Depth of Field for Digital Images

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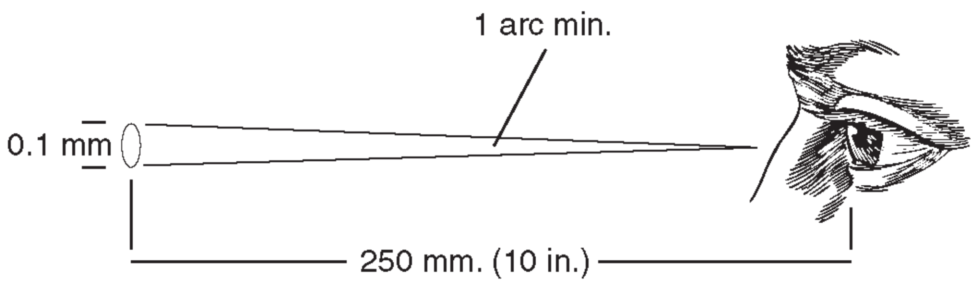
In the days before digital images, before the advent of roll film, photography was accomplished with photosensitive emulsions spread on glass plates. After processing and drying the glass negative, it was contact printed onto photosensitive paper to produce the final print. The size of the final print was the same size as the negative. During this period some of the foundational work into the science of photography was performed. One of the concepts developed was the circle of confusion.

Contact prints are usually small enough that they are normally viewed at a distance of approximately 250 millimeters (about 10 inches). At this distance the human eye can resolve a detail that occupies an angle of about 1 arc minute. The eye cannot see a difference between a blurred circle and a sharp edged circle that just fills this small angle at this viewing distance. The diameter of this circle is called the *circle of confusion*. Converting the diameter of this circle into a size measurement, we get about 0.1 millimeters. If we assume a standard print size of 8 by 10 inches (about 200 mm by 250 mm) and divide this by the circle of confusion then an 8x10 print would represent about 2000x2500 smallest discernible points. If these points are equated to their equivalence in digital pixels, then the resolution of a 8x10 print would be about 2000x2500 pixels or about 250 pixels per inch (100 pixels per centimeter).



The circle of confusion used for 4x5 film has traditionally been that of a contact print viewed at the standard 250 mm viewing distance. Since the viewing distance remains constant, the 0.1 mm circle of confusion used for 8x10 prints is the same for a 4x5 print at the same distance. Using this circle of confusion value, a 4x5 contact print has a resolution of about 1000x1250 pixels.

If the same 4x5 circle of confusion (i.e. 0.1 mm) is applied to a full resolution image from a Better Light Model 6000 camera (6000x8000 pixels), the image would be the equivalent of a 24x30 inch contact print viewed at 250 mm. A Model 8000 (8000x10660 pixels) produces the equivalent of a 32x43 inch contact print. Remember, before enlargers, photographers made images with glass plate negatives of these sizes, and larger!

Depth of field describes the amount of distance in the original scene where any scene point will appear sharply focused and thus it will occupy less area than the circle of confusion when imaged onto the digital sensor (or photographic medium). Since there is a start and an end to this sharp zone, there are two equations that can be used to calculate this area of sharpness for a specified focal point.

Far limit = $sf^2 / (f^2 - Ncs)$

Near limit = $sf^2 / (f^2 + Ncs)$

Depth of Field = Far limit - Near limit

where:

s = point of focus for the lens

f = focal length of the lens

N = aperture of the lens

c = circle of confusion

Example:

150 mm lens focused at 10 feet (3048 mm) with an aperture of f/16 on 4x5 film

s = 3048 mm, f = 150 mm, N = 16, c = 0.1 mm

Far limit = 3048 · 150 · 150 / (150 · 150 - 16 · 0.1 · 3048) = 3891.5 mm = 153.2 inches

Near limit = 3048 · 150 · 150 / (150 · 150 + 16 · 0.1 · 3048) = 2505.0 mm = 98.6 inches

Depth of field = 3891.5 - 2505.0 = **1386.5 mm = 54.6 inches** for 4x5 film

Many photographers have remarked that scan back images do not seem to have the same depth of field they experienced with 4x5 film. They are right, and this difference is caused by a different circle of confusion. A Model 6000 Better Light has a pixel size of 12 microns, or 0.012 millimeters. Since this is the smallest resolvable point in the image, the pixel size can be used for the circle of confusion. The circle of confusion for the Model 6000 is 8.3 times smaller than the 0.1 mm circle of confusion for 4x5 film (i.e. 0.1/0.012 = 8.3). To get close to the 4x5 circle of confusion with a Model 6000, you would need to operate the camera at 12% resolution (0.096 mm). This is the same size as a preview image in the ViewFinder software (~2.1 MB).

So, why do we use the pixel size as the circle of confusion? The original definition for the circle of confusion was based on the resolving ability of the human eye at a viewing distance of 250 millimeters. When we look at digital images on a monitor screen, the images are magnified until each individual image pixel occupies one pixel on the screen. (Since the size of a screen pixel is much larger than the circle of confusion then we can use a single pixel is the smallest resolvable area in the image.) If you remember, the smallest resolvable area is the definition of the circle of confusion when we look at a photographic print. Therefore, the circle of confusion for a screen image shown at a one-to-one relationship between it's pixels and the monitor's pixels is a single pixel in the original digital image. Essentially, when we look at an image on a screen at full resolution, then it is equivalent to looking at a large poster print from a 250 mm distance (10 inches).

So, let's redo the example from above but with a Better Light Model 6000 at 100% resolution with a 150 mm lens focused at 10 feet and set to an aperture of f/16 with the circle of confusion set to a single pixel size and see what a difference it makes to the depth of field.

s = 3048 mm, f = 150 mm, N = 16, c = 0.012 mm

Far limit = 3048 · 150 · 150 / (150 · 150 - 16 · 0.012 · 3048) = 3129.4 mm = 123.2 inches

Near limit = 3048 · 150 · 150 / (150 · 150 + 16 · 0.012 · 3048) = 2970.7 mm = 117.0 inches

Depth of field = 3129.4 - 2970.7 = **158.7 mm = 6.2 inches** for a digital file

Wow! This is almost 1/9 of the 4x5 print depth of field! But, remember that this is the **equivalent of viewing a 24x30 inch print at 10 inches**, something not done normally.

So, how do you deal with the new circle of confusion and what it means to depth of field? Perhaps the best way is to **keep the final reproduction size in mind when shooting the image**. If the final image is a small thumbnail for the Internet, a 0.1 mm circle of confusion (or larger) is more than adequate and a 12% resolution will suffice. If the final image is to be a poster, then use the pixel size of 0.012 mm for the circle of confusion at 100% resolution.

Below is a table of print sizes for the different resolutions available on Better Light cameras using the 4x5 circle of confusion at a 250 mm (~10 inch) viewing distance. All the sizes are in inches.

	Model 4000	Model 6000	Super 6k	Model 8000	Super 8k
150%			35x47		47x63
142%					45x59
137%			32x43		
133%					42x56
125%			30x39		39x52
117%					37x49
112%			27x35		
108%					34x45
100%	15x20	24x31	24x31	31x42	31x42
92%				29x38	29x38
87%		21x28	21x28		
83%				26x35	26x35
80%	12x16				
75%		18x24	18x24	24x31	24x31
67%				21x28	21x28
62%		15x20	15x20		
60%	9x12				
58%				18x24	18x24
50%		12x16	12x16	16x21	16x21
40%	6x8				
42%				13x17	13x17
37%		9x12	9x12		
33%				10x14	10x14
25%		6x8	6x8	8x10	8x10
20%	3x4				
17%				5x7	5x7
12%		3x4	3x4		
8%				2.5x3.5	2.5x3.5

Summary

So what does this mean for Better Light Scan Back users?

1. Depth of field cannot be judged accurately on a Preview Image since the circle of confusion is larger than the higher resolution setting of the final image. Use a full or partial scan at the final resolution to make critical judgements.

2. Be aware that judging sharpness and depth of field on a computer monitor is looking at a poster sized print (image size at 72 dpi) at a distance meant for an 8x10 print. This is an overly critical investigation.

3. A more accurate judgement of sharpness and depth of field would be from a proof print or stepping back from the monitor.

4. Depth of field can be improved by working at a longer subject to camera distance (or shorter focal length lens). Increase the resolution to produce desired file size.

The benefit of using a scan back is that the capture of detail is equivalent to a huge glass plate original. The caution is to understand the laws of physics and optics that impact the relative depth of field. The higher pixel density records the finest details of your subject; the lines and edges are smoother, the color definition is superior and gradations between tones are more gradual and accurate than possible on film.