INTERNATIONAL STANDARD

ISO/IEC 29158

First edition
2020-12

Information technology — Automatic identification and data capture techniques — Direct Part Mark (DPM) Quality Guideline

Technologies de l'information — Techniques automatiques d'identification et de capture de données — Ligne directrice de qualité du marquage direct sur pièce (DPM)

Reference number
ISO/IEC 29158:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

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

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

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Joint Technical Committee ISO/TC JTC 1, *Information Technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

This first edition cancels and replaces ISO/IEC TR 29158:2011, which has been technically revised.

The main changes compared to the previous edition are as follows:

— inclusion of continuous grading;

— expanded grading levels for minimum reflectance (R_{target});

— inclusion of a tilted lighting and camera position;

— reorganized proposed lighting options.

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

Introduction

Direct Part Marking (DPM) is a technology whereby, generally, an item is physically altered to produce two different surface conditions. This alteration can be accomplished by various means including, but not limited to, dot peen, laser mark, ink jetting, and electro-chemical etch. The area of the alteration is called "the mark." The area that includes the mark and background as a whole, when containing a pattern defined by a bar code symbology specification, is called "a symbol."

When light illuminates a symbol, it reflects differently depending on whether it impinges on the background of the part or on the physical alteration. In most non-DPM bar code scanning environments, light is reflected off a smooth surface that has been coloured to produce two different diffuse reflected states. The DPM environment generally does not fit this model because the two different reflected states depend on at least one of the states having material oriented to the lighting such that the angle of incidence is equal to the angle of reflection. Sometimes the material so oriented produces a specular (mirror like) reflectance that results in a signal that is orders of magnitude greater than the signal from diffuse reflectance.

In addition, from the scanner point-of-view, some marking and printing methods generate dots and are not capable of producing smooth lines. This is important for symbologies such as Data Matrix, which is specified to contain smooth continuous lines, but can be marked with disconnected dots in DPM applications.

Current specifications for matrix symbologies and two-dimensional print quality are not exactly suited to reading situations that have either specular reflection or unconnected dots or both. Additionally, symbologies specified to consist of smooth continuous lines may appear with unconnected dots. This is intended to act as a bridge between the existing specifications and the DPM environment in order to provide a standardized image-based measurement method for DPM that is predictive of scanner performance.

As with all symbology and quality standards, it is the responsibility of the application to define the appropriate parameters of this guideline for use in conjunction with a particular application.

Information technology — Automatic identification and data capture techniques — Direct Part Mark (DPM) Quality Guideline

1 Scope

This document is an engineering document intended for verifier manufacturers and application specification developers.

This document describes modifications to the symbol quality methodology defined in ISO/IEC 15415 and a symbology specification. It defines alternative illumination conditions, some new terms and parameters, modifications to the measurement and subsequent grading of certain parameters and the reporting of the grading results.

This document was developed to assess the symbol quality of direct marked parts, where the mark is applied directly to the surface of the item and the reading device is a two-dimensional imager.

When application specifications allow, this method is also potentially applicable to symbols produced by other methods. This is appropriate when direct part marked (DPM) symbols and non-DPM symbols are being scanned in the same scanning environment. The symbol grade is reported as a DPM grade rather than as an ISO/IEC 15415 grade.

2 Normative references

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

ISO/IEC 15415, *Information technology — Automatic identification and data capture techniques — Bar code symbol print quality test specification — Two-dimensional symbols*

ISO/IEC 19762, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19762 and ISO/IEC 15415 and the following apply.

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

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

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

3.1
reference symbol
high-contrast printed calibration card for which results are traceable back to national or international standards and for which the supplier supplies a calibration certificate

3.2
stick
line segment comprised of image pixels that is used to connect areas of the same colour that are near to each other

4 Symbols and abbreviated terms

CM cell modulation

CC cell contrast

CMOD cell module modulation

FPD fixed pattern damage

M_D mean of the grid-centre point histogram of the dark elements

M_L mean of the grid-centre point histogram of the light elements

M_{Lcal} mean of the light lobe from a histogram of the calibrated standard

$M_{Ltarget}$ mean of the light lobe from the final grid-point histogram of the symbol under test

R_{cal} reported reflectance value, R_{max}, from a calibration standard

R_{target} measured percent reflectance of the light elements of the symbol under test relative to the calibrated standard

NOTE R_{target} is graded and reported as the parameter named "Minimum Reflectance".

S_{Rcal} system response parameters (such as exposure and/or gain) used to create an image of the calibration standard

$S_{Rtarget}$ system response parameters (such as exposure and/or gain) used to create an image of the symbol under test

T_1 threshold created using a histogram of the defined grey scale pixel values in a circular area 20 times the aperture size in diameter, centred on the image centre using the algorithm defined in Annex A

T_2 threshold created using the histogram of the reference grey scale image pixel values at each intersection point of the grid using the method defined in Annex A

T_{min} current minimum threshold in the calculation of the optimal threshold according Annex A

T_{max} current maximum threshold in the calculation of the optimal threshold according Annex A

TCL tilted coaxial lighting and camera position

5 Overview of methodology

5.1 Process differences from ISO/IEC 15415

All parameters in the symbology and print quality specifications apply except for:

— a different method for setting the image contrast;

— a different method for creating the binary image;

— a new method for choosing the aperture size;

— an image pre-process methodology for joining disconnected modules in a symbol (where applicable);

— a different process for determining the modulation and reflectance margin parameter renamed cell modulation (CM);

— a different process for determining the symbol contrast parameter which has been renamed cell contrast (CC);

— a different process for computing FPD;

— A new parameter called minimum reflectance (R_{target}).

Axial nonuniformity, grid nonuniformity and unused error correction are applied with their continuous grading grades as defined in Annex C, so long as ISO/IEC 15415 does not provide information on continuous grading for these parameters. If/when ISO/IEC 15415 does provide continuous grading on these parameters, that information will be used. This document explains how to both specify and report quality grades in a manner complementary to, yet distinct from, the method in ISO/IEC 15415.

NOTE Annex F gives a cross reference comparison of this document to ISO/IEC15415.

5.2 Lighting

Lighting environments shall be reported according to 6.2 and 10.2. The lighting environment(s) shall be selected by the application standard in consideration of the properties of the mark and the requirements of the reading equipment and environment of the application.

5.3 Tilted coaxial lighting and camera position (TCL)

TCL is useful for DPM applications that use a geometrical mark which is peened, drilled or carved into a surface. Reading camera and unidirectional illumination are located at a coaxial position with a known fixed tilt angle and object rotation angle and position.

To read dot-peened codes, there are multiple reading setups possible. This document defines several camera and lighting setups in order to address various dot peen geometries.

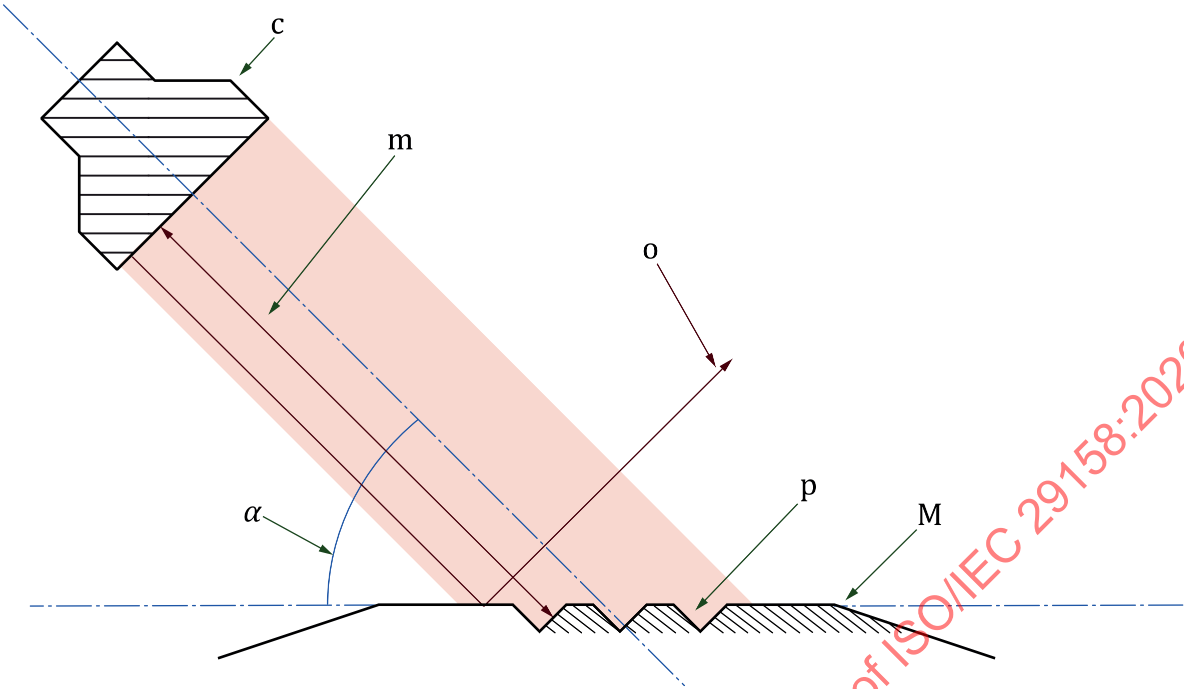
This specific TCL environment is focussing on the system response of the mark (e.g. the image a camera sees). SAE Standard AS9132[2] takes a different approach to specify the mark geometry.

Figure 1 illustrates the setup. The essential parameter is the camera reading angle. Typical camera reading angles include 30°, 45° or 60° in relation to the plane of the mark.

NOTE 1 The camera angle is defined in a compatible way to the lighting angle of ISO/IEC 15415:2011, Figure 3.

NOTE 2 Within the dot peen industry, it is common to specify the stylus angle which is twice the camera angle given in Figure 1.

NOTE 3 In practice, the condition "coaxial lighting" may be implemented by an approximate setup like a high distance ring. The light angle tolerance of ±3° should be respected.



Key

c camera and coaxial lighting
m light beam in mark is reflected to camera
o light beam outside mark is reflected away
α camera reading angle
p peened mark
M marked object

Figure 1 — Tilted coaxial lighting and camera setup

This setup is referenced by the abbreviation "TCL" in the following text.

It is not feasible to grade this setup with a camera angle of 90°. The result will not be significant for this application, as other features of the marked object are measured.

Note that a general-purpose verifier device may not cover this application, as it requires a special construction.

6 Obtaining the image

6.1 Camera position and symbol orientation

6.1.1 Symbol placement

Camera to object position is described in this subclause. By default, the horizontal and vertical axis of the symbol are parallel to a line formed by the edge of the image sensor within ±3° (i.e. nominally no rotation). This symbol orientation should be maintained unless an application specification requires or allows a different orientation. An application specification may specify a different symbol rotation. Since the symbol rotation is determined after decoding, the actual rotation angle should be reported so that the setup can be reproduced easily. In applications in which the rotation angle is specified, the rotation angle shall be reported to confirm conformance to specified requirements.

The part is placed such that the symbol is in the centre of the field of view.

6.1.2 Camera position in a 90 ° camera angle set up

The camera is positioned such that the plane of the image sensor is parallel to the plane of the symbol area. This is identical to a 90° camera angle.

6.1.3 TCL setup

Within the TCL setup, camera and symbol position differs in the following points.

— The camera is positioned in the camera angle defined by the application.

— The raw image is geometrically transformed to correspond to a test image with a virtual camera position with a 90° camera angle, as described in Annex B.

— The symbol rotation angle needs to be specified by the application and shall be respected by ± 5°.

6.2 Lighting environments

6.2.1 General

The lighting environment is specified by the application. This shall include a direction specifier or an angle or both. The format is an extension of the angle specifier used in ISO/IEC 15415. Several examples are given in the following subclauses.

6.2.2 Perpendicular coaxial (90)

The symbol is illuminated with diffuse light such that the specular reflection from the entire field of view is nominally uniform.

6.2.3 Diffuse off-axis (D)

A diffusely reflecting dome is illuminated from below so that the reflected light falls non-directionally on the part and does not cast defined shadows. This is commonly used for reading curved parts. The angle specifier shall be D.

This lighting is also called dome lighting.

6.2.4 Four direction (angle Q)

Light is aimed at the part at the given angle ±3° from the plane of the surface of the symbol from four sides such that the lines describing the centre of the beams from opposing pairs of lights are co-planar and the planes at right angles to each other. One lighting plane is aligned to be parallel to the line formed by a horizontal edge of the image sensor to within ±5°. The lighting shall illuminate the entire symbol area with nominally uniform energy. The angle specifier shall be angle "Q".

EXAMPLE 45Q (angle equal to 45°) or 30Q (angle equal to 30°).

6.2.5 Two direction (angle T)

Light is aimed at the part at the given angle ±3° from two sides. The light may be incident from either of the two possible orientations with respect to the symbol. The lighting plane is aligned to be parallel to the line formed by one edge of the image sensor to within ±5°. The lighting shall illuminate the entire symbol area with nominally uniform energy. The angle specifier shall be angle "T".

EXAMPLE 45T (angle equal to 45°) or 30T (angle equal to 30°).

Since there are two possible orientations in this setup (above and below, and left and right) the particular orientation actually used should be reported. The reporting method may be to indicate the location of the lights with respect to the symbol such as “north-south” when the light is incident from above and below the natural "top" and "bottom" of a symbol. The orientation of a symbol is known after decoding and related to the normal orientation of a symbol as specified in its symbology specification (e.g. a Data Matrix symbol's natural orientation has the solid borders on left and bottom, and for QR code the normal orientation has finder patterns in the upper left, lower left and upper right corners but not lower right corner.)

6.2.6 One direction (angle S)

Light is aimed at the part at the given angle ±3° from one side. The light may be incident from any of the four possible orientations with respect to the symbol. The plane perpendicular to the symbol surface containing the centre of the beam is aligned to be parallel to the line formed by one edge of the image sensor to within ±5°. The lighting shall illuminate the entire symbol area with nominally uniform energy. The angle specifier shall be angle S. Since there are four possible orientations in this setup, the particular orientation of the incident illumination should be reported based on the symbol orientation determined after decoding, with respect to the symbol's normal orientation (see 6.2.5). For example, if a symbol is upside down, and the illumination is incident from below the symbol, such that the illumination is actually oriented toward the "top" of the symbol, then the incident light should be reported as "North".

EXAMPLE 45S (angle equal to 45°) or 30S (angle equal to 30°).

6.2.7 TCL Setup

TCL setup uses coaxial light at the camera reading angle. Light is aimed at the camera reading angle with a tolerance of ±3°. The lighting shall illuminate the entire symbol area with nominally uniform energy.

Typical lighting setups are 30° (30CS), 45° (45CS) or 60° (60CS). The angle specification has an added "C" to indicate the coaxial camera position.

NOTE A camera angle of 90° is not a TCL setup (not tilted). In consequence, a specification of "(90CS)" is not allowed.

6.3 Image focus

The camera is adjusted such that the symbol is in best focus.

6.4 Depth of field

Non-planar surfaces or a TCL setup may require a depth of field range. The condition given in ISO/IEC 15415:2015, 7.3.3 should be fulfilled for the whole depth of field range.

6.5 System response adjustment and reflectance calibration

System response recording is a task performed prior to the use of an instrument. It shall be repeated in regular intervals together with the regular adjustment of an instrument.

Capture an image of the reference symbol (test code on a calibration card, see 3.1). On such a card, a symbol which achieves a SC grade of 4 shall be used. Using an aperture size of 80 % in relation to the test code module size, sample the centre of every element in the symbol including quiet zone and and set the system response so that the mean of the light elements is in the range of 70 % to 86 %, nominally 78 %, of the maximum grey scale, and the black level (no light) is nominally equal to zero. The system response is the nominally linear relationship between the reflectivity of the target and the pixel intensity values in the image as a result of several factors (e.g. shutter speed, imager sensitivity, f-stop, gain, illumination intensity). This procedure requires the ability to adjust at least one of these factors in order to adjust the system response.

Record the system response as the reference system response (S_{Rcal}) and record M_{Lcal}.

NOTE This procedure is not used for lighting configuration 90.

7 Verifying a symbol

7.1 Initial image reflectance

7.1.1 General

The reference grey scale image is created by the following steps.

7.1.2 Initialize aperture size

The minimum and maximum X-dimensions should be specified by the application standard and used by the verifier in this and subsequent steps. Set the aperture to 0,5 of the minimum X-dimension of the application and apply it to the image to create a reference grey scale image.

7.1.3 Create initial histogram

Create a histogram of the reference grey scale pixel values in a circular area 20 times the aperture size in diameter, centred on the image centre, and find the Threshold, T_1, using the algorithm defined in Annex A.

The threshold divides the histogram into two portions: a portion below the threshold which contains dark pixels and a portion above the threshold which contains light pixels (called the “light lobe”).

NOTE If the circular area of 20 times of the aperture size is larger than the field of view of a real device, then the area is limited by the field of view.

7.1.4 Compute mean

Compute the mean of the light lobe.

7.1.5 Optimize image

Adjust the system response by taking new images and repeating steps 7.1.2 and 7.1.3 until the mean of the light elements is 78 % reflectance of the maximum grey scale. A tolerance of ±8 is acceptable for the mean value of the light elements. This results in a range from 70 % to 86 % for system response.

7.2 Obtaining the test image

7.2.1 Matrix symbologies

Matrix symbologies are specified in different appearances. Some are specified to consist of separate, unconnected dots. The reference decode of such symbologies takes care of handling these separated dots. Other symbologies are specified to consist of continuous connected matrix cells. Some marking technologies are not capable of producing such symbols with smooth, continuous lines. Therefore, they appear also with unconnected dots (e.g. if marked by a dot peen process). In this specific case the code image is pre-processed to connect the unconnected dots (see Annex D). After this pre-process the standard reference decode algorithm is applied.

Once the grid of the symbol is determined, the location information is transferred to the evaluation of the reference grey scale image and subsequent processing occurs using the reference grey scale image.

7.2.2 Binarize image

Compute a reference grey scale image using the current aperture size. Using T_1, binarize the entire image.

7.3 Apply Reference Decode Algorithm

7.3.1 General

Attempt to find and process the symbol using the symbology Reference Decode Algorithm and the current aperture size.

If a dot code symbol is detected for which no dot reference decode algorithm exists apply the dot connecting algorithm in Annex D. On a successful attempt, go to 7.4.

NOTE Where a symbology has a reference decode algorithm that operates successfully on nominally disconnected modules (e.g., “dot” codes) the process of connecting modules is inappropriate. With these symbologies, if the application of the Reference Decode Algorithm fails then go to 7.3.2 (not Annex D).

7.3.2 Repeat if necessary

If the decode attempt fails, increase the aperture size by 1/10th of the X dimension range allowed in the application and go to 7.2.1. Stop if the aperture size exceeds the largest X dimension.

7.3.3 Continue until end

Continue until the symbol is successfully decoded or all aperture sizes are tested. If the symbol is not decoded, the symbol grade is Zero.

7.4 Final image adjustment

7.4.1 General

This procedure uses only the nominal centres of modules to create a highly bi-modal histogram of the symbol reflectance states.

7.4.2 Determine grid-point reflectance with two apertures

Re-compute the reference grey scale image using two new aperture sizes equal to 0.5 and 0.8 of the measured average grid spacing. Perform the following calculations and grading for both apertures.

7.4.3 Create a grid-point histogram

Create a histogram of the reference grey scale image pixel values at each intersection point of the grid determined from the decode and find T_2 using the algorithm defined in Annex A.

7.4.4 Measure mean light (M_L)

Measure the mean light of the grid-centre point histogram. If it is 78 % (reflectance) of the maximum grey scale (e.g. 255 for an 8-bit image) then retain the values for mean dark (M_D) and mean light. A tolerance of ±8 is acceptable for the mean light reflectance value. This results in a range from 70 % to 86 % for mean light.

If not, adjust the system response and go to 7.4.2.

NOTE The measurement algorithm for mean light (M_L) and mean dark (M_D) is described in Annex A.

7.4.5 Record parameters

Set $M_{Ltarget}$ equal to mean light (M_L). Record the system response as $\mathbf{S}_{Rtarget}$. Record the new T_2.

7.4.6 Create binarized images for the symbology reference decode

If the dot connecting algorithm in Annex D is to be used in this step 7.4.7, then set the stick size to the average grid spacing and apply the dot connecting algorithm using T_2 on the new reference grey scale image to create the final binarized image. Otherwise, binarize using T_2.

7.4.7 Decode

Decode the final binary image using the steps of 7.3 through 7.4.7 using the symbology reference decode algorithm without applying the dot connecting algorithm.

If the dot connecting algorithm is applicable to the symbology, repeat the decode and the following steps with dot connecting algorithm applied.

NOTE The Data Matrix reference decode algorithm contains a process of searching for clock tracks and quiet zones using minimum and maximum values of transition counts, which thus shall be taken from these two different binarized images separately.

Recalculate T_2 using the grid centres of this decode.

8 Determine contrast parameters

8.1 Initialize aperture size

Calculate the following parameters using the T_2 value and grid centres of 7.4.7.

8.2 Calculate cell contrast (CC)

Calculate CC using Formula (1), referencing the algorithm found in Annex A:

$$C_c = (M_{\text{Ltarget}} - M_D) / M_{\text{Ltarget}} \qquad (1)$$

where C_c is the cell contrast (CC).

8.3 Calculate cell module modulation (CMOD)

Calculate CMOD using the Formula (2):

$$\text{If } (R < T_2) \text{ then } \mathbf{C}_{\text{MOD}} = (T_2 - R) / (T_2 - M_D) \text{ Else } \mathbf{C}_{\text{MOD}} = (R - T_2) / (M_{\text{Ltarget}} - T_2) \qquad (2)$$

where

R is the measured reflectance of the cell;

C_{MOD} is the cell module modulation (CMOD).

8.4 Calculate minimum reflectance (R_{target})

Calculate Minimum Reflectance (R_{target}) using Formula (3):

$$R_{\text{target}} = R_{\text{cal}} \text{ x } (S_{\text{Rcal}} / \mathbf{S}_{\text{Rtarget}}) \text{ x } (M_{\text{Ltarget}} / M_{\text{Lcal}}) \qquad (3)$$

When the lighting is "/90" (specular reflectance), S_{LRCal} and M_{Lcal} are not defined. See 9.2.

9 Grading

9.1 Cell contrast (CC)

The grade levels for cell contrast grading are given in Table 1.

Table 1 — Grade levels of cell contrast

CC %	Grade
≥30	4.0
25	3.0
20	2.0
15	1.0
<=10	0.0

The grade shall be computed as a linearly interpolated value, rounded to the nearest 0.1 in between grade levels.

For example, a Cell Contrast Value of 21 % gets a grade of 2.2 and a Cell Contrast value of 13 % gets a grade of 0,6.

The grade may be evaluated from the cell contrast value using Formulae (4), (5) and (6):

$$C_c \geq 30\ \%\text{: Grade} = 4.0 \tag{4}$$

$$10\ \% < C_c < 30\ \%\text{: Grade} = \text{round10}(\ (20 \times C_c) - 2) \tag{5}$$

$$C_c \leq 10\ \%\text{: Grade} = 0.0 \tag{6}$$

where C_c is the cell contrast (CC).

See Annex C.4 for a definition of the round10() function.

NOTE With an 8-bit grey scale sensor, 15 % is equal to a difference of 30 grey scale values.

9.2 Minimum reflectance (R_{target})

The grade levels for minimum reflectance grading are given in Table 2.

Table 2 — Grade levels of minimum reflectance

R_{target} %	Grade
≥20	4.0
15	3.5
10	2.5
5	1.5
=0	0.0

The grade shall be computed as a linearly interpolated value, rounded to the nearest 0.1 in between grade levels.

For example, a R_{target} Value of 13 % gets a grade of 3.1 and a R_{target} value of 3 % gets a grade of 0.9.

The continuous grade may be evaluated from the minimum reflectance value using Formulae (7), (8), (9), (10) and (11):

$$R_{target} \geq 20\ \%\text{: Grade} = 4.0 \tag{7}$$

$$15\ \% \leq R_{target} < 20\ \%\text{: Grade} = \text{round10}(10 \times R_{target} + 2) \tag{8}$$

$$5\ \% \leq R_{target} < 15\ \%\text{: Grade} = \text{round10}(20 \times R_{target} + 0{,}5) \tag{9}$$

$$0\ \% < R_{target} < 5\ \%\text{: Grade} = \text{round10}(30 \times R_{target}) \tag{10}$$

$$R_{target} = 0\ \%\text{: Grade 0.0} \tag{11}$$

See Annex C.4 for a definition of the round10() function.

When the lighting is "/90", R_{target} is not determined. R_{target} is then either not reported or reported as n/a (not applicable).

9.3 Cell modulation (CM)

The ISO/IEC 15415 Modulation and Reflectance Margin parameters are replaced with CM.

CM calculation follows the method for modulation of ISO/IEC 15415, with the following modifications.

— The value CMOD defined in 8.3 of this document is used instead of the ISO/IEC 15415 value MOD.

— The grade level for CMOD is identical to the grades given by the formula in ISO/IEC 15415 and set to 0 if the module is decoded as error.

Continuous grading as described in Annex C shall be applied to "MOD or MARGIN" and "UEC", as long as ISO/IEC 15415 does not implement continuous grading. For CMOD continuous grading applies always.

9.4 Fixed pattern damage (FPD)

Calculate FPD as described in ISO/IEC 15415 and the symbology specifications, except:

— use the threshold T_2 for the modulation overlay;

— when determining the average grade of the segments, use the average of the notional damage grade at the 1.0 grade level;

— rename average grade as "distributed damage grade";

— use result of dot connecting algorithm for all features of the symbol that are defined to be continuous, such as solid borders and interior solid segments of data matrix finder pattern, but use the unconnected binarized image for features that are not normally continuous, such as clock tracks.

The data matrix reference decode algorithm contains a process of searching for clock tracks and quiet zones using minimum and maximum values of transition counts, which thus shall be taken from these two different binarized images separately.

NOTE 1 The transition ratio test for data matrix should correspondingly use these two separate binarized images.

NOTE 2 Continuous grading is applied as described in Annex B if not implemented in ISO/IEC 15415 or the symbology specification.

9.5 Final grade

Select the best of the results obtained from the two different apertures and the decode with and without the dot connecting algorithm (if applicable) and use the associated image and parameters for the remainder of the grading calculations from ISO/IEC 15415. If there are multiple best choices, select first the decode without the dot connecting algorithm and then the aperture size of 0,8 X.

10 Communicating grade requirements and results

10.1 General

This section discusses the method of signalling grading requirements to the maker of the mark and for reporting the resulting grade to the customer. Depending on the requirements of the application specification, one or more grades for each part may be required. See Annex E.

10.2 Communication of application requirements

The application shall specify a range of X-dimensions (in mils), taking into consideration that large X-dimensions will facilitate greater surface texture. For example, for an application that has a range of X of 10 to 20 mils, the grade requirement is communicated as /10-20/ in place of the aperture size.

The application shall specify the minimum accepting passing grade.

Lighting requirements are communicated as described in 6.2.

The following multiple lighting options may be used:

— Lighting is specified using the separator "|" to designate "or" and the separator "&" to designate "and". Each lighting option is measured independently.

EXAMPLE 1 (30Q|90): the application allows 30Q or 90 lighting to fulfil the requirement.

(30Q&90): the application requires two verifications to pass, one measured with 30Q and the other with 90 lighting.

Lighting angle is reported as the single angle that was used to determine the grade. If the requirement is for more that one angle, then at least the lowest grade shall be reported or optionally one grade reported for each angle.

EXAMPLE 2 A specification of the acceptance criteria of DPM 2.0/05-10/660/(45Q&90) means that each verification shall pass with a 2.0 grade or better with each of the specified lightings and the symbol X dimension range shall be between 0,125 and 0,25 mm.

A specification of DPM 2.0/05-10/660/(45Q | 90) means that either verification with 90 or with 45Q shall pass but not necessarily both.

10.3 Communicating from verifier to application

Grades reported according to this guideline shall be prefaced with "DPM". With the preface of "DPM", the grade, aperture size and light colour are reported in the same way as defined in ISO/IEC 15415, however lighting angle and orientation are communicated as described in 6.2.

The verifier report shall indicate whether the result was obtained with or without the use of the dot connecting algorithm.

10.4 Communicating the use of a proprietary decode

When a proprietary decode is used, the rest of the metrics shall follow the requirements of this document.

When a proprietary decode is used, it shall be clearly reported in the grade report. For example, the verifier shall report a grade of 0 (zero) for decode and may report the other measurements of this guideline.

When a proprietary decode is allowed, it shall be clearly stated in the application specification.

NOTE When a proprietary decode is used, the sampling points for the remaining metrics can differ from verifier to verifier.

Annex A
(normative)

Threshold determination method

A.1 Algorithm description

Start by creating a histogram of the defined grey scale values in the defined region and proceed as follows.

1) Initialize the variable V_{min} to a very large number and initialize T_{min} and T_{max} to zero.

2) For every grey scale value, "t", starting from the lowest grey scale value to the highest grey scale value (0 to 255 for an 8-bit image sensor).

   a) Compute the mean and variance of pixels below t and call it M_{D} (mean dark) and $\mathbf{V}_{\mathrm{D}}$ (dark variance).

   b) Compute the mean and variance of pixels above or equal to t and call it M_{L} (mean light) and V_{L} (light variance).

   c) Compute variance $V = V_{\mathrm{L}} + V_{\mathrm{D}}$.

   d) If $V < V_{\mathrm{min}}$, save V in V_{min} and save t in T_{min}.

   e) If $V = V_{\mathrm{min}}$ save t in T_{max}.

   NOTE Step e) is used to break ties. T_{min} is the smallest grey-level where the variance is the minimum and T_{max} is the largest grey-level where the variance is the same minimum.

3) Optimal threshold $T = (T_{\mathrm{min}} + T_{\mathrm{max}}) / 2$.

A.2 Example

For simplicity, an image with only 100 pixels (a 10 × 10 image) will be used. Additionally, for the purpose of the example, the image is composed of 4-bit pixels (16 grey levels). The sample image is shown in Figure A.1, where each pixel is magnified so that individual pixels can be discerned.

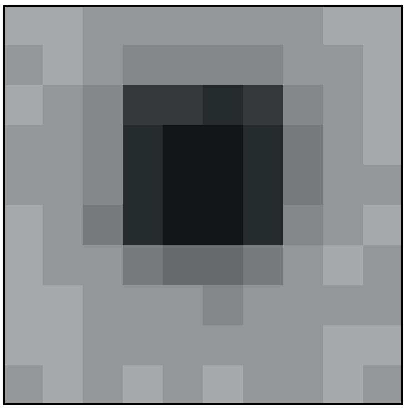


Figure A.1 — Image used in this example

We begin by counting how many pixels are contained in the image with each of the 16 grey levels. The result of this count is shown in Table A.1, and is plotted as a histogram in Figure A.2.

Table A.1 — Count of grey level occurrences

Grey level	Number of pixels with grey level
0	0
1	0
2	6
3	7
4	3
5	0
6	0
7	2
8	5
9	10
10	44
11	23
12	0
13	0
14	0
15	0

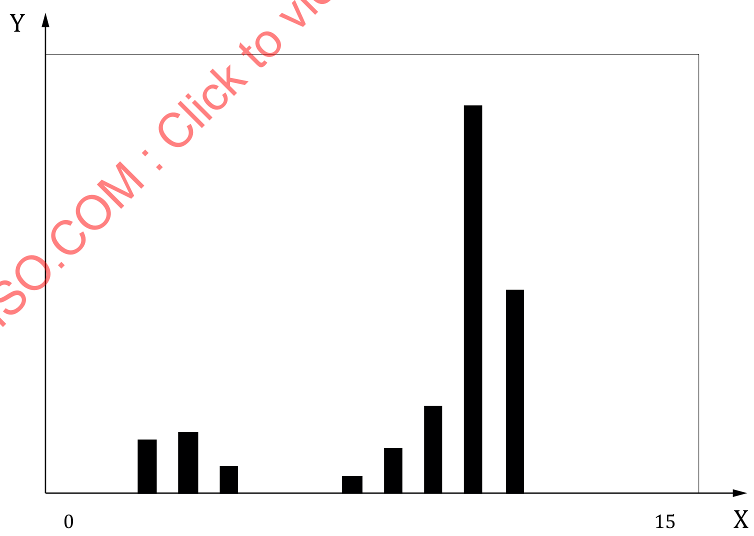


Figure A.2 — Histogram of the data from Table A.1

For each possible threshold, the histogram is separated into two portions – one for the dark elements and one for the light elements. The first possible threshold is between 0 and 1, the next is between 1 and 2, and so on. For each possible threshold, compute the variance of both portions of the histogram.

For example, for the possible threshold between 4 and 5, the dark element histogram contains the grey levels 0, 1, 2, 3 and 4 as shown in Table A.2.

Table A.2 — Dark pixel portion for threshold of 4.5

Grey level	Number of pixels with grey level
0	0
1	0
2	6
3	7
4	3

The variance of this distribution is calculated as follows:

The mean is ((2 × 6) + (3 × 7) + (4 × 3)) ÷ 16 = 2.81, which can be described as the weighted average of Table A.2.

The variance is the average of the square of each element's deviation from the mean:

$(([2.81 - 2]^2 \times 6) + ([2.81 - 3]^2 \times 7) + ([2.81 - 4]^2 \times 3)) \div 16 = .53$

Similarly, the variance of the light elements (those whose pixel value is 5 or greater) is: 0.84

Likewise, the variances of the dark and light portions of the histogram for each threshold can be computed. The results are shown in Table A.3

Table A.3 — List of variances for all possible thresholds

Threshold	Variance of dark elements	Variance of light elements	Sum of variances
0.5	0.00	7.67	7.67
1.5	0.00	7.67	7.67
2.5	0.00	5.00	5.00
3.5	0.25	2.00	2.25
4.5	0.53	0.84	1.37
5.5	0.53	0.84	1.37
6.5	0.53	0.84	1.37
7.5	2.20	0.65	2.85
8.5	5.52	0.40	5.92
9.5	8.50	0.23	8.73
10.5	8.11	0.00	8.11
11.5	7.67	0.00	7.67
12.5	7.67	0.00	7.67
13.5	7.67	0.00	7.67
14.5	7.67	0.00	7.67
15.5	7.67	0.00	7.67

An optimum threshold is chosen such that the sum of variances of both portions of the histogram is minimized. As can be seen from Table A.3, the minimum of the sum of variances is 1.37 which occurs at thresholds 4.5, 5.5, and 6.5. There is a range of thresholds that all give this minimum variance. In this case take the average of the lowest and highest threshold which give this minimum, which is 5.5 in this example.

Note that the threshold obtained by this averaging will not necessarily have the same minimum sum of variances as it does in this example. If there is a single threshold which gives the minimum sum of variances, then take that threshold. This chosen threshold is considered the "optimum" threshold as determined by the algorithm in A.1, because it results in two separate portions of the overall histogram, which are assumed to be most representative of two groups of elements (dark and light).

NOTE The portion of the histogram to the right of the threshold is called the "light lobe".

When the image is binarized using the calculated threshold, the result is shown as in Figure A.3.

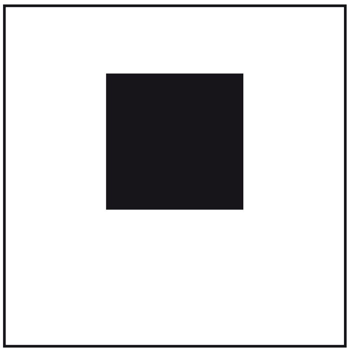


Figure A.3 — Image with threshold applied

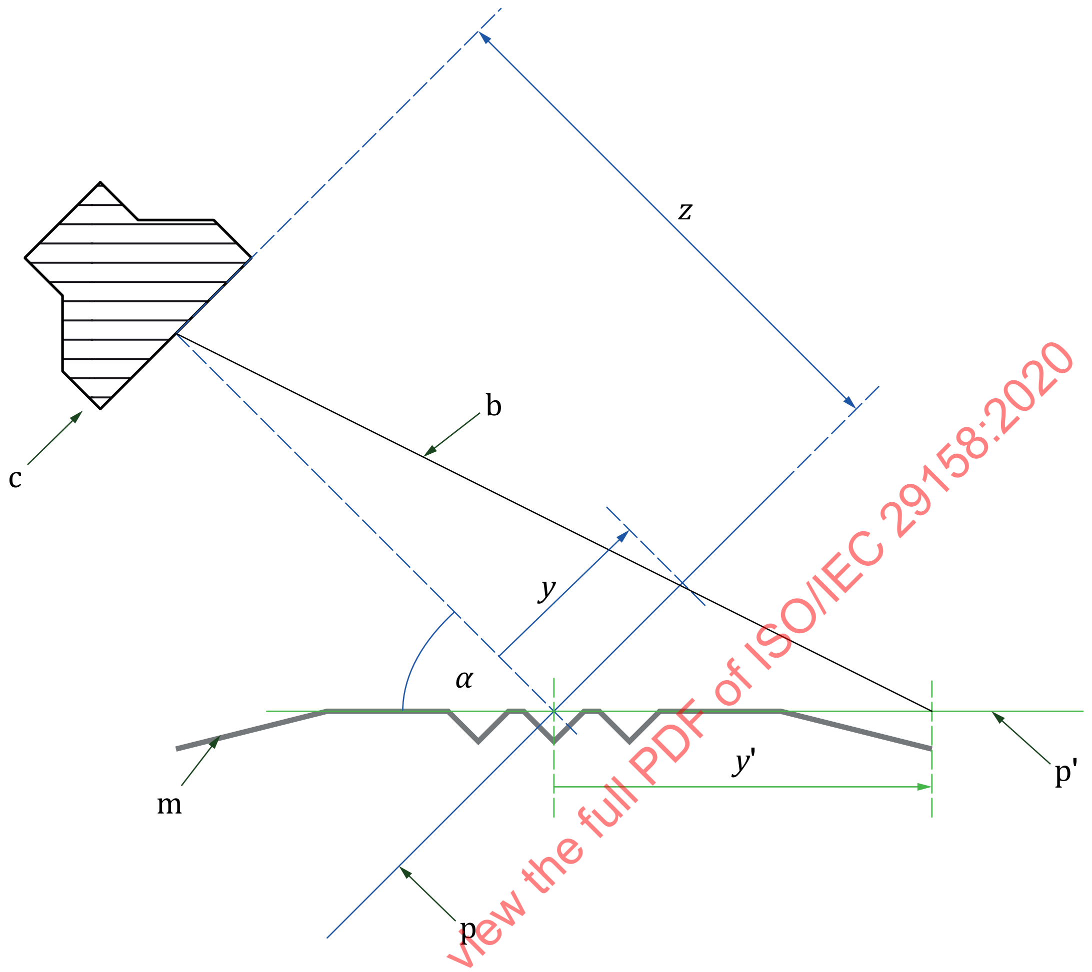
Annex B
(informative)

Evaluation of image at virtual 90° camera position from real tilted camera position

B.1 General

Within TCL setup, the camera position is tilted by the camera reading angle. This annex describes the evaluation of an image with a virtual camera reading angle of 90°.

Figure B.1 shows a side view of the set up. The third dimension (*x*) is not shown.



Key

c	camera
m	marked object
α	camera reading angle
z	camera distance
p	camera image plane
p′	virtual camera image plane for a virtual camera at 90° camera reading angle
b	example light beam connecting example point y on the image camera plane (p) and point y' on the virtual camera image plane (p')
y	y position of the sample point on the camera image plane (p)
y'	y position of the sample point on the virtual camera plane (p′)

Figure B.1 — Relation of the camera image plane and the virtual camera image plane (side view)

The coordinate system of the camera image plane is defined by x (into the drawing plane) and y (tilted axis). The coordinate system of the virtual camera image plane of the virtual camera position of 90° is defined by x' (into the drawing) and y' (horizontal axis). Both coordinate systems join their zero points horizontally on the camera plane.

B.2 Algorithm

The task is to evaluate the virtual image on plane p′ from the image on the camera plane p. Each plane consists of grey level values

The following two-step procedure is performed for each point on the virtual image plane (e.g. for each possible x', y' value).

1) The position of the point of plane p is evaluated with floating point resolution.

2) The value of the image point is evaluated by linear interpolation from the values of plane p.

The two steps are described in the following clauses.

B.3 Evaluation of the point x', y' on the camera image plane p

Images are organized as pixels on positive integer positions. In a first step, the position of each virtual image pixel on the virtual plane x_p, y_p is evaluated by scaling by the resolution and translation to the zero point of the coordinate system.

Then, the position on p′ of a given point on plane p may be evaluated using the Formulae (B.1) and (B.2):

$$x = x' \frac{1}{1 + y' \frac{\cos\alpha}{z}} \tag{B.1}$$

$$y = y' \frac{\sin\alpha}{1 + y' \frac{\cos\alpha}{z}} \tag{B.2}$$

where

x' is the x position on the virtual camera plane (p′);

y' is the y position on the virtual camera plane (p′);

x is the x position on the camera image plane (p);

y is the y position on the camera image plane (p);

α is the camera reading angle; and

z is the camera distance

After this evaluation, the resulting floating point location is scaled and translated to the pixel position of the camera pane p. The result is not rounded to an integer position resulting in an intermediate position on the pixel plane.

EXAMPLE The pixel plane on the virtual plane is 2 000 × 2 000 pixels in size. The 0-point is centred at position 1000,1000. The physical resolution is 400 pixel/mm.

The example point is located at pixel position x_p = 1 400, y_p = 1 600 on the virtual pane. Its physical location is evaluated as:

x' = (1 400 – 1 000)/400 mm = 1 mm

y' = (1 600 – 1 000)/400 mm = 1,5 mm

The camera reading angle is 60° (radian: pi/3) and the distance is 100 mm. The resulting x and y values are x = 0,992 6 mm and y = 1,289 mm.

This physical position is now translated to the pixel pane of the physical camera position pane. The pixel pane has a size of 3 000 × 3 000 pixels. The 0 point is centred at position 1500/1500. The physical resolution is 600 pixel/mm.

The example pixel positions are:

x'_p=0,992 6 mm * 600/mm + 1 500 = 2 095,53

y'_p = 1,289 mm * 600/mm + 1 500 = 2 273,62

B.4 Evaluation of the value of the point x', y' by linear interpolation

The value of the point is evaluated by linear interpolation from the surrounding 4 pixels.

The 4 surrounding pixels of the physical image plane are located at the integer positions around the floating point pixel position. The values of the pixels are named v_{00}, v_{01}, v_{10} and v_{11}, with the first subscript indicating the column and the second subscript indicating the row.

The remaining distance fraction (from 0,0 to not including 1,0) is called f_x and f_y.

The pixel value for pixel x_p, y_p is evaluated as:

$$(v_{00} * (1 - f_x) + v_{10} * f_x) * (1 - f_y) + (v_{01} * (1 - f_x) + v_{11} * f_x) * f_y$$

EXAMPLE (continued) The example floating point position is at 2095,53/2273,62.

The surrounding pixels are located at v_{00} (2095/2273), v_{10} (2096/2273), v_{01} (2095/2274) and v_{11} (2096/2274). Lets use the values v_{00} = 50, v_{01} = 80, v_{10} = 70 and v_{11} = 90

The remaining distance fractions are f_x = 0,53 and f_y = 0,62.

The resulting value for the pixel at 1400/1300 is evaluated as:

(50 * (1 – 0,53) + 70 * 0,53) * (1 – 0,62) + (80 * (1 – 0,53) + 90 * 0,53) * 0,62

= (50 * 0,47 + 70 * 0,53) * 0,38 + (80 * 0,47 + 90 * 0,53) * 0,62

= 75,914

Annex C
(normative)

Continuous grading for ISO/IEC 15415 parameters

C.1 General

As long as continuous grading is not implemented within ISO/IEC 15415 or a referenced symbology specification, the following continuous grading definitions apply for the parameters "Axial nonuniformity", "Grid nonuniformity", "Unused error correction", "MOD or MARGIN" and "Fix pattern damage".

C.2 Grades and mapping

Continuous grading uses 41 grade values, which are mapped to the grades A to F as follows.

— Grade A: 3.5, 3.6, 3.7, 3.8, 3.9, 4.0

— Grade B: 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4

— Grade C: 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4

— Grade D: 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4

— Grade F: 0.0, 0.1, 0.2, 0.3, 0.4

C.3 Interpolation definition (AN, GN, UEC and Mod or MARGIN)

The grade shall be computed as an interpolated value, rounded to the nearest 0.1 in between grade levels. The parameter values below grade value 1.0 are obtained by a linear continuation of the curve, which heads to the following point.

— Axial nonuniformity: 0.14, Grade 0.0

— Grid nonuniformity: 0.88, Grade 0.0

— Unused error correction: 0.125, Grade 0.0

— MOD or MARGIN: 0.1, Grade 0.0

The ISO/IEC 15415 tables for unused error correction and Grid nonuniformity are rounded on the 2nd digit. For the purpose of obtaining a linear curve, the following mappings apply.

— Grid nonuniformity: GN 0.375: Grade 4.0, GN 0.625: Grade 2.0

— Unused error correction: UEC 0.625: Grade 4.0, UEC 0.375: Grade 2

C.4 Mathematical formulas (AN, GN, UEC and MOD or MARGIN)

The resulting formulae for each parameter are:

Axial nonuniformity (AN):

— $A_N \geq 0.14$: Grade 0

— $0.14 > A_N > 0.06$: Grade = round10(7 - (50 * A_N))

— $A_N \leq 0.06$: Grade 4

Grid nonuniformity (GN):

— $G_N \geq 0.875$: Grade 0

— $0.875 > G_N > 0.375$: Grade = round10(7 - (8 × G_N))

— $G_N \leq 0.375$: Grade 4

Unused error correction (UEC):

— $U_{EC} \leq 0.125$: Grade 0

— $0.125 < U_{EC} < 0.625$: Grade = round10((8 × U_{EC}) - 1)

— $U_{EC} \geq 0.625$: Grade 4

MOD or MARGIN

— $M_M \leq 0.1$: Grade 0

— $0.1 < M_M < 0.5$: Grade = round10(0.1 + 0.1 × M_M)

— $M_M \geq 0.5$: Grade 4

where

A_N is axial nonuniformity (AN);

G_N is grid nonuniformity (GN);

U_{EC} is unused error correction (UEC);

M_M is MOD or MARGIN.

The function "round10()" rounds on the second digit after the point and may be defined as:

round10(x) := round(x*10)/10

The function "round(x)" rounds to the next integer as follows: round(x) = $\lfloor x+0.5 \rfloor$

C.5 Modulation calculation procedure

The modulation calculation algorithm described in ISO/IEC 15415:2015, 7.8.4.1 builds up a decision table for 5 grade values (ISO/IEC 15415:2015, Table 7[A]). Within continuous grading, all 41 continuous grade values are considered. In consequence, there are 41 rows in the continuous grading decision table.

A sample decision table is shown in Table C.1.

Table C.1 — Sample decision table for modulation calculation

Index i	Notional modulation grade	Number of codewords at each notional modulation grade step (CW_i)	Codewords treated as errors ($120\text{-}x_i$)	Notional UEC (%) ($NOTIO_{UEC}$)	Notional UEC grade	Lower of notional modulation and UEC grade (G)	Modulation grade (highest grade of column G)
1	4	25	95	exceeded	0.0	0.0	
2	3.9	6	89	exceeded	0.0	0.0	
3	3.8	8	81	exceeded	0.0	0.0	
4	3.7	7	74	exceeded	0.0	0.0	
5	3.6	6	68	exceeded	0.0	0.0	
6	3.5	8	60	exceeded	0.0	0.0	
7	3.4	10	50	exceeded	0.0	0.0	
8	3.3	10	40	exceeded	0.0	0.0	
9	3.2	6	34	exceeded	0.0	0.0	
10	3.1	8	26	13.3	0.1	0.1	
11	3	6	20	33.3	1.7	1.7	
12	2.9	1	19	36.7	2.0	2.0	
13	2.8	2	17	43.3	2.5	2.5	
14	2.7	1	16	46.7	2.8	2.7	
15	2.6	1	15	50.0	3.1	2.6	
16	2.5	3	12	60.0	3.9	2.5	
17	2.4	1	11	63.3	4.0	2.4	
18	2.3	1	10	66.7	4.0	2.3	
19	2.2	4	6	80.0	4.0	2.2	
20	2.1	0	6	80.0	4.0	2.1	
21	2	1	5	83.3	4.0	2.0	
22	1.9	1	4	86.7	4.0	1.9	
23	1.8	0	4	86.7	4.0	1.8	
24	1.7	0	4	86.7	4.0	1.7	
25	1.6	0	4	86.7	4.0	1.6	
26	1.5	0	4	86.7	4.0	1.5	
27	1.4	0	4	86.7	4.0	1.4	
28	1.3	1	3	90.0	4.0	1.3	
29	1.2	1	2	93.3	4.0	1.2	
30	1.1	0	2	93.3	4.0	1.1	
31	1	0	2	93.3	4.0	1.0	
32	0.9	0	2	93.3	4.0	0.9	
33	0.8	0	2	93.3	4.0	0.8	
34	0.7	0	2	93.3	4.0	0.7	
35	0.6	0	2	93.3	4.0	0.6	
36	0.5	1	1	96.7	4.0	0.5	
37	0.4	0	1	96.7	4.0	0.4	
38	0.3	0	1	96.7	4.0	0.3	
39	0.2	1	0	100.0	4.0	0.2	
40	0.1	0	0	100.0	4.0	0.1	
41	0	0	0	100.0	4.0	0.0	2.7

C.6 Fixed Pattern Damage (FPD)

FPD is symbology dependent and may be defined in ISO/IEC 15415 or in a symbology specification. If not specified otherwise, continuous grading should be implemented by the following procedure.

a) The given measurement for grades 1,2,3 and 4 should be connected by linear lines on the measurement to grade diagram.

b) An additional virtual point 0 should be defined by continuing the line between 1 and 2 in direction grade 0.0.

c) The continuous grade value limits are taken as points on these lines. The condition on the measurements (≥ or ≤) are the same as for grade 1 to 3.

d) All measurements beyond the point corresponding to grade 4 get grade 4.0 assigned.

e) All measurements beyond the virtual point 0.0 get grade 0.0 assigned.

f) In any complex calculation (like modulation), the number of grades is extended from 5 to 41.

Any grade decision table (like Table C.1) should be extended to cover all continuous grades. Thus, the table length grows from 5 grades (0, 1, 2, 3, 4) to 41 grades (0.0, 0.1, 0.2, ... 4.0).

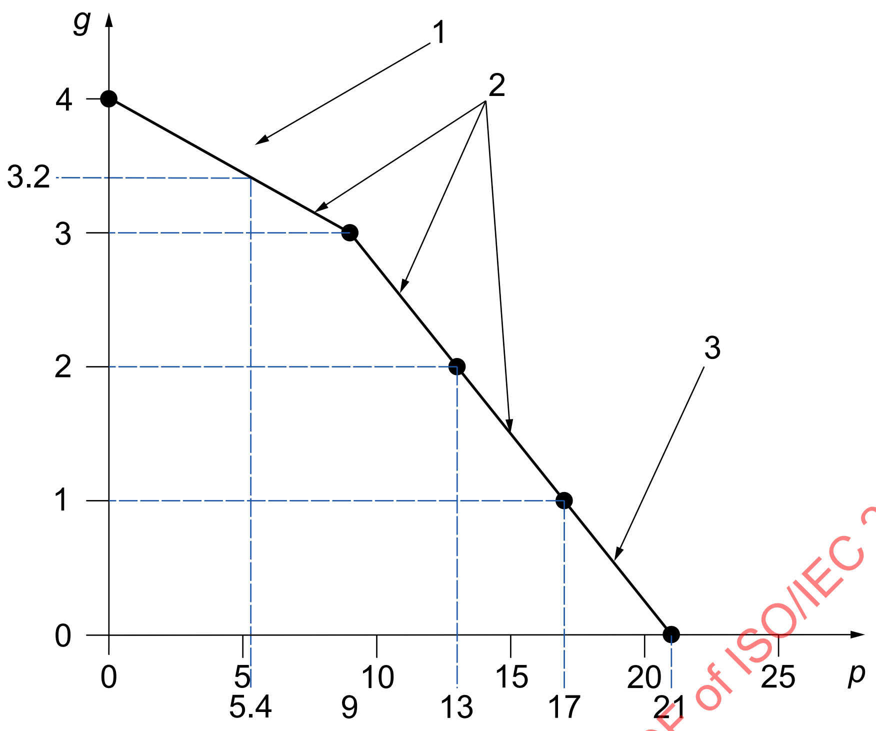
As an example, the data matrix grading of notional damage is used (ISO/IEC 16022:2006, Table M.4).

The current definition is shown in Table C.2.

Table C.2 — Example grading of notional damage from ISO/IEC 16022:2006, Table M.4

Percentage of modules damaged (%)	Grade
0	4
≤9	3
≤13	2
≤17	1
>17	0

The grade diagram is shown in Figure C.1.



Key

p percentage of modules damaged

g grade

1 continues grade measurement

2 lines between full grades

3 continued line toward grade 0.0

Figure C.1 — Example grade diagram

The lines between the full grades are visible between grade 4.0, 3.0, 2.0 and 1.0. The last line is extended to grade 0.0.

The example value for grade 3.2 is shown and may be determined from the diagram to correspond to 5,4 % damaged modules.