DIGITAL CAMERA SENSORS

Bill Betts

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Camera Sensors

- The soul of a digital camera is its sensor - to determine image size, resolution, low-light performance, depth of field, dynamic range, lenses and even the camera's physical size, the sensor is key.

  - *TechHive Demystifying digital camera sensors once and for all*

Camera Sensors

- The sensor is the equivalent to a negative
  - It captures the photons in silicon and converts the image to digital data
  - It sets the limit on the amount of information that can be captured by the camera.
- Film
  - A negative captured photons in silver nitrate and dyes

Camera Processors

- The processor develops the image
  - The digital processor manipulates the digital data to:
    - Create the full color palate
    - Remove physical effects of the camera and lens from the image
    - Post-processes the image per the user's setup of the camera
      - Creates an exportable file either in RAW or JPEG
    - The digital image can be manipulated an infinite number of ways

- The film negative is developed and printed onto paper.
    - The film image is limited on the amount of manipulation that can be done on it

Camera Sensors - Size

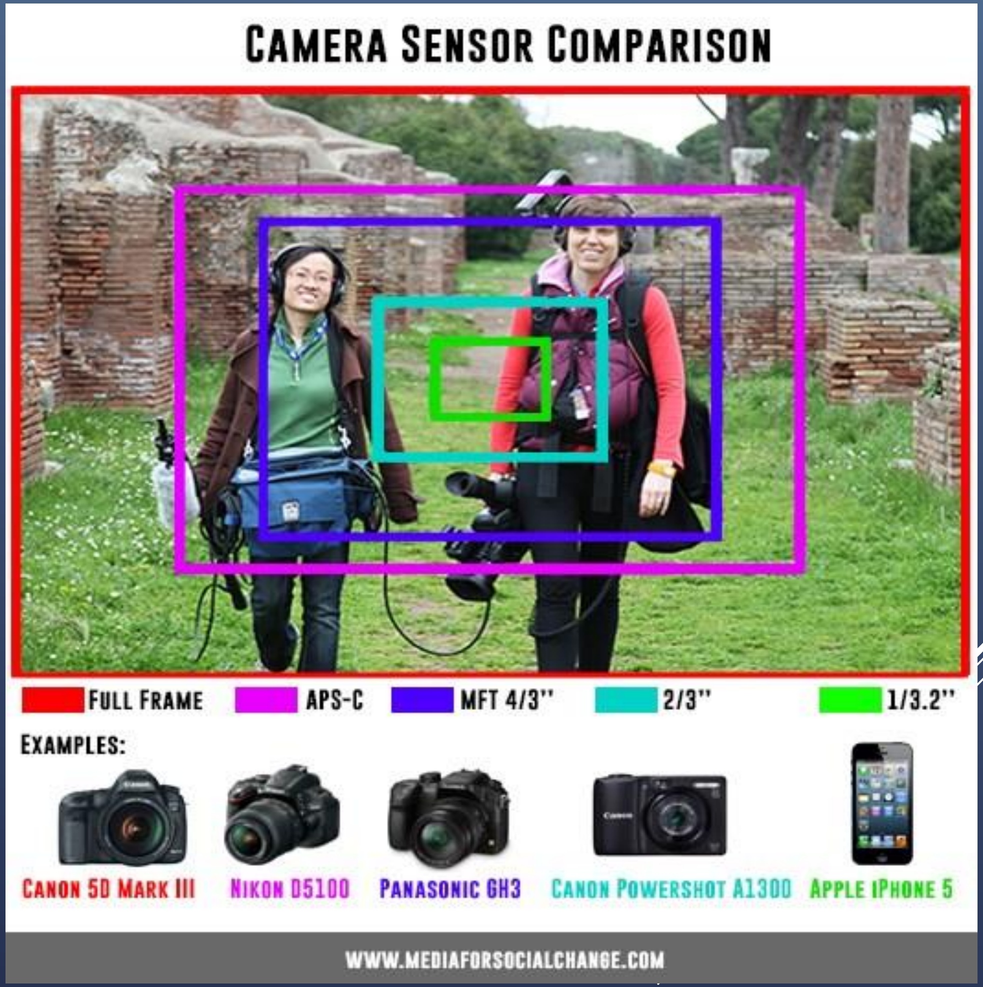
- Four DSLR sizes
  - Medium Format (0.64 crop)
  - Full Frame same as 35mm negative
  - Smaller “crop” sizes
    - APS-H (1.29 crop)
      - Canon 1D Mark III and IV
    - APS-C (1.52 crop)
    - 4/3 (2.0 crop)

Camera Sensors - Size

Sensor Name	Medium Format	Full Frame	APS-H	APS-C	4/3	1"	1/1.63"	1/2.3"	1/3.2"
Sensor Size	53.7 x 40.2mm	36 x 23.9mm	27.9x18.6mm	23.6x15.8mm	17.3x13mm	13.2x8.8mm	8.38x5.59mm	6.16x4.62mm	4.54x3.42mm
Sensor Area	21.59 cm²	8.6 cm²	5.19 cm²	3.73 cm²	2.25 cm²	1.16 cm²	0.47 cm²	0.28 cm²	0.15 cm²
Crop Factor	0.64	1.0	1.29	1.52	2.0	2.7	4.3	5.62	7.61
Image									
Example									

Camera Sensors - Size

- Illustration of the **reduced field-of-view** with "cropping" sensors
- A sensor does not magnify



Camera Sensors – The Scale

- Physical items on a sensor are measured metrically
    - 1 micron (1 millionth of a meter) = 0.0000394 inches or 39.4 millionths of an inch
    - Interconnection wires can be as small as 0.0.02 microns
    - Pixels, lenses and Bayer filter elements can be as small as 4 microns x 4 microns.
    - Transistors can be much smaller – 0.02-.03 microns
- Current memory technology is at 7 nanometers (0.007 microns)

Camera Sensors – Structure

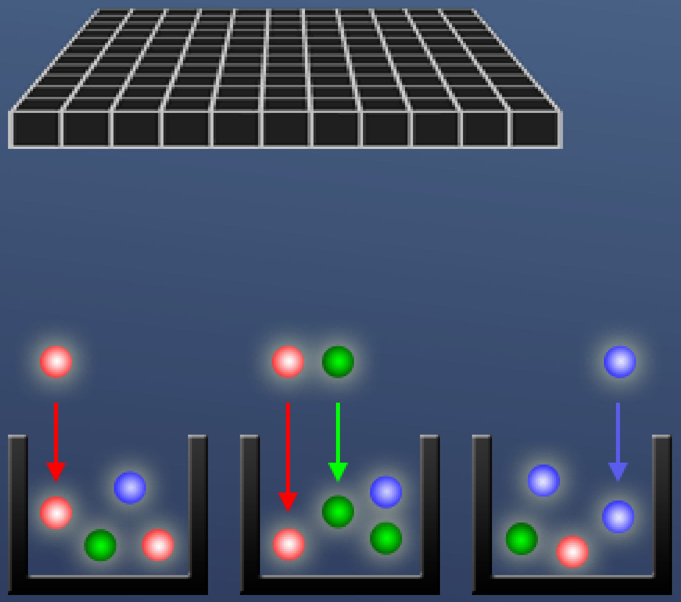
- The sensor is constructed in silicon and includes
  - Analog circuits
    - Photo-sensitive diodes to capture light using same principles as solar panels
    - Amplifiers – Charge-to-Voltage converters
    - Anti-noise circuitry
    - Analog-to-digital converters
    - Signal paths and switches
  - Physical items
    - Micro-lenses
    - Bayer filters
  - Digital circuits
    - Control logic, data paths and switches

Camera Sensors – Structure

- A cavity array of photon sensitive elements collects photons, converts each photon to a charge

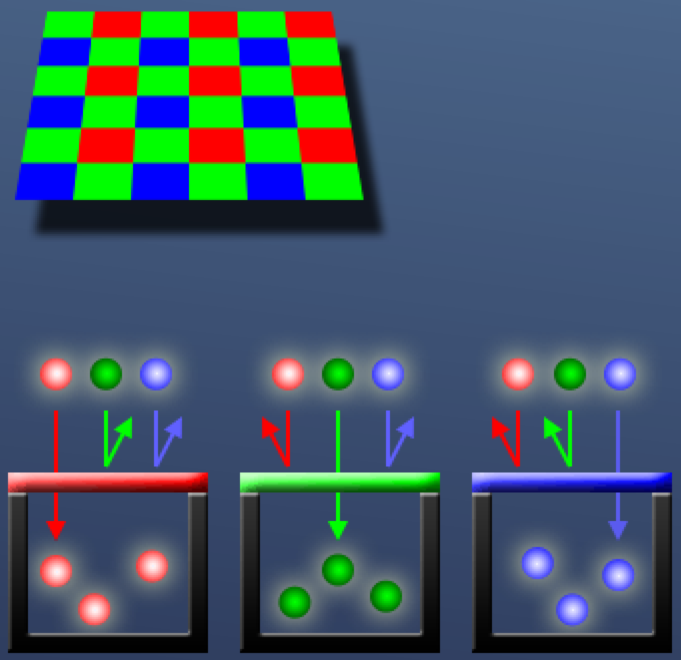
- The total charge of the image is proportional to the number of photons striking the cavity

- Noise adds some amount of charge to the cavity



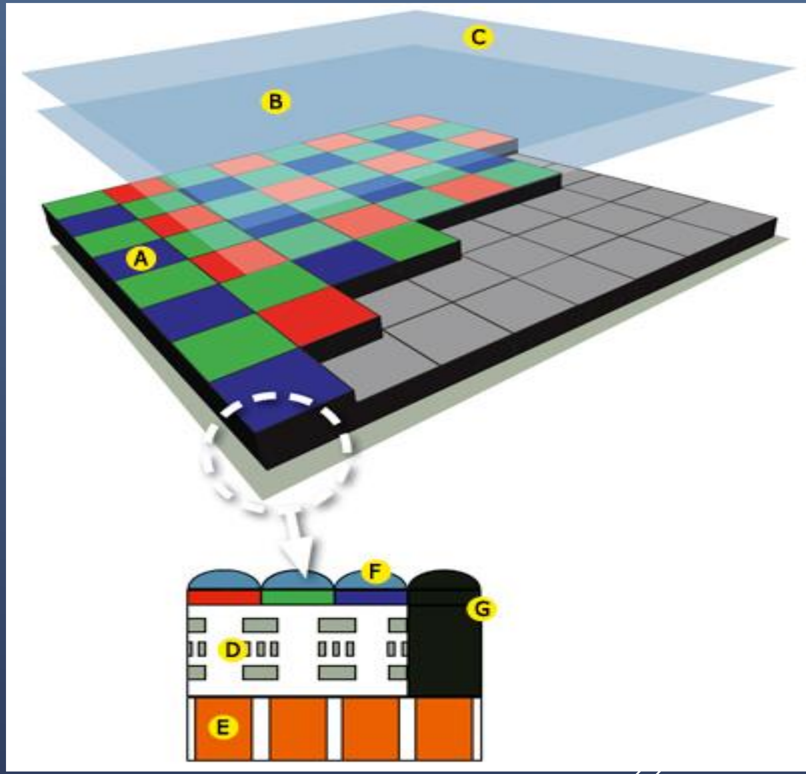
Camera Sensors – Structure

- A Bayer color filter array separates the photons into green, red and blue streams
- Each photosensitive cavity captures the photons of a single color based on the filter covering it
- The human eye is more sensitive to green light than red and blue
- Images with more green pixels appear less noisy and have finer detail

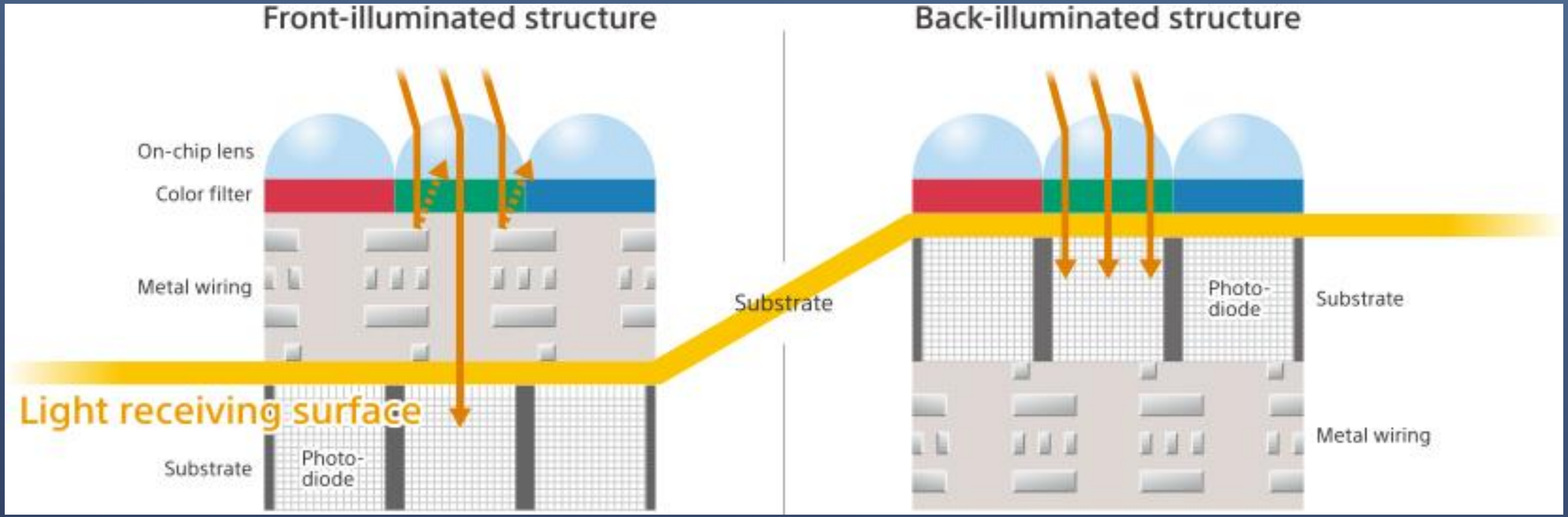


Camera Sensors – Structure

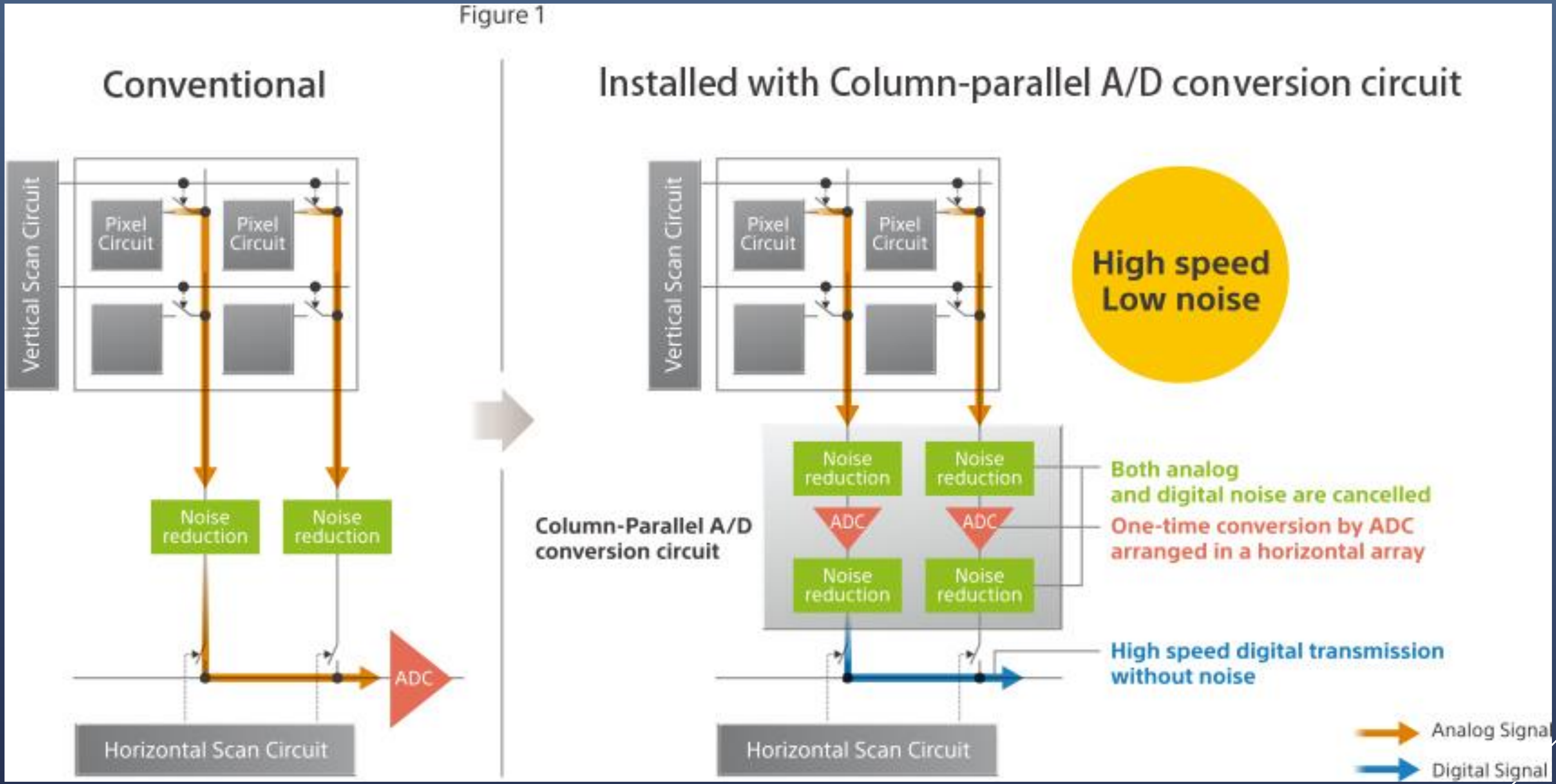
- A pixel is made up of:
  - (F) Micro-lens to guide light to the photo-diode
  - (A) A Bayer color filter array element
  - (E) A photo-diode (converts light to a charge)
  - (D) Circuitry for outputting the voltage
  - (G) Can be a black pixel
- Anti-noise amplifiers
- Analog-to-digital converters
- External Filters
  - (B) Lowpass & anti-aliasing
  - (C) Infrared



Camera Sensors



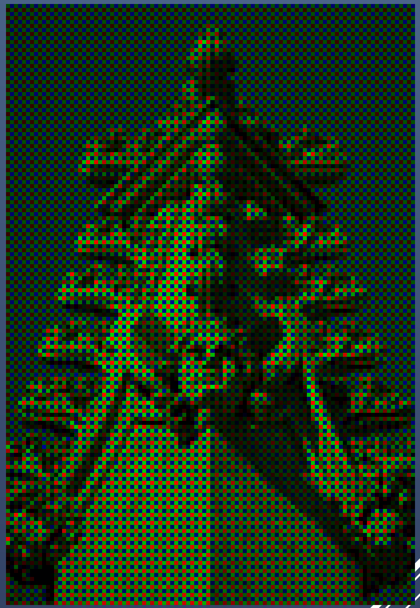
Camera Sensors



Camera Sensors – Structure

Original scene

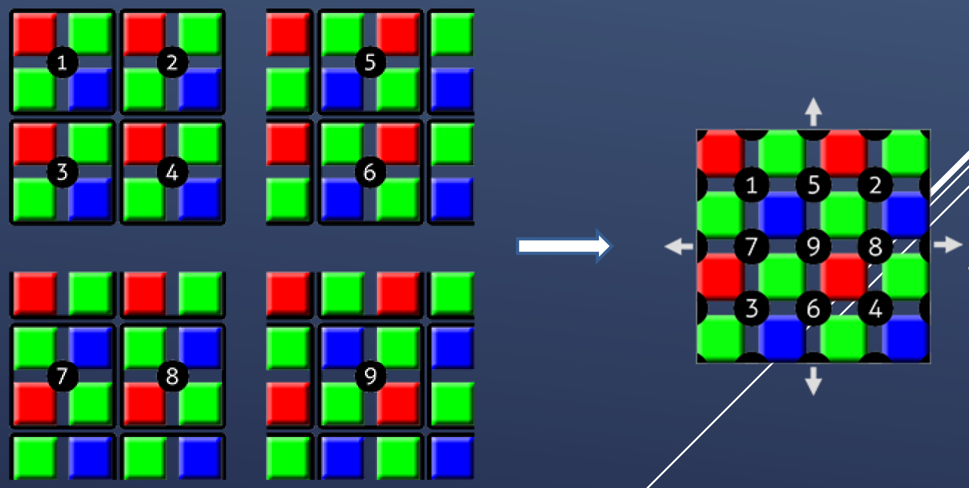
- What the sensor sees through the Bayer filter
- This is the information passed to the processor



Camera Sensors – Bayer Demosaicing

- Bayer demosaicing done in the processor
  - Translates the Bayer array of primary colors into a final image with full color information in each pixel
  - Think of each 2x2 array of RGB as a single full color cavity
  - Cameras use multiple overlapping arrays

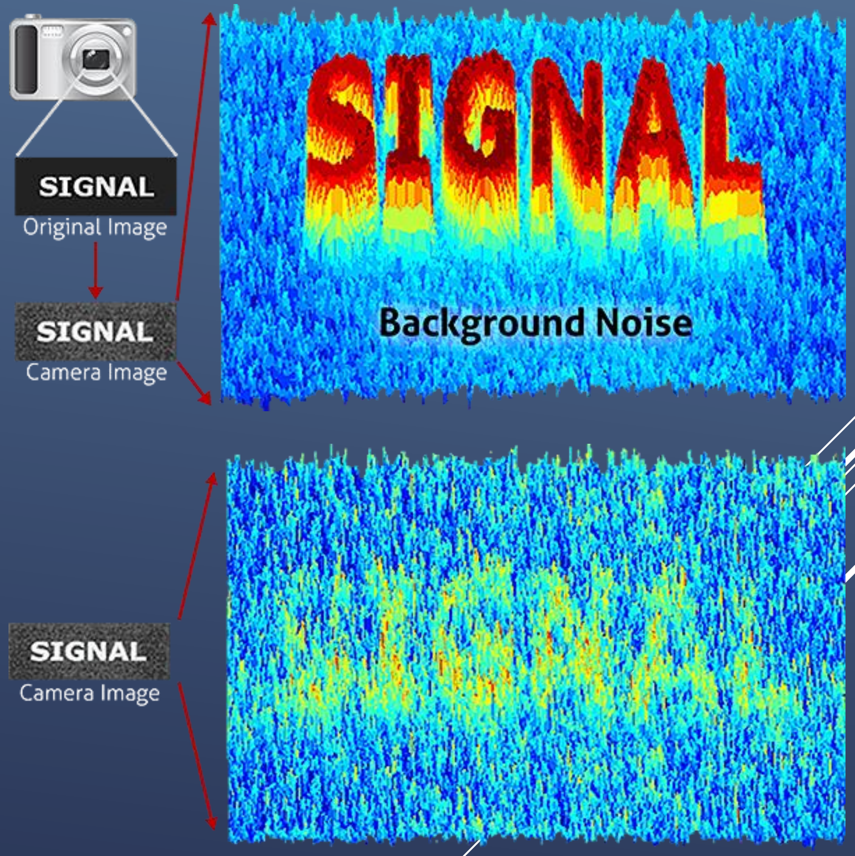
- Small-scale detail near the resolution limit of the sensor can produce artifacts
  - Most common is moiré (more-ray)
  - Optical low-pass filters (OLPF) or anti-aliasing (AA) filters used to control this.
  - A thin layer in front of the sensor that blurs potentially problematic details finer than the resolutions of the sensor



Camera Sensors – Noise

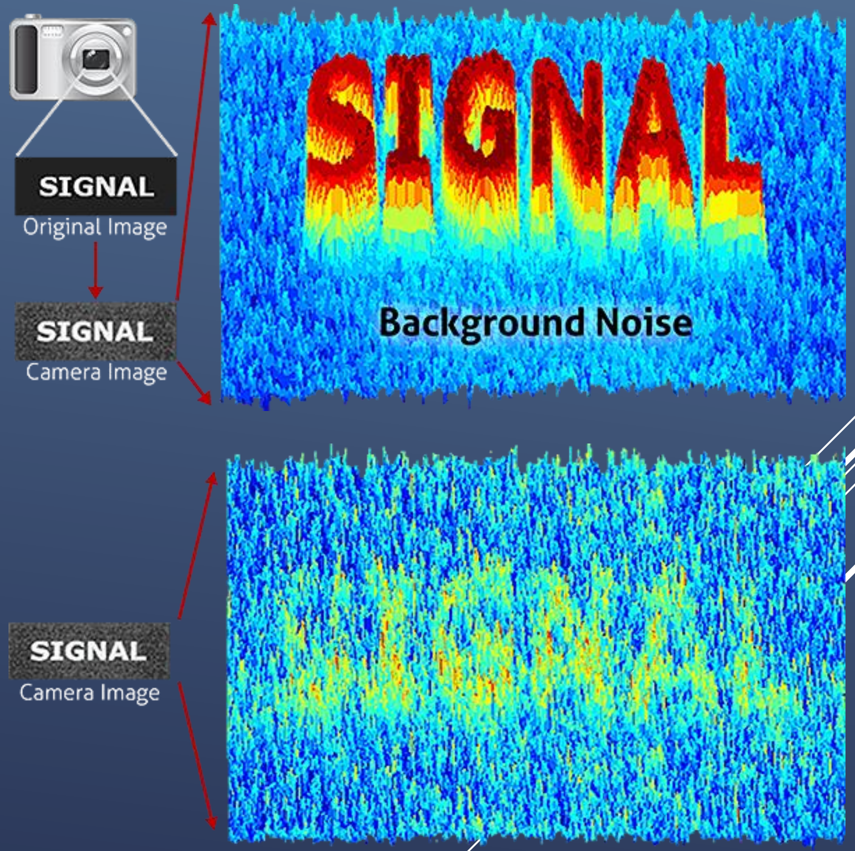
- Noise is any voltage or charge that is not from a photon striking the sensor

- Sources
  - Thermal, Coupling, Digital



Camera Sensors – Noise

- ISO is a measure of the sensor's sensitivity to light
- Each camera has a Base ISO, typically 100
  - The level where the sensor doesn't have to amplify the signal to get a usable image
- When the signal is amplified, the noise is amplified



If the noise = 1 and the signal = 10 and the amplification = 10, the result is the noise = 10 and the signal = 100. Noise = <u>10%</u> of the amplified signal.

If the noise = 1 and the signal = 2, then noise = 10 and signal = 20. Noise = <u>50%</u> of the signal.

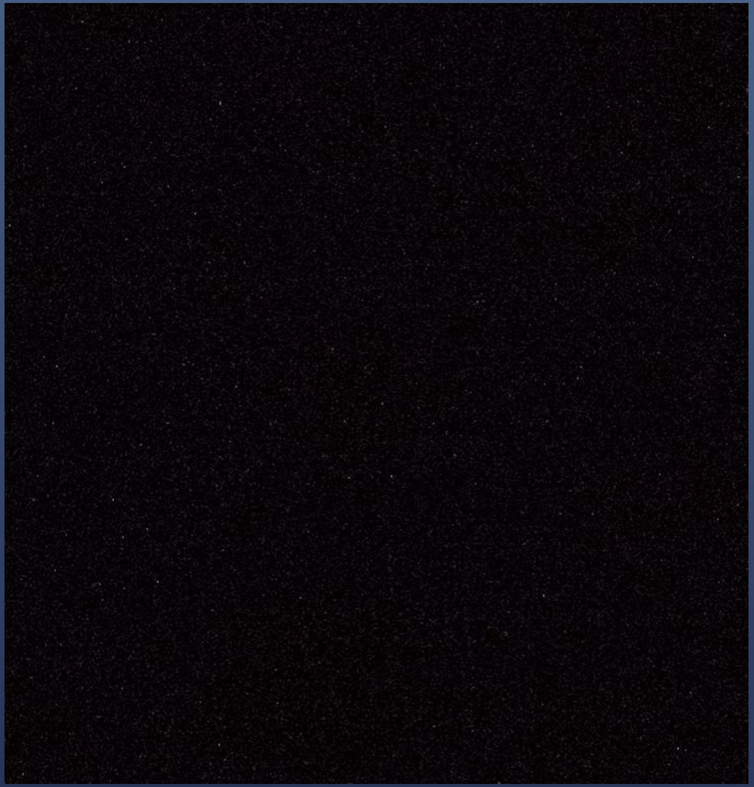
Camera Sensors – Noise

- The processor uses the data from the black pixels to remove noise from the other pixels

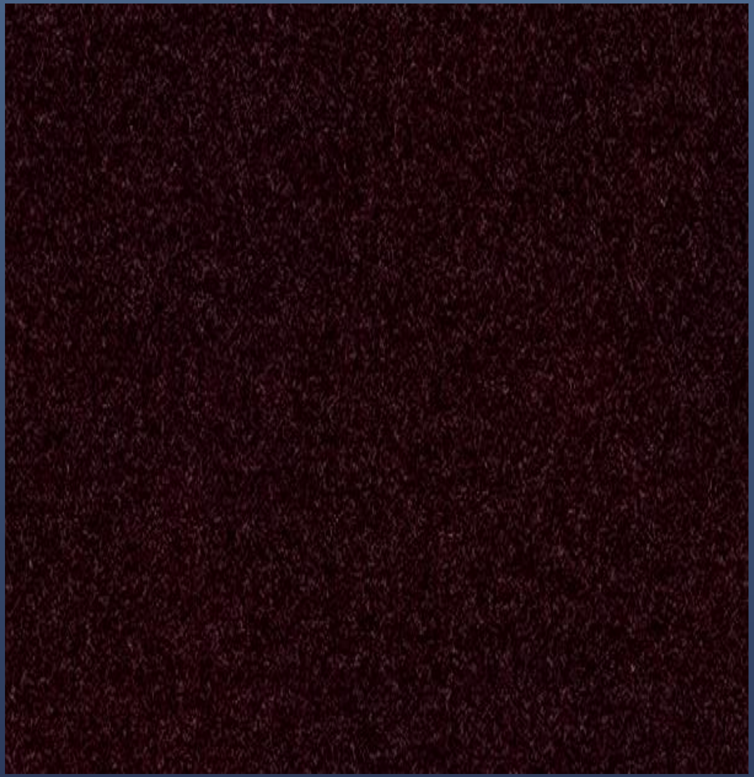
- Newer cameras
  - Have better dynamic range – more efficient conversion of light to charge
  - Have lower background noise levels – better technology

- Test the noise in your camera
  - Raise the ISO setting to the highest allowed
  - Leave your lens cap on and take a picture
  - Look at it in Lightroom or PS and maximum magnification

Camera Sensors – Noise

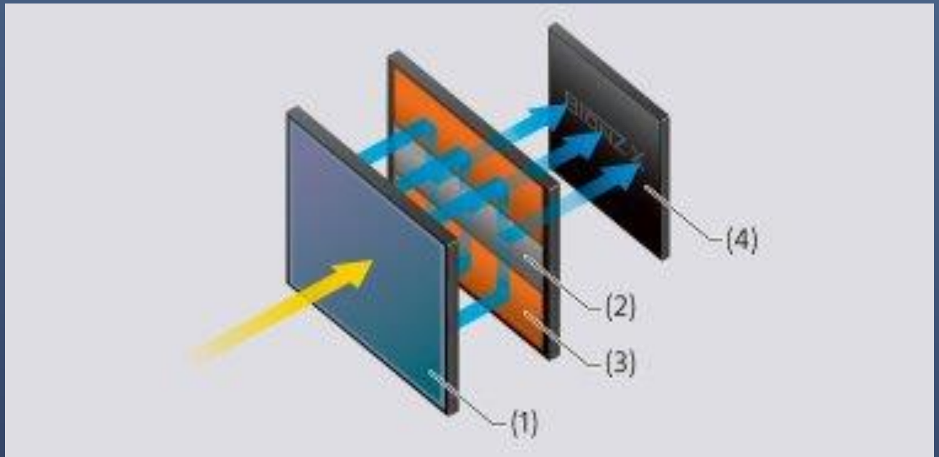


Nikon D850 @ ISO 25600 – sensor
1year old – 1,128,976 dark pixels



Sony A77m2 @ ISO 25600 – sensor
8 years old – 400,000 dark pixels

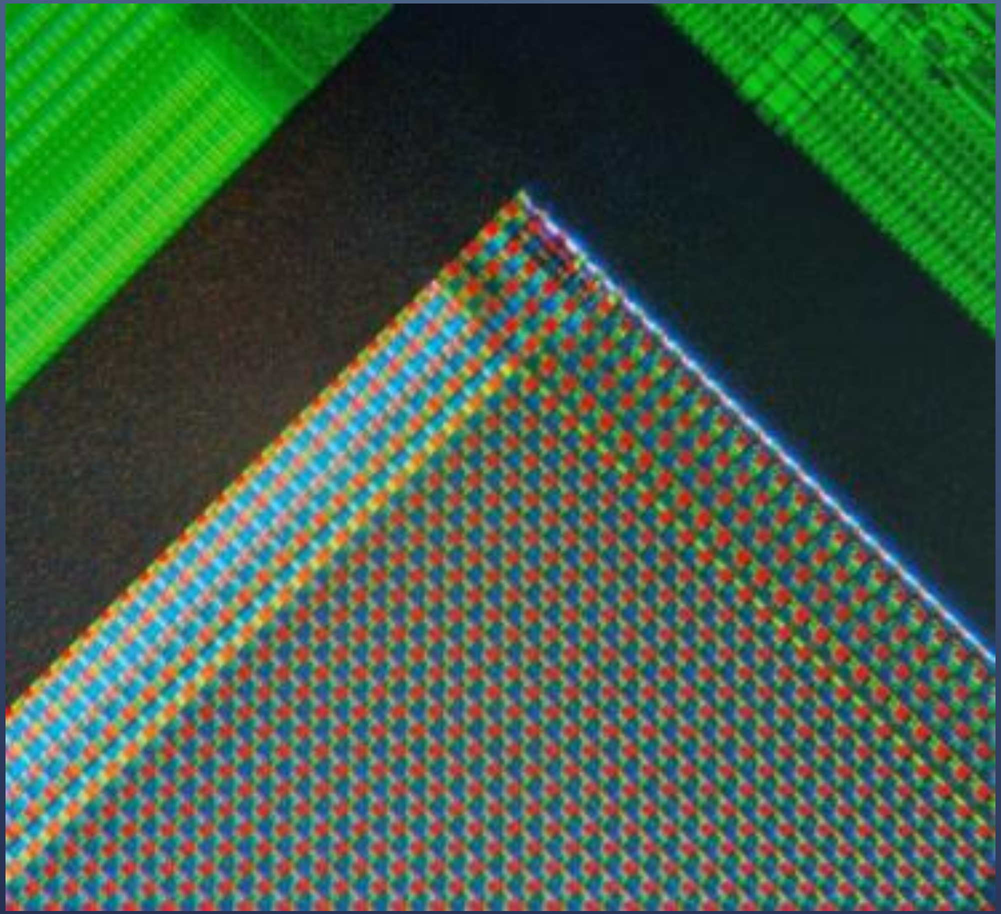
Camera Sensors – Making the Image



Up to 204800 ISO with the design of back-illuminated structure
(1) Pixel area
(2) Integral memory
(3) Hi-speed signal processing circuit
(4) Image processing engine

Sony A9

Camera Sensors



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Links

- Very mathematical analysis of sources of noise
  - http://photonstophotos.net/Emil%20Martinec/noise.html#thermalnoise
- https://www.cambridgeincolour.com/tutorials/camera-sensors.htm
- https://www.techhive.com/article/2052159/demystifying-digital-camera-sensors-once-and-for-all.html
- https://www.cambridgeincolour.com/tutorials/digital-camera-sensor-size.htm
- https://www.cambridgeincolour.com/tutorials/image-noise-2.htm
- Interested in astrophotography
  - http://galleries.aaronpriestphoto.com/Articles/NPF-Rule-for-Sharp-Stars