Broadcast

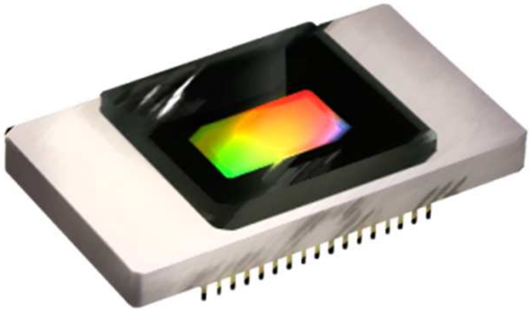
Peter Centen
VP R&D Cameras
The Netherlands, Breda

FUTURE-READY

grass valley
A BELDEN BRAND

Agenda

- Broadcast and the rabbit
- Numbers and Pixels
- 4k, 8k
  - Sensitivity
  - MTF
- HDR
  - Display was the limiting factor
  - PQ, HLG
  - HDR is forgiving



Acknowledgement

- Dalsa, Philips: CCD only☺
  - Albert Theuwissen, Holger Stoldt, Jan Bosiers
- TowerJazz
  - Amos Fenigstein, Assaf Lahav, Adi Birman
- Viimagic, Thomson
  - Stefan Lehr, Sabine Roth, Rainer Schweer
- GrassValley, Thomson, Francisco Partners, Bosch, Philips
  - Jeroen Rotte, Klaas Jan Damstra, Ruud van Ree
- Developments where done with funding of the local government's and Europe: Medea (ASIC-CCD, PICS, TritonZ), Catrene (HiDRaLoN, ICAF), Eniac (Panorama).


Capturing Emotion Around The World
AnyLight
3G
TRANSMISSION
XCU
LDX
SERIES

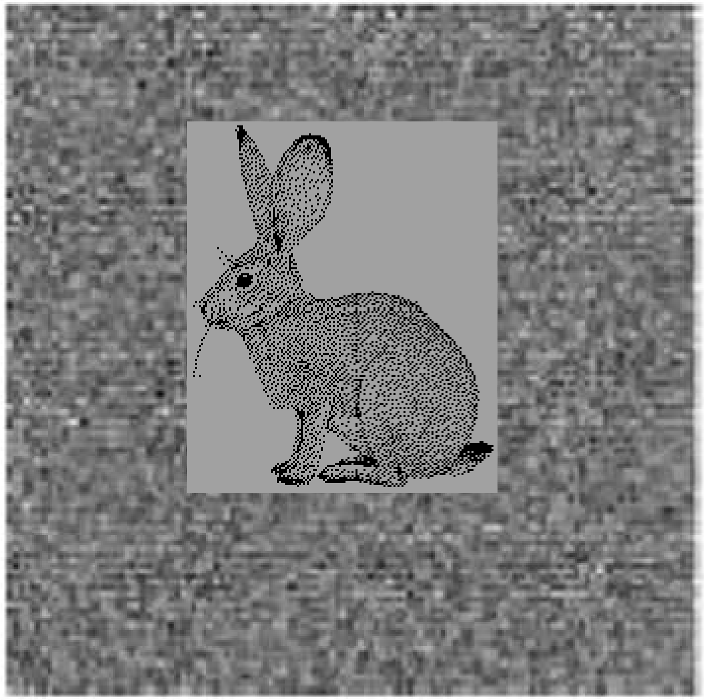
History

Tube Cameras	1960's	**LDK** 1/3/33/13 (EL 8521/8526)
	1970's	**LDK** 2/5/14/15/25; Triax transmission
	1980's	**LDK** 6/26/614/54
CCD Cameras	**1988**	**LDK** 90/900
	1990	**LDK** 91/910
	1992	**LDK** 9000; **LDK** 93/9/9P
	1995	**LDK** 10/10P
Digital Cameras	**1996**	**LDK** 20/20P
	1997	**LDK** 100; **LDK** 120
	1998	**LDK** 23HS; **LDK** 2000
	1999	**LDK** 140, 150; **LDK** 100IT(W), **LDK** 110
	2000	**LDK 23HS mkII; LDK 200**
HD-DPM+ Cameras		**LDK 6000**
	2001	***Viper FilmStream***
	2002	**LDK** 6000 mkII
	2003	**LDK** 300; **LDK** 500; Wireless SD; C2IP control
	2004	**LDK** 6200 HD SuperSlomo
	2006	**LDK** 8000
	2007	**Infinity DMC 1000**
	2008	**LDK** 8300; **LDK** 8000 Elite
Xensium™ Cameras	***2009***	***LDK 3000; HD Fiber 1080p50/60 transmission***
	2010	3D OCP; HD Triax Dynamic Air Control, 7" NoTube
CMOS	**2011**	**LDK** 3000+, 9" NoTube, 3G Transmission and RefleX flexibility
	2012	***LDX Series and 2.7" VF***
	2014	**LDX** 86 XtremeSpeed and HiSpeed
	2015	**LDX** 86 4K and Universe

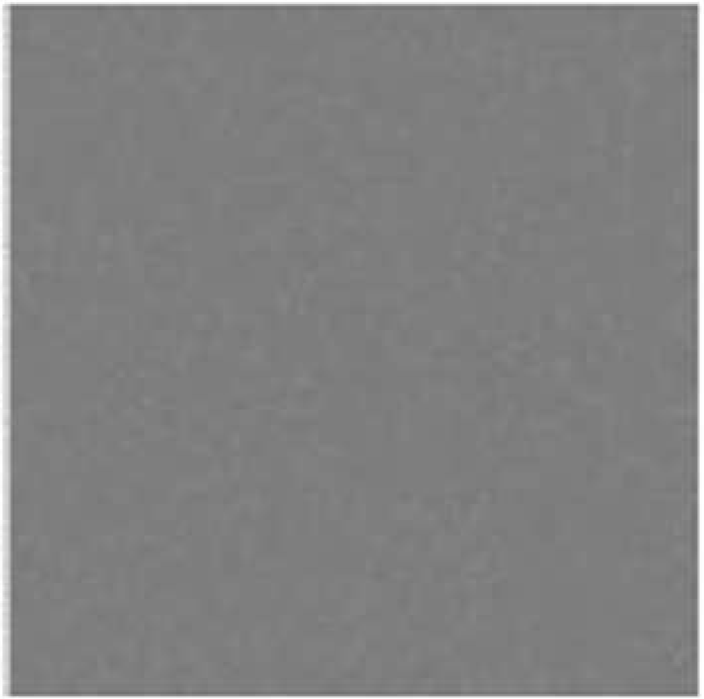
grass valley
A BELDEN BRAND

Eliminating Fixed Pattern Noise

Without DDS



With DDS



Sensitivity and Noise

- 2000lux, scene illuminance
- 89.9%, reflection
- 3200K, color temperature
- 60dB, SNY
- f-number of the lens is the variable
- 2/3” image diagonal (11mm)
- B4 lens mount
- 3 imagers on a color splitter

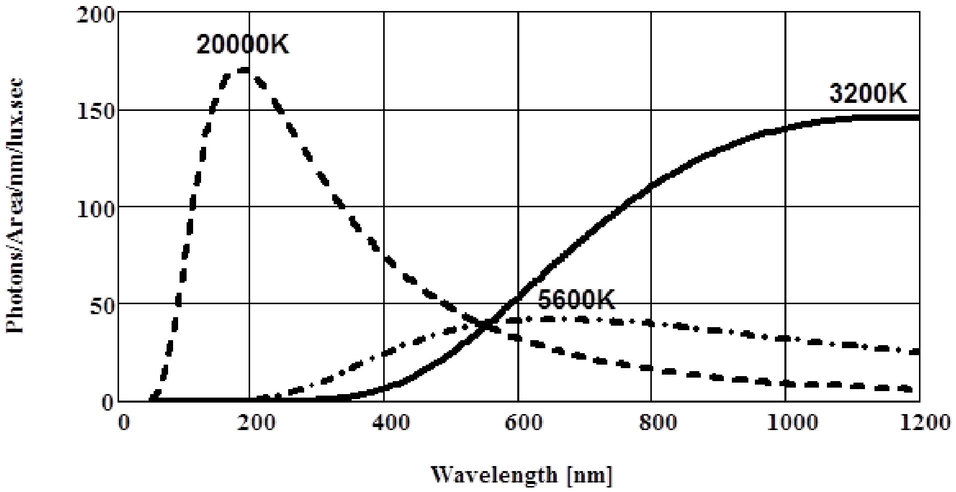
Pixels

- SDTV mainstream 2/3” (11mm image diagonal)
  - Pixel race: 720…..960
  - Aspect ratio 4:3 and/or 16:9
  - 12 phase addressing
    - 4/3 and 16/9 aspect ratio
    - 1080p, 1080i, 720p, 576i, 480p, 480i with one imager at fixed image diagonal
- HDTV
  - 1” (16mm image diagonal)
    - Europa versus Japan
  - 2/3”, mainstream
    - 1920x1080 and 1280x720
    - SNR race, read noise and QE improvement and speed improvement

Signal levels in Broadcast

- Photon flux of a blackbody radiator at 3200K, 5600K and 20000K, Area is in [µm2].

$$\mathrm{photonsG(T)} := \frac{A_{cell} \cdot T_{int}}{h \cdot c} \cdot \frac{E_v \cdot \rho}{4 \cdot F^2} \cdot \frac{\int_{400}^{750} P(\lambda, T) \cdot \tau_{IR}(\lambda) \cdot \tau_{lens}(\lambda) \cdot \tau_{KssG}(\lambda) \cdot \lambda \, d\lambda}{\int_{400}^{750} V(\lambda) \cdot P(\lambda, T) \, d\lambda}$$



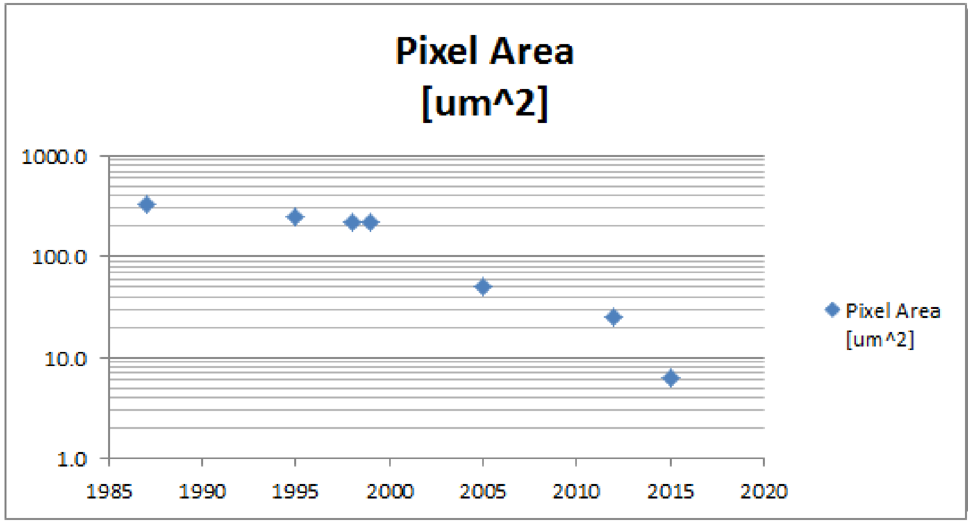
Acell: Pixel area
Tint: exposure time
Ev: scene illumination
Rho: reflection coefficient: 89.9%
F: f-number of the lens
P: blackbody radiator
IR: transmittance curve of the IR filter
KSS: transmittance of the colorsplitter
V: the eye weight curve

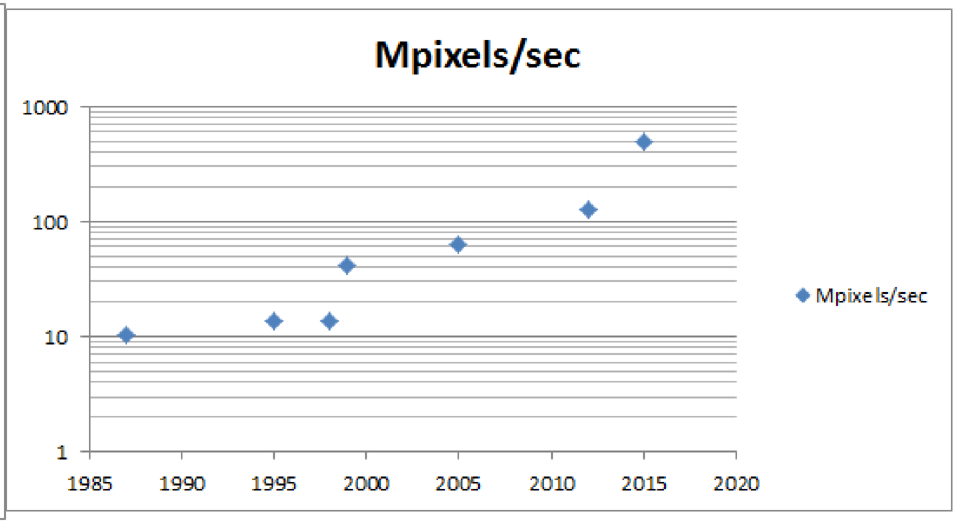
Signal levels in Broadcast

- 2000 lux; 89.9 %; 3200K, f/11
- Blackbody radiator 3200K: 6000 photons/lux.sec/um2@BW+IR
  - A 5um pixel collects in 16.67ms this is HDTV

Mastergain	Red	Green	Blue
0dB	**3206 photons**	**3029 photons**	**1114 photons**
0dB	1924 electrons	1818 electrons	668 electrons
+12dB	481 electrons	454 electrons	167 electrons

Noise and sensitivity improvements

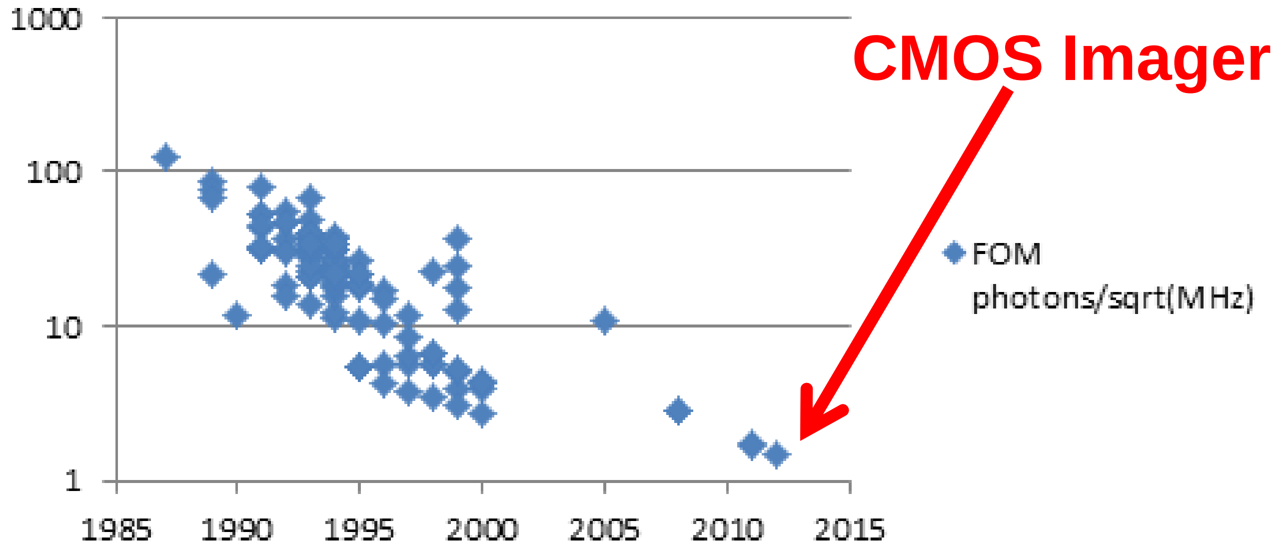




Pixel area 25x smaller , Bandwidth 10x higher

Noise and sensitivity improvements

$$\mathrm{FOM} := \frac{\mathrm{ReadNoise}}{\mathrm{QE}\cdot\sqrt{\mathrm{BW}}}$$



4k, 8k

FUTURE-READY

grass valley

A BELDEN BRAND

4k-implementations

- Single imager 8Mpixels (Large format imagers, 35mm)
  - Not really 4k
- 3 imagers 2Mpixel each=>6Mpixels (2/3”)
  - Not really 4k
- 4 imagers 2xG, 1xB, 1xR 2Mpixel each=>8Mpixels (2/3”)
  - Not really 4k, reduced MTF due to large pixel aperture
- 3 imager 8Mpixels each=>24Mpixels (2/3”)
  - Really 4k
- Single imager 32Mpixels (NHK, large format)
  - Really 4k+

4k-continued

- Large format imagers 35mm
  - In live sports the depth-of-field is a problem
  - There are no 100x zoom lenses as in 2/3”
- 2/3”
  - Problem is sensitivity
    - pixel in HD 5um
    - pixel in 4k 2.5um, drop of 4x (2-fstops) in photons or f/11=>f/5.6
  - Problem is diffraction limiting MTF
  - F/4-F/5.6 is the natural f-stop number in live event
    - For HD with its f/11 at 0dB that means using ND filters
    - For 4k it is a natural fit, f/11->f/5.6 and NO ND filters

MTF at Nyquist

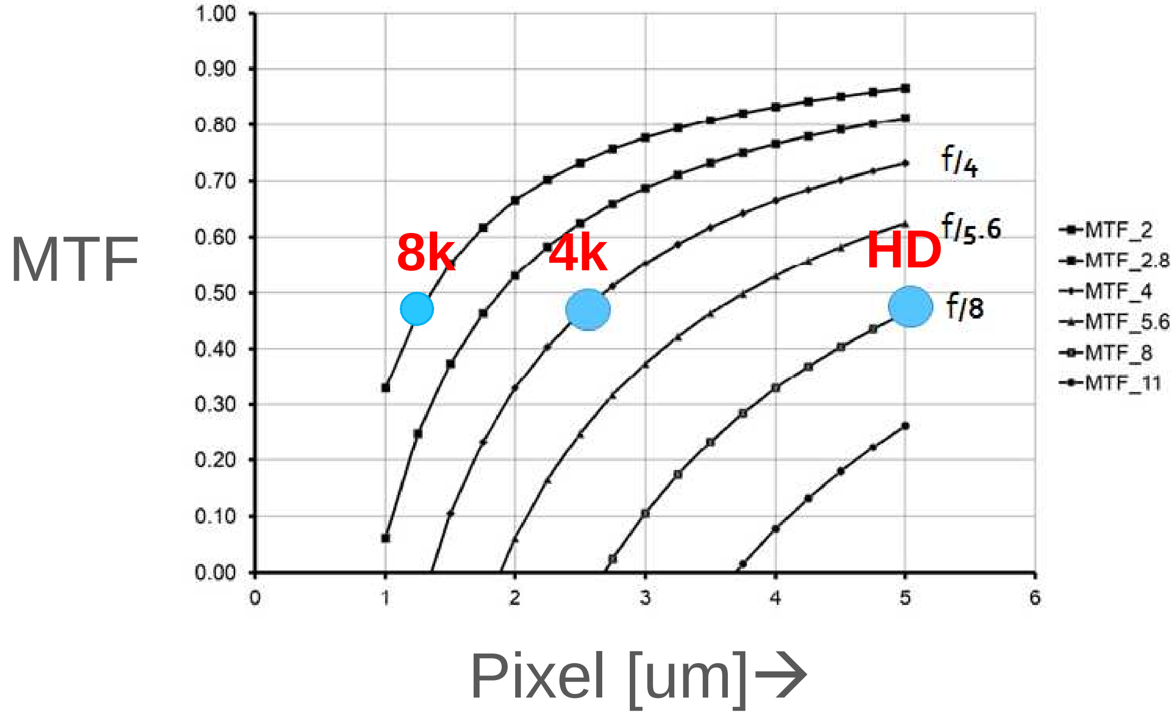
- An imager is a 2-dimensional spatial sampler.
- The Nyquist frequency is half the sample frequency. It is the frequency up to which one can reconstruct a sampled signal
  - The sample frequency can be expressed in lp/mm and is 1/pixel-pitch

Diagonal [mm]	8k	4k	2k
	Pixel [um]		
8.0	0.9	1.8	3.6
11.0	1.2	2.5	5.0
22.0	2.5	5.0	10.0
24.0	2.7	5.4	10.9
35.0	4.0	7.9	15.9

Diagonal [mm]	8k	4k	2k
	Nyquist [lp/mm]		
8.0	551	275	138
11.0	401	200	100
22.0	200	100	50
24.0	184	92	46
35.0	126	63	31

Lens MTF at Nyquist for different pixels

- For equal number of photons
  - HD f/11 (5.0um pixel)
  - 4k f/5.6 (2.5um pixel)
  - 8k f/2.8 (1.25um pixel)
  - Equal MTF



HDR

FUTURE-READY

grass valley
A BELDEN BRAND

Dynamic range

- Imager side: As we normally do, expressed in dB

$$20 \cdot \log\left(\frac{\mathrm{Qmax}}{\mathrm{Noise}}\right)$$

  - What it says: how often fits the (rms) noise in the (maximum) signal range
- Is noise really a measure for perception?
- Display side: A Weber Fechner step of 1% is not visible
  - 70 is the number of 1% steps in a factor 2 (is 1 Fstop)

$$(1.01)^{70} = 2.0$$

$$(1.02)^{35} = 2$$

HD-SDI

- Transmission in broadcast is serial digital 10bit.
  - 10 bit is 1024 levels or 70x14.6 levels
  - For each 70 levels you can cover 1 Fstop
  - The 10 bit interface allows for 14-15 Fstop dynamic range
  - With Dither (eg shotnoise) even more
- Dolby devised a curve known as the perceptual quantizer (PQ).
  - standardized as SMPTE 2084 and now at ITU
  - based on the work of Barten
  - It is a curve with the minimum amount of codewords to cover 10knits without visible artifacts per codeword-step

- Non-linear coding
- Code
- 100=>1000.0nits ; add 1%
- 101=>1010.0nits ; add 1%
- 102=>1020.1nits ; add 1%
- 110=>1104.6nits ; 10 times 1%
- 150=>1644.6nits ; 50 times 1%
- 170=>2006.7nits ; 70 times 1%
- 240=>4027 nits
- 310=>8081 nits

HDR: a display problem

- The imager could do High-Dynamic-Range already for a long time
- It was the display together with the background illumination of the room that posed the problem
- Then came
  - Dolby with PQ and their quantum dots display but most of all their PQ curve (Perceptual quantized)
  - NHK and BBC with yet an other curve: HLG (Hybrid Log Gamma)
  - now both at ITU
- Displays from 100nits moving up to 1000nits, 4000nits..10knits

HDR: it is about a curve and a display

- Either in the display: EOTF=PQ, with OETF=PQ^-1

$$EOTF^{-1}[L] = \left(\frac{c_1 + c_2 Y^{m_1}}{1 + c_3 Y^{m_1}}\right)^{m_2}$$

$$Y = L / 10000$$

- Either in the camera: OETF=HLG, with EOTF=HLG^-1

$$E' = \mathrm{OETF}[E] \begin{cases} \sqrt{3E} & 0 \le E \le \frac{1}{12} \\ a \cdot \ln(E-b) + c & \frac{1}{12} < E \end{cases}$$

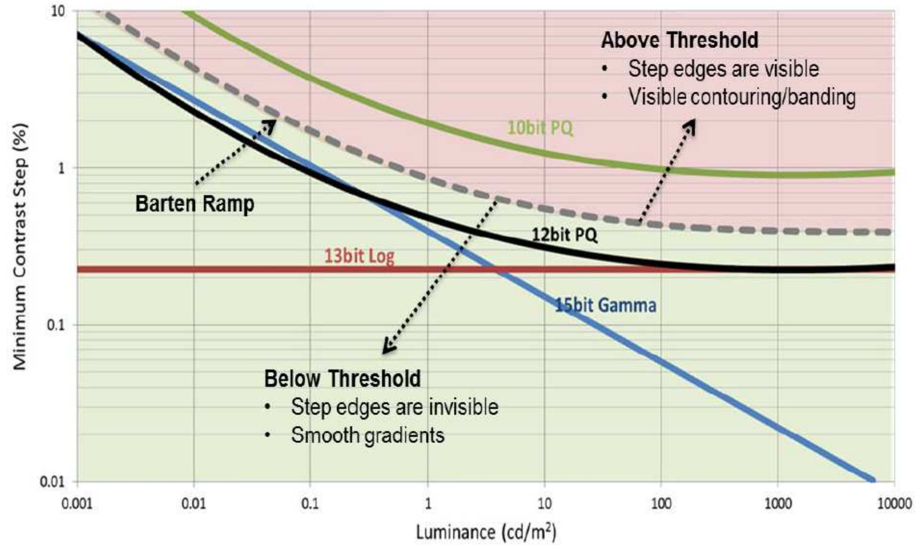
- Both need an OOTF in the camera which is not 1:1
  - Artistic, noise near black, infinite gain near black

Camera ⇨ OOTF ⇨ OETF | ⇨ EOTF ⇨ Display

----------Camera-------- -----Display---

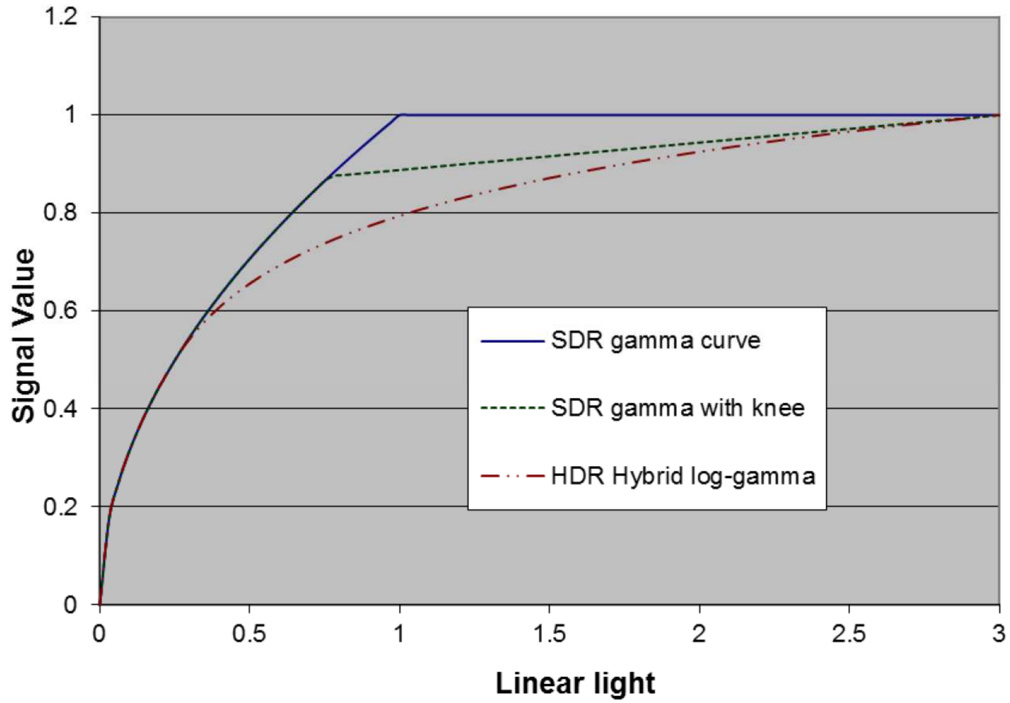
HDR solutions – SMPTE 2084 (Dolby PQ)

- A solution optimized to match quantization to human visibility
  - Pro
    - – Optimum use of the bit range
      - 10 bits enough for “noisy” camera signals
    - – Support up to 10.000nit displays
    - – The EOTF is part of the UHD blue ray standard
  - Con
    - – Limited compatibility for distribution
    - – HDR to SDR remapping needed
      - SDR to HDR remapping might be needed too

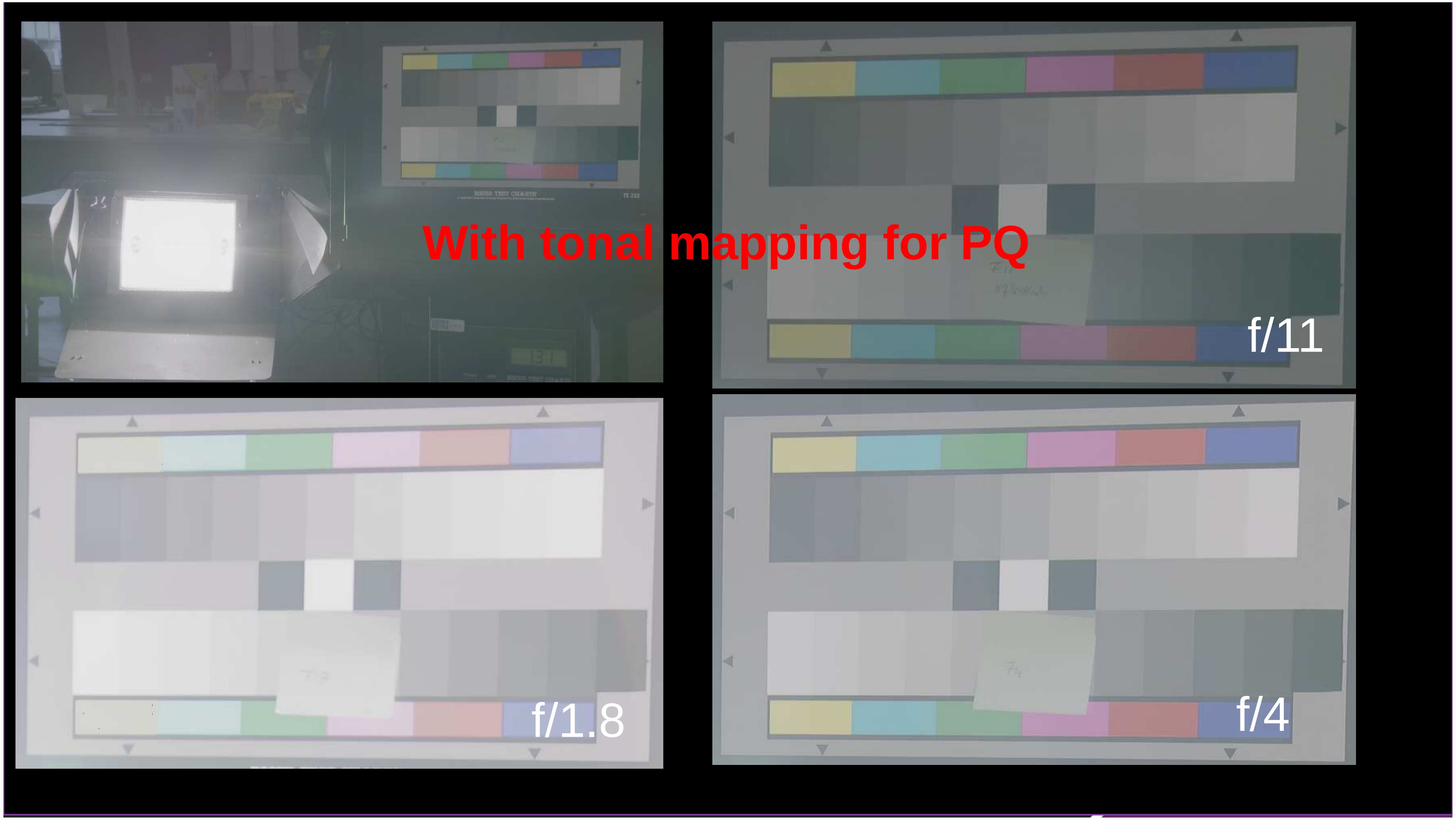


HDR solutions – BBC/NHK Hybrid log-gamma

- A „fully“ backwards compatible SDR/HDR solution
  - Pro
    - – Backwards compatible
    - – No change of infrastructure
  - Con
    - – Limited range of HDR
    - – Reduced SDR performance



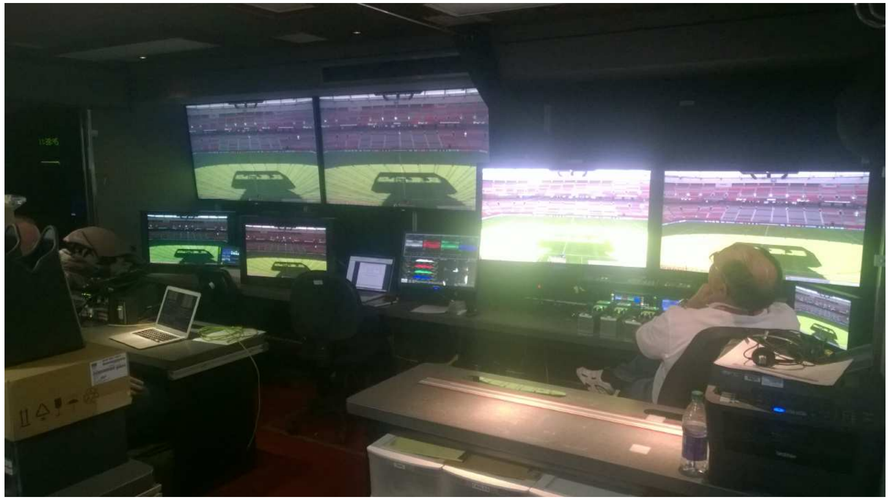
[redacted] **Hybrid log-gamma and SDR OETFs**


With tonal mapping for PQ
f/11
f/1.8
f/4

HDR for live applications – Test productions

- Since August 2014 we did multiple live HDR tests
  - From single camera shot at the European Athletics Championship…
    …to multiple camera production at the MotoGP…
    …several soccer production…

  - Extensive tests was done at the Woman Soccer World Cup in Canada
    – 1080i versus 1080p
    – HD versus 4K
    – SDR versus HDR



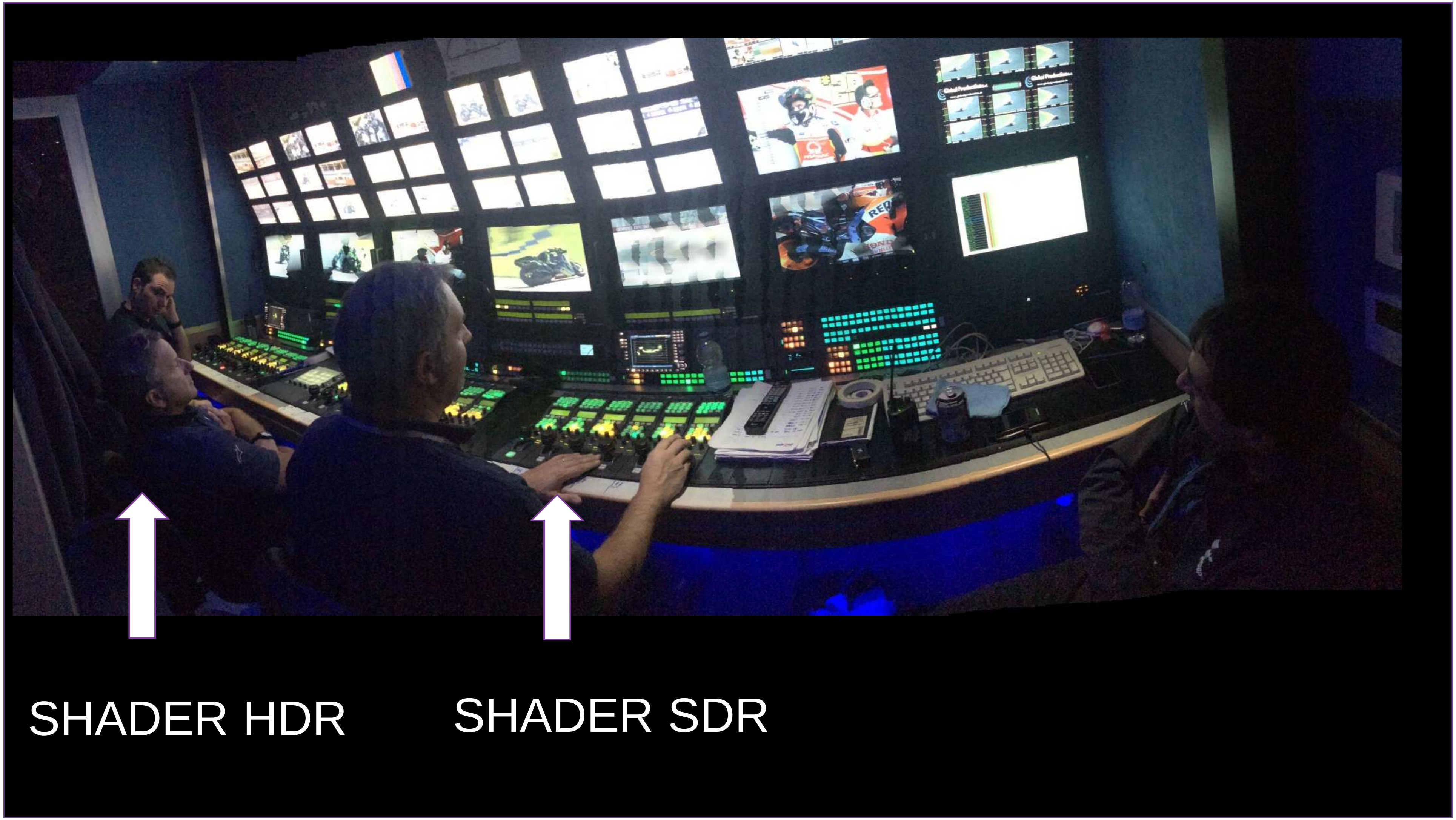
HDR - For challenging lighting conditions

- High scene contrasts are most challenging in live broadcast applications

  - Lighting conditions are typically not under control
  - Pictures must be perfect at any time, and can't be fixed in post

Motogp valencia


HDR feed
Life feed


SHADER HDR
SHADER SDR

Wrap-up

- Grass Valley moved from CCD only to CMOS only
- With signal levels as low as 3000 photons per pixel we get nice images to the HDTV-homes
- 4k in 2/3" comes at the cost of 2 f-stop lesser sensitivity and 8k at 4 f-stop
  - For sufficient MTF, in 4k, the lens should be at <f/ 8 (MTF=0 at Nyquist) preferably f/4 (MTF=50%)
- One of the big surprises of the HDR tests was the relative insensitivity to the lens f-number
  - The shader didn't have much to do even in difficult scenes with large contrast variation
  - Even the typical football field scenes with one part of the field sunny the other part of the field in the shadows where no problem at all and pleasing to view.
  - Images in 1080p HDR gave the viewer the experience as looking at 4k images.
  - Mapping in the camera is still in investigation, no standard yet. Specifically for the OOTF.