The Circle of Confusion in the Print

The circle of confusion (CoC) is, "the largest blur spot that will still be perceived by the human eye as a point, when viewed on a final image from a standard viewing distance."

The nature of CoC has been known since 1829, applied to images viewed through telescopes. By 1866, CoC was used to determine the nearest and the farthest objects that are in acceptably sharp focus, within the depth of field (DoF) in the print.

The diameter of CoC is commonly calculated from the diagonal (d) of an image as d/1500. This applies to the print when viewed from a controlled distance. It does not work as well with a digital image displayed on a digital screen.

DoF calculators provide a means of *predicting* what the DoF is going to look like in the final print. The film or digital format, aperture, focal length and focus distance helps us to estimate that DoF.

The CoC for a particular sensor or film format is also d/1500 to account for the magnification needed to produce a standard print, usually 8x10" or 8x12" when viewed from about 25cm (10") by someone with normal eyesight.

An 8x10" image viewed from about 10" has a corresponding CoC of 0.217mm (0.0085") for someone with normal acutance. The CoC at the sensor or film plane usually needs enlargement to make a standard print.

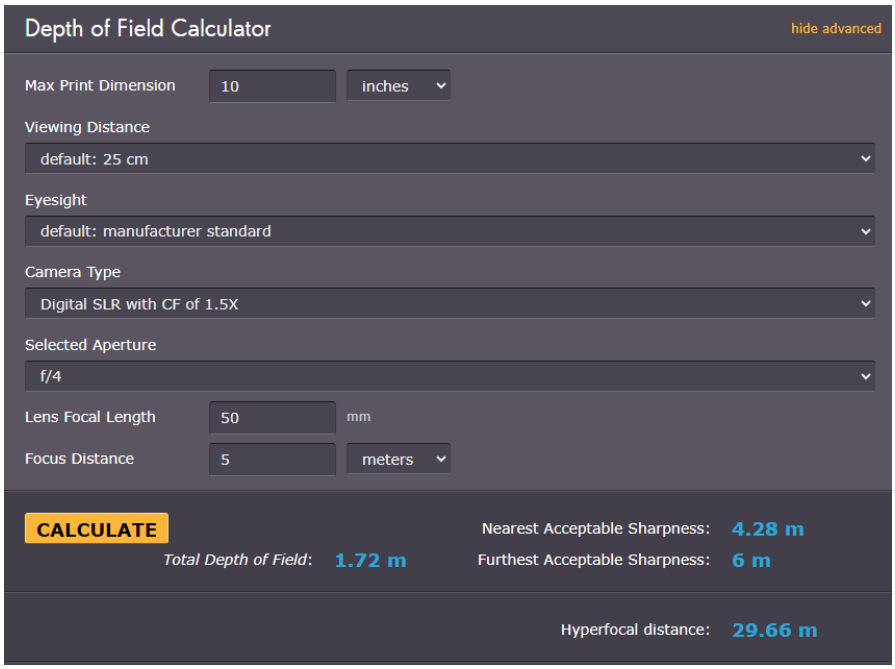
Sensor/film format mm				CoC mm	
	height	width	d	d/1500	magnified
8x10" print	8	10	12.8	0.217	1.00
Medium format	33	44	55.0	0.037	5.91
Fx	24	36	43.3	0.029	7.52
Dx	16	24	28.8	0.019	11.28
Micro 4/3	13.5	18	22.5	0.015	14.46

DoF

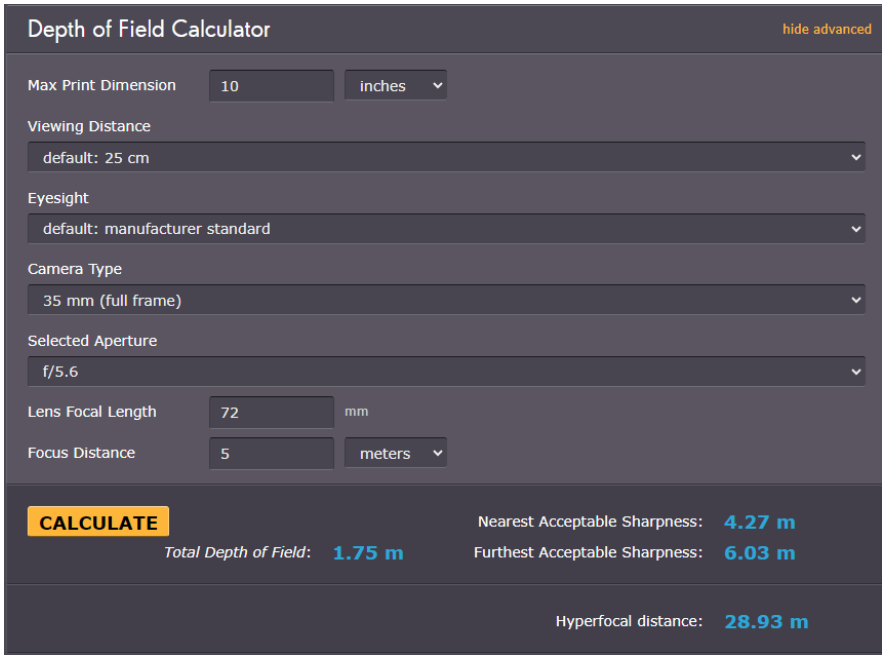
An ordinary camera can focus at only one distance at a time. A point at the focused distance will record as a point on the film or sensor. Any point closer or further from the camera will be out of focus and will record as a small circle or blur spot. But the viewer cannot see that in the print until the spot is as large as the CoC of the print. Anything within this DoF appears sharp until it is beyond the DoF limits.

DoF Calculatiors

Here is the DoF calculator from Cambridge in Colour:

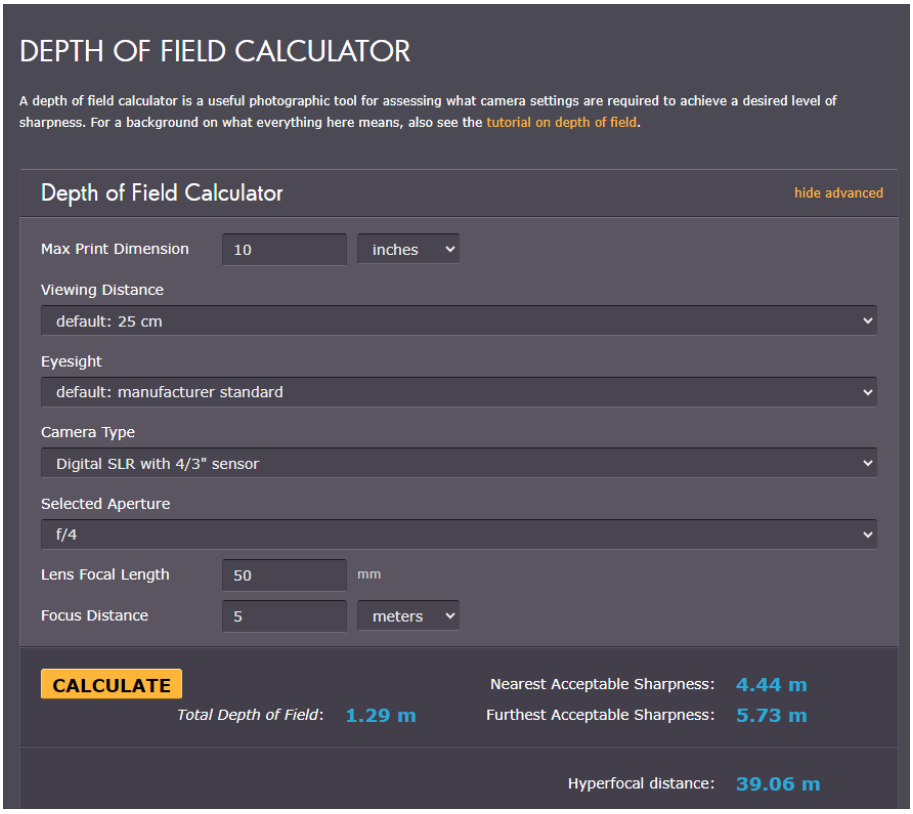


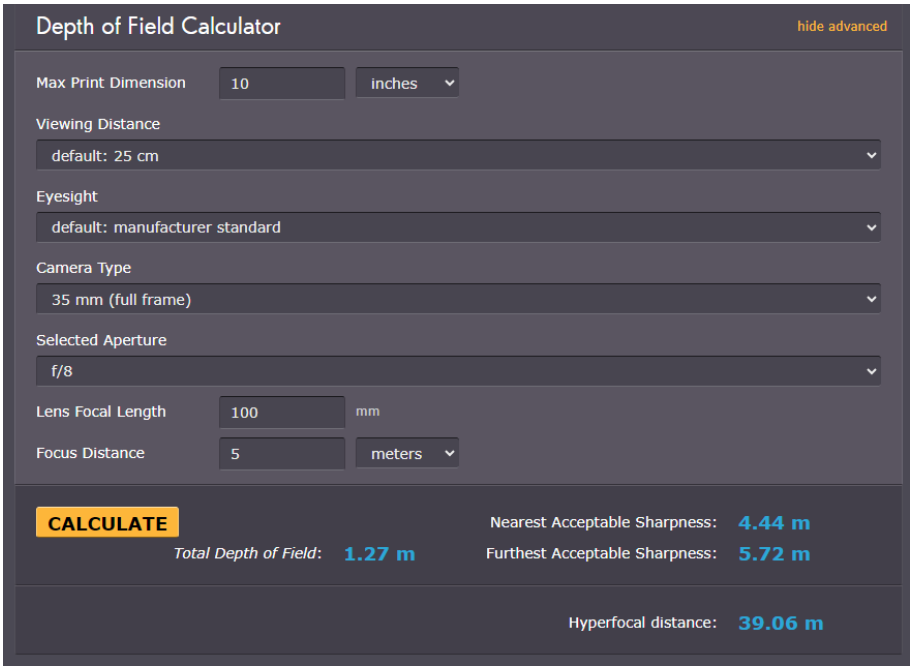
To get the same image for a full frame sensor takes a longer lens and an adjustment to the aperture. The focal lengths needed to be adjusted to compensate for the crop factor in order to capture the same scene:



The numbers do not match precisely because f/5.6 is rounded from 5.65685 (2^2.5).

Comparing Micro 4/3 (2x crop factor) to full frame:





The numbers agree almost exactly despite the difference in aspect ratio (3:4 vs. 2:3).

The adjustment to the f-stop resulted in using the same physical opening – 50/4 = 100/8 = 12.5mm.

How Many Pixels are in the Circle of Confusion

A digital image is recorded with a rectangular array of square pixels. The total number of pixels depends on the size of each pixel and the size of the sensor. The area of the CoC is larger than the area of a pixel.

The size of the pixels depends on the MP of the sensor so the number of pixels that fit into the CoC varies.

Here is a comparison for an image aspect ratio of 2:3:

Fx MP	p/mm^2	pixels in CoC
12	13889	9.1
16	18519	12.1
24	27778	18.2

Dx MP	p/mm^2	pixels in CoC
12	31250	9.1
16	41667	12.1
24	62500	18.2

An aspect ratio of 3:4 produces a similar result:

33x44mm	p/mm^2	pixels in CoC
12	8264	8.7
16	11019	11.6
24	16529	17.5

Micro 4/3	p/mm^2	pixels in CoC
12	49383	8.7
16	65844	11.6
24	98765	17.5

Since something as large as the CoC is indistinguishable from a point at the normal viewing distance for the print, we cannot see whether square pixels form a smooth circle.

Conclusion

Although CoC calculators address the fundamental question of DoF in the print they do not remind us of the effect of cropping the original image before making the final print. Cropping is the same as using a smaller format since the image (and the blur circle) will be magnified more.

It is difficult to see how the DoF will look on a digital display. A 12" display 1920 pixels wide (2k) viewed from 12" away renders only 160ppi. A display 3840 pixels wide (4k) would render 320ppi. Those resolutions would look the same in a 24" display viewed from 24".

A standard print only needs 300ppi when making an 8x10 print to be viewed from about 12 inches. That's only 7.2MP (8.6MP for an 8x12 image) and a little more if you crop slightly. An enlarged version of the image viewed from a proportionately greater distance does not need an increase in MP.

Viewed at half the normal distance you would need only 28.8MP and 34.6MP but when you do that you will not be able to see the entire print like a normal viewer. Additional megapixels are expensive and unnecessary unless you crop a lot.

At 300ppi there are about 5.2 pixels inside the 0.0085" CoC.