READABILITY OF DIRECTLY-MARKED TRACEABILITY SYMBOLS ON PCBs

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INTRODUCTION:

Compliance with ISO 9001 and lean PCB manufacturing relies heavily on traceability data to assist with inventory control, automatic machine setup, warranty claims, optimization of production capabilities, and reduction of waste in terms of material handling and material scrap. Requirements from the military, aerospace, automotive, and medical device industries make it essential to be able to identify individual panels, boards, and parts at each production step. Recent recalls have shown how important it is to have this data available to reduce recall costs. The most widely-used method has been manual application of labels. Keeping up with modern production capabilities can be a challenge, and most companies are now transitioning to inkjet or laser marking. The goal is to apply markings that can be read throughout the overall process and by the end-customer, and can also be relied upon in the case of recalls and recycling programs.

BARCODES

It is critically important to choose the right barcode size and type, since the part number, supplier code, manufacturing traceability data, environmental information, and occasionally even country of origin need to be encoded. Due to limitations of board and component space, several manufacturers are moving from 1D to 2D symbologies to take advantage of the higher data density (Table 1). Data Matrix (DM) ECC 200 symbols are preferred for their robust built-in error correction, which ensures readability even if as much as 50% of the symbol is obstructed. There are several standards concerning PCB identification. The main ones are ANSI/EIA 706 and EIA PN 3497. These standards describe how components like PCBs, parts, and populated PCBs need to be marked. This paper focuses specifically on 2D Direct Part Mark (DPM) symbols covered in these standards.

Table 1 – Data Capacity of Square DM Symbols

Square	Data Capacity	
Symbol Size	Numeric	Alphanumeric
48x48	348	259
52x52	408	304
64x64	560	418
72x72	736	550
80x80	912	682
88x88	1152	862

Table 2 – Data Capacity of Rectangular DM Symbols

Rectangular	Data Capacity	
Symbol Size	Numeric	Alphanumeric
8x18	10	6
8x32	20	13
12x26	32	22
12x36	44	31
16x36	64	46
16x48	98	72

MARKING METHODS

Most PCB manufacturers use one of four methods to mark PCB boards and panels:

- Inkjet printer
- Labels
- Laser marker
- Laser marker with silkscreen pad

Each of these marking methods have advantages in certain situations. There are still instances of older application designs using labels for individual marking due to easier readability, better code quality, or customer requirements. The comparison (Table 2) doesn't include the laser silkscreen pad as it is very similar to laser marking. The pad is normally applied by the PCB manufacturer and provides better contrast than direct marks:

Table 3 – Marking Methods

	Inkjet	**Label**	**Laser**
Easy Changeover	Yes	No	Yes
Speed	Good	Manual application method can slow down process	Good
Operating Costs	Medium	High	Low
Consumables	~1.7ct/mark	3-10ct/label	~0.03ct/mark
Permanence	Permanent after wave solder or curing	Can be removed	Will last as long as the surface integrity

Maintenance	Weekly	NA	Monthly
Code quality	A-D	A-C	A-D
Color	Yes	Yes	No

Most new SMT lines use laser marking systems at the beginning of the production process, as they allow permanent individual board marking, easy changeover at high speeds, and low operating costs. PCBs can be marked with either CO2, YAG, or fiber lasers. Of these types of lasers, fiber lasers produce the best edge definition and have highly accurate depth control, but they are also the most expensive. For the best marking results, it is necessary to optimize pulse energy, pulse duration, and repetition rate.

VERIFICATION VS. VALIDATION

It is becoming increasingly critical to add a verification step into the manufacturing system to help achieve the benefits of data capture and to ensure readability throughout the supply chain. Automated data capture is crucial for a company's success, as the results of decode failures can have a serious impact. Additionally, verification can be used to monitor how well the label printer or direct part marking equipment is performing, and reduce the risk of manufacturing errors or downtime caused by unreadable codes. Verification catches deteriorations in the marking process early so that countermeasures can be employed before unacceptable product enters the production line. This helps manufacturers avoid rejections of product by the end customer (Figure 1).

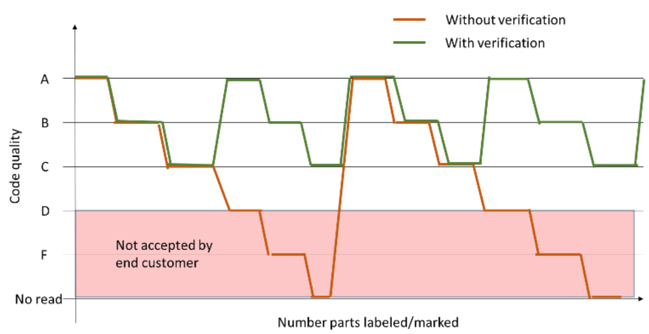


Figure 1: Impact of Symbol Verification

Many manufacturers validate readability by using a reader to ensure that that a code is readable. But this doesn't ensure that it can be read by other readers later in the production process. True verification provides information about how well the code can be read and can provide indications about printing and marking process stability. Verification ensures that any correctly-functioning reader can decode the given symbol. Verification is either keyed to an internal standard to ensure process stability, or to one of the following standards:

- ISO 15415/ISO 29158: 2D Symbols
- AS9132: 2D symbols

Verification is performed by camera-based systems with specific lighting, and results come in the form of a grade, from A (perfect) to F (least likely to be decodable by most readers). ISO 15415 is for printed labels while ISO 29158 is for directly-marked parts. The following evaluation parameters are measured specifically for ISO 15415 and ISO 29158:

Axial Non-Uniformity (ISO 15415/ISO 29158)
Axial Non-Uniformity is the amount of deviation along the symbol's major axes. In Figure 2 (A), the symbol's Y-axis dimension is clearly greater than its X-axis dimension. This indicates that the marking process is resulting in the Y-dimensions of individual modules being greater than their X-dimensions. This inconsistency of X- and Y-dimensions typically indicates movement of the object as it is being marked.

Symbol Contrast (ISO 15415)
Symbol Contrast is the value difference between light and dark symbol elements, and between the quiet zone and perimeter elements. Figure 2 (B) shows a low-contrast symbol. The dark elements (etched) and the light elements (the substrate) are too close in value, which undermines readability.

Cell Contrast (ISO 29158)
Cell Contrast is the value difference between light and dark symbol elements, and between the quiet zone and perimeter elements. Figure 2 (C) shows a low-contrast direct part mark symbol. The light and dark elements are too close in value, which undermines readability.

Modulation (ISO 15415)
Modulation refers to the reflectance uniformity of a symbol's light and dark elements. In Figure 2 (D), notice that the light and dark values of some elements are inconsistent.

Cell Modulation (ISO 29158)
Cell Modulation refers to the reflectance uniformity of a symbol's light and dark elements. In Figure 2 (E), notice that the light and dark values of some of the elements in the dot peen mark are inconsistent.

Decodability (ISO 15415/ISO 29158)
Decodability refers to a symbol's ability to be decoded per a standard reference decode algorithm. Figure 2 (F) shows a high-quality 2D symbol.

Fixed Pattern Damage (ISO 15415/ISO 29158)
Fixed Pattern Damage refers to finder pattern and clock pattern damage. Notice the missing elements in the clock pattern and the damaged L-pattern in Figure 2 (G).

Grid Non-Uniformity (ISO 15415/ISO 29158)
Grid Non-Uniformity refers to a symbol's cell deviation from the ideal grid of a theoretical "perfect symbol". The Data Matrix reference decode algorithm is applied to a binarized image of the symbol, comparing its actual grid intersections to ideal grid intersections. The greatest distance from an actual to a theoretical grid intersection determines the Grid Non-Uniformity grade. The symbol shown in Figure 2 (H) exhibits a high degree of Grid Non-Uniformity.

Minimum Reflectance (ISO 29158)
Minimum Reflectance refers to the minimum reflectance of light by the symbol's light elements. In Figure 2 (I), notice that the symbol's light elements exhibit a minimum reflectance to ensure contrast against the dark substrate to allow readability.

Reflectance Margin (ISO 15415)
Reflectance Margin measures how well each element of a symbol is correctly distinguishable as light or dark in comparison to the global threshold. Low reflectance margin, such as that illustrated in Figure 2 (J), may increase the probability that a symbol element will be incorrectly identified as dark or light.

Unused Error Correction (ISO 15415/ISO 29158)
Unused Error Correction indicates the amount of available Error Correction in a symbol. Error Correction is a method of reconstructing or replacing data that is lost through symbol damage. 100% Unused Error Correction is ideal, as shown in Figure 2 (K).

Over- and under-print can also occur, causing symbol decodability problems.

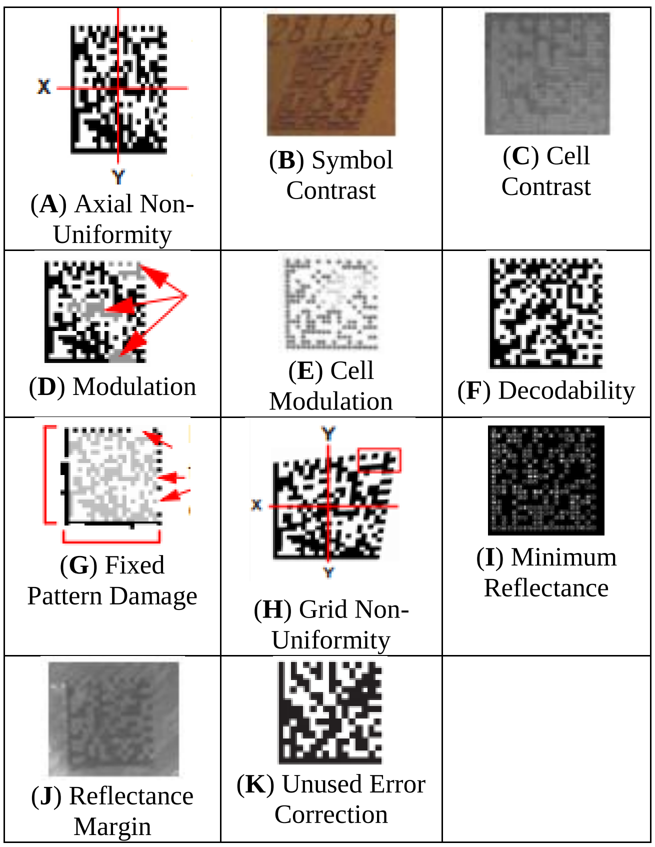


Figure 2: Verification Evaluation Parameters

Symbol verification immediately following the printing or marking process ensures proper readability throughout the application, and can help with the setup of the inkjet or laser marker. These systems must be properly calibrated with specialized calibration cards if verifying to the ISO 15415 or ISO 29158 standard.

1D/2D READERS
Modern barcode readers use a variety of techniques to ensure that codes can be read properly. These readers can either come in a handheld or fixed-mount form. Figure 3 shows the components of a compact fixed-mount reader.

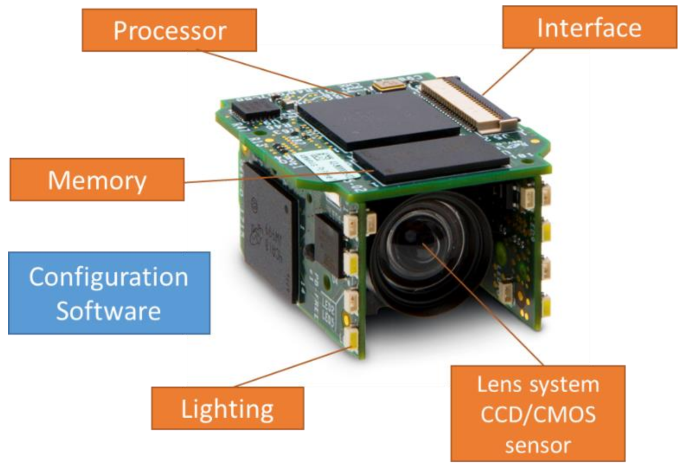


Figure 3: 2D Reader Components

Lighting
The lighting system ensures maximum symbol reflectance. For optimal performance, proper mounting of the reader is essential. The reader is normally positioned 30° to 45° perpendicular to the symbol. The more powerful the lighting system, the more accurately low-contrast symbols can be decoded.

Lens System and CCD/CMOS Sensor
The lens system, in combination with the CCD/CMOS sensor, ensures that codes as small as 2.5 mil can be decoded at the required reading distance. Readers typically come with specification charts that show field of view, depth of field, and minimum readable symbol size. Additional features such as autophotometry may also be available, allowing you to adapt gain and shutter speed automatically. Autophotometry optimizes image exposure and allows readability of codes on variously-colored PCBs.

Processor
The processor runs the decoding software with advanced algorithms, allowing the reader to decode difficult-to-read symbols.

Memory
The reader's memory can be used to store no-read images for further analysis.

Interface
RS-232, USB, or Ethernet are most commonly used. Various industrial protocols such as EtherNet/IP and PROFINET can be supported by modern barcode readers.

Configuration Software

Traditionally, users must download and install specialized configuration software to make reader parameter modifications. Modern readers can leverage web browser technology for configuration and testing. By simply entering the IP address on any web-enabled device, all reader parameters can be configured. This means that no software needs to be installed. Browser-based configuration programs support different operating systems (Windows, MacOS, iOS, Android) and run on any web-enabled device (PC, tablet, phone). Intuitive user interfaces limit the amount of clicks necessary to start decoding (Figure 4).

Figure 4: Web-Based Configuration Software Results

RESULTS:

We tested 2D readers on different colored boards that were laser marked with 5mil (0.127mm) codes:

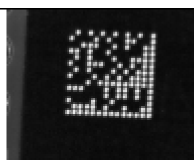
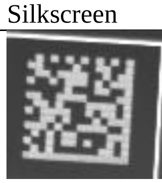
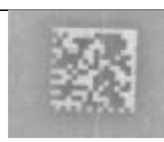
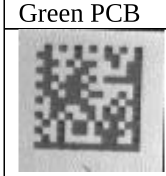
 (A) Black PCB	 (B) Black Silkscreen	 (C) Blue PCB
 (D) Copper on Green PCB	 (E) Green PCB	 (F) Red PCB
 (G) White Silkscreen		

Figure 5: Tested Boards

First we used a UID DPM verifier and verified the codes according to ISO 29158. As expected, these were high-quality codes, the only exception being the code on the red board which was Grade B due to lower cell contrast and fixed pattern damage. We tested comparable, standard, off-the-shelf, second generation miniature readers from different vendors. The first test was to unpack the reader, download and install software, connect, and power up the reader.

	Setup Time
Reader 1	2 min. (Web-based configuration)
Reader 2	19 min.
Reader 3	28 min. (6 min. to find the right software to install)

Placement of the code was slightly easier with reader 1 as it had a larger field of view (21.7 cm^2 vs. 10.6 cm^2 for reader 2 and 4.2 cm^2 for reader 3). Additionally, the web-based user interface was much more intuitive. The next step was to try to read the codes on the PCBs without any additional adjustments.

	Grade	**Reader 1**	**Reader 2**	**Reader 3**
Black PCB	A	Yes	Yes	Yes
Black Silkscreen	A	Yes	Yes	Yes
Blue PCB	A	Yes	Yes	Yes
Copper on Green PCB	A	Yes	Yes	Yes
Green PCBs	A	Yes	Yes	Yes
Red PCB	B	Yes	No	Yes
White Silk Screen	A	Yes	Yes	Yes

Two of the readers were able to read all the codes right out of the box while reader 2 couldn’t read the code on the red board. This was very likely due to insufficient illumination provided by the reader. After full adjustment, reader 2 was still unable to decode the symbol on the red PCB.

CONCLUSION

Modern traceability systems in SMT production lines rely heavily on proper board marking and advanced readers. Adding verification directly after the marking process ensures symbol decodability throughout the application, and helps with the setup and testing of inkjet or laser markers. As tests have shown, most readers are capable of handling small codes on different colored boards. This is essential to ensuring that proper production data is stored, communicated throughout the production line, and used in production to initiate job changes. Tests also show that web-based configuration software has an immediate advantage as no software has to be installed, there is no need to worry about version conflict, and any computer can run the web-based configuration user interface.

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