Image acquisition in broadcast: will CMOS and CCD imager coexist?

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R&D Camera's

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My World

In cooperation with DALSA we added functionality to the CCD-imager, that was not found in imagers of the competition. It gave a competitive edge

Recently we developed our own CMOS imager

Topics/Agenda

- Technical requirements for broadcast camera’s
- CCD imagers
  - An example: What we do with a CCD pixel
  - Multi-format imager
- CMOS imagers
  - why did it take so long
  - a self fulfilling prophesy
  - An example: Xensium
- Conclusion

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Technical requirements for broadcast camera's

Technical requirements for broadcast camera's

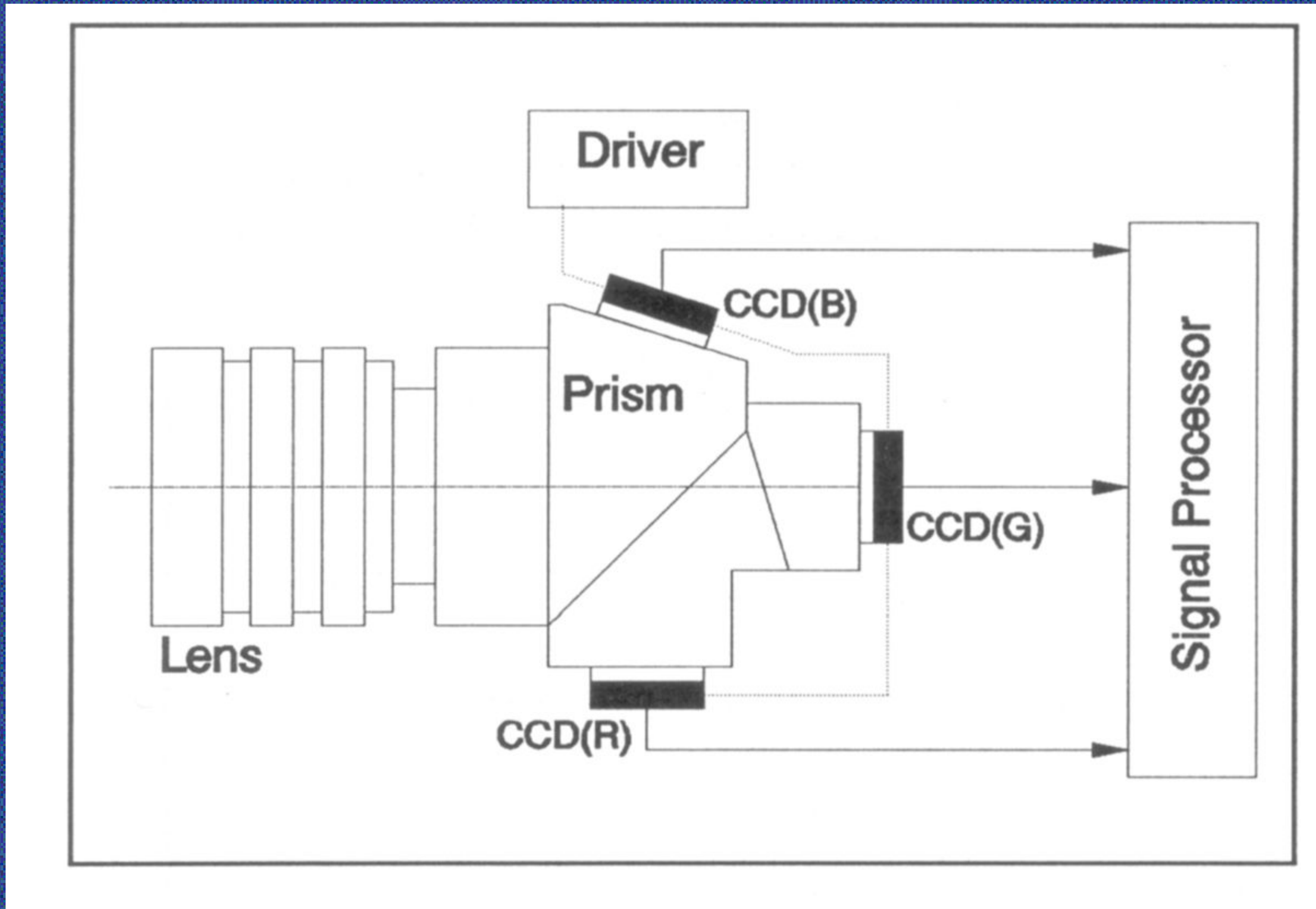
- **Broadcast is a low volume high performance market**
  - We always ride the edge of what is technical possible because we must.......
  - Love/hate relation ship
- **Special challenges in (HDTV) broadcast applications**
  - 1920(H)x1080(V) :5**μ**mx5**μ**m pixels and 11.0mm image diagonal
  - Multimode :Interlaced (eg. **1080i60**), progressive (**eg. 1080p30, 1080p60, 720p60**)
  - QE and Noise :2000 lux, 3200 K, 90%, f/8-f/11, SNR=54 dB in Y
  - Dark current :FPN, shot noise
  - Qmax :over exposure margin >500%
  - Lag :None
  - 'Blooming' :must handle 16-fstop overexposure
  - Pixel-to-pixel :PRNU<1%
  - column-to-column:<0.06%
  - 3-imagers synchronized for use in R,G and B simultaneously
  - And many other imaging related topics both optical and electrical

Technical requirements for broadcast camera’s

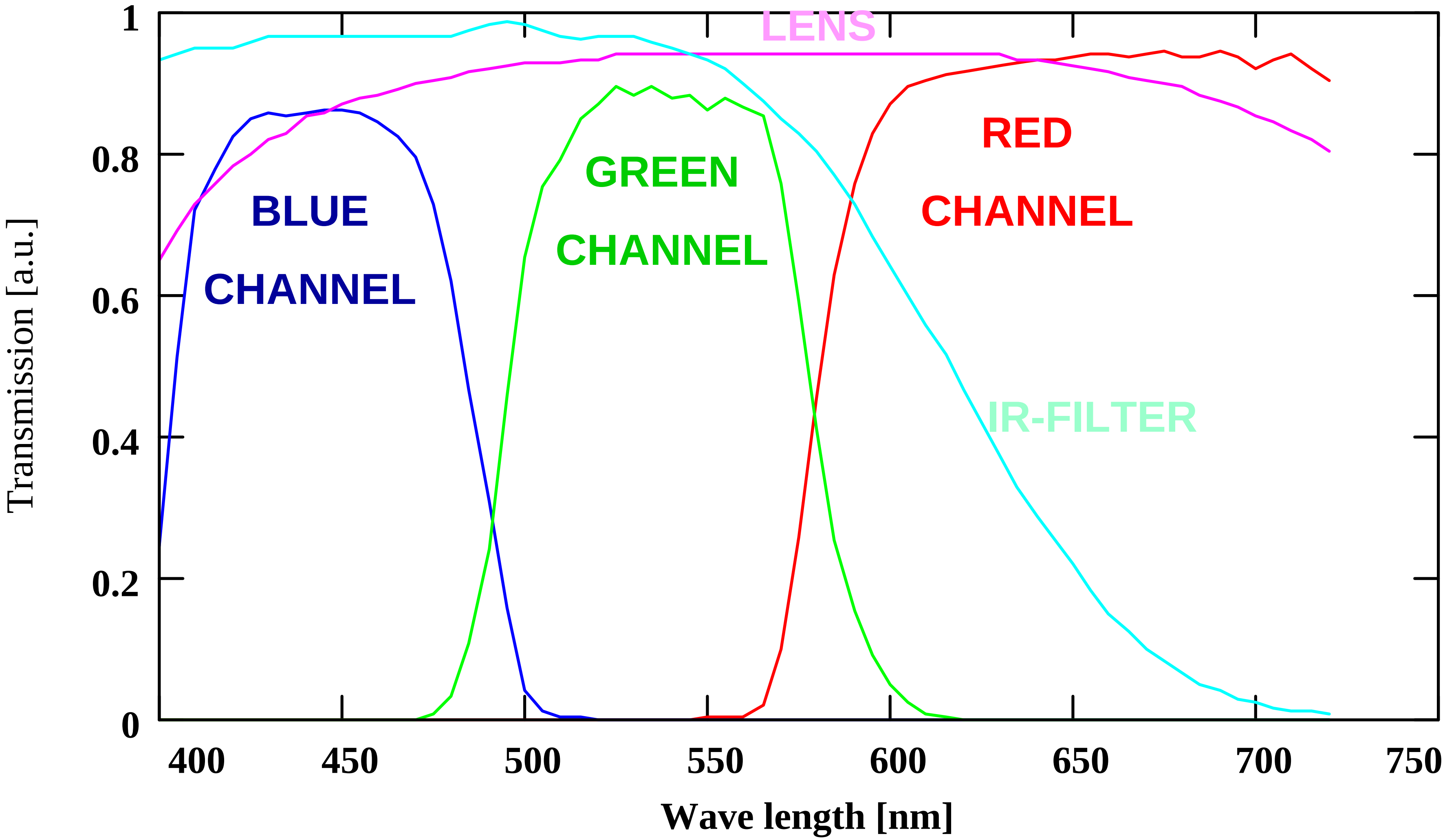
WHAT DOES THAT MEAN

2000 lux, f/11, 90%, 3200K
and
54dB in Y
and
16-Fstop oversexposure

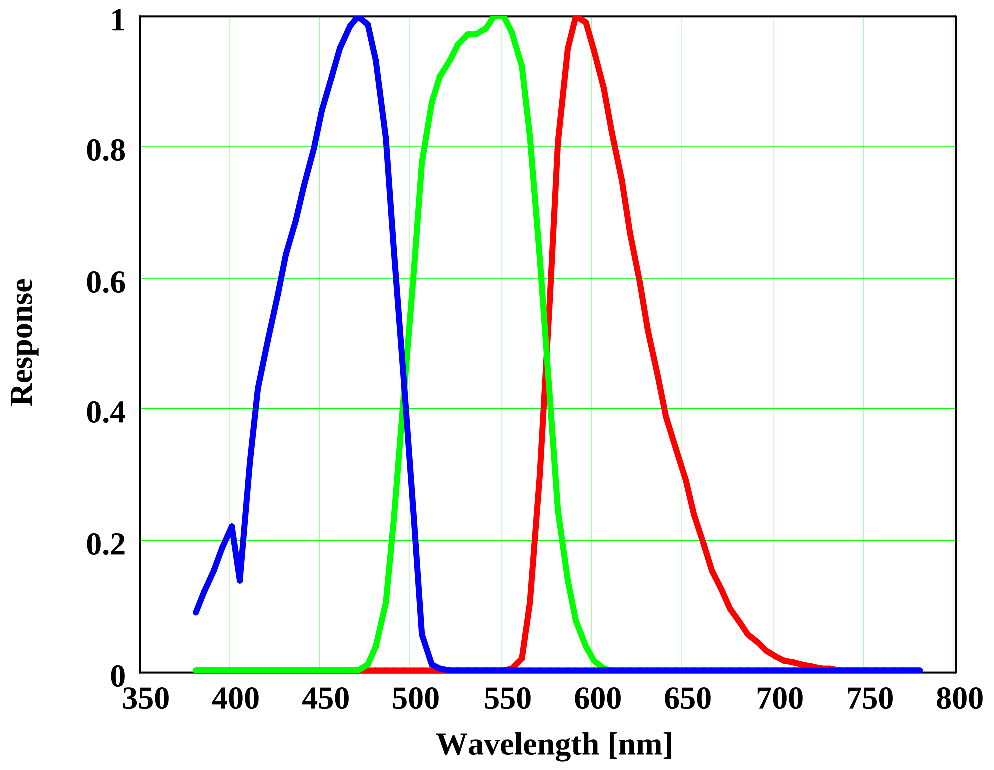
3 Imager Optical Block



Optical elements



Imager RGB-output



SEN

Technical requirements for broadcast camera's

- **Photon flux in a broadcast camera at 2000lux; f/11; 3200K and 89.9% scene reflection**
  - R 8.5k photons/um^2/sec
  - G 7.5k photons/um^2/sec
  - B 2.5k photons/um^2/sec
- Pixel is **5x5um^2** and **30 frames/sec** ; Photons per pixel
  - R 7.0kph
  - G 6.2kph
  - B 2.0kph
  - Assume overall **QEeff=60%** (QE x Aperture x(1-reflection) x ulens) then
    - ✓ Charge packet in Green **NG=3k7e** and for SNY=54 dB noiselevel must be **Nrms<=10e**
  - **FPN<=2e at 35C**
- **Qmax=20kel/pixel** (for at least 5x overexposure)

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Technical requirements for broadcast camera's

- **Camera at +0dB +12dB**

	+0dB	+12dB
R	4200e	1050e
G	3700e	925e
B	1200e	300e

- **But at bright daylight the pixel must also handle a photonflux of about 8x10^8 photons/um^2/sec (10^5 more than nominal)**
  - Assume scene with a welder in a studio or the sun in the image
    - ✓ bright sun 50.000-100.000 lux
    - ✓ cloud bright 10.000-25.000 lux
    - ✓ studio 2000 lux
    - ✓ good street lighting 10-20 lux
    - ✓ At +12dB the camera produces an image with 16 lux
    - ✓ sunset 1-100 lux
    - ✓ full moon 0.01-0.1 lux

A Multi-format HDTV CCD

The importance of 4320 photo-sensitive elements per column

Or:

What we do with a CCD-pixel

Multi-Format Imager

Scanning Format	Prime decomposition	Log-prime notation
1080P	$2^3.3^3.5$	[3,3,1,0,0,0]LP6
1080I	$2^2.3^3.5$	[2,3,1,0,0,0]LP6
720P	$2^4.3^2.5$	[4,2,1,0,0,0]LP6
480P	$2^5.3.5$	[5,1,1,0,0,0]LP6
480I	$2^4.3.5$	[4,1,1,0,0,0]LP6

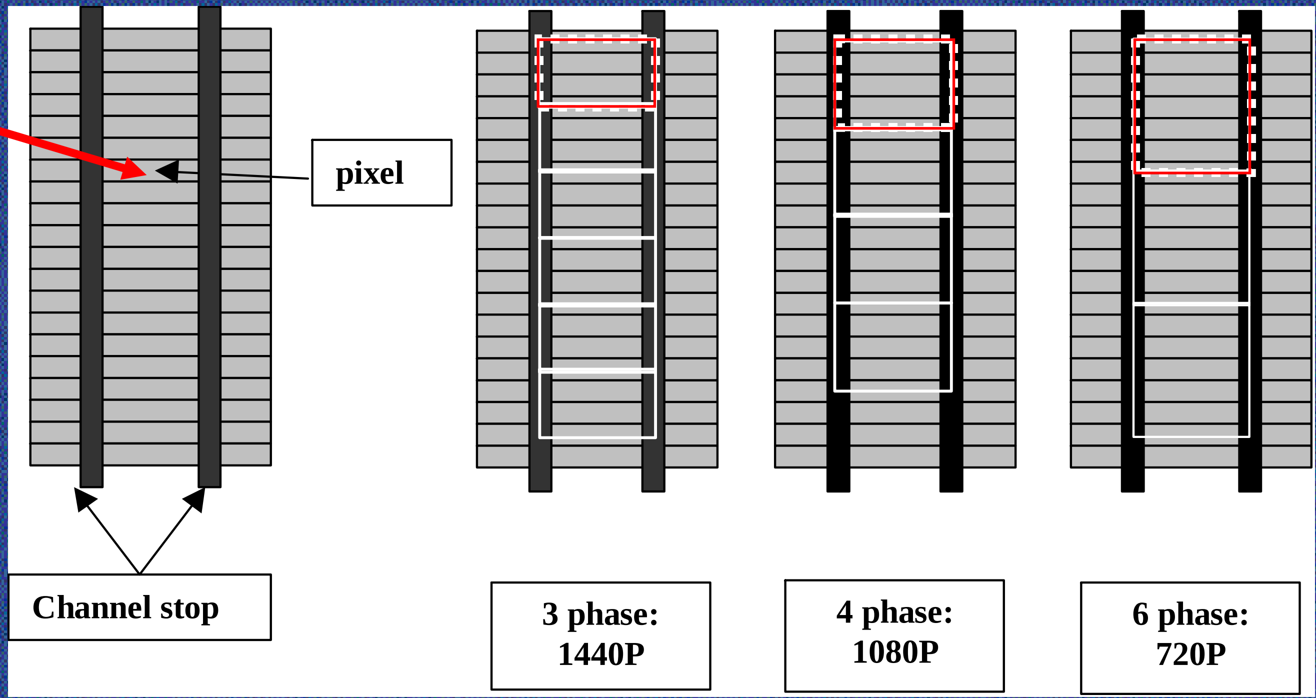
Least Common Multiple : 2^5*3^3*5 = 4320

Multi-Format Imager

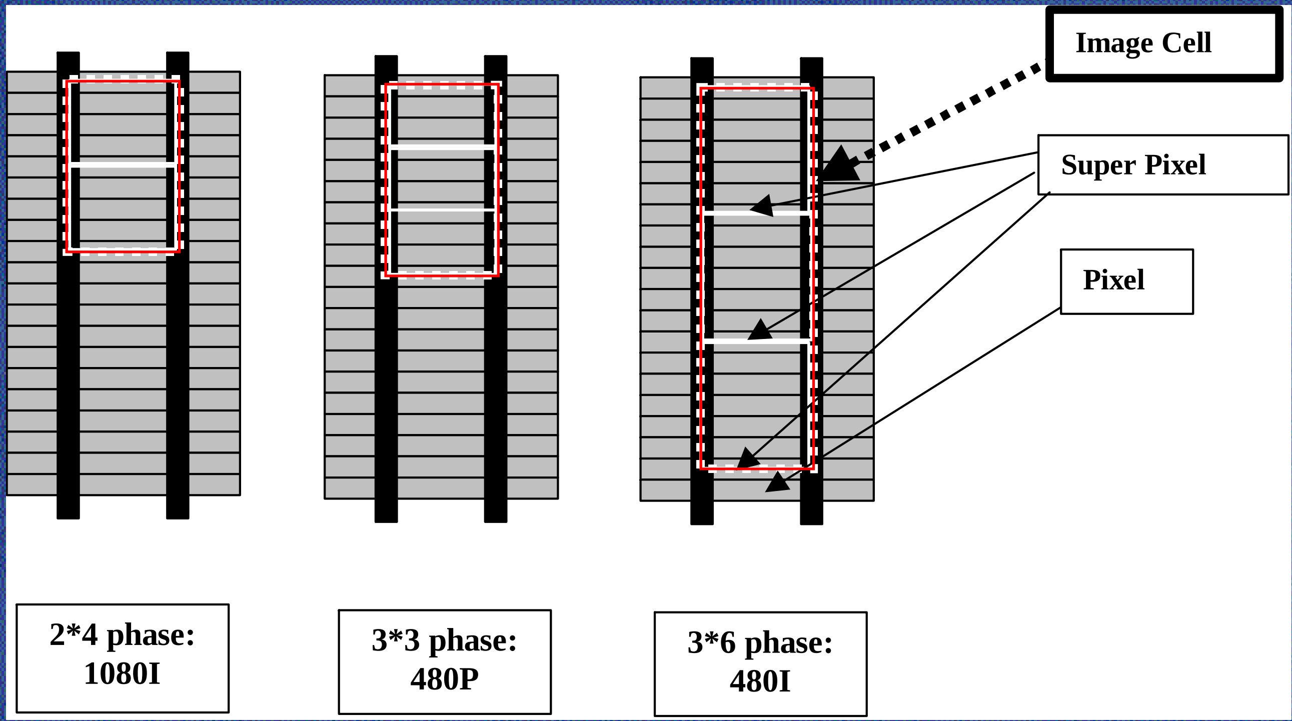
- 1920 (H) x 4320 (V)
- Binning light sensitive elements enables the many scanning formats
  - 4320 = 1080 x 4 => 1080p
  - 4320 = 720 x 6 => 720p
  - 4320 = 540 x 8 => 1080i
  - 4320 = 480 x 9 => 480p
  - 4320 = 240 x 18 => 480i
- Minimal number of interconnections
  - 8 = 2 x 4 , 9 = 3 x 3, 18 = 3 x 6
  - with 12 interconnections, or a 12-phase driving system,

12 = 3 x 4 = 4 x 3 = 2 x 6 one can do it all

Multi-Format Imager

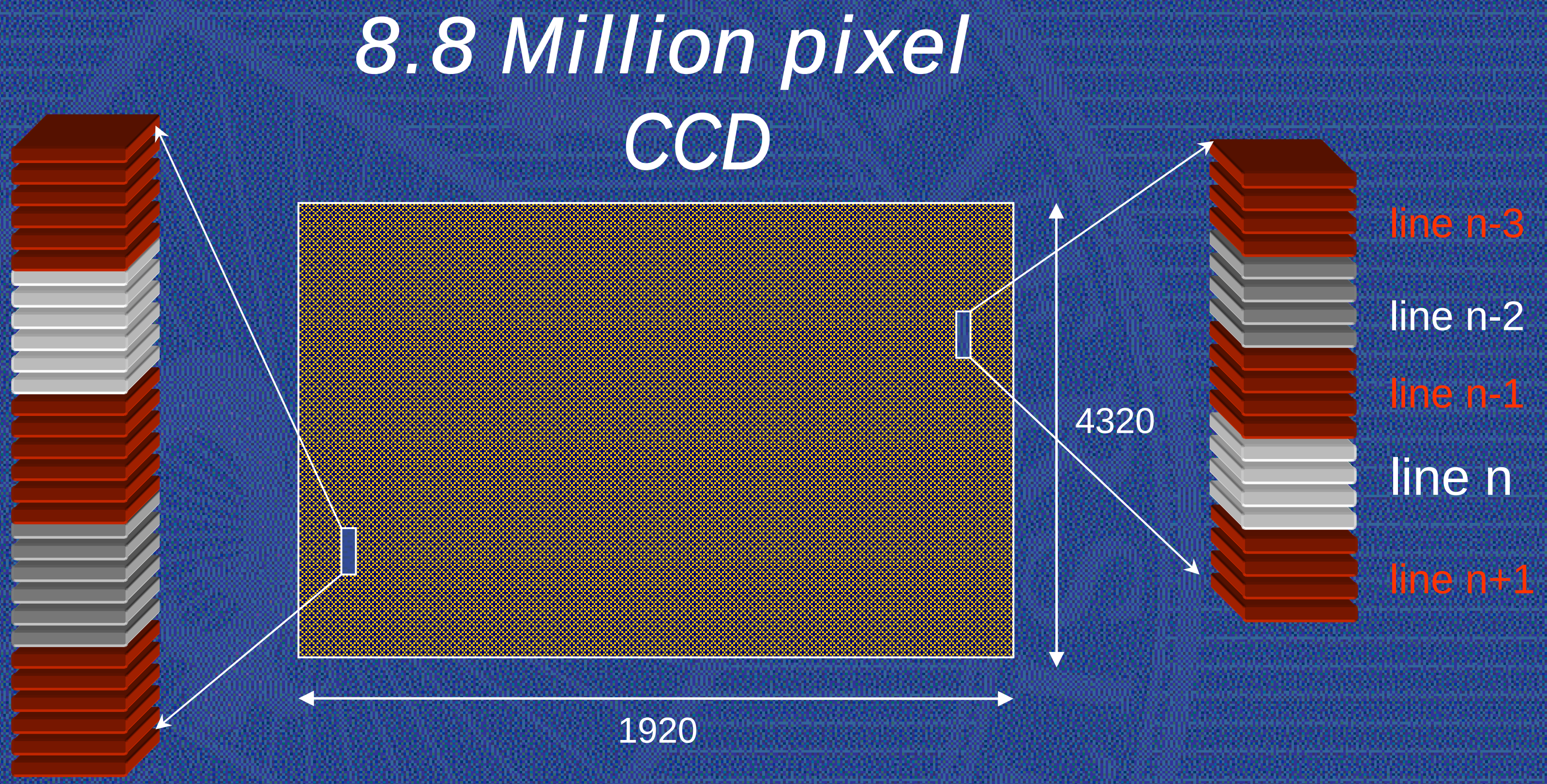


Multi-Format Imager



Pixel : one light sensitive element
Super Pixel : addition of pixels
Image Cell : equals one scanning line

Multi-Format Imager

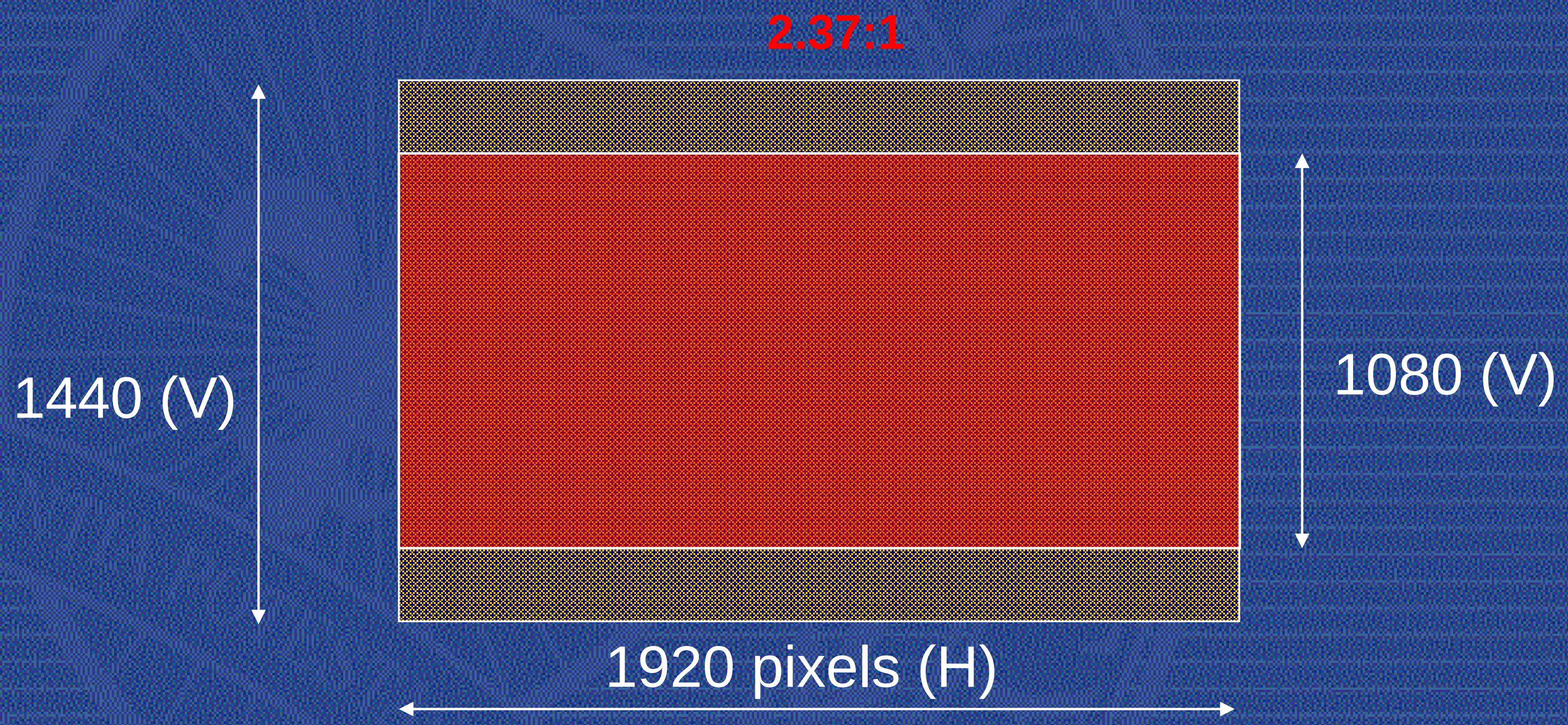


Combining vertical pixels for 720 lines

Combining vertical pixels for 1080 lines

Multi-Format Imager

1920x1080 with 2.37:1 aspect ratio for Digital Cinematography



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Teaser 1: Linguistics

- Panavison has GENESIS
- Dalsa has ORIGIN
- We have VI

Having some beer

- GENESIS . .   In the beginning there was LIGHT
- ORIGIN . . . . Then there was a Camera
- VIPER . . . .Along came that serpent that changed the world

HD-DPM Imager

The CCD imager is here

but is he here to stay?

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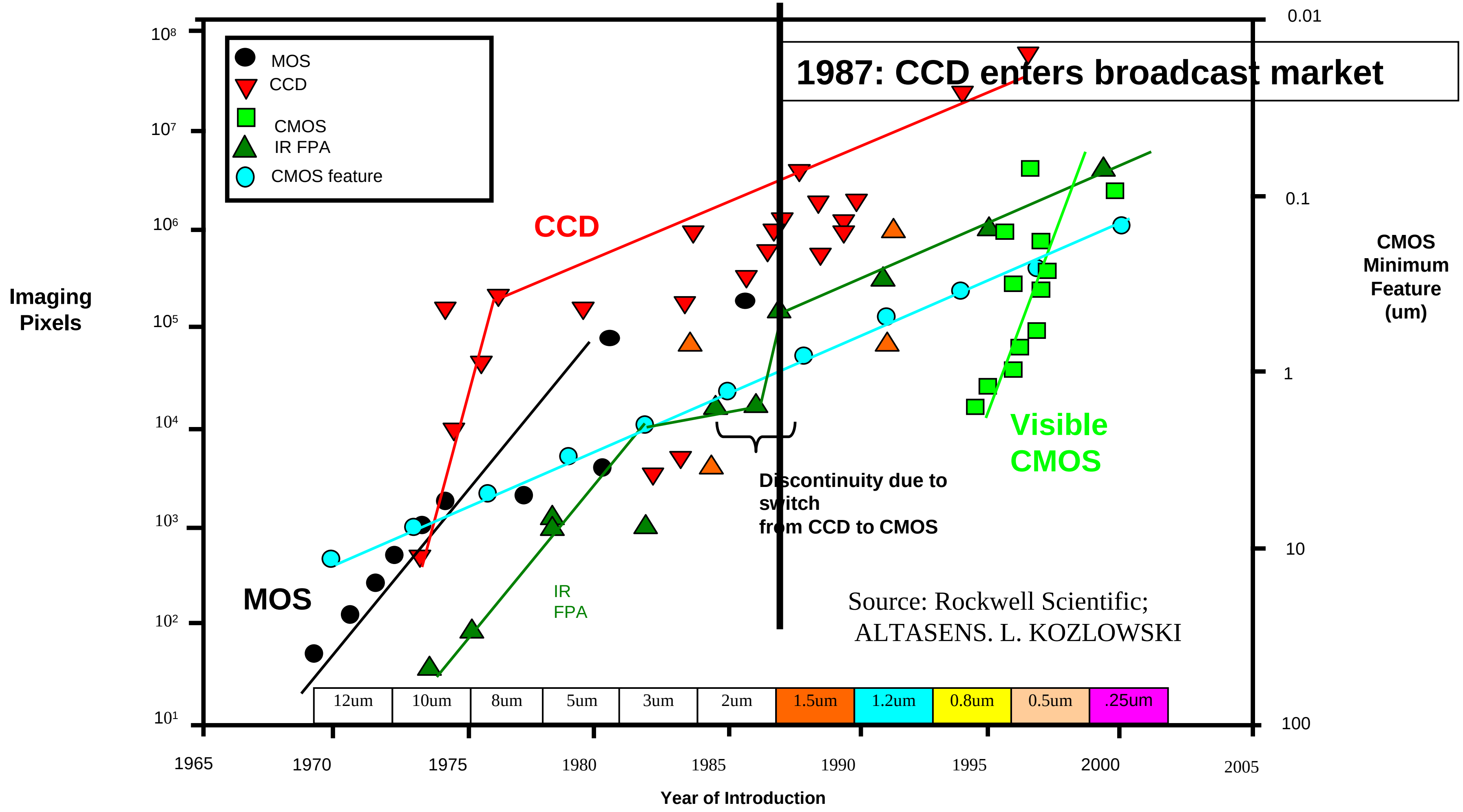
CMOS imagers

Why did it take so long?

Feature Size and CMOS Imagers



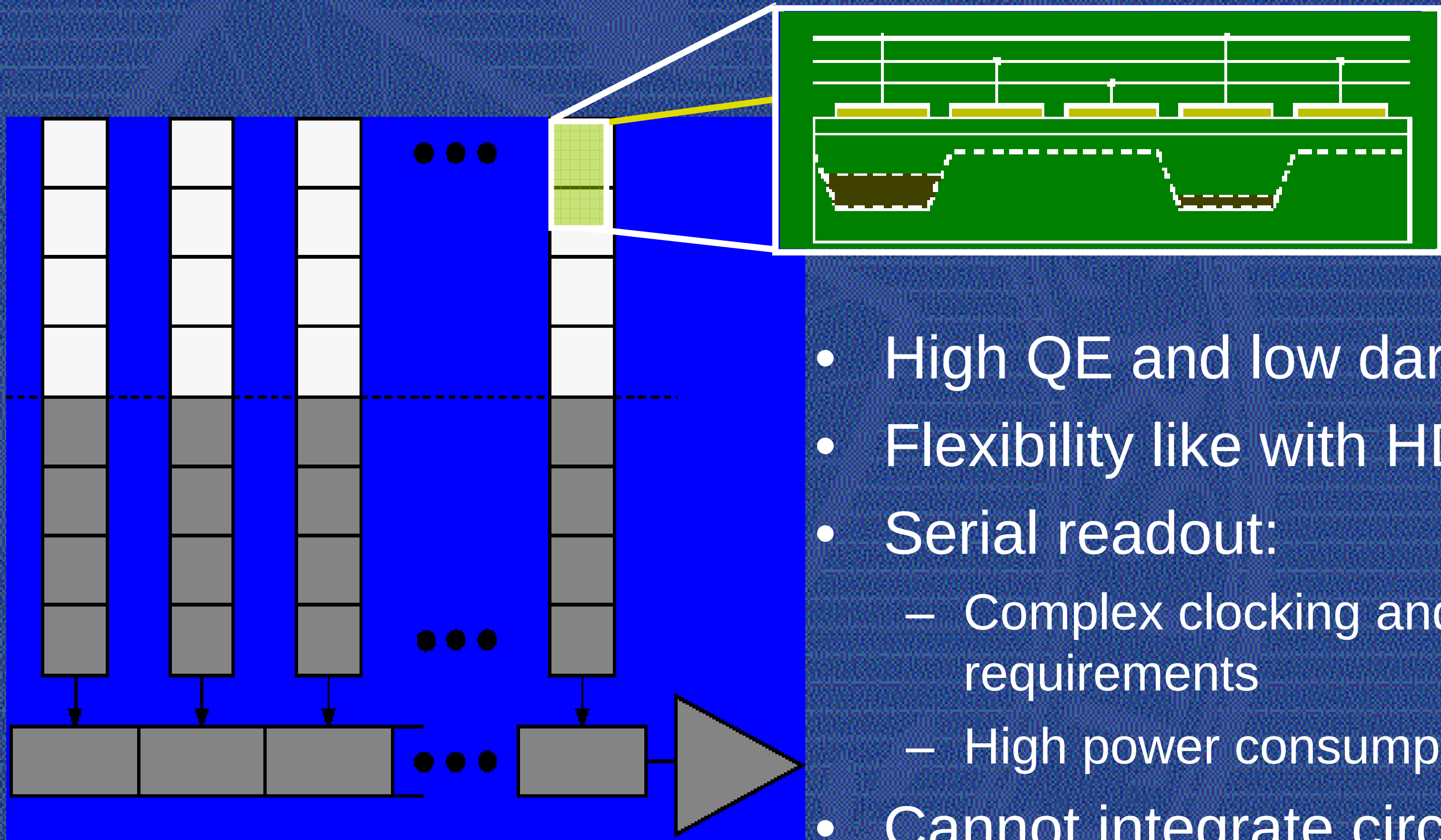
Notice the early ramp up of CCD imagers (1973) and the delayed ramp up of CMOS imagers (1970 /1995)

Feature Size and CMOS Imagers

- MOS 1967 Wecker&Noble
- CCD 1970 Boyle&Smith

- Why did it take so long for CMOS imagers to enter the market, even though they where conceived before the CCD imagers?
  - The word is **Lithographic Feature Size**
  - In general a CCD-pixel is simpler than a CMOS-pixel, the latter contains more active elements

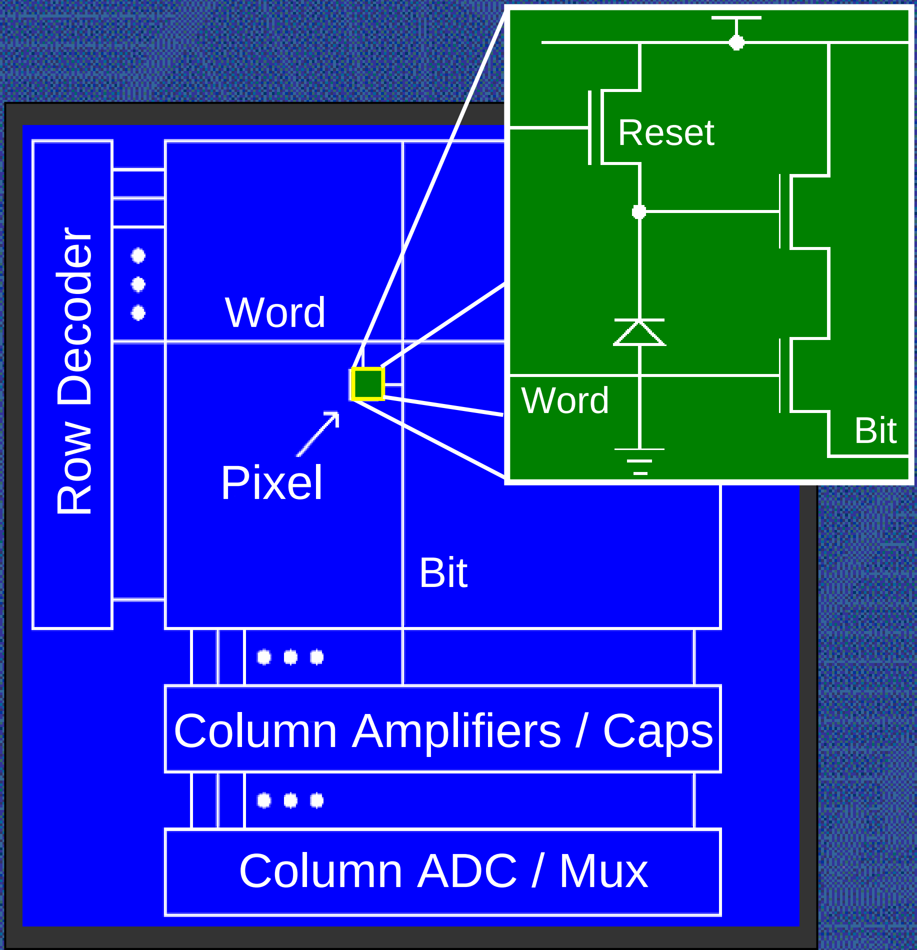
Feature Size and CMOS Imagers



- High QE and low dark current
- Flexibility like with HD-DPM
- Serial readout:
  - Complex clocking and supply requirements
  - High power consumption
- Cannot integrate circuitry on chip

IEDM 2002 Gamal

Feature Size and CMOS Imagers



IEDM 2002 Gamal

- Memory-like readout:
  - Enables high speed operation
  - Low power consumption
  - Region of interest
- Integration

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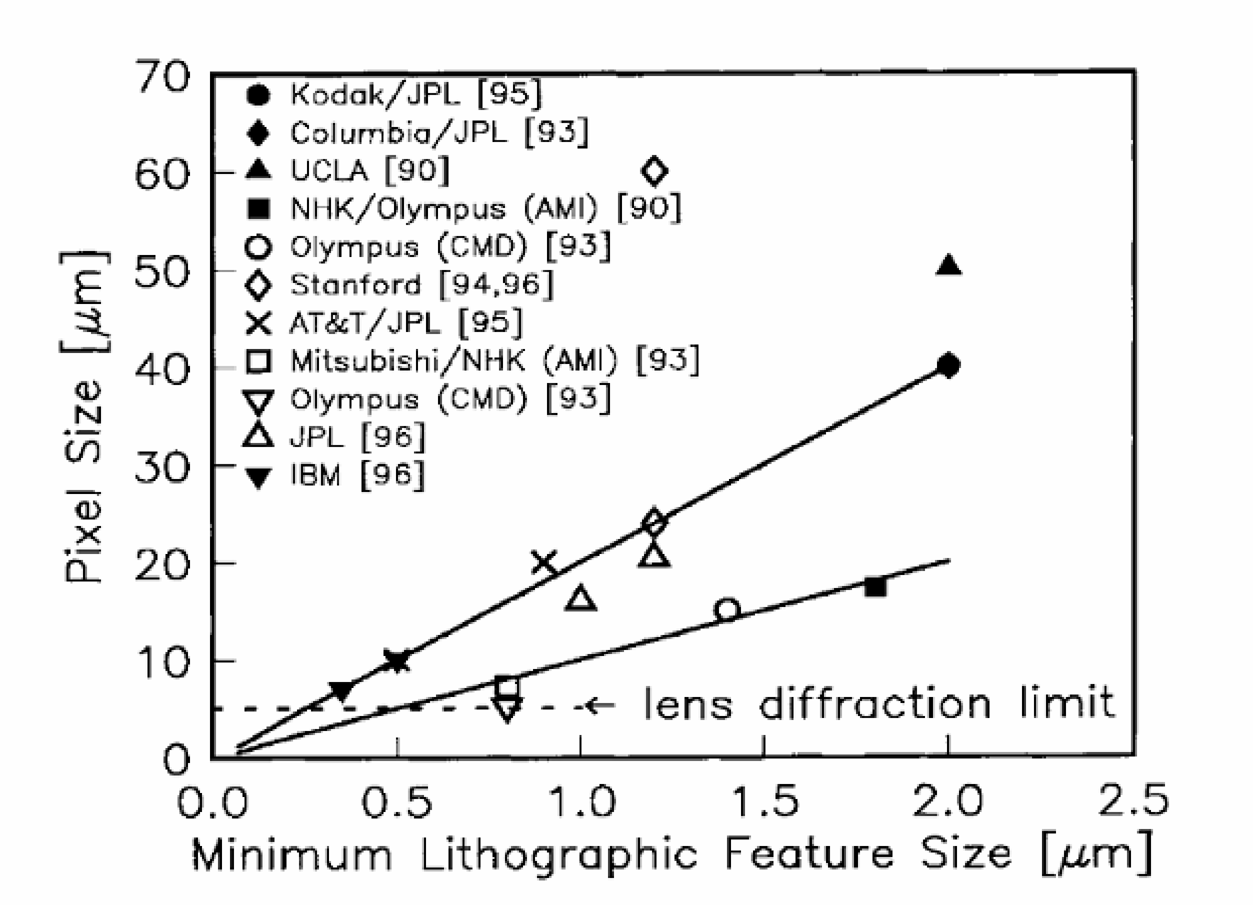
Feature Size and CMOS Imagers

Pixel size is about Feature_Size*20.................still valid



IEEE ED Vol 43, DEC 1996, Hon-Sum Wong

Feature Size and CMOS Imagers

- The average pixel size in a SDTV (PAL, NTSC) imager
  - **10um** ; 7.5um; 5um
- The average pixel size in HDTV
  - 720p: 7.5um; 5.0um; 4.0um
  - **1080P: 5um**; 3.6um; 2.7um
- ***2/3-inch; ½-inch; 1/3-inch***

- Using the safe rule of thumb between Feature Size and Minimum Pixel dimension of a factor 20 (Wong)
  - One needs a **litho of <0.5um** for **SDTV** imagers
  - And <0.25um for **HDTV** Imagers

- **CMOS imagers to become feasible in Broadcast**

CCD and CMOS Imagers

- Both have
  - PIXELs where photons are converted into electron-hole pairs (*usually only electrons are used and the holes are drained to substrate)*
    - ✓ In CMOS the charge is converted in a VOLTAGE in the pixel
    - ✓ In a CCD the charge stays in the CHARGE domain until it reaches the single output where it is converted in a voltage
  - an analog or a digital output
- Addition of pixel information
  - for CCDs in the CHARGE domain=>SNR≈ #
  - for CMOS in the VOLTAGE or CURRENT domain=> SNR ≈ √(#)
- Scanning
  - ✓ CCDs takes a snapshot
  - ✓ CMOS has a rolling shutter and scans like a tube camera, maybe (high performance) snapshot becomes available in the near future

CMOS Imagers:
A Self fulfilling Prophesy

CMOS Imagers: A Self fulfilling Prophesy

- **PERCEPTION**
  - CMOS imagers are cheap and have low quality
  - Is the perception correct
    - ✓ Yes............but not complete
- The sentence could also read
  - CMOS imagers are expensive and have high quality
- Basically when you don't apply all the skills and technology available then CMOS is kept cheap and at low quality
  - it is a mass market problem

CMOS Imagers: A Self fulfilling Prophesy

- Parameters that matter
  - Temporal **Noise** or readnoise
  - **Sensitivity** (QE and Fillfactor)
    - ✓ Together with readnoise it defines SNR
  - **Overexposure** margin (Qmax, Vsat)
    - ✓ Together with the readnoise it defines dynamic range
  - **Darkcurrent** or leakage current per pixel
  - **Fixed Pattern Noise in dark** or offset differences per pixel
  - **Fixed Pattern Noise in exposed images** or gain differences per pixel

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A Self fulfilling Prophesy

- CCDs have a long history and as such solved many of the performance related parameters
  - **Sensitivity**
    - ✓ uLens
  - **Noise**
    - ✓ real CDS
  - **Darkcurrent, FPN and LAG**
    - ✓ P+toplayer
  - THESE solutions can be applied too in CMOS imagers but that needs additional masks and technology steps and hence is more **expensive**

The design of Xensium

A CMOS imager for broadcast applications

Acknowledgement

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  R&D Image Capture Solutions

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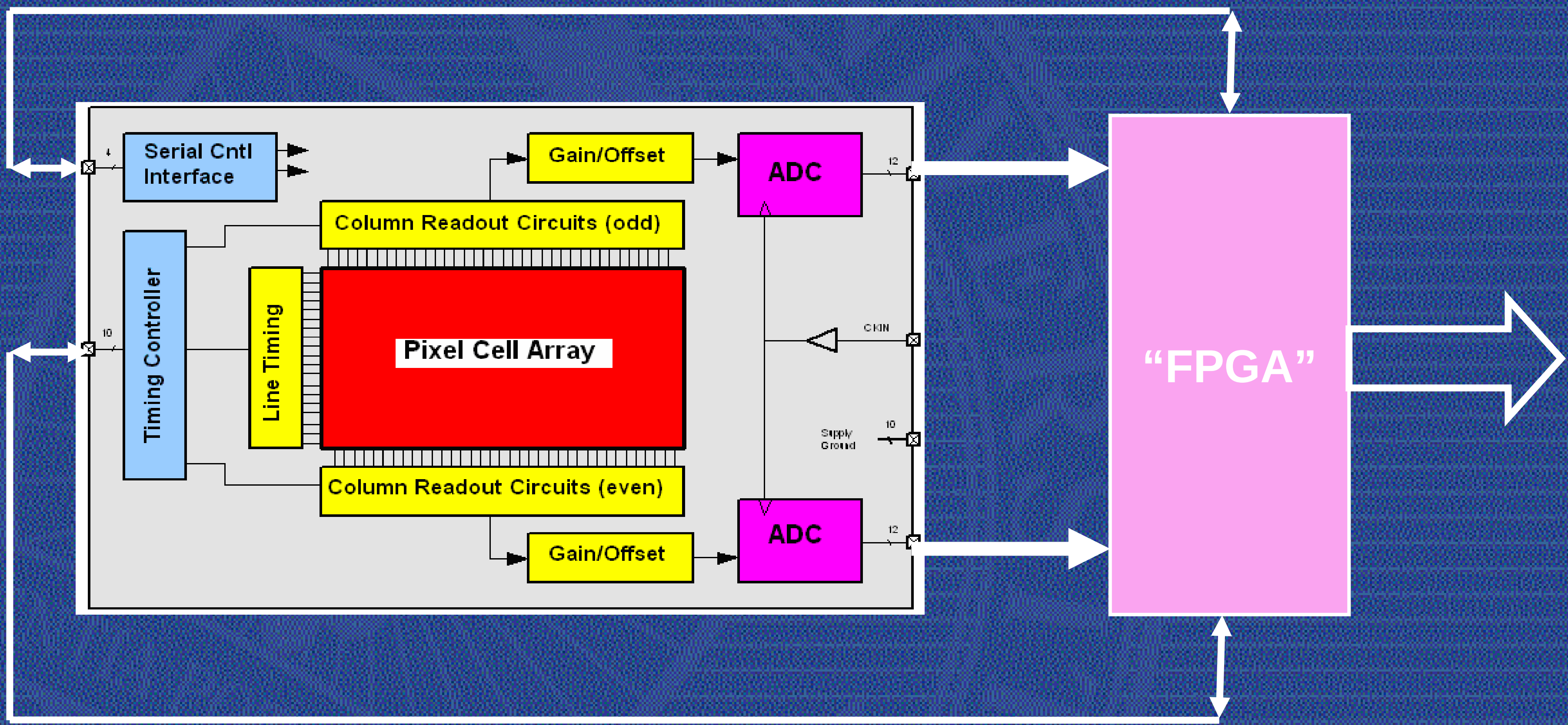
  C. Thébault, W. Endress, R. Zwing

Design Approach

- **An imager is an ANALOG device**
  - Keep the imager as simple as possible and make use of of-the-shelf components like FPGA, memory, processing blocks
  - Allow for a simple state machine and ADC's on-chip
  - Flexibility in readout and in frame rate
  - Choose a camera architecture: video processing and imager, that eases CMOS image sensor design
  - Use a 3T-pixel in 0.18μm process
    - ✓ do real CDS off-chip
    - ✓ use hard reset, no soft reset because of inherent lag problems
    - many other advantages

Chip Block Diagram



Black Reference Pixels

-80 black reference columns

-40 black reference rows

Active Pixels

-1978 active columns (1920)

-1108 active rows (1080)

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Flexible Scanning

- **At 2/3 inch image diagonal**
  - 1920(H) x 1080p(V)
  - 1920(H) x 1080i(V) with Frame or Field mode
  - 1920(H) x 540p(V) with 1080p or 540p aperture
- **At different image diagonals (ROI)**
  - 1280(H) x 1440i(V)
  - 1280(H) x 720p(V)
  - 1724(H) x 485p(V)
  - 1724(H) x 485i(V)
- **Raw frame rates for the 3 main modes**
  - 1080p90 or 1080i180 or 720p180 (=>1080p120)
  - Maximum clock frequency ADCs: 2x112 MHz
    - ✓ (=>demonstrated 2x148 MHz)

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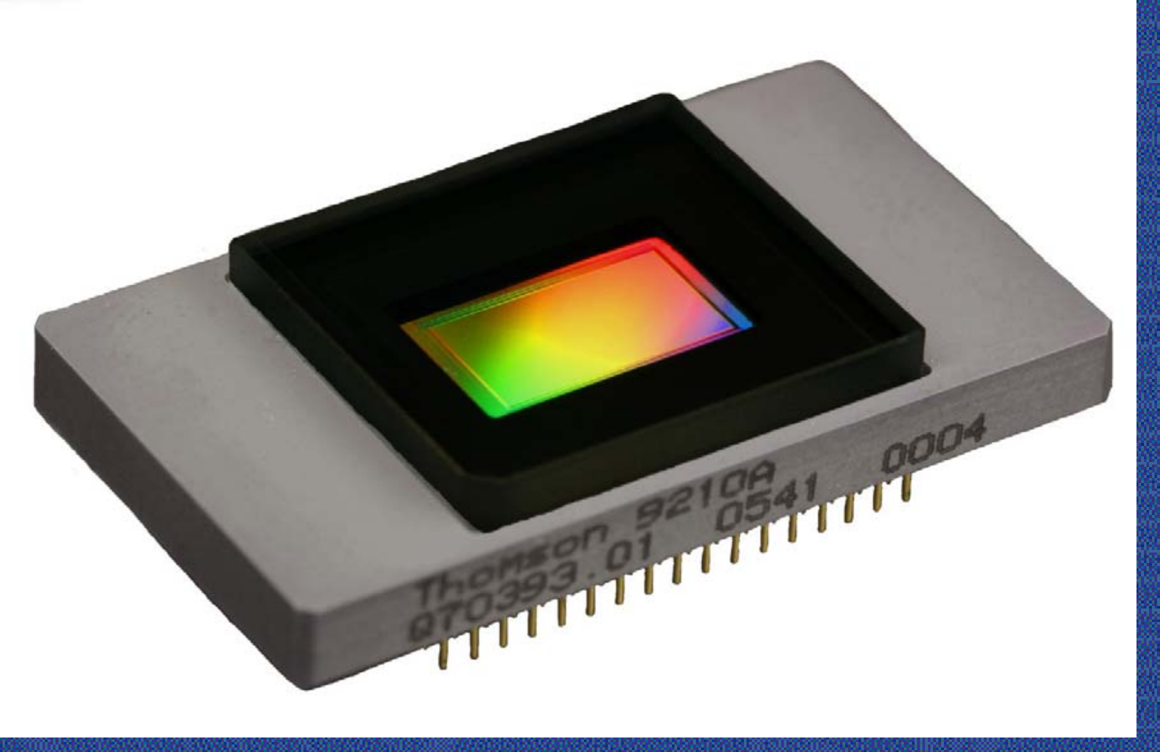
Flexible Scanning

Mode	f-number@54dB; 2000lux; 3200K; 90%
1080p30	f/11
1080p60	f/8
1080i60 Field mode	f/8-f/10
1080i60 Frame mode	f/11
720p60	f/8-f/10

Table of characteristics

Pixel size, transistor count	5µm x 5µm; 3T
Number of pixels including opt. black	2048(H) x 1148(V)
Pixel fill factor (without micro-lens)	56%
Analog to digital conversion	2 ADCs of 12bit
Scanning rate demonstrated (2x148MHz)	1080i240 or 1080p120
Conversion gain FD	80µV/e^-
Idark @ 60ºC	0.4nA/cm^2
Temporal noise, pixel only, 27ºC	4e^-
Temporal noise, all contributors, 27ºC	11.5e^-
Sensitivity in green (color splitter)	32ke^-/lux-sec
Maximum reachable dynamic range	116dB in interlaced mode 122dB in progressive mode
Linear saturation level	>15ke^-
Power dissipation	550mW@1080i120

The Imager



@Michael Schreiber

Will CMOS and CCD imager coexist?

Wrap-up

- CCDs started to emerge in Broadcast cameras in 1987
  - The drive was in pixel count: smaller pixels while maintaining the same or better signal-to-noise and Qmax and …..
  - They can support other applications like triple speed for sports
  - Need for moving the barriers for sensitivity and noise and bandwidth and speed and dynamic range

- CMOS emerged only recently in Broadcast cameras
  - There is a drive for smaller pixels but only for a couple of years now the CMOS feature size and related technology is such that it supports pixels for Broadcast cameras
  - Performance issues like FPN, Noise, Rolling and Global shutter (Scanning), Crosstalk are to be tackled and a lot can be learned and is learned from CCDs
  - CMOS imagers are emerging and applied in demanding markets like photography, medical, automotive, security and GSM there will be a big economic push to solve many of the technological problems.

- **Even though CMOS has potential to outperform CCDs it will be CCDs for a number of years to come…..so yes they will coexist.**