Trends in Digital Imaging

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51. Photogrammetric Week

Stuttgart, September 4th 2007

Institute for Microelectronics Stuttgart

Si Technology

Lithography

ASICs

Vision

Learning

Outline

- Introduction
  - Imaging Basics
  - CCD vs. CMOS Imagers
  - Generic CMOS Imager Pixel Cells
- High Dynamic Range CMOS (HDRC®) Pixel Cell
- Signal Processing for HDRC®
- CCD vs. HDRC®
- HDRC® Sensors and Cameras
- HDRC® Applications and Challenges
  - Automotive and Traffic
  - Industrial Automation
  - Space
  - Medical Diagnostics and Aids
- Conclusions

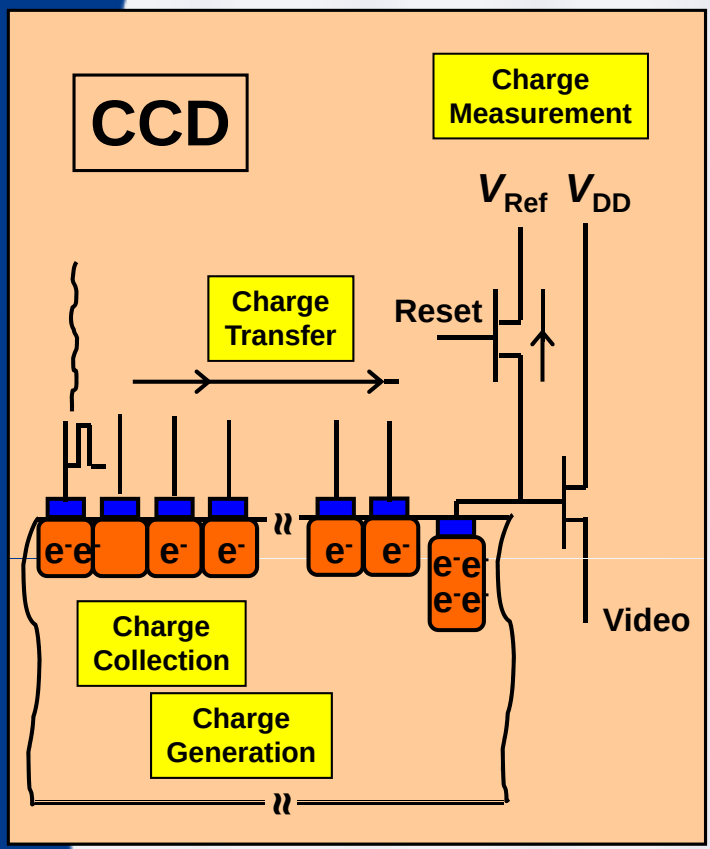
Imaging

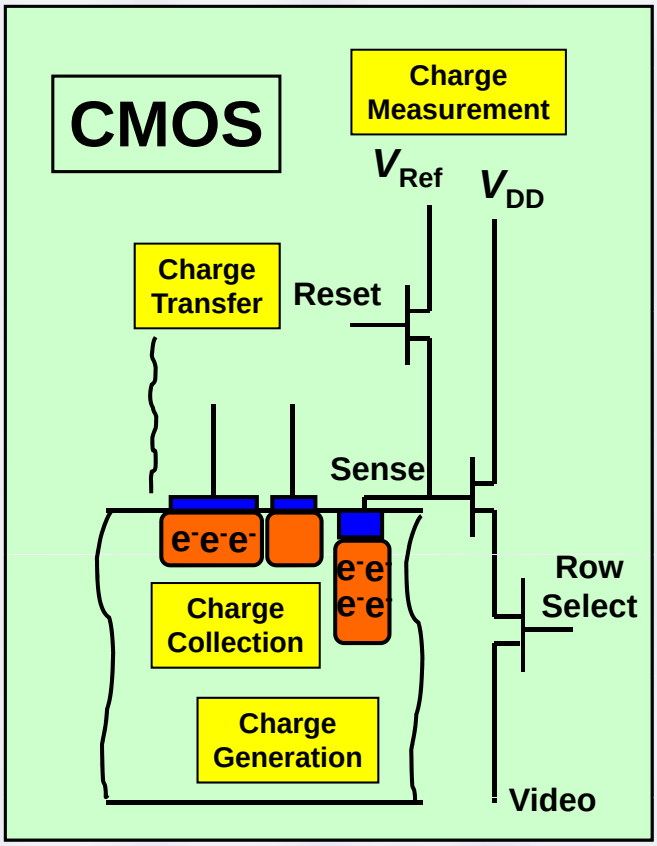
IMAGING	RESPONSE	SCENE DYNAMIC RANGE	COLOR CONSTANCY
Our eyes	Logarithmic	Very high	Yes
Painting	Eye-like, logarithmic	High	Depending on the artist
Film	Pseudo eye-like, pseudo logarithmic	High	Yes
Vidicon	Linear	Small	No
CCD	Linear	Small	No
Other CMOS	Linear	Small	No
HDRC®	Eye-Like, logarithmic	Very high	Yes

CCD: 1969, Boyle/Smith at Bell Labs → **CCD Imagers: 70‘s**

CMOS Imager Concept: 70‘s → **CMOS Imagers: End of 80‘s**

CCD and CMOS Imager Basics





Imager Vendors

CCD‘s

- Sony
- MATSUSHITA
- SHARP
- FUJI

Special CCD

- KODAK
- DALSA
- THOMSON
- MARCONI

CMOS APS

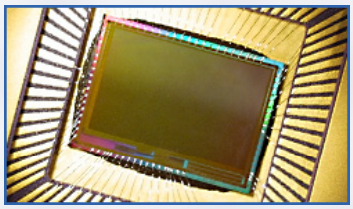
- AGILENT
- MICRON (Photobit)
- ST MICRO
- KODAK (NS)
- OMNIVISION
- SHARP, other Japanese
- DIALOG (Sarnoff)
- SMAL

Special

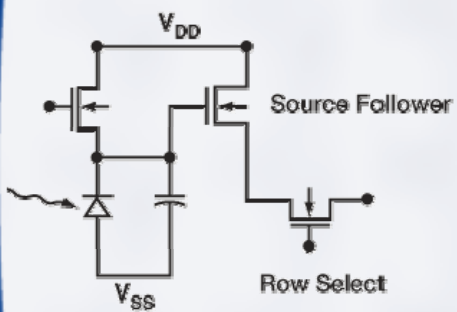
- FILLFACTORY-CYPRESS
- FOVEON
- IMS CHIPS
- PHOTONFOCUS

Selection (automotive focused)

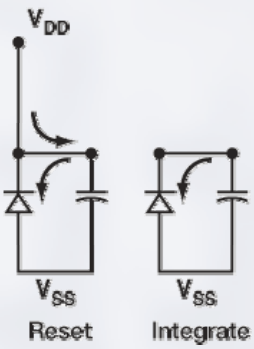
Generic CMOS Imager Pixel Cells



MOS ACTIVE PIXEL



LINEAR
Charge Integration Mode



LOG
Continuous Current Mode

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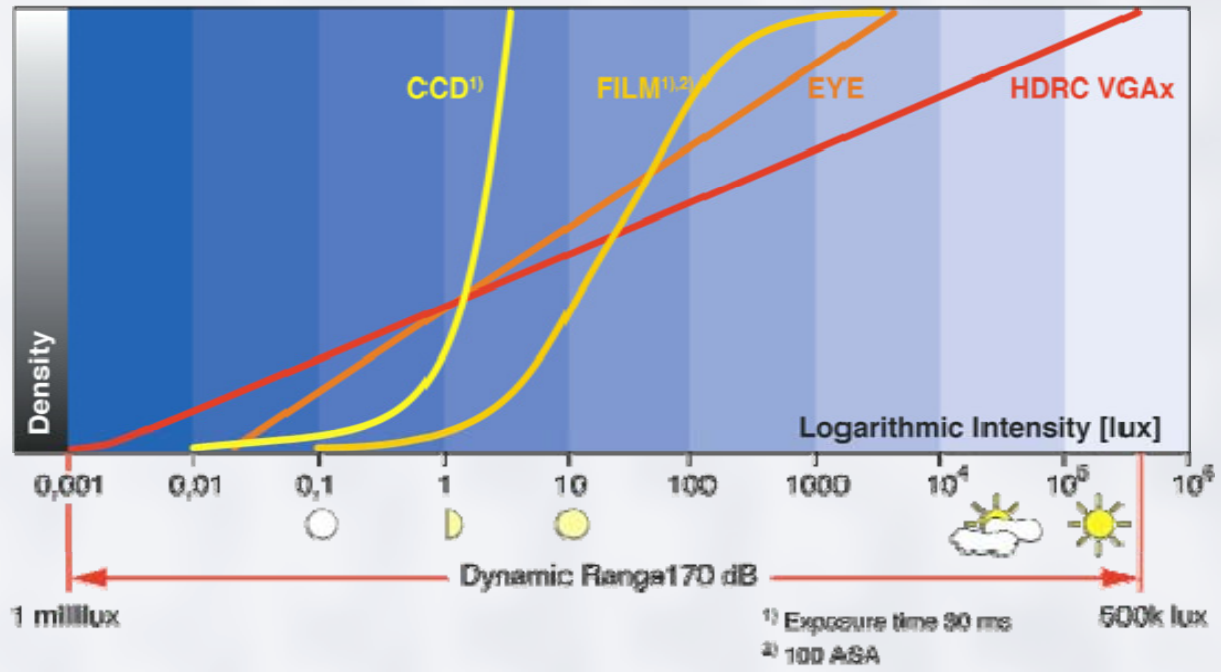
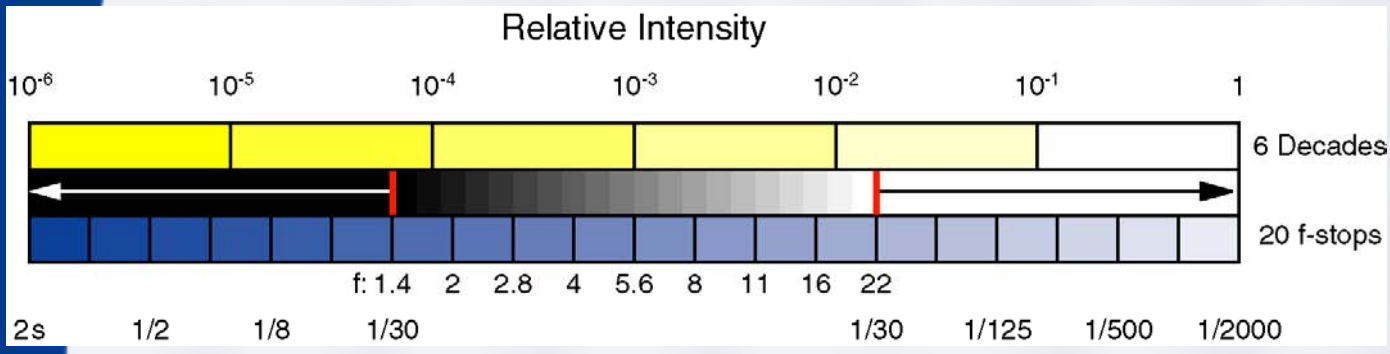
Types of Imagers

Response Curves of the HDRC® and other Sensors



Dynamic Range

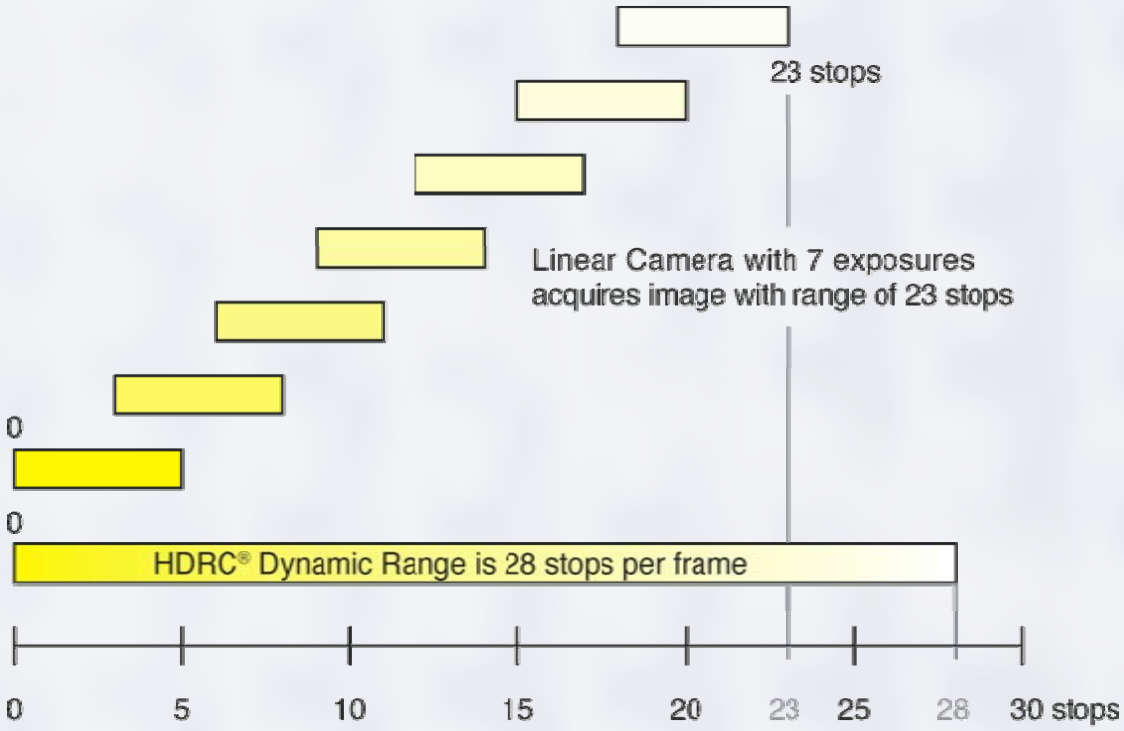


Maximum Aperture + Increase of Exposure Time

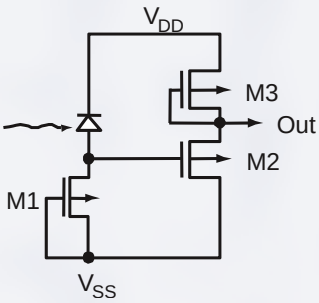
Varied Aperture at 1/30 s Exposure

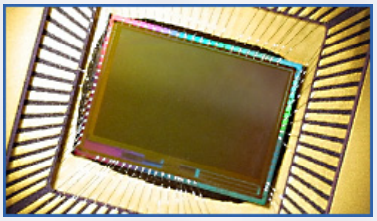
Minimum Aperture + Reduction of Exposure Time

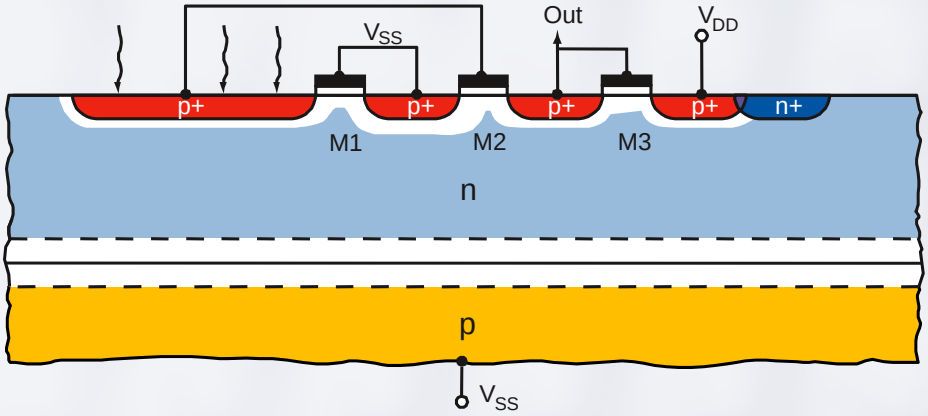
High-Dynamic-Range Acquisition



Time-Continuous Log-Compressing Pixel







Filed 03/24/1992 International Patents

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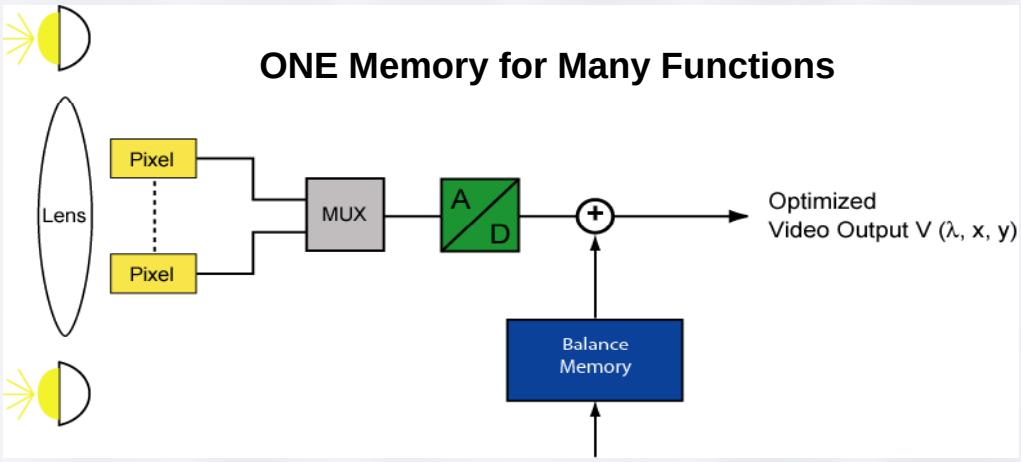
HDRC® Balance Memory



$I(\lambda, x, y) = L(\lambda) \cdot Refl(\lambda, x, y) \longrightarrow \log I(\lambda, x, y) = \log L(\lambda) + \log Refl(\lambda, x, y) \sim V(x,y)$

e.g. "Red"

$$V_R(x,y) = \log Refl_R(x,y) + \log L(x,y) + \log \alpha_R + \log T_R(x,y) + FP(x,y)$$

Adjustment for:

- ✓ Lens Nonuniformities T(λ,x,y)
- ✓ Nonuniform Illuminance L(λ,x,y)
- ✓ Object Reflectances Refl (x,y)
- ✓ Pixel Nonuniformity FP(λ,x,y)
- ✓ Spectral Sensitivity ⟨(λ)

Illuminance Equalisation

Original HDRC® Frame

Log Illuminance (Spotlight)

HDRC® Frame after Log Illuminance Offset

Spotlight Illumination of the Face

Excellent Face Recognition with HDRC®

Improvement by Irradiance Equalisation

White and black saturation of the CCD pixels limits any gains from pre-processing

Offset Adjustment

Over- or Under-exposeure? No Problem for HDRC®

F: 1.8, 1/30 s

F: 4, 1/30 s

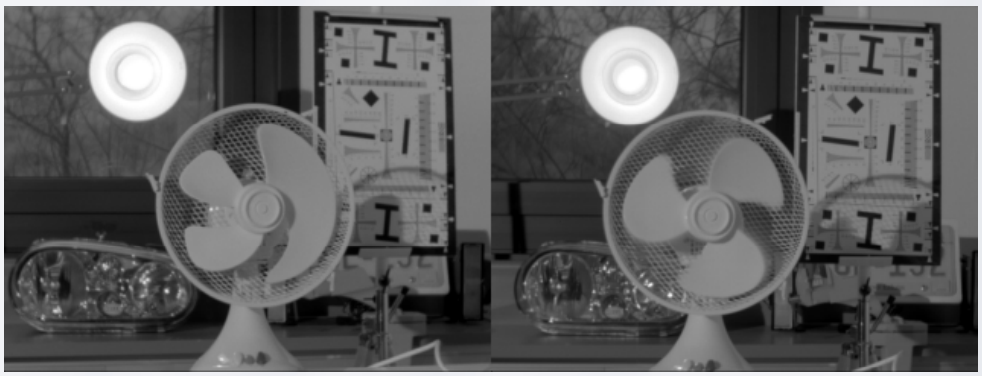
F: 8, 1/30 s

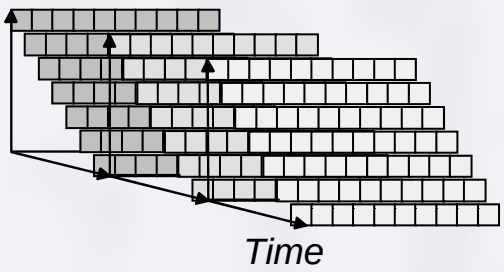
Recorded HDRC® images displayed after offset adjustment.

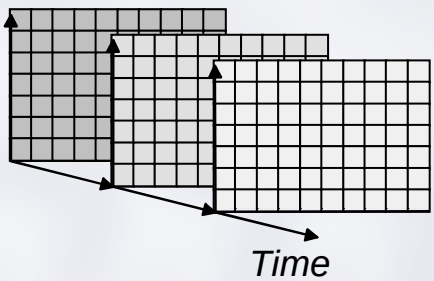
Global vs. Rolling Shutter

- ✓ Camera Frame Rate: 40 fps @ VGA Resolution
- ✓ Rotating Fan 3000 Rounds per Minute

Rolling Shutter (Comparison) ***New*** **HDRC Sensor with Global Shutter**







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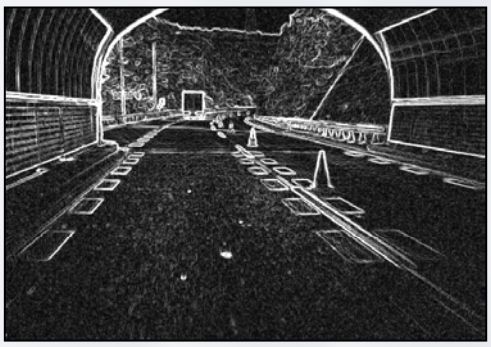
CCD vs. HDRC®

Very bright

Changing

Very dark

Sobel Operator

	CCD	HDRC
Original Image		
Sobel Operator		

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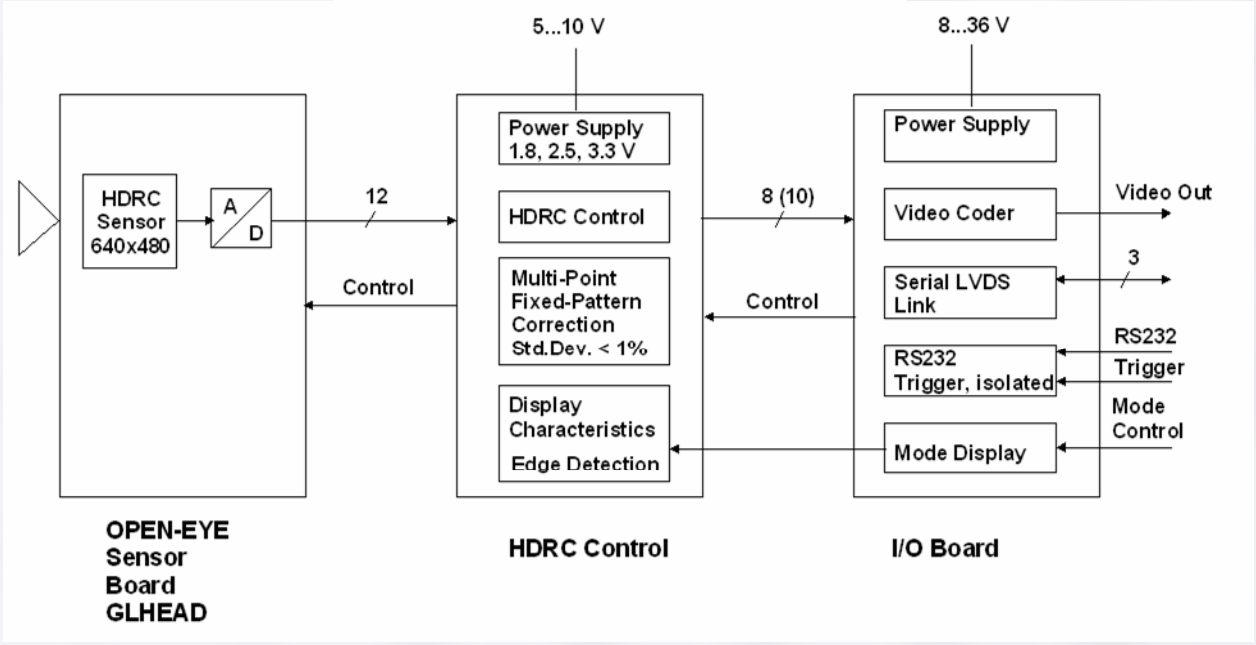
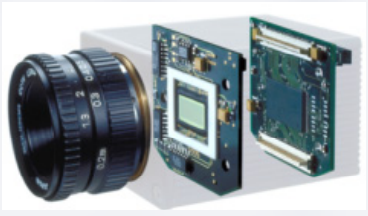
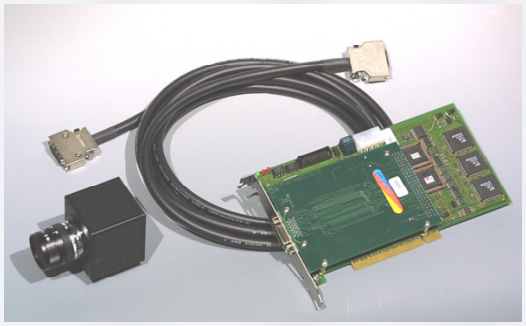
HDRC® CCTV Smart Camera



Digital HDRC® Camera System





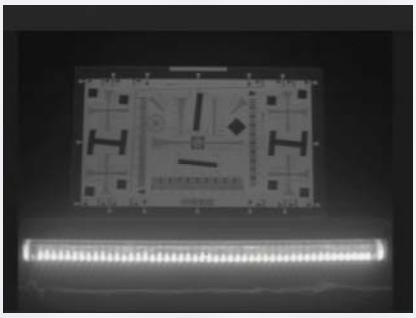
Features

- **768 x 496 (640x480) Pixel**
- **> 140 dB Dynamic Range**
- **Camera Link Interface, 12 Bit per Pixel, Base Configuration**
- **30 fps at Full-, 35 fps at VGA-, 118 fps at CIF-Resolution**
- **12 MHz Pixel Rate**
- **User defined Sub Framing**
- **Very compact, only 54mm x 46mm x 46.4 mm (H, W, L)**
- **Standard C-Mount Lens**

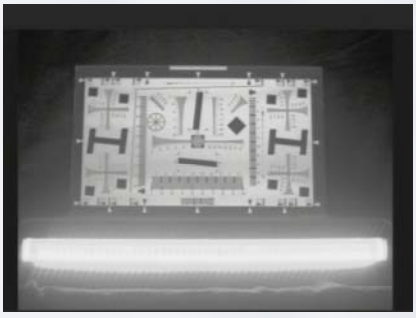
Real Time Processing Modes

Smart camera with 15 different output modes:

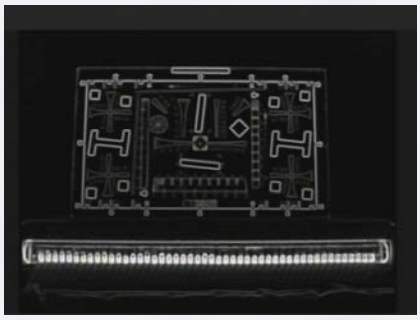
Mode 2: Min-Max Stretch



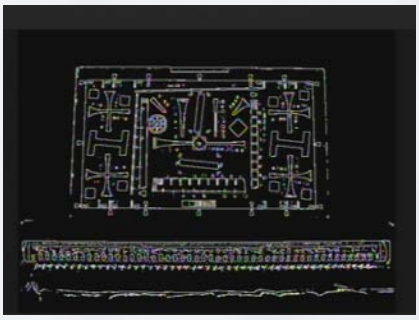
Mode 4: Histogram Equalization



Mode B: Gradient Vector Magn.



Mode E: Contour Points

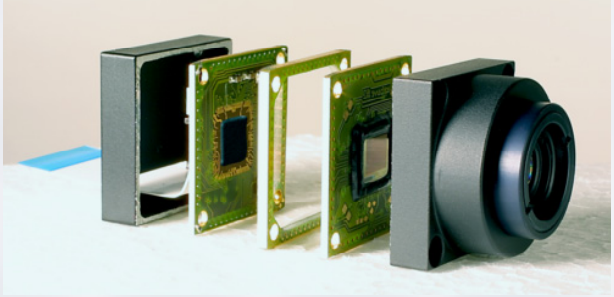


HDRC® Cam Cube

Miniaturized Camera Module

25 x 25 x 25 mm³

- **HDRC® Image Sensor**
- **Flash Memory**
- **ASIC Controller**
- **10 Bit digital Image Data**



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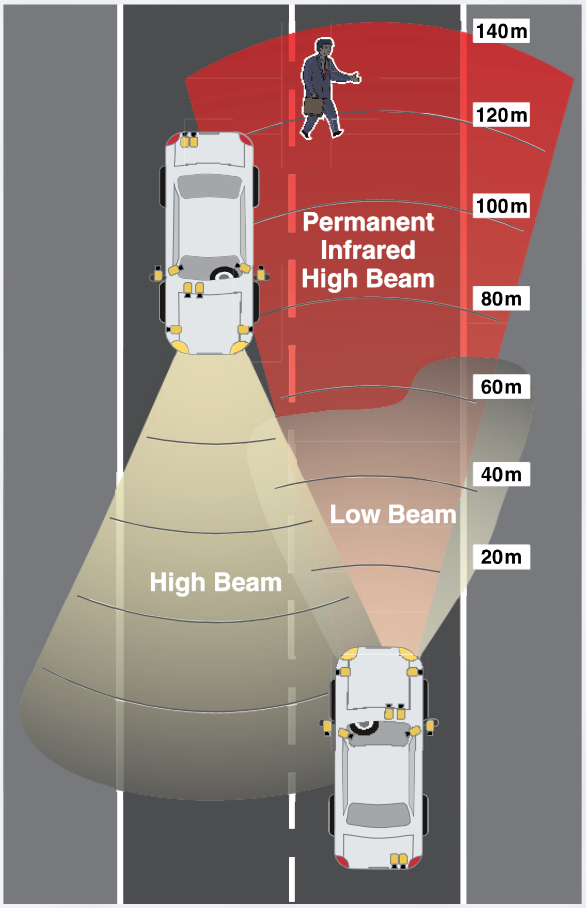
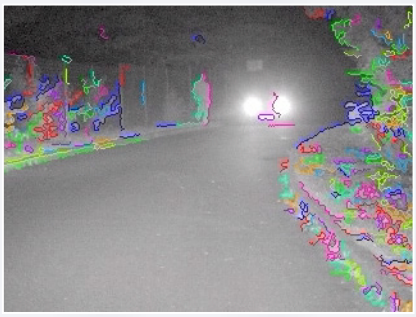
Night Vision Concept



Night Vision Performance



Edge enhanced frame

With permanent infrared high beam

Aircraft Docking System

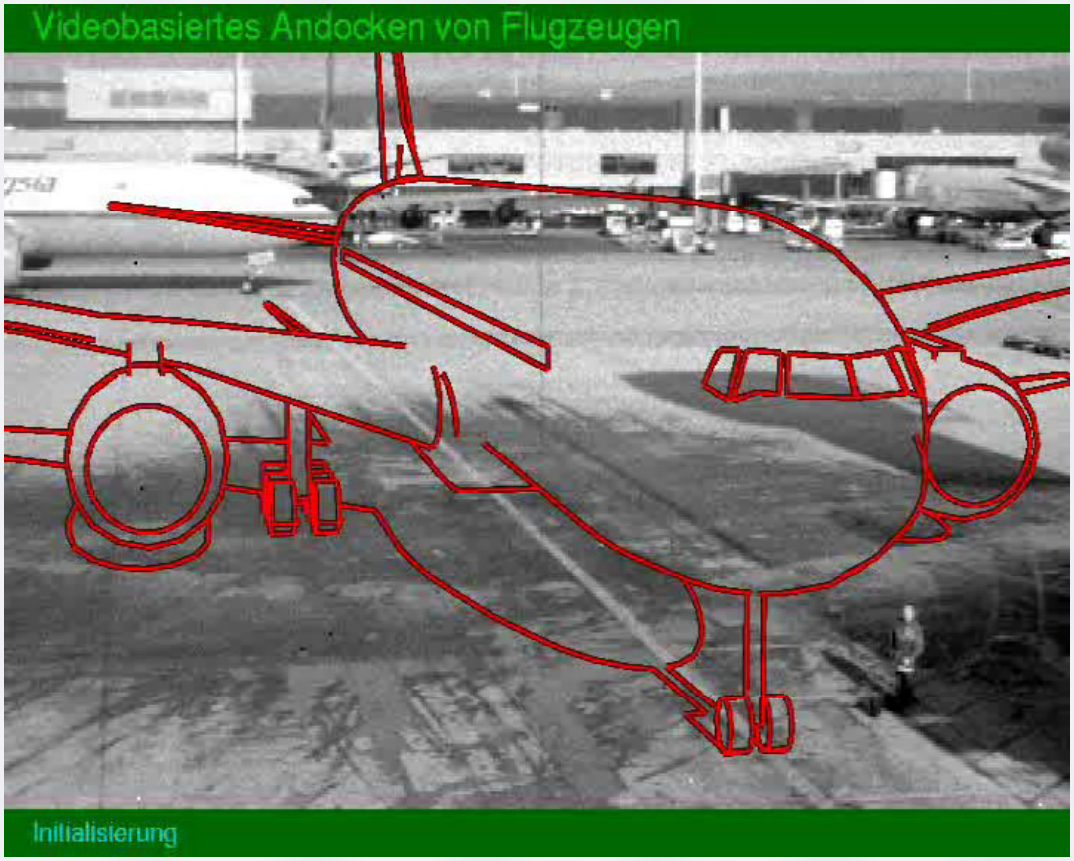
HDRC® Camera-Guided Aircraft Docking

Barcelona
Billund
Brussels
Dresden
Hannover
Leipzig
Madrid
Peking
Kanton
Seoul
Tel Aviv

- High dynamic range
- High sensitivity
- High contrast resolution
- One camera setting for all

Courtesy: Honeywell Airport Systems and Gevitec

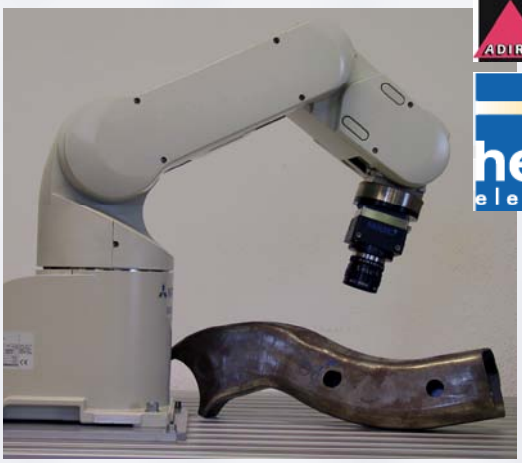
Aircraft Docking (Gate)



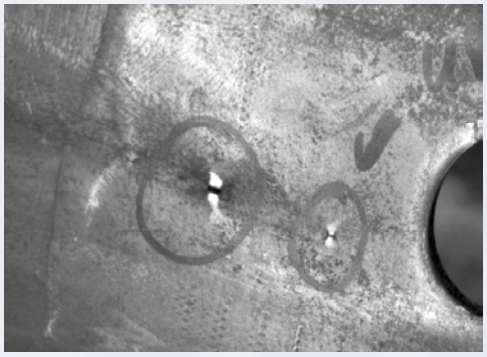
Aircraft Docking (Pilot)

Inspection of Metal Surfaces

- ✓ Random positioning of test sample
- ✓ No pre-selection of area of interest
- ✓ Only select type/size of fault



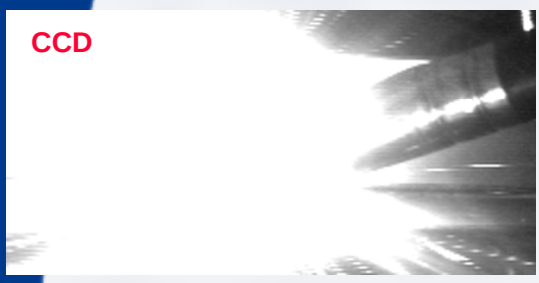
Surface with Faults



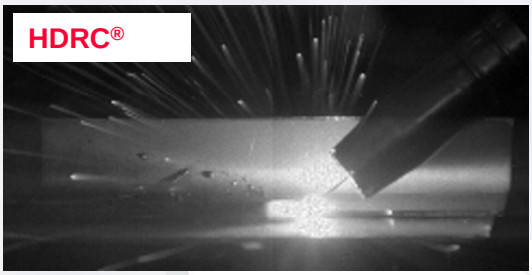
Surface with Marked Faults

Welding Process Control

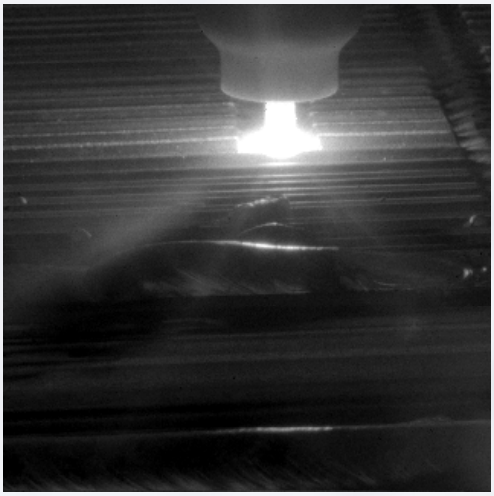
CCD



HDRC®



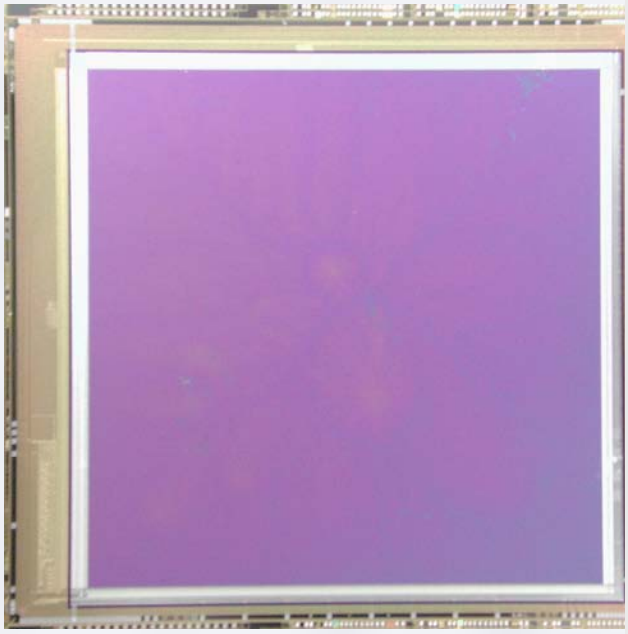
TIG Welding

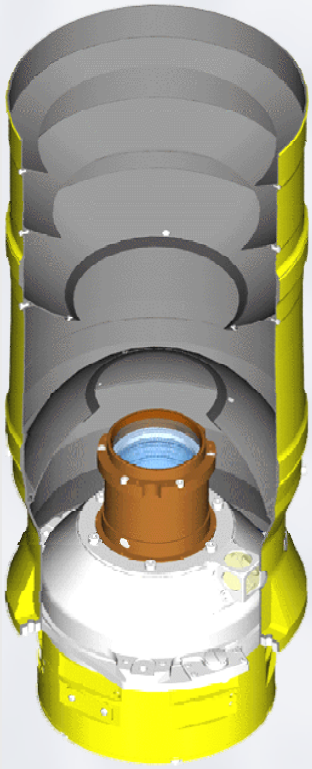


hema electronic GmbH
www.hema.de

Star Sensor (I)

- ✓ Optical sensor for satellite positioning
- ✓ Radiation-hard image sensor for star navigation
- ✓ Image sensor with maximum fill factor
- ✓ Interpolation over 7x7 pixel array

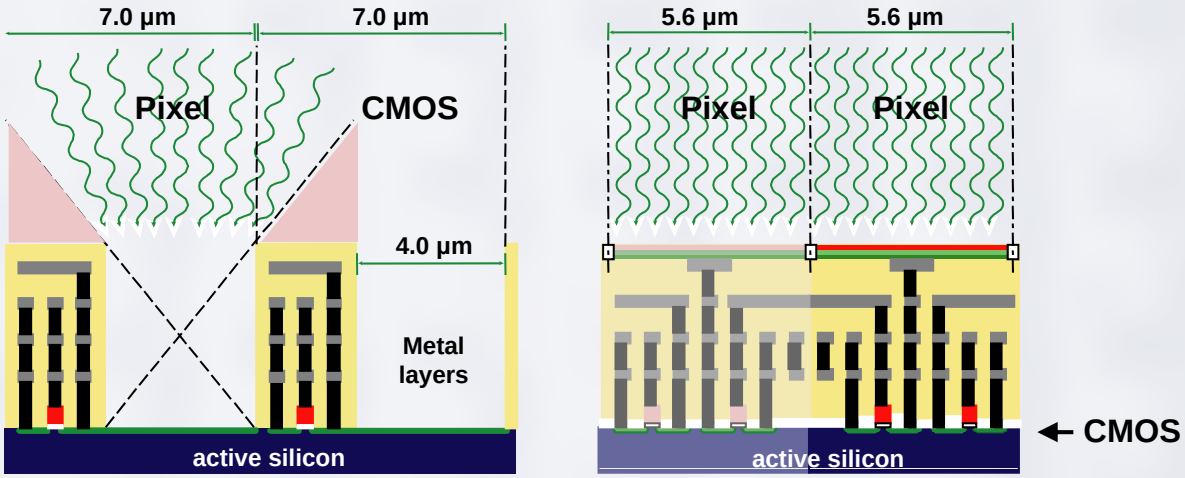




Courtesy: Jena Optronik

Star Sensor (II)

Conventional vs. Thin-Film-on-CMOS (TFC)

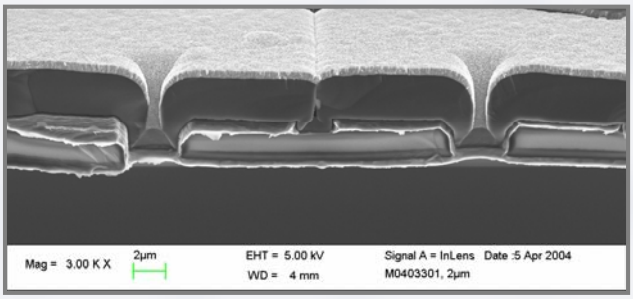


- ✓ Standard CMOS
- ✓ 30% fill factor
- ✓ Diode area16 µm²

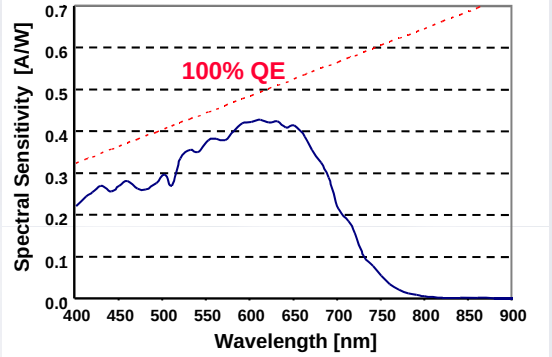
- ✓ Thin-Film-on-CMOS (α - Si:H)
- ✓ 90% fill factor
- ✓ Diode area 30 µm²
- ✓ Diode properties adjustable (C, Ge)

Star Sensor (III)

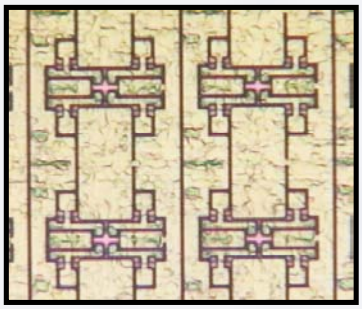
2-µm TFC Diodes over CMOS



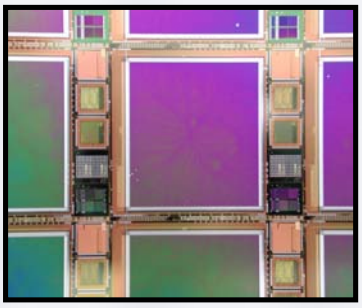
Spectral Sensitivity Relative to Image Area



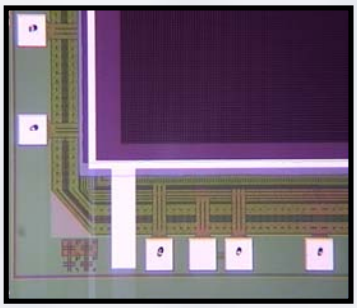
CMOS prior to TFC deposition



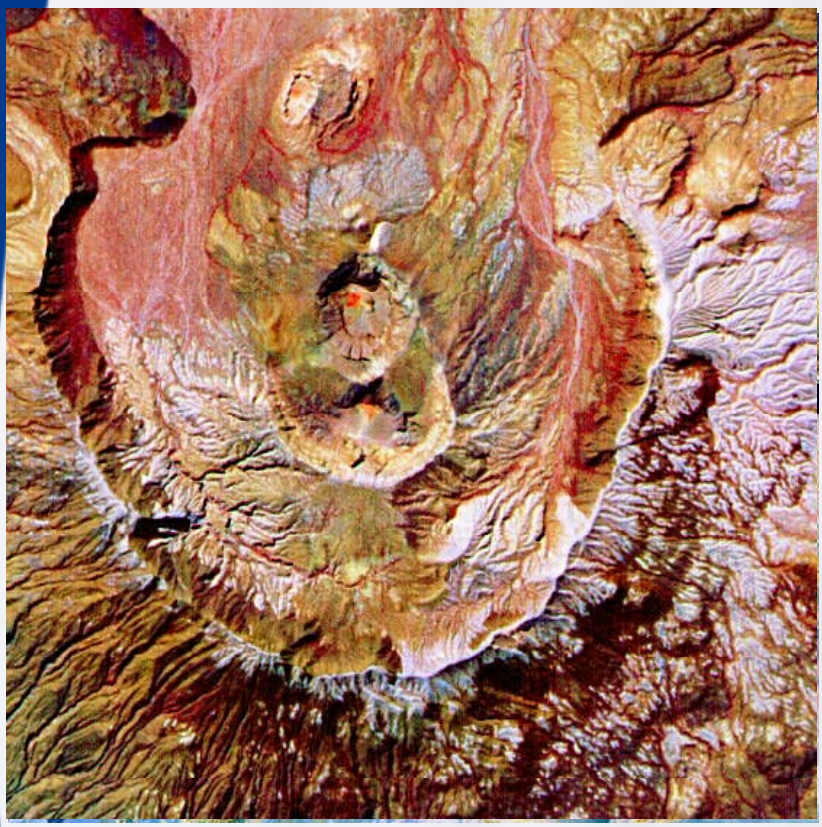
CMOS with TFC film



Final sensor with ZnO top contact



10,000 Pixel Line Scan Imager (I)



Vulcano in Ethyopia

10,000 Pixel Line Scan Imager (II)

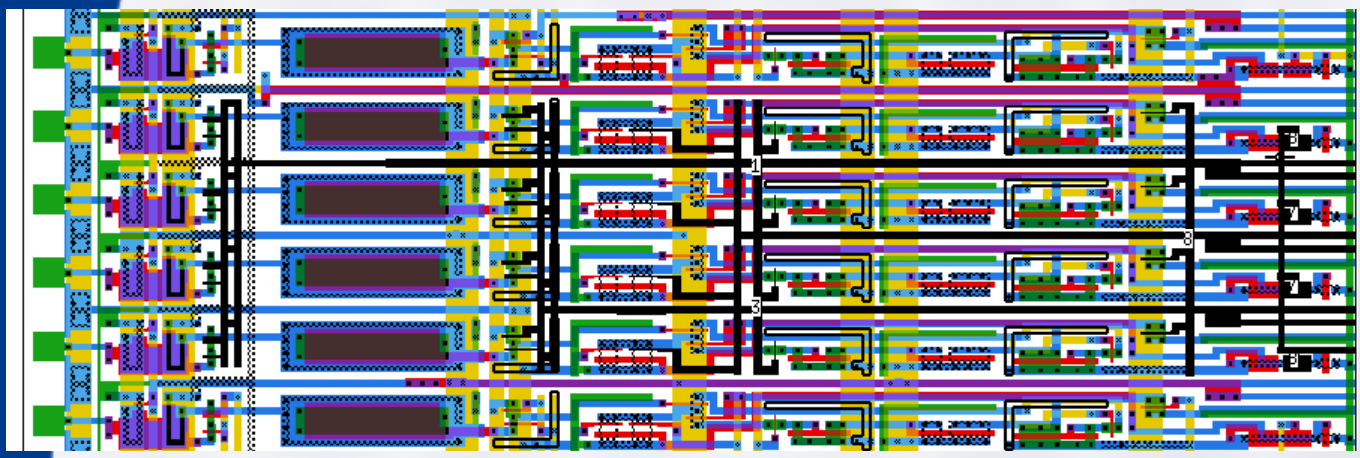
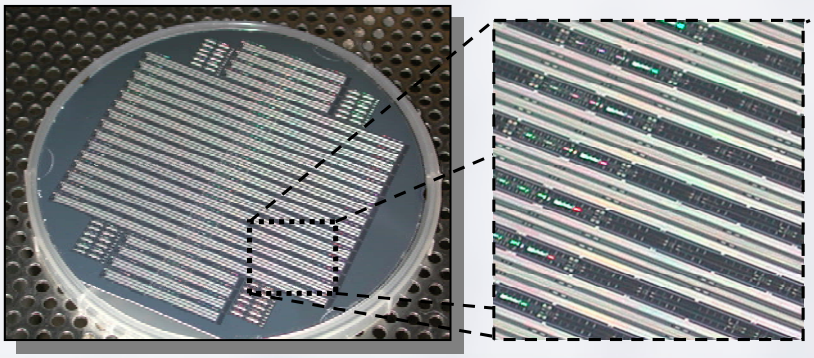
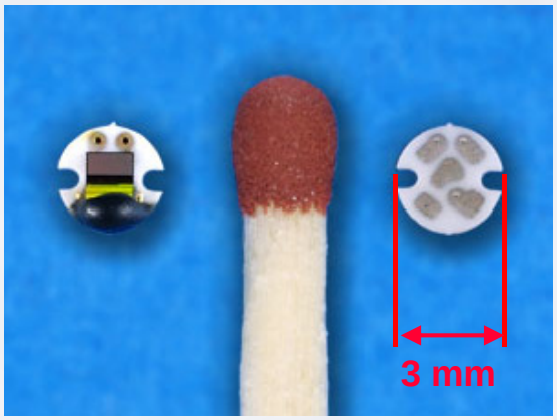
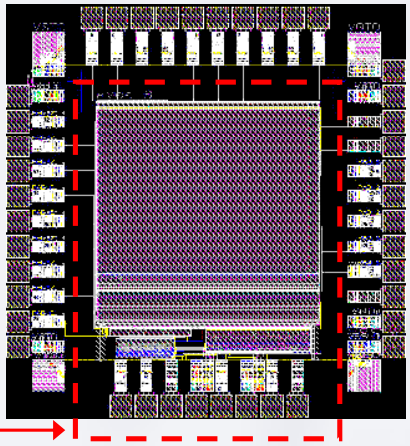


Photo diodes *Integrators* *CDS* *Analog Buffers*



Video Mini-Endoscope





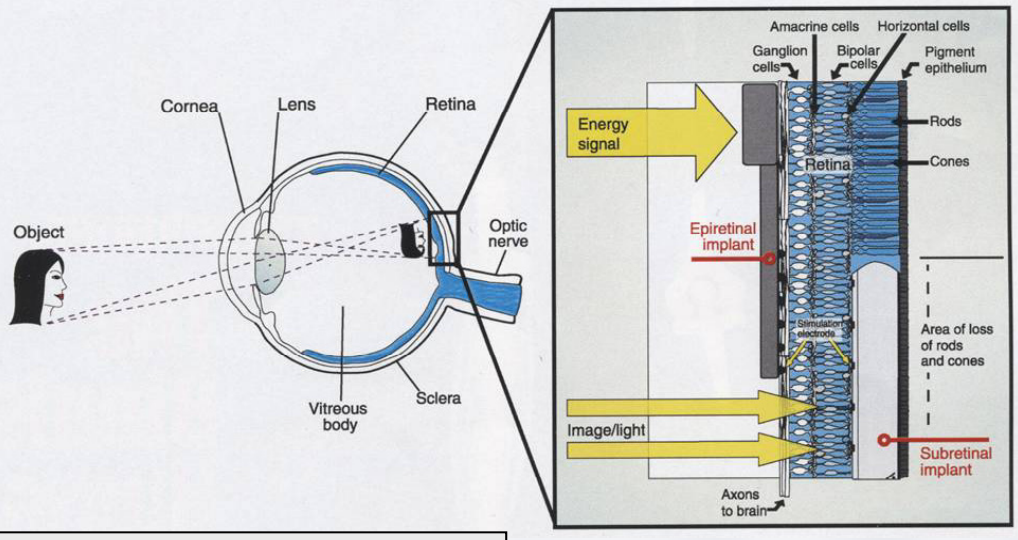
Cut after testing

Challenges

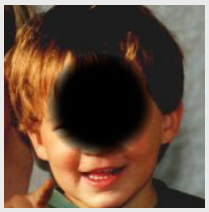
- Dark/bright lighting extremes
- Miniature size

Imager Field	200 x 180 Pixel
Pixel Pitch	4.6 µm
Chip Size	1.7 x 1.3 mm²

Sub-Retinal Implant (I)



- Makula degeneration
- Retinitis Pigmentosa

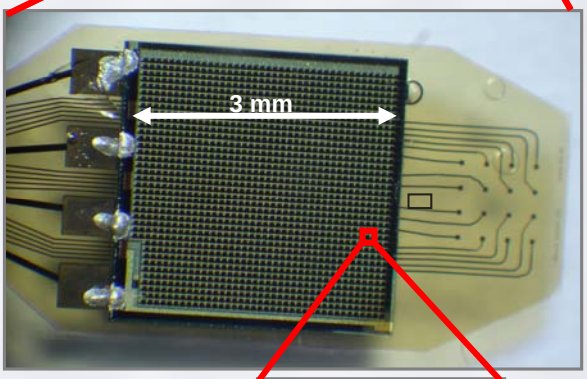



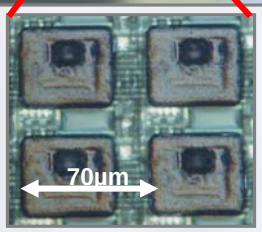

Challenges:

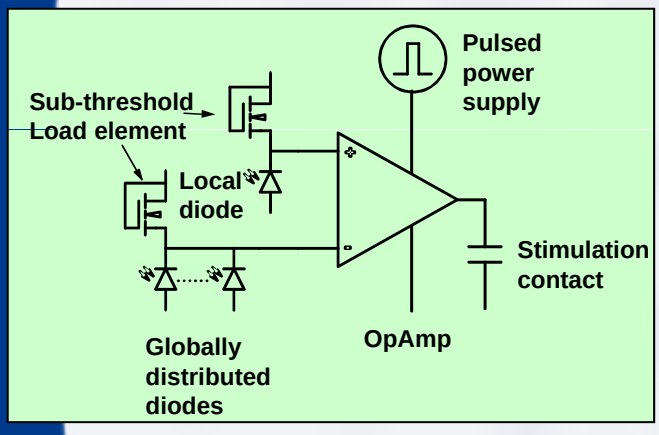
- Long-term reliability
- Bio-compatibility

Sub-Retinal Implant (II)

- Frontside pixel + electrode
- Brightness adjustment
- Low power dissipation







Conclusions

- CCD vs. CMOS competition will continue
- CMOS imagers lead whereever functionality is needed
- HDRC® offers
  - Superior edge detection capability
  - Balance memory for convenient parameter adjustment
- Designated application of HDRC®
  - Imaging at dark, very bright and changing illumination
  - Combined dark/bright scenes
  - Maschine optical detection
- Fully developed HDRC® sensor and camera technology
- New applications of HDRC® will emerge