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CCD Technology for HD Production

Ian Sheldon

Sony Professional Solutions Europe

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Overview

- History
- HD camera market requirements
- CCD technology
- CCD Benefits
- HD technology in the production marketplace

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The road to HD CCD cameras

SD

HD

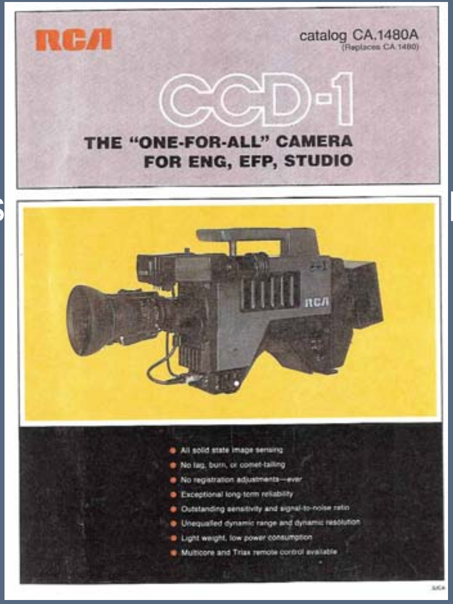
1960s — First Solid state X-Y imagers demonstrated

1979 — Bosch FDL-60 CCD-based telecine (line array) 1000 pixels

1982 — Sony makes 1“ Tube HD camera with NHK

1984 — First commercially available HD camera, Sony HDC-300 (1” Saticon Tube)

1992 — **First CCD HD camera, Sony HDC-500 (1” CCD)**

S  B

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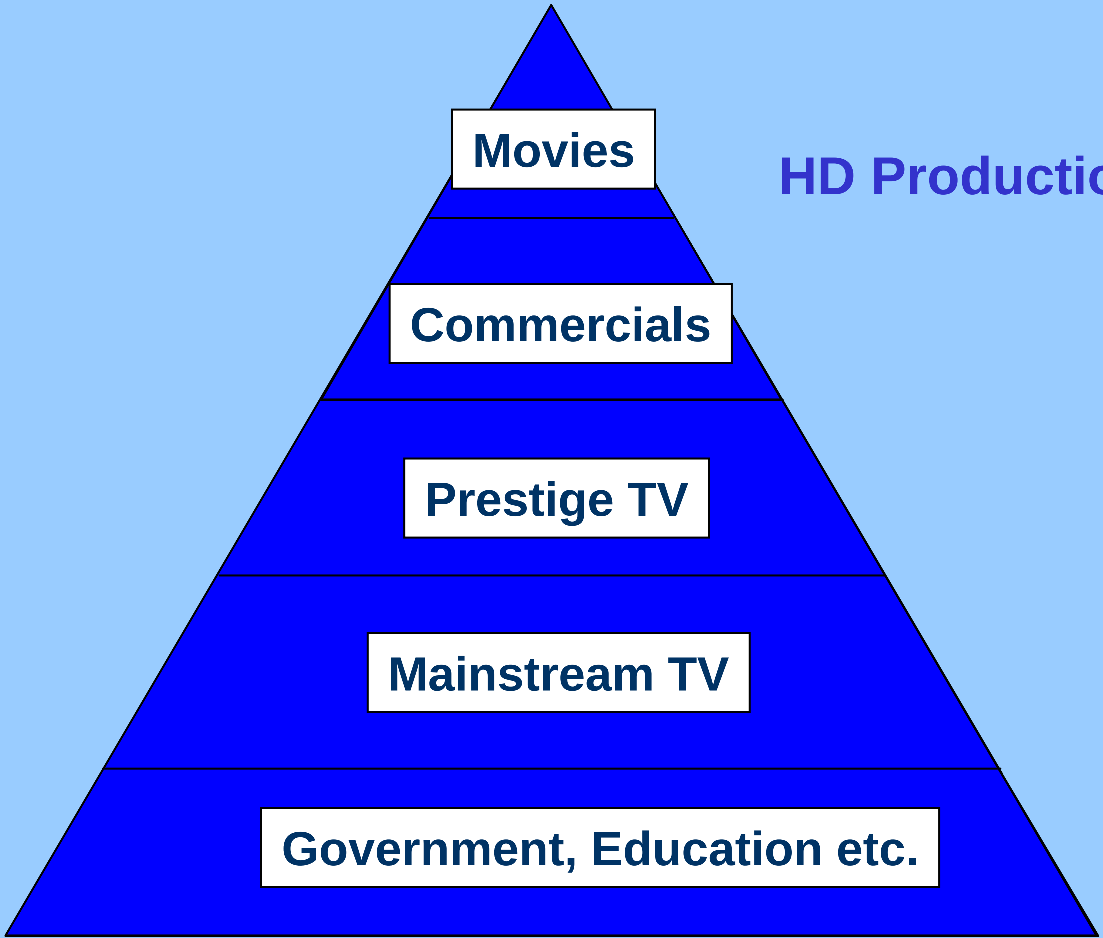
HD Customer Requirements

- Low noise
- High sensitivity
- No smear/blooming/highlight overload effects
- High resolution
- Low aliasing
- Lens compatibility (=2/3” Image format)
- Low power consumption
- Support for multiple frame rates
- Low cost

- Ease of manufacture

HD Applications



HD Production

Customer requirements will differ by application

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Imager technology

- CCD and CMOS
  - both use arrays of discrete pixels
  - both analogue devices
  - Both require A/D conversion process, usually external to the sensor

CMOS

- Individual charge-to-voltage convertors for every pixel
- Random access - pixels can be read out in any sequence, as required
- Voltage readout
- *Possibility* for integrated sensor and image processing

CCD

- Charge Coupled Device
  - Charge transfer through the device structure
- Single charge to voltage convertor at output
- Pixels addressed in predetermined sequence

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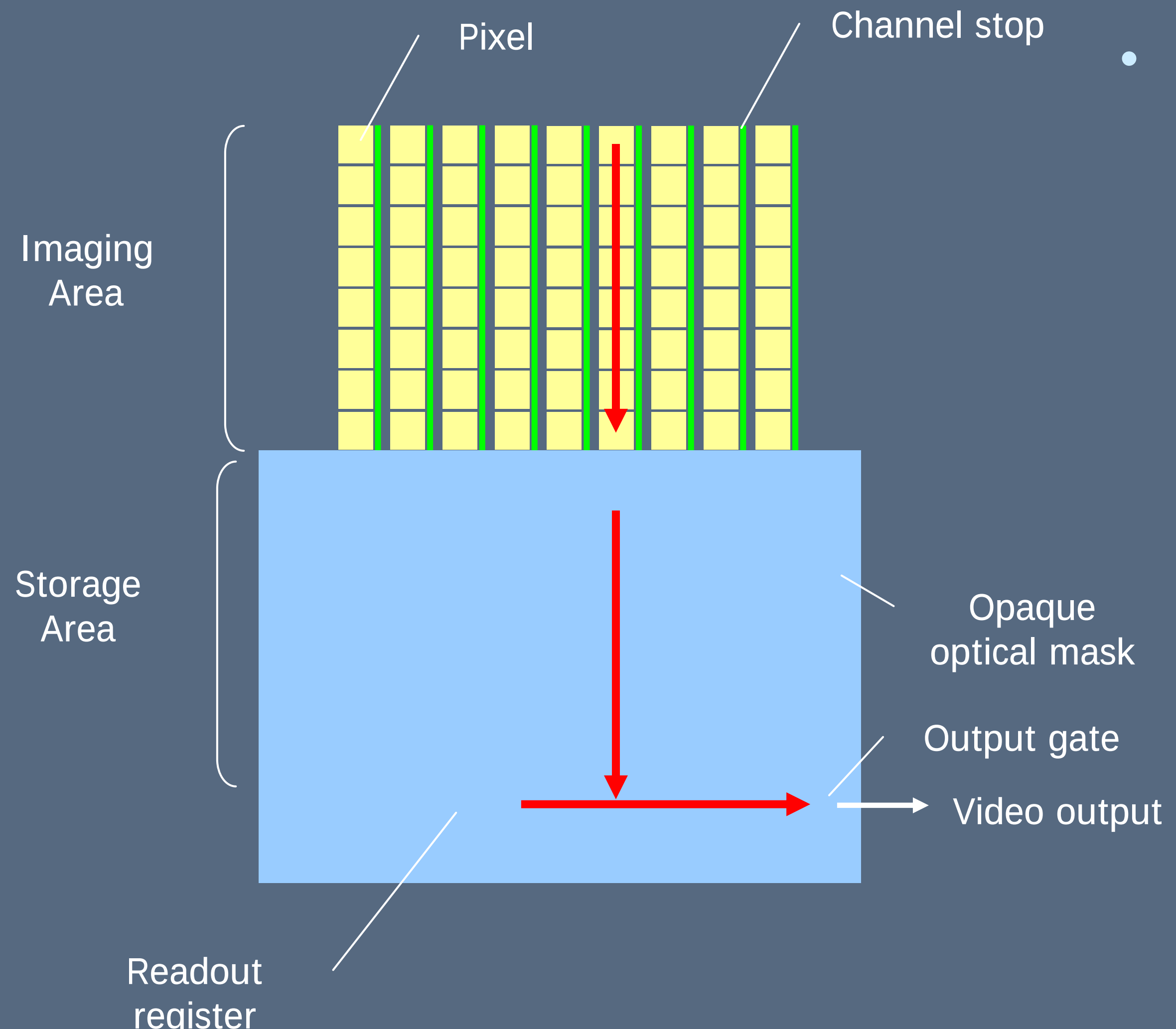
Types of CCD sensor

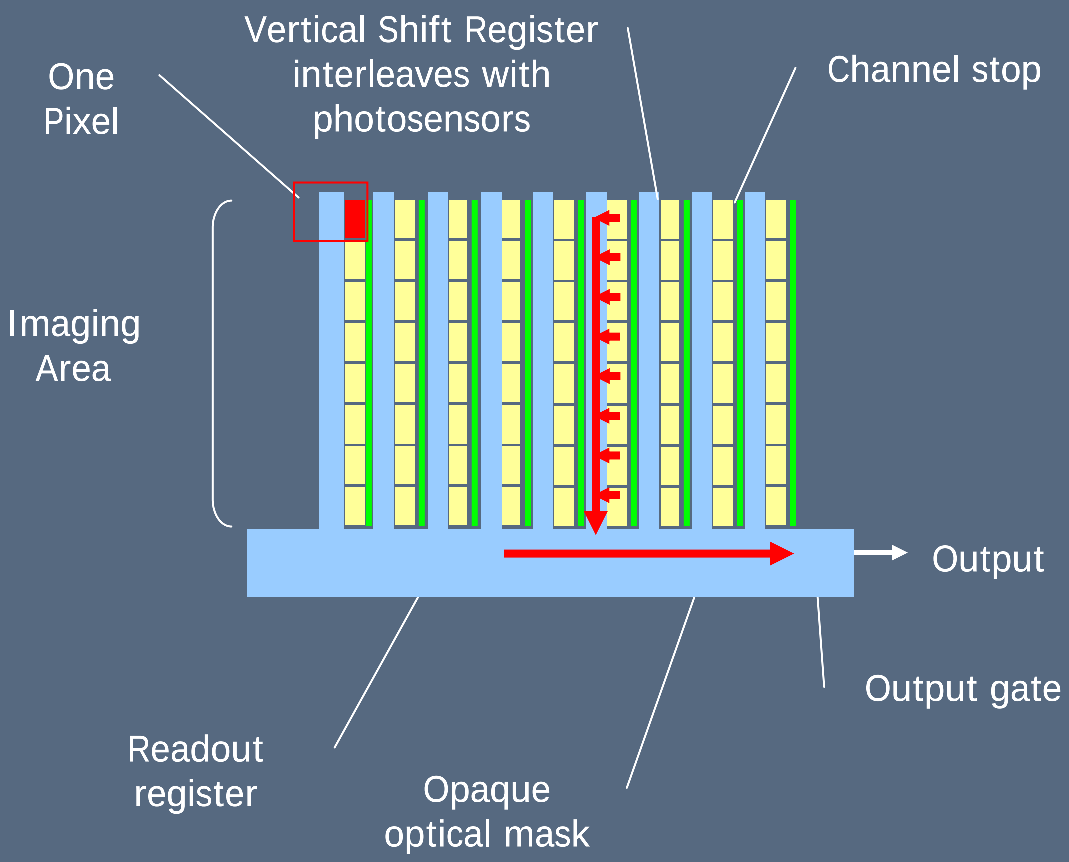
- FT (Frame Transfer)
- IT (Interline Transfer)
- FIT (Frame Interline Transfer)

Frame Transfer (FT)



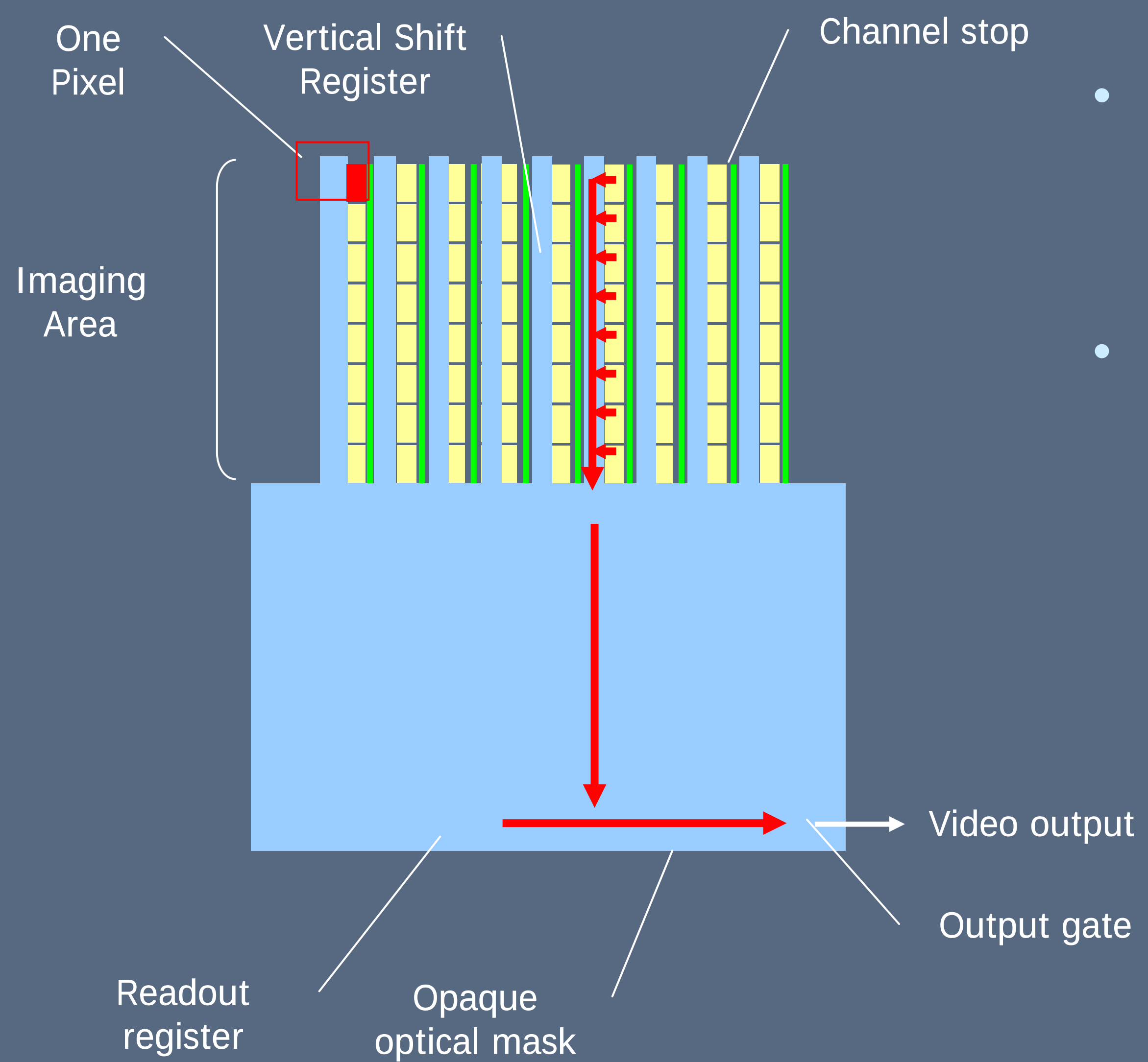
- Disadvantage:
  - requires optomechanical shutter
  - large physical size
  - pixels have to act as shift register
  - Rapid transfer to storage area is required

Interline Transfer (IT)



- Advantages
  - smaller physical size
  - Lower manufacturing cost
  - dedicated shift register
- Disadvantage:
  - smaller photosensitive area
  - possibility for light and/or charge to leak sideways into shift register to cause vertical smear

Frame Interline Transfer (FIT)



- Advantages
  - Separate storage area, immune to highlight effects
- Disadvantage:
  - large physical size
  - Complex structure

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CCD development

- In *concept*, CCD is unchanged since the mid 1980s
- In practice, there have been numerous refinements in the technology, and manufacturing process, leading to major user benefits

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Factors to be considered

- Noise
- Sensitivity
- Dynamic range
- Highlight artefacts
- Resolution
- Aliasing
- Dark current
- Lag
- Shading/uniformity
  - Black and white
- Spectral Response
- Colour fidelity
- Flare
- Readout speed
- Power consumption
  - Smaller technology
    - Reduced supply voltage
- "Dead" pixels

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Noise in CCD Sensors

- Many factors influence noise
  - Thermal noise, reset noise, 1/f noise
  - Optical shot noise
  - Fixed pattern noise
    - Caused by non uniformity of sensitivity and dark current
- Design improvements
  - Hole Accumulation Layer
    - Heavily doped layer at the surface of the sensor, used to minimise noise caused by impurities at the surface
    - Also eliminates lag due to poor readout efficiency
  - Correlated Double Sampling (CDS) readout amplifiers
  - Floating Diffusion Amplifier (FDA)

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Dark Current

- *Dark current* is signal output from the sensor when no light reaches it
- Early sensors suffered badly from this effect
- Strongly temperature dependent
- Leads to shading and other effects
- Can be compensated by sensing output from extra (optically shielded) pixels.

- HAD sensor dramatically reduced this phenomenon.

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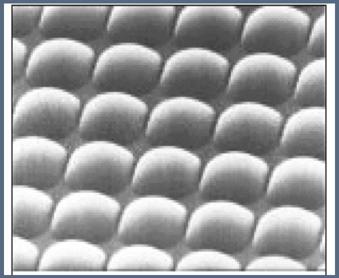
Sensitivity of CCD Sensors

- Increased pixel counts leads to smaller pixels, and hence lower sensitivity
- Countered by:
  - better optical conversion efficiency
  - Micro Lenses
    - Individual lenses located above each pixel



  - Note that different applications have differing sensitivity requirements

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Highlight handling of CCD Sensors

- Vertical smear
- Highlight blooming
- Highlight lag
  - Have all been limitations of CCD devices
  - Smaller pixel sizes for HD can lead to reduced overload margin
  - FT sensors can also suffer from highlight artefacts
- Improvements in internal sensor structure has eliminated most causes of highlight problems
  - FIT technology has become redundant

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Sony Power HAD EX CCD Technology Improvements

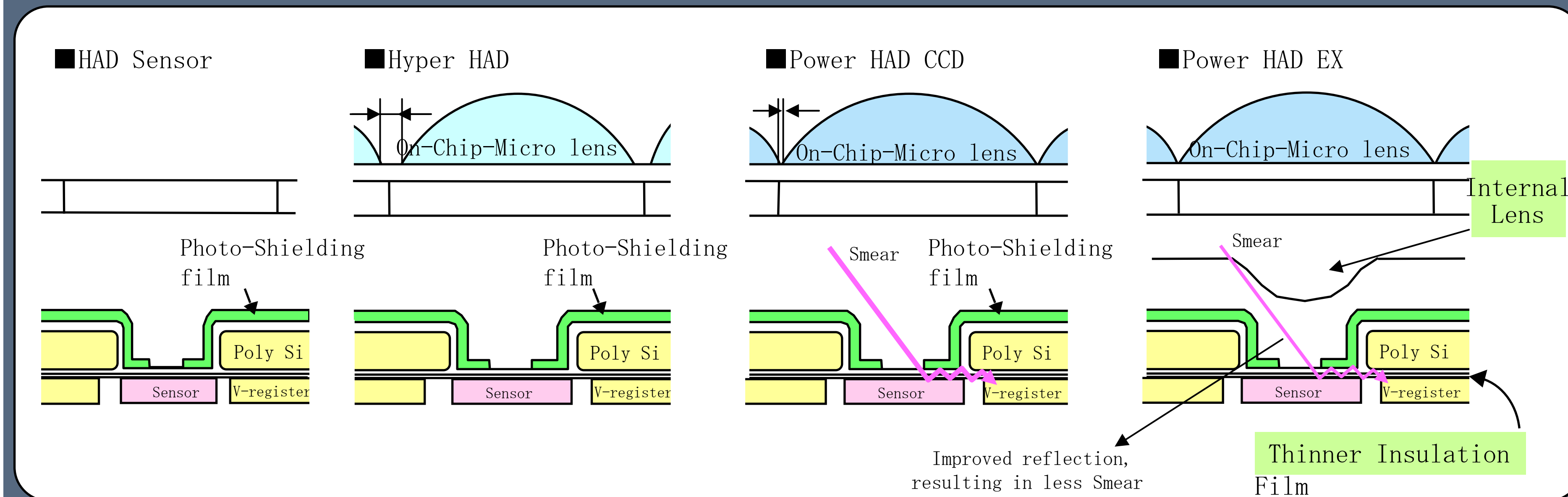
1985 HAD Sensor
- Low Dark Current
- E-Shutter

1990 On-Chip-Micro lens
- On-Chip-Lens Technology
  →High Sensitivity
  Low Smear

1998 Power HAD CCD
- Re-construction (Gapless)
  →High Sensitivity

1999 New Construction CCD
- Internal Lens
  →High Sensitivity
- Thinner Insulation Film
  →Low Smear

2001 Power HAD EX CCD
- Further Improvement
  →High Sensitivity
  Low Smear



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Power consumption

- Improvements in semiconductor technology have allowed the use of ever smaller cell geometry
- Smaller geometry can use lower operating voltage, hence lower power consumption
- Lower power leads to additional benefit with lower noise level
  - But increased pixel numbers

  = higher clock frequencies

  = <u>increased</u> power!

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Resolution and aliasing

- CCD resolution has risen to the point where in most circumstances it is the lens rather than the sensor which determines overall performance
- To minimise aliasing, good optical low pass filtering is required
  - Typically 3 dimensional LPF
- OLPF structure related to pixel size
  - Not possible with sensors which use variable pixel geometry

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Shading and Uniformity

- Early CCD sensors had very poor uniformity, leading to noticeable picture degradation at low video levels
  - “dirty window” effect
- Largely eliminated on modern CCDs
- Potentially a bigger problem on CMOS devices, due to individual pixel amplifiers.
- Can be compensated using stored noise cancelling pattern, but introduces additional processing delay.

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Spectral Response and Colour fidelity

- Early CCD sensors had poor blue sensitivity
  - early sensors used rear illumination of the sensor, which gave very low blue sensitivity
- Early CCD sensors had heavy infra-red filtering
  - Partially to reduce vertical smear due to deep electron generation
  - Partially to match plumbicon tube characteristics
- Modern devices have very wide spectral response

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Quality Control

- Any manufacturing process is subject to a certain level of failures
- What is an acceptable level?
  - 1%?
  - 0.1%
  - 0.000045%

  - That would represent one pixel failure on an HD CCD sensor!
  - In Sony broadcast CCD sensors, even this level is not acceptable

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Pixel Errors

- Pixels can have other failure modes, which result in a white spot (at black level) or dark spot (at white level)
- Not unique to any one type of sensor
- Pixel is still fully functional
  - Sony terminology is Residual Point Noise (RPN)
- Can be managed by compensation and concealment techniques
- These can be fully automatic and require no user intervention
- Undetectable in operation
- Provides effective field “repair”

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HD CCD Technology today

- CCD devices have a long and successful history
- Well proven, mature technology
- Main performance limitations have been identified and eliminated or minimised
- Provide very satisfactory, reliable and stable operation

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HD CCD Technology today

- Low noise
  - Fundamental technology improvements
- High sensitivity
  - Not quite at SD camera levels, but close
- Wide dynamic range/highlight handling
  - As good, or better than SD
- High clock rates, at reasonable power level
  - Frame rates up to 1080p/50
- Aliasing
  - Well controlled
- Shading
  - Negligible

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CCD - CMOS Comparison

	CCD	CMOS
Sensitivity	Excellent Efficiency of O-E conversion	Good Efficiency of AMP gain
S/N	Excellent FD AMP	Poor Performance of Transistor
Dark Current	Excellent Exclusive Process	Good CMOS LSI Process
Smear	Good Fundamental Phenomenon	No Smear Can be ignored
D-Range	Good	Good Depending on pixel no.
Power Consumption	Good	Excellent

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CMOS Benefits

- High speed
- Random access (scan invert, variable readout size
- No smear
- Low power
- Potential for integration with processing

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The future

- CMOS technology now starting to reach maturity
- Already in use for HD
  - Consumer
  - High-end
- Has benefits if higher resolution and/or higher frame rates are required
- Probably inevitable that it will spread to other applications
  - But the industry has more than 20 years experience with CCD technology, that will not be easily replaced

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HD in the real world

- Over 2000 units of Sony HD studio and OB cameras are in use world wide

HDCAM

- Over 5000 units of Sony HDCAM camcorders are in use worldwide
- And now, …..

HDV

- Since the beginning of 2005, more than 15000 units (consumer and professional) have been sold.
- HD for Everyone