2D Barcodes and Imaging Scanner Technology

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2D Barcodes

MaxiCode

High Speed Sortation
Invented by UPS
Used only by UPS

QR Code

- **Widely used in Japan**
- **High Data Content**

Data Matrix

- **Part marking**
- **Electronics Industry**

Postal Codes

- Postnet
- 4-State

PDF417

- **Data files**
- **Logistics**
- **Shipping**
- **Production broadcast**
- **Identification**

= Must be Imaged!

2D Barcodes

- **Invented in the early 90's**

- **Data capacity to carry 100's of bytes of data**
  - More than just a database address

- **Error correction for robustness and tolerance to symbol damage**

- **Imaging scanner performance was limited until 2002-03 time frame**
  - Reader performance was enabled by advancements in image sensors and embedded processors

2D Barcodes

- ID cards and driver's licenses
- Postage E-stamps
- Shipping labels
- Cosmetics
- Consumer goods
- Direct part marks (DPM)

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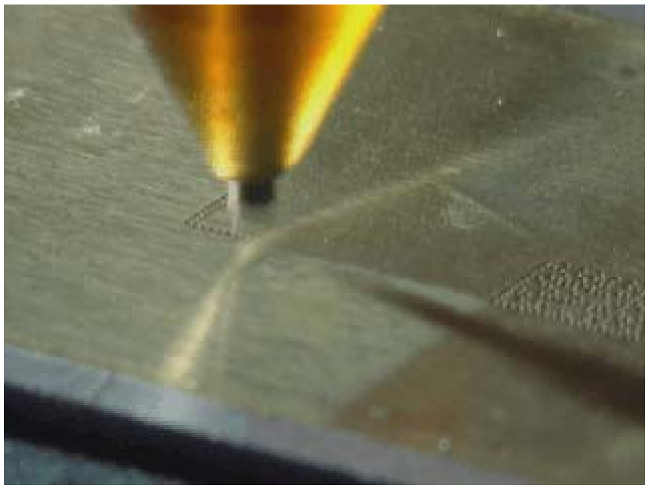
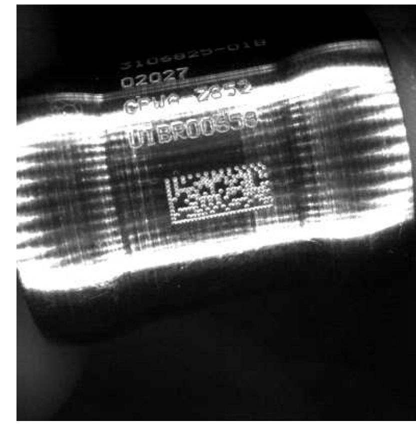
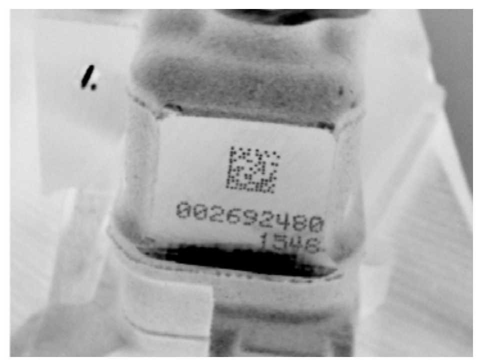
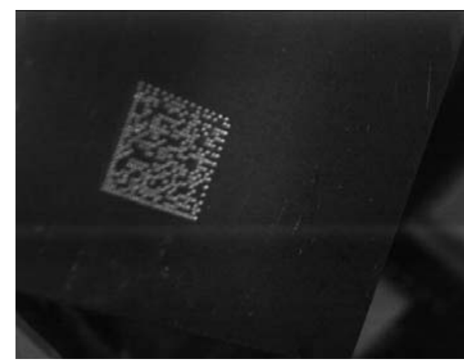
Dot peen (aka: rapid indent, pin stamp)

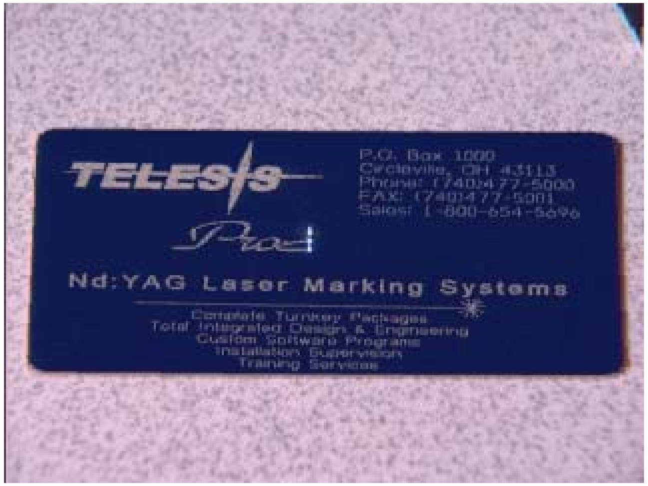








Laser etch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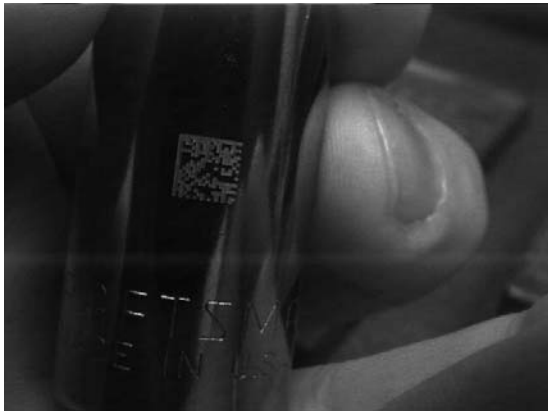
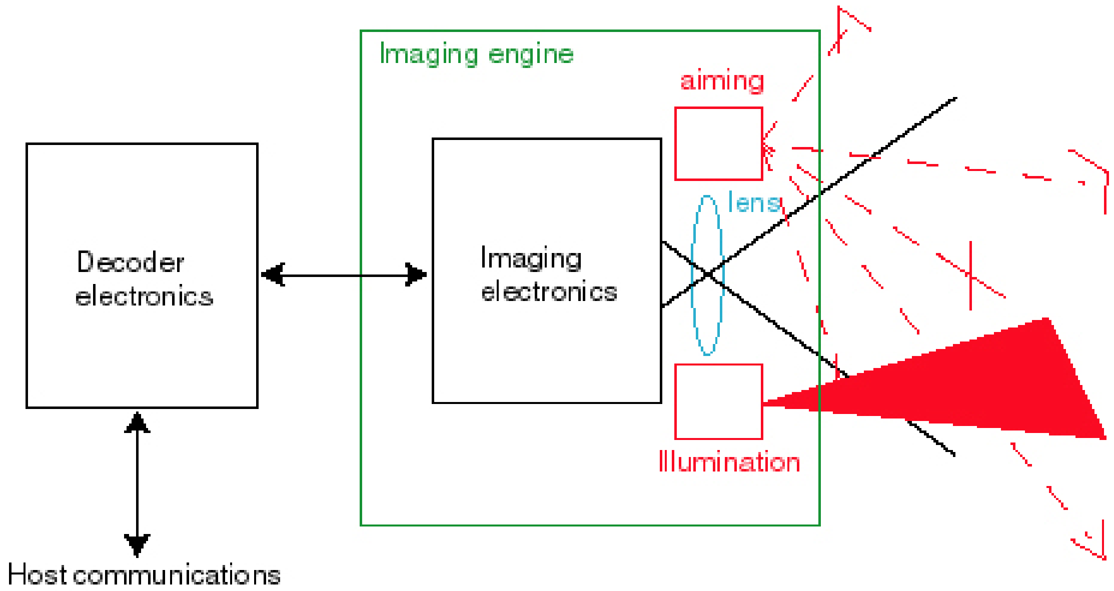


Imaging Scanner Basics



Imaging Electronics

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- **Image sensor array**
  - A 2D array of light sensitive elements that convert photons to electrons
  - A read-out circuit that accesses the elements and converts the electron charge signal to a digital number

- **When an image is formed on the array with a lens the elements produce a picture**
  - The elements are referred to as pixels (picture elements)

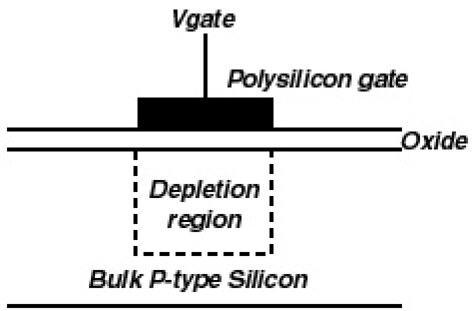
•CCD (Charge Coupled Device)

- Charge is read-out by shifting it sequentially through a chain of parallel capacitors
- The charge is converted to a voltage by a single amplifier
- The voltage is converted to a digital number on a separate IC

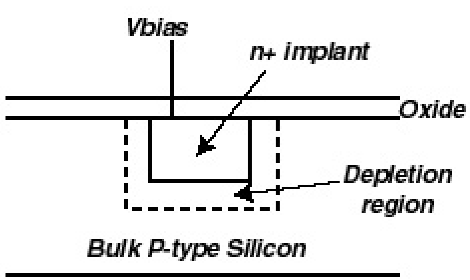
Basic CCD Pixel Structure

CCD Photodetector

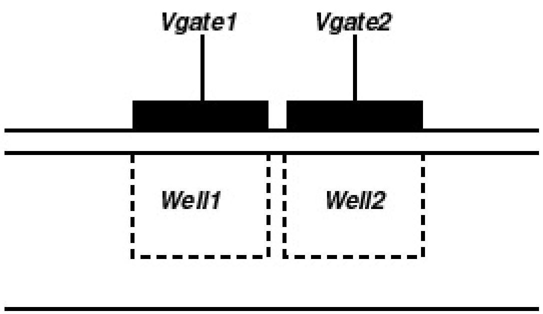
Photogate



Photodiode

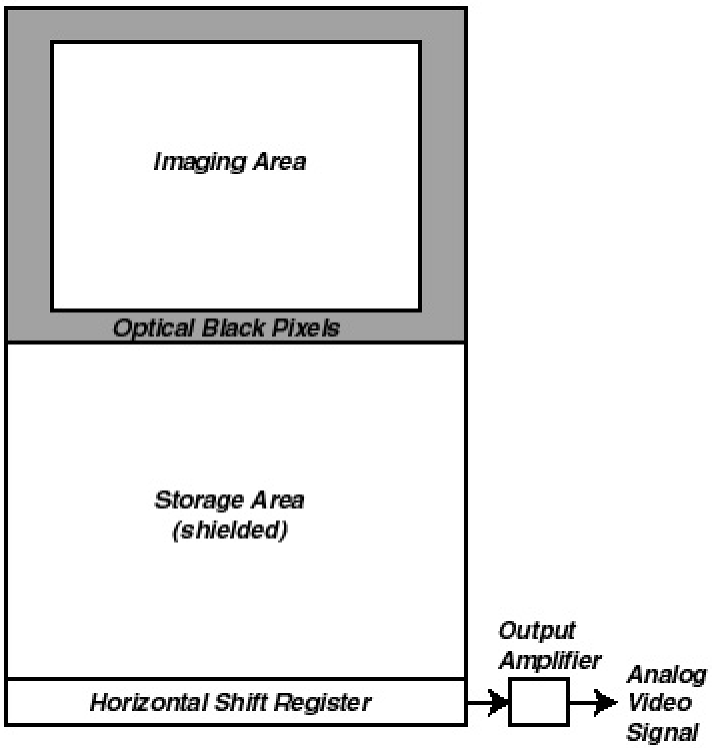


CCD Shift Register

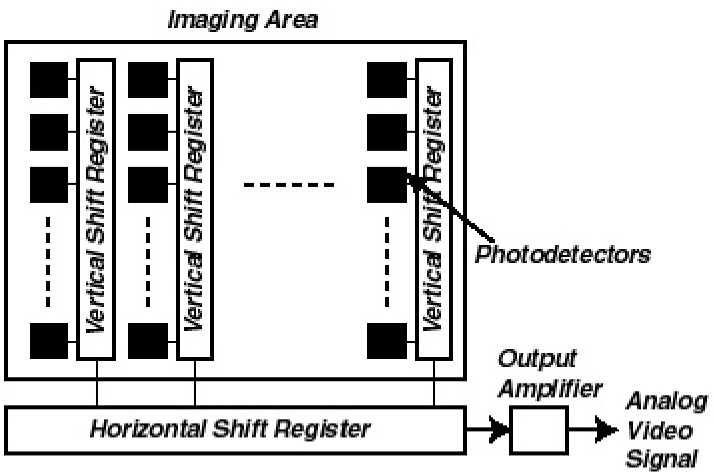


CCD Image Sensor Array Architectures

Frame Transfer Architecture



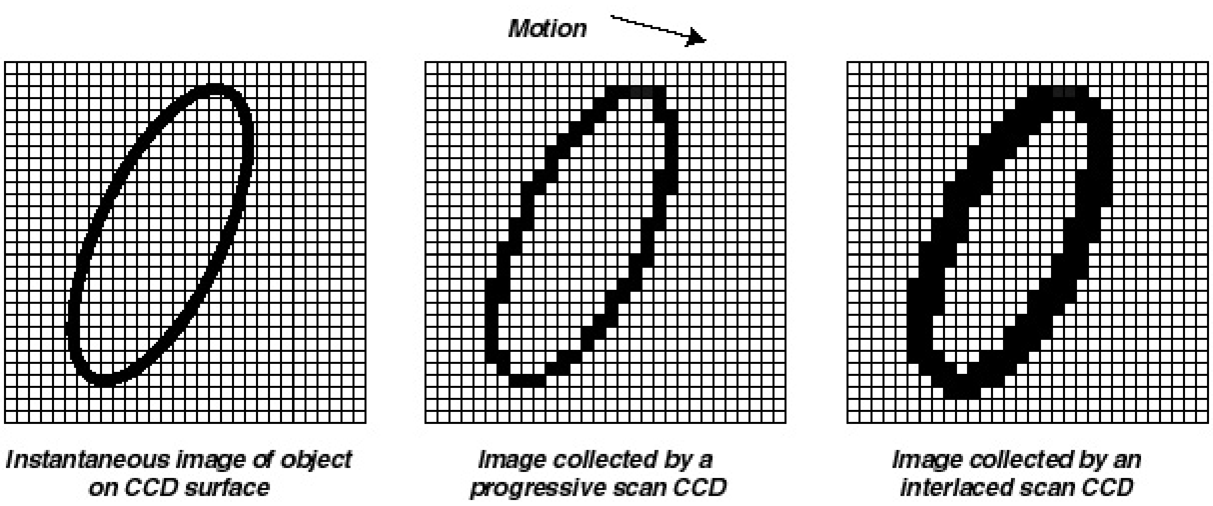
Interline Transfer Architecture



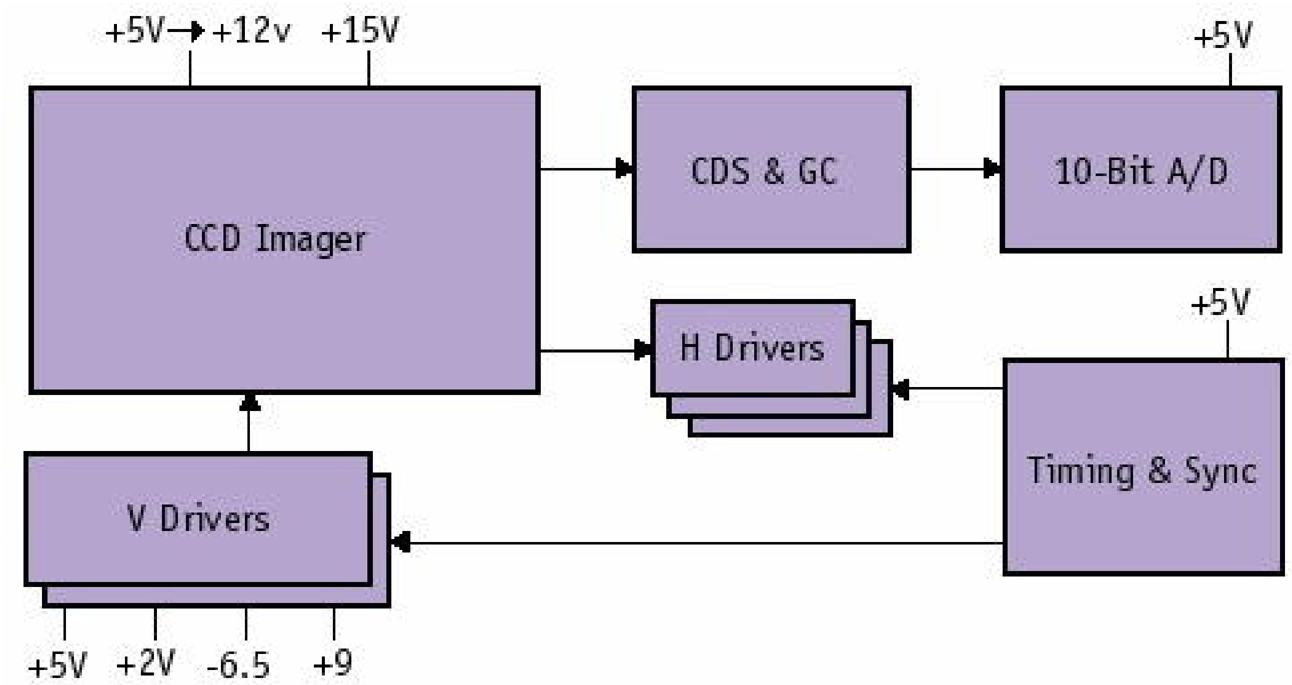
CCD Image Sensor Array Read-out

Progressive Scan Frame read in a single field

Interlaced Scan Frame read in two fields (odd and even)



Typical CCD Camera System Electronics



Commercial CCD Cameras

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Studio camera (>$10,000)

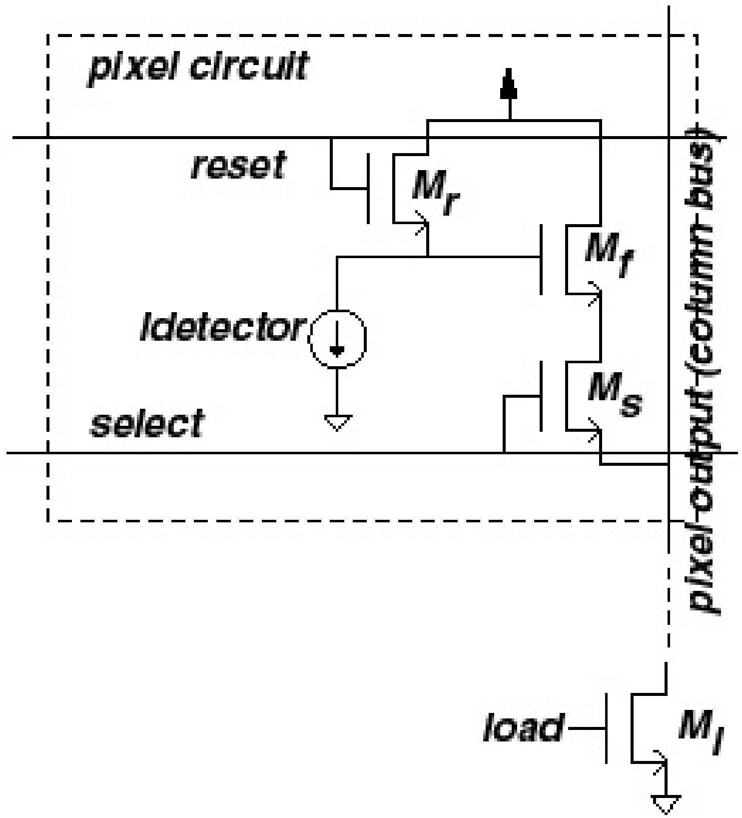
Hobbyist camera (<$500)

Professional camera (>$2,000)

•**CMOS (Complementary Metal-Oxide Semiconductor)**

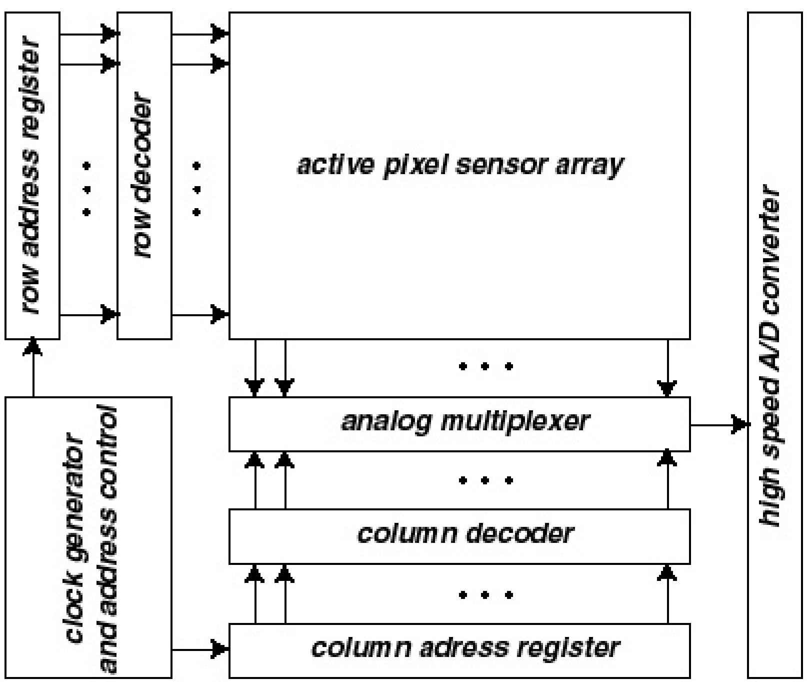
- Charge is converted to a voltage in the pixel with a source follower amplifier
- The voltage signals are read-out by a sequential addressing scheme
- The voltage is converted to a digital number on the same IC

Basic CMOS Pixel Structure

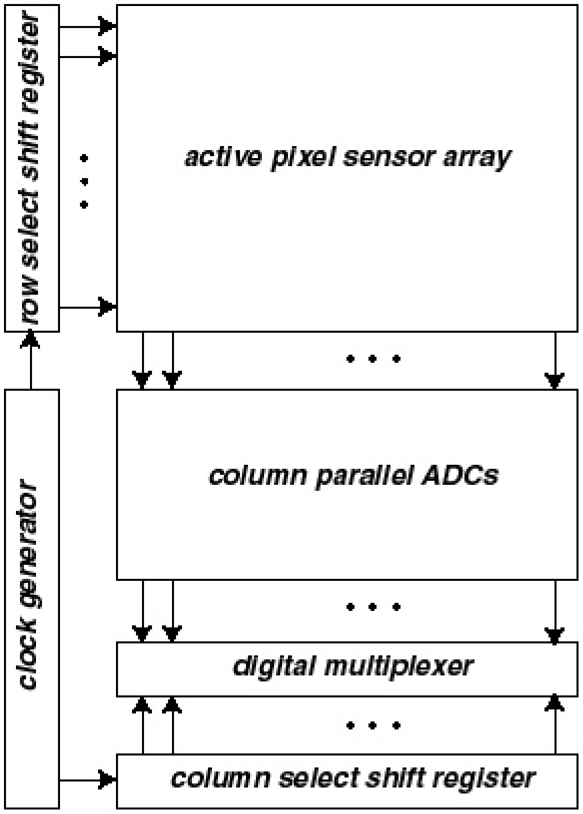


CMOS Image Sensor Array Architectures

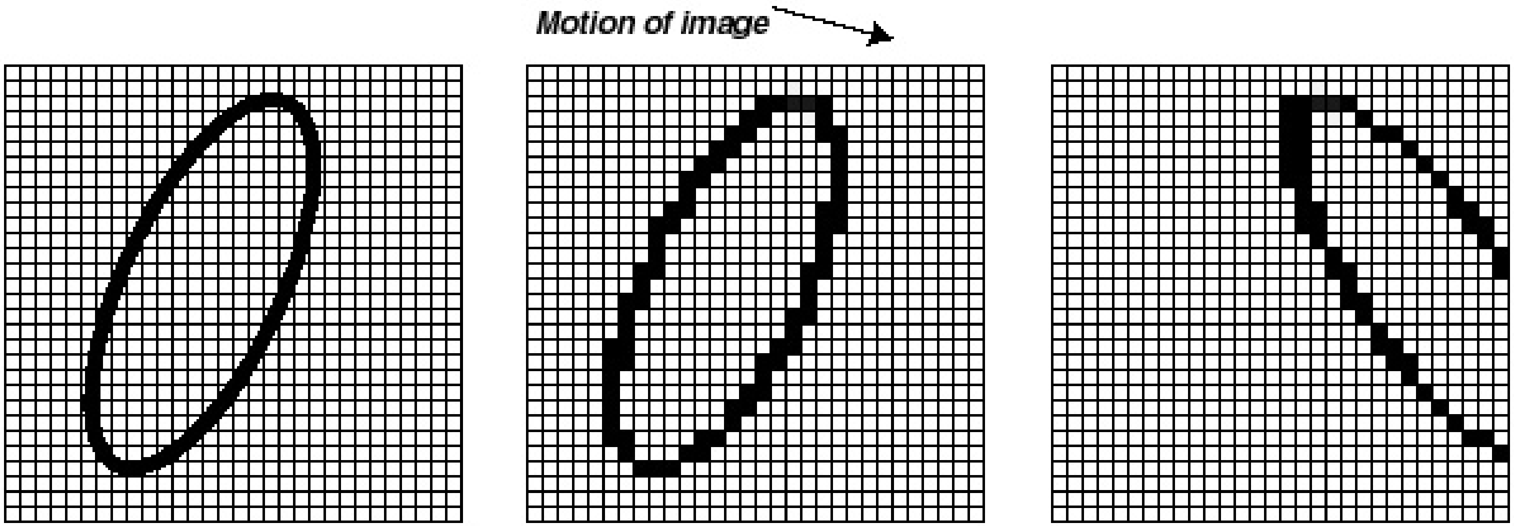
Single ADC Architecture



Column Parallel ADC Architecture



CMOS Image Sensor Array Read-out (rolling shutter)

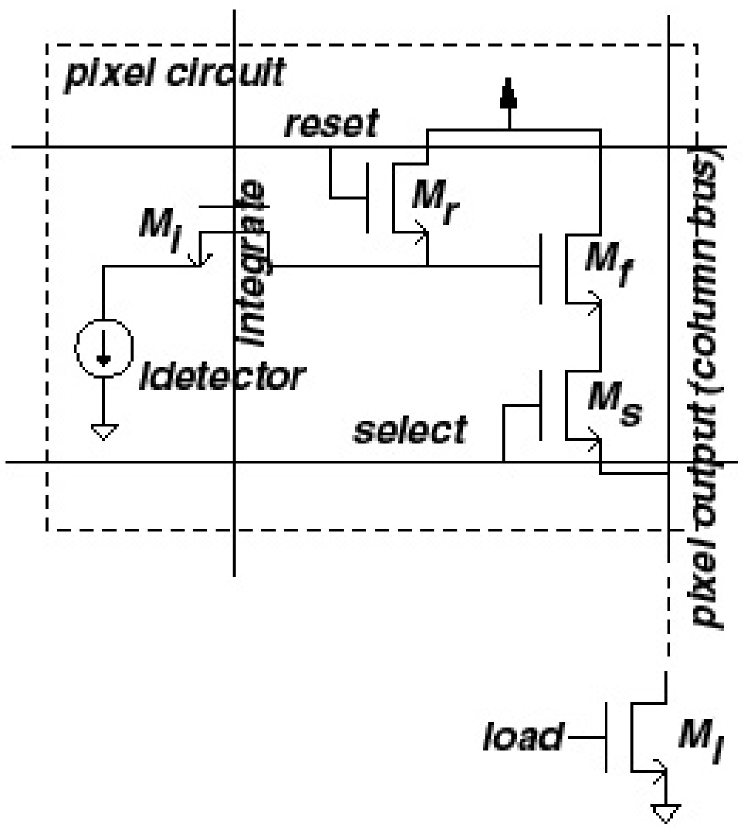


Instantaneous image of object on CCD surface

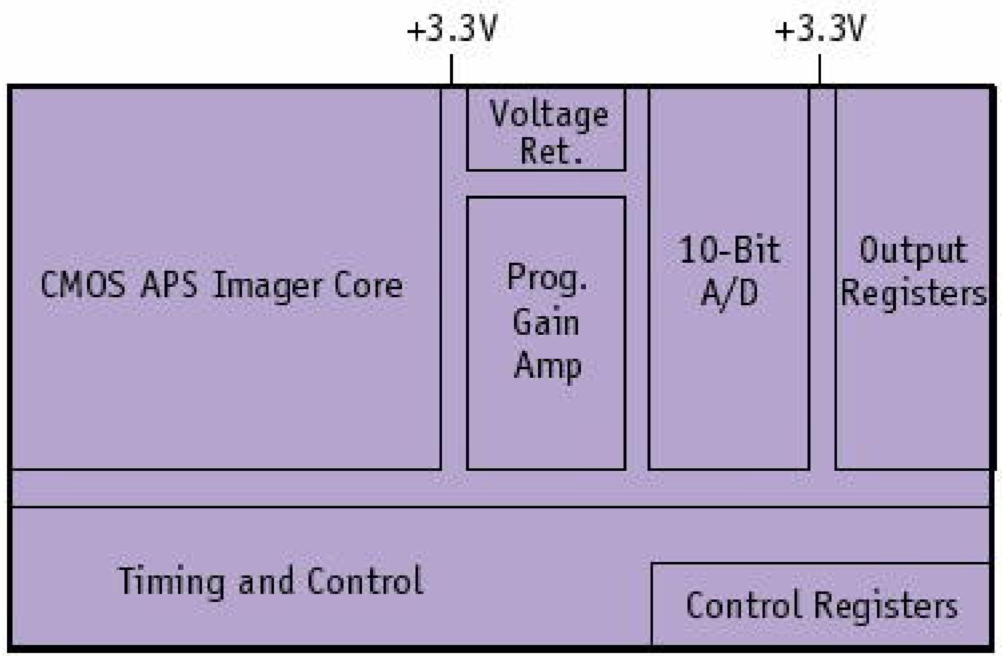
Image collected by a progressive scan CCD

Image collected by a rolling shutter CMOS sensor

CMOS Pixel for Progressive Scan (snap shutter) Read-out

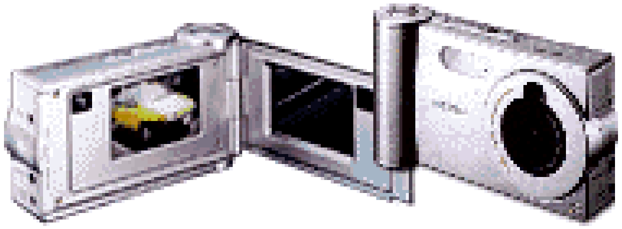


Typical CMOS Camera System Electronics (monolithic IC)



Commercial CMOS Cameras

Low end consumer camera (<$200)



USB video camera (<$50)

Toys (<$30)

Mobile Phone Cameras (<$20)

CCD vs. CMOS Camera Architectures

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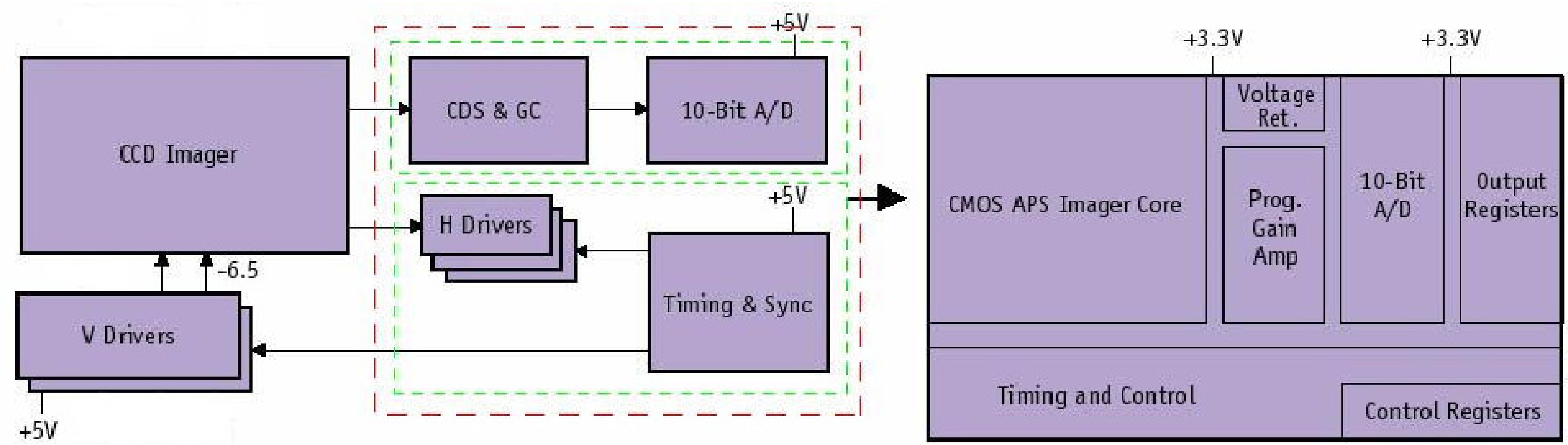

CCD vs. CMOS Advantages

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CCD Advantages

- Greater sensitivity
- Lower noise

CMOS Advantages

- ~~Small camera~~ size
- Lower power dissipation
- Integration of ASSP
- ~~Single supply voltage~~
- Lower cost

CCD vs. CMOS Sensitivity and Noise

CCD

- Optimize sensitivity with custom fabrication process
- High fill factor
- Pixel to pixel variations are minimal
- kT/C noise can be minimized

CMOS

- Fabless companies use standard fabrication process
- Low fill factor
- Pixel to pixel circuit variations are significant
- kT/C noise in the pixel

CCD vs. CMOS

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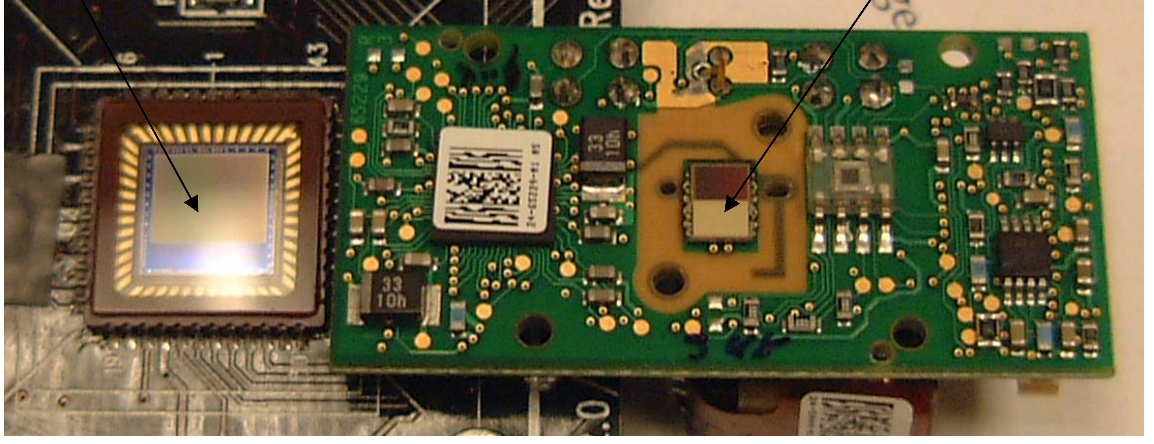
CMOS imager

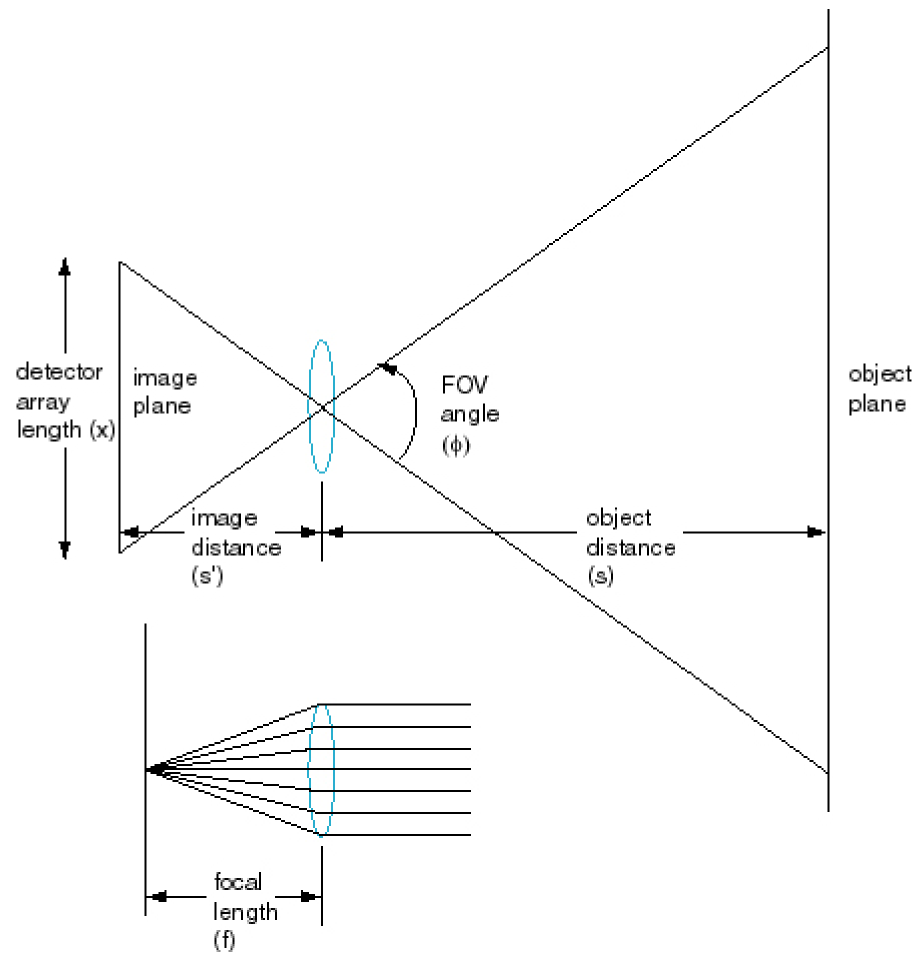
CCD imager



Imaging Basics: Optics

$$\tan\frac{\phi}{2} = \frac{x}{2s'}$$

$$\frac{1}{f} = \frac{1}{s'} + \frac{1}{s}$$



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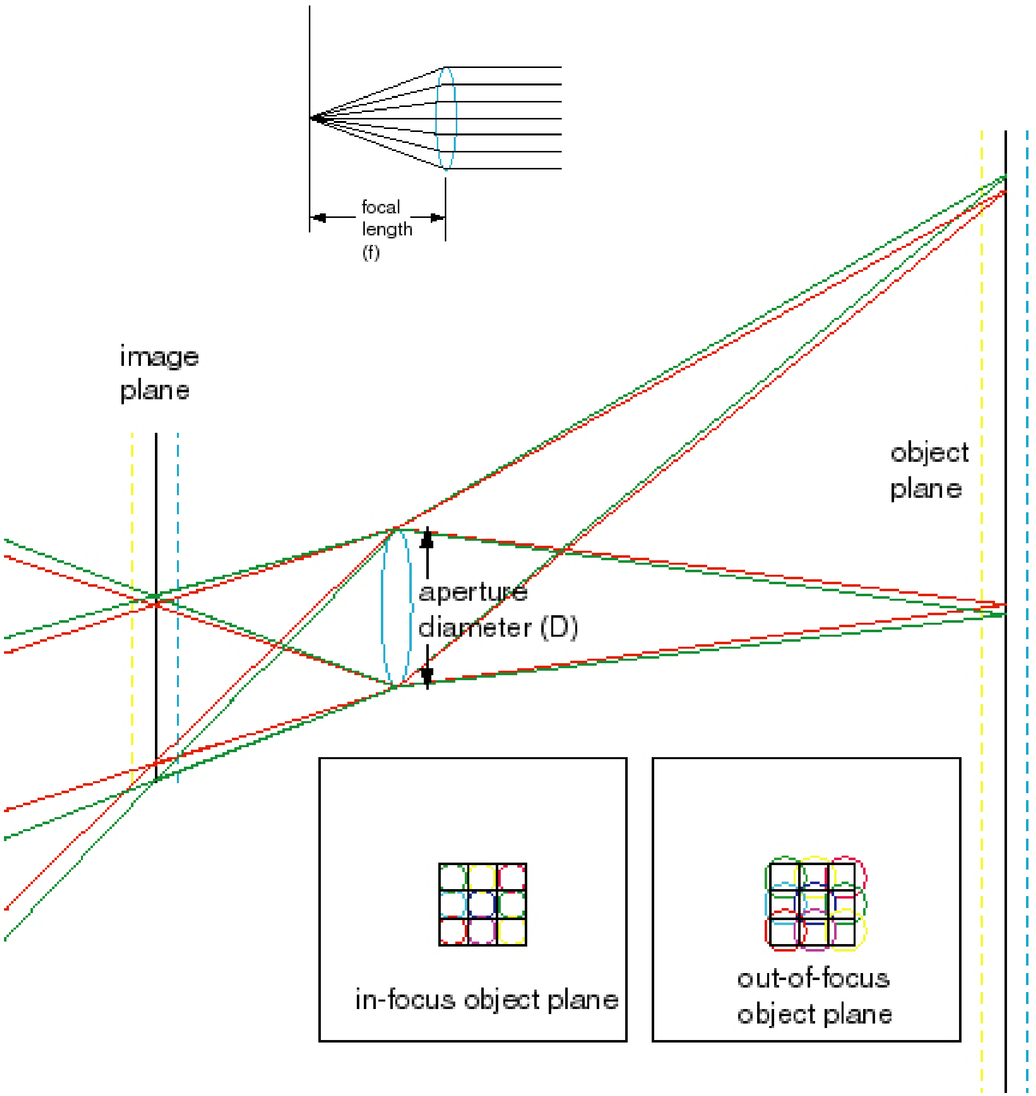
Lens F# = f/D

Depth of field is proportional to 1/D and resolution is proportional to f

Lens throughput

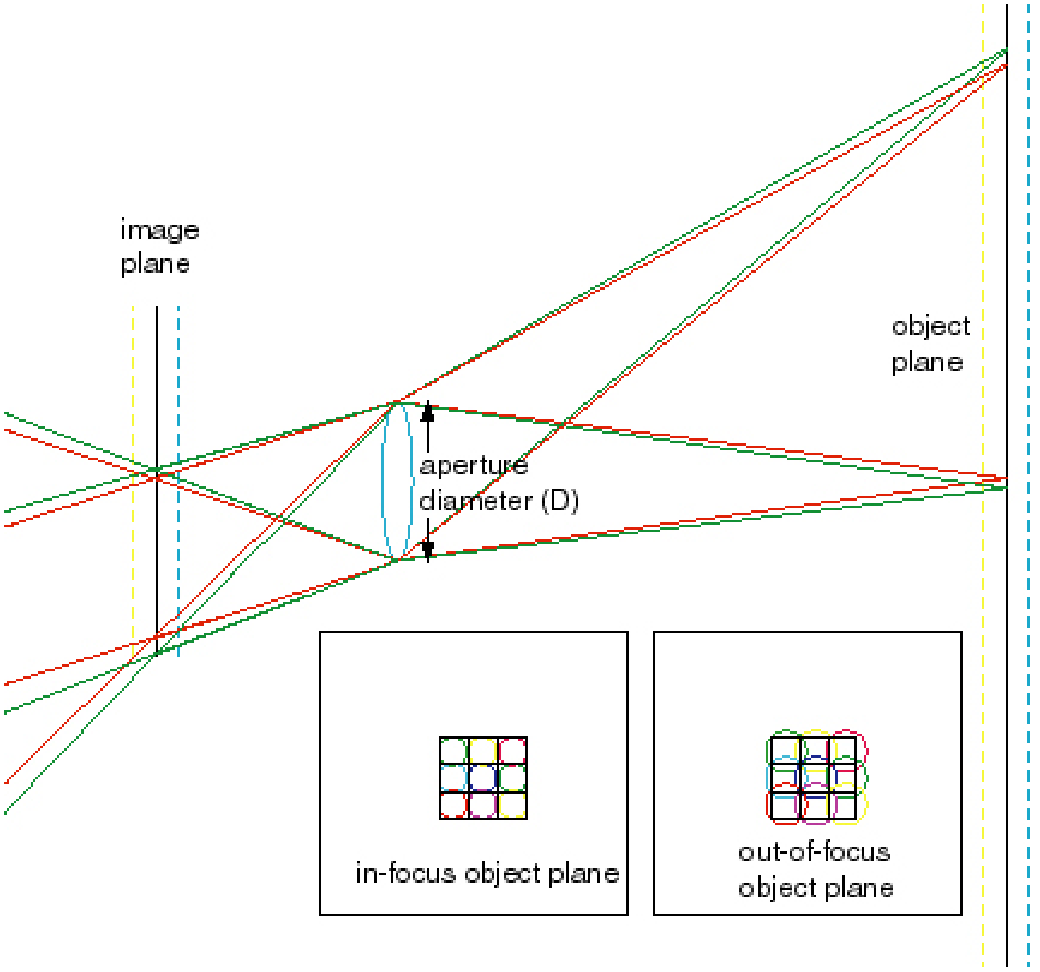
$$\frac{1}{4F^2}$$



Focus

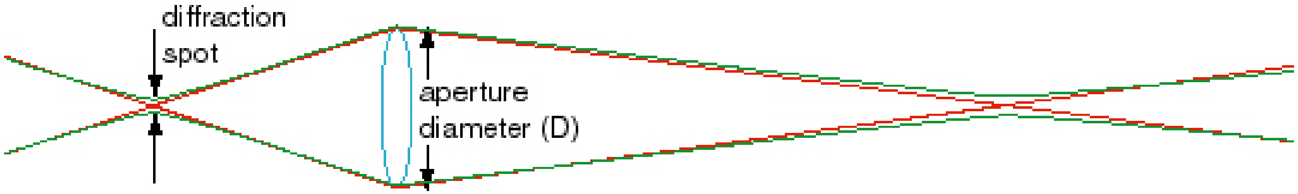
F# = f/D

Depth of focus is determined by the focal length and aperture diameter



The effect of Light bending around obstacles (aperture)

Limit of resolution



$$\Delta\ell_{\min} = \frac{1.22\, f\lambda}{D}$$

Modulation Transfer Function

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Optics (circular aperture)

$$MTF_{optics}(f,w)=\tfrac{4}{\pi}\int_{0}^{1-f}\cos(8\pi wrf)\sqrt{1-(f+r)^2}\,dr$$

CCD

$$MTF_{CCD}(f,\theta)=\left|\begin{array}{ll}\mathrm{sinc}(2\pi f u_1(\theta)) & \text{if } u_2(\theta)=u_1(\theta)\\ \max\begin{pmatrix}\left|p_y\sin(\theta)\right|\\ \left|p_x\cos(\theta)\right|\end{pmatrix}^{-1}\cdot\dfrac{(u_2(\theta)\,\mathrm{sinc}(\pi f u_2(\theta)))^2-(u_1(\theta)\,\mathrm{sinc}(\pi f u_1(\theta)))^2}{u_2(\theta)-u_1(\theta)} & \text{otherwise}\end{array}\right.$$

Optics (rectangular aperture)

$$\begin{aligned}MTF_{optics}(f_x,f_y,w_x,w_y,\theta)=\Lambda(f_x\cos(\theta))\cdot\mathrm{sinc}(8\pi w_x f_x\cos(\theta)(1-\left|f_x\cos(\theta)\right|))\cdot\\ \Lambda(f_y\sin(\theta))\cdot\mathrm{sinc}(8\pi w_y f_y\sin(\theta)(1-\left|f_y\sin(\theta)\right|))\end{aligned}$$

Light Throughput of the Lens

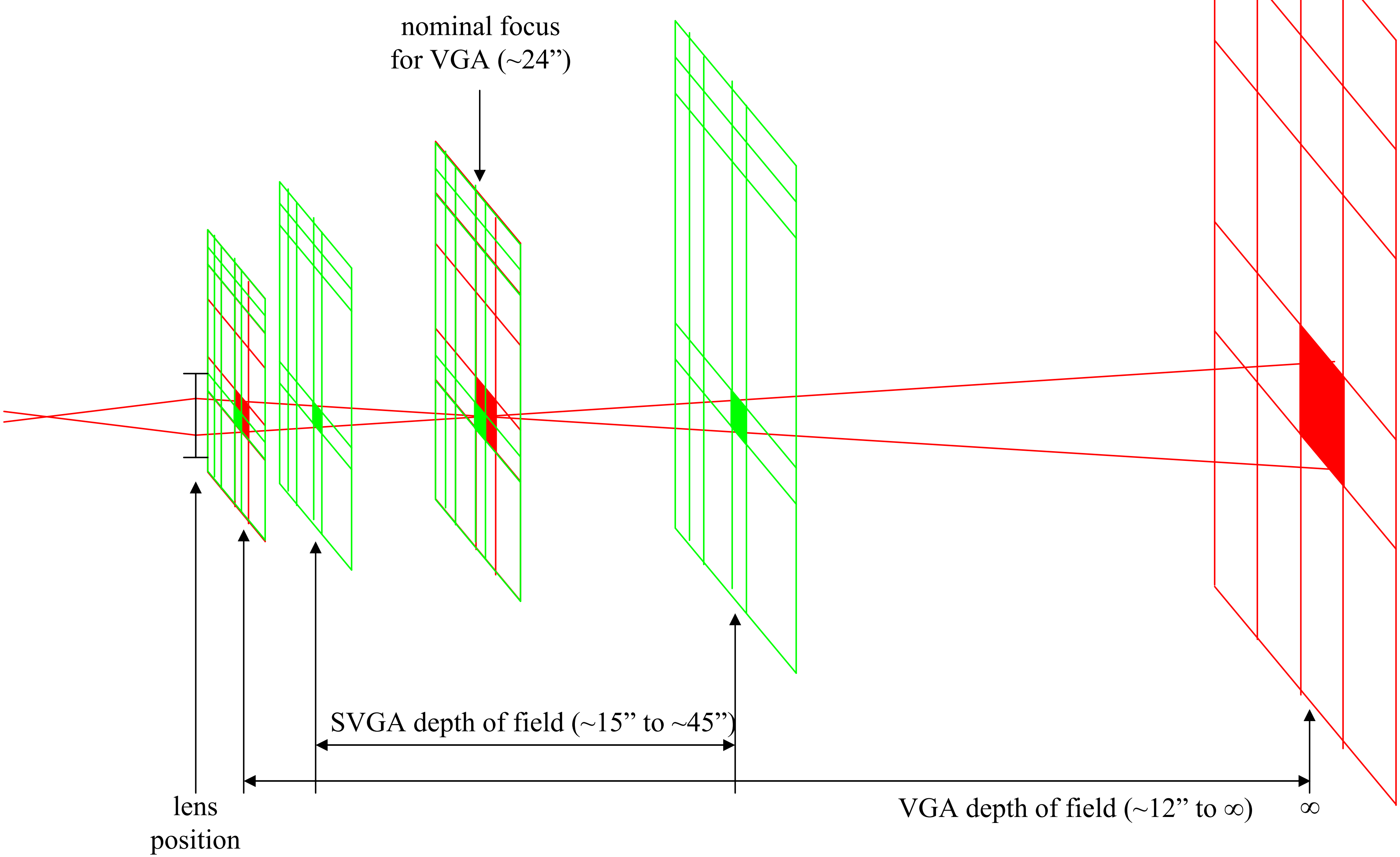
The amount of light collected from an object of size A_{object} at a distance s from the lens is

$$\frac{A_{object} A_{aperture}}{\pi s^2}$$

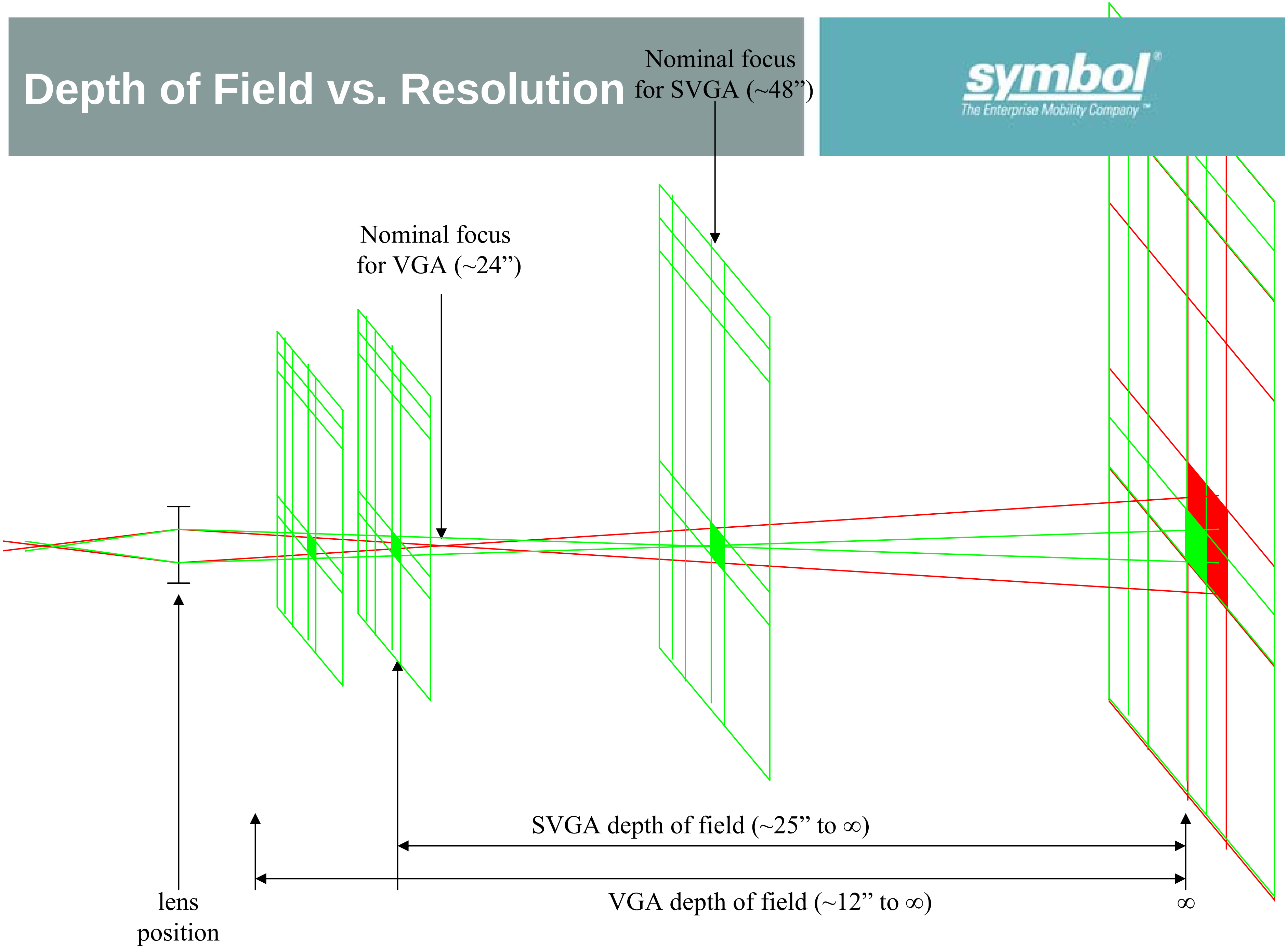
If the aperture is circular, then this can be reduced to

$$\frac{1}{4F^2(1+m)^2}$$

Depth of Field vs. Resolution



Depth of Field vs. Resolution



Decoder Electronics

- RISC microprocessor core with rich set of pheripherals (e.g., USB)

- High speed (48 MHz) image acquisition channel

- SDRAM, FLASH

Decoder Software

- Image acquisition
- Camera control
- Automatic gain/exposure control
- Aiming/illumination control
- Video/picture/barcode mode
- Image processors for barcode decoding
- Host communication

Barcode Decoding Software

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- Locate the barcode in the image
- Digitize the bar (1D) or module (2D) pattern
- The pattern is passed to a decoder to determine the data content
- Auto-discriminate the type of barcode

Sample Images

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Aiming Pattern

- Projected on the target to assist the user in aiming at the barcode
- Laser or LED technology with diffractive or conventional optics
- Displays are not useful because the attention of the user is on the barcode

Illumination

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- Projected on the target to provide reflected light to the camera

- Enables scanning in dark environment

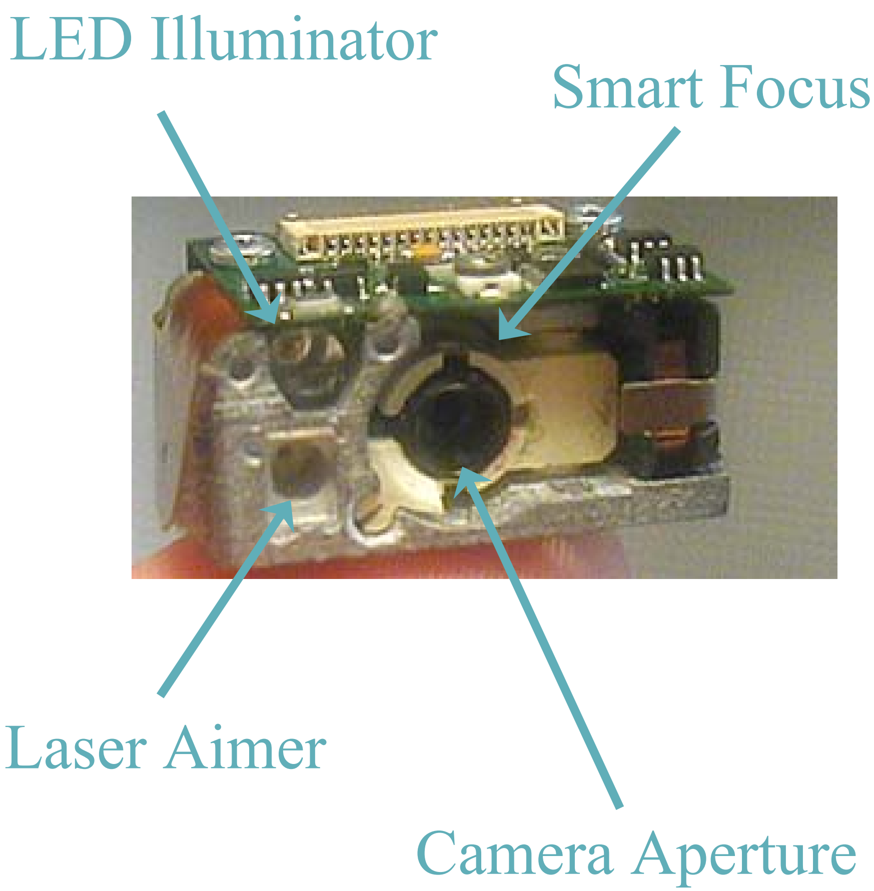
- Decreases exposure time to limit the effect of hand motion

Host Communications

- **Corded**
  - USB, RS232, Keyboard wedge
- **Cordless**
  - Bluetooth, custom
- **Wireless**
  - WiFi, WAN

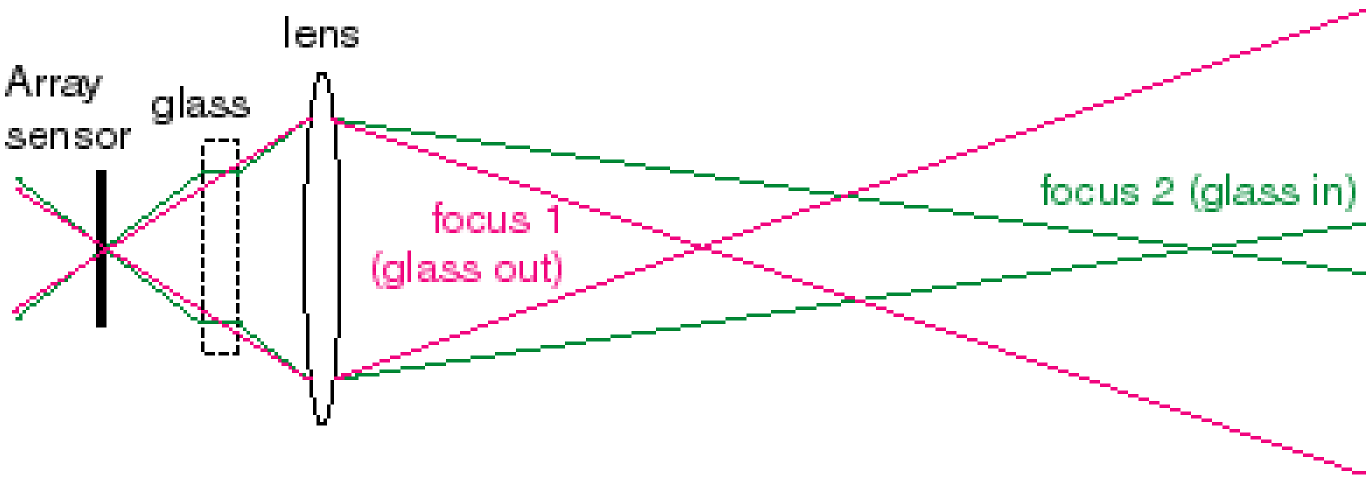
SE4400 Imaging Engine

- Laser-like scanning aggressiveness
- Basic building block for our imaging-based mobile computers and industrial scanners
  - Smart focus optics (5” and 9”)
  - CCD sensor array
  - Laser aiming
  - Built-in LED illumination



Smart Focus

- Enables larger aperture because depth of field is maintained with two focus positions
- Enables a wide range of barcode densities to be read with one product



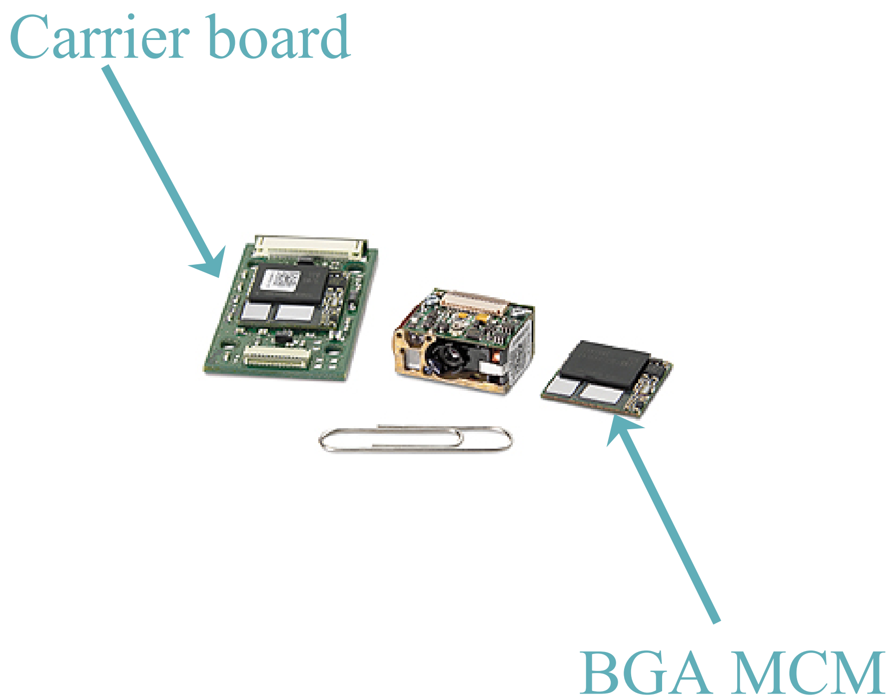
Imaging Products

Mobile computers

- PDT8100
- MC9000K/S/G
- MC3000
- MC50

PL4407 Decoder MCM

- Freescale MXL with Arm9 core
- 150 MIPS
- 100 mA @ 3V
- 8 MB SDRAM
- 2 MB Flash
- Video port

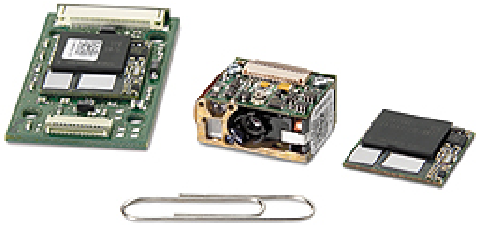


Digital (Imaging) Scanners

- Industrial scanners
  - DS3407/08 corded
  - DS3478 cordless

- DS6707/08 retail digital scanner
  - 1.3 MP resolution
  - Fixed focus optics

- OEM



Thank You For Your Time And Attention!

Questions