Application of Data Matrix Verification Standards

Data Matrix symbol verification at its most basic level eliminates the subjective quality determination that causes discord between marking and reading suppliers, and replaces those subjective opinions with objective measurements regarding the quality of the mark. Standards for verification take this process further to allow an even field of play for all measurement systems, such that cross-company and cross-industry applications may use an adopted standard to ensure the readability of symbols through their processes by setting limits based upon agreed standards. This document introduces the standards ISO/IEC 16022, SAE AS9132, ISO/IEC 15415, AIM DPM-1-2006, ISO/IEC 15434, and ISO/IEC 15418, discusses the parameters measured by each standard, and explains where the standard has been applied, especially regarding the United States Department of Defense Item Unique Identification initiative MIL-STD-130.

ISO/IEC 16022

The Data Matrix symbology was invented by International Data Matrix, Inc. The Association for Automatic Identification and Mobility (AIM) promulgated the Data Matrix as a public standard in 1996 as "International Symbology Specification – Data Matrix." This standard was then adopted by ISO as standard ISO/IEC 16022 in May of 2000. The second revision of ISO/IEC 16022 was released in September of 2006. ISO/IEC 16022 Appendix N contains the first public standard for measurement of Data Matrix symbols. This standard includes measurement of the following parameters:

- Reference Decode
- Symbol Contrast
- Print Growth
- Axial Non-Uniformity
- Unused Error Correction

The lowest of the grades for the above parameters becomes the overall grade for the Data Matrix, and then the parameters are combined. The limitations of this standard are its over-reliance on contrast with regard to the overall quality of a symbol. This is because the standard is modeled after a guideline for linear (1D) symbols.

This standard has some application for symbols produced using black ink on white paper. However, very few marks of this type are used in the MIL-STD-130 application. The first version of MIL-STD-130 to include verification was MIL-STD-130L (October 10, 2003) which stated that marks must be graded as no less than "B" when generated and no less than "C" through the life of the mark, by the standards of ISO/IEC 16022.

Lighting requirements for ISO/IEC 16022 verification are not specified aside from the need for uniformity across the field of view. However, the standard recommends lighting from two or more sides at a 45° angle of incidence.

SAE AS9132

The Society of Automotive Engineers (SAE) first published Aerospace Standard (AS)9132 in 2002. This standard differs from other standards in two significant respects. AS9132 covers three specific marking methods: dot peen, laser etch, and electro-chemical etch. Also, AS9132 is a pass or fail standard that does not lend itself to process control, as there are no intermediate steps between success and failure. The parameters measured by AS9132 are:

Dot Peening

- Cell Fill
- Cell Size
- Dot Size Offset
- Dot Center Offset
- Angle of Distortion
- Dot Ovality
- Matrix Size

Laser and Electro-Chemical Etching

- Cell Fill
- Contrast
- Angle of Distortion
- Matrix Size
- Cell Size

If any one of the measured parameters for a mark fail then the overall grade for that mark is a failure. There are no lighting or imaging requirements stated in the AS9132 standard.

ISO/IEC 15415

The first ISO/IEC standard designed to address Data Matrix verification was ISO/IEC 15415 (June, 2004). This standard attempted to correct the insufficiencies of the previous standards by addressing the components of direct part marking. The parameters measured by ISO/IEC 15415 are:

- Symbol Contrast
- Axial Non-Uniformity
- Grid Non-Uniformity
- Unused Error Correction
- Fixed Pattern Damage
- Modulation
- Reference Decode
- Print Growth (may be reported but is not included as a grade component)

ISO/IEC 15415 specifies that the verification report must include the following information, with each element separated by a forward-slash character:

- Grade (Arithmetic mean to one decimal place of the grades measured from all images)
- Aperture (Diameter of the artificial aperture to the nearest thousandth of an inch)
- Light (Wavelength in nanometers)
- Angle (Assumed to be 45° and only reported if different than 45°)

One of the requirements of ISO/IEC 15415 is capturing five images each taken at 72° (± 5°) from each other, such that the symbol is measured at five orientations through one complete rotation. Another limitation of ISO/IEC 15415 is its over-sensitivity to minute changes in grayscale across the symbol and quiet zone, resulting in failing grades for modulation and fixed pattern damage on many easy-to-read parts.

AIM DPM-1-2006

The AIM Direct Part Mark Quality Guideline was released in December 2006. The basic differences between ISO/IEC 15415 and AIM DPM-1-2006 are enumerated in Sections 5.1 and 5.2 of the guideline as follows:

5.1 Process Differences from ISO/IEC 15415

All parameters in the symbology and print quality specifications apply except for:

- A different method for setting the image contrast.
- A different method for creating the binary image.
- A new method for choosing the aperture size.
- An image pre-process methodology for joining disconnected modules in a symbol.
- A different process for determining the Modulation parameter renamed Cell Modulation.
- A different process for determining the Symbol Contrast parameter which has been renamed Cell Contrast.
- A different process for computing Fixed Pattern Damage.
- A new parameter called Minimum Reflectance.

This guideline explains how to specify and report quality grades in a manner complementary to, yet distinct from, the method in ISO/IEC 15415.

5.2 Lighting

This guideline recommends three specific lighting environments consisting of two forms of diffuse (non-directional) lighting:

- *Diffuse on-axis illumination* uses a diffuse light source illuminating the symbol approximately perpendicular to its surface (nominally parallel to the optical axis of the camera).
- *Diffuse off-axis illumination* uses light from an array of LEDs reflected from the inside of a diffusely reflecting surface of a hemisphere, with the symbol at its center, to provide even incident illumination from all directions.
- *Directional illumination* is oriented at a low angle (approximately 30 degrees) to the mark surface.

The parameters measured by AIM DPM-1-2006 are:

- Cell Contrast
- Axial Non-Uniformity
- Grid Non-Uniformity
- Unused Error Correction
- Fixed Pattern Damage
- Cell Modulation
- Reference Decode
- Minimum Reflectance

As with other standards, the overall grade is the lowest of any of the sub-grades. Highlights of the physical setup for AIM DPM-1-2006 are:

- The image sensor plane must be parallel to the surface of the part although no tolerance is specified for the parallelism.
- The symbol must be oriented such that one edge is parallel to the side of the image sensor (±5°).
- A specific set of lights must be used for this verification type: 90° (90), dome (D), 30° from four directions (30Q), 30° from two directions (30T) and 30° from one direction (30S).
- The image must be in the best possible focus, but there is no stated focus tolerance.

ISO/IEC 15434 and ISO/IEC 15418

These standards concern the syntax and semantics (formatting) of the string for Data Matrix symbols used in the IUID program as specified by the MIL-STD-130. The string must start with the characters “[)>” followed by a Record Separator (ASCII decimal 30) and ends with the Record Separator and the End of Transmission (ASCII decimal 4). The string may be formatted using one of three formats:

- Application Identifiers (AI)
- Data Identifiers (DI)
- Text Element Identifiers (TEI)

All data elements in the string include a data qualifier specifying what type of information follows, and the Group Separator (ASCII decimal 29) separates individual elements. Unique Item Identifier (UII) strings using the AI or DI format may use a macro that replaces the leading “[)>$^{R}{}_{S}$05$^{G}{}_{S}$” or “[)>$^{R}{}_{S}$06$^{G}{}_{S}$” and trailing “$^{R}{}_{S}{}^{E}{}_{OT}$” with a single byte, thus saving data capacity in the Data Matrix symbol.

Application of Verification Standards in MIL-STD-130

During the various releases of the MIL-STD-130, the definition of acceptable Data Matrix marking quality has gone through several stages, and has used parts of each of the standards mentioned earlier in this document. The table below describes the standards referenced in MIL-STD-130 and how they are applied.

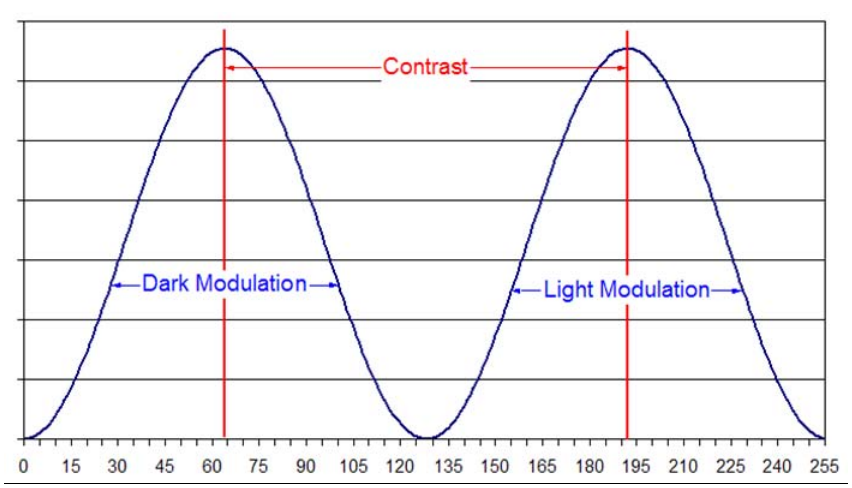
Date	MIL-STD-130 Version	Verification Standard	Application
Oct. 10, 2003	MIL-STD-130L	ISO/IEC 16022	All marks
Dec. 21, 2004	MIL-STD-130L Change 1	AS9132/IAQG or ISO/IEC 15415	AS9132 for DPM; ISO/IEC 15415 for labels
Dec. 2, 2005	MIL-STD-130M	ISO/IEC 15415 then AS9132	Use ICO/IEC 15415 first then AS9132
June 15, 2007	MIL-STD-130M Change 1	AIM DPM-1-2006 and ISO/IEC 15415	AIM DPM-1-2006 for DPM; ISO/IEC 15415 for labels
Jan. 14, 2008	MIL-STD-130N	AIM DPM-1-2006	AIM DPM-1-2006 imaging, lighting, grading requirements

1. Exceptions to ISO/IEC 15415 in MIL-STD-130:
   - No rotational averaging
   - Contrast and Modulation grades allowed to be as low as “C”
   - 660nm lighting requirement
2. Exceptions to AIM DPM-1-2006 in MIL-STD-130:
   - Dome light not allowed
   - Quad-directional 45° medium-angle light from ISO/IEC 15415 allowed
   - Only applies to direct part marks – not labels

Parameters Used in Verification

Below is a brief description of the parameters used in measuring Data Matrix symbols. Many of these measurements use the concept of the "ideal grid." This is the equally spaced array of line segments formed by using the four corners and dividing the entire Data Matrix by the number of rows horizontally and columns vertically.

- Angle of Distortion – The difference from perpendicular of the two solid edges of the Data Matrix, measured in degrees.
- Axial Non-Uniformity – The difference between the height and the width with respect to the rows and columns.
- Cell Contrast – In AIM DPM-1-2006, the difference in the population of dark pixels to the population of light pixels (see histogram) using the sample principle as "Symbol Contrast" with modified definition.
- Cell Size – The overall width divided by the number of columns or the overall height divided by the number of rows.
- Cell Modulation – In AIM DPM-1-2006, a measurement of the uniformity of the color of the dark areas and the light areas of the Data Matrix (see histogram) similar to "Modulation" but differing in implementation.
- Dot Center Offset – The linear difference of the location of the center of the cell compared to the center of the ideal grid center calculated as a percentage of the nominal cell size.
- Dot Size Offset – The difference in the apparent size of each individual data element in the Data Matrix.
- Fixed Pattern Damage – A measurement of the errors in the borders of the Data Matrix as well as any errors in the quiet zone around the symbol necessary for the decoding process.
- Grid Non-Uniformity – The difference of the measured grid in relation to the ideal grid formed from the four corners of the Data Matrix.
- Matrix Size – The overall size of the symbol as measured linearly across the width or height.
- Minimum Reflectance – Lowest reflectance of any sample area in the Data Matrix.
- Modulation – In ISO/IEC 15415, a measurement of the uniformity of the color of the dark areas and the light areas of the Data Matrix (see histogram) similar to "Cell Modulation" but differing in implementation.
- Module Fill – The percentage of completeness of the ideal grid.
- Nominal Module Size – The scalable X-dimension of a typical symbol cell.
- Dot Ovality – The difference of the widest part of a round cell versus the narrowest part of the cell.
- Print Growth – The positive or negative size relation of the cells as printed with respect to the ideal grid.
- Reference Decode – This is a pass/fail measurement of the Data Matrix based upon a binary image of the symbol as specified in ISO/IEC 16022 (First edition – 2000, Second edition – 2006).
- Symbol Contrast – The difference in the population of dark pixels to the population of light pixels (see histogram) similar to AIM DPM-1-2006 "Cell Contrast".
- Unused Error Correction – The amount of error correction that can be read incorrectly when the symbol is still readable that is currently being read correctly, expressed as a percentage.



Histogram showing pixel color populations for a bimodal distribution typically found in the Data Matrix symbology.

Verification Parameters vs. Standards

Standard	Date	Angle of Distortion	Axial Nonuniformity	Cell Size	Dot Center Offset	Dot Size Offset	Fixed Pattern Damage	Grid Nonuniformity	Matrix Size	Minimum Reflectance	Modulation	Module Fill	Nominal Module Size	Ovality	Print Growth	Reference decode	Symbol Contrast	Unused Error Correction	Applicability	MIL-STD-130
		Parameters Measured																		
ISO/IEC 16022	May 2000		■												■	■	■	■	Labels	130L
ISO/IEC 15415	June 2004		■				■	■			■				■	■	■	■	All	130L Chg.1/130M
AS9132 Laser Etch	Feb. 2002	■		■					■			■					■		Laser DPM	130L Chg.1/130M
AS9132 Dot Peen	Feb. 2002	■			■	■			■			■	■	■					Dot DPM	130L Chg.1/130M
AS9132 Electrochem Etch	Feb. 2002	■		■					■			■					■		EC Etch DPM	130L Chg.1/130M
AIM DPM-1-2006	Dec. 2006		■				■	■		■	■					■	■	■	DPM	130M Chg.1/130N

