Real-time color imaging with a CMOS sensor having stacked photodiodes

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Summary

- Techniques for color separation
- Layered image sensor
  - Architecture
  - Operation
  - Image characteristics
- Real-time camera design
- Sample images
- Paths for development

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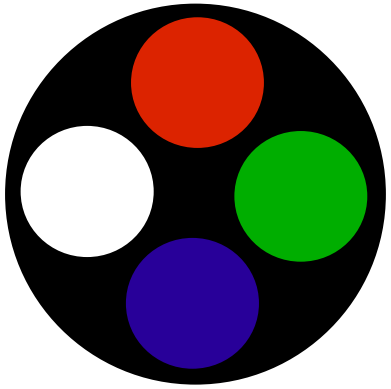
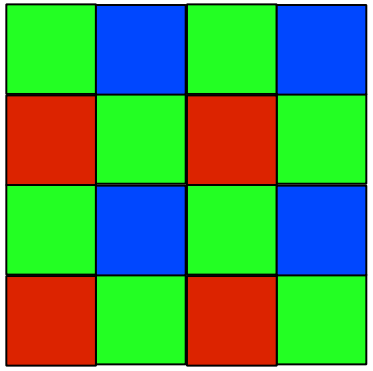
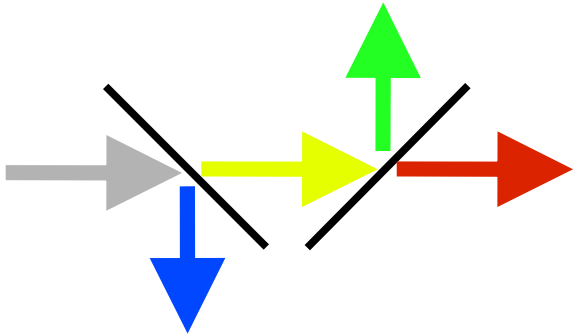
Three-channel color separation



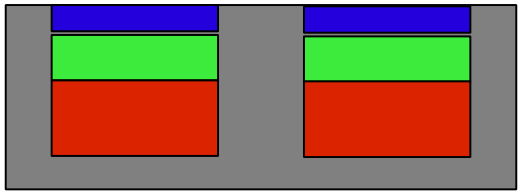
Filter wheel



Color filter array

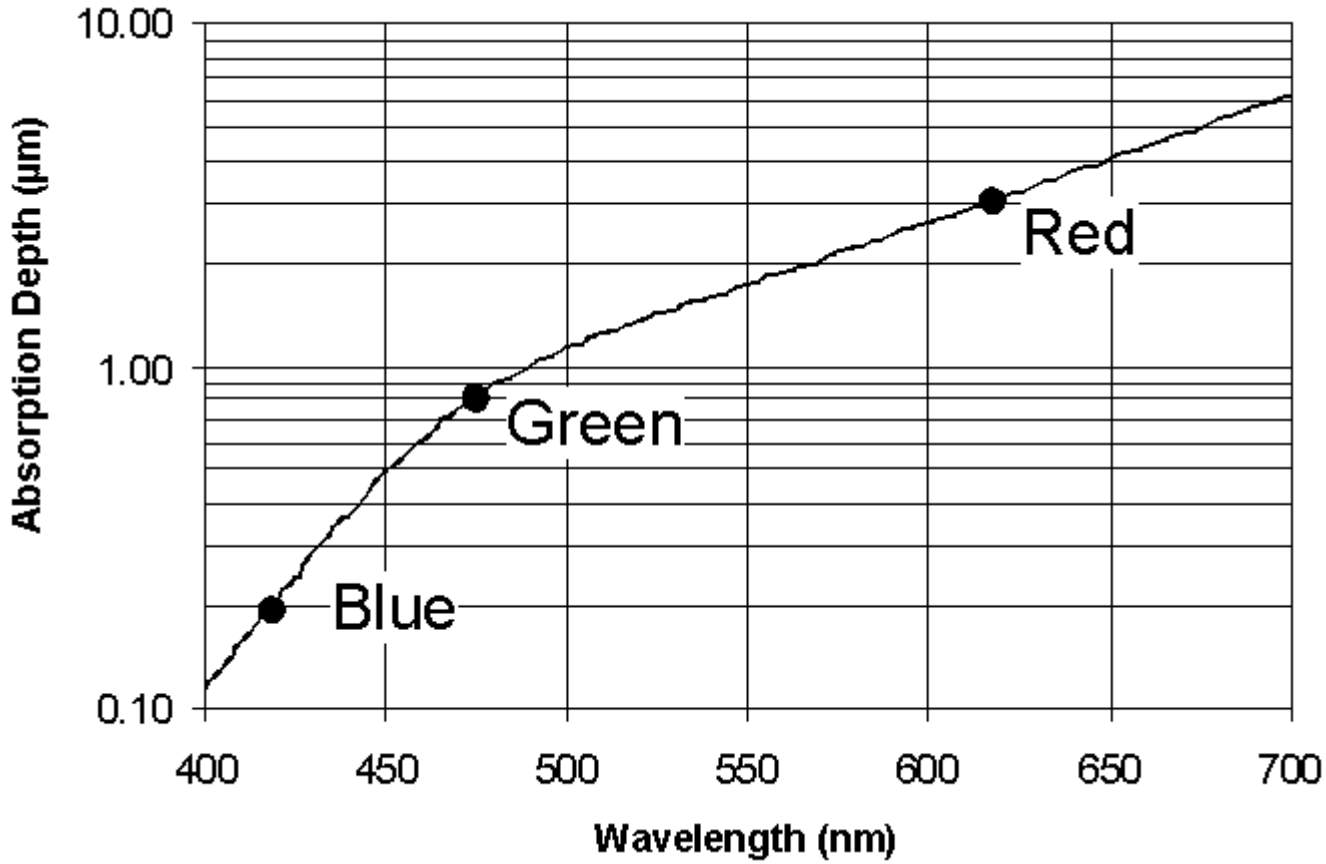


Three sensors



Layered photodiodes

Where to put the diodes



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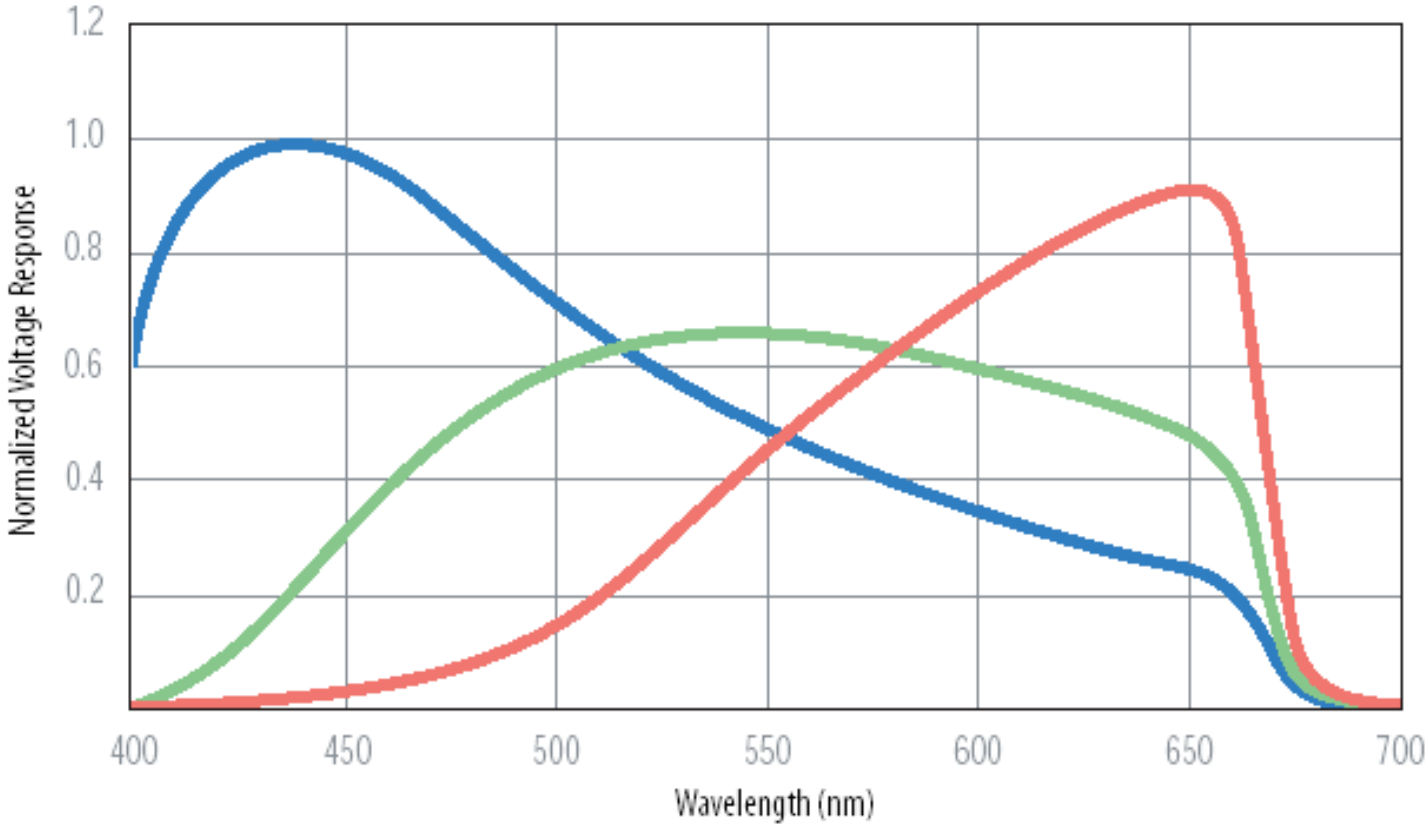
Spectral Characteristics



Includes effect of 400-660 nm pass filter

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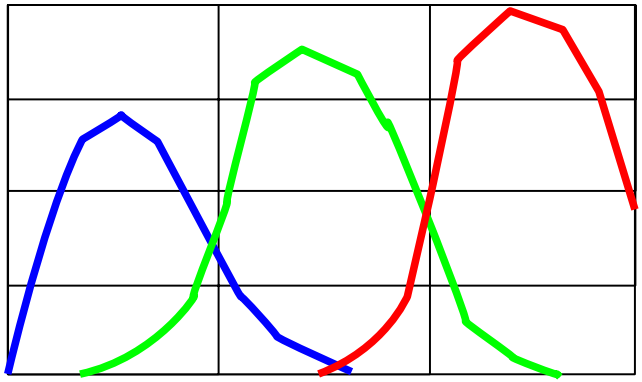
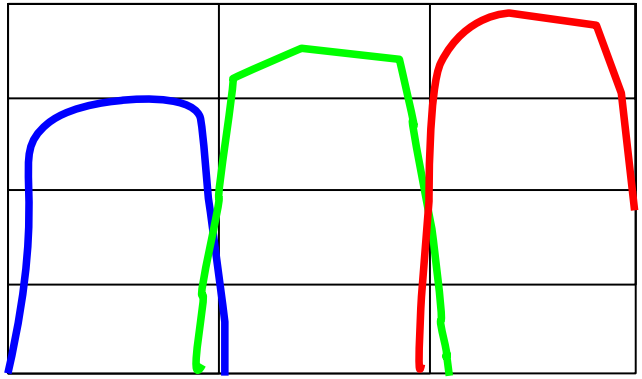
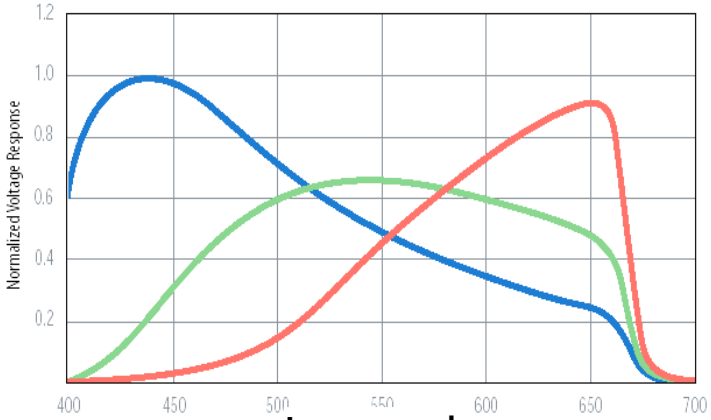
Color channel comparison



Filter wheel & One-chip



Three-chip



Layered

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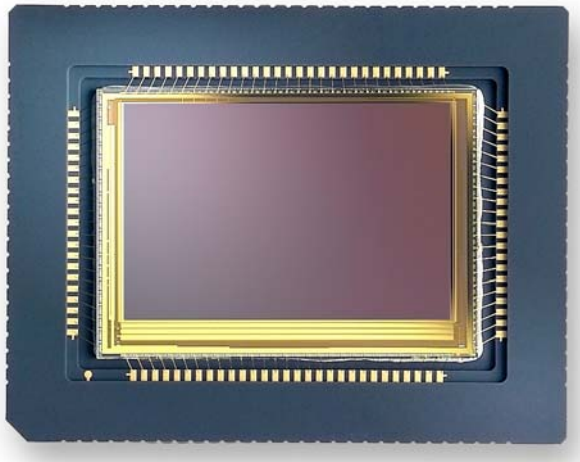
The first commercial sensor

- 2268 x 1512 active pixel locations
- 3 photodiodes per pixel location
- ~54% fill factor
- 9.12 x 9.12 µm pitch
- Black matrix mask
- 0.18 µm, 3.3 V CMOS
- 400 – 660 nm window
- 100-pin CLCC package



Special Features

- Extensive scan control
  - Select any rectangular regoion of interest
  - Group H and V independently in 2^n steps
  - Skip every n lines or columns
- Adjustable analog voltages
  - Output levels
  - Anti-blooming level
- Three exposure control modes
  - Synchronized external shutter – still shot
  - Full-frame with no shutter
  - Rolling shutter down to one line interval

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Performance

- 49% QE at 625 nm
- 61 db dynamic range
- Dark current ~1na/cm^2 at 25C
- PRNU < ±1%
- 80 mW maximum power
- 24 MHz clock – 4 fps for full sensor
- 7.14 µV/electron sensitivity
- Noise = 70 electrons rms (mostly kTC)

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Scan Rate Ranges

- Clock rate - 0 to 24 MHz
- Line period – 49 µs + 41.6 ns/pixel
  - Pixel grouping reduces line count
- Typical scan rates
  - 2268 x 1512 – 4 Hz
  - 1024 x 1024 – 10 Hz
  - 640 x 480 – 27 Hz
- Scan configuration change < 50 µs

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Real-time processing steps

- Linearization
  - Reverses roughly logarithmic response
  - 3 - 4k static lookup tables
  - Not temperature or time varying
- Dark field subtraction
  - Reduces fixed pattern noise and offsets
  - Data changes with exposure
- Color transformation
  - Converts sensor data to desired color space
  - Does not vary with time

Real-time camera

HanVision HVDUO-10M

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Camera configuration

- CameraLink Base or parallel LVDS interface
  - 8 or 12 bit per color transfer modes
- Serial control of camera setup
  - ASCII text string command set
  - ASCII text file linearization & color tables
- Internal automatic dark frame shutter
- F-mount for optics (others available)
- Front, side and tripod mount holes
- 15 volt DC power

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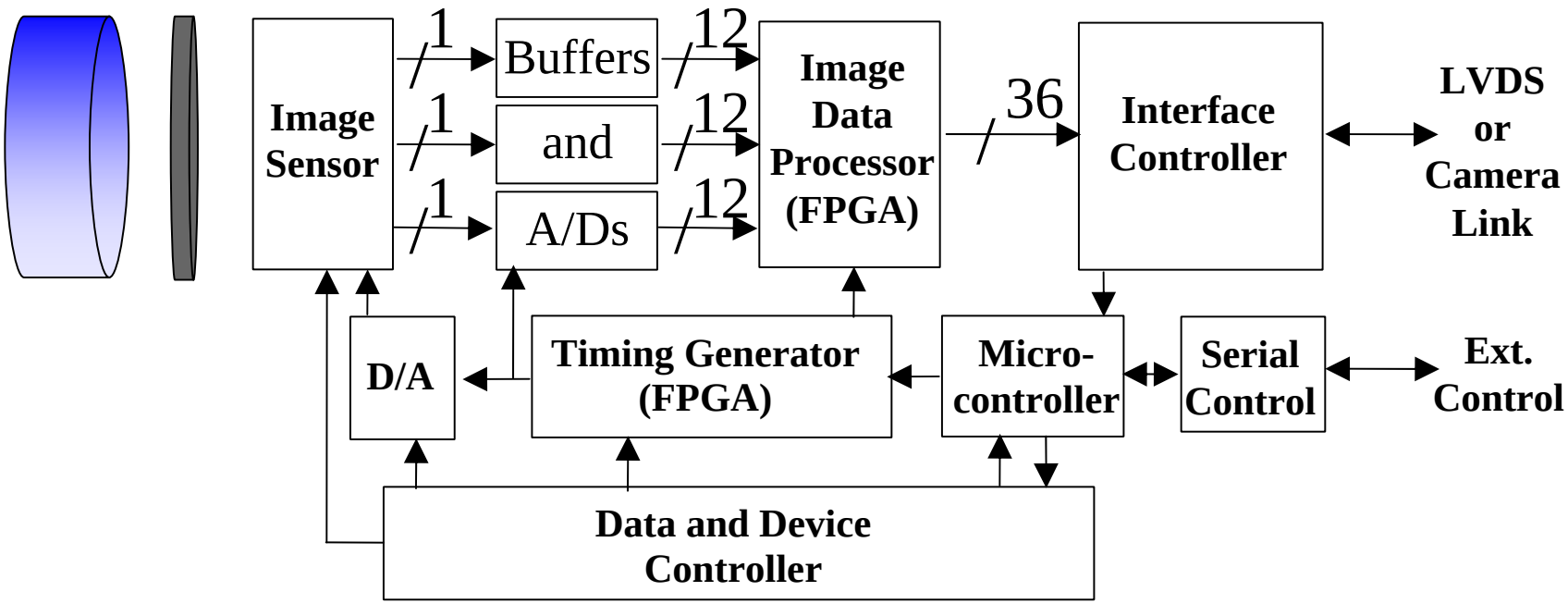
Camera Block Diagram



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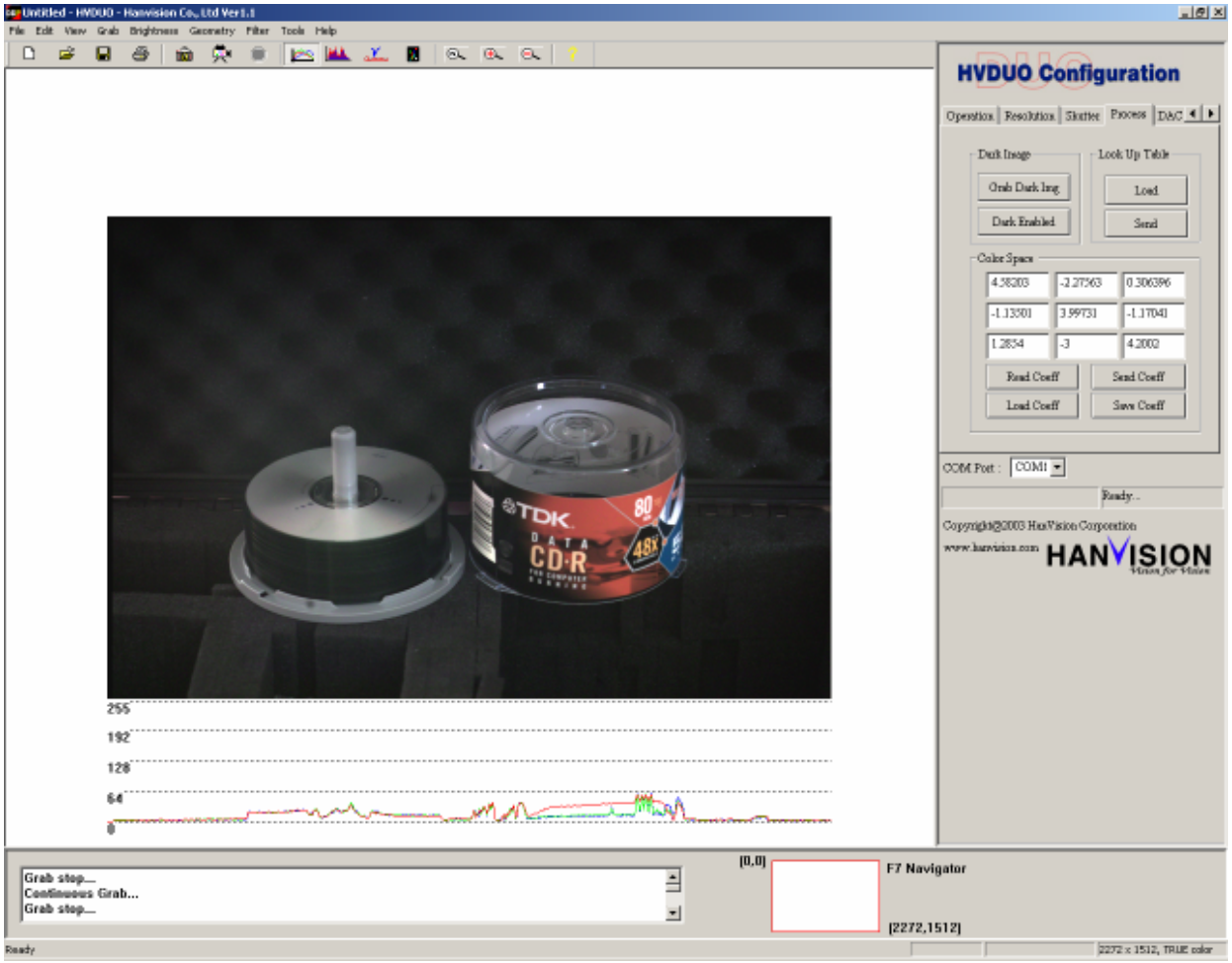
HVDUO Control & View Software



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Sample images

- Foveon sample design
  - Aliasing
- HanVision HVDUO-10M
  - Color
- AVC Design Support Kit
  - Infrared and ultraviolet
- Sigma SD-9: Links
  - Pbase SD-9 galleries –
    http://www.pbase.com/sigmasd9
  - DPReview SD-9 sample images –
    http://www.dpreview.com/gallery/sigmasd9_samples/

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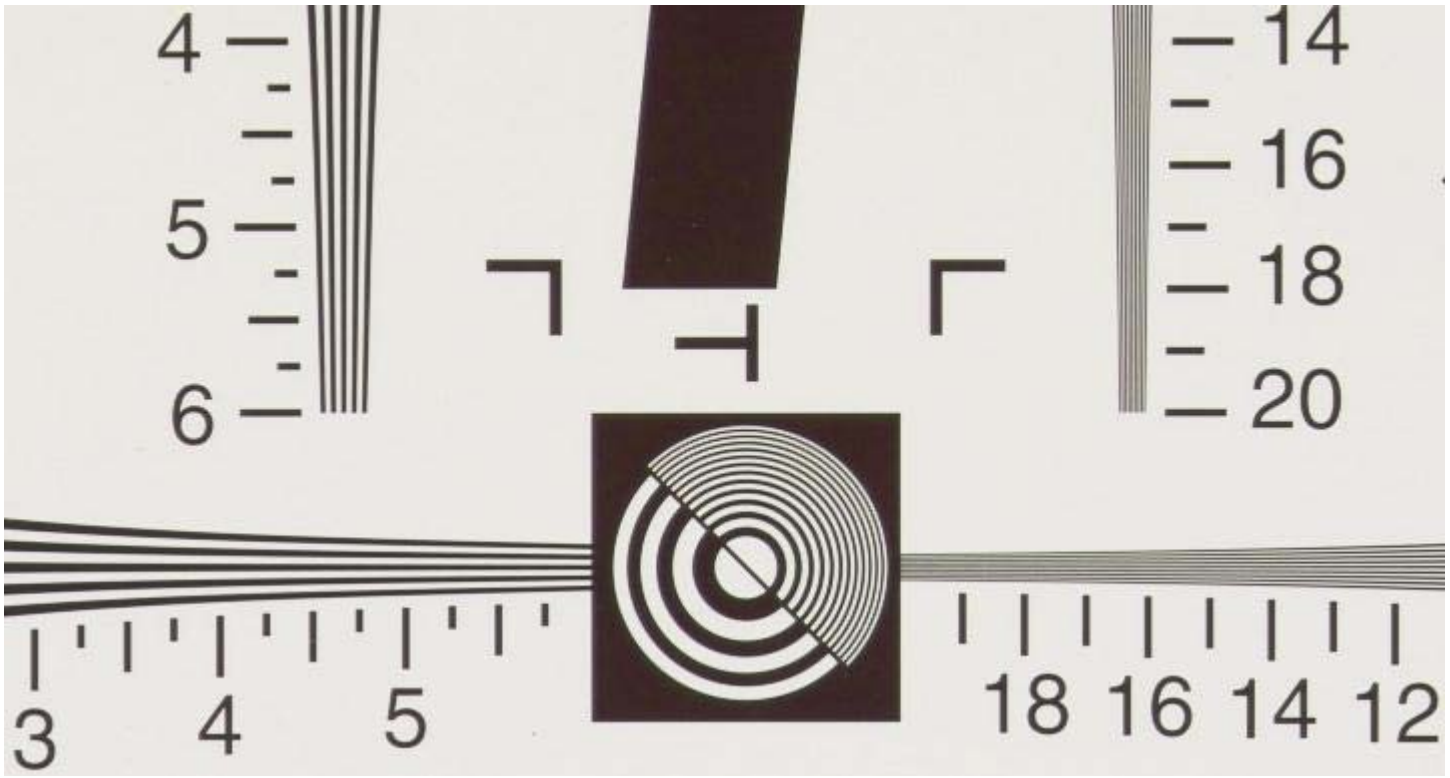
No color aliasing



This is a color image

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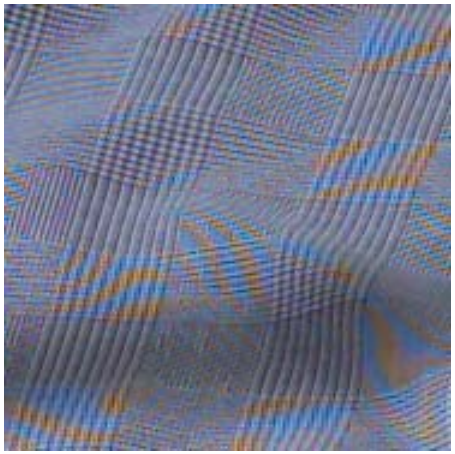
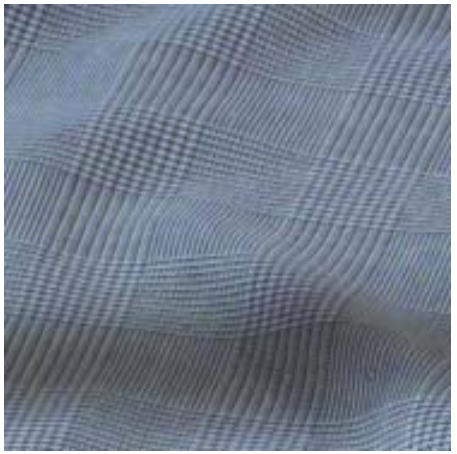
Aliasing comparison



Filter Array



X3

Same pixel spacing at object

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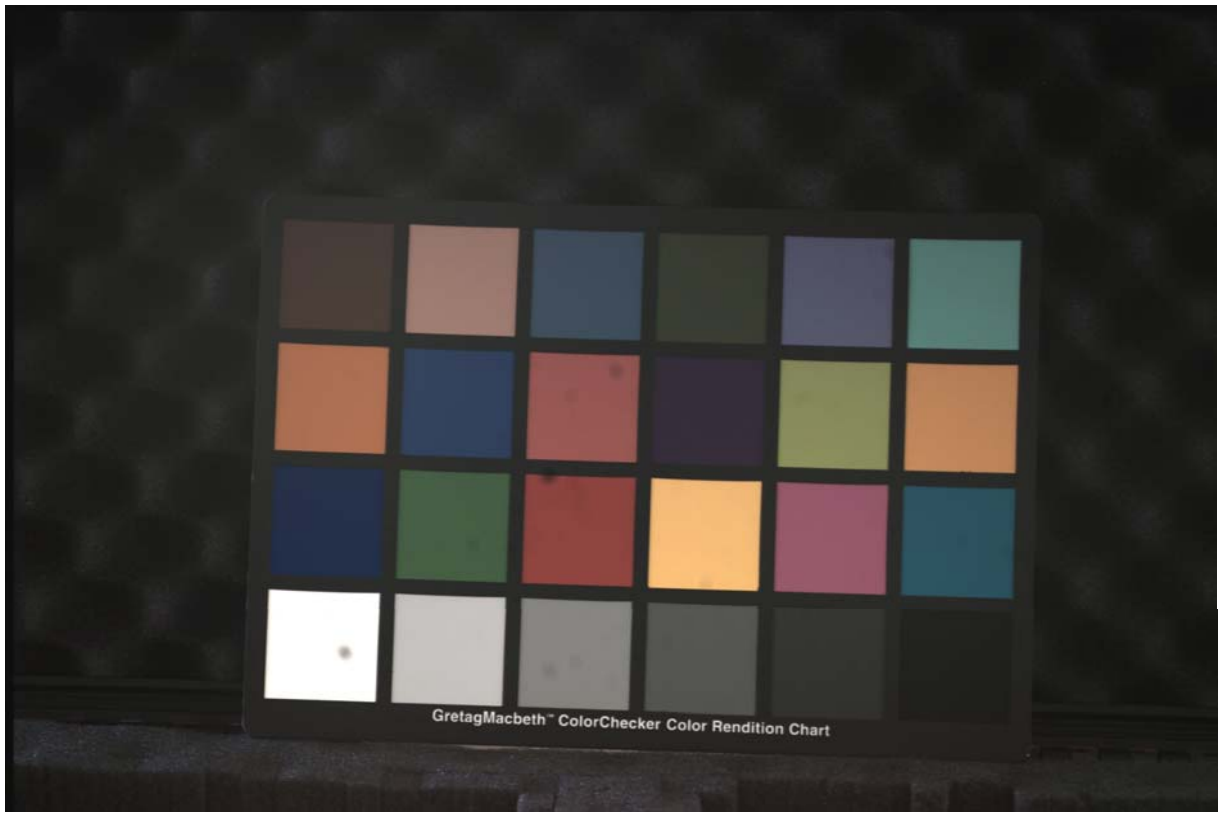
ColorChecker chart



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Blue response

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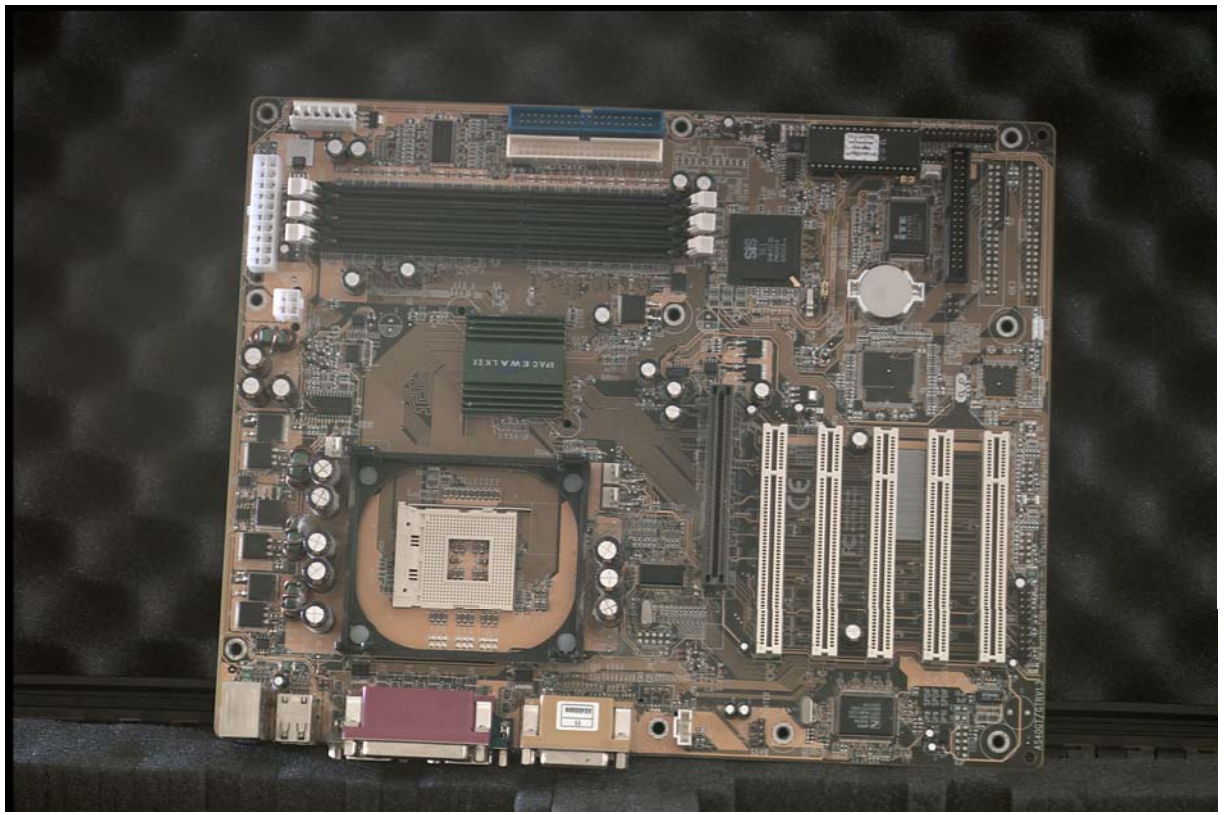
Motherboard



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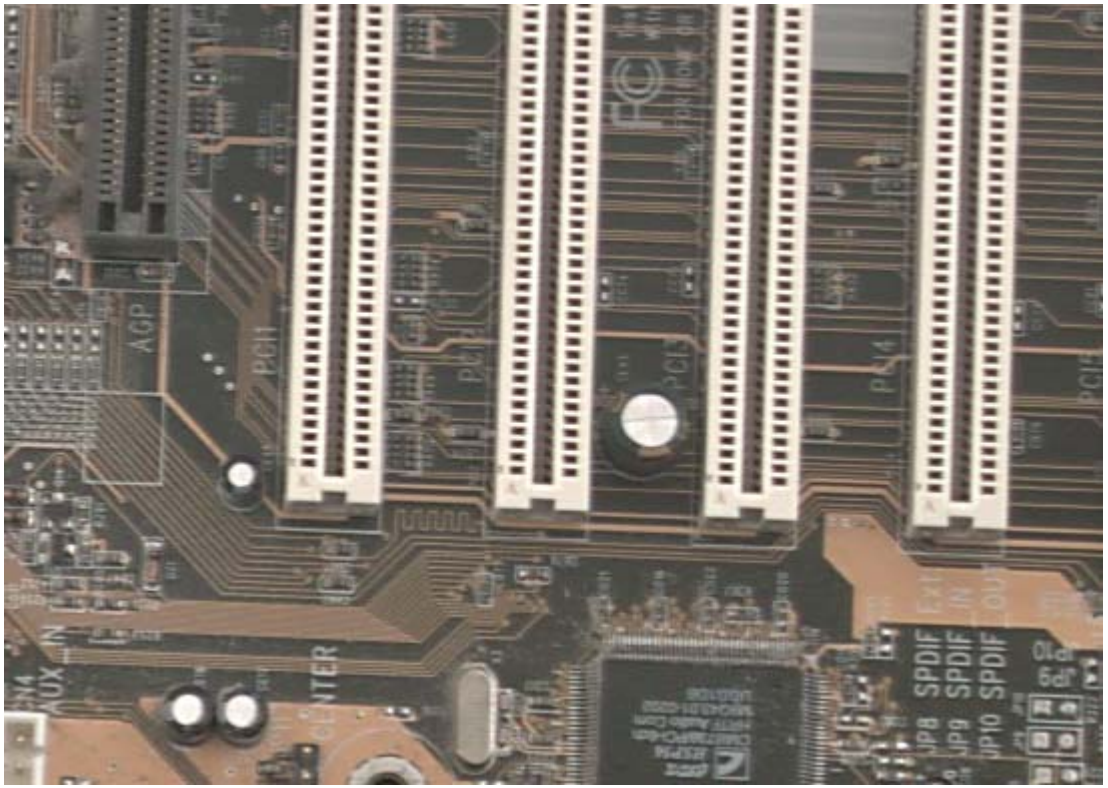
Motherboard detail



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Bottles

HVDUO-10M

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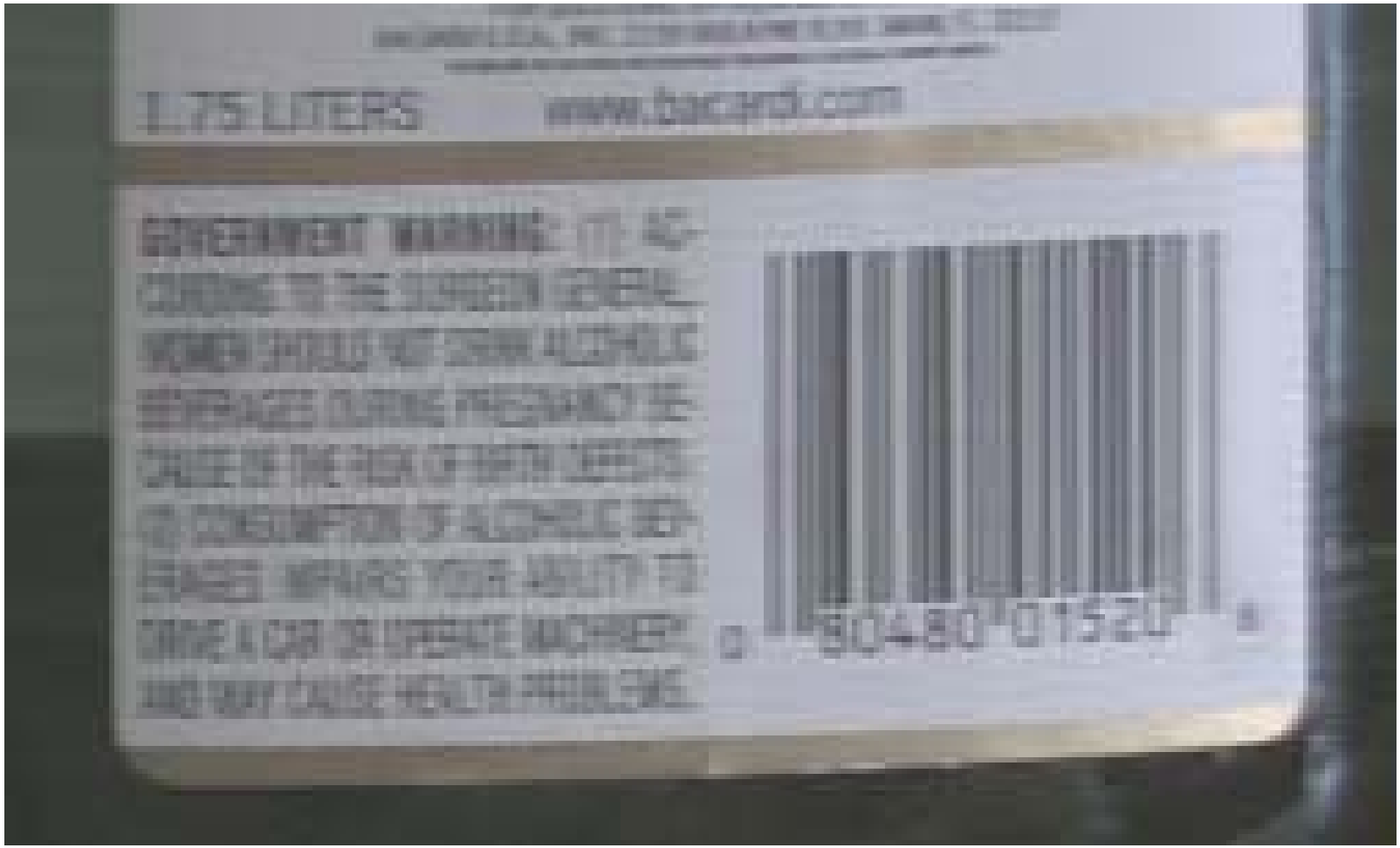
Bottles – detail



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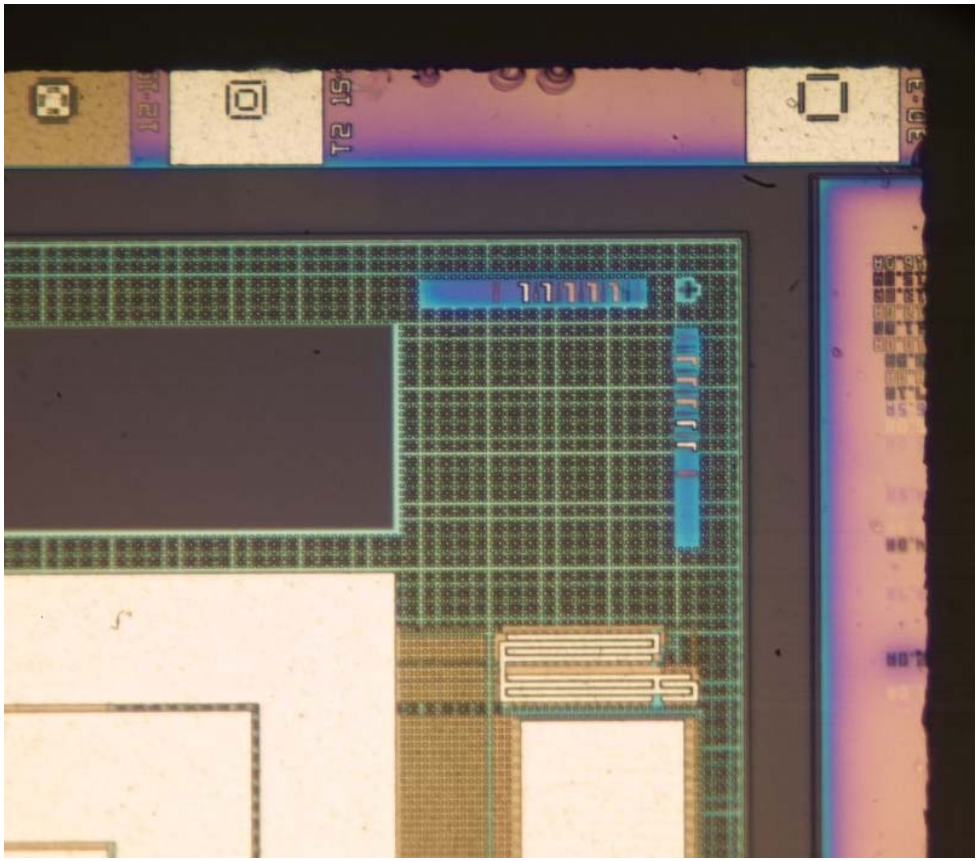
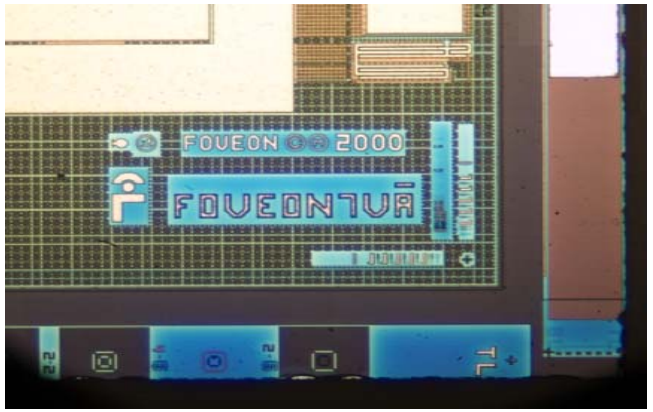
Self-portrait





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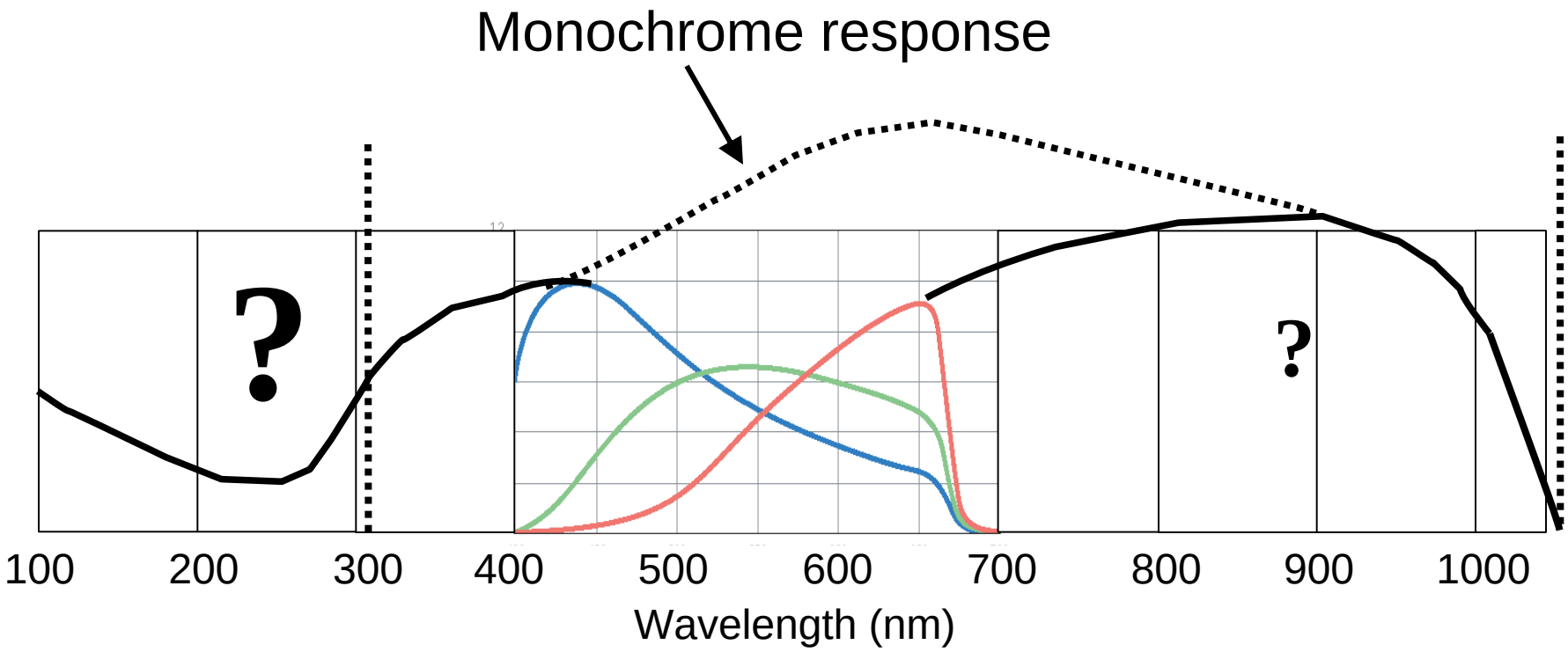
Unfiltered spectral response



Naked diode at the surface

Depletion into the substrate

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Ultraviolet imaging

- Daylight
- 300-400 nm
- 10% IR leakage
- Not a UV lens
- 3 channels summed

Infrared imaging - wideband

- Daylight
- 720+ nm
- Not an IR lens
- 3 channels summed

Future directions

- Next commerical device – X3 5M
  - 1088 x 1440 pixels locations, 5 µm pitch
  - 9 fps full sensor, 43 fps 640 x 480
- More integration
  - A/D conversion
  - Stored configurations
  - Electronic shuttering & noise reduction
- Microlenses
- More readout channels?

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