Elaborazioni di Immagini per Dispositivi Mobile

Ing. Alessandro Capra

Advanced System Technology

11 March 2008

STMicroelectronics

Agenda

- Introduction
- Mobile camera Devices
- Pre-processing: Auto Focus, Auto Exposure
- Color interpolation
- Color interpolation
- Noise management
- Noise estimation
- Croma management
- Codecs still/video
- Codecs still/video
- Applications
- Red eye

INTRODUCTION

Who I am

- 1998: University degree in Electronic Engineering
- 1999: Joined ST
- ST Mission: "*To offer strategic independence to our partners worldwide, as a profitable and viable broad range semiconductor supplier*"
- AST Mission: "*To provide the advanced system technology able to establish ST as the leading company in the system on a chip market*"
- Imaging Team: founded 1999, currently 13 employs + 2 collaborators

Who You are

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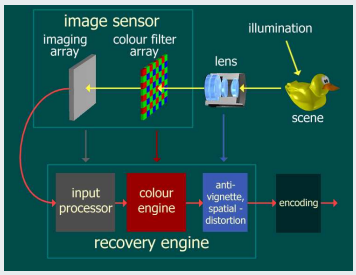
Developed Algorithms

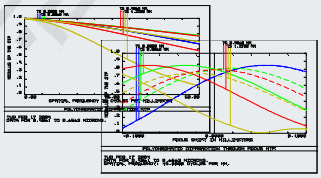
Wide range of applications aimed to cover all the steps of a image reconstruction pipeline, from the sensor to the final encoded output



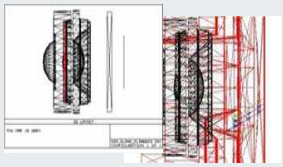
- Defect pixels removal / Noise Reduction
- Anti Vignetting
- Auto Focus
- Geometric Distortion Correction
- Depth of Field Extension
- Auto White Balancing
- Colour Interpolation and false colour removal
- Automatic Contrast Enhancement
- Expected Colour Rendition
- Digital Image Stabilisation (Video and Still)
- HDR & Dynamic Range Extension
- Adaptive Zooming
- Tone Mapping
- Panoramic view
- Fixed length visual lossless Bayer and colour compression
- JPEG rate control
- DCT artefact removal

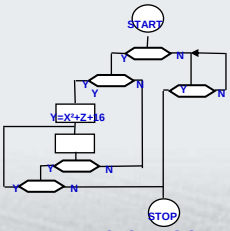
Miniature Camera Required know-how

Optics

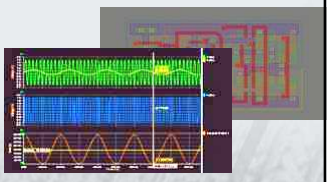


Mechanics





DSP/Algorithms



Electronics

Vision

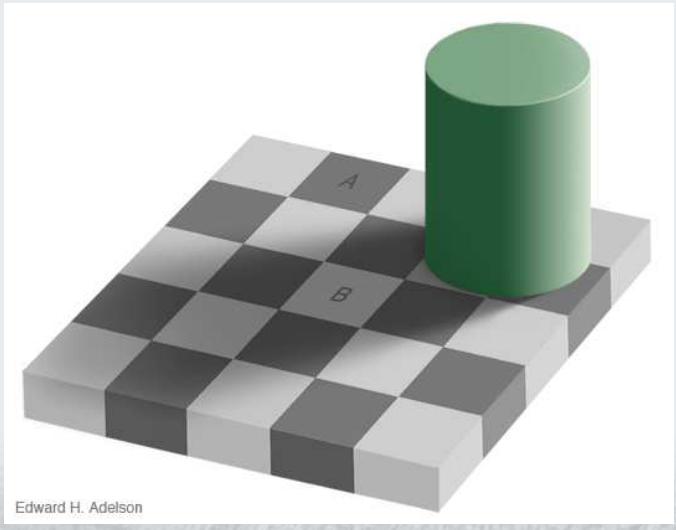
With the Highest QUALITY

This translates to:

- QUALITY
- USABILITY:
  - Enhanced User Interaction
  - Sharing
  - Archiving

STV0986 + VB6850 3MP

Eye is magic…



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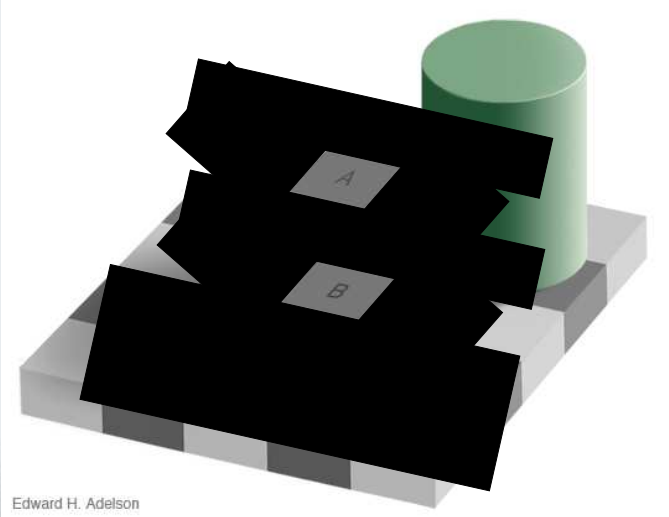
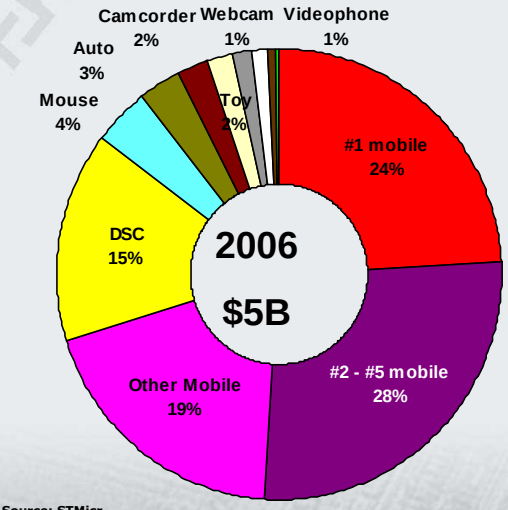


MOBILE CAMERA DEVICES: OVERVIEW

Camera Phones now account for 2/3 of the WW Imaging Market*

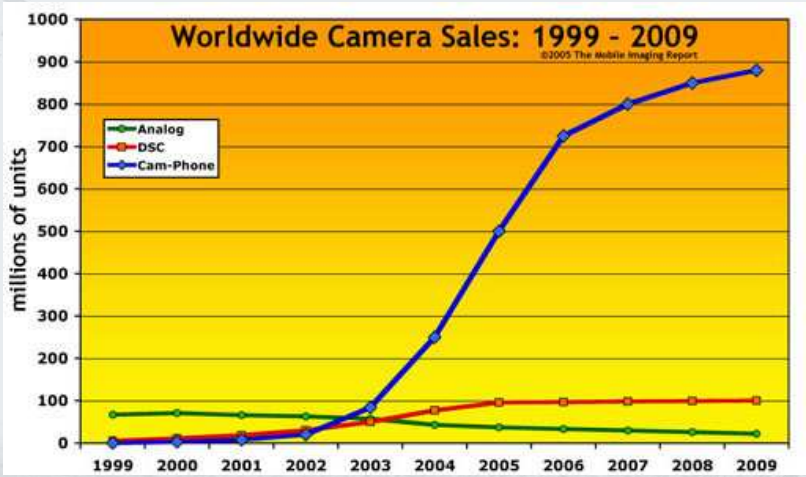


- Market now dominated by camera phones
- Camcorder segment declining
- Automotive segment becoming perceptible
- Other new markets yet to emerge

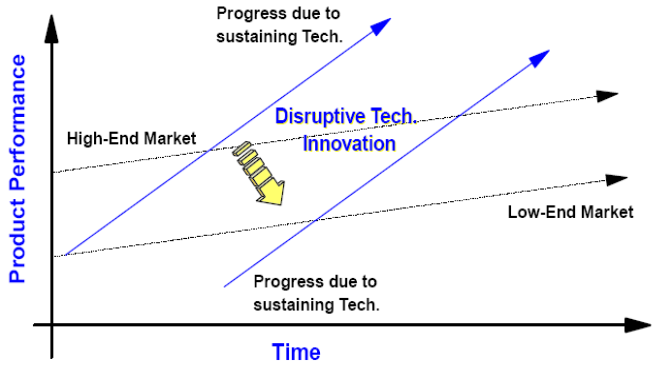
Source: STMicr.

* excluding CCD sensors

WW Camera Market



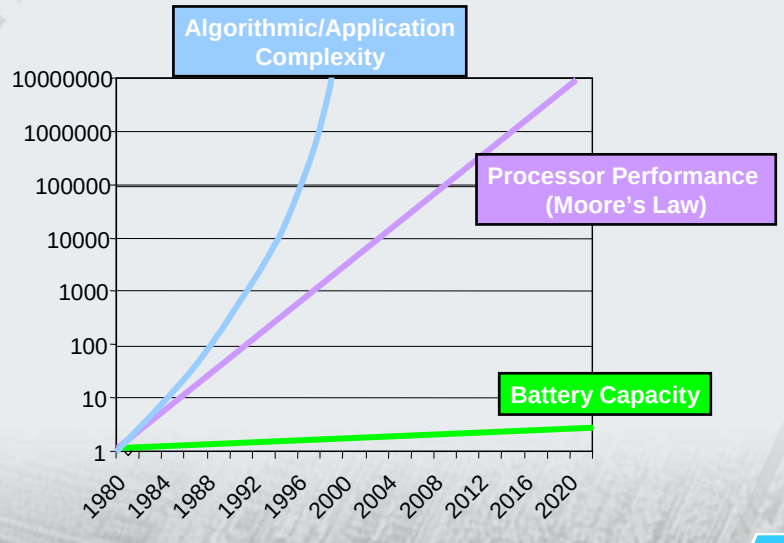
CMOS Image Sensor: A disruptive technology



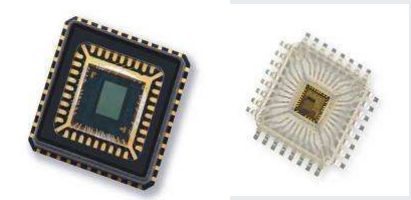
- **Sustaining Technologies:** "Technologies improving the performances of established products".
- **Disruptive Technologies:** "Technologies that underperform established products in mainstream market. But they have other features [...] cheaper, simpler, smaller, and, frequently, more convenient to use".

Source: C.M. Christensen Innovators Dilemma HBS Press

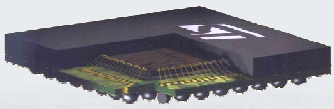
The challenge for embedded computing architecture



STMicroelectronics Imaging Products

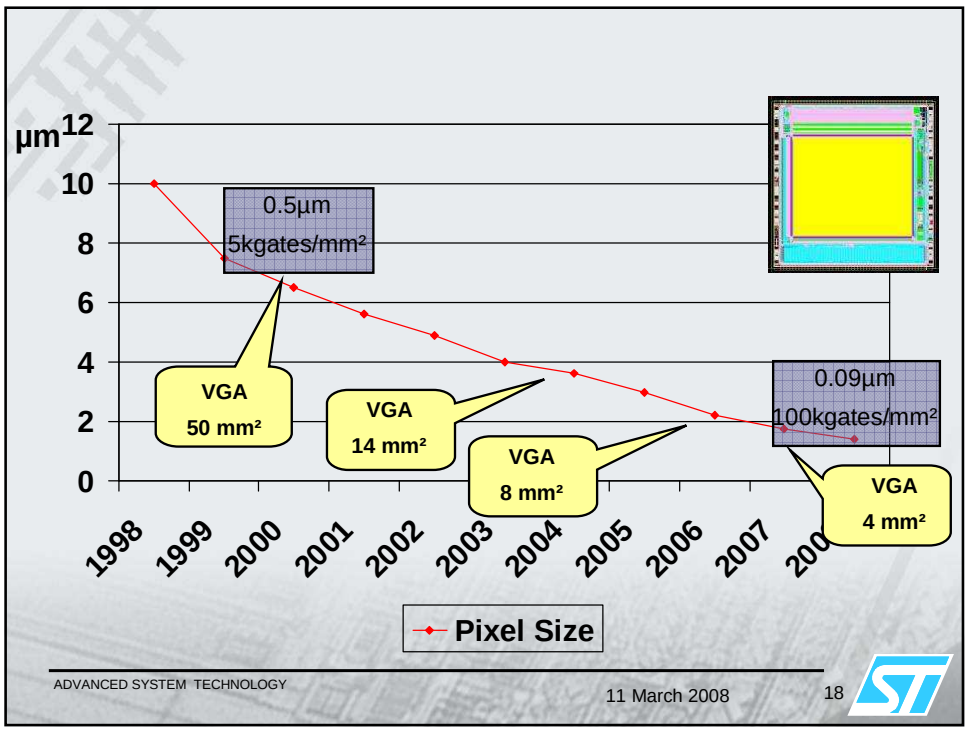


1. CMOS Sensors



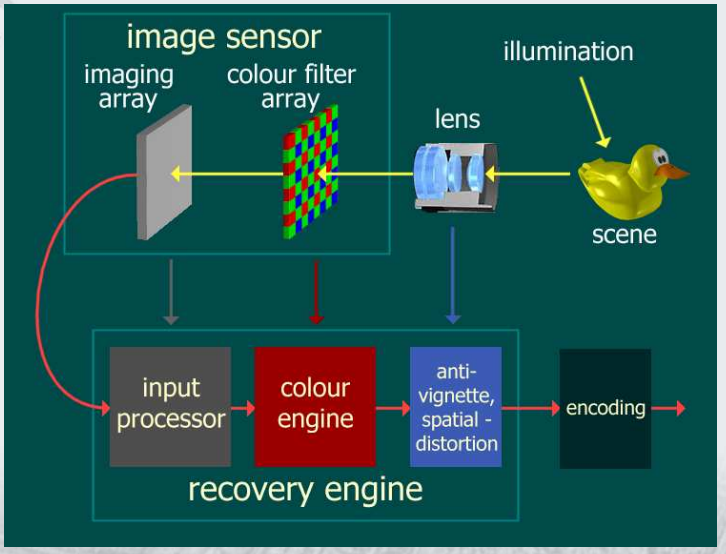
2. ISP

3. Micro-modules



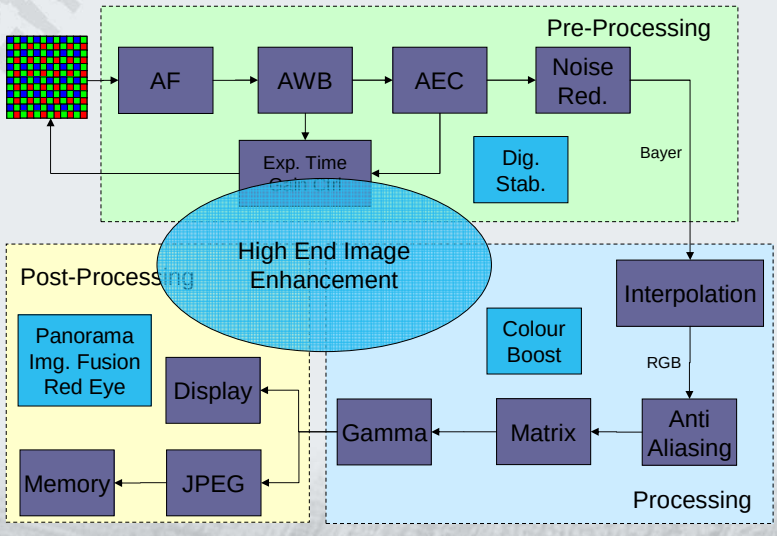
VGA Module : smaller and smaller

System: The Yellow Duck



PROCESSORS & INTERFACES

Processor: Algorithm Pipeline



Processor: High Level Performances

Nikon
- Nikon image processing engine

Canon
- Digic III
- Vivid Photo
- Photo Optimizer Pro
- iSAPS

Kodak
- KAF
- Colour Science Image Processing
- Perfect Touch
- Easy Share

SAMSUNG
- DNIe

PHILIPS
- Natural Motion
- LifePix
- Pixel Plus

SONY
- WEGA
- Digital Reality Creation
- RGBE CCD

JAVA MIDP 1.0

OpenGL ES x

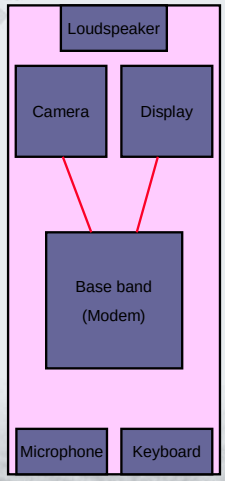
Quality

Computational Power

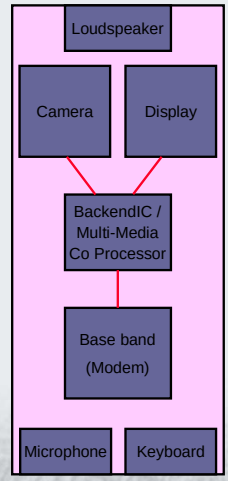
Power Consumption

Camera-Phone Architectures

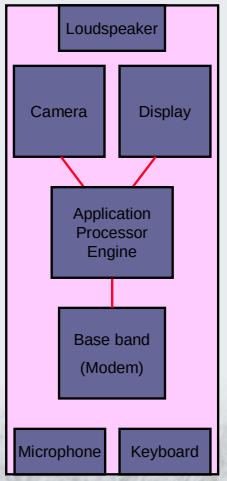
Single Chip phone
Legacy Baseband or Super Basebands



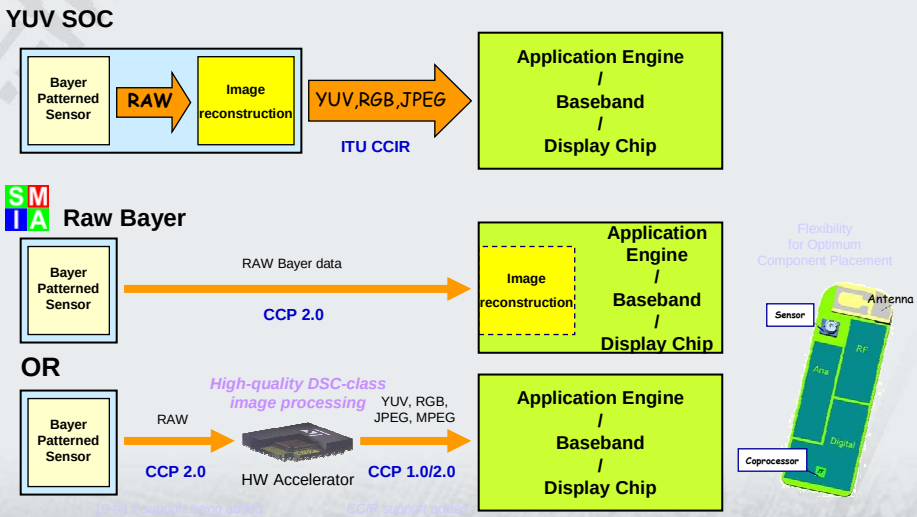
2 Chip Phone
Baseband + BackendIC



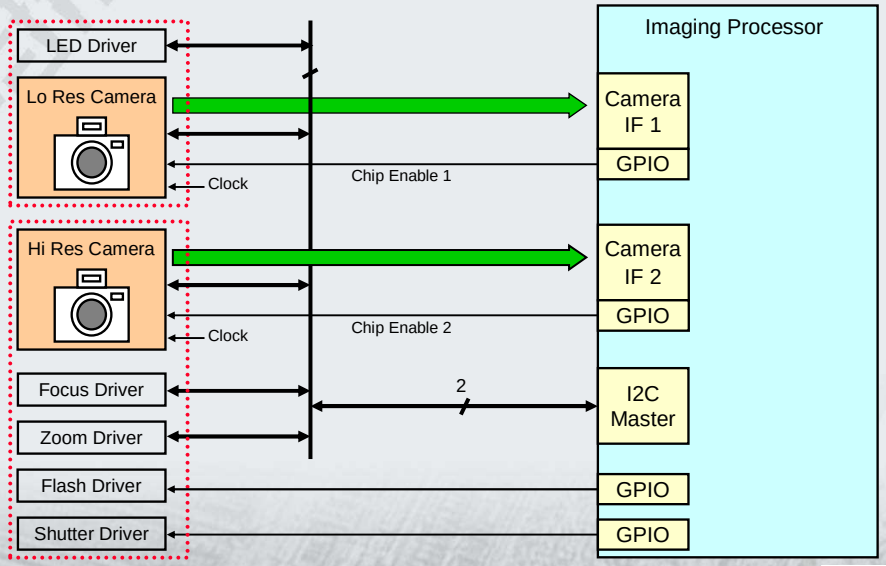
2 Chip Phone (High End)
Baseband + APE



Camera System Partitioning in Mobile Phones



Increasing Functionalities & System Complexity



Standard Mobile Imaging Architecture

Multi sourcing

- The standard supports the volume growth of cameras in mobile phones by allowing components to be commoditised.

Serial interface

- The standard includes a high speed serial interface for high frame rate, low pin count and low EMC emissions

Efficient / Versatile ISP architecture

- The standard can support an efficient architecture where ISP is integrated in the host device
- Versatile as the same device can be used with integrated or discrete ISP.

SMIA is a Complete Camera Module Spec

- Standard Frame/Field Format
- Standard Register Map Functions
  - Set-up
  - Control
  - Sensor Capabilities
- SMIA SW architecture
- Logical device driver

- Electrical Serial Interface, CCP2
  - Max bandwidth 650Mbps
- Output Image Format
  - Raw Bayer Data

- Reference architecture
- Example Camera Device Driver

Functionality
Serial interface
Software
Mechanics
Characterisation
Reliability

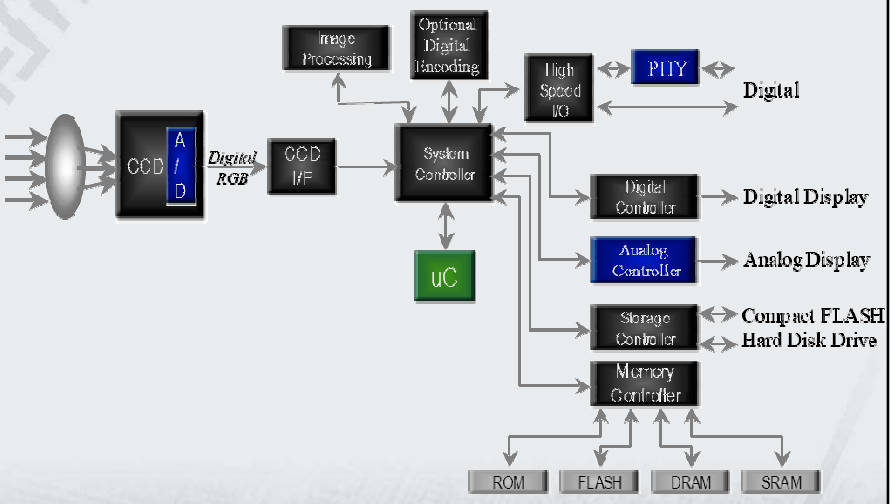
SMIA 1.0

- Sizes (SMIA65, SMIA85, SMIA95)
- Socket variants (SMD, through hole, flex)
- Optional EMC shielded

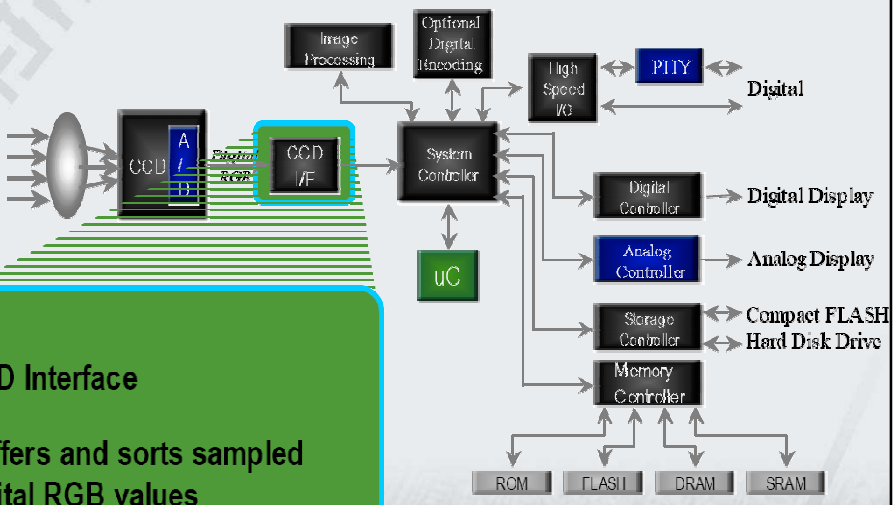
- Characterization Methods
  - Functional performance
- Test methods

- Qualification test requirements

Processor: Architecture



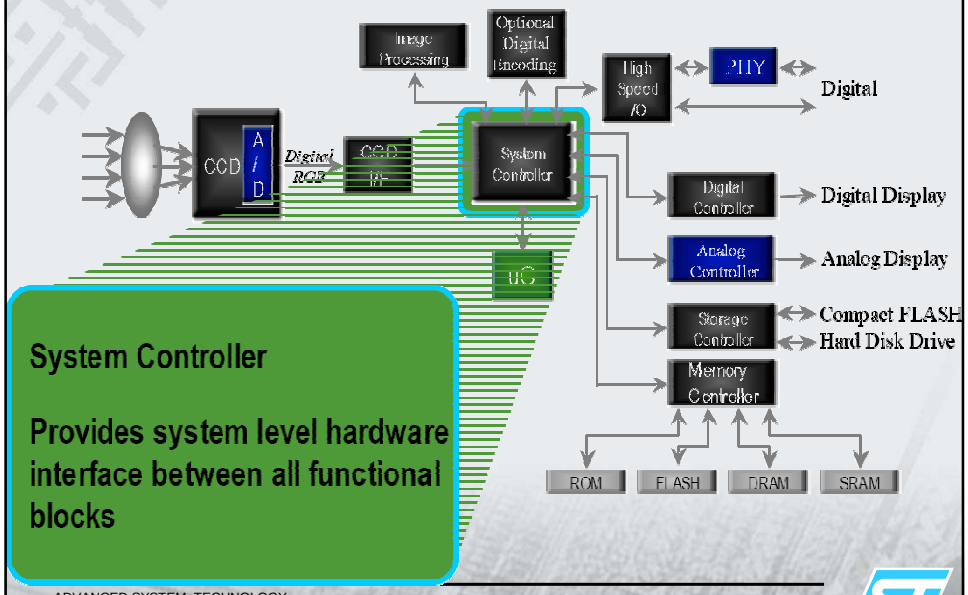
Processor: Architecture



CCD Interface

Buffers and sorts sampled digital RGB values

Processor: Architecture



System Controller

Provides system level hardware interface between all functional blocks

Processor: Architecture

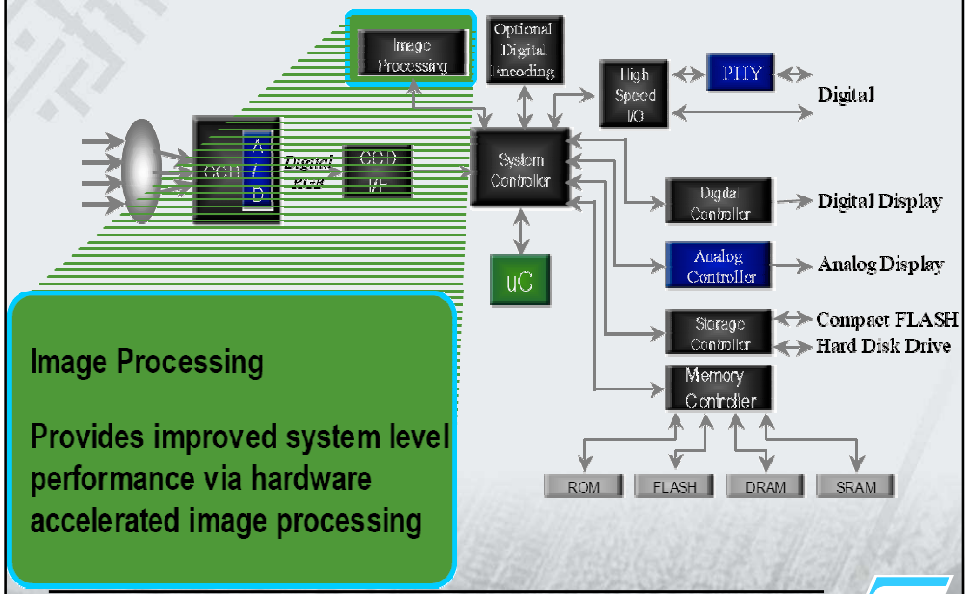
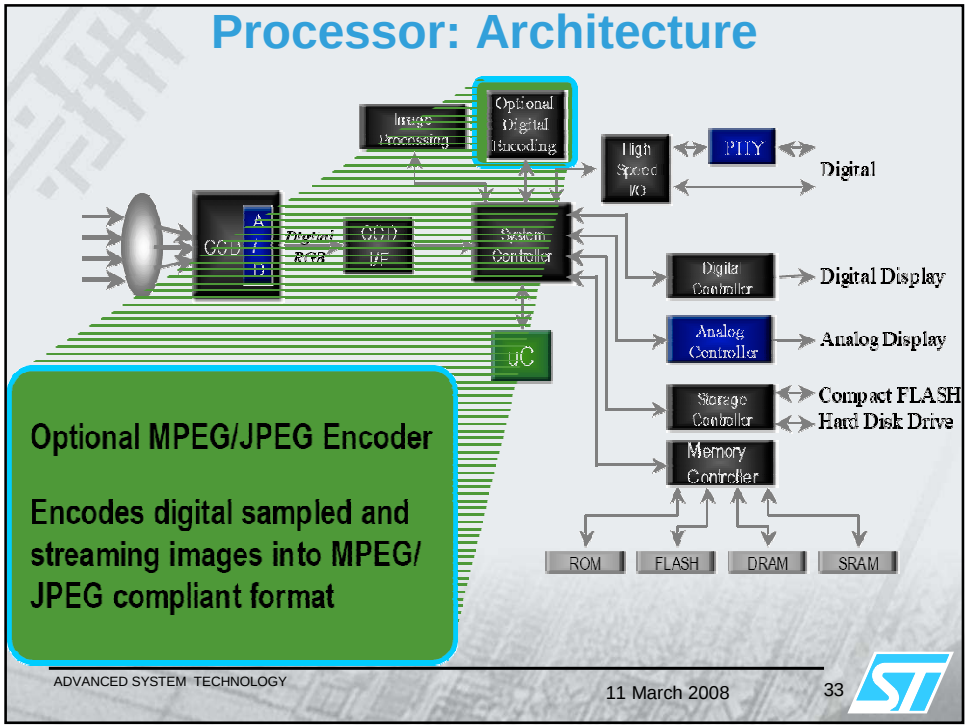


Image Processing

Provides improved system level performance via hardware accelerated image processing

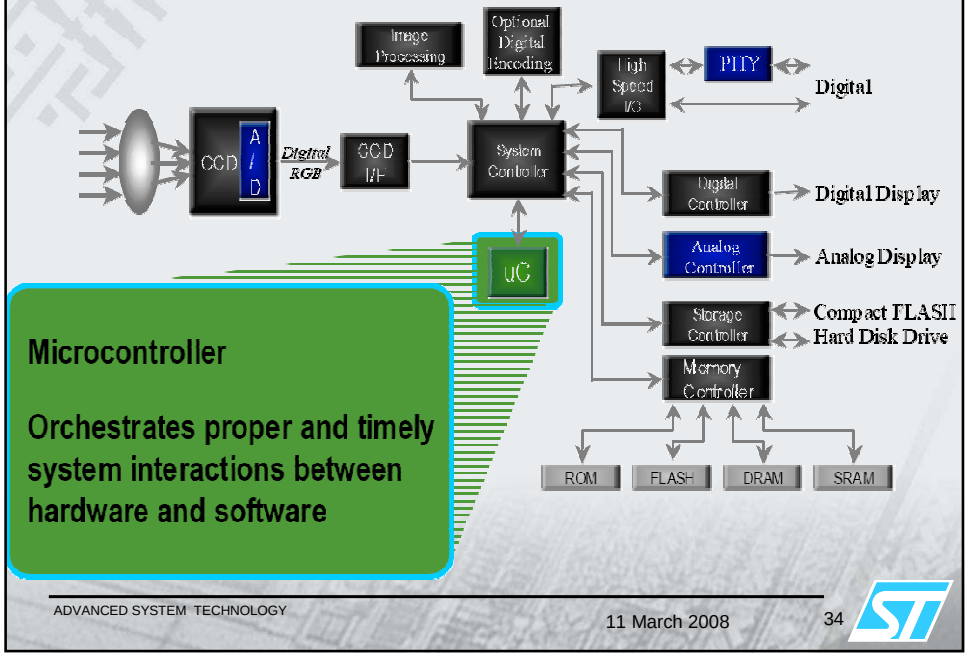
Processor: Architecture



Optional MPEG/JPEG Encoder

Encodes digital sampled and streaming images into MPEG/ JPEG compliant format

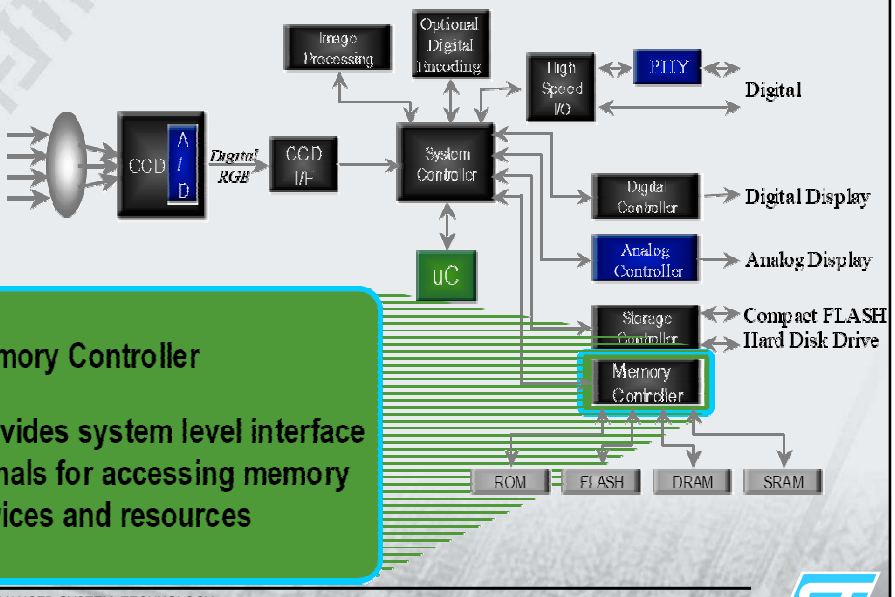
Processor: Architecture



Microcontroller

Orchestrates proper and timely system interactions between hardware and software

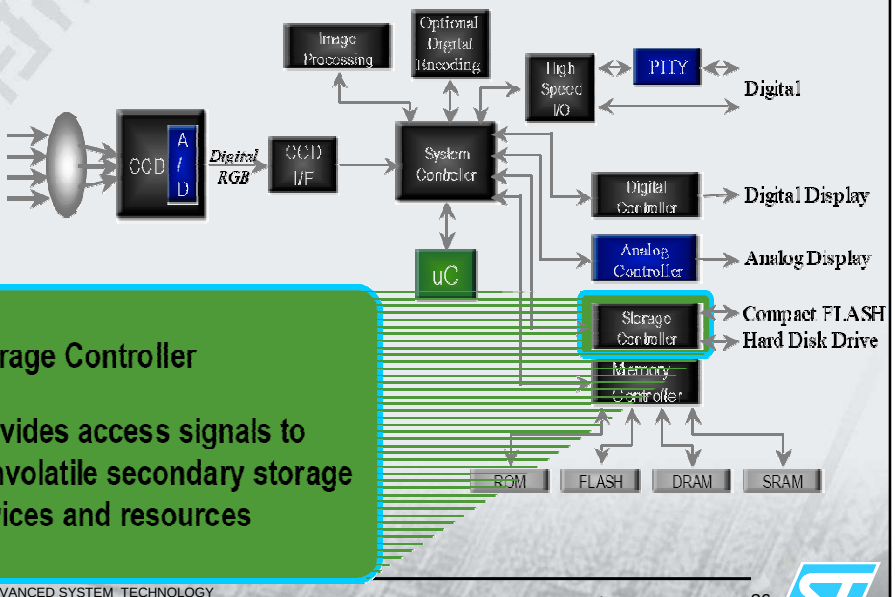
Processor: Architecture



Memory Controller

Provides system level interface signals for accessing memory devices and resources

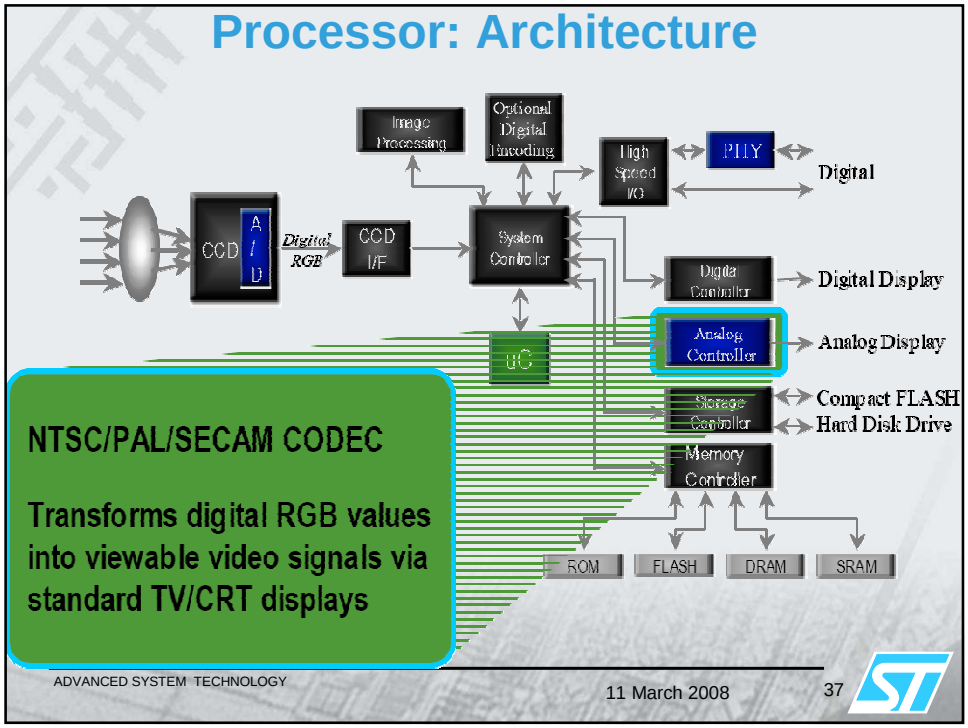
Processor: Architecture



Storage Controller

Provides access signals to nonvolatile secondary storage devices and resources

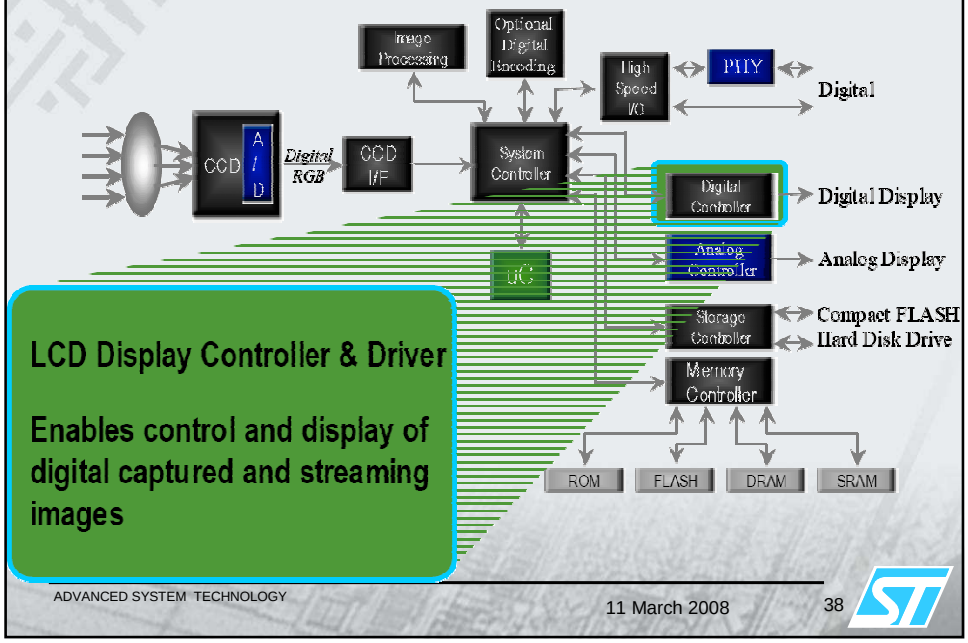
Processor: Architecture



NTSC/PAL/SECAM CODEC

Transforms digital RGB values into viewable video signals via standard TV/CRT displays

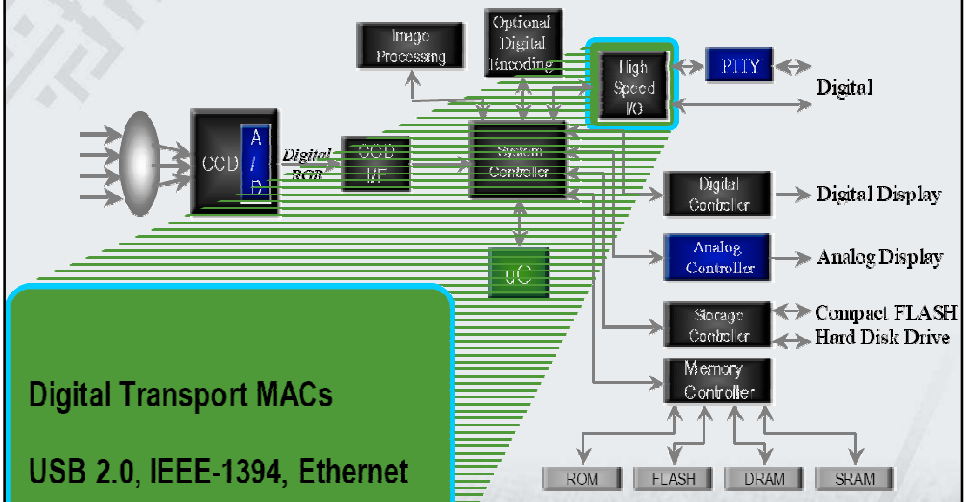
Processor: Architecture



LCD Display Controller & Driver

Enables control and display of digital captured and streaming images

Processor: Architecture

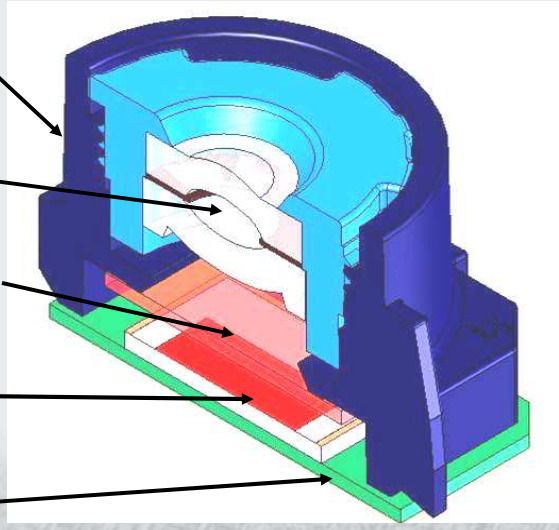


Digital Transport MACs

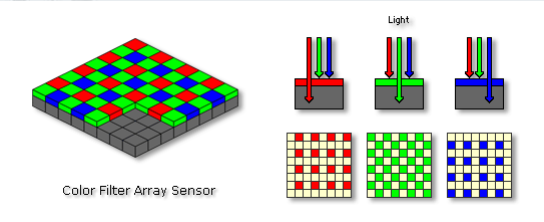
USB 2.0, IEEE-1394, Ethernet

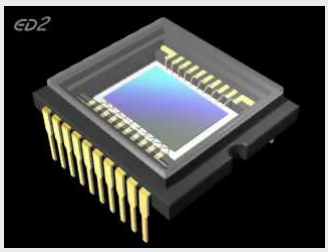
SENSOR MODULE

Miniature camera: inside view



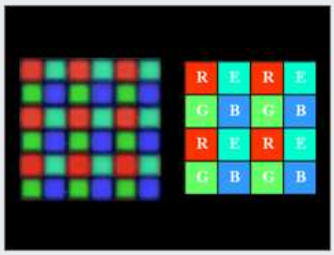
Colour Filter Array





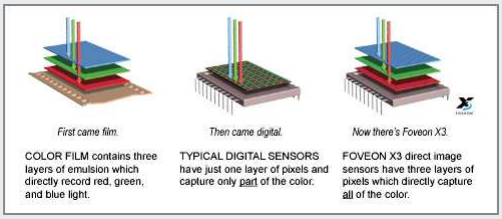
Each "pixel" on a digital camera sensor contains a light sensitive photo diode which measures the brightness of light. Because photodiodes are monochrome devices, they are unable to tell the difference between different wavelengths of light. Therefore, a "mosaic" pattern of colour filters, a colour filter array (CFA), is positioned on top of the sensor to filter out the red, green, and blue components of light falling onto it. The GRGB Bayer Pattern shown in this diagram is the most common CFA used since 1976.

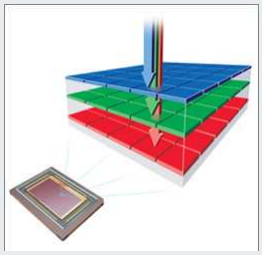
CFA: 4 colours filters



Instead of the traditional RGB color filter array this CFA is made up of Red, Green, Blue and Emerald (like Cyan) color filters. Sony claims that this expands the gamut of color which the sensor can capture and greatly improves color response.

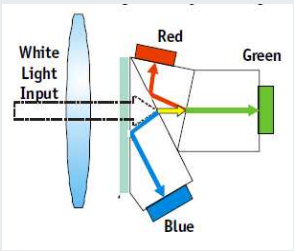
CFA: 3 layers sensor





Foveon X3 image sensors have three layers of pixels. The layers of pixels are embedded in silicon to take advantage of the fact that red, green, and blue light penetrate silicon to different depths – forming the first and only image sensor that captures full color at every point in the captured image.

CFA: 3-CCD Technology



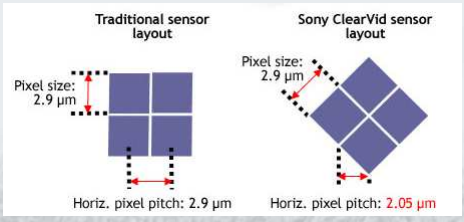
Canon, Philips

For each pixel all colour components are acquired.
For best image quality and ease of use, separation prisms should have a few simple characteristics:

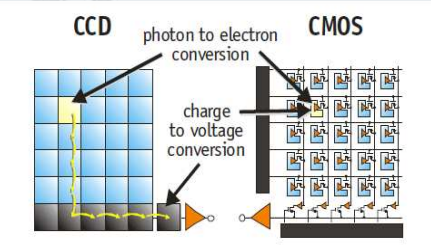
- All output images should be oriented in the same direction as the input image
- All channels must have the same optical path length
- The prism transmission should handle all polarizations with good uniformity
- All coatings should be protected from the environment
- Ample space should be available for mounting of filters and sensors

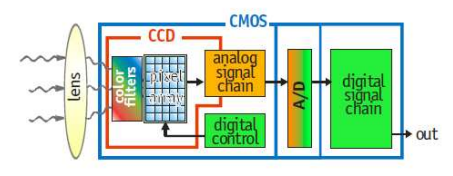
CFA: ClearVid CMOS sensors

A standard Bayer sensor features two green sensors for every red and blue sensor. Sony ClearVid CMOS sensors have six green sensors for every red and blue sensor. Sony are claiming that a two megapixel ClearVid sensor will yield a sensor resolution equivalent to a four megapixel camera, roughly a 1.4x resolution advantage over a standard two megapixel image sensor.



Sensor: CCD vs CMOS





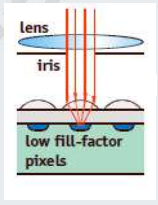
Charge-Coupled Device:

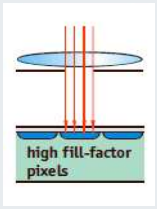
- the charge is actually transported across the chip and read at one corner of the array
- use of a special manufacturing process to create the ability to transport charge across the chip without distortion.
- Higher Fill Factor

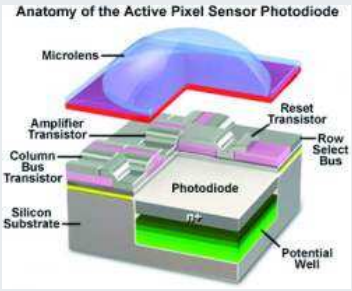
Complimentary Metal-Oxide Semiconductor:

- several transistors at each pixel amplify and move the charge using more traditional wires
- is more flexible because each pixel can be read individually
- use of the same traditional manufacturing processes to make most microprocessors.
- Easy integration.
- Lower Fill Factor

Sensor: Microlens filter

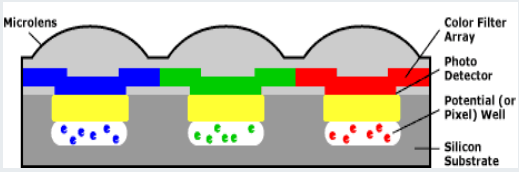






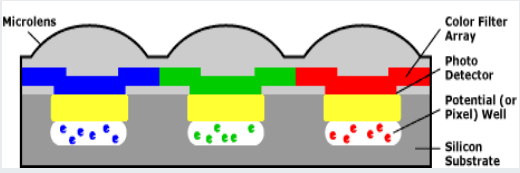
To compensate for lower fill factor (typically 30-50%), most CMOS sensors use microlenses, individual lenses deposited on the surface of each pixel to focus light on the photosensitive area. Microlenses can boost effective fill factor to approximately 70%, improving sensitivity (but not charge capacity) considerably.

Sensor: Microlens filter



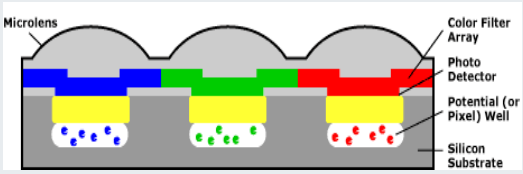
Ideal Charging
All the photons intersecting at any angle a filter element in the CFA are colour filtered and accumulated in the photodetector under the filter element.

Sensor: Microlens filter



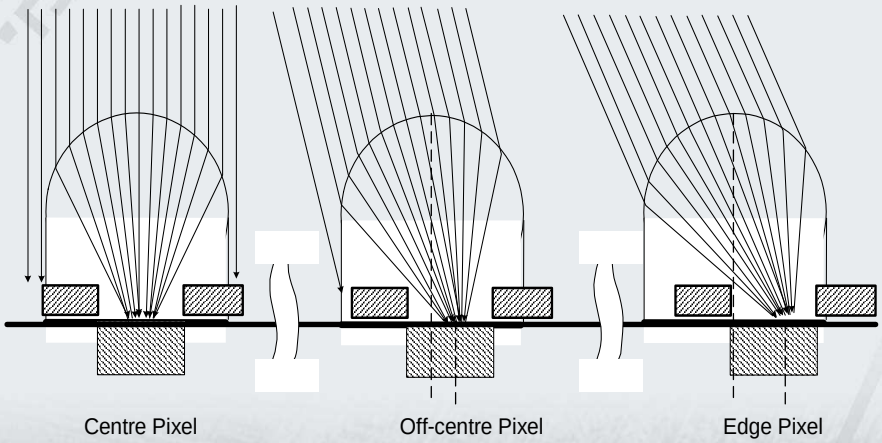
Optical Crosstalk
Optical Crosstalk results when a photon intersects at an angle with a filter element in the CFA and enters the adjacent pixel's photodetector (photodiode) and not the photodetector under the filter element. This can contaminate the adjacent pixel's charge packet.

Sensor: Microlens filter



Electrical Crosstalk
In electrical crosstalk, photons passing through the red filter travel further into the silicon before generating electrons. This leads to a non-uniform response to the different colors, a loss of charge into the substrate and electrons wandering into the wrong pixel well.

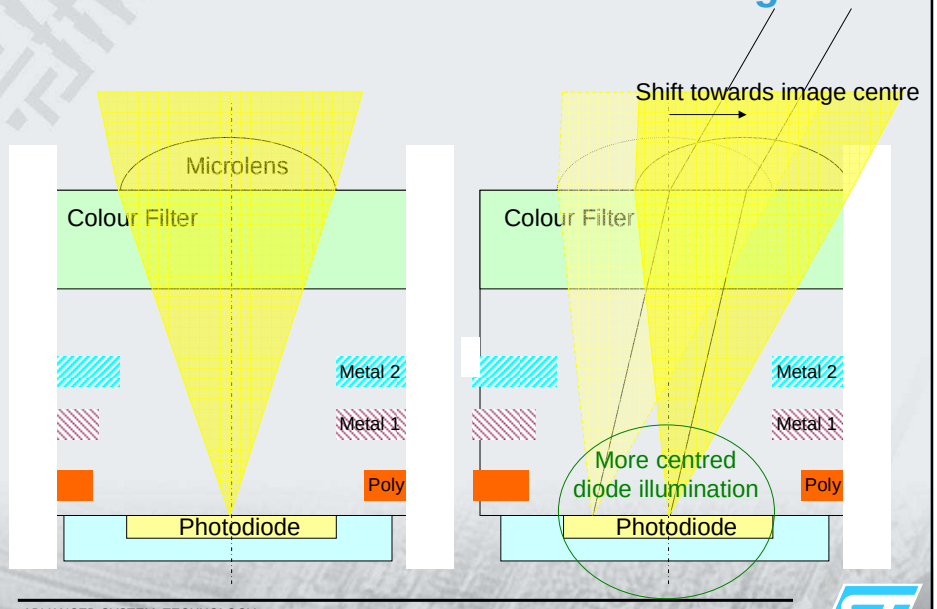
CMOS Sensors – Microlens Vignetting → Anti-vignette microlens (radial shift)



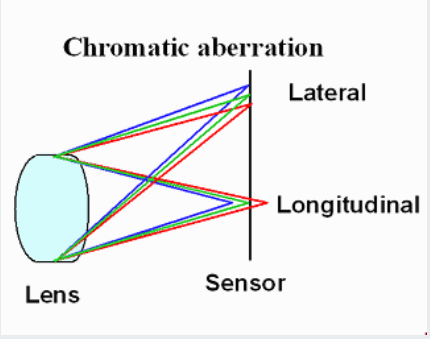
US6884985 Jeff
US7049168 Keith

- Move microlens wrt pixel → NO Vignetting

The Need For Microlens Shifting



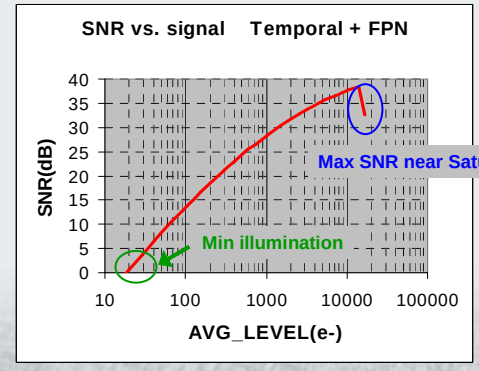
Chromatic Aberration



Chromatic aberration of a single lens causes different wavelengths of light to have differing focal lengths. As a consequence a given point in the scene is represented in different pixels in the sensor.

Signal to noise ratio

- SNR is the primary figure of merit for image quality
  - SNR max : maximum image quality
    - related to saturation level and PRNU at saturation
  - Minimum illumination : image quality at very low light level
    - Noise : Charge transfer, Dark current, Temporal noise, Fixed Pattern Noise. Quantization…
    - Sensitivity : number of electrons vs light.

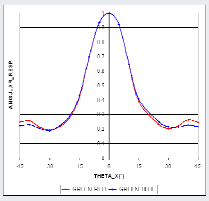


Effect of lens/ulens vignetting on Image

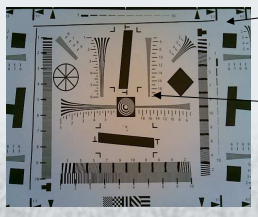
- Relative Illumination

$$RelativeIllumination\,/\% = \frac{DarkestCorner}{Centre} \times 100$$

  - Lens
    - typically only 50-60% illumination in image corners
  - Pixel
    - CRA > angular response of pixel
    - extra RI reduction



- Colour
  - IR Filter
    - Reflective interference filter
  - Pixel
    - Crosstalk – colour matrix
    - Delta Gr / Gb
    - Hue, colour ratio



Q&A