INTERNATIONAL STANDARD

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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.

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

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

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

ISO 15739 was prepared by Technical Committee ISO/TC 42, *Photography*.

Introduction

Noise is an important attribute of electronic photographic systems. Standardization assists users and manufacturers in determining the quality of images that may be obtained from an electronic still-picture camera. The camera noise measurements described in this International Standard are performed in the digital domain, using digital analysis techniques. For electronic cameras that include only analogue outputs, the analogue signal has to be digitized, so that the digital measurement can be performed. The digitizing equipment has to be characterized, so that the effects of the digitization can be removed from the measurement results. When this is not possible, the type of digitizing equipment used is to be reported along with the measurement results.

Since the noise performance of an image sensor may vary significantly with exposure time and operating temperature, these operating conditions are specified. The visibility of noise to human observers depends on the magnitude of the noise, the apparent tone of the area containing the noise and the spatial frequency of the noise. The magnitude of the noise present in an output representation depends on the noise present in the stored image data and the contrast amplification or gain applied to the data in producing the output. The noise visibility is different for the luminance (or monochrome) channel and the colour (or colour difference) channels. Therefore, this International Standard accounts for these factors in measuring and reporting the camera noise measurements. Annex A gives the construction of an ISO standard camera noise test chart. Annex B specifies the method for determining the components of the digital camera noise from a number of samples. Annex C describes a procedure using a human visual model as a method for weighting the spectral components of the noise.

Many electronic still-picture cameras use extensive signal processing to reduce noise in uniform areas, and the noise levels measured in the large area test defined in this International Standard may not be representative of the noise levels found in the pictures taken by the camera. Therefore, new methods of measuring edge noise have been investigated. One method is described in Annex D. The incremental gain calculation is given in Annex E.

INTERNATIONAL STANDARD **ISO 15739:2003(E)**

Photography — Electronic still-picture imaging — Noise measurements

1 Scope

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

2 Normative references

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

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

ISO 12232:1998, *Photography — Electronic still-picture cameras — Determination of ISO speed*

ISO 14524:1999, *Photography — Electronic still-picture cameras — Methods for measuring opto-electronic conversion functions (OECFs)*

ITU-R BT.709-5, *Parameter values for the HDTV Standards for production and International programme exchange*

3 Terms and definitions

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

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

NOTE The units of measurement for this function are $\log_{10}$ candelas per square metre.

3.2
digital output level
digital code value
numerical value assigned to a particular output level

3.3
digital still camera
DSC
camera incorporating an image sensor which outputs a digital signal representing a still picture, or records a digital signal representing a still picture on a removable medium, such as a memory card or magnetic disk

3.4
electronic still-picture camera

camera incorporating an image sensor which outputs an analogue or digital signal representing a still picture, and/or records an analogue or digital signal representing a still picture on a removable medium, such as a memory card or magnetic disk

3.5
image sensor

electronic device which converts incident electromagnetic radiation into an electronic signal

NOTE A charge coupled device (CCD) array is an example of an electronic signal.

3.6
incremental gain function

change in the output level (digital code value) divided by the change in the input level (luminance or exposure) as a function of the light level

NOTE 1 For the determination of incremental gain values, log input values are not used.

NOTE 2 If the input exposure points are very finely spaced and the output noise is small compared to the quantization interval, the incremental gain function can have a jagged shape. Such behaviour is an artefact of the quantization process and is removed by using an appropriate smoothing algorithm, or by fitting a smooth curve to the data. In some cases, it may be desirable to fit a curve to the input-output data and then determine the incremental gain function by taking the first derivative of the function used for the curve fit.

3.7
incremental output signal

input level (luminance or exposure, not logged) multiplied by the system incremental gain at that level

3.8
incremental signal-to-noise ratio

ratio of the incremental output signal to the root mean square (rms) noise level, at a particular signal level

NOTE This is typically expressed as a graph or table showing the rms noise level versus output signal level for the full range of output signal levels.

3.9
ISO DSC dynamic range

ratio of the maximum luminance level which appears unclipped to the minimum luminance level which can be reproduced with an incremental signal-to-temporal-noise ratio of at least 1, as determined in accordance with ISO 15739

3.10
noise

unwanted variations in the response of an imaging system

3.10.1
total noise

all the unwanted variations captured by a single exposure

3.10.2
fixed pattern noise

unwanted variations which are consistent for every exposure

3.10.3
temporally varying noise

random noise due to sensor dark current, photon shot noise, analogue processing and quantization, which varies from one image to the next

3.11

noise spectral power distribution

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

3.12

photosite integration time

total time period during which the photosites of an image sensor are able to integrate the light from the scene to form an image

3.13

signal processing

operations performed by electronic circuits or algorithms which convert or modify the output of an image sensor

3.14

video signal-to-noise ratio

ratio of the maximum (peak) output signal level to the root mean square (rms) noise level in video systems

NOTE 1 This value is typically expressed in decibels (dB).

NOTE 2 This term is not used to express the noise in an electronic still-picture imaging system.

4 Test conditions

4.1 General

The following measurement conditions should be used as nominal conditions when measuring the noise of an electronic still-picture camera. 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.

4.2 Illumination

4.2.1 Characteristics

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

4.2.2 Daylight illumination

For daylight measurements without the camera lens, a source conforming to the ISO sensitometric daylight illuminant specified in Table 1 of ISO 7589:2002 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 illuminant shall be equivalent to CIE illuminant D55.

4.2.3 Tungsten illumination

For tungsten measurements without the camera lens, a source conforming to the ISO sensitometric tungsten illuminant specified in Table 2 of ISO 7589:2002 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 illuminant shall be equivalent to the product of the average spectral power distribution of experimentally measured sources having a colour temperature of approximately 3 050 K.

4.2.4 Reflection illumination

For measurements using a reflection test chart, the illumination should meet the uniformity requirements of the measurement procedures described in Clause 5. 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.

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.

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.

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 Colour noise weighting

For colour cameras using a single exposure process, the camera noise may be determined using a weighted sum of the colour outputs to derive the luminance. If the proper luminance weighting values for the RGB channel spectral sensitivities are known, they shall be used to calculate the luminance channel data. If these values are not known, the following weighting, given in ITU-R BT.709, shall be used:

$$\mathrm{Y} = 0{,}2125\ \mathrm{R} + 0{,}7154\ \mathrm{G} + 0{,}0721\ \mathrm{B} \tag{1}$$

For colour cameras with luminance and colour-difference outputs, the standard deviation of the camera noise may be computed from the luminance channel standard deviation $\sigma(\mathrm{Y})$, the red minus luminance channel standard deviation σ (R-Y) and the blue minus luminance channel standard deviation σ (B-Y). The following Equation (2), as specified in 6.2.3 of ISO 12232:1998 shall be used:

$$\sigma(D_H) \text{ or } \sigma(D_L) = [\sigma(\mathrm{Y})^2 + 0{,}64\ \sigma(\mathrm{R\text{-}Y})^2 + 0{,}16\ \sigma(\mathrm{B\text{-}Y})^2]^{1/2} \tag{2}$$

4.8 Compression

If the electronic still-picture camera 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

5.1 General

These measurement procedures shall be used to determine the camera noise, the camera signal-to-noise ratio and the camera dynamic range. The minimum requirement is to specify the signal-to-total-noise ratio and the dynamic range of the digital camera under test. In addition, the fixed pattern and temporal noise components can be expressed individually and the total noise weighted to match a known expression for human visual response.

5.2 Uniform field noise measurement methods

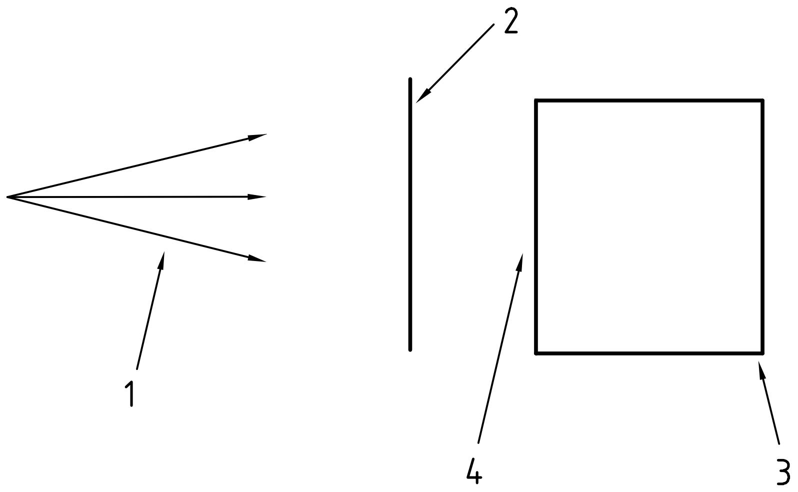
The method of measuring the uniform field noise will be dependent on the type of camera and its level of exposure automation. If the camera lens can be removed, then the sensor noise level can be measured without any shading effects from the lens.

On automatic exposure cameras having through the lens (TTL) exposure control and no manual exposure control override capability, the test chart and measurement methods described in 5.6 shall be used.

5.3 Cameras with removable lenses

5.3.1 General

This method involves the exposure of the electronic still-picture camera 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 1. Reflective surfaces shall not be placed where they could cause additional illumination to be incident on the sensor.



Key

1 light source
2 test density
3 camera under test
4 lens removed

Figure 1 — Illumination for cameras with removable lenses

5.3.2 The camera OECF shall first be measured according to ISO 14524.

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

5.3.4 The light source 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.

5.3.5 Test densities shall completely cover the area exposed, when the camera lens was removed.

5.4 Whole camera

5.4.1 General

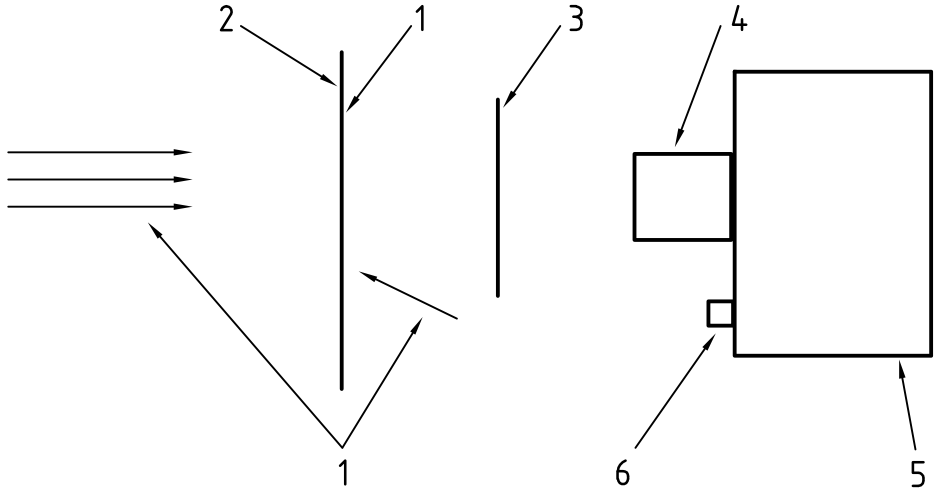
These measurements shall be used for all cameras that use manual exposure control, or exposure control based on a separate exposure control sensor.

5.4.2 The camera OECF shall first be measured according to ISO 14524.

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

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

5.4.5 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).



Key

1 uniform fixed level light source
2 diffuser
3 test density
4 camera lens
5 camera under test
6 camera exposure control sensor

Figure 2 — Uniform field noise measurements

5.4.6 The light source and diffuser shall be adjusted to give the maximum unclipped signal level from the camera. If necessary, an appropriate spectrally neutral density filter shall be used to cover the camera exposure control sensor to adjust the signal level, in order to provide the maximum unclipped signal level from the camera.

5.4.7 Test densities shall only cover the camera lens.

5.5 Density measurements for methods 5.3 and 5.4

5.5.1 A test density of 0,9 (13 % transmittance) shall be used to provide an “18 % reference” signal level equal to that of an 18 % reflectance card with a camera peak signal level of 140 %, corresponding to the saturation signal level in ISO 12232.

5.5.2 A test density of 2,0 (1 % transmittance) shall be used to provide a “black reference” signal level to determine the camera dynamic range.

5.5.3 Any optional additional test densities should correspond to the test chart densities listed in ISO 14524.

5.6 Test chart noise measurements

5.6.1 General

These measurements shall be used for TTL automatic exposure cameras having no manual exposure control override.

5.6.2 The camera OECF shall first be measured in accordance with ISO 14524.

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

5.6.4 The light source shall be adjusted to give the maximum unclipped level from the camera, on the lightest patch of the test chart, e.g. patch 12 on the OECF or noise test chart. If necessary, an appropriate neutral density filter should cover the camera exposure control sensor, in order to adjust the lightest patch signal level, to the maximum unclipped level.

5.6.5 The test chart shall be either the test chart specified in ISO 14524 or the test chart specified in Annex A. The test chart can be either transmissive or reflective (see Figure 3).

5.6.6 If a transmissive test chart is used, the diffuser shall be uniform. If a reflective test chart is used, the chart illumination shall be as described in 4.2.4. Additional shielding of the camera may be necessary to prevent stray illumination from the light sources, or from other reflections, entering the camera lens.

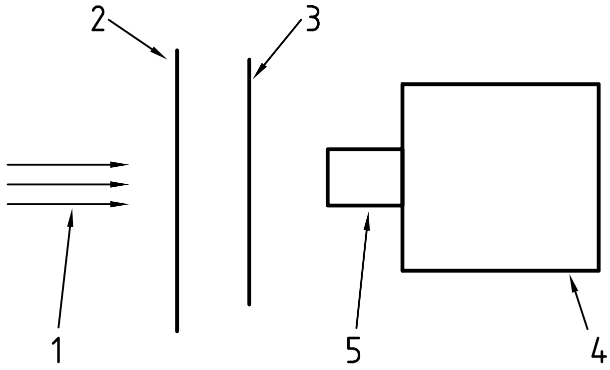
5.6.7 Non-uniformity in the test chart density patches shall be less than one tenth of the expected camera noise level, and any image structure spatial components shall be at a spatial frequency of at least 10 times higher than the camera limiting resolution.

5.6.8 In order to overcome erroneous results due to gamma lookup tables in the digital still-picture cameras, the noise measurement at the density of 0,9 shall be averaged with measurements at densities either side of 0,9 (measurements at densities of 1,05 and 0,77).

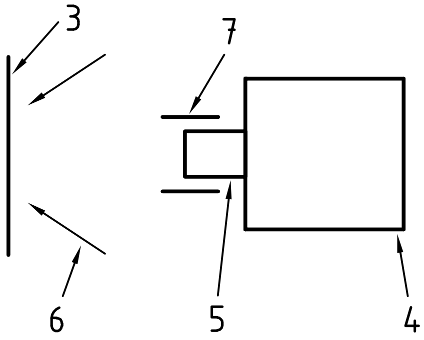
5.6.9 Shading from the illumination should be such that the effect of the shading does not affect the standard deviation of the digital code values by more than one digital level across the sample patch.

5.6.10 The test target shall be correctly focused by the camera under test.

5.6.11 The whole apparatus shall be securely mounted to reduce movement between exposures to less than one quarter of a pixel.



a) **Test arrangement using a transmissive test chart**



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 3 — Test chart noise measurements

6 Calculation and reporting of results

6.1 General

The measurements made in 5.5 and 5.6 are converted to reported noise values as follows.

For the measurements made according to 5.3 and 5.4, a minimum of eight images shall be captured for each test density. The mean code value and the rms noise level shall be determined from an area of not less than 64 × 64 pixels in the centre of each of the images.

For the test chart case, a minimum of eight images shall be captured in a single session. The mean code value and rms noise level shall be determined from an area of not less than 64 × 64 pixels in the centre of each of the patches of the test chart specified in Annex A. The calculation can be conducted by using the plug-in software described in 6.5.

6.2 Signal-to-noise ratios — large area

6.2.1 General

The signal-to-noise ratio is determined from data captured at the "18 % reference" signal level. In methods 5.3 and 5.4, this is accomplished by using the densities specified in 5.6.7, and in method 5.6, by using the density patches in block 13 on the test chart specified in Annex A.

The total noise is converted to an input referred incremental signal-to-noise ratio for the test density, and reported as the ISO standard camera signal-to-noise ratio.

6.2.2 The signal-to-total-noise ratio is determined by:

$$\frac{L_{\mathrm{sat}} \times 0{,}18 \times \text{incremental gain}}{\sigma_{\mathrm{total}}} \tag{3}$$

for the case of a density of 0,9, where:

L_{sat} is the target luminance which gives the maximum unclipped output from the camera, e.g. for an eight bit system, this is 255;

0,18 is the 18 % reflectance of the target of a density of 0,9 with respect to a maximum level of 140 %.

The incremental gain is the first derivative of the OECF, determined by the method in ISO 14524 and the noise is calculated from the standard deviations with the precision defined by the digital resolution used for the maximum level.

The average of the total noise is the average of the standard deviations of "n" samples of the total noise and is given by:

$$\sigma_{\mathrm{total}} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\sigma_{\mathrm{total},j}^{2}} \tag{4}$$

6.2.3 The fixed pattern signal-to-noise ratio is determined by averaging a minimum of eight exposures and then applying a correction to determine the true level of the fixed pattern noise. The fixed pattern noise is converted to an input referred incremental signal-to-noise ratio for the test density, and reported as the ISO standard camera fixed pattern signal-to-noise ratio.

For a test density of 0,9 the ISO standard camera fixed pattern signal-to-noise ratio is determined by:

$$\frac{L_{\mathrm{sat}} \times 0{,}18 \times \text{incremental gain}}{\sigma_{\mathrm{fp}}}$$

The average of the fixed pattern noise is:

$$\sigma_{\mathrm{fp}} = \sqrt{\sigma_{\mathrm{ave}}^{2} - \frac{1}{n-1}\sigma_{\mathrm{diff}}^{2}} \tag{5}$$

where

σ_{fp} is the standard deviation of the fixed pattern noise;

σ_{ave} is the standard deviation of the code values of the average of "n" images;

σ_{diff} is the average standard deviation of the code values of all the differences of the average and the individual images that make up the average.

The average of the sum of all the difference images is:

$$\sigma_{\text{diff}}^2 = \frac{1}{n}\sum_{j=1}^{n}\sigma_{\text{diff},j}^2 \tag{6}$$

where $\sigma_{\text{diff},j}$ is the standard deviation of the code values of the difference of the average and the jth image.

The derivation of Equations (5) and (6) is shown in Annex B

6.2.4 The temporal signal-to-noise ratio is determined by measuring the standard deviation of the difference of each image and the average image and applying a correction to determine the true level of the temporal noise. The temporal noise is converted to an input referred incremental signal-to-noise ratio for the test density, and reported as the ISO standard camera temporal signal-to-noise ratio.

For a test density of 0,9 the temporal signal-to-noise ratio is determined by:

$$\frac{L_{\text{sat}} \times 0{,}18 \times \text{incremental gain}}{\sigma_{\text{temp}}}$$

The average of the temporal noise is:

$$\sigma_{\text{temp}} = \sqrt{\frac{n}{n-1}\sigma_{\text{diff}}^2} \tag{7}$$

where

σ_{temp} is the standard deviation of the temporal noise;

σ_{diff} is the average standard deviation of the code values of all the differences of the average and the individual images that make up the average, shown in more detail in 6.2.3.

6.3 ISO DSC dynamic range

The ISO DSC dynamic range is the ratio of the maximum unclipped luminance level to the minimum luminance level that can be reproduced with a signal-to-temporal noise-ratio of at least 1. In order to avoid black level clipping problems, the camera dynamic range is obtained by measuring the camera signal-to-temporal-noise ratio using a 2,0 density “black reference”. The measured signal-to-black-temporal-noise ratio is then multiplied by the ratio of the camera maximum level to the camera level from the “black reference”. The result is reported as the ISO DSC dynamic range.

ISO DSC dynamic range is given by:

$$\frac{L_{\text{sat}} \times 0{,}014 \times \text{incremental gain} \times 100}{\text{average black temporal noise}}$$

where

0,014 is the 1,4 % reflectance of the target of a density of 2,0 with respect to a maximum level of 140 %;

× 100 is the ratio of the target reflectance to the 100 % output level;

black temporal noise	is the temporal noise of the “black reference” signal level in 5.3 or 5.4, or the 2,0 density patch in 5.6.

The black temporal noise is derived in a similar way to the temporal noise in 6.2.4, by measuring the standard deviation of the difference of each image and the average image, and then applying a correction to determine the true level of the temporal noise:

$$\sigma_{\text{temp}} = \sqrt{\frac{n}{n-1}\sigma_{\text{diff}}^2} \qquad (8)$$

where

σ_{temp} is the standard deviation of the temporal noise;

σ_{diff} is the average standard deviation of the code values of all the differences of the average and the individual images that make up the average, shown in more detail in 6.2.3.

6.4 Visual noise measurements

The visual noise level can vary depending on the viewing distance, spatial frequency, density, colour and viewing conditions. A method for measuring visual noise has not yet been standardized, and is the subject of ongoing research. A method for measuring the visual noise level is provided in Annex C.

6.5 Evaluation of noise measurements with software

The evaluations of both the total noise measurements and the visual noise measurements can be conducted using Photoshop(1) (or equivalent) software as described below:

a) the measurement area for evaluation shall be the same as the area in the total noise measurements;

b) the evaluation procedure using the software shall be as follows:

    1) display the image with Photoshop (or equivalent) software;

    2) choose the test chart area by rectangular tool;

    3) from the “Filter” tool, in Photoshop, select “ISO Standards” and then “Noise Measurement”;

    4) save the test result in a text file after completing the calculation according to the instruction;

    5) plot the test results.

An example of an actual plug-in algorithm is described in Annex C.

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1) Photoshop is the trade name of a product supplied by Adobe Systems Incorporated. This information is given for the convenience of the users of this International Standard and does not constitute an endorsement by ISO of this product.

Annex A
(normative)

Test chart

A.1 Test chart image

Figure A.1 shows an example of an ISO standard camera noise test chart. This is, however, a half-tone reproduction and should not be used for actual noise measurements.

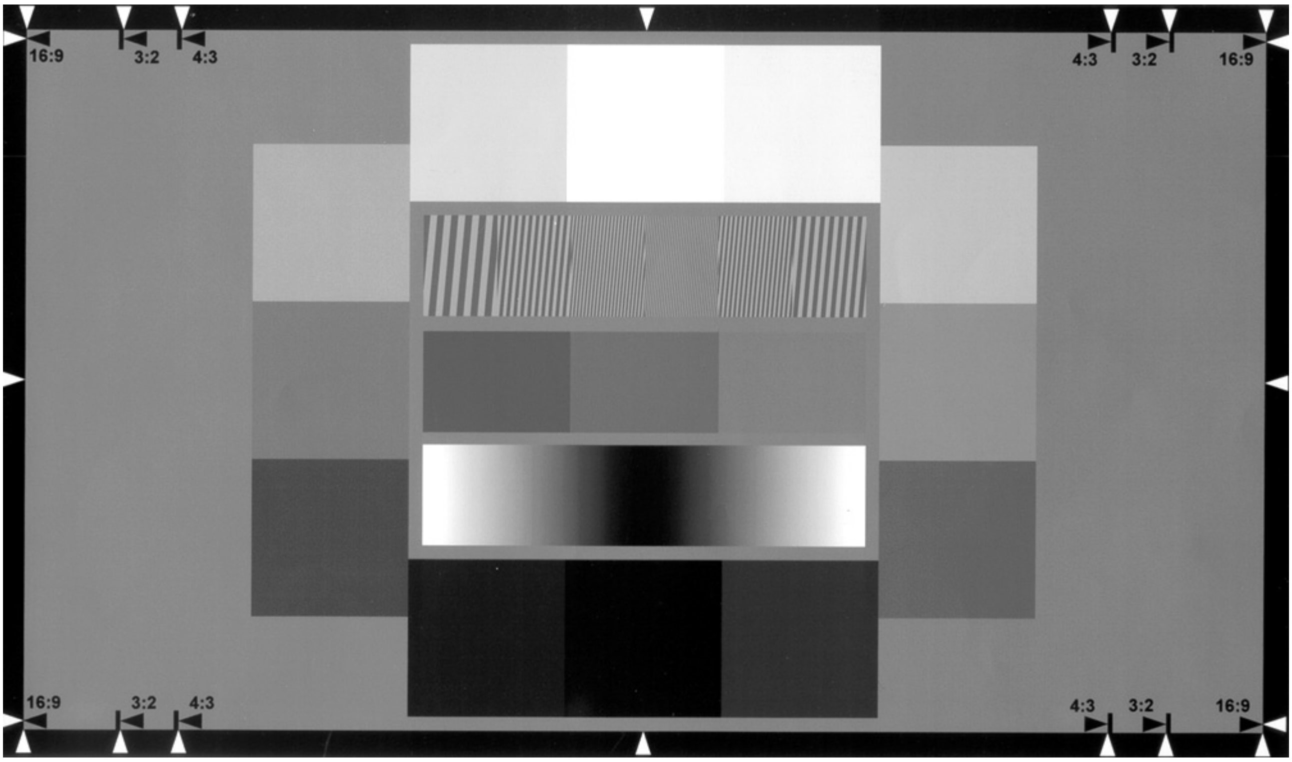


Figure A.1 — Illustration of an example ISO standard camera noise test chart

A.2 ISO standard camera noise test chart construction

A.2.1 General description

a) Box 1 to box 12 are uniform density patches for the OECF measurements.

b) Box 13 comprises three densities patches for the basic noise measurements.

c) Box 14 contains six sets of tilted modulation bars for the high frequency noise measurements.

d) Box 15 is a swept density patch for checking the noise level at different densities.

e) Any other part of the test chart is a uniform background density.

A.2.2 Test chart feature sizes

Box 1 to box 12 are square boxes of each side equal to 0,225 × height, h.

Boxes 13, 14 and 15 are 0,144 × h high by 0,636 × h long.

Each density block in box 13 is 0,144 × h by 0,212 × h long.

Each block of modulation bars in box 14 is 0,144 × h high by 0,106 × h long.

A.2.3 Feature positioning

Box 1 to box 12 are arranged in four blocks of three adjacent boxes as shown in Figure A.2.

The side blocks 4, 6, 8 and 5, 7, 9 are centralized vertically with a gap of 0,1 625 × h between the top and the bottom of the chart. The top and bottom blocks 10, 12, 11 and 2, 1, 3 are centred horizontally with a 0,02 × h gap to the top and bottom edge of the chart respectively.

The centre blocks are also centralized, within the rectangle bounded by the first 12 boxes, with a gap of 0,0 195 × h between the horizontal and vertical edges.

The complete array of blocks is centralized within the whole test chart.

A.2.4 Box 1 to box 12, density values

The density values are as defined in the 80:1 standard reflection chart specified in Annex A of ISO 14524:1999. The boxes numbered 1 to 12 in Figure A.2 correspond to the step numbers 1 to 12 in the OECF test chart.

The background density of the noise chart given in Figure A.2 is as defined for the OECF test chart.

A.2.5 Box 14, modulation bars

Six blocks of modulation bars are defined, all the bars are tilted 5° to the right at the top, to minimize aliasing artefacts.

The blocks are defined in lines per picture height, as follows:

Block number	Frequency, lines per picture height
14a	100
14b	200
14c	400
14d	600
14e	300
14f	150

The average density of the modulation bars should be equal to the background density with the modulation bar density equal to one OECF patch above and below the background density. The increment is as defined in the 80:1 standard reflection chart given in Annex A of ISO 14524:1999.

A.2.6 Box 13

Box 13 is divided into three blocks of density, as follows:

13a	1,05
13b	0,90
13c	0,77

A.2.7 Box 15, swept density

The swept density box covers the same range as the OECF patches, but in a continuous density sweep rather than in steps. The density starts at the OECF minimum, at the left hand edge, rises to the OECF maximum patch density at the centre of the box, and then falls back to the minimum at the right hand edge of the box. The average density of the box is equal to the background density of the chart.

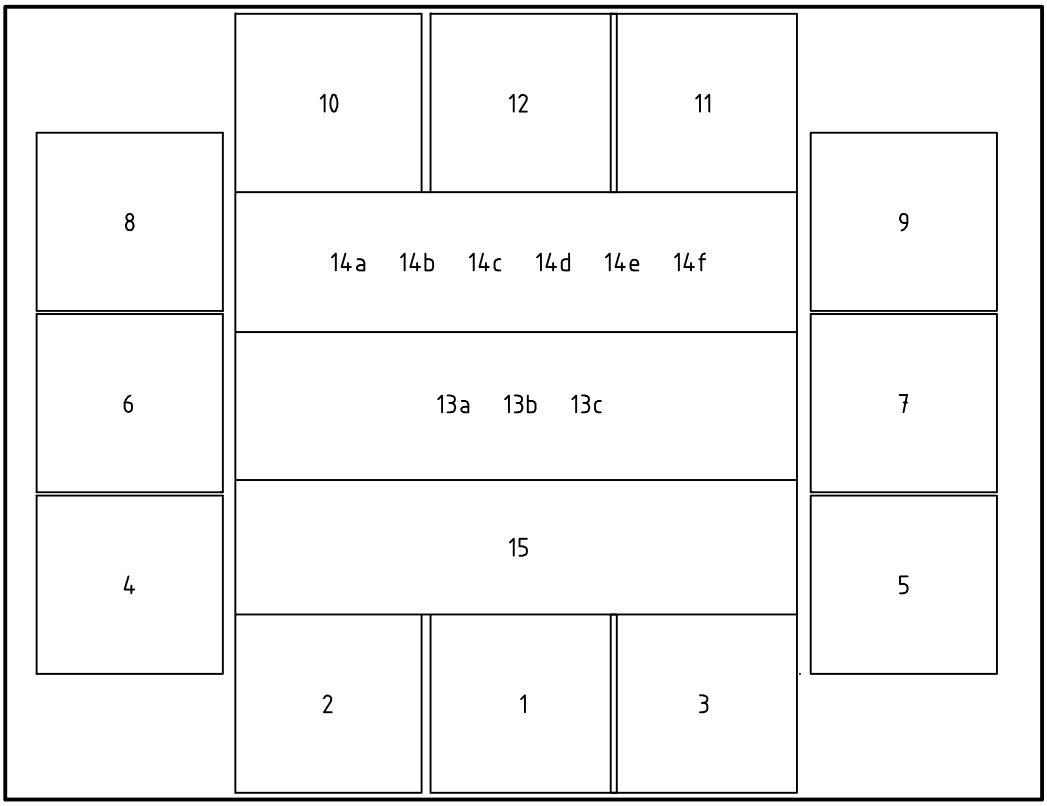


Figure A.2 — Test chart feature positions

Annex B
(normative)

Noise component analysis

B.1 Object

B.1.1 General

The object of this analysis is to show that the true levels of the noise components can be calculated from a number of samples and the average of those samples. In principle, it is possible to reduce the number of images captured to just two. However, this increases the statistical uncertainty of the noise value.

The noise in an image from a digital camera consists of a fixed pattern component and a temporally varying component. It is assumed that the two noise components are not correlated and the relationship for the total noise is as shown in Equation B.1:

$$\sigma_{\text{total}}^2 = \sigma_{\text{fp}}^2 + \sigma_{\text{temp}}^2 \tag{B.1}$$

B.1.2 Analysis

The following notation shall be used for the noise component analysis.

$g(x,y)$	are the digital code values of pixel (x,y) of an image;
$g_{\text{fp}}(x,y)$	is the fixed pattern part of the image;
$g_{\text{temp}}(x,y)$	is the temporally varying part of the image;
σ_{total}	is the standard deviation of $g(x,y)$, total noise;
σ_{fp}	is the standard deviation of $g_{\text{fp}}(x,y)$, fixed pattern noise;
σ_{temp}	is the standard deviation of $g_{\text{temp}}(x,y)$, temporal noise;
σ_{ave}	is the standard deviation of the code values of the average of several images;
σ_{diff}	is the standard deviation of the code values of the difference of two images.

B.1.3 Fixed pattern noise

The fixed pattern noise is determined by analysing the average image of “n” images, g_1 to g_n. Since the fixed pattern part of the image is, by definition, equal for all images, the code values of the average image are:

$$\overline{g}(x,y) = \frac{1}{n}\sum_{j=1}^{n} g_j(x,y) = g_{\text{fp}}(x,y) + \frac{1}{n}\sum_{j=1}^{n} g_{\text{temp},j}(x,y)$$

Since there is no correlation of the temporal noise of different images, the variance of the code values of the average image is:

$$\sigma_{\text{ave}}^2 = \sigma_{\text{fp}}^2 + \frac{1}{n^2}\sum_{j=1}^{n} \sigma_{\text{temp},j}^2$$

If the mean of the variances of the temporal noise is denoted as σ_{temp}^2, then

$$\sigma_{\mathrm{ave}}^2 = \sigma_{\mathrm{fp}}^2 + \frac{1}{n}\sigma_{\mathrm{temp}}^2 \tag{B.2}$$

Thus, σ_{ave} consists of the fixed pattern noise plus an additional, residual contribution due to the temporal noise.

B.1.4 Temporal noise

The temporal noise is determined by analysing the standard deviation of the difference of each image and the average image. The code values of the difference images are:

$$\Delta g_j(x,y) = \left[\frac{1}{n}\sum_{j=1}^{n} g_j(x,y)\right] - g_j(x,y) = \left[\frac{1}{n}\sum_{j=1}^{n} g_{\mathrm{temp},j}(x,y)\right] - g_{\mathrm{temp},j}(x,y)$$

The mean of the variances of the code values of the difference images is then:

$$\sigma_{\mathrm{diff}}^2 = \frac{1}{n}\sum_{j=1}^{n}\sigma_{\mathrm{diff},j}^2 = \frac{n-1}{n^2}\sum_{j=1}^{n}\sigma_{\mathrm{temp},j}^2 = \frac{n-1}{n}\sigma_{\mathrm{temp}}^2$$

The standard deviation of the temporal noise is thus given by:

$$\sigma_{\mathrm{temp}} = \sqrt{\frac{n}{n-1}\sigma_{\mathrm{diff}}^2}$$

Using this result, the standard deviation of the fixed pattern noise can be obtained with the result derived in Equation B.2:

$$\sigma_{\mathrm{fp}} = \sqrt{\sigma_{\mathrm{ave}}^2 - \frac{1}{n-1}\sigma_{\mathrm{diff}}^2}$$

NOTE If the fixed pattern noise standard deviation is much smaller than the temporal noise standard deviation, it may be possible, with a small number of samples, that the sample uncertainty results in the fixed pattern noise being the square root of zero or a negative number. The solution is to increase the number of samples.

B.2 Method using eight images

B.2.1 Step-by-step description

a) To exploit the full information of the images captured, first the average image is calculated and the standard deviation of the average image is evaluated to give σ_{ave}.

b) The second step is to calculate the difference of each image and the average image.

c) The third step is to calculate the standard deviations of the code values of the difference images to give $\sigma_{\mathrm{diff},j}$, where j = 1 to 8.

d) The fourth step is to calculate the mean of all squared standard deviations of the difference images, to give:

$$\sigma_{\mathrm{diff}}^2 = \frac{1}{8}\sum_{j=1}^{8}\sigma_{\mathrm{diff},j}^2$$

e) The standard deviation of the temporal noise is then calculated as:

$$\sigma_{\text{temp}} = \sqrt{\frac{8}{7}\sigma_{\text{diff}}^{2}} \tag{B.3}$$

f) The standard deviation of the fixed pattern noise is calculated as

$$\sigma_{\text{fp}} = \sqrt{\sigma_{\text{ave}}^{2} - \frac{1}{7}\sigma_{\text{diff}}^{2}} \tag{B.4}$$

B.2.2 Evaluation of the method using example data

B.2.2.1 Example data

Table B.1 shows an example of the mean code values of eight images, example standard deviation values σ_{total} for each image, and the standard deviation of the code values of the difference of each of the eight images and the average image.

Table B.1 — Example noise data for eight images

Image *n*	**Mean code value**	σ_{total}	σ_{diff}
1	91,27	2,17	1,91
2	91,04	2,18	1,92
3	91,05	2,10	1,87
4	90,96	2,14	1,89
5	90,95	2,12	1,89
6	90,89	2,13	1,92
7	91,10	2,12	1,91
8	91,13	2,19	1,93

B.2.2.2 Evaluation

Step 1 The mean code value of the average image is 91,05 (from Table B.1) and the standard deviation of the code values of the average of the eight images is given as 1,01, i.e. $\sigma_{\text{ave}} = 1,01$.

Steps 2 to 4 The mean of the squared standard deviations of the eight difference images is 3,63 (from Table B.1), i.e. $\sigma_{\text{diff}}^{2} = 3,63$.

Step 5 Equation (B.3) yields 2,04 for the standard deviation of the temporal noise, i.e. $\sigma_{\text{temp}} = 2,04$.

Step 6 The standard deviation of the fixed pattern noise can be calculated according to Equation (B.4), $\sigma_{\text{fp}} = 0,71$.

The result of the calculation can be verified by checking that the squared sum of the temporal and the fixed pattern noise results in the total noise shown in Table B.1.

The square root of the sum of the squares of the temporal and fixed pattern noise is 2,16 and the average of the total noise from Table B.1 is 2,14.

Annex C
(informative)

Visual noise measurements

C.1 General

As stated in 6.4, a method for measuring visual noise has not yet been standardized, and is the subject of ongoing research. This annex provides one method for measuring the visual noise level. The visual noise is evaluated as an output referred noise, unlike the ISO standard camera signal-to-noise ratio described in 6.2. It uses the plug-in software “Noise Measurements” described in detail below. The general steps of the method are given below.

a) The image data of each density patch is converted to the spatial frequency domain using the discrete Fourier transform applied to the opposite colour components: white-black, red-green and yellow-blue.

b) The noise power spectra are weighted with human spatial responses consistent with a specific viewing angle with respect to the image height. The weighted power spectra are converted back to the spatial domain using the inverse discrete Fourier transform.

c) The weighted sums of the three standard deviations of the filtered noise for each axis in a uniform colour space, defined by the CIE, are calculated.

C.2 Algorithm used by the plug-in for the visual noise measurements

C.2.1 The R, G and B signals should be as defined in the sRGB standard IEC 61966. The R, G and B digital output levels of the image are transferred into the tristimulus values, X_{D}, Y_{D} and Z_{D} by the matrix obtained by colorimetric characteristics of sRGB.

C.2.2 The CRT white point is converted to an appropriate chromaticity, which is used in the visual model in the next step. The tristimulus values are transferred into another set of tristimulus values, X_{S}, Y_{S} and Z_{S} using the Von Kries adaptation model [9] with primaries as proposed by Hunt [10].

$$\begin{bmatrix} X_{\mathrm{S}} \\ Y_{\mathrm{S}} \\ Z_{\mathrm{S}} \end{bmatrix} = M_{\mathrm{adapt}} \cdot \begin{bmatrix} X_{\mathrm{D}} \\ Y_{\mathrm{D}} \\ Z_{\mathrm{D}} \end{bmatrix} \tag{C.1}$$

C.2.3 The tristimulus values are transferred into the opponent colour responses: white-black (W-K), red-green (R-G), yellow-blue (Y-B) and according to a visual model.

$$\begin{bmatrix} S_{\mathrm{W\text{-}K}} \\ S_{\mathrm{R\text{-}G}} \\ S_{\mathrm{Y\text{-}B}} \end{bmatrix} = M_{\mathrm{opposite}} \cdot \begin{bmatrix} X_{\mathrm{S}} \\ Y_{\mathrm{S}} \\ Z_{\mathrm{S}} \end{bmatrix} \tag{C.2}$$

C.2.4 The set of the responses for line data in the specified test patch area is transferred into the frequency domain by the discrete Fourier transform.

C.2.5 In the frequency domain, each response is weighted by a set of corresponding spatial responses of the human visual system.

C.2.6 Each compensated response is transferred into the spatial domain by the inverse discrete Fourier transform.

C.2.7 The three opponent colour responses are transferred into tristimulus values, X'_{S}, Y'_{S} and Z'_{S}, by inverting step C.2.3.

$$\begin{bmatrix} X_{\mathrm{S}} \\ Y_{\mathrm{S}} \\ Z_{\mathrm{S}} \end{bmatrix} = M_{\mathrm{opposite}}{}^{-1} \cdot \begin{bmatrix} S_{\mathrm{W\text{-}K}} \\ S_{\mathrm{R\text{-}G}} \\ S_{\mathrm{Y\text{-}B}} \end{bmatrix} \tag{C.3}$$

C.2.8 The values are transferred into tristimulus values, X'_{D}, Y'_{D} or Z'_{D}, by inverting step C.2.2.

$$\begin{bmatrix} X'_{\mathrm{D}} \\ Y'_{\mathrm{D}} \\ Z'_{\mathrm{D}} \end{bmatrix} = M_{\mathrm{adapt}}{}^{-1} \cdot \begin{bmatrix} X'_{\mathrm{S}} \\ Y'_{\mathrm{S}} \\ Z'_{\mathrm{S}} \end{bmatrix} \tag{C.4}$$

C.2.9 The tristimulus values are converted into the CIE L^*u^*v* colour space. The visual noise is defined as the sum of the three standard deviations of the colour noise along the three axes (L^*, u^*, v*) of the uniform colour space. The equation to determine the visual noise value is as follows.

$$\text{Visual Noise} = w_L \cdot N_L + w_{c1} \cdot N_{c1} + w_{c2} \cdot N_{c2} \tag{C.5}$$

Equation (C.5) is defined only to measure the visual noise for the purpose of spatial frequency weighting and is an example. For total noise, signal-to-noise ratio and dynamic range, Equation (2) is used.

C.2.10 The steps from C.2.1 to C.2.9 are performed for both the horizontal and vertical directions for each test patch area.

C.2.11 The representative visual noise amount is averaged with measurements at densities either side of 0,9 at 1,05 and 0,77 (boxes 13a, 13b, and 13c in Figure A.2) for both the horizontal and vertical directions.

C.3 Visual noise measurements

C.3.1 General

These measurements will give simulated visual noise levels at various illuminant levels.

C.3.2 Test conditions

C.3.2.1 The test chart illumination is shown in Figure 3.

C.3.2.2 The light source is fixed level with combined short term and supply amplitude variations of less than ± 2 %.

C.3.2.3 The test chart is either the chart described in ISO 14524:1999, or the chart described in Annex A. The test chart can be either transmissive or reflective.

C.3.2.4 If a transmissive test chart is used, the diffuser should be uniform. If a reflective test chart is used, the chart illumination should be uniform.

C.3.2.5 The light source and camera should be adjusted to give the maximum unclipped level from the camera on the test target reference white.

C.4 Test method

C.4.1 The calculation is performed with the plug-in running on the Photoshop (or equivalent) software. The evaluation procedure is as follows.

C.4.2 The image is displayed with Photoshop or equivalent graphic software.

C.4.3 The test image is selected by the rectangular tool.

C.4.4 The measurement plug-in is selected.

C.4.5 (Display a dialogue box.) Choose a parameter file defining

M_{adapt} calculated by:

$$M_{\text{adapt}} = A^{-1} \cdot \begin{bmatrix} \frac{L_{\text{W-S}}}{L_{\text{W-D}}} & 0 & 0 \\ 0 & \frac{M_{\text{W-S}}}{M_{\text{W-D}}} & 0 \\ 0 & 0 & \frac{S_{\text{W-S}}}{S_{\text{W-D}}} \end{bmatrix} \cdot A$$

$$\begin{bmatrix} L_{\text{W-S}} \\ M_{\text{W-S}} \\ S_{\text{W-S}} \end{bmatrix} = A \cdot \begin{bmatrix} X_{\text{W-S}} \\ Y_{\text{W-S}} \\ Z_{\text{W-S}} \end{bmatrix}$$

$$\begin{bmatrix} L_{\text{W-D}} \\ M_{\text{W-D}} \\ S_{\text{W-D}} \end{bmatrix} = A \cdot \begin{bmatrix} X_{\text{W-D}} \\ Y_{\text{W-D}} \\ Z_{\text{W-D}} \end{bmatrix}$$

$X_{\text{W-S}}$, $Y_{\text{W-S}}$, and $Z_{\text{W-S}}$: white point of illuminant E

$X_{\text{W-D}}$, $Y_{\text{W-D}}$, and $Z_{\text{W-D}}$: white point of illuminant D65.

An example of matrix A is:

$$A = \begin{bmatrix} 0{,}389\,71 & 0{,}688\,98 & -0{,}078\,68 \\ -0{,}229\,81 & 1{,}183\,4 & 0{,}046\,41 \\ 0{,}0 & 0{,}0 & 1{,}0 \end{bmatrix}$$

- opposite colour matrix: M_{opposite}
- spatial responses of the human visual system
- weighting values for the visual noise: w_L, w_{c1}, w_{c2}

Reference [4] in the Bibliography gives an example set of the above parameters.

C.4.6 Specify viewing distance (default viewing distance is five times the image height).

C.4.7 (Display a file name dialogue box.) Choose a file name to be saved. An example output file from the plug-in is shown in Table C.1.

Table C.1 — Example output file

Lightness L^*	Noise level H	Noise level V
8,33	1,26	2,00
16,67	1,89	2,39
25,00	2,38	2,68
33,33	2,72	2,88
41,67	2,93	2,98
50,00	3,00	2,99
58,33	2,93	2,91
66,67	2,72	2,74
75,00	2,38	2,48
83,33	1,89	2,12
91,67	1,26	1,67
100,00	0,50	1,13

Annex D
(informative)

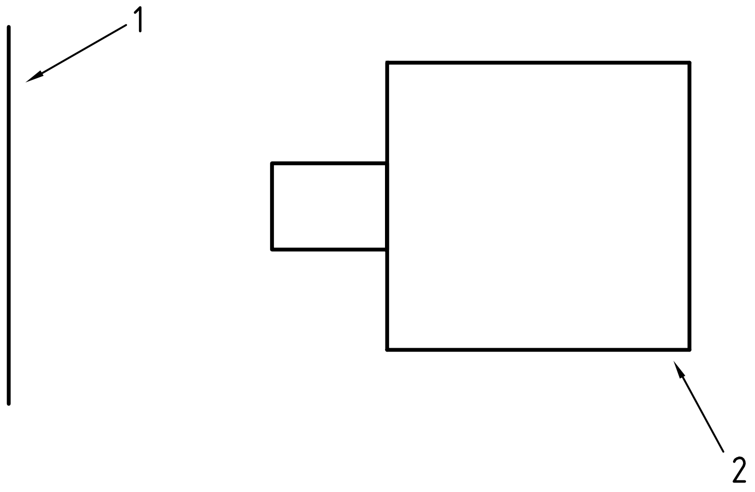
Method for measuring edge noise

D.1 Test conditions

D.1.1 General

Many electronic still-picture cameras use extensive signal processing to reduce noise in uniform areas, and the noise levels measured in the large area test defined in Clause 5 may not be representative of the noise levels found in the pictures taken by the camera. Therefore, the use of an edge noise test is being investigated. This uses the test chart shown in Annex A.

This test measures the noise level at high frequencies by using a low modulation square wave target, blocks 14 on the test chart in Annex A. The high frequency noise measurement test set-up is shown in Figure D.1.



Key

1 test chart

2 camera under test

NOTE Chart illumination is as in Figure 3a) or 3b).

Figure D.1 — High frequency noise measurement

D.1.2 The camera OECF is first measured according to ISO 14524.

D.1.3 The light source is fixed level with combined short term and supply amplitude variations of less than ± 2 %.

D.1.4 The test chart is the chart described in Annex A. The test chart can be either transmissive or reflective.

D.1.5 If a transmissive test chart is used, the diffuser behind the chart, as shown in Figure 3a), is uniform. If a reflective test chart is used, the chart illumination should be as in Figure 3b) and comply with 4.2.4.

D.1.6 The test target should be correctly focused by the camera under test.

D.1.7 The light source and camera should be adjusted to give the maximum unclipped level from the camera on the test target reference white.

D.1.8 The whole apparatus is to be securely mounted, to reduce movement between exposures to less than one tenth of a pixel.

D.1.9 A minimum of eight images of the test chart is captured.

D.2 Test method

The high frequency signal-to-noise ratio is determined in the same way as the temporal noise in 6.2.4; by measuring the standard deviation of the difference of each image and the average image and applying a correction to determine the true level of the high frequency noise. The high frequency noise is converted to an input referred incremental signal-to-noise ratio for the average density of the modulation bars, and reported as the ISO standard camera high frequency signal-to-noise ratio.

For the modulation bar average density of 0,74, the high frequency signal-to-noise ratio is determined by the maximum level multiplied by one hundred divided by the high frequency noise multiplied by the incremental gain.

The average of the high frequency noise is:

$$\sigma_{\text{hf}} = \sqrt{\frac{n}{n-1}\sigma_{\text{diff}}^2} \quad \text{(D.1)}$$

where

σ_{hf} is the standard deviation of the high frequency noise;

σ_{diff} is the average standard deviation of the code values of all the differences of the average, and the individual images that make up the average.

Annex E
(informative)

Incremental gain calculation

E.1 Introduction

The incremental gain can also be calculated by the method described in Annex A of ISO 12232:1998, as the average of the slope between three close input exposures, the measurement point, one above and one below, i.e. using the three central patches, 13a, 13b and 13c on the example test chart described in Annex A. The accuracy of this method will depend on the calibration of the test chart and the closeness, in density, of the three patches. The first derivative of the OECF will always give the highest accuracy.

E.2 Assumptions

It is assumed that the lightest patch on the test chart exactly saturates the camera output signal.

It is further assumed that patch, j, has a reflectance of 0,18 assuming a 140 % maximum level, this corresponds to a density of 0,9 with respect to the lightest patch. If this is not the case, the following method is not valid.

E.3 Incremental gain derivation

The incremental gain at 0,18 L_{sat} is as follows:

$$g\left(0{,}18 L_{\text{sat}}\right) = g\left(R_j L_{\text{sat}}\right) = \frac{\text{OL}\left(R_j\right) - \text{OL}\left(R_i\right)}{2 \times L_{\text{sat}} \times \left(R_j - R_i\right)} + \frac{\text{OL}\left(R_k\right) - \text{OL}\left(R_j\right)}{2 \times L_{\text{sat}} \times \left(R_k - R_j\right)} \tag{E.1}$$

where

$\text{OL}(R_j)$ is the digital output signal for patch j having a reflectance of $R_j = 0{,}18$;

$\text{OL}(R_i)$ is the digital output signal for patch i having a reflectance of $R_i < 0{,}18$;

$\text{OL}(R_k)$ is the digital output signal for patch k having a reflectance of $R_k > 0{,}18$.

For Equation (3)

$$\left(\frac{S}{N}\right)_{\text{total}} = \frac{L_{\text{sat}} \times 0{,}18 \times \text{incremental gain}}{\sigma_{\text{total}}} \tag{E.2}$$

Inserting Equation (E.1) into (E.2)

$$\left(\frac{S}{N}\right)_{\text{total}} = \frac{0{,}18 \times L_{\text{sat}}}{\sigma_{\text{total}}} \times \left[\frac{\text{OL}\left(R_j\right) - \text{OL}\left(R_i\right)}{2 \times L_{\text{sat}} \times \left(R_j - R_i\right)} + \frac{\text{OL}\left(R_k\right) - \text{OL}\left(R_j\right)}{2 \times L_{\text{sat}} \times \left(R_k - R_j\right)}\right] \tag{E.3}$$

The L_{sat} term cancels giving:

$$\left(\frac{S}{N}\right)_{\text{total}} = \frac{0{,}18}{\sigma_{\text{total}}} \times \left[\frac{\text{OL}\left(R_j\right) - \text{OL}\left(R_i\right)}{2 \times \left(R_j - R_i\right)} + \frac{\text{OL}\left(R_k\right) - \text{OL}\left(R_j\right)}{2 \times \left(R_k - R_j\right)}\right] \tag{E.4}$$

The same method can also be applied to Equations (6) and (7), but, for the dynamic range equation, the incremental gain has to be calculated for densities either side of 2,0 with respect to the lightest patch, rather than 0,18.

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