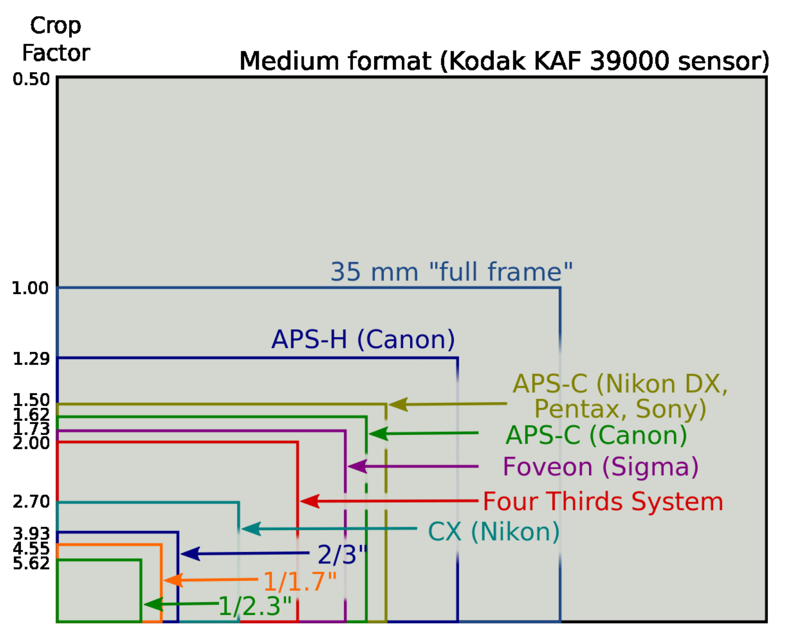
Image sensor format

In digital photography, the **image sensor format** is the shape and size of the image sensor.



Comparative dimensions of sensor sizes

The image sensor format of a digital camera determines the angle of view of a particular lens when used with a particular camera. In particular, image sensors in digital SLR cameras tend to be smaller than the 24 mm × 36 mm image area of full-frame 35 mm cameras, and therefore lead to a narrower angle of view.

Lenses produced for 35 mm film cameras may mount well on the digital bodies, but the larger image circle of the 35 mm system lens allows unwanted light into the camera body, and the smaller size of the image sensor compared to 35 mm film format results in cropping of the image. This latter effect is known as field of view crop. The format size ratio (relative to the 35 mm film format) is known as the field of view crop factor, crop factor, lens factor, focal length conversion factor, focal length multiplier or lens multiplier.

Sensor size and depth of field

Three possible depth of field comparisons between formats are discussed, applying the formulae derived in the article on depth of field. The depths of field of the three cameras may be the same, or different in either order, depending on what is held constant in the comparison.

Considering a picture with the same subject distance and angle of view for two different formats:

$$\frac{\mathrm{DOF}_2}{\mathrm{DOF}_1} \approx \frac{d_1}{d_2}$$

so the DOFs are in inverse proportion to the absolute aperture diameters d_1 and d_2.

Using the same absolute aperture diameter for both formats with the “same picture” criterion (equal angle of view, magnified to same final size) yields the same depth of field. It is equivalent to adjusting the f-number inversely in proportion to crop factor – a smaller f-number for smaller sensors. (This also means that, when holding the shutter speed fixed, the exposure is changed by the adjustment of the f-number required to equalise depth of field. But the aperture area is held constant, so sensors of all sizes receive the same total amount of light energy from the subject. The smaller sensor is then operating at a lower ISO setting, by the square of the crop factor.)

And, we might compare the depth of field of sensors receiving the same photometric exposure – the f-number is fixed instead of the aperture diameter – the sensors are operating at the same ISO setting in that case, but the smaller sensor is receiving less total light, by the area ratio. The ratio of depths of field is then

$$\frac{\mathrm{DOF}_2}{\mathrm{DOF}_1} \approx \frac{l_1}{l_2}$$

where l_1 and l_2 are the characteristic dimensions of the format, and thus l_1/l_2 is the relative crop factor between the sensors. It is this result that gives rise to the common opinion that small sensors yield greater depth of field than large ones.

An alternative is to consider the depth of field given by the same lens in conjunction with different sized sensors (changing the angle of view). The change in depth of field is brought about by the requirement for a different degree of enlargement to achieve the same final image size. In this case the ratio of depths of field becomes

$$\frac{\mathrm{DOF}_2}{\mathrm{DOF}_1} \approx \frac{l_2}{l_1}.$$

Sensor size, noise and dynamic range

Discounting pixel response non-uniformity (PRNU), which is not intrinsically sensor-size dependent, the noises in an image sensor are shot noise, read noise, and dark noise. The overall signal to noise ratio of a sensor (SNR), observed at the scale of a single pixel, is

$$\mathrm{SNR} = \frac{PQ_e t}{\sqrt{PQ_e t + Dt + N_r^2}}$$

where P is the incident photon flux (photons per second in the area of a pixel), Q_e is the quantum efficiency, t is the exposure time, D is the pixel dark current in electrons per second and N_r is the pixel read noise in electrons. Each of these noises has a different dependency on sensor size.

Exposure and photon flux

Image sensor noise can be compared across formats for a given fixed photon flux per pixel area (the *P* in the formulas); this analysis is useful for a fixed number of pixels with pixel area proportional to sensor area, and fixed absolute aperture diameter for a fixed imaging situation in terms of depth of field, diffraction limit at the subject, etc. Or it can be compared for a fixed focal-plane illuminance, corresponding to a fixed f-number, in which case *P* is proportional to pixel area, independent of sensor area. The formulas above and below can be evaluated for either case.

Shot noise

In the above equation, the shot noise SNR is given by

$$\frac{PQ_e t}{\sqrt{PQ_e t}} = \sqrt{PQ_e t}\,.$$

Apart from the quantum efficiency it depends on the incident photon flux and the exposure time,which is equivalent to the exposure and the sensor area; since the exposure is the integration time multiplied with the image plane illuminance, and illuminance is the luminous flux per unit area. Thus for equal exposures, the signal to noise ratios of two different size sensors of equal quantum efficiency and pixel count will (for a given final image size) be in proportion to the square root of the sensor area (or the linear scale factor of the sensor). If the exposure is constrained by the need to achieve some required depth of field (with the same shutter speed) then the exposures will be in inverse relation to the sensor area, producing the interesting result that if depth of field is a constraint, image shot noise is not dependent on sensor area.

Read noise

The read noise is the total of all the electronic noises in the conversion chain for the pixels in the sensor array. To compare it with photon noise, it must be referred back to its equivalent in photoelectrons, which requires the division of the noise measured in volts by the conversion gain of the pixel. This is given, for an active pixel sensor, by the voltage at the input (gate) of the read transistor divided by the charge which generates that voltage, $CG = V_{rt}/Q_{rt}$. This is the inverse of the capacitance of the read transistor gate (and the attached floating diffusion) since capacitance $C = Q/V$. Thus $CG = 1/C_{rt}$.

In general for a planar structure such as a pixel, capacitance is proportional to area, therefore the read noise scales down with sensor area, as long as pixel area scales with sensor area, and that scaling is performed by uniformly scaling the pixel.

Considering the signal to noise ratio due to read noise at a given exposure, the signal will scale as the sensor area along with the read noise and therefore read noise SNR will be unaffected by sensor area. In a depth of field constrained situation, the exposure of the larger sensor will be reduced in proportion to the sensor area, and therefore the read noise SNR will reduce likewise.

Dark noise

The dark current contributes two kinds of noise: dark offset, which is only partly correlated between pixels, and the shot noise associated with dark offset, which is uncorrelated between pixels. Only the shot-noise component *Dt* is included in the formula above, since the uncorrelated part of the dark offset is hard to predict, and the correlated or mean part is relatively easy to subtract off. The mean dark current contains contributions proportional both to the area and the linear dimension of the photodiode, with the relative proportions and scale factors depending on the design of the photodiode. Thus in general the dark noise of a sensor may be expected to rise as the size of the sensor increases. However, in most sensors the mean pixel dark current at normal temperatures is small, lower than 50 e- per second, thus for typical photographic exposure times dark current and its associated noises may be discounted. At very long exposure times, however, it may be a limiting factor. And even at short or medium exposure times, a few outliers in the dark-current distribution may show up as "hot pixels".

Dynamic range

Dynamic range is the ratio of the largest and smallest recordable signal, the smallest being typically defined by the 'noise floor'. In the image sensor literature, the noise floor is taken as the readout noise, so $DR = Q_{max}/\sigma_{readout}$ (note, the read noise $\sigma_{readout}$ is the same quantity as N_r referred to in)

The measurement here is made at the level of a pixel (which strictly means that the DR of sensors with different pixel counts is measured over a different spatial bandwidth, and cannot be compared without normalisation). If we assume sensors with the same pixel count but different sizes, then the pixel area will be in proportion to the sensor area. If the maximum exposure (amount of light per unit area) is the same then both the maximum signal and the read noise reduce in proportion to the pixel (and therefore the sensor) area, so the DR does not change. If the comparison is made according to DOF limited conditions, so that the exposure of the larger sensor is reduced in proportion to the area of the sensor (and pixel, for sensors with equal pixel count) then Q_{max} is constant, and the read noise ($\sigma_{readout}$) falls with the sensor area, leading to a higher dynamic range for the smaller sensor. Summarising the above discussion, considering separately the parts of the image signal to noise ratio due to photon shot noise and read noise and their relation to the linear sensor size ratio or 'crop factor' (remembering that conventionally crop factor increases as the sensor gets smaller) then:

	Shot noise SNR	Read noise SNR	Dynamic range
Fixed exposure	Inversely proportional to crop factor	No change	No change
DOF constrained	No change	Proportional to square of crop factor	Proportional to square of crop factor

It should be noted that this discussion isolates the effects of sensor scale on SNR and DR, in reality there are many other factors which affect both these quantities.

Sensor size and diffraction

The resolution of all optical systems is limited by diffraction. One way of considering the effect that diffraction has on cameras using different sized sensors is to consider the modulation transfer function (MTF) due to diffraction, which will contribute a factor to the overall system MTF along with the other factors, typically the MTFs of the lens, anti-aliasing filter and sensor sampling window. The spatial cut-off frequency due to diffraction through a lens aperture is

$$\xi_{\mathrm{cutoff}} = \frac{1}{\lambda N}$$

where λ is the wavelength of the light passing through the system and N is the f-number of the lens. If that aperture is circular, as are (approximately) most photographic apertures, then the MTF is given by

$$\mathrm{MTF}(\xi/\xi_{\mathrm{cutoff}}) = \frac{2}{\pi}\left\{\cos^{-1}(\xi/\xi_{\mathrm{cutoff}}) - (\xi/\xi_{\mathrm{cutoff}})\left[1-(\xi/\xi_{\mathrm{cutoff}})^2\right]^{1/2}\right\}$$

for $\xi < \xi_{\mathrm{cutoff}}$and $0$for $\xi \geq \xi_{\mathrm{cutoff}}$The diffraction based factor of the system MTF will therefore scale according to ξ_{cutoff} and in turn according to $1/N$ (for the same light wavelength).

In considering the effect of sensor size, and its effect on the final image, the different magnification required to obtain the same size image for viewing must be accounted for, resulting in an additional scale factor of $1/C$ where C is the relative crop factor, making the overall scale factor $1/(NC)$. Considering the three cases above:

For the 'same picture' conditions, same angle of view, subject distance and depth of field, then the F-numbers are in the ratio $1/C$, so the scale factor for the diffraction MTF is 1, leading to the conclusion that the diffraction MTF at a given depth of field is independent of sensor size.

In both the 'same photometric exposure' and 'same lens' conditions, the F-number is not changed, and thus the spatial cutoff and resultant MTF on the sensor is unchanged, leaving the MTF in the viewed image to be scaled as the magnification, or inversely as the crop factor.

Sensor format and lens size

It might be expected that lenses appropriate for a range of sensor sizes could be produced by simply scaling the same designs in proportion to the crop factor. Such an exercise would in theory produce a lens with the same F-number and angle of view, with a size proportional to the sensor crop factor. In practice, simple scaling of lens designs is not always achievable, due to factors such as the non-scalability of manufacturing tolerance, structural integrity of glass lenses of different sizes and available manufacturing techniques and costs. Moreover, to maintain the same absolute amount of information in an image (which can be measured as the space bandwidth product) the lens for a smaller sensor requires a greater resolving power. The development of the 'Tessar' lens is discussed by Nasse, and shows its transformation from an f/6.3 lens for plate cameras using the original three-group configuration through to an f/2.8 5.2 mm four-element optic with eight extremely aspheric surfaces, economically manufacturable because of its small size. Its performance is 'better than the best 35 mm lenses – but only for a very small image'.

In summary, as sensor size reduces, the accompanying lens designs will change, often quite radically, to take advantage of manufacturing techniques made available due to the reduced size. The functionality of such lenses can also take advantage of these, with extreme zoom ranges becoming possible. These lenses are often very large in relation to sensor size, but with a small sensor can be fitted into a compact package.

Small body means small lens and means small sensor, so to keep smartphones slim and light, the smartphone manufacturers use tiny sensor usually less than 1/2.3" which usually use in most Bridge cameras and until now only Nokia 808 PureView uses 1/1.2" sensor which sensor size almost three times of 1/2.3" sensor size. To use bigger sensor has advantage of better image quality, but with sensor technology improves, small sensor initial to catch larger sensor, although the bigger sensor always on the lead, but not all of the consumers need superb photo quality or bigger sensor as we can see that smartphone has toppled low and middle end compact camera sales and uses for taking images.

Sensor size and shading effects

Semiconductor image sensors can suffer from shading effects at large apertures and at the periphery of the image field, due to the geometry of the light cone projected from the exit pupil of the lens to a point, or pixel, on the sensor surface. The effects are discussed in detail by Catrysse and Wandell . In the context of this discussion the most important result from the above is that to ensure a full transfer of light energy between two coupled optical systems such as the lens' exit pupil to a pixel's photoreceptor the geometrical extent (also known as etendue or light throughput) of the objective lens / pixel system must be smaller than or equal to the geometrical extent of the microlens / photoreceptor system. The geometrical extent of the objective lens / pixel system is given by

$$G_{\mathrm{objective}} \simeq \frac{w_{\mathrm{pixel}}}{2(f/\#)_{\mathrm{objective}}},$$

where w_{pixel} is the width of the pixel and $(f/\#)_{\mathrm{objective}}$ is the f-number of the objective lens. The geometrical extent of the microlens / photoreceptor system is given by

$$G_{\mathrm{pixel}} \simeq \frac{w_{\mathrm{photoreceptor}}}{2(f/\#)_{\mathrm{microlens}}},$$

where $w_{\mathrm{photoreceptor}}$ is the width of the photoreceptor and $(f/\#)_{\mathrm{microlens}}$ is the f-number of the microlens. So to avoid shading,

$$G_{\mathrm{pixel}} \geq G_{\mathrm{objective}}, \text{ therefore } \frac{w_{\mathrm{photoreceptor}}}{(f/\#)_{\mathrm{microlens}}} \geq \frac{w_{\mathrm{pixel}}}{(f/\#)_{\mathrm{objective}}}$$

If $w_{\mathrm{photoreceptor}} / w_{\mathrm{pixel}} = ff$, the linear fill factor of the lens, then the condition becomes

$$(f/\#)_{\mathrm{microlens}} \leq (f/\#)_{\mathrm{objective}} \times ff$$

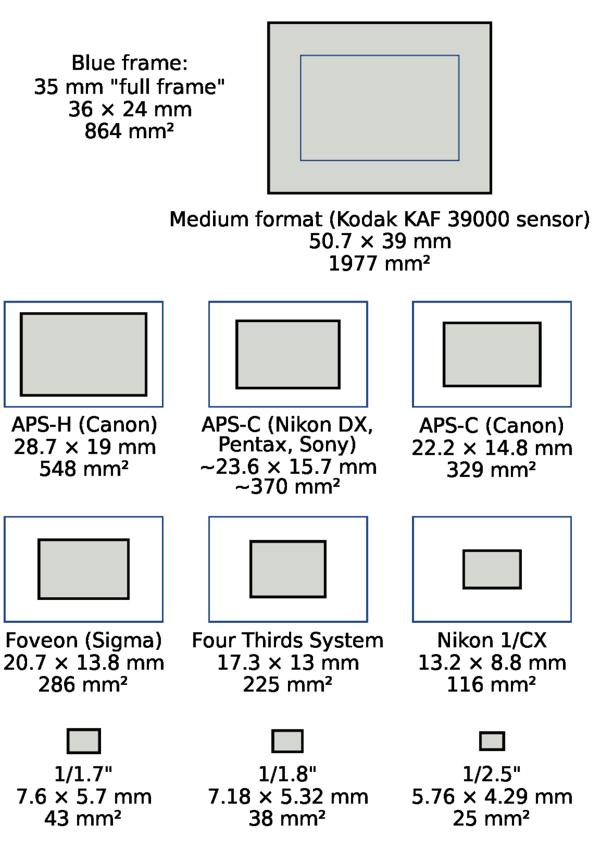
Thus if shading is to be avoided the f-number of the microlens must be smaller than the f-number of the taking lens by at least a factor equal to the linear fill factor of the pixel. The f-number of the microlens is determined ultimately by the width of the pixel and its height above the silicon, which determines its focal length. In turn, this is determined by the height of the metallisation layers, also known as the 'stack height'. For a given stack height, the f-number of the microlenses will increase as pixel size reduces, and thus the objective lens f-number at which shading occurs will tend to increase. This effect has been observed in practice, as recorded in the DxOmark article 'F-stop blues'

In order to maintain pixel counts smaller sensors will tend to have smaller pixels, while at the same time smaller objective lens f-numbers are required to maximise the amount of light projected on the sensor. To combat the effect discussed above, smaller format pixels include engineering design features to allow the reduction in f-number of their microlenses. These may include simplified pixel designs which require less metallisation, 'light pipes' built within the pixel to bring its apparent surface closer to the microlens and 'back side illumination' in which the wafer is thinned to expose the rear of the photodetectors and the microlens layer is placed directly on that surface, rather than the front side with its wiring layers. The relative effectiveness of these stratagems is discussed by Aptina in some detail.

Common image sensor formats

Medium-format digital sensors

The most common sensor size for medium-format digital cameras is approximately 48 mm × 36 mm (1.9 in × 1.4 in)[citation needed], due to the widespread use of Kodak's 22-megapixel KAF-22000 and 39-megapixel KAF-39000 CCDs in that format. Phase one offers the P65+ digital back with Dalsa's 53.9 mm × 40.4 mm (2.12 in × 1.59 in) sensor containing 60.5 megapixels and Leica offers an "S-System" DSLR with a 45 mm × 30 mm (1.8 in × 1.2 in) sensor containing 37-megapixels. In 2010, Pentax released the 40MP 645D medium format DSLR with a 44 mm × 33 mm (1.7 in × 1.3 in) sensor.



Sizes of the sensors used in most current digital cameras relative to a standard 35mm frame.

Sensors equipping most DSLRs and mirrorless interchangeable-lens cameras

Some professional DSLRs use full-frame sensors, equal to the size of a frame of 35 mm film.

Most consumer-level DSLRs and MILCs/EVILs use relatively large sensors, either around the size of a frame of APS-C film, with a crop factor of 1.5-1.6; or 30% smaller than that, with a crop factor of 2.0 (this is the Four Thirds System, adopted by Olympus and Panasonic).

On September 2011, Nikon announced their new format CX, whose size is 1" (2.7 crop factor).[1] It has been adopted for the Nikon 1 camera system (Nikon J1 and V1 models), and subsequently, Sony released the pocket size Cybershot DSC RX-100 digital camera, in 2012, which also uses a 1" sensor.

As of November 2013[2] there is only one MILC model equipped with a very small sensor, typical of compact cameras: it is the Pentax Q7, equipped with a 1/1.7" sensor (4.55 crop factor). See Sensors equipping Compact digital cameras and camera-phones section below. Many different terms are used in marketing to describe DSLR/MILC sensor formats, including the following:

- Full-frame digital SLR format, with sensor dimensions nearly equal to those of 35 mm film (36 × 24 mm)
- Canon's APS-H format for high-speed pro-level DSLRs (crop factor 1.3)
- Leica's M8 and M8.2 sensor (crop factor 1.33).
- APS-C refers to a range of similarly-sized formats, including
  - Nikon, Pentax, Samsung, Konica Minolta/Sony, Fujifilm, Epson, Sigma (crop factor 1.5)
  - Canon (crop factor 1.6)
- Foveon X3 format used in Sigma SD-series DSLRs and DP-series mirrorless (crop factor 1.7) (latest models include SD1, DP2 Merrill use crop factor 1.5 foveon sensor)
- Four Thirds System and Micro Four Thirds System format (crop factor 2.0)
- Nikon CX format used in Nikon 1 series (crop factor 2.7)

When full-frame sensors were first introduced, production costs could exceed twenty times the cost of an APS-C sensor. Only twenty full-frame sensors can be produced on an 8 inches (20 cm) silicon wafer that would fit 100 or more APS-C sensors, and there is a significant reduction in yield due to the large area for contaminants per component. Additionally, the full frame sensor originally required three separate exposures during the photolithography stage, which requires separate masks and quality control steps. The APS-H size was selected since it was then the largest that could be imaged with a single mask to help control production costs and manage yields. Newer photolithography equipment now allows single-pass exposures for full-frame sensors, although other size-related production constraints remain much the same.

Due to the ever-changing constraints of semiconductor fabrication and processing, and because camera manufacturers often source sensors from third-party foundries, it is common for sensor dimensions to vary slightly within the same nominal format. For example, the Nikon D3 and D700 cameras' nominally full-frame sensors actually measure 36 × 23.9 mm, slightly smaller than a 36 × 24 mm frame of 35 mm film. As another example, the Pentax K200D's sensor (made by Sony) measures 23.5 × 15.7 mm, while the contemporaneous K20D's sensor (made by Samsung) measures 23.4 × 15.6 mm.

Most DSLR image sensor formats approximate the 3:2 aspect ratio of 35 mm film. Again, the Four Thirds System is a notable exception, with an aspect ratio of 4:3 as seen in most compact digital cameras (see below).

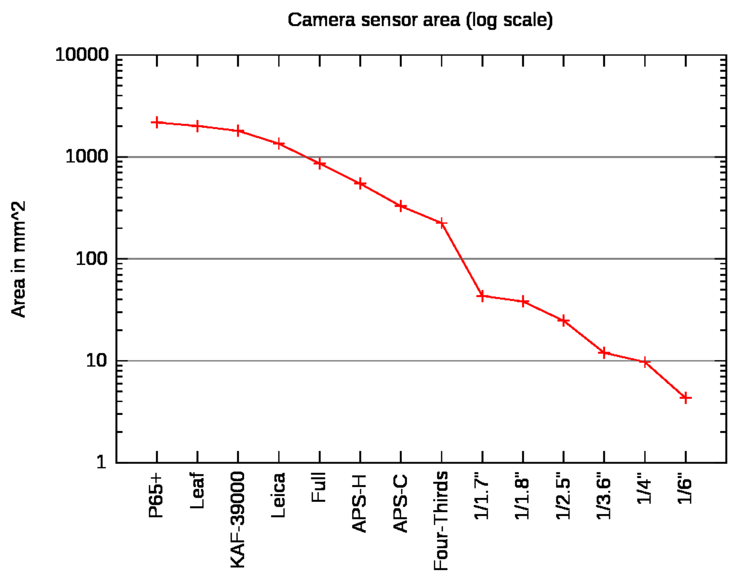
Sensors equipping compact digital cameras, mega-zoom (bridge) cameras and camera-phones

Most image sensors equipping compact cameras have an aspect ratio of 4:3. This matches the aspect ratio of the popular SVGA, XGA, and SXGA display resolutions at the time of the first digital cameras, allowing images to be displayed on usual monitors without cropping.

As of December 2010[2] most compact digital cameras used small 1/2.3" sensors. Such cameras include Canon Powershot SX230 IS, Fuji Finepix Z90 and Nikon Coolpix S9100. Some older digital cameras (mostly from 2005–2010) used a tiny 1/2.5" sensor: these include Panasonic Lumix DMC-FS62, Canon Powershot SX120 IS, Sony CyberShot DSC-S700, and Casio Exilim EX-Z80.

High-end compact cameras using sensors of nearly twice the area than sensors equipping common compacts include Canon PowerShot G12 (1/1.7") and Powershot S90/S95 (1/1.7"), Ricoh GR Digital IV (1/1.7"), Nikon Coolpix P7100 (1/1.7"), Samsung EX1 (1/1.7"), Panasonic DMC-LX5 (1/1.63") and Olympus XZ-1(1/1.63"). Fujifilm FinePix X-10 has a 2/3" sensor, the largest sensor on camera small enough to be labelled as compact (despite weighing 353 grams) until June 2012. That is until Sony announced DSC-RX-100, a real compact (weight: 213 grams) equipped with a 1" sensor (i.e. one only used on MILCs until then). Actually, Canon labels "compact camera" its PowerShot G1 X, equipped with a huge 1.5" sensor (i.e. a sensor larger than the 4/3" sensors equipping some compact DSLR). Nonetheless, weighing well over half a kilo (534 grams) G1 X is arguably a bridge camera rather than a compact.[*citation needed*]

As of 2012[2] most bridge cameras, including the Sony CyberShot DSC-HX100V and the Canon PowerShot SX40 HS, use a small 1/2.3" sensor (i.e. same size as those used in common compact cameras). The high-end bridge camera Fuji XS-1, though, is equipped with a much larger sensor (2/3" – twice the area of a 1/2.3" sensor: see table further on).



For many years until Sep. 2011 a gap existed between compact digital and DSLR camera sensor sizes. The x axis is a discrete set of sensor format sizes used in digital cameras, not a linear measurement axis.

The sensors of camera phones are typically much smaller than those of typical compact cameras, allowing greater miniaturization of the electrical and optical components. Sensor sizes of around 1/6" are common in camera phones, webcams and digital camcorders. The Nokia N8's 1/1.83" sensor was the largest in a phone in late 2011. The Nokia 808 surpasses compact cameras with its 41 million pixels, 1/1.2" sensor.[3]

Table of sensor formats and sizes

Sensor formats of digital cameras are mostly expressed in the non-standardized "inch" system as approximately 1.5 times the length of the diagonal of the sensor. This goes back to the way image sizes of video cameras used until the late 1980s were expressed, referring to the outside diameter of the glass envelope of the video camera tube. David Pogue of *The New York Times* states that "the actual sensor size is much smaller than what the camera companies publish – about one-third smaller." For example, a camera advertising a 1/2.7" sensor does not have a sensor with a diagonal of 0.37"; instead, the diagonal is closer to 0.26". Instead of "formats", these sensor sizes are often called *types*, as in "1/2-inch-type CCD."

Due to inch-based sensor formats being not standardized, their exact dimensions may vary, but those listed are typical. The listed sensor areas span more than a factor of 1000 and are proportional to the maximum possible collection of light and image resolution (same lens speed, i.e., minimum F-number), but in practice are not directly proportional to image noise or resolution due to other limitations. See comparisons.[4][5] Film format sizes are included for comparison.

Type	Diagonal (mm)	Width (mm)	Height (mm)	Area (mm^2)	Stops (area)	Crop factor[6]
1/10"	1.60	1.28	0.96	1.23	-9.51	27.04
1/8"	2.00	1.60	1.20	1.92	-8.81	21.65
1/6"	3.00	2.40	1.80	4.32	-7.64	14.14
1/4"	4.00	3.20	2.40	7.68	-6.81	10.81
1/3.6" (Nokia Lumia 720)	5.00	4.00	3.00	12.0	-6.16	8.65
1/3.2" (iPhone 5)	5.68	4.54	3.42	15.50	-5.80	7.61
Standard 8mm film frame	5.94	4.8	3.5	16.8	-5.73	7.28
1/3" (iPhone 5S)	6.00	4.80	3.60	17.30	-5.64	7.21

1/2.7"	6.72	5.37	4.04	21.70	-5.31	6.44
Super 8mm film frame	7.04	5.79	4.01	23.22	-5.24	6.15
1/2.5" (Sony T5)	7.18	5.76	4.29	24.70	-5.12	6.02
1/2.3" (Pentax Q) (Sony DSC-W330)	7.66	6.17	4.55	28.50	-4.92	5.64
1/2" (Fujifilm HS30EXR)	8.00	6.40	4.80	30.70	-4.81	5.41
1/1.8" (Nokia N8)	8.93	7.18	5.32	38.20	-4.50	4.84
1/1.7" (Pentax Q7)	9.50	7.60	5.70	43.30	-4.32	4.55
1/1.6"	10.07	8.08	6.01	48.56	-4.15	4.30
2/3" (Nokia Lumia 1020, Fujifilm X-S1 [7], X20, XF1)	11.00	8.80	6.60	58.10	-3.89	3.93
Standard 16mm film frame	12.7	10.26	7.49	76.85	-3.49	3.41
1/1.2" (Nokia 808 PureView)	13.33	10.67	8.00	85.33	-3.34	3.24
Blackmagic Pocket Cinema Camera	14.32	12.48	7.02	87.6	-3.30	3.02
Super 16mm film frame	14.54	12.52	7.41	92.80	-3.22	2.97
1" Nikon CX, Sony RX100 and Sony RX10	15.86	13.20	8.80	116	-2.90	2.72
1"	16.00	12.80	9.60	123	-2.81	2.70
Blackmagic Cinema Camera EF	18.13	15.81	8.88	140	-2.62	2.38
Four Thirds, Micro Four Thirds ("4/3", "m4/3")	21.60	17.30	13	225	-1.94	2.00
1.5" Canon G1X	23.36	18.70	14.00	262	-1.72	1.85
Blackmagic Production Camera 4K	24.23	21.12	11.88	251	-1.78	1.79
original Sigma Foveon X3	24.90	20.70	13.80	286	-1.60	1.74
Canon EF-S, APS-C	26.70	22.20	14.80	329	-1.39	1.62
Standard 35mm film frame	27.20	22.0	16.0	352	-1.34	1.59
APS-C (Nikon DX, Pentax K, Samsung NX, Sony α DT)	28.2–28.4	23.6–23.7	15.60	368–370	-1.23	1.52–1.54
Super 35mm film frame	31.11	24.89	18.66	464	-0.95	1.39
Canon APS-H	33.50	27.90	18.60	519	-0.73	1.29
35mm full-frame, (Nikon FX, Sony α, Canon EF)	43.2–43.3	36	23.9–24.3	860–864	0	1.0
Leica S	54	45	30	1350	+0.64	0.80
Pentax 645D	55	44	33	1452	+0.75	0.78
Standard 65mm film frame	57.30	52.48	23.01	1208	+0.81	0.76
Kodak KAF 39000 CCD	61.30	49	36.80	1803	+1.06	0.71
Leaf AFi 10	66.57	56	36	2016	+1.22	0.65
Medium-format (Hasselblad H5D-60)	67.08	53.7	40.2	2159	+1.26	0.65
Phase One P 65+, IQ160, IQ180	67.40	53.90	40.40	2178	+1.33	0.64
IMAX film frame	87.91	70.41	52.63	3706	+2.05	0.49

Notes and references

[1] Nikon unveils J1 small sensor mirrorless camera as part of Nikon 1 system (http://www.dpreview.com/news/1109/11092119nikonJ1.asp#press) at dpreview.com

[2] http://en.wikipedia.org/w/index.php?title=Image_sensor_format&action=edit

[3] http://europe.nokia.com/PRODUCT_METADATA_0/Products/Phones/8000-series/808/Nokia808PureView_Whitepaper.pdf Nokia PureView imaging technology whitepaper

[4] Camera Sensor Ratings (http://www.dxomark.com/index.php/Cameras/Camera-Sensor-Ratings) DxOMark

[5] Imaging-resource: Sample images Comparometer (http://www.imaging-resource.com/IMCOMP/COMPS01.HTM) Imaging-resource

[6] Defined here as the ratio of the diagonal of a full 35 frame to that of the sensor format, that is $CF = diag_{35mm} / diag_{sensor}$.

[7] http://www.imaging-resource.com/PRODS/XS1/XS1A.HTM

External links

- Eric Fossum: Photons to Bits and Beyond: The Science & Technology of Digital (http://www.youtube.com/watch?v=JkBh71zZKrM), Oct. 13, 2011 (YouTube Video of lecture)
- Joseph James: Equivalence (http://www.josephjamesphotography.com/equivalence/) at Joseph James Photography
- Simon Tindemans: Alternative photographic parameters: a format-independent approach (http://www.21stcenturyshoebox.com/essays/formatindependence/) at 21stcenturyshoebox
- Compact Camera High ISO modes: Separating the facts from the hype (http://web.archive.org/web/20110605233923/http://www.dpreview.com/articles/compactcamerahighiso/) at dpreview.com, May 2007
- The best compromise for a compact camera is a sensor with 6 million pixels or better a sensor with a pixel size of >3µm (http://6mpixel.org/en/) at 6mpixel.org

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