Digital Camera Sensors

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Agenda

- Basic Parts of a Digital Camera
- The Pixel
- Camera Sensor Pixels
- Camera Sensor Sizes
- Pixel Density
- CMOS vs. CCD
- Digital Signal Processors
- ISO, Noise & Light
- Sensor Comparison
- Questions

The Propeller Hat

- Slides that have the propeller hat in the upper right are detailed topics.
- This information will not make you a better photographer.
- Feel free to sleep, daydream or tell me if you care less.

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Basic Parts of a Digital Camera

- Lens
- **Sensor**
- Internal Memory (Cache)
- Removable Memory (Flash Memory)
- CPU (Central Processing Unit)
- **DSP (Digital Signal Processor)**
- Display
- User Control (Buttons and Such)

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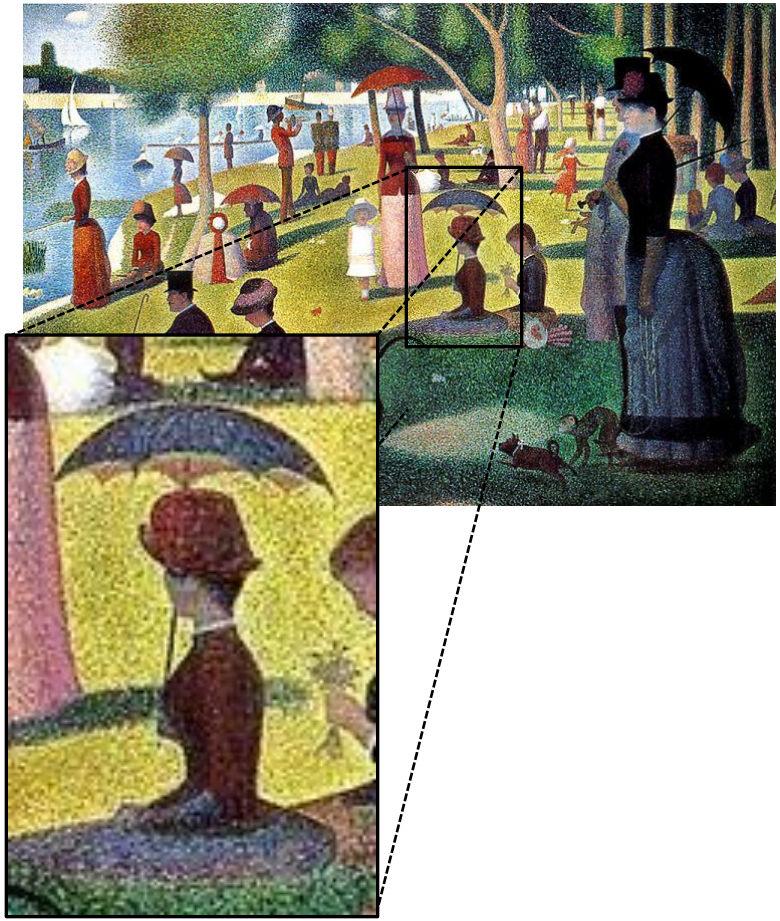
Pixels

- *Pixel* is a contraction of the words *pix* (for “picture”) and *el* (for “element”).
- All digital images are made up of pixels.
- Not all pixels are equal. Some pixels are less than others, i.e. sub-pixels.

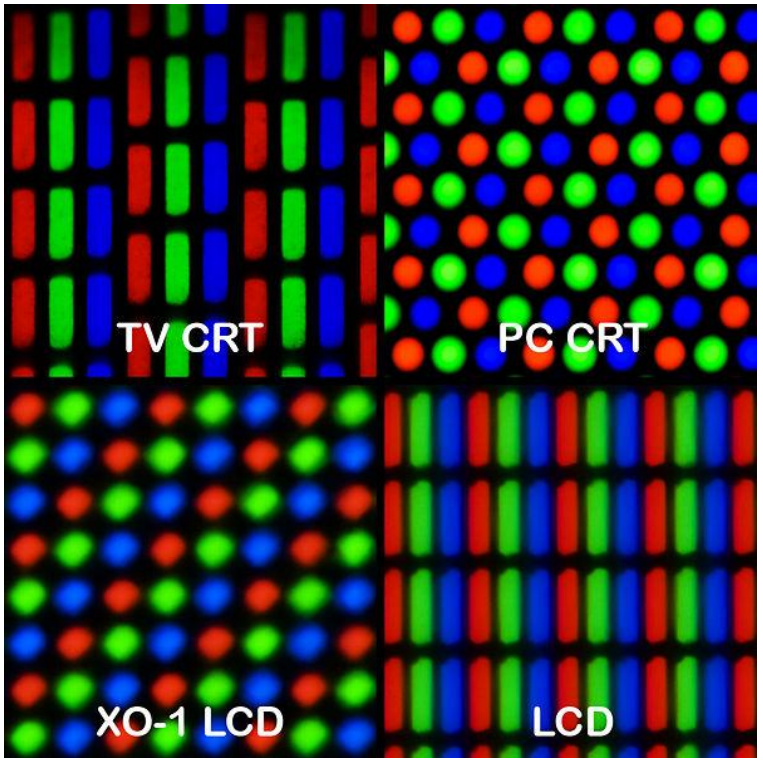
Early Pixels

- French Painter Georges-Pierre Seurat used pointillism as a technique for blending colors much like ink jet printers to today.



Pixels Today

- Pixels differ depending on the display technology.
- Today's screens have to use three sub-pixels to make one pixel.
- Photo developing services and dye sublimation use "stacked" blending.



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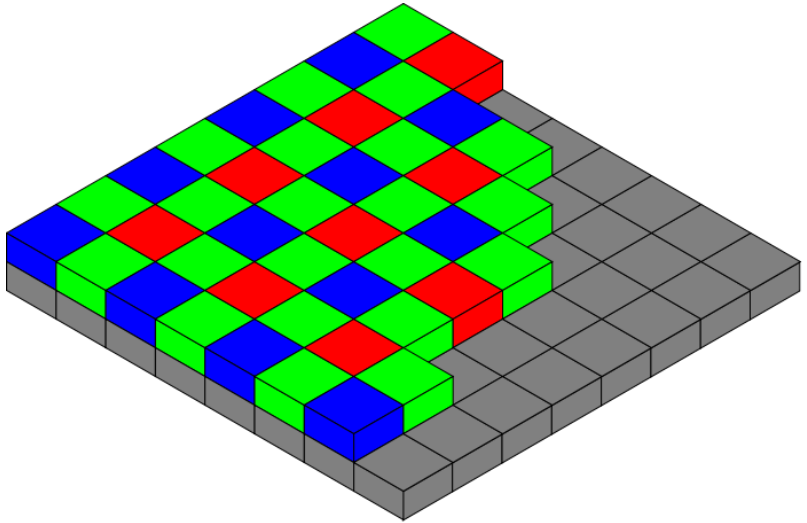
Camera Sensor Pixels

- Most digital cameras have red, green or blue pixels that are combined with neighboring pixels to create full color pixels.
- The most common is the Bayer pattern.
- This can give some interesting color artifacts such as blotching.
  - Basically a slight blurring of the color.

Bayer Pattern

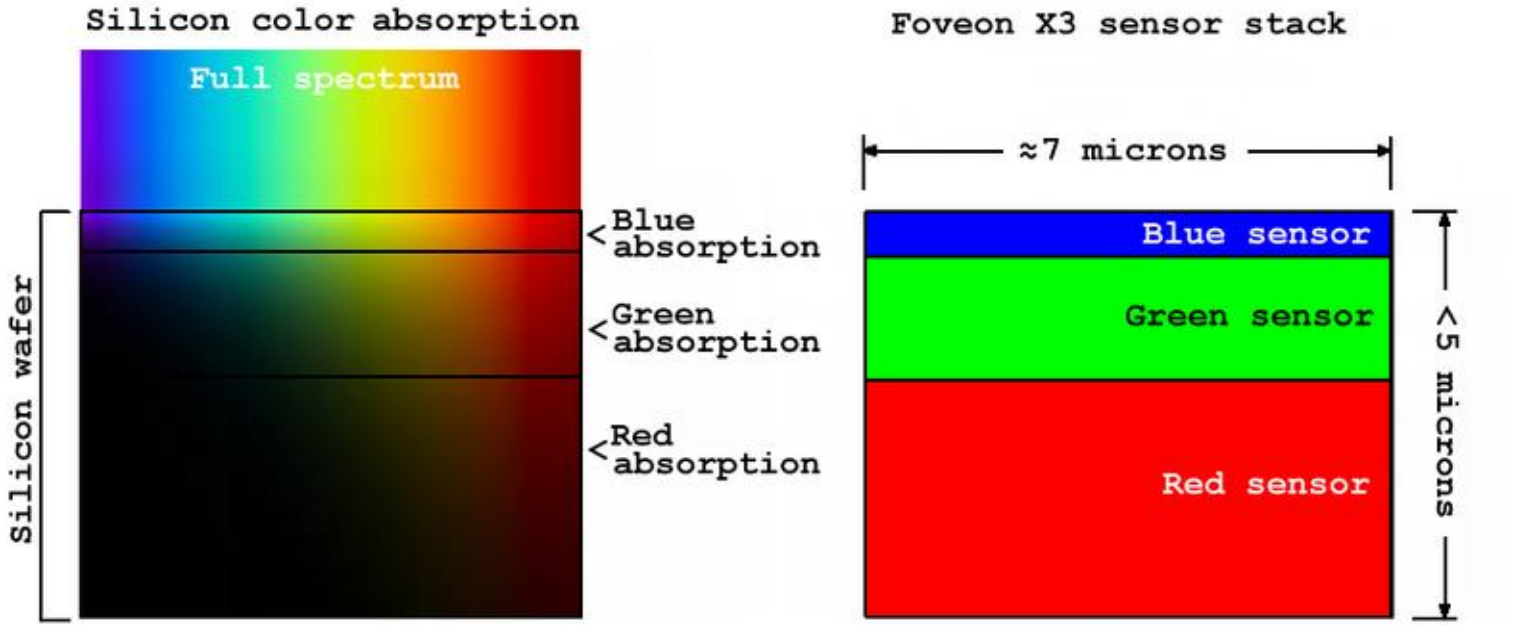
- The filter pattern is 50% green, 25% red and 25% blue, hence is also called GRGB or other permutation such as RGGB.
- It is named after its inventor, Dr. Bryce E. Bayer of Eastman Kodak.
- Different algorithms requiring various amounts of computing power result in varying-quality final images.
- Twice as many green elements as red or blue are used to mimic the human eye's greater resolving power with green light.



Sensor Alternatives

- CYGM filter (cyan, yellow, green, magenta)
- RGBE filter (red, green, blue, emerald)
- Foveon X3 sensor, which layers red, green, and blue sensors vertically rather than using a mosaic
- Three separate CCDs, one for each color (more expensive)
- One black & white sensor with filters for each color.
  - Requires multiple pictures for each color image.
  - Uses in high-end astrophotography

Foveon X3 Sensor



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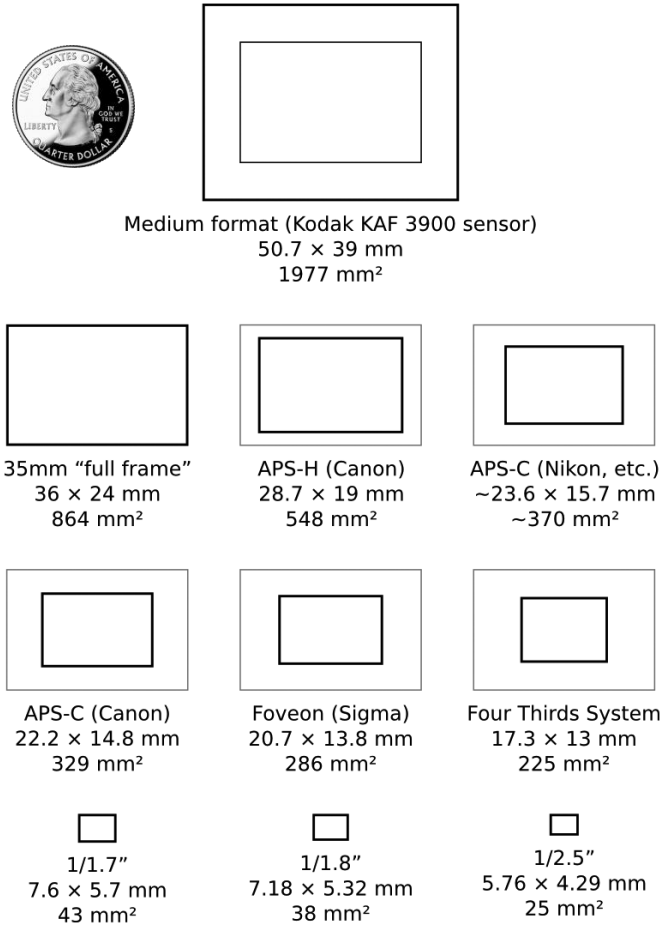
Common Sensor Sizes

- 35mm “Full Frame”, 36 x 24 mm, 864 mm²
- Most Nikon SLRs have a 1.5 crop factor
  - 23.6 x 15.7 mm, 370 mm²
- Most Canon SLRs have a 1.6 crop factor
  - 22.2 x 14.8 mm, 329 mm²
- Crop factor does not change the depth of field.



Various Sensor Sizes

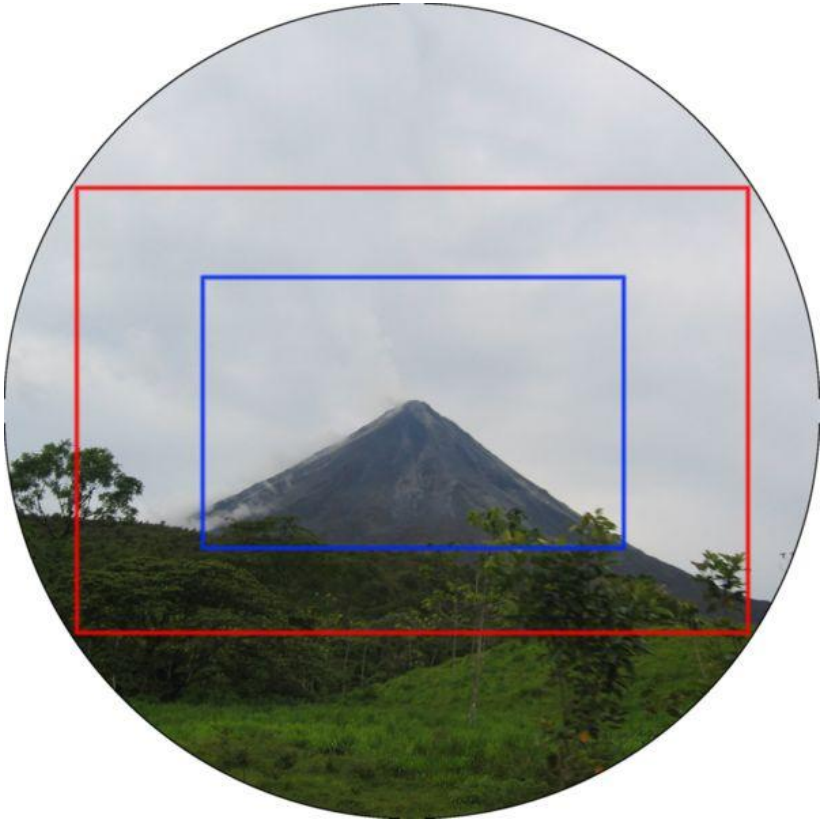
Type	Aspect Ratio	Diagonal (mm)	Width (mm)	Height (mm)	Area (mm^2)
1/3.6"	4:3	5.0	4.0	3.0	**12**
1/3.2"	4:3	5.7	4.5	3.4	**15**
1/3.0"	4:3	6.0	4.8	3.6	**17**
1/2.7"	4:3	6.7	5.4	4.0	**22**
1/2.5"	4:3	7.2	5.8	4.3	**25**
1/2.3"	4:3	7.7	6.2	4.62	**28**
1/2.0"	4:3	8.0	6.4	4.8	**31**
1/1.8"	4:3	8.9	7.2	5.3	**38**
1/1.7"	4:3	9.5	7.6	5.7	**43**
2/3"	4:3	11.0	8.8	6.6	**58**
1"	4:3	16.0	12.8	9.6	**123**
4/3"	4:3	22.5	18.0	13.5	**243**
1.8” (“Crop”)	3:2	28.4	23.7	15.7	**372**
35 mm Film	3:2	43.3	36.0	24.0	**864**

Sensor Size Trivia

- Type designation using imperial fractions such as 1/1.8" or 2/3"
- Larger than the actual sensor diameters.
- The type designation harks back to a set of standard sizes given to TV camera tubes in the 1950s. These sizes were typically 1/2", 2/3" etc.
- The size designation does not define the diagonal of the sensor area but rather the outer diameter of the long glass envelope of the tube.
- The usable area of this imaging plane was approximately two thirds of the designated size.

Example of Crop Factor

- The outer, red box displays what a 36 × 24 mm (full frame) sensor would see.
- The inner, blue box displays what a 23 × 15 mm (1.6 crop factor) sensor would see.
- The actual image circle of most lenses designed for 35 mm SLR format is larger than shown; the circle shown is the minimum to cover the corners of the full frame format.
- Crop factor does not change the depth of field.
- Lenses are available that work only with smaller sensors.



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Pixel Density

- *Pixel Density* is the number of pixels per unit area.
- This helps compare sensor sizes between camera types.
- The higher the pixel density the smaller the pixel.
- The smaller the pixel the less light it can capture in a given amount of time.
- The larger the pixel the more light it can capture in a given amount of time.
- Smaller pixels give more noise.
- We are approaching the point that pixel density will surpass low end lens resolution.

Pixel Density Examples

- Canon EOS 10D (February 2003)
  - 6.3 MP, 1.6 Crop Factor, 329 mm^2, **1.8 MP/cm^2**
- Canon EOS 5D (August 2005)
  - 12.7 MP, No Crop Factor, 864 mm^2, **1.5 MP/cm^2**
- Canon EOS 30D (February 2006)
  - 8.2 MP, 1.6 Crop Factor, 329 mm^2, **2.4 MP/cm^2**
- Canon PowerShot S5 IS (May 2007)
  - 8.0 MP, 1/2.5”, 25 mm^2, **32 MP/cm^2**
- Canon EOS 50D (August 2008)
  - 15.1 MP, 1.6 Crop Factor, 329 mm^2, **4.5 MP/cm^2**
- Canon EOS 5D Mark II (September 2008)
  - 21.0 MP, No Crop Factor, 864 mm^2, **2.4 MP/cm^2**
- Canon PowerShot SX10 IS (September 2008)
  - 10.0 MP, 1/2.3”, 28 mm^2, **35 MP/cm^2**

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CMOS vs. CCD

- Should you care which technology is used? No.
- CMOS stands for Complimentary Metal-Oxide Semiconductor
- CCD stands for Charge-Coupled Device
- CCD sensors generate less noise than CMOS sensors.
- The light sensitivity of CMOS tends to be lower than CCD.
- CMOS traditionally consumes little power. About 100 times less than CCDs.
- CMOS chips can be fabricated on just about any standard silicon production line, so they tend to be extremely inexpensive compared to CCD sensors.
- CCD sensors have been mass produced for a longer period of time, so they are more mature. They tend to have higher quality and more pixels.
- Don’t worry, the camera designers understand the issues and have designed the cameras accordingly.

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The Digital Signal Processor (DSP)

- Does a lot of very specialized math in a very short amount of time.
- Processing must be done in a reasonable amount of time.
- Should not take too much power (battery size).
- Today's DSPs are better than yesterday's.
- Engineers have better techniques and have more DSP power to do what they want in a reasonable amount of time.
- New DSPs show up in high end cameras first.

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ISO & Noise

- You can select an ISO for your camera but the sensor does not change.
- Doubling the ISO will tell the DSP to adjust for half as much light reaching the sensor.
  - The resulting data will have to be amplified.
  - Very much like pushing a roll of film.
- With less light the amplified information contains more noise (signal to noise ratio).
  - The higher the signal to noise ratio the better.

ISO & Noise

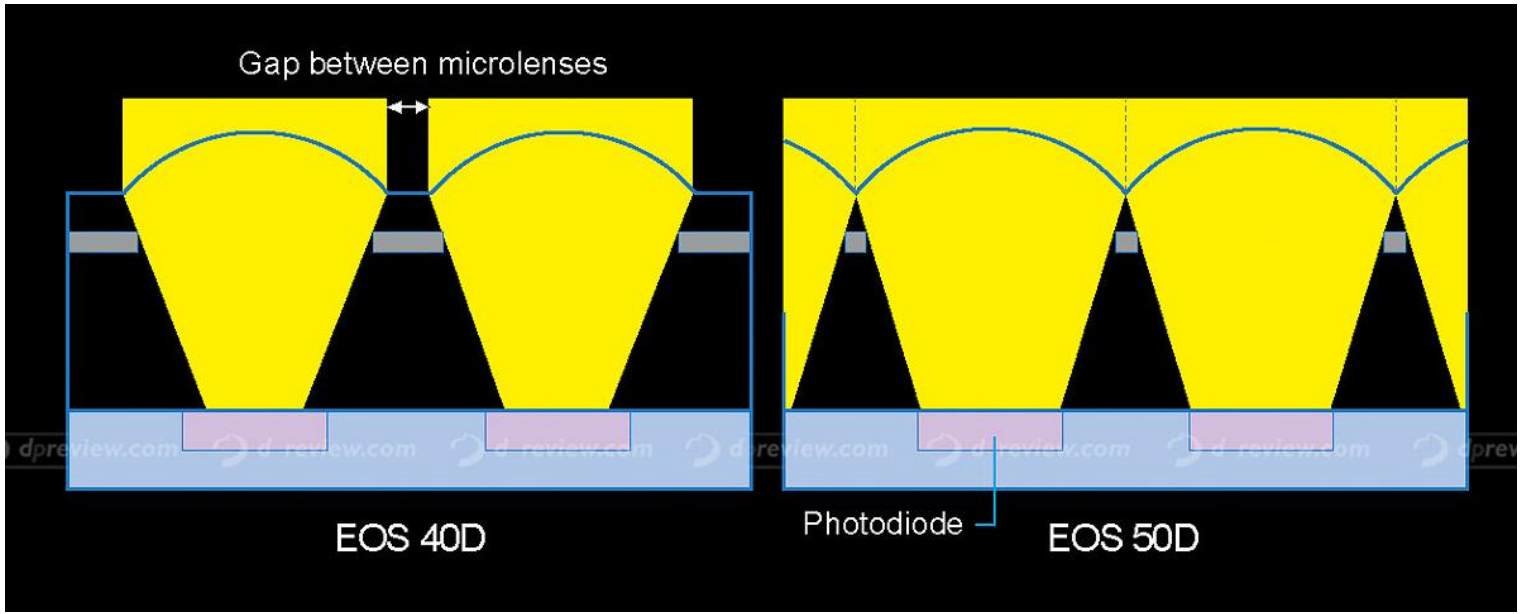
- Camera noise comes from the thermal noise caused by moving electrons.
- The higher the ambient temperature the more the electrons move and thus the more noise.
- In very cold temperatures the thermal noise can be drastically reduced.

Light Capturing Capabilities

- The larger the pixel the more light it can capture.
  - The larger the side of the barn the better chance of hitting it.
- Each generation it gets better.
- Today's smaller pixels can outperform yesterdays' larger pixels.
  - Better materials
  - Novel designs
  - Better algorithms (ways of doing something)
  - Faster hardware
  - More hardware (i.e. more internal memory)

Novel Design Example (Gapless Microlenses)

- How Canon captures more light per pixel by using gapless microlenses over each pixel.



Source: http://DPReview.com

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Sensor Comparison

- Cameras Compared
  - Canon EOS 30D (February 2006)
    - 8.2 MP, 1.6 Crop Factor, 329 mm^2, **2.4 MP/cm^2**
  - Canon PowerShot S5 IS (May 2007)
    - 8.0 MP, 1/2.5”, 25 mm^2, **32 MP/cm^2**
- ISOs 100, 400 & 1600
- f/8 for all images
- Same shutter speeds for both cameras

Sensor Comparison, ISO 100 (f/8, 0.6 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 100 (f/8, 0.6 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 100 (f/8, 0.6 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 400 (f/8, 1/6 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 400 (f/8, 1/6 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 400 (f/8, 1/6 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 1600 (f/8, 1/25 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 1600 (f/8, 1/25 sec)

Canon 30D

Canon PowerShot S5 IS

Sensor Comparison, ISO 1600 (f/8, 1/25 sec)

Canon 30D

Canon PowerShot S5 IS

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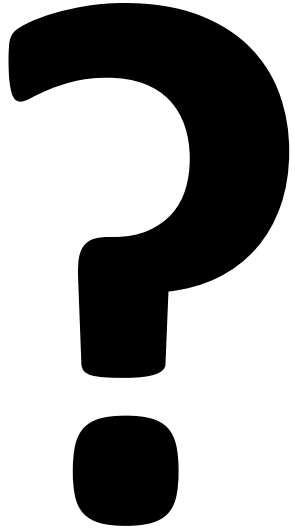

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