

# IEEE Standard for Camera Phone Image Quality

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# IEEE Standard for Camera Phone Image Quality

Sponsor

**Corporate Advisory Group**  
of the  
**IEEE Standards Association Board of Governors**

Approved 22 September 2016

**IEEE-SA Standards Board**

**Abstract:** Quantifying the performance of camera-equipped mobile devices is covered in this standard, with an emphasis on metrics and procedures appropriate to the types of sensors, lenses, and signal processing routines present on such devices. It is not intended as a general image quality standard for photographs produced by high-end dedicated cameras, e.g., DSLRs. Metrics include spatial frequency response, color uniformity, chroma level, lateral chromatic displacement, local geometric distortion, texture blur, and visual noise.

**Keywords:** camera, cell phone, IEEE 1858™, image quality, mobile, photography, visual quality

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## Introduction

This introduction is not part of IEEE Std 1858-2016, IEEE Standard for Camera Phone Image Quality.

Camera-equipped mobile devices have become ubiquitous, displacing dedicated digital cameras as many users' primary tools for photography. However, consumers have little guidance about the quality of the images produced by a particular device. That lack of guidance is due in part to a lack of uniform image quality testing for the devices, and what testing is done seldom is accessible to the layperson. This standard attempts to establish a uniform means of evaluating the quality of cameras in mobile devices, allowing objective comparison between device models and manufacturers, using a variety of metrics that are relevant to consumer photography.

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# IEEE Standard for Camera Phone Image Quality

## 1. Overview

### 1.1 Scope

This intent of this standard is to quantify the performance of camera-equipped mobile devices. There is an emphasis on metrics and procedures appropriate to the types of sensors, lenses, and signal processing routines present on such devices. It is not intended as a general image quality standard for photographs produced by high-end dedicated cameras, e.g., digital single-lens reflex (DSLR) cameras.

### 1.2 Purpose

Camera-equipped mobile devices have become ubiquitous, displacing dedicated digital cameras as many users' primary tools for photography. However, consumers have little guidance about the quality of the images produced by particular device models. That lack of guidance is due in part to a lack of uniform image quality testing for the devices, and what testing is done seldom is accessible to the layperson. This standard attempts to establish a uniform means of evaluating the quality of cameras in mobile devices, allowing objective comparison between devices, models, and manufacturers, using a variety of metrics that are relevant to consumer photography.

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 61966-2-1, Multimedia systems and equipment—Colour measurement and management—Part 2-1: Colour management—Default RGB colour space—sRGB.<sup>1</sup>

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<sup>1</sup>IEC publications are available from the Sales Department of the International Electrotechnical Commission, (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute (<http://www.ansi.org/>).

ISO 7589:2002 Photography—Illuminants for sensitometry—Specifications for daylight, incandescent tungsten and printer.<sup>2</sup>

ISO 12233:2014 Photography—Electronic still-picture imaging—Resolution and spatial frequency responses.

ISO 14524:2009 Photography—Electronic still-picture cameras—Methods for measuring opto-electronic conversion functions (OECFs).

ISO 15739:2013 Photography—Electronic still-picture imaging—Noise measurements.

ISO 16067-1:2003 Photography—Spatial resolution measurements of electronic scanners for photographic images—Part 1: Scanners for reflective media.

ISO 20462:2012 Photography—Psychophysical experimental methods for estimating image quality.

ISO 20462-3:2012 Photography—Psychophysical experimental methods for estimating image quality—Part 3: Quality ruler method.

### 3. Definitions, acronyms, and abbreviations

#### 3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.<sup>3</sup>

**acutance:** An objective, integrated spatial frequency response (SFR) metric that is used as a correlate to subjective sharpness.

**chroma level:** An objective metric indicating the level of chromatic intensity relative to the original scene.

**chrominance non-uniformity:** The gradual variation of the chrominance signal components within the image field.

**color uniformity:** An objective metric that characterizes chrominance non-uniformity.

**hyperfocal distance:** When the lens is focused at this distance, all objects at distances from half of the hyperfocal distance out to infinity will be acceptably sharp.

**image height:** The vertical size of an image.

**lateral chromatic displacement (LCD):** A phenomenon caused by different wavelengths of light being magnified to different levels by the lens (different wavelengths are focused at different positions in the focal plane).

**local geometric distortion (LGD):** The variation of magnification in the image field.

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<sup>2</sup>ISO publications are available from the ISO Central Secretariat (<http://www.iso.ch/>). ISO publications are also available in the United States from the Sales Department, American National Standards Institute (<http://www ansi.org/>).

<sup>3</sup>*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>.

**mobile device:** A portable device containing a camera system that is not a dedicated image capture device.  
*Example:* A cell phone containing front and rear facing cameras, a tablet containing a camera, etc.

**near infrared (NIR):** Light with wavelengths between 750 nm through 1.4  $\mu\text{m}$ .

**Nyquist frequency:** The spatial frequency that is half the sampling frequency of a discrete system.

**reflective target:** A test target made of a material designed to reflect light.

**sharpness:** The perceived level of detail in an image, represented as the modulation of contrast between the original scene and the reproduced image.

**spatial frequency:** How often a periodic pattern (*e.g.*, a sinusoid) repeats per unit of distance.

**spatial frequency response (SFR):** The amplitude of the modulation of a periodic pattern.

**spectrally neutral:** Visible light that has relative spectral energy that does not vary by more than 5% over the range of 400 nm to 700 nm.

**texture detail:** Mid-to-high spatial frequency image content of low contrast such as foliage, grass, and uniformly colored fabrics. Generally, spatial content of frequency greater than 150 line pairs per picture height and with a contrast ratio of 40% or less of the maximum contrast.

**transmissive target:** A test target made of a material designed to transmit light.

### 3.2 Acronyms and abbreviations

|        |                                                                                      |
|--------|--------------------------------------------------------------------------------------|
| AEC    | auto exposure control                                                                |
| CCT    | correlated color temperature                                                         |
| CFA    | color filter array (Bayer filter)                                                    |
| CIE    | International Commission on Illumination                                             |
| CIELAB | CIE defined color space for perceptual uniformity including Luminance, $a^*$ , $b^*$ |
| CIEXYZ | CIE defined color space analogous to least mean square cone response of human eye    |
| CMOS   | complementary metal–oxide–semiconductor                                              |
| CPD    | cycles per degree                                                                    |
| CPIQ   | camera phone image quality                                                           |
| CRA    | chief ray angle                                                                      |
| CSF    | contrast sensitivity function                                                        |
| DPI    | dots per inch                                                                        |
| DSC    | digital still camera                                                                 |
| DSLR   | digital single lens reflex                                                           |

|       |                                     |
|-------|-------------------------------------|
| DVC   | digital video camera                |
| ESF   | edge spread function                |
| FFT   | fast Fourier Transform              |
| FoV   | field of view                       |
| G     | green                               |
| GUI   | graphic user interface              |
| JND   | just noticeable difference          |
| LCD   | lateral chromatic displacement      |
| LGD   | local geometric distortion          |
| LP/PH | line pairs per picture height       |
| LSF   | line-spread function                |
| MP    | mega-pixels                         |
| MTF   | modulation transfer function        |
| NIR   | near infrared                       |
| NPS   | noise power spectrum                |
| OECF  | opto-electronic conversion function |
| ppi   | pixels per inch                     |
| PSD   | power spectral density              |
| QE    | quantum efficiency                  |
| QL    | quality loss                        |
| RGB   | red green blue tristimulus          |
| ROI   | region of interest                  |
| SFR   | spatial frequency response          |
| SNR   | signal to noise ratio               |
| SQS   | standard quality scale              |
| sRGB  | standard RGB                        |
| TV    | television                          |
| VGA   | 640 × 480 pixel resolution          |

## 4. Test conditions and apparatus

The charts, illuminants, and setup described here apply generally to the tests in this specification. If a particular test requires a different setup, it will be noted in the test.

### 4.1 Environment

The ambient room temperature during the acquisition of the test data shall be  $23\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$  and the relative humidity shall be  $50\% \pm 30\%$ .

### 4.2 Charts

Common charts include:

- Spatial frequency response (SFR)
- Dot
- X-Rite Digital ColorChecker® SG<sup>4,5</sup>

Additional charts are specified in tests when needed.

#### 4.2.1 Dot chart

The test chart contains black circular dots placed on a regular square grid on a uniform white background. It must be planar according to 4.2.2. See Figure 1 below for an example of a dot chart.

It can be either a printed reflective test chart (in which case it is front illuminated) or a transmissive test chart (if rear illuminated). Printed charts can be glued on glass for a better planarity.

The size and the number of dots should depend on the sensor pixel count of the camera and the field of view (FoV):

- The number of dots on a 4:3 aspect ratio image should be no less than  $21 \times 15$  dots.
- The diameter of each dot should be no less than 10 sensor pixels under the test capture conditions.
- The numbers of rows and columns of dots should each be odd to have a dot in the center from which the grid can be calculated.

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<sup>4</sup> Digital ColorChecker® is a registered trademark of X-Rite, Incorporated.

<sup>5</sup> This information is given for the convenience of users of this standard and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to the same results.

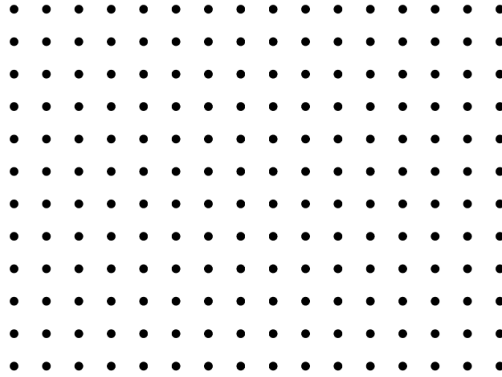


Figure 1—Dot chart

#### 4.2.2 Planarity

It is important that the test target be flat so as to avoid artifacts caused by focus and other variations across a non-flat surface.

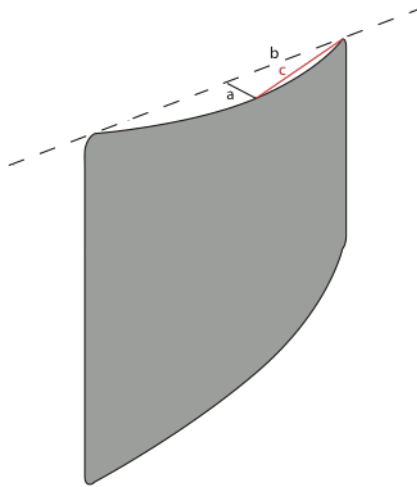


Figure 2—Chart planarity

The planarity  $\delta$  of the chart, as shown in Figure 2, (as a percentage) can be calculated by:

$$\delta = \frac{a}{c} \times 100\% \quad (1)$$

The test chart must be planar to within 3%, which corresponds to a local geometric distortion (LGD) of at most 0.045%.

#### 4.2.3 Alignment

The chart shall be orthogonal to the optical axis of the camera, with the center of the chart within 3% of the image center. Failure to properly align the chart will result in inconsistent results across the FoV.

The camera shall be positioned to properly frame the test target. The target shall be oriented so that the horizontal edge of the chart is approximately parallel to the horizontal camera frame line. The approximate distance between the camera and the test chart should be reported along with the measurement results.

The alignment can be performed by using a mirror as shown in Figure 3. Frame the chart as necessary in the camera's viewfinder. Place the mirror in the center of the frame flat against the chart. Adjust the orientation of the camera until the center of the camera's lens appears at the center of the camera's viewfinder within 3% of the image center. When that occurs, the chart and camera are aligned correctly, and the mirror can be removed.

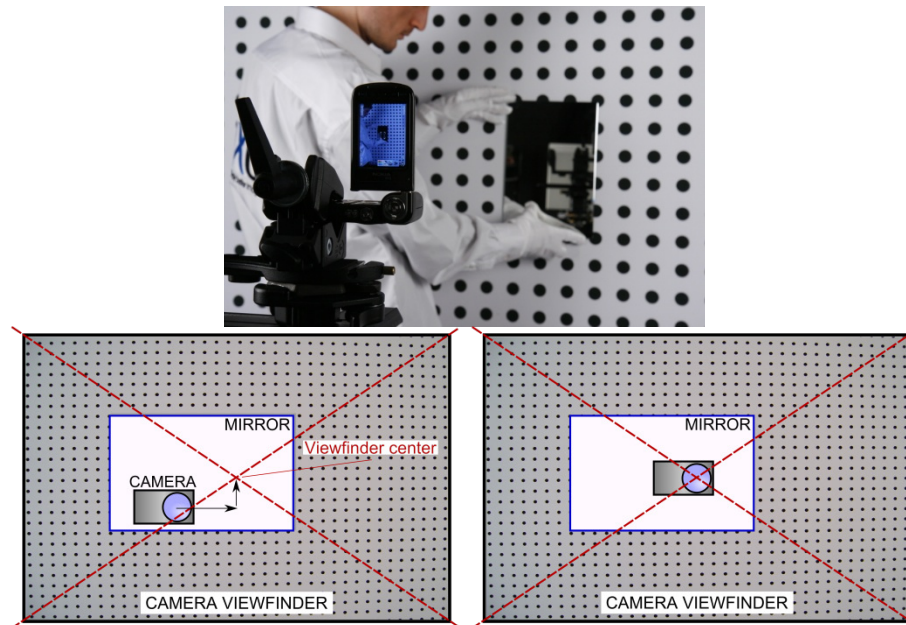


**Figure 3—Collimation using a mirror. Rotate the camera until the image of the camera in the viewfinder is at the image center.**

## 4.3 Lighting

### 4.3.1 Illuminants

The following illuminants are recommended:

- D55 based on ISO 7589:2002<sup>6</sup>
- Tungsten (3050 K incandescent) based on ISO 7589:2002
- TL84
- 5700 K  $\pm$  1000 K

NOTE—The tungsten illuminant specified here is a standard Tungsten bulb with a correlated color temperature (CCT) of 3200 K. When a diffuser made of common materials such as translucent polyethylene is placed in the path of the light, the CCT of Tungsten is changed to approximately 3050K. The use of Tungsten in this document assumes the use of a diffuser that causes this phenomenon.

<sup>6</sup> Information on references can be found in Clause 2.

The individual tests specify the appropriate illuminant for that test, which may be different than the four illuminants specified above.

No specific light level is recommended for any test. The light level used shall be reported.

If discontinuous sources (e.g., fluorescent tubes) are used, they should be connected to high-frequency ballasts (>42 kHz) so as to minimize flicker.

#### 4.3.2 Uniformity

Lighting uniformity should be maintained at 80% or better across the chart area for reflective charts and 90% or better across the chart area for transmissive charts, unless specified differently for a particular metric.

The target uniformity is calculated by obtaining measurements across the target in at least a grid of three horizontal regions by three vertical regions. The maximum, minimum, and average values are obtained from these measurements, and the uniformity is computed via:  $\text{uniformity} = 1 - (\text{max} - \text{min}) / \text{average}$ .

#### 4.3.3 Setup

The test charts must be mounted on a spectrally neutral, 18% gray, wall. The illuminants should be baffled to prevent flare, i.e., the luminous parts of the light sources should not be directly visible from the location of the camera. The illuminants and camera should be positioned so as to minimize glare. The camera shall not cast a shadow on the chart. A lighting system diagram is shown below in Figure 4.

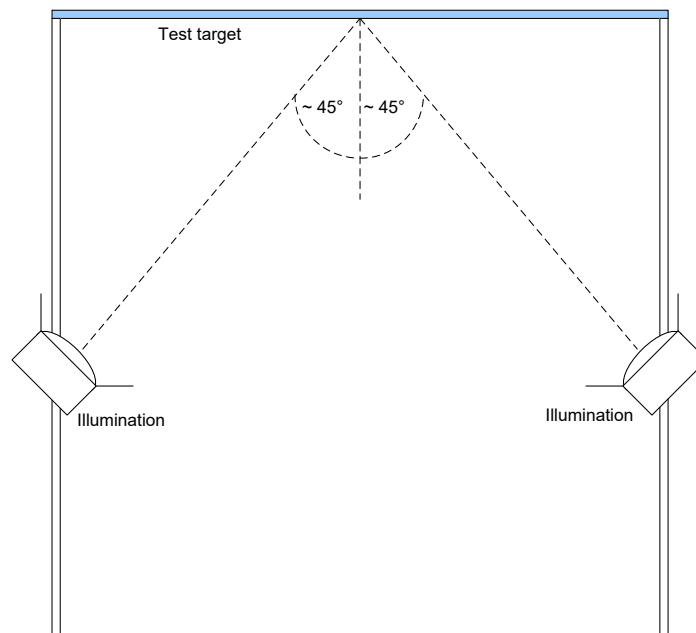


Figure 4—Lighting system diagram

## 4.4 Camera settings

### 4.4.1 Exposure

The illumination shall be set such that the auto-exposure of the camera gives a suitable result according to the specific requirements of a given metric. More precisely, the image must not be clipped either in bright or dark parts of the target.

If clipping is present, it must be mitigated through adjustments to exposure before executing a test.

### 4.4.2 White balance

White balance should be set to automatic unless specified differently for a particular metric.

## 5. Spatial frequency response (SFR)

### 5.1 Introduction

To the extent that they have lenses, color filter arrays (CFAs), detectors, apertures, image processing, and are hand-held, there are few operational or architectural differences between today's mobile device cameras and consumer digital still cameras (DSCs). Nevertheless, significant differences in the level of imaging performance do exist. These differences are driven by physical and economic constraints, as well as by image-capture environments.

The SFR is perhaps one of the more important imaging performance elements to consider for mobile device cameras, because it acts as a parent metric for derivative metrics such as resolution, sharpening, and acutance. The current protocols of ISO 12233:2014 are suitable for measuring SFR of mobile device cameras. However, applying them and reporting results requires some accommodation for strong field-dependent behaviors, signal-dependent image processing, and non-optimal test conditions at capture. The slanted-edge SFR technique of ISO 12233:2014 using low contrast edge features similar to those in ISO 16067-1:2003 is the recommended method for measuring the SFR of mobile device cameras. This document describes modifications to the existing standard in terms of test charts and a modification to the slanted edge algorithm to allow for other scanning directions than 0° and 90° to accommodate tangential and sagittal measurements of the SFR. It also presents a method for calculating a visually correlated global sharpness measure.

### 5.2 Scope

This subclause describes the target and the protocol to measure the sharpness in a mobile device camera image from its spatial edge response. The detailed algorithms to compute the SFR from a slanted-edge image are thoroughly described in the ISO 12233:2014. Modifications to this algorithm to adapt it to mobile device cameras are described in this document.

## 5.3 Test conditions and methods

### 5.3.1 Apparatus and hardware

The lighting conditions described in 4.3.3 shall be used. Because SFR results may depend on lux level due to reduced signal to noise ratio (SNR) in dimly illuminated situations, the lux level used should be reported along with test results.

### 5.3.2 Gamma correction

The processed signal representing the image from an electronic still-picture camera is a non-linear function of the scene luminance values. Because the SFR measurement is defined on a linearized output signal, and such a non-linear response will affect SFR values, ISO 12233:2014 requires that the signal shall be linearized before the data analysis is performed. As described in ISO 12233:2014, linearization is accomplished by applying the inverse of the camera opto-electronic conversion function (OECF) to the output signal via a lookup table or appropriate equation. The measurement of the OECF shall be as specified in ISO 14524:2009, using the standard reflection camera OECF test chart or using an integrated OECF/SFR chart.

However, measuring the OECF is a relatively cumbersome procedure and the linearization may be simplified by observing that the largest contributor to the nonlinearities is the gamma curve. This is applied in the final stage rendering of the image to compensate for display nonlinearities. Because the gamma curve is usually known [e.g., for standard RGB (sRGB)], it can be inverted and applied to the rendered image. Such an inversion is performed as part of the conversion from sRGB data to CIEXYZ as described in 5.3.3 and no further linearization should therefore be needed in that case. The remaining non-linearity typically shows a weak “S” shaped characteristic with a linear central part. By utilizing a test chart with low-contrast features and controlling the exposure through an appropriately chosen distribution of grey values, the SFR algorithm can be made to operate on data that is sufficiently linear. An example is shown in Annex G.

### 5.3.3 Luminance and color measurements

SFR measurements should be performed on the camera luminance signal. The luminance signal is given by the Y channel of the CIE 1931 XYZ color space. For sRGB, which is the typical format of saved captured images in mobile devices, the transformation into CIEXYZ is described in IEC 61966-2-1 [B17]. In a summary form, the sRGB transformation is included here:

$$Y(i) = R(i) \times 0.2126 + G(i) \times 0.7152 + B(i) \times 0.0722 \quad (2)$$

where

- $Y$  is the CIEXYZ luminance channel
- $R$  is the gamma corrected red channel
- $G$  is the gamma corrected green channel
- $B$  is the gamma corrected blue channel
- $i$  is the  $i^{\text{th}}$  pixel in the image array

### 5.3.4 Test target

To satisfy the  $32 \times 32$  pixel sampling requirement of ISO 12233:2014, two test charts are specified; one for cameras with VGA sensor size ( $640 \times 480$  pixels) and one for higher pixel-count cameras. The test charts are shown in Figure 5 and Figure 6. For purposes of illustration, these figures also contain markers (green and red squares) for the regions of interest (ROI) used for the SFR measurements together with their corresponding field positions. These markers are not part of the printed test chart.

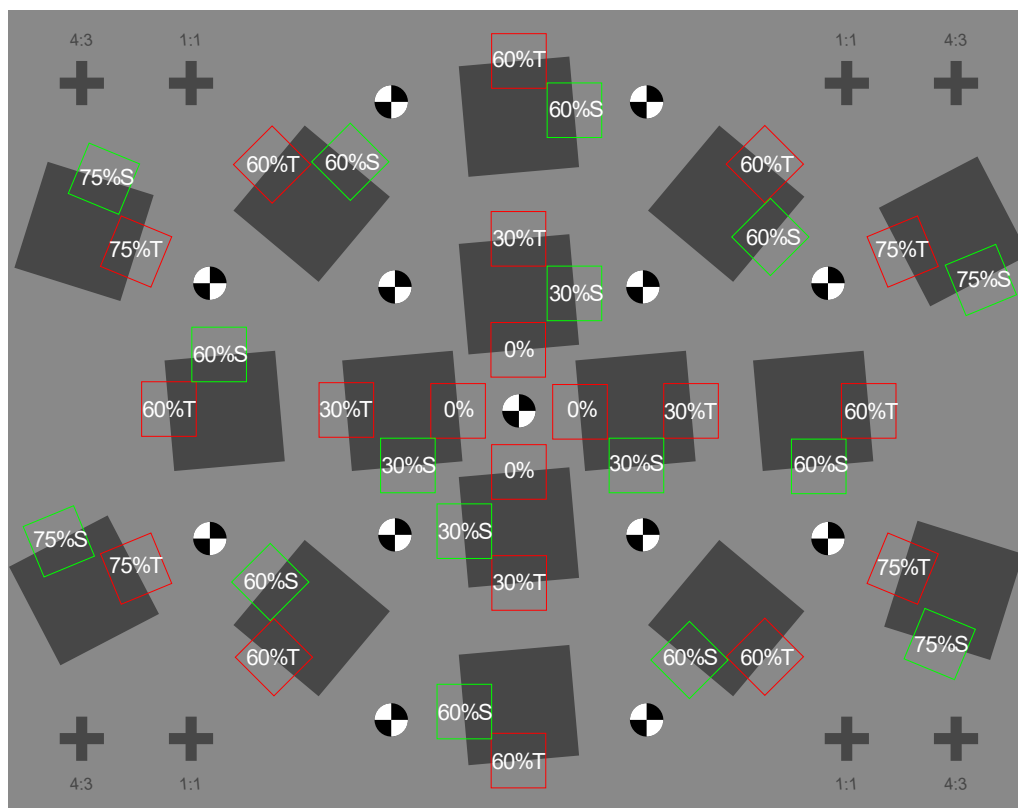


**Figure 5—Test target format for VGA cameras. The red and green squares indicate the ROI, each either sagittal (S) or tangential (T), for the SFR measurements and are not part of the chart.**

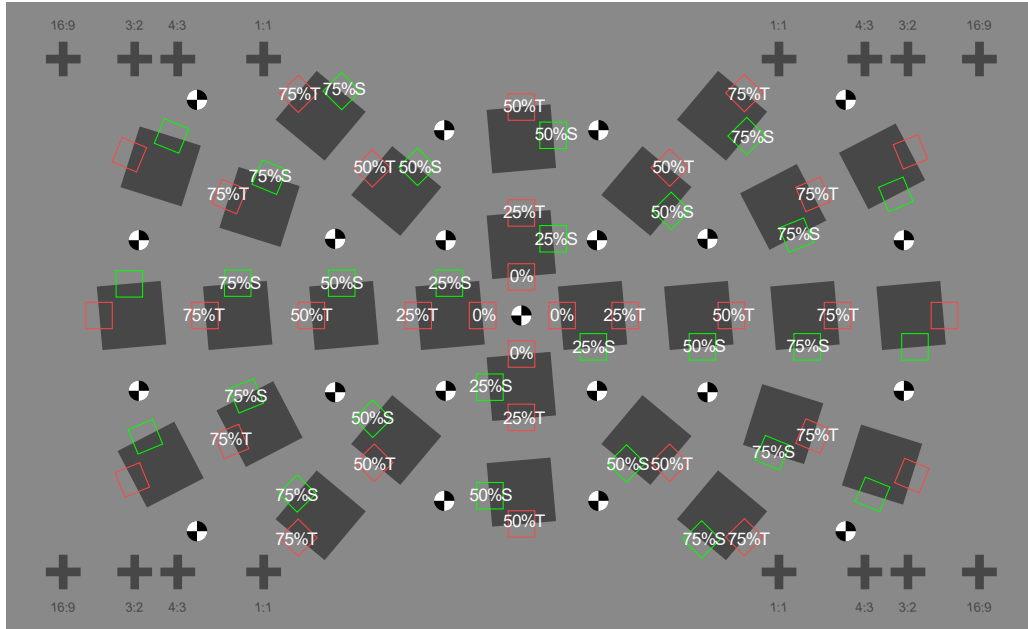


**Figure 6—Test target format for cameras with higher pixel counts than VGA. The red and green squares indicate the ROI for the SFR measurements and are not part of the chart.**

All field positions are related to the diagonal of the 4:3 target aspect ratio. The targets contain different features whose characteristics and application are as follows:

- There should be features aiding in framing the image. These features could be framing arrows, or as illustrated in Figure 5 and Figure 6, crosses where appropriate framing is obtained if one quarter of each of the four crosses for a particular format are visible in the image.
- The mean reflectance or transmittance of the active area (i.e., the area containing the squares) shall be between 0.15 and 0.25. The recommended target width size is 20 in to 40 in.
- All slanted-edge squares shall have a size and edge ROI that is sufficiently large to satisfy the  $32 \times 32$  pixels sample requirement of ISO 12233:2014. The edge shall have a modulation contrast between 0.55 and 0.65 with a mean level of between 0.12 and 0.25 reflectance. Table 1 below provides a number of possible minimum/maximum density pairs that satisfy this criterion based on the following equations:

$$D_{\text{avg}} = -\log_{10} \left[ 10^{(-D_{\text{min}})} + 10^{(-D_{\text{max}})/2} \right]$$

$$\text{Contrast modulation} = C_{\text{mod}} = D_{\text{max}} - D_{\text{min}}$$

- The minimum frequency content of the edge features is further specified in Table 2. This table describes the minimum spatial frequency (cy/mm) associated with the 80% SFR level of each specified target size and sensor size pair. Correction for this finite target SFR is required before reporting the camera SFR. Unless otherwise noted, a 5% positional tolerance relative to the nominal field position is allowed. Except for the center squares, the slanted-edge squares may have a tilt of up to  $10^\circ$  relative to the polar coordinates if geometric distortion of the lens requires such accommodation. If this occurs, then all slanted-edge squares within the active area shall also have the same degree of relative tilt.
- The center slanted-edge squares shall be at a  $5^\circ$  tilt with a rotational tolerance of  $\pm 2^\circ$ . They shall be centered within the active area.

- For the large-sized test chart, there shall be slanted-edge squares used to measure SFR centered at multiples of 16.5% of the 4:3 aspect ratio image height in the radial direction from the edge of the nearest square closer to the center of the image. For the squares closest to the image center, the center should be located at 16.5% of the 4:3 image height relative to the center of the image. The positions of the squares shall extend radially from the center of the chart in the  $0^\circ$ ,  $\pm 45^\circ$ ,  $\pm 90^\circ$ ,  $\pm 135^\circ$ , and  $180^\circ$  directions. The sides of the squares shall be 15% of the 4:3 aspect ratio image height. Optionally, squares can also be placed at the  $\pm 22.5^\circ$  and  $\pm 157.5^\circ$  directions. There is no requirement to measure SFR at these positions, because this puts very high requirements on the printing device.
- For the VGA camera test chart, there shall be slanted-edge squares used to measure SFR centered at multiples of 21.5% of the 4:3 aspect ratio image height in the radial direction from the edge of the nearest square closer to the center of the image. For the squares closest to the image center, the center should be located at 21.5% of the 4:3 image height relative to the center of the image. The positions of the squares shall extend radially from the center of the chart in the  $0^\circ$ ,  $\pm 45^\circ$ ,  $\pm 90^\circ$ ,  $\pm 135^\circ$ , and  $180^\circ$  directions. The sides of the squares shall be 20% of the 4:3 aspect ratio image height. Optionally, squares can also be placed at the  $\pm 22.5^\circ$  and  $\pm 157.5^\circ$  directions. There is no requirement to measure SFR at these positions, because this puts very high requirements on the printing device.
- A focusing aid feature shall be used. This feature also aids in centering the image. An example of such a feature is a circle divided into high contrast black and white quadrants.
- There should be features for automatic target detection. These features should be placed within the active area aspect ratio, but may be placed for convenience as dictated by particular use cases. An example of such a feature is the focusing aid feature described above.

**Table 1—Minimum/maximum density pair options for different contrast modulations and average density levels**

| D <sub>min</sub> /D <sub>max</sub> pairs for low contrast slant-edge target (modulation, contrast) pairs |      |                  | Contrast modulation level |      |      |      |      |      |      |      |      |      |      |
|----------------------------------------------------------------------------------------------------------|------|------------------|---------------------------|------|------|------|------|------|------|------|------|------|------|
|                                                                                                          |      |                  | 0.55                      | 0.56 | 0.57 | 0.58 | 0.59 | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 |
| Density associated with average edge transition reflectance                                              | 0.92 | D <sub>max</sub> | 1.27                      | 1.28 | 1.29 | 1.30 | 1.31 | 1.32 | 1.33 | 1.34 | 1.35 | 1.36 | 1.38 |
|                                                                                                          |      | D <sub>min</sub> | 0.73                      | 0.73 | 0.72 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.71 | 0.70 |
|                                                                                                          | 0.89 | D <sub>max</sub> | 1.23                      | 1.24 | 1.25 | 1.26 | 1.27 | 1.28 | 1.29 | 1.31 | 1.32 | 1.33 | 1.34 |
|                                                                                                          |      | D <sub>min</sub> | 0.70                      | 0.69 | 0.69 | 0.69 | 0.68 | 0.68 | 0.68 | 0.68 | 0.67 | 0.67 | 0.67 |
|                                                                                                          | 0.85 | D <sub>max</sub> | 1.20                      | 1.21 | 1.22 | 1.23 | 1.24 | 1.25 | 1.26 | 1.27 | 1.29 | 1.30 | 1.31 |
|                                                                                                          |      | D <sub>min</sub> | 0.66                      | 0.66 | 0.66 | 0.66 | 0.65 | 0.65 | 0.65 | 0.64 | 0.64 | 0.64 | 0.64 |
|                                                                                                          | 0.82 | D <sub>max</sub> | 1.17                      | 1.18 | 1.19 | 1.20 | 1.21 | 1.22 | 1.23 | 1.24 | 1.26 | 1.27 | 1.28 |
|                                                                                                          |      | D <sub>min</sub> | 0.63                      | 0.63 | 0.63 | 0.63 | 0.62 | 0.62 | 0.62 | 0.61 | 0.61 | 0.61 | 0.61 |
|                                                                                                          | 0.80 | D <sub>max</sub> | 1.14                      | 1.15 | 1.16 | 1.17 | 1.18 | 1.19 | 1.20 | 1.22 | 1.23 | 1.24 | 1.25 |
|                                                                                                          |      | D <sub>min</sub> | 0.61                      | 0.60 | 0.60 | 0.60 | 0.59 | 0.59 | 0.59 | 0.59 | 0.58 | 0.58 | 0.58 |
|                                                                                                          | 0.77 | D <sub>max</sub> | 1.12                      | 1.13 | 1.14 | 1.15 | 1.16 | 1.17 | 1.18 | 1.19 | 1.20 | 1.21 | 1.23 |
|                                                                                                          |      | D <sub>min</sub> | 0.58                      | 0.58 | 0.57 | 0.57 | 0.57 | 0.57 | 0.56 | 0.56 | 0.56 | 0.55 | 0.55 |
|                                                                                                          | 0.74 | D <sub>max</sub> | 1.09                      | 1.10 | 1.11 | 1.12 | 1.13 | 1.14 | 1.15 | 1.16 | 1.18 | 1.19 | 1.20 |
|                                                                                                          |      | D <sub>min</sub> | 0.55                      | 0.55 | 0.55 | 0.55 | 0.54 | 0.54 | 0.54 | 0.54 | 0.53 | 0.53 | 0.53 |
|                                                                                                          | 0.72 | D <sub>max</sub> | 1.07                      | 1.08 | 1.09 | 1.10 | 1.11 | 1.12 | 1.13 | 1.14 | 1.15 | 1.16 | 1.18 |
|                                                                                                          |      | D <sub>min</sub> | 0.53                      | 0.53 | 0.53 | 0.52 | 0.52 | 0.52 | 0.51 | 0.51 | 0.51 | 0.51 | 0.50 |
|                                                                                                          | 0.70 | D <sub>max</sub> | 1.05                      | 1.06 | 1.07 | 1.08 | 1.09 | 1.10 | 1.11 | 1.12 | 1.13 | 1.14 | 1.15 |
|                                                                                                          |      | D <sub>min</sub> | 0.51                      | 0.51 | 0.50 | 0.50 | 0.50 | 0.49 | 0.49 | 0.49 | 0.49 | 0.48 | 0.48 |
|                                                                                                          | 0.68 | D <sub>max</sub> | 1.02                      | 1.03 | 1.04 | 1.05 | 1.06 | 1.08 | 1.09 | 1.10 | 1.11 | 1.12 | 1.13 |
|                                                                                                          |      | D <sub>min</sub> | 0.49                      | 0.48 | 0.48 | 0.48 | 0.48 | 0.47 | 0.47 | 0.47 | 0.47 | 0.46 | 0.46 |
|                                                                                                          | 0.66 | D <sub>max</sub> | 1.00                      | 1.01 | 1.02 | 1.03 | 1.04 | 1.06 | 1.07 | 1.08 | 1.09 | 1.10 | 1.11 |
|                                                                                                          |      | D <sub>min</sub> | 0.47                      | 0.46 | 0.46 | 0.46 | 0.46 | 0.45 | 0.45 | 0.45 | 0.45 | 0.44 | 0.44 |
|                                                                                                          | 0.64 | D <sub>max</sub> | 0.99                      | 0.99 | 1.00 | 1.02 | 1.03 | 1.04 | 1.05 | 1.06 | 1.07 | 1.08 | 1.09 |
|                                                                                                          |      | D <sub>min</sub> | 0.45                      | 0.45 | 0.44 | 0.44 | 0.44 | 0.43 | 0.43 | 0.43 | 0.43 | 0.42 | 0.42 |
|                                                                                                          | 0.62 | D <sub>max</sub> | 0.97                      | 0.98 | 0.99 | 1.00 | 1.01 | 1.02 | 1.03 | 1.04 | 1.05 | 1.06 | 1.08 |
|                                                                                                          |      | D <sub>min</sub> | 0.43                      | 0.43 | 0.42 | 0.42 | 0.42 | 0.42 | 0.41 | 0.41 | 0.41 | 0.40 | 0.40 |
|                                                                                                          | 0.60 | D <sub>max</sub> | 0.95                      | 0.96 | 0.97 | 0.98 | 0.99 | 1.00 | 1.01 | 1.02 | 1.03 | 1.05 | 1.06 |
|                                                                                                          |      | D <sub>min</sub> | 0.41                      | 0.41 | 0.41 | 0.40 | 0.40 | 0.40 | 0.40 | 0.39 | 0.39 | 0.39 | 0.39 |

**Table 2—Target spatial frequency content specification**

| Target sizes  |          |       |       |       |       |       |       |       |       |
|---------------|----------|-------|-------|-------|-------|-------|-------|-------|-------|
| Common sizes  | A series | 24 MP | 20 MP | 16 MP | 12 MP | 10 MP | 8 MP  | 6 MP  | 5 MP  |
|               | 4A0      | 1.37  | 1.19  | 1.02  | 0.84  | 0.77  | 0.69  | 0.59  | 0.54  |
|               | 2A0      | 1.92  | 1.68  | 1.44  | 1.19  | 1.09  | 0.97  | 0.84  | 0.77  |
|               | A0       | 2.71  | 2.37  | 2.03  | 1.68  | 1.54  | 1.37  | 1.19  | 1.09  |
|               | A1       | 3.84  | 3.36  | 2.88  | 2.38  | 2.17  | 1.94  | 1.68  | 1.54  |
|               | A2       | 5.43  | 4.75  | 4.07  | 3.36  | 3.07  | 2.74  | 2.38  | 2.17  |
| 11 × 17 in    | A3       | 7.67  | 6.71  | 5.75  | 4.75  | 4.34  | 3.88  | 3.36  | 3.07  |
| 8.5 × 11 in   | A4       | 10.85 | 9.49  | 8.13  | 6.71  | 6.13  | 5.48  | 4.74  | 4.33  |
|               | A5       | 15.3  | 13.4  | 11.5  | 9.48  | 8.65  | 7.74  | 6.7   | 6.12  |
|               | A6       | 21.5  | 18.8  | 16.1  | 13.33 | 12.17 | 10.89 | 9.43  | 8.61  |
|               | A7       | 30.5  | 26.7  | 22.8  | 18.87 | 17.22 | 15.41 | 13.34 | 12.18 |
| Business card | A8       | 43.1  | 37.7  | 32.3  | 26.67 | 24.34 | 21.77 | 18.85 | 17.21 |

To achieve the highest quality edge features for the measured regions with raster print devices such as inkjet printers, it is recommended that the digital test target artwork of Figure 5 and Figure 6 be rotated counter-clockwise by 5° before printing, such that the edge features are aligned with the horizontal and vertical raster of the print engine. Upon printing, the target can then be trimmed to appear as in Figure 5

and Figure 6. Extra care should be taken with respect to the squares located along the diagonals when performing this procedure. This procedure will only improve the edges of the center four squares, which are currently the only measured regions in this standard.

### 5.3.5 Image and camera settings

Multiple SFR measurements may be reported for different camera settings, including a setting using the maximum lens aperture size (minimum  $f$ -number) and a setting using maximum camera gain.

#### 5.3.5.1 Exposure

The camera exposure setting shall be the factory default setting. The chart is designed to expose such that signal clipping will not occur on edge transitions. The scene surrounding the chart shall not cause the exposure to change in such a way that this signal clipping occurs.

#### 5.3.5.2 Compression

Mobile devices typically include image compression to reduce the size of the image files and allow more images to be stored. The use of image compression can significantly affect SFR measurements. The values of all camera settings that may affect the results of the measurement, including lens focal length, aperture, and image output size or compression mode (if adjustable), shall be reported along with the measurement results. The setting with minimal compression shall be used.

#### 5.3.5.3 Camera focusing

The camera focus should be set using the camera autofocus system (if available). Maximum performance can be determined by repeating a series of image captures and selecting the image that provides the highest average modulation level at a spatial frequency approximately one fourth of the camera half-sampling (Nyquist) frequency.

#### 5.3.5.4 White balance

The camera white balance should set to automatic.

## 5.4 Acutance calculation

Acutance shall be used as the transition measure to derive sharpness. Acutance,  $Q$ , shall be calculated as:

$$Q = \frac{\int_0^{v_{cut}} \text{SFR}(v) M(v) \text{CSF}(v) dv}{\int_0^{\infty} \text{CSF}(v) dv}. \quad (3)$$

$\text{CSF}(v)$  is an agreed-upon visual system contrast sensitivity. This effort will use the contrast sensitivity function (CSF) described in ISO 16067-1:2003. Its functional form is:

$$\text{CSF}(\nu) = a\nu^c e^{-b\nu}. \quad (4)$$

where

$a$  is 1  
 $b$  is 0.2  
 $c$  is 0.8

For these values, the denominator of Equation (3) can be calculated analytically, whereby the acutance may be expressed as:

$$Q = \frac{\int_0^{\nu_{\text{cut}}} \text{SFR}(\nu) M(\nu) \text{CSF}(\nu) d\nu}{16.88}. \quad (5)$$

where

$\nu$  is spatial frequency expressed in cycles per degree (CPD)  
 $M(\nu)$  is the modulation transfer function (MTF) of the display device or printer and paper, depending on viewing condition

The procedure for converting SFR data as function of spatial frequency in cycles per pixel to CPD is described in Annex B. The camera phone image quality (CPIQ) viewing conditions are summarized in Annex B. For a display device:

$$M(\nu) = M_{\text{disp}}(\nu) = \left| \frac{\sin(\pi k_{\text{disp}} \nu)}{\pi k_{\text{disp}} \nu} \right|. \quad (6)$$

where

$k_{\text{disp}}$  is dependent on viewing condition according to Table 3

**Table 3—Factor  $k_{\text{disp}}$  in various viewing conditions**

| Viewing condition                            | $k_{\text{disp}}$ (degrees) |
|----------------------------------------------|-----------------------------|
| Computer monitor viewing: 100%<br>at 100 ppi | 0.0243                      |
| 4.5-in cell phone display                    | 0.0176                      |
| 30-in 4K monitor                             | 0.02                        |

For the print case,  $M(\nu)$  is given by:

$$M(\nu) = M_{\text{print}}(\nu) = \exp\left(-\frac{\nu}{k_{\text{print}}}\right). \quad (7)$$

Because there exists a large number of printing devices, it is not possible to obtain a general printer and paper MTF, and a reasonable representative case has to be established. In this document, the above formula

was based on measurement results on inkjet printers obtained from the literature (Koopipat, et al [B27]<sup>7</sup> and Bonnier & Lindner [B8]). The factor  $k_{\text{print}}$  has the value given in Table 4 depending on viewing conditions.

**Table 4—Factor  $k_{\text{print}}$  in various viewing conditions**

| Viewing condition      | $k_{\text{print}}$ (degrees) |
|------------------------|------------------------------|
| Small print 10 × 15 cm | 21.8                         |
| Large print 40 × 60 cm | 65.4                         |

The spatial frequency  $\nu$  is in all cases expressed in CPD.

$\nu_{\text{cut}}$  is a cutoff spatial frequency. This should be set to the lowest of the camera or display/printer half-sampling (Nyquist) frequency expressed in CPD. In the printer cases, a resolution of 600 dots per inch (dpi) is assumed. Table 5 contains the half-sampling frequencies of the display devices and prints for the different viewing conditions.

**Table 5—Half sampling frequencies of output devices by viewing condition**

| Condition                 | Distance (cm) | $\nu_{\text{cut}}$ (CPD) |
|---------------------------|---------------|--------------------------|
| Small print 10 × 15 cm    | 25            | 51.5                     |
| Large print 40 × 60 cm    | 75            | 155                      |
| Computer monitor at 100%  | 60            | 20.6                     |
| 4.5-in cell phone display | 25            | 30.0                     |
| 30-in 4K monitor          | 50            | 25.1                     |

## 5.5 Subjective evaluation

This subclause describes how to transform the acutance value into a just noticeable difference (JND) value. A JND transform provides a mathematical formula to convert an objective metric to JND degradations. Normally such a transform is obtained through subjective evaluation of test images. In the case of perceived sharpness, this transform was created using published material.

ISO 20462-3:2012 provides a link between MTFs and the quality JND values in two equations [listed below as Equation (8) and Equation (9)]. The equations define a set of modulation transfers  $m(\nu)$  of the complete imaging system, as follows:

$$m(\nu) = \frac{2}{\pi} \left( \cos^{-1}(k\nu) - k\nu \sqrt{1 - (k\nu)^2} \right) \quad k\nu \leq 1 \quad (8)$$

$$m(\nu) = 0 \quad k\nu > 1 \quad (9)$$

where

- $\nu$  is spatial frequency in CPD at the retina of the observer
- $k$  is a reciprocal measure of the system bandwidth in CPD

<sup>7</sup> The numbers in brackets correspond to those of the bibliography in Annex U.

In the context of this document, these functions are equivalent to the product of the SFR and printer or display MTFs. The mapping from the SFR curves in Equation (8) and Equation (9) into JND values as described in ISO 20462-3:2012 is performed according to Equation (10):

$$JND = \frac{17249 + 203792k - 114950k^2 - 3571075k^3}{578 - 1304k + 357372k^2} \quad 1 \leq 100k \leq 26 \quad (10)$$

Figure 7 shows the proposed CSF curve as well as a sample array of the SFR curves  $m(\nu)$  used in this test. To relate the acutance,  $Q$ , as defined in Equation (3), to subjective quality loss ( $QL$ ) in JNDs, an objective metric of blur,  $B$ , is defined in Equation (11). Whereas acutance increases with increasing sharpness,  $B$  is a metric that increases with increasing blur. The threshold value 0.8859 is the acutance value above which increases in acutance are not accompanied by increases in perceived quality, because the appearance of the image is sufficiently close to that perceived by an observer directly viewing an original scene (acutance = 1). The relationship of JND  $QL$  due to blur versus the blur metric  $B$  can be seen in Annex T. A numerical equation was found to fit the data well, and the formula for the JND transform is shown in Equation (12):

$$B = \begin{cases} 0.886 - Q & Q \leq 0.886 \\ 0 & Q > 0.886 \end{cases} \quad (11)$$

$$QL = \frac{0.00336 - 2.34 \times B + 164 \times B^2 - 192 \times B^3 + 16.3 \times B^4}{1 - 0.0866 \times B + 0.968 \times B^2 - 2.31 \times B^3} \quad (12)$$

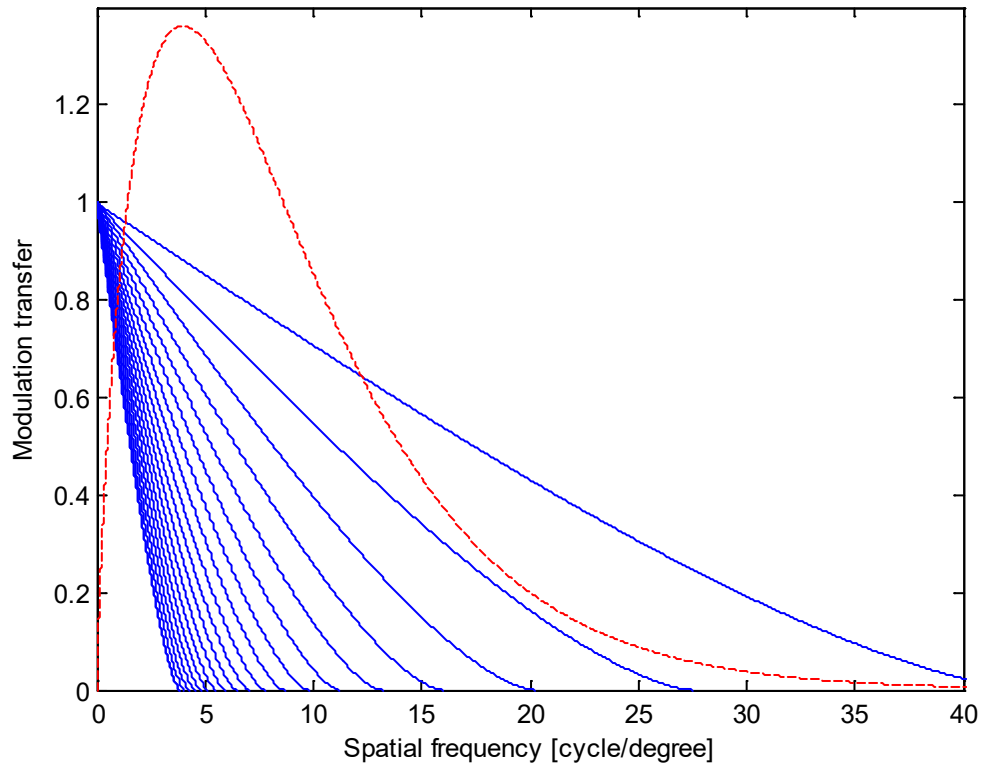


**Figure 7—The CSF curve is shown as the red dashed curve; SFR curves generated in a series are shown as the blue curves**

## 6. Lateral chromatic displacement

### 6.1 Introduction

Lateral chromatic displacement (LCD) is caused by different wavelengths of light being magnified to different levels by the lens (different wavelengths are focused at different positions in the focal plane). The most significant effect of LCD can be seen as color fringes around sharp edges in the image. LCD is usually, though not always, stronger on the borders of the field. LCDs are generally radially symmetric for a single lens. This may not always be the case for mobile device optics, because of off-centering and tilt between the different optical elements and the sensor plane, however, this is still a reasonable first order approximation. This clause provides the method and protocol to derive an objective measurement of LCD from a single image, and how to correlate this value with subjective image quality.

#### 6.1.1 Scope

Clause 6 describes how to measure LCD on a mobile device and its impact on subjective image quality.

#### 6.1.2 Definition

LCD is defined as the dependence on wavelength of the position in the image of a point light source. Because LCD is mainly due to light refraction inside the lenses, it depends on the position in the image field. For lens symmetry reasons, LCD is also mostly radially symmetric, although this may not be the case for mobile devices' optics, due to manufacturing tolerances (in particular, tilt and off centering).

In a red green blue tristimulus (RGB) image, LCD is characterized by the difference in position of the three channels. The green (G) channel is commonly used as a reference. The relative position of the red (R) and blue (B) channels shall be measured with respect to G. In the approximation of a radially symmetric LCD, it suffices to report the distance between R, G, and B in the radial direction, as shown in Figure 8.

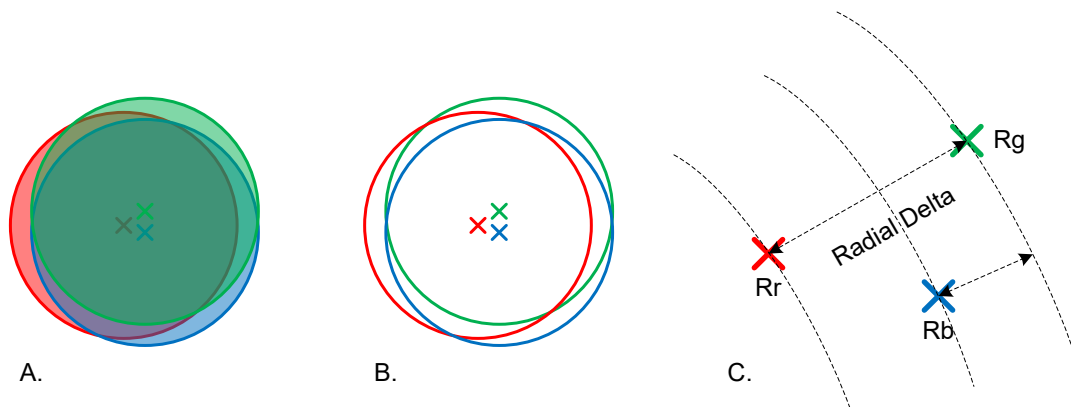


Figure 8—Illustration of LCD and its radial approximation

## 6.2 Measurements

LCD is measured on a target of black dots over a uniform white background. See specification of the target in 4.2.1. For each of the R and B channels, the radial position difference with respect to the G channel is measured on each dot, and plotted as a function of the distance of the G channel to the image center.

The radial chromatic displacement in pixels ( $DR_{RCDabs}$ ,  $DB_{RCDabs}$ ) shall be calculated as follows:

$$\Delta R_{RCDabs,i} = \sqrt{(G_{H,i})^2 + (G_{V,i})^2} - \sqrt{(R_{H,i})^2 + (R_{V,i})^2}$$

$$\Delta B_{RCDabs,i} = \sqrt{(G_{H,i})^2 + (G_{V,i})^2} - \sqrt{(B_{H,i})^2 + (B_{V,i})^2}$$

The relative radial chromatic displacement ( $DR_{RCDrel}$ ,  $DB_{RCDrel}$ ) is defined by the ratio of radial chromatic displacement to the diagonal length of the image. The relative radial chromatic displacement shall be calculated as follows:

$$\Delta R_{RCDrel,i} = \frac{\sqrt{(G_{H,i})^2 + (G_{V,i})^2} - \sqrt{(R_{H,i})^2 + (R_{V,i})^2}}{\sqrt{H^2 + V^2}} \times 100\%$$

$$\Delta B_{RCDrel,i} = \frac{\sqrt{(G_{H,i})^2 + (G_{V,i})^2} - \sqrt{(B_{H,i})^2 + (B_{V,i})^2}}{\sqrt{H^2 + V^2}} \times 100\%$$

where

- $G_H$  is the horizontal distance of the dot centre for the green channel from the centre of the image
- $G_V$  is the vertical distance of the dot centre for the green channel from the centre of the image
- $H$  is the number of output pixels in the horizontal direction
- $V$  is the number of output pixels in the vertical direction

The red and blue channels are named in an equivalent manner.

An example is shown in Figure 9.

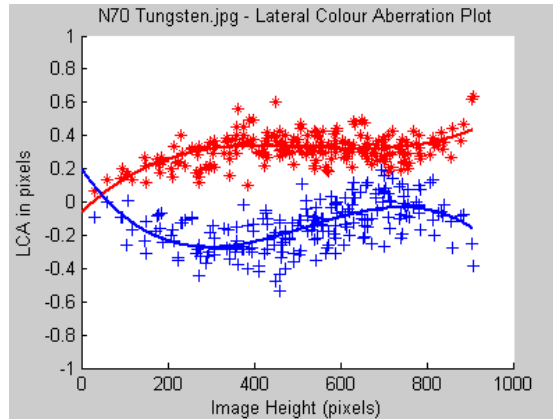


**Figure 9— Lateral chromatic displacement measurement. Each symbol represents, for a chart dot, the radial position difference of the R or B channel with respect to G as a function of the radial position of G. A third order polynomial fit is performed to smooth the data set.**

A best fit by a third order polynomial is computed as seen in Figure 9. The valid range for the fit is from the smallest dot center field position to the largest dot center field position.

The LCD objective metric is the worst case shift of either of the best fit curves for the red and blue color planes over the whole field, expressed as arcminutes.

### 6.3 Test conditions and methods

The camera, lighting, and charts must be configured as described in Clause 4. This test makes use of the dot chart under the  $5700\text{ K} \pm 1000\text{ K}$  illuminant condition. The specified illuminant shall have energy in all wavelengths, such that an image will have energy in all three primary color channels. This is necessary to ensure a complete measure of LCD.

#### 6.3.1 Image/camera settings

Set the camera at minimal gain (if possible), so as to minimize noise. White balance should be set to automatic. All special color modes or tone mode should be deactivated or set to automatic. Compression should be set to minimal (if possible).

#### 6.3.2 Influencing factors

Some camera settings or shooting parameters may influence the results and should be reported with the results.

- Focal length (for variable focal length lenses)
- Distance to the object

LCD intrinsically depends on wavelength. Therefore, the measurement is not only related to the optical properties of the lens but also depends on the spectral responses of the sensor. The illuminant used for the measurement also influences the result to some extent. It shall be reported for better repeatability.

### 6.3.3 Specific test procedures

The chart must fill the FoV. Therefore, the size and the spacing of the dots shall be adapted to the camera pixel count and FoV so that at least 300 dots with 10 pixel diameters are visible. The lens should be focused on the chart.

## 6.4 Analytical approach and presentation of results

The measurement consists of:

- Extracting the dots
- Determining precisely the position of the center of the dots for each color channel
- Plotting the difference of radial position of the dots on the red and blue channels, relatively to the green channel, as a function of the radial position of the green channel
- Fitting these profiles by a third order polynomial
- Reporting the worst case for either of the red and blue channels over the whole image field (whichever is worse) as arcminutes

The position of the dots is sensitive to noise and blur, because both degradations damage the dots boundary. Light and color shading also give some variability to dots detection. If LCD is very strong, the edges of the dots are also blurry (depending on the sensor spectral response), and this also decreases the measurement accuracy. An informative reference algorithm is proposed in Annex K.

## 6.5 Subjective evaluation

The final arbiter of image quality in any imaging application is the end user, and in the case of mobile devices, it is the consumer. Estimating or predicting the response of a typical mobile device user is the purpose of a subjective evaluation program. Three participating companies used their internal facilities and processes to perform subjective evaluations of images with various levels of LCD applied. The actual methods used are described in Annex A.

A suite of six high-quality pictorial images was used for the subjective testing, drawn from the ruler images of ISO 20462:2012. The images were selected to represent a range of sensitivity to the effects of LCD. Eight levels of LCD were applied to each image, resulting in nine test files (including the original) for each of the six scenes, 54 test files in all. The levels tested were 0, 0.5, 1, 1.5, 2, 3, 4, 5, and 6.5 pixels of LCA at 50% image height radial distance. For the image height of 816 pixels used in the subjective study, this represents 0, 0.06, 0.12, 0.18, 0.25, 0.37, 0.49, 0.61, and 0.80% of the image height, respectively.

Three companies each conducted subjective evaluations using the softcopy quality ruler method, or a modified version of it. The results were very similar, differing primarily in the error variance from having different numbers of observers. Pooling the results, weighted by the number of observers used, and fitting curves to the data, produced equations that can be used to estimate the degradation in subjective image quality due to LCD.

The subjective quality value for LCD shall be calculated using Equation (13) and shall be reported with the results. The experimental data used to derive this equation can be seen in Annex T.

$$QL = \begin{cases} 0 & LCD \leq 0.5654 \\ \frac{LCD - a}{b} - \frac{c \times \ln\left(1 + b \times \frac{LCD - a}{c}\right)}{b^2} & LCD > 0.5654 \end{cases} \quad (13)$$

where

$QL$  is the subjective QL for LCD  
 $LCD$  is the LCD in arc minutes  
 $a$  is the constant 0.5654  
 $b$  is the constant 0.3642  
 $c$  is the constant 0.1350

## 7. Chroma level

### 7.1 Introduction

Almost all of today's cameras capture color images and the saturation of the colors is one important quality aspect of those images. Saturation describes what is also called the purity of a color. This reaches from a neutral grey to a very strong or pure color. For artistic reasons the decrease of color saturation is sometimes intended but generally people like the colors in their images to be slightly more saturated than the original colors. This is the result of a study made by Aptina (Keelan, Jenkin, and Jin [B25]). As a result, most cameras used for conventional photography do not try to match the original colors but try to produce a pleasing image with colors shifted to a look that most people like. To reduce the complexity of the metric, chroma is used in place of more traditional definitions of saturation. Chroma is often used to indicate color intensity and is used in this standard as an approximation of saturation. This standard provides a measurement procedure for chroma level based on a test chart with known color values and the interpretation of this measurement derived from a psychophysical study. The further the results are from the aim point presented in the study the higher the QL reported as JND that becomes part of the overall camera quality analysis.

### 7.2 Test conditions and methods

#### 7.2.1 Apparatus and hardware

The following hardware is necessary to control and report the test conditions:

- An X-Rite Digital ColorChecker® SG target<sup>8</sup>
- Two light sources
- Luminance meter

<sup>8</sup> X-Rite Inc, Part #: MSDCCSG ([http://xritephoto.com/ph\\_product\\_overview.aspx?ID=938](http://xritephoto.com/ph_product_overview.aspx?ID=938)). This information is given for the convenience of users of this standard and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to the same results.

### 7.2.2 Lighting

The lighting arrangement should be configured as described in 4.3. Two illuminants are recommended for this test: D50 and D65.

These illuminants are provided for convenience. Any Standard D illuminant (Judd, et al [B22]) can be used that meets the conditions set by ISO 7589:2002. The light source used shall be reported with the results.

NOTE—This lighting specification is primarily recommended due to the subjective model. The provided model is only applicable under these light sources. It is possible to evaluate chroma level under other illuminants but only as an objective metric.<sup>9</sup>

### 7.2.3 Test chart

The X-Rite Digital ColorChecker® SG target features 140 color patches arranged in a 14 x 10 grid array. The individual color patches are identified to represent natural objects such as human skin tone, foliage, and blue sky. A genuine reproduction of the target should be obtained from the manufacturer to ensure accuracy of the test. The background surrounding the target should be a spectrally neutral, 18% gray wall.

### 7.2.4 Camera settings

Set the camera at minimal gain (if possible), so as to minimize noise. If available, white balance, exposure, and color saturation settings must be set to automatic. All special color modes or tone modes should be deactivated or set to automatic. Compression should be set to minimal (if available), or alternatively, image quality set to maximum (if available).

### 7.2.5 Influencing factors

Some camera settings or shooting parameters may influence the results and shall be reported with the results. These factors include the following:

- Illuminant
- Light level
- White balance mode

### 7.2.6 Specific test procedures

The target shall be centered within the image frame. It is recommended that the target occupies roughly one third of the vertical FoV to ensure balanced exposure metering, and each patch occupies a minimum of 8×8 pixel array. The remaining FoV shall be encompassed by a spectrally neutral, 18% gray wall.

An example of the recommended framing appears in Figure 10.

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<sup>9</sup> Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.



Figure 10—Example of recommended framing

## 7.3 Chroma level metric

### 7.3.1 Color target

#### 7.3.1.1 Target calibration

The required target for CPIQ is the X-Rite® Digital ColorChecker SG. It is recommended that reference data be measured from the target that appears in the image being analyzed. This data can be measured by using a spectrophotometer or spectroradiometer to collect CIEXYZ values for each patch. If acquiring reference data for the used target is not possible, using the reference data provided by X-Rite<sup>10</sup> is allowed.

#### 7.3.1.2 Patch subset

The Digital ColorChecker SG has 140 individual patches. There are a large number of neutral patches present on this target, which can skew the reported chroma. To prevent this, a subset of patches are used to calculate chroma level.

<sup>10</sup> [http://www.xrite.com/documents/apps/public/digital\\_colorchecker\\_sg\\_l\\_a\\_b.txt](http://www.xrite.com/documents/apps/public/digital_colorchecker_sg_l_a_b.txt)

The following patches shall be excluded from any measurement of the chroma level:

- A1 through A10
- B1, B10
- C1, C10
- D1, D10
- E1, E5, E6, E10
- F1, F5, F6, F10
- G1, G5, G6, G10
- H1, H5, H6, H10
- I1, I5, I6, I10
- J1, J5, J6, J10
- K1, K10
- L1, L10
- M1, M10
- N1 through N10

Figure 11 shows the excluded patches highlighted in red as they appear in the standard Digital ColorChecker SG design.

|    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | A1  | B1  | C1  | D1  | E1  | F1  | G1  | H1  | I1  | J1  | K1  | L1  | M1  | N1  |
| 2  | A2  | B2  | C2  | D2  | E2  | F2  | G2  | H2  | I2  | J2  | K2  | L2  | M2  | N2  |
| 3  | A3  | B3  | C3  | D3  | E3  | F3  | G3  | H3  | I3  | J3  | K3  | L3  | M3  | N3  |
| 4  | A4  | B4  | C4  | D4  | E4  | F4  | G4  | H4  | I4  | J4  | K4  | L4  | M4  | N4  |
| 5  | A5  | B5  | C5  | D5  | E5  | F5  | G5  | H5  | I5  | J5  | K5  | L5  | M5  | N5  |
| 6  | A6  | B6  | C6  | D6  | E6  | F6  | G6  | H6  | I6  | J6  | K6  | L6  | M6  | N6  |
| 7  | A7  | B7  | C7  | D7  | E7  | F7  | G7  | H7  | I7  | J7  | K7  | L7  | M7  | N7  |
| 8  | A8  | B8  | C8  | D8  | E8  | F8  | G8  | H8  | I8  | J8  | K8  | L8  | M8  | N8  |
| 9  | A9  | B9  | C9  | D9  | E9  | F9  | G9  | H9  | I9  | J9  | K9  | L9  | M9  | N9  |
| 10 | A10 | B10 | C10 | D10 | E10 | F10 | G10 | H10 | I10 | J10 | K10 | L10 | M10 | N10 |
|    | A   | B   | C   | D   | E   | F   | G   | H   | I   | J   | K   | L   | M   | N   |

**Figure 11—Digital ColorChecker SG excluded patch diagram**

### 7.3.2 Chroma level

The mean chroma level calculation is a percentage value of the ratio of mean chroma between measured data from a captured image and reference data. This calculation is performed in the CIELAB space and all data shall be transformed into that space.

Chroma is defined as the Euclidean distance of a color in CIELAB space from the  $L^*$  axis (most often represented as the Z-axis).

Once the measured data has been transformed into CIELAB space, mean chroma can be calculated by:

$$C_M = \frac{1}{N} \sum_{i=1}^N \sqrt{a_{Mi}^2 + b_{Mi}^2} . \quad (14)$$

$$C_R = \frac{1}{N} \sum_{i=1}^N \sqrt{a_{Ri}^2 + b_{Ri}^2} . \quad (15)$$

where

- $a_{Mi}$  and  $b_{Mi}$  are the CIELAB  $a^*$  and  $b^*$  values for the measured data at  $i$
- $a_{Ri}$  and  $b_{Ri}$  are the CIELAB  $a^*$  and  $b^*$  values for the reference data at  $i$
- $N$  is the number of CIELAB triplets
- $C_M$  is the mean chroma for the measured data
- $C_R$  is the mean chroma for the reference data

Finally, the chroma level ( $CL_{sg}$ ) can be calculated by:

$$CL_{sg} = \frac{C_M}{C_R} \times 100 . \quad (16)$$

where

$CL_{sg}$  is the chroma level

## 7.4 Subjective evaluation

Twelve high-quality pictorial images were used in the subjective evaluation study, drawn from the ruler images of ISO 20462:2012. The scenes were select to represent a range of sensitivity to the effect of color saturation treatment. Eight treatment levels of chroma difference were applied to each of the 12 images. Figure 12 shows the effect of color treatment using a Digital ColorChecker SG chart with four treatment levels.

Subjective evaluation was conducted by 34 observers using the softcopy quality ruler method described in Annex A [B25].

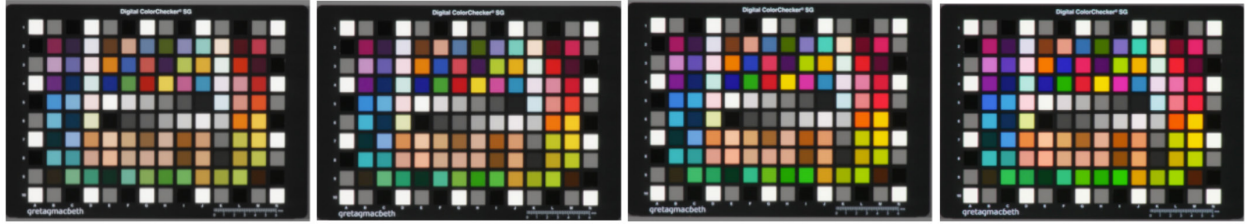


**Figure 12—Visual illustration of chroma level using the Digital ColorChecker SG images.  
Chroma level increases from left to right.**

The results of subjective evaluation can be seen in Annex T. Each data point was derived from the averaging of 408 ruler judgments made by 34 observers on 12 images, and represents the QL in JND due to chroma level deviating from the optimal position.

The QL model fitting results uses the following formula:

$$QL = k \times \left( 1 - e^{-\left( (a \times |CL_{sg} - p|)^r \right)} \right) \quad (17)$$

where

$QL$  is the subjective quality loss  
 $k$ ,  $a$ ,  $p$ , and  $r$  are constants defined in Table 6

**Table 6—Model fitting parameters for the chroma level QL equation**

| Constant | CLsg ≤ 102 | CLsg > 102 |
|----------|------------|------------|
| p        | 102        | 102        |
| a        | 0.0064     | 0.0402     |
| r        | 1.36       | 1.98       |
| k        | 38.3       | 6.22       |

## 8. Color uniformity

### 8.1 Introduction

Clause 8 describes how to measure the color uniformity of a camera and how it relates to subjective image quality evaluation.

Color variations within the image can be caused by several factors, all of which will cause varying degrees of non-neutrality within an ideal uniform, gray exposure. Some of the primary factors include an inaccurate match between the complementary metal–oxide–semiconductor (CMOS) microlens optical acceptance angle and the lens’s chief ray angle (CRA) over the FoV, spatially varying spectral transmittance differences from the infrared rejection filter (usually most significant at the cutoff wavelength), and inherent spectral sensitivity differences across the array. Consistent, systematic variations can be reduced through correction via image processing, but residual color variations may remain due to scene spectral variations and other factors.

The information that follows defines the recommended approach for creating a test scene to use for the evaluation of color non-uniformity, as well as specifying the conditions for illumination and exposure. The currently proposed analysis approach to quantify the magnitude of color variations is described, along with an indication of the subjective effects expected for varying degrees of the color non-uniformity. It is important to understand that this specification is related to the degree of color variation that is apparent in the image, not the specific color accuracy. Thus, an image that appeared pink but was uniformly pink over the entire image would be equivalent to a perfectly uniform gray field according to this color non-uniformity specification.

## 8.2 Test conditions and methods

### 8.2.1 Apparatus and hardware

The following hardware is necessary to control and report the test conditions:

- A uniform field target (reflective or transmissive, see 8.2.3)
- At least two light sources for a reflective target or a single light source for a transmissive target, providing an illumination with at least 92% uniformity
- Luminance meter

### 8.2.2 Lighting

The lighting should be configured as described in Clause 4 except with the tighter tolerances for uniformity described below. The two recommended sources for this test (a subset of those in 8.2.3.1) are:

- D55
- Tungsten incandescent according to ISO 7589:2002

Both daylight (D55) and tungsten incandescent light contain strong near infrared (NIR) contents, which can cause significant color shading during capture due to the characteristics of the IR-cut filter. Some cameras also exhibit noticeable color shading under fluorescent light sources, which can be caused by color shading correction in an image processing pipeline when an incorrect calibration profile is used. Additional fluorescent light sources may be used for testing color shading introduced by image processing operations.

### 8.2.3 Test chart

#### 8.2.3.1 Design and characteristics

The target should provide a spectrally neutral<sup>11</sup>, uniform luminance distribution over the entire imaged FoV. It can be either transmissive or reflective in design and should provide a uniformity of at least 92% (see 4.3.2) across the entire imaged area, with an average luminance no less than 50 cd/m<sup>2</sup> and a target level of 100 cd/m<sup>2</sup>.

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<sup>11</sup> Spectral neutrality is achieved if the relative spectral energy from the target does not vary by more than 5% over the range between 400 nm and 700 nm.

### 8.2.3.2 Reflective target (recommended)

The target material for a reflective target should be a high reflectance ( $>90\%$ ) matte surface to eliminate any surface “hot spots” or unwanted reflections. Use a luminance meter to verify that the average target luminance is between 50 and 100  $\text{cd/m}^2$ , and that the uniformity across the target is 92% or higher. A target containing dots as used for distortion and LCD measurement can also be used, provided a suitable procedure to ignore the dots is performed.

### 8.2.3.3 Transmissive target

If a transmissive target is used, the distance between target and camera should be at least 4 cm to avoid artifacts due to stray light, and to better simulate the operational illumination geometry. Placing the camera lens directly onto the light source is not recommended, as this procedure allows scattered rays to be collected that would not normally be focused onto the image plane. Reflections from the surroundings and camera on the target should be avoided by shielding the camera behind a black mask that is large enough to extend beyond the FoV.

To avoid scene non-uniformities appearing when a source is used together with a color correction filter, an additional opal diffuser may be used. For this situation, the filter is placed between the light source and the diffuser. The diffuser may be eliminated if it can be shown that the influence of the filter on the color non-uniformity is negligible. As with the reflective target, use a luminance meter in contact or spot mode to verify that the luminance at the opal diffuser surface is at least 100  $\text{cd/m}^2$  and the opal diffuser surface uniformity is 92% or higher within an area that fully encompasses the camera’s FoV.

### 8.2.4 Image/camera settings

At least two images should be captured, one for each light source (described in 8.2.2). These images should be saved at “full resolution” using the highest quality (least compression) setting.

The camera should be set for auto-exposure and the average gray value in the image shall be reported. If exposure tuning is available, exposure should be adjusted to give an average gray value between 110 and 130 (on a zero to 255 sRGB scale) or a  $L^*$  value of between 46 and 54.

### 8.2.5 Influencing factors

Influencing factors shall be reported with measurement results. The measurement depends on the illuminant and the chosen reference white point for computing CIELAB coordinates.

## 8.3 Analytical approach and presentation of results

For analysis, the image is divided into  $20 \times 15$  blocks of pixels for 4:3 aspect ratio,  $24 \times 16$  blocks for 3:2 aspect ratio, and  $32 \times 18$  blocks for 16:9 aspect ratio. Pixels within one block are averaged. The resulting image data (typically in RGB format) is converted to the CIELAB color space (see Annex I for a description of how to perform the conversion). The absolute value of the reference white point can be taken; e.g., to  $Y=100$ . The value shall be reported in the measurement.

Analysis of the color shading is performed by first calculating the average  $a^*(i)$  and  $b^*(i)$  coordinates of the  $i^{\text{th}}$  block of pixels, and then computing the overall average  $\bar{a}$  and  $\bar{b}$  for the entire image using the block averages. The deviation of the  $i^{\text{th}}$  block is defined by: