INTERNATIONAL STANDARD

ISO 16067-2

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Photography — Electronic scanners for photographic images — Spatial resolution measurements —

Part 2:
Film scanners

Photographie — Scanners électroniques pour images photographiques — Mesurages de la résolution spatiale —

Partie 2: Scanners pour films

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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 16067-2 was prepared by Technical Committee ISO/TC 42, *Photography*.

ISO 16067 consists of the following parts, under the general title *Photography — Electronic scanners for photographic images — Spatial resolution measurements*:

— *Part 1: Scanners for reflective media*

— *Part 2: Film scanners*

Introduction

One of the most important characteristics of an electronic film scanner is the ability to capture the fine detail found in the original film. This ability to resolve detail is determined by a number of factors, including the performance of the scanner lens, the number of addressable photoelements in the image sensor(s) used in the scanner, and the electrical circuits in the scanner. Different measurement methods can yield different metrics that quantify the ability of the scanner to capture fine details.

This International Standard specifies methods for measuring the limiting visual resolution, and spatial frequency response calculated from a slanted edge (Edge SFR) imaged by a film scanner. The scanner measurements described in this International Standard are performed in the digital domain, using digital analysis techniques. A test chart of appropriate size and characteristics is scanned and the resulting data is analysed. The test chart described in this International Standard is designed specifically to evaluate continuous tone film scanners. It is not designed for evaluating electronic still-picture cameras, video cameras, or bi-tonal document scanners.

The edge SFR measurement method described in this International Standard uses a computer algorithm to analyse digital image data from the film scanner. Pixel values near slanted vertical and horizontal edges are used to compute the SFR values. The use of a slanted edge allows the edge gradient to be measured at many phases relative to the image sensor photoelements, so that the SFR can be determined at spatial frequencies higher than the half sampling frequency, sometimes called the Nyquist limit. This technique is mathematically equivalent to a moving knife-edge measurement.

Part 1 of this International Standard deals with reflective media.

Photography — Electronic scanners for photographic images — Spatial resolution measurements —

Part 2: Film scanners

1 Scope

This International Standard specifies methods for measuring and reporting the spatial resolution of electronic scanners for continuous tone photographic negatives and reversal (e.g. slide) films. The International Standard applies to both monochrome and colour film scanners.

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 5-2, *Photography — Density Measurements — Part 2: Geometric conditions for transmission density*

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

ISO 12231, *Photography — Electronic still-picture cameras — Terminology*

ISO 12233, *Photography — Electronic still-picture cameras — Resolution Measurements*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12231 and the following apply.

3.1
addressable photoelements
number of active photoelements in an image sensor

NOTE This is equal to the number of active lines of photoelements, multiplied by the number of active photoelements per line.

3.2
aliasing
reconstructed image artefacts in sampled imaging systems where the combined spatial frequency energy of the input image and scanner combination is significant beyond the half-sampling frequency of the scanner

NOTE These artefacts usually manifest themselves as moiré patterns in repetitive image features or as jagged stair stepping at edge transitions.

3.3
digital output level
numerical value assigned to a particular output level, also known as the digital code value

3.4
edge spread function
ESF
normalized spatial signal distribution in the linearized output of an imaging system resulting from imaging a theoretical infinitely sharp edge

3.5
effectively spectrally neutral
having spectral characteristics that result in a specific imaging system producing the same output as for a spectrally neutral object

3.6
electronic scanner for photographic films
scanner incorporating an image sensor that outputs a digital signal representing a still film image

3.7
fast scan direction
scan direction corresponding to the direction of the alignment of the addressable photoelements in a linear array image sensor

3.8
gamma correction
process that alters the image data in order to modify the tone reproduction

3.9
image sensor
electronic device that converts incident electromagnetic radiation into an electronic signal; e.g. a charge coupled device (CCD) array

3.10
resolution
measure of the ability of a digital image capture system, or a component of a digital image capture system, to capture fine spatial detail

NOTE Resolution measurement metrics include resolving power, limiting visual resolution, SFR, MTF and CTF.

3.11
sampled imaging system
imaging system or device which generates an image signal by sampling an image at an array of discrete points, or along a set of discrete lines, rather than a continuum of points

NOTE The sampling at each point is done using a finite size sampling aperture or area.

3.12
sample spacing
physical distance between sampling points or sampling lines, measured in units of distance (e.g. µm, mm)

NOTE The sample spacing may be different in the two orthogonal sampling directions.

3.13
sampling frequency
reciprocal of sample spacing

NOTE Expressed in samples per unit distance (e.g. dots per inch).

3.14
scanner
electronic device that converts a fixed image, such as a film or film transparency, into an electronic signal

3.15
scanner opto-electronic conversion function
scanner OECF
relationship between the input density and the digital output levels for an opto-electronic digital capture system

3.16
slow scan direction
direction in which the scanner moves the photoelements (perpendicular to the lines of active photoelements in a linear array image sensor)

3.17
spatial frequency response
SFR
R_{SFR}
measured amplitude response of an imaging system as a function of relative input spatial frequency

NOTE 1 The SFR is normally represented by a curve of the output response to an input sinusoidal spatial luminance distribution of unit amplitude, over a range of spatial frequencies. The SFR is normalized to yield a value of 1,0 at a spatial frequency of 0.

NOTE 2 In equations, the symbol R_{SFR} rather than the abbreviation SFR is used for clarity.

3.18
spectrally neutral
test chart in which the relative spectral power distributions of the incident and reflected (or transmitted) light are equal

3.19
test chart
arrangement of test patterns designed to test particular aspects of an imaging system

3.20
test pattern
specified arrangement of spectral reflectance or transmittance characteristics used in measuring an image quality attribute

3.21
test pattern types

3.21.1
bi-tonal patterns
patterns that are spectrally neutral or effectively spectrally neutral, and consist exclusively of two reflectance or transmittance values in a prescribed spatial arrangement

NOTE Bi-tonal patterns are typically used to measure resolving power, limiting resolution and SFR.

3.21.2
grey scale patterns
patterns that are spectrally neutral or effectively spectrally neutral, and consist of a large number of different reflectance or transmittance values in a prescribed spatial arrangement

NOTE Grey scale patterns are typically used to measure opto-electronic conversion functions.

3.21.3
spectral patterns
patterns that are specified by the spatial arrangement of features with differing spectral reflectance or transmittance values

NOTE Spectral patterns are typically used to measure colour reproduction.

4 Test chart

4.1 Representation and recommended size

This clause defines the type and specifications of the test chart depicted in Figure 1. This test chart can be made at various sizes to correspond to popular film sizes. The recommended size is 24 mm × 36 mm, which corresponds to the 35 mm film format.

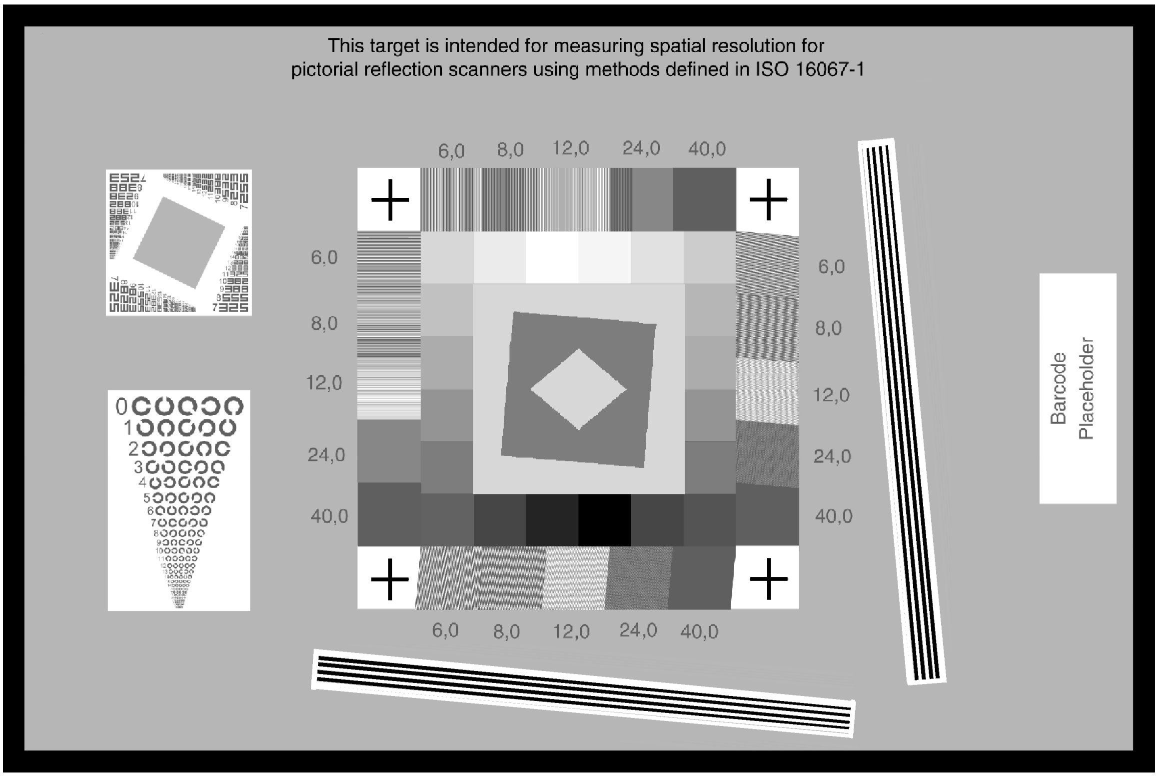


Figure 1 — Representation of the test chart

4.2 General characteristics of the test chart

4.2.1 The test chart shall be a transmission test chart based on a current monochrome photographic film material. The film material shall be spectrally neutral with tolerances as specified in ISO 14524, and resistant to fading.

4.2.2 The active height and width of the reflection test chart should be no less than 16,7 mm. Additional white space may be added to the width or height to include target management data or other test chart elements not defined by this International Standard.

4.2.3 The test chart shall include grey scale patterns and should include bitonal elements. Grey scale patches are necessary to measure the opto-electronic transfer function of the scanner. The bitonal elements may be used to assess limiting visual resolution and aliasing. (See Clause 7.)

4.2.4 The density values of the grey patches shall be in accordance with Annex A. The densities shall be measured as specified in ISO 5-2.

4.2.5 The target manufacturer should state the spatial frequency at which the target's frequency content is 0,2. These declarations should be cited in both cycles per millimetre (cycles/mm) and equivalent dots-per-inch (DPI), where the DPI value equals 50,8 times the spatial frequency in cycles/mm. Suggested wording is, "This target suitable for SFR measurements to XXX cycles per millimetre (xxx dpi)".

The spatial frequency content of the edge features should be the same for both near horizontal, near-vertical, and near-45º edge features, and should be indicated as a graph (Figure 2), or should be characterized with a closed form equation or equations up to the frequency having a 0,2 modulation response.

An example equation corresponding to Figure 2 is the N-th order polynomial:

$$\text{Target Modulation} = C_0 + C_1 \nu^1 + C_2 \nu^2 + C_3 \nu^3 + C_4 \nu^4 + C_5 \nu^5 + C_6 \nu^6 + C_7 \nu^7 \qquad (1)$$

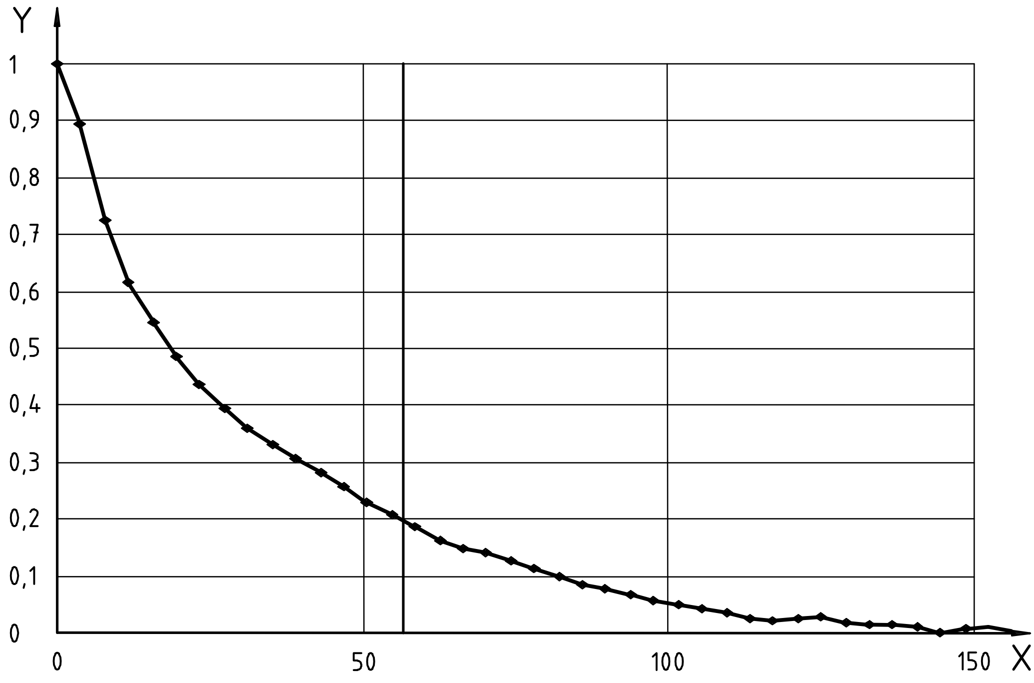
Where ν = spatial frequency in terms of line pairs per millimetre

C_i = polynomial coefficients associated with the i^{th} term

$C_0 = 1{,}0000\text{e} \times 10^{0}$ $C_1 = -1{,}0161\text{e} \times 10^{-2}$ $C_2 = -5{,}9389\text{e} \times 10^{-3}$ $C_3 = 5{,}6116\text{e} \times 10^{-4}$

$C_4 = -2{,}3443\text{e} \times 10^{-5}$ $C_5 = 5{,}0997\text{e} \times 10^{-7}$ $C_6 = -5{,}6120\text{e} \times 10^{-9}$ $C_7 = 2{,}4681\text{e} \times 10^{-11}$

The above-mentioned 7th order polynomial is only valid, as an example frequency response characteristic, for spatial frequencies in the range DC to approximately 58,154 1 cycles/mm.



Key

X frequency (cycles/mm)

Y modulation

Figure 2 — Frequency content of a transmission edge's spatial derivative

4.3 Test chart elements

4.3.1 General

For testing purposes, the test chart shall include elements to measure the scanner opto-electronic conversion function, and SFR in the fast scan and slow scan directions. (See Figure 3.)

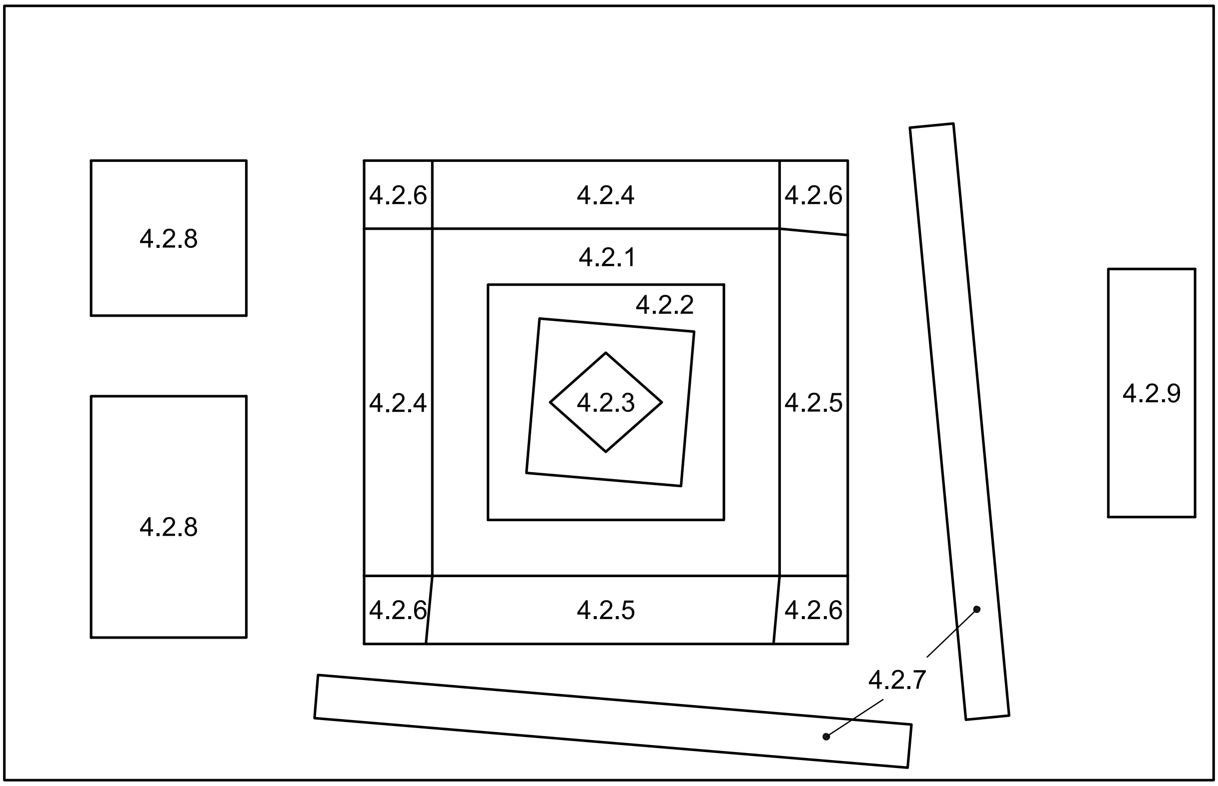


Figure 3 — Test chart elements labelled by section number

4.3.2 Grey scale patches for measuring the scanner OECF

The test chart shall include 20 neutral grey scale patches with specified visual densities. The maximum patch density shall be at least 1,5 times the maximum density of the central slanted square (4.2.2). The minimum patch density shall be equal to the transmissive media minimum density. The spatial arrangement of the patches shall be designed to minimize flare between adjacent patches as depicted in Figure 1. A suggested spatial arrangement is given in Annex A.

4.3.3 Near-vertical and near-horizontal slanted edges to measure the vertical and horizontal edge SFR

The test chart shall include a slanted (approximately 5º) square feature used to measure vertical and horizontal edge SFR. The density of the square shall exceed that of the immediate surrounding area. The central square's surround density shall have a visual diffuse density of greater than or equal to 0,40 and less than or equal to 0,60. The square patch density shall have a visual diffuse density of greater than or equal to 1,5 and less than or equal to 2,4.

NOTE These values insure sufficiently low edge transition contrasts to aid robust SFR measurements.

4.3.4 Near-45º edges to measure 45º SFR

The test chart should include a diamond shaped feature (approximately 50º from vertical) to measure the SFR at 45º. The density of this feature should match that of the surround area defined in 4.3.2.

4.3.5 Vertical and horizontal square wave features

The test chart shall include horizontal and vertical square wave features of extended length to aid in the visual detection of aliasing. These features shall have a spatial frequency of 25, 33,3, 50, 100, and 166,7 cycles/mm. The minimum and maximum densities should nominally match the D_{max} and D_{min} of the grey scale patches.

NOTE The square wave features have a spatial frequency corresponding to approximately 1200, 1600, 2400, 5000 and 8400 DPI.

4.3.6 Near-vertical and near-horizontal square features

The test chart shall include horizontal and vertical square wave features of extended length to aid in the detection of aliasing. These features shall have the same frequencies as indicated in 4.3.4. The minimum and maximum densities should nominally match the D_{max} and D_{min} of the grey scale patches.

NOTE These slanted lines eliminate the ambiguity of phase-induced patterns in resolution measurements.

4.3.7 Fiducial marks to aid in automatic SFR and scanner OECF measurement

The test chart should include fiducial marks in the corners of the central target features. These marks can aid in the automatic analysis of grey patch and slanted edge features for scanner OECF and SFR measurements.

NOTE The vertical and horizontal distance between fiducial marks in Figure 1 is 12,19 mm. This distance can be used to verify scanner sampling frequency.

4.3.8 Slightly Slanted Extended Lines to check scan linearity, “stair stepping” and cyclical scan artefacts

The test chart should include horizontal and vertical slightly slanted lines to check scan linearity, and cyclical scanner behaviours such as colour channel misregistration.

4.3.9 Bi-tonal spatial resolution elements

The test chart should include bi-tonal spatial patterns to aid in evaluating limiting visual resolution. These elements should be of high contrast (D_{max} and D_{min}) and accompanied with numbered groups that are keyed to know spatial frequencies.

4.3.10 Administrative elements

The test chart should include administrative elements to aid in tracking the genealogy and characteristics of the test chart being used. These may be items such as manufacturer's insignia, creation date or barcode that aids in populating metadata elements.

5 Test conditions

5.1 General

The following measurement conditions should be used as nominal conditions when measuring the scanner OECF and spatial resolution. 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.

5.2 Temperature and relative humidity

The ambient temperature during the acquisition of the test data shall be (23 ± 2)°C, as specified in ISO 554, and the relative humidity should be (50 ± 20) %.

5.3 Luminance and colour measurements

For a colour scanner, the spatial resolution measurements should be performed separately on each colour record. If desired, a luminance resolution measurement may be made on a luminance signal formed from an appropriate combination of the colour records. In either case, the channel on which the measurement is performed shall be reported.

5.4 Linearization

The scanner output signal will likely be a non-linear function of the film density values. Linearization is accomplished by applying the inverse of the scanner OECF to the output signal via a lookup table or appropriate equation, and then converting from density to reflectance. The measurement of the scanner OECF shall be as specified in Clause 6.

5.5 Scanner settings

The spatial resolution should be measured with the manufacturer's recommended default settings. If different settings are used, they shall be reported.

6 Measuring the scanner OECF

The scanner OECF shall be calculated from values determined from the same chart and the same scan as the values for the resolution measurements. Many scanners will automatically adapt to the dynamic range and the luminance distribution of the film. The results may also differ if the scan mode is grey scale or RGB.

A minimum of four trials shall be conducted for each resolution measurement and scanner OECF determination. A trial shall consist of one scan of the test chart. For each trial, the digital output level shall be determined from a 64 × 64[1)] pixel area located at the same relative position in each patch. Identical, non-aligned patches may be averaged, or the patch with the least scanning artefacts, such as dust or scan lines, may be used. The scanner OECF so determined shall be used to calculate the resolution measurements for this trial. If the scanner OECF is reported, the final digital output level data presented for each step density shall be the mean of the digital output levels for all the trials.

7 Limiting visual resolution and its relation to SFR

To determine the limiting visual resolution, the image of the test target is reproduced on a monitor or hard copy film, and the visual resolution is subjectively judged. To ensure that the monitor or hard copy filmer does not reduce the visual resolution value, the digital image may be enlarged by pixel replication prior to viewing or filming, so that the individual pixels are visible. Observers should be well acquainted with the appearance of aliasing, so that they do not seriously misjudge the visual resolution of the scanner. The test chart includes vertical and horizontal elements that are used to perform this test. The limiting visual resolution is the lowest value of the test pattern where the individual black and white lines can no longer be distinguished, or are reproduced at a spatial frequency lower than the spatial frequency of the corresponding area of the test chart, as a result of aliasing. The limiting visual resolution value shall not exceed the half sampling frequency. The limiting visual resolution in the fast scan direction is normally determined by observing the vertical elements. The visual resolution in the slow scan direction is normally determined by observing the horizontal elements. A

1) It is possible that with very low resolution scans the images of the test chart patches will not be large enough to contain a 64 × 64 pixel area. In this case, the sample area should be slightly smaller than the image of the patch area so that the effects of imaging the patch edge are not included.

very good correlation between limiting visual resolution and the spatial frequency associated with a 0,10 SFR response has been found experimentally. Should this frequency exceed the half-sampling frequency, the limiting visual resolution shall be the spatial frequency associated with the half-sampling frequency.

8 Edge SFR test measurement

The SFR of a film scanner is measured by analysing the scanner data near a slanted edge transition. The near-vertical edges shown in Figure 1 are normally used to measure the SFR in the fast scan direction, and the near-horizontal edges are normally used to measure the SFR in the slow scan direction. The SFR measurement can be performed automatically by image processing software. To perform the measurement, the scanner output data along the edges of the slanted square in the middle of the test chart are analysed by a mathematical algorithm.

The SFR algorithm is given in Annex B. A flow chart form and a diagram depicting the key steps of the SFR algorithm, and sample C-code, is described in ISO 12233. The SFR algorithm can be implemented as part of an easy-to-use image processing or analysis software package[2]. The algorithm can automatically compute and report the SFR, using image data from a user-defined rectangular region of the image that represents a vertically-oriented slanted edge, depicting a “horizontal” transition. To measure the SFR in the orthogonal direction, a horizontally-oriented edge is used, and the digital image data is rotated 90º before performing the calculation. If the image is a colour image, the algorithm performs calculations on the separate red, green and blue colour image records. The image code values are linearized by inverting the scanner OECF, and converting the film densities to reflectances.

Next, for each line of pixels perpendicular to the edge, the edge is differentiated using the discrete derivative “-0,5; +0,5”, meaning that the derivative value for pixel “X” is equal to -1/2 times the value of the pixel immediately to the left, plus 1/2 times the value of the pixel to the right. The centroid of this derivative is calculated to determine the position of the edge on each line. A best line fit to the centroids is then calculated. Error messages shall be reported if any centroid is within 2 pixels of either side of the input image edges, or if the edge does not contain at least 20 % modulation. The number of lines used in the analysis shall be truncated to provide an equal number of lines at each phase of the edge position relative to the horizontal centre of the pixel. This may be accomplished by keeping the largest integer number of phase rotations within the block, and deleting any remaining rows at the bottom of the block. A one-dimensional super sampled line spread function shall be formed using the derivatives of the truncated two-dimensional image data. Using the first line as reference points, the data points from all the other lines shall be placed into one of four “bins” between these reference points, according to the distance from the edge for that particular line. This creates a single super-sampled “composite” line spread function, having four times as many points along the line as the original image data.

The line spread function shall be multiplied by a Hamming window, to reduce the effects of noise by reducing the influence of pixels at the extremes of the window, which have response due to noise but little response due to the image edge located at the centre of the window. The discrete Fourier transform (DFT) of the windowed line spread function shall be calculated. The SFR shall be equal to the magnitude of the DFT of the line spread function. The SFR shall be reported as defined in Clause 9.

9 Presentation of results

9.1 General

The results of resolution measurements shall be reported for both the slow and the fast scan directions. The spatial resolution should be measured with the manufacturer's recommended default settings. The scan settings shall be explicitly stated, such as:

— make and model;

2) For example, as part of the development of this International Standard, the SFR algorithm has been incorporated into a Matlab software module.

- sampling frequency (in samples per millimetre) in the slow and fast scan directions;
- sharpening setting;
- grey scale or RGB scan mode;
- scan speed;
- brightness, contrast and gamma correction settings;

For settings that are manufacturer-specific, the manufacturer's language shall be used.

9.2 Scanner OECF

9.2.1 General

The results of the scanner OECF shall be presented in tabular or graphical form. All logarithmic values shall be base 10. The table heading or figure caption shall indicate the scan settings.

9.2.2 Table presentation

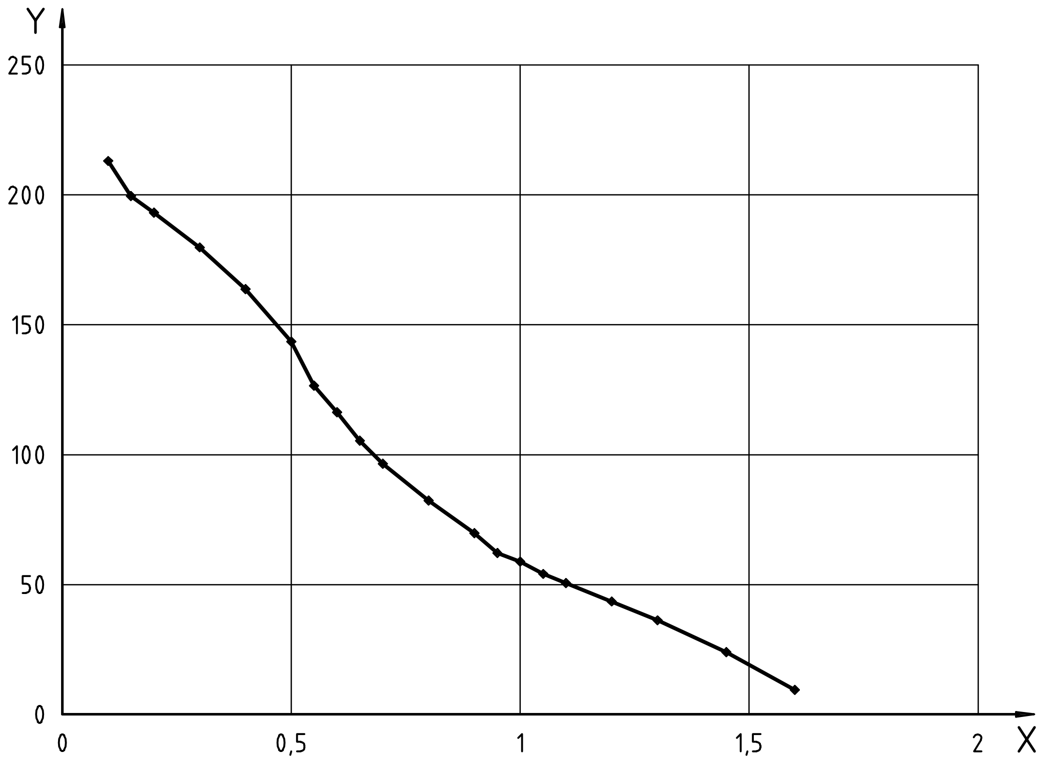
The table shall report the input densities of all the test chart patches and the mean output levels for the luminance channel if the scan mode is grey scale, or the mean output levels for all three channels if the scan mode is RGB.

Table 1 — Scanner OECF

OECF step	Density	Digital values
1	0,10	213,0
2	0,20	199,6
3	0,30	193,1
4	0,40	179,7
5	0,60	163,7
6	0,80	143,5
7	1,00	126,5
8	1,20	116,3
9	1,40	105,3
10	1,60	96,4
11	1,80	82,3
12	2,00	69,7
13	2,20	62,1
14	2,40	58,8
15	2,60	54,0
16	2,80	50,5
17	3,00	43,4
18	3,20	36,1
19	3,40	23,9
20	3,60	9,3
NOTE The above data is for scanner X, model Y, with 40 samples/mm in fast and slow scan directions, no sharpening, grey scale scan mode and normal scan speed.		

9.2.3 Graphical presentation

The graphical presentation shall be a plot of the digital output level, or $\log_2$ of the digital output level, vs. the input densities of all the test chart patches. An example of a sample scanner OECF curve for an electronic scanner is shown in Figure 4. If the scanning system is a multi-spectral system, the digital output levels for all spectral bands, or the luminance channel used in SFR calculation shall be plotted.



Key

X transmission density

Y count value

NOTE The above data is for scanner X, model Y, with 40 samples/mm in fast and slow scan directions, no sharpening, grey scale scan mode and normal scan speed.

Figure 4 — Sample scanner OECF curve for an electronic scanner

9.3 Resolution Measurements

The results of the resolution measurement shall be reported as described below. The values of all scanning settings that may affect the results of the measurement shall be reported along with the measurement results.

9.3.1 Limiting visual resolution

The limiting visual resolution values shall be reported as spatial frequency values, in LP/mm, for the slow scan and the fast scan direction.

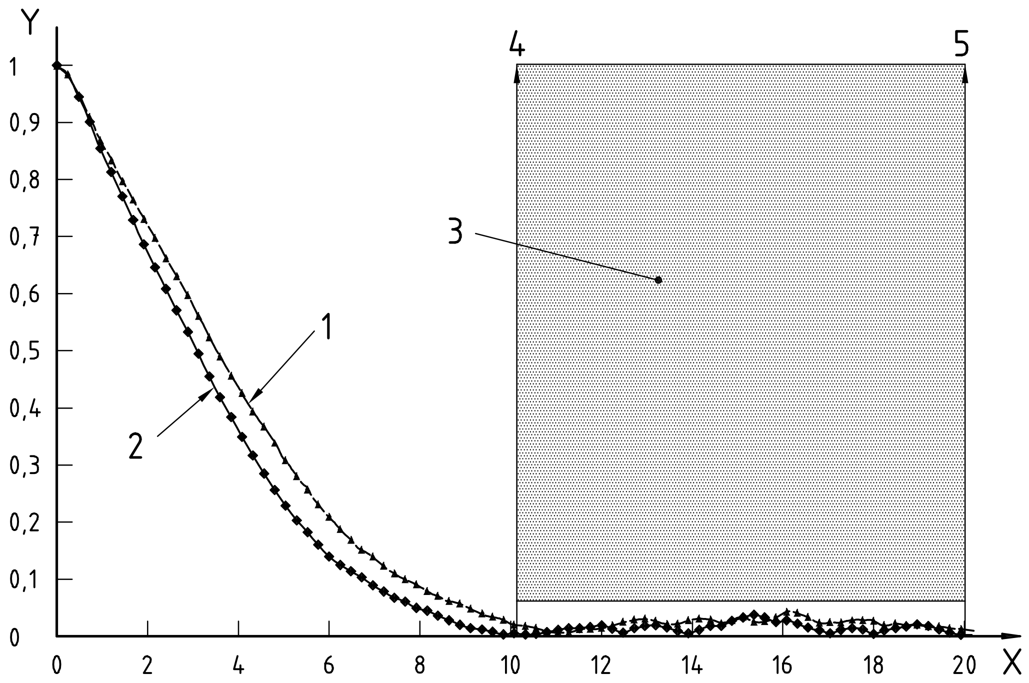
9.3.2 Edge SFR

The edge SFR results shall be reported as a graph that depicts the modulation level (having a value of 1,0 at 0 spatial frequency) versus spatial frequency, or as a list of SFR values versus spatial frequency. The SFR values shall be reported separately for the slow and fast scan directions. The values shall be the average of four SFR measurements of a dark to light edge, and four SFR measurements of a light to dark edge.

The frequency content of the edge used to measure the SFR shall be reported in cycles/mm or sampling frequency (in cycles per unit distance) versus modulation. SFR measurements for spatial frequencies that exceed the frequency where the edge has a modulation of 0,2 or less are invalid.

For absolute SFR measurements, the target's frequency content shall be accounted for by dividing the measured SFR results by the target frequency modulation for any given frequency up to the frequency having modulation of 0,2.

The measurement location shall be the slanted square in the middle of the test chart (4.2.2). The spatial frequency axis should be labelled with cycles/mm on the chart. There shall be a minimum of 32 equally spaced measurement values for spatial frequencies between 0 and the sensor sampling frequency. The scanner's half sampling frequency should be reported. Values between 0,5 and 1,0 times the sensor sampling frequency should be marked so as to indicate that these spatial frequencies lead to aliasing. Figure 5 demonstrates one suitable graph depicting SFR values.



Key

X frequency (cy/mm)
Y SFR
1 SFR Horizontal
2 SFR Vertical
3 aliasing region
4 Nyquist frequency
5 sampling frequency

NOTE The above data is for scanner X, model Y, with 40 samples/mm in fast and slow scan directions, no sharpening, grey scale scan mode and normal scan speed.

Figure 5 — Edge SFR for fast (horizontal) and slow (vertical) scan direction for a sampling frequency of 20 cycles per millimetre, and a Nyquist frequency of 10 cycles per millimetre

Annex A
(normative)

Scanner OECF test patches

The grey scale used to calculate the scanner OECF shall consist of 20 neutral (grey scale) patches. The maximum patch density shall be at least 1,5 times the maximum density of the central slanted square. The minimum patch density shall be equal to the reflective media minimum density. To minimize flare, the arrangement of the patches should be as depicted in Figure 1. The nominal densities for these patches shall be as indicated in Table A.1. Step 1 is located in the upper left corner. Subsequent step numbering in Table A.1 follows in a clockwise fashion around the central features found in 4.2.2. Table A.1 assigns a predominance of the grey scale densities to the edge transition region for accurate data linearization via the OECF. Test charts shall be produced using varying exposure on fine-grain silver halide film material.

Table A.1 — Density values for each OECF step

Step	Visual density
1	0,60
2	0,30
3	D_{min} or 0,10
4	0,20
5	0,40
6	0,80
7	1,20
8	1,60
9	2,00
10	2,40
11	2,80
12	3,20
13	3,60
14	3,40
15	3,00
16	2,60
17	2,20
18	1,80
19	1,40
20	1,00
The tolerances on all density values shall be ± 0,04 as measured with a 3 mm aperture.	

Annex B
(informative)

SFR algorithm

The SFR measurement algorithm used in this International Standard for analysis of slanted edge transition data from images of the test chart defined in this International Standard uses the normalized DFT of a single line spread function:

$$R_{SFR}(k) = \frac{\sum_{j=1}^{N-1} \bar{f}'_{\mathrm{LSF,w}}(j)\,\mathrm{e}^{-2\pi kj/(N-1)}}{\sum_{j=1}^{N-1} \bar{f}'_{\mathrm{LSF,w}}(j)} \qquad \text{(B.1)}$$

where

$\bar{f}'_{\mathrm{LSF,w}}$ is the windowed, average, centred, super-sampled line spread function formed from the selected region of the chart image.

Much of the data processing in the algorithm and employed in the SFR measurement algorithm is involved in preparing $\bar{f}'_{\mathrm{LSF,w}}$.

In step B, the data in the region of interest are transformed into a luminance array as a weighted sum of red, green and blue image records at each pixel. Steps A and B can be combined in the following equation for all p, r:

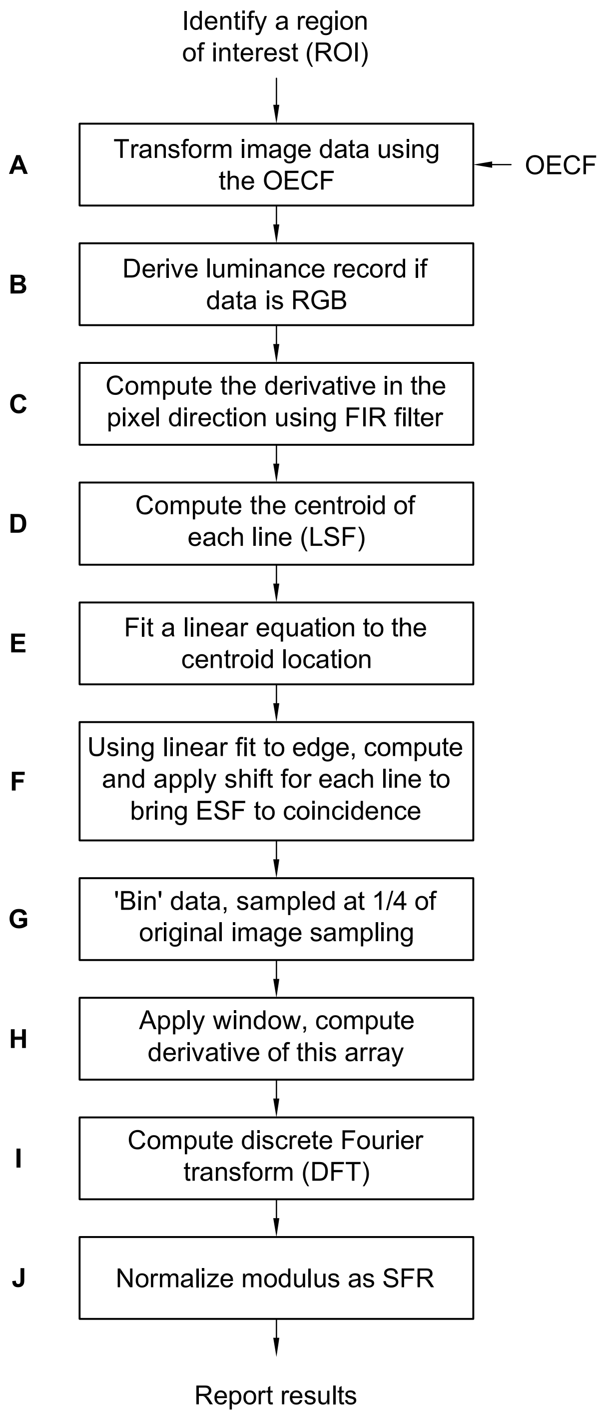
$$\phi(p,r) = a f_{\mathrm{OECF}}\left[N_{\mathrm{DN,red}}(p,r)\right] + b f_{\mathrm{OECF}}\left[N_{\mathrm{DN,green}}(p,r)\right] + c f_{\mathrm{OECF}}\left[N_{\mathrm{DN,blue}}(p,r)\right] \qquad \text{(B.2)}$$

where

a, b and c are the colour weighting coefficients;

f_{OECF} is the OECF transformation function;

N_{DN} is the array of digital code values.



NOTE The edge is assumed to be oriented in a near-vertical direction.

Figure B.1 — Description of the ISO 12233 spatial frequency response evaluation method

Each row (r) of the edge spread image is an estimate of the camera edge spread function (ESF). Each of these ESFs is differentiated to form its discrete line spread function (LSF) (step C). The position of the centroid (C) of each of the total number of rows (R) of the LSFs is determined along the continuous variable x.

$$C(r) = \frac{\sum_{p=1}^{P-1} p \times \left[\phi(p+1,r) - \phi(p,r)\right]}{\sum_{p=1}^{P-1} \phi(p+1,r) - \phi(p,r)} \quad \text{(B.3)}$$

The slope of the best fit line relating the x positions of the centroids to the r index of each row is computed in step E.

$$m = \overline{\left(\frac{\Delta r}{\Delta C(r)}\right)} \quad \text{(B.4)}$$

This slope m is used to compute a shift $S(r)$ to be applied to each row to bring each ESF to coincidence around a common origin at x = 0. This effectively takes the tilt out of the edge in step F. This is equivalent to projecting the data along the direction of the edge. The shift for line r is:

$$S(r) = \overline{C} + \left[(R/2) - r\right]/m \quad \text{(B.5)}$$

The slope is also used to truncate the number of rows of data to the largest number, R', that will have an integer number of full phase rotations. For example, if the fit to the centroid moves 0,1 pixels per row, then the largest multiple of 10 rows that is less than R will be used. A check is made to confirm that there is at least one full phase rotation.

The next step is the super-sampling and averaging of step G. This step forms a composite resampled ESF over the discrete variable j, where j is four times more finely sampled than p but is not a continuous variable such as x. The super sampling factor is 4, so $N = 4X$ bins are created, each with an effective width of 0,25 pixels.

$$\overline{ESF'}(j) = \frac{\sum_{r=1}^{R'} \sum_{p=1}^{P} \phi(p,r) \times \alpha(p,r,j)}{\sum_{r=1}^{R'} \sum_{p=1}^{P} \alpha(p,r,j)} \quad \text{(B.6)}$$

The function alpha, α, is simply a counter and a switch to include or exclude a value in any bin.

$$\alpha(p,r,j) = \begin{cases} 1, & -0{,}125 \leqslant \left[p - s(r) - j\right] < 0{,}125 \\ 0, & \text{otherwise} \end{cases} \quad \text{(B.7)}$$

The average super sampled edge spread function is then differentiated and windowed in step H.

$$\overline{LSF_w'}(j) = W(j) \times \left\{\left[\overline{ESF}(j) - \overline{ESF'}(j-1)\right]/2\right\} \quad \text{(B.8)}$$

$$W(j) = 0{,}54 + 0{,}46 \times \cos\left[\left(2\pi(j - 2\mathrm{X})/4\mathrm{X}\right)\right] \quad \text{(B.9)}$$

Substitution of Equation B.7) into Equation (B.1) produces SFR(f) where $f = k/X$, so that the data are reported in cycles/pixel, (steps I and J).

To report the data in frequency units of cycles/mm on the image sensor, the frequency values must be multiplied by half the number of rows of photosites per millimetre on the sensor (for vertical SFR measurements) or half the number of columns of pixels per millimetre on the sensor (for horizontal SFR measurements).

Annex C
(informative)

Using slanted edge analysis for colour spatial registration measurement

C.1 Introduction

The recording of detail in a digital colour image requires that the colour records be detected and stored in spatial registration. Signals stored as triplets of red, green and blue pixel values should indeed correspond to the sampled original images at the same locations. If a digital image is captured with misregistration between the colour records, the colour image displayed or filmed from these records can exhibit a loss of sharpness (blur), or colour distortion artefacts, particularly at the edges of objects in the scene. In addition, the performance of any subsequent image processing step that relies on the colour records being registered, such as colour metric transformation, image compression or filming, suffers when misregistration is present. While this procedure describes how to calculate colour registration errors for photographic film scanners, the method is also applicable for digital cameras and photographic transparency scanners.

C.2 Measurement of colour spatial registration by slanted edge gradient

A robust measure of colour image translation and rotation error can be computed as a step of the Edge SFR calculation. The procedure uses a tilted edge to derive an edge derivative (line spread function), and compute the spatial frequency response. By applying the first few steps of the recommended Edge SFR analysis to each of the colour channels, the effective translation error between them can be calculated.

First, the selected image data in the region of interest (ROI) are transformed to compensate for the scanner photometric response (log density-digital signal). This is done using three one-dimensional look-up tables, collectively known as the Scanner Opto-Electronic Conversion Function (OECF).

The edge location and direction (in the form of a linear equation) are estimated. The image data at all pixels are then projected along the direction of the edge to form a one-dimensional “super sampled” line spread function. After application of a smoothing Hamming window, DFT and normalization, the SFR is reported.

An implementation of this method that reports the edge fitting equation for each colour record can be used to measure the edge location within the (n lines $\times$ m pixels) ROI. Specifically, the equation for the linear fit to the set of line centroid data can be expressed as the inverse of the usual linear equation:

$$x = a + b(y - 1) \tag{C.1}$$

where x is the x-direction (pixel) location [$1 - m$], y the y-direction line number [$1 - n$], and a and b are constants. The value of a is the location of the edge on the first line of the ROI. Since the ROI is chosen to be identical for each colour record, the corresponding values of a and b are expressed in the same coordinates. The above procedure was implemented in software and tested[3].

3) A Matlab version of the software is available.

C.3 Results

Taking one record as a reference, the effective colour translation misregistration can be calculated. Adopting the convention of reporting the edge (pixel) location at the centre of the region of interest, Equation (C.1) is evaluated at $y = (n - 1)/2$. The results are reported in Table C.1.

Table C.1 — Measured edge locations, in units of pixels, for a photographic film scanner image

	Location	Shift
Red	39,57	0,36
Green	39,21	0,00
Blue	40,05	0,84

NOTE The green record was used as a reference.

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