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Photography — Spatial resolution measurements of electronic scanners for photographic images —

Part 1: Scanners for reflective media

Photographie — Mesurages de résolution spatiale de scanners électroniques pour images photographiques —

Partie 1: Scanners pour milieux réfléchissants

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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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 16067-1 was prepared by Technical Committee ISO/TC 42, *Photography*.

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

— *Part 1: Scanners for reflective media*

— *Part 2: Film scanners*

Introduction

One of the most important characteristics of an electronic print scanner is the ability to capture the fine detail found in the original print. 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 part of ISO 16067 specifies methods for measuring the limiting visual resolution and spatial frequency response calculated from a slanted edge (Edge SFR) imaged by a print scanner. The scanner measurements described in this part of ISO 16067 are performed in the digital domain, using digital analysis techniques. A test chart of appropriate size and characteristics is scanned and the resulting data analysed. The test chart described in this part of ISO 16067 is designed specifically for the evaluation of continuous tone print 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 part of ISO 16067 uses a computer algorithm to analyse digital image data from the print 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.

Photography — Spatial resolution measurements of electronic scanners for photographic images —

Part 1: **Scanners for reflective media**

1 Scope

This part of ISO 16067 specifies methods for measuring and reporting the spatial resolution of electronic scanners for continuous tone photographic prints. It is applicable to both monochrome and colour print 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 (all parts), *Photography — Density measurements*

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

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

ISO 14524:1999, *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 equal to the number of active lines of photoelements, multiplied by the number of active photoelements per line

3.2
aliasing
output image artefacts that occur in a sampled imaging system for input images having significant energy at frequencies higher than the Nyquist frequency of the system

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

3.3
digital output level
digital code value
numerical value assigned to a particular output level

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 which result in a specific imaging system producing the same output as for a spectrally neutral object

3.6
electronic scanners for photographic prints
scanner incorporating an image sensor that outputs a digital signal representing a still print 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
signal processing operation that changes the relative signal levels in order to adjust the image tone reproduction

NOTE 1 Gamma correction is performed in part to correct for the nonlinear light-output versus signal input characteristic of the display. The relationship between the light input level and the output signal level, called the OECF, provides the gamma correction curveshape for an image capture device.

NOTE 2 The gamma correction is usually an algorithm, look-up table or circuit which operates separately on each colour component of an image.

3.9
image sensor
electronic device that converts incident electromagnetic radiation into an electronic signal

EXAMPLE 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 depict spatial picture 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

NOTE 1 The sample spacing may be different in the two orthogonal sampling directions.

NOTE 2 It is measured in units of distance (e.g. micrometres, millimetres).

3.13
sampling frequency
reciprocal of sample spacing

NOTE It is expressed in samples per unit distance [e.g. dots per inch (DPI)]

3.14
scanner
electronic device that converts a fixed image, such as a print 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
measured amplitude response of an imaging system as a function of relative input spatial frequency

NOTE 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, and is normalized to yield a value of 1,0 at a spatial frequency of 0.

3.18
spectrally neutral
exhibiting reflective or transmissive characteristics which are constant over the wavelength range of interest

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

NOTE The test pattern spectral characteristics include the types given in 3.21.1 to 3.21.3.

3.20.1
bitonal patterns
pattern that is spectrally neutral or effectively spectrally neutral, and which consists exclusively of two reflectance or transmittance values in a prescribed spatial arrangement

NOTE Bitonal patterns are typically used to measure resolving power, limiting resolution and SFR.

3.20.2
grey-scale patterns
pattern that is spectrally neutral or effectively spectrally neutral, and which consists 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.

3.20.3
spectral pattern
pattern that is 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 General

This clause defines the type and specifications of the test chart depicted in Figure 1. The test chart can be made in various sizes to correspond to popular print sizes.

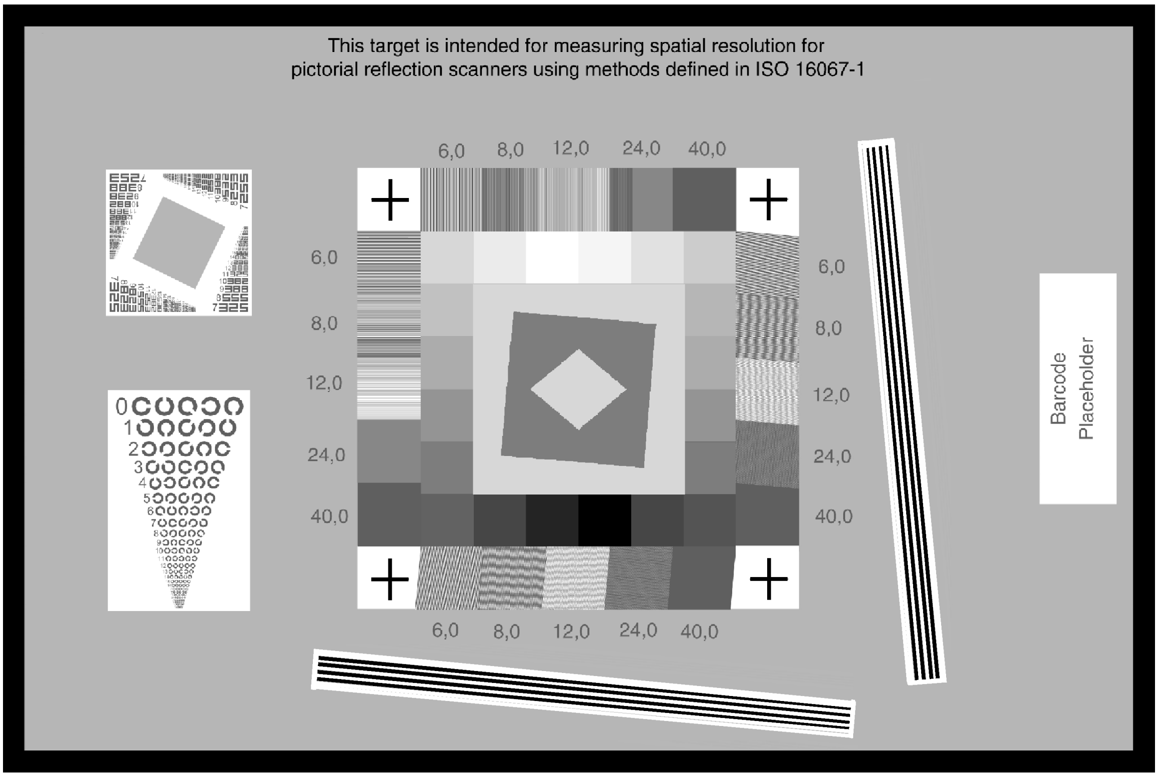


Figure 1 — Representation of test chart

4.2 General characteristics

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

4.2.2 The active height and width of the reflection test chart should be no less than 100 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 part of ISO 16067.

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.

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 per millimetre. Suggested wording is, "This target suitable for SFR measurements to XXX cycles per millimetre (xxxx dpi)".

The spatial frequency content of the edge features should be the same for both near-horizontal, near-vertical, and near-45° 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.

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

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

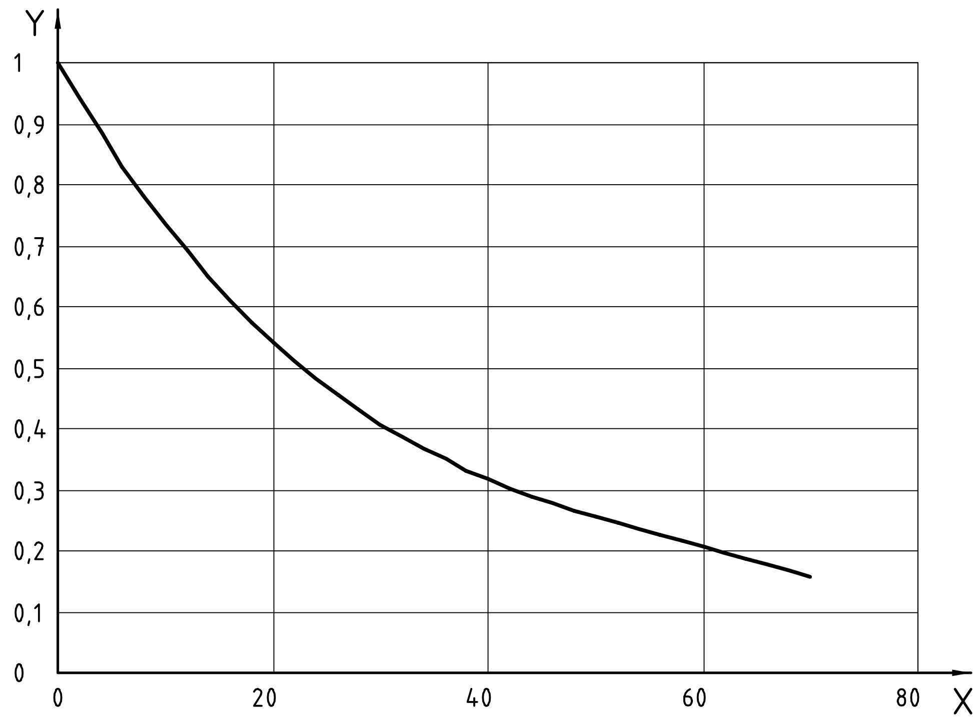
where

ν is the spatial frequency in terms of line pairs per millimetre;

C_i are the polynomial coefficients associated with the ith term

C_0 = 1,000 0e + 00 C_1 = – 1,016 1e – 02 C_2 = – 5,938 9e – 03 C_3 = 5,611 6e – 04

C_4 = – 2,344 3e – 05 C_5 = 5,099 7e – 07 C_6 = – 5,612 0e – 09 C_7 = 2,468 1e – 11



X spatial frequency (in cycles per millimetre)
Y modulation

Figure 2 — Example of the frequency content of a reflection edge's spatial derivative

4.3 Test chart elements

4.3.1 General

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

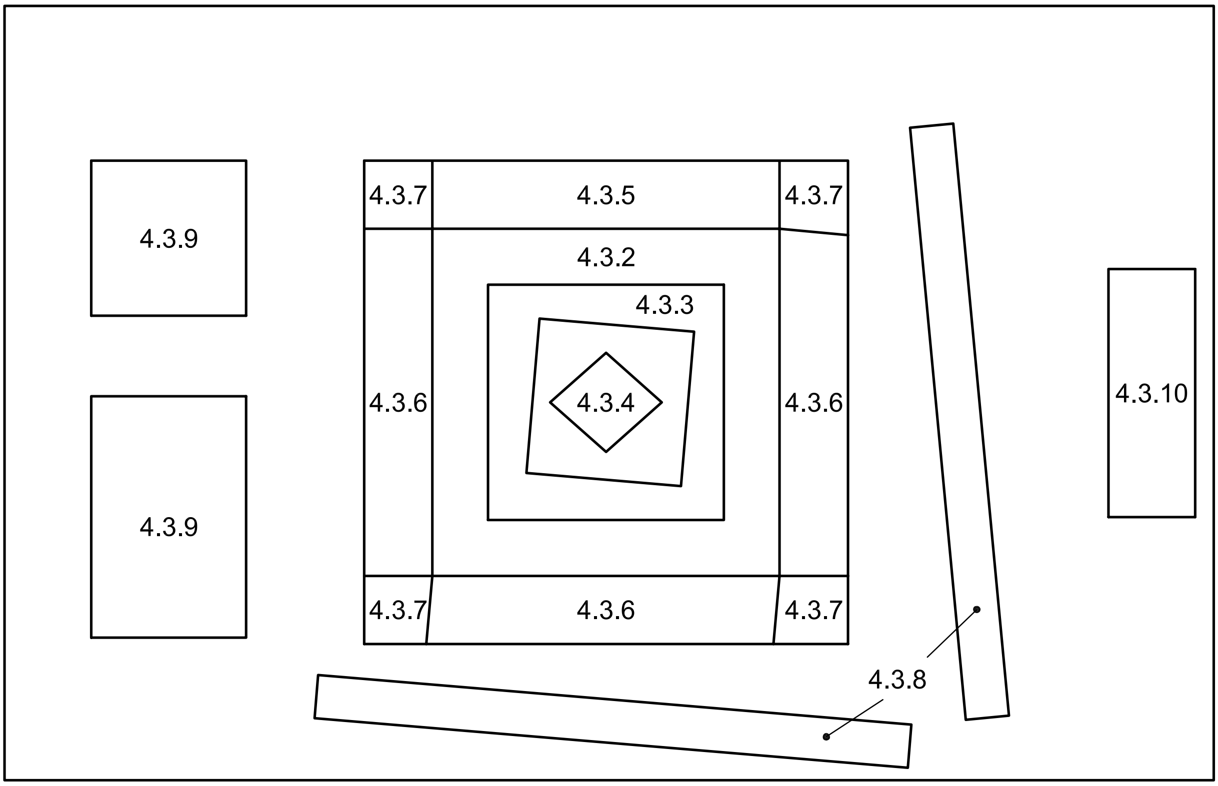


Figure 3 — Test chart elements (see subclauses indicated and Figure 1)

4.3.2 Grey-scale patches

The test chart shall include twenty neutral grey-scale patches with specified visual densities for measuring the scanner OECF. The maximum patch reflection density shall be at least 1,5 times the maximum density of the central slanted square (see 4.3.3). The minimum patch density shall be equal to the reflective 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

The test chart shall include a slanted (approximately 5°) 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 $\geqslant$ 0,40 and $\leqslant$ 0,60. The square patch density shall have a visual diffuse density of $\geqslant$ 1,00 and $\leqslant$ 1,20.

NOTE These values ensure sufficiently low edge transition contrasts to facilitate robust SFR measurements.

4.3.4 Near-45° edges

The test chart should include a diamond-shaped feature (approximately 50° from vertical) for measuring the SFR at 45°. The density of this feature should match that of the surround area defined in 4.3.3.

4.3.5 Vertical and horizontal square wave features

The test chart should 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 6 cycles/mm, 8 cycles/mm, 12 cycles/mm, 24 cycles/mm and 40 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 300 DPI, 400 DPI, 600 DPI, 1 200 DPI and 2 000 DPI.

4.3.6 Near-vertical and near-horizontal square features

The test chart should 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 4.3.8. 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

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 50,8 mm. This distance can be used to verify scanner sampling frequency.

4.3.8 Slightly slanted extended lines

The test chart should include horizontal and vertical, slightly slanted lines for the checking of scan linearity, “stairstepping” and cyclical scanner behaviours such as colour channel misregistration.

4.3.9 Bitonal spatial resolution elements

The test chart should include bitonal spatial patterns to aid in evaluating limiting visual resolution. These elements should be of high contrast (D_{max} and D_{min}) and accompanied by numbered groups keyed for recognition of 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.

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 on each colour record separately. 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 print 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 scan as the values for the resolution measurements. Many scanners will automatically adapt to the dynamic range and the luminance distribution of the print. 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 pixel by 64 pixel area located at the same relative position in each patch. 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 pixel by 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.

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 print, and the visual resolution is subjectively judged. To ensure that the monitor or hard-copy printer does not reduce the visual resolution value, the digital image may be enlarged by pixel replication prior to viewing or printing, 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. Should this frequency exceed the half-sampling frequency, the limiting visual resolution shall be the spatial frequency associated with 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 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 spatial frequency response (SFR) of a print 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 given in ISO 12233. The SFR algorithm can be implemented as part of an easy-to-use image processing or analysis software package[1]. The algorithm can automatically compute and report the SFR, using image data from a user-defined rectangular region of the image which 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 90° 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 print 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 supersampled 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 supersampled "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 in accordance with Clause 9.

9 Presentation of results

9.1 General

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

— make and model,

— sampling frequency (in samples per millimetre) in the slow and fast scan directions,

— software driver and version number,

1) For example, as part of the development of this part of ISO 16067, the SFR algorithm has been incorporated into a Matlab® software module. Matlab® is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 16067 and does not constitute an endorsement by ISO of this product.

— grey scale or RGB scan mode,

— scan speed, and

— brightness, contrast, sharpening, 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 presentation

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 (see, for example, Table 1) 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 — Example scanner OECF values

OECF step	Density	Digital values
1	0,10	213,0
2	0,15	199,6
3	0,20	193,1
4	0,30	179,7
5	0,40	163,7
6	0,50	143,5
7	0,55	126,5
8	0,60	116,3
9	0,65	105,3
10	0,70	96,4
11	0,80	82,3
12	0,90	69,7
13	0,95	62,1
14	1,00	58,8
15	1,05	54,0
16	1,10	50,5
17	1,20	43,4
18	1,30	36,1
19	1,45	23,9
20	1,60	9,3
EXAMPLE Scanner used here: 40 samples/mm, no sharpening, line illumination, grey-scale scan mode, normal scan speed.		

9.2.3 Graphical presentation

An example of a plot of the digital output level vs. the input densities of all the test chart patches 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.

X reflection density

Y count value

Figure 4 — Example OECF curve for electronic scanner

9.3 Resolution measurements

9.3.1 Report

The results of the resolution measurement shall be reported as follows. The values of all scanning settings that could affect the results of the measurement shall be reported along with the measurement results.

9.3.2 Limiting visual resolution

The limiting visual resolution values shall be reported as spatial frequency values, in LP per millimetre, for the slow scan and fast scan directions.

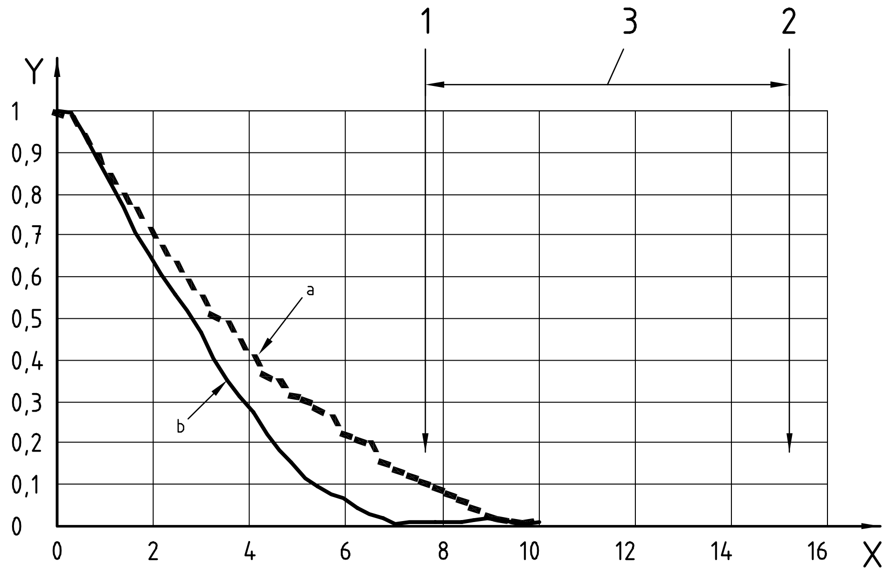
9.3.3 Edge SFR

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 per millimetre 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's 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 (see 4.2.2). The spatial frequency axis should be labelled with cycles per millimetre 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 a suitable graph depicting SFR values.



Key

1 half-sampling frequency

2 sampling frequency

3 aliasing region

X spatial frequency (in cycles per millimetre)

Y percentage modulation

[a] Fast scan.

[b] Slow scan.

EXAMPLE Scanner used here: spacing: 7,9 samples/mm, no sharpening, grey-scale scan mode, normal scan speed.

Figure 5 — Example SFR of fast (horizontal) and slow (vertical) scan direction for sampling frequency of 15,8 cycles/mm, Nyquist frequency of 7,9 cycles/mm

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 depending on the nominal surface gloss characteristics. 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 of element 4.3.3. 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 print material.

Table A.1 — Density values for each OECF step

Step (Starting at upper left, proceeding clockwise)	**Visual density**[a]
1	0,50
2	0,30
3	D_{min} or 0,10
4	0,20
5	0,40
6	0,60
7	0,70
8	0,80
9	0,90
10	1,00
11	1,20
12	1,40
13	1,60
14	1,50
15	1,30
16	1,10
17	1,00
18	0,90
19	0,80
20	0,70

[a] The tolerances on all density values shall be ± 0,04 as measured with a 3 mm aperture.

Annex B
(normative)

SFR algorithm

The SFR measurement algorithm used in this part of ISO 16067 for analysis of slanted edge transition data from images of the test chart defined in this part of ISO 16067 uses the normalized discrete Fourier transform (DFT) of a single line spread function:

$$SFR(k) = \frac{\left| \sum_{j=1}^{N} \overline{LSF}'_w(j) e^{-i2\pi kj/(N-1)} \right|}{\sum_{j=1}^{N} \overline{LSF}'_w(j)} \tag{B.1}$$

Where $\overline{LSF}'_w(j)$ 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 $\overline{LSF}'_w(j)$ for the DFT. This is outlined in Figure B.1.

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,

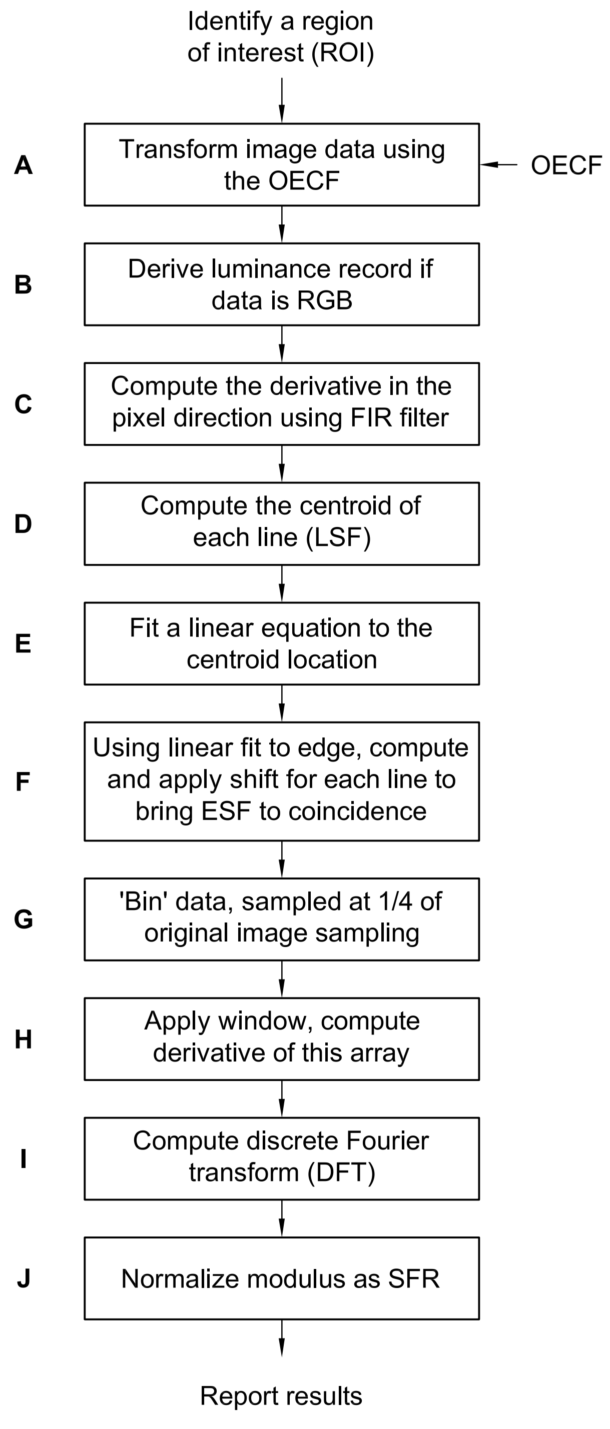
$$\phi(p,r) = aOECF\left[DN_{\text{red}}(p,r)\right] + bOECF\left[DN_{\text{green}}(p,r)\right] + cOECF\left[DN_{\text{blue}}(p,r)\right], \text{ for all } p, r \tag{B.2}$$

where

a, b, c are the colour weighting coefficients;

$OECF$[ ] is the OECF transformation function;

DN is the array of digital code values.



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

Figure B.1 — 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 R LSF is determined along the continuous variable x.

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

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:

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

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

$$S\left(r\right)=\overline{C}+\left[\left(R/2\right)-r\right]\Big/m \tag{B5}$$

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 ten 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 like x. The super sampling factor is 4, so n = 4X bins are created, each with an effective width of 0,25 pixels.

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

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

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

The average super-sampled edge spread function is then differentiated and windowed in Step H:

$$\overline{LSF}'\left(j\right)=W\left(j\right)\times\left[\overline{ESF}\left(j\right)-\overline{ESF}'\left(j-1\right)\right]\Big/2 \tag{B.7}$$

$$W\left(j\right)=0{,}54+0{,}46\times\cos\left[2\pi\left(j-2X\right)\big/4X\right] \tag{B.8}$$

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

To report the data in frequency units of cycles per millimetre on the image sensor, the frequency values must be multiplied by 1/2 the number of rows of photosites per millimetre on the sensor for vertical SFR measurements, or 1/2 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 General

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 image at the same locations. If a digital image is captured with misregistration between the colour records, the colour image displayed or printed 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 printing, suffers when misregistration is present. While this procedure describes how to calculate colour registration errors for photographic print 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 OECF.

The edge location and direction (in the form of an 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, discrete Fourier transform and normalization, the spatial frequency response (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 × 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 is the y-direction line number [1 – n];

a, *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.[2)]

C.3 Results

Taking a single 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 a table (see Table C.1).

Table C.1 — Example of measured edge locations, in units of pixels, for a photographic print scanned image

Colour[a]	Location	Shift
Red	39,57	0,36
Green	39,21	0,00
Blue	40,05	0,84

[a] The green record was used as a reference.

2) A Matlab® version of the software is available. Matlab® is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 16067 and does not constitute an endorsement by ISO of this product.

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