Image Formation

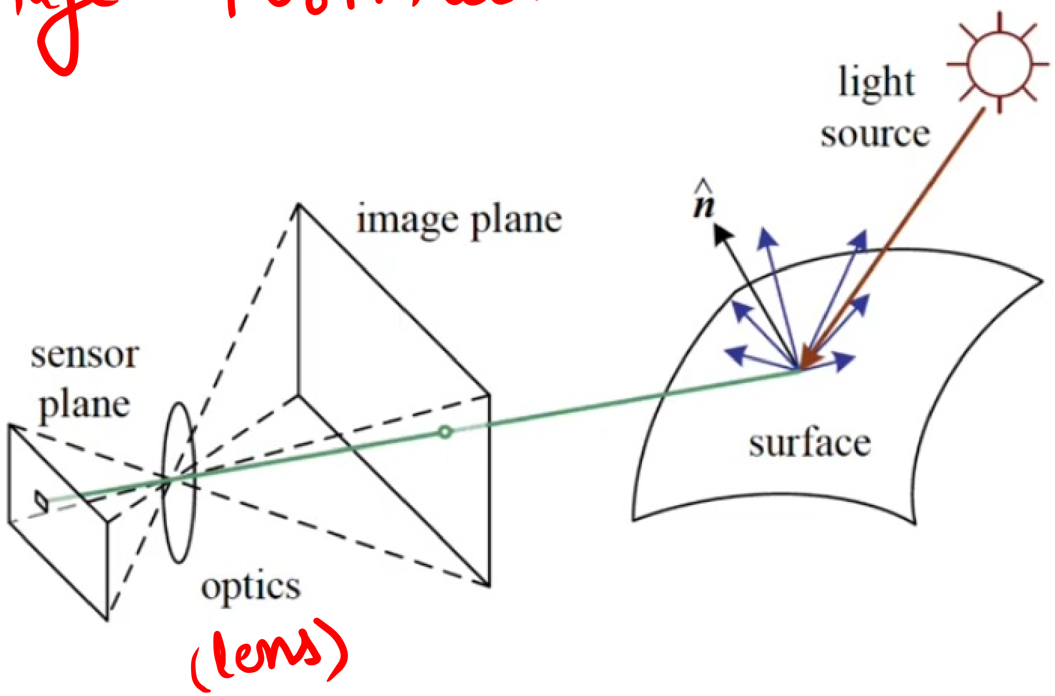
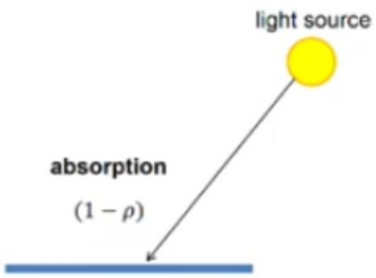


Image formation factors

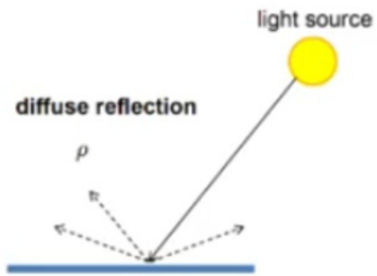
1) Light source strength and direction
2) Surface geometry, material and nearby surfaces.
3) Sensor capture properties
4) Image representation and color

Different Light reflection models

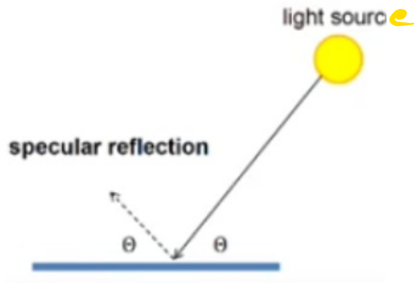


ρ = albedo

(a)



(b)



(c)

when light hits a surface

* Some light is absorbed $(1-\rho,\ \rho = \text{albedo})$

Albedo is the measure of diffuse reflection of solar radiation out of the total solar radiation

diffuse — spread over a wide area

(b) Some light is reflected diffusively, independent of viewing direction

E.g. Brick, cloth, rough wood

Lambert cosine law: Amount of reflected light proportional to $\cos\theta$

(c) Some light is reflected specularly depends on viewing direction

E.g. mirror

Reflection Models

- Most surfaces have both specular and diffuse components
- Intensity depends on illumination angle because less light comes in at oblique angles
- Other possible effects
  1) Transparency
  2) Refraction
  3) Surface scattering
  4) Flouresence, phosphoresence

To make a glow-in-the-dark toy, what you want is a phosphor that is energized by normal light and that has a very long persistence. Two phosphors that have these properties are Zinc Sulfide and Strontium Aluminate.

(1) (2) (3)

And in addition to absorption, diffuse reflection and specular reflection, there are other actions possible like

there is transparency, where light could pass through the surface

there is refraction such as a prism where light could get refracted

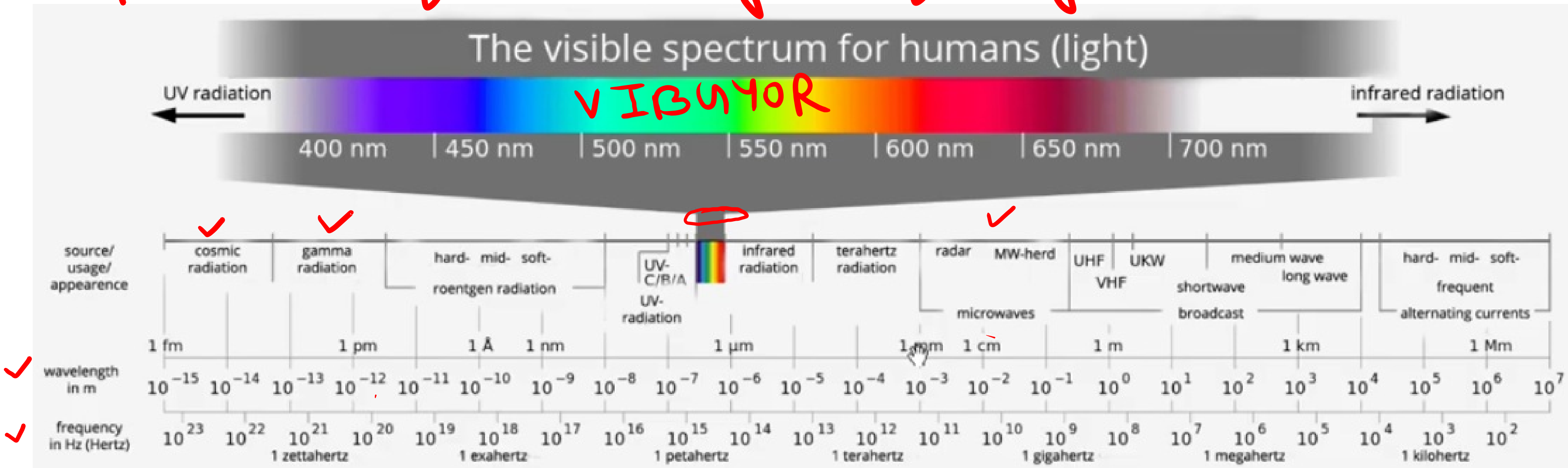
there is also sub surface scattering, where multiple layers of the surface could result in certain levels of scattering

And finally, there are also phenomena such as fluorescence, where the output wavelength could be different from the input wavelength or other phenomena such as phosphorescence.

Phosphorescence is a type of photoluminescence related to fluorescence. When exposed to light of a shorter wavelength, a phosphorescent substance will glow, absorbing the light and reemitting it at a longer wavelength. Unlike fluorescence, a phosphorescent material does not immediately reemit the radiation it absorbs.

- Bidirectional Reflection Distribution Function (BRDF): model of local reflection that tells a how bright a surface appears when viewed from one direction when light falls on it from another.

Spectrum of wavelengths of lights



The shorter the wavelength, the higher the frequency.

Frequency and wavelength are inversely proportional to each other.

Because all light waves move at the same speed in a vacuum, the number of wave crests passing at a given spot in one second is determined by the wavelength.

H.W.

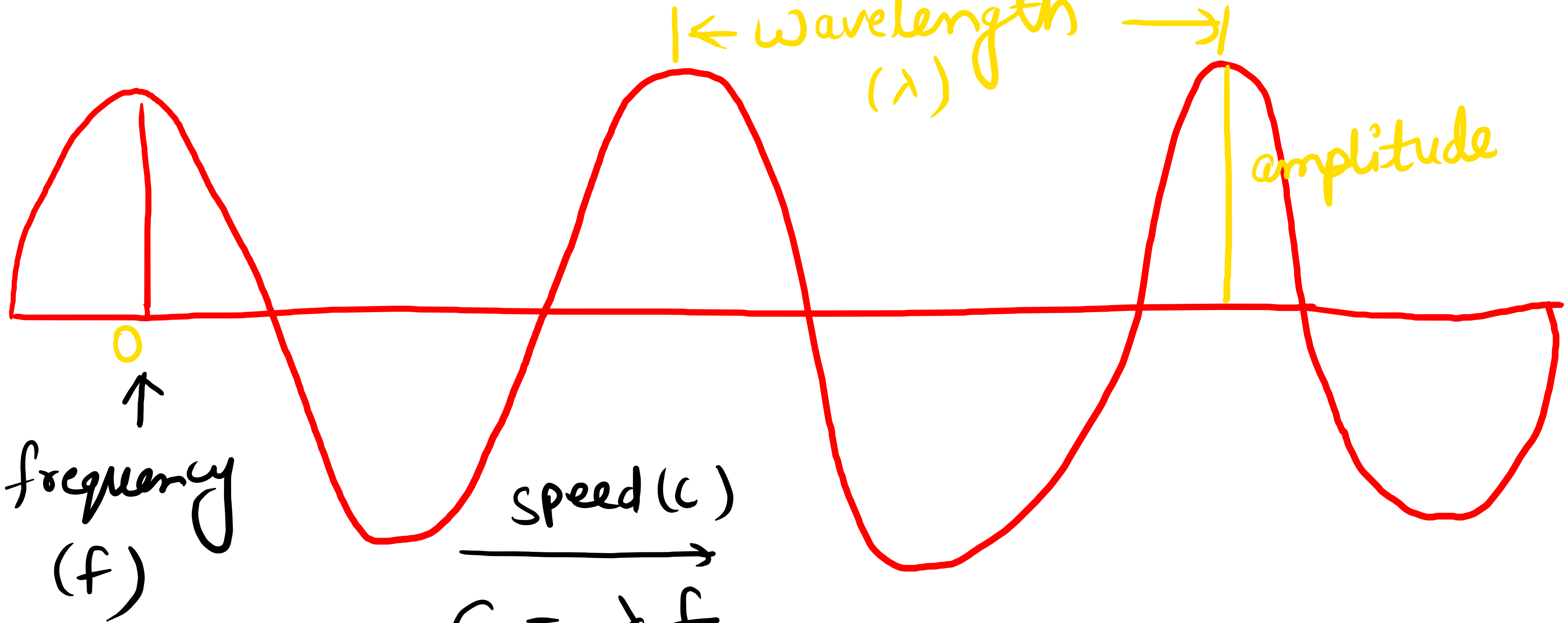
Application of radiations in real life

Shortwave broadcast is radio transmission using shortwave radio frequencies. There is no official definition of the band, but the range always includes all of the high frequency band, which extends from 3 to 30 MHz

The roentgen or röntgen is a legacy unit of measurement for the exposure of X-rays and gamma rays, and is defined as the electric charge freed by such radiation in a specified volume of air divided by the mass of that air.

Alternating current is an electric current which periodically reverses direction and changes its magnitude continuously with time in contrast to direct current which flows only in one direction.

Wavelength and Frequency in electromagnetic Radiation



$$C = \lambda f$$

Wavelength (λ) = distance between two wave crest

frequency (f) = the number of wave crests that pass over the origin in every second

Speed = wavelength × frequency

$$c = \lambda f = \frac{x}{t}$$

speed of light

$2.998 \times 10^{8}\ m\,s^{-1}$

wavelength

(in m)

frequency

(in s^{-1} or Hz)

Calculate the frequency of the violet color

$$\lambda f = c$$

$$f = \frac{c}{\lambda}$$

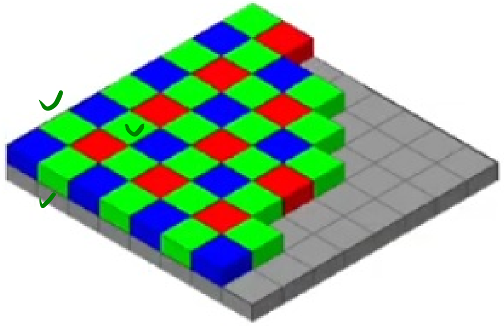
$$c = 2.998 \times 10^{8}\ ms^{-1}$$

$$\lambda = 400nm = 400 \times 10^{-9}\ m$$

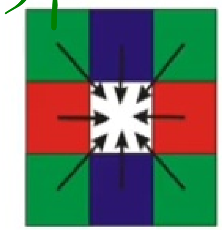
$$f = \frac{2.998 \times 10^{8}\ ms^{-1}}{400 \times 10^{-9}\ m}$$

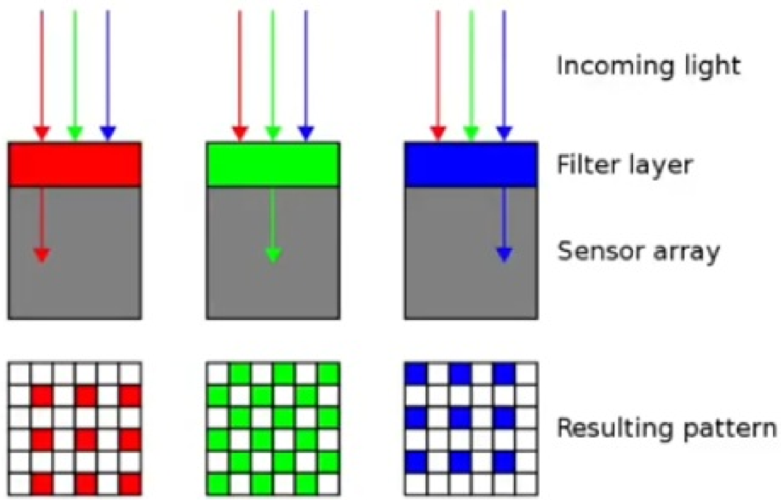
$$f = 7.50 \times 10^{14}\ Hz$$

Bayer Grid / Filter (How Camera sensor color is computed)



(x xx) G





25%   50%   25%

A demosaicing algorithm is a digital image process used to reconstruct a full color image from the incomplete color samples output from an image sensor overlaid with a color filter array.

It is also known as Color Filter Array (CFA) interpolation or color reconstruction.

Bayer Grid/ Filter

- Bayer arrangement of color filters on a camera sensor
- Filter pattern is 50% green, 25% red and 25% blue
- To obtain full color image, surrounding pixels used to estimate values for a particular pixel.

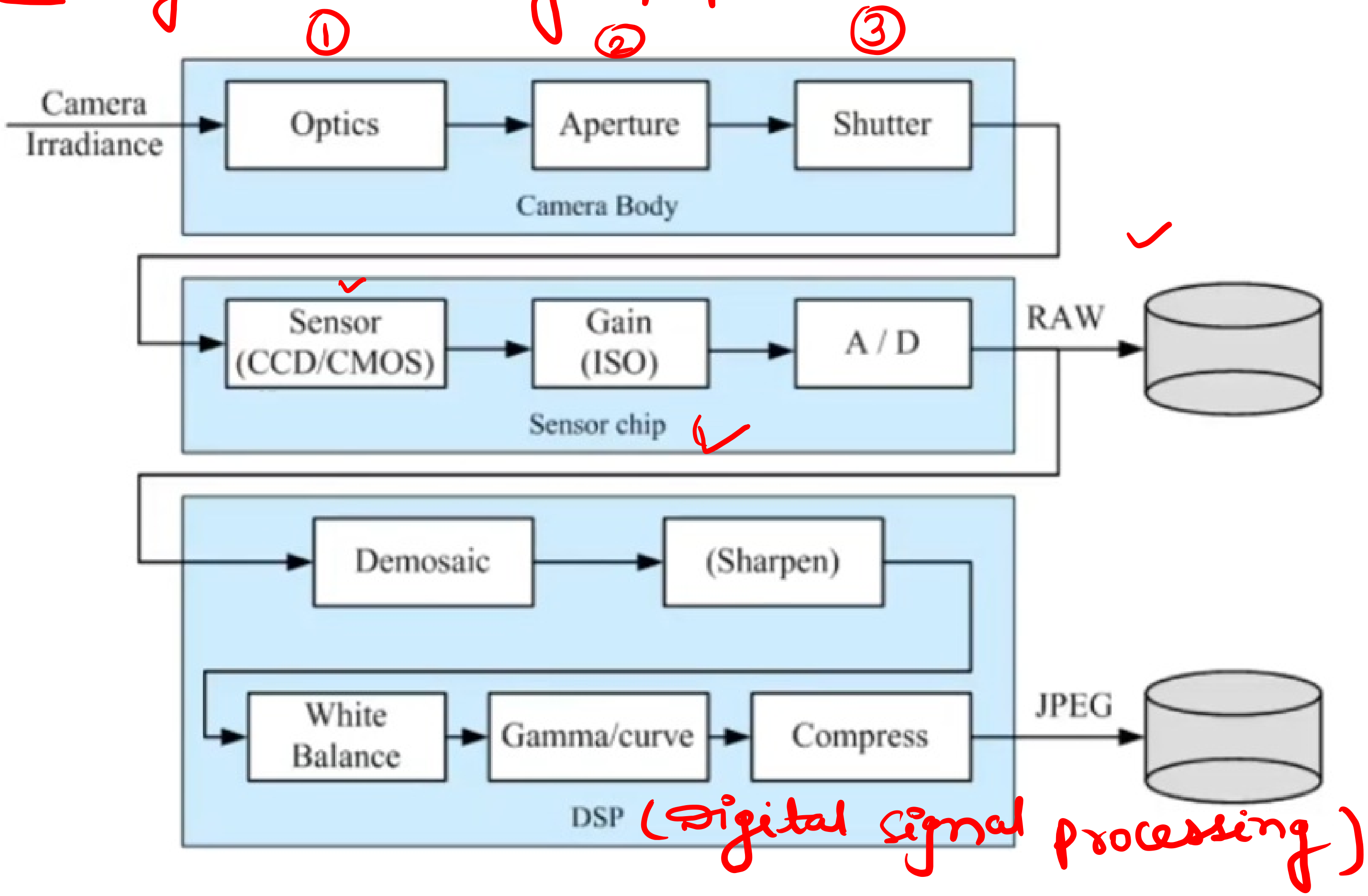
- In a real camera device, you would have a sensor array and there is a set of sensors that captures only red light, there is set of sensors that captures the green light, there is set of sensors that captures the blue light

- To obtain the full colour image demosaicing algorithms are used where surrounding pixels are used to contribute the value of the exact colour at a given pixel. So, that particular sensing element will have its own colour

- So demosaicing algorithms use the surrounding elements to find out to assign a colour at that particular sensing element.

- Bayer Filter is one filter that is more popular especially in single sensors cameras, but there has been other kinds of filters, other kind of colour grading mechanism that have been developed over the years too.

Image Sensing pipeline



1 the optics is the lens. The light falls in through that.

2-3 You have an aperture and shutter parameters that you can specify or adjust and from there light falls onto the sensor.

4 Sensor can be CCD or CMOS

5 Then there is a gain factor (amplify the signal)

6 Then the image is obtained in an analog or digital form which represents the raw image that you get

7 the typically cameras do not stop there, you then use demosaicing algorithms

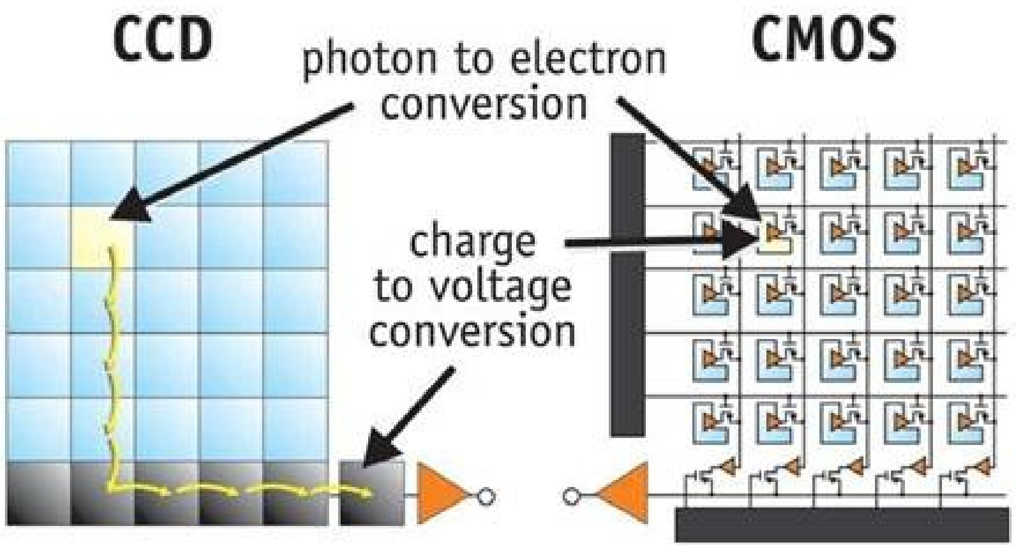
8 you could sharpen the image if you like or any other important image processing algorithms. Some white balancing, some other digital signal processing methods to improve the quality of the image

9 and finally you compress the image into a suitable format to store the image.

So, this is the general pipeline of image capture.

CCD vs. CMOS

CCD generates a charge at each sensing element and then it moves that photogenerated charge, so the charge generated by a photons striking that sensing elements from pixel to pixel and you convert it to a voltage at an output node on that particular column.



Then an analog to digital converter (ADC) converts each pixel's value into a digital value.

X ADC

CCD (Charged Coupled Device)

- move photogenerated charge from pixel to pixel and convert it to voltage at output node.
- An analog-to-digital (ADC) then turn each pixel's value into a digital value.

CMOS (Complementary metal oxide semiconductor)

- CMOS converts charge to voltage inside each element.
- uses several transistors at each pixel to amplify and move the charge using more traditional wires.
- CMOS signal is digital. so it needs no ADC.

Digital Image Sensor properties

Shutter speed:	Controls the amount of light reaching the sensor (also called *exposure time*)
Sampling pitch:	Physical spacing between adjacent sensor cells on the imaging chip
Fill factor: (active sensing area size)	Active sensing area size as a fraction of the theoretically available sensing area (product of horizontal and vertical sampling pitches)
Chip size:	Size/area of the chip
Analog gain:	Amplification of the sensed signal using automatic gain control (AGC) logic (controlled using ISO setting on cameras)
Sensor noise:	Noise from various sources in the sensing process
Resolution:	How many bits for each pixel, decided by analog-to-digital conversion module (CCD or CMOS)
Post-processing:	Digital image enhancement methods often used before compression and storage of captured image

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If you use 8 bits to represent each pixel, so you could get a value going from 0 to 255 for each pixel that gives you the sensing resolution for that particular pixel

Mirrorless vs mirror cameras

- DSLR - Digital Single Lens Reflex Camera

Uses a mirror mechanism to reflect light from lens to a viewfinder, or let light fully pass onto image sensor by moving the mirror out of the way

Pros of DSLR: picture quality, versatility and functionality, physical shutter, variable focal length/ aperture

Pros of mirrorless cameras: Low cost, Accessability, portability.