Autofocus Accuracy Specifications in Canon EOS Digital SLR Cameras

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ABSTRACT

Canon, Inc. typically expresses the accuracy tolerance of the autofocus system in their EOS digital SLR cameras as a fraction of the *depth of focus*. Of interest in relating this specification to its impact on actual photographic work is how this relates to *depth of field*. In this article, we describe that relationship, as well as the basic significance of the specification, and of depth of focus itself.

INTRODUCTION

Canon, Inc. usually states, in the published specifications for their various digital single-lens reflex (SLR) cameras, an accuracy tolerance for the autofocus (AF) system in terms of a fraction of the *depth of focus* of the camera. Often, for the "basic" AF mode, that specification is "within the depth of focus". For the "high precision" AF mode that applies in certain circumstances, that specification is often "within 1/3 the depth of focus".

Often, users ask, "Isn't that the same as 'within the depth of field' (or 'within 1/3 the depth of field')?" Usually the response is, "Certainly not—those are two vastly different quantities." But in fact the answer isn't quite that simple.

In any case, it is difficult for a photographer to relate an AF accuracy expressed in terms of the depth of focus to its impact on practical photographic work.[1] Typically, the photographer may wonder whether she can expect, when focusing on an object, that the actual focus setting produced by the AF system will be close enough to the object distance that the object will be "within the depth of field" for that situation—that is, whether she can expect the image, despite the AF error, to still be in "adequately sharp focus".

In this article, we will examine the relationship between AF accuracy specifications expressed in term of depth of focus and the implications of those specifications in terms of depth of field.

DEPTH OF FOCUS

Depth of focus is ordinarily defined in this way. Imagine a camera aimed at a test object at a certain distance. The lens generates a perfectly-focused image of a test object at a particular distance behind the lens (hopefully, at the location of the film

[1] As an actual distance, the depth of focus is perhaps only ±0.04 mm!

or digital sensor). We then ask this question: at what range of distances behind the lens is an image produced that, while not perfectly focused, may still be considered "adequately sharp"? That range of distances is defined as the *depth of focus* for the particular situation.

Of course, for this to be meaningful we must have a quantitative definition of what constitutes "adequately sharp". As in the case of depth of field, we do this by stating that an image will be considered adequately sharp if the "circle of confusion" (blur circle) produced in the imperfectly-focused image from a point on the object does not have a diameter greater than some value we arbitrarily adopt (the "circle of confusion diameter limit", or COCDL).

This definition of depth of focus has classically been related to the question, "with the lens 'properly' focused, how far can the film be displaced from its intended position and still have the image adequately sharp".

We see this concept of depth of focus in Figure 1. Note that the COCDL used there is unrealistically large so as to make the depth of focus large enough for a convenient illustration.

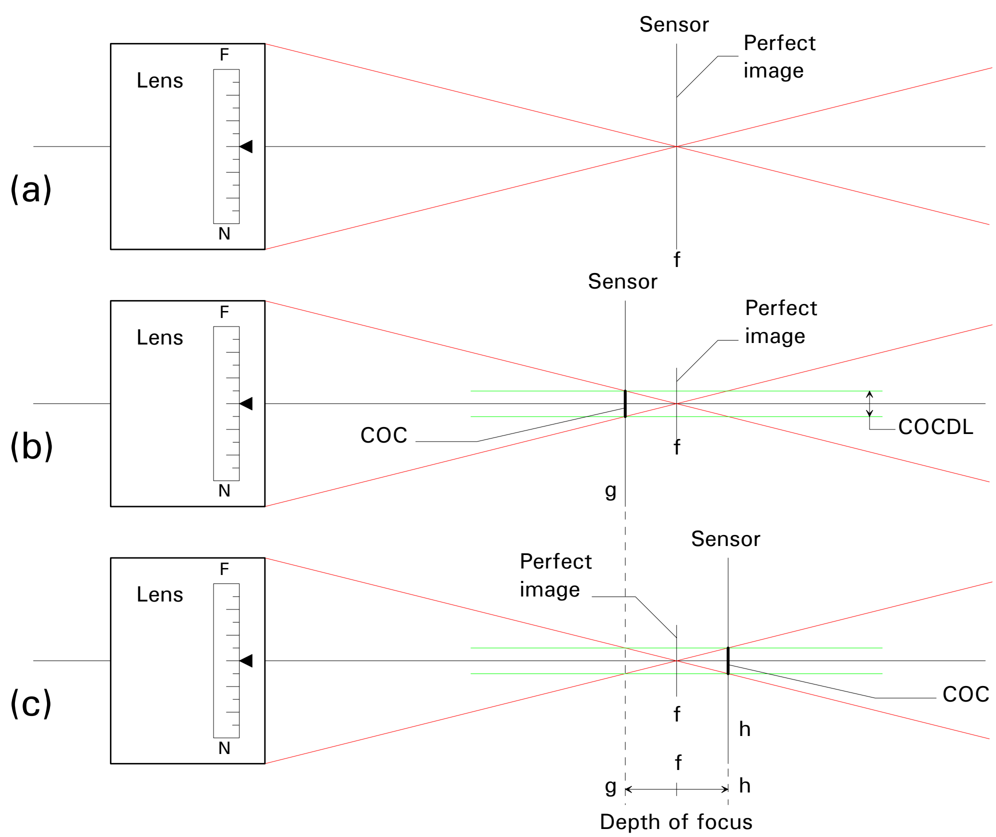

Figure 1. Depth of focus

The red lines in the figure show the convergence of the outermost rays originating at a point on the object.

In Part (a), we see the lens properly focused on some object, such that a “perfectly focused image” of the object is formed on the sensor, at location f, presumably the intended location of the sensor. In Part (b), we move the sensor forward to point g. There, a blurred image is formed, one whose circle of confusion has just the diameter we established as our circle of confusion diameter limit (COCDL), our criterion of “acceptable sharpness”. In Part (c), we move the sensor backward to point h. There. we also have a blurred image, again one whose circle of confusion has the diameter of our COCDL.

The depth of focus in this situation is said to extend from point f to point g.

The other “depth of focus” definition

There is also a second, subtly different, definition of depth of focus. This time, imagine the perfectly focused image of a test object falling precisely on the sensor. Then consider shifting the focus setting of the lens so as to move the perfectly focused image forward and back. We ask the question: for what range of distances to the perfectly focused image is the image on the sensor itself still “adequately sharp”?

For all cases of interest, the numerical results of these two definitions will be almost identical. But it is important to recognize the conceptual difference between them. Otherwise, some of the story won’t seem quite right.

In particular, it is really this second definition that directly relates to the specification of AF error in terms of depth of focus. Here, we don’t have an “error” in the position of the sensor, with the perfect image formed where the sensor is supposed to be. Rather, we have an error in lens focus setting such that the perfectly focused image is created closer to the lens, or farther from it, than the location of the sensor.

We see this concept of depth of focus in figure 2. As before, in Part (a) we see the lens properly focused on some object, such that a “perfectly focused image” is formed on the sensor, at location f, presumably the intended location of the sensor.

In Part (b), due to an error in the AF system, the lens is not focused on the object but in fact at a greater distance. We see this by noting the indicator on the lens focus scale at a position farther toward the “far” direction than in Part (a).

As a result of this misfocus, the perfectly-focused image of the object is formed not at the sensor but at location k (or it would be if the sensor were not in the way!). At the sensor, a blurred image is formed, one whose circle of confusion has the diameter of our COCDL. Thus the image on the sensor just barely satisfies our criterion of “acceptable focus.

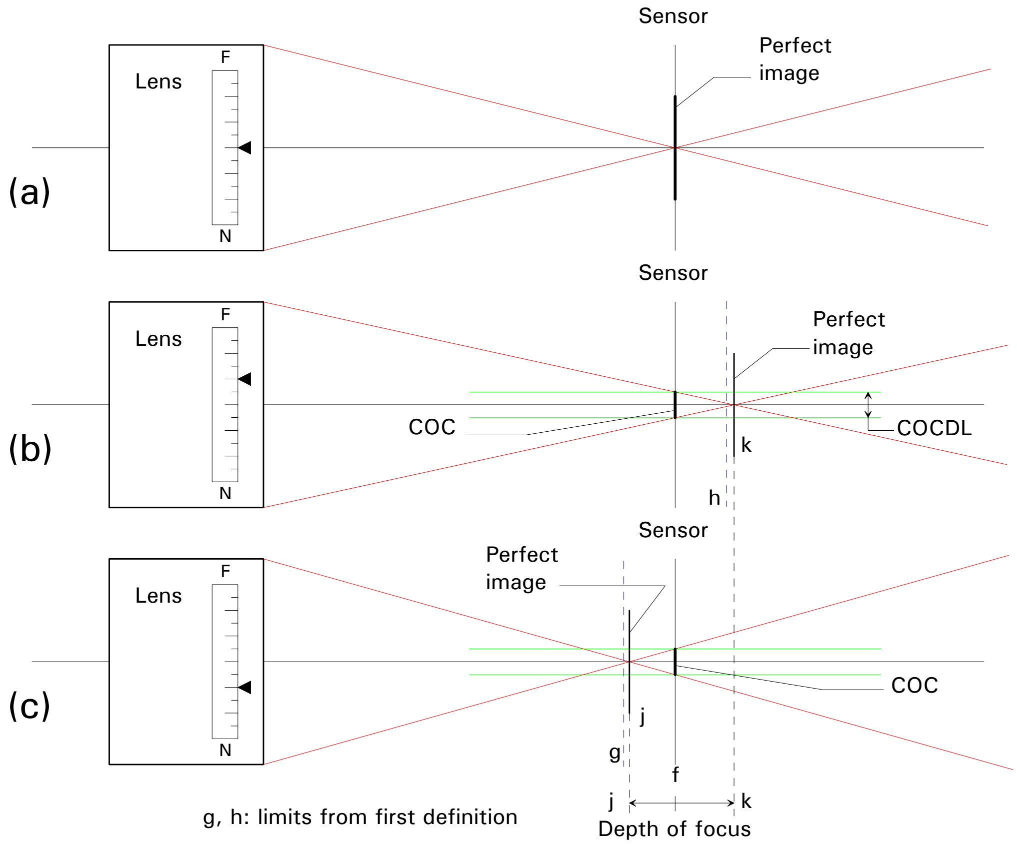

Figure 2. Depth of focus (definition 2)

In Part (c), we see a situation in which the lens has (through AF error) been focused at a distance closer than the object. In this case, the perfectly-focused image of the object is formed at location j, in front of the sensor. Again, the image on the sensor is blurred, with a circle of confusion whose diameter is just that of our COCDL, an image that just barely satisfies our criterion of “acceptable sharpness”.

Under “definition 2”, the depth of focus of this system is said to extend from location j to location k.

On this figure we have also shown locations g and h, the limits of the depth of focus in this situation under “definition 1”. Note that they are not quite the same as the limits of depth of focus under definition 2 (locations j and k). Of course, as mentioned previously, we have shown depth of focus for an extremely large COCDL. With a COCDL in the range usually used, the difference between the limits for the two definitions of depth of focus would be negligible.

How big is it, anyway?

Often (under either definition) the difference between the nearest and farthest distance is itself said to be “the depth of focus”. But we have to be very careful about that usage. Suppose that under definition 1 the depth of focus for a sensor plane 50.00 mm from the lens ran from 49.96 mm to 50.04 mm. (It always comes out symmetrical for definition 1.) Then, the depth of focus, under that usage, would be stated as "0.08 mm".

But of course if we are using the depth of focus as a tolerance limit on AF error, does this mean that it is acceptable for the AF system to produce the perfectly focused image at a location that is "off" by 0.08 mm? No. It is only allowed to be off by 0.04 mm (one way or the other, of course)—falling within the "range" of the depth of focus.

To avoid any misunderstanding, its is better to say that the depth of focus in this situation is "±0.04 mm". And the AF error tolerance specification, under the "within the depth of focus" specification, would best be said to be "±0.04 mm".

THE SPECIFICATION

We will assume here that when Canon states an AF accuracy specification as "within the depth of focus", it is in light of our second definition of depth of focus—its the only one that fits the AF accuracy "model". However, for the cases of interest, the numerical limits for the two definitions are essentially identical, so we really don't have to be concerned with which outlook they use.

Note that here the COCDL is not one that we get to choose, but rather the one Canon has adopted as appropriate when stating AF accuracy. I have heard that this is 0.035 mm for full-frame 35-mm sensor size cameras, and 0.020 mm for cameras such as the EOS 20D.

What determines depth of focus?

Having chosen a COCDL criterion, the depth of focus depends on two parameters of the optical system: the actual diameter of the aperture of the lens (not the f/number) and the distance from the second principal point of the lens to the sensor. (The aperture of interest for our purpose is the maximum aperture of the lens, since that is the aperture in effect when the AF process is conducted.)

We normally reckon depth of focus for the situation in which the test object is at a distance much greater than the focal length of the lens. Having done so, we can then replace the distance to the sensor with the focal length of the lens. Then, having introduced the focal length, we can rearrange the equation to use the f/number rather than the actual diameter of the aperture. (And when we do that, the focal length drops out altogether!)

For the first (normal) definition, the depth of focus is given by:

$$d = \pm cn$$

where d is the depth of focus (the "single-sided" value, thus the "±" on the right side), c is the applicable COCDL, and n is the f/number of the lens.

For the second definition of depth of focus (the one that really pertains to this topic), the equation is much more complicated, but for any reasonable f/number, the results are almost identical, so we won't bother with it here.

IN OBJECT SPACE

So far, our work has been totally in "image space", that is, in the region between the lens and the sensor. Now, on figure 3, we will direct our attention to "object space", the region in front of the lens. Our objective here is to relate the accuracy specification in terms of depth of focus to its impact on actual photographic work, and to explore the relationship of that specification to depth of field.

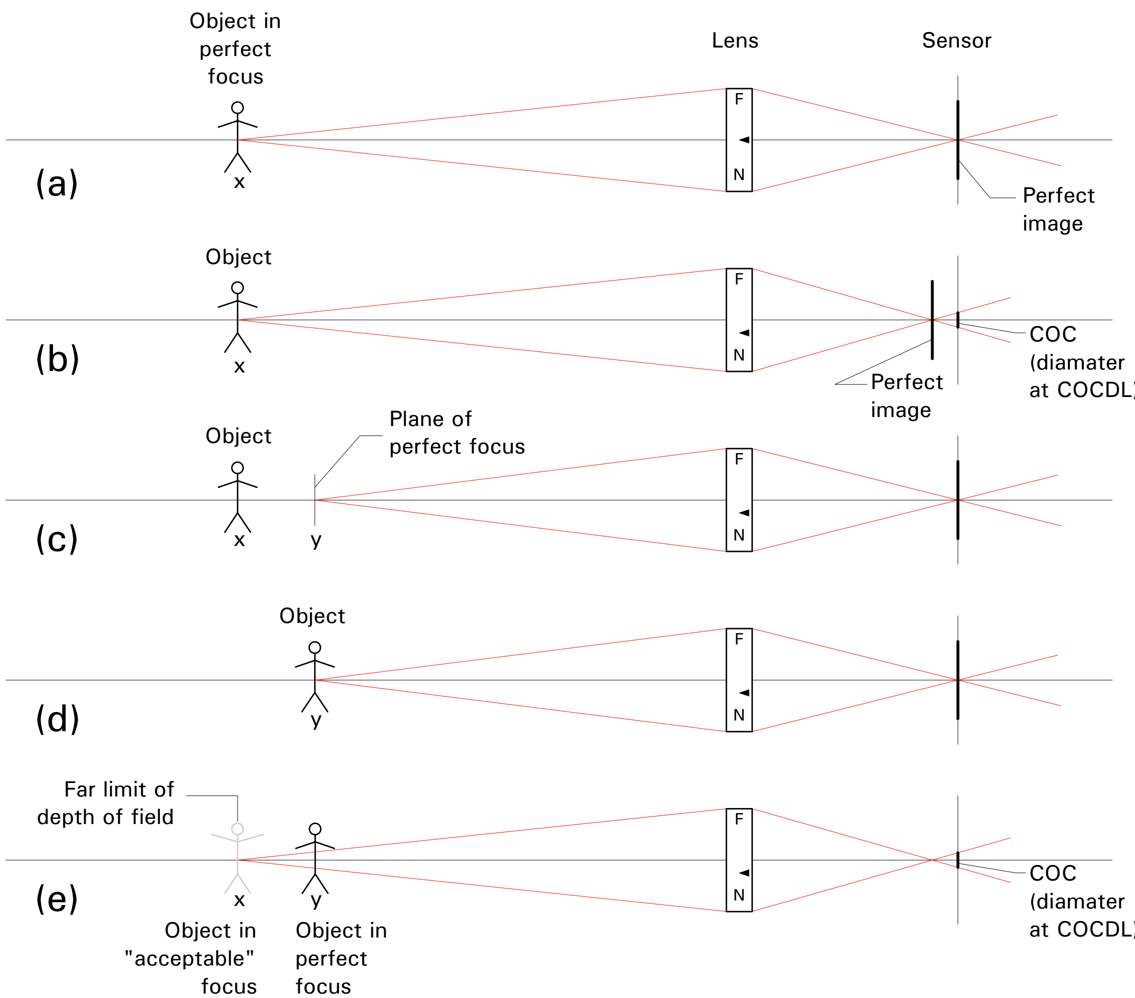

Figure 3. Imperfect focus seen in object space

In Part (a) we see the situation in which the lens is perfectly focused on the object (at point x), meaning that a perfectly-focused image of the object falls on the sensor. In Part (b), we see an AF error such that the perfect image falls in front of the sensor, and a blurred image falls on the sensor. The degree of the error is such that the diameter of circle of confusion of the image on the sensor is just the

COCDL—the image on the sensor just barely meets the criterion of "acceptable focus". This then corresponds to an AF error that is just "within the depth of focus"

In Part (c), we see that this corresponds to the system being actually focused at a point short of the object (point y). (This is the situation colloquially described by photographers as "front focusing".)

Now let's look at this from another perspective. Part (d) of the figure shows the very same incorrect focus situation as shown in Part (b). Now, however, we have an object at point y, the point at which the lens is actually focused. That object will thus be given a perfectly focused image on the sensor.

In Part (e), we think of another object at point x. We know from Part (b) that an object at point x would be imaged with blurring that was just acceptable under the applicable COCDL criterion. This is precisely the definition of the far limit of depth of field for focus on an object at point y. Hold that thought!

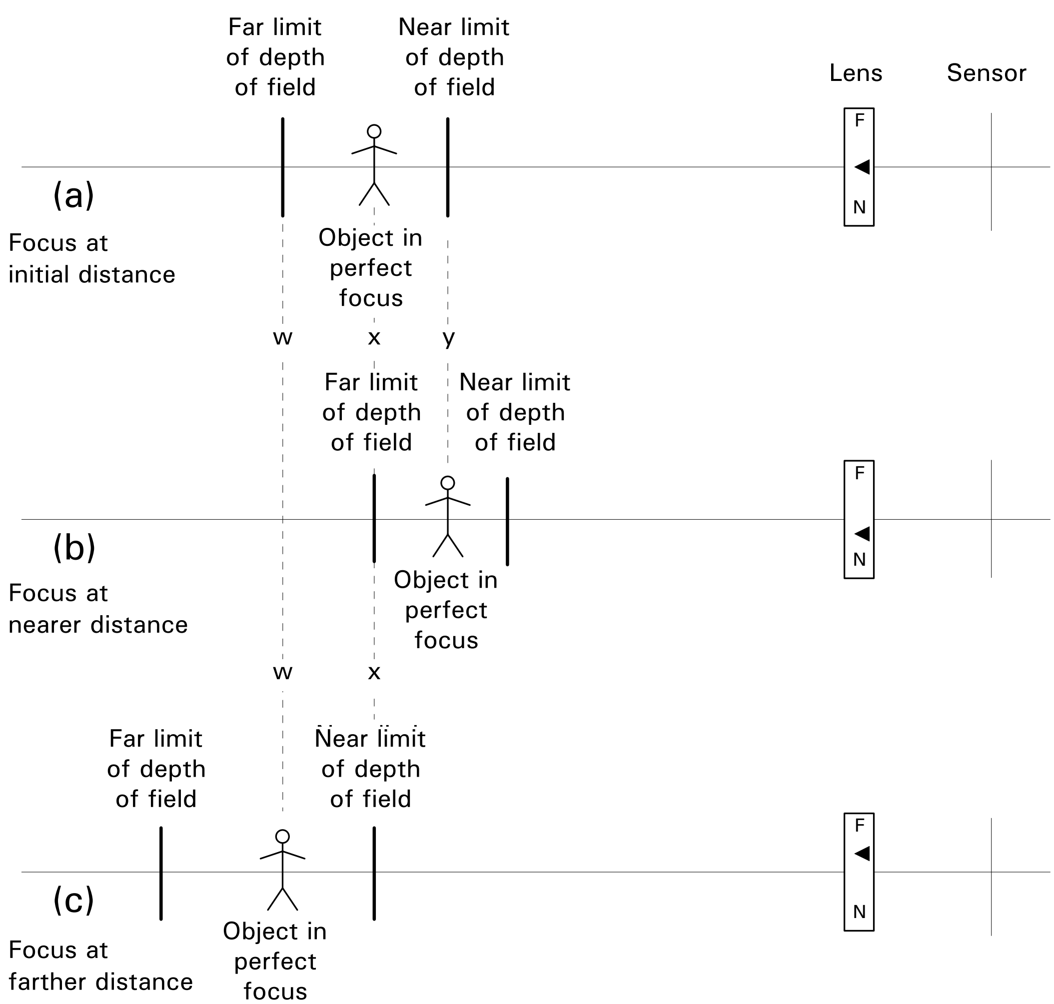

Figure 4. Symmetry of depth of field

Now, to complete our story, let's look at figure 4, which shows an interesting symmetry in depth of field.

In Part (a), we see the camera focused on an object at point x. The far and near limits of depth of field for that situation are at points w and y. Now, in Part (b), we focus on an object at point y. It turns out that the far limit of depth of field for that situation is precisely at point x!

Then in Part (c), we focus on an object at point w. It turns out that the near limit of depth of field for that situation is precisely at point x!

This symmetry is not just an approximation, valid when the depth of field is small compared to the focus distance; it applies for any situation (so long as none of the limits are at or beyond infinity). The mathematical proof is this is rather tedious, but you can readily demonstrate it empirically by playing with any competent depth of field calculator.

Now, with this in hand, returning to figure 3, Part (e), we now realize (from figure 4) that if, for focus at point y, the far limit of depth of field is at point x (as shown in the figure), then for focus at point x, the near limit depth of field will be at point y. But, as seen in Part (c), point y is the nearest possible point of actual focus, under the "within the depth of field" accuracy specification, for attempted focus at point x.

Thus, we find that the near limit of actual (but incorrect) focus distance for attempted focus on an object is precisely the near limit of depth of field for focus on that object.

Precisely the corresponding relationship is true for the far limits.

This can be summarized:

> The range over which the actual focus distance can occur within the "one depth of focus" specification of autofocus accuracy is exactly the same as the range of distance that constitutes the depth of field for focus at the distance of our test object.

Implications on photographic work

This is of course a very useful fact in assessing the practical photographic impact of potential AF error.

It means that a photographer, concerned over the possibility of AF error, can:

1. Determine the in-specification limits of focusing error, in terms of focus distance, with any handy depth of field calculator.

2. Be comfortable that, even with an AF error of the greatest amount allowed under the specification, the object (focus target) will fall within the depth of field (even if the shot will be at the maximum aperture of the lens).

THE "1/3 THE DEPTH OF FOCUS" SPECIFICATION

In many of the cameras of interest, Canon's AF accuracy specification for certain situations (for example, for one of the center AF detectors of certain cameras when the aperture of the lens is greater than a certain value) is "within 1/3 the depth of focus".

Does the happy situation we discussed above still apply here? That is, are the nearest and farthest distances at which the camera could focus, while still remaining within the "1/3 depth of focus" tolerance, distances that are 1/3 as far from the object distance as the near and far limits of depth of field?

No, not quite. In fact the far limit of incorrect focus distance will not be quite as far from the object as 1/3 the distance from the object to the far limit of depth of field; the near limit of incorrect focus distance will be a little farther from the object than 1/3 the distance from the object to the near limit of depth of field.

The precise distances that are the allowable limits of the focus distance under the "within 1/3 the depth of focus" specification can, however, still be calculated using a normal depth of field calculator. Just enter, as the value for the circle of confusion diameter limit (COCDL), a value that is 1/3 the actual COCDL Canon has adopted as the criterion of "acceptable sharpness". The resulting near and far limits of the depth of field will be the allowable limits of focus distance under the "within 1/3 the depth of focus" specification.

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