Field of View in Photography

Douglas A. Kerr, P.E.

Issue 2
February 2, 2006

ABSTRACT

The *field of view* of a camera refers is the region in three dimensional space which is taken in by the camera's view. It is basically an angular property. There are a number of ways in which its extent can be numerically stated. In this article we discuss the significance of field of view, various approaches to its quantification, and of terms used in that connection.

Field of view

The term *field of view* of a camera refers to the region in three dimensional space which is taken in by the camera's "view"—the region within which all objects will be captured in the image recorded by the camera (assuming of course that there is not something in front of them!).

Assuming that the lens in use is roughly rectilinear (that is, is not a "fisheye" lens) and that the camera's image format is rectangular, the field of view is essentially a rectangular pyramid with its apex at the camera[1] and extending outward from the camera to "infinity".

We can characterize the extent of the field of view by stating the two angles at its apex—one in the horizontal plane and one in the vertical plane. It is also possible to state the "diagonal" angle of the field of view (the one measured between two diagonally-opposite edges of the pyramid). In fact, it is common, for conciseness, to state only the diagonal angle of a field of view. This turns out, though, to be of questionable practical use—we rarely know or can even guess the diagonal angular scope of some scene we wish to photograph!

Quantitative expression

The angles characterizing the field of view of a camera can be quantitatively expressed in two ways:

- In angular measure (most often using the unit *degree*, although of course any angular unit can be used, including the *radian*). Example: "36°". Note that of course we need to state which angle is being mentioned—horizontal, vertical, or even diagonal.

---

[1] To be precise, at the center of the entrance pupil of the lens. A proof of this is given in Appendix A.

- By stating the "chord" embraced by the angle at some stated arbitrary range. Example: "65 feet at a range of 100 feet". Note that this is still a legitimate form of expression of an angle. Again of course we need to state which angle is being mentioned.

The first form is perhaps the most fundamental. The second form, however, can be very convenient in judging the suitability of a certain field of view for many types of photographic tasks (such as photographing a 20-foot "wide" car from a distance of 50 feet—that would require a field of view a bit larger than "40 feet at a range of 100 feet".

"Angular field of view"

Some writers prefer to use the term "angular field of view" to mean this quantitative measure of field of view, apparently believing that it best reminds the reader of the angular nature of the phenomenon of interest.[2] The term is equally apt for either form of expression of the angle.

Some writers use the term "angle of view", apparently believing that the term "field" is not apt for a three-dimensional region.[3]

Another implication of the field of view

In many cases, we are actually not interested in the field of view as a pyramidal phenomenon (defined by its apex angles) extending to infinity, but rather are interested in the linear dimensions (width and height) of the two-dimensional plane region embraced by the field of view at a specific actual distance from the camera (often called the "object field" at that distance[4]). This most commonly arises when we are performing closeup photography (sometimes called *macrophotography*) and wish to know the actual linear dimensions of the object field at some close distance to which the lens can be focused (often the closest distance).

Thus we may say, "with this lens on this camera, at closest focus, the field of view will be 30 mm × 20 mm." Such a situation, for example, would be well suited for the photography of an object 24 mm × 16 mm in size with the lens at its closest focus setting.

---

[2] It is not more precise than "field of view"—the quantity is inherently angular in nature. The user not familiar with the concept will perhaps get a good clue from the fact that the quantity is usually denominated in degrees.

[3] I discourage use of that term. It does not well identify the thing whose size is being spoken of—its name is "field of view", regardless of what attribute we choose to measure or how we choose to state it. Further, "angle of view" has another, totally different meaning, also encountered in connection with cameras: the range of angle of observation over which a display (such as the back panel monitor on a camera) can be viewed with acceptable brightness and contrast.

[4] Some people believe that the term "field of view" should only be applied to this plane region.

What determines field of view?

The field of view of a camera depends on three factors:

- The focal length of the lens in use
- The dimensions of the camera's "format"; that is the dimensions of the image captured on the camera's film frame or digital sensor.
- The distance at which the lens is focused (a "minor" consideration in most cases)

For a given format size, the greater the focal length, the smaller the field of view. For a given focal length, the larger the format, the larger the field of view.

Later we will give the mathematical relationships involved, including the role of focus distance.

Photographers' practice

In practice, few photographers who have the opportunity to enact different fields of view by changing the focal length of their lens think of the result in terms of the angle(s) characterizing the field. Rather, they learn which focal lengths, on their particular camera, give them fields of view suitable for various photographic tasks.

The 35-mm camera reference

Often field of view is expressed by stating the focal length of the lens which, if used on a "full-frame 35-mm"[5] camera, would yield the same field of view as the focal length of the lens of interest does on the camera under discussion.

Often the use of this convention is justified based on the notion that a large fraction of photographers have substantial experience with full-frame 35-mm cameras, and thus will likely recognize the significance of such an expression.

That is in fact hardly true today, where many avid photographers have never used a full-frame 35-mm camera. That notwithstanding, the use of this manner of expression provides for a "standard language" of expression of field of view without introducing the notion of angles.[6]

---

[5] The term "full-frame 35-mm" refers to the most widely used 35-mm still camera format, 36 mm × 24 mm in size, as distinguished from the much-less used "half-frame 35-mm" format, 18 mm × 24 mm in size. The term is sometimes shortened to just "full frame". Some take that (inappropriately) as meaning that the 36 mm × 24 mm format is the "ultimate" size out of all possible formats. Shortening the designation to just "35-mm" would be just as unambiguous in most contexts, and would avoid that inappropriate interpretation.

[6] Why that is attractive remains a mystery to me. It is a little bit like stating distances on highway signs in terms of the time it would take to travel there at a speed of 55 miles per hour.

This hypothetical focal length is often called (to give it a more tediously-precise name than is usually used) the *full-frame 35-mm equivalent focal length* of the lens of interest as used on the camera of interest.

To calculate the full-frame 35-mm equivalent focal length of a certain lens as used on a certain camera, we divide the focal length of the lens by the relative size (in terms of a selected linear dimension) of the format of the camera of interest as compared to the size of the format of the full-frame 35-mm camera (which is 36 mm × 24 mm).

For example, if we have a camera with a format size of 22.5 mm × 15.0 mm (such as my Canon EOS 20D digital SLR), its format is 0.625 of the size of the 36 mm × 24 mm format of a full-frame 35-mm camera. Thus, if we contemplate using a lens with a focal length of 50 mm on that camera, we find that resulting field of view can be described by saying that the "full-frame 35-mm equivalent focal length" of the lens when used on that camera is 80 mm (50 mm/0.625).

In actual practice, since division is more difficult to "do in the head" than multiplication, we usually take note of the **inverse** of the relative size of the format of the camera of interest and multiply the focal length by that inverse ratio. In the example, we would multiply 50 mm by the factor 1.6 (since 1/0.625 = 1.6) to get the full-frame 35-mm equivalent focal length, again yielding 80 mm.

Note that the full-frame 35-mm equivalent focal length is not a focal length of the lens under any circumstances. Focal length is an optical property of the lens, expressed in absolute terms. It does not depend on the format size of the camera on which the lens is being used nor is it (as we sometimes hear) "expressed in 35-mm terms".

The 35-mm equivalent focal length is merely the answer to the question, "what focal length lens, used on a full-frame 35-mm camera, would yield the same field of view that "this" lens does on "this" camera.

The factor whose value is 1.6 in the example is often known as (again, to give it a more precise name than is commonly used) the *full-frame 35-mm equivalent focal length factor* for a particular camera (or for its format size), and shortened versions of that term are common. It is sometimes called the "35-mm lens factor". The term was formerly often called the "focal length multiplier", but that was deprecated as it tended to suggest that the smaller sensor actually caused an increase in the focal length of the lens.

Note that if the aspect ratio (ratio of horizontal to vertical dimension) of the format of the camera of interest is not the same as that of the full-frame 35-mm camera (3:2), we cannot precisely state with a single number the relative size of the sensor of the camera of interest—it would differ depending on whether we consider the horizontal, vertical, or diagonal dimensions of the two formats. In such case, it is customary to proceed anyway, using the ratio of the diagonal dimensions of the two formats as the indicator of "relative size". For example, for a camera with a format size of 8.8 mm × 6.6 mm (a common size for digital cameras), the full-frame 35-mm equivalent focal length factor is considered to be about 6.74.

"Field of view crop"

A few years ago, somebody decided that the fact that:

> the field of view afforded by a certain focal length lens on a camera with a format size smaller than the format of the full-frame 35-mm camera
>
> is smaller than
>
> the field of view that would be afforded by a lens of that same focal length on a full-frame 35-mm camera

should be looked at as the smaller field of view having been "cropped out of" the larger field of view.

A related outlook is that the sensor of the smaller-format camera "crops its image out of" the larger image that **would have been** captured by the frame of a full-frame 35-mm camera.

Based on these outlooks, it has become common, in certain circles, to refer to the factor mentioned above (1.6 in the first example) as the "field of view crop factor", "FOV crop factor", "FOV crop", or just "crop" of a particular smaller-sensor camera (or of its format size).[7]

THE MATHEMATICS

Calculation of the field of view

If we assume that the exit pupil of the lens is located at its 2nd nodal point, the field of view of a lens of a certain focal length, used on a camera of a certain format size, expressed in terms of the angle in angular measure, is given by:

$$A = 2\arctan\frac{d}{2Q} \qquad (1)$$

---

[7] I discourage the use of any of those terms. "Crop" in photography describes the extraction of part of a specific photographic image. It is not well suited for describing the fact that a certain something is smaller than the corresponding something in a different situation. A 10" dinner plate is not a crop of an 12" dinner plate. A 22.5 mm × 15.1 mm sensor does not crop a portion that size out of a 36 mm × 24 mm image formed in the camera. Almost never is the image formed by the lens in any camera 36 mm × 24 mm in size. The 22.5 mm × 15.1 mm image is merely smaller than the 36 mm × 24 mm image that would have been captured by the frame of a full-frame 35 mm camera.

where A is the angle describing the field of view (in the horizontal, vertical, or diagonal direction), d is the actual dimension of the format (in that same direction), Q is the distance from the 2nd nodal point of the lens to the focal plane[8] (d and Q being measured in the same units), and arctan represents the trigonometric *arc tangent* (or *inverse tangent*) function, the angle whose tangent is the value that follows.

The value of Q can be found from:

$$Q = \frac{Pf}{P - f} \qquad (2)$$

where f is of course the focal length of the lens and P is the distance at which the lens is focused, measured from the 1st nodal point of the lens.[9].

If we wish to consider the field of view for focus at a distance that is large compared to the focal length, then (as we can see from equation 2) Q becomes approximately equal to f, the focal length, and so we can use this handier equation:

$$A = 2\arctan\frac{d}{2f} \qquad (3)$$

For this situation, if we wish to describe the angle of the field of view in terms of the chord it embraces at a stated arbitrary range, that is given by:

$$s = \frac{dr}{f} \qquad (4)$$

where s is the span characterizing the angle (which can be the angle in the horizontal, vertical, or diagonal direction), r is the arbitrary range to be stated, d is the corresponding dimension of the format, and f is the focal length of the lens.

It is convenient, in this regard, to take note of what I call the *field of view constant* for the camera of interest (that is, for its format size). If we wish to express field of view in terms of its width in feet at a range of 100 feet (or its width in meters at a range 100 meters), then the field of view constant is just $100w$, where w is the width of the format in millimeters.

Then, to determine the width of the field of view at the arbitrary range of 100 feet (or 100 meters), we just divide the field of view constant for the camera by the

[8] Q is also the distance to the focal plane from the 2nd principal point of the lens. This dual significance is possible since, if both object space and image space are in the same medium (and in our case they are: air), the nodal points coincide with the principal points.

[9] P is also the distance from the object to the 1st principal point of the lens.

focal length of the lens in millimeters. The result will be in feet at a range of 100 feet (or in meters at a range of 100 meters).

Once could of course establish a similar constant for use in determining the height, or the diagonal extent, of the field of view at a stated arbitrary range (but in practical fact the diagonal value is actually of very limited interest).

Being more precise

In fact, equation 1 is not truly precise for focus at a close distance for lens designs in which the entrance and exit pupils are not located at the 1st and 2nd nodal points of the lens. If we wish to take account of this situation, then the precise equation is:

$$A = 2\arctan\frac{d}{2(Q - my)} \qquad (5)$$

where again A is the angle describing the field of view in some direction; d is the dimension of the sensor in that direction; Q is (as defined above) the distance from the 2nd principal point of the lens to the focal plane, in the current focus situation; m is the image magnification for the current focus distance (and is given by Q/P); and y is the distance that the entrance pupil lies in front of the 1st nodal point of the lens (y is negative if the entrance pupil actually lies behind the 1st nodal point).

Note that even with this more precise equation, for focus at a very large distance, where Q approaches f and m approaches 0, the equation still degenerates to equation 3. Thus in the situation of focus at a large distance we need not concern ourselves with pupil location.

The underlying geometry behind equation 5 is described in Appendix A, whose main purpose is to make the reader comfortable with the fact that the apex of the field of view lies at the center of the entrance pupil of the lens and not at the 1st nodal point (unless of course the entrance pupil is located there).

#

APPENDIX A

Location of the apex of the field of view

It is widely but incorrectly believed that the apex of the rectangular pyramid bounding the field of view is located at the 1st nodal point of the lens (which is in the same place as the 1st principal point for the cases of interest to us, where both object and image spaces are in air).

In fact, the apex is located at the center of the entrance pupil of the lens. Of course, in certain "classical" lens designs, the entrance pupil is located at the 1st nodal point, so this would be a distinction without a difference. But in many lenses, the pupils are displaced from the nodal points. This is in fact recognized by the precise formula for field of view, equation 5.

But the idea that the apex is located at the entrance pupil at first seems counterintuitive. After all, aperture doesn't really seem to be involved, and all the equations and geometric relationships involved in image formation work with respect to either the principal points or the nodal points. But it is true. We can see that with the assistance of figure 1.

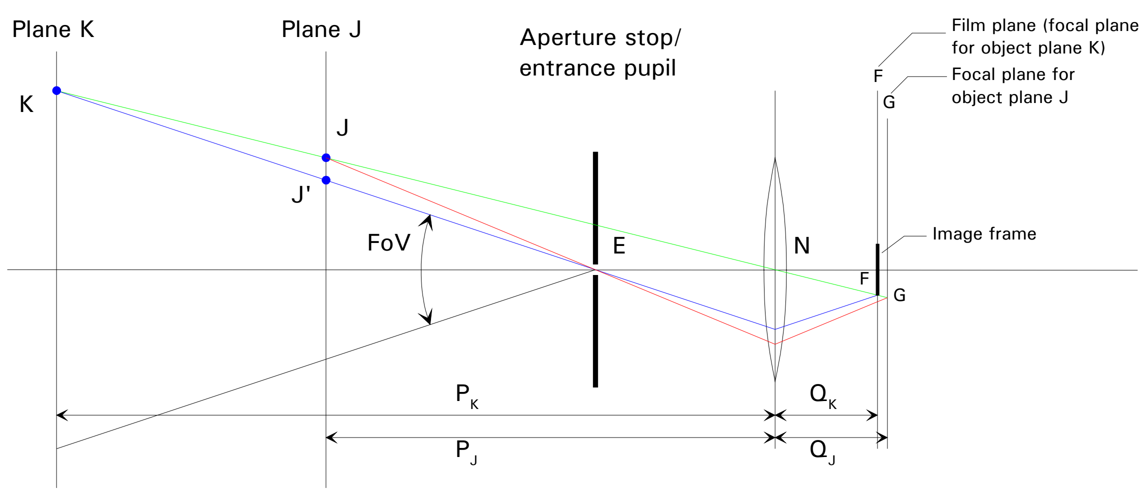

Figure 1. Apex of field of view

As we so often do, we will here assume the use of the fanciful "thin lens", which has no thickness. Thus both nodal points and both principal points are all located at the same place.[10] That place is labeled N.

[10] It is popular to say that they are all "at the center of the lens", but since the lens actually has no thickness (notwithstanding the way we draw it so it is easy to recognize on the drawing), that has no meaning. They are just "at the lens".

We will assume an aperture stop substantially in front of the lens proper. Thus the entrance pupil is identical to the aperture stop (which makes the presentation simpler).

We will assume a very small aperture. In that way, we need not be concerned with the matter of blurring of objects in the field of view that are not located at the plane of perfect object focus.

However, we nevertheless need to be concerned with focus matters, since the geometry of image formation depends on distances related to the concept of focus.

We will use two specific but arbitrary planes in object space for our investigation, plane K and plane J. We will assume the lens is focused at the distance of plane K. That means that the “film plane”, F, is at the focal plane for objects at plane K. The distances P_k and Q_k are related by the Gaussian focus equation, with the focal length of the lens as a parameter.

We also need to recognize, with the lens focused this way, the focal plane for objects in plane J. This falls behind the film plane, at a plane we identify as G. This again can be reckoned by calculating the relationship between the distances P_J and P_K under the Gaussian focus equation.

In the film place we see a heavy line segment that represents the vertical extent of the film frame (which delimits the vertical field of view).

We will chose a point, F, at the lower edge of the frame. We wish to see what object point, in object plane K, would produce an image point there.

To do that, we merely project back a *nodal ray* from point F. In a thin lens, any ray which passes through the common nodal point does so without being deflected by refraction. (This in fact flows from the definition of the nodal points.) Thus we can project this nodal ray back as an unbroken straight line (green).

Where it crosses object plane K, a place which we call point K, will be the uppermost point in plane K whose image falls within the film frame. It thus by definition lies on the upper surface of the field of view.

But in fact the nodal ray, while useful in our “construction”, cannot actually reach the film plane—it would be blocked by the aperture stop.

So let’s consider a ray from point K that **would** pass through the aperture stop—the one in fact that would pass through its center, called the *chief ray* (blue). We can plot its path beyond the lens, where it is deflected by refraction, by noting that (assuming no aberrations), all the rays from a object point will converge at the location of the perfectly focused image—at point F in this case.

Now, if in fact the apex of the field of view were at the lens nodal point(s), then if we consider objects in object plane J, point J would be the uppermost point in that plane whose image still fell in the frame.

Now, with regard to objects in this plane, to be able to do optical geometry, we must consider the plane at which rays from such a point would converge. We earlier said that this would be plane G, behind the film plane.

Thus we draw a nodal ray from point J and see where it intersects plane G. That is where the lens would form a perfectly-focused point image of point J.

But as before, this nodal ray can't actually reach the film, as it would be blocked by the aperture stop. So again, we consider the chief ray from object point J, which passes through the center of the aperture.

As before, we know that it, like all rays from point J, must arrive at point G.

So we plot the journey of the chief ray from point J to point G (red). And we find that when it gets to the film (plane F), it falls outside the frame boundary—below point F.

Thus, point J in fact lies outside the field of view (probably not what we were expecting).

Now, what point in plane J **would** lie just at the top edge of the field of view? Well, its chief ray would have to arrive at point F, the lower edge of the frame at the film plane. But we have already drawn a ray passing through the center of the aperture stop that lands at point F—the chief ray from point K (blue). Its path is equally valid whether we think of it as originating at point K or at some point in plane J on that same line. This is independent of focus considerations (a single ray knows nothing about where it and other rays from the same object point, if any, might converge—its path is just dictated by the optical elements in its path.)

Thus we know that the "highest included point" in the field of view within plane J must lie on that blue chief ray. We label that point J'.

Of course, if we did this for other object planes, we would find that always the uppermost point that would be included in the field of view would lie on the blue line. Accordingly, the blue line represents the upper surface of the pyramidal field of view, and the apex of the field of view lies where the blue line crosses the lens axis— at the center of the entrance pupil (point E).

Quod erat demonstrandum.

The precise equation

Further analysis of the relationships shown in figure 1 allows us to derive the precise formula for field of give expressed by equation 5. I will spare all of us the math involved.

Acknowledgement

In fact, until just recently I too believed that the apex of the field of view lay at the 1st nodal point of the lens. My thanks to my colleague, the noted optics maven Paul van Walree, who pointed out my error, and in ensuing correspondence as I sought to rationalize this, pointed out the importance of the matter of focus distance to this issue.

#