A 2/3 inch CMOS Image Sensor for HDTV Applications with Multiple High-DR Modes and Flexible Scanning

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Agenda

- Design approach
- Chip Block diagram and Architecture
- Flexible scanning
- High-DR modes
- Results
- Conclusion

Design Approach

- **Broadcast is a low volume high performance market**
  - In Q1 2005 nobody in the CMOS field was interested in a dedicated development or had a design available!
- **Special challenges for a CMOS-imager in broadcast applications**
  - 1920(H)x1080(V) :5**µ**mx5**µ**m pixels and 11mm image diagonal
  - Multimode :Interlaced (eg. 1080i60), progressive (eg. 1080p30)
  - 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 >400%
  - 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

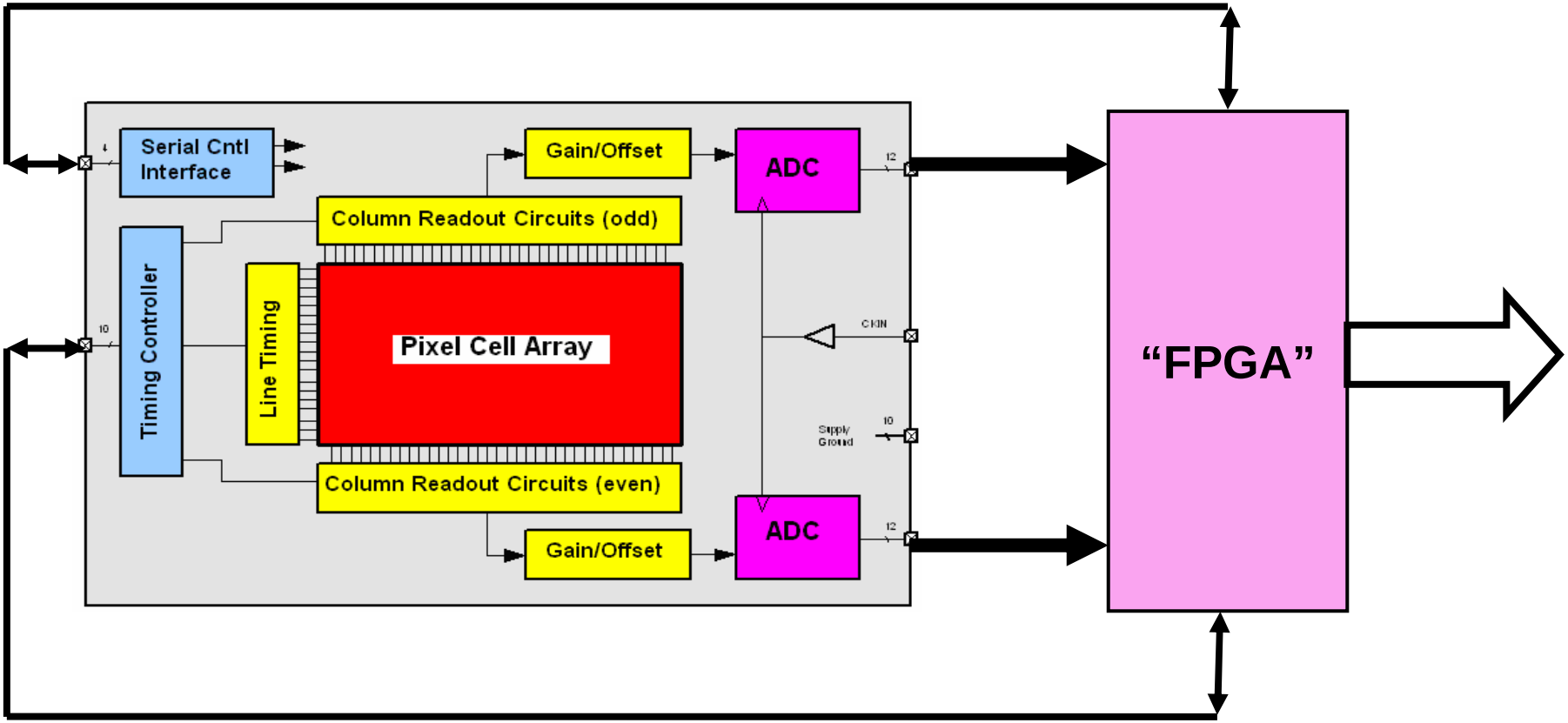
Design Approach

- **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
  - Chose a camera architecture: video processing and imager, that eases CMOS image sensor design
  - Use a 3T-pixel in 0.18**µ**m process
    - do real CDS off-chip
    - use hard reset, no soft reset because of inherent lag problems

    ➢the same performance as a 4T-pixel

    ➢many other advantages

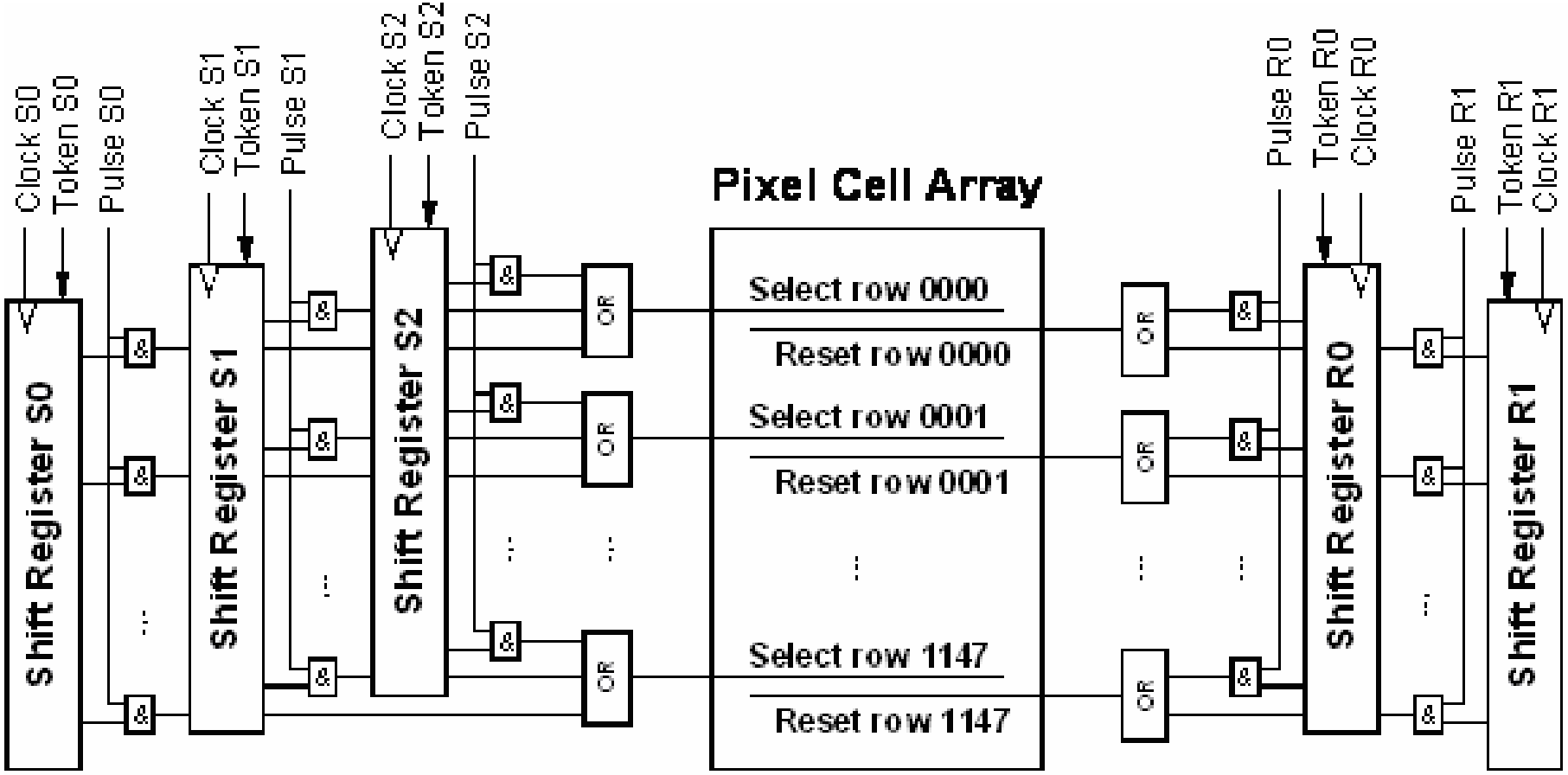
Chip Block Diagram



Black Reference Pixels	Active Pixels
-80 black reference columns	-1978 active columns (1920)
-40 black reference rows	-1108 active rows (1080)

Shift Registers

Multiple select and reset shift registers for flexible scanning



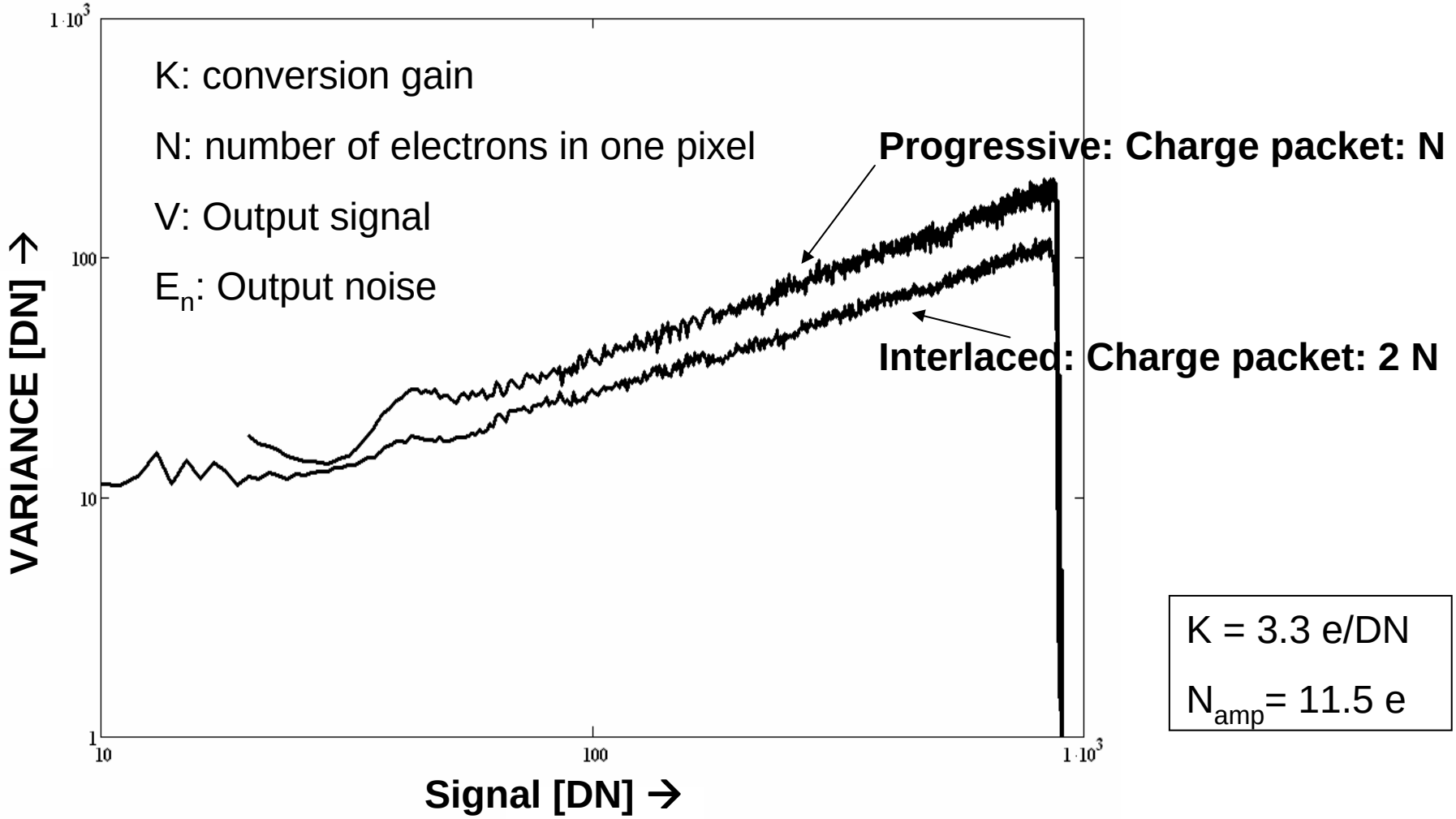
Flexible Scanning

- *Load the shift register with a proper "000XX00" pattern and define the ROI*
- 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 (=> 2x148 MHz)

Evaluation: Shot Noise Transfer Curve

Signal: V = K N Noise: VARIANCE = $E_n^2 = K^2 (N + N^2_{amp})$

Asymptotically: $En^2 = K V$ => K can be determined

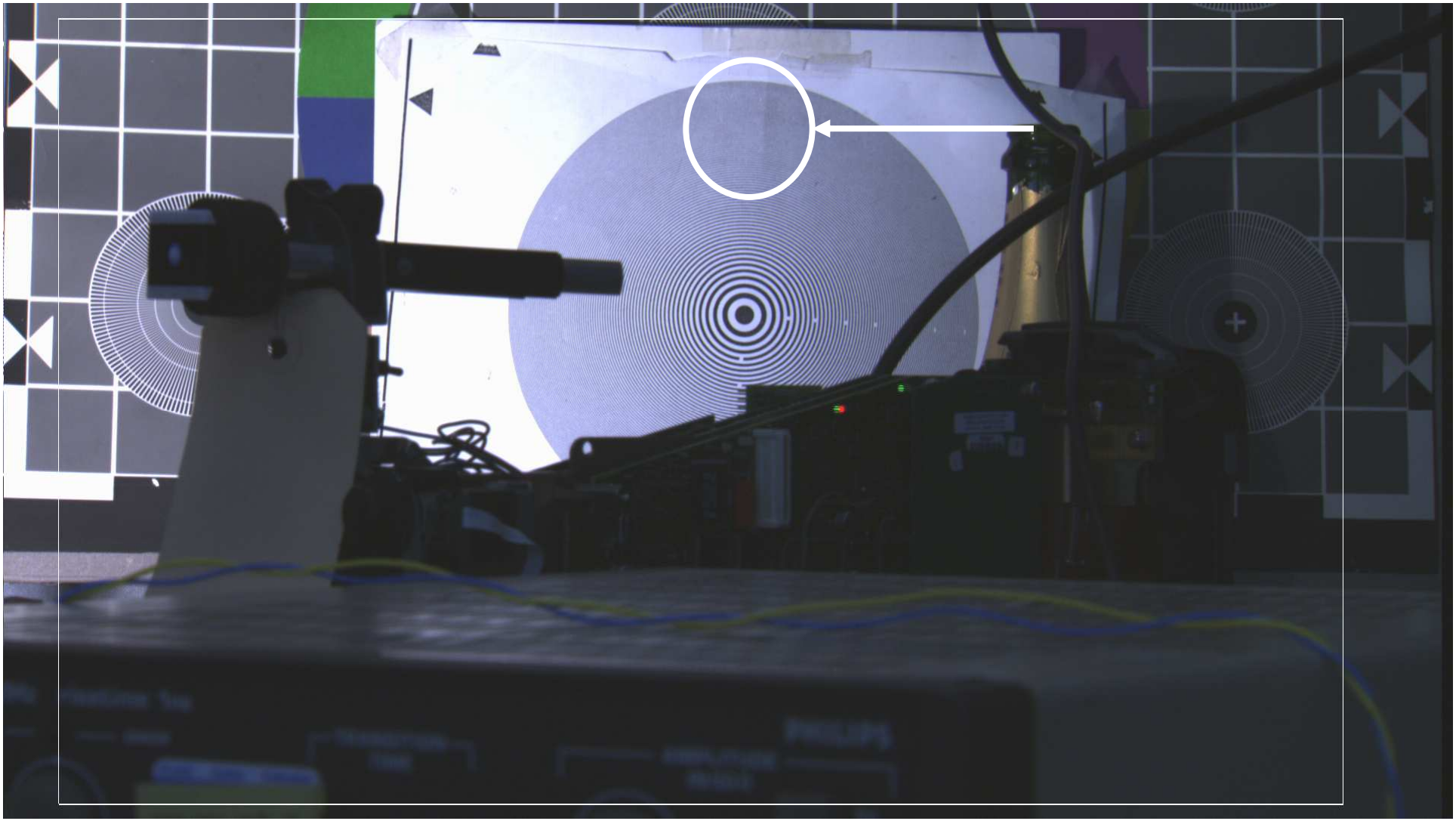


K = 3.3 e/DN

N_{amp}= 11.5 e

Evaluation: Zonechart

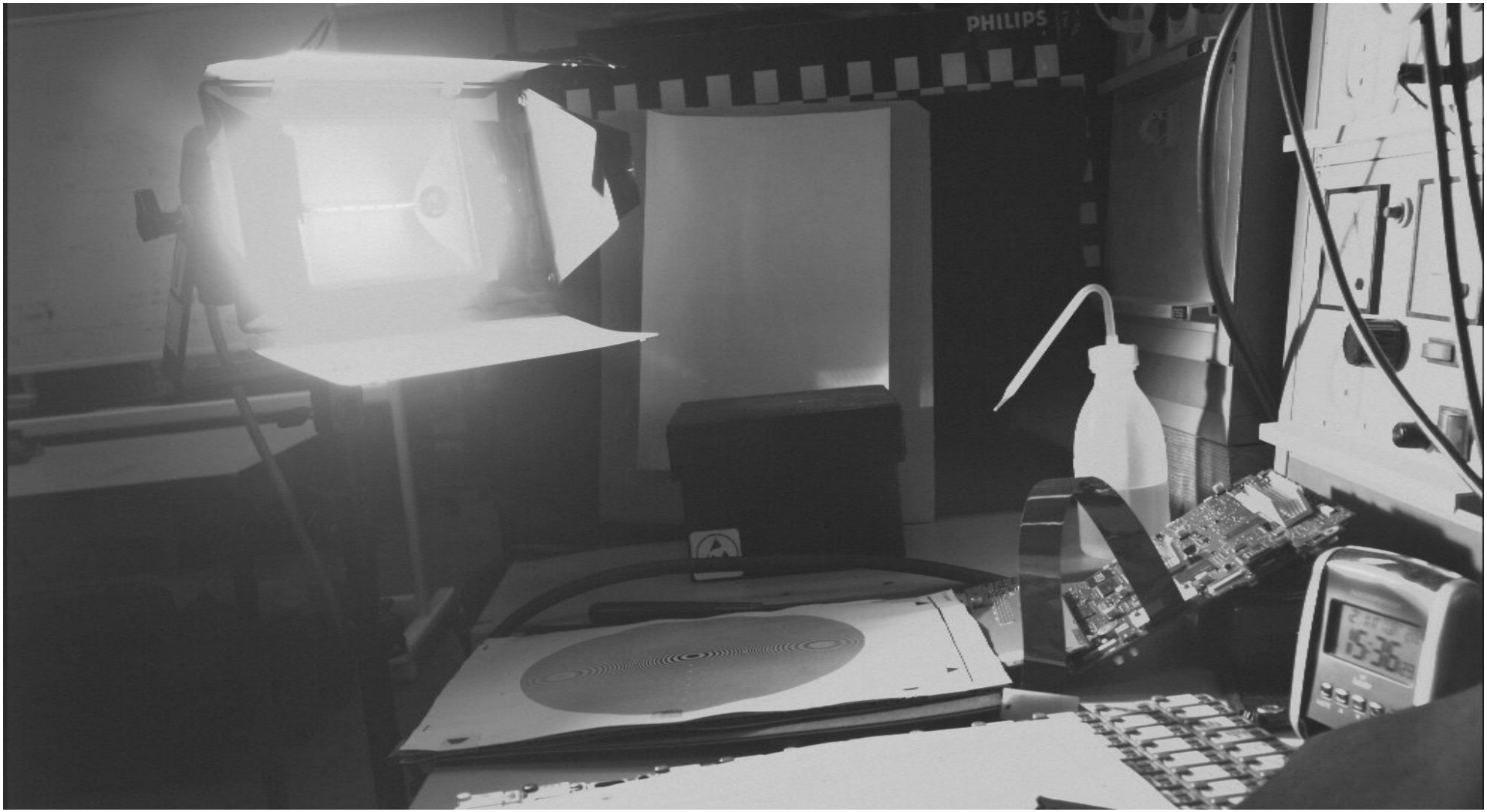
- **The ALIASING in 1080i60, after adding two consecutive lines, is gone**



High-DR modes

- *Implemented and under investigation*
- Time sub sampling, 3 samples of the pixel voltage
  - First sample at black
  - Second sample at eg ¼ of the nominal integration time
  - Third sample at the end nominal integration time
- Vertical sub sampling
  - Even rows have pixels with a nominal integration time
  - Odd rows have pixels with eg ¼ of the nominal integration time
- Horizontal sub sampling
  - Even columns have pixels with a nominal integration time
  - Odd columns have pixels with eg ¼ of the nominal integration interval
- Adjustable Linear-Logarithmic pixel

Evaluation: High-DR Image



New Technique for Dark Current Investigation

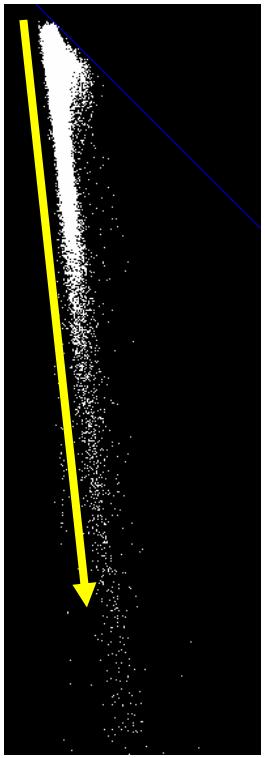
2-Dimensional Binarized Histogram

-2-images at different temperature

Eg 50C and 70C;

-A pixel-by-pixel comparison in both images

for m,n do HISTO[IMAGE1[m,n] , IMAGE2[m,n]]:=1



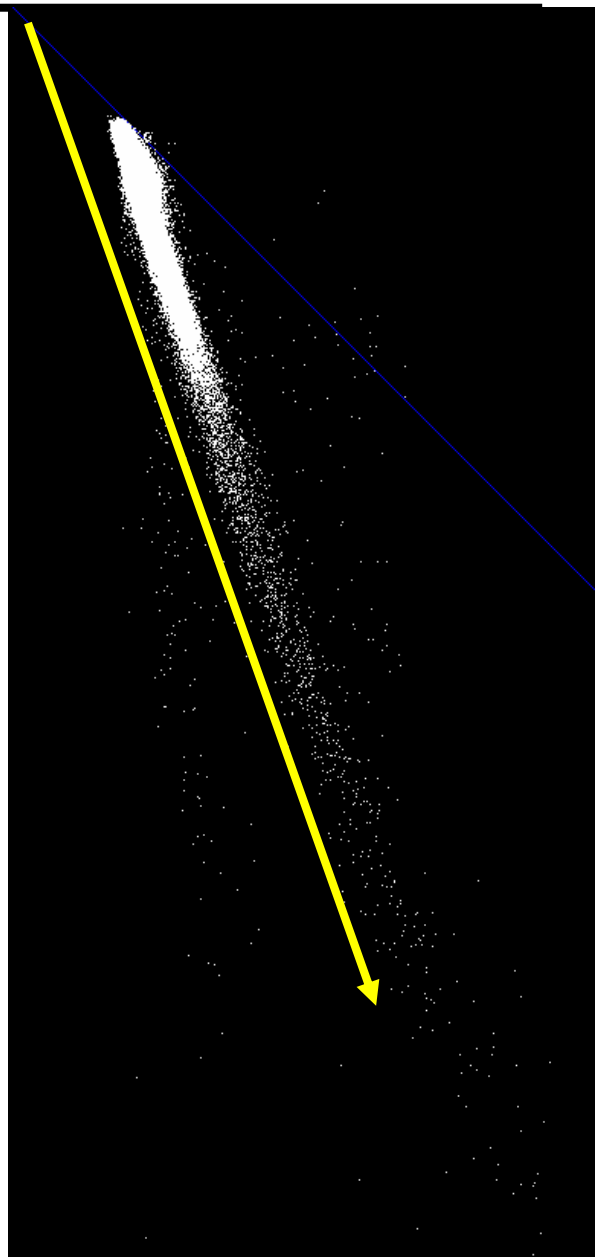
Y-axis: 70C=>

X-axis: 50C=>

Info on activation energy for ALL pixels!

<=Y-axis: 70C

<=X-axis: 31C



Chip Micrograph

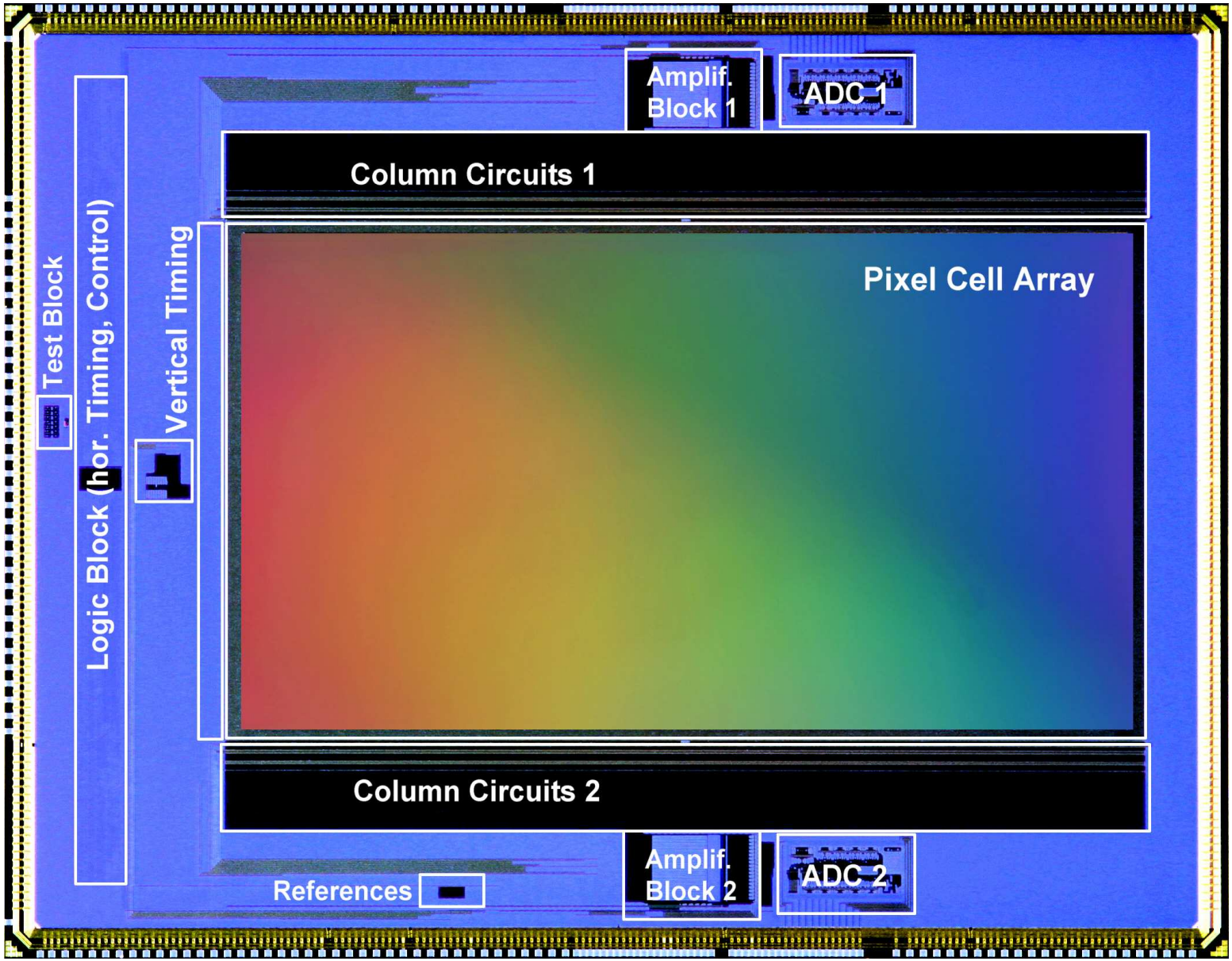


Table of characteristics

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 @ 60°C	0.4nA/cm^2
Temporal noise, pixel only, 27°C	4e^-
Temporal noise, all contributors, 27°C	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

Conclusion

- A 2/3 inch CMOS image sensor with 3T-pixel, in 0.18**µ**m 1P4M process, is presented that fulfills full HDTV broadcast quality
- Among the many scanning formats are 1080p, 1080i and 720p with matched anti-aliasing properties
- The imager has multiple ways for generating High-DR images
- Compared with a CCD application with the additional pulse pattern generator + CDS + gain stages + ADC the power consumption went down with a factor of 3
- A noise level of $4e^-$ for the pixel and $11.5e^-$ overall was obtained with off-chip CDS
- At 2000 lux, 90%, 3200K and 54dB in Y
  - In 1080i60 the f-number is f/8 and f/11 in 1080p30
- The maximum raw capture rate is 1080i180, 1080p90 and 720p180
  - 1080i240 or 1080p120 has been demonstrated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