IBC2009

NEXT GENERATION CMOS IMAGER FOR BROADCAST CAMERAS

Peter Centen
Grass Valley Image Capture Solutions
R&D

grass valley

50 Years of On-Air Innovation

www.grassvalley.com

IBC2009

Acknowledgement

- Grass Valley R&D Image Capture Solutions, Netherlands
  - J.Rotte, N.J. Damstra, F.van der Weegen
- Thomson Imager Design Center, Germany
  - S.Lehr, S.Roth, F.Heizmann, V.Neiss, M.Schreiber, N.Mallory, S. de la Torre, B.Braicu, K.Schaaf, H.Schemmann, R.Schweer, R.Dohmen, W.Yan

IBC2009

Agenda

- CMOS Imagers
  - Self fulfilling prophesy
  - Feature size
- Xensium A CMOS imager for Broadcast Cameras
- Food for Thought
  - Noise, Shotnoise and SNR in 1080p50 and beyond

Peter.centen@grassvalley.com

IBC2009

CMOS Imagers
A Self fulfilling Prophesy?

grass valley

50 Years of On-Air Innovation

www.grassvalley.com

IBC2009

A Self fulfilling Prophesy

- **Perception**
  - CMOS imagers are cheap and have low quality
- **The sentence could also read**
  - CMOS imagers are expensive and have high quality
- 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

Peter.centen@grassvalley.com

IBC2009

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

Peter.centen@grassvalley.com

IBC2009

A Self fulfilling Prophesy

- CCDs have a long history in which many of the performance related parameters are improved
  - **Sensitivity (quantum efficiency)**
    - uLens
    - Back Side Illumination (BSI)
  - **Noise**
    - real Correlated Double Sampling (CDS)
    - ***Shotnoise*** (relates to sensitivity)
  - **Darkcurrent**, FPN and LAG
    - P+toplayer
  - THESE solutions can be applied too in CMOS imagers at the expense of additional masks and technology steps and hence is more **expensive**

Peter.centen@grassvalley.com

IBC2009

CMOS imagers
Why did it take so long?

grass valley

50 Years of On-Air Innovation

www.grassvalley.com

IBC2009

Feature Size

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

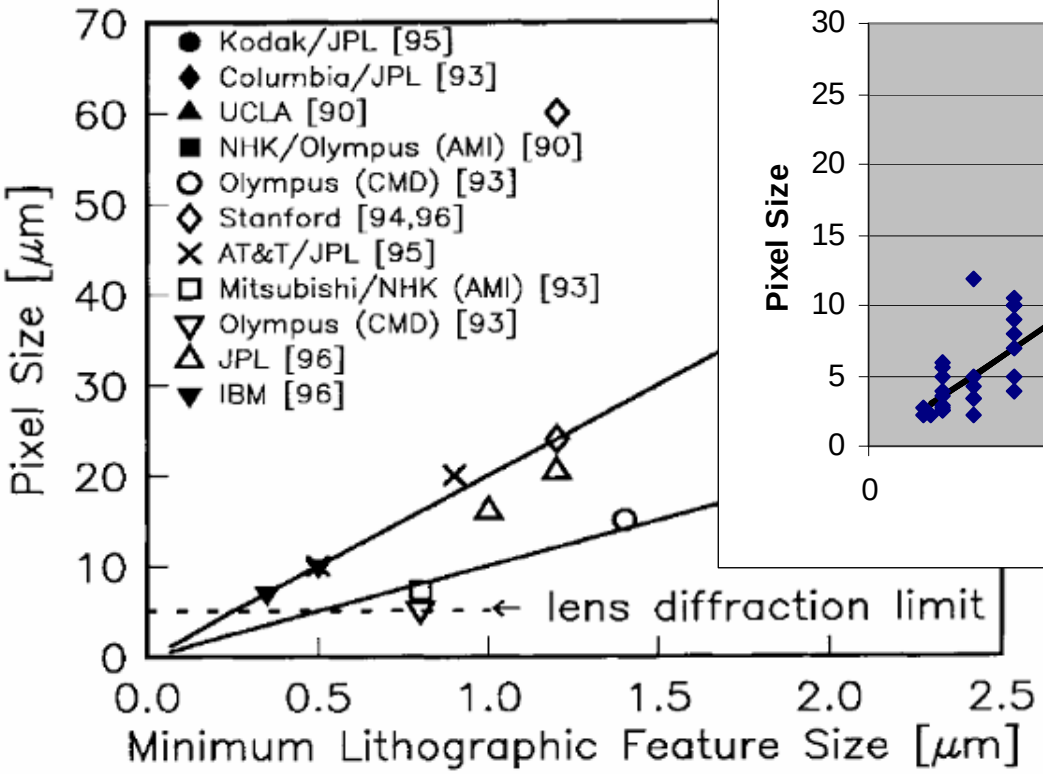
- Why did it take so long for CMOS imagers to enter the market, even though they where conceived before the CCD imagers?
  - The word is **Lithographic Feature Size**
  - In general a CCD-pixel is MUCH simpler than a CMOS-pixel, the latter contains more active elements

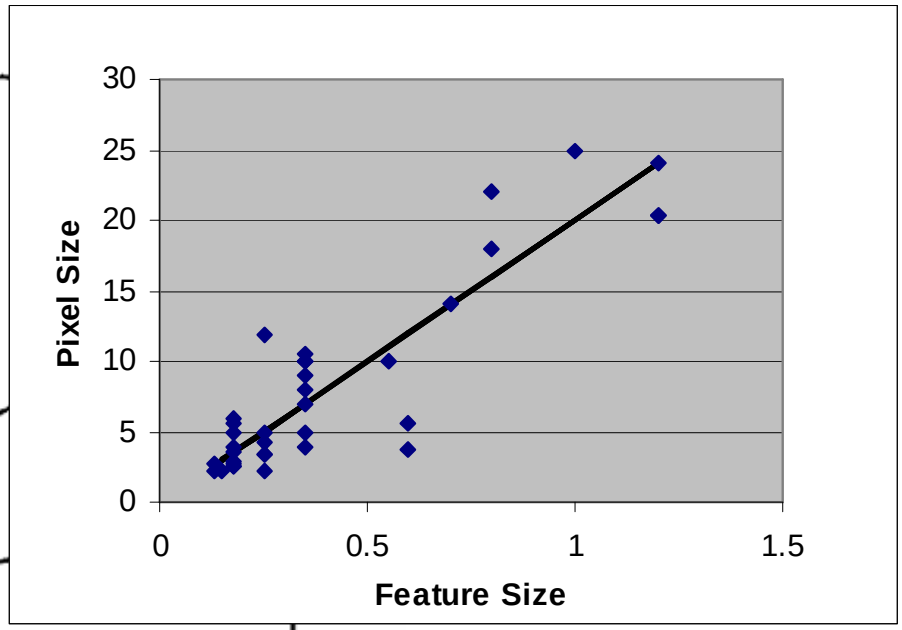
Peter.centen@grassvalley.com

IBC2009

Feature Size

Pixel size: Feature-Size*20





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

IBC2009

Feature Size

- The average pixel size in HDTV
  - **1080P: 5.0um; 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 **<0.25um** for 2/3" HDTV Imagers*
  - *0.18um and 0.13um are at present mainstream CMOS imaging*

CMOS imagers are feasible in Broadcast Cameras

Peter.centen@grassvalley.com

IBC2009

The design of Xensium
A CMOS imager for Broadcast applications

grass valley

50 Years of On-Air Innovation

www.grassvalley.com

IBC2009

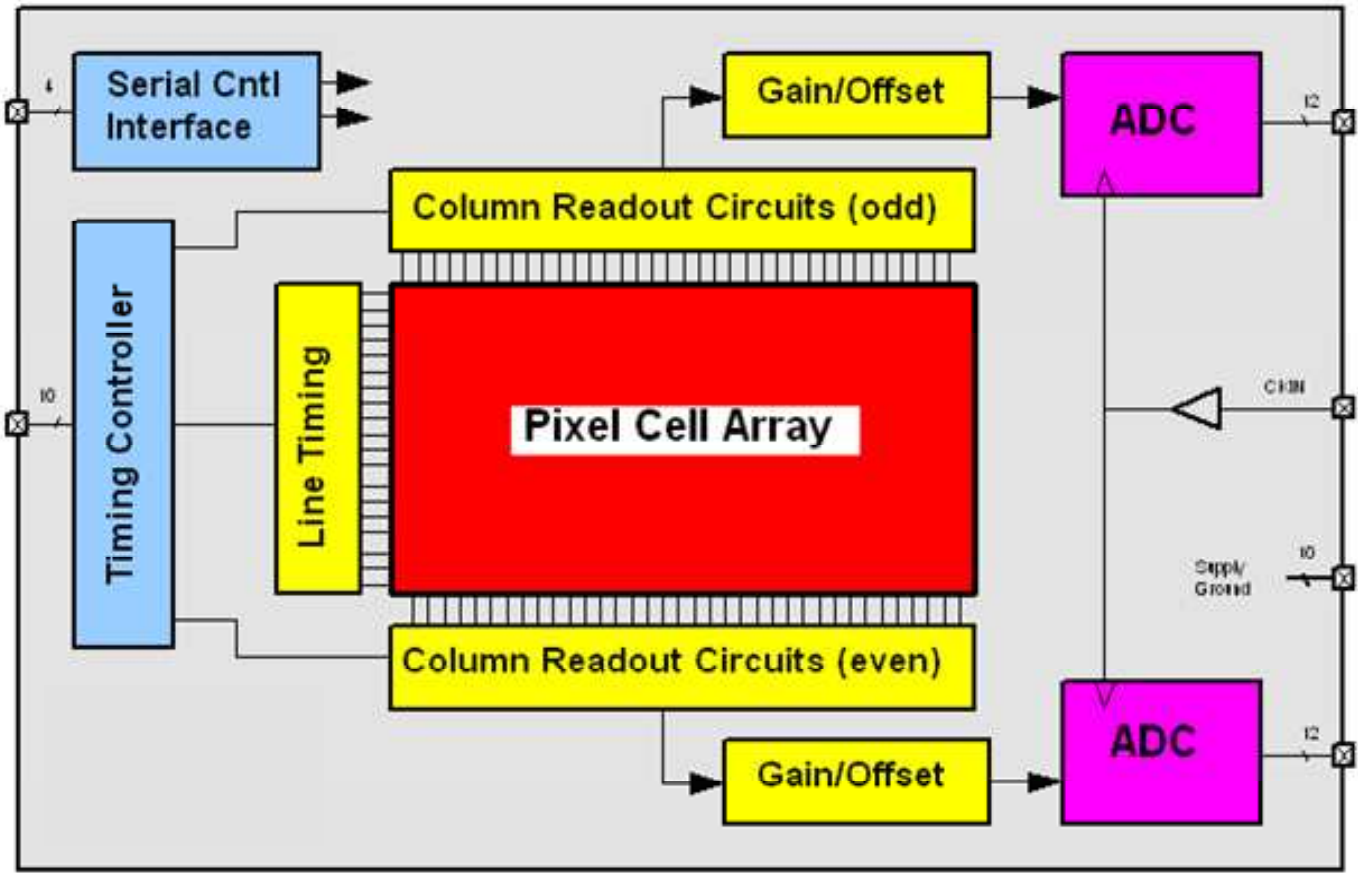
Xensium

- An imager is an ANALOG device
  - Keep the imager as simple as possible and make external 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
- Build on the many years of video processing experience and choose a camera and imager architecture, that eases CMOS image sensor design
- Design a pixel in a 0.18µm process
  - do real CDS off-chip
  - use hard reset and no soft reset because of inherent lag problems

Peter.centen@grassvalley.com

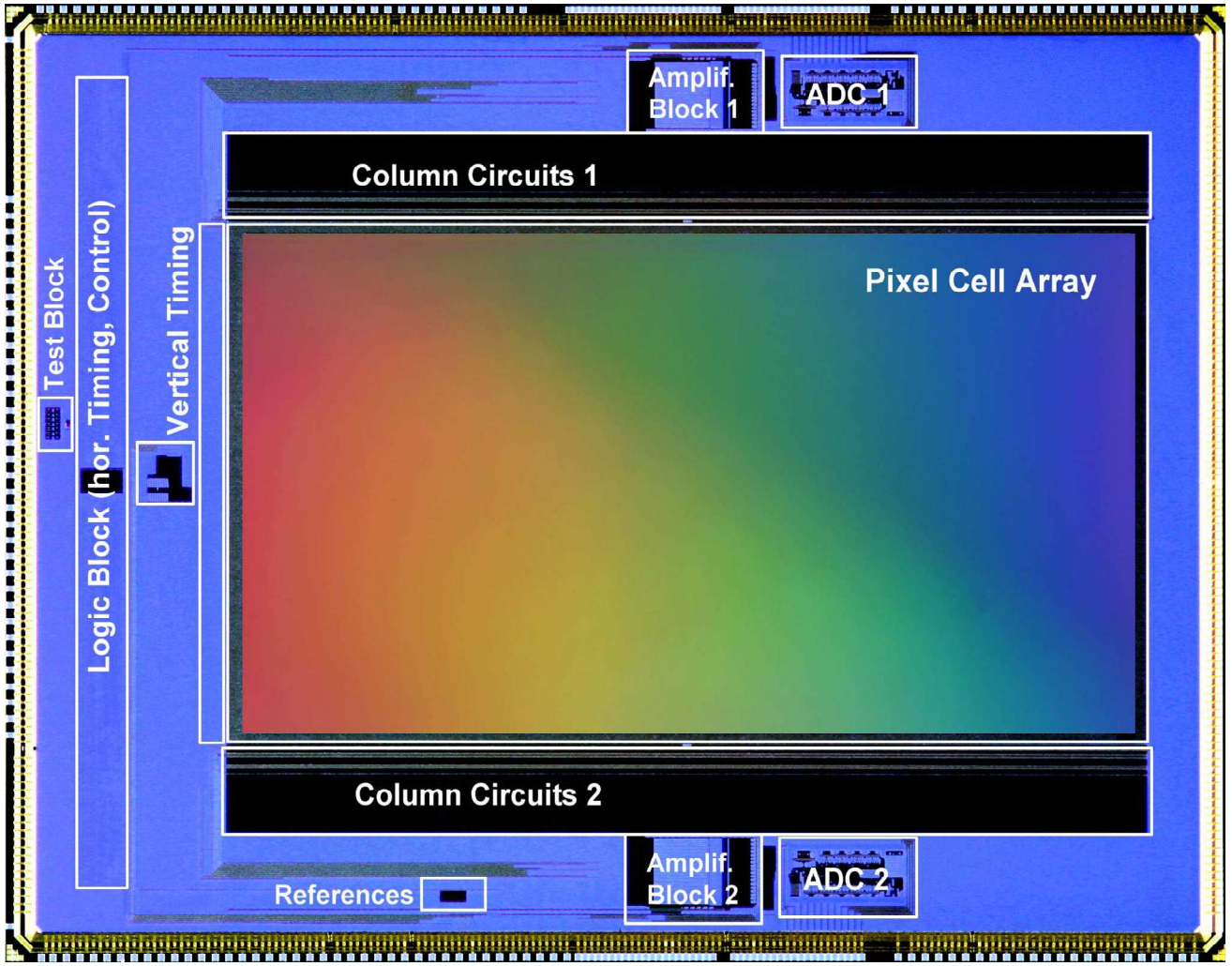
IBC2009

Xensium



IBC2009

Xensium



Peter.centen@grassvalley.com

IBC2009

Food for Thought

SHOTNOISE

A parameter that matters in 1080p50 or beyond

grass valley

50 Years of On-Air Innovation

www.grassvalley.com

IBC2009

Broadcast Camera's

2000 lux, f/10, 89.9 %, 3200 K

and

54 dB in Y

@

1080i50

WHAT DOES THAT MEAN IN 1080p50?

Peter.centen@grassvalley.com

IBC2009

Signal-to-Noise

- SNR=54dB in Y at 1080i50
  - Linear camera setting and 0dB mastergain
    - Camera signal chain as clean as possible
      - Contour off, Gamma off.
  - The SNR is defined with two numbers
    - The amount of light needed for 700mV video
      - The **f-number** for which we get 700mV video given the 2000 lux, 89.9%, 3200K
    - The **noise** without illumination
      - It is NOT the noise that belongs to the signal level

- 54dB@1080i50 or **51dB in 1080p50**
  - 1080i50 is the addition of two 1080p50 pixels

Peter.centen@grassvalley.com

IBC2009

Broadcast Camera's

- At 2000lux; f/10; 3200K and 89.9% scene reflection
- 2/3" full HDTV imager with pixel of **5x5um²** and **50frames/sec.**
- #Photons per pixel to reach 700mV video at 0dB mastergain
  - R 5400 photons/pixel
  - G 4800 photons/pixel
  - B 1500 photons/pixel
- Assume overall **QE = 60%** then
  - Charge packet in Green **n=2800 e** and
  - for SNR in **Y=51 dB** noise level must be **N_{ro}=10 e**
- **BUT PHYSICAL LIMIT**
  - **number of electrons <= number of photons**
  - **or 4800e in green, 1500e in blue and 5400e in red**
- BTW: To reach same numbers in 1/3" f/5 is equ. f/10 in 2/3"

Peter.centen@grassvalley.com

IBC2009

Shotnoise

n: number of photon generated electrons

Output signal:

$$V_{out} = gain * n$$

Noise:

$$U_n = gain * \sqrt{N_{ro}^{\ 2} + n}$$

Peter.centen@grassvalley.com

IBC2009

Shotnoise

- 1080p50 and 2/3” imagers and camera at 0dB mastergain and f/10

QE	60%	(100%)
– R signal	3200e	(5400e)
– G signal	2800e	(4800e)
– B signal	920e	(1500e)

- SNR in **Y** at 0dB (G =>Y => +2dB)
  - Broadcast
    - 20*log(2800/√(10^2 + **0**))+2dB=51dB **(55dB)**
  - Signal-to-noise at 700mV
    - 20*log(2800/√(10^2 + **2800**))+2dB=36dB **(38dB)**
  - **Noise increases due to SHOTNOISE**

Peter.centen@grassvalley.com

IBC2009

Shotnoise curve

- The noise in dB referenced to nominal output level
- No Weeber-Fechner but two pragmatic reference curves
  - The SDTV 60dB, 625i50
    - Perceived as excellent
  - The HDTV 54dB, 1080i50
    - Perceived as just acceptable

Peter.centen@grassvalley.com

Shotnoise curve

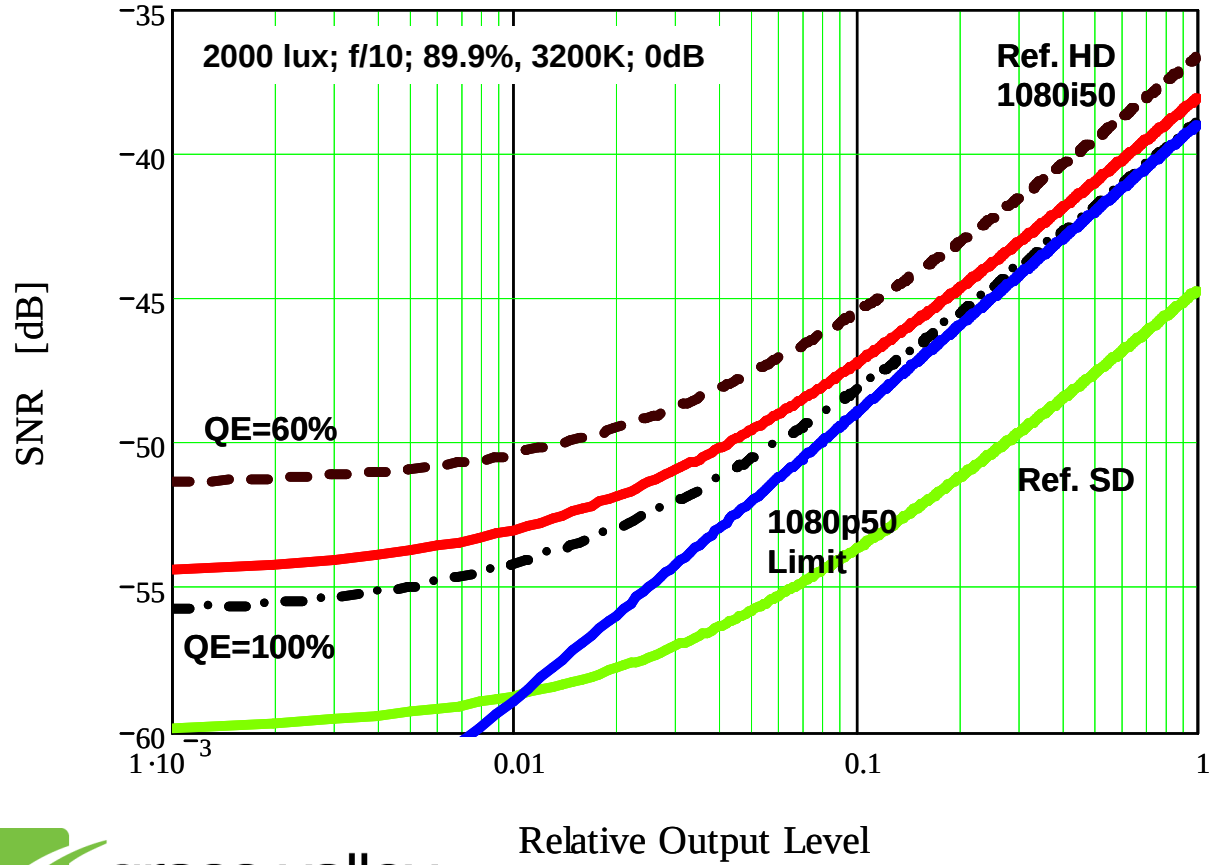
-1080p50

QE=60%, 100%

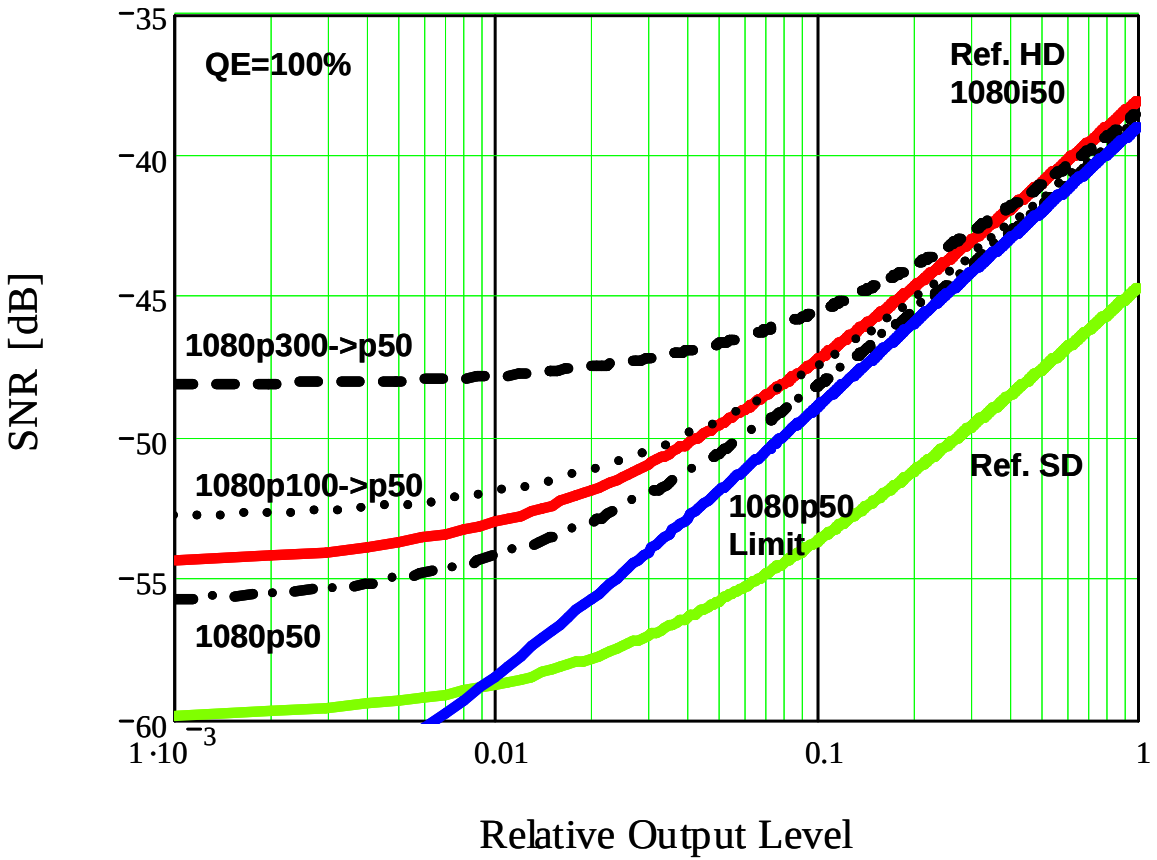
Ref: f/11; 625i50; SDTV

Ref: f/11; 1080i50; HDTV

-1080p50 no noise in black and QE=100%



Shotnoise curve



IBC2009

Conclusion

- CMOS imagers for full HDTV are becoming viable.
  - With the reporting of Xensium the first full HDTV imager is presented that offers broadcast quality images.
  - The architectural choices of Xensium enabled the development of a camera that reaches broadcast and Pro/AV quality.
- Due to the shotnoise the limits of physics are reached for 2/3” Imagers used in 1080p50 at f/10. The images are on the edge of being noisy.
  - If one wants to achieve the same noise impression as SD one either has to apply noise reducers or accept that f-numbers in the range of f/5.6 are needed as a 0dB setting for the camera.
- Generating 1080p50 from a 1080p300 source will have the same noise impression for the exposed parts, as if it was captured in native 1080p50.
  - The dark areas in the images will be too noisy until the readout noise (noise in black) is reduced substantially.

Peter.centen@grassvalley.com

grass valley

50 Years of On-Air Innovation

www.grassvalley.com

References

- L. Kozlowksi, Performance Limits in Visible and Infrared Image Sensors, IEDM DEC 1999, pp 36.1.1-36.1.4.
- H. Wong, Technology and Device scaling considerations for CMOS imagers, IEEE ED Vol. 43, pp. 2131-2142, DEC 1996.
- M. Loose et al. 2/3-inch CMOS Imaging Sensor for High Definition television, IEEE workshop on charge-coupled devices and advanced image sensors, June 7-9, 2001.
- M. Schubin, Optics of Small-Format HDTV Acquisition, SMPTE 147th Technical Conference and Exhibition, Nov. 9-12, 2005
- A. Theuwissen, Solid-State Imaging with Charge-Coupled Devices, 1995, Kluwer Academic Publishers, ISBN 0-7923-3456-6.
- P.Centen et. al., Aspect Ratio switching with equal horizontal pixel count, Technical Papers International Broadcast Convention, pp. 1-7, Amsterdam, September 1994.
- P. Centen, T. Moelands, J.v. Rooy, M. Stekelenburg, A Multi-Format HDTV Camera Head, proceedings of the 142st SMPTE Technical Conference and Exhibition, Pasadena, October 18-21, 2000.
- Invited, P. Centen, 2/3”- Cameras Challenging the Latitude of FILM, NAB Conference and Exhibition, Digital Cinema Summit 12-13 April 2008, Las Vegas.

Peter.centen@grassvalley.com

IBC2009

References

- Y. Ishihara, K. Tanigaki, A High Photosensitive IL-CCD Image Sensor with Monolitic Resin Lens Array, Technical Digest IEDM, pp 497-500, Dec 6-8, 1963.
- M. Blouke, J. Breitzmann, J. Hall; Three-phase, backside illuminated 500×500 CCD imager, Solid-State Circuits Conference. Digest of Technical Papers. Feb-1978, Volume: XXI, page(s): 36- 37.
- J. Gambino et. al, CMOS Imager with Copper Wiring and Lightpipe, Electron Devices Meeting, 2006. IEDM apos;06. International, Volume , Issue , 11-13 Dec. 2006 Page(s):1 – 4,.
- M. White et al, "Characterisation of Surface Channel CCD Image Arrays at Low Light Levels", IEEE JSSC, Vol. SC-9, No. 1, pp 1-13, 1974.
- Y. Nishida et.al, Design concept for a low-noise CCD image sensor based on subjective evaluation; Electron Devices, IEEE Transactions on, Volume 36, Issue 2, Feb 1989 Page(s):360 – 366
- J. Janesick, K. Klaassen, T. Elliott, Charge-coupled-device charge-collection efficiency and the photon transfer technique, Optical engineering, October 1987, Vol. 26, No.10, pp 972-980.
- P. Centen, Applied Mathematics to Simplify Imager and Camera Analyses Proceedings of the IEEE International Image Sensor Workshop, 7-10 June 2007, pp 121-124.
- P. Centen et. al, A 2/3-inch CMOS Image Sensor for HDTV Applications with Multiple High-DR Modes and Flexible Scanning, ISSCC2007, San Francisco, 11-14 February 2007, pp 512-513.

Peter.centen@grassvalley.com