0{,}25 \quad (27)$$

For UN REGULATION NO. 46 class II CMS, the acceptable range shall be:

$$-0{,}42 \le 1 - \frac{M_{system/hor/avg}}{M_{system/ver/avg}} \le 0{,}3 \quad (28)$$

For UN REGULATION NO. 46 class III CMS, the acceptable range shall be:

$$-0{,}34 \le 1 - \frac{M_{system/hor/avg}}{M_{system/ver/avg}} \le 0{,}25 \quad (29)$$

For UN REGULATION NO. 46 class IV CMS, no restriction in magnification ratio is required (see B.3.4).

6.6 Monitor integration inside the vehicle

The following requirements and recommendations should refer to the portion of the monitor which shows the intended field of view.

a) The obstruction of the view onto the mandatory field of vision on the monitor shall be restricted to a minimum according to national regulation for the view on the appropriate mirror class.

b) It should be possible to view the monitor with a gaze angle not more than 30 ° down from the eye point according to Reference [3] Regarding the maximum angle where the monitor is allowed to be located, the monitor position shall fulfill any individual mirror regulations of the national body. The monitor should be protected from ambient light or mounted accordingly. The monitor should be oriented in a way that ambient light does not illuminate the monitor from a central critical specular light direction (see also ISO 15008). The installation of the monitor should be optimized for a perpendicular viewing direction.

NOTE The gaze angle for commercial vehicles can be larger than 30 ° due to the driver seating height.

c) The installation of the monitor should not lead to annoying reflections on the windscreen or other window panes.

d) The arrangement of the monitor inside the vehicle shall be in such a way as expected by a driver. This means, that the image of the right side FOV is displayed on the right side of the monitor arrangement, the image of the centre FOV is displayed in the intermediate region of the monitor arrangement and the image of the left side FOV is displayed on the left side of the monitor arrangement. If the CMS has only one display, non-continuous images shall be clearly separated from each other. For additional commercial vehicle requirements, see A.3.2.

e) Obstruction of the driver's direct view caused by the installation of the CMS (especially of the monitor) shall be restricted to a minimum according to national regulation (e.g. UN Regulation No. 125).

f) The monitor may be adjustable by the driver in order to achieve the minimum image quality required by 6.8. In that case, the adjustment shall be possible without any tool.

6.7 Image quality

The following requirements refer to the monitor defined size, if not stated otherwise.

6.7.1 Monitor isotropy

The monitor shall conform to optical requirements over a relevant range of viewing directions.

6.7.1.1 Directional uniformity

When driven by an artificial 70 % grey-scale image, the deviation of the monitor luminance from the luminance white level as defined 3.19 with specific viewing direction $(\Theta,\Phi) = (\Theta_{monitor/D}, \Phi_{monitor/D})$ shall be such that the ratio relative to the luminance white level for the same specific viewing direction $L(\Theta_{monitor/D}, \Phi_{monitor/D})$ does not exceed 35 % of the luminance white level for the monitor standard isotropy range as defined in 3.4.31 and shall not exceed 50 % of the luminance white level for the monitor extended isotropy range as defined in 3.4.32.

For the standard isotropy range:

$$\frac{\max\left\{\left|L_i - L\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right)\right|\right\}}{L\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right)} < 35\%\text{, for points I = 1, 2, 3, 4, 6, 7, 8, 9 as defined in Table 3} \quad (30)$$

For the extended isotropy range:

$$\frac{\max\left\{\left|L_{i'} - L\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right)\right|\right\}}{L\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right)} < 50\%\text{, for points i' = 1, 2, 3, 4, 6, 7, 8, 9 as defined in Table 4} \quad (31)$$

RATIONALE: In the extended isotropy range a higher amount of quality deterioration is accepted, as long as there is no sudden loss of the image.

6.7.1.2 Lateral uniformity

The luminance white lateral dependency shall satisfy:

$$\frac{\max\left\{\left(L_{j/white}\left(\Theta,\Phi\right)\right)\right\}-\min\left\{\left(L_{j/white}\left(\Theta,\Phi\right)\right)\right\}}{\max\left\{\left(L_{j/white}\left(\Theta,\Phi\right)\right)\right\}}<35\,\%$$, for points j = 1, 2, 3, 4, 5, 6, 7, 8, 9 as defined in Table 5 where $\left(\Theta,\Phi\right)=\left(0,0\right)$ (32)

6.7.2 Luminance and contrast rendering

For luminance and contrast rendering the following requirements apply:

— The minimum luminance contrast at the monitor reproducing a high contrast pattern shall be:

  — for direct sunlight condition: 2:1;

  — for day condition with diffuse ambient light: 3:1;

  — for sunset condition: 2:1;

  — for night condition: 5:1.

NOTE 1 The definition of the "luminance contrast" is given in ISO 9241-302. The luminance contrast is measured by "contrast ratio". According to ISO 9241-302, as well as ISO 15008, the "contrast ratio" is defined as the ratio between the higher luminance L_H (L_{High}) and the lower luminance L_L (L_{Low}). All remaining definitions follow ISO 15008.

NOTE 2 To take into account the needs of older drivers, the minimum luminance contrast for night condition should be 10:1.

— Night condition for the cameras field of view is replicated in a dark environment such that the maximum illuminance on the objects to be measured shall not exceed 2,0 lx.

— The background luminance of the monitor should be limited under night condition. Depending on the installation of the monitor inside the vehicle, this will reduce annoying reflections on the windscreen or other window panes as well. The maximum background luminance under night condition should be less than 2,0 cd/m^2.

— The operator's manual shall contain a note that sunlight or light from other intense light sources upon the monitor reduces the luminance contrast which may require the driver to be especially alert and attentive.

6.7.3 Colour rendering

For colour rendering, the hue angle of reproduced colour of the chart patches on the monitor shall satisfy the following requirements. The colour coordinates are described based in the CIE 1976 uniform colour space:

— red colour coordinates shall not exceed the range of [0 °, 44,8 °] or [332,2 °, 360 °];

— green colour coordinates shall not exceed the range of [96,6 °, 179,9 °];

— blue colour coordinates shall not exceed the range of [209,9 °, 302,2 °];

— yellow colour coordinates shall not exceed the range of [44,8 °, 96,6 °];

— to keep distinguishability from white, define distance from white as $R_i \geqq 0{,}02$, where R_i is the chromatic distance of each colour patch (i = red, green, blue, yellow), relative to white (i = white).

Figure 21 shows an illustrative tolerance range described on CIE 1976 uniform colour space.

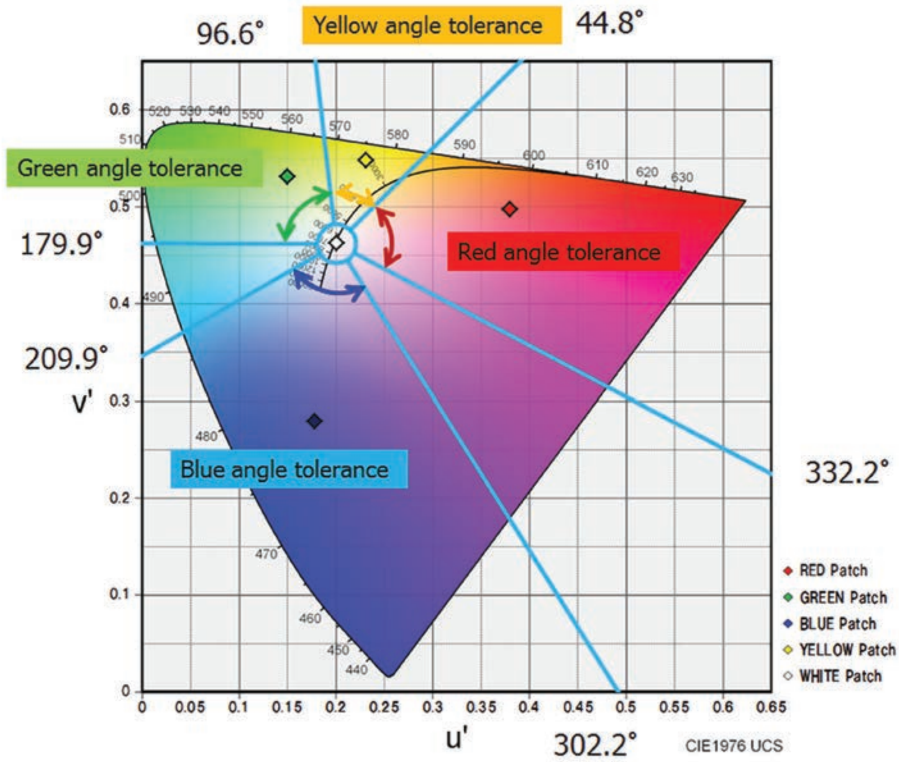


Figure 21 — Tolerance of colour deviation on the CIE 1976 UCS chromaticity diagram

For colour rendering of vehicle signal lamps, the amber lamps should be recognizable as amber, blue lamps as blue, red lamps as red.

6.7.4 Artefacts

The operator's manual shall refer to possible artefacts and their result of partial occlusion of the field of view and of the objects which may require the driver to be especially alert and attentive.

6.7.4.1 Smear

Smear causes partial occlusion of the field of view and of the objects. Smear shall not be more than 50 % of the maximum luminance value of the image.

6.7.4.2 Blooming and lens flare

Blooming and lens flare cause partial occlusion of the field of view and of the objects. Blooming and lens flare artefacts shall not cover more than 25 % of the displayed image (see test method 4.1 in 7.8.2).

RATIONALE: UN REGULATION NO. 46 currently defines 15 % for mirrors of class V and VI. However, the test method only covers blooming artefacts and is not clearly defined.

6.7.4.3 Point light sources

For safety reasons point light sources (e.g. low beam headlights) should be rendered as point light sources and be distinguishable.

6.7.4.4 Colour noise

Annoying colour noise should be avoided under night condition.

6.7.4.5 Chromatic aberration

Annoying chromatic aberration should be minimized.

6.7.5 Sharpness and depth of field

6.7.5.1 Sharpness

Sharper images enable faster perception of the content shown in an image. The sharpness is represented by the $MTF50_{(1:1)}$ as described in 3.18 and it shall satisfy

— horizontal and vertical $MTF50_{(1:1)}$ at centre

$$MTF50_{(1:1)} \geq \frac{1}{2} MTF10_{MIN(1:1)} \text{ [LW/PH]} \tag{33}$$

— horizontal and vertical $MTF50_{(1:1)}$ at corners (70 % of image height)

$$MTF50_{(1:1)} \geq \frac{1}{2}\left(\frac{1}{2} MTF10_{MIN(1:1)}\right) \text{[LW/PH]} \tag{34}$$

with $MTF10_{MIN(1:1)}$ as defined in 3.16 and 3.17 and $MTF50_{MIN(1:1)}$ as defined in 3.18, both assuming an aspect ratio of 1:1.

6.7.5.2 Depth of field

The CMS shall enable the driver to observe the object space and perceive the content shown within the range of interest with enough resolution to discern the details. The $MTF10_{(1:1)}$, when measured at different distances to the object, shall satisfy at least the minimum resolution for the following points:

— resolution at point 1 (10 m as representative point for infinity) and point 2 (middle distance at 6 m)

$$MTF10_{(1:1)} \geq 0{,}9 * MTF10_{MIN(1:1)} \text{ [LW/PH]} \tag{35}$$

— resolution at point 3 (close distance at 4 m)

$$MTF10_{(1:1)} \geq \frac{1}{2} MTF10_{MIN(1:1)} \text{ [LW/PH]} \tag{36}$$

RATIONALE: The main focus of the depth of field evaluation is to measure the CMS capability to recognize objects at any distance within the required field of view. As objects at nearer distances are displayed larger, the requirement at those distances can be reduced.

6.7.6 Geometric distortion

The distortion of the image relative to the rectilinear projection on the monitor should be minimized.

6.7.7 Further image quality requirements

6.7.7.1 Pixel faults

The monitor should be in the fault class, ClassPixel 0. In case of an occurrence of pixel or sub pixel faults that can severely affect the usage of the CMS, the operators manual should advise the driver to repair or replace the system.

6.7.7.2 Flicker

The entire image area of the monitor should be free of flicker for at least 90 % of the user population.

6.7.7.3 Visual artefacts

The entire image area of the monitor should be free of other visual artefacts to enable the user to perform the task in an effective and efficient way (see ISO 9241-307:2008, 5.3, Table 64).

6.7.7.4 Gloss of the monitor housing

The monitor housing should have a surface that avoids glare and distraction due to reflection of sunlight in the monitor housing. The gloss value of the monitor housing should not exceed 10 gloss units, when measured in a 60 ° measurement geometry according to ISO 2813.

6.8 Time behaviour

6.8.1 Frame rate

Movements of objects in front of the camera shall be rendered smooth and not jerky. The minimum frame rate of the system (update rate of the image information) shall be at least 30 Hz. At low light conditions or while manoeuvring at low speed, the minimum frame rate of the system (i.e. update rate of the image information) can drop (e.g. due to longer exposure times or image processing) but shall be at least 15 Hz.

6.8.2 Image formation time

The image formation time of the monitor should be less than 55 ms at room temperature 22 °C ± 5 °C.

6.8.3 System latency

A CMS shall have a sufficient short latency in order to render the scenery nearly at the same time. The latency shall be lower than 200 ms at room temperature 22 °C ± 5 °C.

6.9 Failure behaviour

In case of a CMS failure, it shall be recognizable to the driver until the CMS performs a successful self-test. The operator's manual shall inform how a failure is indicated and should provide instructions for the provisional remedies if available for the indicated failure, as well as necessary instructions until the system is repaired.

For any additional functional safety requirements refer to Clause 8.

6.10 Quality and further ergonomic requirements

For quality and further ergonomic requirements refer to the national body (e.g. UN REGULATION NO. 46, chapters 15.1.2 and 15.1.3).

6.10.1 Needs of older persons

6.10.1.1 Decreasing accommodation

In order to fulfil the visual task in an effective and efficient way the displayed scene on the monitor should be observable as sharp. Depending on the age of the driver, this can require

— the use of bifocal or multifocal (i.e. progressive) lenses or contact lenses, or

— installation of the monitor at an suitable distance.

The installation of the monitor inside the vehicle should follow the needs of the intended user group. The operator's manual shall give advice about the decreasing accommodation capacity of the human being and shall recommend suitable aids according to the user needs.

6.10.1.2 Glare due to high luminance of the monitor

In order to avoid glare due to high luminance of the monitor the luminance shall be dimmable under night condition either manually or automatically. The maximum luminance under night condition should not exceed 20 cd/m^2.

6.11 Influences from weather and environment

The following weather and environment influences should be considered:

— Rain, snow, sun, fog, etc.

— The soiling conditions at the position for the camera onto the vehicle should be taken into account.

— The air flow at the housing and corners of the CMS should be analysed in order to minimize sedimentation onto e.g. the lens of the camera. The housing and corners of the CMS should be designed accordingly.

— In order to maintain a clear view, the CMS and in particular the camera in the outer area as well as the monitor in the interior area of the vehicle should be cleaned regularly if necessary. The operators manual shall give cleaning instructions and relevant safety instructions.

7 Test methods

7.1 System documentation

Verify that the necessary technical specification and operators manual for the required tests exists.

7.2 Intended use

Verify that the intended use is defined in the operator's manual.

7.2.1 Default view

Verify that the CMS has a default view. If not stated otherwise all test procedures in Clause 7 refer to the default view. Verify that the minimum requirements as defined in Clause 6, in particular, the minimum required field of view (see 6.4), the average and minimum magnification factor (see 6.5.1 and 6.5.2), and the resolution (see 6.5.3) are fulfilled in the default view.

7.2.2 Adjusted default view

Verification is not required.

7.2.3 Temporary modified view

In case a temporary modification of the intended field of view and/or magnification factor is admissible in certain driving situations (e.g. driving backward in a parking lot), verify that the temporary modification is indicated in an ergonomically appropriate way and the operators manual gives advice on the temporal modifications.

7.2.4 Luminance and contrast adjustment

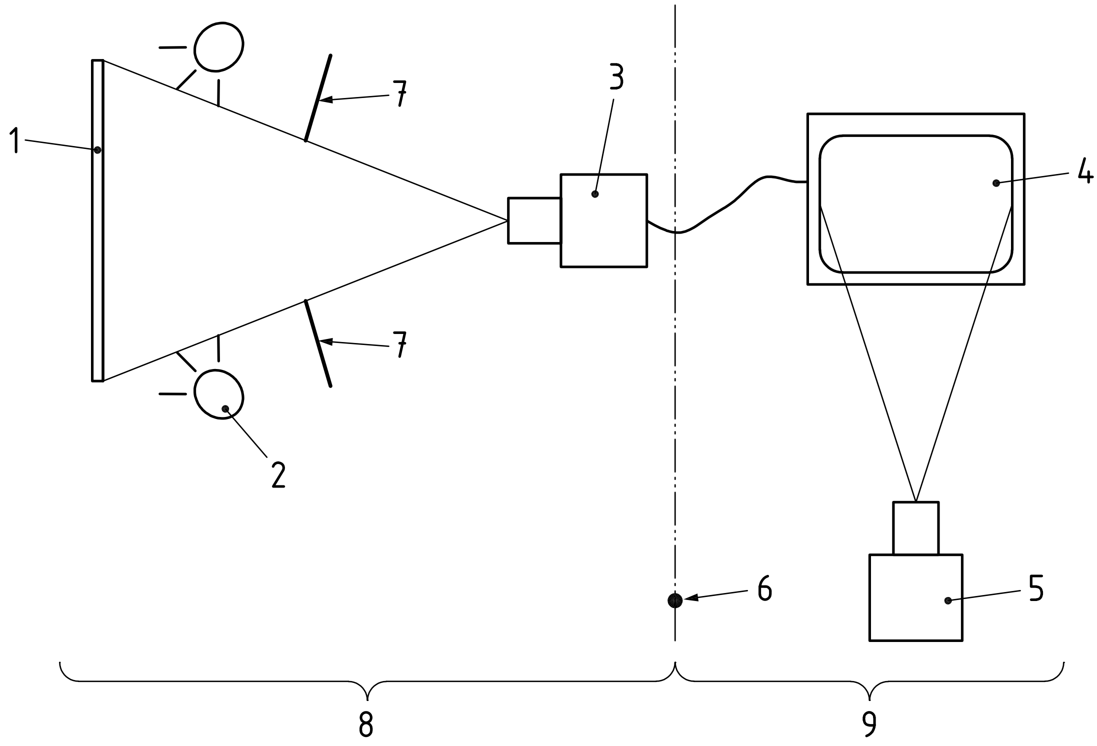
Verify that changing the CMS luminance is possible manually or automatically. Verify that the operator's manual gives advice on how the luminance and contrast settings are changed.

7.2.5 Overlays

Verify by visual inspection that overlays which are displayed within the required field of view as defined in 6.4 are temporal and transparent (not opaque).

7.3 Operating readiness (system availability)

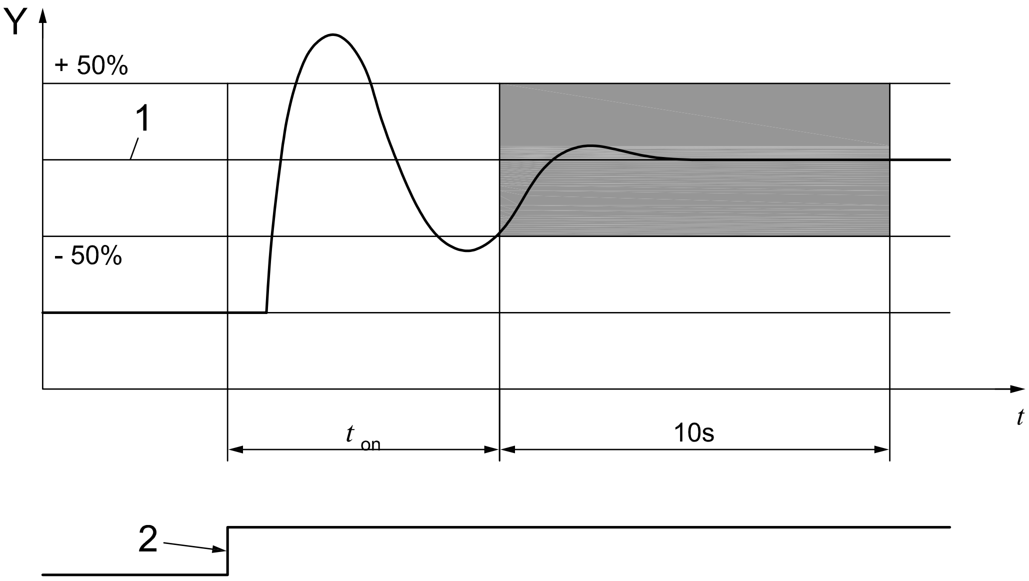
Verify that the CMS is fully operational within a maximum start up time t_{ON} as defined in 6.3 after the system is powered on for a standard laboratory environment at 22 °C ± 5 °C. The start point of the full operational state is defined as the time point where the variations of a monitor reference signal of the CMS looking at a still scene (e.g. chessboard chart) remain within a ±50 % range for at least 10 further seconds with a clear visible image (see Figure 23). The test setup for the CMS is shown in Figure 22. The test is performed with a scene illumination of 10 000 lux (bright scene) and 2 lux (dark scene). The reference signal may be generated by measuring the time resolved luminance value Y or equivalent of the CMS output image on the monitor using a reference camera, optical transient recorder or may be taken from the system (e. g. auto exposure state, mean grey value of the monitor image, etc.).



Key

1 test chart (e.g. chessboard chart), aligned perpendicular to optical axis
2 illumination for test chart
3 camera
4 monitor
5 reference camera, digital photometer, or optical transient recorder
6 optical or spatial isolation between camera and monitor lightning environment
7 optical isolation barrier to avoid direct light into lens
8 camera-side
9 monitor-side

Figure 22 — Measuring setup for system availability



Key

1 stationary state signal level

2 power ON point in time

Figure 23 — Definition of the startup-time t_{ON}

7.4 Field of view

Verify that the technical specification for the CMS contains the camera field of view and the percentage of the camera field of view displayed on the monitor (see 3.4.26 and 3.4.27).

Verify that the system field of view of the CMS following the definition in 3.5.4 covers the field of view at least that is required by the national body for conventional mirrors of the same class. Verification (e.g. by using CAD) should include the opening horizontal and vertical angles and camera orientation.

7.5 Magnification and resolution

7.5.1 Average magnification factor

Verify that the CMS technical specification contains the monitor design viewing angle ($\Theta_{monitor/D}$, $\Phi_{monitor/D}$ or $\theta_{monitor/hor/D}$, $\theta_{monitor/ver/D}$, see 3.4.11, 3.4.12, 3.4.13, and 3.4.14), the monitor design viewing distance ($a_{monitor/D}$, see 3.4.10), the size of the monitor's defined size ($W_{monitor/hor}$, $H_{monitor/ver}$ see 3.4.17 and 3.4.18), the camera's field of view ($\alpha_{camera/hor}$, $\alpha_{camera/ver}$, see 3.3.15 and 3.3.16) and the camera's percent field of view as displayed on the monitor (3.4.26 and 3.4.27).

7.5.1.1 Average magnification factor (driver side)

Verify that the average magnification factor of the CMS calculated according to Formulae (13) and (14) given in 3.5.9 and 3.5.10 in both horizontal and vertical direction, is not lower than the average magnification factor of a mirror on driver side given in 3.2.23.

7.5.1.2 Average magnification factor (passenger side)

Verify that the average magnification factor of the CMS calculated according to Formulae (13) and (14) given in 3.5.9 and 3.5.10 in both horizontal and vertical direction, is not lower than the average magnification factor of a mirror on passenger side given in 3.2.24.

7.5.2 Minimum magnification factor

The following measurement procedure applies:

a) Position the camera of the CMS such that its optical axis is aligned to the perpendicular orientation of a chessboard chart (e.g. as shown in Figure 24). Target the CMS camera to capture the chart within the monitor defined size with at least 20 visible squares in horizontal or vertical direction. The rotation of the chessboard chart shall be such that the horizontal lines of the chessboard appear as horizontal lines on the monitor.

b) Measure the distance of the individual square edges of the chessboard chart from one outermost displayed edge to the other outermost displayed edge along the image centre line (see example given in Figure 25).

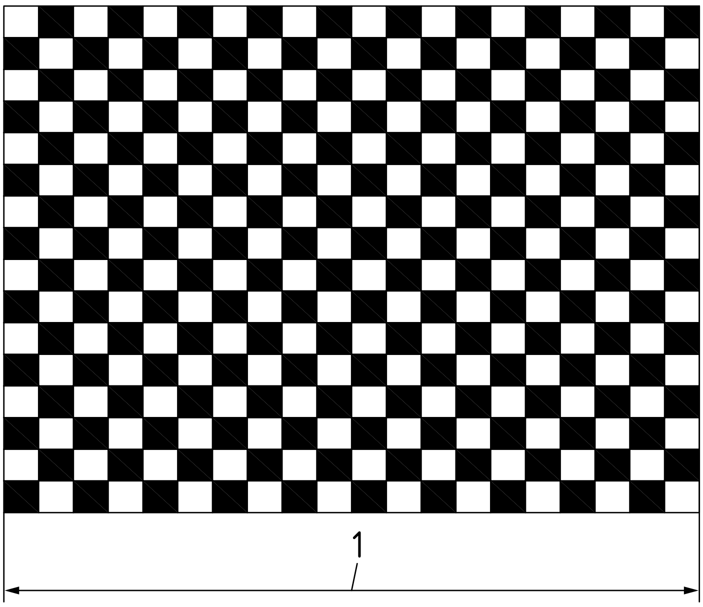
c) Plot the measured distance on the monitor versus the real distance on the chart. Then obtain a 3rd or 5th order polynomial curve fit of the plotted points. Then calculate the 1st differential function of the obtained polynomial curve fit (see example given in Figure 29).

   The derived function multiplied by $\frac{d}{a_{monitor/D}}$ gives the local magnification across the measured line, where d is the distance from the camera entrance pupil to the chart. Obtain the minimum magnification $M_{system/hor/min}$ as minimum of the function within the limits of the monitor defined size.

d) Repeat steps b) to d) for the image centre column to obtain $M_{system/ver/min}$.

NOTE For an ideal rectilinear projection the minimum magnification factor equals the average magnification factor.

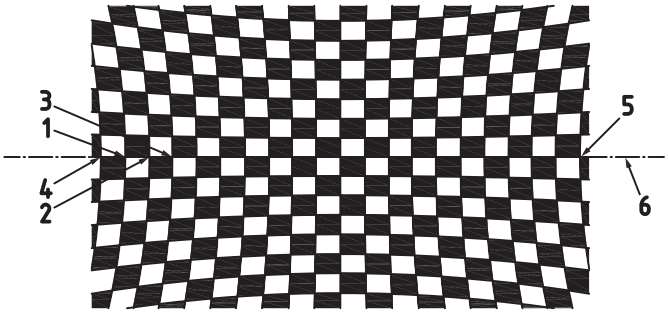
It is recommended to use the angular magnification as described in C.3 at least for wide-angle mirrors with radius of curvature $r_{mirror} \leq 400$ mm (e.g. UN REGULATION NO. 46 class IV mirrors) instead of the dimensional magnification verification given in this subclause.



Key

1 20 square box

Figure 24 — Example of a chessboard chart for magnification measurement



Key

1 point 1

2 point 2

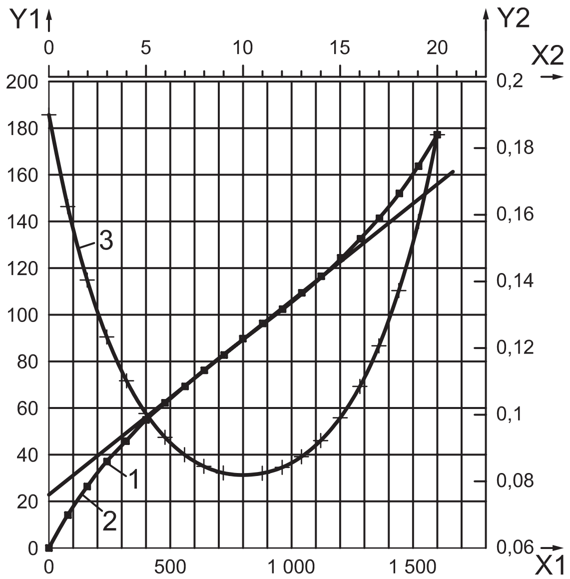
3 point 3

4 left outermost displayed edge

5 right outermost displayed edge

6 centre line

Figure 25 — Example of measuring points in horizontal direction on an image with pincushion distortion



Key

1 measured distance of the individual square edge

2 polynomial curve fit

3 local magnification

X1 original chart distance from relevance point (mm)

X2 number of chart square edge

Y1 position of the monitor output image (mm)

Y2 $\Delta W_{monitor}/\Delta W_{chart}$

Figure 26 — Example of a magnification measurement plot

7.5.2.1 Minimum magnification factor (driver side)

Verify by using a chessboard chart that the minimum magnification factor of the CMS inside the required field of view (see 6.4) is not lower than the required minimum magnification factor and the formula in 6.5.2.1 is fulfilled for both horizontal and vertical direction.

7.5.2.2 Minimum magnification factor (passenger side)

Verify by using a chessboard chart that the minimum magnification factor of the CMS inside the required field of view (see 6.4) is not lower than the required minimum magnification factor and the formula in 6.5.2.2 is fulfilled for both horizontal and vertical direction.

7.5.3 Resolution (MTF)

7.5.3.1 Horizontal resolution

1) Calculate $\mathrm{MTF10}_{\mathrm{MIN(1:1)/hor}}$ based on Formula (15).

2) Position the camera of the CMS such that its optical axis is aligned to the perpendicular orientation of a hyperbolic resolution chart (e.g. as shown in Figure 22 or Figure 27). Target the CMS camera to display the chart in the middle of the monitor defined horizontal size. The distance from the camera entrance pupil to the chart d shall be 6 m or less if the focal distance is lower than 6 m. The rotation of the hyperbolic resolution chart shall be such that the lines appear as vertical lines on the monitor. Ensure that there is no over- or underexposure to the image of the chart.

3) Measure the width of the nine lines at chart position 1 on the monitor $w'_{chart/hor}$ [see example shown in Figure D.1,key (h)] and determine the spatial frequency corresponding to chart position 1:

$$K_{hor} = \frac{W_{monitor/hor}}{w'_{chart/hor}} \cdot 9 \qquad (37)$$

This corresponds to the number of lines visible that fits within the monitor defined horizontal size $W_{monitor/hor}$ if the line pattern at chart position 1 would be repeated for the whole monitor defined horizontal size.

4) Calculate the frequency multiplication factor to find the required chart position, P_{hor}, to be checked for the MTF requirement.

$$P_{hor} = \frac{MTF10_{MIN(1:1)/hor}}{K_{hor}} \qquad (38)$$

This corresponds to the chart position where exactly $\mathrm{MTF10}_{\mathrm{MIN(1:1)/hor}}$ is reproduced within the monitor defined horizontal size $W_{monitor/hor}$. The frequency multiplication factor is indicated adjacent to the hyperbolic chart (see example in Figure D.1 with explanation for the number given at key (a). Some commercially available charts can contain the frequency values directly printed on the chart instead of this multiplication factor).

5) Verify that all lines can be observed and distinguished at the chart position P_{hor}. This ensures that the $\mathrm{MTF10}_{\mathrm{(1:1)/hor}}$ is at least equal or greater than the $\mathrm{MTF10}_{\mathrm{MIN(1:1)/hor}}$. In case the test fails, the countercheck defined in D.3 shall be used.

7.5.3.2 Vertical resolution

1) Calculate $\mathrm{MTF10}_{\mathrm{MIN(1:1)/ver}}$ based on Formula (16).

2) Position the camera of the CMS such that its optical axis is aligned to the perpendicular orientation of a hyperbolic resolution chart (e.g. as shown in Figure 22). Target the CMS camera to display the chart in the middle of the monitor defined vertical size. The distance from the camera entrance pupil to the chart d shall be 6 m or less if the focal distance is lower than 6 m. The rotation of the

hyperbolic resolution chart shall be such that the lines appear as horizontal lines on the monitor. Ensure that there is no over- or underexposure to the image of the chart.

3) Measure the height of the nine lines at chart position 1 on the monitor $h'_{chart/ver}$ [see example shown in Figure D.1, key (h)] and determine the spatial frequency corresponding to chart position 1:

$$K_{ver} = \frac{H_{monitor/ver}}{h'_{chart/ver}} \cdot 9 \qquad (39)$$

This corresponds to the number of lines visible within the monitor defined vertical size $H_{monitor/ver}$ if the line pattern at chart position 1 would be repeated for the whole monitor defined vertical size.

4) Calculate the frequency multiplication factor to find the required chart position, P_{ver}, to be checked for the MTF requirement.

$$P_{ver} = \frac{MTF10_{MIN(1:1)/ver}}{K_{ver}} \qquad (40)$$

This corresponds to the chart position where exactly $\mathrm{MTF10}_{\mathrm{MIN(1:1)/ver}}$ is reproduced within the monitor defined vertical size $H_{monitor/ver}$.

5) Verify that all lines can be observed and distinguished at the chart position P_{ver}. This ensures that the $\mathrm{MTF10}_{\mathrm{(1:1)/ver}}$ is at least equal or greater than the $\mathrm{MTF10}_{\mathrm{MIN(1:1)/ver}}$. In case the test fails, the countercheck defined in D.3 shall be used.

EXAMPLE Assuming an UN ECE class III CMS for driver side with x_{camera} = 0,5 m, y_{camera} = 0,15 m, and z_{camera} = 1.24 m resulting in $\alpha_{mirror/hor/\min} = 12{,}2°$

$$MTF10_{MIN(1:1)/hor} = M_{mirror/driver/avg} * \left(\frac{\alpha_{monitor/hor}}{\alpha_{mirror/hor/\min}}\right) * \alpha_{mirror/hor/\min} * V_{eye/\min} * 60\frac{\text{arcmin}}{°}$$

(41)

By inserting, the number of required observable lines within the monitor displayed horizontal field of view (assuming $\alpha_{monitor/hor} = 20°$) is calculated:

$$MTF10_{MIN(1:1)/hor} = 0{,}31 * \left(\frac{20°}{12{,}2°}\right) * 12{,}2° * 0{,}7\frac{1}{\text{arcmin}} * 60\frac{\text{arcmin}}{°} = 260{,}4$$

Assuming a monitor defined horizontal size of $W_{monitor/hor}$ = 0,2 m and a width of the nine lines at chart position 1 on the monitor of $w'_{chart/hor}$ = 0,031 m

$$K = \frac{W_{monitor/hor}}{w'_{chart/hor}} * 9 \qquad (42)$$

By inserting:

$$K = \frac{0{,}2m}{0{,}031m} * 9 = 58{,}07$$

$$P = \frac{MTF10_{MIN(1:1)/hor}}{K} \qquad (43)$$

By inserting:

$$P = \frac{260{,}4}{58{,}07} = 4{,}5$$

Thus, verification is needed that all lines can be observed and distinguished at the chart position 3.5.

7.5.3.3 Resolution at corners

1) Repeat the measurements for horizontal and vertical resolution at the corner measurement points at 70 % of the monitor defined horizontal and vertical size (see Figure 20).

2) Verify that the corresponding requirement is fulfilled (half of the $MTF10_{MIN(1:1)}$ resolution is required in the corners).

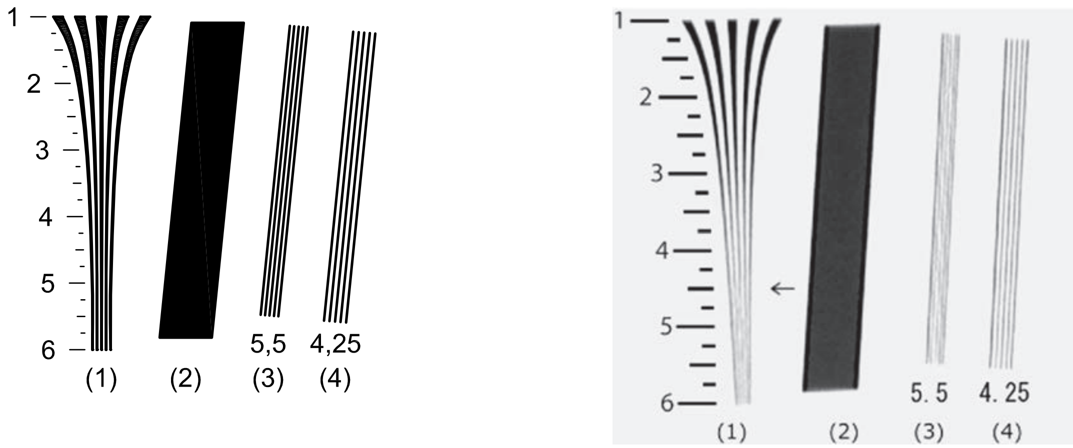


Figure 27 — Example of an original (left) and captured resolution chart (right)

7.6 Magnification aspect ratio

The difference between the average magnification factor for horizontal and vertical direction of a CMS shall be calculated as:

$$1-\frac{M_{system/hor/avg}}{M_{system/ver/avg}} \tag{44}$$

Alternatively, it is measured using a chessboard chart. The corner points of the chessboard squares should be geometrically measured over the monitor screen and the ratio of the horizontal pitch to the vertical of the chessboard individual square corners pitch gives the local magnification aspect ratio. The average ratio shall satisfy the criteria given in 6.6.

For the magnification aspect ratio measurement, the chessboard chart measurement may be evaluated by observation in the perpendicular orientation to the monitor. The measured horizontal and vertical magnification factor from the monitor perpendicular direction shall be multiplied by $\cos(\theta_{monitor/hor/D})$, $\cos(\theta_{monitor/ver/D})$ respectively, as the corrective factor when monitor is actually viewed from the design viewing direction $\theta_{monitor/hor/D}$ and $\theta_{monitor/ver/D}$ (see 3.4.13 and 3.4.14).

7.7 Monitor integration inside the vehicle

The following verifications according to the list in 6.7 shall be considered:

a) Verify that the obstruction of the view onto the mandatory field of vision on the monitor is kept to a minimum.

b) Verification is not required.

c) Verification is not required.

d) Verify by visual examination that the image of the right side FOV is displayed on the right side of the monitor arrangement, the image of the centre FOV is displayed in the intermediate region of the monitor arrangement and the image of the left side FOV is displayed on the left side of the monitor arrangement. If the CMS has only one display, verify by visual examination that non-continuous images are clearly separated from each other. For additional commercial vehicle verifications, see Annex A.

e) Verify (e.g. by using the vehicle construction data from a CAD tool) that the obstruction of the driver's direct view caused by the installation of the CMS is restricted to a minimum according to national regulation (e.g. UN Regulation No. 125).

f) If the monitor is adjustable in order to achieve a perpendicular viewing direction, verify that the adjustment is possible without any tool.

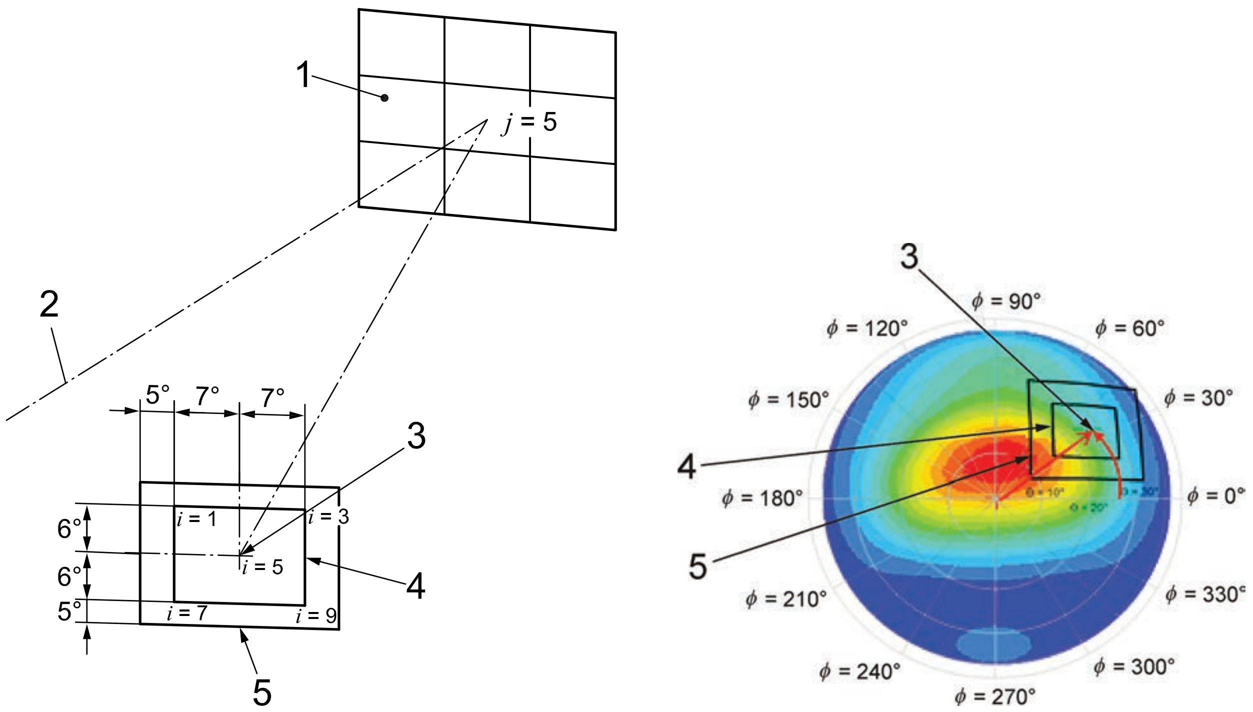
7.8 Image quality

7.8.1 Monitor isotropy

7.8.1.1 Directional uniformity

Measurements are made by using a goniometer or a conoscopic measurement system or equivalent. The measurement shall ensure that the luminance variation does not exceed the limits defined in 6.8.1.1. The monitor luminance dependency is measured for different measurement directions as described in Table 3 and Table 4. The measurement shall at least cover measurement directions from the monitor extended isotropy range.

The left part of Figure 28 describes the measuring range for the directional uniformity measurement, with measuring point located at the centre of the monitor, indicated as point j = 5. The colour plot given in the right part of Figure 28 is an example of a measurement result of an LCD monitor using a conoscope, in polar coordinates. The luminance level is plot depending on different orientation and angular range. The luminance level is colour coded, whereas colour red indicates high luminance levels and colour blue indicates low luminance levels. The small windows represents an example of the monitor standard isotropy range and monitor extended isotropy range for an assumed monitor design viewing direction of $\Theta_{monitor/D}$ = 25°, $\Phi_{monitor/D}$ = 38°.



Key

1 monitor

2 nominal line of monitor surface

3 monitor design viewing direction ($\Theta_{monitor/D}$, $\Phi_{monitor/D}$)

4 monitor standard isotropy range

5 monitor extended isotropy range

Figure 28 — Example of directional uniformity measurement

Table 3 — Measurement directions for standard isotropy range

Direction i	hor/ degree	ver/ degree
1	−7	+6
2	0	+6
3	+7	+6
4	−7	0
5	N/A	N/A
6	+7	0
7	−7	−6
8	0	−6
9	+7	−6

Table 4 — Measurement directions for the extended isotropy range

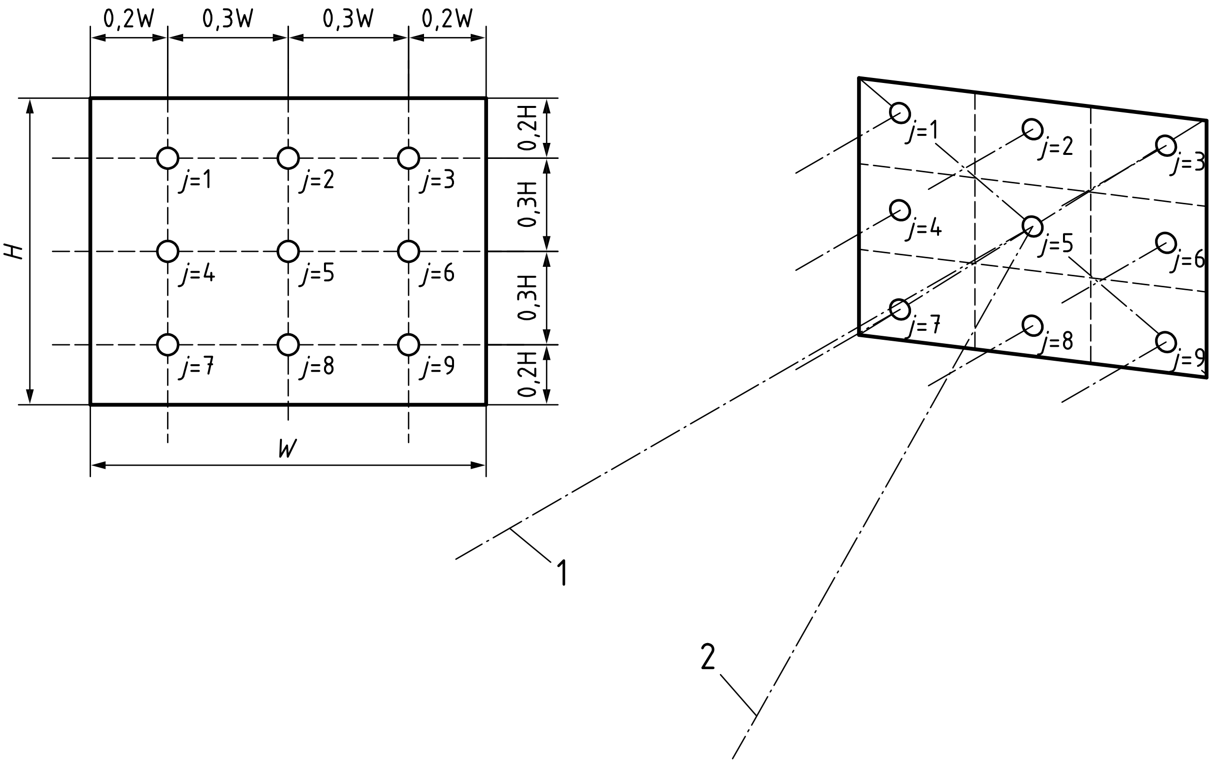
Direction i’	hor/ degree	ver/ degree
1	−12	+11
2	0	+11
3	+12	+11
4	−12	0
5	N/A	N/A
6	+12	0
7	−12	−11
8	0	−11
9	+12	−11

7.8.1.2 Lateral uniformity

Table 5 and Figure 29 describe the measuring points j = 1, 2, 3, 4, 5, 6, 7, 8, 9 and measuring orientation for the lateral uniformity measurement. The luminance of the monitor is measured for the perpendicular orientation to the monitor, that is, for orientation where ($\Theta_{monitor}$, $\Phi_{monitor}$) = (0 °,0 °).

Table 5 — Measurement points for the lateral uniformity

Point j	Percentage of $W_{monitor/hor}$ from top left corner	Percentage of $H_{monitor/ver}$ from top left corner
1	20	20
2	50	20
3	80	20
4	20	50
5	50	50
6	80	50
7	20	80
8	50	80
9	80	80



Key

1 normal line of monitor surface

2 monitor design viewing direction ($\Theta_{monitor/D}$, $\Phi_{monitor/D}$)

H $H_{monitor/ver}$

W $W_{monitor/hor}$

Figure 29 — Points for non-uniformity measurements on the monitor

7.8.2 Luminance and contrast rendering

— Check if the CMS has the possibility for manual or automatic adjustment of the luminance and report the result value.

— Check if the operators manual contain the required information on the influence of sunlight or light from other intense light sources upon the monitor concerning reduction of the luminance contrast which may require the driver to be especially alert and attentive.

This procedure consists of five tests in different ambient illumination conditions.

a) direct sunlight exposure (contrast perceptibility at the monitor with 45 klx illumination by a spot light source to the monitor);

b) day condition with diffuse sky-light exposure (contrast perceptibility at the monitor within the reflection of an extended diffuse light source of 1 500 cd/m^2 luminous density);

c) night condition (contrast rendering of a dark scene at max 2 lx illumination to the scene);

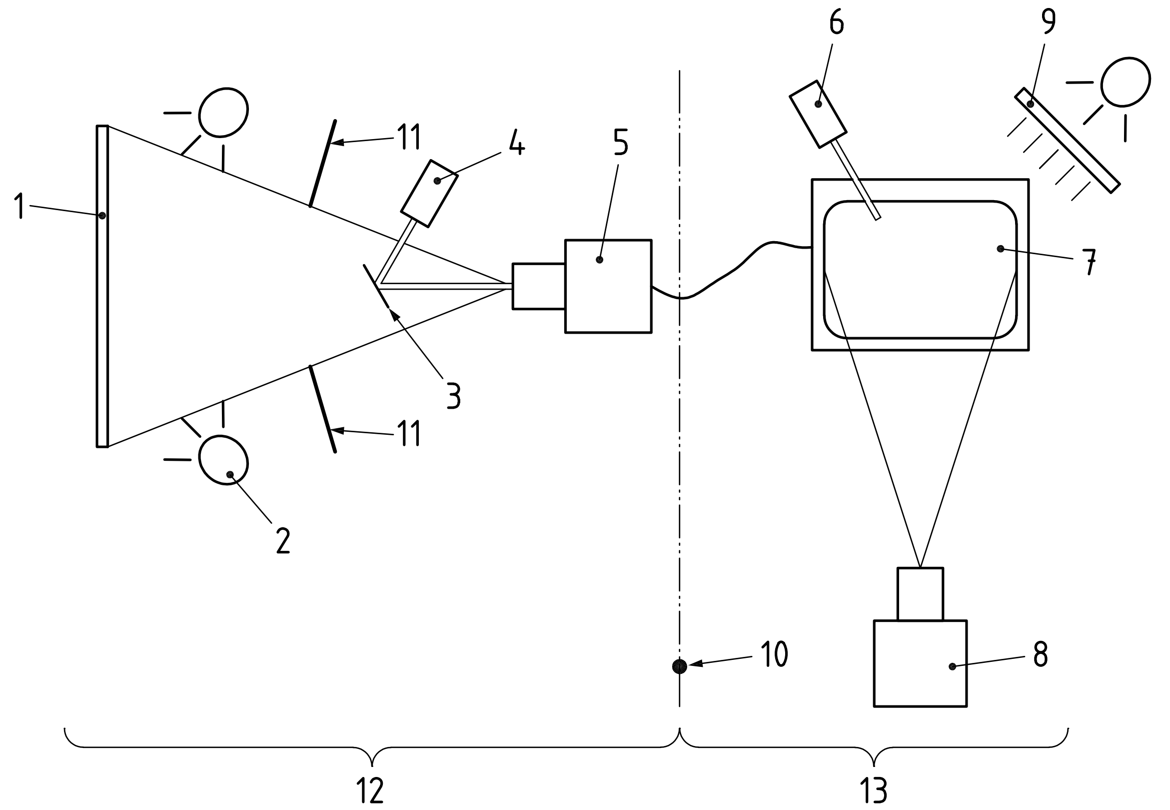
d) sunset condition, camera artefacts (image area that is affected by artefacts produced by a high-intensity glare light source shining on the camera lens);

e) sunset condition, camera contrast (contrast rendering with a high-intensity glare light source within the cameras field of view).

NOTE Using a reflective chart with a diffuse reflectance (ρ), the luminance (L) of the reflective chart can be estimated from the illuminance (E) onto the reflective chart by using Formula (45):

$$L = \frac{\rho \times E}{\pi} \tag{45}$$

A general overview of the test elements is shown in Figure 30. Note that not all equipment is needed for each test at the same time.



Key

1 test chart (contrast chart, black chart)
2 illumination for test chart
3 mirror
4 high-intensity glare light for camera evaluation (with oriented light beam)
5 camera under test
6 illumination for monitor under test
7 monitor under test
8 reference camera, digital photometer (e.g. area luminance photometer)
9 diffuse illuminator
10 optical or spatial isolation between camera and monitor lightning environment
11 optical isolation barrier to avoid direct light into camera lens
12 camera-side
13 monitor-side

Figure 30 — Test arrangement for luminance and contrast rendering

Parameters to specify the entire scene in the camera's field of view: A contrast chart with a balanced distribution of white and black parts (e.g. chessboard pattern with at least five alternating black and white squares in each direction) providing a luminance contrast $CR \geq 20$ at the point of measurement shall be used. Both reflective and transmissive charts (1) with a Lambertian characteristic can be used. If using reflective charts, the adjustment of the light source (2) can be arranged by measuring the illumination in lux at the chart or measuring the required luminance values in cd/m^2 with a reference camera or other luminance meter [same as (8) used for the monitor tests] at the position and orientation of the camera under test (5). Using a spherical transparency illuminator, the adjustment is arranged by measuring luminance values at the position and orientation of the camera under test (5).

If neither daylight nor sunlight are used, the illumination shall be similar to the CIE D65 standard illuminant and have a correlated colour temperature of T_C = 6 500 K with a tolerance of ±1 500 K or the illumination shall be similar to the CIE D55 standard illuminant and have a correlated colour temperature of T_C = 5 500 K with a tolerance of ±1 500 K. For night condition an illumination similar to the CIE A standard illuminant with a correlated colour temperature of T_C = 2 848 K with a tolerance of ±1 000 K may be used.

Test 1: Direct sunlight exposure onto the monitor

Setup: contrast chart (1), illumination for test chart (2), camera under test (5), illumination for monitor under test (6), monitor under test (7), and reference camera (8).

This test simulates direct sunlight shining through the windshield of a vehicle on the monitor. Therefore, the illumination for the monitor under test (6) shall be point like and produce a parallel and uniform incident light for the measuring point.

The luminance contrast ratio, *CR*, of the monitor shall be measured at the centre of the monitor defined size using a contrast chart. Brightness setting of the monitor shall be adjusted to maximum. The inclination angle of the reference camera on the monitor shall equal the monitor design viewing inclination angle $\Theta_{monitor/D}$. The inclination angle of the incident light source is $\Theta_S = \Theta_{monitor/D}+15\,°$ and lies in the measuring plane that is spanned by the monitor normal and the design viewing direction (see Figure 31). The contrast ratio is obtained by measuring the luminance of a white and black patch subsequently allocated to the measurement location (e.g. by inverting the patches only in the centre of the chart or moving the camera to point to a different patch) or equivalent. The final contrast ratio is calculated using Formula (46):

$$CR = \frac{L_{monitor/chart/white/ambient}}{L_{monitor/chart/black/ambient}} \qquad (46)$$

For flexibility, the luminance contrast may be calculated out of separate measurement of the emitted and reflected luminance. The luminance contrast is then calculated using Formula (47):

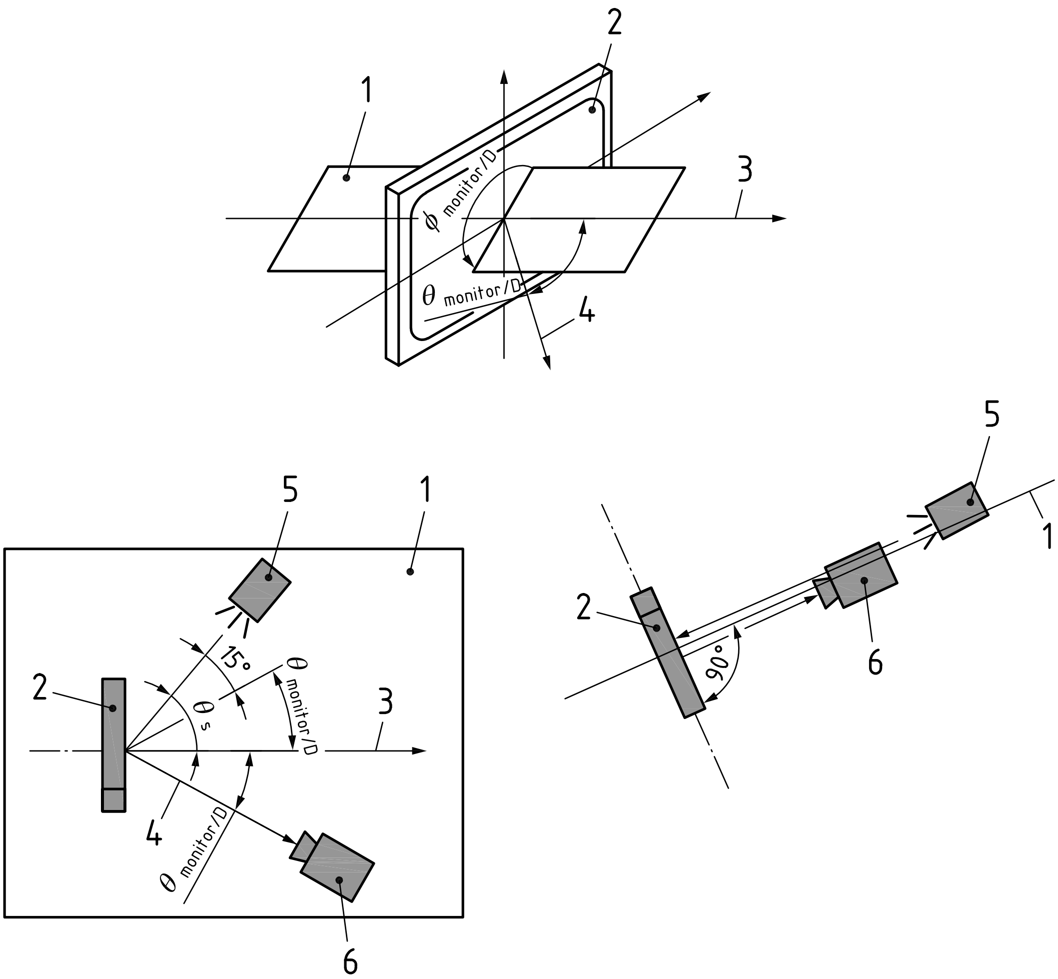
$$CR = \frac{L_{monitor/chart/white}\left(\Theta_{monitor/D},\Phi_{monitor/D}\right) + L_{r/white}\left(\Theta_{monitor/D},\Phi_{monitor/D}\right)}{L_{monitor/chart/black}\left(\Theta_{monitor/D},\Phi_{monitor/D}\right) + L_{r/black}\left(\Theta_{monitor/D},\Phi_{monitor/D}\right)} \qquad (47)$$

$L_{monitor/chart/white}$ and $L_{monitor/chart/black}$ are the emitted luminance values measured under darkroom conditions at the monitor. Depending on the displayed image, the reflected luminance might vary (e.g. due to different state of the liquid crystals of an LCD). The reflected luminance from high-intensity glare light is determined for each state (white, black patch of the chart displayed on the monitor) by the following procedure and Formulae (48) and (49):

$$L_{r/white} = L_{monitor/chart/white}\left(glare\,light\,switched\,on\right) - L_{monitor/chart/white}\left(glare\,light\,switched\,off\right)$$
(48)

$$L_{r/black} = L_{monitor/chart/black}\left(glare\,light\,switched\,on\right) - L_{monitor/chart/black}\left(glare\,light\,switched\,off\right)$$
(49)

NOTE The procedure follows the basic principle for determination of the reflected light as introduced in ISO 9241-305:2008, 6.1.2.



Key

1 measuring plane
2 monitor under test
3 monitor normal
4 design viewing direction
5 high-intensity glare light
6 reference camera

Figure 31 — Setup for direct sunlight exposure

NOTE 1 For an inclination angle of $\Theta_{monitor/D}$ = 30 ° and azimuth angle $\Phi_{monitor/D}$ = 0 °, this test is similar to ISO 15008-1/SAE, J1757 procedure 2B, section 4.1.2.4.

In the case where $\Theta_{monitor/D}$ = 0 °, θ_S shall be measured in a plane, where $\Phi_{monitor/D}$ = 0 ° and 180 °. The reading with the lowest contrast shall be used.

The test parameters for the camera and the monitor are summarized in Table 6.

Table 6 — Test parameters for the camera and the monitor for direct sunlight exposure

Test	Orientation	Property	Unit	Value	Comment
Test parameters "Direct sun-light exposure"	Camera side	$L_{chart/white}$	cd/m^2	400 to 800	Luminance white at contrast chart
		Contrast ratio chart		≥20	$L_{chart/white}$/ $L_{chart/black}$
	Monitor side	Ambient illumination range measured at monitor position	lx	40k to 50k	
		Inclination angle reference camera (8) to monitor normal	degree	$\Theta_{monitor/D}$	
		Inclination angle, Θ_S, light source (6) to monitor normal	degree	$\Theta_{monitor/D}$ + 15°	
Results to be reported	Monitor side	Measure the luminance contrast ratio of the test chart image on the monitor			Measure the luminance white and luminance black at the monitor and obtain the contrast ratio

Verify that the measured contrast ratio meets the requirement for direct sunlight condition.

Test 2: Day condition with diffuse sky-light exposure

Setup: contrast chart (1), illumination for test chart (2), camera under test (5), illumination for monitor under test (6), monitor under test (7), reference camera (8), and diffuse light source (9).

This test simulates diffuse skylight reflected on the monitor. Therefore, the illumination for the monitor under test (9) shall be extended and produce a uniform reflection within the field of measurement on the monitor surface.

Test setup and procedure is identical with Test 1 using the diffuse illumination instead of the point like light source. This may be reproduced by placing a transparent diffusor between point light source and monitor. The field of measurement shall be completely covered by the reflection of the diffusor from the reference cameras point of view and the diffusor shall at least cover a diameter of at least 15° measured from the measuring point of view (extended source according to ISO 9241-305). The required luminous density is measured at the diffusor/diffuse illuminator surface at an angle of 15°.

The luminance contrast ratio, CR, of the monitor shall be measured at a contrast step within the displayed image of the contrast chart. Measuring location shall be the near the centre of the display. Brightness setting of the monitor shall be adjusted to maximum. The measured contrast ratio is obtained using Formula (50):

$$CR = \frac{L_{monitor/chart/white/ambient}}{L_{monitor/chart/black/ambient}} \tag{50}$$

For flexibility, the luminance contrast may be calculated out of separate measurement of the emitted and reflected luminance. The luminance contrast is then calculated using Formula (51):

$$CR = \frac{L_{monitor/chart/white}\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right) + L_{r/white}\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right)}{L_{monitor/chart/black}\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right) + L_{r/black}\left(\Theta_{monitor/D}, \Phi_{monitor/D}\right)} \tag{51}$$

$L_{monitor/chart/white}$ and $L_{monitor/chart/black}$ are the emitted luminance values measured under darkroom conditions at the monitor. Depending on the displayed image, the reflected luminance might vary due to different state of the liquid crystals. The reflected luminance from high-intensity glare light is determined for each state (white, black patch of the chart displayed on the monitor) by the following procedure and Formulae (52) and (53):

$$L_{r/white} = L_{monitor/chart/white}\left(diffuseilluminationswitchedon\right) - L_{monitor/chart/white}\left(diffuse\,illumination\,switched\,off\right) \quad (52)$$

$$L_{r/black} = L_{monitor/chart/black}\left(diffuse\,illumination\,switched\,on\right) - L_{monitor/chart/black}\left(diffuse\,illumination\,switched\,off\right) \quad (53)$$

NOTE The procedure follows the basic principle for determination of the reflected light as introduced in ISO 9241-305:2008, 6.1.2.

The test parameters for the camera and the monitor are summarized in Table 7.

Table 7 — Test parameters for the camera and the monitor with diffuse sky-light exposure

Test	Orientation	Property	Unit	Value	Comment
Test parameters "Day condition with diffuse sky-light exposure"	Camera side	$L_{chart/white}$	cd/m^2	400 to 800	Luminance white at contrast chart
		Contrast ratio chart		≥20	$L_{chart/white}$/ $L_{chart/black}$
	Monitor side	Luminance diffuse illuminator	cd/m^2	1 300 to 1 500 cd/m^2	Luminance at the surface of the diffuse light source
		Inclination angle reference camera (8) to monitor normal	degree	$\Theta_{monitor/D}$	
		Inclination angle, Θ_S, light source (6) to monitor normal	degree	$\Theta_{monitor/D}$ + 15°	
Results to be reported	Monitor side	Measure the luminance contrast ratio of the test chart image on the monitor			Measure luminance white and luminance black at the monitor and obtain the contrast ratio

NOTE For an inclination angle of $\Theta_{monitor/D}$ = 30 ° and azimuth angle $\Phi_{\mathrm{monitor/D}}$ = 0 °, this test is similar to ISO 15008-1/SAE, J1757 procedure 2B, section 4.1.2.5.

Verify that the measured contrast ratio meets the requirement for day condition with diffuse ambient light.

Test 3: Night condition

Setup: contrast chart (1), illumination for test chart (2), camera under test (5), monitor under test (7), and reference camera (8).

This test simulates a camera scene at night condition where an illumination of 2 lx produces typical luminance values of 0.5 cd/m^2 to 0.7 cd/m^2. If available, the monitor automatic luminance adjustment should be enabled. Alternatively, if available, the standard setting for low light condition of the monitor manual luminance adjustment should be used.

The luminance contrast ratio, *CR*, of the monitor shall be measured. Viewing direction for the reference camera (8) shall be the design viewing direction on the monitor.

The test parameters for the camera and the monitor are summarized in Table 8.

Table 8 — Test parameters for the camera and the monitor for night condition

Test	Orientation	Property	Unit	Value	Comment
Test parameters “Night condition”	Camera side	$L_{chart/white}$	cd/m^2	0,5 to 0,7	Luminance white at contrast chart
		Contrast ratio chart		≥20	$L_{chart/white}$/ $L_{chart/black}$
	Monitor side	Ambient illumination range	lx	0 to 10	
Results to be reported	Monitor side	Measure the luminance contrast ratio of the test chart image on the monitor			Measure luminance white and luminance black at the monitor and obtain the contrast ratio
		Measure the background luminance	cd/m^2		Measure luminance black at the monitor

Verify that the measured contrast ratio meets the requirement for night condition.

Test 4: Sunset condition, camera artefacts

Setup: black test chart (1), mirror (3), high-intensity glare light source (4), camera under test (5), monitor under test (7), and reference camera (8).

This test simulates a camera scene where a high-intensity glare light source as e.g. the sun at the horizon produces artefacts in the camera image. Luminance setting of the monitor shall be adjusted to maximum.

The area affected by camera artefacts (blooming, flares, etc.) induced the high-intensity glare source shall be determined.

Test 4.1: Blooming and smear

The camera under test is directed at the high-intensity glare light source (4). Alternatively a mirror and an adjustable aperture can be used in order to fulfill the required extension of the glare source in the field of view. The background around the light source is dark (black test chart). The angle between the normal of the sensor plane of the camera and the line connecting the midpoint of the sensor and the light source shall be 10 °. The luminance values of the monitor shall be measured relative to the maximum value in the centrepoint of the glare source displayed on the monitor. Viewing direction for the reference camera (8) shall be the design viewing direction on the monitor. Monitor regions displaying camera artefacts as blooming, smear and flares will have higher luminance values than areas where only the dark background is displayed. The area of the monitor where the ratio of the maximum luminance to the actual monitor value falls below 2:1 is determined.

Test 4.2: Lens flares

The test shall be repeated for different incident angles of the light source to the sensor normal in order to identify a worst case scenario where a maximum amount of camera artefacts appear. The light source shall always be visible on the monitor in order to ensure stable conditions for camera exposure and gain settings. After the worst case scenario is determined, measure the signal output level on the monitor, and find (and segment) the area on the monitor image covered with the image where signal output level (luminance) with the flare is greater than the half of the glare induced maximum level. Calculate the percentage of the above affected area against the area of the whole CMS image on the monitor.

The test parameters for the camera and the monitor are summarized in Table 9.

Table 9 — Test parameters for the camera and the monitor for sunset condition, camera artefacts

Test	Orientation	Property	Unit	Value	Comment
Test parameters Camera artefacts	Camera side	Luminance black (background)	cd/m^2	<2	
		Glare source luminance (4)	cd/m^2	(5 to 10) Mio	Glare source can be the sun near the horizon
		Glare source angular size at the camera's point of view	arcmin	30 to 34	Glare source can be the sun near the horizon
	Monitor side	Ambient illumination range	lx	0 to 10	Dark room conditions, no direct reflections on the monitor
Results to be reported	monitor side	Measure the affected area by camera artefacts	Percentage of display area		Measure the signal output level on the monitor, and find (segment) the area on the monitor image covered with image where signal output level is greater than the half of the glare induced level (maximum level) and calculate the percentage of the affected area on the whole monitor area
		Smear intensity	Percentage of max. luminance		Measure the luminance of the visible smear

Verify that the measured artefacts area and the smear luminance intensity meet the requirements defined in 7.8.4.1 and 7.8.4.2.

Test 5: Sunset condition, camera contrast

Setup: Contrast chart (1), mirror (3), illumination for test chart (2), high-intensity glare light source (4), camera under test (5), monitor under test (7), and reference camera (8).

The luminance contrast of the monitor shall be measured of a scene that is showing a high-intensity glare light source.

The camera under test is directed at the contrast chart. The high-intensity glare light source (4) is placed within the field of view of the camera under test (5) as described in Test 4.1. Alternatively a mirror (3) can be used. Viewing direction for the reference camera (8) shall be the design viewing direction on the monitor. The luminance contrast of the contrast chart is measured in an area that is visibly unaffected by camera artefacts as determined in Test 4.1.

The test parameters for the camera and the monitor are summarized in Table 10.

Table 10 — Test parameters for the camera and the monitor for sunset condition, camera contrast

Test	Orientation	Property	Unit	Value	Comment
Test parameters Contrast with glare source	Camera side	$L_{chart/white}$	cd/m^2	200 to 400	
		Contrast ratio chart		≥20	$L_{chart/white}$/ $L_{chart/black}$
		Glare source luminance (4)	cd/m^2	(5 to 10) Mio	Glare source can be the sun near the horizon
		Glare source angular size at the camera point of view	arcmin	30 to 34	Glare source can be the sun near the horizon
	Monitor side	Ambient illumination range	lx	0 to 10	Dark room conditions, no direct reflections on the monitor
Results to be reported	Monitor side	Measure the luminance contrast ratio of the test chart image on the monitor			Measure luminance white and luminance black at the monitor and obtain the contrast ratio

Verify that the measured contrast ratio meets the requirement for sunset condition.

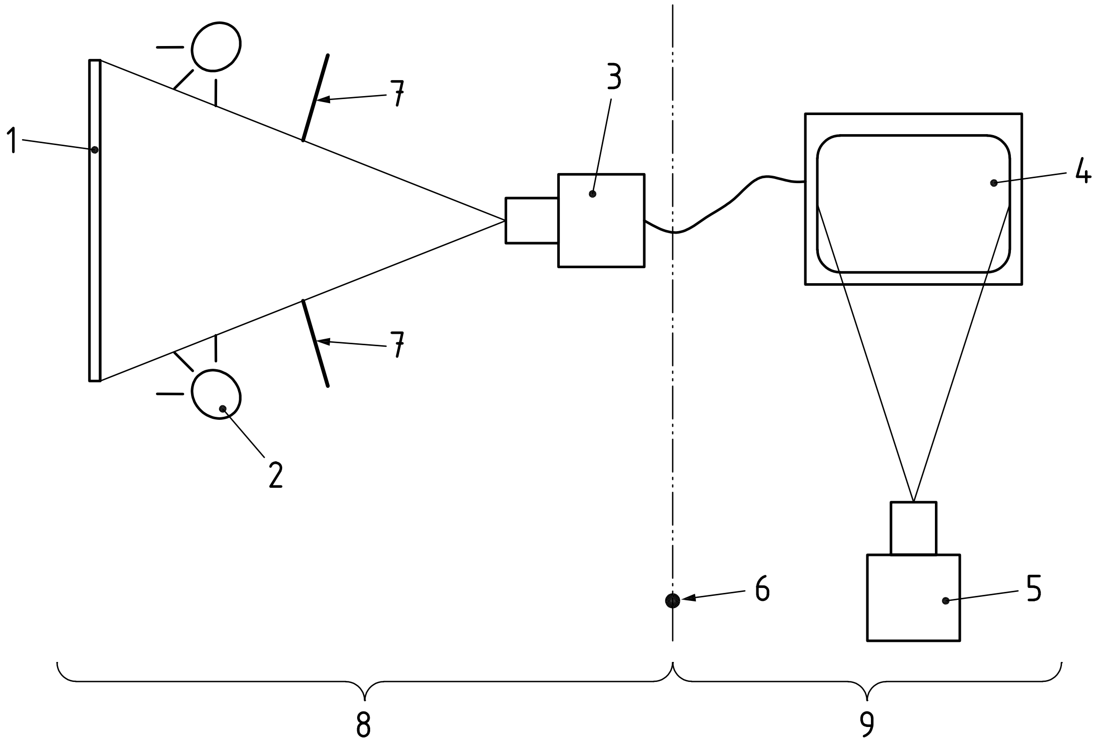
7.8.3 Colour rendering

Verify that the CMS is capable to reproduce colours as specified in 6.8.3.

The colours of chart reproduced on the CMS monitor, as well as the target chart patches, shall be measured and converted to colour coordinates based on CIE 1976 uniform colour space. The test arrangement for the colour rendering measurement is described in Figure 32.

— A spectroradiometer or colourimeter is used to measure the colour coordinates of the chart patches and reproduced colours on the monitor.

— The spot size of the spectroradiometer or colourimeter should be small enough to measure colour coordinates of each single patch or a two dimensional spectroradiometer or colourimeter capable to analyse each single patch colour precisely.



Key

1 test chart [eight colours (R, G, B, Ye, Cy, Mg, black, and white)]
2 illumination for test chart (D65), >500 lux
3 camera under test
4 monitor under test
5 spectroradiometer or colourimeter (measure u', v' values)
6 optical or spatial isolation between camera and monitor lightning environment
7 optical isolation barrier to avoid direct light into lens
8 camera-side
9 monitor-side

Figure 32 — Test arrangement of colour rendering

Figure 33 shows the colour chart used to measure the colour rendering.

Dimensions in millimetres

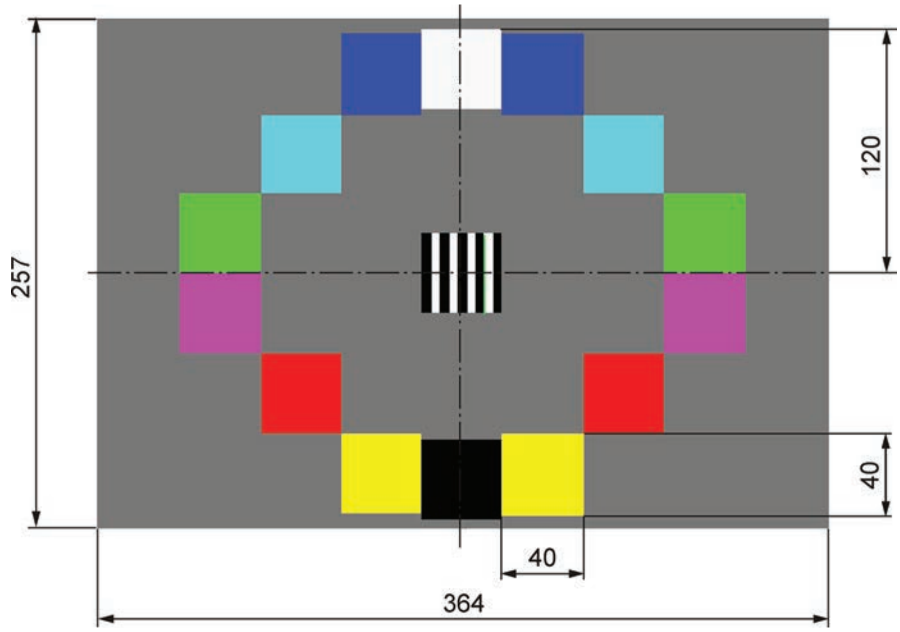


Figure 33 — Test chart for colour rendering

A test chart according to Figure 27 should be used. For flexibility of the measurement, the size of the colour patches and their location on the test chart might be different to take into account a uniform illumination of the test chart and the individual camera field of view of the CMS under test.

Use eight colours (R, G, B, Ye, Cy, Mg, black, and white) based on x-rite “ColorChecker” chart or equivalent. (The “ColorChecker” chart is the chart known as the former Macbeth ColourChecker, which was widely used in the photographic industry for colour managing application).

— The colour patches shall be arranged to keep an even distance from the image centre.

— The arrangement order shall have the complementary colour on the opposite side.

— The background of the patches should be covered with a neutral grey colour having a diffuse reflectance ρ of about 18 %.

— The positioning of the illumination 2 and the relative distance of CMS camera to the chart should be adjusted so that there are no direct reflective or direct incident light from the illumination 2 to camera objective.

— If neither daylight nor sunlight are used, the illumination shall be similar to the CIE D65 standard illuminant and have a correlated colour temperature of T_C = 6 500 K with a tolerance of ±1 500 K.

  These colour patches are known to be time deteriorating. It shall be properly renewed and avoid using an aged product or chart product that have been over exposed to sunlight or to UV light source as well.

— The whole camera image area should be covered by the chart image and avoid disturbance of adjustment due to unknown background image and/or illumination (e.g. measure under a stable automatic white balance adjustment).

— The measurement should be started once the camera finalizes the auto white balancing operation. If there remains any deviation of the neutral grey colour after the standard automatic white balance convergence operation, the deviation value should be reported aside the colour patches measurement, and any instability in the convergence point, if any, shall be reported alike. In general, due to the automatic white balancing characteristics of a camera system, CMS can exhibit some amount of deviation from the ideal white balance.

— If manual white balancing is applicable to the measurement, the camera should be pre-adjusted with a white neutral chart, prior to the colour rendering chart measurement.

— The test arrangement should be tested prior to the measurement and adjusted to keep an even illumination of the overall area of the chart under standard CIE D65 illuminant and any chromatic disturbance due to illumination effect should be eliminated from the measurement arrangement (e.g. unbalanced illumination, exterior incident light, reflected light from non-neutral surroundings).

Measure the colour coordinates of the patches of the target chart for i = R, G, B, Ye, and white using spectroradiometer or colourimeter, based on CIE 1976 uniform colour space, as coordinates (u', v'). Measure and report the original colour patch and the colour temperature of the illumination under which the chart colour patches are measured. The measured data of colour patches in itself is not directly used for any of the further calculation, but a record of data is advised as a way for confirming that the chart used and illumination are appropriate. Note that charts exposed to UV ray or aged colour charts suffer colour degradation and the chart measurement record helps to self-check the chart deterioration status.

Measure the reproduced colour patch portion for i = R, G, B, Ye, and white on the CMS output monitor, as $(u', v') = (u'_{it}, v'_{it})$ and $(u', v') = (u'_r, v'_r)$ for the reference white respectively. Then, calculate the relative chromatic hue angle of each colour patches, in reference to the referential white patch on the monitor and verify that hue angle satisfy the requirement described in 6.8.3 (an illustration of the requirement is shown in Figure 21). The chromatic hue angle of the reproduced patch on the output monitor is given by Formulae (54) to (57):

$$\theta_{icolor} = \arctan\left(\frac{v'_{it} - v'_r}{u'_{it} - u'_r}\right), \text{ for 1st quadrant where } (u'_{it} - u'_r) \geq 0 \text{ and } (v'_{it} - v'_r) \geq 0 \quad (54)$$

$$\theta_{icolor} = 180° + \arctan\left(\frac{v'_{it} - v'_r}{u'_{it} - u'_r}\right), \text{ for 2nd quadrant where } (u'_{it} - u'_r) < 0 \text{ and } (v'_{it} - v'_r) \geq 0 \quad (55)$$

$$\theta_{icolor} = 180° + \arctan\left(\frac{v'_{it} - v'_r}{u'_{it} - u'_r}\right), \text{ for 3rd quadrant where } (u'_{it} - u'_r) < 0 \text{ and } (v'_{it} - v'_r) < 0 \quad (56)$$

$$\theta_{icolor} = 360° + \arctan\left(\frac{v'_{it} - v'_r}{u'_{it} - u'_r}\right), \text{ for 4th quadrant where } (u'_{it} - u'_r) \geq 0 \text{ and } (v'_{it} - v'_r) < 0 \quad (57)$$

where u'_{it} and v'_{it} are the measured colour coordinates values of the target "i" colour patches (for i = R, G, B, Ye) of the chart on the monitor and (u'_r, v'_r) is the colour coordinates value of the reference "white" patch (or i = white) reproduced on the monitor.

NOTE Several engineering software provide a single trigonometric function to calculate all angular value for the four quadrants as a single function, given within the range from −180 ° to 180 °, making the definition expressed in a simple single formula, [e.g. atan2($u'_{it} - u'_r$, $v'_{it} - v'_r$)].

Verify that the reproduced colour patch on the monitor for i = R, G, B, Ye are distinguishable from the neutral white patch. To verify, measure the Euclidean distance for each of measured colour patch "i" from white patch (i = white) as:

$$R_i = \sqrt{(u'_{it} - u'_r)^2 + (v'_{it} - v'_r)^2} \quad (58)$$

The R_i shall be larger than the value defined in 6.8.3.

7.8.4 Artefacts

Check if the operators manual refers to possible artefacts and their result of partial occlusion of the field of view and of the objects which may require the driver to be especially alert and attentive.

7.8.4.1 Smear

Use the Test 4.1 defined in 7.8.2 and first check if there is any occurrence of smear effects. If any smear is observed, check that the luminance level caused by the smear is less than 50 % of the maximum luminance value of the displayed glare source luminance level, which is causing the smear effect.

7.8.4.2 Blooming and lens flare

Use the test methods 4.1 and 4.2 as defined in 7.8.2 to check if the blooming and lens flare requirements are fulfilled.

7.8.4.3 Point light sources

Verification is not required.

7.8.4.4 Colour noise

Verification is not required.

7.8.4.5 Chromatic aberration

Verification is not required.

7.8.5 Sharpness, resolution, and depth of field

7.8.5.1 Sharpness

The sharpness is expressed as the $MTF50_{(1:1)}$, as defined in 3.18. It may be measured by obtaining the spatial frequency response function SFR of a slanted edge chart, as defined by ISO 12233 or by using a hyperbolic resolution chart as presented in 7.5.3.

The typical sharpness shall be measured at the focal distance of the camera. The distance of the test chart from the camera entrance pupil to the chart d shall be 6 m or less if the focal distance is lower than 6 m.

The used chart, including the grey background/foreground, should be illuminated uniformly by a diffused light source, type D65.

A typical chart composed with five black squares to form the slanted edges for the spatial frequency response (SFR) measurement is shown in Figure 34. In case chart size is not sufficient to cover the complete field of view of the camera at the measuring distance please follow the instructions given in Annex F using a foreground masking chart.

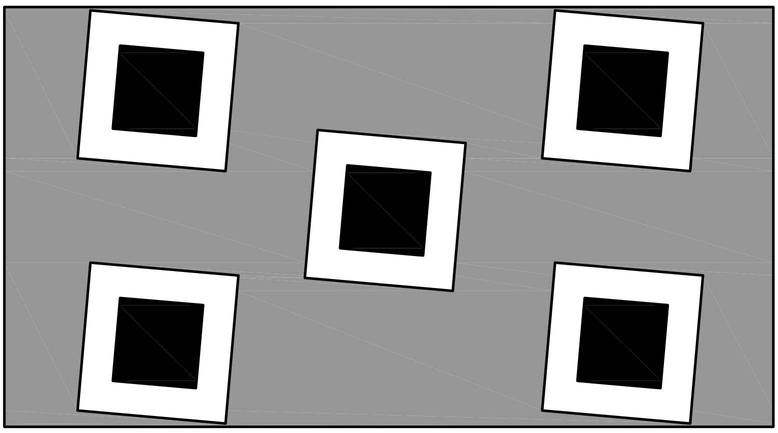


Figure 34 — Slanted edges composed by black squares

The instructions for the location of the measuring image height described below apply to the sharpness measurement and the depth of field measurement, whenever applicable. The centre black square and corner black square are representative points for the measurement of sharpness at centre and 70 % of image height. (Note that 100 % "image height" refer to maximum size of the image toward the diagonal size from the image centre). The 18 % grey level background is intended to keep the CMS auto exposure system adjusted to an appropriate level, avoiding underexpose or overexposure during the evaluation. The chart maximum luminance contrast shall not be more than 80:1. For the slanted edges analysis, a 60 % luminance modulation of the edge is recommended.

Most of the engineering software for SFR measurements consider that the output edge of these slanted edge are formed by a roughly 5 degrees rotated edge. If lens distortion causes the black square to be inappropriately rotated, the chart should be rotated accordingly to compensate the lens distortion and achieve an image output with edges of roughly 5 degrees rotation.

The SFR is calculated on an image that is taken by a reference camera on the monitor of the CMS displaying the test chart. The reference camera should take a partial close up image with at least four times pixels of the cropped image.

The measured $MTF50_{(1:1)}$ values should be reported in the following table.

Table 11 — Example for the sharpness report

Position	Centre	Left top	Left bottom	Right top	Right bottom
Hor. Sharp. [LW/PH]					
Ver. Sharp. [LW/PH]					

Step-by-step instruction:

1) Arrange the chart in the desired distance and verify that the monitor of the CMS displays the test pattern surrounded only by the 18 % grey field.

2) Capture the output image on the CMS monitor using a reference camera.

3) Perform the SFR measurement on the above capture image with an appropriate software tool (see ISO 12233), and obtain the spatial frequency value where the SFR curve response drops to 50 %. When the SFR measurement is not available, the hyperbolic resolution chart is used to directly verify the $MTF50_{(1:1)}$ spatial frequency point.

4) Perform the test on all required point and fill this value in the according Table 11.

For conversion of units, refer to D.3, D.4, or D.5

7.8.5.2 Depth of field

The depth of field measurement is required to ensure the capability of the CMS to observe and recognize details within the range of interest behind the vehicle. Thus, the resolution (MTF) of the CMS shall achieve necessary criteria to recognize objects at different distances.

The term "depth of field" used in this International Standard refers specifically to the range that the CMS can properly reproduce the image on the monitor according to the need of the CMS, and it does not coincide with the common term "depth of field" used in photographic industry.

The intention of this test is to detect changes within the range of the depth of field. Hence only differences in resolution are relevant to observe. For simplification the depth of field, it is assumed to be solely affected by the lens and sensor characteristics.

For verification of the requirements given in 6.8.5.2 follow the MTF test procedure given in 7.5.3 for the centre point with chart distance d equals 4 m, 6 m, and 10 m.

For CMS replacing wide-angle mirrors with radius of curvature $r_{mirror} \leq 400$ mm (e.g. UN REGULATION NO. 46 class IV mirrors), the measurement at 10 m may be omitted.

7.8.6 Geometric distortion

Verification is not required.

7.8.7 Further Image quality requirements

7.8.7.1 Pixel faults

Verification is not required.

7.8.7.2 Flicker

Verification is not required.

7.8.7.3 Visual artefacts

Verification is not required.

7.8.7.4 Gloss of the monitor housing

Verification is not required.

7.9 Time behaviour

7.9.1 Frame rate

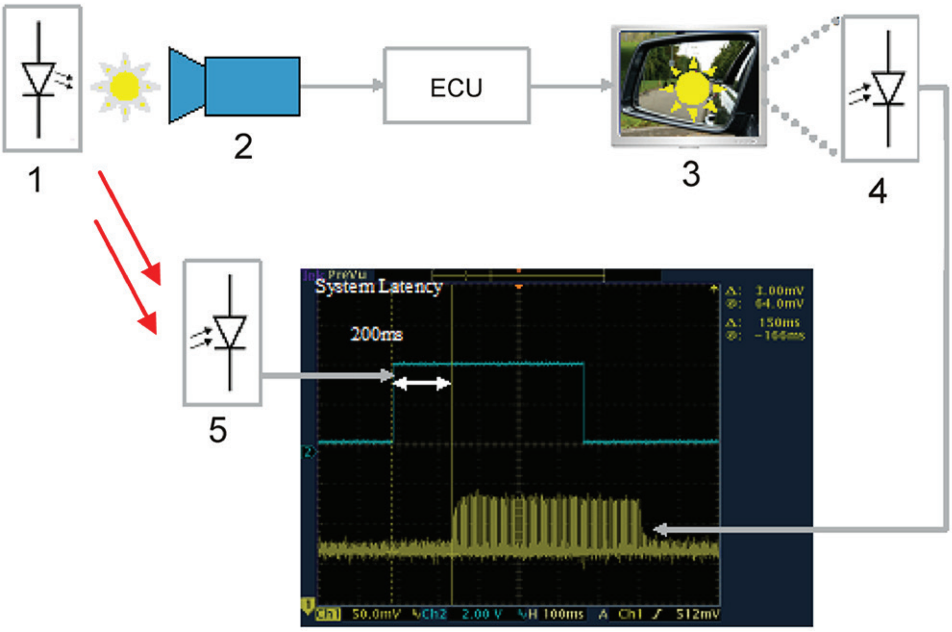
It needs to be ensured that the manufacturer of the CMS provides information on the frame rate of the system.

7.9.2 Image formation time

Verification is not required.

7.9.3 System latency

The system latency describes the latency of the complete CMS. The system latency t_{SL} is the time between a light flashes on in front of the camera until it is visible in the display (e.g $t_{SL} < 200$ ms). Figure 35 shows a setup for the measurement of the complete system latency independent of the technologically implementation of the CMS. The test area is a darkroom and the environmental temperature is room temperature 22 °C ± 5 °C.



Key

1 light source
2 camera
3 monitor
4 light intensity measurement device 1 at the monitor
5 light intensity measurement device 2 near the camera position

Figure 35 — Setup for the measurement of the complete system latency

The light source generates light within the visible spectrum and the light intensity measurement devices are sensitive within the visible spectrum.

For testing, a white LED can be used as a light source. The light intensity measurement device shall use a sensor that is approximately adapted to the human eye sensitivity V(λ). All (modern) 2-channel oscilloscopes with an analogues bandwidth of >100 MHz (digitizing rate > 0,5 GSamples/sec) are suitable.

The light intensity measurement at the camera captures the start of the light flash and is required in order to compensate the rise time of the light source. The light intensity measurement at the display is arranged in the centre of the display. Both light intensity measurement devices 1 and 2 are connected to a standard 2-channel digital sampling oscilloscope with *Delta-Time-Measurement-Modus*. The time difference of these signals is the system latency, t_{SL}. Figure 35 shows an example screenshot of such a measurement.

7.10 Failure behaviour

Verify whether examples of possible failures exist in the operator's manual. Verify that in case of failure of the CMS, the driver can recognize the system failure according to the examples in the operator's manual.

7.11 Quality and further ergonomic requirements

7.11.1 Needs of older persons

7.11.1.1 Decreasing accommodation

Verify that the operator's manual gives advice about the decreasing accommodation capacity of the human being and recommends suitable aids according to the user needs.

7.11.1.2 Glare due to high luminance of the monitor

Verify that the CMS is dimmable under night condition either manually or automatically.

7.12 Influences from weather and environment

Verify that the operator's manual gives suitable cleaning instructions and relevant safety instructions in order to maintain a clear view.

8 Functional safety

Camera Monitoring Systems covered by this International Standard have to be considered as safety-relevant systems because

a) their correct function is a necessary aid to the driver in various traffic situations, and failure to perform this function can therefore lead to accidents, and

b) misbehaviour of those systems can lead to irritation or distraction of the driver, in consequence leading him to cause an accident.

Therefore, application of the safety standards relevant to the application domain (e.g. ISO 26262) shall be considered.

Annex A
(normative)

Standard application on class II and IV mirrors in commercial vehicles

A.1 General

This Annex provides specific requirements for commercial vehicles when implementing CMS that replace UN REGULATION NO. 46 class II and IV mirrors. Rationales for these specific requirements are also provided.

A.2 Specific vision considerations for commercial vehicles

This subclause provides rationales why commercial vehicles sometimes need specific requirements compared to what can be valid for passenger cars.

The main reasons behind the need for specific requirements are:

— Indirect vision is much more important in commercial vehicles in relation to the direct vision. This is a consequence from significantly larger blind spots that result from a combination of lower portions of window surfaces and higher driver locations over the road surface.

— Commercial vehicles are usually more complex, heavier, and bigger than passenger cars. They are often also not as dynamic as passenger cars regarding what speeds and accelerations are achievable. Spatial orientation in relation to the surroundings (infrastructure and other road users) is therefore of additional importance.

— It is common that drivers switch between different vehicles with different direct and indirect viewing conditions.

— Class IV and main mirrors for the Japanese market have smaller radius than the other rearview mirrors covered by this International Standard. In actual usage, mirrors with smaller radii are rather used to notice objects than to get a detailed representation of surrounding objects.

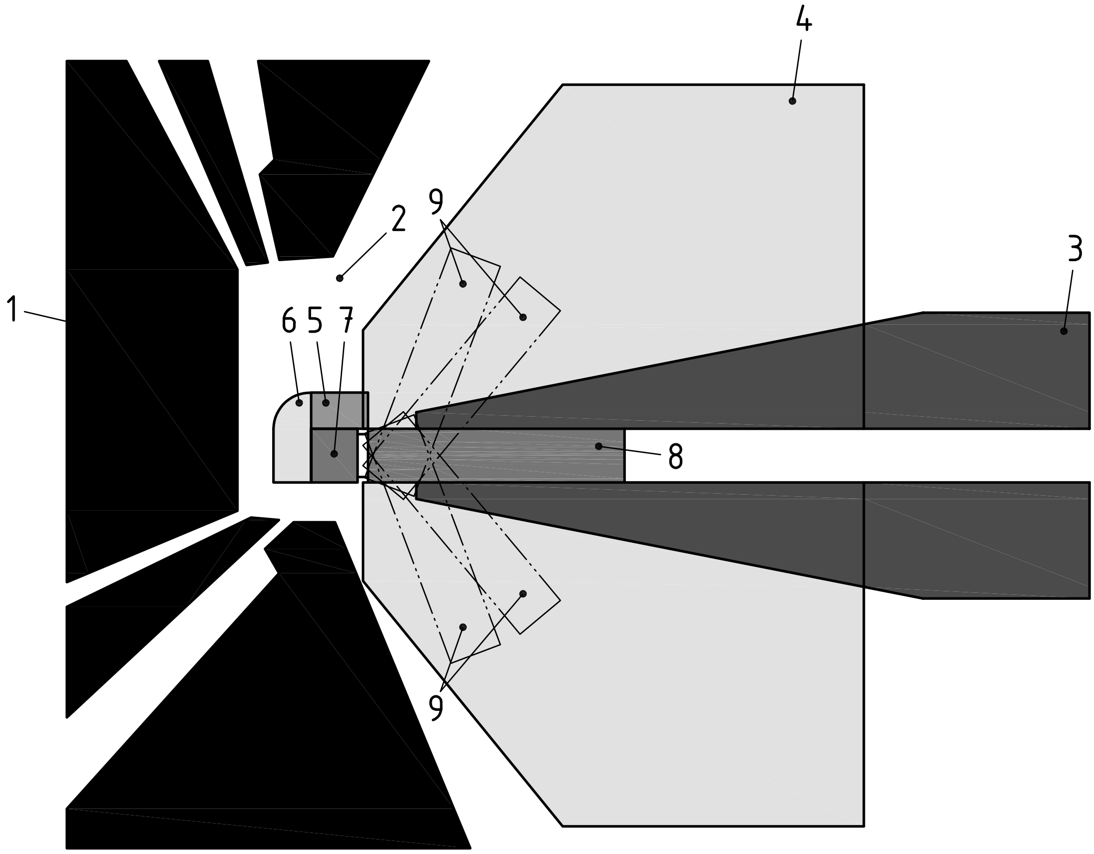
— The distinction between front-mounted and side-mounted mirrors is common in certain markets and for certain vehicle types that predominantly are equipped with one or the other installation concept. The different installation concepts provide different performance levels.

— The use cases for picking up people and/or goods often depend on the existing infrastructure of terminals and delivery locations. The provided vision should therefore be established based on the necessary driving behaviour to handle these specific use cases.

A.3 Requirements

A.3.1 Field of view

The complexity of vision in a truck and semitrailer combination is shown in Figure A.1. The ground level is covered by different means of vision, direct vision via window openings as well as indirect vision provided by different classes of mirrors. The direct vision to the rear is often blocked by the superstructure. In this case indirect vision is the only solution to provide the required fields of view. The fields of view for class II and class IV mirrors have an intersection set that is covered by both mirror classes. While driving a commercial vehicle, different folding angles between truck and trailer lead to panned areas of interest regarding indirect vision.



Key

1 examples of areas of direct vision
2 examples of areas of blind spots
3 regulated field of class II main mirrors
4 regulated field of class IV wide-angle mirrors
5 regulated field of class V close-up kerb-view mirror or camera
6 regulated field of class VI close-up front mirror or camera
7 cabin
8 trailer
9 trailer positions in special driving situations

Figure A.1 — Area on ground covered by different means of vision

A.3.1.1 Changed field of view for special driving situations

With traditional mirrors, these special driving situations are normally handled by additional head movements resulting in the panning of what can be seen via the rearview mirrors.

With a CMS, the changed fields of view should be achieved in other ways. 6.2.3 and 6.2.2 provide basic requirements for this. However, for commercial vehicles there are more use cases that need more detailed consideration regarding changed fields of view (see more information in Clause 5 and B.5). Based on the needs for specific vision considerations for commercial vehicles (according to A.2), it gets very important to provide these changed fields of view.

It is not possible to establish precise requirements that can be valid for all vehicle variants and combinations. The OEM has, therefore, to derive the minimum requirements from a thorough analysis of the intended vehicle variants or combinations. These requirements are there to secure that the CMS is performing at least as good as the traditional mirror system that it replaces. Grouping into categories of vehicle variants and combinations is allowed, where each category corresponds to a different level of requirements according to the bullet list below. Examples of such categories are provided in B.2.4.4.

Requirements describing the changed fields of view shall be established with consideration to the following aspects:

— The displayed fields of view should correspond to the result of an analysis of what is needed in the special driving situations for the vehicle combination and transport purpose that the changed fields of view are intended for (see B.2.4.2 and B.4.).

— The displayed fields of view sizes shall result from a thorough analysis of what changed fields of view are gained by head movements in corresponding vehicles with traditional mirrors. (See example in B.2.4.1 as well as specific input regarding panned fields of view in B.2.4.3.2.).

— In case of expanded fields of view by changed magnification: Changed fields of view shall be provided so that continuous lines remain continuous (see B.2.4.3.1.).

— The changed fields of view shall be temporary and shown for the adequate time-period according to the analysis of the special driving situation (see B.2.4.3.3.).

— If automatically activated, the changed field of view shall appear gradually in order not to distract the driver. If a non-gradual changed field of view is still proposed as beneficial, the benefit of providing it this way shall come from a thorough analysis of the specific driving situation when it is to be used (see B.2.4.3.4.).

— The functionality of the changed fields of view that the CMS provides shall be clearly and comprehensibly described within the operator's manual.

See B.2.4 that summons more details of the procedure to use when establishing these bulleted requirements, including an example for one category of vehicle combination.

A.3.1.2 Showing different fields of view in the same monitor

When implementing CMS replacements for more than one mirror class, it gets natural to show more than one field of view in the same display. However, in that case all images of the different fields of view shall be shown simultaneously.

As a development it can also be envisaged that one monitor is able to cover a combined view from more than one field of view. Still the minimum requirements outlined in this International Standard shall be met though. Redundant information can be avoided for the driver.

A.3.2 Monitor integration inside vehicle

In addition to the requirements provided in 6.7, the following requirements apply for commercial vehicles.

The image of the right side field of view shall be presented to the right of the longitudinal vertical plane through the ocular reference point. The image of the left side field of view shall be presented to the left of the longitudinal vertical plane through the ocular reference point.

RATIONALE: See A.2 specific vision considerations for commercial vehicles.

NOTE 1 A deviation from this arrangement can be allowed for specific vehicles used in typical driving conditions. This is, however, only allowed in case studies show significant advantages for these specific vehicle classes in the typical driving conditions.

NOTE 2 The fulfilment of the requirement will in unclear cases be based on a judgement where fulfilment is secured if the main portion of the monitor is fulfilling the requirement.

A.3.3 Magnification and resolution

A.3.3.1 Average magnification factor

The minimum requirements are given in 6.5.1 of the main standard text. These correspond to the replacement of front-mounted mirrors.

However, when replacing side-mounted mirrors, it is recommended that the corresponding average magnification factor is used. This is derived from applying the maximum a_{mirror} values found in the table provided in B.6.1. This subclause provides these magnification factor values. The calculation formulae are found in B.3.

A.3.3.1.1 Average magnification factor for side-mounted mirrors (driver side)

For UN REGULATION NO. 46 class II mirrors on the driver side, the value calculates to:

$M_{driver/avg/side}$ = 0,31 for side-mounted mirrors

And in the same way, for UN REGULATION NO. 46 class IV mirrors on the driver side, the value calculates to:

$M_{driver/avg/side}$ = 0,091 for side-mounted mirrors

A.3.3.1.2 Average magnification factor for side-mounted mirrors (passenger side)

For UN REGULATION NO. 46 class II mirrors on the passenger side, the value calculates to:

$M_{passenger/avg/side}$ = 0,16 for side-mounted mirrors

Similarly, for UN REGULATION NO. 46 class IV mirrors on the passenger side, the value calculates to:

$M_{passenger/avg/side}$ = 0,046 for side-mounted mirrors

A.3.3.2 Magnification factor variation

The magnification factor is allowed to vary under the following conditions:

— The average value of the varying magnification shall stay above the average required magnification as given in 6.5.1 and A.3.3.1.1 and A.3.3.1.2.

— The minimum value of the varying magnification factor of the system shall stay above the below values for each mirror replacement.

— Continuous lines shall be displayed as continuous.

— The variation should have an appearance of continuity to the driver, or otherwise be clearly shown (e.g. by a dotted line).

— The behaviour of the varying magnification within the required field of view should also be either constant or go from higher to lower values with increasing total viewing angles β.

For CMS replacing side-mounted mirrors, the definition for the mirror minimum magnification factor given in 3.2.26 and 3.2.27 shall be replaced by the following values:

Class II:

$M_{driver/min/side}$ = 0,28 for side-mounted mirrors

$M_{passenger/min/side}$ = 0,14 for side-mounted mirrors

Class IV:

$M_{driver/min/side}$ = 0,054 for side-mounted mirrors

$M_{passenger/min/side}$ = 0,016 for side-mounted mirrors

See B.6 for more information about varying and minimum magnification factors.

Annex B
(informative)

Formula applications, explanations, and guidelines

B.1 General

This Annex summons the formulas as well as explanations and guidelines to be used when establishing requirements for each of the UN REGULATION NO. 46 mirror classes covered by this International Standard or any other national regulation with similar mirror installations.

NOTE The software to calculate the magnification factor requirements is available at ISO website (http://standards.iso.org/iso/16505/).

B.2 Field of view (design guidelines)

This subclause is based on the field of view definitions found in 3.3.14, 3.3.15, and 3.3.16.

B.2.1 Minimum horizontal field of view

The subclause describes the minimum allowed value for $\alpha_{system/hor}$ as defined by the responsible national body. This is denoted as $\alpha_{mirror/hor/min}$ for the mirror to be replaced, and is measured in degree.

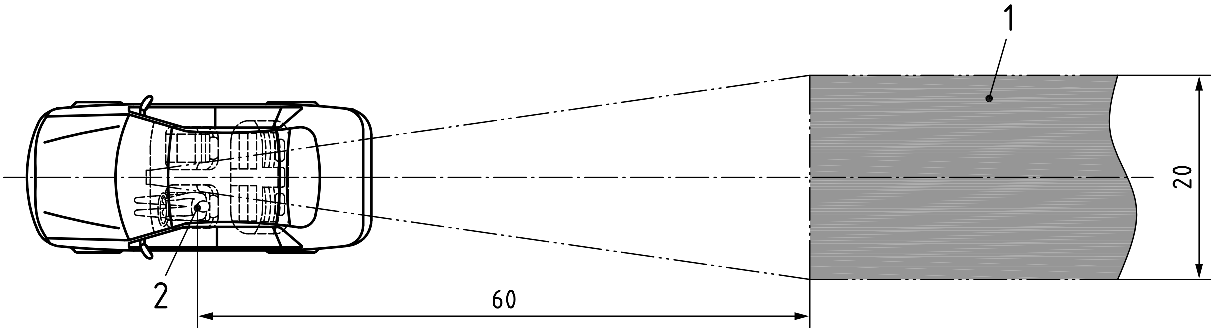
B.2.1.1 Minimum horizontal field of view for UN REGULATION NO. 46 class I mirrors

For class I UN REGULATION NO. 46 mirror replacements, this means:

$$\alpha_{system/hor} \geq \alpha_{mirror/hor/\min} \geq \arctan\left(\frac{\left(\frac{20}{2}\right)m - y'_{camera}}{\sqrt{\left(x_{camera} + 60m\right)^2 + z_{camera}^2}}\right) + \arctan\left(\frac{\left(\frac{20}{2}\right)m + y'_{camera}}{\sqrt{\left(x_{camera} + 60m\right)^2 + z_{camera}^2}}\right) \quad \text{(B.1)}$$

$$\alpha_{system/hor} = \alpha_{monitor/hor} = \alpha_{camera/hor} * p_{camera/hor} \quad \text{(B.2)}$$

Dimensions in metres



Key

1 ground level

2 drivers ocular point

Figure B.1 — Area on ground to be covered by class I mirrors

RATIONALE: The precise wording accompanying Figure B.1 in UN REGULATION NO. 46 states:

The field of vision shall be such that the driver can see at least a 20 m wide, flat, horizontal portion of the road centred on the vertical longitudinal median plane of the vehicle and extending from 60 m behind the driver's ocular points to the horizon.

B.2.1.2 Minimum horizontal field of view for UN REGULATION NO. 46 class II mirrors

For class II UN REGULATION NO. 46 mirror replacements on commercial vehicles, this means:

$$\alpha_{system/hor} \geq \alpha_{mirror/hor/\min} = \max\begin{bmatrix} \arctan\left(\dfrac{1m - y_{camera}}{\sqrt{\left(x_{camera}+4m\right)^2 + z_{camera}^2}}\right) + \arctan\left(\dfrac{y_{camera}}{\sqrt{\left(x_{camera}+4m\right)^2 + z_{camera}^2}}\right) \\ \arctan\left(\dfrac{5m - y_{camera}}{\sqrt{\left(x_{camera}+30m\right)^2 + z_{camera}^2}}\right) + \arctan\left(\dfrac{y_{camera}}{\sqrt{\left(x_{camera}+30m\right)^2 + z_{camera}^2}}\right) \end{bmatrix}$$

(B.3)

$$\alpha_{system/hor} = \alpha_{monitor/hor} = \alpha_{camera/hor} * p_{camera/hor} \qquad \text{(B.4)}$$

RATIONALE: The minimum field of vision that shall be covered by class II mirrors according to UN REGULATION NO. 46 is illustrated and described below. Which part of the two formulas that will provide the highest value depends on how much the mirrors protrude outside the maximum width of the vehicle.

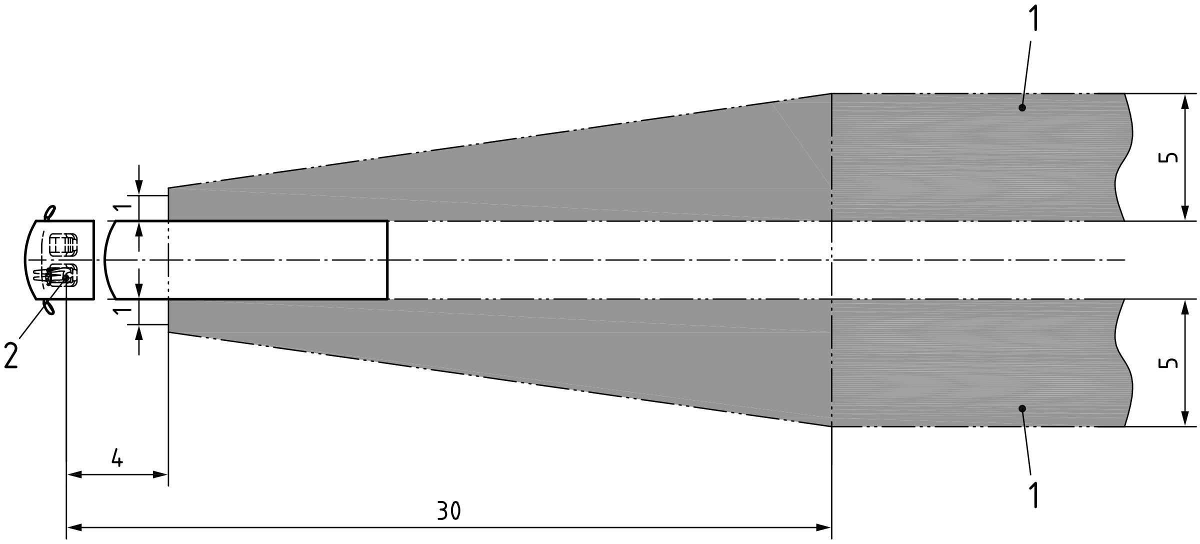
The precise wording accompanying Figure B.2 in UN REGULATION NO. 46 states:

The field of vision shall be such that the driver can see at least a 5 m wide, flat, horizontal portion of the road, which is bounded by a plane which is parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle on the driver's side of the vehicle and extends from 30 m behind the driver's ocular points to the horizon.

In addition, the road shall be visible to the driver over a width of 1 m, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle starting from a point 4 m behind the vertical plane passing through the driver's ocular points.

The corresponding text is valid on the passenger side.

Dimensions in metres



Key

1 ground level

2 driver's ocular point

Figure B.2 — Area on ground to be covered by class II mirrors

NOTE The field of vision extends rearwards to the horizon, i.e. also vertical vision has to be provided rearwards at a level similar to the height of the ocular reference point.

B.2.1.3 Minimum horizontal field of view for UN REGULATION NO. 46 class III mirrors

For class III UN REGULATION NO. 46 mirror replacements, this means:

$$\alpha_{system/hor} \geq \alpha_{mirror/hor/\min} = \max \begin{bmatrix} \arctan\left(\dfrac{1m - y_{camera}}{\sqrt{(x_{camera}+4m)^2 + z_{camera}^2}}\right) + \arctan\left(\dfrac{y_{camera}}{\sqrt{(x_{camera}+4m)^2 + z_{camera}^2}}\right) \\ \arctan\left(\dfrac{4m - y_{camera}}{\sqrt{(x_{camera}+20m)^2 + z_{camera}^2}}\right) + \arctan\left(\dfrac{y_{camera}}{\sqrt{(x_{camera}+20m)^2 + z_{camera}^2}}\right) \end{bmatrix}$$

(B.5)

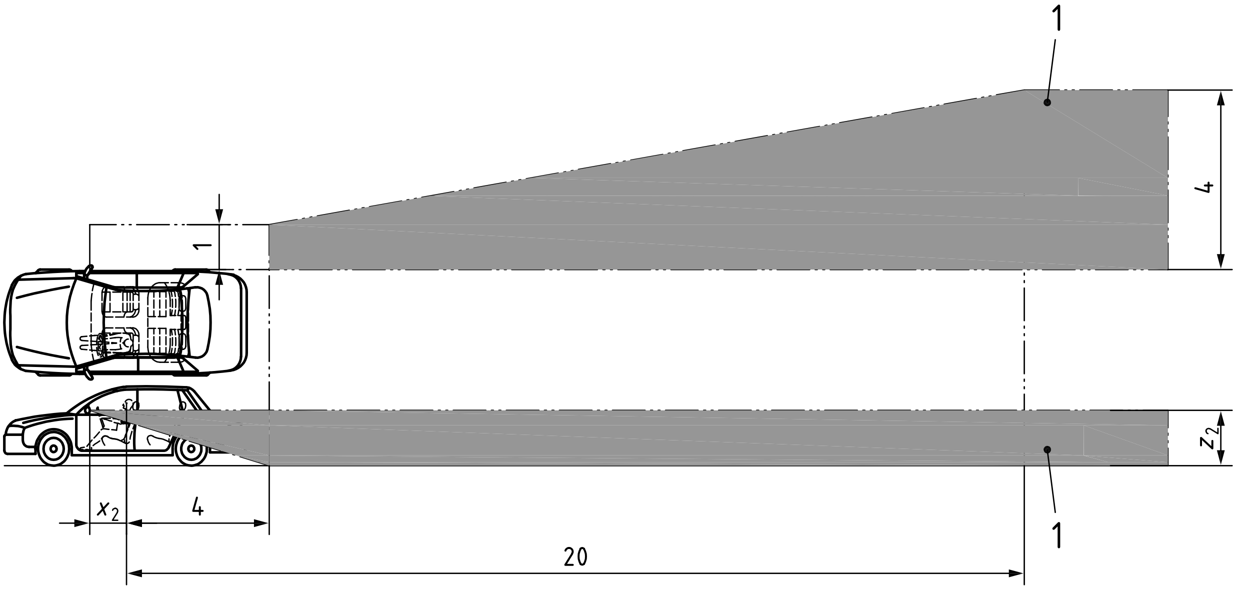
$$\alpha_{system/hor} = \alpha_{monitor/hor} = \alpha_{camera/hor} * \rho_{camera/hor} \quad \text{(B.6)}$$

RATIONALE: The precise wording accompanying Figure B.3 in UN REGULATION NO. 46 states:

The field of vision shall be such that the driver can see at least a 4 m wide, flat, horizontal portion of the road, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle on the driver's side of the vehicle and extends from 20 m behind the driver's ocular points to the horizon. In addition, the road shall be visible to the driver over a width of 1 m, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle starting from a point 4 m behind the vertical plane passing through the driver's ocular points.

The corresponding text is valid on the passenger side.

Dimensions in metres



Key

X_2 X_{mirror}

Z_2 Z_{mirror}

1 ground level (minimum horizontal field of view)

2 minimum vertical field of view

Figure B.3 — Field of view for class III mirror as defined in UN REGULATION NO. 46

B.2.1.4 Minimum horizontal field of view for UN REGULATION NO. 46 class IV mirrors

For class IV UN REGULATION NO. 46 mirror replacements, this means:

$$\alpha_{system/hor} \geq \alpha_{mirror/hor/\min} = \max\left[\begin{array}{l} \arctan\left(\frac{4{,}5m - y_{camera}}{\sqrt{\left(x_{camera}+1{,}5m\right)^2 + z_{camera}^2}}\right) + \arctan\left(\frac{y_{camera}}{\sqrt{\left(x_{camera}+1{,}5m\right)^2 + z_{camera}^2}}\right) \\ \arctan\left(\frac{15m - y_{camera}}{\sqrt{\left(x_{camera}+10m\right)^2 + z_{camera}^2}}\right) + \arctan\left(\frac{y_{camera}}{\sqrt{\left(x_{camera}+10m\right)^2 + z_{camera}^2}}\right) \end{array}\right] \quad \text{(B.7)}$$

$$\alpha_{system/hor} = \alpha_{monitor/hor} = \alpha_{camera/hor} * \rho_{camera/hor} \quad \text{(B.8)}$$

RATIONALE: The minimum field of vision that shall be covered by class IV mirrors according to UN REGULATION NO. 46 is illustrated below. Which part of the two formulas that will provide the highest value depends on how much the mirrors protrude outside the maximum width of the vehicle.

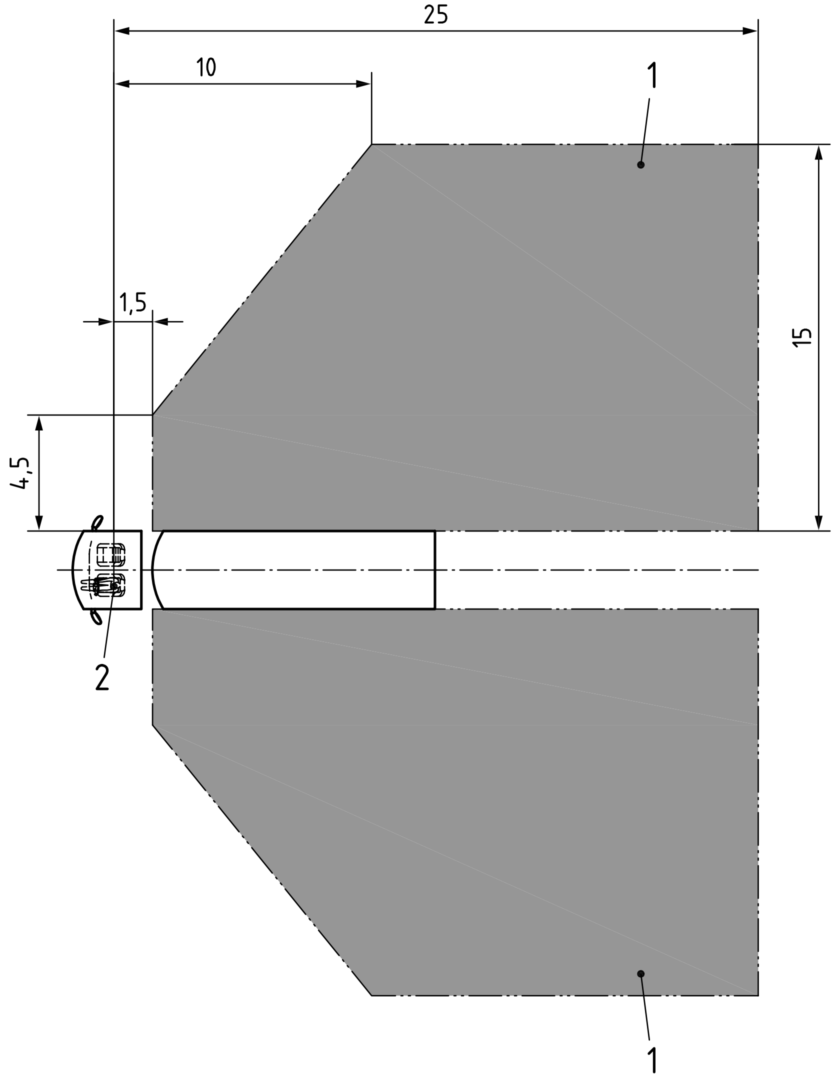
The precise wording accompanying Figure B.4 in UN REGULATION NO. 46 states:

The field of vision shall be such that the driver can see at least a 15 m wide, flat, horizontal portion of the road, which is bounded by a plane parallel to the median longitudinal vertical plane of the vehicle and passing through the outermost point of the vehicle on the driver's side and which extends from at least 10 m to 25 m behind the driver's ocular points.

In addition, the road shall be visible to the driver over a width of 4,5 m, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle starting from a point 1,5 m behind the vertical plane passing through the driver's ocular points.

The corresponding text is valid on the passenger side.

Dimensions in metres



Key

1 ground level

2 driver's ocular point

Figure B.4 — Area on ground to be covered by class IV mirrors

B.2.2 Minimum vertical field of view

The subclause describes the minimum allowed value for $\alpha_{system/ver}$ as defined by the responsible national body. This is denoted as $\alpha_{mirror/ver/min}$ for the mirror to be replaced, and is measured in degree.

B.2.2.1 Minimum vertical field of view for UN REGULATION NO. 46 class I mirrors

For class I UN REGULATION NO. 46 mirror replacements, this means:

$$\alpha_{system/ver} \geq \alpha_{system/ver/\min} = \arctan\left(\frac{z_{camera}}{x_{camera} + 60m}\right) \quad \text{(B.9)}$$

NOTE See rationale in B.2.1.1.

B.2.2.2 Minimum vertical field of view for UN REGULATION NO. 46 class II mirrors

For class II UN REGULATION NO. 46 mirror replacements, this means:

$$\alpha_{system/ver} \geq \alpha_{system/ver/\min} = \arctan\left(\frac{z_{camera}}{x_{camera} + 4m}\right) \quad \text{(B.10)}$$

NOTE See rationale in B.2.1.2.

B.2.2.3 Minimum vertical field of view for UN REGULATION NO. 46 class III mirrors

For class III UN REGULATION NO. 46 mirror replacements, this means:

$$\alpha_{system/ver} \geq \alpha_{system/ver/\min} = \arctan\left(\frac{z_{camera}}{x_{camera} + 4m}\right) \quad \text{(B.11)}$$

NOTE See rationale in B.2.1.3.

B.2.2.4 Minimum vertical field of view for UN REGULATION NO. 46 class IV mirrors

For class IV UN Regulation No. 46 mirror replacements, this means:

$$\alpha_{system/ver} \geq \alpha_{system/ver/\min} = \arctan\left(\frac{z_{camera}}{x_{camera} + 1{,}5m}\right) - \arctan\left(\frac{z_{camera}}{x_{camera} + 25m}\right) \quad \text{(B.12)}$$

NOTE According to Figure B.4, the vertical field of vision is only limited by the area specified on ground. See rationale in B.2.1.4.

B.2.3 Minimum field of view for vehicle types in Japan

To fulfil the corresponding Japanese regulation, the following area on the ground and in height above that area should be covered by a combination of the main mirror on the passenger side, the front close-up mirror ("front mirror"), the side close-up mirror ("side under mirror"), and direct vision through the windows.

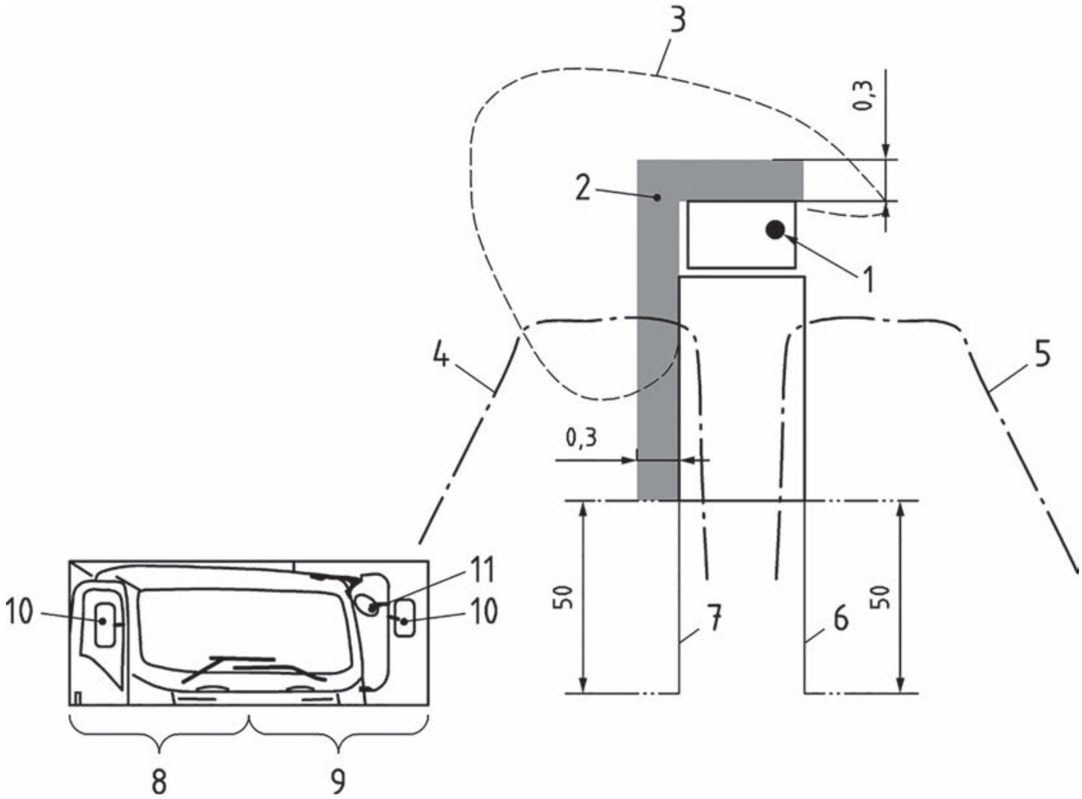
NOTE 1 For the Japanese vision regulation, there are also requirements for the vertical field of view. However, as the area on ground can be covered by a combination of mirrors and direct vision, it is not possible to include a formula or state a general requirement. Figure B.5, B.6, B.7, and Table B.1 show the areas to be covered for the different vehicle types.

NOTE 2 Japanese REGULATION main mirror means "Those mirrors used mainly for observing obstacles showing up around the rear portion on the left side of the vehicle".

NOTE 3 Japanese REGULATION front mirror means "Those mirrors used mainly for observing obstacles in front of the vehicle".

NOTE 4 Japanese REGULATION side under mirror means "Those mirrors used mainly for observing obstacles showing up around the front portion on the left side of the vehicle."

Dimensions in metres

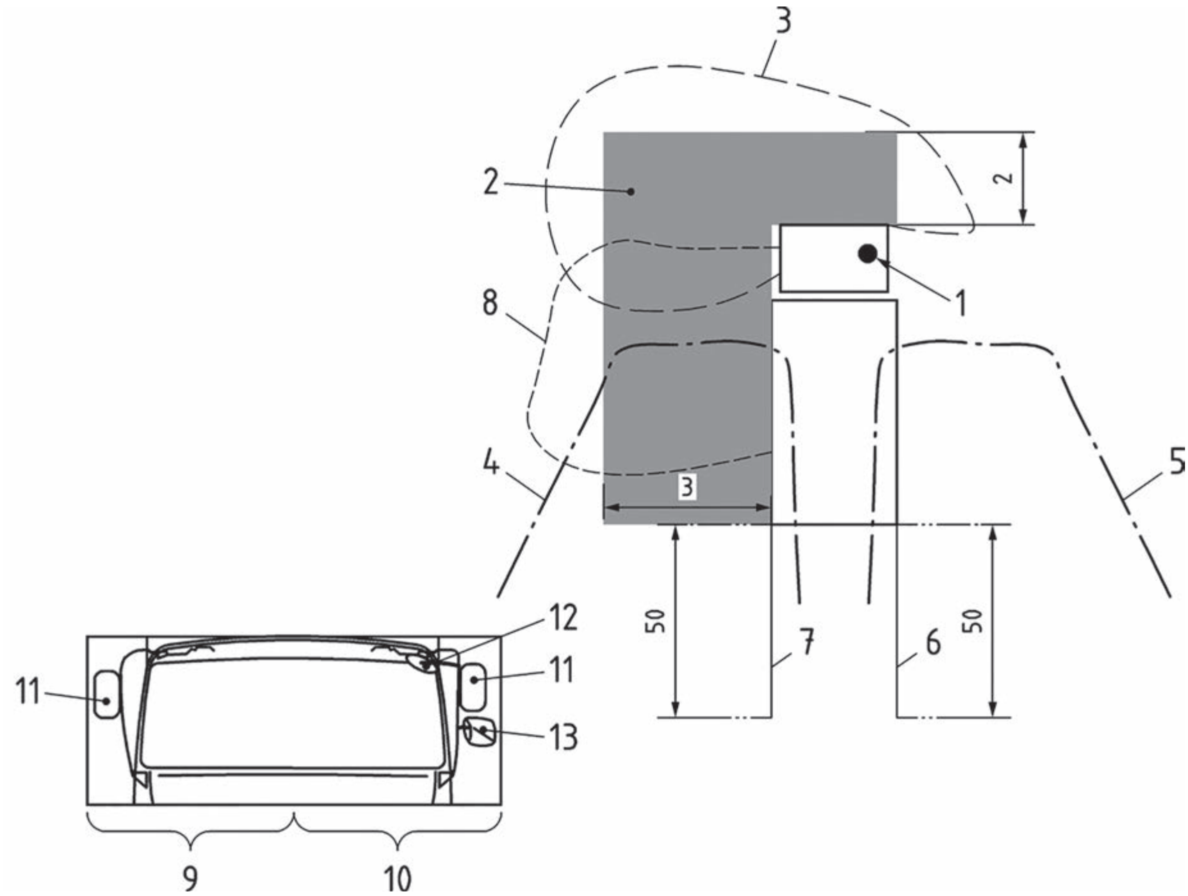


Key

1 ocular reference point
2 field of vision for passenger side
3 front under mirror field of view (r_{mirror} ≥ 0,15 m) passenger
4 passenger side main mirror field of view (r_{mirror} ≥ 0,6 m)
5 driver side main mirror field of view (r_{mirror} ≥ 0,6 m)
6 outmost point of driver side
7 outmost point of passenger side
8 driver side
9 passenger side
10 main mirror
11 front under mirror

Figure B.5 — Area on ground to be covered for cab-over type trucks according to the Japanese vision REGULATION NO. 44 (GVW < 8 ton)

Dimensions in metres

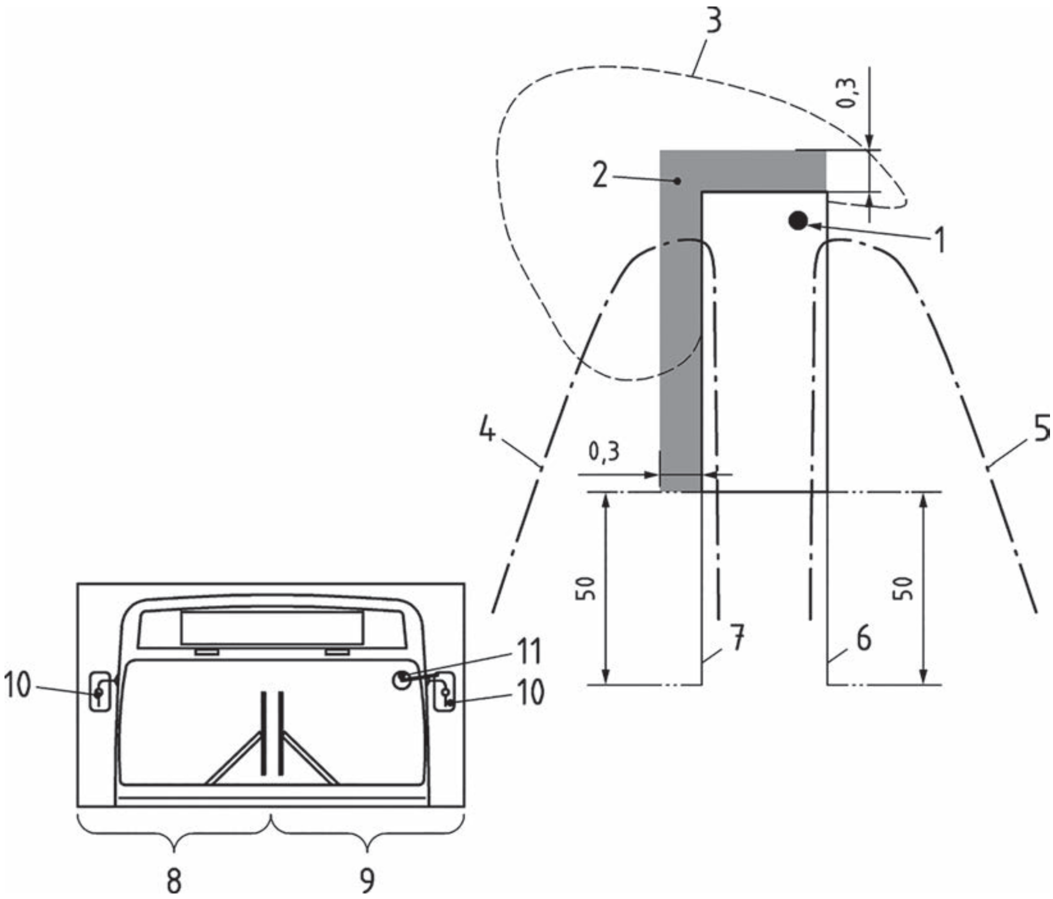


Key

1 ocular reference point
2 field of vision for passenger side
3 front under mirror field of view (r_{mirror} ≥ 0,2 m) passenger side
4 passenger side main mirror field of view (r_{mirror} ≥ 0,6 m)
5 driver side main mirror field of view (r_{mirror} ≥ 0,6 m)
6 outmost point of driver side
7 outmost point of passenger side
8 side under mirror field of view (R ≥ 0,3 m)
9 driver side
10 passenger side
11 main mirror
12 front under mirror
13 side under mirror

Figure B.6 — Area on ground to be covered for cab-over type trucks according to the Japanese vision REGULATION NO. 44 (GVW ≥ 8 ton)

Dimensions in metres



Key

1 ocular reference point

2 field of vision for passenger side

3 front under mirror field of view (r_{mirror} ≥ 0,15 m) passenger side

4 passenger side main mirror field of view (r_{mirror} ≥ 0,6 m)

5 driver side main mirror field of view (r_{mirror} ≥ 0,6 m)

6 outmost point of driver side

7 outmost point of passenger side

8 driver side

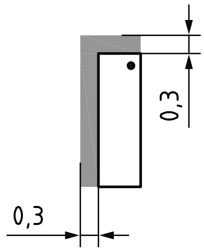
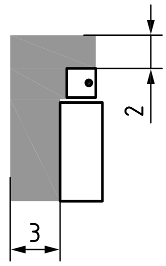
9 passenger side

10 main mirror

11 front under mirror

Figure B.7 — Area on ground to be covered for motor vehicles with a passenger capacity of 11 persons or more according to the Japanese vision regulation

Table B.1 — Dimensional requirements for different vehicle types within the Japanese vision regulation

Vehicle category	Requirements (field of vision)		
	Rear traffic condition **0 m to 50 m behind the vehicle (driver and passenger side)**	Dimensions in millimetres 	Dimensions in millimetres 
Cab-over type truck (GVW ≥ 8 ton)	X	N/A	X
Cab-over type truck (GVW < 8 ton)	X	X	N/A
Motor vehicle with a passenger capacity of 11 persons or more (all)	X	X	N/A
Passenger car	X	X	N/A
NOTE X: valid requirement.			

B.2.4 Considerations regarding changed fields of view

B.2.4.1 Background for sizes of changed fields of view (example for class II and IV)

Special driving situations require changed fields of view to keep track of where the vehicle is in relation to the surroundings. This is as mentioned in A.1 specifically important for commercial vehicles. Figures B.8 gives two illustrated typical examples of situations in which changed fields of view are needed in relation to what is offered by different means of vision like direct vision via window openings and indirect vision from regulated mirrors or cameras (see also Figure A.1).

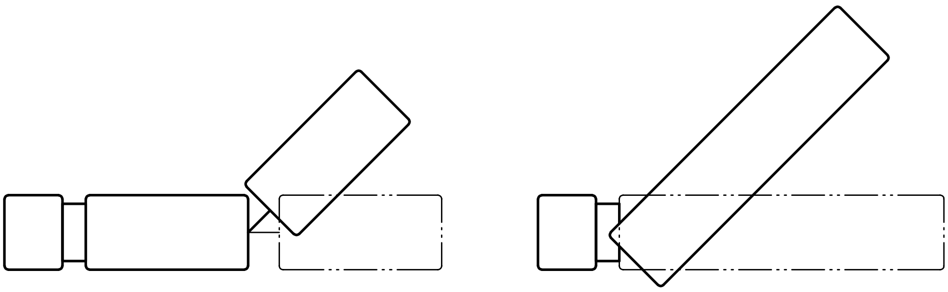


Figure B.8 — Typical driving situations where truck combinations get folded: Rigid truck with trailer (left) and truck tractor with semi-trailer (right)

Studies have been made of the head movements that drivers of heavy commercial vehicles make in order to keep track of the surroundings in special driving situations. Table B.2 gives the results for the example of a truck tractor connected to a semi-trailer (as illustrated in right part of Figure B.8). The table gives the head movements in different directions for three typical driving situations together with the rated benefits and what mirrors were used.[7]

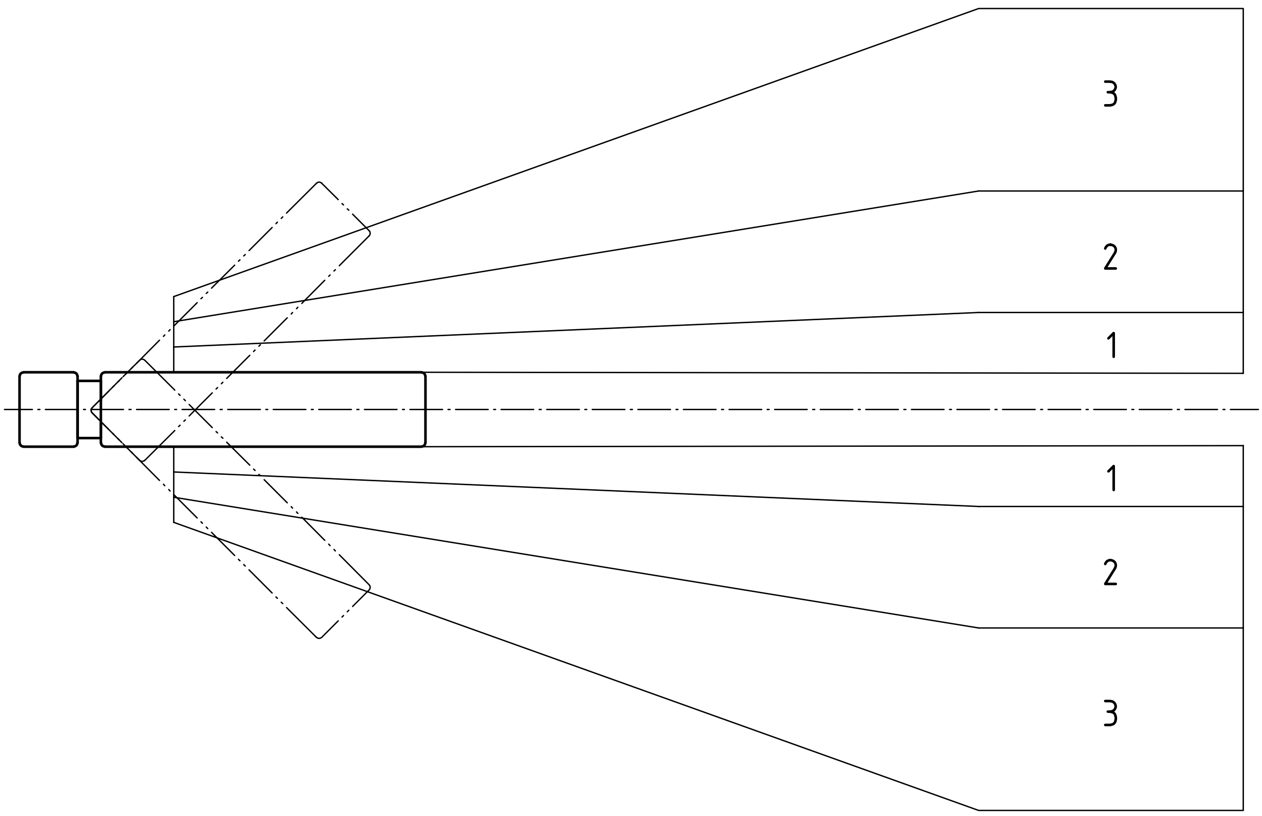
Table B.2 — Examples of head movements in special driving situations for a truck tractor connected to a semi-trailer

	Head movement						
Driving situation	**Forwards**	**Rearwards**	**Left**	**Right**	**Average/Max**	**Benefit (5-degree scale, 1 equals poor and 5 equals excellent)**	**Mirrors used**
Round-about	83 %	17 %	50 %	50 %	17/30 cm	4	83 % class II driver side 67 % class II passenger side
Reversing	100 %	0 %	71 %	71 %	33/50 cm	4,8	100 % class II passenger side 57 % class II driver side
Turning	75 %	0 %	50 %	50 %	17/20 cm	4,5	75 % class II passenger side 50 % class IV passenger side

As can be seen in the right-most column of Table B.2, the changed field of view achieved by head movements is mainly used for the class II main mirrors when comparing with to what extent head movements are used together with the class IV wide-angle mirrors.

The amount of head movement will depend on vehicle/vehicle combination as well as under what driving conditions the vehicle is used. In case of a vehicle equipped with a CMS that replaces traditional mirrors, these head movements correspond to requirements for changed fields of view necessary to keep track of where the vehicle is in relation to the surroundings. Changed fields of view may be supported either by adjusted default views or temporary modified views.

Based on studies like this, it is possible to get a picture of the additional fields of view that existing mirrors provide in special driving situations thanks to head movements. These additional fields can then be compared with what is the minimum regulated field of view and what a vehicle manufacturer might provide as extra indirect vision going beyond the regulation requirement. An illustration of this is provided below in Figure B.9.



Key

1 regulation: legally required ground level area for class II mirrors according to ECE 46-02

2 ordinary driving: additional area covered in the driver side class II mirror

3 special driving situations: additional area covered in the driver side class II mirror when head movements are utilized

Figure B.9 — Illustration of the relations between mirror class II areas

The important thing to recognize is that the additional fields of view provided by head movements with traditional mirrors is quite big compared to the minimum area required by regulation and what a vehicle manufacturer can provide in addition to that.

It is also important to remember that the different mirror classes provide different magnification factors and resolutions due to the different allowed minimum radii. Due to this, it becomes natural that drivers rather use the class II main mirrors if they can as they provide more detail and less distortion than class IV and similar mirrors with smaller allowed glass radii. This is also identified in the results from research as visible in Table B.2.

B.2.4.2 Recommendations for quantifying the changed fields of view

The size of the changed field of view to be used in special driving situations should come from studies of how much is gained from the head movements for each mirror class in vehicle combinations and driving situations that the vehicle will be used in. An example of such studies is given in Table B.2 and in Reference [7].

There are always worst case vehicle combinations and driving situations that correspond to maximum required sizes of the changed fields of view. These maximum required sizes are, however, not useful in every special driving situation. This indicates that the system needs to provide the maximum required size for the worst case vehicle combination and driving situation, but how much of that should be used is either set by the driver or automatically set from triggering on vehicle or driving condition parameters.

Even though it is not legally required, OEMs (Original Equipment Manufacturers) normally provide an additional field of view except from what is required by regulation. The changed field of view should therefore be established with reference to the actual field of view that the OEM provides, and not only to the regulatory field of view.

B.2.4.3 Recommended provisions for providing changed fields of view

B.2.4.3.1 Recommended provisions regarding expanded fields of view by changed magnification

In special driving situations, it is allowed to expand the field of view in case it cannot be shown completely with the original magnification. The change in magnification should however fulfil certain requirements linked to how it is provided. Two typical requirements that still would need to be considered are that

— continuous lines should be displayed as continuous, and

— the variation should have an appearance of continuity to the driver, or otherwise be clearly shown (e.g. by a dotted line).

Figure B.10 shows an example of what it can look like when the field of view is expanded by changed magnification. See more about the behaviour of the varying magnification factor in mirror systems in B.3.1.

Key

1 squeezed area

Figure B.10 — Example showing an expanded field of view where the outer part has a different magnification factor

B.2.4.3.2 Recommended provisions regarding panned fields of view

When the driver changes the field of view by moving his/her head, what actually takes place is panning. This means that the shown field of view is transferred to show another area of the surroundings. An example of what this panning can look like is shown below in Figure B.11.

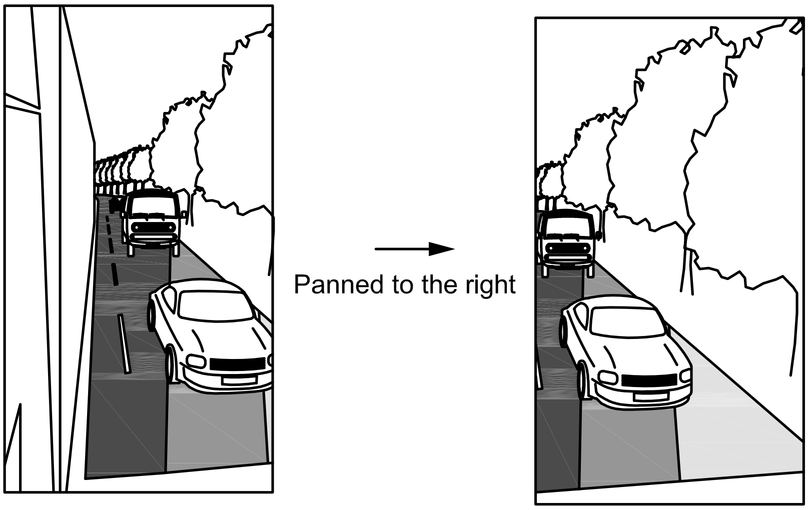


Figure B.11 — Illustration of panned fields of view

With a CMS, panning can be one way of providing the changed field of view. Panning is allowed if at least one of the following provisions is fulfilled:

a) if the field of view changes instantly as fast as the driver can move the head with the traditional mirrors;

b) if it is clearly shown that drivers will not have any use of not shown fields of view in special driving situations and that this does not cause any safety risks.

B.2.4.3.3 Recommended provisions regarding time-periods for showing changed fields of view

The changed fields of view shall be provided for a period of time linked to the special driving situations when they are needed.

Changed fields of view (expanded or panned) normally will need to return to the original field of view that is most useful in ordinary driving. The temporary transitions between original and changed fields of view can take place in different ways:

— manual activation by the driver with a switch only and directly used for the function of the changed field of view;

— manual indirect activation by the driver in combination with a vehicle condition (e.g. secondary activation by the indicator when the vehicle is already in a turn; i.e. the driver knows in advance what will happen);

— activation trigged automatically by a vehicle or environment condition (e.g. the vehicle combination is bent over a certain angle under a certain speed, etc.).

If the change is temporary, the changed field of view can be available for a time period, and then it returns to the original field of view.

If the changed field of view means the regulated area is no longer covered or that it is not shown by fulfilling general requirements on magnification, etc.; then the changed field of view shall return to the original after a certain time period. The time period has to be established from thorough analysis of the valid use cases applicable to the changed field of view.

B.2.4.3.4 Recommended provisions regarding user interactions for providing changed fields of view

For manual activation it is allowed to show the changed field of view at once or that it gradually shows up to the maximum extent.

Automatic activation shall come gradually until the changed field of view is shown to its maximum extent.

When gradually changing the field of view, the time period until the maximum extent of the field of view is shown should be defined. This is valid for both for manual and automatic activation. The time period should be established from thorough analysis of the valid driving situations applicable to the changed field of view.

The OEM has to take care that automatic activation will not cause annoyance for the drivers.

At a restart, the automatically changed field of view shall return to the original field of view that is most useful in ordinary driving.

See also the valid requirements in 6.2.

B.2.4.4 Categories of vehicles for changed field of view analyses

As mentioned in A.3.1.1, the requirements for the changed field of view shall come from an analysis of the special driving situations with a certain vehicle combination used for a certain transport purpose.

In order to facilitate the establishment of these requirements, it is possible to group the vehicles and vehicle combinations into different categories. The vehicles within one such category will then have to fulfil the same level of requirements. The creation of these categories makes it easier to establish valid requirements without having to analyse each and every single vehicle variant and combination.

In Figure B.12 typical vehicle combinations are shown.

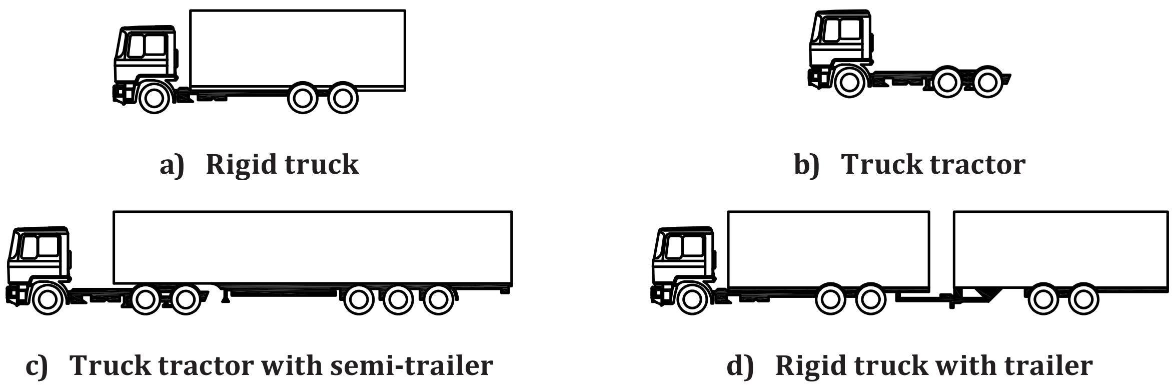
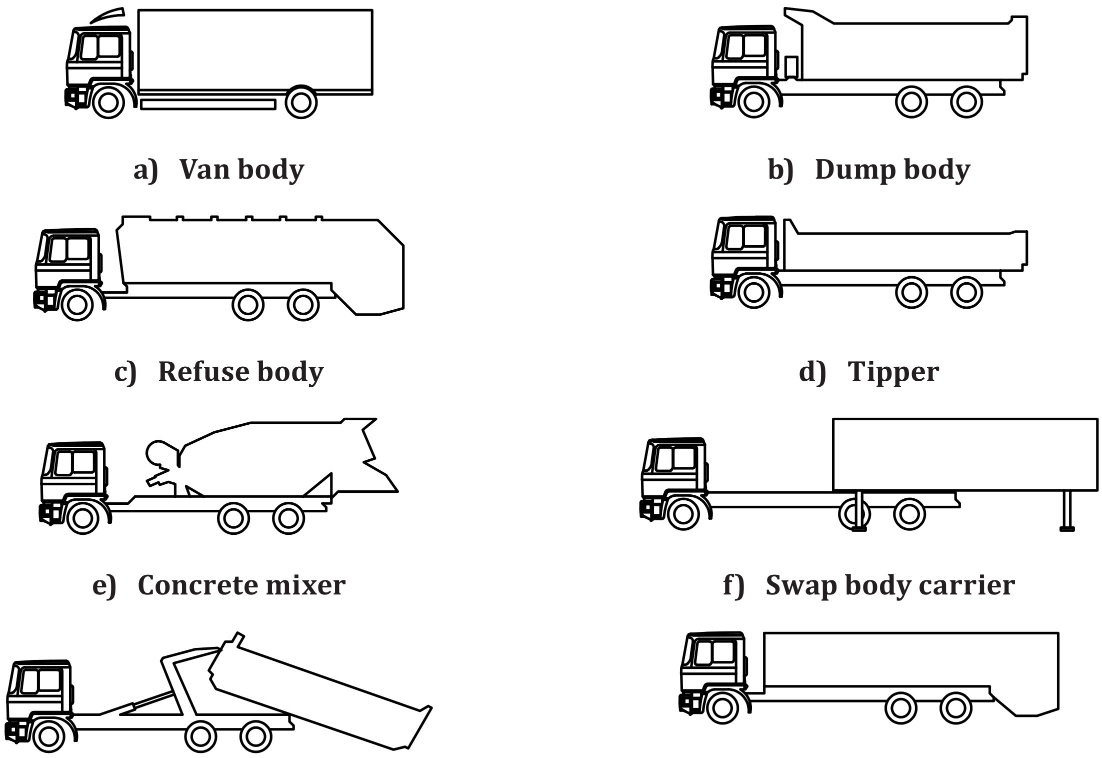


Figure B.12 — Typical vehicle combinations involving heavy trucks

When looking into requirements to handle changed fields of view, it is normally sufficient to consider some of the categories within Figure B.12, i.e. the rigid truck and the truck tractor with a semi-trailer.

The rigid truck category will then represent all different usages that rigid trucks can have. It will also be representative for the case of a truck tractor without any semi-trailer connected to it. Figure B.13 below shows examples of different usages for rigid trucks.



a) Van body

b) Dump body

c) Refuse body

d) Tipper

e) Concrete mixer

f) Swap body carrier

g) Hook lift

h) Tanker

Figure B.13 — Examples of rigid truck usages

The second category to consider corresponds to a different level of requirements and is formed by the truck tractor with semi-trailer. By focusing on this, it will at the same time be possible to use the corresponding requirements for the other vehicle combinations, see Figure B.13.

RATIONALE: The reason for why this is sufficient can be seen in Figure B.8. When comparing a truck tractor with a semi-trailer and a rigid truck with a trailer, the rear end of the semi-trailer sweeps the largest area. This corresponds to the need for the largest changed field of view. Hence the truck tractor with a semi-trailer will need the highest level of requirements.

B.3 Magnification factor (explanations)

B.3.1 Magnification factor variation

The magnification factor in rearview mirrors vary depending on different aspects:

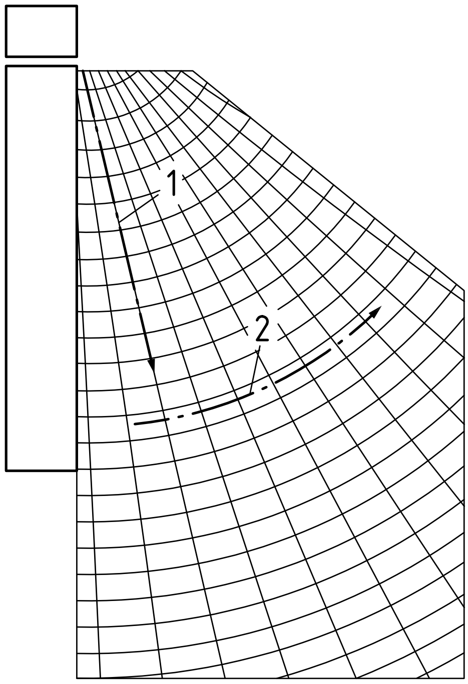
— distance, a_{mirror}, from eye-point to mirror;

— radius, r_{mirror}, of the mirror;

— distance, d_{object}, from the mirror to the object;

— viewing angle, β, (total angle between the ray leaving the object and reaching the eye-point after bouncing into the mirror surface).

Considering the magnification factor of an image seen through a mirror, the r_{mirror} is a constant and a_{mirror} is also treated as a constant because the effect due to variation on viewing points are almost negligible in this case. However, the magnification is largely affected by d_{object} and β. Therefore a detailed evaluation is done to determine a relevant magnification value representative for the traditional mirror to be replaced by a CMS. These dependencies are illustrated in Figure B.14.



Key

1 d-variation (increasing)

2 β-variation (increasing)

NOTE The figure shows the different distances, d_{object}, and viewing angles, β

Figure B.14 — Top view of the class IV field of view on the passenger side for a truck and semi-trailer combination

Figure B.15 and Figure B.16 show the effects of varying d_{object} and β respectively:

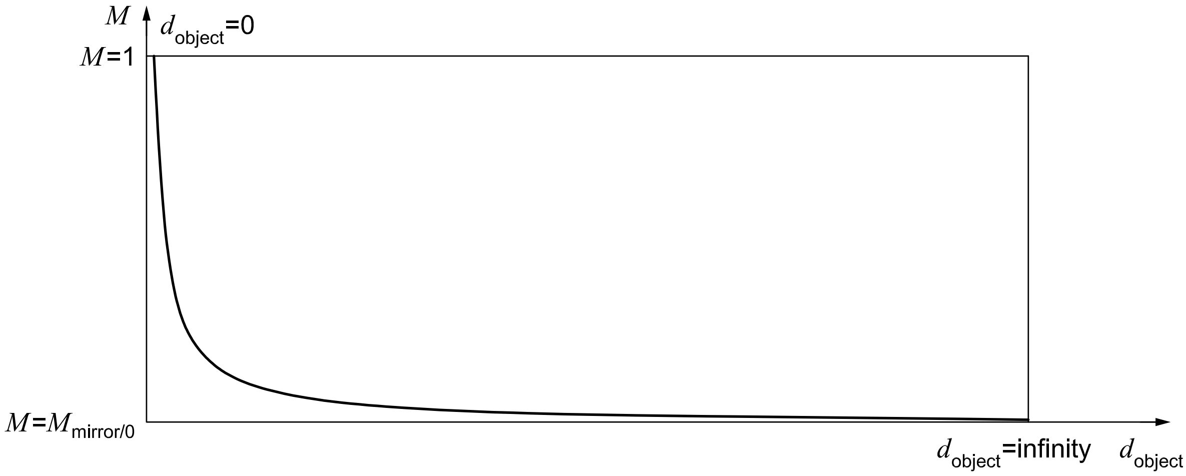


Figure B.15 — Magnification factor variation, M, depending on distance to object, d_{object} (with β = 0)

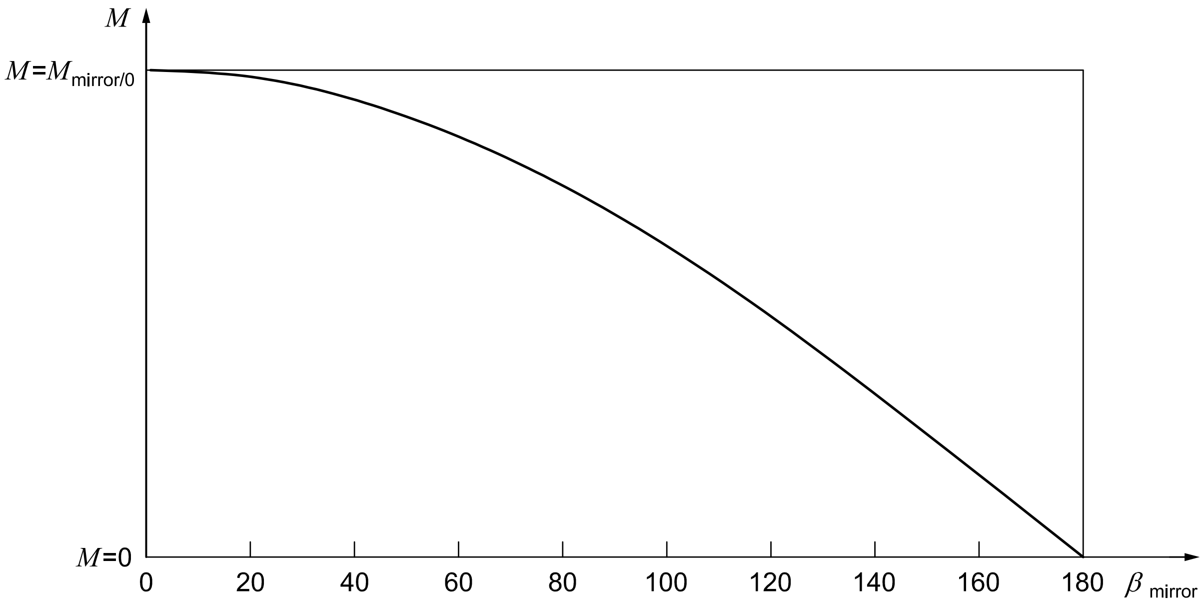
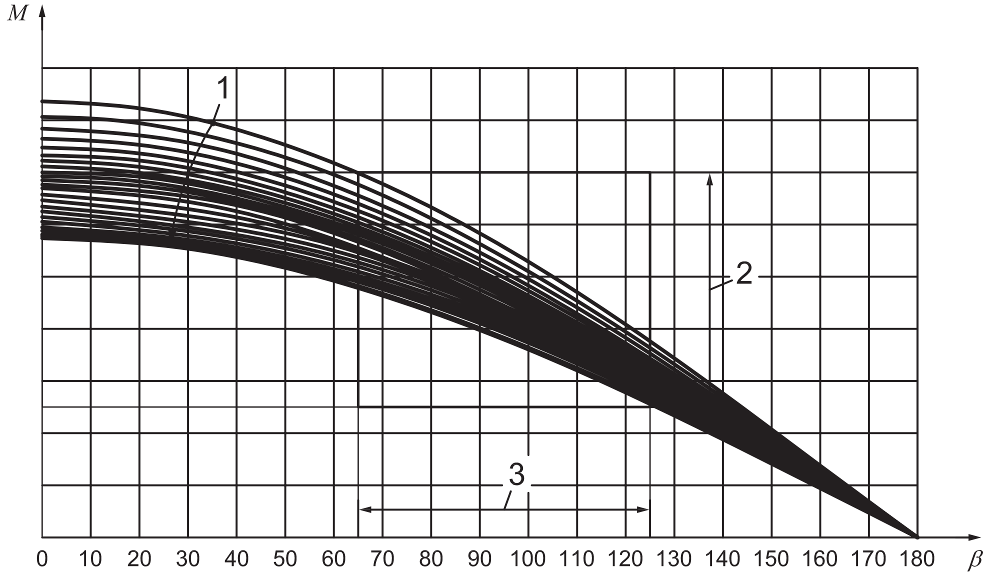


Figure B.16 — Magnification factor variation depending on total viewing angle, β (with $d_{object} = \infty$)

In case of traditional mirror systems, only a limited angular range is used. This is the shown relevant β-range, which leads to a relevant magnification-range. Only that area has to be considered when defining a required magnification-value (see Figure B.17). The relevant β-range comes from a study of the required field of view in a variety of mass production vehicles in today's market.



Key

1 d_{object}-variation (increasing)

2 relevant M-range

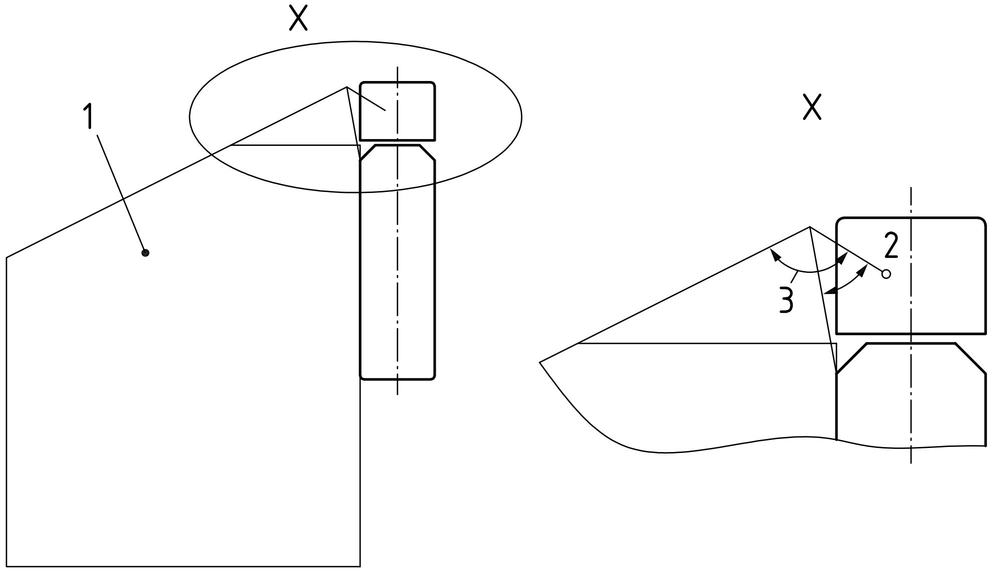
3 relevant β-range (restricted to the required field of view)

NOTE The example comes from the class IV mirror on the passenger side.

Figure B.17 — Magnification factor variation depending on both distance to object, d_{object}, and total viewing angle, β

Figure B.17 gives an example of simulation result of magnification affected by the viewing angle and object distance. The magnification with objects in the infinity converges to the lower curve.

The relevant β-range for the different mirror types has been established by measuring the minimum and maximum viewing angles to cover the required field of view. This procedure is illustrated in Figure B.18 for the case of a class IV mirror replacement.



Key

1 required field of view according to UN REGULATION NO. 46

2 driver ocular reference point

3 $\beta_{mirror/driver/min}$ on the inner side of the required field of view and $\beta_{mirror/driver/max}$ on the outer side of the required field of view

NOTE This example shows the case of a class IV mirror replacement on the driver side.

Figure B.18 — Relevant β-range resulting from the minimum viewing angle, $\beta_{mirror/driver/min}$, and the maximum viewing angle, $\beta_{mirror/driver/max}$, to cover the required field of view

The study to establish the β-values on today's products is done in a 2D top view by letting a line start from the Ocular Reference Point, continue via the centre point of the mirror glass, and then pass either side of the required field of view.

The following photograph in Figure B.19 illustrates what these dependencies can look like in reality.

Figure B.19 — Magnification factor variation exemplified with a class IV mirror field of view

B.3.2 Magnification factor formulas

Magnification factor formulas are needed to facilitate that requirements can be established to make sure that the Camera Monitor System behaves at least as good as the traditional mirror system.

The formula for M_0 that corresponds to $d_{object} \to \infty$ and $\beta = 0$ (i.e. when standing straight in front of the mirror) is shown below:

$$M_0\left(\beta = 0, d_{object} = \infty\right)$$

$$M_0\left(a_{mirror}, r_{mirror}\right) = \frac{1}{1 + \frac{2a_{mirror}}{r_{mirror}}} \tag{B.13}$$

The formulae used for establishing the estimated magnification factor are provided below.

Formula (B.14) gives the variation in magnification that comes from varying the total viewing angle, β, while the distance to object, d_{object}, is kept as infinity.

$$M_0\left(\beta, d_{object} = \infty\right)$$

$$M = \lim_{\Delta\alpha \to 0} \frac{\Delta\alpha}{\Delta\beta - \Delta\alpha} = \lim_{\Delta\beta \to 0} \frac{\Delta\alpha}{\Delta\beta - \Delta\alpha}$$

$$\to M = \lim_{\beta_1 \to \beta_2} \frac{\arcsin\left(\frac{r}{a+r} * \sin\frac{\beta_2}{2}\right) - \arcsin\left(\frac{r}{a+r} * \sin\frac{\beta_1}{2}\right)}{\beta_2 - \beta_1 - \arcsin\left(\frac{r}{a+r} * \sin\frac{\beta_2}{2}\right) + \arcsin\left(\frac{r}{a+r} * \sin\frac{\beta_1}{2}\right)}$$

$$\beta_2 > \beta_1 ; a = a_{mirror;} r = r_{mirror} \qquad \text{(B.14)}$$

Formula (B.15) gives the variation in magnification that comes from varying the distance to the object, d_{object}, while keeping the total viewing angle, β, at 0.

$$M\left(\beta = 0, d_{object}\right)$$

$$M = \frac{1}{1 + \frac{2a_{mirror} * d_{object}}{r_{mirror}\left(a_{mirror} + d_{object}\right)}} \qquad \text{(B.15)}$$

Formula (B.16) provides the approximation of the real magnification factor taking into account variations of both total viewing angle, β, and distance to object, d_{object}. It utilizes Formulae (B.13), (B.14), and (B.15).

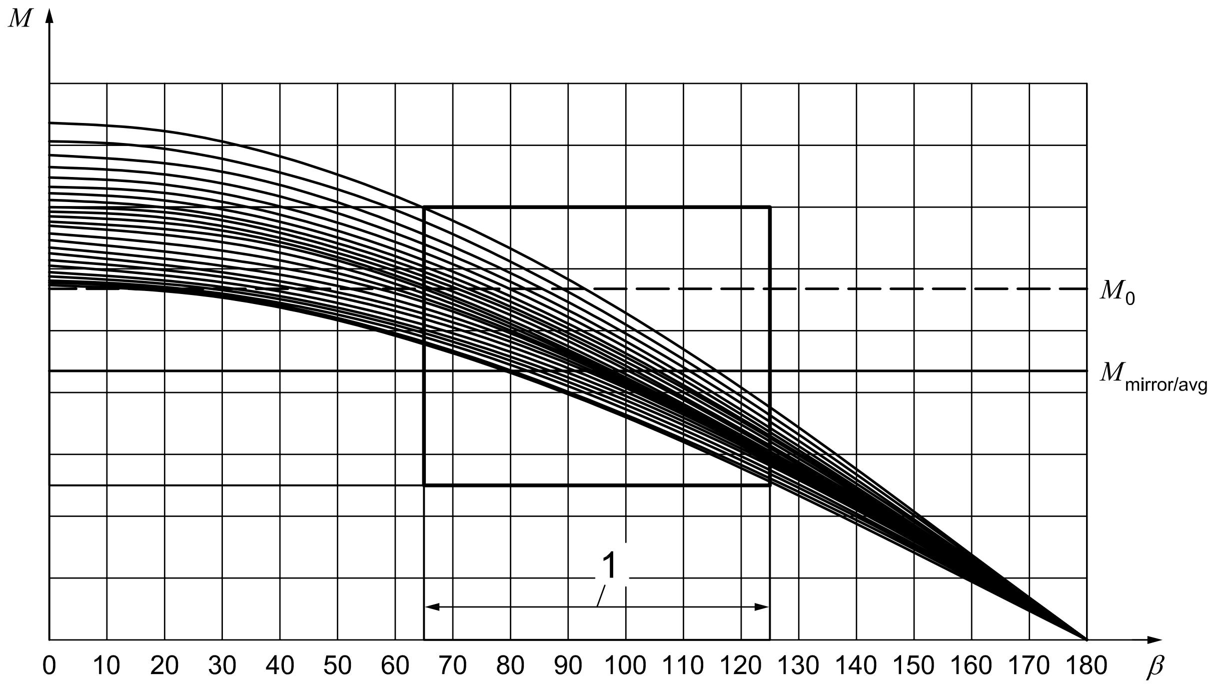
$$M\left(d_{object}, \beta\right) approximation$$

$$M(\beta, d_{object}) \approx \frac{M\left(\beta = 0, d_{object}\right) * M\left(\beta, d_{object} = \infty\right)}{M_0} \qquad \text{(B.16)}$$

With the Formula (B.16), all relevant d-values and β- values are brought together into one graph. The resulting M-factors are shown in Figure B.20. The constant value, $M_{mirror/avg}$, representing the average of all the relevant M-values within the β-range, has to be defined for all mirror classes. In Figure B.20, the $M_{mirror/avg}$ is shown as an example for the mirror class IV on the passenger side. The graph shows also the differences between the value of M_0 (for the irrelevant case $\beta = 0$) and the defined $M_{mirror/avg}$.

NOTE 1 Due to the varying density of the curves representing the variation from different distances to object, $M_{mirror/avg}$ does not necessarily appear at the mid-point of the relevant M-range.

NOTE 2 For the exact data that results in the given $M_{mirror/avg}$ for the different mirror classes, *see the Excel sheet "magnification with radius and distance calculator" provided at* http://standards.iso.org/iso/16505/.



Key

1 relevant β-range

Figure B.20 — Principle of magnification factor variation over the full field of the rearview mirror (introducing M_0 and $M_{mirror/avg}$)

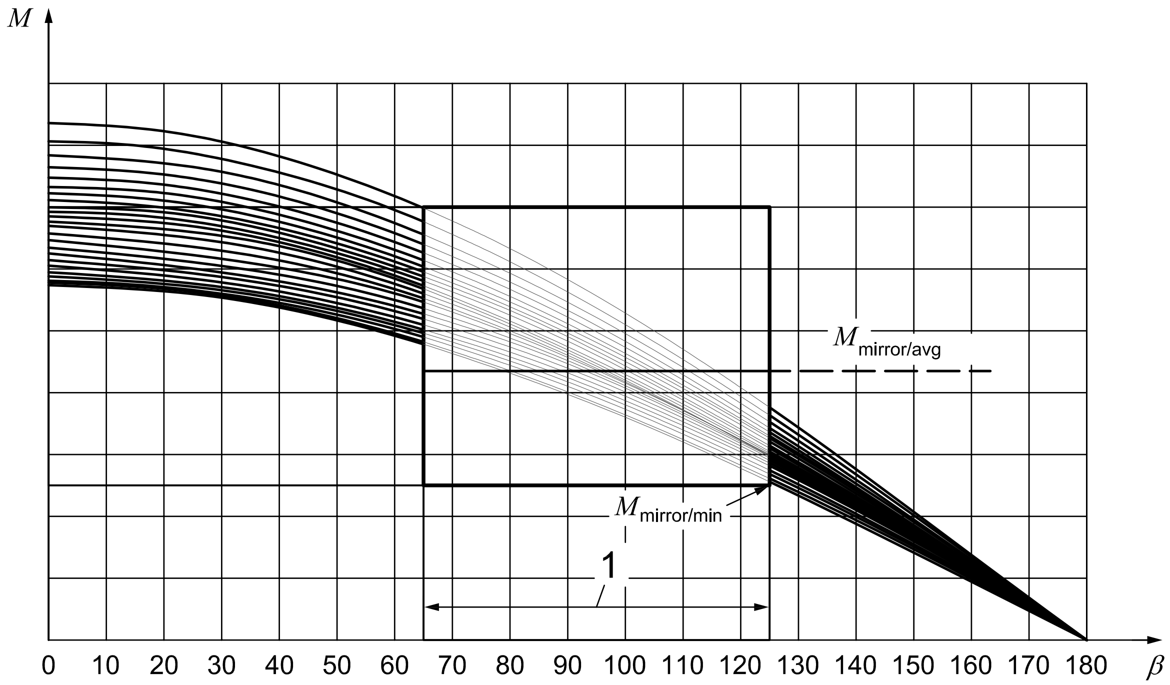
B.3.3 Average and minimum magnification factor recommendations

The average magnification in the mirror is defined and used as the requirement for the average magnification factor, $M_{mirror/avg}$. When doing this, it becomes important that the biggest and smallest viewing angles, β, found in existing vehicles are considered.

If only the average magnification is used as a requirement, magnification values within the range of total viewing angles could deviate quite a lot from the behaviour of a traditional rearview mirror. It is reasonable to allow a variation of the magnification inside the field of view, where the magnification can be lower than $M_{mirror/avg}$ in the outer parts (increasing β) of the displayed fields of view.

For rearview mirror systems, the magnification factor actually varies depending on from what direction the mirror is being viewed. More details of what this variation depends on are found in B.3.

Figure B.21 below shows the resulting magnification range for the relevant β–angle range described above.



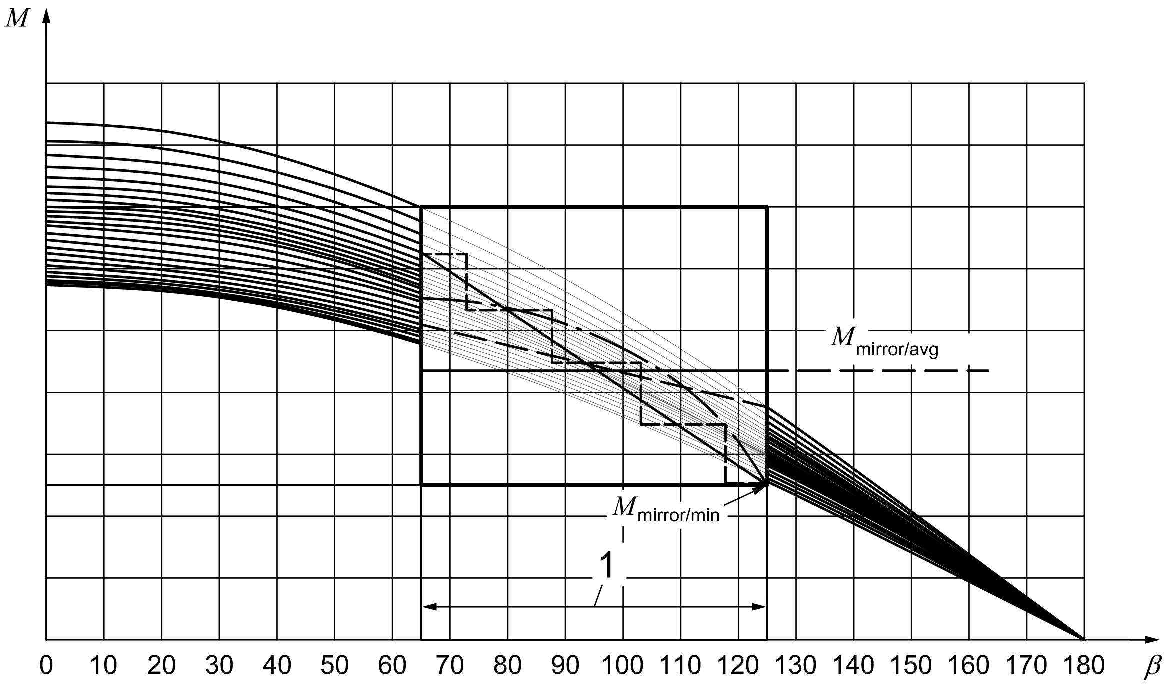
Key

1 relevant β-range

Figure B.21 — Resulting magnification factor value based on the variation of the traditional rearview mirror

In order to secure the appropriate performance of the CMS, it gets important to avoid magnification values that go below the ones of the corresponding traditional mirror system for the same range of total viewing angles. This means that an additional requirement for the minimum allowed magnification, $M_{mirror/min}$, is necessary. The behaviour of the varying magnification within the required field of view should also be the same as for the corresponding traditional mirror system with respect to viewing angles, β.

In addition to this, Figure B.22 shows different alternatives for how the magnification factor can vary including aspects of being continuous or not for varying viewing angles, β.



Key

1 relevant β-range

Figure B.22 — Examples of possible magnification factor variations

Figure B.23 shows what it would look like in reality for the example where the magnification factor is kept constant for a limited number of β-ranges.

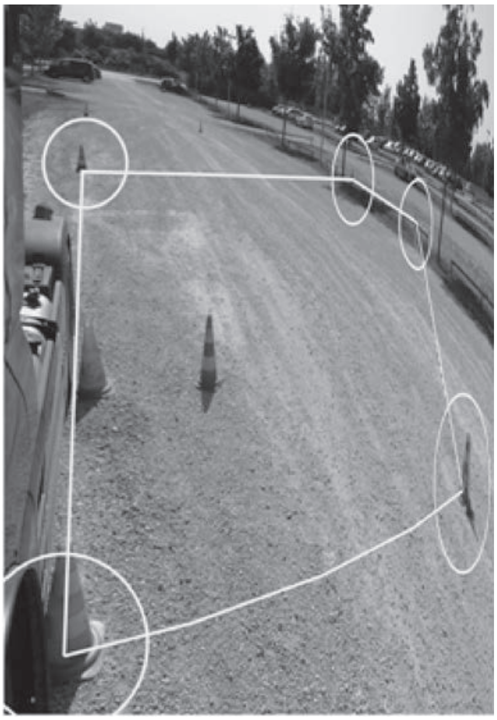


Figure B.23 — Example of a possible magnification factor variation with an appearance of continuity

B.3.4 Magnification aspect ratio

The magnification aspect ratio in mirrors depends on mainly the same values as the magnification factor. The magnification aspect ratio is defined as the ratio between horizontal and vertical magnification factor in a mirror.

To get the values for the allowed magnification aspect ratio, Formula (B.17) is used:

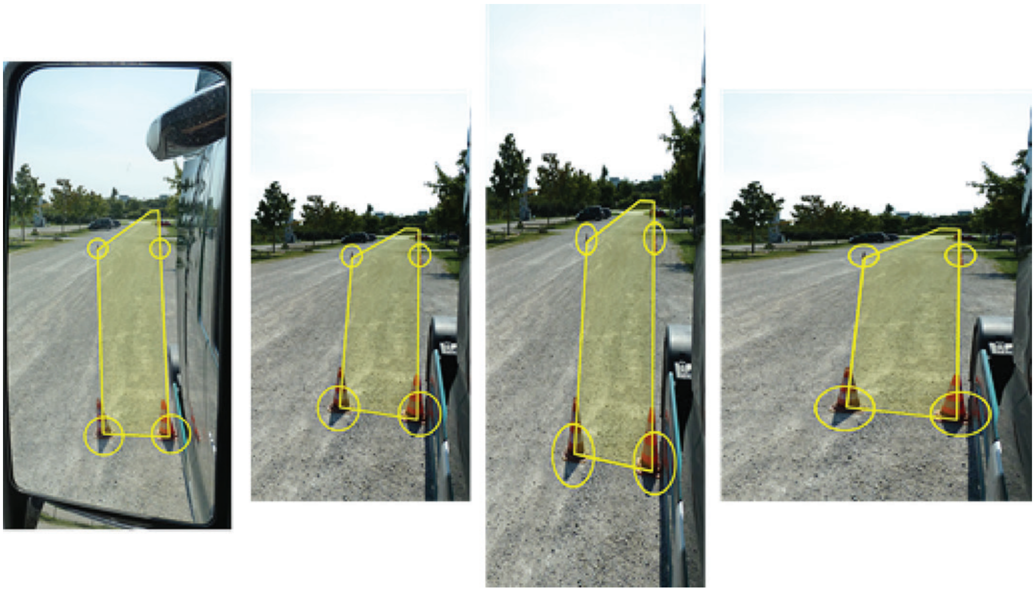
$$\frac{M(\beta, d=\infty)}{M_0} \leq \frac{M_{hor}}{M_{ver}} \leq \frac{M_0}{M(\beta, d=\infty)} \quad \text{(B.17)}$$

To simplify the process of defining the magnification aspect ratio, the values are defined for both sides of the different mirror classes. Still the requirements for the magnification factors in horizontal and vertical direction have to be fulfilled.

For replacing close-up mirrors (with $r \leq 400$mm like the wide-angle class IV mirror on commercial vehicles), no magnification aspect ratio restriction is required.

RATIONALE: Mirrors with a radius smaller than 400 mm are mainly used to notice surrounding objects rather than observing them precisely. The magnification in horizontal and vertical direction is not impaired by that, and has to be fulfilled. That is, higher magnification aspect ratios mean that objects in the display are getting bigger than they are with a magnification aspect ratio = 1.

Figures B.24 and B.25 show examples of what different magnification ratios will look like for the class II and class IV mirrors respectively.



NOTE From left to right: magnification within the actual mirror, M = 1, M = 0,7, and M = 1,42.

Figure B.24 — Example for class II mirrors on the passenger side

NOTE From left to right: magnification within the actual mirror, M = 1, M = 3, and M = 0,33.

Figure B.25 — Example for class IV mirrors on the passenger side

B.4 System resolution (guidelines)

To have a high probability to fulfill the MTF resolution requirement defined in 6.5.3, a system design proposal is to make sure that the optics itself is fulfilling the MTF requirement. Increasing the pixel resolution of both, the camera and monitor by a factor of 1,5 compared to the $MTF10_{MIN(1:1)}$ as defined in 3.16 and 3.17 can be used as a guideline to cope for signal degradation by the CMS and avoid aliasing. A person who is “skilled in the art” would know that using a factor of at least 1,5 is reasonable for reproducing the random content of an image.

Nevertheless, the MTF resolution requirement defined in 6.5.3 shall be fulfilled with the final system.

B.5 Use case descriptions (guidelines)

B.5.1 Use cases related to driving situations

B.5.1.1 Driving situations where changed fields of view are important

From the list of use cases in Clause 6, the main identified special driving situations where head movements are essential while using conventional mirrors are

a) pulling out into a main road from an attaching road at an angle (see Figure B.26),

b) driving through a round-about with trailer connected (see Figure B.27),

c) manoeuvring towards an exact location for leaving or picking up people and/or goods (see Figure B.28), and

d) turning left or right around corners with connected trailer (see Figure B.29).

Situations b), c), and d) come from research made with truck drivers. Similar investigations could be done with heavy buses, passenger cars with different trailers or other big or more complex vehicles/vehicle combinations where visibility problems are expected.

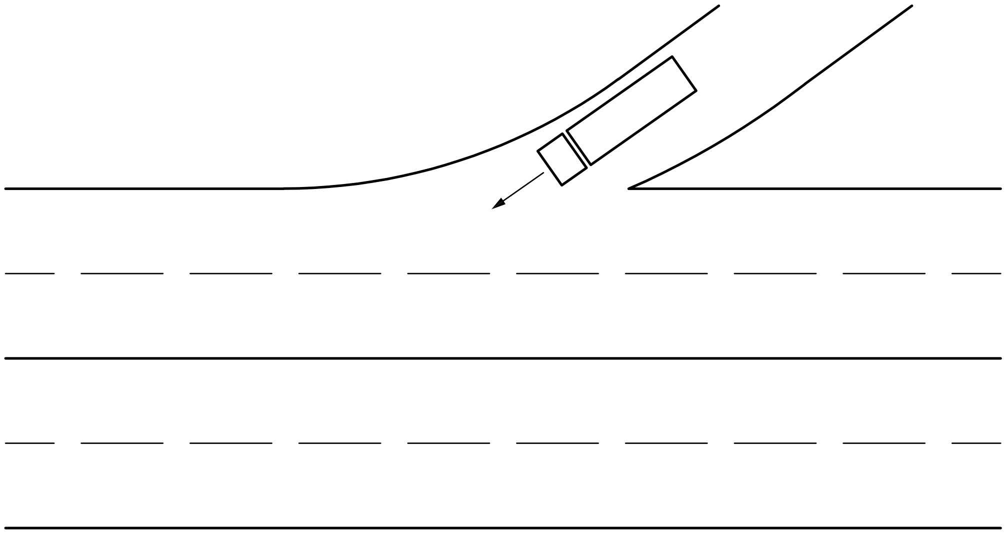


Figure B.26 — Pulling out into a main road from an attaching road at an angle

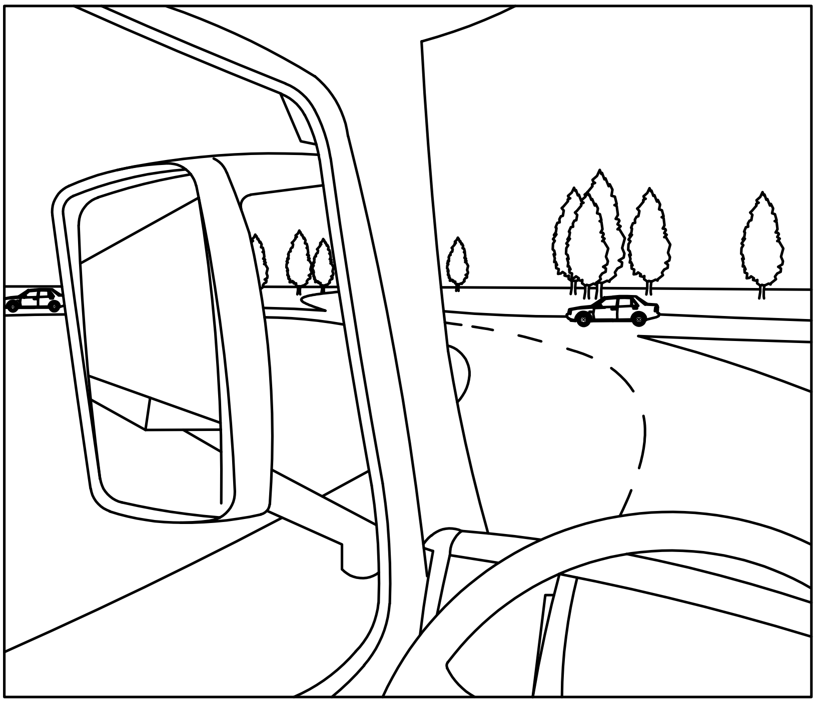


Figure B.27 — Driving in a round-about with a trailer connected

Figure B.27 shows the condition with a tractor truck and a semi-trailer, but it is equal with e.g. a passenger car and a caravan. By moving the head it will be possible for the driver to see the semi-trailer rear end in the mirror.

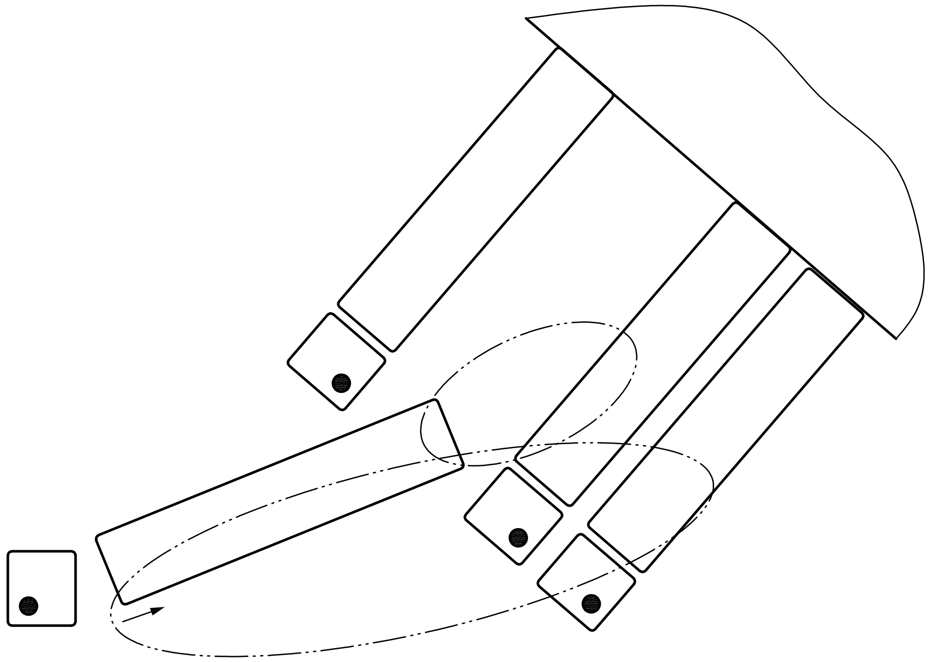


Figure B.28 — Manoeuvring towards an exact location for leaving or picking up people and/or goods

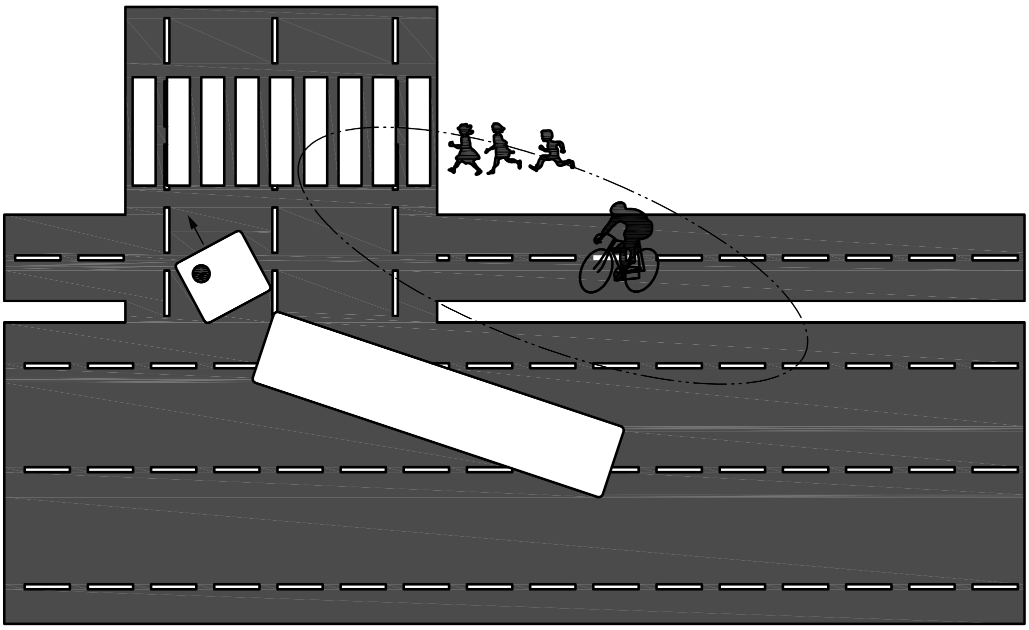


Figure B.29 — Turning left or right around corners with a connected trailer

Figure B.28 and Figure B.29 shows a tractor truck with a semi-trailer, but the vehicle combination could also be, for example, a passenger car with a caravan.

These driving situations are used as typical examples. However, depending on vehicle type and transport task, there are probably additional driving situations that will also need to be taken into account.

B.5.2 Use cases related to non-driving situations (heavy truck examples)

Except from indirect vision while driving, indirect vision is also required in cases where the driver or any passenger intend to leave the vehicle. In order to set the exact requirements for this, each specific use case should normally be analysed.

Here are the stages of some use cases that are typical when using heavy trucks. As reference, the ordinary entrance and start-up procedure is also included. Not all of the listed stages are directly influencing the activation of a CMS. However, several of them might either be used for activation or be influencing how the system needs to be controlled.

B.5.2.1 Normal entrance and start-up procedure

1) Unlock initiation
2) Opening door from outside
3) Getting seated and applying seat belt
4) Ignition switch activation
5) Parking brake released

B.5.2.2 Normal close-down and exit procedure

1) Vehicle stationary
2) Parking brake engaged
3) Ignition switch turned off
4) Removal of seat belt and leaving seat
5) Opening door
6) Closing door
7) Locking vehicle from outside

B.5.2.3 Resting exit procedure

1) Driver and/or passenger in vehicle
2) Manual or automatic activation (compare foldable mirrors)
3) Opening door from inside
4) Closing door (for deactivation)

B.5.2.4 Resting start-up procedure

1) Driver and/or passenger in vehicle
2) Getting seated
3) Ignition switch activation

B.5.2.5 Working exit procedure (e.g. at a construction site)

1) Engine on idle
2) Power take-offs engaged

3) Leaving seat

4) Opening door from inside

5) Closing door from outside

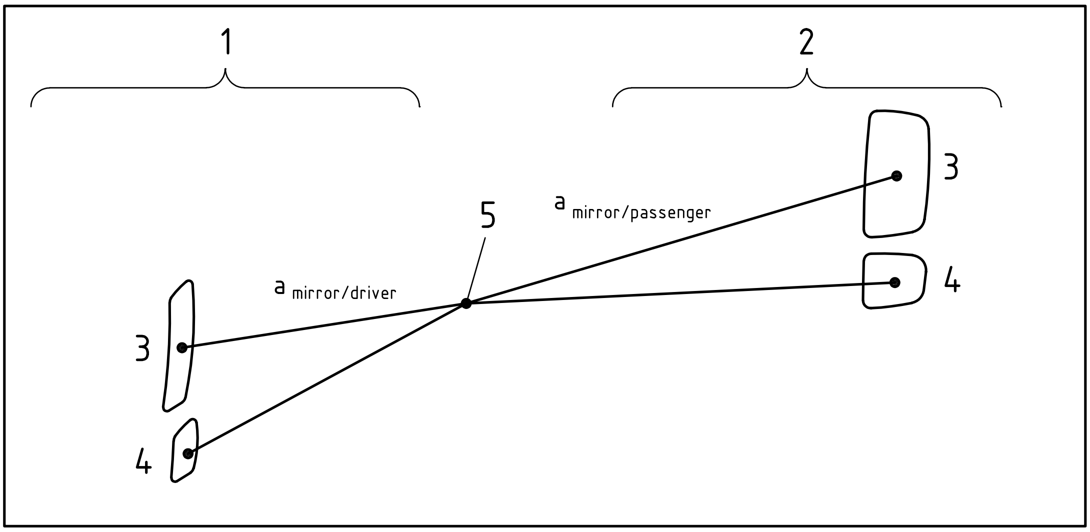
6) Possible need to lock door from outside while engine is still running

B.6 Mirror positions on commercial vehicles

This subclause outlines additional considerations in regard to mirrors.

B.6.1 Distance to driver ocular reference point in existing vehicles

The distance from the driver ocular reference point to each respective mirror on an existing vehicle forms an important input for establishing the magnification requirements. Figure B.30 shows these distances in the example of class II and IV mirrors on a heavy left hand drive commercial vehicle.



Key

1 driver side mirrors

2 passenger side mirrors

3 class II

4 class IV

5 driver ocular reference point

Figure B.30 — Distances between driver ocular reference point and class II and IV mirrors on driver and passenger side for a left hand drive vehicle

Table B.3 lists distance values from ocular reference point to each mirror glass for different existing vehicles.

The distance values within bracket are valid for front-mounted or "hanging" mirrors as opposite to distance values for side-mounted mirrors provided without bracket. When the mirrors are of the front-mounted concepts, values naturally become bigger. An illustration of these two different types of mirror concepts is given in Figure B.31.

Table B.3 — Typical values for some different commercial vehicles

Vehicle type: brand and model (model year 2012)	Distance from ORP to DS class II mirror (mm)	Distance from ORP to PS class II mirror (mm)	Distance from ORP to DS class IV mirror (mm)	Distance from ORP to PS class IV mirror (mm)
Heavy buses				
Mercedes Travego	(1 471)	(2 422)	(1 403)	(2 363)
Setra TC 400	(1 362)	(2 357)	(1 296)	(2 310)
Setra S 515	(1 564)	(2 467)	(1 576)	(2 480)
Volvo 9700	(1 624)	(2 505)	(1 591)	(2 475)
Heavy trucks				
DAF XF (2,6 m variant)	881	2 195	1 002	2 258
HINO 700(2,5 m cab) Lowest ground height	831	2 104	915	2 142
ISUZU GIGA (2,5 m cab)	893	2 146	826	2 182
ISUZU GIGA (2,5 m cab)	(1 117)	(2 421)	—	(2 490)
Mack Pinnacle	930	1 885	950	1 920
MAN TGS (2,3 m cab)	878	2 016	947	2 054
MAN TGX (2,5 m cab)	797	2 114	872	2 150
Mercedes Actros (2,3 m cab)	904	2 080	987	2 115
Mercedes Actros (2,5 m cab)	806	2 144	894	2 177
UD Quon LHD	816	2 123	954	2 202
UD Quon RHD	(988)	(2 370)	—	(2 409)
Volvo FH (2,5 m cab)	890	2 150	1 020	2 220
Volvo FM	890	2 160	1 010	2 230
Volvo VN	992	2 006	1 032	2 019
Medium-heavy trucks				
DAF CF (2,55/2,6 m variant)	903	2 198	1 034	2 246
HINO 500 (2,2 m narrow cab) Lowest ground height	1012	2 012	1 070	2 046
HINO 500 (2,4 m wide cab) Lowest ground height	833	2017	914	2 055
ISUZU FORWARD (2,2 m cab) Short mirror arm	889	1 873	959	1 923
ISUZU FORWARD (2,2 m cab) Long mirror arm	1 021	2 018	1 087	2 064
ISUZU FORWARD (2,2 m cab)	(1 102)	(2 147)	—	(2 200)
ISUZU FORWARD (2,4 m cab) Short mirror arm	889	2063	959	2 109

Table B.3 *(continued)*

Vehicle type: brand and model (model year 2012)	Distance from ORP to DS class II mirror (mm)	Distance from ORP to PS class II mirror (mm)	Distance from ORP to DS class IV mirror (mm)	Distance from ORP to PS class IV mirror (mm)
ISUZU FORWARD (2,4 m cab) Middle mirror arm	952	2 122	1 018	2 166
ISUZU FORWARD (2,4 m cab)	(1 102)	(2 315)	—	(2 363)
Mercedes Atego (2,3/2,45 m cab)	946	2 069	1 022	2 103
Renault Midlum (min mirror offset 0 mm, 2,3 m cab)	808	1 996	744	1 982
Renault Midlum (max mirror offset 200 mm, 2,3 m cab)	942	2 173	884	2 096
Renault Premium (mirror offset 100 mm, 2,3 m cab)	942	2 154	884	2 096
UD Condor LHD (2,1 m cab)	837	1 839	765	1 813
UD Condor RHD (2,1 m cab)	(1 002)	(2 098)	—	(2 151)
UD Condor RHD (2,3 m cab)	(1 002)	(2 251)	—	(2 299)
Volvo FL	978	2 008	1 040	2 073
Light trucks				
ISUZU ELF (1,7 m cab) Short mirror arm	(1 143)	(1 805)	—	—
ISUZU ELF (1,8 m cab) Middle mirror arm	906	1 759	—	—
ISUZU ELF (1,8 m cab) Long mirror arm	(1 167)	(1 955)	—	—
ISUZU ELF (2,0 m cab) Long mirror arm	1 029	1 933	—	—
ISUZU ELF (2,0 m cab) Long mirror arm	(1 177)	(2 115)	—	—
Mercedes Sprinter/VW Crafter (short mirror arm)	962	1 726	—	—
Mercedes Sprinter/VW Crafter (medium mirror arm)	922	1 828	—	—
Mercedes Sprinter/VW Crafter (long mirror arm)	990	1 877		
Average dimensions	917 (1 283)	2 029 (2 261)	952 (1 466)	2 098 (2 354)
Max dimensions	1 029 (1 624)	2 198 (2 505)	1 087 (1 591)	2 258 (2 490)

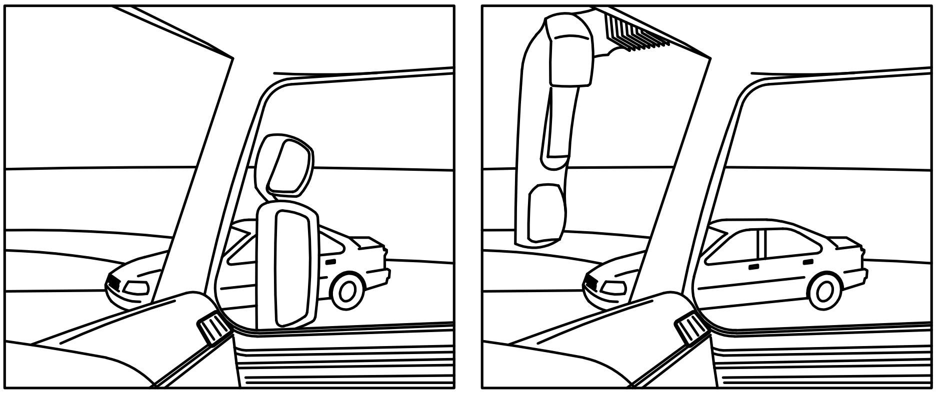
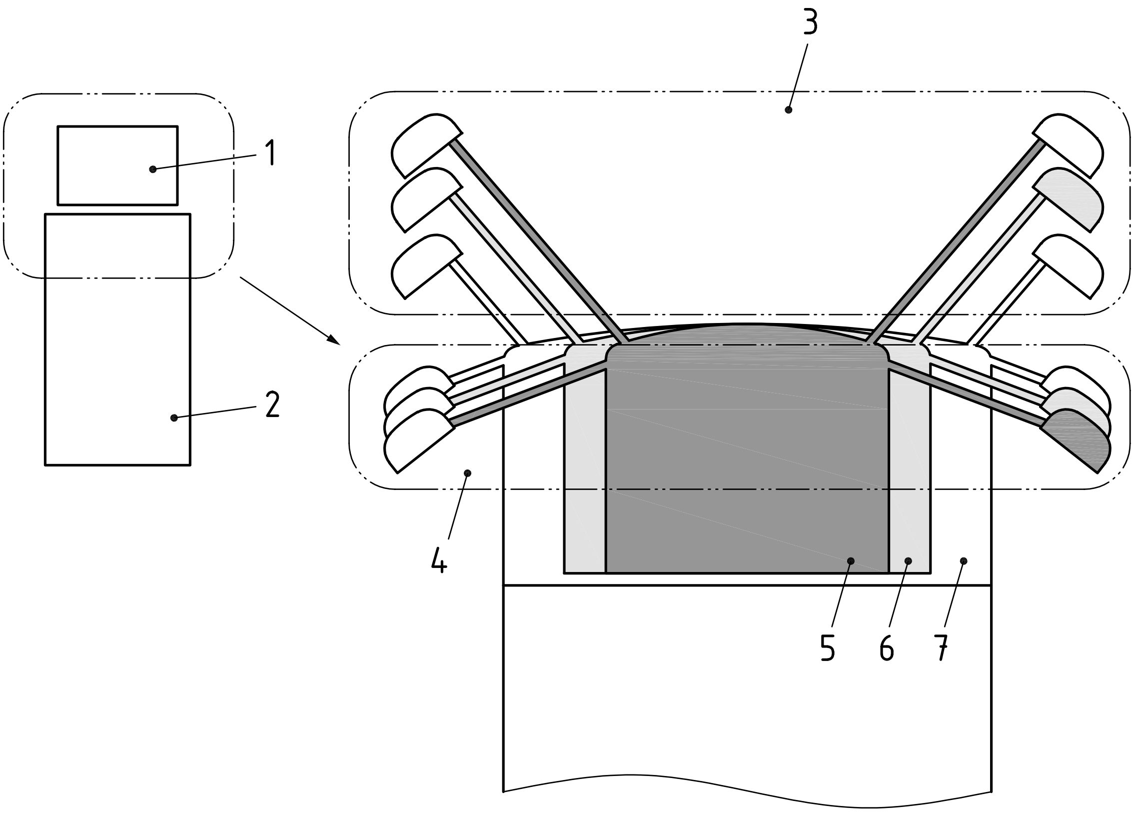


Figure B.31 — Difference between side-mounted (left) and front-mounted (right) mirror concepts

Figure B.32 illustrates the necessary relation between mirror positions and the total superstructure width for side-mounted and front-mounted mirrors.



Key

1 cabin
2 rear body
3 front mounted mirrors
4 side mounted mirrors
5 narrow cabin
6 wide cabin
7 coach bus

Figure B.32 — Relation between mirror concepts and typical commercial cabin widths

The main standard text provides the minimum requirements for class II and IV mirror replacements based on the larger maximum distances coming from the front-mounted mirrors. However, it is also recommended that the actual maximum distances for side-mounted mirrors are used when replacing them by a CMS. From this, the images provided by the CMS get as similar as possible to those provided by the corresponding traditional mirror system. See A.1 for more input on specific vision considerations for commercial vehicles.

Below these complementary values are given for the two classes of side-mounted mirrors.

B.6.2 Maximum distance to driver ocular reference point (driver side)

This subclause describes the maximum value for $a_{mirror/driver}$ that is found in existing homologated vehicles for the given mirror class. It is denoted as $a_{mirror/driver/max}$ and is measured in metres.

For class II and IV UN REGULATION NO. 46 mirrors, this value is defined as:

$a_{mirror/driver/max/side}$ = 1,1 m for side-mounted mirrors

The same value can also be used for vehicles meeting a different national regulation.

RATIONALE: See Table B.2 above for further explanations.

B.6.3 Maximum distance to driver ocular reference point (passenger side)

This subclause describes the maximum value for $a_{mirror/passenger}$ that is found in existing homologated vehicles for the given mirror class. It is denoted as $a_{mirror/passenger/max}$ and is measured in metres.

For class II and IV ECE-R 46 mirrors this value is defined as:

$a_{mirror/passenger/max/side}$ = 2,3 m for side-mounted mirrors

The same value can also be used for vehicles meeting a different national regulation.

RATIONALE: See Table B.2 above for further explanations.

B.7 Maximum mirror distance for a new vehicle with a different layout than existing vehicle types

In the case of a completely new vehicle with a layout that to a great extent differs from the common layouts of existing vehicles within the markets, the performance of the CMS should be adapted to the different geometrical properties of the new layouts. Examples can be vehicles with a central driving position or vehicles where the driver is positioned particularly high or low above the ground. In order to do this, it should be beneficial to study the different coordinate components of the distance a_{mirror} between driver ocular reference point and mirror centre. These component values in the x, y, and z coordinate directions can then be studied and compared against typical values for vehicles that already exist within the market(s) that the vehicle is intended for.

Annex C
(informative)

Calculation of the dimensional magnification and of a correction factor to obtain the angular magnification

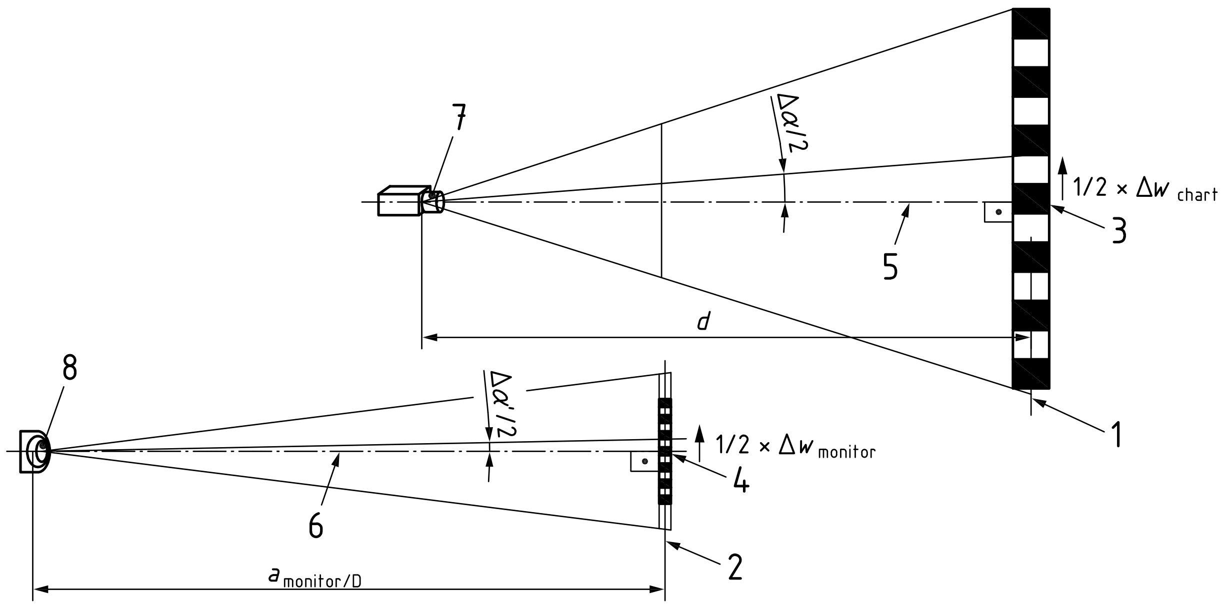
C.1 General

This Annex provides detailed information on the calculation of the dimensional magnification and of a necessary correction factor to obtain the angular magnification in an optically symmetrical design.

C.2 Calculation of the dimensional magnification

The calculation is given for an ideal case with the chart aligned perpendicular to the optical axis of the CMS camera and displayed on the CMS monitor and viewed from a perpendicular observation point onto the chart centre displayed on the monitor.

Figure C.1 describes a test arrangement for measuring the magnification by using a chessboard chart. The CMS camera entrance pupil to chart distance is d, the ORP to CMS monitor distance is $a_{monitor/D}$, and image radial height $1/2{*}\Delta w_{chart}$ and $1/2{*}\Delta w_{monitor}$ refers to the distance from the optical axis point on the chart to the chart specific measuring point (edge of a square) and the corresponding distance of the image displayed on the monitor measured from the image point displaying the optical axis, which is the cross point of the perpendicular line passing the optical centre. The angular size $\Delta\alpha/2$ and $\Delta\alpha'/2$ are given by the following formulae.



Key

1 chart plane

2 monitor display plane

3 optical axis centre on the chart plane

4 displayed chart optical centre point on the monitor

5 CMS camera optical axis aligned perpendicular onto the chart centre

6 perpendicular from chart image centre displayed on the CMS monitor

7 CMS camera entrance pupil

8 optical reference point

Figure C.1 — Sketch describing the test arrangement for measuring the magnification using a chessboard chart

$$\tan\left(\frac{\Delta\alpha}{2}\right)=\frac{\left(\frac{\Delta w_{chart}}{2}\right)}{d} \text{ and } \tan\left(\frac{\Delta\alpha'}{2}\right)=\frac{\left(\frac{\Delta w_{monitor}}{2}\right)}{a_{monitor/D}} \qquad \text{(C.1)}$$

For near axial angular size at centre of the image, the following applies:

$$\Delta\alpha \rightarrow 0 \text{ gives } \tan\left(\frac{\Delta\alpha}{2}\right)\approx\frac{\Delta\alpha}{2} \text{ and}$$

$$\Delta\alpha' \rightarrow 0 \text{ gives } \tan\left(\frac{\Delta\alpha'}{2}\right)\approx\frac{\Delta\alpha'}{2}$$

NOTE 1 The approximation is for “α” given in radian units, but the degree to radian conversion factor is later cancelled in the Formula (C.2).

This provides the on-axis local angular magnification, given as:

$$M_{system}(axial)=\frac{\Delta\alpha'}{\Delta\alpha}=\frac{\Delta w_{monitor}}{\Delta w_{chart}} * \frac{d}{a_{monitor/D}} \qquad \text{(C.2)}$$

And independent on how the Formula (C.2) is derived, this formula alone can be interpreted to provide a relative distribution of dimensional magnification of the displayed image on the monitor along the measured line. Therefore, the measurement given in 7.5.2 provides the planar dimensional magnification of 2D images on a chart plane perpendicular to the optical axis. As the dimensional magnification exhibits a deviation to the angular magnification as the image radial height increases, a correction factor is required for accurate verification of the CMS angular magnification. Note that expression used here as "image radial height" refers to the image distance toward the diagonal orientation from the image centre.

NOTE 2 For an easier understanding that Formula (C.2) provides an in-planar relative magnification, consider decomposing the Formula (C.2) into a term referencing to a unit width $\Delta w_{reference}$ and rewrite as:

$$M_{system}(axial) = \frac{\Delta\alpha'}{\Delta\alpha} = \frac{\Delta w_{monitor}}{\Delta w_{reference}} * \left(\frac{\Delta w_{reference}}{\Delta w_{chart}} * \frac{d}{a_{monitor/D}} \right) \tag{C.3}$$

The first term $\Delta w_{monitor}/\Delta w_{reference}$ shows that the Formula (C.3) is a self-consistent relative dimensional distribution of image on the monitor, and second term gives the dimensional magnification of the chart viewed on the monitor at a reference point.

C.3 Calculation of the angular magnification

Angular magnification of the actually observed scene at position out of the optical axis point is influenced by the effective viewing angle of the CMS camera and by the driver's view angle onto the monitor. Figure C.2 illustrates the definition of $\Delta\alpha/2$, $\alpha/2$, and w_{chart} used to calculate the angular magnification. (The a used in this subclause does not necessarily refer to the maximum angular size but it is used to describe any angular size within the displayed size. And same applies to the monitor viewing angle.)

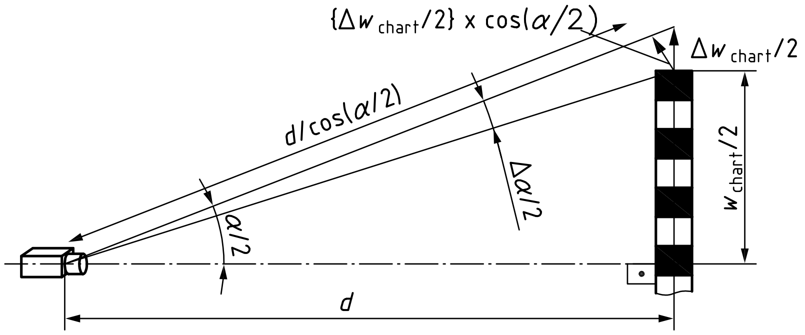


Figure C.2 — Sketch showing the $\Delta\alpha/2$, $\alpha/2$, and w_{chart} definitions

The observed effective width of the chart width, $1/2*\Delta w_{chart}$, when viewed with a viewing angle, $\alpha/2$, shall be corrected by $\cos\left(\frac{\alpha}{2}\right)$, and the observed distance is extended by $\frac{1}{\cos\left(\frac{\alpha}{2}\right)}$.

The viewing angular size, $\Delta\alpha/2$, of the width, $1/2*\Delta w_{chart}$, on the chart plane satisfies:

$$\tan\left(\frac{\Delta\alpha}{2}\right) = \frac{\cos\left(\frac{\alpha}{2}\right) * \left(\frac{\Delta w_{chart}}{2}\right)}{\left(\frac{d}{\cos\left(\frac{\alpha}{2}\right)}\right)} = \cos^2\left(\frac{\alpha}{2}\right) * \left(\frac{\Delta w_{chart}}{2d}\right) \tag{C.4}$$

where $\tan\left(\frac{\alpha}{2}\right) = \frac{\left(\frac{w_{chart}}{2}\right)}{d}$

And similarly, the viewing angle onto the monitor satisfies:

$$\tan\left(\frac{\Delta\alpha'}{2}\right)=\frac{\cos\left(\frac{\alpha'}{2}\right)*\left(\frac{\Delta w_{monitor}}{2}\right)}{\left(\frac{a_{monitor/D}}{\cos\left(\frac{\alpha'}{2}\right)}\right)}=\cos^2\left(\frac{\alpha'}{2}\right)*\left(\frac{\Delta w_{monitor}}{2a_{monitor/D}}\right) \tag{C.5}$$

where $\tan\left(\frac{\alpha'}{2}\right)=\frac{\left(\frac{w_{monitor}}{2}\right)}{a_{monitor/D}}$

And for $\Delta\frac{\alpha}{2}\to 0$ gives $\tan\left(\frac{\Delta\alpha}{2}\right)\approx\frac{\Delta\alpha}{2}$ and

$\Delta\frac{\alpha'}{2}\to 0$ gives $\tan\left(\frac{\Delta\alpha'}{2}\right)\approx\frac{\Delta\alpha'}{2}$

This provides the angular magnification of the scene observed at CMS viewing angle, $\alpha/2$, to be calculated as:

$$M_{system}\left(\frac{\alpha}{2},\frac{\alpha'}{2}\right)=\frac{\Delta\alpha'}{\Delta\alpha}=\frac{\cos^2\left(\frac{\alpha'}{2}\right)}{\cos^2\left(\frac{\alpha}{2}\right)}*\frac{\Delta w_{monitor}}{\Delta w_{chart}}*\frac{d}{a_{monitor/D}} \tag{C.6}$$

A precise measurement of the angular magnification requires the measurement of the distance from the axial centre position. Therefore, it is necessary to re-calculate the individual square edges of the chessboard chart given in step b of 7.5.2 to read the position as a differential distance (height) relative to the optical axis centre position, and then obtain the respective $\alpha/2$ and $\alpha'/2$ value of the individual square edge points in interest.

The discrepancy between the dimensional magnification and the angular magnification increases with increasing viewing angle and the dimensional magnification shall be corrected by a factor of $\left\{\cos^2\left(\frac{\alpha'}{2}\right)/\cos^2\left(\frac{\alpha}{2}\right)\right\}$ to obtain a precise angular magnification. The discrepancy between the angular magnification and dimensional magnification is perceptually not significant in narrow field of view application like class I, II, and III mirror but might require care when class IV is considered. The correction to angular magnification is not compulsory unless separately required.

An installation of monitor too close to driver's ORP is not suitable from ergonomic point of view and a CMS monitor with installation condition that satisfy: $w_{monitor} << a_{monitor/D}$, the following approximation $\cos^2\left(\frac{\alpha'}{2}\right)\approx 1$ is applicable.

C.4 Practical hints and precaution for the angular magnification measurement

For measuring the magnification precisely, it is necessary to precisely orient the camera optical axis perpendicular to the chart planar surface. If the camera optical axis is tilted from the perpendicular line of the chart, the captured image will show asymmetry of the chart square and lines. Adjust the tilting until symmetry is achieved. Depending on the precision of the assembly process of the CMS optical system, some amount of asymmetry can remain even after best alignment. After tilt alignment of optical axis perpendicular to chart plane, shift the chart so that the measuring line comes centre to cross the optical axis.

C.4.1 Perpendicular adjustment of the chart

A flat mirror placed parallel to the chart is useful to orient the CMS camera optical axis perpendicular to the chart. The reflected mirror image of the self-portrait camera centre observed on this flat mirror indicates the base point of the perpendicular line crossing the CMS optical centre. Therefore, adjusting the camera orientation to bring the self-portrait image optical centre exactly to image centre makes CMS orientation aligned in parallel to chart perpendicular line. Aforementioned procedure assumes that camera optical centre is precisely adjusted to image optical centre.

If the optical centre axis point is unknown, or if the camera field of view representing the monitor defined size is outside the optical axis, consider aligning to the most probable centre point.

Next, if the measuring reference line is placed with an off-set shift from optical axis centre, the line becomes curved. See examples of curved lines for all lines not passing the optical centre in Figure 25 of 7.5.2. Readjust by shifting the chart in parallel so that the measuring line crosses the optical centre until obtaining a straight or nearly straight measuring line.

C.4.2 Procedure for high distortion cases

It is accepted to verify and report the compliance in accordance to the range determined by the flat, horizontal portion of the road area, as described for determining the required field of view in Annex B, instead of the angular range given in 3.2.18 or 3.2.20, as indicated in 7.5.2.1.

C.4.3 Asymmetric or irregular design cases

All measurement procedures, remarks and related explanation above were considering an optically symmetric design. But in practical use, it is also possible that some intentional asymmetry is applied to the CMS design. A known example is the case of ultra wide view camera combined with image conversion, in which an intended portion of captured camera image is displayed on the monitor, with view perspective differing from the actual CMS camera optical axis and adjusted to provide a view with perspective correction according to intended view orientation.

In such a CMS system which is designed to have an intended viewing orientation differing from the optical axis of CMS camera, the performance characteristics of the CMS shall be measured so that the “optical axis” is replaced by this “intended viewing orientation”, and the evaluation chart aligned orthogonal to this “intended viewing orientation”. Verify the performance according to the design intended orientation. (e.g. if a cropped image out of a wide view lens is used to display and replace a specific class of traditional mirror, verify that the requirements according to that specific cropped image, assuming its optical axis orientated to that particular intended cropped image view, and align the chart so that it lays orthogonal to this intended orientation).

Annex D
(informative)

Complementary information for resolution measurement

D.1 General

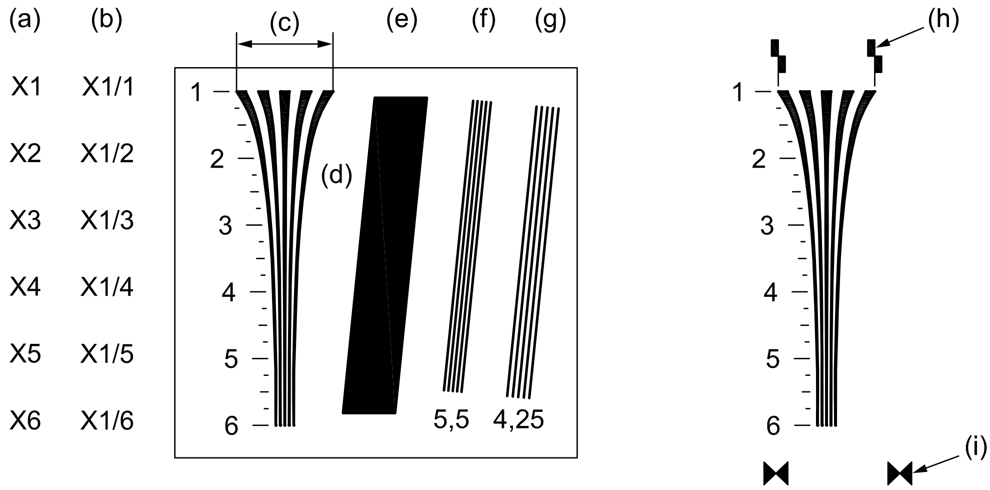
This Annex provides complementary information to the measurement method described in 7.5.3. This Annex describes the additional guidelines when difficulties occur in the judgment of the measurement results. In addition, it provides information for converting the measured value when standard ISO 12233 resolution measurement is applied.

The test method described in 7.5.3 provides a practical measurement procedure to directly verify the spatial frequency on the chart, and steps to determine the limit point. The limit resolution MTF10 is described in 3.13 as a measurable in units of line widths per picture height [LW/PH] of a hypothetical square image. Therefore, a conversion is required when resolution is measured according to ISO 12233 for a rectangular image $W_{monitor/hor} \times H_{monitor/ver}$.

D.2 Design of hyperbolic chart

This subclause provides some basic design information of the hyperbolic test chart, in case only the hyperbolic part of ISO standard chart is partially used to the image when evaluating a CMS. When partial hyperbolic chart is used, the reference image height is not explicitly given on the chart and therefore, the reference “height” shall be cared by referencing to the 9 lines width as described in the Figure D.1, and printed appropriately like in the example in the figure at right side.

Figure D.1 gives detailed explanations on how a hyperbolic chart is designed. The surrounding area shall be covered with an 18 % reflection neutral grey area (for details see Annex F). The example shown in the figure also contains two additional parallel bar charts with a determined spatial frequency. The parallel chart is used complementary in case difficulty occurs in determining the limit resolution only from hyperbolic chart. The parallel bar chart shall be composed of at least four bars. The parallel bar shown at (f) is a parallel bar chart with line and space spatial frequency which is 5,5 times higher than at chart position (c), and at (g) is a parallel bar chart with line and space spatial frequency which is 4,25 times higher than at chart position (c). The spatial frequency of the additional parallel bar chart (f) and (g) shall be determined according to the target verification criteria of the system to be evaluated, which is used for final verification of compliance to minimum requirement. Follows instruction given in 7.5.3 to calculate the spatial frequency of the parallel chart appropriate to verify the requirement limit. When a standard chart is partially used, the reference “HEIGHT” of the chart is lost and a new reference width is required nearby the hyperbolic chart to be used. An example of reference width indicator symbol is show at the right side of Figure D.1. (The term “line” and “space” are used to indicate the “black” and “white” line widths, respectively).



Key

(a) multiplication factor for spatial frequency at respective position on the chart
(b) multiplication factor for line width at respective position on the chart
(c) width of nine lines at reference position 1 on the chart
(d) area used to detect reference white level
(e) area used to detect reference black level or for SFR measurement
(f) exemplar line and space parallel bar chart with spatial frequency 5,5 times higher than reference position 1
(g) exemplar line and space parallel bar chart with spatial frequency 4,25 times higher than reference position 1
(h) example of reference width indicator (box cross edge symbol, nine-line width in this example)
(i) example of reference width indicator (triangular cross edge symbol, nine-line width in this example)

Figure D.1 — Detail of a hyperbolic chart and examples of reference width indicator

NOTE The hyperbolic charts which are available on the market indicate the nominal spatial frequency at reference position 1. The respective width of a single line at this reference position 1 equals to the image “HEIGHT” divided by the nominal spatial frequency given for position 1, independent of the chart orientation.

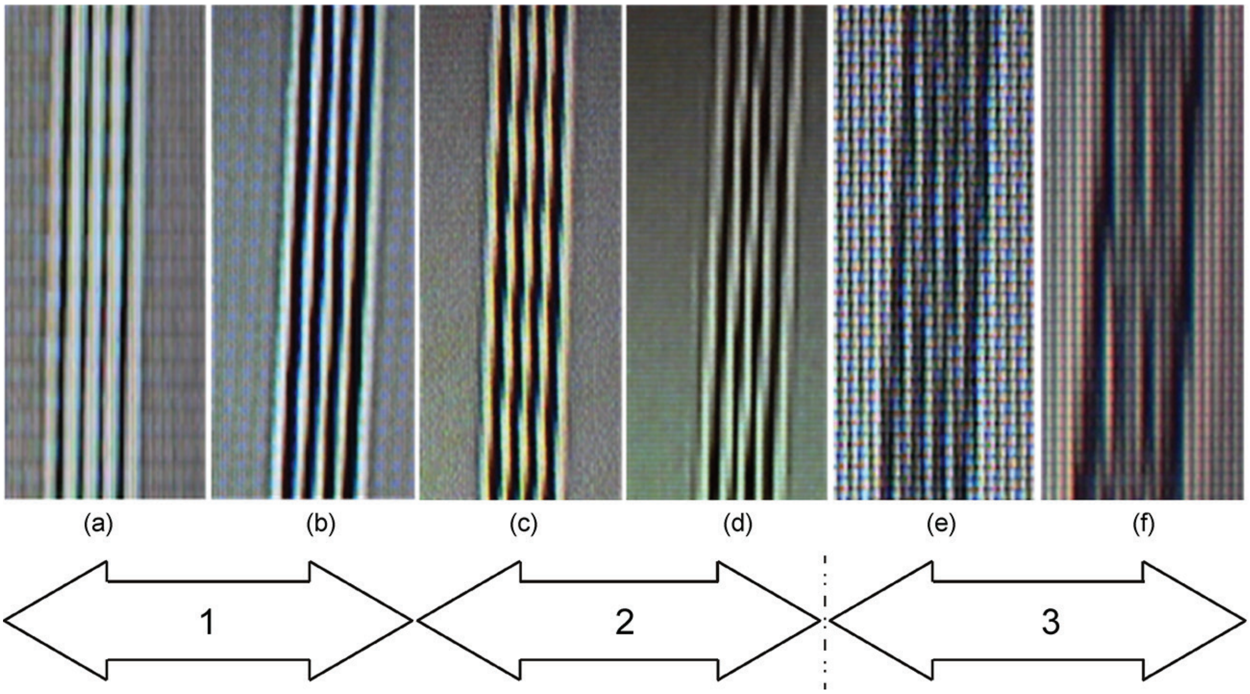
EXAMPLE Chart with image HEIGHT = 1 000 [mm/PH] and its hyperbolic chart at position 1 indicating 200 [LW/PH] means that a single line width at position 1 is 1 000 [mm/PH]/200 [LW/PH] = 5 [mm/LW]. At position 4 for example, the spatial frequency is increased four times and the width is reduced by 1/4 compared to the line at position 1, and the resulting line width at position 4 is 5/4 [mm/LW], while the frequency is 4 × 200 [LW/PH].

D.3 Guideline on the classification of acceptance level of the complementary parallel bar chart reproduced on CMS monitor

The resolution (MTF) is analysed by reading directly the output signal response amplitude on the monitor display in respect to the spatial frequency of the hyperbolic zone plate black and white chart (see Figure D.1) or equivalent. The position where the output amplitude that corresponds to the 10 % of the amplitude of original black and white level gives the spatial frequency for MTF10, as described in 3.13.

The output signal amplitude is verified from lower frequency toward higher frequency until reaching a point where the output signal amplitude is reduced to 10 % of the neighbouring black and white reference chart output level. In some CMS system or measuring environment, the signal amplitude of the CMS output displayed image captured using an evaluation reference camera might not decrease down to 10 %. This can occur due to low sampling frequency of the system, due false dark signal of inter-pixel “screen door effect” observed when using a high resolution reference camera, due to image enhancement post-processing in the CMS, or further others side effects. All such effects prevent an exact determination of the spatial frequency point where modulation intensity might decrease down to 10 % of the original chart image. In such case, the limiting resolution of the CMS shall be determined by way of "Visual Resolution" evaluation as defined in ISO 12233, combined by the complementary parallel bar chart for distinguishability limit verification.

By preparing a specific bar chart with the spatial frequency equal to the acceptance limit of the CMS under compliance test, the output image of the CMS is compared to the exemplar image as given for acceptance limit guideline in Figure D.2. The CMS output image shall at least satisfy the bar chart distinguishability in the perception level classified as (c) or (d). Images equal to or inferior to examples given in (e) or (f) are classified as non-compliant to requirement as CMS.



Key

1 distinguishable examples of displayed image of the captured parallel bar chart

2 barely distinguishable examples of displayed image of the captured parallel bar chart

3 non-distinguishable examples of displayed image of the captured parallel chart which are not suitable as CMS

Figure D.2 — Guide of visual acceptance level

Figure D.2 shows a classification using exemplar output image and acceptance level of the output image displayed on the monitor display. The observed image on the CMS monitor screen classified among (a) to (b) are examples of good distinguishability by CMS, (c) to (d) are examples of barely distinguishable case. The (e) to (f) are examples classified as non-distinguishable case. In case of example (c) and (d), the image already exhibit some amount of aliasing, but the four bars are still clearly distinguishable independent of image position. But in case (e) and (f), false bars are generated to certain amount along the chart, making difficult the interpretation of the scene depending on the position observed. Therefore, such CMS as (e) and (f) are no longer suitable to observe the scene containing details higher than that spatial frequency range of the chart.

D.4 Conversion required when applying standard resolution MTF measurement on CMS with different aspect ratio than 1:1

The resolution unit given in line widths per picture height [LW/PH] in ISO 12233 refers to the image "HEIGHT", where "HEIGHT" is the shorter edge or dimension of the rectangular image under evaluation, whichever is the layout orientation of the image. The requirement for resolution and sharpness in this International Standard, ISO 16505, is defined in a 1:1 aspect ratio monitor to make the definition neutral to aspect ratio of each design specific CMS in a hypothetical square image, where the field of view lays equally in horizontal and vertical image size. Following ISO 12233 for measuring the resolution, it is necessary that the measured value is appropriately cared for different aspect ratio. The "line widths per picture height" units or [LW/PH] is described in ISO 12233:2014, 3.14.

The following subclause provides information for conversion of resolution $\mathrm{MTF10}_{(\mathrm{W,H})}$ measured in a display with aspect ratio of $W_{monitor/hor}$:$H_{monitor/ver}$ and the definition of resolution requirement $\mathrm{MTF10}_{(1:1)}$ given on a 1:1 aspect ratio image. For evaluation using partially cropped square image, refer to D.5.

For a CMS displayed on a monitor with aspect ratio:

$$\frac{W_{monitor/hor}}{H_{monitor/ver}} \neq 1 \tag{D.1}$$

and resolution or sharpness measured according to ISO 12233, a correction might be required according different cases of measuring orientation or display layout orientation.

a) Correction is necessary for horizontal resolution when displayed on monitor with aspect ratio $W_{monitor/hor}:H_{monitor/ver} > 1$.

b) Correction is not necessary for vertical resolution when displayed on monitor with aspect ratio $W_{monitor/hor}:H_{monitor/ver} \geq 1$.

c) Correction is not necessary for horizontal resolution when displayed on monitor with aspect ratio $W_{monitor/hor}:H_{monitor/ver} \leq 1$.

d) Correction is necessary for vertical resolution when displayed on monitor with aspect ratio $W_{monitor/hor}:H_{monitor/ver} < 1$.

NOTE The same conversion applies to sharpness measurement.

D.4.1 Horizontal resolution, displayed in an aspect ratio $W_{monitor/hor}:H_{monitor/ver} > 1$

Figure D.3 illustrates a relation of the square dimension "A × C", A = C (in phantom lines) corresponding to the definition of CMS resolution requirement and a rectangular hatched image sized $W_{monitor/hor} \times H_{monitor/ver}$ where the resolution could actually be measured according to ISO 12233.

The horizontal resolution $\mathrm{MTF10}_{(\mathrm{W,H})/hor}$ (measured in [LW/PH] units according to ISO 12233) for the hatched area, $W_{monitor/hor} \times H_{monitor/ver}$, is given as a spatial frequency in terms of number of lines in the shorter dimension of the rectangle, which in this case is $H_{monitor/ver}$.

Furthermore the horizontal resolution requirement of CMS is defined on a square image as $\mathrm{MTF10}_{(1:1)/hor}$ is given by the number of lines contained in the hypothetical height with dimension $A = W_{monitor/hor}$, which is $W_{monitor/hor}/H_{monitor/ver}$ times higher than the value of $\mathrm{MTF10}_{(\mathrm{W,H})/hor}$ contained within $H_{monitor/ver}$.

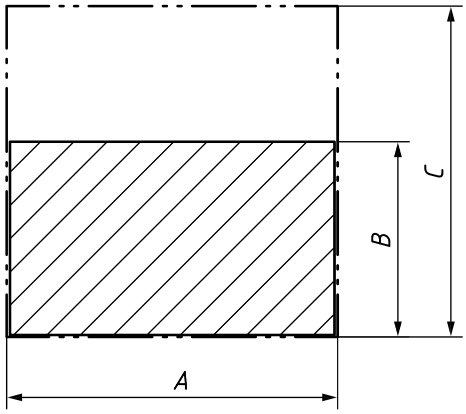
Therefore, it is necessary to compensate the measured $\mathrm{MTF10}_{(W:H)/hor}$ value for the increased "height" by:

$$MTF10_{(1:1)/hor} = \frac{W_{monitor/hor}}{H_{monitor/ver}} * MTF10_{(W:H)/hor} \tag{D.2}$$

where

$\mathrm{MTF10}_{(1:1)/hor}$ is the horizontal spatial frequency as described in 3.14 in the hypothetical square image;

$\mathrm{MTF10}_{(\mathrm{W:H})/hor}$ is the spatial frequency as measured according to ISO 12233 in [LW/PH] units.



Key

A actual horizontal dimension, $W_{monitor/hor}$

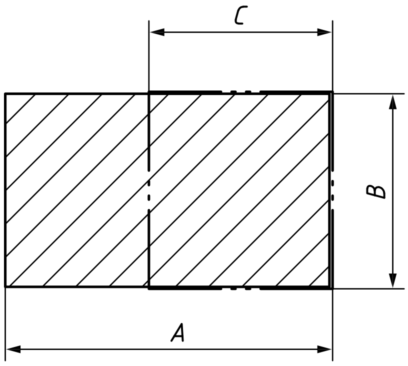
B actual vertical dimension, $H_{monitor/ver}$, "height" of the current displayed hatched area

C hypothetical vertical dimension to define requirement in 1:1 aspect ratio

Figure D.3 — Horizontal resolution for $W_{monitor/hor}:H_{monitor/ver} > 1$

D.4.2 Vertical resolution, displayed in an aspect ratio $W_{monitor/hor}:H_{monitor/ver} \geq 1$

Figure D.4 illustrates a relation of the square dimension "B × C", B = C (in phantom lines) corresponding to the definition of CMS resolution requirement and a rectangular hatched image size $W_{monitor/hor} \times H_{monitor/ver}$, where the resolution could actually be measured according to ISO 12233.



Key

A actual horizontal dimension, $W_{monitor/hor}$

B actual vertical dimension, $H_{monitor/ver}$, "height" of the current displayed hatched area

C hypothetical horizontal dimension to define requirement in 1:1 aspect rotation

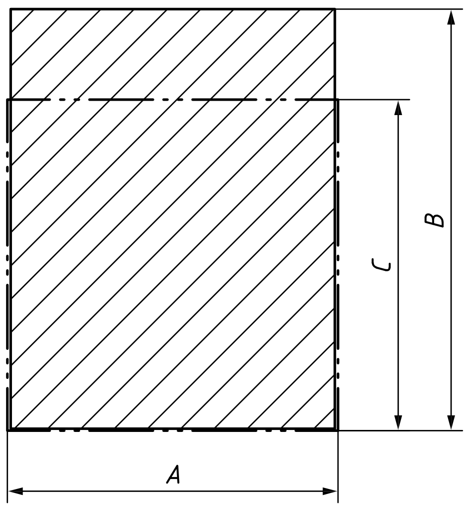
Figure D.4 — Vertical resolution for $W_{monitor/hor}:H_{monitor/ver} \geq 1$

The square dimension height is corresponding to the definition of CMS resolution requirement "B" equals the actual height of the rectangular image size $W_{monitor/hor} \times H_{monitor/ver}$. Therefore:

$$MTF10_{(1:1)/ver} = MTF10_{(W:H)/ver} \quad \text{(D.3)}$$

D.4.3 Horizontal resolution, displayed in an aspect ratio $W_{monitor/hor}:H_{monitor/ver} \leq 1$

Figure D.5 illustrates a relation of the square dimension "A × C", A = C (in phantom lines) corresponding to the definition of CMS resolution requirement and a rectangular hatched image sized $W_{monitor/hor} \times H_{monitor/ver}$, where the resolution could actually be measured according to ISO 12233.



Key

A actual horizontal dimension, $W_{monitor/hor}$, “height” of the current displayed hatched area

B actual vertical dimension, $H_{monitor/ver}$

C hypothetical vertical dimension to define requirement in 1:1 aspect rotation

Figure D.5 — Horizontal resolution for $W_{monitor/hor}:H_{monitor/ver} \leq 1$

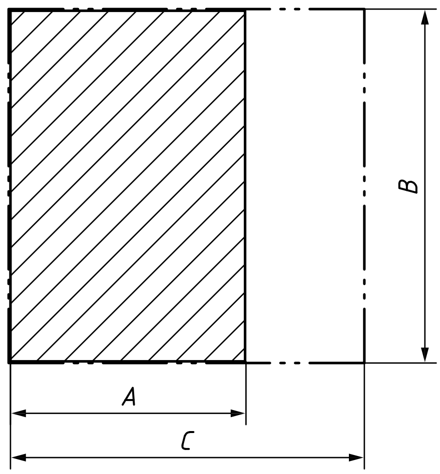
The square dimension height corresponding to the definition of CMS resolution requirement “A” equals the actual height (= the shorter dimension) of the rectangular image size $W_{monitor/hor} \times H_{monitor/ver}$. Therefore:

$$MTF10_{(1:1)/hor} = MTF10_{(W:H)/hor} \quad \text{(D.4)}$$

D.4.4 Vertical resolution, displayed in an aspect ratio $W_{monitor/hor}:H_{monitor/ver} < 1$

Figure D.6 illustrates a relation of the square dimension “B × C”, B = C (in phantom lines) corresponding to the definition of CMS resolution requirement and a rectangular hatched image sized $W_{monitor/hor} \times H_{monitor/ver}$ where the resolution could actually be measured according to ISO 12233.

The vertical resolution $\text{MTF10}_{(W,H)/hor}$ (measured in [LW/PH] units according to ISO 12233) for the hatched area $W_{monitor/hor} \times H_{monitor/ver}$ is given as a spatial frequency in terms of number of lines in the shorter dimension of the rectangle “A”, which in this case is $W_{monitor/hor}$.



Key

A actual horizontal dimension, $W_{monitor/hor}$, "height" of the current displayed hatched area

B actual vertical dimension, $H_{monitor/ver}$

C hypothetical horizontal dimension to define requirement in 1:1 aspect ratio

Figure D.6 — Vertical resolution for $W_{monitor/hor}:H_{monitor/ver} < 1$

The vertical resolution requirement of CMS is defined on a square image as $\mathrm{MTF10}_{(1:1)/\mathrm{hor}}$ is given by the number of lines contained in the hypothetical height with dimension "C" = $H_{monitor/ver}$, which is $H_{monitor/ver}/W_{monitor/hor}$ times higher than the value of $\mathrm{MTF10}_{(\mathrm{W,H})/\mathrm{hor}}$ contained within $W_{monitor/hor}$.

Therefore, it is necessary to compensate the measured $\mathrm{MTF10}_{(\mathrm{W:H})/\mathrm{hor}}$ value for the increased "height" by:

$$MTF10_{(1:1)/ver} = \frac{H_{monitor/ver}}{W_{monitor/hor}} * MTF10_{(W:H)/ver} \quad \text{(D.5)}$$

where $\mathrm{MTF10}_{(1:1)/\mathrm{ver}}$ is the vertical spatial frequency as described in 3.15 in the hypothetical square image, and $\mathrm{MTF10}_{(\mathrm{W:H})/\mathrm{ver}}$ is the spatial frequency as measured according to ISO 12233 in [LW/PH] units.

D.5 Evaluation in a partially captured image within the displayed field of view

This subclause provides information to work with cropped image size. When evaluating the CMS resolution with a partial portion of the monitor output image captured by a reference camera, a practical way is to measure the resolution with a square cropped image. The benefit of evaluating a square cropped image is that the measured value can be handled independent of the aspect ratio of the original displayed image.

If the image size of evaluation area is reduced from the monitor defined horizontal size $W_{monitor/hor}$ or monitor defined vertical size $H_{monitor/ver}$ to a cropped image with size of $W_{crop} \times H_{crop}$ where $W_{crop} = H_{crop}$, the number of periodic lines observable within the cropped image is reduced by the formulae below, respectively, depending on the horizontal or vertical orientation in interest.

$$\left(\frac{W_{crop}}{W_{monitor/hor}}\right) \text{ or } \left(\frac{H_{crop}}{H_{monitor/ver}}\right)$$

Therefore, the requirement value measured to within the square cropped image is uniquely reduced by this ratio. Formula (15) or (16) gives the requirement as the number of distinguishable within the defined field of view, while the number of distinguishable within the partial square cropped image is recalculated as:

for horizontal, and

$$M_{mirror/avg} * \left(\frac{W_{crop}}{W_{monitor/hor/\min}} \right) * \alpha_{mirror/hor/\min} * V_{eye/\min} * 60 \frac{arc \min}{\circ} \qquad \text{(D.6)}$$

for vertical.

$$M_{mirror/avg} * \left(\frac{H_{crop}}{H_{monitor/ver/\min}} \right) * \alpha_{mirror/ver/\min} * V_{eye/\min} * 60 \frac{arc \min}{\circ} \qquad \text{(D.7)}$$

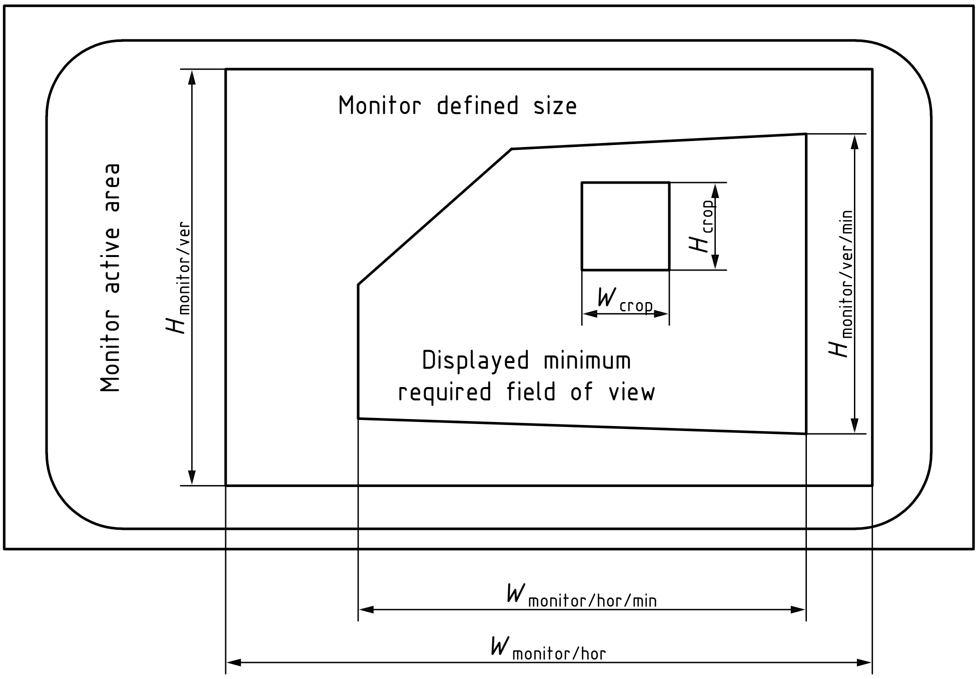


Figure D.7 — Measure cropped image resolution with reference camera

Note that the value of Formulae (D.6) or (D.7) given in [LW/PH] unit uses its own height $W_{crop} = H_{crop}$ as reference, and the chart “HEIGHT” shall be adjusted according to this square cropped image height.

EXAMPLE If the horizontal resolution requirement of a CMS defined to an image displayed on a monitor horizontal size 0,2 [m] is 260,4 [LW/PH], measuring the displayed image cropped for an image size of 0,08 [m] width means that the number of lines distinguishable in this reduced area is proportionally reduced by same ratio and the number of distinguishable lines shall satisfy at least 0,08/0,2 of the 260,4 = 104,2 [LW/PH] within this cropped 0,08 [m] square image. When measuring with a hyperbolic chart, adjust the chart height to this 0,08 [m] image “HEIGHT” and verify that it satisfy 104,2 [LW/PH] in within this cropped image.

NOTE The same applies for sharpness measurement.

D.6 Evaluation with SFR method in a partially captured image within the displayed field of view

When measured using SFR method from square image captured by a reference camera, and with the results given in units of pixel sampling frequency, the obtained pixel sampling frequency values from the SFR measurement shall be multiplied by the number of rows of pixels per image height of the cropped square image in pixel counts of the reference camera. This calculation converts the frequency given in pixel sampling frequency units to frequency units of [LW/PH] of the cropped image size. The value corresponds to requirement given by Formula (D.6) or (D.7).

In a square image of N × N pixels, the sampling frequency is equal to 1 for signals frequency containing N sampled data or equivalent to N row in height, which gives N × 1 [LW/PH]. Details of unit conversion for SFR measurement is found in the ISO 12233:2014, Annex H.

NOTE 1 If SFR is processed directly onto the CMS original camera output cropped square image itself, the number of rows of pixels corresponds to its own number of pixel in the square cropped image height.

EXAMPLE If SFR is measured in a cropped square image containing 100 × 100 pixels on the monitor, and using a reference camera with four times more pixel per row and column, that is 400 × 400 pixels, the sampling frequency point equal to (0,8/4) = 0,2 in the reference camera output contains information equal to 400 * (0,8/4) = 80 line widths per picture height, to that specific cropped image. Or a sampling frequency point equal to 1/4 = 0,25 in the reference camera output contains 400 * (1/4) = 100 line widths per picture height. (Note that in this example, the four times increased over-sampling frequency with a reference camera, relative to the cropped image pixel counts, provides results in a frequency region well under the frequency region where the reference camera can exhibit some aliasing. Aliasing due to the sampling frequency might be observed at sampling frequency region above the Nyquist frequency point.)

NOTE 2 The spatial frequency given in sampling frequency units is dependent on the measuring pixel numbers while the spatial frequency given in [LW/PH] units is independent to the measuring pixel and only dependent on the image height. Therefore, value converted to [LW/PH] in the reference camera remains valid as image displayed on the monitor pixels with different pixel counts.

NOTE 3 The same correction applies for sharpness measurement when using SFR measurement.

NOTE 4 Otherwise noticed, the sampling frequency unit to [LW/PH] conversion considers a square pixel.

Annex E
(informative)

Correlation between Resolution (MTF) and spatial frequency measured using SFR method for depth of field evaluation or sharpness evaluation

E.1 General

The spatial frequency response (SFR) measurement method has been introduced in ISO 12233 as one efficient method to quantitatively evaluate the electro-optical system spatial resolution capability of an electronic still-camera. It enables reproducible results when applied properly to system evaluation, not exhibiting false signals.

However, several limitations emerge due to the intentional post processing of camera signal which is often applied to enhance an image. Edge enhancement is a well-known technology among others techniques but such a processing will strongly affect the reproducibility of the SFR measurement. Along the discrete sampling of image; the SFR measurement improperly used can lead to incorrect results of limit resolution measurement.

In a manually adjustable digital camera evaluation, the evaluation can be done analytically, by individual components of the system, by properly controlling the side effects. On the other hand, in a CMS system, it comes as an integrated system without the capability to turn off part or entire image processing of such enhancement, or any other process affecting the measurement. Thus, results obtained by the evaluation of the spatial frequency response of the slanted edge spread function SFR measurement might not provide precise information of the system limit resolution. Therefore, a traditional resolution measurement method using black and white hyperbolic resolution chart is advised to be used to evaluate the resolution (MTF) performance of the CMS.

Nevertheless, the SFR slanted edge spread function measurement has the benefit of using a simple black slanted edge chart, independent of distance as long as certain amount of image size is captured for evaluation.

The resolution measurement using SFR method in ISO 12233 is performed on linearized conversion images, or properly corrected. But due to the difficulties to obtain a linear gamma = 1 relation in a CMS closed system, it is not mandatory to precisely obtain the correct optoelectronic conversion (OECFs) according to ISO 14524:2009;[5] but it is advised to follow whenever possible.

To take the advantage of the usage of SFR measurement as alternative method for limit resolution evaluation, a look-up table of correlation shall be obtained between the perceptual limit resolution (MTF) and the SFR measurement of the specific CMS. Actual limit resolution MTF10 of the CMS can be estimated from the SFR measurement results once this deviation of the limit resolution value existing between the actual visual limit resolution (MTF) and SFR method is obtained in a form of look-up table, and as a function of spatial frequency measured by SFR method. This correlation is maintained as long the CMS system is evaluated under same luminance environment that the look-up table is created.

Illumination conditions among others can alter the obtained correlation.

E.2 How to create a correlation curve

A practical way to obtain such a deviation curve for the estimation of actual limit resolution (MTF) is by plotting the spatial frequency values observed by hyperbolic resolution chart analysis versus spatial frequency values obtained from SFR resolution curve, for several different focusing conditions of the CMS.

An example of the SFR characterization curve is shown in Figure E.2 (c). SFR is a function of sampling frequency, and later referred to as SFR(f) whenever appropriate. For the purpose of CMS evaluation, the spatial frequency deviation is obtained for MTF10 for limit resolution and MTF50 for sharpness evaluation, which corresponds to the sampling frequency which gives SFR(f) = 0,1 and SFR(f) = 0,5 respectively. The corresponding frequency are abbreviated as f_{SFR}(SFR = 0,1) and f_{SFR}(SFR = 0,5) in the following explanation.

In an ideal case with no false signals, the spatial frequency obtained from the SFR characterization curve for SFR = 0,1, that is the f_{SFR}(SFR = 0,1), equals the spatial frequency MTF10 and the spatial frequency obtained from the SFR characterization curve for SFR = 0,5, that is the f_{SFR}(SFR = 0,5), equals the spatial frequency MTF50.

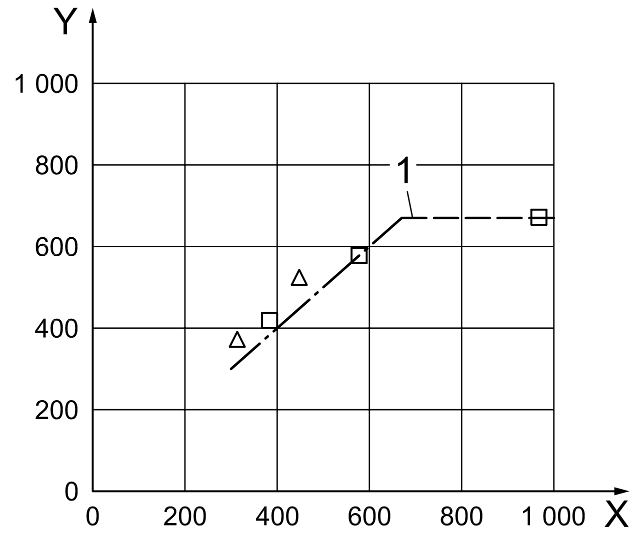
The CMS is expected to be designed as fixed focus camera, making it difficult to vary the lens focus over different focusing distance. But a rough estimation of perceptual limit resolution MTF10 versus the spatial frequency value measured by SFR method as f_{SFR}(SFR = 0,1) can still be obtained by plotting several measurement points, with a chart placed at several close-up distance conditions to artificially create a defocused image, although this is not precisely true from optical point of view.

Using a chart with hyperbolic resolution chart and an adjacent black slanted edge chart, the limit resolution MTF10 is evaluated using a hyperbolic chart, and in parallel, the SFR is calculated from the small portion of the adjacent slanted edge [see examples of the charts in Figure D.1 chart under (c) and chart (e) respectively]. The limit spatial frequency MTF10 is determined from the position on the chart where the output signal amplitude is reduced to 10 %; and in parallel, the spatial frequency value where SFR = 0,1, f_{SFR}(SFR = 0,1), is read from the SFR curve of the adjacent slanted edge. Artificially defocus the CMS camera by positioning the chart at multiple close-up distances to make a deviation curve plot. As an example of one measurement point, see Figure E.2 (a) where the limit resolution MTF10 is obtained from the position of the chart that outputs 10 % of signal amplitude around frequency position 4.3, and the sampling frequency from SFR = 0,1 point obtained from Figure E.2 (c) curve at f_{SFR}(SFR = 0,1) = 0,395. In this particular example with low image edge enhancement case and without false signals, deviation observed between the MTF10 and the spatial frequency obtained from SFR measurement for SFR(f) = 0,1 is small.

From multiple measured points, a correlation of the frequency obtained from the hyperbolic chart which gives the MTF10 frequency and the spatial frequency value obtained to give SFR = 0,1 is obtained as f_{SFR}(SFR = 0,1) for the respective SRF measurement, and plotted to estimate the visual resolution MTF10 from the f_{SFR}(SFR = 0,1) value to create the look-up table. The spatial frequency f_{SFR}(SFR = 0,1) can now be used to estimate the visual limit resolution MTF10 of the CMS system using this look-up table.

As defined in Annex D, the input chart periodic signal can deteriorate to a level that the original periodic signal image are no longer perceived correctly on the monitor output image. In those range of spatial frequency, the classification as defined in D.2 shall be used to find the limit frequency of MTF10 and correlated to the spatial frequency measured by SFR method. The higher spatial frequency obtained beyond this point from the SFR curve as f_{SFR}(SFR = 0,1) are results of false signals and the actual visual resolution of output image is “saturated” and limited to the spatial frequency classified by (c) or (d), which is defined as MTF10 in this International Standard for such situation. After taking multiple evaluation points, a correlation curve is obtained.

An illustrative example of such correlation curve is shown in Figure E.1. In the lower frequency range, a linear correlation might be observed but at higher sampling frequency of the f_{SFR}(SFR = 0,1) beyond the CMS limit resolution capability, the actual observed image limit resolution MTF10 becomes saturated. At this range, the f_{SFR}(SFR = 0,1) value obtained from the SFR measurement curve no longer reflects the perceivable CMS limit resolution. In such range, the frequency value f_{SFR}(SFR = 0,1) given by SFR method can largely deviate from actually perceivable limit as shown in this example.



Key

□	f_{SFR}(SFR = 0,1)
△	f_{SFR}(SFR = 0,5)
— · —	slope = 1 curve
— — —	limit resolution
1	absolute limit
X	f_{SFR}(SFR = 0,1) or f_{SFR}(SFR = 0,5) [LW/PH]
Y	MTF10 or MTF50 direct signal analysis [LW/PH]

Figure E.1 — An illustrative example of correlation curve between frequency obtained by f_{SFR}(SFR = 0.1) **versus direct limit resolution MTF10 from hyperbolic chart signal analysis**

NOTE 1 For the conversion of sampling frequency units to line widths per picture height or [LW/PH] units, see D.5.

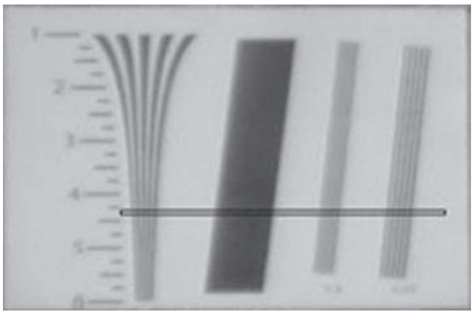
NOTE 2 The frequency estimated by this SFR method does not provide an absolute capability of the CMS. A confirmation of the resolution (MTF) using the parallel black and white bar chart is always advised.

NOTE 3 Image processing with edge enhancement will give steep tone gradation and an apparent increase in spatial response. However, this virtual increase in sharpness does not necessarily contribute in perceiving detail of the scene, which is a critical requirement when considering the observation of small scene details far behind the vehicle. Thus, actual resolution (MTF) measurement is also required to ensure capability to observe the detail of the scene far behind the vehicle, aside from the sharpness measurement.

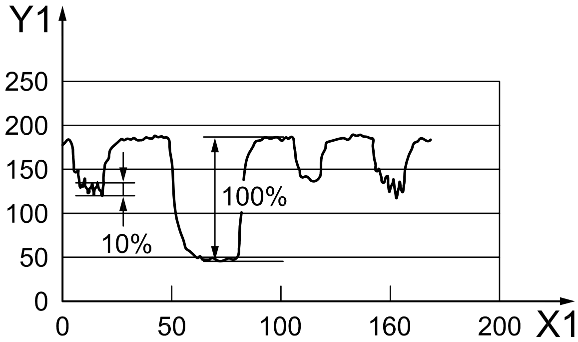
E.3 Example of SFR measurement affected by image processing

An example of the effect observed by different levels of image edge enhancement process in a camera is demonstrated. A combination of image of the camera output signal, its luminance output signal amplitude read value at specific spatial frequency point, and its spatial frequency SFR characteristic are shown in Figure E.2 (a) to (g).

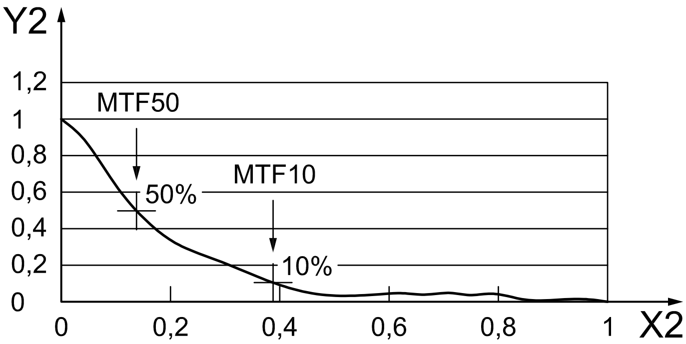
Figures E.2 (a) to (c) are for an image of camera with low edge enhancement process, and Figures E.2 (d) to (g) are for the same image processed with middle level edge enhancement.



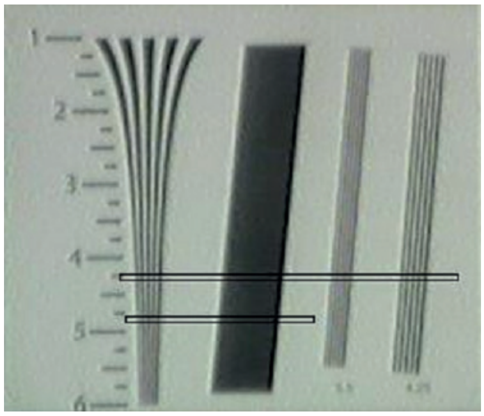
(a) Image with low enhancement



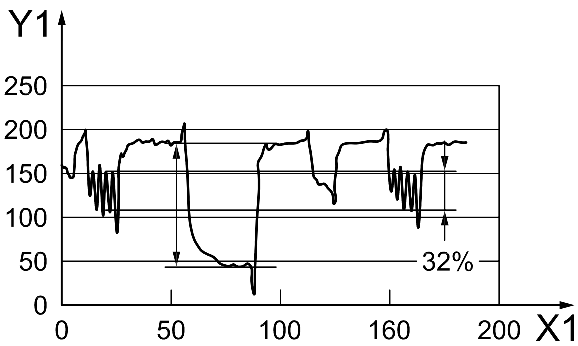
(b) The signal amplitude along indicate horizontal line, frequency point 4,3



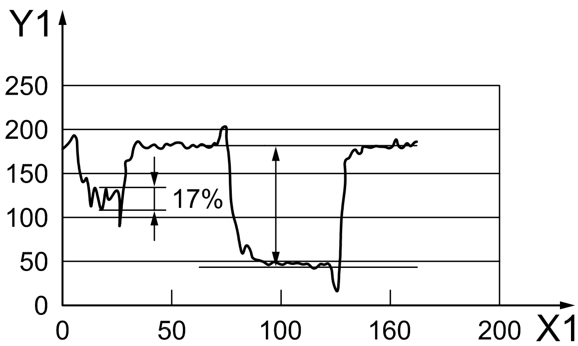
(c) The SFR characteristic of image (a)



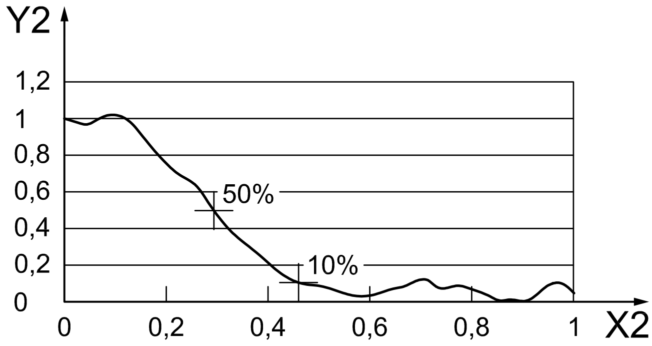
(d) Image with middle enhancement



(e) The signal amplitude along horizontal upper line, frequency point 4,25



(f) The signal amplitude along horizontal lower line, frequency point 4,8



(g) The SFR characteristic of image (d)

Key

X1 pixel position

Y1 pixel signal level

X2 relative spatial frequency

Y2 SFR

Figure E.2 — Illustrative explanation for reading the 10 % amplitude resolution chart and respective SFR measurement from the slanted edge

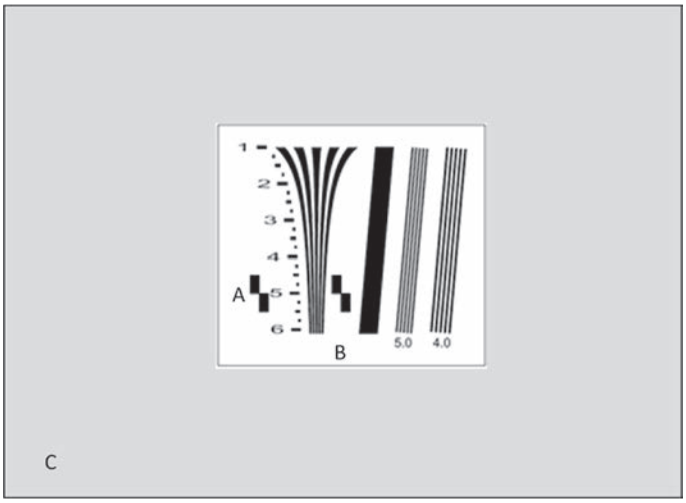
Figure E.2 (a) is an example of camera signal processed with a low level edge enhancement. The respective signal amplitude along the indicated horizontal line of the capture image (a) is shown in (b) and the SFR characteristics measured for the adjacent slanted edge at chart position (e), given in Figure D.1, is shown in (c). In this example with a low edge enhancement, the output image exhibits a signal response of 10 % at spatial frequency addressed as frequency point 4,3, and this frequency is taken as the MTF10 representative spatial frequency for the limit resolution of this particular CMS under evaluation. Simultaneously, the sampling frequency is obtained from Figure E.2 (c) SFR characterization curve as f_{SFR}(SFR = 0.1).

As an example of effect of edge enhancement, Figure E.2 (d) shows camera signal processed with a middle level edge enhancement, from the same camera output given in (a). An increase of the resolution is observed and the MTF10 point is shifted to higher spatial frequency and the signal amplitude response at spatial frequency indicated as 4,25 increases to 32 %. Going to higher frequency point on the hyperbolic test chart, the signal amplitude at second horizontal sampling line indicated at around 4,8 shows output signal amplitude of roughly 17 %, but it has an emerging irregular signal periodicity. This means that some of the sampling points within the image start losing signal amplitude and lost as visual information; and image information are no longer correctly reproducible beyond this spatial frequency. Therefore, any frequency obtained from SFR measurement with value higher to this frequency point is actually not providing a correct detailed visual information of the scene and the capability of the CMS is limited by spatial frequency determined by the chart position 4,8.

Annex F
(informative)

Complementary charts and method for long distance measurements

The depth of field measurement requires large charts and multiple different charts in order to cover the entire field of view.



Key

A marks to indicate reference width

B main hyperbolic chart area (black and white two tone chart area)

C neutral grey background area surrounding the central main chart

Figure F.1 — Centred single target black square chart

Figure F.1 shows an example of a centred single hyperbolic chart. The main hyperbolic chart area should be surrounded by neutral grey area with reflectance about 18 % to keep the camera automatic exposure adjustment function operating properly without under exposure of overexposure to hyperbolic chart area.

The chart is to be placed according to measuring image position within field of view of the camera. If the size of the chart is not enough large to cover the entire field of view of the CMS camera, the surrounding area is masked with a complementary neutral grey mask of about 18 % reflectance. An "L" shaped neutral grey mask as shown below Figure F.2, is practical to cover the foreground area, as it can be freely adjusted to most different condition according to the arrangement.

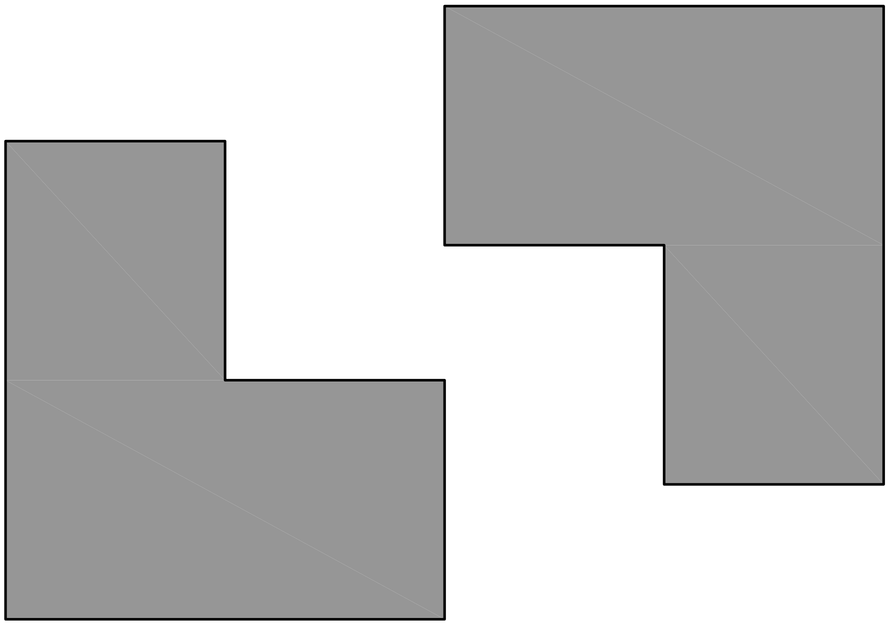
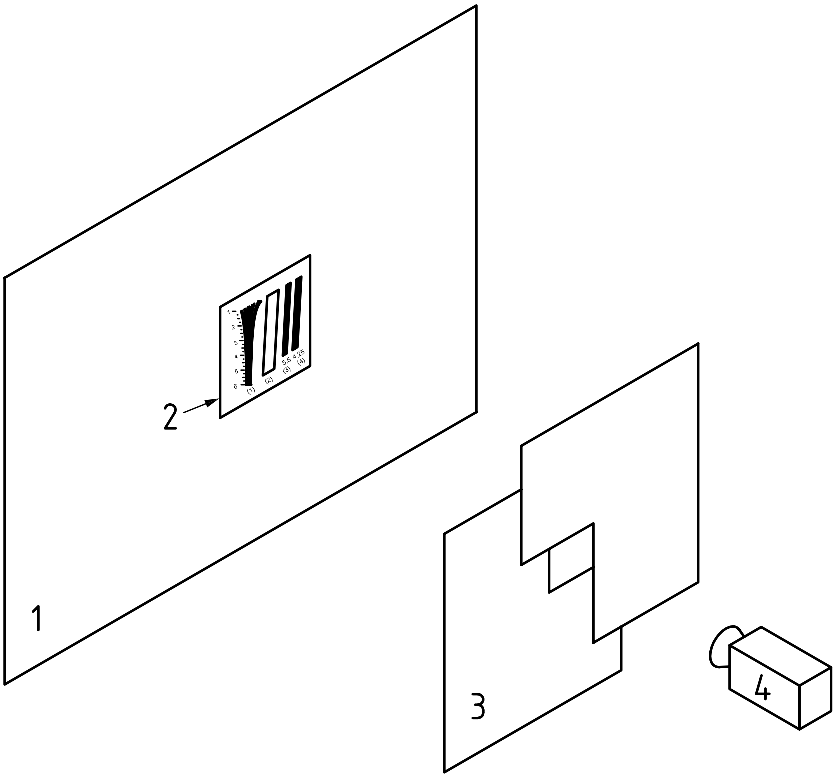


Figure F.2 — Complementary foreground masking chart, composed by a set of two individual "L" shaped grey charts



Key

1 chart grey background area
2 main hyperbolic chart area
3 foreground grey chart
4 CMS camera

Figure F.3 — Example of usage of the complementary foreground grey mask chart

Figure F.3 shows an example how the “L” shaped mask is used to cover the foreground external area around the central measuring area. The “L” shaped mask is used to overlap the outer part of the single chart when positioned far away, thus enabling use of a small hyperbolic chart for partial evaluation, by shifting according to the area to be evaluated. This neutral grey mask appropriately used to cover the field of view avoids the deviation of the automatic exposure. Placing at foreground keeps the mask small and practical. Light illumination is cared to maintain a uniform illumination, avoiding shadow formation on the measuring target chart.

Annex G
(informative)

Distortion measurement

G.1 General

This Annex provides basic information on different distortion definition and its measurement methods.

Distortion is the amount of deviation from an ideal defined case, and the definition for a distortion differs depending on what it is considered to be an ideal case. For practical reason, two major definitions of distortion are described hereinafter, TV (or picture height) distortion and geometric radial distortion relative to rectilinear projection. The "TV distortion" is a referential single value widely used as a practical way to show the amount of curvature bending that could be observed on a TV system, while the "Geometric Distortion" is given as a variant function according to image radial height or incident angle, which gives a more precise local physical characterization of the system.

Note that expression used in this subclause as "image radial height" and given in small letter "h" refers to the image distance toward the radial orientation from the image centre and shall be differentiated from the "Picture Height" or "image height" and given in capital letter "H".

G.2 TV distortion

The TV distortion is a single point ratio used to indicate the amount of curvature of the outermost longer line of a rectangular image area. If a monitor is positioned in panorama view layout wider in horizontal orientation, it is measured as the amount of curvature deviation of the outermost horizontal line in its orthogonal vertical orientation, at corner.

The "TV Distortion", [or also referred as "Picture Height Distortion (PHD)"], is defined as:

$$TVDistortion = \Delta H \,/\, H * 100\% \qquad (G.1)$$

where

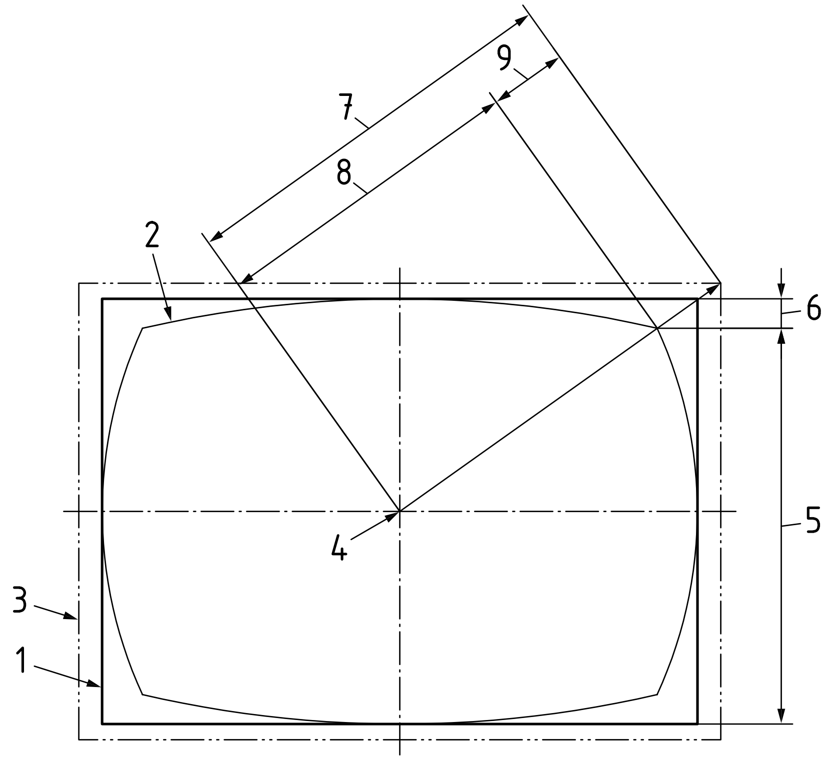
H is the picture height, from bottom to top of the image displayed on the monitor at the image horizontal centre vertical line;

ΔH is the amount of vertical deviation of image at the diagonal corner of the image.

If a monitor is positioned in portrait view layout wider in vertical orientation, it is measured as the amount of curvature deviation of the outermost vertical line in the orthogonal horizontal orientation, at corner, and the measurable value is equivalent to evaluating in a 90 degree rotated condition.

It is negative for a barrel distortion and positive for pin-cushion distortion. Therefore, the TV distortion is a single representative value that shows the apparent amount of distortion. Otherwise stated, the TV distortion refers to the amount of bending/deviation of the longer dimension corners point towards the vertical orientation when evaluating a panorama layout as shown in Figure G.1.

Note that this value is affected by the amount of field of view displayed, and therefore it shall be considered in combination to displayed field of view, aspect ratio or magnification aspect ratio. As output image format of the CMS function display area is not restricted to the traditional television system with determined aspect ratio like 4:3 or 16:9, the TV distortion value measured on CMS shall explicitly mention the measured aspect ratio. Otherwise explicitly mentioned, the TV distortion shall be given measured on corner point of an aspect ratio 4:3 condition and the respective measuring point of the image shall be reported.



Key

1 actual displayed image area of CMS monitor

2 projection of scene rectangular area in object space whose lines are the outermost continuous line displayed inscribed on CMS monitor 1, with distortion

3 ideal image in rectilinear projection of scene rectangular area, whose actual projected image on monitor is tangential to the monitor outermost border line (see line 2)

4 image centre

5 H: output image vertical height on monitor at image horizontal centre

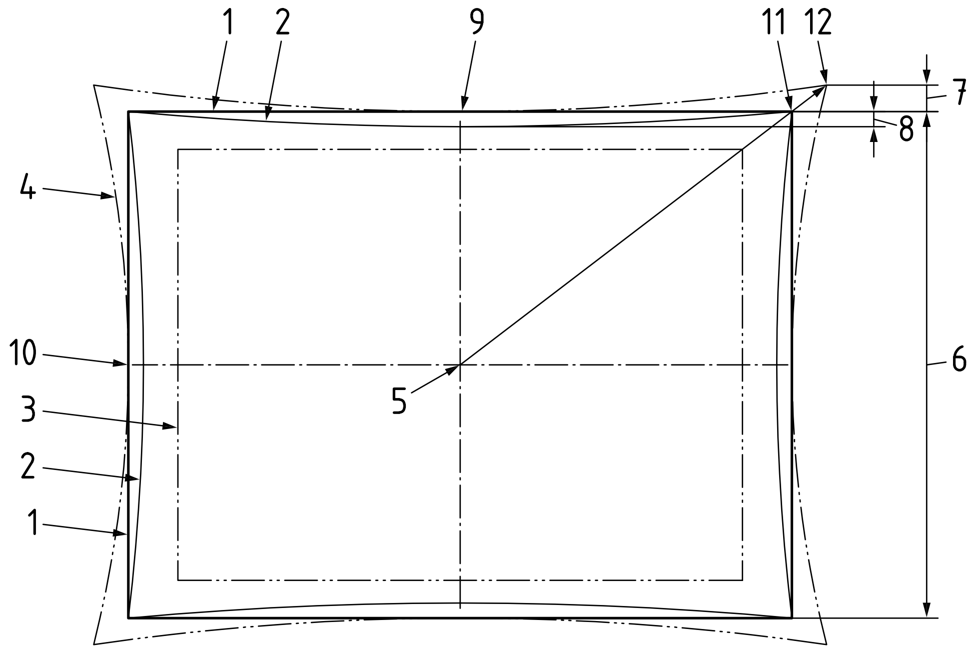
6 ΔH: vertical deviation (between corner points of the line 2 and 1) of the image outermost continuous line

7 h_{ideal}: ideal image radial height with rectilinear projection (distance from optical centre axis)

8 $h_{monitor}$: actual image radial height with distortion on monitor

9 Δh: deviation of the image radial height from ideal rectilinear projection

Figure G.1 — Distortion of the outermost bordering lines for barrel distortion and ideal rectilinear lines



Key

1 actual displayed image area of CMS monitor

2 projected image of a rectangle scene inscribed within the monitor rectangular outermost four corner points (see point 11)

3 ideal image of the inscribed rectangle scene 2 when displayed without distortion

4 imaginary projected image on the monitor of rectangular area inscribing the monitor outermost line, at points 9 and 10 (The lines are not observable within CMS displayed image because the lines are distorted out of the monitor image area 1.)

5 image centre

6 *H*: output image vertical height on monitor at image horizontal centre

7 ΔH_1: vertical amount of deviation of target scene horizontal outermost line at corner, whose line is tangential to monitor outermost border line at point 9 (This point is not observable within the CMS output image and therefore only measurable when the optical intermediate image is accessible.)

8 ΔH_2: vertical amount of deviation of scene horizontal line crossing the image corner point 11

9 tangential point of monitor outermost horizontal border line with the outermost horizontal line, the only point which is observable within the CMS monitor

10 tangential point of monitor outermost vertical border line with the outermost vertical line, and the only point which is observable within the CMS monitor

11 corner point of monitor and cross point of inscribing rectangle

12 cross point of imaginary border line of the rectangle described by line 4

Figure G.2 — Distortion (lines and measuring point for pincushion distortion)

For a pincushion TV distortion case, traditionally the TV distortion is defined as shown in the following formula by obtaining the ΔH_1 separately from design data or optical measurement:

$$TVDistortion = \Delta H_1 / H * 100\%$$

This definition was used because the output displayed image on a cathode ray tube could exhibit a pin-cushion distortion. However, the TV distortion in CMS needs to be measured in a self-consistent way, using captured image displayed on the monitor, which is an absolute rectangle in most of todays' flat panel display (FPD). In an optical system exhibiting pin-cushion distortion, the ΔH_1 is not directly observable on the monitor active area. Therefore, the TV distortion for pin-cushion is calculated as:

$$TVDistortion = \Delta H_2 / H * 100\%$$

where

H is maximum image height at horizontal centre.

G.3 Geometric radial distortion

The geometric radial distortion is the ratio of the deviation referred to an ideal rectilinear projection. In the rectilinear image projection, straight line in the 3D real object world would be projected onto 2D image plane as a straight line. The ideal case under this definition is often called distortion free projection, or ideal pin-hole projection. The geometric radial distortion described herein is the ratio of deviation relative to this ideal rectilinear projection.

The geometric radial distortion of a symmetric lens is calculated similar to magnification measurement. The geometric radial distortion is the ratio of the image radial height, Δh, to the expected image radial height in an ideal rectilinear lens h_{ideal}:

$$RadialDistortion = \Delta h / h_{ideal} = \left(h_{monitor} - h_{ideal}\right) / h_{ideal} = h_{monitor} / h_{ideal} - 1 \qquad \text{(G.2)}$$

where

$h_{monitor}$ is the observed image radial height;

h_{ideal} is the non-observable theoretical image radial height from optical axial centre point of the rectilinear projection.

To obtain the distortion curve, the image radial height of projected image, $h_{monitor}$, of an ideal projection, h_{ideal}, shall be obtained from measurement. From the chessboard chart measurement it can be calculated as:

$$h_{monitor}(i) = \frac{1}{2}\left(w_{monitor}(i) - w_{monitor}(i_{center})\right) \qquad \text{(G.3)}$$

and i_{centre} is the estimated centre of the chart where the optical axis is be found. Normally, a camera system has its optical axis centre aligned to the image centre, and therefore the image centre is assumed to be the optical centre. The factor 1/2 on $w_{monitor}$ used here is only for the purpose to give consistency to description used in 7.5.2, where the image radial height was described as 1/2 * $w_{monitor}$ for the minimum magnification calculation.

The h_{ideal} is a non-observable point on the captured image and the height shall first be estimated from the measured curve. In an ideal rectilinear lens, an image on a planar surface perpendicular to the optical axis exhibit a constant magnification throughout the entire image and the image radial height would increase linearly on the projected image according to the off-set distance from the optical axis (centre).

The distortion is referenced to the ideal image radial height expanded from the optical axis with rectilinear projection. This subclause provides calculation and data processing procedure to obtain the distortion profile of the CMS lens system. To obtain the distortion characteristic of the entire image area, the distortion characteristic is measured along the entire diagonal orientation, instead of measuring along the centre horizontal line. But example given hereinafter is described for a measurement to the horizontal line.

The procedure below describes steps to obtain the distortion curve respective to an ideal rectilinear lens system.

a) Capture the chessboard chart image and measured the position of each chart squares projected on the monitor 1/2 * $w_{monitor}(i)$, where i is the i^{th} step of the chart. For a detailed instruction to orient the camera axis perpendicular to the chart, follow the instruction given within Annex C.

b) Make an assumption of the optical centre in the measurement data and parameterize the expected centre point as i_{centre}. If the estimated i^{th} image centre point is not appropriate, it shall be corrected to minimize the error as shown in step i). (The i as measured is a discrete step according to the chart square step, but the actual i_{centre} is a real number and not necessarily a discrete integer value. When the chart square step i_{centre} does not lay perfectly adjusted to optical axis centre, it will be an intermediate real number.)

c) For each of measured chart square position i on the monitor, calculate the distance (radial height) from the estimated centre as $h_{monitor} = 1/2 * \left(w'_{monitor}(i) - w'_{monitor}(i_{centre})\right)$ and plot the radial height versus the chart BOX square edge. It could be plotted using the original i position but to simplify the following formula, it should be re-plotted with a new shifted horizontal axis j to bring the optical axis to the origin point j = 0 of this axis, with $j = i - i_{centre}$.

d) From the plot in step c, obtain a 3rd or 5th order polynomial interpolation curve according to required accuracy (e.g. $h_{monitor}(j) = aj^5 + bj^4 + cj^3 + dj^2 + ej + f$) and get the first order differential curve from the interpolated polynomial curve as $dh_{monitor}(j)/dj$, (which respectively gives $dh_{monitor}(j)/dj = 5aj^4 + 4bj^3 + 3cj^2 + 2dj + e$. Higher order polynomial interpolation can provide a more accurate approximation for complex distortion but also it might risk to be affected by measuring inaccuracy. For complex distortion characteristics, apply the interpolation only to near the optical axis to obtain the $dh_{monitor}(j)/dj$ necessary to calculate the ideal image radial height of rectilinear projection. This procedure corresponds to estimating the axial focal length of the system for the calculation of the theoretical ideal rectilinear projection.

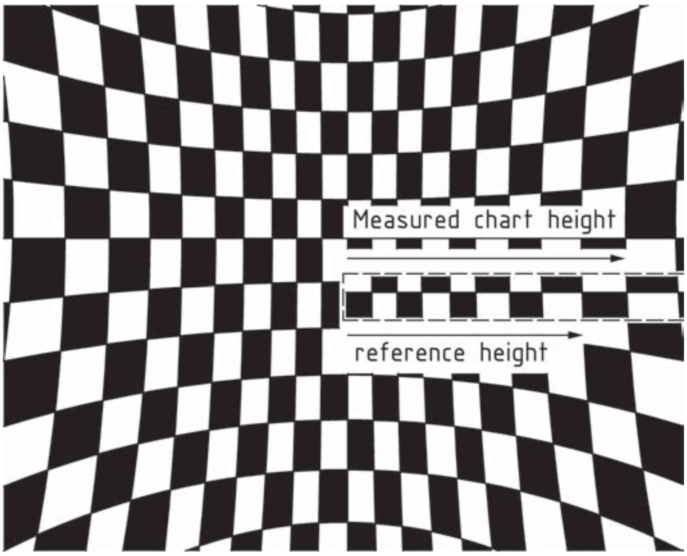
e) The first order differential of the polynomial obtained in step d) at the optical axis provides the increasing ratio of the chart image projected on the monitor according the chart square steps in an ideal rectilinear case. The theoretical image radial height is obtained by multiplying the slope $dh_{monitor}(j)/dj$ value at image centre ($dh_{monitor}(j)/dj\big|_{j=0}$) which is constant through the entire image for a rectilinear system with j, and it is given as $h_{ideal}(j) = \left\{dh_{monitor}(j)/dj\big|_{j=0}\right\} * j$.

f) Convert the horizontal axis of plot in step c to the ideal rectilinear image radial height according to calculation of step e. The plot will now exhibit a 1:1 relation at the optical centre j = 0.

g) Calculate the ratio of $h_{monitor}(j)$ versus the ideal rectilinear reference distance, $h_{ideal}(j)$, subtracted by 1, according to Formula (G.2) to obtain the geometric radial distortion.

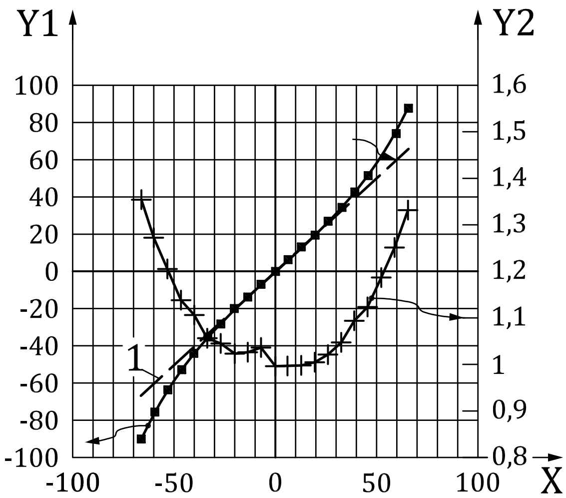
h) As the ideal image radial height is a theoretical point for an ideal rectilinear projection which is not directly observable on an output image, reconvert the horizontal axis with the actually observable monitor image position. See Figure G.1 and Figure G.2.

i) In a symmetric system, this distortion curve should be symmetric across the optical centre. Asymmetry can occur to the plotted data due to wrong assumption of the image centre point in step b. In such case, readjust the parameterized centre point, i_{centre}, to minimize the asymmetry and obtain a smooth curve across the centre point. If properly adjusted, the distortion curve at centre will be zero and continuous across the image centre point.



NOTE The “reference height” is a hypothetical distance estimated from centre of the image, illustrated within the broken line.

Figure G.3 — Illustrative measuring distance to calculate the distortion from estimated image centre



Key

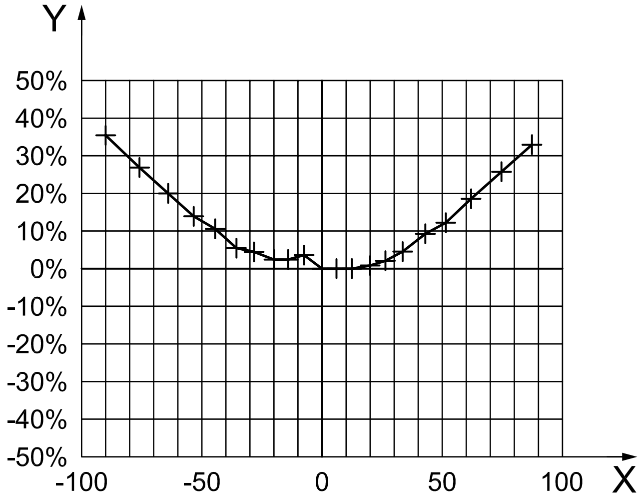
X hypothetical position on rectilinear projection assumption [mm]

Y1 position of the chart square on the monitor image [mm]

Y2 1 + radial distortion

1 ideal image position for rectilinear (= distortion free) projection (dashed line with slope = 1)

Figure G.4 — Hypothetical image position in horizontal axis and the measured chart distance from centre



Key

X measured actual position on monitor [mm]

Y radial distortion [%]

Figure G.5 — Radial distortion according to the position on the monitor

NOTE The optical centre when estimated from output image should be adjusted such that the above discontinuity of the curve is minimized. If the lens designs only exhibit distortion at image periphery, the effect of centre discontinuity will not be so apparent and asymmetry of the distortion curve might become observable only at periphery of the image. If the distortion curve at periphery exhibits some asymmetry, and in such case adjust the estimated image centre so that symmetry of distortion curve at periphery is achieved. But the cause of the asymmetry might be the tilted assembly of the CMS optics including tilted assembly of the image sensor device causing an intrinsic asymmetry of the CMS distortion characteristic.

Bibliography

[1] Platzer G. The Geometry of Automotive Rearview Mirrors – Why Blind Zones Exist and Strategies to Overcome Them, SAE Technical Paper Series 950601, 1995

[2] DIN 5031, *Physics of radiation in the field of optics and illuminating engineering*

[3] Alliance's Driver Focus-Telematics Working Group "Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In- Vehicle Information and Communication Systems" Revision June 24, 2006, Principle 1.4

[4] ISO 26262:2011, *Road Vehicles — Functional safety (all parts)*

[5] ISO 14524:2009, *Photography — Electronic still-picture cameras — Methods for measuring opto-electronic conversion functions (OECFs)*

[6] ISO 4513:2010, *Road vehicles — Visibility — Method for establishment of eyellipses for driver's eye location*

[7] Fornell Fagerström K., & Gårdlund A. Mirror replacement in trucks, Master of Science Thesis in Product Development, Chalmers University of Technology, 2012

[8] ISO 8596, *Ophthalmic optics — Visual acuity testing — Standard optotype and its presentation*

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

[10] ISO 15008, *Road vehicles — Ergonomic aspects of transport information and control systems — Specifications and test procedures for in-vehicle visual presentation*

[11] SAE J1757-1:2007, *Standard metrology for vehicular displays*

[12] FMVSS 111, *Rearview Mirrors (US homologation)*

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