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Fourth edition
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Photography — Electronic still-picture imaging — Noise measurements

Photographie — Imagerie des prises de vue électroniques — Mesurages du bruit

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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This document was prepared by Technical Committee ISO/TC 42, *Photography*.

This fourth edition cancels and replaces the third edition (ISO 15739:2017), which has been technically revised.

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The main changes are as follows:

— several terms and definitions have been modified, added, and deleted (see Clause 3);

— calculation procedures of camera noise, signal-to-noise ratios, and DSC dynamic range have been revised for measurement accuracy (see Clause 6);

— presentation of results has been specified expressly (see Clause 7);

— description of noise component analysis has been revised to be more detailed (see Annex A);

— measurement method of visual noise has been revised to model the human visual system more closely (see Annex B);

— method for removing low frequency variations from the image signals has been revised and changed from informative to normative processing (see Annex C);

— description of procedure for determining signal-to-noise ratio has been revised (see Annex D);

— introduction of perceptually uniform mapping of visual noise to noisiness JND has been added (see Annex F).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Noise is an important attribute of electronic still-picture imaging. If noticeable levels of noise exist in the images captured by a camera, then detail textures of objects are lost in reproduction and the visibility of the images is degraded. Therefore, measurement methods for noise are very important and are needed to provide important information relevant to evaluating image fidelity and the visibility of noise in captured images. Measurement methods are also important for assessing camera performance relative to these image quality factors.

The primary sources of noise in captured images are photon shot noise, dark current shot noise, analogue processing readout noise of image sensors, and quantization noise of A/D converters. This type of noise source adds spatially random noise to captured still images, whose spatial pattern differs from frame to frame. The other type of noise source includes dark current pattern noise, row/column pattern noise, and photo response non-uniformity of image sensors. This type of noise source also introduces spatially random noise in captured images; however, its spatial pattern does not change under the same shooting conditions.

The noise level introduced by these sources in output images is highly dependent on shooting conditions, such as the camera exposure time, aperture value, and ISO sensitivity. Camera operating temperature is also an influential factor. Some camera processing, such as contrast amplification and noise reduction, heavily influence the noise spectrum, in addition to the noise level itself.

The image quality metrics described in this document are determined from the measurement of spatially distributed noise in the output still image that is viewed by an observer. The metrics include the effect of the internal camera processing on the spectrum and level of the noise.

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When observers view output images, several factors affect how they perceive noise in images, in addition to the noise level itself. Observers view noise differently depending on the apparent tone of the area being viewed, the luminance and colour channels where noise exists, the noise spectrum, and the viewing conditions.

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This document specifies methods for measuring noise and related metrics of digital still cameras accounting for these influential factors. Measurement conditions are specified to minimize the influence of disturbance factors, to ensure that temporal and spatial statistical property changes are negligible, and to provide a good estimate of the noise level.

The main body of this document specifies methods for measuring input-referred noise, signal-to-noise ratios, and DSC dynamic range. Noise is determined as an estimate of the perceived noise computed using root mean square values measured in image signals linearized from the camera output signals. The two types of spatially random noise, temporal and fixed pattern, are determined using a noise component analysis applied to multiple captured images, the details of which are provided in Annex A.

Annex B describes a procedure for measuring the visual noise (an output-referred noise metric) using a human visual model that aims to predict the perceived quality of the image. The model weights spectral components of the noise and takes into account the noise spectrum, viewing conditions, and the perceived difference between luminance and colour channels. The metric has been shown to provide a high level of correlation with human perception of noise in images.

Low frequency variations may be introduced in the captured image due to lens shading and non-uniform test chart illumination. Since these variations can influence the noise measurement a method for removing low frequency variations from the image is provided in Annex C.

Annex D provides a recommended step-by-step procedure for determining the signal-to-noise ratio.

Annex E describes recommendations for practical viewing conditions for various output media.

Annex F introduces perceptually uniform mapping of visual noise to noisiness JND.

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Photography — Electronic still-picture imaging — Noise measurements

1 Scope

This document specifies methods for measuring and reporting the noise versus signal level and dynamic range of digital still cameras. It applies to both monochrome and colour electronic digital still cameras.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 554, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 7589:2002, *Photography — Illuminants for sensitometry — Specifications for daylight, incandescent tungsten and printer*

ISO 12232:2019, *Photography — Digital still cameras — Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index*

ISO 14524, *Photography — Electronic still-picture cameras — Methods for measuring opto-electronic conversion functions (OECFs)*

ITU-R BT.709-6, *Parameter values for the HDTV Standards for production and International programme exchange*

IEC 61966-2–1, *Multimedia systems and equipment — Colour measurement and management — Part 2-1: Colour management — Default RGB colour space — sRGB*

IEC 61966-2–1/Amd.1:2003, *Multimedia systems and equipment — Colour measurement and management — Part 2-1: Colour management — Default RGB colour space — sRGB — Amendment 1*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
camera opto-electronic conversion function
camera OECF
relationship between the input scene log luminances and the output pixel values for an opto-electronic digital capture system

Note 1 to entry: The unit of luminance (L) is cd/m^2. Log luminance is dimensionless, expressed as $\log_{10}(L/L_0)$, where L_0 = 1 cd/m^2.

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3.2
clipping value
pixel value that remains constant for further increases in exposure (highlight clipping value) or for further decreases in exposure (dark clipping value)

3.3
digital still camera
DSC
camera that produces a digital still image from the digitized output of a solid-state photo sensor and records the digital still image using a digital memory, such as a removable memory card

3.4
DSC dynamic range
ratio of the input signal (luminance or exposure) saturation level to the minimum input signal level that can be captured with a signal-to-temporal noise ratio of at least 1

3.5
exposure time
total time period during which the photo sensor is able to integrate the light from the scene to form an image

3.6
focal plane opto-electronic conversion function
focal plane OECF
relationship between the input focal plane log exposures and the output pixel values for an opto-electronic digital image capture system

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Note 1 to entry: The unit of exposure (H) is lx·s. Log exposure is dimensionless, expressed as $\log_{10}$ (H/H_0), where H_0 = 1 lx·s.

3.7
image sensor
electronic device which converts incident electromagnetic radiation into an electronic signal

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Note 1 to entry: A complementary metal oxide semiconductor (CMOS) image sensor and a charge coupled device (CCD) image sensor are examples of image sensors.

3.8
noise
unwanted variations in the response of an imaging system

3.8.1
total noise
all the unwanted variations, consisting of *fixed pattern noise* (3.8.2) and *temporal noise* (3.8.3), of the values in the image signals captured by a single exposure

Note 1 to entry: The procedure in this document for calculating the total noise requires multiple frames.

3.8.2
fixed pattern noise
FPN
unwanted spatial pixel variations of the values in the image signals which remain constant from frame to frame given the same illumination, aperture value, integration time, and ISO sensitivity setting

Note 1 to entry: Most fixed pattern noise (FPN) varies in digital number with sensor gain and ISO sensitivity setting and cannot, therefore, be considered static relative to exposure. There are three classes of fixed pattern noise, (1) static with integration time, for example, pixel FPN, column FPN and row FPN, (2) varies with integration time, for example dark current FPN, but static from frame to frame, and (3) signal dependent FPN such as photo response non-uniformity (PRNU), but still static from frame to frame.

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Note 2 to entry: PRNU is a pixel to pixel gain mismatch. It is normally expressed as a percentage of signal because it is a gain error. It is static from frame to frame and, thus, contributes to fixed pattern noise but its magnitude is a function of signal level. It is, therefore, considered as a signal dependent FPN.

3.8.3
temporally varying noise
temporal noise
unwanted variation in the values of the image signals that changes from frame to frame due to sensor dark current shot noise, photon shot noise, analogue processing, and quantization

3.9
noise spectrum
curve or equation which expresses the image noise as a function of two-dimensional image spatial frequencies

3.10
saturation
condition where the camera output signal reaches the maximum valid (not clipped or bloomed) value

3.10.1
exposure saturation
minimum focal plane exposure that produces the maximum valid (not clipped or bloomed) camera output signal

Note 1 to entry: The exposure saturation is expressed in lux-seconds (lx·s).

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3.10.2
luminance saturation
minimum scene luminance that produces the maximum valid (not clipped or bloomed) camera output signal

Note 1 to entry: The luminance saturation is expressed in candelas per square meter (cd/m^2).

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Note 2 to entry: The luminance saturation is determined for a fixed exposure setting of the camera under test.

3.11
signal-to-noise ratio
ratio of the input signal (luminance or exposure) level to the root mean square (rms) noise level, at a particular signal level

Note 1 to entry: In this document, the output pixel value is converted to an input signal level by applying the inverse OECF. The average of the input signal levels corresponds to the scene luminance (focal plane exposure) value when capturing an image. Unwanted variations exist in the converted input signal level that are centred about its average. This variation in input signal level is noise and is measured as the rms value.

Note 2 to entry: This is typically expressed as a graph or table showing the signal-to-noise ratio versus input signal level for the full range of input signal levels.

3.12
test density
spectrally non-selective transmittance filter used to reduce an input luminance to a predefined ratio of the unfiltered luminance

4 Test conditions

4.1 General

The following measurement conditions should be used as nominal conditions when measuring the noise of a DSC. If it is not possible or appropriate to achieve these nominal operating conditions, the actual operating conditions shall be listed along with the reported results.

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4.2 Illumination

4.2.1 Characteristics

The noise measurements shall indicate whether illumination conforming to the standard photographic daylight or tungsten illuminant was used. ISO 7589 describes the procedures for determining if the characteristics of the illumination used in a specific noise determination test are an acceptable match to the standard photographic daylight and tungsten illuminants.

4.2.2 Daylight illumination

For daylight measurements without the camera lens, illumination conforming to the ISO sensitometric daylight illuminant specified in ISO 7589:2002, Table 1 shall be used. This illuminant is defined as the product of the spectral power distribution of CIE Illuminant D55 and the spectral transmittance of the ISO standard camera lens. For measurements with the camera lens in place, the spectral characteristics of the illumination shall conform to CIE illuminant D55.

4.2.3 Tungsten illumination

For tungsten measurements without the camera lens, illumination conforming to the ISO sensitometric tungsten illuminant specified in ISO 7589:2002, Table 2 shall be used. This illuminant is defined as the product of the average spectral power distribution of experimentally measured sources having a colour temperature of approximately 3 050 K and the spectral transmittance of the ISO standard camera lens. For measurements with the camera lens in place, the spectral characteristics of the illumination shall conform to the average spectral power distribution of experimentally measured sources having a colour temperature of approximately 3 050 K.

4.2.4 Uniformity of illumination and reflection test chart illumination geometry

The illumination should meet the uniformity requirements of the measurement procedures described in Clause 5. For reflection test charts, the sources are positioned so that the angular distribution of influx radiation is at its maximum at 45° to the test chart normal, and is negligible at angles of less than 40° or more than 50° to the normal, at any point on the test chart.

Additional shielding of the camera may be necessary to prevent stray illumination from the light sources, or from other reflections, entering the camera lens. The illuminance incident on reflection charts, or the luminance used to illuminate transmission charts, shall not vary by more than 2 % from the mean value over the surface area of the chart as defined in ISO 14524.

NOTE In particular, if a transmissive chart is used, light from the chart can reflect off the camera or camera operator back to the surface of the chart and be imaged by the camera. Such reflections need to be avoided. This can be accomplished by shrouding the camera with black cloth and having the operator stand in a position that avoids such reflections.

4.2.5 Light source amplitude variations

The light source shall be fixed-level with combined short-term and supply amplitude variations of less than ±2 %.

4.3 Temperature and relative humidity

The ambient room temperature during the acquisition of the test data shall be 23 °C ± 2 °C, as specified in ISO 554, and the relative humidity shall be 50 % ± 20 %. Additional measurements at 0 °C and 40 °C are recommended. The normal camera operating temperature (internal rise above ambient) shall be achieved before beginning the tests. If the ambient temperature varies throughout the room, for example as a result of heat generated by light sources, the ambient room temperature shall be measured at a distance of between 0,1 m and 0,2 m from the camera under test at the same height.

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4.4 White balance

For a colour camera, the camera white balance shall be adjusted, if possible, to provide proper white balance (equal RGB signal levels) for the illumination light source, as specified in ISO 14524.

NOTE In the visual noise measurement specified in Annex B, a colour cast can result in some errors being introduced into the calculation of visual noise values.

4.5 Infrared (IR) blocking filter

If required, an infrared blocking filter shall be used, as specified in ISO 14524.

4.6 Photosite integration time

The photosite integration time should not be longer than 1/30 s.

4.7 Compression

If the DSC includes any form of lossy compression, the compression shall be disabled, if possible, during the noise measurements. If the compression cannot be turned off, then measurements should be taken and the compression level reported with the noise measurement result, for example, the actual camera switch setting (fine, standard, etc.) and the approximate average number of bits per pixel.

5 Noise measurement procedures

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5.1 General

These measurement procedures shall be used to determine the noise, the midtone signal-to-noise ratio, and the DSC dynamic range. The method of measuring noise on the spatially uniform field (luminance or exposure) will be dependent on the type of camera and its level of exposure automation.

On all cameras, the test chart and measurement methods described in 5.2 shall be used except in the following cases.

On cameras having manual exposure control, the measurement methods described in 5.3 shall be used when exclusion of scene dependency is required. On cameras having manual exposure control and removable lenses, the measurement methods described in 5.4 shall be used when exclusion of lens dependency, in addition to scene dependency, is required.

NOTE Readers are referred to ISO 14524 for the details about dependency of scene and lens that characterises differences between these three measurement methods.

5.2 Measurement of a DSC using a test chart

5.2.1 General

These measurements shall be used for all cameras except in the cases when dependency of scene and/or lens is required.

5.2.2 OECF measurement

The camera opto-electronic conversion function (camera OECF) shall first be measured in accordance with ISO 14524.

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5.2.3 Adjustment of illumination

For a camera that generates 8-bit per channel sRGB encoded signals, as defined in IEC 61966-2–1, the light source should be adjusted to give a pixel value equal to 118 from the background of the centre portion of the OECF test chart defined in ISO 14524. The test chart background shall be rendered to a pixel value of not less than 110 and not greater than 130.

If the camera is unable to deliver a pixel value in the range specified above, for example due to automatic exposure control, then the transmittance (or reflectance) of the central portion of the OECF may be varied. For a transmissive chart, the central portion of the chart may be replaced by a neutral density (ND) filter. For a reflective chart, an ND reflectance patch can be placed over the central portion of the chart. The transmittance (reflectance) of the filter (patch) is initially selected to approximate the transmittance (reflectance) of the chart background. If the chart background level exceeds 130, a lower density ND filter (higher reflectance patch) is selected. The automatic exposure control system of the camera will select a lower exposure level to compensate for the increase in light from the chart. This will result in a lower chart background level. Note that the chart background level is measured from the original background area of the test chart and not from the replacement ND filter. If the camera is still unable to deliver a pixel value in the specified range, then it shall be reported that the camera was unable to deliver the required test chart level and the pixel value of the chart background that was delivered shall be reported.

For a camera that generates signals in other colour encodings, the light source should be adjusted to give an output pixel value equal to the encoding values that correspond to a perceptual midtone for the background of the OECF test chart. The perceptual midtone value achieved should be reported.

NOTE If the digital camera uses a separate camera exposure control sensor, as shown in Figure 2, an appropriate neutral density filter can be used to cover the camera exposure control sensor, in order to adjust the chart background signal to the required level.

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5.2.4 Test chart

The test chart shall be a camera OECF test chart in accordance with ISO 14524. The test chart can be either transmissive or reflective (see Figure 1). The chart shall have sufficient density range so that the lightest patch is at or above the camera highlight clipping value when the test chart background is at the required encoding value. In most cases, this requires a high-contrast transparent chart and back illumination. A high-contrast transmissive 20 patch OECF test chart with a contrast ratio of 10,000:1 is recommended.

5.2.5 Non-uniformity and image structure spatial components

Non-uniformity in the test chart density patches shall be less than one tenth of the expected camera noise level, and any image structure spatial components shall be at a spatial frequency of at least 10 times higher than the camera limiting resolution. If the spatial components in the test chart have frequencies that are less than this level, then either the chart size in the image shall be decreased to achieve the required spatial frequencies, or the image of the target shall be defocused, so that the structure does not affect the noise measurement results. Test chart manufacturers shall provide information about the maximum limiting resolution a chart will support when the chart fills the camera frame.

5.2.6 Camera lens focus

The test target should be correctly focused by the camera under test. The target may be slightly out of focus, if necessary, to fulfil the requirements of 5.2.5.

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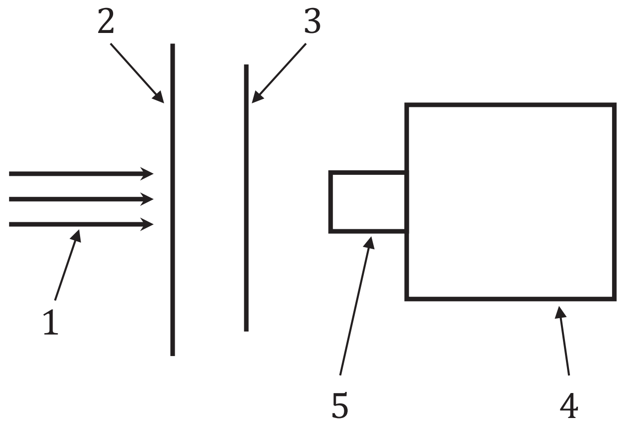
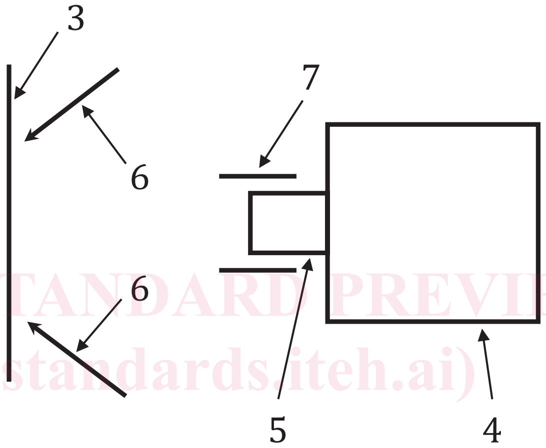


a) Test arrangement using a transmissive test chart



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b) Test arrangement using a reflective test chart

Key

1 uniform fixed level light source
2 diffuser
3 test chart
4 camera under test
5 camera lens
6 45° uniform illumination
7 additional shielding

Figure 1 — Test chart noise measurements

5.3 Measurement of a DSC having manual exposure control

5.3.1 General

These measurements shall be used for cameras that use manual exposure control, or exposure control based on a separate exposure control sensor, when exclusion of scene dependency is required.

5.3.2 OECF measurement

The camera OECF shall be measured according to ISO 14524.

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5.3.3 Adjustment of illumination

The light source and diffuser shall be adjusted to give the maximum unclipped level from the camera. If necessary, an appropriate neutral density filter should be used to cover the camera exposure control sensor in order to adjust the signal level to provide the maximum unclipped level from the camera. In some circumstances, it may not be possible to reach the maximum unclipped level due to the limitations in the resolution of the exposure adjustment or in the light source used. In this case, expose the uniform field in such a way that the exposure is increased by the smallest possible step from the exposure leading to the maximum unclipped level so that the output signal is "just clipped."

5.3.4 Test densities

A set of test densities shall be used to provide signal levels to determine the camera OECF. The densities should correspond to the densities of the patches from a test chart specified in ISO 14524. The density of the lightest patch shall provide a signal level that is at or above the maximum unclipped level from the camera. The density of the darkest patch should be greater than or equal to 2,0. If the density of the darkest patch is less than 2,0, then a test density of 2,0 density (1 % transmittance) shall be used to provide a "black reference" signal level to determine the DSC dynamic range.

Test densities shall completely cover the field of view of the camera.

5.3.5 Diffuser setting

The diffuser shall be uniform and close to the camera, preferably less than one tenth of the minimum focus distance of the camera under test, to prevent diffuser blemishes from influencing the noise measurements. The diffuser may be illuminated by either transmissive or reflective light (see Figure 2).

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5.3.6 Camera lens focus

If the camera lens focus is adjustable, it shall be set to infinity.

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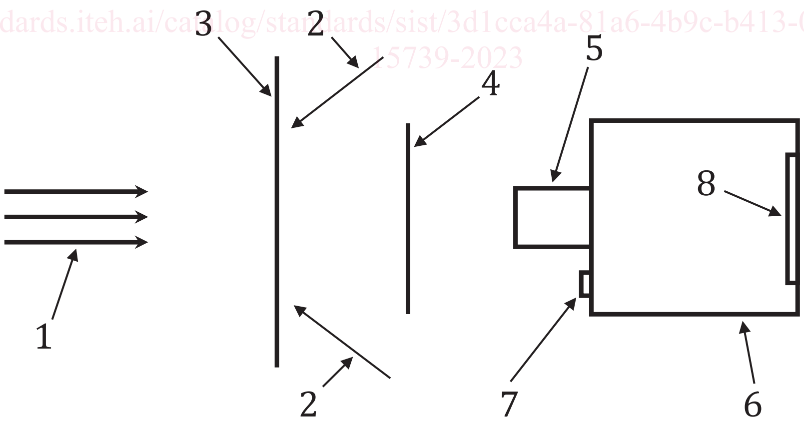

Key

1 transmissive uniform fixed level light source

2 reflective uniform fixed level light source

3 diffuser

4 test density

5 camera lens

6 camera under test

7 camera exposure control sensor

8 digital image sensor

Figure 2 — Uniform field noise measurements

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5.4 Measurement of a DSC having a removable lens

5.4.1 General

This measurement shall be used for cameras having manual exposure control, or exposure control based on a separate exposure control sensor, and removable lenses, when exclusion of lens dependency, in addition to scene dependency, is required.

This method involves the exposure of the DSC sensor directly to specific quantities of uniform illumination with the lens removed. The illumination shall have the spectral characteristics specified in 4.2 and shall be produced by a small source at a distance, such that the largest dimensions of the source and the sensor are no greater than one twentieth of the distance between them, as shown in Figure 3. Reflective surfaces shall not be placed where they could cause additional illumination to be incident on the sensor.

5.4.2 OECF measurement

The focal plane opto-electronic conversion function (focal plane OECF) shall be measured in accordance with ISO 14524.

5.4.3 Adjustment of illumination

The specifications described in 5.3.3 shall be applied.

5.4.4 Test densities

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The test densities specified in 5.3.4 shall be used. They shall completely cover the area exposed, when the camera lens is removed.

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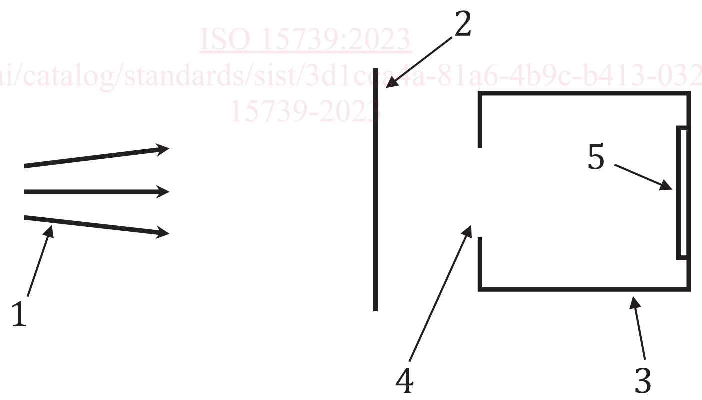

Key

1 light source

2 test density

3 camera under test

4 lens removed

5 digital image sensor

Figure 3 — Illumination for cameras with removable lenses

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