Information sheet:

Data Matrix and DM-qode Gen1 – Generating and reading codes

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1. DataMatrix basics

What is a Data Matrix Code (DMC)?

The Data Matrix code is a 2D barcode that encodes information in a structured pattern of "black and white" squares and was developed for storing large amounts of data in a small space. Originally developed in the late 1980s by the US company *ID Matrix*, Data Matrix was acquired by RVSI/Acuity CiMatrix, later by Siemens AG, and finally by Microscan Systems. Data Matrix codes are now regulated by several ISO/IEC standards. They are public for many applications and can be used without license fees.

Data Matrix is a two-dimensional symbology and is therefore available in two basic forms: either as a square with a size between 10×10 and 144×144 modules in equal increments of two, or as a rectangle with a size between 8×16 and 16×48. Compared to the equally well-known QR code, the Data Matrix code has the advantage of higher storage density, better error tolerance, and more flexible shape and size.

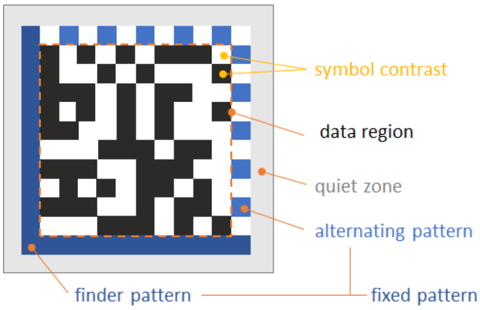


Figure 1: *General structure of the Data Matrix code*

Standardization of the Data Matrix code

The DMC is internationally standardized in ISO/IEC 16022:2024. There are different coding algorithms (ECC0 to ECC140 and ECC200), but **ECC200** is the latest generation with higher data compression and improved error correction (using Reed-Solomon code, as for compact discs). For these reasons, it is recommended to use only ECC200, which can be used by all reading and marking devices currently on the market.

Data Matrix encoding process

In the standard procedure, the encoding process uses the ASCII format (*American Standard Code for Information Interchange*), which comprises 128 unique characters and enables the transmission of text data in digital form. For example, to encode the letter "A", the corresponding code word must contain the ASCII value 65, as this is the number assigned to "A" in the ASCII code.
Here is an example of how the word "Hello" is encoded:

Code word	1	2	3	4	5
Value	72	97	108	108	111
Meaning	'H'	'a'	'l'	'l'	'o'

Abbildung 2: *Genereller Aufbau des Data Matrix Codes*

Encoding scheme

The ASCII encoding scheme is not limited to pure text data; it also allows the representation of double-digit numbers or the entire extended ASCII character set. There are also other schemes, which are shown in the excerpt directly from the ECC200 standard:

Encoding scheme	Character types	Bits per data character
ASCII	Two-digit numbers ASCII characters 0-127 Extended ASCII characters 128-255	4 8 16
C40	Uppercase alphanumeric characters Lowercase letters + special characters	5.33 10.66
Text	Lowercase letters alphanumeric Uppercase letters + special characters	5.33 10.66
X12	ANSI X12 EDI data set	5.33
EDIFACT	ASCII values (characters) 32-94	6
Base 256	All values (characters) 0-255	8

Figure 3: *ECC200 coding scheme according to ISO/IEC 16022*

Different sizes of the DMC therefore result in different amounts of information (i.e., data capacity) that can be stored in the code. The table below shows these relationships.

Symbol size of the DMC	Data range	Code words Data | Error	Data capacity Numeric	Data capacity alphanumeric	Error correction*
10 x 10	8 x 8	3 | 5	6	3	2
12 x 12	10 x 10	5 | 7	10	6	3
14 x 14	12 x 12	8 | 10	16	10	5
16 x 16	14 x 14	12 | 12	24	16	6
18 x 18	16 x 16	18 | 14	36	25	7
20 x 20	18 x 18	22 | 18	44	31	9
22 x 22	20 x 20	30 | 20	60	43	10

Figure 4: *ECC200 Properties of square Data Matrix Codes (DMC) *maximum number of destroyed code words*

2. **Data Matrix codes using DM-qode Gen1**

The **DM-qode Gen1** mold insert has 144 heating elements, which produce a Data Matrix Code with **12x12 modules**. With **ECC 200 encoding**, up to five data code words can be accommodated. Each of these code words consists of 8 bits. Although each of the five code words contains 8 bits, the storage capacity does not reach the theoretical maximum value of 2 to the power of 40, which would result from 5 code words times 8 binary units (bits) each. The reason for this is that some bits are required for control information during the encoding process. These are used to define the type of encoded data and to distinguish between different data formats such as ASCII, text, or numerical values. This slightly reduces the effective storage capacity for the user data.

Choice of encoding scheme

If a coding scheme other than ASCII is used, this must be specified in the coding software. To switch to a different scheme, an entire code word is typically used for the format switch. This means that only four code words are available for the actual user data. An exception is the Base 256 scheme, which requires two code words for format switching and specifying the code size.

Marking examples for DM-qode Gen1

- To encode "matriq" in ASCII format, each character would require one code word, for a total of six code words. However, a 12x12 DataMatrix code only has space for five code words, which is not enough.

- If, on the other hand, the text scheme is used, only one code word is required for the format change and then less than one code word per letter, which makes it possible to encode the word "matriq" within the capacity limit of five code words.

Marking examples for DM-qode Gen1

Content in the data area	Encodable content
Text with special characters: upper and lower case letters and special characters (+,», %, &, etc.), a total of 95 possibilities per code word	95^5 characters (7,737,809,375 possibilities)
Text: Alphanumeric characters, upper **or** lower case (36 characters)	36^6 characters (2,176,782,336 possibilities)
Number: Serial number	10 characters (0 - 9,999,999,999)
Date using Unix timestamp (www.unixtimestamp.com) as a number	Year/month/day/hour/minute/seconds
Mixed text characters with numbers "Letter + hyphen + number" "Letter + number"	8 characters: A-000'000 to A-999'999 (999,999 possibilities) 9 characters: A00'000'000 to A99'999'999 (99'999'999 possibilities)
Text characters and numbers can be mixed as desired. The following applies: 1 code word per text character 1 code word per pair of numbers	Examples: • A-00-00 to Z-99-99 • A00X00Z to A99X99Z • 00=00=00 to 99=99=99 , etc.

Figure 5: *Possible marking contents for DM-qode Gen1.*

When reading codes produced using matriq mold inserts of the DM-qode Gen1 type, there are a few aspects to consider in order to achieve optimal results.

3. The DPM (Direct *Part Marking*) process

DM-qode is used to apply ISO/IEC 16022-compliant **Data Matrix** 2D codes in their current ECC200 implementation (the standardized error correction method) to plastic parts. In the current version of **DM-qode Gen1**, this is a 12x12 code with a total of 144 modules, as the pixels of the code are called. When the code is applied by DM-qode, the topography of the surface is changed locally, but there is no change in color. Therefore, ISO/IEC 29158, which was designed for so-called direct ***part marking*** (**DPM**) processes, is used to check and assess the quality of the code.

The aim when producing and reading the markings is to achieve optimum code legibility under controlled conditions. This is influenced by external circumstances and the choice of reading instruments used.

This document focuses on the reading of the code. For the optimization of the marking on the manufacturing side, please refer to the document "Material and Process Compatibility DM-qode Gen1". However, some of the manufacturing parameters are listed here.

4. Fundamentals of optical code reading

When it comes to DPM codes (DPM: *direct part marking*), the choice of lighting is of central importance. It must create an optical contrast between the logical 1 and logical 0 based on the existing topographical difference between the modules, which is then captured by the camera. The image below shows a schematic representation of the reflection behavior of the surface in both logical states. The photo in the center shows an image of a typical code generated by DM-qode. On the left side of the image, you can see how the relatively smooth surface of the module in question reflects the light from the illumination into the camera. On the right, however, a module is shown that has a rougher surface due to the marking process and therefore scatters the light more strongly, preventing it from being directed into the camera. This creates the code contrast.

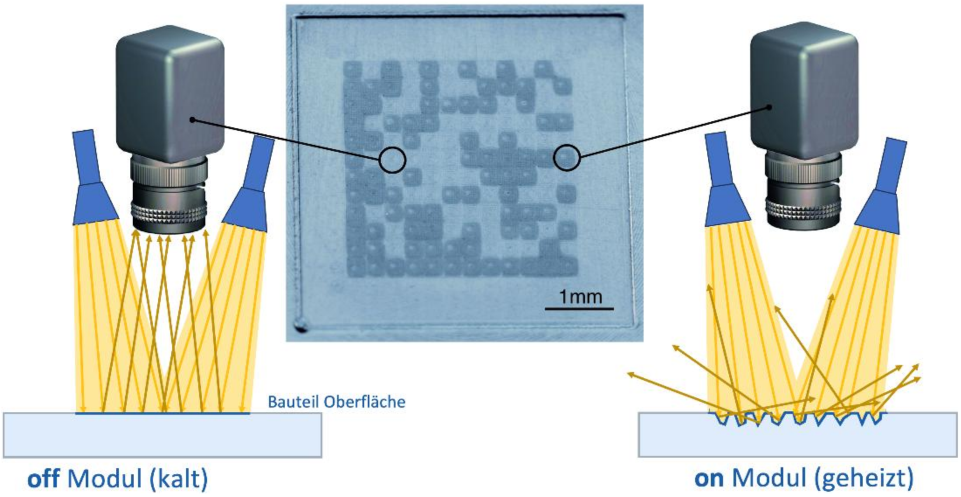


Figure 6: *Schematic representation of how logical "0" (left) and logical "1" modules (right) are generated on the plastic part by the 144 heaters of the DM-qode.*

Evaluation of a code

terms of the application. Codes created with DM-qode Gen1 are DPM codes, as they are also evaluated for needle embossing, laser marking, inkjet printing, and electrochemical etching. The ISO/IEC 29158 standard was adopted for such codes, which therefore differs significantly from the ISO 15415 standard for printed 2D codes ("black on white").

Various aspects of the code are considered when evaluating a **Data Matrix code according to ISO/IEC 29158**. Due to the specific characteristics of code application by DM-qode, it is important to understand these parameters and, if necessary, monitor or optimize them during use.

***Cell* contrast:** Cell contrast describes the contrast between the light and dark modules of the code. Good contrast means that the difference in brightness between light and dark modules is as great as possible. A contrast of 30% or more is the maximum rating for this parameter.

Cell modulation: Modulation is a measure of the uniformity of reflection of the dark and light modules.

Fixed pattern errors: This parameter describes whether there are errors in the "finder pattern," *the "quiet* zone," etc. of the code. These areas of the code do not contain any data, but are used for the correct detection and decoding of the code. Poor contrast or modulation also leads to fixed pattern errors.

Detailed descriptions and calculation methods can be found directly in the standard.

Influencing factors

The factors that have a certain effect on code reading are summarized here.

Illumination angle: If the component is tilted too much, the readability of the code may be reduced depending on the illumination. The component surface should always be perpendicular to the optical axis of the camera lens if possible.

Indentations on the code: Indentations on the component at the location of the code can cause the code surface to be tilted locally. See Illumination angle for more information. Indentations on the code should be avoided.

Color of the plastic: Light-colored plastics produce more scattered light than darker plastics, which can negatively affect the code contrast.

Fillers such as glass fibers: Glass fibers or similar fillers on or just below the surface of the component can generate irregular scattered light, which negatively affects code reading.

5. **Selecting a suitable camera for DM-qode written DMC**

Important aspects to consider when choosing

There are a variety of code reader cameras available on the market from companies such as Keyence, Cognex, Omron, Datalogic, IOSS, Zebra, Hikrobot, and many more. We have tested some of the cameras (see list below) and are constantly working to expand the list. When selecting a suitable camera, the following aspects should be taken into account:

To read codes generated by DM-qode, the **camera** used should be **explicitly designed for reading DPM codes**. Cameras with this feature have a more robust algorithm for code detection and code evaluation compared to standard cameras.

Modern cameras also use reading software that optimizes code recognition based on **training/learning algorithms** (AI/ML), thus providing significantly higher reading reliability for DPM codes. Most well-known camera manufacturers are incorporating this improvement and offering corresponding cameras. Manual training by the customer is typically not necessary.

With many cameras, the resolution and lens, which determine the image field, working distance, and light intensity, can be selected. The camera manufacturer must be consulted when selecting these parameters. Typically, higher resolutions are unnecessary for reading individual codes.

The image field is not only determined by the camera itself, but is also influenced by the lighting, which is particularly true for DPM codes. Another important aspect is the PPM (pixels per module) value. This refers to how many pixels of the camera are used to read a code module (a point of the code). Only the pixels in one direction of the camera are counted. A good value range is 3 to 10. More than this does not improve readability. It can even reduce the camera's decoding performance.

Many cameras have one or more integrated lights. It is not possible to make a general statement about the suitability of these integrated lights. In many cases, the reading performance of a camera can be improved with additional lighting. This can be varied as required during use and, in some circumstances, replaced with different applications.

Code quality assessment

Depending on the application, the assessment of code quality plays an important role. For internal applications, the assessment of readability by a code reader camera is often sufficient to qualify a good part. Some cameras can also indicate readability using a non-standardized value, which allows the stability of the marking process to be assessed.

For customer specifications that require defined readability according to a standard, it is common practice to evaluate the (DPM) code according to ISO/IEC 29158. Some cameras offer the option of code grading based on this standard, but this is only suitable for orientation or assessment of a change in quality. A correct determination of the grade can only be made by a verifier. This is a camera/lighting combination that strictly follows the specifications of the standard.

Selection of additional lighting

Ideally, the best lighting should be selected on the basis of a sample part or a comparable sample in the same color and made of the same material. The lighting built into the cameras is often sufficient for simple reading tasks, but additional lighting can be used to reliably read more challenging codes. In many cases, good results are achieved with coaxial lighting or ring lights. With the latter, the distance between the lighting and the surface as well as the angle of the emitted light are often decisive. Especially with challenging parts, readability can be further increased with the light color and targeted polarization/filtering.

Many camera or lighting manufacturers offer a service to select the best lighting. All you need to do is provide the components. In addition to the camera manufacturers mentioned above, here is a non-exhaustive list of lighting manufacturers:

- Falcon Illumination (Untereisesheim, Germany)
- CCS Europe (Sint-Pieters-Leeuw, Belgium)
- Opto Engineering (Grünwald, Germany)

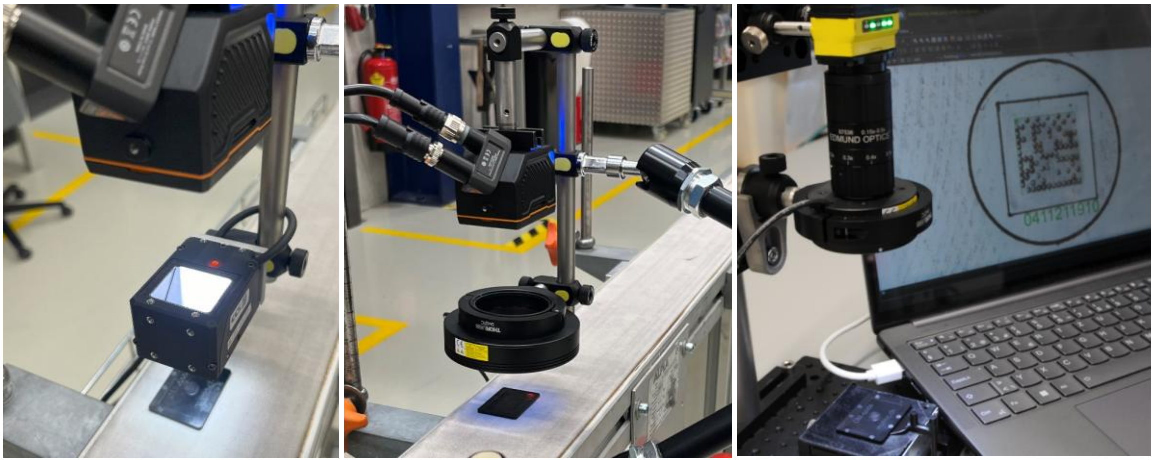


Figure 7: *Various cameras used for reading plastic parts with DM-qode manufactured DMC; left with coaxial light source (CCS LFV3-G-27SW), center with ring light (Falcon FLDR-i90B-W), and right with Cognex camera series IS2800.*

Handheld readers and mobile phones

There are several handheld readers (hand scanners) on the market that are also supposed to be suitable for DPM codes. The devices tested by matriq never achieved the reading performance of stationary devices. The use of simple handheld readers is therefore not recommended.

There are good apps for mobile phones (e.g., *Scandit SDK Showcase*) that can evaluate Data Matrix codes. Alternatively, “Google Lens” on Android smartphones can read these codes. However, this requires a device with a camera that can capture the code, which is only about 4 mm in size, and resolve the individual modules sufficiently well. In addition, it takes some practice, experience, and favorable ambient lighting conditions to successfully read the code. Therefore, the standard use of mobile phones for these DPM codes is not recommended.

List of camera systems tested by matriq

matriq uses various cameras for code reading in-house, some with and some without additional lighting.

The following camera types showed good reading performance at matriq:

Keyence SR-X300

Hikrobot HIK MV-ID3050XM

Cognex DataMan 290 Serie

The following camera types will be tested by matriq in the near future (good reading performance expected)

Datalogic Matrix 220 XAI

IOSS DMR410/420

6. **Examples of read codes DM-qode Gen1 marked parts**

DM-qode in injection molding for serialization of components

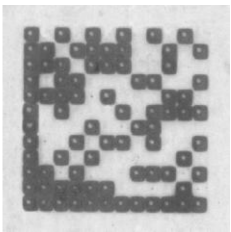
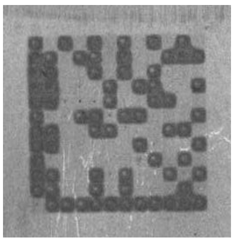
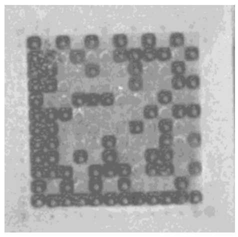
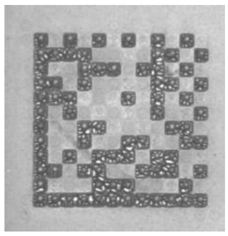
PS 486 M, transparent	PC/ABS black	PBT black	PP Bormed RF825, natural
			
Coded: 3849619865	coded: 7034363516	coded: 1734825604	coded: 6075027395

Figure 8: *Camera images and evaluation of the code on different injection-molded components.*

DM-qode in blow molding (EBM and SBM) for the serialization of components

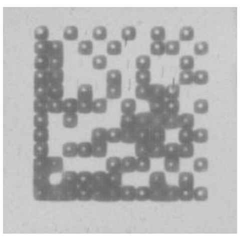
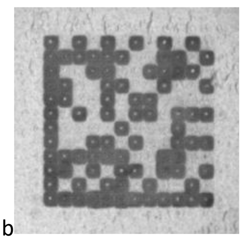
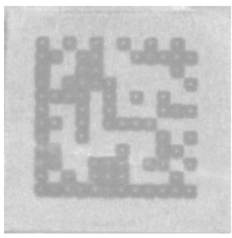
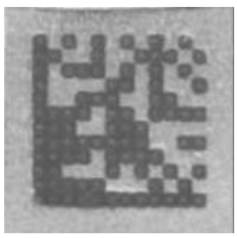
PET transparent	PP natural	HDPE white	HDPE black
	b 		
coded: 2534277216	Encoded: 5474217351	encoded: 8609208648	Encoded: 1522562728

Figure 9: *Camera images and evaluation of the code on different extruded and injection-blown components.*

7. **References**

ISO/IEC 16022:2024, Information technology — Automatic identification and data capture techniques — Data Matrix bar code symbology specification

ISO/IEC 29158:2025; Automatic identification and data capture techniques — Bar code symbol quality test specification — Direct part mark (DPM)