Barcodes and Symbology Basics for Machine Vision

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Introduction, Topics, and Goals

- Who I am
  - Introduce myself
- Who are you?
  - Show of hands in audience – MV people, Integrators, Bar Code users
- Topics we will cover
  - Definition, Reading, Marking/Coding, System Design, and Quality Control
- What we will achieve
  - Awareness of issues and constraints for bar code marking, reading and system design
  - Understand that code reading is a machine vision topic.

What are Barcodes?

- *Optical, machine readable, representation of data.*
- It all started with rail cars – then moved on to chewing gum and *everything* else.
- Typically contain a number
  - Index to a look-up
  - Identification number
- Can contain text
- There are many types…
- Called symbologies

Types of Barcodes – Typology of Symbologies

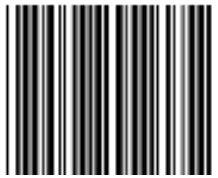
1D Bar Codes

UPCA

I 2 of 5

Code 93

Code 39



Code 128

Codabar

"2D Bar Codes"

GS1 DataBar

Code 16

Code 49

Maxicode

PDF 417

Data Matrix

Stacked 1D codes and true 2D codes

Best code for Direct Part Marking

Who Uses Barcodes?

Why Barcodes Are Important

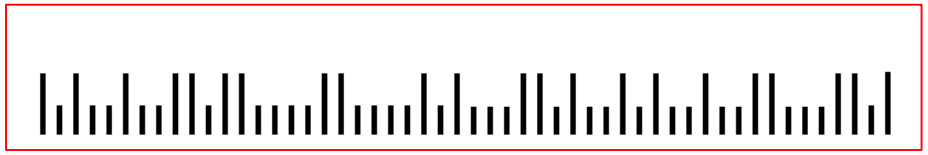
- **<u>Provide an efficient method of product or item identification</u>**

- Revolutionized retail since 1974
  - Checkout, stock management, asset tracking
- Essential for logistics
  - Package tracking, baggage handling….
- Allow item level track and trace and identification
  - ID documents, medical samples, industrial WIP tracking, life cycle management
- Powerful marketing tool
  - All those QR codes
- Support showrooming
  - You have all done this

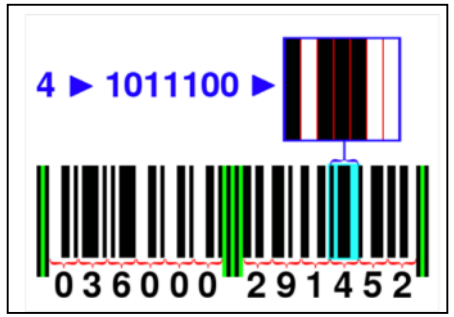
- <u>Reliable Coding and Reading Systems are Mission Critical to Most Enterprises</u>

How Typical Barcodes Work

- Variable shapes that encode information
- Typical codes have
  - Bars
  - Spaces
  - Quiet Zones
  - A few symbologies encode with height

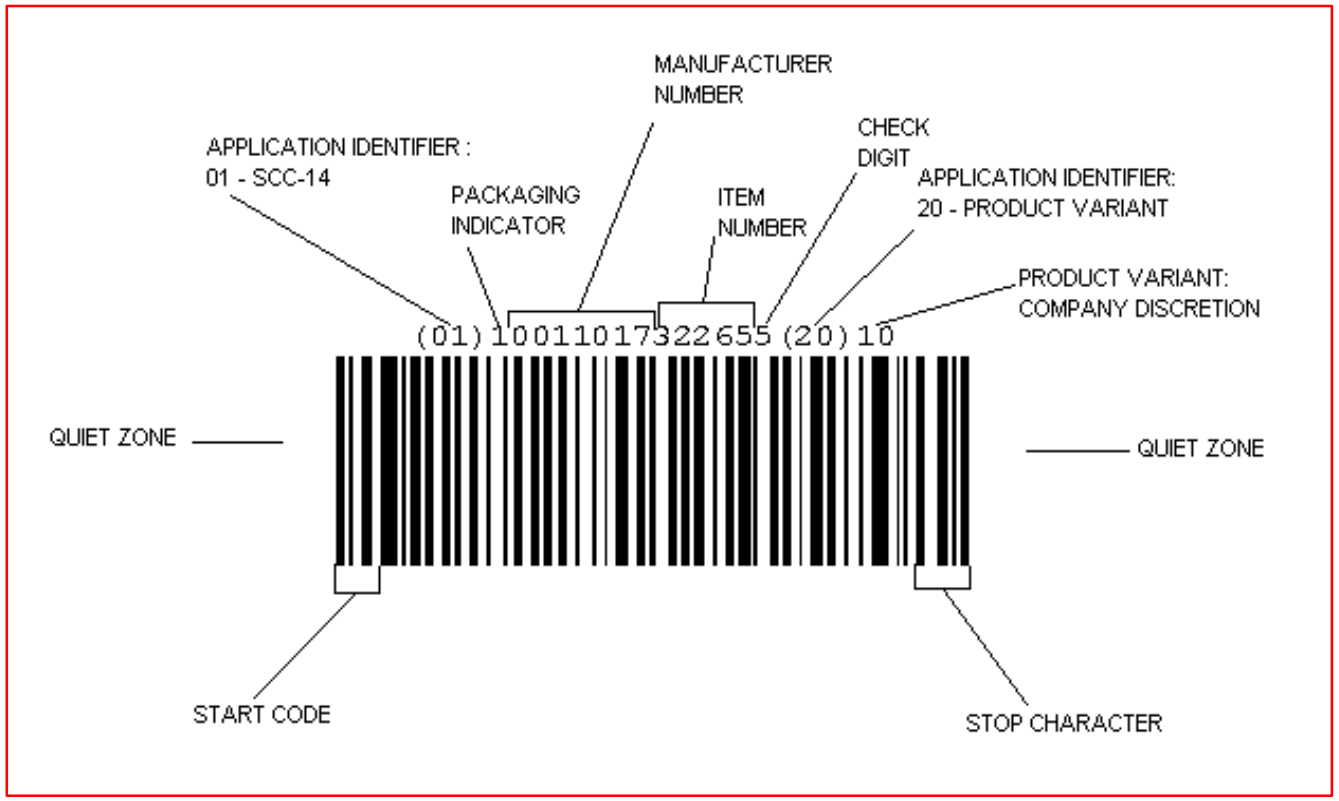


- Varying widths of bars and spaces encode information
  - Example: UPC Code bars and spaces can be 1 to 4 units wide
  - UPC Code encodes each character in 7 units of bars and spaces

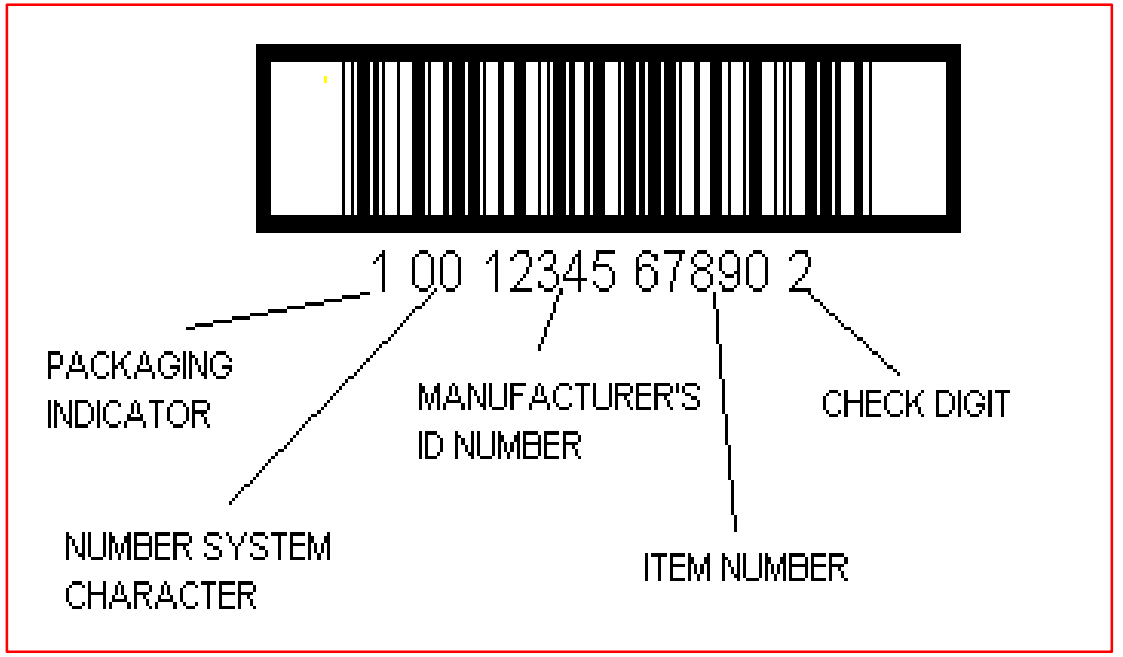


Encoding Examples

Examples of encoding data



GS1-Code 128



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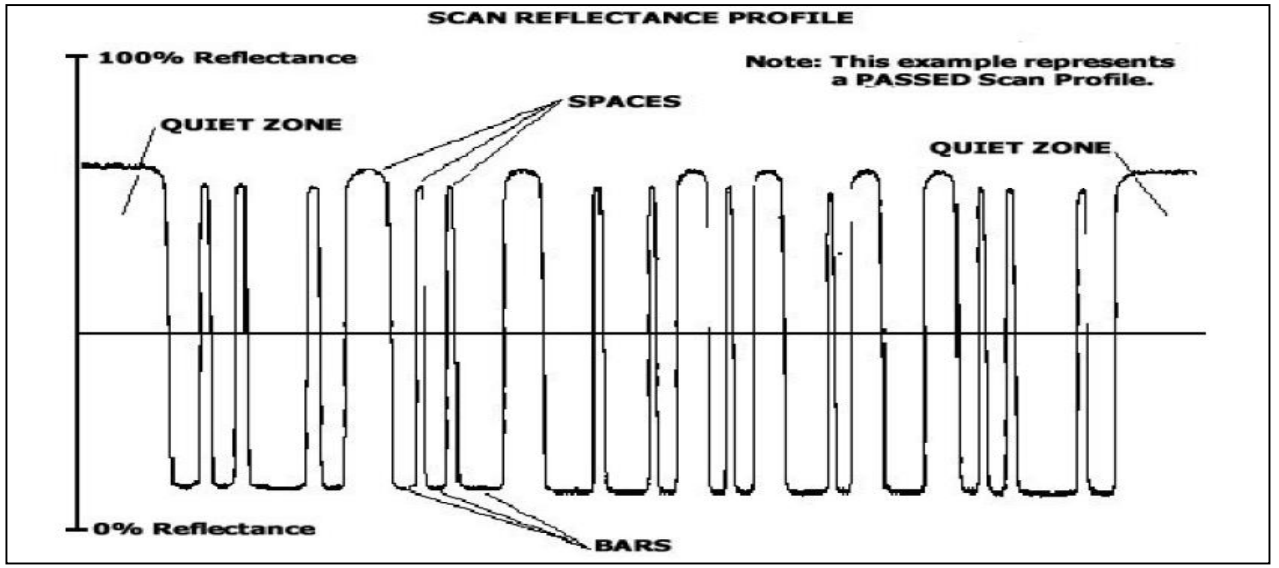
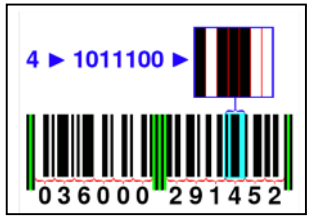
1D Code Reading

- Scan with a laser and measure reflected signal
- Or image with a imaging sensor

- Create a scan reflectance profile

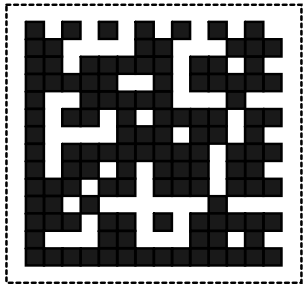


- Detect threshold crossings
- Create a space/bar List
- Pass to a decoder
- Essentially an analog process

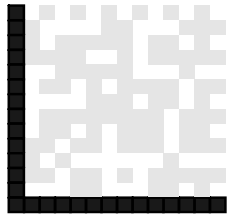


2D Code Construction - Data Matrix

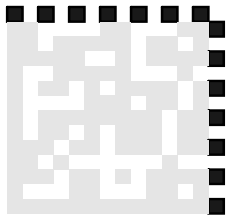
- 4 Physical Components
  - Solid border
  - Broken border/clock pattern
  - Data storage
  - Quiet zone



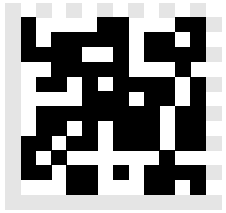
Data Matrix symbol shown complete



Solid Border



Broken Border



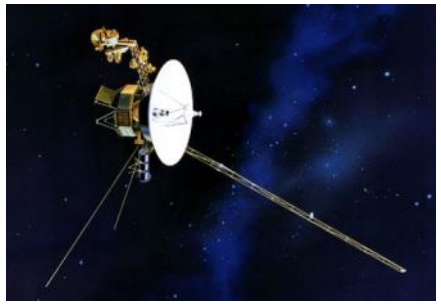
Data Storage

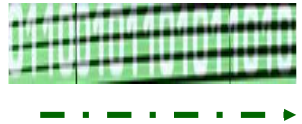
- Consists of evenly spaced “cells” (squares or dots)
- Each “cell” represents either a “0” or a “1”
- Binary – therefore “Digital” in the common tongue.

Data Matrix has Error Correction

- Built in error correction **allows the code to be read with ~20% damage making it the ideal symbology for DPM applications.**

- Reed-Solomon algorithm for error correction
- Origins in NASA Deep Space Network
- Voyager 1 still phoning home from > 2.1×10^{10} km (138 AU) – at 160 bps



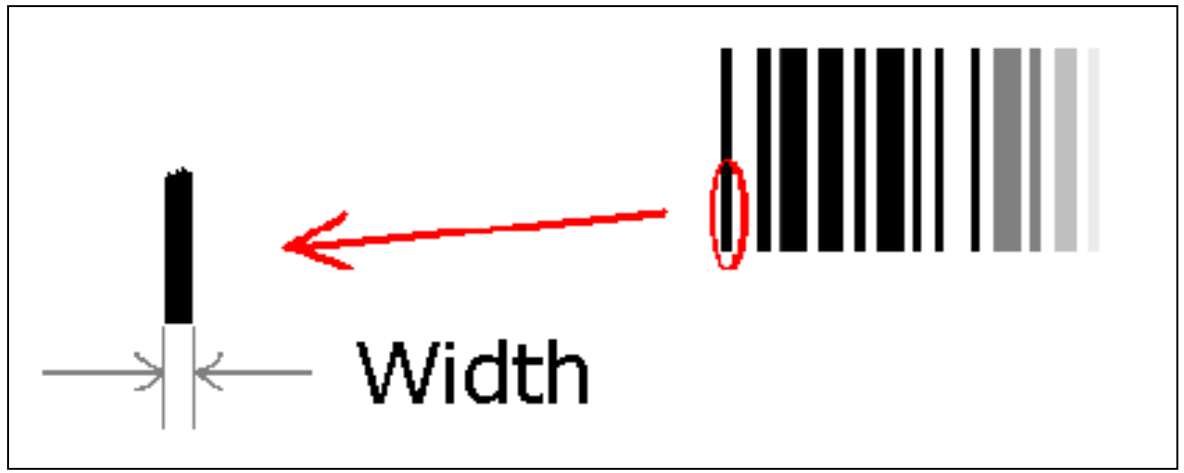


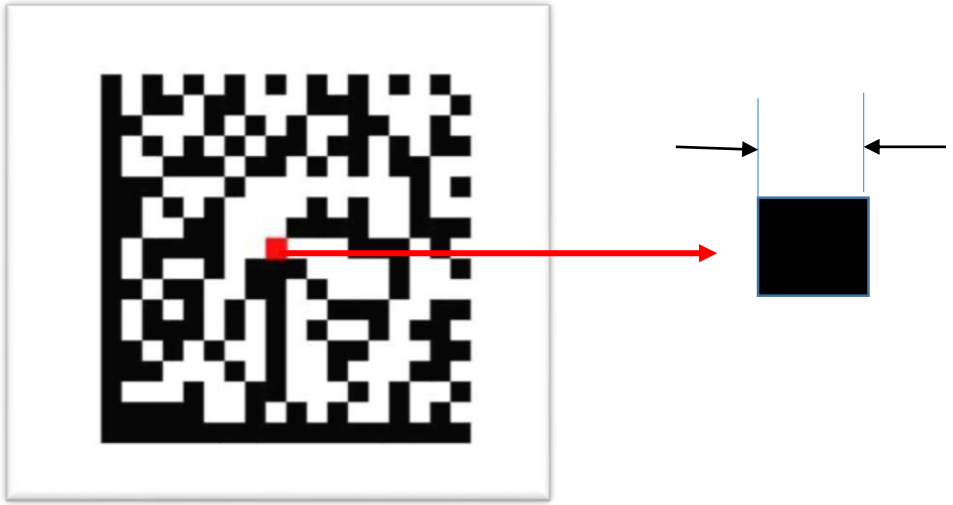
Pros and Cons of Different Codes

- Making Good Choices

	Pros	Cons
1D Codes	• Simple readers (low cost) • Large infrastructure in commerce • Well understood marking methods • High read rates	• Limited content • Unidirectional • Readers can not read 2D codes • **Requires high contrast marking** • Not suitable for Direct Part Marking • Analog reading can produce error
2D Codes	• **Compact codes** • **High potential code content** • **Includes error correction** • **Omni directional reading** • Imaging readers can decode 1D codes • High end readers can do OCR etc. • Read at low contrast • Potential for Direct Part Marking	• Requires imaging reader • Require task specific lighting • Requires slightly higher resolution printing and imaging • Marking/printing requires more care

Key Code Properties





Narrow Element Width
The nominal width of the narrowest bars in the code
Other terms commonly used for narrow bar width:
- X-dimension
- Mil size
- Module width

Cell Size
The nominal width of the individual black or white cell
Other terms commonly used for cell size:
- Mil size
- Module size
- Z-Dimension

Essential for code specification – overall size by itself does not mean much

Specified in "Mil. = 0.001" (primarily in the US) or millimeters

Typical Laser Code Readers

- Hand held

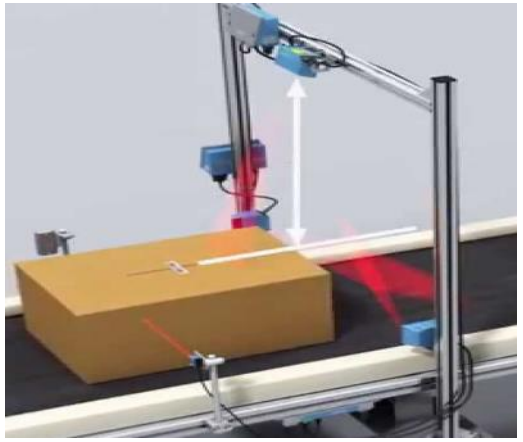


- Embedded



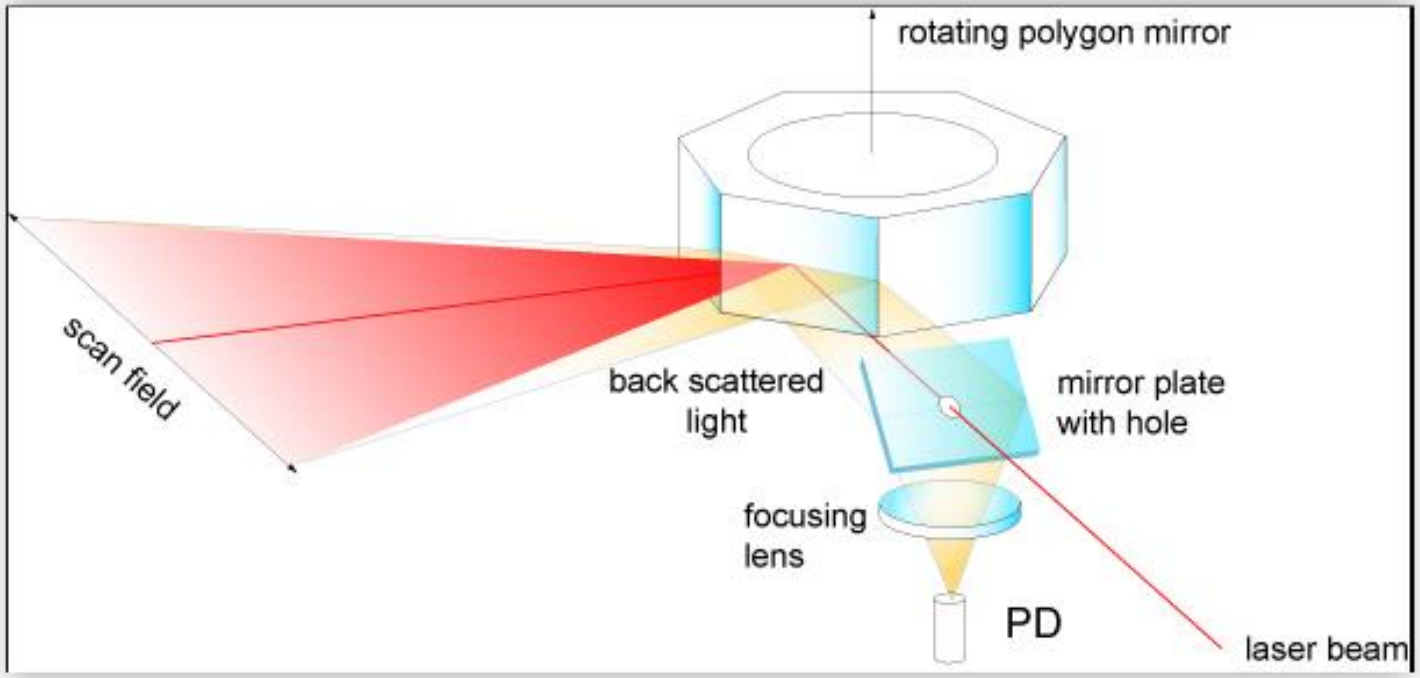


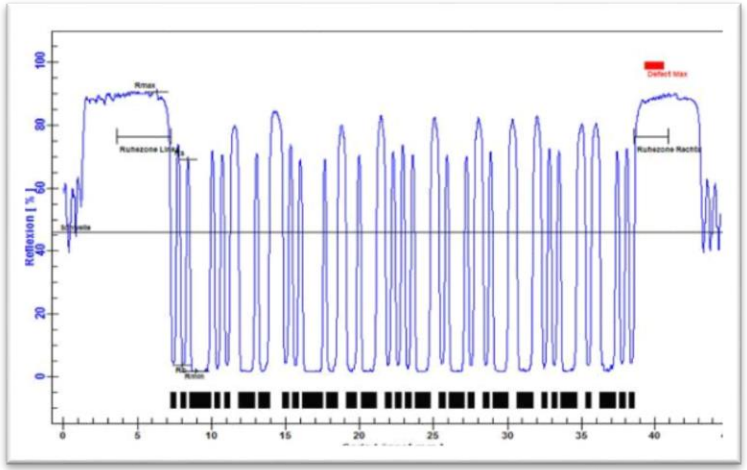
- Tunnel Scanners



Laser Reader Basics

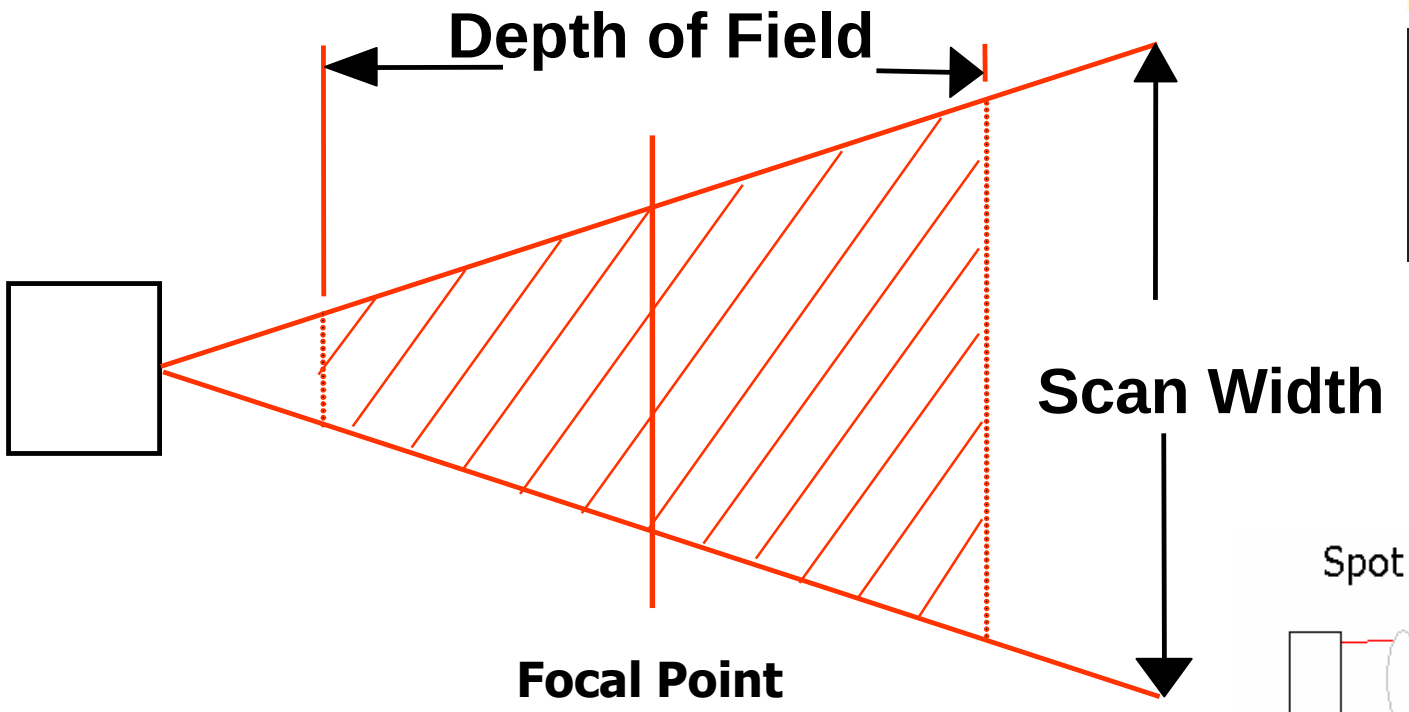
- How it works
  - Drags a laser dot across the code
  - Digitizes reflectance signal
  - Creates a scan reflectance profile
  - Passes to decoder





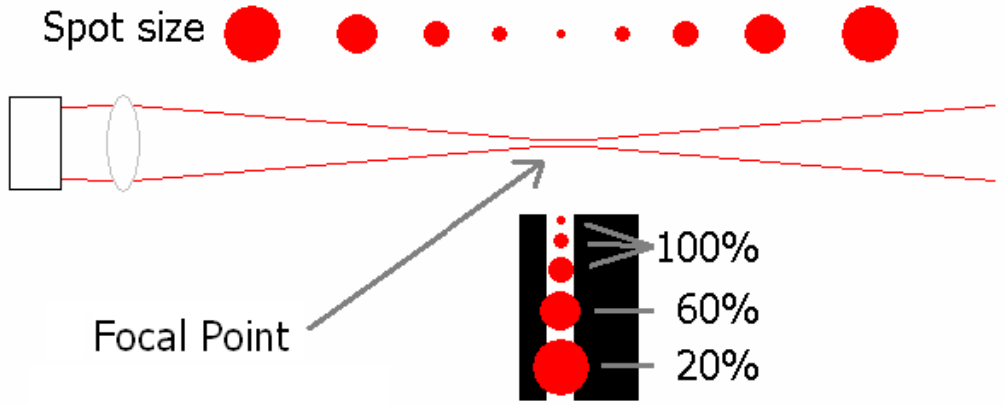
Laser Bar Code Reading - Critical Parameters

- Depth of Field vs X size vs Scan Width



MEDIUM DENSITY RANGE DATA

.0075" (0.191 mm)	2.5 to 5.5" (64 to 140 mm)
.010" (0.254 mm)	1.5 to 7.0" (38 to 178 mm)
.015" (0.381 mm)	1.5 to 8.5" (38 to 216 mm)
.020" (0.508 mm)	1.5 to 11" (38 to 280 mm)
.030" (0.762 mm)	1.0 to 12" (25 to 304 mm)



- Speed (read per second)
- Connectivity

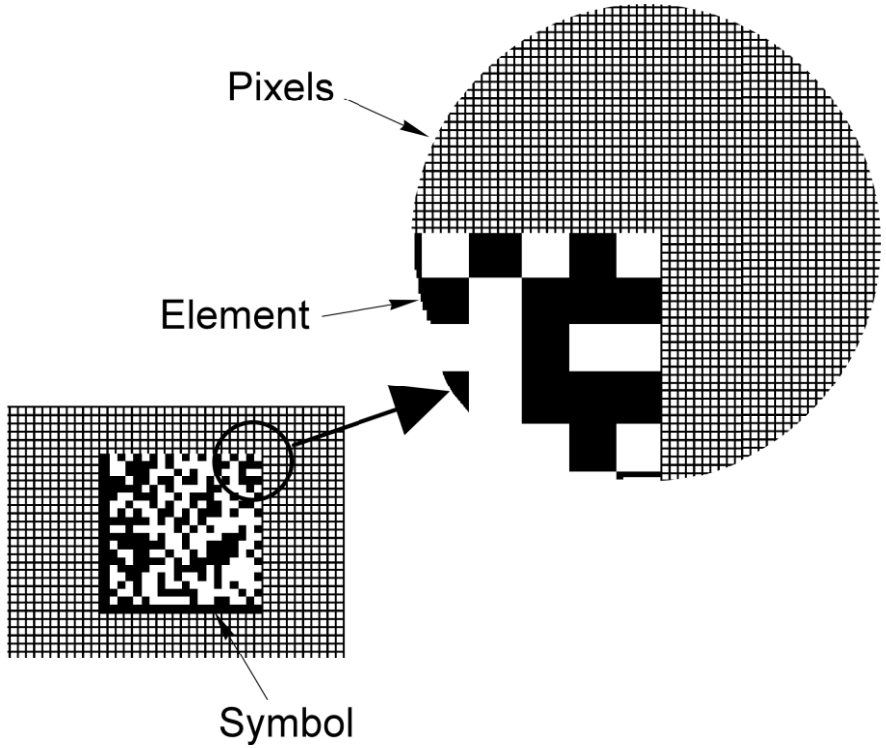
Typical Imaging Reader

- Embedded
- Handheld
- Mini’s
- Smart Cameras
- Discrete Cameras

Image stretching optics for 1D codes

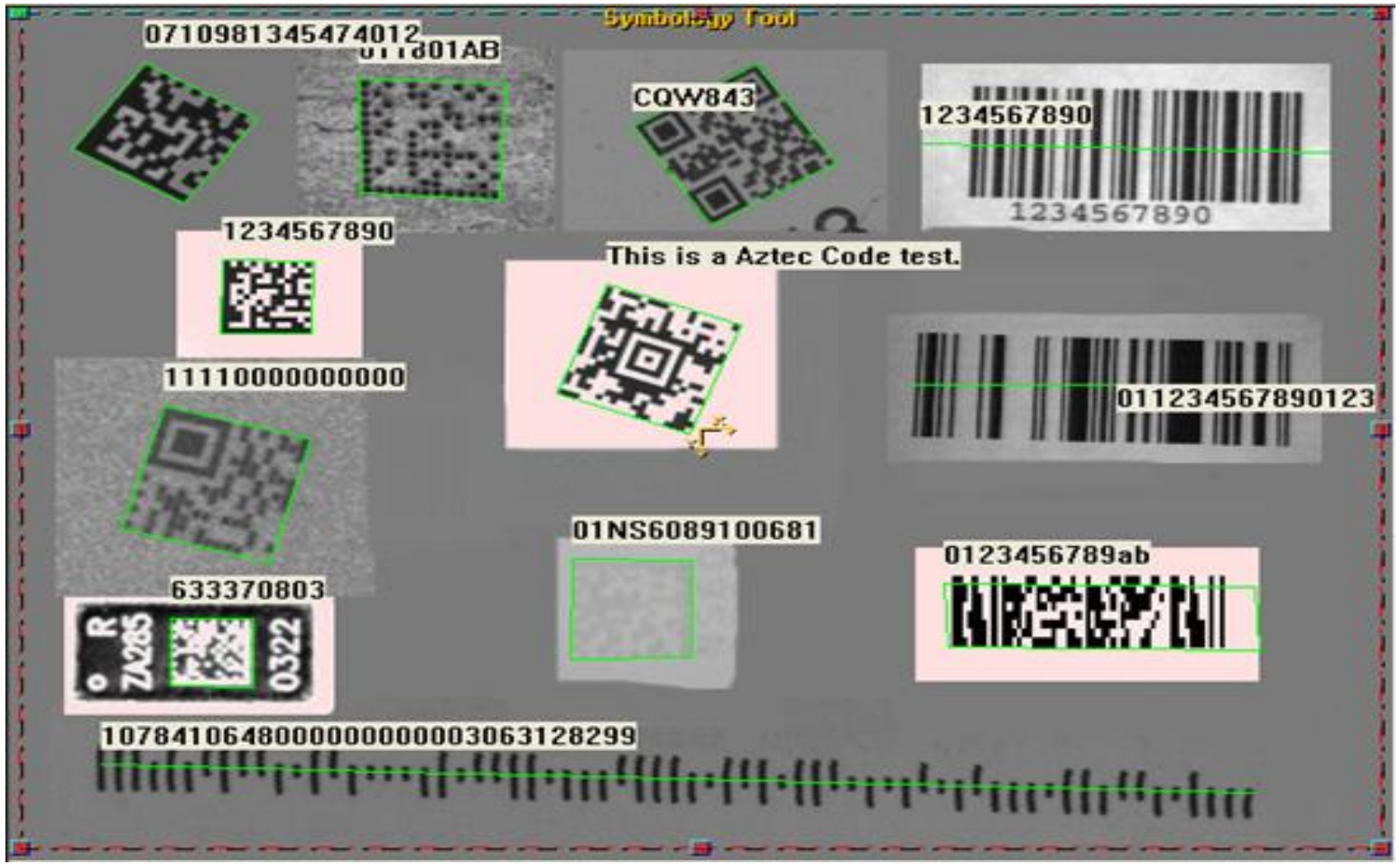
Imager Code Reading - Critical Parameters

- Resolution and FOV Calculations
- Inputs
  - Required Pixels/Element (Module Size)
  - Overall Code Size
  - Camera Resolution
- Suggested Minimums
  - 2D codes - 4 pixels per element
  - 1D codes – 2 pixels per element
- Sample calculation 2D code
  - Element size = 0.020”, Code Size = 0.40” (20 by 20 code)
  - Therefore maximum pixel size = 0.005” (0.020/4)
  - Code size in pixels is 80 by 80
  - Now you can work out how well the part needs to be fixtured at a given resolution



Decoding Multiple Codes With An Imager

- 1D / 2D
- Black on White
- White on Black
- Mirrored
- Low Contrast
- GS1 Check
- DPM
- Multi-code



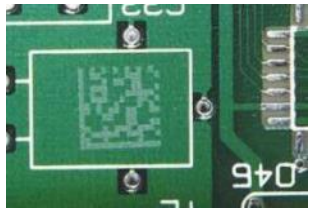
Marking Methods

- Label Printing
  - Flexographic (Offset Printing)
  - Ink Jet (Thermal or Drop on Demand)*
  - Thermal Transfer (Print and Apply)*
  - Laser*

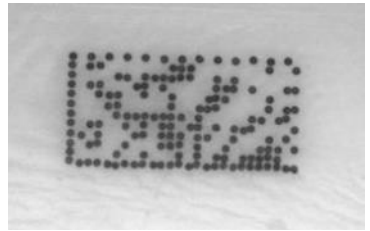
Good Practice

- *Methods than can produce serialized labels
- Do not print red bar codes!
- Match the DPI to the desired X dimension
- Allow for ink bleed
- Use ladder orientation on curved surfaces
- Use rectangular Data Matrix codes when required

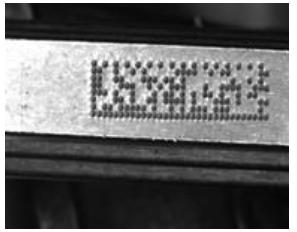
- Direct Part Marking
  - Laser*



  - Ink Jet*

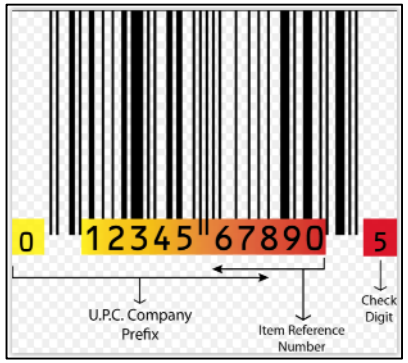


  - Dot Peen*



How To Encode Data So It Makes Sense

- It you know the code is a UPC then OK



- But what if you read a label and see this?

- In this case it is GS1 syntax. The embedded “tags” identify the data fields. Use them to extract meaningful data
  - (01) = Product ID
  - (17) = Expiration Date
  - (10) = Lot Number

GS1 Symbol and Format Definition

- GS1 = Global Standard 1. Formerly UPC and EAN
- GS1 symbols contain data fields with defined applications identifiers (AI) that identify the purpose of the data field and define the content format.
- Commonly used AIs:

AI	Data Definition	Format (AI / data)*
01	GTIN	n2+n14
10	Batch or Lot Number	n2+an..20
11	Production Date (YYMMDD)	n2+n6
15	Best Before Date (YYMMDD)	n2+n6
17	Expiration Date (YYMMDD)	n2+n6
21	Serial Number	n2+an..20

n	Numeric digit
an	Alphanumeric characters
n2	Fixed length of two numeric digits
an...20	Variable length with a maximum of 20 alphanumeric characters

(01)00613994493736(17)221111(10)123456789

http://www.gs1.org/barcodes-epcrfid-id-keys/gs1-general-specifications

441 Pages of good information…….

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The Quality Question – What Is The Answer?

Pain and Problems

Unreadable Codes…

Incorrect Text Format or Content

Loss of Identity or Traceability

Process Downtime

Upset or Confused Customers

Vendor Compliance Penalties

Regulatory Issues

Verification Of 1D And 2D Codes

- Verification (also called Grading) is a Measurement
  its purpose is to:

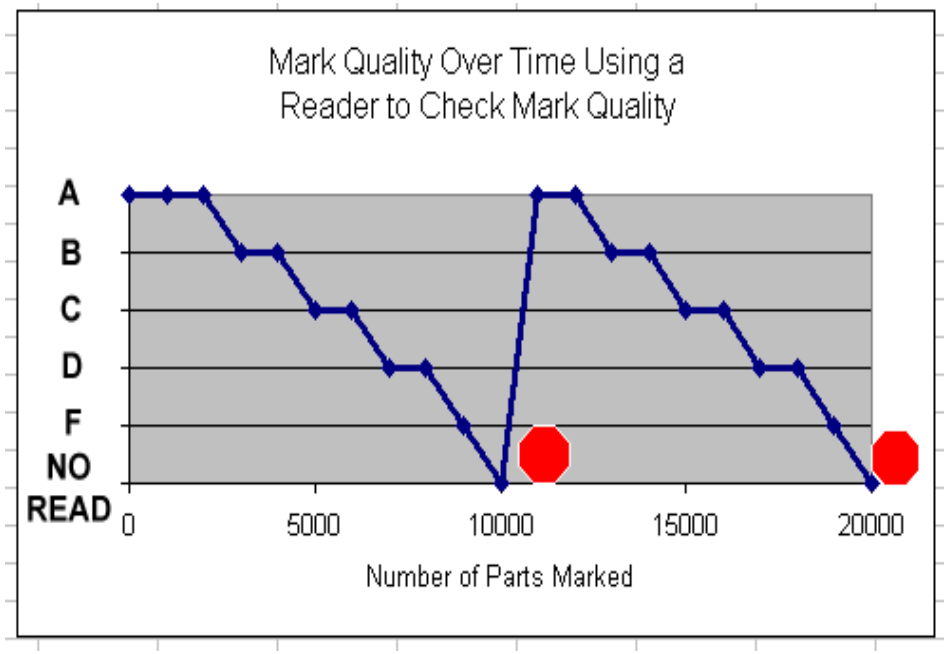
  - Predict Readability – Trading partners, etc.
    - and/or
  - Monitor Marking System – Simple SPC
    - and/or
  - Confirm Conformance – Government, or Customer Specifications etc.

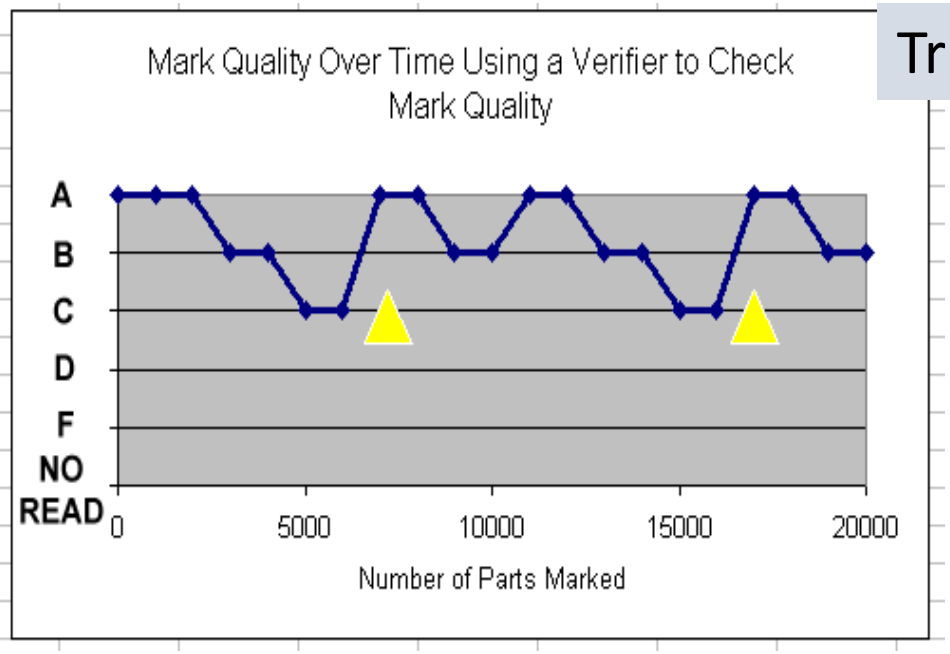
Confirming that a code reads at point of marking is not verification.

Verification is the process of Grading your symbol to a defined specification.

Q - Why Verify 1D And 2D Codes?

A - Because *all* marking/printing systems degrade over time and the code never gets better





Trust but Verify!

Just checking that the code can be read is not good enough. It must be read with an adequate margin

Without verification, some “bad” parts escape into the process

With verification, we <u>prevent</u> bad codes from ever being made

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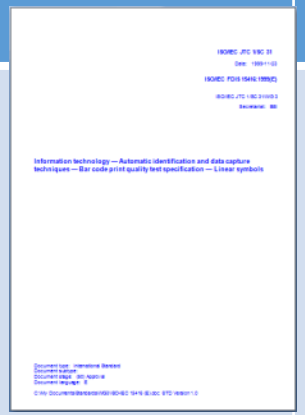
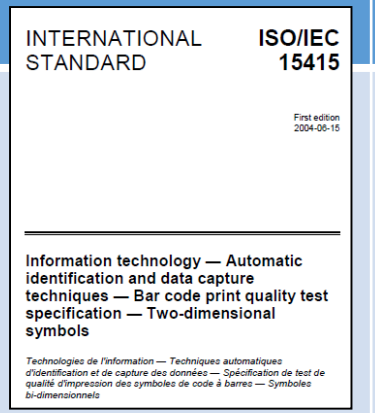
Without Standards There Is Chaos

ISO 15416
1D codes



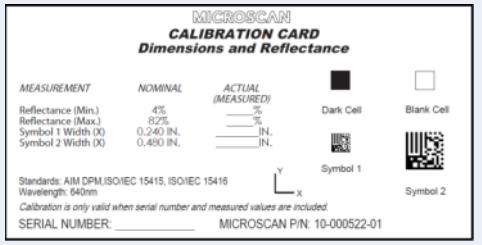
ISO 15415
Printed 2D codes



AIM DPM -1-2006/ISO 29158
Direct Part Marks

Standards specify =

- Lighting wavelength and geometry
- Camera geometry
- Reflectance calibration
- Image processing
- Scan profile(1D) or grid (2D) determination
- Profile or grid analysis steps
- Overall grade determination
- Reporting scale and report content



Reflectance Calibration Standard

ANSI to ISO Grade Conversion Table	
A	3.5 to 4.0
B	2.5 to 3.4
C	1.5 to 2.4
D	0.5 to 1.4
F	Less than 0.5

GS1 Resources

GS1 General Specification

- 441 pages of compelling reading
- Essentially incorporated by reference in GS1 rules
- Basis of many Application Standards
- A lot of good information all in one place
- Marking methods, symbol size, symbol location, quality standards etc.

3.2. GS1 Application Identifiers in Numerical Order

Figure 3.2-1. GS1 Application Identifiers

AI	Data Content	Format (*)	FNC1 Required (****)	Data Title
00	Serial Shipping Container Code (SSCC)	N2+N18		SSCC
01	Global Trade Item Number (GTIN)	N2+N14		GTIN
02	GTIN of Contained Trade Items	N2+N14		CONTENT
10	Batch or Lot Number	N2+X..20	(FNC1)	BATCH/LOT
11 (**)	Production Date (YYMMDD)	N2+N6		PROD DATE
12 (**)	Due Date (YYMMDD)	N2+N6		DUE DATE
13 (**)	Packaging Date (YYMMDD)	N2+N6		PACK DATE
15 (**)	Best Before Date (YYMMDD)	N2+N6		BEST BEFORE or BEST BY
16 (**)	Sell By Date (YYMMDD)	N2+N6		SELL BY
17 (**)	Expiration Date (YYMMDD)	N2+N6		USE BY OR EXPIRY
20	Variant Number	N2+N2		VARIANT
21	Serial Number	N2+X..20	(FNC1)	SERIAL

Figure 5.5.2.7.4-1. GS1 System Symbol Specification Table 4

Symbol(s) Specified	(*) X-dimension mm (inches)			(**) Minimum Symbol Height for Given X mm (inches)			Quiet Zone		Minimum Quality Specification
	Minimum	Target	Maximum	For Minimum X-dimension	For Target X-dimension	For Maximum X-dimension	Left	Right	
EAN-13	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.28 (0.720")	22.85 (0.900")	45.70 (1.800")	11X	7X	1.5/06/660
EAN-8	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	14.58 (0.574")	18.23 (0.718")	36.45 (1.435")	7X	7X	1.5/06/660
UPC-A	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.28 (0.720")	22.85 (0.900")	45.70 (1.800")	9X	9X	1.5/06/660
UPC-E	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.28 (0.720")	22.85 (0.900")	45.70 (1.800")	9X	7X	1.5/06/660

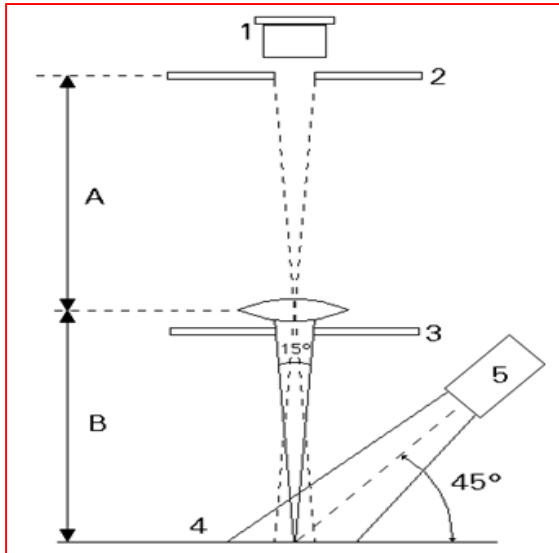
Figure 2.1.4-5. Cell size in relation to surface roughness

Average Roughness	Cell Size Minimum
0,508 micrometers (20 micro inches)	0.1905 mm (0.0075 in.)
1,524 micrometers (60 micro inches)	0.2286 mm (0.009 in.)
3,048 micrometers (120 micro inches)	0.381 mm (0.015 in.)
5,08 micrometers (200 micro inches)	0.508 mm (0.020 in.)
7,62 micrometers (300 micro inches)	0.635 mm (0.025 in.)
10,668 micrometers (420 micro inches)	0.762 mm (0.030 in.)

1D Verification - Imaging and Scanning

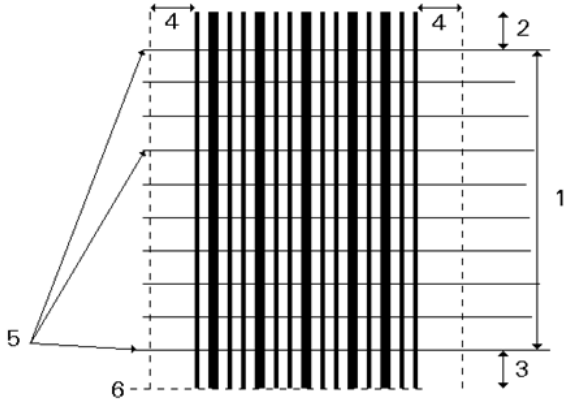
- Image generation
  - Image at 90 to the code
  - Light at 45 degrees
  - Prefer red (monochrome) light
  - At least 8 pixels per thin line
- Scan profile generation
  - Create reflectance (brightness) profiles with a synthetic aperture of (for instance) 50% of line width
- Scan repeats and pattern
  - 10 scans evenly spaced

Result is 10 scan profiles

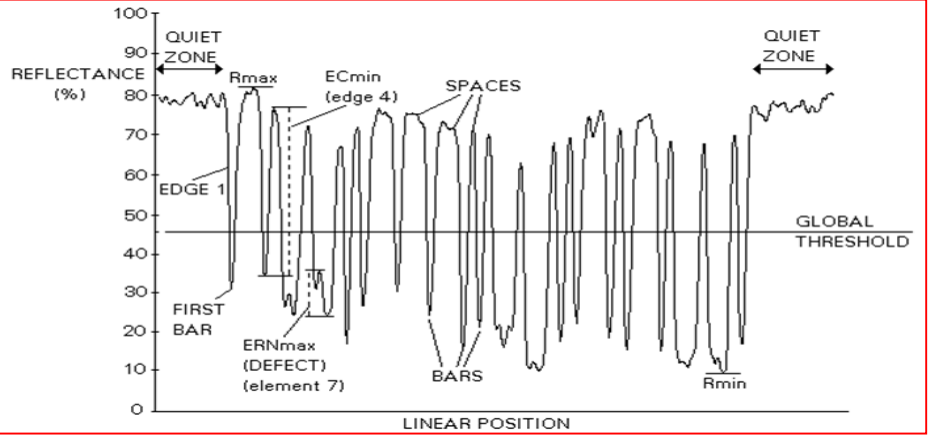


1 - Light sensing element
2 - Aperture at 1:1 magnification (measurement A = measurement B)
3 - Baffle
4 - Sample
5 - Light source

Figure 1 — Reference optical arrangement



1 - Inspection band (normally 80% of average bar height)
2 - 10% of average bar height, or aperture diameter if greater, above inspection band
3 - 10% of average bar height, or aperture diameter if greater, above average bar bottom edge
4 - Quiet zones
5 - Scanning lines
6 - Average bar bottom edge



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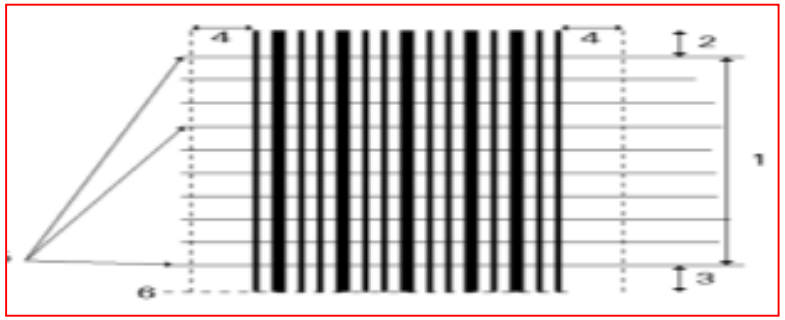
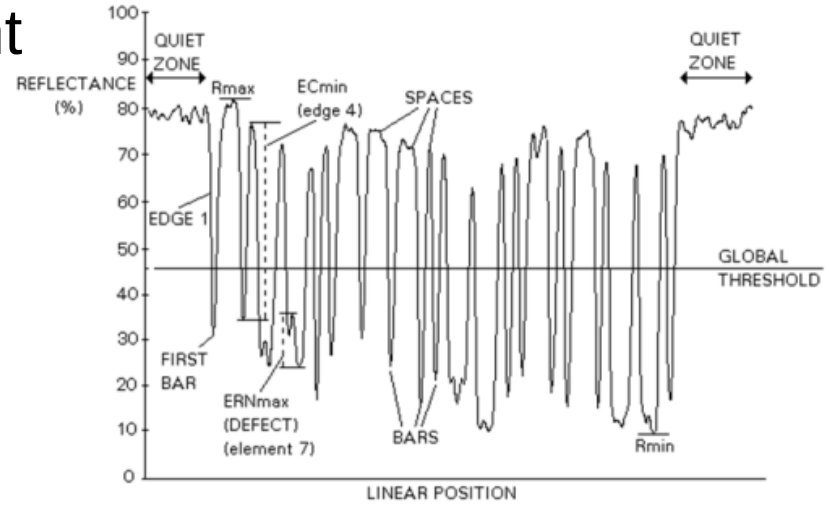
1D Code Grading Process

- Calculate number grades for 9 different measurement on each reflectance profile (9 numbers on 10 scans)
  - Reference Decode
  - Contrast
  - Minimum Reflectance
  - Minimum Edge Contrast
  - Modulation
  - Decodability
  - …….





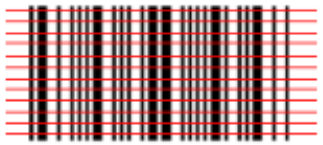
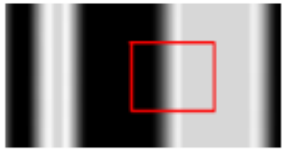
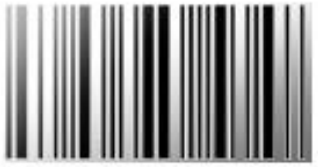
- Score each scan with the worst score (10 numbers)
- Average the worst score numbers (1 number)
- This is the symbol grade (4 – good, 0 = really bad/fail)
- Standard uses number grades
- Translate to letter grades

Numeric range	Alphabetic grade
3,5 to 4,0	A
2,5 to 3,5	B
1,5 to 2,5	C
0,5 to 1,5	D
below 0,5	F

1D Code Defects

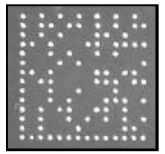
1D Verification Evaluation Parameters:

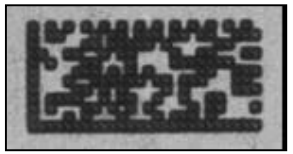
High Quality Symbol:

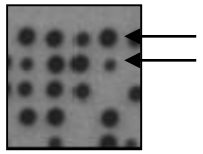
Parameter	Description	Example
Decodability	Legibility per a reference decode algorithm	
Defects	Voids in bars or spots in spaces	
Edge Determination	Detection of all bars and spaces using a global threshold	
Minimum Edge Contrast	Minimum reflectance difference for any bar/space combination	
Minimum Reflectance	Reflectance of the darkest bar and the lightest space	
Modulation	Relation between wide and narrow elements in the symbol Consistency of light and dark bars	
Symbol Contrast	Difference in reflectance between the darkest bar and the lightest space	
Quiet Zone	Size of the quiet zone	

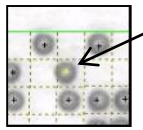
2D Mark Quality Problems

- Improper or inconsistent mark dot/cell size
- Improper or inconsistent mark dot/cell location
- Improper overall mark geometry
- Mark or part surface damage
- Very low or inconsistent mark contrast
- Quiet Zone Violation

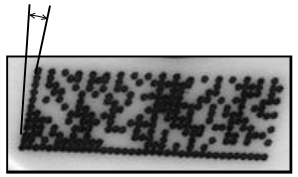


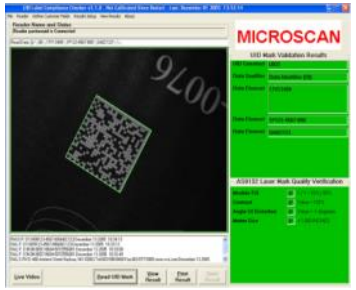






Offset cell





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Off Line Verification Systems for 1D codes

- Off Line Systems

Desktop Verification System

Portable Verification System

Handheld Verification System

Provide Grade and Diagnostic Information

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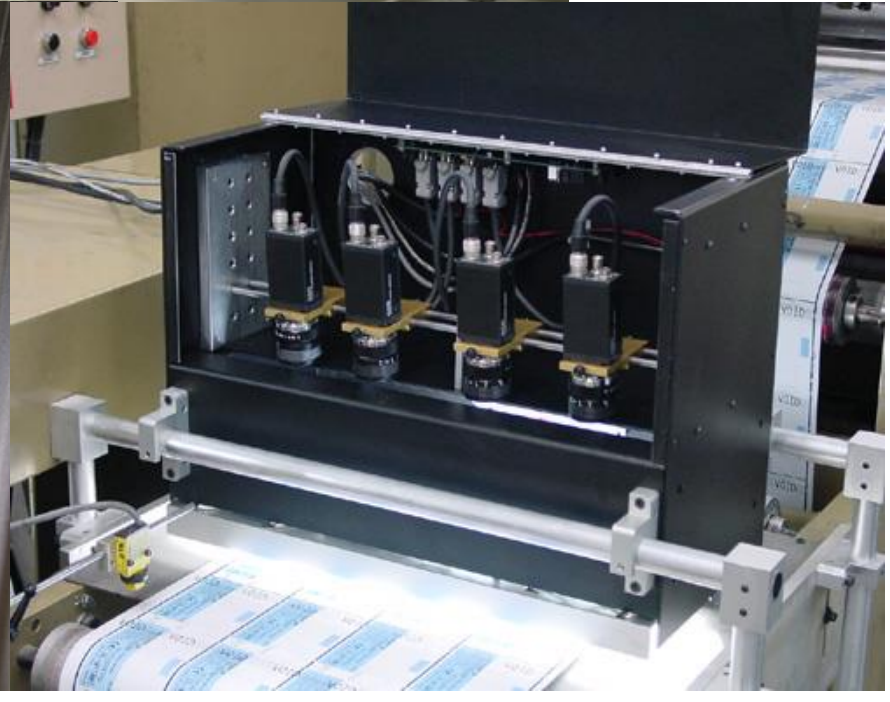
In-Line Verification Systems



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Verification Systems for 2D codes

- Off Line Systems

Desktop Verification System

Portable Verification System

Handheld Verification System

- On Line Systems

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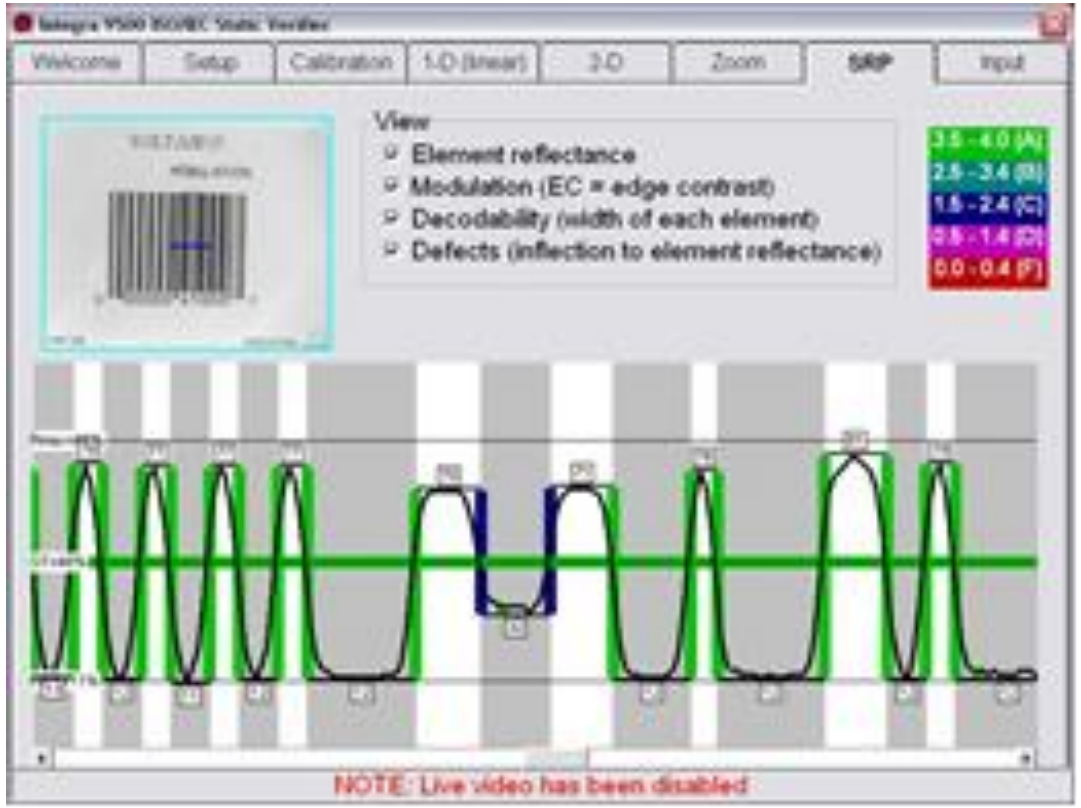
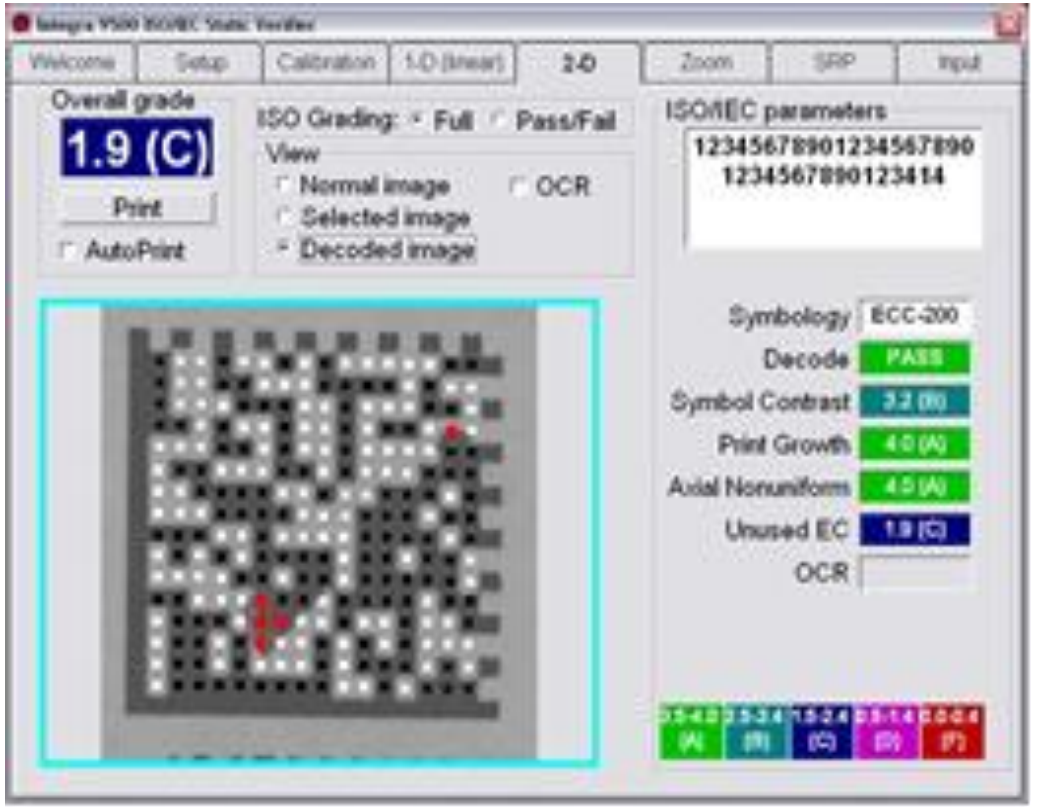
Print Quality Verification

- Defects in the print quality of the symbol



Scan Refelectance profile
for Linear symbols



2D Analysis for 2D symbols

Verification ≠ Validation

- Verification = Measuring the quality of the code to predict readability
- Validation = Checking the format and content of a code

- Verification = how neat and legible was the writing

- Validation = check on grammar and/or content

Data Structure Analysis – Format Validation

Checks the data structure based on the specified Application Standard.
The example below is the GS1 data syntax.
Error flagged on right: SSCC is required to contain 18 characters.

4.0/08/660 (A)

Embedded data	Description	Value
<232>	FNC1	<FNC1>
01	Global Trade Item Number (GTIN)	(01)
00000123000000	Global Trade Item Number (GTIN)	00000123000000
10	Batch or Lot Number	(10)
ABC123	Batch or Lot Number	ABC123
<232>	FNC1	<FNC1>
17	Expiration Date (YYMMDD)	(17)
150527	Expiration Date (YYMMDD)	150527
21	Serial Number	(21)
1	Serial Number	1

Data is structured Correctly

0.0/08/660 (F)

Embedded data	Description	Value
<232>	FNC1	<FNC1>
00	SSCC (Serial Shipping Container Code)	(00)
00000123000017	SSCC (Serial Shipping Container Code)	Size < 18

Data is not structured properly to the selected GS1 Application standards.

New Things (the TLAs)

- What is a TLA? –
- *CIA, NSA,NRO,DHS….?*

- Market Wide Initiatives
  - GS1 – Global Standard 1
  - UDI - Unique Device Identifier (Medical Devices)
  - UID - Unique ID (Military Equipment)
  - SNI - Standard Numerical Identifiers (Drugs)
  - PTI - Produce Traceability Initiative (Farm Produce)
  - ……..

Summary And Take Aways

- **Code reading is mission critical to many enterprises**
- **Code reading is a machine vision application**
- **You have to think about lighting, imaging, resolution and signal**
- **Code quality is a key factor in successful system design**
- **Check quality at the point of marking**
- **Reading is not verifying**

That’s All Folks

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