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Automatic identification and data capture techniques — Bar code symbol print quality test specification — Two-dimensional symbols

Techniques automatiques d'identification et de capture des données — Spécification de test de qualité d'impression des symboles de code à barres — Symboles bidimensionnels

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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

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Foreword

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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 or www.iec.ch/members_experts/refdocs).

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

This third edition cancels and replaces the second edition (ISO/IEC 15415:2011) which has been technically revised.

The main changes are as follows:

— a continuous (or decimal) grading has been introduced;

— a more optimal threshold calculation has been introduced;

— a more stable symbol contrast calculation has been introduced;

— a definition of grading for print growth has been added;

— modulation and reflectance margin have been combined into a single measurement.

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 and www.iec.ch/national-committees.

Introduction

The technology of bar coding is based on the recognition of patterns encoded, in bars and spaces or in a matrix of modules of defined dimensions, according to rules defining the translation of characters into such patterns, known as the symbology specification. Symbology specifications may be categorised into those for linear symbols, on the one hand, and two-dimensional symbols on the other; the latter may in turn be subdivided into “multi-row bar code symbols” sometimes referred to as “stacked bar code symbols”, and “two-dimensional matrix symbols”. In addition, there is a hybrid group of symbologies known as “composite symbologies”; these symbols consist of two components carrying a single message or related data, one of which is usually a linear symbol and the other a two-dimensional symbol positioned in a defined relationship with the linear symbol.

Multi-row bar code symbols are constructed graphically as a series of rows of symbol characters, representing data and overhead components, placed in a defined vertical arrangement to form a (normally) rectangular symbol, which contains a single data message. Each symbol character has the characteristics of a linear bar code symbol character and each row has those of a linear bar code symbol; each row, therefore, may be read by linear symbol scanning techniques, but the data from all the rows in the symbol must be read before the message can be transferred to the application software.

Two-dimensional matrix symbols are normally square or rectangular arrangements of dark and light modules, the centres of which are placed at the intersections of a grid of two (sometimes more) axes; the coordinates of each module need to be known in order to determine its significance, and the symbol must therefore be analysed two-dimensionally before it can be decoded. Some matrix codes are comprised of unconnected dots, in which the individual modules do not directly touch their neighbours but are separated from them by a clear space.

Unless explicitly specified otherwise, the term “symbol” in this document refers to either type of symbology.

The bar code symbol must be produced in such a way as to be reliably decoded at the point of use, if it is to fulfil its basic objective as a machine-readable data carrier.

Manufacturers of bar code equipment and the producers and users of bar code symbols therefore require publicly available standard test specifications for the objective assessment of the quality of bar code symbols, a process known as verification, to which they can refer when developing equipment and application specifications or determining the quality of the symbols. Such test specifications form the basis for the development of measuring equipment for process control and quality assurance purposes during symbol production as well as afterwards.

The performance of measuring equipment for the verification of symbols, also known as verifiers, is covered in ISO/IEC 15426-1 and ISO/IEC 15426-2.

The methodology described in this document is intended to achieve comparable results to the linear bar code symbol quality standard ISO/IEC 15416, the general principles of which this document has followed. It should be read in conjunction with the symbology specification applicable to the bar code symbol being tested, which provides symbology-specific details necessary for its application. Two-dimensional multi-row bar code symbols are verified according to the ISO/IEC 15416 methodology, with the modifications described in Clause 6; different parameters and methodologies are applicable to two-dimensional matrix symbols. The procedures described in this document must necessarily be augmented by the reference decode algorithm and other measurement details within the applicable symbology specification, and they may also be altered or overridden as appropriate by governing symbology or application specifications.

The method of quality assessment described in this document is most applicable to reading environments wherein printed and otherwise marked symbols are read predominantly by diffuse reflection. For direct part mark applications, in which symbols and substrates may be glossy, specular, low contrast, etc., a modified and extended version of the methodology defined in this document has been defined in ISO/IEC 29158 and provides for lighting arrangements and enhanced algorithms which more closely match reading equipment commonly used in DPM applications.

NOTE The Bibliography provides official and industry standards containing symbology specifications, among other references, to which this document applies. However, the Bibliography does not provide an exhaustive list of symbology specifications.

Automatic identification and data capture techniques — Bar code symbol print quality test specification — Two-dimensional symbols

1 Scope

This document

— specifies two methodologies for the measurement of specific attributes of two-dimensional bar code symbols – one of which applies to multi-row bar code symbologies and the other to two-dimensional matrix symbologies;

— specifies methods for evaluating and grading these measurements and deriving an overall assessment of symbol quality;

— gives information on possible causes of deviation from optimum grades to assist users in taking appropriate corrective action.

This document applies to two-dimensional symbologies for which a reference decode algorithm has been defined, however the methodologies in this document can be applied partially or wholly to other similar symbologies.

NOTE While this document can be applied to direct part marks, better correlation between measurement results and scanning performance can be obtained with ISO/IEC 29158 in combination with this document.

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 15416, *Information technology – Automatic identification and data capture techniques — Bar code print quality test specification — Linear symbols*

ISO/IEC 15426-2, *Information technology — Automatic identification and data capture techniques — Bar code verifier conformance specification — Part 2: 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, ISO/IEC 15416 and the following apply.

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

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

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

3.1
binarised image
binary (black/white) image created by applying a threshold to the *pixel* (3.7) values in the *reference grey-scale image* (3.9)

3.2
effective resolution
resolution obtained on the surface of the symbol under test and calculated as the resolution of the image capture element multiplied by the magnification of the optical elements of the measuring device

Note 1 to entry: The effective resolution is normally expressed in *pixels* (3.7) per mm (or pixels per inch).

3.3
error correction capacity
number of codewords, or units of data, in a symbol (or error control block) assigned for erasure and error correction, minus the amount reserved for error detection

3.4
inspection area
portion of an image which contains the entire symbol to be tested inclusive of its quiet zones

3.5
grade threshold
boundary value separating two grade levels, the value itself being taken as the lower limit of the upper grade

3.6
module error
module of which the apparent dark or light state in the *binarised image* (3.1) is inverted from its intended state

3.7
pixel
individual light-sensitive element in an array

EXAMPLE Charge coupled device (CCD), complementary metal oxide semiconductor (CMOS) device.

3.8
raw image
plot of the reflectance values in x and y coordinates across a two-dimensional image, representing the discrete reflectance values from each *pixel* (3.7) of the light-sensitive array

3.9
reference grey-scale image
plot of the reflectance values in x and y coordinates across a two-dimensional image, derived from the discrete reflectance values of each *pixel* (3.7) of the light-sensitive array by convolving the *raw image* (3.8) with a *synthesised aperture* (3.10)

3.10
synthesised aperture
convolutional kernel used to blur an image

4 Symbols and abbreviated terms

4.1 Symbols

E_{cap} error correction capacity of the symbol

D distance across or width of an element in a symbol

D_{NOM} expected or nominal width of an element in a symbol

e number of erasures

M_{MOD} measure of the difference in reflectance between a module and the threshold

M_{ANU} measure of axial nonuniformity

M_{GNU} measure of grid nonuniformity

M_{UEC} measure of unused error correction, accounting for the number of errors, erasures and capacity

R reflectance

R_{max} indicative reflectance of the brightest area of a symbol

R_{min} indicative reflectance of the darkest area of a symbol

ΔR_{SC} symbol contrast, i.e. the difference in reflectance between R_{max} and R_{min}

t number of errors

T threshold

X_{AVG} average spacing of modules in the horizontal axis

Y_{AVG} average spacing of modules in the vertical axis

4.2 Abbreviated terms

ANU axial nonuniformity

CU contrast uniformity

FPD fixed pattern damage

GNU grid nonuniformity

MOD modulation

PG print growth

SC symbol contrast

UEC unused error correction

5 Quality grading

5.1 General

The measurement of two-dimensional bar code symbols is designed to yield a quality grade, reported as the symbol grade, indicating the overall quality of the symbol. This can be used by producers and users of the symbol for diagnostic and process control purposes and is broadly predictive of the read performance to be expected of the symbol. The process requires the measurement and grading of defined parameters, from which the symbol grade is derived. The symbol grade is sometimes called the “overall symbol grade” when used in a context in which the modifier “overall” helps to clarify and distinguish the symbol grade from other parameter grades.

As a consequence of the use of different types of reading equipment under differing conditions in actual applications, the levels of quality required of two-dimensional bar code symbols to ensure an acceptable level of performance will differ between different real-world applications. Application specifications should therefore define the required symbol quality in terms of aperture, light (angle, orientation and wavelength), and minimum symbol grade in accordance with this document. The guidelines in Annex C are provided as an aid in writing application specifications according to this document. Annex D provides additional information regarding substrate properties. When this document is used without an applicable application specification, suitable choices for aperture, light (angle and wavelength), and minimum grade, must be made by the user. However, if these choices are not suited to the intended application, then the achieved symbol grade cannot be relied upon as an indicator of reading performance in the intended application. Thus, it is highly preferred to follow an agreed upon application specification when using this document (such as a specification mutually agreed upon or published by an industry standards body or regulatory authority).

This document defines the method of obtaining a quality grade for individual symbols. The use of this method in high volume quality control regimes may require sampling in order to achieve desired results. Such sampling plans, including required sampling rates are outside of the scope of this document.

NOTE Information on sampling plans can be found in ISO 3951-1, ISO 3951-2, ISO 3951-3, ISO 3951-5 and ISO 28590.

5.2 Expression of quality grades

This document specifies a numeric basis for expressing quality grades on a descending scale from 4,0 to 0 in steps of 0,1. The highest quality is represented by 4,0. Alphabetic grades are not formal and should not be reported as the formal grade. The link between numeric and alphabetic grades is given in Table 1. Numeric grades are more precise because they express a grade with ten steps within each letter grade range. Overall numeric grades should not be rounded to the nearest whole number. When using alphabetic grades for convenience they shall be accompanied by a numerical grade.

Table 1 shows the correspondence between alphabetic and numeric grades.

Table 1 — Correspondence between numeric and historical alphabetic quality grades

Numeric range	Alphabetic grade
≥3,5 (i.e. 3,5; 3,6; 3,7; 3,8; 3,9; 4,0)	A
2,5 to 3,4	B
1,5 to 2,4	C
0,5 to 1,4	D
≤0,4 (i.e. 0,0; 0,1; 0,2; 0,3; 0,4)	F

5.3 Symbol grade

The symbol grade shall be calculated in accordance with 6.2.6 or 6.3 or 7.6 or Clause 8 and as applicable to the type of symbol.

5.4 Specifying the symbol grade requirement in an application specification

An application specification shall specify the minimum grade requirement as well as the grading conditions, shown in the format:

grade/aperture/light/angle

where

- grade — indicates the minimum grade required;
- aperture — indicates the aperture reference number (from ISO/IEC 15416 for linear scanning techniques), or the diameter in thousandths of an inch (to the nearest thousandth) of the aperture defined in 5.6.2;
- light — indicates the numeric value of the peak light wavelength (i.e. the illumination) in nanometres (for narrow band illumination); the alphabetic character W indicates broadband (nominally, “white light”), the spectral response characteristics of which must imperatively be defined or specified in kelvin in parenthesis after the W designated by a number followed by the letter K, or have their source specification clearly referenced;
- angle — indicates the angle of incidence (an additional parameter) in degrees (relative to the plane of the symbol) of the illumination from four sides (as a default, unless another orientation is specified by an application) – see Figure 1 and Figure 2.

The angle shall be included in the specification of grading requirements when the angle of incidence is other than 45°. While it may be included for 45°, its absence indicates that the specified angle of incidence is 45° by default. Application specifications may specify a different angle of incidence instead of leaving it blank.

The orientation of light refers to the number of directions, the default being four. Light from only two sides may be specified by appending the letter "T" to the angle, such as 30T. The letter "S" may be used to indicate only one side. The letter "Q "may be used to indicate four sides, but omitting it implies four sides so 45Q is equivalent to 45 but 45Q is explicit regarding the orientation.

EXAMPLE 1 An application specification can specify a symbol quality requirement as 1,5/05/660 to indicate that the required symbol quality is 1,5 or higher obtained using an aperture size of 0,125 mm (reference number 05) with 660 nm light incident from 45° from four sides.

EXAMPLE 2 Using a white light with 5400 K, the light source is 1,5/05/W(5400 K).

Other lighting options are defined in ISO/IEC 29158 which can be more appropriate for direct part marking applications, especially in applications which utilize symbols marked on reflective substrates. Therefore, ISO/IEC 29158 should be specified by an application specification as the method of grading when such lighting options are preferred in an application.

5.5 Reporting of symbol grade

A symbol grade is only meaningful if it is reported in conjunction with the illumination and aperture used. It should be shown in the format:

grade/aperture/light/angle

where

grade	indicates the symbol grade as defined in 5.3;
aperture	indicates the aperture reference number (from ISO/IEC 15416 for linear scanning techniques, or the diameter in thousandths of an inch (expressed to the nearest thousandth or a to higher precision) of the aperture defined in 5.6.2;
light	indicates the numeric value indicates the peak light wavelength (i.e. the illumination) in nanometres (for narrow band illumination); the alphabetic character W indicates that the symbol has been measured with broadband illumination ("white light") the spectral response characteristics of which must imperatively be defined or have their source specification clearly referenced;
angle	indicates the angle of incidence (an additional parameter, relative to the plane of the symbol) of the illumination from four sides.

The angle shall be included in the reporting of the overall symbol grade when the angle of incidence differs from the default orientation of 45° from four sides. While it may be included for the default orientation, its absence indicates that the angle of incidence is 45° from four sides.

The notation used to specify a minimum grade that is required in an application is similar to the notation used to report a grade result, but the grading requirement specifies a minimum for the grade in an application, whereas the result specifies a specific occurrence of a grade produced by verifying a symbol.

EXAMPLE 1 2,8/05/660 indicates that the overall grade was 2,8 and was obtained with the use of a 0,125 mm aperture (reference number 05) and a 660 nm light source, incident at 45° from four sides.

EXAMPLE 2 2,8/10/W/30Q indicates that the grade of a symbol was 2,8 and was obtained with broadband light, measured with light incident at 30° from four sides and using a 0,250 mm aperture (reference number 10), but would need to be accompanied either by a reference to the application specification defining the reference spectral characteristics used for measurement or a definition of the spectral characteristics themselves.

EXAMPLE 3 2,8/10/670 indicates that the grade of a symbol was 2,8 and was obtained using a 0,250 mm aperture (reference number 10), and a 670 nm light source, incident at 45° from four sides.

NOTE The previous edition of this document defined the use of a * to indicate the presence of extreme reflectance in or near the symbol. This has been removed in this edition of this document.

5.6 Optical setup and obtaining the test images

5.6.1 General requirements

Equipment for assessing the quality of symbols in accordance with this clause shall comprise a means of measuring and analysing the variations in the reflectivity of a symbol on its substrate over an inspection area which shall cover the full height and width of the symbol including all quiet zones. All measurements on a two-dimensional matrix symbol shall be made within the inspection area defined in accordance with 5.6.4.

The measured reflectance values shall be expressed in percentage terms by means of calibration to a reference reflectance standard traceable to National Measurement Institutes.

NOTE Maximum white diffuse reflectance is taken as 100 %.

The peak light wavelength or, in the case of applications designed for the use of broadband illumination, the reference spectral response characteristics, should be specified in the application specification to suit the intended scanning environment. Light sources may either have inherently narrow band or near-monochromatic characteristics or have broad bandwidths. Special care is necessary when making measurements with broadband illumination. The overall spectral response of the measurement and reading systems shall be defined and matched in order to make accurate and repeatable measurements of the grey-scale reflectance of a sample area that correlate with the intended system. Overall spectral response includes the spectral distribution of the light source, the response of the detector and any associated filter characteristics.

Refer to Annex C for guidance on the selection of the light source.

5.6.2 Convolving with the measuring aperture

The measuring aperture is specified by the application specification to suit the *X* dimensions of the symbols in the application and the intended scanning environment. The measuring aperture is applied by convolving the raw image with a synthetic aperture and defined by a kernel of equal weights within a round area and zero outside. The purpose of applying an aperture is

a) to reduce the effect of small imperfections in the symbol, such as substrate texture and printing defects, and

b) to standardize the operation of verification devices, independent of the pixel density (resolution) of each device.

NOTE The aperture can be a physical one, as is common for implementations of ISO/IEC 15416. In any case, this convolving aperture is not to be confused with an aperture of a lens.

5.6.3 Geometry of the optical setup

A reference optical geometry is defined for reflectivity measurements and consists of:

— flood incident illumination, uniform across the inspection area, from a set of four light sources arranged at intervals of 90° around a circle concentric with the inspection area and in a plane parallel to that of the inspection area, at a height which allows incident light to fall on the centre of the inspection area at an angle of 45° (or another angle if specified for the application) to its plane, and

— a light collection device, the optical axis of which is perpendicular to the inspection area and passes through its centre, and which focuses an image of the test symbol on a light-sensitive array.

The light reflected from the inspection area (see 5.6.4) shall be collected and focussed on the light-sensitive array.

Two principles govern the design of the optical set-up.

— First, the test image's grey-scale shall be nominally linear and not be enhanced in any way (such as a gamma correction). Filters which modify the spectral characteristics of the light source should only be used to remove unwanted ambient light and/or to produce the spectral characteristics of illumination specified for an application (such as a particular narrow band). Other filters should be avoided or used only when they are consistent with an application specification (see C.1.1) in which case it shall be reported along with the grade. A filter that merely restricts the spectral components to the specified wavelength need not be reported, but one which introduces special effects, such as a UV (ultraviolet) filter, shall be reported. In any case where the use of a filter significantly affects a measurement, the usage of the filter shall be reported along with the grade.

— Second, the image resolution shall be adequate to produce consistent readings. Implementations should have sufficient resolution irrespective of the rotation, unless the manufacturer defines handling instructions which restricts the angle of the symbol in relation to the camera sensor orientation.

NOTE 1 The conformance requirements in ISO/IEC 15426-2 are useful for confirming adequate resolution.

Alternative optical arrangements may be used in an implementation, provided that the measurements obtained with them can be correlated with the use of the reference or the specified optical arrangement. In particular, the tolerances specified in ISO/IEC 15426-2 shall be met. Furthermore, application specifications can establish alternative optical arrangements, in accordance with 5.4, which are better aligned to an application and thus can result in different results than the reference optical arrangement.

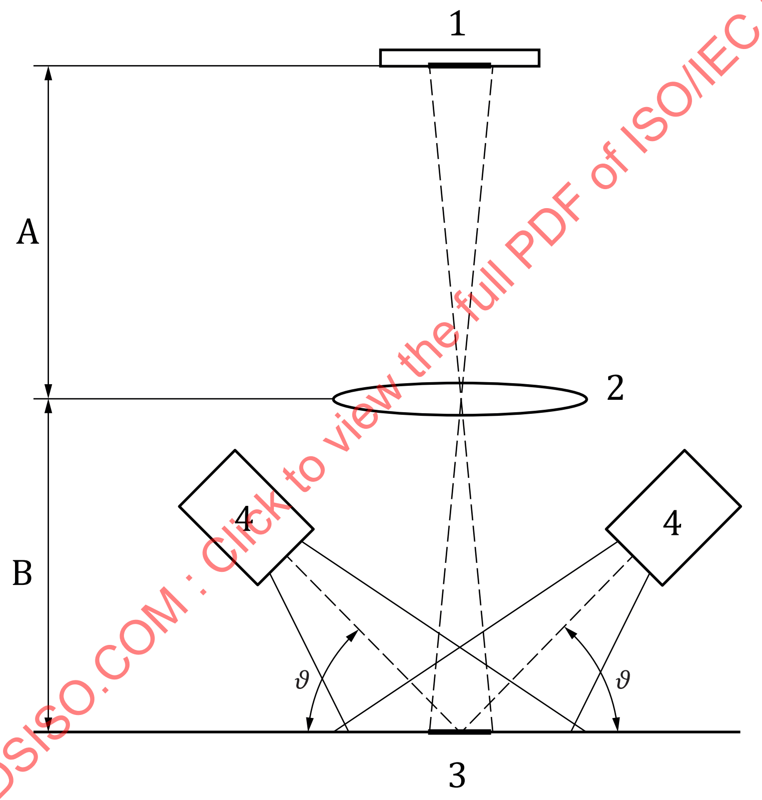
Figures 1 and 2 illustrate the principle of the optical arrangement but are not intended to represent actual devices; the magnification of the device in particular is likely to differ from 1:1.

The general test set-up defined in this optical geometry should work suitably for many open applications with methodology described in this document. However, for direct part mark applications, application specifications should consider using ISO/IEC 29158 instead.

NOTE 2 ISO/IEC 29158 establishes an extension of the methodology described in this document and is more appropriate for many direct part marking applications.

This reference geometry is intended to provide a basis to assist the consistency of measurement and does not necessarily correspond with the optical geometry of individual scanning systems. As stated in 5.4, specialised applications, and especially those involving direct part marking which employs physical changes to the surface of the substrate for the creation of the graphic image, can require the angle of illumination in particular to be set to a different particular angle, such as 30°, to the plane of the symbol. If an angle and/or orientation, other than the default is used, then the angle of incidence and orientation of the light shall be stated as a fourth parameter when reporting the overall symbol grade, as described in 5.5.

The modified methodology that is specified in ISO/IEC 29158 intended for direct part marking applications defines more illumination options and should be used in applications where diffuse lighting from four sides does not provide adequate correlation with the requirements of a specialised application.



Key

1 light sensing element

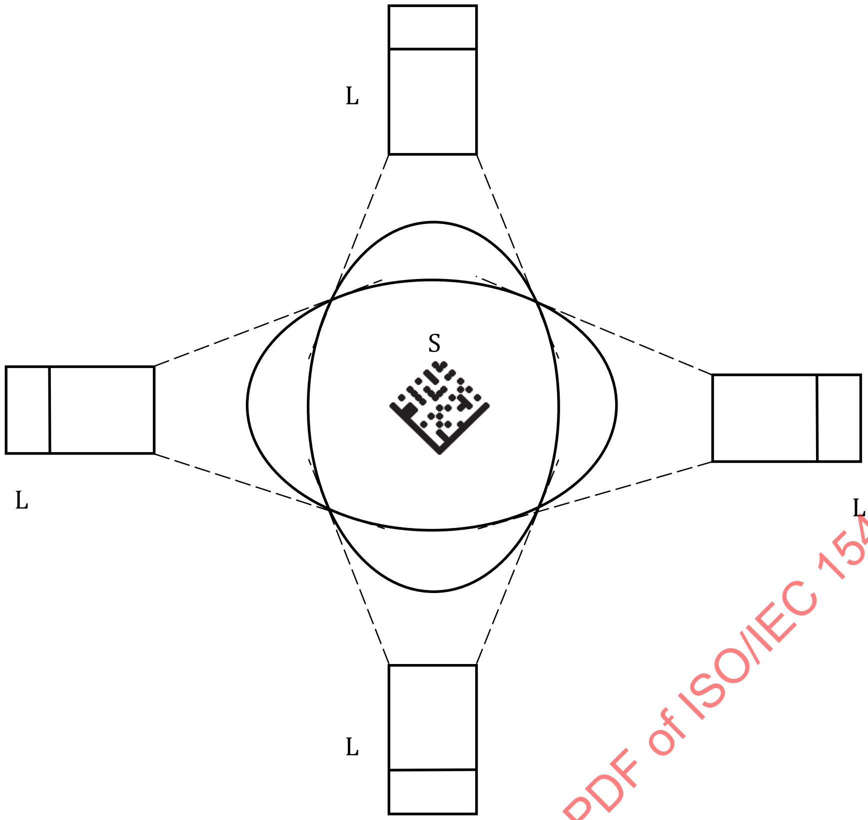
2 lens providing 1:1 magnification (i.e. measurement *A* equals to measurement *B*)

3 inspection area

4 light sources

ϑ angle of incidence of light relative to plane of symbol (the default is equal to 45°, optionally 30° or 90° diffuse)

Figure 1 — Reference optical arrangement — Side view



Key

L light source

S symbol

Figure 2 — Reference optical arrangement — Plan view

5.6.4 Inspection area

The inspection area for all measurements shall be an area framing the complete symbol, including quiet zones. The centre of the inspection area shall be as close as practicable to the centre of the field of view.

NOTE The inspection area is not the same as the field of view of the verifier, which is often larger.

5.6.5 Measurement conditions

A test image of the symbol shall be obtained in a configuration that mimics the typical scanning situation for that symbol, but with substantially higher resolution (see 5.6), uniform illumination and at best focus. The reference optical arrangement is defined in 5.6.3. Alternative optical arrangements are also discussed in 5.6.3.

Measurements shall be made with the light of a single peak wavelength or a set of spectral characteristics, in accordance with 5.4. Ambient light levels shall be controlled to have no significant influence on the measurement results.

Whenever possible, measurements shall be made on the symbol in its final configuration, i.e. the configuration in which it is intended to be scanned. The geometry of the optical setup described in 5.6.3 is intended to prevent extreme reflectance values outside the symbol area (e.g. when surrounded by free air or a highly specular reflective surface) from distorting the symbol contrast measurements.

6 Measurement methodology for two-dimensional multi-row bar code symbols

6.1 General

The evaluation of two-dimensional multi-row bar code symbols shall be based on the application of the methodology of ISO/IEC 15416, modified as described in 6.2.2 or 6.3, and if appropriate for the symbology, on the application of the additional provisions described in 6.2.3, 6.2.4 and 6.2.5, to derive an overall symbol grade. Ambient light levels shall be controlled in order not to have any influence on the measurement results. The symbol shall be scanned using the light wavelength(s) and the aperture size specified in the appropriate application specification.

When performing a measurement, the scan lines should

— be perpendicular to the height of the bars in the start and stop characters, and

— pass, as far as possible, through the centres of rows in order to minimise the effect of cross-talk from adjacent rows.

In the case of area imaging techniques, a number of scan lines, perpendicular to the height of the bars and sufficient to cover all rows of the symbol, shall be synthesised to produce scan reflectance profiles as described in ISO/IEC 15416.

6.2 Symbologies with cross-row scanning ability

6.2.1 Basis of grading

The distinguishing feature of these symbologies is their ability to be read with scan lines that cross row boundaries. Symbologies of this type typically also share the feature that the start and stop patterns (or equivalent features of the symbol, e.g. the row address patterns of MicroPDF417 symbology specified in ISO/IEC 24728) are constant from row to row, or the position of only one edge in these patterns varies by no more than 1X in adjacent rows of the symbol. These symbologies shall be graded with respect to

— the analysis of the scan reflectance profile based on ISO/IEC 15416 (see 6.2.2),

— the codeword yield (see 6.2.3),

— the unused error correction (see 6.2.4),

— the codeword print quality (see 6.2.5), and

— the scan reflection profiles that are produced from the raw image by convolving with the specified aperture.

6.2.2 Grade based on analysis of scan reflectance profile

The start and stop or equivalent (e.g. row address) patterns of the symbol shall be evaluated in accordance with ISO/IEC 15416. Regions with data content are evaluated separately as described in 6.2.3, 6.2.4 and 6.2.5. Test scans of the start and stop patterns shall be graded using all parameters specified in ISO/IEC 15416.The effective aperture size is specified in the appropriate application specification or is the default aperture size appropriate for the symbol X dimension given in ISO/IEC 15416.

For the analysis of the scan reflectance profiles, the number of scans should be ten or the height of the symbol divided by the measuring aperture if this quotient is less than ten. Scans should be approximately evenly spaced over the height of the symbol. For example, in a twenty-row symbol, the ten scans can be performed in alternate rows. In a two-row symbol, up to five scans can be performed in each row, at different positions in the height of the bars. The symbology specification can give more specific guidance on the selection of the scans to be used.

The methods given in ISO/IEC 15416 shall be used to identify bars and spaces and the edge locations. For the evaluation of the parameters 'decode' and 'decodability' the reference decode algorithm for the symbology shall be applied. Each scan shall be graded as the lowest grade for any individual parameter in that scan. The grade based on scan reflectance profiles shall be the arithmetic mean of the grades for the individual scans, as defined in ISO/IEC 15416.

The measurement of print growth or loss may be used for process control purposes. However, this method is not sensitive to printing variations parallel to the height of the start and stop characters. If a full analysis of the printing process is desired, symbols should be printed and tested in both orientations.

6.2.3 Grade based on codeword yield

6.2.3.1 Overview of method

Grade based on codeword yield measures the efficiency with which linear scans can recover data from a two-dimensional multi-row symbol. The codeword yield is the number of validly decoded codewords expressed as a percentage of the maximum number of codewords that can be decoded (after adjusting for tilt). A poor codeword yield, for a symbol whose other measurements are good, can indicate a Y-axis print quality problem (such as those shown in Table B.1).

6.2.3.2 Qualifying scans

Obtain a matrix of the correct symbol character values, such as would result from successful completion of the unused error correction (UEC) calculations (see 6.2.4). This matrix is used as the "final decode of the symbol" used in subsequent steps to determine validly decoded codewords.

An individual scan qualifies for inclusion in the codeword yield calculation if it meets either of the following two conditions.

a) The scan did not include recognised portions of either the top or the bottom row of the symbol. At least one of the start or stop (or row address) patterns shall have been successfully decoded from that scan, together with at least one additional codeword or the corresponding second start or stop pattern, or row address pattern.

b) The scan included recognised portions of either the top or the bottom row of the symbol. Both the start and stop patterns of the symbol shall have been successfully decoded from that scan.

It is important to note that an extension to the symbology's reference decode algorithm is required, in order to detect and decode a pair of start and stop patterns when neither of the adjacent codewords is decodable. As examples, a linear search for a matching pair of PDF417 start and stop patterns, or a linear search for a matching pair of MicroPDF417 row indicator patterns, would fulfil this requirement for scans where the reference decode algorithm alone did not decode both patterns; thus, this extension can qualify a scan where no codewords, other than the matched end patterns, were decoded.

NOTE A scan that contains only a single decoded start or stop pattern found by this linear search does not count as a qualified scan, if no other codewords or corresponding second start or stop pattern, or row address pattern, are also decoded.

6.2.3.3 Decoding the symbol completely and populating the symbol matrix

For each qualified scan, compare the codewords actually decoded with the codewords in the symbol matrix and count the number of codewords that match. Accumulate the total number of validly decoded codewords, and update a count of the number of times each codeword of the symbol has been decoded and a count of the number of times each row has been detected. Record a count of the number of detected row crossings in each scan (a crossing is “detected” when a scan line yields correctly-decoded codewords from adjacent rows).

6.2.3.4 Calculation and grading

After processing each scan, calculate the maximum number of codewords that can have been decoded thus far, as the number of qualified scans multiplied by the number of columns in the symbol (excluding the fixed patterns, such as the start and stop patterns of PDF417 or the row address indicators of MicroPDF417).

The entire symbol shall be scanned multiple times until three conditions are met:

a) the maximum number of codewords that can be decoded is at least ten times the number of codewords in the symbol,

b) the highest and lowest decodable rows (which is not necessarily the first and last rows) of the symbol have each been scanned at least three times, and

c) at least $0{,}9 \cdot n$ of the codewords (data or error correction) have been successfully decoded two or more times, where n is the number of non-error-correction data codewords in the symbol.

EXAMPLE Taking a PDF417 symbol with 6 rows and 16 columns and error correction level 4, the total number of codewords is 96, of which 64 are data and 32 error correction. To fulfil condition a), the maximum number of codewords that can be decoded is at least 960. To fulfil condition c), since n is 64, at least 58 of the codewords have to be decoded twice or more ($0{,}9 \times 64 = 57{,}6$).

If the ratio of the total number of validly decoded codewords to the total number of detected row crossings is less than 10:1, then discard the measurements just obtained, and repeat the measurement process, adjusting the tilt angle of the scan line to reduce the number of row crossings.

Otherwise, to compensate for any residual tilt, subtract the number of detected row crossings from the calculated maximum number of codewords that can be decoded.

Codeword yield shall be graded from 4,0 to 0, rounded down to the nearest 0,1, in between grade levels in accordance with Table 2. For example, for codeword yield of 0,70 shall result in a grade of 3,8 and a codeword yield of 0,54 shall result in a grade of 1,5.

Table 2 — Grading of codeword yield

Codeword yield	Grade
≥71 %	4,0
64 % and <71 %	3,0 to 3,9
≥57 % and <64 %	2,0 to 2,9
≥50 % and <57 %	1,0 to 1,9
≥40 % and <50 %	0,0 to 0,9
<40 %	0,0

6.2.4 Grade based on unused error correction

Decode the symbol completely and process scans until the number of decoded codewords stabilises. Calculate the UEC as

$$1{,}0 - [(e + 2t) / E_{cap}]$$

where

e is the number of erasures;

t is the number of errors;

E_{cap} is the error correction capacity of the symbol (i.e. the number of error correction codewords minus the number of error correction codewords reserved for error detection).

If no error correction has been applied to the symbol, and if the symbol decodes, unused error correction shall be taken as 1. If $(e + 2t)$ is greater than E_{cap}, unused error correction shall be taken as 0. In symbols with more than one (e.g. interleaved) error correction block, the unused error correction shall be calculated for each block independently and the lowest value shall be used for grading purposes. The unused error correction shall be graded as shown in Table 3 on a scale from 4,0 to 0 rounded down to the nearest 0,1.

Table 3 — Grading of unused error correction

Unused error correction	Grade
≥0,62	4,0
≥0,50 and <0,62	3,0 to 3,9
≥0,37 and <0,50	2,0 to 2,9
≥0,25 and <0,37	1,0 to 1,9
≥0,20 and <0,25	0,0 to 0,9
<0,20	0,0

6.2.5 Grade based on codeword print quality

The approach detailed in this subclause provides additional diagnostic information and enables allowance to be made for the effect of error correction in masking less than perfect attributes of the symbol that influence symbol quality, by applying an overlay technique as described in Annex E. It enables the decodability, defects and modulation parameters of scan reflectance profiles covering the entire data region of the symbol to be graded in accordance with ISO/IEC 15416.

This approach uses the following procedure for the assessment of each of the three parameters. In symbols with more than one (e.g. interleaved) error correction block, it shall be applied to each block independently and the lowest value shall be used for grading purposes.

The entire symbol shall be scanned until $0{,}9 \cdot n$ codewords (where n is the number of non-error-correction data codewords in the symbol) have been decoded ten times or until it is certain that each codeword has been scanned at least once without inter-row interference. In each scan, the decodability, defects and modulation parameters shall be measured in each symbol character in accordance with ISO/IEC 15416. The calculation of all three parameters shall be based on the value of symbol contrast obtained from R_{max} and R_{min} in that scan line. The interim codeword grade of each parameter (modulation, defects and decodability) for each codeword is the highest codeword grade for that parameter obtained on any scan for that codeword.

Where the rows include overhead characters (other than the start and stop, or equivalent patterns), for example row indicators in PDF417 symbols, that are not included in the error correction calculation, these overhead characters shall be assessed first for each row together with the corresponding characters from the rows immediately above and below the row being considered. The highest interim codeword grade for any of these six (or four, in the case of the top or bottom row) characters shall be the overhead grade used to moderate the interim codeword grades for the codewords in the row. If a data codeword's interim codeword grade is higher than the grade obtained by the overhead characters, the data codeword's interim codeword grade shall be reduced to the overhead grade. The interim parameter grades so obtained shall then be modified to allow for the influence of error correction, as described in the next paragraph, and expounded upon in Annex E and in Table 4.

For each parameter, the cumulative number of symbol characters achieving each grade from 4,0 to 0 in steps of 0,1 or a higher grade, and those not decoded, shall be counted, and the counts shall be compared with the error correction capacity of the symbol. For each of these 41 grade levels, assuming that all symbol characters not achieving that grade or a higher grade are erasures, a notional grade shall be derived for unused error correction, on a scale of 4,0 to 0 in steps of 0,1, as described in 6.2.4, based on the percentage thresholds shown in Table 3. The codeword interim grade for each grade level shall be the lower of the grade level and the notional unused error correction grade. The final codeword parameter grade for the symbol shall be the highest codeword interim grade for all grade levels.

NOTE 1 This notional grade is not related to and does not affect the unused error correction grade for the symbol as calculated according to 6.2.4, but it is a means of compensating for the extent to which error correction can mask imperfections in a symbol. If one symbol has higher error correction capacity than another symbol, then the former symbol can tolerate a greater number of codewords with poor values for the parameter in question than the latter symbol. See Annex E for a more detailed description of the approach.

Table 4 shows an example of grading one parameter in a symbol containing 100 symbol characters (codewords) with an error correction capacity of 32 codewords. The 100 codewords consist of 68 data codewords, 3 error correction codewords reserved for error detection and 29 error correction codewords to be used for correcting erasures or errors, giving an erasure correction capacity of 29. The final codeword parameter grade would be 1,2 for the parameter concerned (the highest value in the right-hand column).

NOTE 2 A similar calculation is performed for parameter modulation, defects and decodability.

Table 4 — Example of codeword print quality parameter grading in symbols with cross-row scanning ability with the overlay procedure in Annex E

MOD/defect/ decodability grade level *a*	Number of codewords at grade level *a*	Cumulative number of codewords at grade level *a* or higher *b*	Remaining codewords treated as erasures (100 – *b*) *c*	Notional UEC capacity (29 – *c*)	Notional UEC %	Notional UEC grade *d*	Codeword interim grade (lower of *a* or *d*) *e*
4	30	30	70	(exceeded)	<0	0	0
3,9	6	36	64	(exceeded)	<0	0	0
3,8	1	37	63	(exceeded)	<0	0	0
3,7	1	38	62	(exceeded)	<0	0	0
3,6	0	38	62	(exceeded)	<0	0	0
3,5	1	39	61	(exceeded)	<0	0	0
3,4	0	39	61	(exceeded)	<0	0	0
3,3	0	39	61	(exceeded)	<0	0	0
3,2	1	40	60	(exceeded)	<0	0	0
3,1	2	42	58	(exceeded)	<0	0	0
3,0	3	45	55	(exceeded)	<0	0	0
2,9	4	49	51	(exceeded)	<0	0	0
2,8	4	53	47	(exceeded)	<0	0	0
2,7	3	56	44	(exceeded)	<0	0	0
2,6	2	58	42	(exceeded)	<0	0	0
2,5	1	59	41	(exceeded)	<0	0	0
2,4	1	60	40	(exceeded)	<0	0	0
2,3	0	60	40	(exceeded)	<0	0	0
2,2	0	60	40	(exceeded)	<0	0	0
2,1	0	60	40	(exceeded)	<0	0	0
2,0	1	61	39	(exceeded)	<0	0	0
1,9	2	63	37	(exceeded)	<0	0	0
1,8	3	66	34	(exceeded)	<0	0	0
1,7	3	69	31	(exceeded)	<0	0	0
1,6	2	71	29	0	0	0	0
1,5	1	72	28	1	3,45	0	0
1,4	0	72	28	1	3,45	0	0
1,3	5	77	23	6	20,7	0	0
1,2	4	81	19	10	34,5	1,7	1,2
1,1	5	86	14	15	51,7	3,1	1,1
1,0	1	87	13	16	55,2	3,4	1,0
0,9	0	87	13	16	55,2	3,4	0,9
0,8	0	87	13	16	55,2	3,4	0,8
0,7	0	87	13	16	55,2	3,4	0,7
0,6	0	87	13	16	55,2	3,4	0,6
0,5	0	87	13	16	55,2	3,4	0,5
0,4	0	87	13	16	55,2	3,4	0,4
0,3	0	87	13	16	55,2	3,4	0,3
0,2	0	87	13	16	55,2	3,4	0,2
0,1	0	87	13	16	55,2	3,4	0,1

Table 4 *(continued)*

MOD/defect/ decodability grade level *a*	Number of codewords at grade level *a*	Cumulative number of codewords at grade level *a* or higher *b*	Remaining codewords treated as erasures (100 – *b*) *c*	Notional UEC capacity (29 – *c*)	Notional UEC %	Notional UEC grade *d*	Codeword interim grade (lower of *a* or *d*) *e*
0	0	87	13	0.00	55,2	3,4	0
not decoded	13	100	0	29	100	4	0
				Parameter grade (highest value of *e*):			1,2

6.2.6 Overall symbol grade

The overall symbol grade shall be the lowest of the grade based on analysis of the scan reflectance profile in accordance with 6.2.2, and the grades based on codeword yield, unused error correction and each codeword parameter grade (decodability, modulation and defects) in accordance with 6.2.3, 6.2.4 and 6.2.5. Figure 3 summarizes this process.

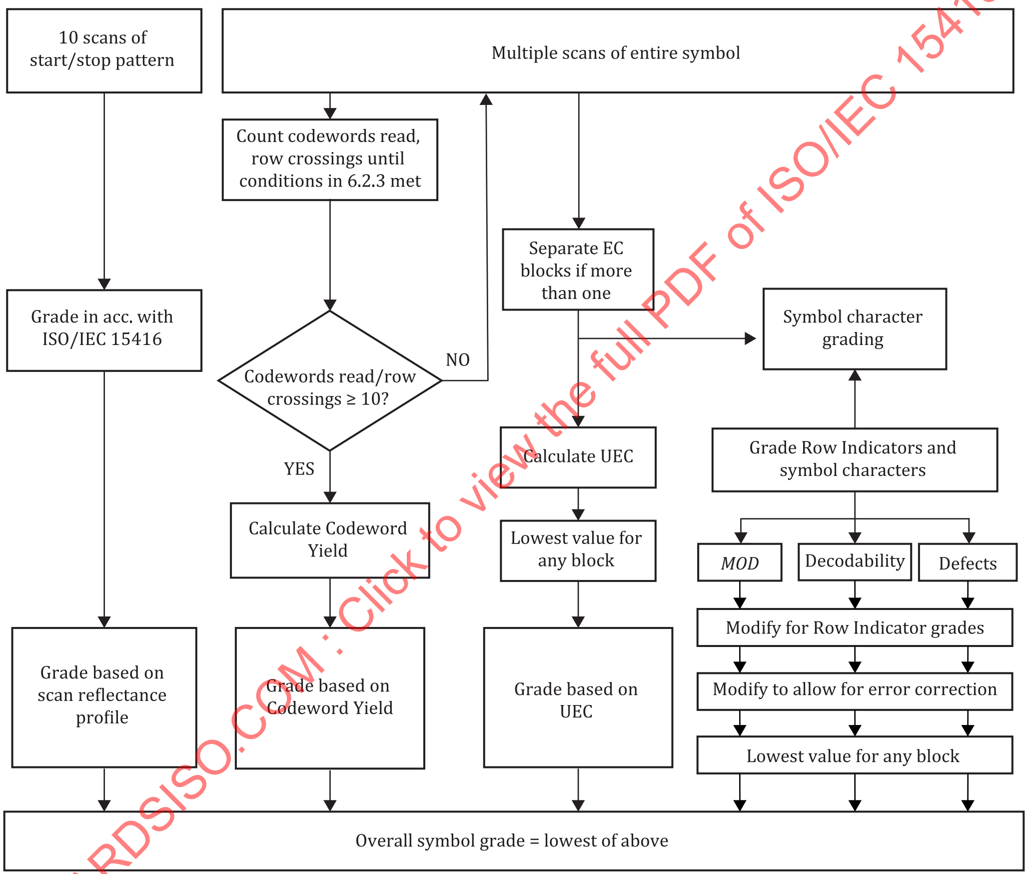


Figure 3 — Grading process for multi-row symbols with cross-row scanning ability

6.3 Symbologies requiring row-by-row scanning

The distinguishing feature of these symbologies is that they require a scan line to traverse a complete row from start to stop pattern (or in the reverse direction) without crossing into an adjacent row and that they require all rows to be scanned.

Each row shall be evaluated in accordance with ISO/IEC 15416 as though it were a separate symbol. Scan lines shall pass through the inspection band of the central 80 % of the height of each row, as specified in ISO/IEC 15416, in order to minimise the effects of cross-talk from adjacent rows. The number of scans per row should be the lower of ten, or the inspection band height divided by the aperture diameter. The overall symbol grade shall be the lowest overall grade obtained for any row.

7 Measurement methodology for two-dimensional matrix symbols

7.1 Overview of methodology

The measurement methodology defined in this clause is based on reflectivity and dimensional measurements and is intended to correlate with conditions encountered in two-dimensional matrix scanning systems.

The method starts by obtaining the raw image, as described in 5.6, which is a high-resolution grey-scale image of the symbol captured under controlled illumination and viewing conditions. The raw image is then converted into a reference grey-scale image, by convolving the raw image with a specified aperture. A binarised image is produced from the reference grey-scale image by applying a specially computed threshold (see Annex A), and this binarised image is then analysed by the reference decode algorithm of the applicable symbology to determine a grid of module centres. The grades for the parameters: decode, axial nonuniformity, grid nonuniformity and unused error correction, are determined from the results of the reference decode algorithm. The grades for the parameter symbol contrast is measured from the reference grey-scale image within the symbol region including its quiet zones that is determined by the reference decode algorithm. The reference grey-scale image is examined at the module centre locations determined by the reference decode algorithm to obtain values used for grading the parameters: modulation and fixed pattern damage. These steps are described in greater detail in 7.2 to 7.6.

NOTE The previous edition of this document recognised possible extreme reflectance values in the neighbourhood of the symbol, which can interfere with reading; however, only their presence was indicated in the report of the overall symbol grade by the use of an asterisk (*) character. This edition of this document removes the process of recognizing and indicating the presence of extreme reflectance and recommends the use of ISO/IEC 29158 in applications in which there is concern regarding the effect of extreme reflectance on reading performance.

In addition, print growth or loss may be measured and graded according to 7.5.10.

The symbol grade is the lowest grade achieved for these parameters and any others specified for a given symbology or application.

7.2 Test images

7.2.1 Raw image

The raw image consists of the actual reflectance values for each pixel of the light-sensitive array, from which are derived the reference grey-scale image and the binarised image.

7.2.2 Reference grey-scale image

The reference grey-scale image is obtained from the raw image by processing the individual pixel reflectance values through a synthetic aperture as defined in 5.6.2. It is used for the calculation of a threshold and then to generate the binarized image.

7.2.3 Binarised image

The binarised image is obtained from the reference grey-scale image by applying a threshold determined in Annex A. It is analysed by the reference decode algorithm of the applicable symbology to determine a grid of module centres and for the assessment of the parameters decode, axial nonuniformity, grid nonuniformity, and unused error correction.

NOTE The threshold is an optimized value based on a histogram of reflectance levels, not the mid-point between R_{max} and R_{min} as previously defined in a past edition of this document.

7.3 Reference reflectivity measurements

7.3.1 Application specification defines the aperture size

An application specification should specify an aperture size as defined in 5.4. An aperture size in the range of 50 % to 80 % of the smallest X dimension to be encountered in an application is recommended (but in all cases is defined by the application specification). In an application where symbols of differing *X* dimensions will be encountered, the application specification should either

a) ensure that all measurements are made with the aperture appropriate to the smallest *X* dimension to be encountered, or

b) specify more than one acceptance criteria with a different aperture size in each acceptance criteria.

An application specification has full discretion to define any number of acceptance criteria. This is normally the symbol grade along with other conditions defined in 5.4. When more than one criterion (e.g. with different apertures and a minimum allowed grade) is offered in an application specification, the specification shall define the acceptance logic. One option is to accept the symbol when one criterion passes. The other option is that both (or more) specified criteria shall pass. However, it is not advisable for an application specification to allow more than one lighting angle and wavelength because those physical attributes of a verifier are not mutable.

NOTE 1 Since the synthetic aperture can be modified in software in practical verifier implementations, this allows a higher flexibility of synthetic aperture definitions within an application specification.

EXAMPLE 1 The acceptance criteria using an aperture size appropriate to the smallest *X* dimension to be encountered is:

1,5/08/660/45

In this case, a grade of 1,5 or higher must be obtained with an aperture of 08.

EXAMPLE 2 The acceptance criteria using a variable aperture dependent upon the measured nominal module size is:

1,5/80 %/660/45Q

In this case, an aperture of 80 % of the measured Z dimension is to be used.

EXAMPLE 3 The acceptance criteria using two aperture sizes with different minimum acceptable grades is:

1,5/10/660/45 OR 0,5/20/660/45

In this case, a symbol that obtains a grade of either

a) a grade of 1,5 or higher measured with an aperture of 10, or

b) a grade of 0,5 or higher measured with an aperture of 20 is acceptable.

In applications in which a single aperture size or lighting does not adequately predict the scanning performance, the use of ISO/IEC 29158 may be chosen over this document alone.

7.4 Grading procedure

The grading procedure is as follows.

— Centre the symbol in the field of view or region of interest.

— Capture the raw image (see 7.2.1).

— Apply the aperture defined in 5.6.2 to the raw image to create a reference grey-scale image (see 7.2.2).

— A circular area in the reference grey-scale image with a diameter 20 times the aperture diameter, centred in the region of interest, shall be used to find the initial threshold in accordance with Annex A.

— Create a binarised image (see 7.2.3), find the symbol and perform an initial decode.

— Once the symbol has been decoded, compute a new threshold in accordance with Annex A within the reference grey scale of the image. The area taken into account is only the symbol including its quiet zones. Also compute a revised, or final, R_{max} and R_{min}, according to 7.5.3 within the inspection area of the reference grey-scale image.

— Create a new binarised image using this new threshold. Perform a final decode using the applicable reference decode algorithm to determine the definitive grid of module centres for the symbol.

— Calculate all graded parameters of the symbol based on information in the foregoing steps.

7.5 Image assessment parameters and grading

7.5.1 Use of reference decode algorithm

The symbology reference decode algorithm found in the symbology specification is to be used in the verification process. The reference decode performs the following tasks needed for subsequent measurement of the symbol quality parameters.

— It locates and defines the area covered by the test symbol in the image.

— It determines reference points from the fixed patterns of the symbol, typically the extreme corners, to be used in constructing an ideal grid for measuring GNU.

— It adaptively creates a grid mapping of the data module nominal centres so as to sample them.

— It determines the nominal grid centre spacings in each axis of the symbol (the symbol X dimension).

— It performs error correction, detecting if symbol damage has consumed any of the error capacity.

— It attempts to decode the symbol.

These functions each facilitate the determination of one or more of the parameters described in 7.5.2 to 7.5.11.

If this document is applied to a symbology for which there is no standard reference decode algorithm, then this should be noted in the verification report, along with the overall grade.

7.5.2 Decode

The decode parameter tests, on a pass or fail basis, whether the symbol has all its features sufficiently correct to be readable by the reference decode algorithm. The symbology reference decode algorithm shall be used to decode the symbol by computing the module centre positions on the grid determined by processing the binarised image.

If the image cannot be decoded using the symbology reference decode algorithm (even if a proprietary algorithm can be used to decode it), then it shall receive the failing grade 0. In the case of successful decode, codewords are checked to confirm that the codewords are valid according to the symbology specifications (e.g. invalid order, pad characters or use of undefined values are not valid). If any invalid encodation is detected, the decode shall also receive grade 0. Otherwise, it shall receive the grade 4.

7.5.3 Computing R_{max} and R_{min}

For the purposes of Clause 7, R_{min} shall be computed as the average of the darkest 1 % of the pixels and R_{max} shall be computed as the average of the brightest 1 % of the pixels in the inspection area.

NOTE These descriptions of R_{max} and R_{min} differ from those in the previous edition of this document and from the descriptions in Clause 6; they apply only to Clause 7.

7.5.4 Symbol contrast

The symbol contrast parameter measures the two reflective states in the symbol, namely light and dark, and the grade indicates the degree to which they are distinct within the symbol.

Symbol contrast (SC) is the difference between R_{max} and R_{min} values determined as described in 7.5.3:

$$\Delta R_{SC} = R_{max} - R_{min}$$

Symbol contrast shall be graded on an interpolated scale from 4,0 to 0 and rounded down to the nearest 0,1 as shown in Table 5.

Table 5 — Symbol contrast grading

Symbol contrast	Grade
≥70 %	4,0
≥55 % and <70 %	3,0 to 3,9
≥40 % and <55 %	2,0 to 2,9
≥20 % and <40 %	1,0 to 1,9
≥15 % and <20 %	0 to 0,9
<15 %	0,0

7.5.5 Modulation and related measurements

7.5.5.1 Modulation

Modulation is a measure of the uniformity of reflectance of the dark and light modules respectively. Factors such as print growth or loss, misplacement of a module relative to the grid intersection, the optical characteristics of the substrate and uneven printing can reduce the absolute value of the difference between the reflectance of a module and the threshold. A low modulation can increase the probability of a module being incorrectly identified as dark or light.

For symbologies that utilize error correction, some incorrectly identified modules may be tolerated within the error correction capacity of the symbol, so the grade assigned to modulation takes this into account. Furthermore, modules that have reflectivity close to the threshold and therefore may have higher probability to be incorrectly identified as dark or light, are also taken into account. Therefore, grading of modulation is closely related to the grading of unused error correction, as explained below and in Annex E. While modulation is graded only considering the data modules within the symbol, the values of MOD for modules within the fixed pattern are used to grade fixed pattern damage.

The value of MOD for each module is calculated from the reference grey-scale image value, R, at each module centre (determined by applying the symbology reference decode algorithm to the binarised image), R_{max}, R_{min} and the threshold as follows:

— for modules whose correct state is light:

$M_{MOD} = (R - T) / (R_{max} - T)$ for $R \geq T$ and $R < R_{max}$

$M_{MOD} = 100$ for $R \geq R_{max}$

$M_{MOD} = 0$ for $R < T$

— for modules whose correct state is dark:

$M_{MOD} = (T - R) / (T - R_{min})$ for $R < T$ and $R \geq R_{min}$

$M_{MOD} = 100$ for $R < R_{min}$

$M_{MOD} = 0$ for $R \geq T$

where

M_{MOD} is the modulation value for the module;

R is the reflectance of the module, given by the reference grey scale image at the module centre;

T is the threshold computed by Annex A over all the pixels within the symbol area;

R_{max} is the average maximum reflectance determined in accordance with 7.5.3;

R_{min} is the average minimum reflectance determined in accordance with 7.5.3.

Assign the grade level for each module in accordance with Table 6. For each codeword, select the minimum modulation grade of all modules in the codeword. Since M_{MOD} will be zero for all modules which are detected as a module error (i.e. R higher than T for a dark module or R is lower than T for a light module), the module grade shall also be 0 for those modules.

Table 6 — Module grading for modulation

MOD	Module grade
≥0,50	4,0
≥0,40 and <0,50	3,0 to 3,9
≥0,30 and <0,40	2,0 to 2,9
≥0,20 and <0,30	1,0 to 1,9
≥0,175 and <0,20	0,0 to 0,9
<0,175	0,0

Since grades are assigned on a scale from 4,0 to 0 in steps of 0,1, there are 41 possible grade levels. The cumulative number of codewords achieving each grade shall be counted and compared with the error correction capacity of the symbol as follows:

For each grade level, assuming that all codewords not achieving that grade or a higher grade are errors, derive a notional unused error correction grade as described in 7.5.9. Take the lower of the grade level and the notional UEC grade.

NOTE 1 This notional grade does not affect, the UEC grade for the symbol as calculated according to 7.5.9, but is a means of compensating for the extent to which error correction can mask imperfections in a symbol. If one symbol has higher error correction capacity than another symbol, then the former symbol can tolerate a greater number of codewords with low modulation than the latter. See Annex E for a fuller description of the approach.

Then the modulation grade for the symbol shall be the highest of the resulting values for all grade levels. When the symbol consists of more than one (e.g. interleaved) error correction block, each block shall be assessed independently and the lowest grade for any block shall be taken as the modulation grade of the symbol.

Tables 7 and 8 show examples of grading modulation in a data matrix symbol containing 18 codewords, 10 of which are error correction codewords with a capacity to correct up to 5 errors in a single error correction block. The modulation grade of the symbol in Table 7 is 2,2 (the highest value in the right-hand column) because that is the notional UEC grade for all levels of M_{MOD} codeword grade greater than 2,2. The modulation grade in Table 8 is 3,4 because the notional UEC grade is greater than 3,4 for all MOD levels below 3,4.

NOTE 2 The previous edition of this document defined reflectance margin and modulation. This edition of this document merges these into one parameter called modulation.

Table 7 — Example of modulation grading in a 2D matrix symbol with the overlay procedure in Annex E

MOD codeword grade level *a*	Number of codewords at level *a*	Cumulative number of codewords at level *a* or higher *b*	Remaining codewords treated as errors (18 – *b*) *c*	Notional UEC capacity (10 – *c*)	Notional UEC	Notional UEC grade *d*	Codeword interim grade (lower than *a* or *d*) *e*
4,0	10	10	8	exceeded	<0	0	0
3,9	5	15	3	2	0,40	2,2	2,2
3,8	0	15	3	2	0,40	2,2	2,2
3,7	0	15	3	2	0,40	2,2	2,2
3,6	0	15	3	2	0,40	2,2	2,2
3,5	0	15	3	2	0,40	2,2	2,2
... (21 rows: 3,4 to 1, 4)	... (0 in each row)	... (15 in each row)	... (3 in each row)	... (2 in each row)	... (0,40 in each row)	... (2,2 in each row)	... (2,2 in each row)
1,3	0	15	3	2	0,40	2,2	1,3
1,2	0	15	3	2	0,40	2,2	1,2
1,1	0	15	3	2	0,40	2,2	1,1
1,0	0	15	3	2	0,40	2,2	1,0
0,9	1	16	2	3	0,60	3,8	0,9
0,8	0	16	2	3	0,60	3,8	0,8
0,7	1	17	1	4	0,80	4,0	0,7
0,6	0	17	1	4	0,80	4,0	0,6
0,5	0	17	1	4	0,80	4,0	0,5
0,4	0	17	1	4	0,80	4,0	0,4
0,3	0	17 7	1	4	0,80	4,0	0,3
0,2	0	17	1	4	0,80	4,0	0,2
0,1	0	17	1	4	0,80	4,0	0,1
0	1	18	0	5	1,00	4,0	0
					Modulation grade (highest value of *e*):		2,2

Table 8 — Example of modulation grading in a 2D matrix symbol with the overlay procedure in Annex E

MOD codeword grade level *a*	Number of codewords at level *a*	Cumulative number of codewords at level *a* or higher *b*	Remaining codewords treated as errors (18 – *b*) *c*	Notional UEC capacity (5 – *c*)	Notional UEC	Notional UEC grade *d*	Codeword interim grade (lower than *a* or *d*) *e*
4,0	10	10	8	Exceeded	<0	0	0
3,9	5	15	3	2	0,60	2,2	2,2
3,8	0	15	3	2	0,60	2,2	2,2
3,7	0	15	3	2	0,60	2,2	2,2
3,6	0	15	3	2	0,60	2,2	2,2
3,5	0	15	3	2	0,60	2,2	2,2
3,4	3	18	0	5	1,00	4,0	3,4
3,3	0	18	0	5	1,00	4,0	3,3
3,2	0	18	0	5	1,00	4,0	3,2
... (28 rows: 3,1 ... 0,4)	... (0 in each row)	... (18 in each row)	... (0 in each row)	... (5 in each row)	... (1,00 in each row)	... (4,0 in each row)	... (3,1 to 0,4)
0,3	0	18	0	5	1,00	4,0	0,3
0,2	0	18	0	5	1,00	4,0	0,2

Table 8 *(continued)*

MOD codeword grade level *a*	Number of codewords at level *a*	Cumulative number of codewords at level *a* or higher *b*	Remaining codewords treated as errors (18 − *b*) *c*	Notional UEC capacity (5 − *c*)	Notional UEC	Notional UEC grade *d*	Codeword interim grade (lower than *a* or *d*) *e*
0,1	0	18	0	5	1,00	4,0	0,1
0	0	18	0	5	1,00	4,0	0
					Modulation grade (highest value of *e*):		3,4

7.5.5.2 Reporting contrast uniformity

Take the lowest value of M_{MOD} of any module in the data region of the symbol, as computed in 7.5.5.1 and report it as contrast uniformity (CU). This value is not graded, but only used for conformance testing and for process control, because it is the worst-case modulation found in any data module within the symbol.

NOTE Contrast uniformity is non-zero only when unused error correction is 100 % since otherwise at least one value of M_{MOD} will be zero.

7.5.6 Fixed pattern damage

This parameter grades damage to the finder pattern, quiet zone, timing, navigation and other fixed patterns in a symbol that can reduce the ability of the reference decode algorithm to locate and identify the symbol within the field of view. The particular patterns to be considered and the amounts of damage corresponding to the various grade thresholds must be specified independently for each symbology. Fixed pattern damage (FPD) shall be graded using the rules appropriate to each symbology, using the rules specified in the applicable symbology specification or, for the maxicode symbology specifically, as specified in ISO/IEC 15415:2011, Clause A.3.

Fixed pattern damage is evaluated in terms of the number of modules with low modulation and modules that appear as the inverse of the intended colour in the feature (or part of the feature) concerned. The MOD value of each module in the fixed pattern is calculated as defined in 7.5.5.1 and is assigned a module grade (in the range of 0 through 4,0 in steps of 0,1) according to Table 6. This way, the fixed pattern damage is graded on a continuous scale between 4,0 and 0,0 rounded down to the nearest 0,1.

7.5.7 Axial nonuniformity

Two-dimensional matrix symbols include data fields of modules nominally lying in a regular polygonal grid, and any reference decode algorithm must adaptively map the centre positions of those modules to extract the data. Axial nonuniformity (ANU) measures and grades the spacing of the mapping centres, i.e. the sampling points, or intersections of the grid obtained by applying the reference decode algorithm to the binarised image, in the direction of each of the grid's major axes. Axial nonuniformity tests for uneven scaling of the symbol which would hinder readability of the symbol.

The spacings between adjacent sampling points are independently sorted for each polygonal axis, then the average spacings X_{AVG}, Y_{AVG}, ... along each axis are computed. Axial nonuniformity is a measure of how much the sampling point spacing differs from one axis to another, namely:

$$M_{ANU} = \text{abs}(X_{AVG} - Y_{AVG}) / [(X_{AVG} + Y_{AVG}) / 2]$$

where abs() yields the absolute value.

If a symbology has more than two major axes, the axial nonuniformity is computed for those two average spacings which differ the most.

Axial nonuniformity shall be graded as shown in Table 9.

Table 9 — Axial nonuniformity grading

Axial nonuniformity	Grade
≤0,06	4,0
≤0,08 and >0,06	3,0 to 3,9
≤0,10 and >0,08	2,0 to 2,9
≤0,12 and >0,10	1,0 to 1,9
≤0,14 and >0,12	0,0 to 0,9
>0,14	0,0

7.5.8 Grid nonuniformity

Grid nonuniformity (GNU) measures and grades the largest vector deviation of the grid intersections, determined by the reference decode algorithm from the binarized image of a given symbol, from their ideal theoretical position.

Using the reference decode algorithm for the symbology, plot the positions of all grid intersections in the data area of the symbol and compare these positions with the ideal grid in a theoretical perfect symbol of the same nominal dimensions. The ideal grid is evenly spaced and based on the minimum number of points that defines the symbols borders or axes. The symbology specification should define these points for the purpose of grading the grid nonuniformity. The greatest distance between the actual and the theoretical position of any intersection, expressed as a fraction of the *X* dimension of the symbol, shall be taken for grading purposes.

Grid nonuniformity shall be graded as shown in Table 10.

Table 10 — Grid nonuniformity grading

Grid nonuniformity	Grade
≤0,38	4,0
≤0,50 and >0,38	3,0 to 3,9
≤0,63 and >0,50	2,0 to 2,9
≤0,75 and >0,63	1,0 to 1,9
>0,75	0,0
NOTE The GNU grade is zero whenever the GNU value exceeds 0,75 with no gradual change between 1,0 and 0.	

7.5.9 Unused error correction

The unused error correction parameter tests the extent to which regional or spot damage in the symbol has eroded the reading safety margin that error correction provides. Unused error correction is graded based on the amount of error and erasures found by the reference decode algorithm. The amount of unused error correction is calculated as

$$M_{\mathrm{UEC}} = 1{,}0 - [(e + 2t) / E_{\mathrm{cap}}]$$

where

e is the number of erasures;

t is the number of errors;

E_{cap} is the error correction capacity of the symbol (i.e. the number of error correction codewords minus the number of error correction codewords reserved for error detection).

If no error correction has been applied to the symbol, and if the symbol decodes, unused error correction is taken as 1. If (e + 2t) is greater than E_{cap}, unused error correction is taken as 0. In symbols with more than one (e.g. interleaved) error correction block, unused error correction shall be calculated for each block independently and the lowest value shall be used for grading purposes.

Unused error correction shall be graded as shown in Table 11.

Table 11 — Unused error correction grading

Unused error correction	Grade
≥0,62	4,0
≥0,50 and <0,62	3,0 to 3,9
≥0,37 and <0,50	2,0 to 2,9
≥0,25 and <0,37	1,0 to 1,9
≥0,20 and <0,25	0,0 to 0,9
<0,20	0,0

7.5.10 Print growth

Print growth (PG) tests that the graphical features comprising the symbol have not grown or shrunk from its nominal state so much as to hinder readability with less favourable imaging conditions than the test condition. The print growth parameter, the extent to which dark or light markings appropriately fill their module boundaries, is an important indication of process quality which affects reading performance. Print growth may be measured and evaluated independently in more than one axis to determine, for example, both horizontal and vertical growth.

Print growth shall be graded according to a symbology specification, if defined. If a symbology specification states that print growth shall be graded, but does not define a specific method, it shall be graded as defined in this clause. Otherwise, it is not a graded parameter but should be reported as an informative measure for the purposes of process control.

Print growth can be measured in the general way described in this subclause but it can be more specifically defined in a symbology specification.

Identify the graphical structures particular to the symbology that are most indicative of element growth or shrinkage in each axis of the symbol, which are generally fixed structures or isolated elements, such as clock tracks. Based on the symbology specification and its reference decode algorithm, determine for each of these structures, in each axis, its nominal dimension in modules. Measure the actual dimension in modules, of the structure along the grid lines derived by the use of the reference decode algorithm and passing through each structure to be measured in the symbol axis in question. The difference between the actual dimension and the nominal dimension, as a fraction of a module, is the print growth for each fixed structure. Print growth shall then be calculated for each axis as the arithmetic mean of the print growth of all fixed structure measured as described above. Where the result is negative, it represents print loss.

Unless specified differently in a symbology specification, and where a symbology specification states that print growth shall be graded in accordance with this document and not defined alternately, the print growth grade shall be calculated in accordance with Table 12 in the range from 0,0 to 4,0 rounded down to the nearest 0,1 by using the absolute value of print growth.

Table 12 — Default print growth grading

Absolute value of print growth	Grade
≤0,10	4,0
≤0,28 and >0,10	3,0 to 3,9
≤0,34 and >0,28	2,0 to 2,9
≤0,40 and >0,34	1,0 to 1,9
≤0,60 and >0,40	0,1 to 0,9
>0,60	0,0

NOTE The recommendation that print growth be a graded parameter is a new feature of this edition of this document, see 7.5.11.3.

7.5.11 Additional grading parameters

7.5.11.1 General

Either symbology or application specifications, or both, can define additional parameters which may be graded and accounted for in the calculation of the overall symbol grade.

7.5.11.2 Application specifications

An application specification can require, among other things, that the *Z* dimension is within a certain range or that the data encoded within a symbol meets certain defined criteria.

7.5.11.3 Symbology specifications

Symbology specifications should define fixed pattern damage grading.

It is recommended that symbology specifications define print growth as a graded parameter because print growth is not always detected by other graded parameters especially when the aperture size is small relative to the *X* dimension (see Clause F.4). If print growth is to be graded, but the general approach described in this document for grading print growth does not fit the symbology, then an alternate definition for measuring and grading of print growth should be defined in the symbology standard.

Symbology standards must also define the reference decode algorithm to be used for the parameter decode and for defining the symbol grid which is used for evaluating many other parameters, as well as the basis for defining the ideal grid used for computing grid nonuniformity.

7.6 Symbol grade

The symbol grade shall be the lowest grade of any parameter as measured in accordance with 7.5.2 through 7.5.11, excluding 7.5.5.2.

In order to determine the causes of grades of poor quality, it is necessary to examine the grades for each parameter, especially the one(s) with the lowest grade(s). Annex B offers some guidance on the interpretation and possible root causes for low grades.

Overall symbol grades shall be expressed on a numeric scale ranging in descending order of quality from 4,0 to 0,0 rounded down to the nearest 0,1.

8 Measurement methodologies for composite symbologies

Each component shall be measured and graded separately. The linear component shall be measured and graded in accordance with ISO/IEC 15416. When the two-dimensional composite component uses a multi-row bar code symbology, then the methodology specified in Clause 6 shall be applied to the two-dimensional composite component; when it uses a two-dimensional matrix symbology, then the methodology specified in Clause 7 shall be applied to it. Both the overall grade for the linear component so measured and the overall grade for the two-dimensional composite component shall be reported, to assist users who only require to read the linear component as well as those requiring to read the complete symbol.

Annex A
(normative)

Thresholding algorithm based on histogram

A.1 Algorithm description

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

a) Initialize the variable minVariance to a very large number and initialize Tmin and Tmax to zero.

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

1) Compute the mean and variance of pixels below g and call it MeanDark and VarianceDark.

2) Compute the mean and variance of pixels above or equal to g and call it MeanLight and VarianceLight.

3) Compute Variance = VarianceLight + VarianceDark.

4) If Variance < minVariance, save Variance in minVariance and save g in Tmin.

5) If Variance = minVariance save g in Tmax.

NOTE Step 5 is used to break ties. Tmin is the smallest grey-level where the variance is the minimum and Tmax is the largest grey-level where the variance is the same minimum.

c) Optimal threshold T = (Tmin + Tmax) / 2.

A.2 Example

For simplicity, an image with only 100 pixels (a 10 × 10 image) is 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.

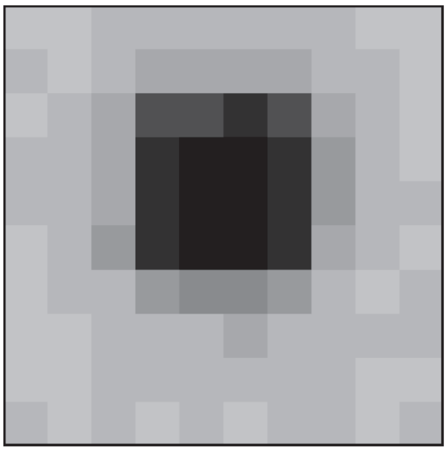


Figure A.1 — Image used in this example

Firstly, the number of pixels contained in the image with each of the 16 grey levels are counted. 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

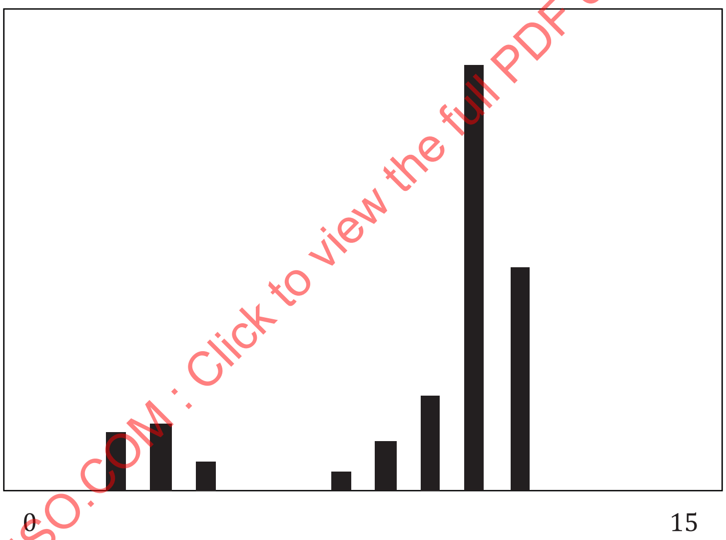


Figure A.2 — Histogram of the data in Table A.1

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, the variance of both portions of the histogram is computed. 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

$[(2 \times 6) + (3 \times 7) + (4 \times 3)] \div 16 = 2{,}81$

and it 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

$(([2{,}81-2]^2 \times 6) + ([2{,}81-3]^2 \times 7) + ([2{,}81-4]^2 \times 3)) \div 16 = 0{,}53$

Similarly, the variance of the light elements (those whose pixel value is 5 or greater) is: 0,84.

The variances of the dark and light portions of the histogram for each threshold can be computed in a similar manner. 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 gives this minimum which is 5,5 in this example.

Note that the threshold obtained by this averaging does 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 Clause 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 in Figure A.3.

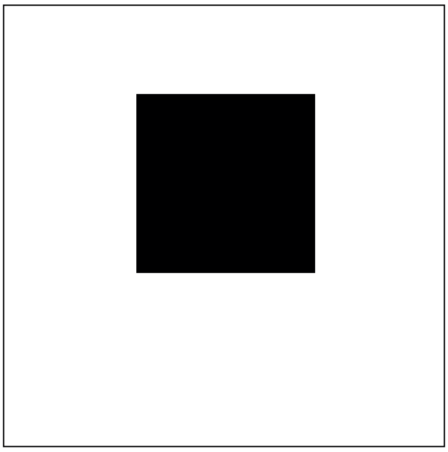


Figure A.3 — Image with threshold applied

Annex B
(informative)

Interpreting the scan and symbol grades

This Annex describes possible causes of reduced grades, either in a multi-row symbol or a matrix symbol.

Table B.1 identifies factors that can lead to low or failing grades for the parameters indicated, which can be similar or can differ for the two classes of two-dimensional symbols.

Table B.1 — Possible causes of low grades

Parameter	Multi-row symbols	Matrix symbols

Symbol contrast	— low background or light module reflectance, due to:
	  — incorrect substrate e.g. blue paper for red light
	  — glossy laminate/overwrap
	  — inappropriate angle of illumination (direct marked symbols)
	— high dark module reflectance, due to
	  — low absorption of incident light by ink (unsuitable formulation/colour)
	  — insufficient ink coverage (e.g. non-overlapping ink-jet dots)
	  — inappropriate angle of illumination (direct marked symbols)
		— low background or light module reflectance, due to:
		  — incorrect substrate e.g. blue paper for red light
		  — glossy laminate/overwrap
		  — inappropriate angle of illumination (direct marked symbols)
		— high dark module reflectance, due to
		  — low absorption of incident light by ink (unsuitable formulation/colour)
		  — insufficient ink coverage (e.g. non-overlapping ink-jet dots)
		— inappropriate angle of illumination (direct marked symbols)

Decode	— many factors – see other parameters in this table — software errors in printing system	— many factors - see other parameters in this table — software errors in printing system
Unused error correction	— physical damage (scuffing, tearing, obliteration) — bit errors due to defects — excessive print growth in one or two axes — local deformation — misplaced modules	— physical damage (scuffing, tearing, obliteration) — bit errors due to defects — excessive print growth in one or two axes — local deformation — misplaced modules
Minimum reflectance, R_{min}	— reflectance of all bars >0,5R_{max} – see symbol contrast for possible causes	—
Minimum edge contrast	— excessive print growth/loss — too large measuring aperture — irregular substrate reflectance — low ink coverage — showthrough	—

Table B.1 *(continued)*

Parameter	Multi-row symbols	Matrix symbols
Modulation	— print growth/loss — too large measuring aperture — irregular substrate reflectance — variation in ink coverage — showthrough	— print growth or loss — too large measuring aperture — misplaced modules — defects (spots or voids) — irregular substrate reflectance — variation in ink coverage — showthrough
Defects	— spots of ink or other dark marks on background — voids in printed areas — faulty print head elements — too small measuring aperture	—
Decodability	— local distortion — pixel errors in printing — slippage during printing — blocked inkjet nozzle — faulty thermal element	—
Codeword yield	— excessive tilt of scan line — *Y* axis print growth — thermal "drag"	—
Fixed pattern damage	—	— blocked printer nozzle — faulty thermal element — physical damage (tearing, scuffing, obliteration)
Axial nonuniformity	—	— mismatch of transport speed in printing with symbol dimensions — printing software errors — verifier axis not perpendicular to symbol plane
Grid nonuniformity	—	— transport errors in printing (acceleration/deceleration, vibration, slippage) — variation in printhead to substrate distance — verifier axis not perpendicular to symbol plane — pixel errors in printing
Print growth or loss	— print process-dependent factors — absorbency of substrate — dot size (ink-jet, dot peening, etc.) — incorrect thermal print head temperature	— print process-dependent factors — absorbency of substrate — dot size (ink-jet, dot peening, etc.) — incorrect thermal print head temperature

Annex C
(informative)

Guidance on selecting grading parameters in application specifications

C.1 Selection of measurement wavelength

C.1.1 General considerations

The wavelength of light used for verification is very important and should be specified by the appropriate application. This Annex provides guidance to applications with respect to typical sources of illumination and so that verification of symbols can correlate to scanning performance in actual applications. The application standard may select any appropriate source of illumination, whether or not it is listed in this Annex. In the absence of an application specification giving illumination (and other) parameters, verification results are not reproducible.

Clauses 6 and 7 require measurements to be made using light of the same characteristics as those which the intended scanning environment will use. If, as can happen, an application specification does not specify the light source, a judgment must be made in order to determine the most probable light source for reading, to enable valid measurements to be made and to be sure that the results will be properly indicative of likely scanning performance in the application.

It should be noted that for maximum correlation, it is not only the light source (including any filters that modify its spectral distribution) that must be taken into account, but also the spectral sensitivity of the sensor, since reflectance at a given wavelength is a function of the product of the intensity of the light emitted and the sensitivity of the sensor. However, for the purposes of this Annex, the sensor sensitivity is ignored.

In general, the sensor should be nominally linear and not enhanced in any way, as described in 5.6.3. Specific care shall be taken if any filters are used since they can modify the raw image significantly and produce results that are not reproducible. Filters, including polarization, low pass, high pass or notch filters, should only be used according to an application specification which specifies the use of such filters for an application specific purpose. In any case in which the use of a filter significantly affects a measurement, the use of the filter should be reported along with the grade.

C.1.2 Light sources

Light sources for bar code scanning applications normally fall into two areas:

— narrow band illumination in either the visible or the infra-red spectrum, or

— broadband illumination covering a large part of the visible spectrum, sometimes referred to as "white light" although it can have a bias to a colour; very few specialised applications may call for light sources of unusual characteristics such as ultra-violet for fluorescent symbols.

Multi-row bar code scanning almost always uses narrow band visible light, with light sources with a peak wavelength in the red part of the spectrum, between 620 and 700 nm. Infra-red scanning uses sources with peak wavelengths between 720 nm and 940 nm.

Two-dimensional matrix symbols are scanned under a variety of illumination conditions, with the most common being white light and, in a number of hand-held reading devices, the same visible red area of the spectrum as for linear and multi-row bar code symbols.

The most common light sources, but not a complete list, that may be used for these purposes are:

a) narrow band:

   1) light-emitting diode (near-monochromatic, at numerous visible and infra-red peak wavelengths), and

   2) solid-state laser diode (most usually 650 nm and 670 nm) (multi-row bar code symbols only);

b) broadband:

   1) incandescent lamp (nominally white light with a colour temperature in the range 2800 K to 3200 K), and

   2) light-emitting diode (LED) with nominally “white light” characteristics that emit different intensities for red, green and blue components; their actual spectral distribution can show a number of peaks, for example, in the blue and yellow or orange regions with a colour temperature in the range of 2000 K to 7000 K) depending on the specific LED type,

   NOTE 1 A formal grade including a light specifier of /W(7000 K) is an example of white light-emitting diode illumination.

   3) halogen lamps (nominally white light with a colour temperature in the region of 2800 K to 3200 K), and

   4) gas discharge lamps (light of various characteristics).

NOTE 2 Broadband illumination is often the ambient light in a scanning environment.

The key characteristics of these are as follows.

A light-emitting diode is a low-power solid-state component most frequently found as the light source in a light pen (wand) or CCD (charge coupled device) scanner. Operating wavelengths in the visible spectrum may be from 620 to 680 nm; most commonly either 633/640 or about 660 nm. In the infra-red spectrum, 880 to 940 nm is the most common range of wavelengths. In the UV (ultraviolet) spectrum, 365 nm to 395 nm is the most common range of wavelengths.

A laser diode is also a low power solid-state component emitting highly monochromatic coherent light. Typical wavelengths in the visible spectrum used by these, at the date of publication of this document, is 650 nm. In the infra-red spectrum, 780 nm is common. They are frequently found in hand-held (laser) scanning equipment and a number of fixed scanners.

Broadband light sources are mainly found in systems using two-dimensional imaging and image processing technology rather than scanning techniques.

Incandescent lamps have a power distribution covering much of the visible spectrum and well into the near infra-red spectrum; their optical characteristics are more easily defined in colour temperature terms rather than in those of peak wavelength, because of the wide bandwidth and relative absence of clearly-defined peaks in the power distribution. These broadband power distribution characteristics mean that the symbol contrast values obtained from symbols may vary with different colour temperatures to a significantly lesser extent than values obtained with light sources whose power distributions peak sharply with narrow bandwidth.

Halogen lamps (also known, more correctly, as tungsten halogen lamps) are a development of incandescent lamps with a higher colour temperature and a smooth power distribution curve across the spectrum, extending well into the near infra-red.

Fluorescent light sources also produce nominally white light and have broadband power distribution characteristics, which, in comparison with those of an incandescent source, tend more towards the bluer region of the visible spectrum, often with a significant ultra-violet component, and a number of peaks in their spectral power distribution. Typical colour temperatures for such lighting are in the region of 3200 K to 5500 K. The physical structure of a fluorescent lamp is that of a tube which can be formed into various shapes, and an annular shape concentric with the optical axis of a reading device provides very satisfactory uniform diffuse illumination.

Light emitting diodes with nominally "white light" characteristics emit "cool" white light and may have a nominal colour temperature in the region of 7 000 K. Their actual spectral distribution can show a number of peaks, for example, in the blue, and yellow or orange regions.

Gas discharge lamps tend to have spectral distributions with multiple sharp peaks at wavelengths depending on the precise mixture of gases used. For example, sodium vapour emits light with a well-defined peak at around 580 nm (yellow-orange) and mercury vapour emits a green-blue light at around 520 nm.

The use of filters to modify the spectral distribution of the illumination system is common. For example, when used in conjunction with a Wratten 26 filter, the light characteristics of a 2 856 K lamp approximate to those of a 620 nm to 633 nm source. The use of infra-red and/or ultra-violet absorbing filters is also common in scanning systems. It is possible to alter the apparent colour temperature of a source using filters.

NOTE 3 Light source types, wavelengths and colour temperatures stated above are indicative and can change as the technology evolves. Helium-neon lasers for example are not common anymore and has been removed from the above description in this edition of this document.

C.1.3 Effect of variations in wavelength

The reflectance of a substrate or bar code symbol element varies with the wavelength of the incident light. A black, blue or green printed area tends to absorb visible red light strongly (and appear therefore of low reflectance), whereas a white, red or orange area reflects most of such incident light. In the infra-red spectrum, the apparent colour of the element does not correlate at all with reflectance; it is the nature of the pigmentation used (e.g. the proportion of carbon content) which governs reflectance. Taking reflectance measured at 633 nm as a reference, when measured at 660 or 680 nm the results can differ significantly and sufficiently to cause the symbol grade to change by one or two units, or even more in the case of bars printed on some thermal papers.

In the case of broadband illumination, however, the presence of light at multiple wavelengths in the spectral power distribution of the light means that reflectance values of black inks measured under white light from various sources does not differ significantly; however, there can be some variation (an increase in reflectance) in the case of dye-based black inks where the illumination has a significant infra-red component. With coloured pigments, there is greater variations. Interposing a filter in the light path introduces a more peaked spectral distribution and the spectral response curve of the reader will require to be more closely matched to that of the light source. It is common for the optical system to include both infra-red and ultra-violet absorbing filters.

C.1.4 Considerations affecting selection of broadband light sources

Broadband light sources, by definition, emit light over a band of wavelengths without a clearly defined sharp peak. Nonetheless, the intensity of light emitted at different wavelengths will vary. In particular, the light of a colour temperature in the region of 3000 K is described as "warm" light and the spectral distribution of this light shows higher intensity of emission towards the red (and infra-red) region of the spectrum, whereas light with a higher colour temperature in the region of 6500 K is described as "cool" light and its spectral distribution is biased to the blue-violet region of the spectrum, extending into the ultra-violet. Light with a higher colour temperature will yield higher reflectance values on blue pigments than light with a lower colour temperature. The converse is true for red pigments.

It is possible to modify the apparent colour temperature of a light source by the interposition of an appropriate filter.

It can also be possible to approximate the characteristics of different broadband light sources with sufficient precision for bar code symbol quality assessment purposes by combining reflectance measurements at three narrow band wavelengths across the visible spectrum, e.g. in the red, green and blue regions (assuming that the ultra-violet and infra-red regions have been cut off by the use of appropriate absorbing filters); the results can then be modified to match the spectral response characteristics in the application by applying an appropriate correction factor at each wavelength.

C.2 Selection of aperture

The choice of aperture size is very important, and it must be specified in accordance with 5.4 for matrix symbol grading and ISO/IEC 15416 for stacked symbol grading, in order for symbol grades to be measured consistently. It is the responsibility of an application specification to define an appropriate measuring aperture to be used. As required by 5.5, the aperture size must be reported together with the grade and illumination in order to identify the conditions under which the measurement was made.

NOTE 1 The term "aperture" does not refer to the opening of a lens but to the convolution of the raw image.

The size of the measuring aperture affects whether voids in the symbol will be “filled in” during the verification process. Therefore, the measuring aperture must be selected with reference to the range of nominal module size and expected scanning environment. An aperture that is too small is not able to fill in unintentional voids, or gaps between elements of a direct marked symbol, and that would lead to low grades or undecodable symbols. On the other hand, a measuring aperture that is too large blurs individual modules, resulting in low modulation, and can prevent the symbol from being decoded.

An aperture size in the range of 50 % to 80 % of the minimum allowed module size is a typical choice for an application specification. Importantly however, an application specification that allows a range of nominal module sizes (e.g. a range of 0,25 mm through 0,40 mm) should specify a single aperture size to be used in all cases or should specify more than one acceptance criteria, each with a different aperture size. If more than one acceptance criteria is allowed in an application, scanning all of the acceptable symbols becomes more challenging to practical readers with fixed scanning parameters.

In applications in which a single aperture size does not adequately predict scanning performance, ISO/IEC 29158 should be used instead of this document.

The reason that more than one aperture size can be desirable in an application is that the relatively small measuring aperture required to read the symbols with the smallest module size limits the size of the largest acceptable spots and voids. But, if an overly large aperture is used, the modulation for the smallest module size becomes inadequate. In general, the larger the aperture, the larger the acceptable size of spots and voids. Conversely, the smaller the aperture, the smaller the acceptable module size that can be read. Therefore, a successful application specification must select a measuring aperture that predicts the readability of both the largest and smallest module size symbols. If an application truly contains symbols with a large range of X dimensions, different aperture sizes should be used in order to optimize the performance for all the symbols by using different aperture sizes and thereby offering tolerance of spots and voids in all the symbols to a larger extent than would be possible if using an aperture that was appropriate of the smallest X dimensions.

The choice of measuring aperture(s) specified can be influenced by the scanning equipment that is expected to be prevalent in the application scanning environment. Conversely, the choice of the scanning equipment can also be influenced by the specification of the measuring aperture(s). In both cases, however, a “match” between the verification technique and the scanning environment is made in order to produce a high correlation between grade level and scanning performance.

Table C.1 may be used by application specification writers as a guide. When the measuring aperture diameter is not specified in the application specification, Table C.1 should be used as a guide when applying this document for process control purposes.

NOTE 3 An application specification can specify a range of X dimensions that differs from those listed in Table C.1 and can specify an aperture size that differs from the recommendation of Table C.1.