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

Technologies de l'information — 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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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC 15415 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

This second edition cancels and replaces the first edition (ISO/IEC 15415:2004), which has been technically revised. It also incorporates the Technical Corrigendum ISO/IEC 15415:2004/Cor.1:2008.

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 sub-divided 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. Dot codes are a subset of matrix codes in which the individual modules do not directly touch their neighbours but are separated from them by a clear space.

Unless the context requires otherwise, the term "symbol" in this International Standard may refer 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 standards 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 (verifiers) is the subject of a separate International Standard (ISO/IEC 15426, Parts 1 and 2).

This International Standard is intended to achieve comparable results to the linear bar code symbol quality standard ISO/IEC 15416, the general principles of which it has followed. It should be read in conjunction with the symbology specification applicable to the bar code symbol being tested, which provides symbology-specific detail 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.

There are currently many methods of assessing bar code quality at different stages of symbol production. The methodologies described in this International Standard are not intended as a replacement for any current process control methods. They provide symbol producers and their trading partners with universally standardized means for communicating about the quality of multi-row bar code and two-dimensional matrix symbols after they have been printed. The procedures described in this International Standard 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.

Alternative methods of quality assessment may be agreed between parties or as part of an application specification.

For direct part mark applications, a modified version of the methodology defined in this International Standard has been defined in ISO/IEC TR 29158.

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

1 Scope

This International Standard

— specifies two methodologies for the measurement of specific attributes of two-dimensional bar code symbols, one of these being applicable to multi-row bar code symbologies and the other to two-dimensional matrix symbologies;

— defines 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 International Standard applies to those two-dimensional symbologies for which a reference decode algorithm has been defined, but its methodologies can be applied partially or wholly to other similar symbologies.

While this International Standard can be applied to direct part marks, it is possible that better correlation between measurement results and scanning performance will be obtained with ISO/IEC TR 29158 in combination with this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 19762-1, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 1: General terms relating to AIDC*

ISO/IEC 19762-2, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 2: Optically readable media (ORM)*

ISO 7724-2:1984, *Paints and varnishes — Colorimetry — Part 2: Colour measurement*

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

NOTE The Bibliography lists official and industry standards containing specifications of symbologies to which (inter alia) this International Standard is applicable.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19762-1, ISO/IEC 19762-2, ISO/IEC 15416 and the following apply.

3.1
binarised image
binary (black/white) image created by applying the Global Threshold to the pixel values in the reference grey-scale image

3.2
effective resolution
resolution obtained on the surface of the symbol under test, normally expressed in pixels per millimetre or pixels per inch, and calculated as the resolution of the image capture element multiplied by the magnification of the optical elements of the measuring device

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

3.4
inspection area
rectangular area 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 is inverted from its intended state

3.7
pixel
individual light-sensitive element in an array [e.g. CCD (charge coupled device) or CMOS (complementary metal oxide semiconductor) 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 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 of the light-sensitive array by convolving the raw image with a synthesised circular aperture

3.10
reflectance margin
measurement of modulation using error correction and known module colours

3.11
sample area
area of an image contained within a circle 0,8X in diameter, X being the average module width determined by the application of the reference decode algorithm for the symbology in question or, where the application permits a range of X dimensions, the minimum module width permitted by the application specification

3.12
scan grade
result of the assessment of a single scan of a matrix symbol, derived by taking the lowest grade achieved for any measured parameter of the reference grey-scale and binarised images

4 Symbols and abbreviated terms

AN = Axial Nonuniformity

E_{cap} = error correction capacity of the symbol

e = number of erasures

FPD = Fixed Pattern Damage

GN = Grid Nonuniformity

GT = Global Threshold

MARGIN = a measure of the difference in reflectance between a module and the global threshold, the value of which goes to zero for modules of the incorrect reflectance state

MOD = an absolute measure of the difference in reflectance between a module and the global threshold

R_{max} = highest reflectance in any element or quiet zone in a scan reflectance profile, or the highest reflectance of any sample area in a two-dimensional matrix symbol

R_{min} = lowest reflectance in any element in a scan reflectance profile, or the lowest reflectance of any sample area in a two-dimensional matrix symbol

SC = Symbol Contrast (equal to R_{max} - R_{min})

t = number of errors

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 indicating the overall quality of the symbol which can be used by producers and users of the symbol for diagnostic and process control purposes, and which is broadly predictive of the read performance to be expected of the symbol in various environments. The process requires the measurement and grading of defined parameters, from which a grade for an individual scan (scan reflectance profile grade or scan grade) is derived; the grades of multiple scans of the symbol are averaged to provide the overall symbol grade.

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. Application specifications should therefore define the required performance in terms of overall symbol grade in accordance with this standard. The guidelines in Annex D.4 are provided as an aid in writing application standards which employ this standard.

This standard 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 international standard.

NOTE Information on sampling plans may be found in the following: ISO 3951-1, ISO 3951-2, ISO 3951-3, ISO 3951-5 or ISO 2859-10.

5.2 Expression of quality grades

Although this International Standard specifies a numeric basis for expressing quality grades on a descending scale from 4 to 0, with 4 representing the highest quality, individual parameter grades and individual scan grades may also be expressed on an equivalent alphabetic scale from A to D, with a failing grade of F, in application standards with a historical link to ANSI X3.182.

Table 1 maps the alphabetic and numeric grades to each other.

Table 1 — Equivalence of numeric and alphabetic quality grades

Numeric grade	Alphabetic Grade
4	A
3	B
2	C
1	D
0	F

5.3 Overall Symbol Grade

The overall symbol grade shall be calculated as defined in 6.2.6 or 7.10. Overall symbol grades shall be expressed to one decimal place on a numeric scale ranging in descending order of quality from 4,0 to 0,0.

Where a specification defines overall symbol grades in alphabetic terms the relative mapping of the alphabetic and numeric grades is as illustrated in Figure 1 below. For example, the range of 1,5 to immediately below 2,5 corresponds to grade C.

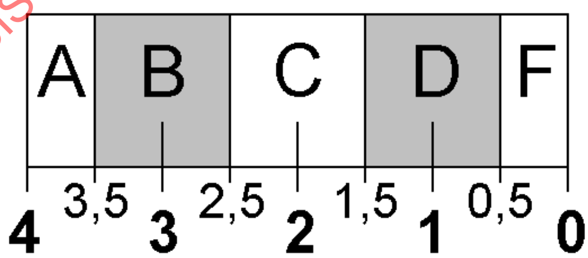


Figure 1 — Mapping of alphabetic and numeric overall symbol grades

5.4 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*" is the overall symbol grade as defined in 6.2.6 or 7.10, i.e. the arithmetic mean to one decimal place of the scan reflectance profile or scan grades,
- *"aperture"* is 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 synthetic aperture defined in 7.3.3),
- "*light*" defines the illumination: a numeric value indicates the peak light wavelength 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"* is an additional parameter defining the angle of incidence (relative to the plane of the symbol) of the illumination. It shall be included in the reporting of the overall symbol grade when the angle of incidence is other than 45°. Its absence indicates that the angle of incidence is 45°.

NOTE While illumination from four sides with an angle of incidence of 45° is the default, other angles of incidence may be specified as requirements for grading by specifying the angle instead of leaving it blank. Other lighting options are defined in ISO/IEC TR 29158 which may be more appropriate for direct part marking applications, especially in applications which rely on symbols marked on reflectance substrates.

An asterisk following the value for "grade", in the case of a two-dimensional matrix symbol, indicates that the surroundings of the symbol contain extremes of reflectance that may interfere with reading - see 7.6.

Examples

2,8/05/660 would indicate that the average of the grades of the scan reflectance profiles, or of the scan grades, was 2,8 when these were obtained with the use of a 0,125 mm aperture (ref. no. 05) and a 660 nm light source, incident at 45°.

2,8/10/W/30 would indicate the grade of a symbol intended to be read in broadband light, measured with light incident at 30° and using a 0,250 mm aperture (ref. no. 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.

2,8*/10/670 would indicate the grade of a symbol measured using a 0,250 mm aperture (ref. no. 10), and a 670 nm light source, and indicates the presence of a potentially interfering extreme reflectance value in the surroundings of the symbol.

NOTE The same notation is used to specify a minimum grade that is required in an application as is a grade that is obtained by measuring a symbol in accordance with this standard. For example, an application standard may specify a symbol quality requirement as 1.5/05/660 and this would be met by a measured grade of X.X/05/660 as long as X.X is a number that is greater or equal to 1.5. However, this requirement would not be met by 2.0/10/660 nor 3.0/05/W nor 3.5/05/660/30.

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 effective aperture size specified in the appropriate application standard. When performing a measurement, the scan lines should be made perpendicular to the height of the bars in the start and stop characters and should as far as possible pass 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 by convolving the raw image with the appropriate synthetic aperture.

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, at the date of publication of this International Standard, also share the feature that the start and stop patterns (or equivalent features of the symbol, e.g. the Row Address Patterns of MicroPDF417) 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 in respect of:

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

— Codeword Yield (see 6.2.3)

— Unused Error Correction (see 6.2.4)

— Codeword print quality (see 6.2.5)

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 according to ISO/IEC 15416. Regions with data content will be evaluated separately as described in 6.1.2, 6.1.3 and 6.1.4. 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 standard 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 might be performed in alternate rows. In a two-row symbol, up to five scans might be performed in each row, at different positions in the height of the bars. The symbology specification may give more specific guidance on the selection of the scans to be used.

To identify bars and spaces, a Global Threshold for each scan has to be determined. Global Threshold shall be equal in reflectance to $(R_{max} + R_{min}) / 2$, where the values R_{max} and R_{min} are respectively the highest and the lowest reflectances in the scan. All regions above the Global Threshold shall be considered spaces (or quiet zones) and all regions below shall be considered bars.

Edge locations shall be determined as the points where the reflectance value is midway between the highest reflectance in the adjoining space and the lowest reflectance in the adjoining bar, in accordance with ISO/IEC 15416.

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.

The measurement of bar width gain or loss may be used for process control purposes. Note that this method will not be 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

This parameter 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 could have been decoded (after adjusting for tilt). A poor Codeword Yield, for a symbol whose other measurements are good, may indicate a Y-axis print quality problem (such as those shown in Table C.1).

Obtain a matrix of the correct symbol character values, such as would result from successful completion of the *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 two conditions:

1) 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.

2) 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 however, that 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, were also decoded.

Decode the symbol completely and populate 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. Also 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).

After processing each scan, calculate the maximum number of codewords that could 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:

1) the maximum number of codewords that could have been decoded is at least ten times the number of codewords in the symbol,

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

3) at least (0.9n) 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 1, the maximum number of codewords that could have been decoded must be at least 960. To fulfil condition 3, since n is 64, at least 58 of the codewords must have been 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 could have been decoded.

Codeword Yield shall be graded as shown in Table 2:

Table 2 — Grading of Codeword Yield

Codeword Yield	Grade
≥ 71%	4
≥ 64%	3
≥ 57%	2
≥ 50%	1
< 50%	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 unused error correction (*UEC*) as $UEC = 1{,}0 - ((e + 2t) / E_{cap})$, where e = the number of erasures, t = the number of errors and E_{cap} = the error correction capacity of the symbol (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, $UEC = 1$. If $(e + 2t)$ is greater than E_{cap}, $UEC = 0$. In symbols with more than one (e.g. interleaved) error correction block, *UEC* 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 3:

Table 3 —Grading of Unused Error Correction

Unused Error Correction	Grade
≥ 0,62	4
≥ 0,50	3
≥ 0,37	2
≥ 0,25	1
< 0,25	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 F. 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*n* codewords (where *n* has the same meaning as in 6.2.3) 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 below.

For each parameter, the cumulative number of symbol characters achieving each grade from 4 to 0 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 as follows:

For each grade level, assuming that all symbol characters not achieving that grade or a higher grade are erasures, derive a notional grade for Unused Error Correction as described in 6.2.4, based on the percentage thresholds shown in Table 3. The codeword parameter grade shall be the lower of the grade level and the notional UEC grade.

NOTE 1 This notional grade is not related to, and does not affect, the UEC grade for the symbol as calculated according to 6.2.4, 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 poor values for the parameter in question than the latter. See Annex F for a fuller description of the approach. The final codeword parameter grade for the symbol shall be the highest codeword interim grade for all grade levels.

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 symbol would be graded 1 for the parameter concerned (the highest value in the right-hand column).

NOTE 2 A similar calculation is performed for each of the parameters Modulation, Defects and Decodability

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

***MOD*/Defects/Decodability grade level (a)**	**No. of codewords at level a**	**Cumulative no. of codewords at level a or higher (b)**	**Remaining codewords (treated as erasures) (100 - b) (c)**	**Notional unused error correction capacity (29 – c)**	**Notional UEC (%)**	**Notional UEC grade (d)**	**Codeword interim grade level (Lower of a or d) (e)**
4	40	40	60	(exceeded)	<0	0	0
3	20	60	40	(exceeded)	<0	0	0
2	10	70	30	(exceeded)	<0	0	0
1	10	80	20	9	31%	1	1
0	7	87	13	16	55%	3	0
Not decoded	13	100					
					Parameter grade (Highest value of **e**)		1

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 codeword print quality in accordance with 6.2.3, 6.2.4 and 6.2.5.

The flowchart in Figure 2 summarises the process.

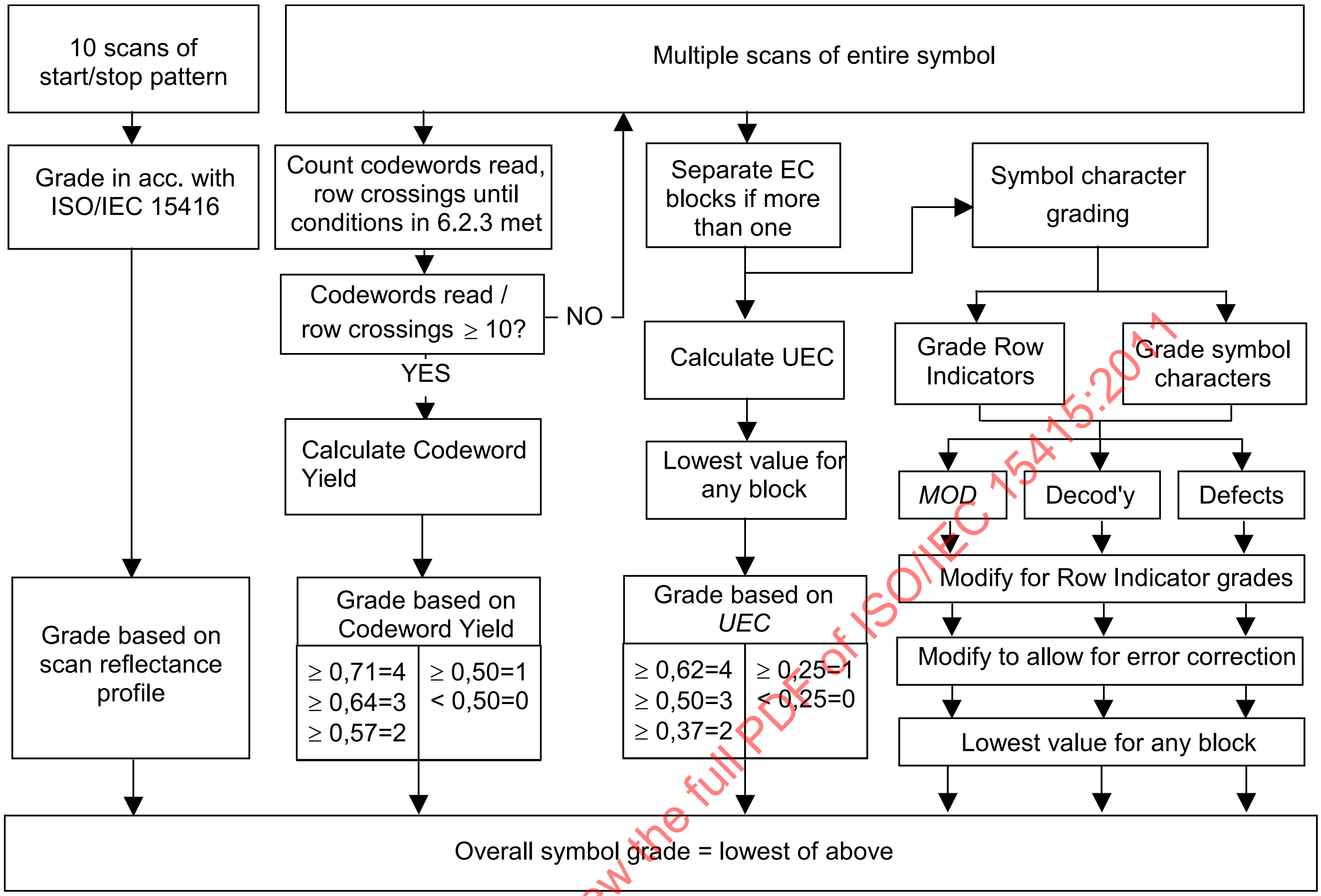


Figure 2 — Grading process for multi-row symbols with cross-row scanning ability

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 designed to maximize the consistency of both reflectivity and dimensional measurements of symbols on various substrates. The basis of this methodology is the measurement of reflectance from the symbol. This methodology is also intended to correlate with conditions encountered in two-dimensional matrix scanning systems.

The method starts by obtaining the raw image, which is a high-resolution grey-scale image of the symbol captured under controlled illumination and viewing conditions. The stored raw image is then converted into a reference grey-scale image, by convolving the raw image with a synthetic circular aperture. From the reference grey-scale image, the Symbol Contrast, Modulation and Fixed Pattern Damage parameters are measured and graded. A secondary binarised image is produced from the reference grey-scale image by applying a Global Threshold, and this binarised image is then analysed and graded for the parameters of Decode, Axial Nonuniformity, Grid Nonuniformity, and Unused Error Correction, together with any additional parameters defined in the symbology or application specification. The methodology recognises possible extreme reflectance values in the neighbourhood of the symbol, which might interfere with reading; however, only their presence is indicated in the report of the overall symbol grade.

In addition, print growth or loss is measured along each axis of the symbol and reported as an ungraded process control measurement.

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

7.2 Obtaining the test images

7.2.1 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 7.3.3), uniform illumination, and at best focus. The reference optical arrangement is defined in 7.3.4 and should be used where application requirements do not call for a specialised optical arrangement; alternative optical arrangements (two of which are defined in 7.3.4) may be used provided that the measurements obtained with them can be correlated with the use of the reference optical arrangement.

Measurements shall be made with light of a single peak wavelength or set of spectral characteristics and a known diameter of measuring aperture, both of which shall be defined by the application specification or determined in accordance with 7.3.2 and 7.3.3. Ambient light levels shall be controlled in order not to have any 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 measurement method is described in 7.6 and 7.7, and Annex B, and is intended to prevent extreme reflectance values outside the symbol area (e.g. when surrounded by free air or a highly specularly reflective surface) from distorting the symbol contrast measurements.

Specialized applications (e.g. the measurement of quality of symbols produced by engraving or etching the substrate surface) clearly must dictate the colour and angle of symbol illumination as well as the required imaging resolution, but the general test set-up defined in 7.3.4 should work suitably for many open applications. For Direct Part Mark applications, a modified version of the methodology described in this standard may be more appropriate. The modified methodology is formally defined in ISO/IEC TR 29158 and may be followed if such is in accordance with the relevant application standard.

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. Second, the image resolution shall be adequate to produce consistent readings. See 7.3.3.

7.2.2 Raw image

The raw image is a plot 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 which are evaluated for the assessment of symbol quality.

7.2.3 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 circular aperture as defined in 7.3.3. It is used for the assessment of the parameters Symbol Contrast, Modulation, Reflectance Margin and Fixed Pattern Damage.

7.2.4 Binarised image

The binarised image is obtained from the reference grey-scale image by applying a Global Threshold midway between R_{max} and R_{min}, determined as defined in 7.6. It is used for the assessment of the parameters Decode, Axial Non-uniformity, Grid Non-uniformity, and Unused Error Correction.

7.3 Reference reflectivity measurements

7.3.1 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 7.3.5.

The measured reflectance values shall be expressed in percentage terms either with reference to the reflectance of a barium sulphate or magnesium oxide reference sample complying with the requirements of ISO 7724-2, which shall be taken as 100 per cent, or by means of calibration and reference to recognised national standards laboratories.

7.3.2 Light source

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. When the peak wavelength or spectral characteristics are not specified in the application specification, measurements should be made using light of characteristics that approximate most closely to those expected to be used in the scanning process. Light sources may either have inherently narrow band or near-monochromatic characteristics or have broad bandwidths; in the latter case the spectral response of the measuring system may be restricted to the desired peak wavelength(s) by the interposition of an appropriate narrow band filter in the optical path.

NOTE Special care is necessary when making measurements with broadband illumination. The overall spectral response of the measurement and reading systems must 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 D for guidance on the selection of the light source.

7.3.3 Effective resolution and measuring aperture

The measuring aperture is specified by the user application specification to suit the *X* dimension of the symbol and the intended scanning environment. Matrix symbol grading shall be carried out using a synthesised aperture. An aperture size in the range of 50% to 80% of the smallest *X* dimension to be encountered in an application is recommended. In an application where symbols of differing *X* dimensions will be encountered, the application standard should ensure that all measurements are made with the aperture appropriate to the smallest *X* dimension to be encountered. See Annex D.2 for guidance in writing application standards and considering the tradeoffs associated with the choice of aperture size.

The effective resolution of an instrument that implements this international standard shall be sufficient to ensure that the parameter grading results are consistent irrespective of the rotation of the symbol. The effective resolution is the product of the resolution of the light-sensitive array and of the magnification of the associated optical system and effected by distortions introduced by the optical system. The reference optical arrangement requires high resolution, such as an effective resolution of not less than ten pixels per module in width and height.

NOTE Implementations (e.g. commercial verifiers) may use fewer pixels per module, providing that the consistency irrespective of rotation mentioned above is achieved on the test symbols specified in ISO/IEC 15426-2.

7.3.4 Optical geometry

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 90 degree intervals around a circle concentric with the inspection area and in a plane parallel to that of the inspection area, at a height which will allow incident light to fall on the centre of the inspection area at an angle of 45° to its plane, and

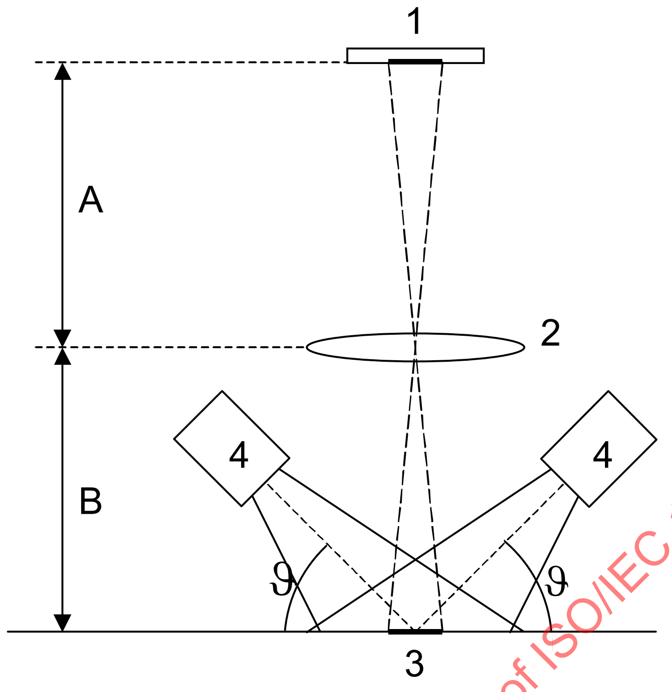
— a light collection device, the optical axis of which is perpendicular to the inspection area and passes through its centre, and which focuses an image of the test symbol on a light-sensitive array.

The light reflected from the inspection area (see 7.3.5) plus the 20*Z* extension defined in 7.7 shall be collected and focussed on the light-sensitive array.

Implementations may use alternative optical geometries and components, provided that their performance can be correlated with that of the reference optical arrangement defined in this section. Figures 3 and 4 illustrate the principle of the optical arrangement, but are not intended to represent actual devices; in particular the magnification of the device is likely to differ from 1:1. In addition, many devices include filters to modify the spectral characteristics or restrict the effect of unwanted spectral components. Implementations should have sufficient resolution irrespective of the rotation as stated in 7.3.3, unless the manufacturer defines handling instructions which restricts the angle of the symbol in relation to the camera chip orientation.

This reference geometry is intended to provide a basis to assist the consistency of measurement and may not correspond with the optical geometry of individual scanning systems. As stated in 7.2, 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, may 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 other than the default is specified in the application specification, then the angle of incidence of the light shall be stated as a fourth parameter when reporting the overall symbol grade, as described in 5.4.

The modified methodology defined in ISO/IEC TR 29158 intended for direct part marking applications defines more illumination options including diffuse illumination at a near-90° incident angle.



1 – Light sensing element

2 – Lens providing 1:1 magnification (measurement *A* = measurement *B*)

3 – Inspection area

4 – Light sources

ϑ - Angle of incidence of light relative to plane of symbol (default = 45°, optionally 30° or 90° diffuse)

Figure 3 — Reference optical arrangement – side view

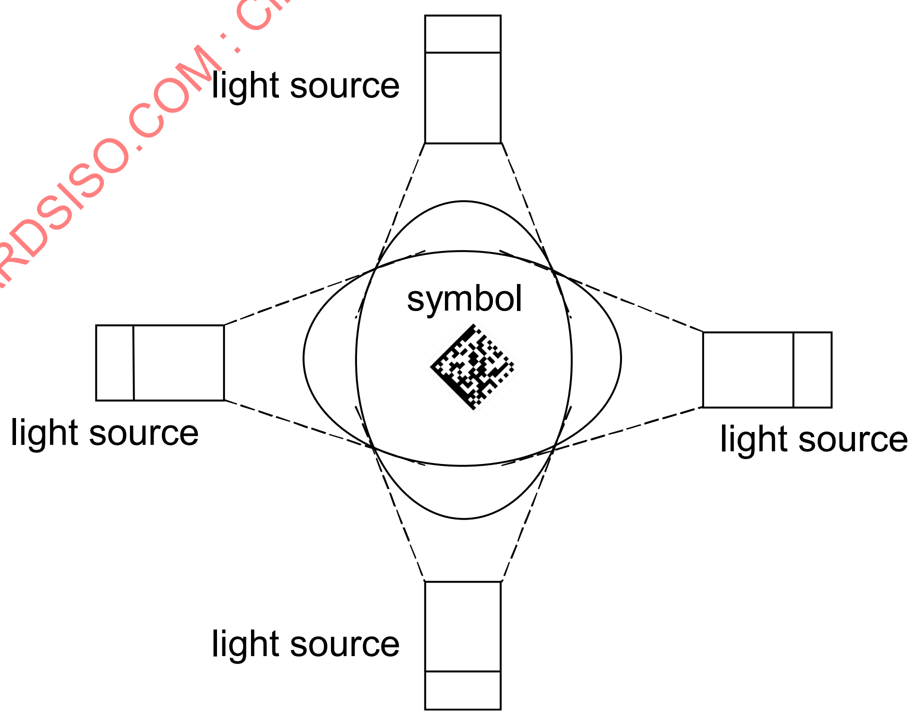


Figure 4 — Reference optical arrangement – plan view

7.3.5 Inspection area

The area within which all measurements shall be made shall be a rectangular 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 should be sufficiently large to include the whole symbol plus the 20*Z* extension described in 7.7.

7.4 Number of scans

The overall symbol grade is obtained through one measurement, with the symbol oriented in any rotation with respect to the measuring device, in a plane perpendicular to the optical axis to the imager sensor. See D.5 for information regarding the fact that this international standard previously required five scans at different rotations to be made and averaged to obtain an overall grade.

Note: This may not be appropriate for symbols on certain substrates or marking methods that do not exhibit uniform diffuse reflection and therefore exhibit variations in symbol reflectance characteristics when viewed in different orientations relative to the axis of the measuring device. Such symbols may be more appropriately measured by following the modified methodology in ISO/IEC TR 29158.

7.5 Basis of scan grading

Two-dimensional symbol quality assessment shall be based on the measurement and grading of parameters of the reference grey-scale image, the binarised image derived from it, and the application of the reference decode algorithm to these, as defined in 7.8. Quality grading of these parameters shall be used to provide a relative measure of symbol quality under the measurement conditions used. Each parameter shall be measured and a grade on a descending scale of integers from 4 to 0 shall be allocated to it. The grade 4 represents the highest quality, while the grade 0 represents failure.

7.6 Grading procedure

A flowchart illustrating the procedure is shown in Annex B.

Centre the symbol in the field of view

Capture the raw image (see 7.2.2).

Find and replace the brightest .005% pixels in the overall image with the median of the nine pixels consisting of itself and its eight immediate neighbours.

Apply the aperture defined in 7.3.3 to the raw image to create a reference grey-scale image (see 7.2.3).

A circular area with a diameter 20 times the aperture diameter, centred in the reference grey-scale image, should be used to find the initial values for R_{min} and R_{max}. Using these values, determine an initial Global Threshold, create a binarised image (see 7.2.4), find the symbol and perform an initial decode.

Once the symbol has been decoded, measure revised R_{min} and R_{max} and recalculate the Global Threshold based on the whole inspection area of the reference grey-scale image (including the quiet zone). These values are used to recalculate module centres. Create a new binarised image. Perform a definitive decode and calculate all of the graded parameters of the symbol. Based on these, determine the scan grade for that image.

7.7 Additional reflectance check over extended area

If the scan grade for each of modulation, decode, and finder pattern damage is 1 or higher, then perform an additional reflectance check as follows:

> Measure R_{min} and R_{max} over an area extending to 20Z beyond the quiet zone on all sides. The field of view must be large enough to contain all points in the extended area.
>
> If either the extended-area R_{min} is lower than the revised R_{min}, or the extended-area R_{max} is higher than the revised R_{max}, then repeat the measurement of modulation and finder pattern damage. If that measurement results in a modulation or finder pattern damage grade of 0, then an asterisk is appended to the overall symbol grade. This asterisk indicates that the substrate surrounding the symbol contains extremes of reflectance that may interfere with reading.

NOTE This additional reflectance check does not alter the reported overall symbol grade nor the reported grades for the symbol contrast, modulation or finder pattern damage parameters.

The additional reflectance check may be omitted, if specifically permitted by the application specification, where the conditions under which the symbol is produced and applied are such that the risk of excessively high or low reflectance values in the extended area is insignificant, and the verifier field of view may then include only the symbol and its associated quiet zones.

7.8 Image assessment parameters and grading

7.8.1 Use of reference decode algorithm

The symbology reference decode algorithm found in the symbology specification is to be used in the verification process. In order to simplify processing the reference decode algorithm may be modified in the verifier by assuming that the symbol to be verified is approximately centred in the field of view of the device. No modifications to the reference decode algorithm that alter the functions listed below (since the adaptive grid mapping are essential to the grading process defined herein) are to be made. The reference decode performs five 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 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 budget.
- It attempts to decode the symbol.

These functions each facilitate one or more of the measurements described in the following subclauses.

The image parameters described in 7.8.2 to 7.8.9 shall be assessed for compliance with this standard.

7.8.2 Decode

The Decode parameter tests, on a Pass/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 using 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, then it shall receive the failing grade 0. Otherwise, it shall receive the grade 4.

7.8.3 Symbol Contrast

Symbol Contrast tests that the two reflective states in the symbol, namely light and dark, are sufficiently distinct within the symbol.

Using the reference grey-scale image of the symbol, measure the highest and lowest reflectance values in the inspection area. Symbol contrast is the difference between the highest and lowest reflectance values in the inspection area. The reflectance values to be used are the revised R_{max} and R_{min} as defined in 7.6.

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

Symbol contrast shall be graded as shown in Table 5.

Table 5 — Symbol Contrast grading

Symbol Contrast	Grade
≥ 70%	4
≥ 55%	3
≥ 40%	2
≥ 20%	1
< 20%	0

7.8.4 Modulation and related measurements

7.8.4.1 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 may reduce the absolute value of the difference between the reflectance of a module and the Global Threshold. A low Modulation may increase the probability of a module being incorrectly identified as dark or light.

The reflectance value of each module in the symbol shall be measured by superimposing on the reference grey-scale image the grid determined by applying the symbology reference decode algorithm to the binarised image. Calculate MOD, the Modulation value of each module as follows:

$$MOD = 2 * (\text{abs}\ (R - GT)) / SC$$

Where MOD = modulation
R is the reflectance of the module
GT is the Global Threshold
SC is the Symbol Contrast

Assign the grade level for each module according to Table 6. For each codeword, select the minimum modulation grade of all modules in the codeword. As suggested by the absolute value in the function for MOD, whether a codeword is decoded correctly has no bearing on the grade level that is assigned. In this way, Modulation differs from Reflectance Margin, see 7.8.4.3.

Table 6 — Module grading for Modulation and Reflectance Margin

MOD or MARGIN	Module Grade
≥ 0,50	4
≥ 0,40	3
≥ 0,30	2
≥ 0,20	1
< 0,20	0

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 7.8.8. Take the lower of the grade level and the notional UEC grade.

NOTE This notional grade is not related to, and does not affect, the *UEC* grade for the symbol as calculated according to 7.8.8, 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 F 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.

Table 7(A) shows an example of grading Modulation in a symbol containing 120 codewords, 60 of which are error correction codewords with a capacity to correct up to 30 errors in a single error correction block. Modulation grade of the symbol in the example would be 2 (the highest value in the right-hand column).

Table 7(A) — Example of Modulation grading in a two-dimensional matrix symbol

MOD codeword grade level (**a**)	No. of codewords at level **a**	Cumulative no. of codewords at level **a** or higher (**b**)	Remaining codewords (treated as errors) (120 - **b**) (**c**)	Notional unused error correction capacity (30 – **c**)	Notional *UEC* (%)	Notional *UEC* grade (**d**)	Lower of **a** or **d** (**e**)
4	25	25	95	(exceeded)	<0	0	0
3	75	100	20	10	33,3%	1	1
2	15	115	5	25	83,3%	4	**2**
1	3	118	2	28	93.3%	4	1
0	2	120	0	30	100%	4	0
					Modulation grade (Highest value of **e**):		2

In this example, some codewords may contain errors but that does not affect the calculation.

7.8.4.2 Contrast Uniformity

Contrast Uniformity is an optional parameter that can be a useful process control tool for measuring localized contrast variations. Contrast Uniformity does not affect the overall grade.

Contrast Uniformity is defined as the minimum MOD value found in any module contained in the data region of the symbol in clause 7.8.4.1.

7.8.4.3 Reflectance Margin

Reflectance Margin is a measure of how well each module is correctly distinguishable as light or dark in comparison to the global threshold. Factors such as print growth (or loss), misplacement of a module relative to the grid intersection, the optical characteristics of the substrate, uneven printing, or encodation errors, may reduce or even eliminate the margin for error between the reflectance of a module and the Global Threshold. A low Reflectance Margin may increase the probability of a module being incorrectly identified as dark or light.

The reflectance value of each module in each codeword in the symbol shall be measured by superimposing on the reference grey-scale image the grid determined by applying the symbology reference decode algorithm to the binarised image.

Since the correct state of each module is known after decoding, any modules which are decoded incorrectly are assigned a *MARGIN* value of 0.

For modules whose correct state is light:

$MARGIN = 2 * (R - GT) / SC$ for $R \geq GT$

MARGIN = 0 for $R < GT$

and for modules whose correct state is dark:

$MARGIN = 2 * (GT - R) / SC$ for $R < GT$

MARGIN = 0 for $R \geq GT$

Where *MARGIN* = the reflectance margin of the module
R is the reflectance of the module
GT is the Global Threshold
SC is the Symbol Contrast

Assign the grade level for each module according to Table 6. For each codeword, select the minimum grade for *MARGIN* of all modules in the codeword. Since codewords which are misdecoded are given grade level of 0, Reflectance Margin differs from Modulation, see 7.8.4.1.

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 7.8.8. Take the lower of the grade level and the notional UEC grade.

NOTE This notional grade is not related to, and does not affect, the *UEC* grade for the symbol as calculated according to 7.8.8, 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 F for a fuller description of the approach.

Then the Reflectance Margin grade for the symbol shall be the highest of the resulting values for all grade levels.

Table **7(B)** shows an example of grading Reflectance Margin in a symbol containing 120 codewords, 60 of which are error correction codewords with a capacity to correct up to 30 errors in a single error correction block. The Modulation grade of the symbol in the example would be 1 (the highest value in the right-hand column).

Table 7(B)— Example of Reflectance Margin grading in a two-dimensional matrix symbol, applying overlay procedure in Annex F

MARGIN **codeword grade level (a)**	**No. of codewords at level a**	**Cumulative no. of codewords at level a or higher (b)**	**Remaining codewords (treated as errors) (120 - b) (c)**	**Notional unused error correction capacity (30 - c)**	**Notional *UEC* (%)**	**Notional *UEC* grade (d)**	**Lower of a or d (e)**
4	15	15	105	(exceeded)	<0	0	0
3	70	85	35	(exceeded)	<0	0	0
2	15	100	20	10	33.3%	1	**1**
1	5	105	15	15	50%	3	**1**
0	15	120	0	30	100%	4	0
					Reflectance Margin grade (Highest value of **e**):		1

This example represents values from the same symbol used in Table 7(A). However, in this example ten codewords from level 4, and five codewords from level 3 are detected to contain at least one module which is on the wrong side of the global threshold and are therefore errors. These codewords are therefore counted at level 0 in this example. The resulting grade too is changed significantly.

7.8.5 Fixed Pattern Damage

This parameter tests that damage to the finder pattern, quiet zone, timing, navigation and other fixed patterns in a symbol does not reduce unacceptably the ability of the reference decode algorithm to locate and identify the symbol within the field of view, by inverting the apparent state of one or more modules from light to dark or vice versa. The particular patterns to be considered, and the amounts of damage corresponding to the various grade thresholds, require to be specified independently for the symbology concerned.

Fixed Pattern Damage is evaluated in the reference grey-scale image in terms of the number of module errors (i.e. modules that appear as the inverse of the intended colour) in the feature (or part of the feature) concerned. Where the symbol comprises a number of distinct features (e.g. finder pattern, timing pattern) each feature may require to be evaluated separately and the worst value used for grading purposes.

Fixed Pattern Damage shall be graded using the threshold values appropriate to each symbology, specified in Annex A, or in the symbology specification, the latter taking precedence.

7.8.6 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 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 at some non-normal viewing angles more than at others.

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:

$$AN = \text{abs}(X_{AVG} - Y_{AVG}) / ((X_{AVG} + Y_{AVG}) / 2)$$

where abs() yields the absolute value. If a symbology has more than two major axes, then Axial Nonuniformity is computed for those two average spacings which differ the most.

Axial Nonuniformity shall be graded as shown in Table 8.

Table 8 — Axial Nonuniformity grading

Axial Nonuniformity	Grade
≤ 0,06	4
≤ 0,08	3
≤ 0,10	2
≤ 0,12	1
> 0,12	0

7.8.7 Grid Nonuniformity

Grid Nonuniformity measures and grades the largest vector deviation of the grid intersections, determined by the reference decode algorithm from the binarised 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 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.

The theoretical grid shall be constructed by equal spacing from the minimum number of reference points defined by the reference decode algorithm from the fixed patterns in the symbol.

Grid Nonuniformity shall be graded as shown in Table 9.

Table 9 — Grid Nonuniformity grading

Grid Nonuniformity	Grade
≤ 0,38	4
≤ 0,50	3
≤ 0,63	2
≤ 0,75	1
> 0,75	0

7.8.8 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.

Decode the binarised image using the reference decode algorithm.

The amount of Unused Error Correction is calculated as $UEC = 1{,}0 - ((e + 2t) / E_{cap})$, where e = the number of erasures, t = the number of errors and E_{cap} = the error correction capacity of the symbol (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, the value of *UEC* is taken as 1. If $(e + 2t)$ is greater than E_{cap}, $UEC = 0$. In symbols with more than one (e.g. interleaved) error correction block, *UEC* 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 10.

Table 10 — Unused Error Correction grading

UEC	Grade
≥ 0,62	4
≥ 0,50	3
≥ 0,37	2
≥ 0,25	1
< 0,25	0

7.8.9 Additional grading parameters

Symbology or application specifications may define additional parameters which may be graded and taken into account in the calculation of the overall symbol grade.

NOTE For example, an application specification may require that the *X* dimension is within a certain range.

7.9 Scan grading

The scan grade for each scan shall be the lowest grade of any parameter in that scan as measured in accordance with 7.8.2 to 7.8.9.

In order to determine the causes of poor quality grades, it is necessary to examine the grades for each parameter in the scan in question as described in Annex C.

Table 11 summarises the test parameters and grade levels.

Table 11 — Test parameters and values

Para-meter Grade	Decode	Symbol Contrast	Fixed Pattern Damage	Axial Non-uniformity	Grid Non-uniformity	Modulation and Reflectance Margin (interim values)	Unused Error Correction
4 (A)	Passes	$SC \geq 0{,}70$	See symbology specification or Annex A for grade thresholds	$AN \leq 0{,}06$	$GN \leq 0{,}38$	See 7.8.4	$UEC \geq 0{,}62$
3 (B)		$SC \geq 0{,}55$		$AN \leq 0{,}08$	$GN \leq 0{,}50$		$UEC \geq 0{,}50$
2 (C)		$SC \geq 0{,}40$		$AN \leq 0{,}10$	$GN \leq 0{,}63$		$UEC \geq 0{,}37$
1 (D)		$SC \geq 0{,}20$		$AN \leq 0{,}12$	$GN \leq 0{,}75$		$UEC \geq 0{,}25$
0 (F)	Fails	$SC < 0{,}20$		$AN > 0{,}12$	$GN > 0{,}75$		$UEC < 0{,}25$

7.10 Overall Symbol Grade

If incorrect data is obtained, then the overall symbol grade, irrespective of the other parameter grades, shall be 0. Otherwise, the overall symbol grade shall be the lowest of the individual parameter grades. Overall symbol grades shall be expressed on a numeric scale ranging in descending order of quality from 4,0 to 0,0.

NOTE The overall grade may be expressed as a real number to one decimal place in keeping with historical precedent.

7.11 Print growth

Print Growth tests that the graphical features comprising the symbol have not grown or shrunk from nominal 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 not be a graded parameter but should be reported as an informative measure for the purposes of process control.

Starting with the binarised image, identify the graphical structures particular to the symbology that are most indicative of element growth or shrinkage in each axis of the symbol, which will generally be fixed structures or isolated elements. Based on the symbology specification and its reference decode algorithm, determine for each of these structures, in each axis, its nominal dimension D_{NOM} in modules.

Determine the actual dimension D in terms of X between the two edges of the structure by counting pixels 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.

In each scan of the symbol, print growth shall then be calculated for each axis as the arithmetic mean of all values of $(D - D_{NOM})$. It shall be reported as the arithmetic mean of the values of print growth for each scan. Where the result is negative, it represents print loss.

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 may only require to read the linear component as well as those requiring to read the complete symbol.

9 Substrate characteristics

Certain characteristics of the substrate, notably gloss, low opacity and the presence of an over-laminate in the case of symbols printed on paper or similar media, and the surface texture and its response to the marking methods used, in the case of symbols directly marked on to the surface of an item, may affect reflectance measurements, and the recommendations in Annex E should be taken into account if any of these factors is present.

Annex A
(normative)

Symbology-specific parameters and values for symbol grading

A.1 Application

Because of differences in symbology structures and reference decode algorithms, the specific grading rules to apply to each symbology (especially with respect to fixed pattern damage) must be defined and specified for each particular symbology, either in this International Standard or within the Symbology Specification for that particular symbology.

This annex defines values corresponding to grade thresholds for Fixed Pattern Damage for Maxicode (ISO/IEC 16023). The first edition publication of this international standard also defined the fixed pattern damage grading parameters for Data Matrix and QR Code but these definitions are now included in the symbology specifications.

Where a symbology specification specifies the basis for grading these parameters, and makes express reference to this International Standard, the basis or values in the symbology specification shall override those indicated in this Annex.

Some symbologies may require additional parameters. These shall be added to the quality assessment of this standard in accordance with 7.8.9.

A.2 Data Matrix Fixed Pattern Damage

Data Matrix Fixed Pattern Damage (FPD) shall be assessed in accordance with ISO/IEC 16022.

NOTE The original version of this International Standard contained details of fixed pattern grading for Data Matrix. Such details are now found in ISO/IEC 16022.

A.3 Maxicode Fixed Pattern Damage

A.3.1 Features to be assessed

The Fixed Patterns of a Maxicode symbol are (a) a 3-ring circular bullseye near the centre of the symbol and (b) six 3-module orientation patterns surrounding it. These are shown in Figure A.1.

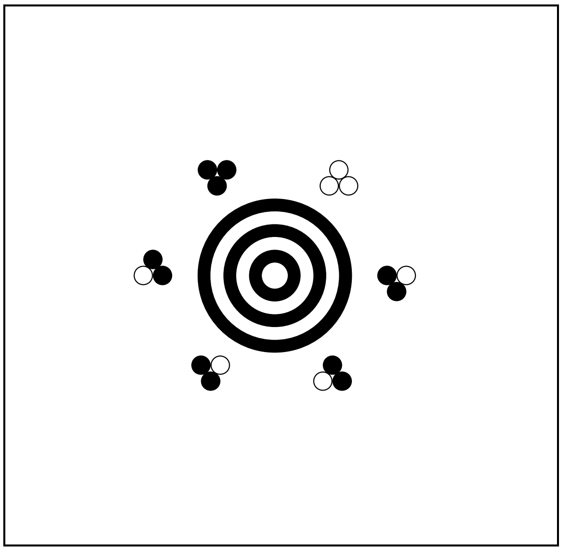


Figure A.1 — Fixed Patterns within a Maxicode symbol

A.3.2 Grading of bullseye

The bullseye is not a natural extension of the hexagonal array of data modules, and thus cannot be graded by sampling module centres. Instead, two other quality measures are performed.

1. Ring Continuity. Each of the three dark rings in the bullseye, and the two intervening light rings, shall be sampled at every image pixel location along a circular path nominally centred within the region, as shown by dotted lines in Figure A.2 below. The central light circular region shall also be sampled along a small circular path whose radius is one third the nominal radius of that region, as also shown.

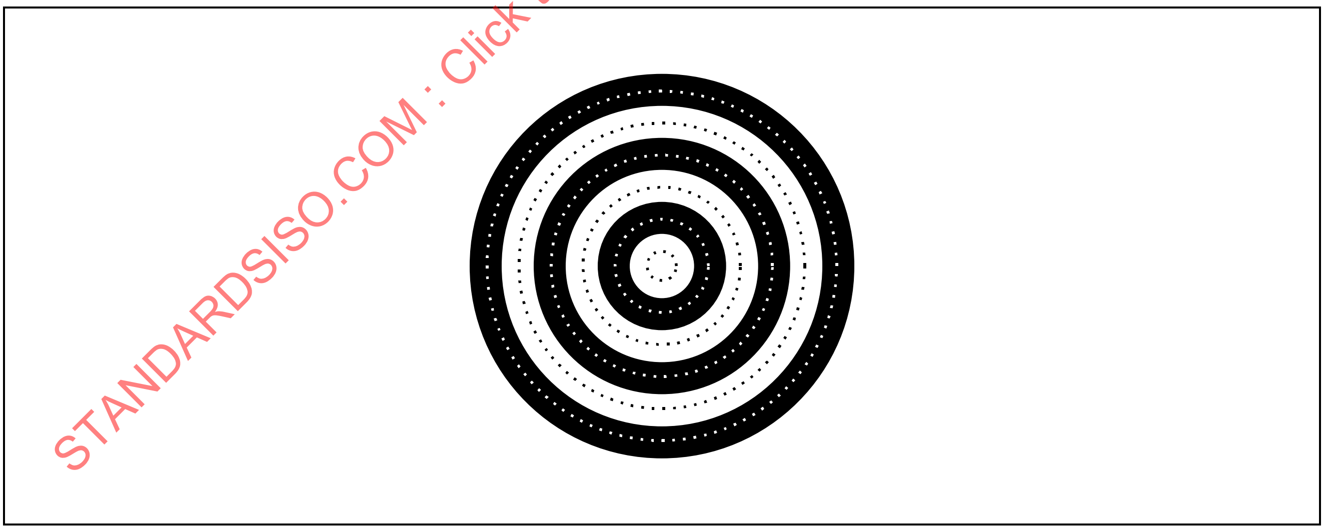


Figure A.2 — Sampling Paths within a Maxicode bullseye

These six groups of sampled points are each graded according to how many samples from along each path are the wrong colour, as a percentage of the total number of samples along that circular path, with the grade assigned as follows:

Table A.1 — Grading of Ring Continuity

Number of samples in error	Grade
0	4
≤ 3%	3
≤ 6%	2
≤ 9%	1
> 9%	0

2. Ring Growth. Scan profiles shall be measured from the grey-scale image along both horizontal and vertical scan paths (relative to the symbol's orientation) through the bullseye's exact centre as shown below, and the edge positions established by the methods in ISO 15416.

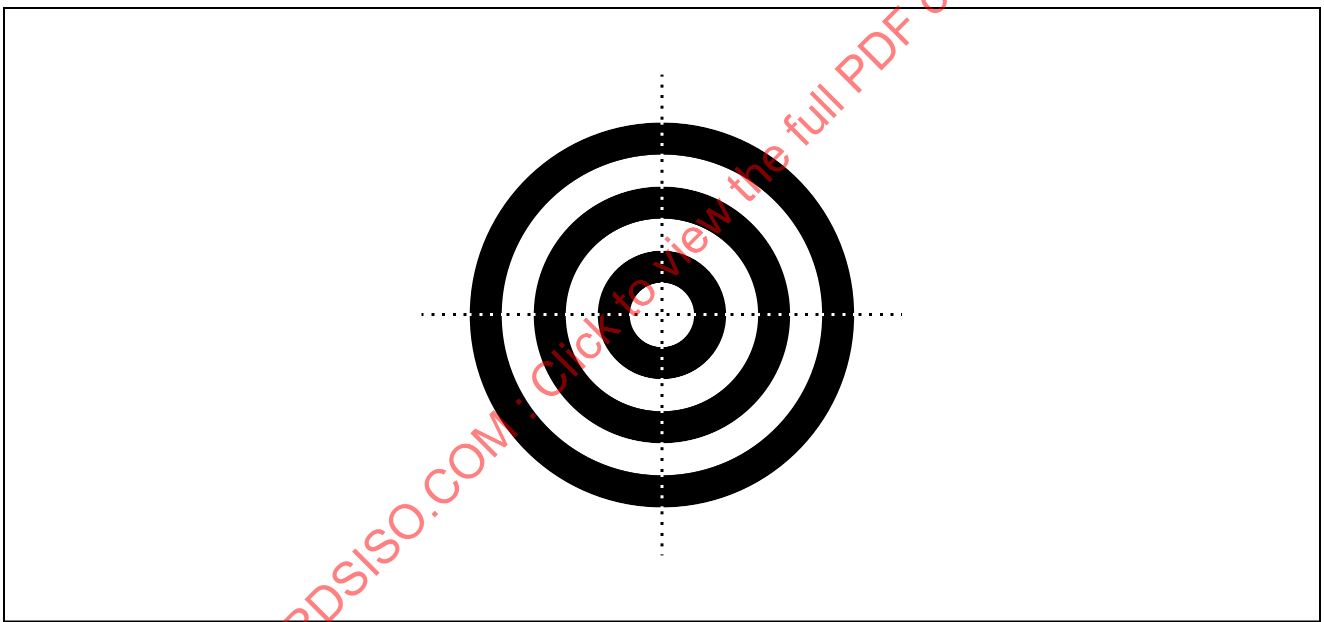


Figure A.3 — Ring Growth Sampling Paths within a Maxicode bullseye

For each profile independently, the ring growth shall be calculated as:

$$RG = (S_{bar} - S_{space}) / (S_{bar} + S_{space})$$

where S_{bar} is the sum of the bar widths

S_{space} is the sum of the space widths

excluding both of the outermost bars (the outer dark ring) and the central space (circle). These horizontal & vertical Ring Growth measurements are then each graded as:

Table A.2 — Grading of Ring Growth

RG	Grade
-0,10 < *RG* < +0,10	4
-0,14 < *RG* < +0,14	3
-0,17 < *RG* < +0,17	2
-0,20 < *RG* < +0,20	1
RG < -0,20 or *RG* > +0,20	0

A.3.3 Grading of Orientation Patterns

The six orientation patterns are taken collectively as a group of 18 modules sampled as part of the data field. Grading is performed based on a count of the number of erroneous (wrong colour) modules as follows:

Table A.3 — Grading of Orientation Patterns

Number of module errors	Grade
0	4
1	3
2	2
3	1
≥ 4	0

A.3.4 Overall Fixed Pattern Damage grade

The overall Fixed Pattern Damage grade is the lowest of the six Ring Continuity grades, the two Ring Growth grades, and the single Orientation Pattern grade achieved.

A.4 QR Code Fixed Pattern Damage and additional parameters

QR Code Fixed Pattern Damage (FPD) and additional parameters shall be assessed in accordance with ISO/IEC 18004.

NOTE The original version of this International Standard contained details of fixed pattern grading for QR Code. Such details are now found in ISO/IEC 18004.

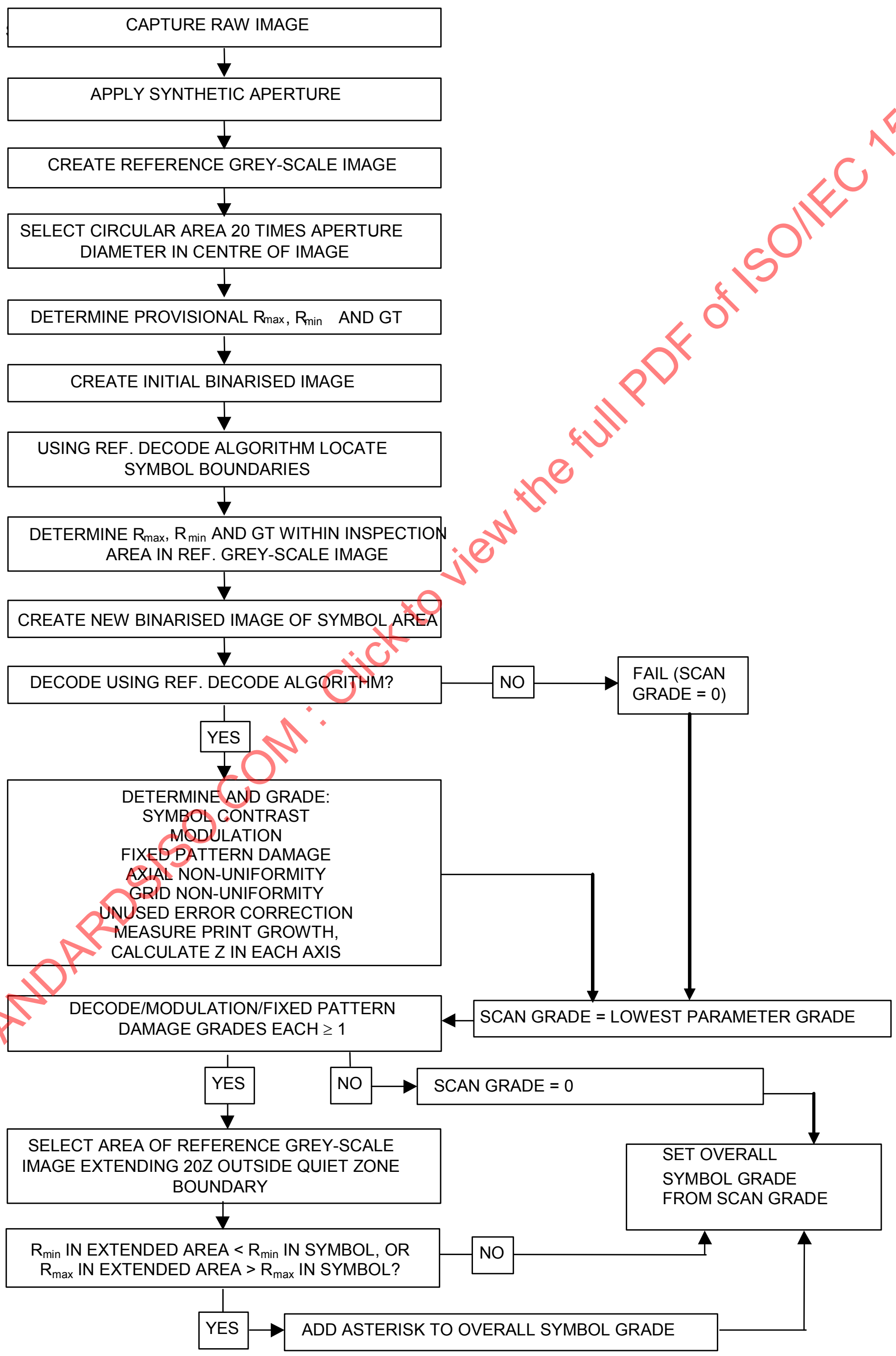
A.5 Aztec Code Fixed Pattern Damage and additional parameters

Aztec Code Fixed Pattern Damage (FPD) and additional parameters shall be assessed in accordance with ISO/IEC 24778.

Annex B
(informative)

Symbol grading flowchart for two-dimensional matrix symbols

This Annex shows the sequence of steps required in order to grade the quality of a two-dimensional matrix symbol.



Annex C
(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.

The table below identifies a number of factors that may lead to low or failing grades for the parameters indicated, which may be similar or differ for the two classes of two-dimensional symbol.

Table C.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 table • software errors in printing system	• many factors - see other parameters in 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	
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	

Parameter	Multi-row symbols	Matrix symbols
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
Print Growth/Loss (ungraded)	• 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 D
(informative)

Guidance on selection of grading parameters in application specifications

D.1 Selection of measurement wavelength

D.1.1 General considerations

Clauses 6 and 7 of this standard require measurements to be made using light of the same characteristics as those which the intended scanning environment will use. If, as may 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.

D.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 may have a bias to a colour; a 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 used for these purposes are:

a) Narrow band

   1) Helium-neon laser (633 nm) (multi-row bar code symbols only)

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

   3) Solid-state laser diode (most usually 660 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)

   2) Fluorescent lighting (nominally white light with a colour temperature in the range of 3200°K to 5500°K)