# EAN•UCC bar code validation and verification

February 2004

# 1 Introduction

The productivity of automated point of sale, point of use, or stock control systems depends on the ability to scan the bar codes on items quickly and accurately. The speed and ease with which a scanner can read the bar code depends on the quality of the printed symbol, scanner capability and maintenance, and operator technique. Retailers and other users of the bar code can select and maintain their scanners and train their operators, but must rely on suppliers to provide good quality bar codes on products.

## 1.1 General bar code performance criteria

There are five general criteria, relevant to all bar codes, which must be followed to ensure good bar code performance:

i) Bar code production.

ii) Number notification – ensuring that the EAN•UCC global trade item numbers (GTINs) and other identifiers are on file with trading partners.

iii) Location of bar codes – ensuring that the bar codes are located sensibly for ease of scanning.

iv) Light margins or quiet zones – adequate light margins or quiet zones must be provided on both sides of a bar code and it is recommended that these are greater than the minimum requirements. Light margin indicators should be used wherever possible to indicate the space required on both sides of a bar code. For ITF-14 bar codes, the H gauges must not infringe the light margins.

v) Bar code colours – the correct contrast between the dark bars and the light background must be maintained.

For more detailed information about bar code production, especially in the fast moving consumer goods sector, please see the GS1 UK document Bar coding - getting it right, and other GS1 UK information.

## 1.2 The validation process

Validation refers to the whole quality assurance process, which includes the following actions:

- Ensure the correct symbol is used for the relevant product, application and scanning environment.
- Re-check the GTIN and other encoded data in any artwork.
- Check the size of the symbol, both its magnification (in effect the x-dimension) and the bar height.
- Check the position of the symbol on the final, made-up product.
- Ensure that there are adequate light margins.
- Check that the contrast between the bars and the background is adequate and that the colours chosen will scan.
- Check the print quality regularly throughout the print run by verifying symbol quality.
- Check that the bar code symbol will remain readable in the environment in which the product will be stored, handled and distributed.
- Notify trading partners of the GTINs and the products they identify in good time.
- Ensure that no shrink-wrap, tape or other printing will obscure the bar code symbol on the finished product.
- Ensure that no other bar code symbols, which may cause problems, will show through from the inside of the pack.
- Carry out regular verification of samples of bar codes on all levels of packaging to ensure that they comply with the required quality standard, and to identify any potential problems.

Note: Remember that if non-standard bar code symbols are produced to meet specific customer requests, these will be unreadable and unusable by other recipients of the goods. Ideally non EAN•UCC bar codes

should not appear on products intended for general distribution as they may cause problems for some automated scanning systems.

# 2 Role of verification

Verification is the measuring and grading of the quality of a printed bar code in its final configuration. This is carried out to international standards and is particularly useful for quality control purposes. Verification can also be used to check how symbol quality is affected by any subsequent wrapping or labelling.

The difference between symbol verification and symbol scanning is that verification measures and grades the quality of a bar code, and can provide information to help diagnose the cause of any problems. Scanning is the process of reading the data from the symbol and it provides no indication of a bar code's quality.

Any verifier used to check the quality of EAN•UCC bar codes should conform to the international standard ISO/IEC 15426-1, which will ensure that the codes are graded according to the standard ISO/IEC 15416.

## 2.1 Using a verifier

### 2.1.1 Calibration

All verifiers must be calibrated to ensure that they report reflectance characteristics within internationally defined tolerances and measure the bar code elements correctly. The performance of a verifier may be affected by changes in electricity supply voltages, operating temperature, and the lighting conditions. Whenever the aperture size is changed (to suit different bar code sizes) the verifier must always be recalibrated.

This process will take one to two minutes to carry out, and must be done with calibration materials that have accurately measured reflectance characteristics and test bar codes that have been produced within very strict tolerances. These calibration cards should be kept in accordance with the manufacturer's instructions, usually in a special folder and away from continuous exposure to light.

As well as the calibration cards that are available from verifier manufacturers, it is also possible to obtain calibrated conformance standard test cards that include symbols with engineered defects and their test results. By verifying these symbols with a particular verifier, users can check that their verifier is measuring the symbols correctly. These standard test cards are available from the GS1 website www.gs1.org.

### 2.1.2 Aperture size

Verifiers use a beam of light to scan the bar codes, and the diameter of this beam of light must be adjusted to suit the size of bar codes being checked. The international standards specify the apertures to be used as set out below, and the aperture size can be easily adjusted by the operator as required. The measurements are given in thousandths of an inch, and these must be included in the header to the verification report.

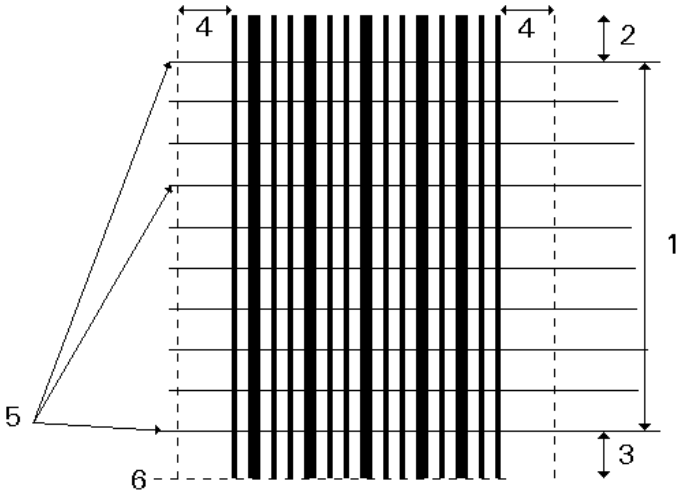
| Symbology | Aperture reference | Nominal diameter in mils (0.001 inch) | Nominal diameter in mm |
|---|---|---|---|
| RSS-14 | 06 | 6 | 0.150 |
| EAN/UPC | 06 | 6 | 0.150 |
| UCC/EAN-128 | 10 | 10 | 0.250 |
| ITF-14, x-dimension < 0.635 mm | 10 | 10 | 0.250 |
| ITF-14, x-dimension ≥ 0.635 mm | 20 | 20 | 0.500 |

### 2.1.3 Wavelength of light

The General EAN•UCC Specifications stipulate that the wavelength of light used by a compliant verifier should be 670 nanometres ± 10 nm. This dimension will be included as part of the reported grade of the bar code, as explained in section 3.

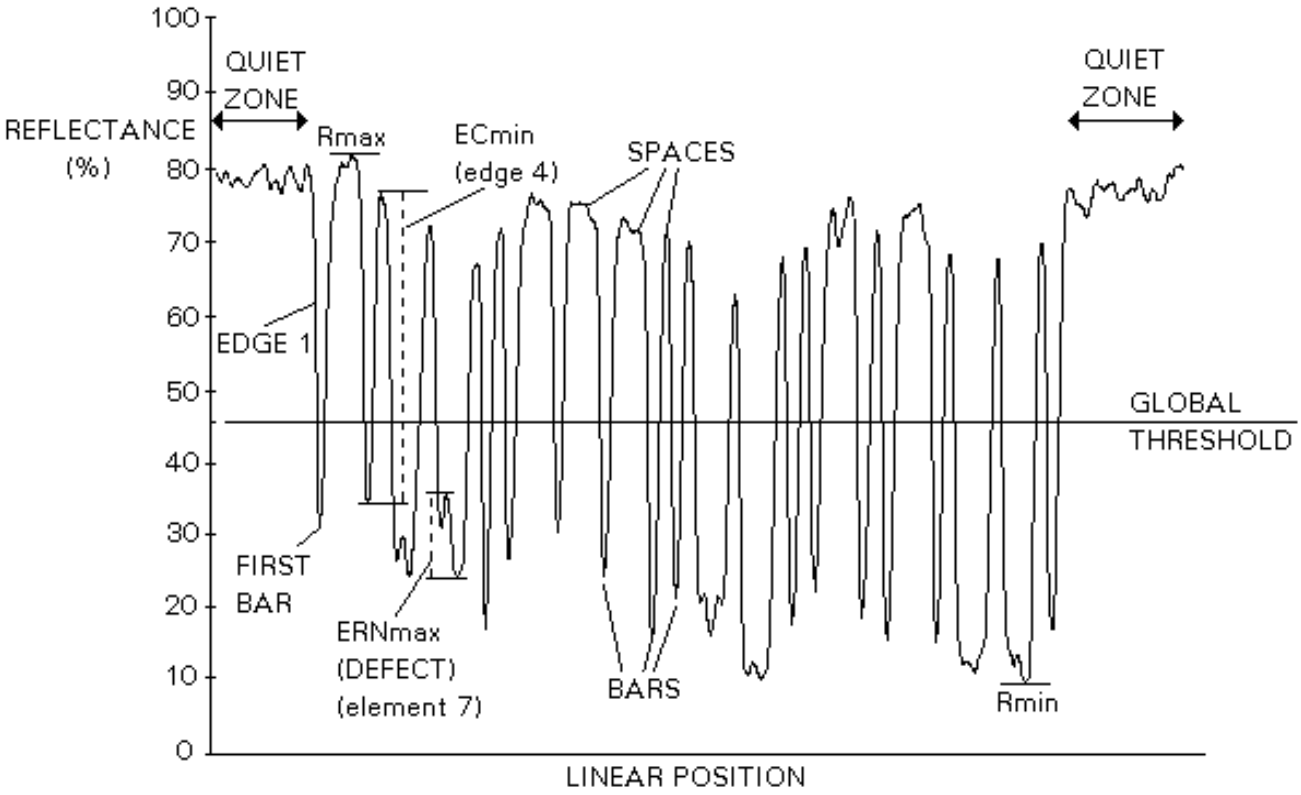
## 2.2 Verifying the bar code

The international standards require each bar code to be scanned ten times across the complete width of the symbol, including its light margins, with these scans being evenly spaced through an inspection band which covers 80% of the height of the bars of the bar code. The inspection band omits the top and bottom 10% of the height of the bars as shown below:




1. Inspection band (normally 80% of average bar height).
2 10% of average bar height above inspection band.
3 10% of average bar height above average bar bottom edge.
4 Light margins or quiet zones.
5 Scanning lines
6 Average bar bottom edge

## 2.3 The reflectance profile




For each scan the verifier produces an individual reflectance profile which measures the reflectance of each bar and space of the bar code. The verifier then takes nine different measurements from the reflectance profile, and grades seven of them individually.

The grade for the scan of the bar code will be the lowest grade for any one of these seven parameters. The overall symbol grade is obtained by averaging the grades of the ten individual scan reflectance profiles.
Each parameter is measured in percentage terms and this is then expressed as a numeric or alphabetic grade. The numeric grade will provide more precise figures, but as the alphabetic grades are still widely used a table showing how they compare is set out below:

| Alphabetic | Numeric range |
|---|---|
| A | 3.5 to 4.0 |
| B | 2.5 to 3.5 |
| C | 1.5 to 2.5 |
| D | 0.5 to 1.5 |
| F | 0 to 0.5 |

The grade for each scan is shown at the foot of each column, and the overall grade for the symbol is the average of these 10 scans. This grade is not necessarily equal to the lowest average of each parameter, and this is made clear below.

| Parameter | | | | | | | | | | | Average over 10 scans |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Decode | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Minimum reflectance | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Symbol contrast | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | 3.5 |
| $EC_{min}$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Modulation | 3 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 2.4 |
| Defects | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3.3 |
| Decodability | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 2.5 |
| **Grade per scan** | **3** | **2** | **2** | **2** | **2** | **2** | **2** | **2** | **2** | **3** | **2.2** |

All EAN/UPC and UCC/EAN-128 bar codes must have a grade of 1.5 (C) or better. ITF-14 bar codes with a magnification of 62.5% or greater (equal to an x-dimension of 0.635 mm or greater) must be grade 0.5 (D) or better.

In general symbols with higher quality grades can be expected to scan more easily and quickly than lower quality symbols of the same magnification. Larger magnification, the absence of truncation, and high print quality contribute to fast, effortless scanning.

Bar codes that fail verification may scan under ideal conditions, but badly or not at all in other environments. This is why a scanner cannot be used to test the quality of a bar code.

## 2.4 Symbol quality attributes graded by a verifier

The international specification for bar code print quality (ISO/IEC 15416) defines seven attributes that must be graded from a scan reflectance profile. These are decode, minimum reflectance, symbol contrast, minimum edge contrast, modulation, defects and decodability, and they are explained in detail below:

To achieve the most relevant results, all measurements should be made with the bar code on the item in its final packaging. The seven attributes and their relationship are:

### 2.4.1 Decode

Dimensional errors in printing a symbol can make it difficult or impossible to scan. A scanner or verifier applies specific rules to the sequence of bars and spaces to decode them into encoded characters and auxiliary characters (guard bars, centre bars, stop and start characters). When a verifier is able to decode a symbol including its auxiliary characters, and when the check digit is consistent with the other digits, the decode attribute is judged to pass. Decode is judged on a pass/fail basis.

The main reason for decode failure is the lack of sufficient light margins or quiet zones to the left and right of the bar code. It is reasonable to accept that all or many of the symbols which were created by the same equipment in a similar period may also be defective.

### 2.4.2 Minimum reflectance ($R_{min}$)

The bar with the lowest level of reflectance must have a reflectance less than half that of the background. This attribute is judged on a pass/fail basis. A failing grade for minimum reflectance will most often indicate that the bars should be printed in a colour that appears darker under red light.

### 2.4.3 Symbol contrast (SC)

Symbol contrast is calculated by finding the difference between the minimum and maximum reflectance ($SC = R_{max} - R_{min}$), and is graded from 0 to 4. The blackest possible bars printed on the whitest possible surface would have a 100% contrast. Practical printing of a symbol on commercial materials results in less than 100% contrast. When the contrast becomes too low, scanners may have difficulty distinguishing the bars from the spaces, so higher contrast is desirable.

A low contrast grade indicates that either the bars are too light (not enough ink or ink not dark enough), or the background is too dark, or both. Because the measurements are made with red light, it can be helpful to inspect the symbol visually through a red filter. When viewed in this fashion, the bars should appear to be much darker than the spaces.

Generally speaking, the background (spaces) should be white or one of the warm colours (red, orange, yellow), and the bars should be black, blue or green.

### 2.4.4 Minimum edge contrast ($EC_{min}$)

Minimum edge contrast is the least difference in reflectance between a bar and an adjacent background. It is graded on a pass/fail basis. A failing grade for minimum edge contrast will always be accompanied by low (0 or 1) grades for symbol contrast or modulation or both.

### 2.4.5 Modulation (MOD)

Modulation is calculated as a ratio of minimum edge contrast to symbol contrast ($MOD = EC_{min}/SC$) and is graded from 0 to 4.

Scanners and verifiers perceive the narrow spaces to be less white than the wide spaces. Similarly, but to a lesser extent, the narrow bars in a symbol look less black than the wide bars. This diminished intensity of narrow elements as compared to that of wide elements causes a variation in the light reflected from the elements of the symbol, and this is known as modulation.

The most probable reason for a low (0 or 1) modulation grade is excessive gain or loss of bar width.

### 2.4.6 Defects

Defects are graded by calculating the ratio of the maximum element reflectance non-uniformity to symbol contrast ($Defects = ERN_{max}/SC$). Defects will be graded from 0 to 4. Element reflectance non-uniformity is a measure of the variation in reflectance of each bar and space of the bar code – if bars were perfectly uniform in blackness there would be no element reflectance non-uniformity.

Printing defects are of two types, voids and spots. Voids are light areas within the bars. Spots are dark areas in the spaces. Defects are undesirable because the scanner might interpret the defect as an additional bar or space within the symbol.

Symbols that produce low (0 or 1) defect grades can be examined with a good quality magnifier (5 to 10 power), and the defects will be clearly visible. Usually, defects are voids that can be reduced or eliminated by increasing the amount of ink. Less often, excessive pigment or dirt may be deposited in the spaces, with resultant spots or inclusions. The use of recycled materials may also result in spots or inclusions in the spaces.

### 2.4.7 Decodability

Decodability is a measure of how close the printed bar code is to its nominal dimensions, and it is the ratio of the printing tolerances not used up to the printing tolerance allowed for each size of symbol. Decodability is graded from 4 to 0, and bar codes that are printed to a high degree of dimensional accuracy will have high decodability grades.

One common reason for low decodability grades is ragged, uneven bar edges. This problem is caused by some of the coarser printing processes and is easily observed by a 5 to 10 power magnifier. Another reason for low decodability is excessive bar width gain or loss, which also tends to adversely affect modulation and edge determination.

The creation of bar codes using an improperly designed graphics based software system is a likely cause of low decodability. Software used with pixel based printers must scale each bar and space to an exact multiple of the pixel pitch of the printer being used.

## 2.5 Symbol attributes not graded by a verifier

### 2.5.1 Global threshold

This is the halfway point between the maximum and minimum reflectances (GT = $R_{max}$ + $R_{min}$ / 2). The reflectance of each space should be greater than this, and the reflectance of each bar should be lower than this. The global threshold is used by the verifier to determine which elements of the scan reflectance profile represent the bars and spaces of the bar code. The verifier will then check that the scan reflectance profile contains the correct number of bars and spaces for the type of bar code being tested (e.g. there are 30 bars and 29 spaces in an EAN-13 bar code, a total of 59 elements).

### 2.5.2 Edge determination

An element edge is defined as the point where the scan reflectance profile intersects the mid point between the reflectance of a bar and the adjacent space. Each bar's reflectance is known as $R_{b,}$ and each space's reflectance is $R_{s,}$ so each edge is measured where the reflectance value is $R_b$+ $R_s$ / 2. (This means that the edges are measured at the halfway point between each peak and trough of the reflectance profile, and not where the reflectance profile crosses the global threshold.) If more than one point meets this definition between a bar and a space the edge position will be ambiguous, and the bar code will fail to decode.

### 2.5.3 Bar width deviation

This is the traditional measurement contribution to the ISO/IEC method, and is calculated as the mean difference between measured bar widths and their theoretical ideal values. Bar width deviation may be expressed as a percentage of the x-dimension or in dimensional terms.

## 2.6 Parameters a verifier cannot grade

All verifiers that meet the international standard for verifiers (ISO/IEC 15426-1, which states that they must measure bar code quality in accordance with ISO/IEC 15416) will grade bar codes using the seven parameters explained in section 2.4.

Other aspects of the bar code are still important but these will not always be measured and checked by all verifiers.

### 2.6.1 Light margins (quiet zones)

All EAN/UPC, ITF-14 and UCC/EAN-128 bar codes require a light margin, or quiet zone, to the left and right hand sides of the bars of the bar code that should be the full height of the symbol. While inadequate light margins will cause the bar code to fail on decode, many verifiers will not measure how much extra space should be provided.

Common causes for failing to meet the light margin specifications are printing text in the light margins, using over wrap to cover this area, and placing the bar code too close to the edge of a product.

If light margin indicators are used it is important to check that these do not appear in the light margins themselves, and are correctly positioned, generally in line with the numbers below the bar code.

### 2.6.2 Truncation

The height of the bars of a bar code is very important and if they are shorter than the General EAN•UCC Specifications stipulate they will not scan as successfully as taller symbols. Most verifiers will not measure bar code height so this must be measured separately.

Any reduction in height is known as truncation.

### 2.6.3 Human readable characters

The human readable characters must be readable with the symbol, and generally be directly underneath the bar code symbol. It is also mandatory for the human readable characters to be consistent with those encoded.

### 2.6.4 Numbering system validity

Ensure that the global trade item number (GTIN) assigned to the product line is unique and correct, and that the check digit calculation is correct. Also check that the correct data is included in any UCC/EAN-128 bar codes.

Some verifiers may not be programmed to check UCC/EAN-128 bar codes correctly, and these may not check for the presence of the Function 1 character immediately after the start character and that the data is correctly encoded.

### 2.6.5 Symbol location

Location of bar code symbols is important to ensure symbols are located sensibly for ease of scanning.

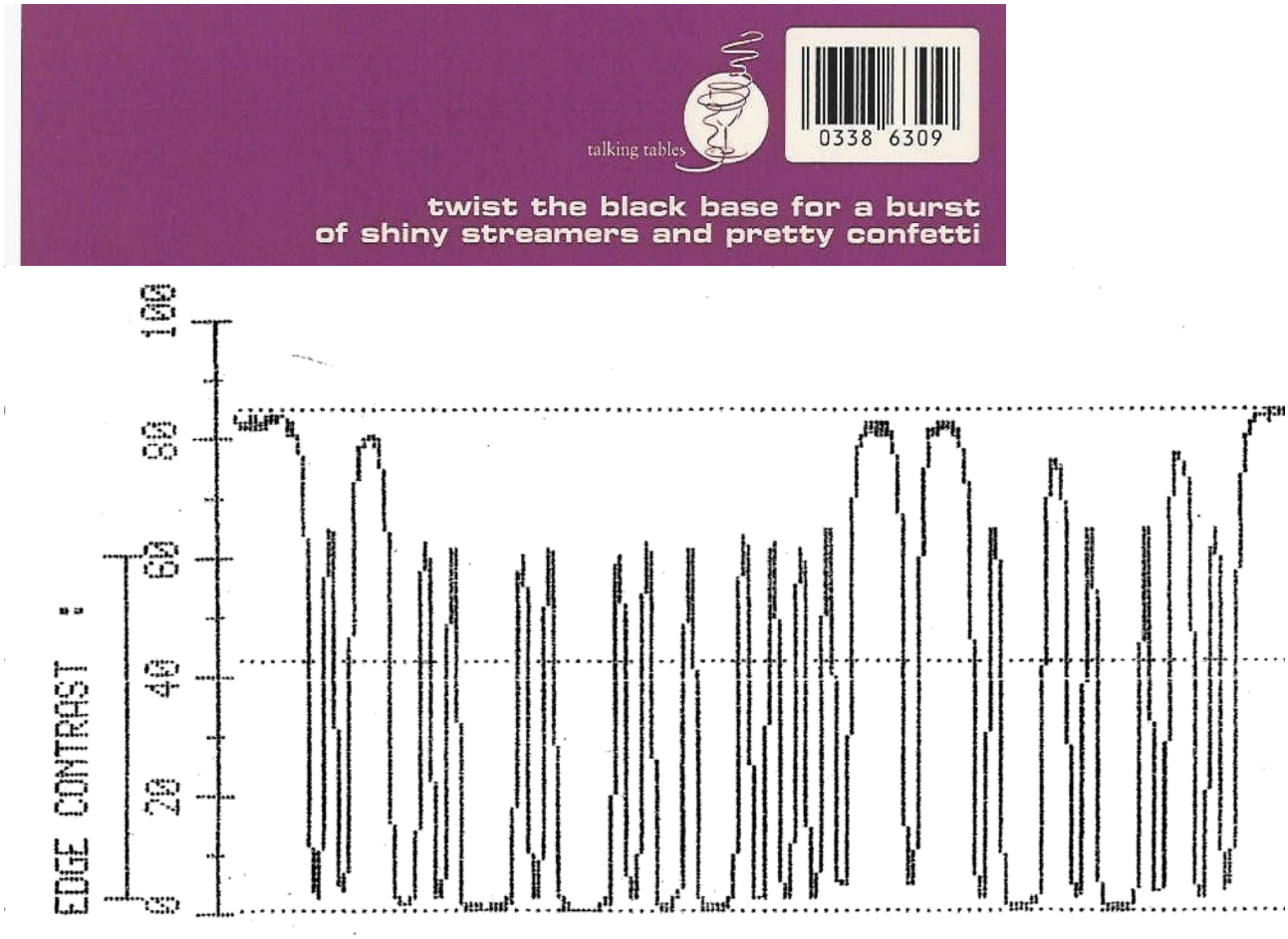
### 2.6.6 Magnification

Magnification or symbol size is an important factor that may be reported by some verifiers, but does not directly affect the bar code's grade. As a general rule larger symbols will have better grades, and users should aim to produce bar codes at their target sizes.

# 3 The verification reports

## 3.1 Example of an EAN-8 verification report

EAN-8 at a magnification of 100% (x-dimension = 0.33 mm)




ANSI evaluation

| | | |
|---|---|---|
| Decode | 4.0 | |
| Edge contrast | 4.0 | 58% |
| Symbol contrast | 4.0 | 85% |
| Modulation | 3.0 | 68% |
| Reflection min/max | 4.0 | 1% |
| Defects | 4.0 | 7% |
| Decodability | 4.0 | 85% |
| | | |
| Overall symbol grade | 3.0 | |

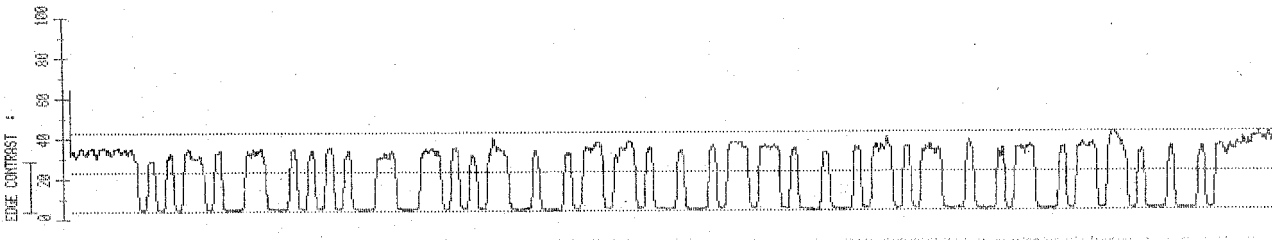
Reported as 3.0/06/670, where 3.0 is grade, 06 the aperture size reference, and 670 the wavelength in nm.

The narrow spaces in the bar code, especially those above the figures 0338 on the left hand side of the bar code do not appear as white as the wider spaces as shown in the lower peaks in the reflectance profile. The bar code is still perfectly acceptable as it is graded B.

The symbol's bars are too short, at 10mm. The minimum is 16 mm, and ideally should be 18 mm.

## 3.2 Example of an ITF-14 report

ITF-14 on brown fibreboard, at a magnification of 70% (x-dimension = 0.71 mm)


ANSI evaluation

| | | |
|---|---|---|
| Decode | 4 | |
| Edge contrast | 4 | 25% |
| Symbol contrast | 1 | 39% |
| Modulation | 3 | 64% |
| Reflection min/max | 4 | 9% |
| Defects | 3 | 16% |
| Decodability | 4 | 67% |
| | | |
| Overall symbol grade | 1 | |

Reported as 1.0/20/670 where 1 is the grade, 20 the aperture size reference, and 670 the wavelength in nm.

ITF-14 symbols on brown fibreboard will always have low symbol contrast, in this case 39%, which brings the selected grade down to 1, which is acceptable for an ITF-14 of this size on brown board. For all other paler substrates the grade should be 1.5 or above.

The height of the bars though is unacceptable at 25 mm. These should be increased to 32 mm.

### 3.3 Using percentage measurements

The international standard converts percentage measurements into five different grades for the four parameters that are graded from 0 to 4 – symbol contrast, modulation, defects and decodability – and it can be useful to look at percentages to gain more accurate information about how close a symbol is to being graded differently. The conversion table for all the parameters being graded is set out below:

| Grade | Decode | Symbol contrast | Minimum reflectance | Minimum edge contrast | Modulation | Defects | Decodability |
|---|---|---|---|---|---|---|---|
| 4 or A | Passes | ≥ 70% | ≤ 0.5 x $R_{max}$ | ≥ 15% | ≥ 0.70 | ≤ 0.15 | ≥ 0.62 |
| 3 or B | | ≥ 55% | | | ≥ 0.60 | ≤ 0.20 | ≥ 0.50 |
| 2 or C | | ≥ 40% | | | ≥ 0.50 | ≤ 0.25 | ≥ 0.37 |
| 1 or D | | ≥ 20% | | | ≥ 0.40 | ≤ 0.30 | ≥ 0.25 |
| 0 or F | Fails | < 20% | > 0.5 x $R_{max}$ | < 15% | < 0.40 | > 0.30 | < 0.25 |

# 4 Verification equipment

The accuracy of verification equipment used for analysing bar code symbols critically affects the validity of any results.

### 4.1 Variance between verifiers

Users occasionally experience variance between verifiers. The ISO/IEC 15426-1 standard has been developed to counter this problem by providing a test method which ensures that verifiers conform to a specified minimum level of accuracy when used under controlled conditions. Factors which may influence performance are:

- Infrequent calibration
- Poor quality calibration sheets
- Irregular scanning motion
- Incorrect aperture settings
- Incorrect wavelength of light
- Local lighting conditions
- Aged equipment
- Poorly maintained equipment
- Operator techniques

Note: In instances where all the above factors have been addressed, users should refer back to the equipment suppliers.

# 5 Quality assurance

The previous sections have discussed some of the factors that affect bar code quality, and how these factors are measured. Due to the growing use of on-demand printing, it is increasingly important to be aware of these issues. Some of the most common problems that occur when printing symbols are highlighted below.

It is also recommended that companies starting the process of using bar codes should co-ordinate all activities to minimise quality problems.

## 5.1 Common Printing Problems

These are some of the most common problems, and those that will be discovered with the correct use of verification equipment. All of theses can be avoided if sufficient care is taken at the design and origination stages.

- Incorrect correction for ink spread (the bar width reduction). The printed bars are out of specification, either being too narrow or too wide.
- Poor quality substrates are substituted for the original specification, resulting in loss of quality, often greater ink spread, or the appearance of voids in the bars. A darker coloured substrate, for example, could result in insufficient symbol contrast.
- Choosing incorrect colour combinations, often orange or red bars on a pale background, which will not scan. Reversed out images, where the bars are white against a coloured background, are again not scannable.
- Using transparent substrates, such as glass or plastic, and hoping that the contents will provide a suitable background colour either for the bars or the spaces.
- Using uncovered metal surfaces as a background or for the bars of a symbol. Again the specular reflectance of the substrate can cause problems, and a solid background should be printed to provide good contrast and eliminate this problem.
- The light margins required by each bar code symbol are not large enough. The UPC-E, EAN-8, UPC-A, EAN-13 and ITF-14 symbols all have physical indicators, if they are printed correctly, but UCC/EAN-128 has no light margin indicators so extra care must be taken.
- Printhead failures that result in extraneous white lines appearing in the symbol. Correct maintenance procedures must be followed.
- Printing bar codes that are either too large or too small.
- Printing EAN-13, UPC-A, EAN-8, UPC-E or UCC/EAN-128 bar codes directly onto brown fibreboard cases. These symbols will generally have insufficient symbol contrast.
- Printing Code 128 symbols instead of UCC/EAN-128 symbols because the Function 1 character does not immediately follow the start pattern.
- Encoding the brackets around the application identifiers as data within a UCC/EAN-128 bar code symbol. These brackets are only used around the application identifiers in the human readable characters printed below the bar code.
- Printing a UCC/EAN-128 symbol wider than 165mm. This dimension includes the light margins which are not explicitly indicated, so special attention must be given.

# 6 Appendix

## 6.1 Definitions

**aperture**
The effective opening in an optical system that establishes the field of view.

**bar**
A dark element corresponding to a region of a scan reflectance profile below the global threshold.

**bar reflectance**
The lowest reflectance value in the scan reflectance profile of a bar element.

**decodability**
Measure of the proportion of the theoretical tolerance derived from the reference decode algorithm, for the element (or distance) deviating most from its nominal dimension in a scan reflectance profile, not consumed by that element or distance.

**decode**
Determination of the information encoded in a bar code symbol.

**edge contrast**
The difference between bar reflectance and space reflectance of two adjacent elements.

**element reflectance non-uniformity**
The reflectance difference between the highest peak and the lowest valley in the scan reflectance profile of an individual element or quiet zone.

**Function 1**
This is the special character that must be used immediately after the start character to indicate that the symbol is a UCC/EAN-128 bar code. It is also used to terminate any variable length fields within a UCC/EAN-128 symbol.

**global threshold**
The reflectance level midway between the maximum and minimum reflectance values in a scan reflectance profile used for the initial identification of elements.

**gloss**
The propensity of a surface to reflect a proportion of incident light in a specular manner.

**inspection band**
The band (usually from 10% to 90% of the height of a bar code symbol) across which measurements are taken (see figure 2).

**measuring aperture**
A circular opening which governs the effective sample area of the symbol, and the diameter of which at 1:1 magnification is equal to that of the sample area.

**modulation**
The ratio of minimum edge contrast to symbol contrast.

**peak**
A point of higher reflectance in a scan reflectance profile with points of lower reflectance on either side.

**sample area**
The effective area of the symbol within the field of view of the measurement device.

**scan reflectance profile**
Plot of variations in reflectance with linear distance along a scan path.

**scan path**
The line along which the centre of the sample area traverses the symbol, including light margins.

**space**
A light element corresponding to a region of a scan reflectance profile above the global threshold.

**space reflectance**
The highest reflectance value in the scan reflectance profile of a space element or quiet zone.

**symbol contrast**
The difference between the maximum and minimum reflectance values in a scan reflectance profile.

**valley**
A point of lower reflectance in a scan reflectance profile with points of higher reflectance on either side.

**vertical redundancy**
The property of a bar code symbol whereby there exist multiple possible scan paths as a result of the symbol being significantly higher than the height of a single scan line.

## 6.2 Abbreviations

| | |
|---|---|
| **EC** | Edge contrast |
| **$EC_{min}$** | Minimum value of EC |
| **ERN** | Element reflectance non-uniformity |
| **$ERN_{max}$** | Maximum value of ERN |
| **GT** | Global threshold |
| **MOD** | Modulation |
| **$R_b$** | Bar reflectance |
| **$R_D$** | Dark reflectance |
| **$R_L$** | Light reflectance |
| **$R_{max}$** | Maximum reflectance |
| **$R_{min}$** | Minimum reflectance |
| **$R_s$** | Space reflectance |
| **SC** | Symbol contrast |