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TNO report

TNO-DV 2007 C344
A critical analysis of ECE-regulation46 & Directive 2003/97/EC

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Contents

1 Introduction

The interpretation of ECE-regulation 46 and EU directive 2003/97/EC relating to the type-approval of devices for indirect vision and of vehicles equipped with these devices appears to be unclear. The question is whether the tests and requirements are specific enough, described sufficiently and whether they are practically feasible. The Dienst Wegverkeer (RDW) has commissioned TNO to analyse the tests and requirements concerning camera - monitor systems, and come up with a set of tests and requirements that is better defined, that can be performed in practice and that leads to good performance under normal and more critical circumstances. The new set of tests and requirements should be clear, i.e. to a lesser extent subject to differences in interpretation. Also, the tests should be practical and robust, i.e. display small variations between test stations and in repeated measurements.

In this study we investigated the following issues:

1. Blooming test (EN-12368): The current regulations refer to EN-12368. However, this norm applies to signal lights and cannot be applied directly to camera – monitor systems. The testing conditions and the requirements are not well defined/specified for camera - monitor systems.
2. Visibility of the critical object. The requirements in the current regulations with respect to the visibility of the critical object are not well defined and the test to determine this is not specified. Also, the critical object appears to be specified with one field of vision (as mentioned in the regulations) in mind (e.g. viewing devices of Class IV), whereas it seems more appropriate to take a different definition of the critical object for class VI devices.
3. Additional tests. We investigated whether the set of tests is sufficient or whether additional tests and requirements are needed.
4. Component testing. We investigated whether it is possible to define requirements and tests for individual components, in a way that assures good operation of the combined camera – monitor system.

ECE-regulation 46 and EU directive 2003/97/EC are very similar. In this document we will refer to the text of ECE-regulation 46.

2 Results

2.1 Blooming test

The text in ECE-regulation 46 reads:

> 6.2.2.2. Functional requirements
>
> 6.2.2.2.1. The camera should function well under low sunlight conditions. The camera shall provide a luminance contrast of at least 1:3 under low sun condition in a region outside the part of the image where the light source is reproduced (condition as defined in EN 12368: 8.4). The light source shall illuminate the camera with 40,000 lx. The angle between the normal of the sensor plane and the line connecting the midpoint of the sensor and the light source shall be 10°.

The testing conditions and the test requirements are not well defined/specified for camera - monitor systems. The norm EN 12368 deals with reflections from traffic lights (i.e., light emitters). This norm does not apply (directly) to cameras (light receivers).

The phrase “a region outside the part of the image where the light source is reproduced” is problematic since the blooming area is not well defined. One may argue that this requirement should not be applied to cameras displaying the Class VI area, since such cameras are directed downwards, and no direct sunlight will hit the camera. However, indirect sunlight (e.g. reflected via wet surfaces) may hit the camera. We therefore propose to maintain this requirement for all classes.

Towards a new blooming regulation
A regulation on camera blooming should take the operational context into account, and requirements resulting from this context. In the case of a vehicle camera system, the blooming area should be limited.

In the following, we will describe a method for measuring the blooming characteristics of a camera. The test makes use of an evenly illuminated black and white (checkerboard pattern) background as the basis of contrast measurements and a high luminance light source casts to induce blooming and smearing phenomena. The area in which blooming decreases the contrast to below a given threshold is determined and this is used as a measure of the camera’s susceptibility to blooming.

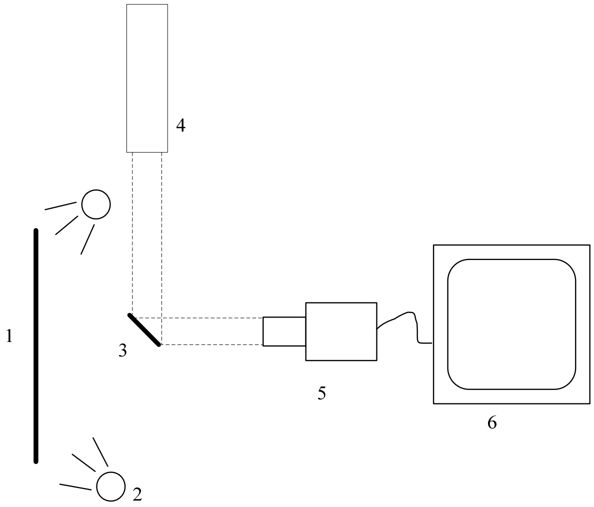

Figure 1 Diagram of the blooming measurement set-up. 1: Black & white background. 2: Lamps to make the background evenly illuminated. 3: Mirror. 4: high luminance light source. 5: Camera. 6: Monitor.

Measurement set-up
A high-intensity light (e.g., theatre spotlight) is reflected into the image using a small mirror. The illuminance of the camera by the light reflected from the mirror should be around 40,000 lx (representative for sunlight from a sun with a low elevation angle of 10° above the horizon, see EN-12368). A black and white checker board pattern (see Figure 2b) is illuminated by a set of lamps to create an even illumination of 3000 (± 25%) lx. This illumination is representative for these lighting conditions: these conditions can be created early morning with the facing side of the critical object away from the sun, with an asphalt reflectance coefficient of 8% (Anderson, Milton & Rollins, 2003) to add to the diffuse light from the sky dome. Calculations provided by S@tel-light, the European database on daylight and solar radiation (http://www.satel-light.com/), yield a diffuse illuminance for this case of about 3000 lx.

We propose to use a setup configuration in which the light enters the camera from a straight angle instead of using an elevation angle of 10°. The advantage is that the setup is better defined and less affected by small changes in the configuration (more robust). This will make the measurements more reproducible and less variable among different test laboratories. That small changes in configuration can have a large impact is often caused by secondary reflections in the camera. In the proposed setup the secondary reflections fall on top of the primary reflections. This setup is easier, better defined and will lead to more robust measurements than when an elevation of 10° would be used.

The sun extends an angle of 0.5°. In practice it is difficult to create an illumination of 40.000 lx with a lamp extending such a small angle. We therefore propose to use an angle of 5° (± 10%) instead (since the lamp size affect the blooming area, the size needs to be prescribed). The amount of blooming in this case is representative, but not equal to the blooming in reality (see Figure 2). *Note that in reality blooming will be less severe.* A schematic drawing of the set-up is given in Figure 1. Photographs showing the resulting blooming can be seen in Figure 2 (in this setup a different test pattern was used).

Figure 2. a) shows the blooming area outdoors in broad daylight (sun illumination of 93500lx) compared to blooming area under test conditions in the lab (b). The blooming area in the latter case is larger (10% compared to 6%) but comparable; the blooming area is defined by the region in which no black squares can be detected (luminance contrast lower than 0.20).

The mirror should be placed such that its image is positioned in the middle of the display. By assuring that the blooming area is symmetric (left-right and top-bottom mirror symmetric) the right configuration can be set up by eye.

Blooming area definition

The blooming area is defined as the area in which the contrast between the black and white parts is lower than 0.20. The contrast (C) is defined by the difference in luminance on the screen between the white (L_w) and black (L_b) regions divided by the luminance of the white regions:

$$C = \frac{L_w - L_b}{L_w} \qquad (1)$$

Note that the threshold contrast differs from the contrast threshold used in the monitor test (sunlight conditions, see ISO 15008, 2003) in which a luminance *ratio* between the white and black regions is required of 2:1. The reason for taking a lower contrast threshold for defining the blooming region is that the proposed threshold value is close to the contrast threshold of the human eye (i.e. could be determined by eye). Secondly, the blooming area thus defined is less affected by changes in the lighting conditions and more closely resembles the blooming area under realistic conditions (see Figure 2). As an example, Figure 3 shows the display image in the blooming test in two separate measurements. The area in which the luminance ratio falls below 2:1 spans 24% of the monitor image in the first measurement and 12% in the second measurement. This is due to the fact that in the first measurement the central blooming area is surrounded by a region in which the contrast is reduced, but in which the test patterns are still visible. The region in which contrast falls below 0.20 is less affected by this: in the first measurement this region spans 13%, and in the second measurement it spans 11% of the monitor image. This definition of the blooming coincides with the central part of the blooming spot. The fact that this region is less affected by differences in lighting condition is also apparent from Figure 2. The inner part of the blooming area in the test condition (Figure 2b) is comparable to the blooming area in a realistic outdoor setting (Figure 2a).

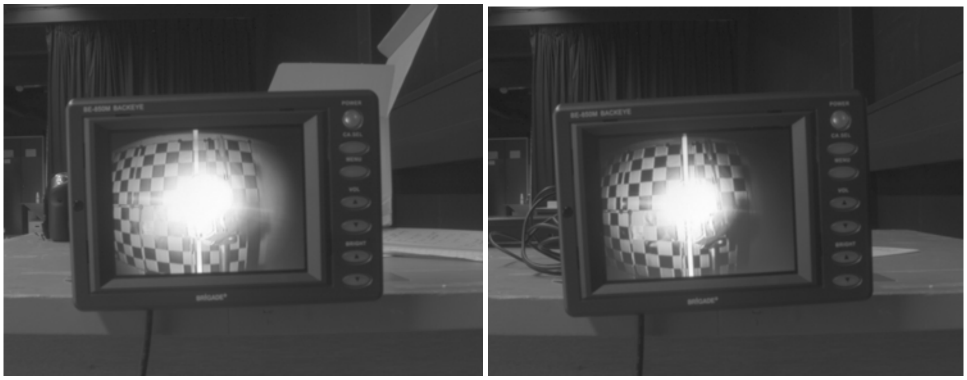

Figure 3. Shown is the monitor image in the blooming test in the first test (a) and at a second test (b). The central blooming area is comparable in size, but in the first test setup the central area is surrounded by a region with reduced contrast. A definition of the blooming area as the region in which contrast falls below 0.20 is therefore less variable than a definition based on a larger contrast ratio (e.g. a luminance ratio of 2:1).

Dynamic effects

We have noticed that many camera systems do not deliver a fixed image under the testing condition. This is probably due to the way the auto gain system is implemented. Figure 4 shows an example of the difference in blooming due to the dynamic changes within the camera. Figure 4a shows the minimum blooming and Figure 4b shows the maximum blooming occurring with this camera. In this case the blooming area is about two times larger at maximum than at minimum blooming. These dynamic variations make it difficult to obtain a sound measure of the magnitude of the blooming area. Since the camera system should perform well under all conditions we propose to use the maximum blooming area as the critical test value.

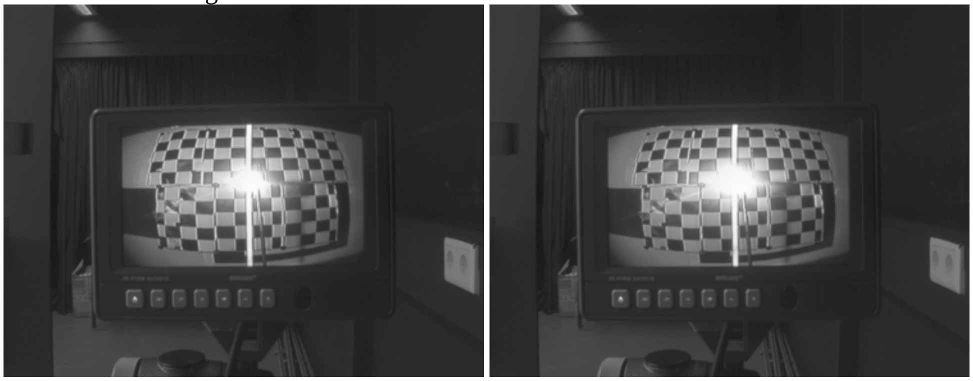

Figure 4. Shown is the monitor image in the blooming test at two instances in time. a) shows coincides with minimum blooming, b) coincides with maximum blooming. The blooming area is about two times larger in the latter case.

Requirement

Blooming is an artifact of cameras in which an overexposed area lowers the contrast in its surroundings. A comparable problem occurs with the eye in the form of *disability glare*. An intense light source causes stray light outside the direct projection area of the light source on the retina, and lowers the local contrast there. One could argue that cameras requirements should not be stricter than the performance of the unaided eye (or when mirrors are used).

ISO-15008 (Specifications and Compliance Procedures For In-vehicle Visual Presentation) requires a minimal luminance ratio of 2:1 for displays used in sunlight conditions. To obtain a more robust measurement of the blooming area we propose to use a threshold contrast (see above, and equation 1) of 0.2.

As appendix A shows, the visual area in which disability glare reduces the contrast to below 0.2 in a setting corresponding to the test described above is a cone with a top angle of about 11.5° centered around the light source.

To include situations in which blooming is not circularly symmetric, the requirement should be translated into a percentage of pixels that may be allowed to have a lower contrast than 0.2. For a typical wide angle camera system a blooming area (i.e. the area in which the contrast falls below 0.2) of 6% is comparable to that of a mirror system (see appendix B). However, the impact of glare is much larger, since its effect prolongs after viewing the mirror (eye sight is temporarily reduced due to overexposure). We therefore propose to use the relaxed requirement that the blooming area should be limited to a maximum of 10% of the display area. We found in previous tests that this requirement allows one to eliminate the (few) camera's that do not function well under exposure by sunlight.

2.2 Visibility critical object

The parts of ECE-regulation 46 that apply to the visibility of the critical object are:

2.1.2.6. "Critical object" means a circular object with a diameter D_0 = 0.8 m.

2.1.2.7. "Critical perception" means the level of perception that the human eye is generally capable of achieving under various conditions. For traffic conditions the limiting value for a critical perception is eight arc-minutes of visual angle.

2.1.2.8. "Field of vision" means the section of the tri-dimensional space in which a critical object can be observed and rendered by the device for indirect vision. This is based on the view on ground level offered by a device and might possibly be limited on the basis of the applicable maximum detection distance of the device.

2.1.2.9. "Detection distance" means the distance measured at ground level from the viewing reference point to the extreme point at which a critical object can just be perceived (the limiting value for a critical perception just barely achieved).

2.1.2.10. "Critical field of vision" means the area in which a critical object has to be detected by means of a device for indirect vision and that is defined by an angle and one or more detection distances.

15.3.1. A device for indirect vision shall give such performances that a critical object can be observed within the described field of vision, taking into account the critical perception.

15.2.4.6.1. …This device must be able to detect an object of 50 cm height and with a diameter of 30 cm within the field…

The first issue concerns the definition of the critical object. The text in 15.2.4.6.1. suggests that the “critical object” of a class VI device is an object of 50 cm high and 30 cm diameter, and not equal to the standard critical object as defined in 2.1.2.6. Therefore, in 2.1.2.6. this exception should be mentioned. For convenience, we propose to use a *spherical* critical object with diameter 80 cm (standard) and 30 cm (Class VI), so that its shape no longer depends on the viewing angle.

Secondly, the definition of the detection distance (2.1.2.9.) is rather vague. Annex 10 (CALCULATION OF THE DETECTION DISTANCE) suggests that the detection distance should be derived from a model using the angle of vision of the camera and the number of video lines of the camera as input. This model is very simple and only gives a rough estimate of the camera performance. It does not take properties of the monitor into account. For instance, in pilot measurements we found an increase in smallest detail by a factor of 2 after replacement of the standard monitor by a high quality monitor. Moreover, these formulas are based on a study by Van der Heide et al. (2001) in which the potential performance of different camera parameters is evaluated. These formulas were not meant to be used for certification purposes: “A highly simplified description (though sufficient for the purpose of this application) of camera and monitor are provided.” We recommend measuring the resolution of the camera-monitor system instead of relying on this simple model.

Whether a test of the resolution of the camera – monitor system should be performed for Classes V and VI may also be questioned. In most cases it can be assumed that the resolution for these areas is sufficient since the maximum viewing distance is limited (in the tests carried out thus far this proved to be the case).

Until recently, certification tests at TNO were performed using Landolt-C test patterns (commonly used in ophthalmologic tests). The smallest detail is defined as the gap size corresponding to a 75% correct identification score. In this test the observer indicates whether the gap is at the top, bottom, left or right side of the circle (see Figure 5a).

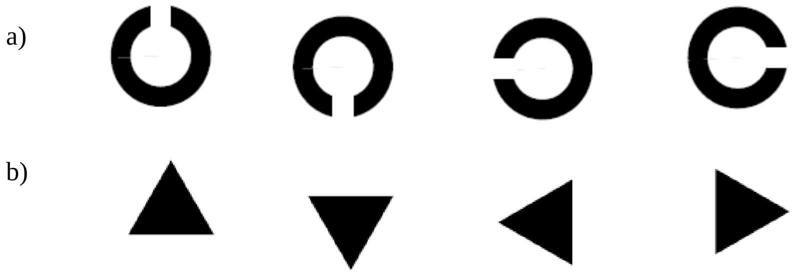

Figure 5. Landolt-C test patterns used in standard ophthalmologic tests (top row) and triangular test patterns used in the TOD method (bottom row). The observer has to indicate the orientation of the test pattern or gap.

The threshold gap size was measured with a well lit, high contrast test chart in front of the camera-monitor system. The observer performed the test while looking at the monitor from a close distance (for details on how to perform such a test, see Bijl & Valeton, 1999). Finally, the critical distance is defined as the distance at which the critical object spans an angle 8 times the threshold gap size, and can be calculated from the threshold gap size using the (left hand size of) equation in 1.3.1. of annex 10 of ECE-regulation 46.

Landolt-C test patterns are well suited for determining visual performance of human subjects. However, various studies show that the TOD method (Triangle Orientation Discrimination, see Bijl & Valeton, 1998a) method in which triangular test symbols are used (see Figure 5b) is better suited for determining the smallest detail (and contrast sensitivity) of sensor systems. One reason for this is that the appearance of a triangular pattern is less critical to the precise position with respect to the detector array than a Landolt-C test pattern. The TOD method assesses the image quality of imaging systems with a human-in-the-loop. The method is simple and practical, has a close resemblance to real object recognition (see e.g. Bijl & Valeton, 1998b), the observer task is easy and can be performed without training, and the results are free from observer bias. Bijl & Valeton (1999) provide practical guidelines on how to perform a TOD measurement. The TOD method has become part of a recommendation by the International Telecommunication Union (ITU) for determining the effective resolution of video-telephony applications (ITU, 2007). Recently, TNO has switched to using the TOD method for determining the smallest detectable detail. In an experiment using an example camera-monitor system intended for use with wheeled vehicles threshold sizes were determined for Landolt-C and for triangular test symbols. The results are shown in Figure 6.

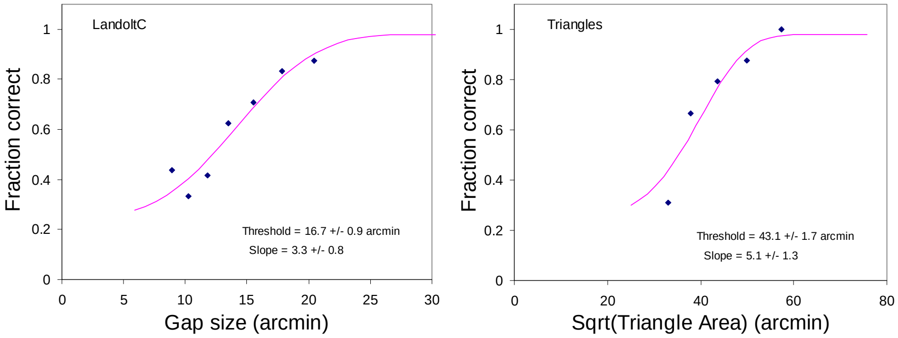

Figure 6. Fraction correct versus the gap size (for Landolt-C symbols) and the square root area of the triangle. The threshold corresponds to the point at which the fraction correct reaches a 75% correct score.

To arrive at the same critical distance for this system the width of the base of the triangle at threshold should be 2.0 times smaller than the diameter of the critical object (see Figure 7b).

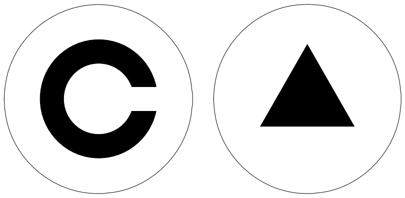

Figure 7. Relationship between the size of the smallest detectable detail and the size of the critical object (outer circle). For Landolt-C symbols the critical detection distance is defined as the distance at which the diameter equals 8 times the threshold gap size. A similar critical distance is obtained with the TOD method by defining the critical distance as the distance at which the diameter of the critical object equals 2 times the base of the triangle.

We propose to use the TOD method for determining the smallest detail and defining the detection distance as the distance at which the diameter of the critical object equals two times the base of the triangle at threshold.

Image distortion

We propose to determine the smallest detail with the TOD method in the centre of the image. An object displayed outside the centre may be displayed smaller than in the centre due to image distortions in the camera. The detection distance outside the centre can be derived from the distortion. The detection distance scales inversely with the visual angle of the pixel. Here, we make the assumption that the smallest detail in pixels is independent of the pixel location (i.e. the optical and other deformations are assumed to be largely independent of the location). The amount of distortion can be measured by putting the camera in front of a test pattern, e.g. a checkerboard pattern (see Figure 8). The squares are displayed smaller in the periphery (see Figure 8b). This is partly due to the distortion within the camera lens and the monitor (barrel and pincushion distortion) and partly due to the fact that figures outside the centre are viewed from an angle (perspective distortion). Also, the distance from the observer to the figures is larger in the periphery of the display than in the centre.

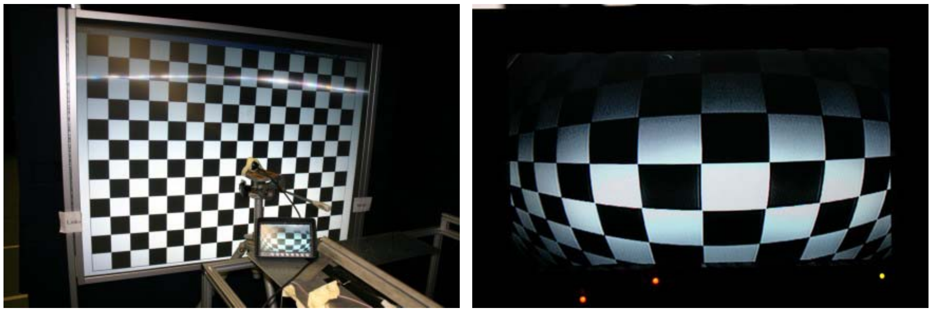

Figure 8. Possible setup for determining image distortion of the camera. Figure 8a shows the test setup with the camera in the centre of the test pattern, and the monitor. Figure 8b shows the monitor image.

To get a more direct/intuitive insight into the distortion the camera could be placed in the centre of a sphere (see Figure 9a) with circles of equal size painted on the sphere. Each circle spans the same solid angle (as viewed from the camera) and differences in viewing angle of the pixels outside the centre become immediately visible. When no sphere is available one could use the projection of circles on a flat surface (projected from the centre of the sphere). Figure 9b shows an example test pattern in which the distance between the projection plane and the camera is 1/8 times the width of the image.

Figure 9d shows that the disks (in this case) do not vary much in size, indicating that the visual angle of each pixel is largely independent of the location in the image. This indicates that the distortion and the smallest detail are largely independent of the location. Since the exact location of the optical centre of the camera is somewhat uncertain it is best to use a large test pattern, thus restricting the uncertainty. In general, the detection distance scales with ratio between the square root of the area at the centre and the square root area at a certain pixel location.

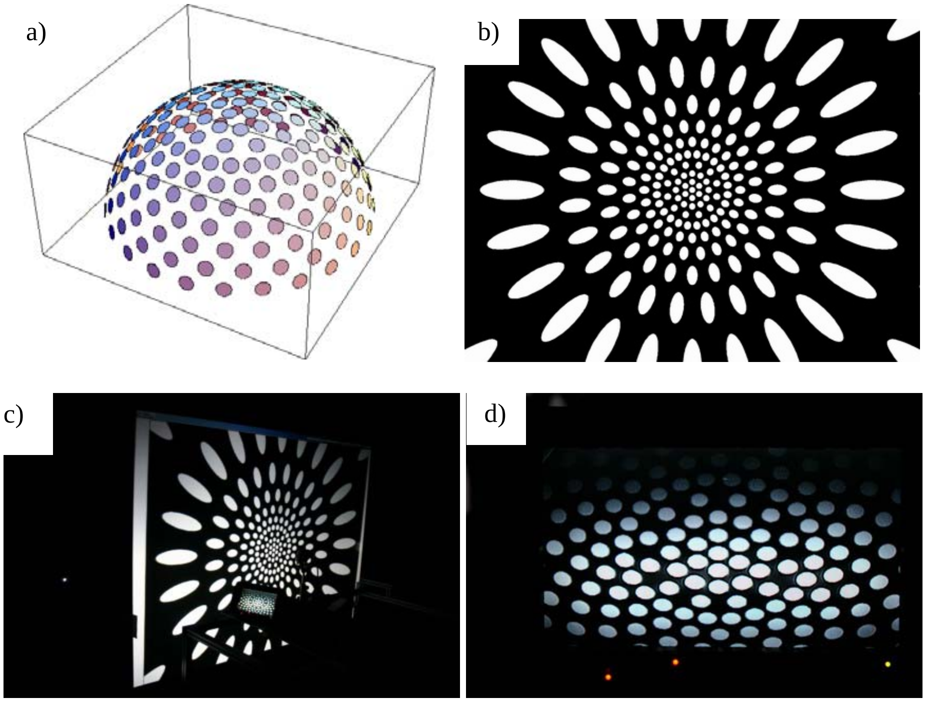

Figure 9. Figure a) shows the sphere with the circles. The visual angle of each circle is the same when viewed from the centre of the sphere. b) shows the projection of the circles on a flat surface. This pattern can be used as a test pattern. Figure c) shows the measurement setup with the projection screen, the camera viewing the centre of the pattern and the monitor image, also shown in Figure d).

2.3 Additional tests

Since the camera – monitor system is used in dynamic situations it seems appropriate to extend the test set with a test evaluating the performance in dynamic situations. The system is also used under circumstances with low light level. Therefore, one could also opt for an extension that includes a performance test under low light level conditions.

Dynamic situations

We propose to use a dynamic acuity test based on the TOD method (see section 2.2) with a test chart moving with a speed that is representative for the conditions encountered in reality. The speeds at which the camera – monitor systems of classes V and VI (see ECE-regulation 46 for a definition) are useful are typically low, e.g. 5 km/h. Together with a typical distance to the critical object of 2.2m (with a camera placed at 2.70 m from the floor and a critical object height of 0.50m) this amounts to a visual speed of 36 deg/s. The test should therefore be performed with a test chart moving with an angular speed of 36 deg/s. One way to create this condition is by using a rotating mirror, see Figure 10.

Figure 10. Setup with a rotating mirror in front of the camera which may be used for dynamic TOD testing.

The same requirement could be used as mentioned in section 2.2., i.e. one could require that the critical object is visible within the area corresponding to the class type.

Low light conditions

The low light sensitivity requirements for vehicle cameras should be based on appropriate light level standards for road lighting. EN 13201-2 defines the required illuminance for a set of quite different traffic situations. We think that the class CE (intended for drivers of motorized vehicles, and other road users, on conflict areas such as shopping streets, road intersections of some complexity, roundabouts, queuing areas etc.) are the most appropriate. From the series of lighting classes available in this category we choose the worst case, lighting class CE5, which has a required average road illuminance of 7.5 lx.

This level is appropriate for cameras aimed at the side of the vehicle, which will not be lit by headlights. Cameras that will be used in areas lit by car lighting may be operating at higher minimum light levels. Field VI for instance, ends at a distance of 2 m from the headlights. With an intensity of a set of halogen headlights of 15,000 cd (ECE-regulation 20), the illuminance at 2 m is about 3750 lx. Hence, no low light level sensitivity specification is needed in this case.

The low light sensitivity as specified by camera manufacturers should be measured in a standardized way to make them comparable. We propose to use the CEA-639-A standard. In the test the camera should be fitted with the same lens that will be used in the vehicle application.

It is imaginable that in some cases additional lighting is supplied e.g. by using a near infra-red (NIR) light source in combination with a camera sensitive to NIR light. In this case, the sensitivity for road lighting levels of 7.5 lx is too low and the requirement should be adjusted to correspond to the lowest light level the NIR achieves within the specific field. However, in such cases it should be made clear that this type of lighting is functional at all times.

2.4 Component testing

In principle it is best to test the complete camera – monitor system. However, for practical reasons it may be desirable to test individual components. The same tests can be applied to the complete system containing the component together with a high quality component (camera or monitor). One of the tests evaluates the contrast of the monitor under different lighting conditions (ISO 15008). The outcome is largely independent of the camera. Another test evaluates blooming of the camera (adaptation of NEN-12368, see above). The outcome is largely independent of the monitor.

The detection distance depends on the resolution of the camera and the monitor and the match between the two components. We seek to define requirements for the separate components that guarantee that a system containing these components passes the test. It is difficult to predict the performance of the whole system on the basis of the performance of the separate components. We have deduced a simple model to predict the acuity of the complete system from the acuity of the individual components (see Appendix B). The smallest visible detail of the complete system is equal to or larger than that of the worst component. The maximum difference between the acuity of the worst component and the acuity of the complete system is obtained for a system consisting of two components for which the smallest detail is the same. The model predicts for that case that the smallest visible detail is 1/0.64 times larger than that of the individual components. To stay on the safe side, we advise that the smallest visible detail of the component is required to be *0.5 times the required smallest detail of the complete system*. We predict that this will assure that the complete system fulfils the requirements.

3 Proposed textural changes in ECE-regulation 46

The sections below provide some suggestions for changes in the text of ECE-regulation 46. Before actually implementing these there should be discussion about the content and the phrasing. Comments that are not meant as text for in the ECE-regulation 46 are put in italics.

3.1 Blooming

6.2.2.2. Functional requirements

6.2.2.2.1. The camera should function well in conditions in which sunlight falls on the camera. The saturated area (defined as the area in which the luminance contrast of a high contrast pattern falls below 0.2) should be limited. In the representative test case with a (simulated sun)light of 40000 lx on the camera, light displayed at the centre of the monitor, a background illumination of 3000 lx (± 25%) and a light source spanning an angle of 5° (± 10%) the saturated area should be less than 10% of the image. A description of a test method is given in Appendix XX

Note that the appendix gives a description of a possible test setup for measuring the saturated area under the conditions mentioned in 6.2.2.2.1. One can think of other tests to determine this. The actual test is not very important. Important are the testing conditions (mentioned in 6.2.2.2.1).

******* START OF APPENDIX XX, intended for inclusion in ECE-regulation 46**********

Appendix XX: Test for determining the saturated area of the camera under the conditions mentioned in 6.2.2.2.1

Measurement set-up

A high-intensity light (e.g., theatre spotlight) is reflected into the image using a small mirror (see Figure 1). The illuminance of the camera by the light reflected from the mirror should be 40,000 lx, which is representative for sunlight from a sun with a low elevation angle (10° above the horizon, see EN-12368). The light source is depicted in the centre of the camera: the light enters the camera from the normal direction. A high contrast black and white pattern (e.g. a checkerboard pattern) is illuminated by a set of lamps to create an even illumination of 3000 (± 25%) lx. This illumination is representative for these lighting conditions.

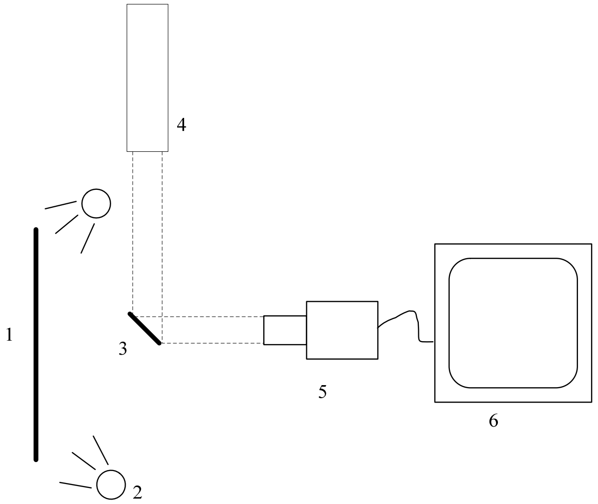

Figure 1 Diagram of the blooming measurement set-up. 1: Black & white background. 2: Lamps to make the background evenly illuminated. 3: Mirror. 4: Spot light. 5: Camera. 6: Monitor.

The glare source should extend an angle (diameter) of 5° (± 10%). Note that this is much larger than the angular subtense of the sun (which is about 0.5°). In practice it is difficult to create an illumination of 40.000 lx with a lamp extending such a small angle. Therefore an angle of 5° is used instead. The saturated area under the test conditions is *representative* for the saturated area in realistic sunlight conditions, but not equal. In reality, the saturation will be less severe. A schematic drawing of the set-up is given in Figure 1.

The mirror should be placed such that its image is positioned in the middle of the pattern. The luminance of the white and black areas in the display image can be measured. The blooming area is defined by the area in which the contrast of a high contrast test pattern falls below 0.2. The contrast (C) is defined by the difference in luminance between the bright (L_w) and dark (L_b; black) and regions divided by the luminance of the bright (white) regions:

$$C = \frac{L_w - L_b}{L_w} \qquad (1)$$

The blooming area should cover 10% or less of the display area.

In case the camera system shows dynamical changes in the blooming area during the test the maximum blooming area should fulfill the requirement.

********************END OF APPENDIX XX**********************

3.2 Visibility critical object

It should be made clear that the detection distance should be based on the smallest detail that can be perceived via the viewing system, and should not be based on the simple model described by the formula in Annex 10 1.1. To avoid confusion we advise to remove this part from the regulation. We also advice to remove the second parts from equation 1.3.1 and replace:

$$r_d = \frac{D_0}{\tan\left(\frac{f.\omega_c}{60}\right)} = \frac{D_0}{\tan\left(\frac{f.\beta_c}{2.N_c}\right)} \qquad r_d = \frac{D_0}{\tan\left(\frac{f.\omega_c}{60}\right)}$$

by

In 1.3.2 the formula should be replaced by:

$$r_{dclose} = \frac{D_0 \cdot 60 \cdot 180}{\omega_c \cdot \pi \cdot f} \qquad [\mathrm{m}]$$

where:

r_{dclose} - detection distance [m]

D_0 - diameter of the critical object [m], which is equal to 0.8 m (see 2.1.2.6)

f - threshold increasing factor, which is equal to 8.

ω_c – smallest discernable detail [arcmin] (see 1.1)

2.1.2.6. The standard "Critical object" corresponds to a spherical object with a diameter of D_0 = 0.3 m,.

One could also choose a different size of the critical object for each class. Note also that we define the critical object to be a spherical object (for convenience) whereas in the current ECE-regulation 46 an object 50 cm high and diameter of 30 cm is mentioned in relation with Class VI.

2.1.2.7. "Critical perception" means the level of perception that can just be obtained under critical conditions via the viewing system that is used. This corresponds to the situation in which the diameter of the critical object is a multiple times larger than the smallest detail that can be perceived via the viewing system.

2.1.2.8. "Field of vision" means the section of the tri-dimensional space in which a critical object can be observed and rendered by the device for indirect vision. This is based on the view on ground level offered by a device and might possibly be limited on the basis of the applicable maximum detection distance of the device.

2.1.2.9. "Detection distance" means the distance measured from the centre of the lens of the camera to the point at which a critical object can just be perceived (as defined by the critical perception).

2.1.2.10. is not used in ECE-regulation 46 and can be omitted.

APPENDIX BB: The Triangle Orientation Discrimination test for determining critical perception conditions

The Triangle Orientation Discrimination method is similar to the Landolt-C test method in many respects and is described in detail by Bijl & Valeton (1999), who provide practical guidelines on how to perform a TOD measurement. In the method, triangular test patterns (see Figure 1) are viewed through the viewing system under test. Each triangle can have one out of four possible orientations (apex up, left, right or down) and the observer indicates/guesses for each triangle its orientation (similar to the method used in a standard ophthalmologic test using Landolt-C symbols). When this procedure is repeated for many (randomly oriented) triangles of different sizes the fraction of correct responses can be plotted (see Figure 2), and increases with test pattern size. The threshold is defined as the point at which the fraction correct crosses the 0.75 level. Critical perception is reached when the critical object diameter equals two times the width of the triangle at threshold size. The *smallest discernable detail is equal to 0.25 times the width of the triangle at threshold* size, and corresponds to the threshold gap size of a standard LandoltC test symbol (a test symbol that is commonly used in ophthalmologic tests, but which is less suited for testing sensor systems)..

Figure 1. Triangular test patterns used in the Triangle Orientation Discrimination (TOD) method

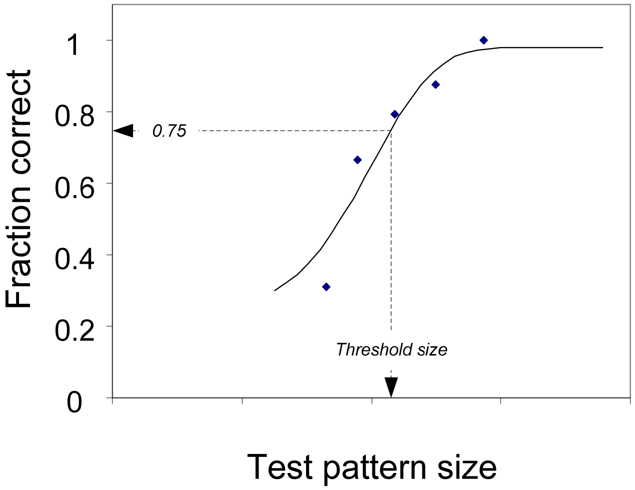

Figure 2. Typical relationship between the size of the triangle and the fraction of correct responses.

The smallest discernable detail at the centre of the viewing system can be determined using the TOD method described by Bijl & Valeton (1999). In the rest of the viewing area the smallest discernable detail can be estimated from the centrally determined critical perception conditions and the local image deformation, in which the local magnification factor should be taken into account. For instance, in the case of a digital camera the smallest discernable detail at a given pixel location (in the display) scales inversely with the solid angle of the pixel.

REFERENCE

Bijl, P.& Valeton, J.M. (1999). Guidelines for accurate TOD measurement. SPIE Proceedings, Vol. 3701 14 - 25.

Proposed text of ANNEX 10:

Annex 10
CALCULATION OF THE DETECTION DISTANCE

1. CAMERA MONITOR DEVICE FOR INDIRECT VISION

1.1. The smallest discernable detail of the naked eye is defined in standard ophthalmologic tests such as the TNO Landolt-C test in which Landolt C test symbols are judged by the subject under test. In accordance with this test the smallest discernable detail is defined as the visual angle of the gap size of the Landolt C symbol at threshold size and is expressed in arcmin. The threshold size corresponds to the size at which the subject judges the orientation correctly in 75% of the trials. The smallest discernable detail is determined in a test involving a human observer. A test chart containing test symbols is placed in front of the camera and the observer judges the orientation of test symbols from the monitor. From the threshold gap size of the Landolt C test symbol d (in m) and the distance between the camera D (in m) the smallest discernable detail ω_c (in arcmin) is calculated as follows:

$$\omega_c = \frac{d}{D} \cdot \frac{180 \cdot 60}{\pi} \qquad [\text{ arcmin}]$$

The TNO Landolt C test can be used to determine the smallest discernable detail of the camera-monitor system. However, for sensor systems it is more suitable to use the TOD (Triangle Orientation Discrimination) method which involves triangular test patterns (see appendix BB). Thresholds obtained with the latter method can easily be transformed into estimates of the smallest discernable detail.

1.2. Determination of the critical viewing distance of the monitor

For a monitor having certain dimensions and properties, a distance to the monitor can be calculated within which the detection distance is dependent only on the performances of the camera. The critical viewing distance r_{mcrit} is defined as the distance at which the smallest discernable detail displayed on the monitor spans 1 arcmin measured from the eye (the acuity threshold of a standard observer).

$$r_{mcrit} = \frac{\delta \cdot 60 \cdot 180}{\pi} \qquad [\text{ m}]$$

where:

r_{mcrit} - critical viewing distance (m)

δ – size of the smallest discernable detail on the monitor (in m)

*Note that δ is determined by the smallest discernable detail ω_c and the magnification of the camera-monitor system. For instance, when the smallest discernable detail (of e.g. 16 arcmin) spans 0.1 mm on the monitor display the critical viewing distance corresponds to 0.1/10*60*180/π = 34 cm.*

1.3. Determination of the detection distance

1.3.1. Maximum detection distance within the critical viewing distance where, due to the installation, the distance eye-monitor is less than the critical viewing distance, the maximum attainable detection distance is defined as:

$$r_{dclose} = \frac{D_0 \cdot 60 \cdot 180}{\omega_c \cdot \pi \cdot f} \qquad [\mathrm{m}]$$

where:

r_{dclose} - detection distance [m]

D_0 - diameter of the critical object [m], which is equal to 0.8 m (see 2.1.2.6)

f - threshold increasing factor, which is equal to 8.

ω_c – smallest discernable detail [arcmin] (see 1.1)

1.3.2. Detection distance greater than the critical viewing distance. Where, due to the installation, the distance eye-monitor is more than the critical viewing distance, the maximum obtainable detection distance is defined as:

$$r_{dfar} = \frac{r_{mcrit}}{r_m} \cdot r_{dclose} \qquad [\mathrm{m}]$$

where:

r_{dfar} - detection distance for distances larger than the critical viewing distance [m]

r_{dclose} - detection distance for distances smaller than the critical viewing distance [m]

r_m – viewing distance, i.e. distance between eye and monitor [m]

r_{mcrit} – critical viewing distance [m], see 1.2

2. SECONDARY FUNCTIONAL REQUIREMENTS

Based on the installation conditions, a determination shall be made to discover whether the entire device can still satisfy the functional requirements listed in paragraph 6.2.2. of this Regulation, especially the glare correction, the maximum and the minimum luminance of the monitor. It shall also be determined the degree to which the glare correction will be addressed and the angle at which sunlight can strike a monitor and these shall be compared to the corresponding measuring results from the system measurements. This can be either based on a CAD-generated model, a determination of the angles of light for the device when mounted on the relevant vehicle, or by carrying out relevant measurements on the relevant vehicle as described in paragraph 6.2.2.2.of this Regulation.

3.3 Additional test

We have not worked out a textural change in ECE-regulation 46 relating to this issue. A discussion is needed to decide whether additional tests are useful.

3.4 Component testing

We have not worked out a textural change in ECE-regulation 46 relating to this issue. A discussion is needed to decide whether this is wanted.

4 References

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Appendix A. Deriving a requirement for the blooming area by comparison with the blooming of the unaided eye

The following parameters are used:

- L_{veil} = veiling luminance [cd/m^2]
- E_{glare} = glare illuminance [lx]
- θ = angle between the glare source and the line of sight [in deg]

The intensity of the veiling luminance L_{veil} depends on E_{glare}, the illuminance at the eye caused by the glare source, and the angle between the glare source and the line of sight θ (in deg, in first order approximation, see CIE, 2002):

$$L_{veil} = \frac{10\,E_{glare}}{\theta^2} \qquad \text{(A.1)}$$

This equation (the Stiles-Holladay Disability Glare equation) is valid for $1 < \theta < 30$ deg. To simulate the effect of a veiling luminance on background contrast one can use a model of a black and white pattern, each with given reflectance coefficients illuminated by an ambient light source (e.g. the sky dome). To both luminance values the veiling luminance is added and the resulting luminance ratio (‘white’ luminance / ‘black’ luminance) is calculated. An example of such a calculation is shown in Figure A1.

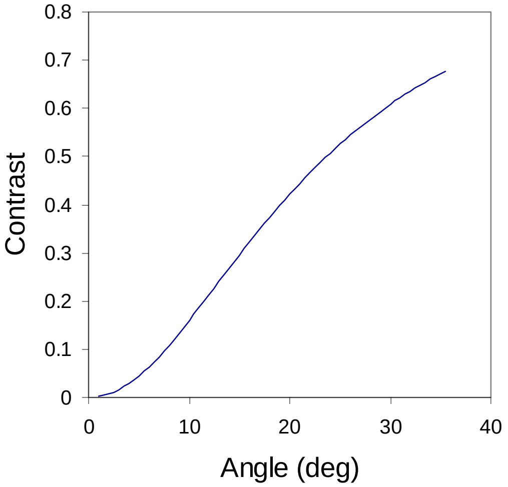

Figure A1 The contrast of a white diffuse reflecting surface (reflectance parameter 85%) and a black surface (reflectance 5%), both illuminated with 3000 lx. A blinding point source (40,000 lx) is placed on the boundary of the two surfaces and the luminance veil calculated with Equation 1 is used to find the resulting luminance ratio as a function of the angle away from the spot light.

The contrast dependents on the background contrasts involved, and both the ambient and spot lighting. It is necessary to pick the values for the disability glare calculation with care, as there is considerable variation with each of the values. For the illuminance of the blinding light source the value used for the traffic light norm from EN 12368 will be used (40,000 lux, corresponding to a sun elevation of 10 deg). A typical value of the background illumination for this situation is 3000 lx (see NEN-EN 15008). For the original object contrast value we pick the values for white and black paper, which have typical reflectance values of 85 and 5 %, respectively.

The resulting disability glare threshold angle for this case is 11.5°. The laboratory spotlight used in the test is considerable larger than the sun (which subtends about 0.5°). In the test, an angle of 5° is used. This means that in laboratory measurements the threshold angle of the disability glare will be about 14° from the incident direction (i.e. 11.5 + 5/2).

To provide a sense of which part of the visual space seen by a typical wide angle camera that we have tested (123° x 92.4°) is taken away by disability glare (a cone with a top angle of 50°) we calculate the area of the surfaces that both visuals spaces cut out from a unit sphere.

The area that a cone with a top angle 2γ cuts out from a unit sphere is given by:

$$A = 2\pi(1 - \cos\gamma) \tag{A.2}$$

The area that a square subtending a horizontal angle α and vertical angle β (as seen from the centre of the sphere) projects on the unit sphere is given by:

$$A = 2\alpha \sin(\beta / 2) \tag{A.3}$$

For a viewing system covering the same viewing angle as that of the example camera system the area that is below the disability glare contrast threshold of 0.2 is about 6% of the total image.

However, the impact of glare is much larger, since its effect prolongs after viewing the mirror (eye sight is temporarily reduced due to overexposure). We therefore propose to use the relaxed requirement that the blooming area should be limited to a maximum of 10% of the display area.

In the above discussion we compared the unaided eye with a camera-monitor system. The change of the former to a flat mirror system is trivial. The question is what happens to disability glare when seen through a curved mirror? When a curved mirror is used that displays the scene a factor 2 smaller, this does not change the luminance of the light source; the angle $d\alpha$ decreases by a factor of 4, i.e. dE decreases by a factor of 4 ($dE = L \cdot d\alpha$). Applying equation A.1, it can be seen that a contrast of 0.2 is reached at a θ that is 2 times smaller, i.e. at the same point on the background test chart. This analysis shows that the point at which a contrast of 0.2 is reached is independent of the curvature of the mirror.

References

CIE 146:2002 (2002) CIE TC 1-50 Report CIE equations for disability glare

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Appendix B. Model for deriving the acuity of a camera – monitor system from the acuity of its components

This simple model assumes that the MTF (Modulation Transfer Function) can be modelled by a system consisting of a single pole. The MTF for such a system can be written as:

$$MTF(f, f_r) = \frac{1}{\sqrt{1+\frac{f^2}{f_r^{\,2}}}}, \qquad \text{(B.1)}$$

in which MTF represents the amplitude modulation function as a function of spatial frequency f (in cycles/deg) for a system with bandwidth given by f_r.

The *MTF* of the complete camera – monitor system is the product of the *MTFs* of the individual components. The bandwidth f_{rtot} is found at the point at which the amplitude is reduced by 1/√2. The bandwidth of the complete system can be written as:

$$f_{rtot} = \frac{\sqrt{-f_1^2 - f_2^{\,2} + \sqrt{f_1^4 + 6f_1^2 f_2^{\,2} + f_2^{\,4}}}}{\sqrt{2}} \qquad \text{(B.2)}$$

The bandwidth of the complete system is always lower than the bandwidth of the poorest component. When, for instance, the smallest detail of the second component is 2 times larger than the smallest detail of the first component, the smallest visible detail of the complete system is larger than the smallest visible detail of the first component. Equation 2 shows that the smallest visible detail of the complete system in this case is 1/0.84 times that of the first component. The reduction factor is the largest for a system consisting of two components with equal bandwidth. In that case the bandwidth is 0.64 times the bandwidth of the individual components, i.e. the smallest visible detail is 1/0.64 times the smallest detail of the components.