过去，电路板上的条码与UPC标示相似。然而，新的Matrix 2D可将50个字符的数据放进2平方毫米的符号中，用CCD设备扫描，然后只以20%对比率读取。

Laser Marking
MATRIX CODES ON PCBS

The one-dimensional barcodes used on groceries don't work as well on circuit boards. The data matrix codes work in low light and can hold a myriad of information. **by RICK STEVENSON**

Manufacturers of a variety of electronic devices are increasingly seeking a reliable, cost-effective method for 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 PCB 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 space available on real estate-conscious PCBs.

The electronics industry has been searching for a cost-effective, technically effective means of applying machine-readable codes to printed circuit boards since the 1980s. 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 2D matrix code provides a means to store alphanumeric character strings in very small areas on the PCB. 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.

FIGURE 1. Example of ECC 200 Data Matrix code on FR-4.

FIGURE 2. ECC 200 code marked in black ink, suitable for ceramic substrates.

ECC 200 2D Matrix Codes

Two-dimensional symbologies encode information in the form of a checkerboard pattern of on/off cells (**FIGURE 1**). Data Matrix is covered by an ISO standard, and the Electronic Industries Association recommends it for labeling small electronic components. Specific advantages of Data Matrix codes over conventional 1D barcodes include:

- Information is encoded digitally, as opposed to the analog encoding of data in conventional barcodes.
- They can accommodate low-contrast printing directly on parts without requiring a label.
- They 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, used extensively 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.

The 2D matrix codes consist of four distinct elements. 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 between 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 anything that could be visible to the reader. The quiet zone should be at least two rows/columns wide for codes constructed of square cells, and at least four rows/columns wide for codes constructed of circular cells (dots).

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 x 144-row array. More realistic symbol dimensions for printed circuit boards can still contain a significant amount of information (**TABLE 1**).

The laser marking system consists of the laser source, the beam-shaping optics and the beam-steering system (**FIGURE 3**). The laser is a light amplifier generating a bright, collimated beam of light at a specific wavelength. For FR-4 and soldermask applications, most users choose an air-cooled CO_2 laser operating at the 10,640 nm far-infrared wavelength. This laser offers several performance and cost advantages, and produces excellent marking results.

The laser beam is projected through two beam-deflecting mirrors mounted to high-speed, high-accuracy galvanometers. Each mirror deflects the laser beam 90° 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 axes to "draw" the desired marking image.

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.

The function of the laser optical train is to focus the laser beam on a small spot and 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.

Marking The Board

When marking a PCB with a laser, 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. Several different variations of this technique can be used for different board/coating materials and background conditions (see **FIGURE 4**).

Soldermask or other conformal coatings on FR-4 boards. The laser beam can alter the texture of the coating, giving it a lighter contrasting appearance, or it can completely remove the coating to expose the underlying substrate or copper ground plane.

Uncoated FR-4. The laser beam alters the texture of the surface of the FR-4, producing a near white appearance.

TABLE 1. Storage capacity for Data Matrix codes of various sizes

SYMBOL SIZE ROW X COLUMN	DATA CAPACITY NUMERIC	DATA CAPACITY ALPHANUMERIC	CODE SIZE 7.5 MIL CELL
10 x 10	6	3	1.9 mm
12 x 12	10	6	2.3 mm
14 x 14	16	10	2.7 mm
16 x 16	24	16	3.0 mm
18 x 18	36	25	3.4 mm
20 x 20	44	31	3.8 mm
22 x 22	60	43	4.2 mm

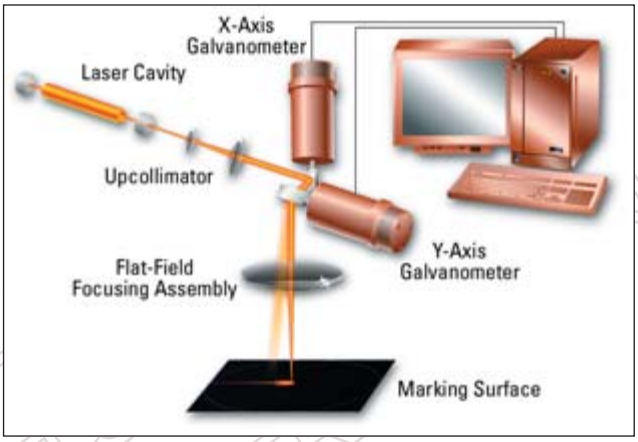

FIGURE 3. Laser set-up for marking matrix codes on PCBs.

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:

1. the background color of the board is similar to the color of the laser mark;
2. underlying circuitry would obscure the marking image to code readers; or
3. the board material is not suitable for laser marking, such as ceramic substrates.

Verification of the legibility and content of the 2D matrix codes is an important step in the overall quality program. After marking each board, 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 of 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

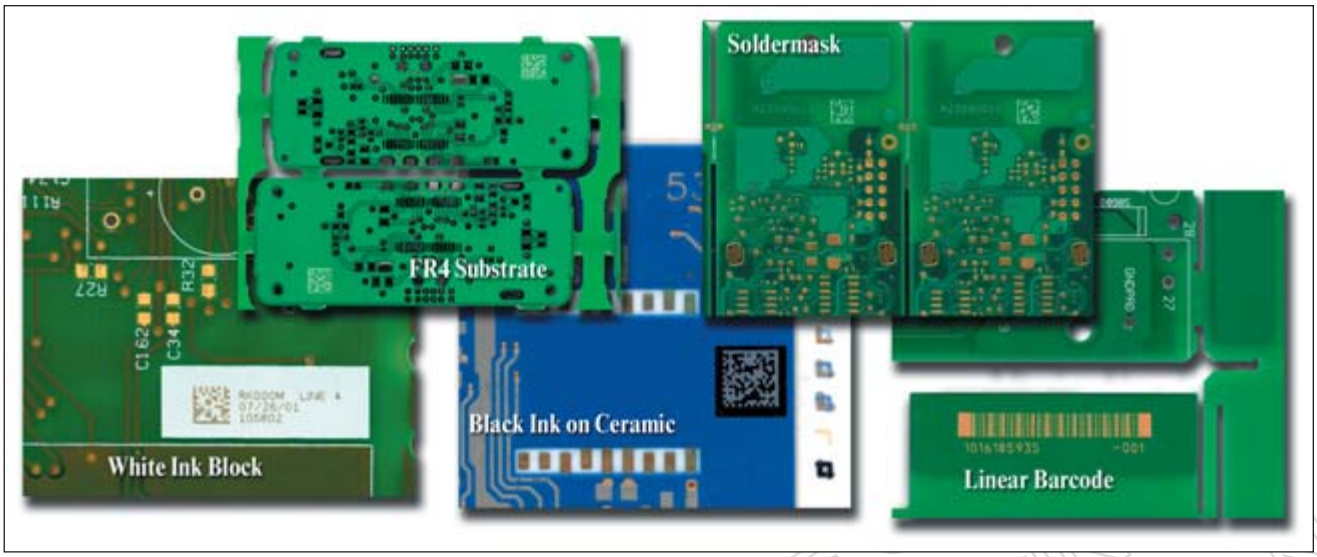

FIGURE 4. Examples of matrix codes and one barcode on PCBs.

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 board in the array.
4. Verification of the marked 2D matrix code (optional).
5. Moving the laser marking head to the next board in the array.
6. Repeat steps 3 and 4 for the remaining boards in the array.
7. Transporting the panel out of the laser marking system (while bringing the next panel in).

TABLE 2 details 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 board. PCB #2 is a 10-up array with a 1.5 second marking time per board and two fiducials on the panel for marking alignment. Both incorporate verification of the 2D matrix codes as part of the marking sequence.

The cost of operation is typically less than $1 per hour. Typical utilities requirements are a 110 VAC, 1-phase, 12 A system. 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 3-5 years at a cost of typically between $1,000 and $1,500. Assuming a 40-hour workweek and a tube life of three 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 cited here, operating costs for laser marking either PCB #1 or PCB #2 would be less than $0.0003 per circuit board.

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. PCD&M

TABLE 2. A comparison of costs of marking codes on a 4-up array vs. a 10-up array

FIXED		
Transport in	3 seconds	
Transport between boards	1 seconds	
Verification/fiducial	0.5 seconds	
Transport out	3 seconds	
Cost of operation	$0.30/Hour	
VARIABLES	**PCB #1**	**PCB #2**
Boards per panel	4	10
Mark time per board	0.5	1.5
Boards to verify per side	4	10
Fiducials	0	2
TIME (SECONDS)	**PCB #1**	**PCB #2**
Transport in	3	3
Fiducial find	–	3
Mark/verify boards	7	29
Total	10	35
Boards per hour	1,440	1,029
Cost per board	$0.00021	$0.00029

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

RICHARD STEVENSON is the sales director for Control Micro Systems. He can be reached at ricks@cmslaser.com.