# ADJUSTING DEPTH-OF-FIELD — Part III

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In Part II of Adjusting Depth of Field (Shutterbug, March 1992) we looked at the ability of a lens focused at infinity to resolve objects in front of the lens. What we learned is that a lens focused at infinity can resolve objects roughly the same size as the working lens opening, no matter how far the objects are from the camera. Diffraction effects do degrade this picture a bit for objects at the longer distances, however.

In Part II we made a significant step in the thought process, though I expect few readers noticed it consciously. By concentrating on what objects the lens can resolve—instead of examining lines per millimeter in the image—we opened up a new way to think about depth of field. Instead of using some arbitrary standard of image resolution, we can actually figure out what objects will or will not be resolved. We can determine what information about our subject will be recorded in the image. We are not constrained to the near ubiquitous 1/30 mm standard for the circle of confusion for 35 mm images, or 1/1500th of the lens focal length for other formats. The new point of view can lead to a very useful way to analyse a photograph before it is taken.

Part II suggested that we should be able to do something which the standard depth of field theories cannot. Traditional depth of field tells us when something is 'sharp enough.' What do we do if we want some object deliberately blurred out? I suppose if we have our photography books at hand, with their depth of field formulas at the ready, we can work it out. But even in the comfort of one's home or studio, it won't be easy. Seems like a job for a computer. Well, there is an easier way, and that's the subject of Part III.

We're going to start by extending what we learned in Part II. It was suggested that we might think of the camera as a projector. A tiny but bright light source on the film would, if the shutter were open, cast a beam of light in front of the camera. With the camera lens focused at infinity, the diameter of that beam is the same at all distances in front of the camera. (Diffraction effects are neglected here, for the moment.) The size of the bright spot cast on some surface shows us what will be resolved in the image. If an object is small compared with the bright spot, it will be missed in the image. If the object is larger than the spot, the object should show up clearly in the image.

If the lens is focused at some distance closer than infinity, the size of the bright spot will vary. For objects very close to the lens the bright spot will be just about the same size size as the lens opening. For objects in the great distance, the spot will be very large. At exactly the distance at which the lens is focused, the spot will be a tiny speck. The principle remains unchanged: the size of that spot of light is the size of the smallest object which will be recorded distinctly in the image.

This line of logic leads to the simple diagram shown here as Figure 1. We don't need to show the film, only the camera lens, what is in front of it, and where the lens is focused. In the case shown, the lens is focused at distance D. At that distance, the spot of light is infinitesimally small. At any other distance, which we'll call X, the spot has a finite size. That size depends only upon three things: the physical diameter of the lens opening, the distance at which the lens is focused, and how far the spot is in front of or behind the plane of exact focus. The 'plane of exact focus' is that surface in front of the camera where any tiny object on that plane would be in perfect focus. We don't need to know the focal length of the lens; we don't need to know the film format. We don't need to know the numerical aperture (that is, f/8 or whatever). The rules are simple. The bigger the lens, the bigger the spot. The bigger the distance from the plane of exact focus, the bigger the spot. The greater the distance at which the lens is focused, the smaller the spot. With respect to distances, what really matters is how far the spot is from the plane of exact focus, expressing that distance as a fraction of the distance D.

If we denote the working diameter of the lens as d, and the difference between D and X as L, the spot size, S, is simply d times L divided by D. In formula form, $S=(d \times L)/D$. This is a pretty simple formula, and even if you forget it, you can probably figure it out again by redrawing Figure 1. The "working diameter" of the lens is

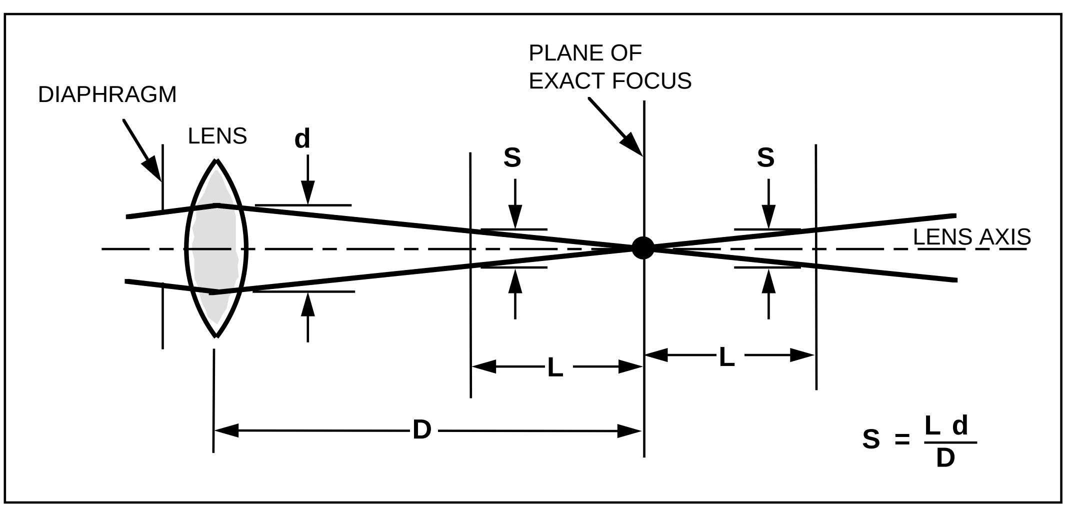


*Figure 1: Diagram showing how the spot size, S, is related to the focusing distance, D, the lens diameter, d, and the distance, L, from the Plane of Exact Focus.*

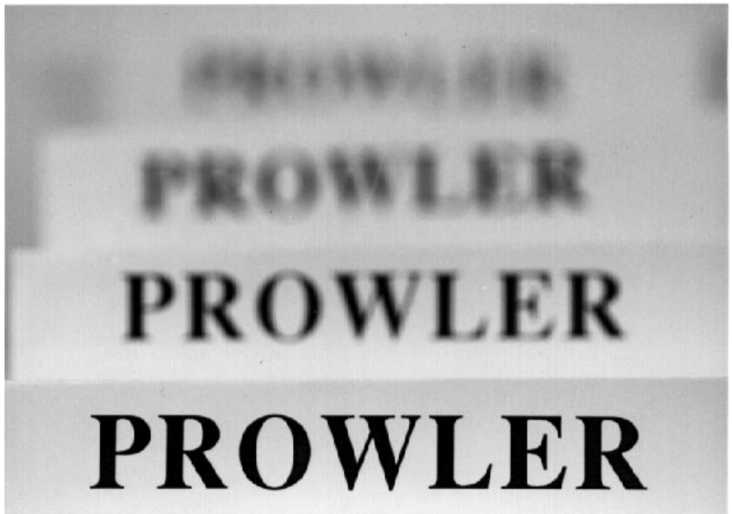


*Figure 2: Photograph of four cards bearing the word "PROWLER". The bottom card is in focus. The remaining cards were arranged so that the spot sizes are one-fifth, one-half, and one times the letter height . To ensure that the word is truly out of focus, the spot size must equal or exceed the letter height.*

defined as the diameter of the diaphragm opening as seen from the front of the lens, with the diaphragm at its working (stopped down) aperture.

An interesting characteristic of the formula is that we can measure lens diameter and distances in different units. For example, let's suppose the lens is focused at 10 feet, the lens diameter is 10 millimeters and we want to know the spot size one foot either side of the plane of exact focus. We plug the numbers in to the formula, and find the spot size to be 1 millimeter. We can measure distances in feet, millimeters, miles, furlongs—anything we like—so long as both L and D are measured in the same units. The spot size will then be expressed in whatever units we use for the lens diameter—typically millimeters.

The formula cited above can also be rewritten as $L=(S\times D)/d$. Now we have a very simple way to determine depth of field. If we must record the existence of objects as small as one millimeter, if we use a 5 millimeter diameter lens (50 mm lens at f/10, for example) and if the lens is focused at 15 feet, we find L=3 feet. In this example, any object one millimeter or larger in size, and lying in the range 12 feet to 18 feet ($15\pm3$ feet) will be recorded in the image. No tables, no computer, no scales to interpret. One simple formula fits all.

What I have so far called "spot size" I like to refer to as the "*disk* of confusion". It's rather like the circle of confusion, but the disk is in front of the camera where I can 'see' it.

I'll illustrate out-of-focus effects with one concrete example. We set a simple goal. Some words on a sign in the background of a scene must *not* be readable. How big does the disk of confusion need to be to ensure that? Figure 2 shows a 'scene' made up of the word "PROWLER" printed the same size on each of four cards. The camera is focused on the card in front. Behind the first card the others are arranged so that the disk of confusion is, respectively, one-fifth, one-half, and one times the height of the letters making up the word. You can easily see that if the disk of confusion is one-fifth the letter height, the word is still quite readable. When the disk of confusion is equal to the letter height, the word is essentially unreadable. There are two simple rules. First, if you want to read the words, the disk of confusion should be no more that about one-fifth of the letter height. Second, if the words are to be unreadable, the disk of confusion must be equal to or greater than the letter height. The exact numbers may depend upon the actual type style used, but they will not be too different from the example shown here.

Up to now we have ignored diffraction effects. Diffraction sets an absolute limit on the minimum spot size that can be achieved. This minimum spot size can only be realized when the lens is perfectly focus. This minimum spot size may be calculated from the approximate formula: S'=D/(5d), where d is the working lens diameter in millimeters and D is distance measured in feet in front of the lens. For this formula, both S' and D must always expressed in the units specified. By way of example, if the working diameter of a lens is 5 millimeters, the diffraction-limited spot size at 25 feet is one millimeter. It is interesting to note that this result does not depend upon focal length. In order to gain greater resolution of a scene, one must in principle use a lens with a larger *diameter*—not necessarily a longer focal length! This result ignores other realities such as film characteristics, however. Also, for a constant f-number, the length and diameter of a lens are directly proportional.

Under any given condition, the minimum spot size for a particular distance in front of a lens will be (approximately) the greater of that calculated from the diffraction formula, and that calculated from the depth-of-field formula.

Another interesting observation is possible. When one is concerned about how a lens sees the world, both diffraction effects and depth of field effects depend only upon lens diameter. A large diameter lens gives high resolution but poor depth of field. A small diameter lens yields poor resolution, but good depth of field. There is no magic format or lens focal length which theoretically has the advantage for resolution or depth of field. Given perfect film, a diffraction limited 50 mm f/5 lens on a 35 mm camera would give identical results to a diffraction limited 150 mm f/15 lens on a view camera. Each lens would provide the same depth of field and the same degree of resolution. If there are differences, they derive from the film emulsion characteristics, how flat the film is, and from the duration of the exposure.

In Part III we have learned that there is a second way to estimate depth of field. We can ask—and easily answer—"What objects in front of my lens will be resolved in my image?" "How big does an object need to be to be seen clearly?" And, "What does it take to ensure an object will be *out* of focus?" The really attractive feature of this second method is that it is entirely independent of format, focal length etc. One simple formula promises to provide virtually all the answers. The really good news is that the photographer is free to choose his desired resolution criteria on the spot. And the criteria can change from picture to picture as appropriate. The bad news is that the method does not lend itself readily to simple depth-of-field scales on lenses. It is not always as convenient as the traditional method.