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Information technology — Automatic identification and data capture techniques — Bar code 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 bi-dimensionnels

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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*.

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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 categorized 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 specification 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

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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.

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

1 Scope

This part of ISO/IEC 15415

— 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.

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 2859-1, *Sampling procedures for inspection by attributes — Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 3951, *Sampling procedures and charts for inspection by variables for percent nonconforming*

ISO 7724-2, *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*

EN 1556, *Bar Coding — Terminology*

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

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1556 and ISO/IEC 15416 and the following apply.

3.1
binarized 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 mm 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
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

3.11
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

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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

MOD = Modulation

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, following the guidelines in Annex D.4.

The sampling method should be based on a statistically valid sample size within the lot or batch being tested. A minimum overall symbol grade for acceptability shall be established prior to quality control inspection. In the absence of a sampling plan defined in formal quality assurance procedures or by bilateral agreement, a suitable plan may be based on the recommendations in ISO 2859 or ISO 3951.

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.

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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.

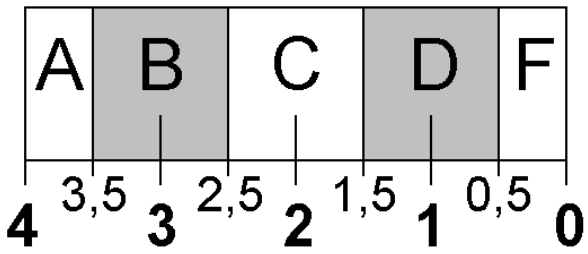


Figure 1 — Mapping of alphabetic and numeric overall symbol grades

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 This International Standard provides for 30° and 90° illumination in addition to the default 45°.

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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.

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 minimize 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 synthesized 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.

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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,

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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 (0,9*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 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
$\geqslant$ 71 %	4
$\geqslant$ 64 %	3
$\geqslant$ 57 %	2
$\geqslant$ 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 stabilizes. 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:

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Table 3 — Grading of Unused Error Correction

Unused Error Correction	Grade
$\geqslant$ 0,62	4
$\geqslant$ 0,50	3
$\geqslant$ 0,37	2
$\geqslant$ 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. For each scan, the lowest of the three parameter values for each codeword in that scan is the codeword grade for that codeword on that scan. The interim codeword grade for each codeword is the highest codeword grade 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.

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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 summarizes the process.

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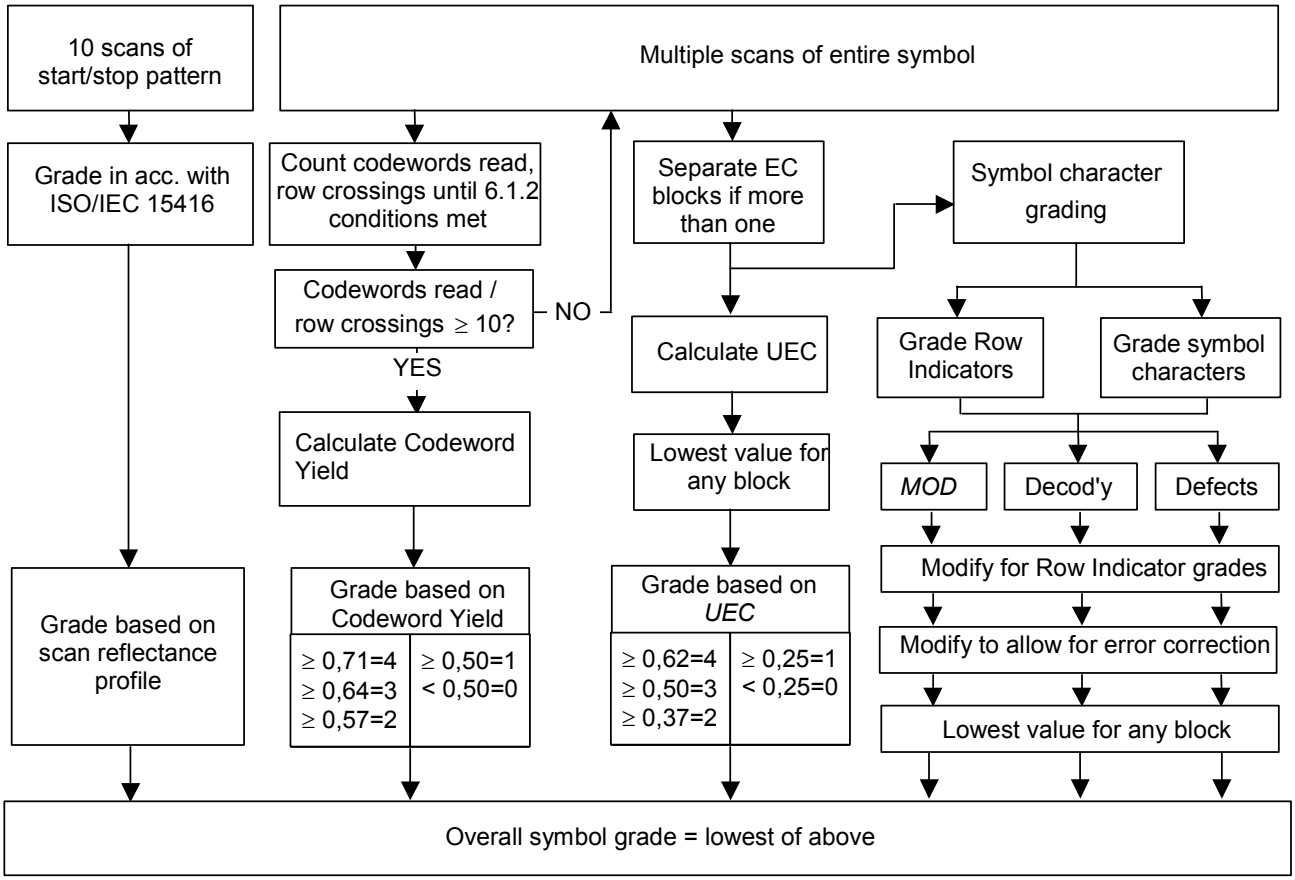


Figure 2 — Grading process for multi-row symbols with cross-row scanning ability

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 minimize the effects of cross-talk from adjacent rows. The number of scans per row should be the lower of ten, or the row 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

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measured and graded. A secondary binarized image is produced from the reference grey-scale image by applying a Global Threshold, and this binarized 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 recognizes 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, and the overall symbol grade is the arithmetic mean of the individual scan grades for a number of tested images of the symbol.

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 specialized 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 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.

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, which generally requires that the module widths and heights span at least five image pixels. 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 and Fixed Pattern Damage.

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7.2.4 Binarized image

The binarized 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 7.8.3. 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 %, or by means of calibration and reference to recognized 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 may be 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 synthesized aperture of 0,8*X* diameter. In an application where symbols of differing *X* dimensions will be encountered, all measurements should be made with the aperture appropriate to the smallest *X* dimension to be encountered. See Annex D.2.

The effective resolution 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. The reference optical arrangement requires an effective resolution of not less than five pixels per module.

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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.

Alternative optical geometries and components may be used, 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.

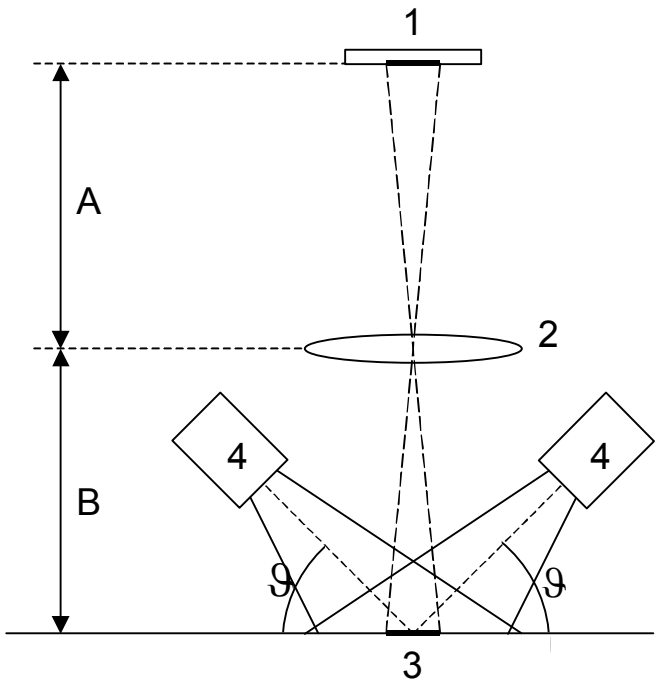
This reference geometry is intended to provide a basis to assist the consistency of measurement and may not correspond with the optical geometry of individual scanning systems. As stated in 7.2, specialized applications, and especially those involving physical changes to the surface of the substrate for the creation of the graphic image, may require the angle of illumination, in particular, to be varied; in this case, it may not be possible to correlate the measurements closely with the reference optical arrangement and two alternative optical arrangements are provided for in this International Standard, viz. incident illumination at 30° to the plane of the symbol, and diffuse illumination at a near-90° incident angle. If one of these alternative angles is used, 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. If none of the three optical arrangements defined is able to provide adequate correlation with the requirements of a specialized application, the optical arrangement of the verifier shall be adjusted to match that of the intended scanning equipment as closely as possible.

As an example, the arrangement described here may be found suitable for many open applications. A standard monochrome video camera images the test symbol directly on axis with its centre and normal to its plane. The lens used is appropriate to frame the entire symbol (including any required quiet zones) in good focus, and with a sufficiently small field of view to minimize optical distortions whilst also ensuring that the effective resolution obtained is appropriate to the *X* dimension of the symbol. Light illumination uniformly floods the symbol area with a 45° angle of incidence. Test images are captured with 8-bit grey-scale digitization using standard frame capture equipment, and the grey-scale is calibrated using targets of known diffuse reflectance.

An implementation of this is described in EIA-706 (see Annex D).

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Key

1 Light sensing element
2 Lens providing 1:1 magnification (measurement *A* = measurement *B*)
3 Inspection area
4 Light sources

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

Figure 3 — Reference optical arrangement – side view

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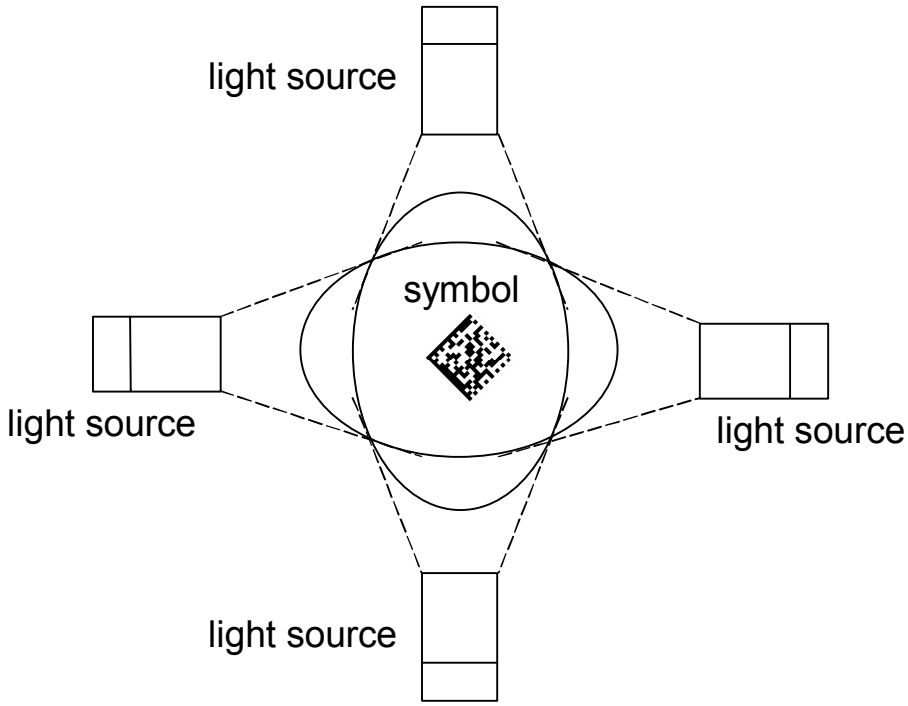


Figure 4 — Reference optical arrangement – plan view

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 7.6 in at least one of the five orientations (as specified by 7.4).

7.4 Number of scans

In order to provide for the effects of variations in apparent symbol characteristics when viewed in different orientations relative to the axis of the measuring device and to provide a basis for averaging grades, five measurements of the symbol shall be made with the appropriate measuring aperture and light source, rotating the symbol through 72° ± 5° around the optical axis of the device between measurements. The first scan shall be performed with the vertical axis of the symbol oriented at 45° ± 5° to the vertical axis of the light sensitive array. The overall symbol grade is determined by averaging the scan grades of the individual images, in accordance with 7.10.

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 binarized 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.

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Centre the symbol in the field of view

Capture the raw image (see 7.2.2).

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 binarized 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 binarized 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

For each of the five images, 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 in every one of the five orientations.

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 in any of the five images, 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 used in the verification process may be found in the symbology specification. 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. 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 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.

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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.

Decodable symbols shall comply with the symbology specification, notably in respect of data and error control character encodation, module positioning, overhead components such as finder and alignment patterns, and quiet zones (where applicable).

The symbology reference decode algorithm shall be used to decode the symbol using the module centre positions on the grid determined by processing the binarized 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 reference grey-scale image. 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
$\geqslant$ 70 %	4
$\geqslant$ 55 %	3
$\geqslant$ 40 %	2
$\geqslant$ 20 %	1
$<$ 20 %	0

7.8.4 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 apparent margin between the reflectance of a module and the Global Threshold. Modulation, if insufficient, 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 binarized image and centring the synthesized aperture defined in 7.3.3 on the grid intersections.

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.

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The module reflectance values shall be compared with the Global Threshold and the value in each codeword or structure nearest to the Global Threshold shall be denoted by *R*. Calculate *MOD*, the Modulation value, for each codeword as

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

where *MOD* = modulation,
R is the reflectance of the module closest to the Global Threshold in the codeword,
GT is the Global Threshold,
SC is the Symbol Contrast.

Take the value of *MOD* for the codeword and assign it a codeword grade in accordance with Table 6.

Table 6 — Codeword grading for Modulation

MOD	Codeword Grade
$\geqslant$ 0,50	4
$\geqslant$ 0,40	3
$\geqslant$ 0,30	2
$\geqslant$ 0,20	1
$<$ 0,20	0

The cumulative number of codewords 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 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 grade for Modulation for the symbol shall be the highest of the resulting values for all codeword grade levels.

Table 7 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. The Modulation grade of the symbol in the example would be 2 (the highest value in the right-hand column).

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Table 7 — Example of Modulation grading in a two-dimensional matrix symbol, applying overlay procedure in Annex F

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	5	120	0	30	100 %	4	1
0	0	120	0	30	100 %	4	0
Not decoded	0	120					
					Modulation grade (Highest value of **e**):		2

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 binarized 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.

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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 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 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 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 binarized 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.

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Unused Error Correction shall be graded as shown in Table 10.

Table 10 — Unused Error Correction grading

UEC	Grade
$\geqslant 0{,}62$	4
$\geqslant 0{,}50$	3
$\geqslant 0{,}37$	2
$\geqslant 0{,}25$	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.

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. For process control purposes the averages of the grades for each parameter obtained from all the scans may provide meaningful guidance.

For each scan, the scan grade is the lowest of the parameter grades achieved in accordance with 7.8. Table 11 summarizes the test parameters and grade levels.

Table 11 — Test parameters and values

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

7.10 Overall Symbol Grade

The overall symbol grade shall be the arithmetic mean of the scan grades for all images. If any two scans of the same symbol yield different decoded data, then the overall symbol grade, irrespective of individual scan grades, shall be 0. 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.

NOTE Where grades from multiple scans are averaged, the precise result may be to more than one decimal place, and will therefore have to be rounded to the nearest single decimal place.

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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 binarized 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.

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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 effect of certain parameters on a symbol's reading performance may vary. This annex defines values corresponding to grade thresholds for Fixed Pattern Damage (as specified in 7.8.5) for the following symbologies:

Data Matrix (ISO/IEC 16022),

Maxicode (ISO/IEC 16023),

QR Code (ISO/IEC 18004).

This Annex also defines additional symbology-specific parameters for grading QR Code symbols.

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

A.2 Data Matrix Fixed Pattern Damage

A.2.1 Features to be assessed

The fixed pattern features to be assessed are contained in the one-module wide perimeter of the symbol and the quiet zone of a minimum of one module width (or more if specified by the application) surrounding the symbol. In larger symbols (square symbols 32×32 modules or larger, or rectangular symbols 8×32 or 12×36 or larger) with internal alignment patterns, the alignment pattern is also part of the fixed pattern. The left and lower side of the symbol should form a one-module wide solid "L" shape and the right and upper sides should consist of alternating dark and light single modules (known as the clock track). The alignment bars and internal clock track of the alignment pattern should similarly be a one-module wide solid bar or a series of alternating dark and light single modules respectively. The grading of Fixed Pattern Damage takes account not only of the total number of damaged modules but also of concentrations of damage.

A.2.2 Grading of the outside L of the fixed pattern

Damage to each side of the L shall be graded based on the modulation of the individual modules that compose it. These measurements are applied to the full length of the L sides and to the associated quiet zones.

Figure A.1 below indicates the four segments L1, L2, QZL1 and QZL2. Segments QZL1 and QZL2 extend one module beyond each end of L1 and L2 respectively, and are shown shaded in Figure A.1. The corner module at the intersection of L1 and L2 is included in both segments, as is that at the intersection of QZL1 and QZL2.

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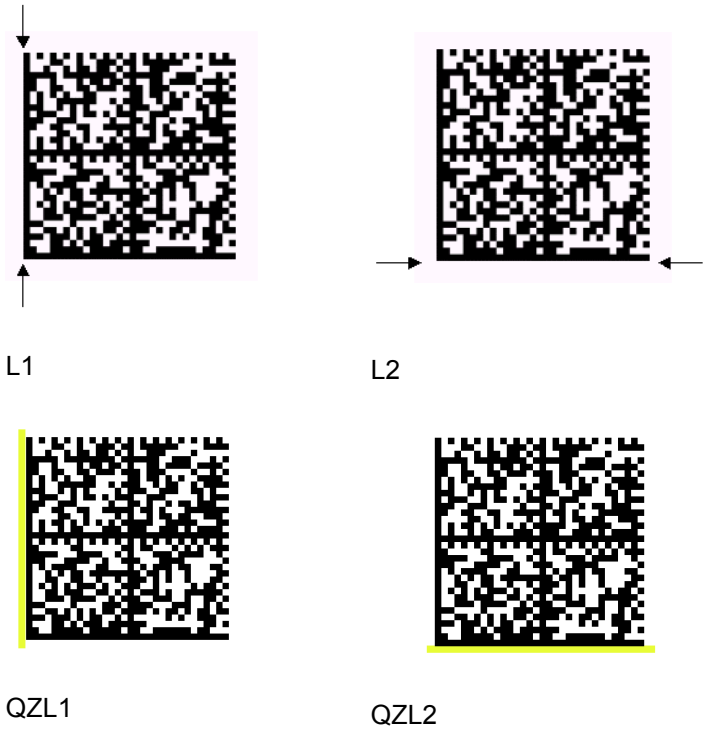


Figure A.1 — Outside L and corresponding quiet zone segments of fixed pattern

The procedure described below shall be applied to each segment in turn.

1) Find the modulation grade for each module based on the values in Table 6. Since the intended light or dark nature of the module is known, any module intended to be dark but the reflectance of which is above the global threshold, and any module intended to be light but the reflectance of which is below the global threshold shall be given modulation grade 0.

2) For each modulation grade level apply the parameter grade overlay technique described in Annex F:

   a) For each side of the L (L1 and L2 in Figure A.1) and each quiet zone area (QZL1 and QZL2, adjacent to L1 and L2 respectively), assume that all modules not achieving that grade or a higher grade are module errors, and derive a notional damage grade based on the grade thresholds shown in Table A.1. Take the lower of the modulation grade level and the notional damage grade.

   b) Additionally, for segments L1 and L2, verify that all gaps are separated by at least 4 correct modules and that no gaps are wider than three modules; if this test fails, the grade from step a) shall be reduced to 0 at that modulation grade level.

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Table A.1 — Grade thresholds for notional damage

Percentage of modules damaged	Grade
0 %	4
⩽ 9 %	3
⩽ 13 %	2
⩽ 17 %	1
> 17 %	0

3) The grade for Fixed Pattern Damage for the segment shall be the highest resulting grade for all modulation grade levels.

A.2.3 Grading of the clock track and adjacent solid area segments

This section defines the measurement of damage to the internal alignment patterns (when present) and also external clock tracks and associated quiet zone areas. These tests are applied separately to each segment of the internal alignment patterns, the clock tracks, and associated quiet zone areas that bound the data region, or individual data regions of larger symbols. Each segment consists of a clock track portion and a solid area portion (which is part either of the quiet zone or of an internal alignment bar). A clock track portion commences with a dark module in the L side or internal alignment bar perpendicular to it and continues to the light module preceding either the quiet zone or the next internal alignment bar. A solid area portion commences with the module adjacent to the first module of the associated clock track portion and continues to the module adjacent to the last module of the associated clock track portion. Figure A.2 illustrates the structures of these segments.

NOTE In a symbol without internal alignment patterns, the external clock track segments extend for the full width or height of the symbol.

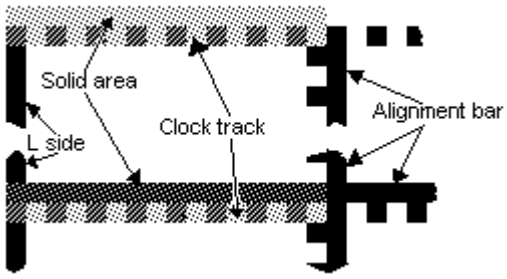


Figure A.2 — Structure of external clock track segment and internal alignment pattern segment

1) For each external clock track segment or internal alignment pattern segment of a symbol (for multi-segment symbols), damage is measured according to the following procedure.

a) Transition ratio test

On every clock track segment in the binarized image, both external (adjacent to the quiet zone) and internal (adjacent to the solid internal alignment bar), count the number of transitions in the clock track side, *Tc*, and the solid line side, *Ts*, and compute and grade the transition ratio *TR* as follows:

$Ts' = \text{Max}(0, Ts - 1)$

$TR = Ts' / Tc.$

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Table A.2 — Grading of Transition ratio

TR	Grade
$TR < 0{,}06$	4
$0{,}06 \leqslant TR < 0{,}08$	3
$0{,}08 \leqslant TR < 0{,}10$	2
$0{,}10 \leqslant TR < 0{,}12$	1
$TR \geqslant 0{,}12$	0

NOTE The end points between which transitions are counted are the intersections of grid lines plotted by the reference decode algorithm in the first and last modules of the clock track or solid area. See Figure A.3.

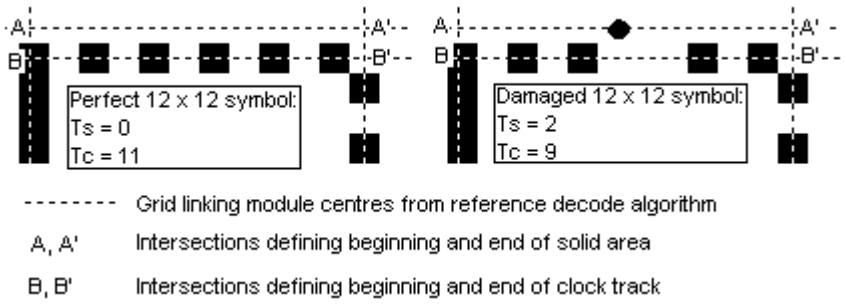


Figure A.3 — Transitions in perfect symbol (left) and damaged symbol (right)

b) Notional damage grade

Find the modulation grade for each module based on the values in Table 6. Since the intended light or dark nature of the module is known, any module intended to be dark but the reflectance of which is above the global threshold, and any module intended to be light but the reflectance of which is below the global threshold shall be given modulation grade 0.

i) For each modulation grade level:

Assume that all modules not achieving that grade or a higher grade are module errors, and derive a notional damage grade based on the following two assessments:

(1) Clock track regularity test

For each segment of clock track, taking groups of five adjacent modules and progressing along the segment in steps of one module, verify that in any group of five adjacent modules no more than two are module errors; if this condition is met, the clock track regularity grade shall be 4, otherwise it shall be 0.

(2) Solid fixed pattern test

For each segment, count the number of incorrect modules in the solid area (internal alignment bar or external quiet zone area) adjacent to the clock track; the percentage *P* of incorrect modules over the length of the area shall result in the following percentage damage grades:

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Table A.3 — Grading of percentage damage to solid area segments

P	Grade
$P < 10\ \%$	4
$10\ \% \leqslant P < 15\ \%$	3
$15\ \% \leqslant P < 20\ \%$	2
$20\ \% \leqslant P < 25\ \%$	1
$P \geqslant 25\ \%$	0

ii) At each grade level take the lowest of the modulation grade level, the clock track regularity grade and the solid fixed pattern percentage damage grade.

iii) The notional damage grade for the segment shall be the highest resulting grade for all modulation grade levels.

2) The Fixed Pattern Damage grade for the segment shall be the lower of the transition ratio grade and the notional damage grade.

3) The overall Fixed Pattern Damage grade for the clock track and adjacent solid area segments is the lowest of the grades obtained for each of the individual segments.

The shaded areas in Figure A.4 below show an example of an internal alignment pattern segment, which includes the clock track portion and solid area portion to which the transition ratio, regularity and solid fixed pattern tests are applied.

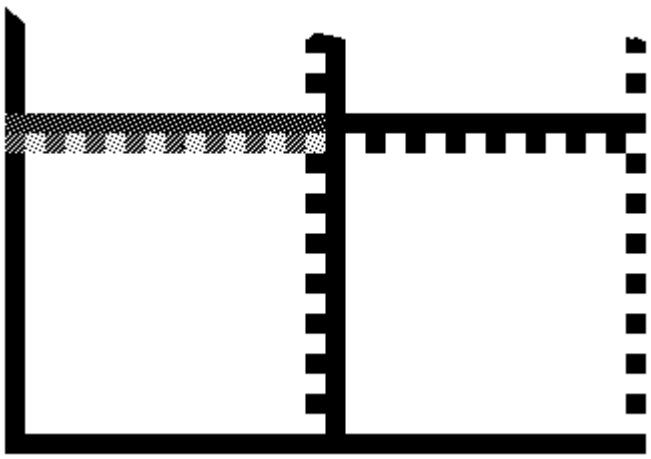


Figure A.4 — Internal alignment pattern segment

The shaded areas in Figure A.5 below show an example of a segment of the external clock track and associated quiet zone to which the transition ratio, regularity and solid fixed pattern tests are applied.

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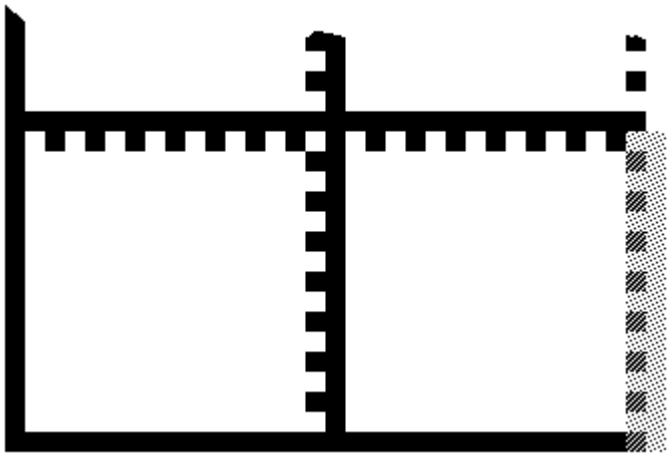


Figure A.5 — External clock track segment

EXAMPLE Figure A.5 shows an example based on grading the L1 segment of a 36 × 36 symbol, with *SC* = 89 % and *GT* = 51 %. The reflectance and modulation values, and modulation grade, are shown in Table A.4 for each of the 36 modules in the segment.



Figure A.6 — Example of L1 segment to show modulation effects

Table A.4 — Example of modulation grading of 36-module segment

Module	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Reflectance (%)	15	13	13	13	9	11	84	11	10
MOD	80	86	86	86	94	90	(74)	90	92
MOD Grade	**4**	**4**	**4**	**4**	**4**	**4**	**0**	**4**	**4**
Module	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Reflectance (%)	9	11	70	13	12	15	11	11	11
MOD	94	90	(42)	86	88	80	90	90	90
MOD Grade	**4**	**4**	**0**	**4**	**4**	**4**	**4**	**4**	**4**
Module	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Reflectance (%)	27	11	14	10	12	50	12	11	14
MOD	54	90	83	92	88	2	88	90	83
MOD Grade	**4**	**4**	**4**	**4**	**4**	**0**	**4**	**4**	**4**
Module	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Reflectance (%)	13	12	37	13	12	13	11	13	12
MOD	86	88	31	86	88	86	90	86	88
MOD Grade	**4**	**4**	**2**	**4**	**4**	**4**	**4**	**4**	**4**

Note that modules 7 and 12 are clearly light and module 24 and to a lesser extent module 30 suffer from low modulation.

Based upon these values, the segment grading would be as shown below:

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Table A.5 — Example of grading of segment

MOD grade level	No. of modules	Cum. no. of modules	Remainder "damaged" modules	Damaged modules %	Notional damage grade	Lower of grades
4	32	32	4	11,1	2	2
3	0	32	4	11,1	2	2
2	1	33	3	8,3	3	2
1	0	33	3	8,3	3	1
0	3	36	0	0	4	0
Final Grade for segment - highest of last column.						2

A.2.4 Calculation and grading of average grade

In addition to the assessment of the individual segments, a calculation of *AG* (average grade) is also made to take account of the cumulative effect of damage that is of relatively minor significance in individual segments but that affects several segments. This is based on averaging the grades for L1, L2, QZL1, QZL2 and the overall clock track and adjacent solid area segment grade.

Once all segments have been graded, calculate the average grade *AG*:

$AG = S / 5$.

Where S is the sum of the segment grades.

Assign a grade to *AG* in accordance with Table A.4.

The Fixed Pattern Damage grade for the symbol shall be the lowest of the five segment grades and the grade for *AG*.

Table A.6 — Grading of *AG*

Mean of five segment grades	Grade
4	4
$\geqslant 3,5$	3
$\geqslant 3,0$	2
$\geqslant 2,5$	1
$< 2,5$	0

EXAMPLES

1) Assume that four of the five segments are graded 4, and one is graded 1. Then

   $(4 \times 4) + (4 \times 1) = 17$

   So $AG = 17 / 5 = 3.4$.

   From Table A.4, a mean of 3.4 will be graded 2. The lowest of the 6 grades is 1, and the symbol Fixed Pattern Damage grade, is therefore 1.

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2) Assume that three of the five segments are graded 4, one is graded 3 and one is graded 1. Then

   $(3 \times 4) + (1 \times 3) + (1 \times 1) = 16$

   So *AG* = 16 / 5 = 3.2.

   From Table A.4, a mean of 3.2 will be graded 2. The lowest of the 6 grades is1, and the symbol Fixed Pattern Damage grade is therefore1.

3) Assume that all of the five segments are graded 3. Then

   $5 \times 3 = 15$

   So *AG* = 15 / 5 = 3.0.

   From Table A.4, a mean of 3.0 will be graded 2. The lowest of the 6 grades is 2, and the symbol Fixed Pattern Damage grade is therefore 2.

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.5 below.

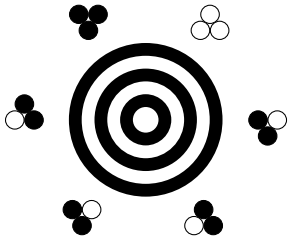


Figure A.7 — Fixed Patterns within a Maxicode symbol

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.6 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.

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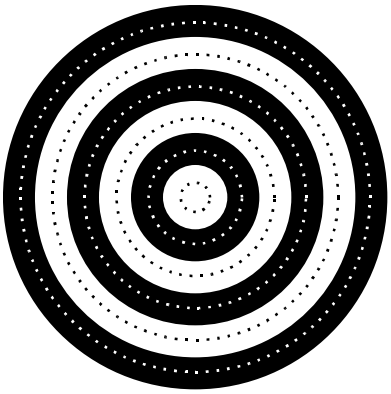


Figure A.8 — Sampling Paths within a Maxicode bullseye

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.7 — Grading of Ring Continuity

Number of samples in error	Grade
0	4
$\leqslant$ 3 %	3
$\leqslant$ 6 %	2
$\leqslant$ 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.

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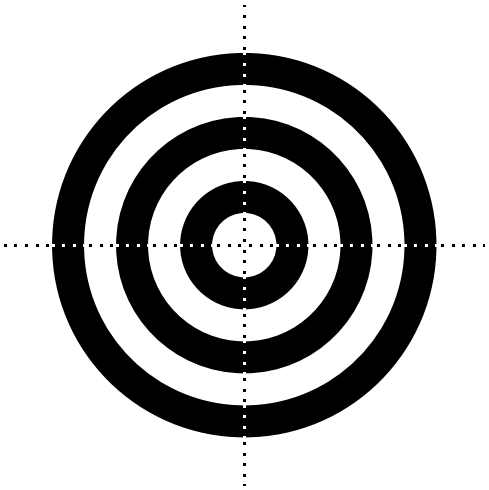


Figure A.9 — Ring Growth Sampling Paths within a Maxicode bullseye

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 and vertical Ring Growth measurements are then each graded as:

Table A.8 — 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:

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Table A.9 — Grading of Orientation Patterns

Number of module errors	Grade
0	4
1	3
2	2
3	1
$\geqslant 4$	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

A.4.1 Fixed Pattern damage

A.4.1.1 Features to be assessed

The features to be assessed are:

- Three corner segments, each including:
  - the 7 × 7 Position Detection Pattern;
  - the 1X wide separators surrounding the two inner sides of the Position Detection Pattern;
  - part of the Quiet Zone of a minimum of four modules width (or more if specified by the application) extending for a length of 15 modules along the two outer sides of the Position Detection Pattern.
- The two timing patterns of alternating dark and light modules linking the inner corners of the Position Detection Patterns.
- The 5 × 5 Alignment Patterns (where present, in Model 2 QR Code symbols of Version 2 or larger).

The features listed above shall be assessed as six segments, viz.:

- the three corner segments (Position Detection Patterns with their associated separators and part of the quiet zone) (Segments A1, A2 and A3 respectively);
- the two Timing Patterns (Segments B1 and B2 respectively);
- the single segment containing all the alignment patterns (Segment C).

Where a Timing Pattern crosses an Alignment Pattern the five modules that coincide with the Alignment Pattern are assessed both as part of the Timing Pattern and of the Alignment Pattern.

In a version 7 symbol (45 × 45 modules) for example, each Segment A occupies 168 modules; each Segment B is 29 modules long, and Segment C occupies a total of 150 modules (i.e. 6 × 25).

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These segments, in the case of a Version 7 symbol, are illustrated in Figure A.10 below. A1, A2 and A3 indicate the three corner segments; B1 and B2 indicate the two timing pattern segments, and C indicates the single Segment C (comprising the 6 Alignment Patterns).

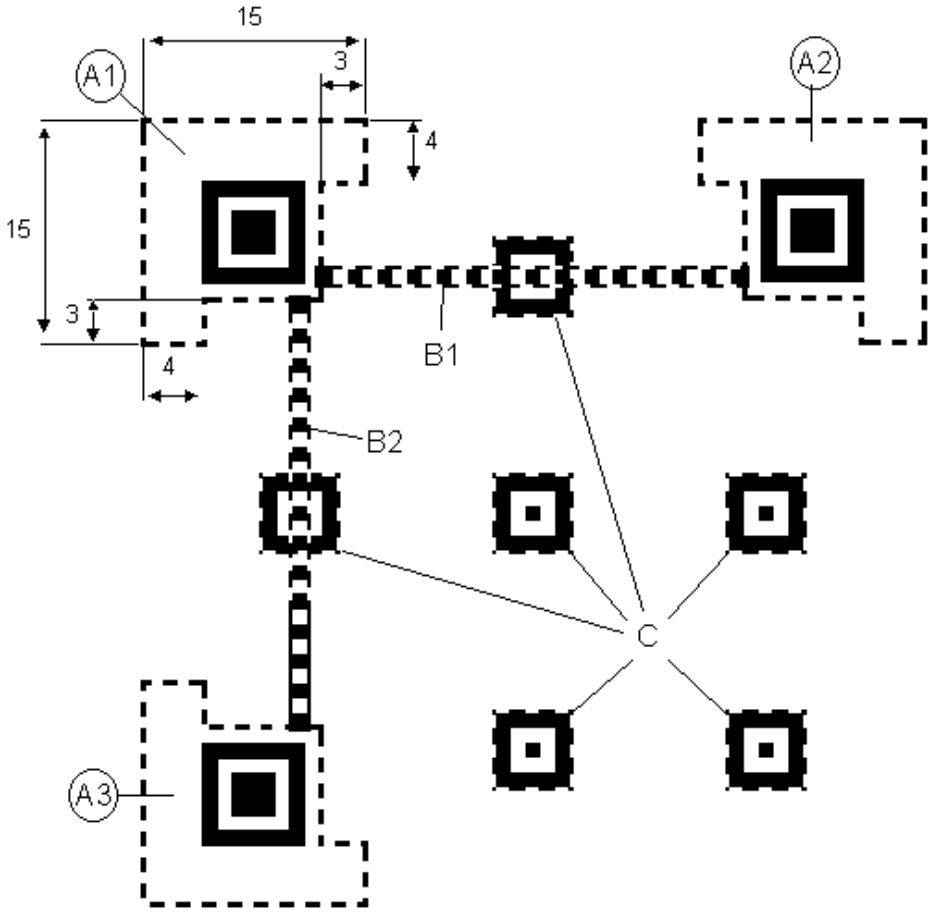


Figure A.10 — QR Code fixed pattern segments

A.4.1.2 Fixed Pattern Damage grading

Damage to each segment shall be graded based on the modulation of the individual modules that compose it.

The procedure described below shall be applied to each segment in turn.

1) Find the modulation grade for each module based on the values in Table 6. Since the intended light or dark nature of the module is known, any module intended to be dark but the reflectance of which is above the global threshold, and any module intended to be light but the reflectance of which is below the global threshold shall be given modulation grade 0.

2) For each modulation grade level, assume that all modules not achieving that grade or a higher grade are module errors, and derive a notional damage grade based on the grade thresholds shown in Table A.6. Take the lower of the modulation grade level and the notional damage grade. The notional damage grade is determined as follows:

   a) For each of Segments A1, A2 and A3, count the number of module errors.

   b) For Segments B1 and B2, count the number of module errors. Express this number as a percentage of the total number of modules in the segment.

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c) For Segments B1 and B2, taking groups of five adjacent modules and progressing along the segment in steps of one module, verify that in any group of five adjacent modules no more than two are damaged; if this test fails, the grade for the segment shall be 0.

d) For Segment C, count the number of Alignment Patterns containing a module error. Express this number as a percentage of the number of Alignment Patterns in the symbol.

e) Assign a notional damage grade to each segment based on the grade thresholds shown in Table A.6.

3) The Fixed Pattern Damage grade for the segment shall be the highest resulting grade for all modulation grade levels

The Fixed Pattern Damage grade for the symbol shall be the lowest of the six segment grades.

Table A.10 — Grade thresholds for QR Code Fixed Pattern Damage

Segments A1, A2 and A3	**Segments B1 and B2**	**Segment C**	
Number of module errors	Percentage of total modules with module errors	Percentage of Alignment Patterns with module errors	**Grade**
0	0 %	0 %	**4**
1	$\leqslant$ 7 %	$\leqslant$ 10 %	**3**
2	$\leqslant$ 11 %	$\leqslant$ 20 %	**2**
3	$\leqslant$ 14 %	$\leqslant$ 30 %	**1**
$\geqslant$ 4	$>$ 14 %	$>$ 30 %	**0**

A.4.2 Grading of additional parameters

A.4.2.1 Features to be assessed

QR Code symbols contain a duplicated set of modules representing information that defines the format of the symbol, and symbols of Version 7 to 40 also contain a duplicated set of modules representing information that defines the symbol size. This data requires to be reliably detected at an early stage of the decoding procedure, and if it cannot be decoded, the remainder of the symbol cannot be decoded. For this reason, the Format Information and Version Information module blocks are graded separately (in a similar way to Fixed Pattern Damage), and their grades are included in the overall symbol grade determination.

A.4.2.2 Grading of Format Information

For each block of Format Information, determine a grade for the block according to the following method.

1) Find the modulation grade for each module based on the values in Table 6. Since the intended light or dark nature of the module is known after decode, any module intended to be dark but the reflectance of which is above the global threshold, and any module intended to be light but the reflectance of which is below the global threshold shall be given modulation grade 0. If the Format Information in the block cannot be decoded, the grade for the block shall be 0.

2) For each modulation grade level:

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a) Assume that all modules not achieving that modulation grade or a higher grade are module errors, and derive a notional grade based on the following:

Table A.11 — Format Information notional grading

Number of module errors	Grade
0	4
1	3
2	2
3	1
$\geqslant 4$	0

b) Select the lower of the MOD grade and the notional grade at each level as the grade for that level, as illustrated in Table A.8.

c) The grade for the block shall be the highest resulting grade, as illustrated in Table A.8

Table A.12 — Example of Grading of Format Information block

Modulation grade	Notional grade	Lower of grades
4	2	2
3	2	2
2	3	2
1	3	1
0	4	0
	Selected (highest) Grade->	2

3) The Format Information grade shall be the average of the grades of the two Format Information blocks, rounded up if necessary to the next integer.

A.4.2.3 Grading of Version Information

For each block of Version Information, determine a grade for the block according to the following method.

1) Find the modulation grade for each module based on the values in Table 6. Since the intended light or dark nature of the module is known after decode, any module intended to be dark but the reflectance of which is above the global threshold, and any module intended to be light but the reflectance of which is below the global threshold shall be given modulation grade 0. If the Version Information in the block cannot be decoded, the grade for the block shall be 0.

2) For each modulation grade level:

a) Assume that all modules not achieving that modulation grade or a higher grade are module errors, and derive a notional grade based on the following:

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Table A.13 — Version Information notional grading

Number of module errors	Grade
0	4
1	3
2	2
3	1
$\geqslant 4$	0

b) Select the lower of the *MOD* grade and the notional grade at each level as the grade for that level, as illustrated in Table A.10.

c) The grade for the block shall be the highest resulting grade, as illustrated in Table A.10

Table A.14 — Example of Grading of Version Information block

Modulation grade	Notional grade	Lower of grades
4	2	2
3	2	2
2	3	2
1	3	1
0	4	0
	Selected (highest) Grade->	2

3) The Version Information grade shall be the average of the grades of the two Version Information blocks, rounded up if necessary to the next integer.

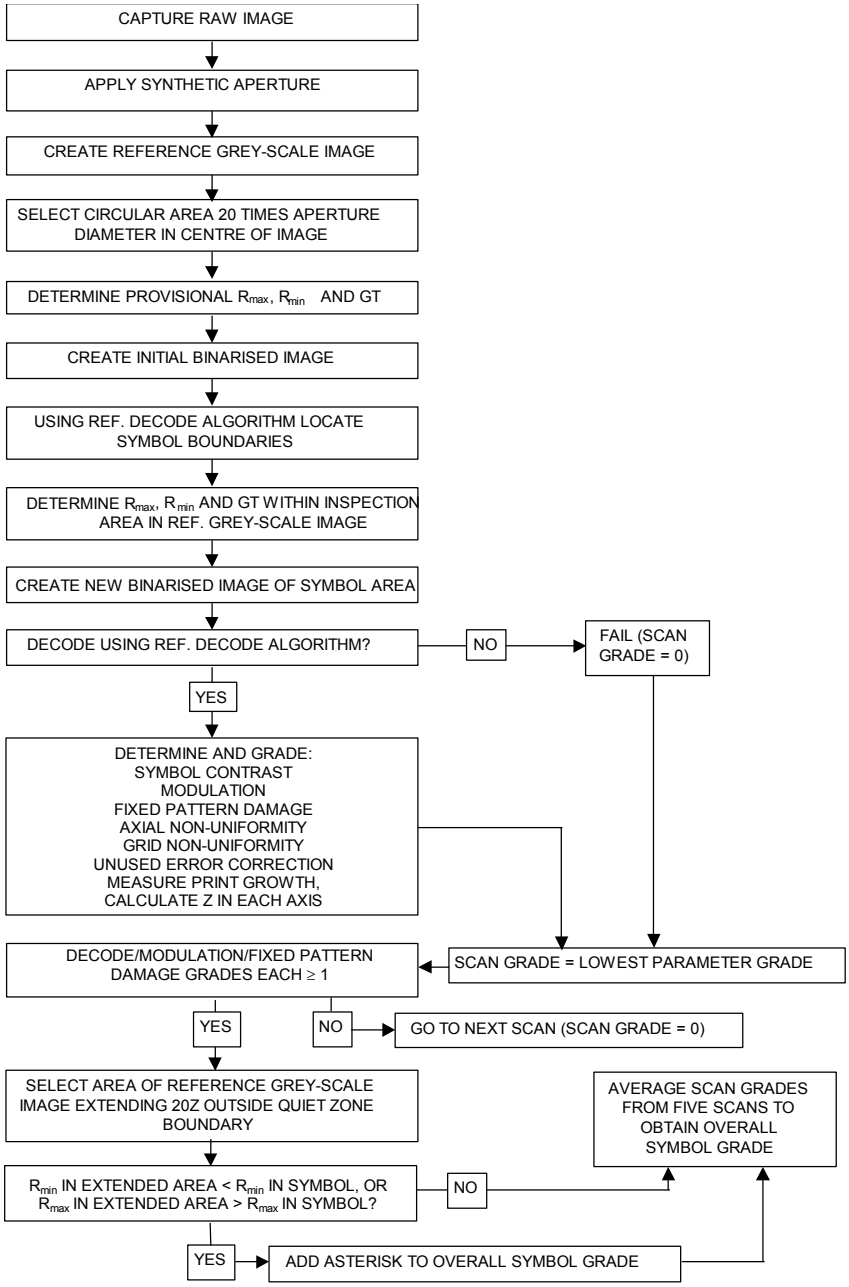
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Annex B
(informative)

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:



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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	

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Table C.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
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

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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 specialized 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 2 800°K to 3200 °K).

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

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3) Light-emitting diode (nominally white light with a colour temperature in the region of 7000 °K).

4) Halogen lamps (nominally white light with a colour temperature in the region of 2 800 °K to 3200 °K).

5) Gas discharge lamps (light of various characteristics).

The key characteristics of these are as follows.

A **helium-neon laser** is a gas-filled laser tube which emits highly monochromatic coherent light at a peak wavelength of 632,8 nm (usually rounded to 633 nm), in the visible red area of the spectrum.

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 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.

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 standard, are 660 nm and 670 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 7000°K. Their actual spectral distribution may show a number of peaks, e.g. 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 2856 °K lamp approximate to those of a 620-633 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 by the use of filters.

NOTE Wavelengths and colour temperatures stated above are indicative and may change as the technology evolves.

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D.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 will tend to absorb visible red light strongly (and appear therefore of low reflectance), whereas a white, red or orange area will reflect 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 (for example 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 may 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 will not differ significantly; there may however 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 will be greater variations. Interposing a filter in the light path will introduce 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 not uncommon for the optical train to include both infra-red and ultra-violet absorbing filters.

D.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, 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 may 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.

D.2 Selection of aperture

The choice of aperture size is very important, and it must be specified in accordance with 7.3.3 or in order for symbol grades to be measured consistently. It is the responsibility of an application specification to define a fixed measuring aperture to be used. As required by 5.4 of this standard, the aperture size must be reported together with the grade and illumination in order to identify the conditions under which the measurement was made.

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 will not fill in unintentional voids, or gaps between elements of a direct marked symbol, that would lead to low grades or undecodable symbols. On the other hand, a measuring aperture that is too large will blur individual modules, resulting in low modulation, and may prevent the symbol from being decoded.

An aperture size equal to 80 % of the minimum allowed module size is a typical choice for the specification. Importantly however, an application specification that allows a range of nominal module sizes (for example a

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range of 0,25 mm through 0,40 mm) should specify a single aperture size to be used in all cases. That is to say that the verification of each symbol is made with an aperture that is not necessarily related to that symbol's module size. For example if 80 % of 0,25 mm were specified, i.e. a 0,20 mm aperture, then all symbols used in that application including 0,40 mm symbols must be measured using a 0,20 mm aperture. Another aperture size may be chosen, even one equal to or larger than the minimum module size. The important factor is that a single measuring aperture be specified and used consistently within an application area.

If a range of module sizes is used within an application specification, then the relatively small measuring aperture required to read the symbols with the smallest module size will limit the size of the largest acceptable spots and voids. If too large an aperture were used, the modulation for the smallest module size would be 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 will predict the readability of both the largest and smallest module size symbols.

A single fixed measuring aperture ensures that all symbols will be measured in a way that will reflect performance in the expected scanning environment. The choice of measuring aperture that is specified will be influenced in some cases by the scanning equipment that is expected to be prevalent in the application-scanning environment. Conversely, the scanning equipment may also be influenced by the specification of the measuring aperture. In both cases however, a "match" between verification technique and scanning environment is made in order to produce a high correlation between grade level and scanning performance.

D.3 Selection of lighting angle

Whereas the default 45° illumination angle is well suited to printed symbols and those marked on even surfaces without localized points of specular reflection, i.e. those from which diffuse reflection does not vary sharply with the angle of incidence or collection of the light, many "direct marked" symbols require to have the angle of incidence adjusted to optimize reading performance. The spectral characteristics of the illumination for use with engraved or similar symbols may therefore be less important than the respective angles of incidence and collection of the light on the symbol. The light source needs to be positioned in such a way that the apparent contrast as seen by the image capture device is maximized. Depending on the nature of the surface and the marking technique used, the spectral characteristics of the light source may also have an influence on its contrast. Broadband illumination is more common than narrow band, and verifiers should use the same source as that used for reading the symbols. As an example, the following description of an optical set-up for use with such symbols is taken from the electronics industry application standard EIA 706:

"The printed or marked symbol to be measured shall be illuminated by a white light source such as a Stocker and Yale Model 9 Circular Illuminator (70 mm (2.9 inch) diameter fluorescent ring light) or equivalent. The light source shall be mounted at a height to provide a 35 to 45 degree angle of incidence, relative to the symbol surface. The distance from the bottom of the fluorescent bulb to the marked surface should be approximately 24 mm (giving a 40 degree angle of incidence).

"Consistent measurements have been achieved using an NEC Model T1324A CCD Camera having a shutter speed of 1/2000th of a second, a 20 mm lens extension tube, and a 50 mm lens set at an f-stop of f/8. The image shall be in focus. The distance from the bottom of the lens to the top of the component (image plane) is recommended to be approximately 160 mm (6.25 inches)."

NOTE This describes, as an example only, a set-up and equipment that has been used for a particular application but is not intended to prescribe these specific components either for that application or for general applications.

D.4 Selection of minimum acceptable grade

The specification of the minimum acceptable grade in an application specification should be based on consideration of the trade-off between the possibly increased cost of producing higher-grade symbols and the improved scanning performance to be obtained by the use of such symbols, together with the data integrity requirements of the application.

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A requirement for higher grade symbols may restrict the choice of the following available to the producer of the symbols:

— Inks (or other marking media) and substrates on which to mark the symbol (e.g. to ensure a high level of symbol contrast, a substrate with high reflectance and/or an ink with low reflectance under the specified illumination are needed, imposing limits on the choice of colour available).

— Marking technology (e.g. those in which the placement of printer dots is less well-controlled may be excluded).

It may also require slower production rates or higher levels of quality control, or lead to higher rejection rates, all of which contribute to higher unit costs.

On the other hand, the receiver of the symbols will benefit from improved read rates, or may have a greater choice of reading technology open to him.

If a low symbol grade is specified, the receiver of the symbols may incur additional costs in:

— Installing higher quality reading equipment.

— Accepting a lower read rate.

— Reprocessing of symbols that failed to scan.

Many applications require a minimum grade of 1,5 (C), which offers them a fair balance between the cost of production and reading performance under the conditions of their application.

The more critical it is that a high read rate be achieved, on grounds not only of cost but also data integrity, the higher the grade that needs to be specified.

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Annex E
(informative)

Substrate characteristics

E.1 Rationale

In certain circumstances for example, the design and production of printed packaging materials incorporating bar code symbols or the production of symbols directly marked on to a surface, it may be necessary or desirable to assess the acceptability of substrates and/or ink colours for a given bar code application, before a bar code symbol is available which could be tested in accordance with this standard. Reference should be made to ISO/IEC TR 17962 for additional guidance on the effects of gloss and low substrate opacity on the reading and verification of these symbols.

E.2 Substrate opacity

The methodology of the International Standard requires that the symbol shall be graded according to the parameters in Clause 6 (multi-row symbols) or 7 (matrix symbols) when measured in its final configuration, e.g. final filled package.

If it is not possible to measure the symbol in this configuration then the effects of show-through of high-contrast interfering patterns may be ignored if when measured as follows the substrate opacity is 0,85 or greater. If the opacity is less than 0,85, the symbol should be measured when backed by a uniform dark surface the reflectance of which is not more than 5 %.

The opacity of the substrate shall be calculated as follows:

Opacity = *R2* / *R1*

where: *R1* = Reflectance of a sample sheet of the substrate backed with a white surface the reflectance of which is 89 % or greater.

R2 = Reflectance of the same sample sheet backed with a black surface the reflectance of which is not more than 5 %.

E.3 Gloss

The reference illumination conditions specified for the measurement of reflectance should enable the maximum rejection of specular reflection while giving a representative assessment of the diffuse reflectance of the symbol and substrate. Highly glossy materials and those whose diffuse reflectance characteristics vary with the angle of incident and/or collected light - as may be the case with many materials on which symbols are directly marked - may yield grades differing from those obtained by the use of the reference optical arrangement with illumination at 45°, and for this reason subclause 7.3.4 provides alternative angles of illumination to enable apparent symbol contrast to be maximized.

E.4 Over-laminate

A symbol intended to be covered with a protective lamination should be graded according to the parameters in Clause 6 (multi-row symbols) or 7 (matrix symbols) when measured with the laminate in place. The thickness of the laminate including its adhesive should be as small as possible in order to minimize its effects on the reading performance of the symbol.

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E.5 Static reflectance measurements

E.5.1 General

In some cases, it may be desirable to carry out static reflectance measurements of samples of the substrate on which a bar code is to be printed and on colour patches or ink samples which replicate the colour in which the bar code will be printed. The following guidelines provide a means which, if it is followed, will predict as closely as is generally possible the results which will be obtained when the symbol is scanned dynamically.

Static reflectance measurements should be made with the wavelength of light, aperture size and optical arrangement which relate to the application and which are specified in accordance with ISO/IEC 15416 (multi-row symbols) of this standard.

Where reflectance measurement equipment meeting the requirements of this Annex is not available, optical density measurements may be made using a standard densitometer with an appropriate light source and converted to reflectance values; density (*D*) and reflectance (*R*) are related as follows:

$$R = 100 / 10^{D}$$

NOTE It is impossible to predict to a high degree of accuracy the symbol contrast and, in particular, the edge contrast which will be achieved in the printed symbol. It is therefore appropriate to allow some safety margin above the minimum values for specified grades.

E.5.2 Prediction of Symbol Contrast (*SC*)

The prediction of *SC* requires that measurements of reflectance be made on samples which simulate the highest (R_{max}) and lowest reflectance (R_{min}) areas which will be present in the finished symbol.

It is probable that in most bar code symbols R_{max} will be found in the quiet zone of the symbol; therefore to simulate the conditions found in the quiet zone, R_{max} should be measured in the centre of a sample area, at least 10*X* in diameter, of the material on which the symbol is to be printed.

It is probable that in most bar code symbols R_{min} will be found in the widest bars of the symbol, or areas with a number of contiguous dark modules; therefore to simulate the conditions most likely to yield a value of R_{min} consistent with that which would be found in practice, reflectance should be measured in the centre of a strip of material 2*X* to 3*X* wide and which matches the colour in which the bars are to be printed.

A predicted value of *SC* can then be calculated:

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

For materials which do not satisfy the tests for opacity, which are detailed in Annex E.1, the measurements which are made for the purpose of predicting *SC* should be made with the test samples backed by a uniform dark surface, the reflectance of which is not more than 5 %. The same measurements should then be made with the test samples backed by a uniform surface the reflectance of which is not less than 89 %. The calculated value of static SC shall be equal to or greater than the minimum value for the grade selected for the application, for tests on both the dark and light backgrounds.

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Annex F
(informative)

Parameter grade overlay applied to two-dimensional symbologies

This Annex describes the technique used in this International Standard to derive a final grade for a parameter from a set of notional grades determined for a set of grade levels, each determined at five fixed grade levels for the parameter.

The technique computes a notional grade for a parameter for each grade level by assuming that only modules or codewords that meet or exceed that grade level for that parameter are actually readable. The modules or codewords which are readable then result in a grade for that parameter according to the rules for that parameter (whether based on unused error correction or fixed pattern damage).

If one considers what the performance would be for a scanner that could only read codewords or modules above a particular parameter grade level, it is clear what will happen – only codewords or modules at or above that grade level may be counted towards the readability calculation for the symbol at that grade level.

For example, if codewords or modules with a grade of 2 must be counted before a grade of 3 on unused error correction or fixed pattern damage may be obtained, then the symbol must be a grade 2.

Furthermore, if codewords graded 3 or better can only result in an unused error correction or fixed pattern damage level of 2, the symbol must also be a grade 2.

However, the readability of a symbol must take into account the readability of codewords or modules at each grade level and the ability of the symbol to be read using error correction or allowing for some fixed pattern damage and the resulting grade should be the highest of these two possible outcomes.

The following procedure can therefore be established:

a) Count the number of codewords in each grade level, including higher grade levels, assume that all remaining codewords are erasures (multi-row symbols) or errors (matrix symbols) and determine an unused error correction or fixed pattern damage grade.

b) For each grade level, take the lower of the grade level and the associated unused error correction or fixed pattern damage parameter grade.

c) Select the highest of the values from step b as the symbol grade for that parameter.

This ensures that a scanner will have performance associated with the assigned grade because the scanner's ability to read codewords or modules of the assigned grade or higher will bring it within the error correction or fixed pattern damage capacity of the assigned grade level or better.

This method provides a way of accounting for imperfections in symbols which are designed to tolerate imperfections. In fact, it favours symbols with more error correction capacity, which certainly does make a symbol easier to read. It also reconciles the print quality measurement method of linear symbols with that of 2D symbols. In a sense the linear approach, which takes the worst case, is the trivial extension of the above rule in the case of no error correction. In this case, the codeword with lowest grade is always needed to get anything other than a 0 for "unused error correction". If this value happens to be a 1, then the symbol must be a 1, even if all other codewords had quality of 4.

NOTE The notional Unused Error Correction or Fixed Pattern Damage grade used in this calculation is not related to, and does not affect, the UEC or Fixed Pattern Damage grade for the symbol as calculated according to 6.2.4, 7.8.8 or 7.8.5 respectively.

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Multi-Row Symbols with cross-row scanning ability

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Multi-Row Symbols without cross-row scanning ability

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Composite Symbologies

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[16] AIM ITS - Aztec Mesas

NOTE 1 Specifications published by AIM Global - viz. AIM International Technical Specifications (ITS) and Uniform Symbology Specifications (USS) - are obtainable from AIM Inc., 634 Alpha Drive, Pittsburgh, PA 15238, USA

NOTE 2 This is not an exhaustive list of symbology specifications.

Other specifications

[17] EIA-706 Component Marking Standard (Data Matrix)
(Published by Electronic Industries Alliance, 2500 Wilson Boulevard Arlington, Virginia 22201, USA)

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