Format Size in Digital Photography

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ABSTRACT

In photography, the term "format size" describes the actual physical size of the image captured by the film frame, digital sensor, or equivalent. The widespread popularity of digital photography has brought to the user community a plethora of different format sizes, most of them unique to digital photography. In this article, we review the effect of format size on a number of camera behavior and performance issues. We also debunk various misconceptions that circulate in this area, and discuss terminology used to identify a significant numerical factor.

INTRODUCTION

The term "format size" describes the physical size of the actual image captured by the camera on its film frame, digital sensor, or equivalent (in some cases, to be precise, the size of the image captured for delivery). The dimensions of the format interact with other parameters to influence a number of camera behavior and performance issues.

Typically, the "model" of camera dictates its format size. There are, however, both film and digital cameras which can provide different formats. Examples are:

- Certain "medium format" film cameras which can be equipped with different "film backs" providing different format sizes (often on a single width of film, such as the "120" size). For example, often format sizes of (nominally) 6 cm x 4.5 cm, 6 cm x 6 cm, or 6 cm x 7 cm can be provided for.

- APS (Advanced Photo System) film cameras, which always capture the same size image but which mark it with one of three format sizes as desired by the photographer so as to dictate the aspect ratio (ratio of width to height) of the images delivered as prints by the photofinishing lab.

- Certain digital cameras which form a certain sized image on their digital sensor but can be set to only process a certain portion of that image. The objective is either to (a) allow delivery of an image having one of two widely used aspect ratios (3:2 and 4:3) or (b) to allow the photographer to attain the properties conferred by different format sizes (as discussed in this article).

Although the concept of format size applies to both film and digital cameras, we will look into the area principally from the perspective of digital cameras. Often, in the digital camera world, the term "sensor size" is used rather than "format size". We will however continue to use the latter term to allow generality across both digital and film contexts, as will be required in connection with many of the issues to be discussed.

FIELD OF VIEW

Concept and definition

"Field of view" describes the "amount of the universe" that is captured by the camera in its image. For most cameras, that falls within the confines of a rectangular pyramid, with its apex at some point in the camera lens.

The "size" of this pyramid (and thus of the field of view that it bounds) can be most directly described in terms of its included angle at its apex, and in the case of the general rectangular pyramid, we must do so in both dimensions (which for convenience we will call the horizontal and vertical directions). There is of course also a corresponding angular measure for the "diagonal" dimension of the pyramid.

Actually, in describing the field of view of a camera, we generally choose to mention one of those three dimensions (vertical, horizontal, or diagonal).

This dimension is an angular property, and so of course may be described in conventional angular measure (in degrees, or, for scientific work, radians). The angular field of view may also be legitimately described in another form, the width (or height, or diagonal size) of the actual field at some arbitrary stated range (such as "120 feet wide at a range of 100 feet").

The field of view afforded by a camera (for the case where the lens is focused at a substantial distance, which we often characterize as "focused at infinity")[1] is determined by the focal length of the lens and the format size, as follows (for "angular measure"):

$$\Theta = 2\arctan(d/2f) \qquad (1)$$

where Θ (upper-case Greek letter *theta*) is the angular field of view (in the chosen direction), d is the corresponding dimension of the format, f is the focal length of the lens, and **arctan** is the trigonometric *arc tangent* function (the angle whose tangent is the value of the expression following **arctan)**.

For field of view expressed in the alternative measure, the relationship (again for focus at infinity) is:

$$D = \frac{d}{f}R \qquad (2)$$

where D is the dimension of choice of the field (*e.g.*, width), d is the corresponding dimension of the format size, f is the focal length of the lens, and R is the range

[1] Do not confuse this dependence on focus distance with the practical fact that for many lenses, their focal length when focused at a shorter distance may not be the "rated" or "marked" focal length. The dependence mentioned here, which of course works on the basis of actual focal length, comes from considerations of geometric optics.

that will be mentioned, *d* and *f* in the same units (*e.g.*, mm) and *D* and *R* in the same units (*e.g.*, feet).

Focal length as a descriptor of field of view

Most photographers do not think in terms of field of view either in degrees or width at a stated range. They come to learn what focal length lenses (on their camera, with its particular format size) produce the effects they need for different photographic tasks. Serious photographers who work with more than one format size learn this lexicon as it applies to each camera type they regularly use.

Today, with relatively-unskilled users getting involved with digital cameras of varying format size, that approach just doesn't work out. It would be handy if there were a way to describe field of view on that simplistic "focal length" basis but in a way that recognizes the impact of format size. One way to do this is to state the focal length that, on some consistent "reference camera", would give the same field of view that the lens of interest would give on the camera of interest.

The **full-frame 35-mm still camera** (to give its tedious precise name) has been for many decades the most widely used type of fairly-sophisticated camera used by both professional photographers and enthusiasts. From here on, we will just call it the "35-mm" camera.[2] Its format size (36 mm x 24 mm) has thus become a sort of "reference format" in certain parts of the photographic field, and it has fallen heir to the title of "reference camera".

Accordingly, it has become common to describe the field of view given by a lens of a certain focal length, used on a particular camera (that is, one with a certain format size), by stating **the focal length of the lens which, used on a 35-mm camera, would give that same field of view**. This number is called the "35-mm equivalent focal length" of the lens of interest as used on the camera of interest.

It is important to note that this number is not a focal length of the lens of interest under any circumstances. It is only the answer to this question:

"What focal length lens, used on a 35-mm camera, would produce the same field of view that **this** lens produces on **this** camera."

I will refer to this question again later, and for convenience then will call it just "The Question".

The factor

A factor that is needed in reckoning "35-mm equivalent focal length" and several other matters is the ratio of (a) a linear dimension (width, height, or diagonal size) of the format of a 35-mm camera to (b) the corresponding linear dimension of the

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[2] Often, in the digital camera world, it is spoken of as a "full-frame" camera, an ambiguous term (since there are "full frame" formats for many different film sizes) and one which is often taken to mean that this format size is the "real thing" among all photographic formats.

format of the camera being discussed. For now, I will avoid giving a name for this factor, but will just represent it by the symbol *J*.

We can then reckon the 35-mm equivalent focal length of any lens, as used on a certain camera, with this relationship:

$$f_e = Jf \qquad (3)$$

where f_e is the 35-mm equivalent focal length of the lens of interest as used on the camera of interest, f is the [actual] focal length of the lens, and J is the factor mentioned above (for the camera of interest).

A problem with aspect ratio

Note that if the camera of interest has a format whose aspect ratio is not the same as that of the reference camera (3:2), we get a different value of J for each possible choice of a dimension (width, height,, or diagonal). And in fact, in such a case, there is no focal length lens which, used on a 35-mm camera, could give truly the same field of view as the lens of interest will give on the camera of interest (as they could not be the same shape).

In order to gave a practical solution to this dilemma, it is customary in such cases to define *J* in terms of the diagonal dimensions of the two formats.

The name of the beast

There are several names that can be attached to the factor *J*, none of which seems really ideal. “35-mm equivalent focal length factor” is one that has been used, since calculating that number is one of the most common uses of the factor (but certainly not the only one).

Through a tortured rationale that I do not find in the slightest appealing, various parties have introduced the practice of calling the ratio *J* the “field of view crop factor” (often today just shorted to “crop factor” or even just “crop”). In Appendix A, I explain the rationale given by the proponents of that term (hopefully, more clearly than they themselves usually articulate it) and then discuss why I do not find the term attractive.

<u>A misconception (the first of many):</u>

The context is an interchangeable-lens camera, with a smaller sensor than 35-mm size, specifically with $J = 1.6$.

“When I put this 50 mm lens on my camera, it becomes an 80 mm lens.”

Wrong. 80 mm is not a focal length of this lens (whose focal length is 50 mm) under any circumstances. 80 mm is just the answer to The Question.

The Canon problem

The digital branch of the Canon EOS single lens reflex (SLR) camera family includes cameras having three different format sizes (if we disregard differences of a millimeter or so). All these cameras can accept and successfully use any of the many lenses in the canon EF lens series, many of which were originally designed when the EOS line only included 35-mm film cameras.

This gives rise to the following:

A misconception

The context is a user of a Canon EOS series digital camera with a smaller sensor than 35-mm size, specifically with $J=1.6$.

"The reason we have to multiply the focal length of my lens by 1.6 is that its focal length is marked in 35-mm camera terms."

Wrong - on two counts. Firstly, we don't "have to multiply the focal length of the lens by 1.6." We only do that if and when we want to answer The Question.

Secondly, the focal length of such a lens is not denoted in terms predicated on any particular type of camera or format size. It is a fundamental physical property of the lens (just like its outside diameter), and is stated in just plain old millimeters. If we take a lens to an optical laboratory and ask that its focal length be measured, the technician doesn't ask us, "what kind of camera is this for", or "what kind of millimeters do you want the answer in."

This misunderstanding perhaps originates in the improper conception that focal length is a measure of field of view (and you can see how the practice mentioned above could lead to that).

Another Canon problem

Now, adding a new opportunity for misunderstanding, Canon in recent years has added to the EF lens family a special sub-class, the EF-S type lens. These lenses are only suitable for use on Canon EOS digital cameras of the smallest format size category, with $J=1.6$. The limitation is that these lenses do not generate an image large enough to deposit a complete image on a larger sensor. (The motivation is to allow these lenses to be smaller, lighter, and hopefully less costly than a lens that would generate an image large enough to support the format of all the EOS cameras.) This has engendered the following:

A misconception

"Since my EF-S 60 mm lens is intended only for use on cameras for which $J=1.6$, I do not need to multiply its focal length by 1.6 to get its 35-mm equivalent focal length."

Wrong. These lenses, like all Canon interchangeable lenses, are marked with their "real" focal length (the only one they have.)

It is often argued that it would be better for Canon to mark EF-S lenses with 1.6 times their focal length, so that on the only cameras on which they can (currently) be used, that would be the 35-mm equivalent focal length for any such a camera.

There are several reasons that would not be a good idea, including:

- That would not be the focal length of the lens, under any circumstances.
- If I had a 50 mm EF lens and a “50 mm” EF-S lens, they would give different fields of view on my camera (since the EF-S lens marked “50 mm” would have a focal length of 31.25 mm).
- It is conceivable (although admittedly unlikely) that Canon would introduce cameras whose format size was smaller (or even slightly larger) than “$J = 1.6$”. Then, used on such a camera these poor lenses would not be marked either with their focal length or their 35-mm equivalent focal length.
- There are many calculations we need to make that involve the [actual] focal length of the lens, and it would be good to know what that is.

The matter of the image circle

The term “image circle” describes the entire round image developed by a normal camera lens (often characterized by its diameter). Thus, we can say that the Canon EF-S-series lenses develop a smaller image circle than the EF-series. On the EF lenses, the image circle, which varies in exact size between different lens models, is always large enough to embrace a 36 mm x 24 mm format (typically not by a lot). On the EF-S lenses, the image circle, which varies in exact size between different lens models, is always large enough to embrace a 22.5 mm x 15 mm format (typically not by a lot).

We often hear this:

<u>A misconception</u>

The context is a Canon EOS digital camera with $J = 1.6$, on which an EF-S lens is mounted.

“Since the lens has an image circle that matches the format size of the camera, we do not have to multiply its focal length by 1.6 to determine its 35-mm equivalent focal length.”

Wrong. Assuming of course that we only use a lens on a camera whose format size is covered by the image circle of the lens (that is, on one on which the lens will work properly), the size of the image circle has nothing to do with how focal length is measured or defined, or on the field of view given by a lens of any given focal length.

An unfortunate practice

There is an unfortunate practice, on some digital cameras with fixed (non-interchangeable) lenses, of marking the lens with the "35-mm equivalent focal length" of the lens. This causes difficulty when one wishes to make a calculation involving the [real] focal length of the lens. We have to get that by dividing the marked "focal length" by *J*! (Is this life imitating art imitating life?)

Another approach to stating and reckoning field of view.

The concept that all photographers will best appreciate field of view in terms of focal length (or in terms of 35-mm equivalent focal length) is very artificial. It is no more natural than if as if our highway signs gave distances in terms of travel time for a gazelle. (Yes, people could learn that system—but why?)

A much more directly usable way is to describe field of view in terms of the width of the field at a certain arbitrary range. And the good news is that this can be reckoned just as quickly as 35-mm equivalent focal length. Here's how it works.

For any given camera (actually, for any given format size) there is a *field of view constant*. To determine the field of view that will be given by a lens of a certain focal length, we just divide the field of view constant for that camera by the focal length in mm. The result will be both:

- The width of the field of view in feet at a range of 100 feet, and
- The width of the field of view in meters at a range of 100 meters

Of course, it will work in the other direction as well. If we know the width of the field we need (in feet/meters at a range of 100 feet/meters), we just divide the field of view constant by that width and get the needed focal length in millimeters.

Now, many at first ask, "Why didn't you make it so it gives the diagonal field of view? That's what we normally think of."

No, that's not what you normally think of—that's just the dimension most commonly stated when giving field of view in angular measure.

But it is rarely useful. "Let's see, I need to shoot the front of this barn from a distance of 100 feet. Let's see—I can just tell from here that its diagonal size is about xxx feet." In fact, if we are to estimate the needed field of view, it will usually be most apparent in terms of width. "Let's see, how wide is that row of people—about 6 feet, I would estimate."

Now, how can we find out the field of view constant for any particular camera. Simple—it's just 100 times the width of the format in millimeters. So for a 35-mm camera (36 mm x 24 mm format), it is 3600; for a Canon EOS 20D (22.5 mm x 15 mm format), it is 2250. For a Sony F828 (8.8 mm x 6.6 mm format) it is 880.

So lets try it for a Canon EOS 20D. I want to stand 10 feet from a group of people whose width I estimate at 6 feet and allow some margin on the edges—perhaps a field of view 8 feet wide at an actual shooting range of 10 feet. That would be 80 feet wide at 100 feet. I take the field of view constant for the camera, 2250, and divide it by 80. The result is 28.1. Aha! My 28 mm lens will be ideal!

How does a 35-mm camera fit into this? Not at all—I am not using one for this shot. All this will work fine if there had never been 35-mm cameras.

DEPTH OF FIELD

Concept

When a camera lens is focused at a particular distance, any object at that distance is given a “perfectly focused” image. Any object at a different distance is given a blurred image.

For any particular camera “setup”, we can ask this question:

“Over what range of distance can we place objects such that, even though they are not given a perfectly focused image, the image they are given exhibits only negligible blurring.” That range of distance is called the “depth of field” of that setup.

Of course, to answer that question, we must establish some objective, quantifiable criterion for what we will consider “negligible blurring”. Normally we do this by setting an upper bound on the allowable diameter of the circular “blur figure” which is created for each point of an imperfectly-focused object. I call this limit the “circle of confusion diameter limit” (COCDL)[3].

Effect of format size

It is often of interest how depth of field performance may differ between two cameras of different format size, “all other factors being equal”.

Of course, we first have to decide what “all other factors being equal” means. A reasonable set of conditions is this:

a. The focal lengths of the lenses on the two cameras would produce the same field of view. (That is, we could use them for the same photographic task, as regards “framing” issues.)

b. Both cameras are focused at the same distance.

c. Both lenses have apertures with the same f/number.

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[3] This “blur figure” is also known as the “circle of confusion”. However, it has become common to describe the limit we place on the diameter of the circle of confusion when reckoning depth of field as the “circle of confusion”’ leaving us with no unambiguous terms for either the circle of confusion itself or its actual diameter.

d. The COCDL values we adopt for the two cameras are a consistent fraction of the format size. (This constitutes a criterion of "greatest negligible blurring" that would be the same for images from the two cameras viewed as the same size print or display.)

In the equations for determining depth of field (in their most common form), format size does not appear. How then does format size have any effect on calculated depth of field? This happens because:

- The format size difference, pursuant to condition (a), above, causes us to assume a different focal length for the two cameras.

- The format size difference, pursuant to condition (d) above, causes us to adopt a different COCDL for the two cameras.

Now, under the conditions of comparison postulated above, the smaller-format camera will exhibit a larger depth of field than the 35-mm camera.

This is often a problematical matter for users of a certain format size digital camera who move to a larger format size camera. For one thing, the smaller depth of field that occurs (for "equivalent" circumstances) makes the setup less forgiving of focusing errors.

If we wished to achieve, on a larger-format camera, the same depth of field achieved on a smaller format camera, we could do that by using on the larger-format camera an aperture whose f/number was J_S/J_L times the f/number of the aperture used on the smaller-format camera, where J_S is the value of J for the smaller-format camera and J_L is the value of J for the larger format camera. (Note that for our reference 35-mm camera, the value of J is 1.0.)

Discussions of this matter are often complicated by the fact that, for many photographic tasks, a **greater** depth of field is desirable. but for some tasks (where blurring of the background is a desirable artistic element), a **lesser** depth of field may be desirable. Thus, we may hear it said, "I am going to buy a larger format camera because it will give me better depth of field." Presumably, by that he means, "it will give me the opportunity, with a lens of an aperture I can afford, to have the smaller depth of field that is desirable for my portrait work, where I desire a blurred background".

IMAGE PERFORMANCE IMPLICATIONS

Why do we have different format sizes anyway? They primarily emerge from the give-and take between two antagonistic considerations:

- A smaller format size offers the prospect of a smaller, lighter, and presumably less costly camera.

- A larger format size affords the potential for better "image performance" in several ways.

What are these image performance issues? Well, for one thing, a larger format size (and thus larger sensor size) makes it easier in manufacture to achieve large "pixel counts", that is, an image with large dimensions in pixels. The pixel dimensions of an image are the biggest factor in the resolution it exhibits (expressed in such terms as "lines per picture height). Of course, ongoing development keeps increasing the possible pixel density, so that small-sensor cameras can now have the same pixel count that a few years ago could only be attained on larger-sensor cameras. But once that happens, larger-sensor cameras can attain even greater pixel counts.

The second consideration is that, for any given pixel count, a larger sensor size allows a larger size for the individual photodetectors than make up the sensor. This typically leads to an improvement in "noise performance", the degree to which there are random (and unwanted) variations in the image caused by random electronic events in the sensor.

PERFORMANCE OF THE SAME LENS ON CAMERAS WITH DIFFERENT FORMAT SIZE

In such camera lines as the Canon EOS series of single-lens reflex (SLR) cameras, it is perfectly practical to use the same lens (if of the EF series) on cameras having any of the three format sizes now found in the line ($J = 1.0$, 1.3, and 1.6).

This raises the issue of whether, when a photographer moves from a smaller-format camera model to a larger-format one, planning to continue to use his EF-series lenses, will there be any difference in optical performance?

Why should there be? Well, an EF-series lens actually develops an image with a round boundary, large enough to embrace the 36 mm x 24 mm format of the largest-format cameras of the line. If we examine the charts showing the performance of the lens, we find that its performance (in several ways, including resolution) almost always declines as we move from the center of the image to its outermost part, at the corners.[4] The corners are 21.6 mm from the center of the image.

If a certain lens is used on, say, a "$J = 1.6$" camera, now the corners of the image are only 13.5 mm from the center. "Wow", we say, "what a break—we are leaving behind the part of the image formed by the lens in which the optical performance is the worst."

Thus we might look forward to "better image performance" with the lens on the smaller format camera than on the larger format camera. (This is sometimes described as the "heart of the image" or "sweet spot" phenomenon.)

[4] We sometimes hear of the "edge performance" of the lens, which most appropriately would refer to performance near the periphery of the round image if forms.

But it's not that simple. Suppose that for example the performance property of interest is resolution: how fine a pattern of contrast change (usually thought of as how fine a pattern of lines) can the camera discern? When a lens is tested, this is reported in terms of lines per millimeter (on the film or sensor plane).[5]

But when we compare the resolution afforded by two different cameras, we must do so on the basis of viewing their images at a consistent size. (We after all do not view the image on the film or sensor.) To account for that, the resolution of a camera is generally restated in terms of "lines per picture height".

Thus a camera with a format 15 mm high, which can resolve 100 lines per mm, or 1500 lines per picture height, will give us the same image performance as a camera with a format 24 mm high, which can resolve 62.5 lines per mm, or 1500 lines per picture height.

Now lets return to our case of the same lens being used on two cameras (and lets assume that the two cameras are those whose format size have been recently mentioned).

Suppose that the lens of interest can deliver a resolution, at a distance of 21.6 mm from the center of the image (at the corner of the "larger format" camera's frame) of 50 lines per mm. Suppose also that, at a distance of 13.5 mm from the center of the image (at the corner of the "smaller format" camera's frame), the lens can deliver a resolution of 80 lines per mm.

Both of these resolutions turn out to be 1200 lines per picture height!

Thus, in this case, there might in fact be no "sweet spot" advantage.

Prediction of this impact of this matter can only be done if we have a plot of the resolution of the lens as a function of distance from the center of the image. Often it is thought that we do have this available in the form of the modulation transfer function (MTF) plots provided by many lens manufacturers for each of their lens models. Unfortunately, the form of that plot usually provided by the manufacturers does not give the resolution as a function of distance from the center of the image. Instead, it gives the "response", for only two different line spacings,[6] as a function of the distance from the center of the plot.

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[5] There is a great opportunity for misunderstanding here. Sometimes, in a test pattern of alternating black and white stripes, the black stripes counted are counted as "lines". Other times, the black and white stripes are each counted as "lines". Sometimes, the pairs of adjacent black and white stripes are counted as "line pairs" (leading to the same number as when only black stripes are counted as lines, but with a different name). In this article, when we say "lines", we mean with both black and white stripes counted as "lines".

[6] Usually 10 and 30 line pairs per mm, stated as "lines per mm". This corresponds to 20 and 60 lines per mm in the notation used in this article.

What about the EF-S lenses?

A misconception

The context is a camera with J = 1.6.

“Since an EF-S lens develops a smaller image circle than an EF-S lens, then with an EF-S lens we will be using a part of the image that is proportionally farther out on the image circle than would be the case if we used an EF lens. Thus the performance of the EF-S lens at the image corners will probably be worse than for an EF lens used on this camera.”

Maybe yes, maybe no. It of course all depends on the resolution of the particular EF-S lens being considered at a distance of 13.5 mm from the center compared to the resolution of some particular EF lens at a distance of 13.5 mm from the center.

MOTION BLUR

Unless a camera is “locked down” on a rigid support (such as a sturdy tripod), the camera may, during the time the shutter is open, move significantly in its position, in the direction of its “axis of aim”, and even in its ”roll attitude”. The result can be displacement of the image on the film or sensor during the exposure, leading to a blurred image. This phenomenon is often called “motion blur” or “camera shake blur”. If the object is at a reasonable distance from the camera, only the “axis shift” and “roll attitude” aspects of the motion is likely to be consequential. Usually the roll axis aspect is inconsequential. We will only discuss here the axis shift aspect.

It should be intuitively obvious that the shorter the exposure time (the faster the shutter speed), the less opportunity there will be for image shift, and thus faster shutter speeds are a tool for ameliorating this phenomenon.

A widely-observed guideline for hand-held photography in the world of 35-mm cameras suggests that, in order that image blur due to unintended camera movement be "negligible", one should avoid shutter speeds slower than $1/f$, where f is the focal length of the lens in mm (that is, $t = 1/f$).

A widely-asked question is, "In applying this guideline when using a camera with a smaller sensor than that of a 35-mm camera, should f be the focal length of the lens in use, or should it be its 'full-frame 35 mm equivalent focal length'?"

Before we can even address this question, we must look into the nature of this guideline. It of course is based on a whole litany of assumptions, principally the following:

1. The image blurring that is of concern here results from unintended change in the pointing direction of the camera.

2. The maximum angular velocity of that change (in degrees per second, or radians per second for the boffins) is assumed to have a certain value during the exposure.

3. "Negligible" blurring is considered to be not over a certain shift of the image on the sensor during the time the shutter is open.

While these are highly arbitrary (and perhaps hard to accept as credible), note that no other set of credible, mutually-consistent assumptions would support the simple guideline, $t = 1/f$. So we are stuck with them if we are going to accept the guideline. Of course what this tells us is that this guideline itself is pretty arbitrary, and those who follow it need to be aware of this.

How does focal length get into this matter anyway? Well, for a certain angular displacement of the camera pointing axis, the displacement of the image on the sensor (for focus at a substantial distance) will be proportional to the focal length.

Now, what happens if we wish to transport this guideline, with all its arbitrary assumptions, and any caveats that come from that, to the situation of a smaller format camera? First, why does format size matter?

Well, regarding assumption (3), which is reminiscent of the COCDL criterion upon which depth of field calculation is predicated, as we consider different format (sensor) sizes, it is only reasonable to define the limit of negligible blurring to be in terms of an image shift of some fraction of the image size. This is because we must assume that, if we were to compare blurring under two different circumstances on an image of the same scene taken with the different cameras, we would do so by looking at the images at the same display (or print) size (and from the same viewing distance). Otherwise, we would have the famous situation, "Gee, the picture on your 3" TV set is really sharp".

If we then follow this back through the entire chain of logic (including the effect of focal length on the image shift for any given change in pointing angle) we find that the corresponding guideline would be to not use a shutter speed slower than $1/Jf$. In other words, yes, we use the 35-mm equivalent focal length.

Caveat

None of the above is intended to counsel blind reliance on this guideline—merely to explain how, if we wish to accept it, warts and all, we can adjust it for equally-credible application to a smaller-format camera setting.

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Appendix A

On the term "field of view crop factor"

BACKGROUND

We begin by recalling that the factor I designate with the symbol *J* is the ratio of (a) a linear dimension (width, height, or diagonal) of the format of a 35-mm camera to (b) the corresponding linear dimension of the format of the camera being discussed. We also recall that one of the uses we make of this factor is in reckoning the "35-mm equivalent focal length" of a lens of a certain focal length when used on a camera with a certain format size.

THE TERM "FIELD OF VIEW CROP FACTOR"

In some photographic circles it has become fashionable to call this factor the "field of view crop factor" (often abbreviated "FOV crop factor" or just "FOV crop", or maybe just "crop factor", or maybe just "crop").

The rationale for doing so appears to be as follows (we will for convenience assume a frame smaller than the 35-mm size):

- The mechanism by which format size affects field of view (*vis-a-vis* the field of view the same focal length lens would give on a 35-mm camera) comes from the fact that a smaller-than-35-mm sensor captures only a portion of the image that would be captured by a 35-mm film frame.

- Thus the smaller format sensor can be thought of as "cropping" the (hypothetical) image that would have been captured by a 35-mm frame.

- By extension of that language, the correspondingly-smaller field of view given by a certain focal length lens on the smaller-sensor camera can be thought of as a "crop" of the field of view that the same focal length lens would give on a 35-mm camera.

- Now if, for example, the sensor of interest has dimensions 0.625 those of the 35-mm frame, then the "cropped" field of view on that camera will have 0.625 times the size of the field of view that focal length lens would produce on a 35-mm camera (not in degrees, but in width at any arbitrary distance, a legitimate description of an angle).

- Thus the numerical value 0.625 would describe the "cropping" that is done to the field of view (*vis-a-vis* the field of view the same focal length lens would give on a 35-mm camera) by the smaller size of the sensor. [I'll call that number the *crop fraction* to avoid confusion with the term under discussion.]

- The most frequent use we make of this fraction is to calculate the "35-mm effective focal length" of the lens of interest. To do that, we must divide the focal length of that lens by the applicable crop fraction—for the example, 0.625.

- However, division is generally more difficult to do “in the head” than multiplication. It would be easier to perform that calculation by **multiplying** the focal length of the lens of interest by the **reciprocal** of the crop fraction, if we knew it. In the example, that number would be 1.6. If we know that number for a particular camera, based on its sensor size, it can be easily used in 35-mm equivalent focal length calculation.

- Thus the reciprocal of the crop fraction (1.6 in the example) should be called the “field of view crop factor”.

A caveat

This presentation of the apparent rationale for the term “field of view crop factor” was developed by the author, based on the fragmentary arguments put forth by the proponents of the term in various discussions and correspondence. It is only through such a logical chain that I can reconstruct the conclusion evidently reached by those proponents. As you will see just below, I do not endorse that conclusion, nor do I claim to have with certainty discerned the thinking of the proponents.

I DON’T THINK IT IS A GOOD TERM

I do not believe that the term “field of view crop factor” (or any of its condensations) is appropriate to designate *the ratio of a linear dimension of the format of a full-frame 35-mm camera to the corresponding linear dimension of the format of another camera*.

Here are my reasons.

There is no cropping going on here

One basic phenomenon being characterized by this factor is the smaller field of view, for any given focal length lens, on a camera with a smaller sensor, compared to that which would be given by a lens of the same focal length on a 35-mm camera.

I think the word “crop” has no business in describing the relative sizes of two things, especially things that arise from separate processes. We would not say that “a 10-inch dinner plate is a crop of a 12-inch dinner plate”.

Now, defenders of the term argue that the word “crop” gets into the vocabulary of this issue legitimately by way of the underlying process that results in the “reduction” of field of view. That process is of course that the “smaller sensor” accepts a smaller image from the lens than would have been accepted by the reference sensor (36 x 24 mm in size). The proponents of the word “crop” speak as though the smaller sensor accepts only part of a 36 x 24 mm image formed by the lens in our camera—thus “cropping” that larger image.

That would be defensible if a 36 x 24 mm image were actually what the lens on "our" camera formed. But no camera lens we are likely to encounter forms a 36 x 24 mm image. For openers, they mostly form images with round outlines. And, depending on the camera involved, (and in some cases of interchangeable lens cameras, the class of lens used on it) that round image might be what can be thought of as "smaller than 36 x 24 mm", or what can be thought of as "larger than 36 x 24 mm".

By that I mean, for example, if we think of a Canon EOS 20D digital SLR camera, if a Canon "EF-S" series lens is mounted, it generates a circular image within which a 36 x 24 mm rectangle will not fit at all. But if we mount a Canon "EF" series lens, it generates a larger circular image, within which a 36 x 24 mm rectangle will fit with room to spare.

If we consider a Sony F828 camera, its lens generates a circular image in which a 36 x 24 mm image doesn't even come close to fitting (it presumably just embraces the 8.8 x 6.6 mm size of the format of that camera).

So no cropping of a 36 x 24 mm image is taking place in any camera. There is certainly a comparison being made between the camera's image size and a 36 x 24 mm image—but no "cropping". The "cropping" is of a hypothetical image captured elsewhere—in an imaginary camera viewing the same scene as our camera from the same place at the same time.

It is as if a craftsman in a trophy shop, having just cut a 6" x 4" block of walnut for a trophy base out of a 12" diameter slab, said, "I cropped this 6" x 4" block from the 8" x 6" block I would have cut if the customer had decided to order the larger trophy his team usually orders."

This inappropriate vision of "cropping" as an actual physical phenomenon in the camera of interest has led to strange misunderstandings of many issues relating to camera performance. I have seen people, trying to analyze some aspect of "smaller-sensor" camera performance, where no comparison to a 35-mm camera was involved in any way, say, "Well, because this is a 1.6 crop factor camera . . ." they have to multiply (or divide) some dimension or parameter by 1.6 before completing their calculation.

Of course neither the camera, nor its lens, nor any of the laws of optics, nor anything else involved "knows" anything about the existence of cameras whose format is 1.6 times as large as that of the camera being analyzed.

The factor is wrong way up

Suppose, though, for the sake of argument, we nevertheless accept the "cropping of a 36 x 24 mm image" metaphor. Let's again turn to our Canon EOS 20D, whose frame size is 22.5 x 15 mm. That is 0.625 the linear size of the reference image (36 x 24 mm). Its field of view (expressed in terms of width at some arbitrary range) is 0.625 the size of the field of view a lens of the same focal length would give on a 35-mm camera. So if something has been cropped, it has been cropped to a size of 0.625 of the "reference size". So why does the factor 1.6 describe this occurrence? (Of course 1.6 is 1/0.625.)

The defenders of the terminology argue, "Well, if we cut the size of something to 0.25 of its original size, it is legitimate to say that it has "been reduced by a factor of 4." Well, maybe. But if the fuel level in our car was at 0.625 of a full tank, would we say, "the level is less than a full tank by a factor of 1.6"? Probably not.

The bottom line

I believe that we should limit our use of the term "crop(ping)" in photography to its normal meaning: the extraction of a portion of an actual image for delivery or display.

SO WHAT WOULD BE BETTER?

There is no term of reasonable length that fully describes the ratio of interest here, that fully tells the story behind the factor. All we can hope to do is to designate it with a term that matches, at least a little, either its nature or its significance, and isn't based on questionable and misleading concepts.

I see two better alternatives than "field of view crop factor":

"Format size factor"

The factor of interest actually tells us the relative sizes of the reference format (36 x 24 mm) and the format of "our" camera. So we could just call it the "format size factor". It would be understood, by convention, what the reference format size was (36 x 24 mm), and which way up the ratio was defined, just as is done in the case of the "field of view crop" terminology.

"Equivalent focal length factor"

The factor figures into several comparisons that may be made involving the optical behavior of lenses on a certain camera as compared to the situation existing in a 35-mm camera. (Why we want to do that, of course, is often a really good question.) But overwhelmingly the use we make of it is in computation of the "35-mm equivalent focal length" of a certain lens as used on a certain camera, as a way of expressing the field of view it would give there.

Thus we could call it the "35-mm equivalent focal length factor" [7]. Because of the widespread acceptance that the full-frame 35-mm situation (36 x 24 mm format) is the basis for comparison if not stated otherwise, "equivalent focal length factor", or even "focal length factor", would be a reasonable shorthand.

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[7] Note that this was common practice for many years prior to the coining of the term "field of view crop factor".