

ESSCIRC 1999 :
**“CCD or CMOS image sensors
for consumer digital still photography ?”**

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Outline

- Introduction
- Principle of CCD and CMOS imagers
- Imager requirements
- Overview CCD vs. CMOS : resolution, signal-to-noise ratio, angular response, dark current, dynamic range, linearity, pixel uniformity, architecture
- Summary and Conclusions

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Introduction

- CMOS is challenging CCD
- Digital still is emerging imaging market
- Today : almost exclusively CCD in DSC
- Tomorrow : CCD or CMOS ?

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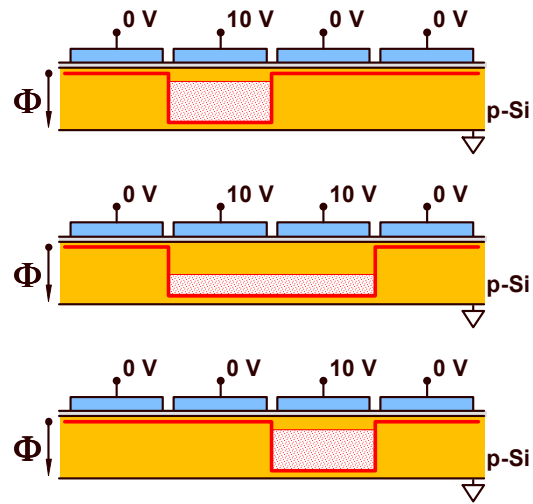
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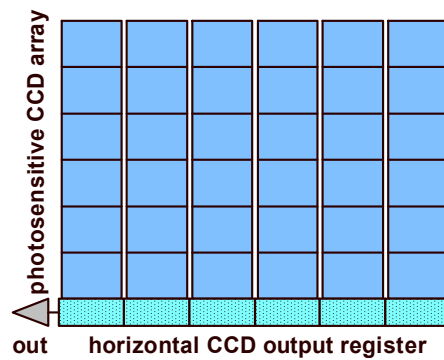
CCD principle (1)



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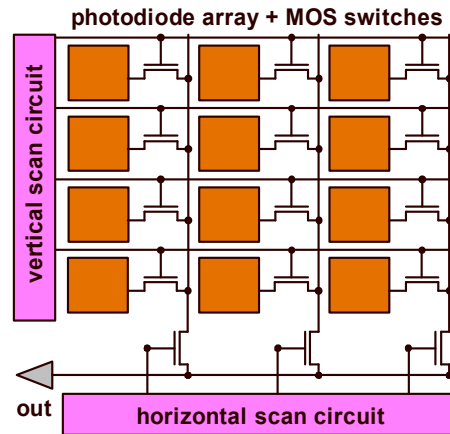
CCD principle (2)



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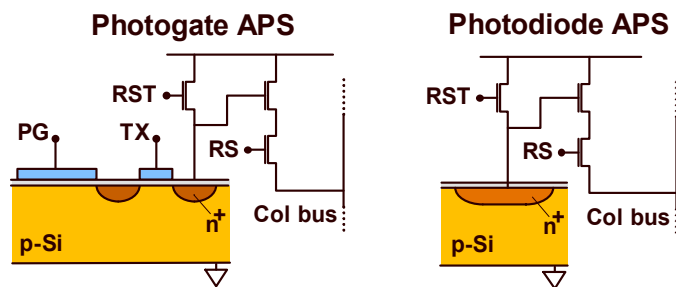
CMOS principle (1)



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CMOS principle (2)



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Image Sensor Aspects (1)

IMAGER
PARAMETER

CAMERA
SPECIFICATION

resolution



sharpness

signal-to-noise ratio



ISO speed

angular response



min. F-stop

dark current



max. exposure
time

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Image Sensor Aspects (2)

IMAGER
PARAMETER

CAMERA
SPECIFICATION

dynamic range



latitude

linearity



colour fidelity

pixel uniformity



granularity

architecture



features

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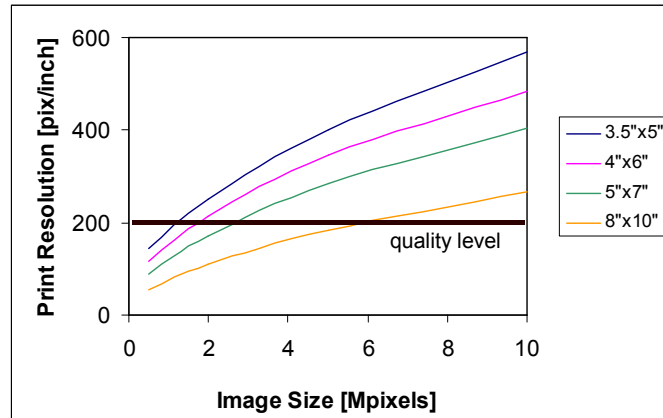
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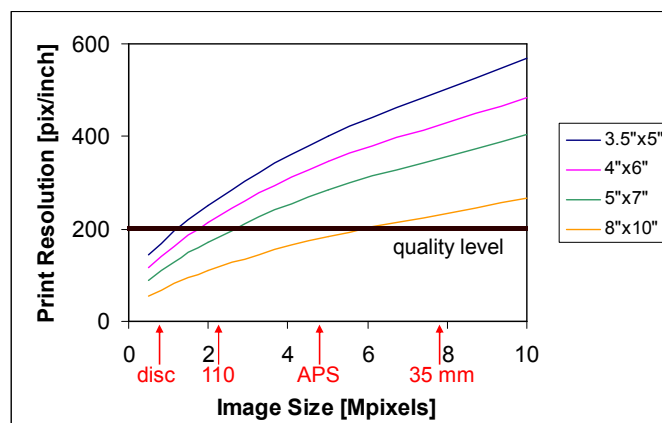
Resolution Requirements (1)



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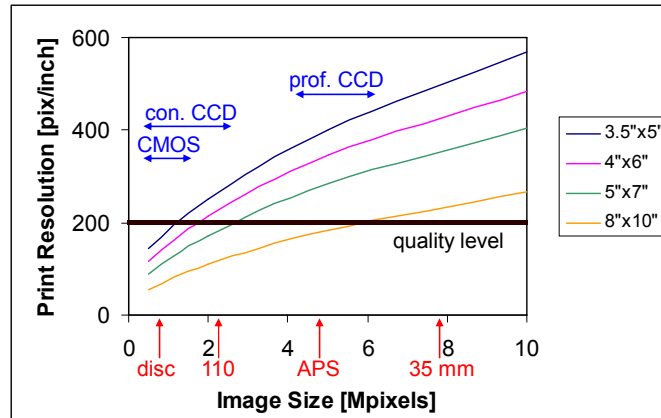
Resolution Requirements (2)



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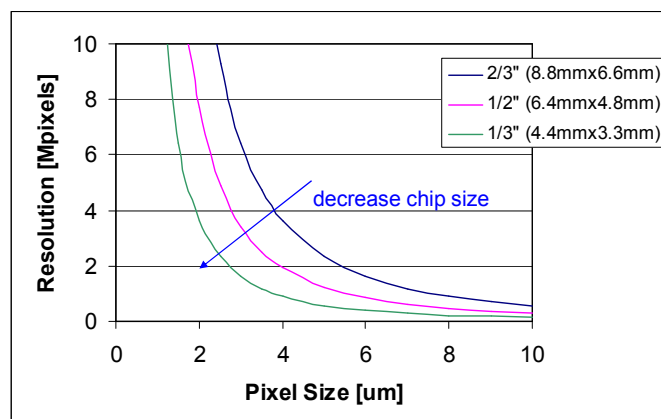
Resolution Requirements (3)



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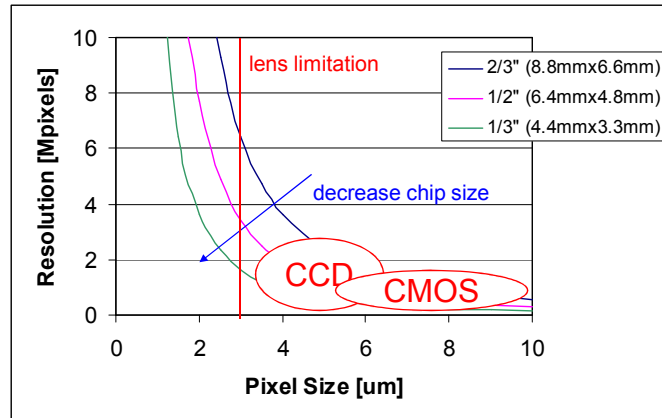
Trend in Resolution (1)



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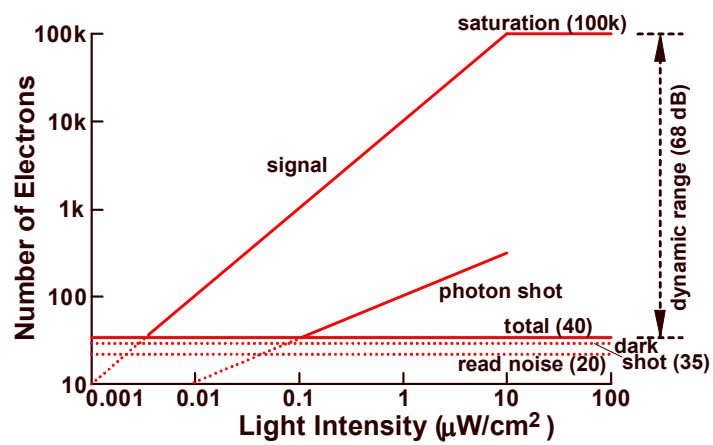
Trend in Resolution (2)



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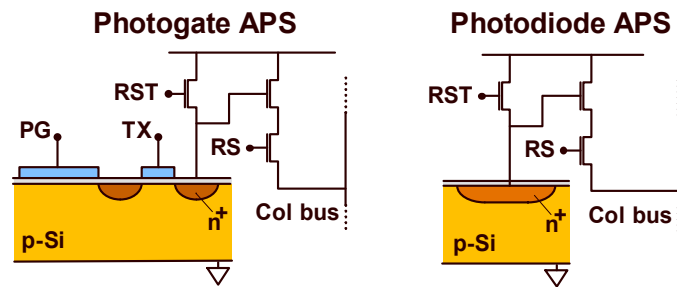
Signal-to-Noise ratio (1)



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Signal-to-Noise ratio (2)



FREE of reset noise

NOT FREE of reset noise

LOW light sensitivity

HIGH light sensitivity

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Signal-to-Noise ratio (3a)

$$ISO_x = \frac{10}{H_x}$$

ISO_x = ISO-speed @ S/N=x
 H_x = exposure to get S/N=x

$$ISO_{40} \propto A \cdot QE$$

A = pixel area

QE = quantum efficiency

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Signal-to-Noise ratio (3b)

$$ISO_{10} \propto \frac{A \cdot QE}{N_r}$$

ISO_x = ISO-speed @ S/N=x

A = pixel area

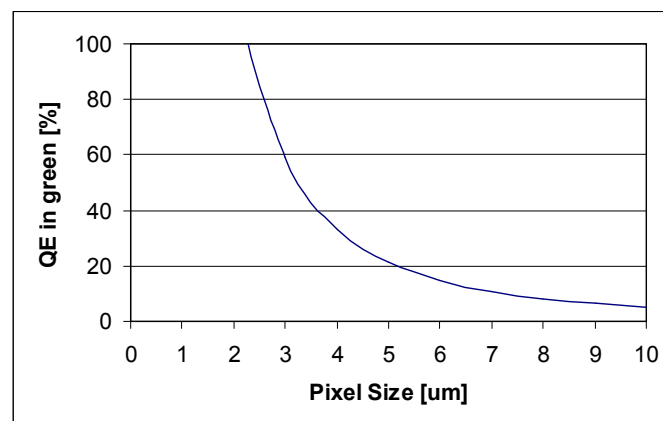
QE = quantum efficiency

N_r = read noise

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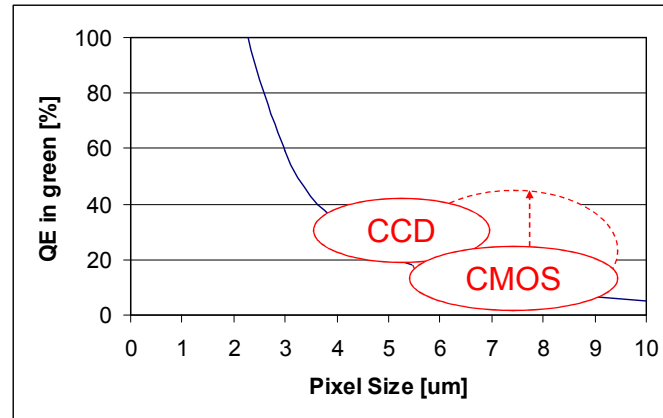
Signal-to-Noise ratio (4)



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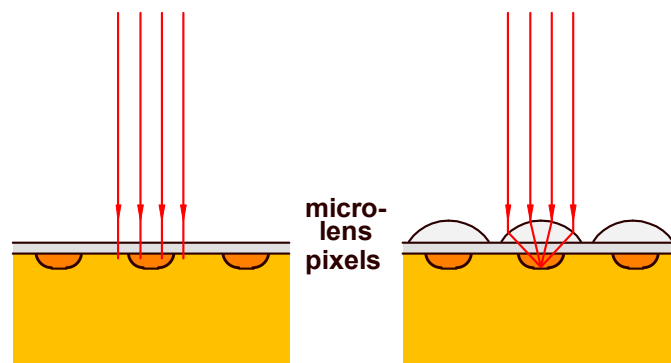
Signal-to-Noise ratio (5)



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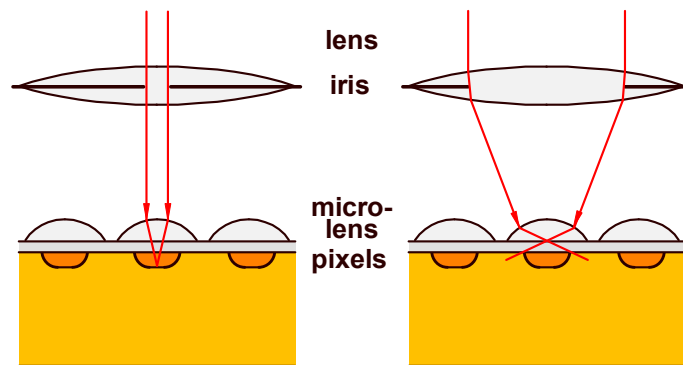
Improvement QE (1)



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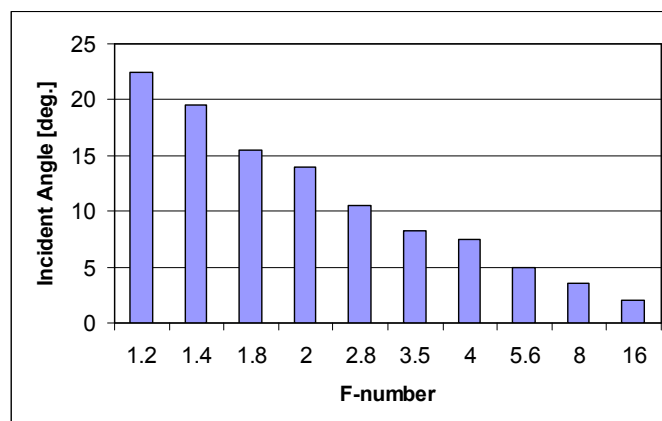
Improvement QE (2)



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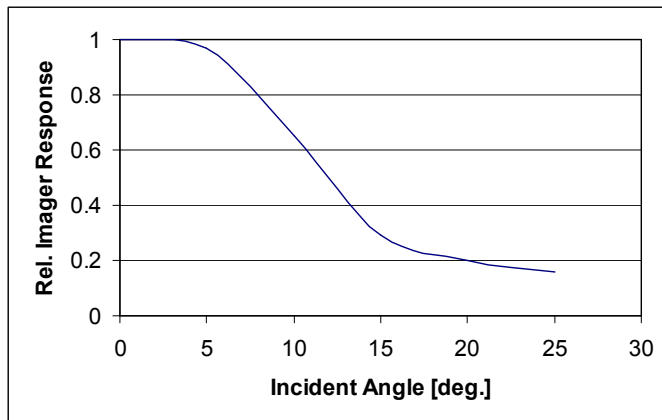
Angular Response (1)



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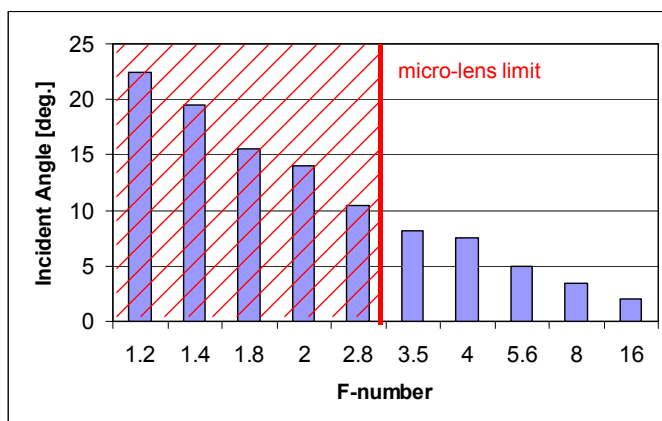
Angular Response (2)



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Angular Response (3)



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Dark Current (1)

- prof. CCD 3 pA/cm² @ RT
- cons. CCD 10 pA/cm² @ RT
- standard CMOS 500 pA/cm² @ RT

Dark current doubles every 6 ... 8°C.

Example : @ 60°C : 32 times higher !

@ -100°C : 32,000 times lower !

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Dark Current (2)

- Compensation for dark current is possible !
- Compensation for dark-current non-uniformities is possible !
- Compensation for dark-current shot-noise is **NOT** possible !

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Dynamic Range (1)

$$DR = \frac{Q_{sat} - Q_{dark}}{\sqrt{N_r^2 + N_{dark}^2}}$$

DR = dynamic range

Q_{sat} = saturation signal

Q_{dark} = dark signal

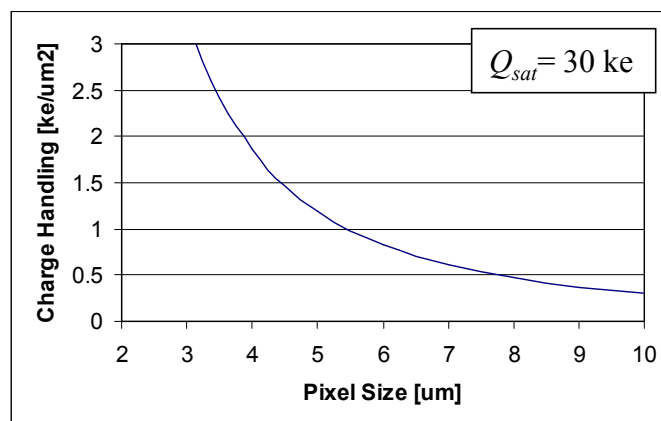
N_r = read noise

N_{dark} = dark shot noise

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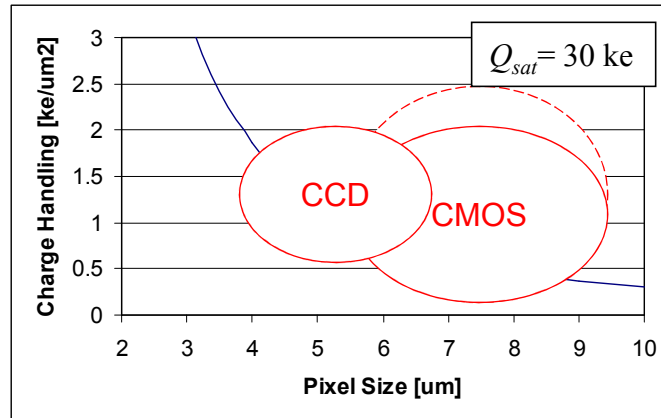
Dynamic Range (2)



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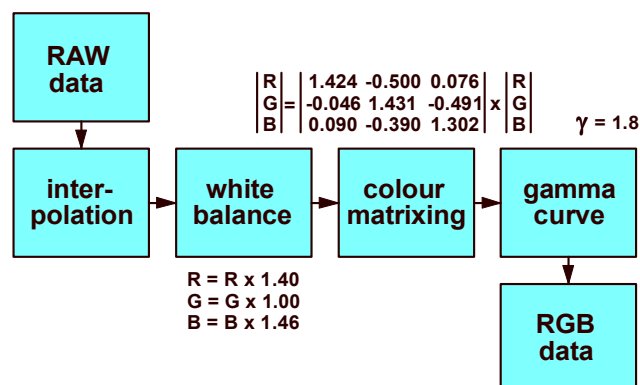
Dynamic Range (3)



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Linearity (1)



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Linearity (2)

- Due to sampling in colour space :
Interpolations,
- Filters do not match perfectly : **Colour corrections.**

- Linearity CCD : 99 % (for 70 % of Q_{sat}),
- Linearity CMOS : 97 % (for 70 % of Q_{sat}).

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Pixel Random Non-Uniformity

- PRNU CCD : < 0.7 ... 1.0 %,
- PRNU CMOS : < 2.0 ... 5.0 %.

- Can be corrected by LUT,
- To be non-visible : PRNU < photon shot noise (0.5 % for 40 ke).

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Architecture (1)

- CCD : parallel integration/reset
- CMOS : rolling integration/reset

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Architecture (2)

- CCD : parallel integration/reset
- CMOS : rolling integration/reset
- can be solved by 1 T and 1 C per pixel extra ...
- costs sensitivity, charge capacity, noise, ...

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Summary (1)

- Resolution : pixel size of CCD smallest
- Noise : CMOS pixels suffer from reset noise
- Quantum efficiency : CMOS and CCD can be similar
- Angular response : limits set by micro-lenses
- Dark current : CCD outstanding

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Summary (2)

- Saturation level can be similar
- Dynamic range of CCD is higher
- Linearity of CCD is better
- Pixel uniformity of CCD is better
- Device architecture of CCD gives more flexibility

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Conclusions (1)

**CCD or CMOS image sensor
for consumer digital still
photography ?**

CCD ? **YES !**

CMOS ? **YES, provided that noise and
dark current problems can be solved !!!**

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Conclusions (2)

- Main issue : performance
- Then benefit from :
 - low power of CMOS,
 - low driving voltages of CMOS,
 - on-chip functionality,
 - selective read-out mechanism,
 - cost advantage.

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Important Remark

This presentation was about digital still photography. For video applications the situation is completely different !!!

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References

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