Describing Digital Camera Sensor Sizes

Douglas A. Kerr

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ABSTRACT AND INTRODUCTION

Several curious conventions are used to describe the general size of sensors in digital cameras. We often find the size of sensors of "compact" digital cameras described with a notation such as 1/1.7" (which refers to a sensor size of about 0.32" x 0.24"). In a larger camera range, we find a sensor size described as 2/3" (that sensor size is about 0.26" x 0.35"). In a larger range yet, we may find an 0.89" x 0.59" (22.5 mm x 15.0 mm) sensor described as "1.6x". That same sensor is sometimes described as being "APS-C" size, or as "APS size". In this article, we describe the premises, evolution, and definitions of these various systems of notation.

THE COMPACT DIGITAL CAMERA

Historical background: television pickup tubes

The first "modern" television "pickup tube" was the image orthicon. Introduced into commercial use in 1946, it made practical a reliable camera for commercial television production. But the tube itself was costly and required a fairly complicated supporting infrastructure.

The Vidicon tube, developed in the 1950's, was smaller, lower in cost, and required a simpler supporting infrastructure. It made practical the "industrial" television camera (for such purposes as process observation and surveillance).

A popular family of Vidicon tubes had a *target* (what we would today, in a digital camera, describe as a "sensor") approximately 8.8 mm x 6.6 mm in size. Eventually, in order to get increased resolution, another family, with a target about 10 mm x 13 mm in size, came into use.

The first type was housed in a cylindrical glass envelope about 2/3" in diameter; the second type in an envelope about 1" in diameter. Different camera families used the two types.

The technicians and operators usually had no awareness of the actual target sizes of the pickup tubes, but thought of them as 2/3" tubes and 1" tubes—just as they were used to describing the different sizes of cathode ray tubes in television receivers and monitors in terms of their nominal envelope diameters (5", 7", 12", and so forth). And, like

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the television receivers and monitors, the cameras themselves came to be known as 2/3″ cameras and 1″ cameras.

For the receivers and monitors, that "envelope diameter" number also approximated the diagonal dimension of the image, but it wasn't even close for the targets of the Vidicon tubes. But then almost nobody knew the size of the targets, so this didn't strike anyone as strange.

Enter the compact digital camera

When the early digital cameras of the "consumer" flavor emerged (which we today would call "compact" cameras, although at first they weren't all that compact), the manufacturers had a rather serious marketing dilemma. If they listed the actual sensor size of their cameras in the published specifications, consumers would be horrified at how small they were—many were less than one quarter inch across the diagonal.

History to the rescue

So the marketing guys came up with a clever ploy. Their first thought was to adopt and extrapolate the system historically used for Vidicon tubes. They in effect pegged the "nominal size" of 0.667″ (2/3″) to a sensor size of 6.6 mm x 8.8 mm (11.0 mm, or 0.433″, for the diagonal). In other words, the "nominal size" would be about 1.5 times the actual diagonal dimension of the sensor.

The size reckoned that way would certainly sound more impressive that the actual size.

But maybe not enough more impressive. As we mentioned, typical early consumer digital cameras might have a sensor whose diagonal dimension was about 0.24″, less than a quarter inch. Even its "nominal size" under the "Vidicon" system would be only about 0.36″, still not very impressive.

The "inverse Vidicon" convention

So the marketing guys came up with a further ploy. For the sensor size we just mentioned, for example, they would call its size not 0.36″, but 1/2.8″. (After all, 1/2.8 **is** about 0.36!)

It looks as if it involves the quantity 2.8″— a nice large number.[1] The "tiny-sounding" number 0.24″ never has to be mentioned. What did the consumers think 2.8″ meant? They had no idea. But it wasn't tiny.

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[1] Of course the notation 1/2.8″ means (1/2.8)″, not 1/(2.8″). If we see 1/2″, we know that. But for the unexpected form 1/2.8″, we are less sure.

Later, cameras with larger sensors came into use, with “sensor size descriptions” of perhaps 1/1.7″. That would, under this approach, mean a sensor with a diagonal size of about 0.40″.

Range of application

This system of notation is still in use for cameras with sensors up to perhaps 10 mm diagonal size. The next size commonly encountered is the 11 mm diagonal size—that is, the size of the sensor in the godfather of this notation system, the so-called 2/3″ Vidicon tube. And, honoring historical practice, that sensor size is usually called 2/3″, not 1/1.5″.

Size equivalents

The table below shows the “theoretical” actual sensor dimensions for several commonly-encountered “sensor size descriptions”, based on rigorous trackback to the 2/3″ Vidicon, the unwitting benchmark for this scheme. Of course, cameras with a certain “nominal size” might not have exactly the “theoretical” sensor dimensions this table presents.

Sensor size description and sensor dimensions

Sensor size description (inches)	Decimal equivalent (inches)	Sensor dimensions (theoretical) (inches)			(mm)		
		Horiz.	Vert.	Diag.	Horiz.	Vert.	Diag.
1/2.8	0.36	0.19	0.14	0.24	4.71	3.54	5.89
1/2.7	0.37	0.20	0.15	0.25	4.89	3.67	6.11
1/2.6	0.38	0.21	0.16	0.26	5.08	3.81	6.35
1/2.5	0.40	0.22	0.16	0.27	5.28	3.96	6.60
1/2.0	0.50	0.27	0.20	0.34	6.60	4.95	8.25
1/1.8	0.56	0.30	0.22	0.37	7.33	5.50	9.17
1/1.7	0.59	0.32	0.24	0.40	7.76	5.82	9.71
1/1.6	0.63	0.34	0.25	0.42	8.25	6.19	10.31
1/1.5	**0.67 (2/3)**	**0.36**	**0.27**	**0.45**	**8.80**	**6.60**	**11.00**

Note that the entry in bold is actually the historical 2/3″ Vidicon size, which is shown only for reference; as mentioned before, this system of notation is not customarily used for that size (and above).

THE FOUR THIRDS SYSTEM

A new standard design paradigm for digital cameras is called the “Four Thirds System”. This name (always spelled out) cleverly has two meanings:

- It refers to the “Vidicon system” sensor size description of the standard sensor for the system, 4/3″. The sensor is 17.3 mm x 13.0 mm in size, approximately twice the size of that of the 2/3″ Vidicon tube.

- It refers to the frame aspect ratio (ratio of horizontal to vertical dimension), 4:3 (which ratio can be written "4/3").

The sensor size description for these cameras is stated as 4/3" (not 1/1.33").

THE "35-MM RELATED" CAMERA GENRE

An important genre of digital cameras can be thought of, somewhat imprecisely, as "cameras somehow related to 35-mm film cameras". The connection may be that they use basic body designs adapted from 35-mm film cameras, or they may utilize interchangeable lenses also suitable for use on 35-mm film cameras, or lenses that have the same mount as those suitable for use on 35-mm film cameras.

Sensor sizes

The format size of the "full-frame 35-mm film camera" (the archetype of this genre) is nominally 36 mm x 24 mm. (We say "full frame" since there were a few film cameras that took an 18 mm x 24 mm image on 35-mm film, which are described as "half-frame 35-mm" cameras.)

Some of the digital cameras in this genre have sensors sized 36 mm x 24 mm. But others have smaller sensors, with sizes down to about 21 mm x 14 mm.[2]

The "equivalent focal length" convention for sensor size

Most users of full-frame 35-mm film cameras came to recognize, at least broadly, the field of view that will be provided by lenses of different focal length. For that community, focal length is thought of mostly as a determinant of field of view.

Now as this same community moves into the use of digital cameras of the "related to 35-mm film cameras" genre, and in particular those with sensors smaller than 36 mm x 24 mm, they find that a given focal length lens gives a smaller field of view. Looking at it in the other direction, a lens of a certain focal length, on such a camera, gives a field of view that would be given, on a full-frame 35-mm camera, by a lens of **greater** focal length.

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[2] Note that in this camera genre, the aspect ratio is usually 3:2, whereas for the "compact" cameras we spoke of before, the aspect ratio was usually 4:3. This is primarily due to the fact that the archetype of this genre is the full-frame 35-mm film camera (whose aspect ratio is 3:2), whereas the compact cameras owe much of their ancestry to video camera technique (where for many years the aspect ratio was 4:3.)

Accordingly, the custom emerged of speaking of the "full-frame 35-mm equivalent focal length" of a certain lens when it is used on a camera of a certain sensor size—the focal length of a lens that, used on a full-frame 35-mm camera, would give the same field of view that the lens of interest gives on the camera of interest.

Suppose, for example, we have a camera whose sensor size is 22.5 mm x 15.0 mm—0.625 times (in linear dimensions) the frame size of a full-frame 35-mm camera. Then, a lens with focal length 50 mm on that camera gives the same field of view that would be given on a full-frame 35-mm camera by an 80 mm lens.

Thus, the conceit is adopted that this 50-mm lens, when mounted on this "0.625 size" camera, has a "full-frame 35-mm equivalent focal length" of 80 mm.[3]

Note that the calculation of the full-frame 35-mm equivalent focal length (EFL) of our lens proceeds this way for the above example:

EFL = 50/0.625 = 80 (mm)

where 50 (mm) is the focal length of the lens and 0.625 is the relative size of the sensor of the camera of interest, compared to the size of the sensor of a full-frame 35-mm camera.

But we can rewrite it this way:

EFL = 50•1.6 = 80 (mm)

since 1.6 is 1/0.625.

Accordingly, an "0.625-size" camera is said to have a "full-frame 35-mm equivalent focal length factor" of 1.6.[4] Sometimes this is just simplified to "focal length multiplier". This, however, is not attractive, as it suggests that the actual focal length depends on sensor size. Even "equivalent focal length factor" is better.

In fact, for this camera genre, it has become common to, for example, describe an 0.625-size sensor succinctly as a "1.6x" sensor. This notation is in fact the most common way to describe the sensor size of cameras in this genre.

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[3] We caution the reader that this is not a focal length of the lens under any circumstance; its focal length is 50 mm whether mounted on our "0.625 size" digital camera, mounted on a full frame 35-mm film camera (assuming that the lens mount permits that), or in our sock drawer.

[4] This constant is sometimes called the "crop factor" for the sensor size. The rationale for this notation is questionable. I discourage its use.

APS notation

The Advanced Photographic System (APS) is a recent film-and-camera design doctrine developed to improve the usability of film cameras for "consumer" users. Its full flower in the marketplace was unfortunately cut short by the emergence of digital photography.

The APS system uses film stock 24 mm wide, housed in a cartridge designed to facilitate automation of everything from loading into the camera to processing. The camera always takes a frame 30.2 mm x 16.7 mm in size. However, for each shot, the user indicates by way of a "switch" on the camera which of three frame sizes, with different aspect ratios, he really wants to use, as follows:

- "H": 30.2 mm x 16.7 mm (1.808:1)

  The "H" is evocative of "HDTV", since this aspect ratio is intended to be comparable to that of HDTV (which is 16:9, or 1.778:1). This corresponds to the entire taken frame.

- "C": 23.4 mm x 16.7 mm (1.401:1)

  The "C" is evocative of "classic". This aspect ratio is intended to be comparable to that of full-frame 35-mm film cameras (which is 3:2, or 1.5:1).

- "P": 30.2 mm x 9.5 mm (3.179:1)

  The "P" is evocative of "panoramic".

The chosen "delivery frame size" (my term) for each frame is coded onto the film when the shot is taken. When the film is processed, the processor automatically crops each frame to the respective "delivery frame size" when printing the frame.

Now, as digital cameras of the "35-mm related" genre emerged, some people thought it would be handy to designate certain ranges of sensor size by reference to some of the "delivery frame sizes" of the APS system. (Because everybody knew how big those were? Hardly.)

So for the sensor size range from about 21 mm x 14 mm ("1.7x") through 24 mm x 16 mm ("1.5x"), they decided to call the size "APS-C". (The APS-C frame is 23.4 mm x 16.7 mm.)

One series of cameras (the Canon EOS 1D series) has a sensor size of around 27 mm x 18 mm ("1.3x"), which they decided to call the "APS-H" size. (The APS-H frame is 30.2 mm x 16.7 mm).

Then, to make things sound simpler, some people decided to speak of the "APS-C size" sensors as being "APS-size".

I discourage the use of the “APS” notation for digital camera sensor sizes.

“Full frame”

In the context of “35-mm related” cameras, it has become common to speak of the 36 mm x 24 mm sensor size as “full frame”. This is an attempt to more concisely invoke the concept of the “full-frame 35-mm” film camera frame size. Beyond that, it is meant to remind us that this is the largest frame size we could have in the 35-mm related camera genre. But without inclusion of “35-mm”, “full frame” isn’t really definitive in the broader context of all digital photography.

If a shorter version of the definitive term “full-frame 35-mm” is desired, just “35-mm” is probably clearer than “full frame”. (Thist term adequately evokes the 36 mm x 24 mm size, since the “half-frame” variant is little known.)

LARGER FORMAT CAMERAS

Once we exceed the 36 mm x 24 mm sensor size, we leave the realm of “35-mm related” cameras, and (blessedly) leave the concept of the “full-frame 35-mm equivalent focal length multiplier”. There are occasionally ill-founded attempts to relate larger sensor sizes to various frame sizes used in film cameras in the “medium format” range (which themselves have imprecise common names), but these approaches have fortunately not congealed into recognized conventions.

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