Laser Marking of ECC 200 2D Matrix Codes on Printed Circuit Boards

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Manufacturers of electronic devices, from home audio equipment to automotive keyless entry systems, are increasingly seeking a reliable, cost effective method for uniquely identifying and tracking products through the manufacturing cycle, sales distribution and after-sale warranty verification. An autonomous, automated tracking system requires that a permanent, machine-readable code be applied to an internal printed circuit board to uniquely identify each product. The code must be durable enough to survive manufacturing processes including wave solder and board cleaning, must not affect circuit performance, and must store information in the small space available on real-estate conscious printed circuit boards.

The 2D matrix code provides a means to store alphanumeric character strings in very small areas of the printed circuit board. Laser marking technology provides a method for permanently applying 2D matrix codes to most board substrates and conformal coatings. The high-resolution and high-accuracy of beam-steered laser marking systems provides the means to create well defined, high reliability codes regardless of code size. Laser marking also provides the user with a computer-controlled marking process for easy implementation into automated product tracking systems.

ECC 200 2D Matrix Codes

Two-dimensional symbologies encode information in the form of a checkerboard pattern of on/off cells. *(See Figure 1)*. Specific advantages of Data Matrix codes over conventional 1D barcodes include:

- **Encode information digitally**, as opposed to the analog encoding of data in conventional barcodes.
- Can accommodate **low-contrast printing** directly on parts without requiring a label
- Offer **very high information density** – the highest among other common 2D codes, which means that you can place a lot of information in a very small area.
- They are **scaleable**, which means that you can print them and read them in various levels of magnification – only limited by the resolution of the available printing and imaging techniques.
- Due to the high information density inherent to Data Matrix codes, they also offer **built-in error-correction** techniques which allow fully recovering the message encoded in a Data Matrix symbol even if the mark is damaged and missing as much as 20% of the symbol.
- They are read by video cameras as opposed to a scanned laser beam used for reading conventional barcodes, which means that they **can be read in any orientation**.

ECC 200 Data Matrix is the most popular 2-D symbology with extensive use in automotive, aerospace, electronics, semiconductor, medical devices and other manufacturing unit-level traceability applications. Data Matrix codes are typically not replacing conventional linear barcodes, but are being used where traditional barcodes were too large, did not provide sufficient storage capacity, or were unreadable.

Data Matrix Code Structure

The 2D matrix codes consist of four distinct elements.

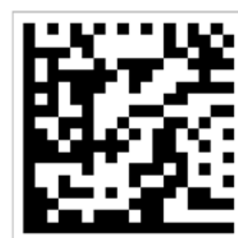

Figure 2

- The Finder "L" Pattern (*the solid lines to the left and bottom of figure 2*) orients the reader to the layout of the 2D code.
- The Clock Track (*the right and upper borders of figure 2*) designate the row/column count to the reader.
- The Data Region is the pattern of black and white cells within the L pattern and the clock tracks that contain the alphanumeric content of the code.
- The Quiet Zone around the code must be free of any features that may be visible to the reader. The quiet zone should be at least two rows/columns wide for codes constructed of square cells. The quiet zone should be at least four rows/columns wide for codes constructed of circular cells (dots).

Data Matrix Storage Capacity

Symbol Size	Data Capacity		Code Size
Row x Column	*Numeric*	*Alphanumeric*	*7.5 Mil Cell*
10 x 10	6	3	1.9mm
12 x 12	10	6	2.3mm
14 x 14	16	10	2.7mm
16 x 16	24	16	3.0mm
18 x 18	36	25	3.4mm
20 x 20	44	31	3.8mm
22 x 22	60	43	4.2mm

ECC 200 Data Matrix codes can store up to 3,116 numeric, 2,335 alphanumeric characters or 1,555 bytes of binary information in a 144 column by 144 row array. More realistic symbol dimensions for printed circuit boards can still contain a significant amount of information. *(See Table)*

Laser Marking System

The laser marking system consists of the laser source, the beam-shaping optics, and the beam-steering system *(see Figure 3)*.

Laser Source

The laser is a light amplifier generating a bright, collimated beam of light at a specific wavelength. For FR4 and solder mask applications, most users choose the air-cooled CO_2 laser operating at the 10,640nm far-infrared wavelength. This laser offers several performance and cost advantages, and produces excellent marking results.

Beam-Steering Galvanometer System

The laser beam is projected through two beam-deflecting mirrors mounted to high-speed, high-accuracy galvanometers. Each mirror deflects the laser beam 90 degrees from the direction of travel. As the mirrors are rotated under direction of the system computer, the laser beam scans across the target marking surface on both the X and Y-axis to "draw" the desired marking image.

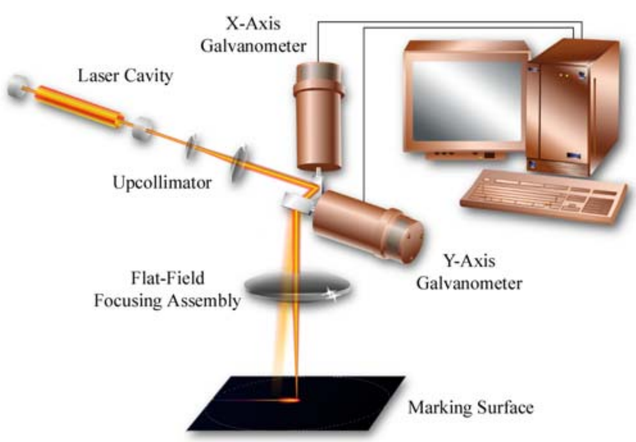

Figure 3 - Laser and Optics Train

Flat-Field Focusing Optics

After the laser beam is deflected from the beam-steering mirrors, it is focused to the smallest spot possible by flat-field focusing optics. The flat-field focusing assembly is a multi-element optical device designed to maintain the focal plane of the focused laser beam on a relatively flat plane throughout the marking field. The focused laser light significantly increases the power density and associated marking power.

Image Generation

The function of the laser optical train is to focus the laser beam to a small spot and to scan the laser beam over the target surface with high speed and accuracy. With the CO_2 laser configuration, the focused spot diameter and associated marking line width is about 0.0035" to 0.004". Man-readable text characters can be as small as 0.040" and 2D matrix codes can be constructed from individual features as small as a single 0.004" dot.

PCB Marking

To mark printed circuit boards, the heat generated by the laser beam thermally alters the surface of the board to create a contrasting, legible mark. The process does not require labels, stencils, punches or any other auxiliary hardware or consumable.

For printed circuit board applications, several different variations of this technique can be used for different board/coating materials and background conditions *(see Figure 4)*.

- *Solder mask or other Conformal Coatings on FR4 Boards -*
  The laser beam can alter the texture of the coating, giving it a lighter contrasting appearance, or can completely remove the coating to expose the underlying substrate or copper ground plane.
- *Uncoated FR4 -*
  The laser beam alters the texture of the surface of the FR4 producing a near white appearance.
- *Silk-screened Ink Block -*
  For users who already silkscreen component identification or other fixed information on the boards, a silk-screened white ink block can function as a background to the 2D matrix code to optimize readability. This technique is particularly helpful when…
  - The background color of the board is similar to the color of the laser mark.
  - Underlying circuitry would obscure the marking image to code readers.
  - The board material is not suitable for laser marking, such as ceramic substrates.

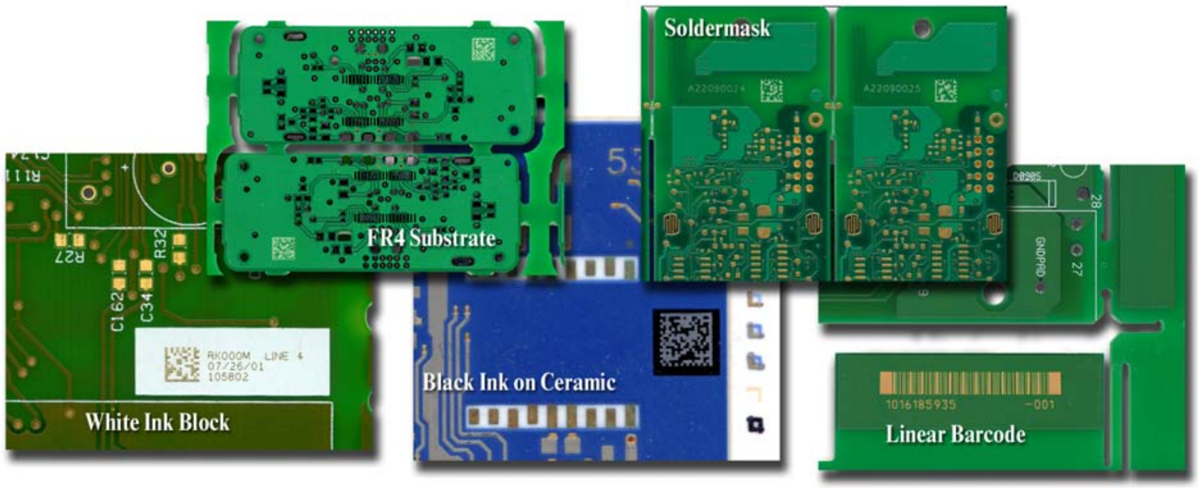

Figure 4 – Marking Techniques

2D Matrix Code Verification

Verification of the legibility and content of the 2D matrix codes is an important step in the overall quality program. After marking of each circuit, the reader verifies the integrity of the mark before indexing the laser marking head to the next marking location. The reader retrieves the alphanumeric text string from the 2D code and compares it with the text string that was to be marked.

The reader also evaluates the legibility of the code based on a variety of parameters including foreground/background contrast, geometric accuracy (skew, squareness, etc.) and the dimensional accuracy of both the marked and unmarked cells. The 2D matrix codes are then categorized as passed (green), warned (yellow) or failed (red). For overall production efficiency, the laser system can be programmed to verify only a select few 2D codes on a panel, then to automatically switch to verifying every code if the code legibility falls below a specified level.

Today's readers do an excellent job reading lower contrast 2D codes. If the laser marking system is installed on an assembly line with older 2D matrix readers downstream from the laser marker, the verification reader can be configured to evaluate the codes based on the performance of the older downstream readers to assure consistent performance throughout the assembly process.

Marking Performance

The typical printed circuit board marker is a fully automated, SMEMA-compliant, through-conveyor laser marking system. The overall productivity of the laser marker is comprised of several steps that make up the marking cycle. The steps required to mark one multi-array panel are…

1. Transport and positioning of the panel in the marking area.
2. Fiducial location *(optional)*
3. Marking of the first circuit in the array
4. Verification of the marked 2D matrix code *(optional)*
5. Motion of the laser marking head to the next circuit in the array.
6. Repeat steps 3 and 4 for the remaining circuits in the array.
7. Transport of the panel out of the laser marking system *(synonymous with bringing the next panel in)*

Following are the calculated estimates for two marking jobs. PCB #1 is a simple 4-up array with a marking time of 0.5 seconds per circuit. PCB #2 is a 10-up array with a 1.5 second marking time per circuit and two fiducials on the panel for marking alignment. Both incorporate verification of the 2D matrix codes as part the marking sequence.

Fixed	
Transport In:	3 seconds
Transport between circuits:	1 seconds
Verification/Fiducial:	0.5 seconds
Transport Out:	3 seconds
Cost of Operation:	$0.30 /Hour

Variables	PCB #1	PCB #2
Circuits per panel:	4	10
Mark time per circuit:	0.5	1.5
Circuits to verify per side:	4	10
Fiducials:	0	2

Time *(seconds)*	PCB #1	PCB #2
Transport In:	3	3
Fiducial Find:	-	3
Mark/Verify Circuits:	7	29
Total:	10	35

Circuits per Hour	1,440	1,029
Cost per circuit	$0.00021	$0.00029

Note: performance can vary significantly when the laser system is configured to specific user requirements.

Cost of Operation

Cost of operation is much less than $1.00 per hour. Typical utilities requirements are 110VAC, 1-phase, 12A. A compressed air source is required for the pneumatics. Total utilities costs at maximum laser power *(the laser should actually operate at less then 80% rated power)* are $0.12 per hour. The primary consumable item is the CO_2 laser tube that must be replaced every 3 to 5 years at a cost of typically $1,000.00 to $1,500.00. Assuming a 40-hour workweek and tube life of 3 years, the tube replacement cost would equate to $0.18 per hour for a total operating cost of $0.30 per hour under worst case conditions. Actual operating costs will be lower due to less than maximum electrical usage and longer tube life.

For the two examples above, operating costs for laser marking of either PCB #1 or PCB #2 would be less than $0.0003 per circuit.

Summary

The electronics industry has been searching for a cost and technically effective means of applying machine-readable codes to printed circuit boards since the 1980's. Early attempts included laser marking linear barcodes on the board edge, a daunting challenge for reader alignment, and marking linear barcodes next to circuit traces, also a challenge for barcode readers. Barcode content was limited to a few characters due to limited space and the barcodes character-per-inch capacity.

The development of the 2D matrix code combined with the resolution, permanence and speed of beam-steered laser marking technology now offers manufacturers a reliable, cost-effective, flexible and verifiable means to uniquely identify every product through production, distribution and after-sale.