

# Contact and Optical Printing Sharpness

## Some Ultimate Comparisons

by Dennis Couzin\*

*Contact printing is sharper than optical printing if the contact is good. If there is a gap between the original and print emulsions then contact printing sharpness suffers, and when the gap reaches a certain measure optical printing is sharper. The first part of this paper arrives at this measure. Of course, it cannot be presumed that what causes the gap in contact does not also cause optical defocus. For example, a warped original can cause both. The second part of this paper compares contact and optical printing sharpness for such cases.*

While the grain and sharpness of the film emulsions will be ignored and the optics of contact and projection somewhat idealized, this paper should nevertheless provide a basis for realistic comparisons. The everyday question "To contact or to optical?" motivated it. In Part I optical printing will be found a stronger contender than is commonly thought while in Part II contact printing will be. One way in which the optics are not idealized is that they are physical rather than geometrical. When comparing contact and optical printing sharpness, ignoring diffraction yields wrong answers.

### Part I

A common example of gapped contact printing is printing through the base. This printing preserves the emulsion position of the original in the print. Optical printing can accomplish the same. Here too the original is printed through the base, but now the lens can be focused through the base, on the original emulsion, and there is no compromise of sharpness.

Obviously diffuseness of illumination exacerbates the effect of contact printing gap, as explained by simple geometry. Highly specular illumination is prescribed, and according to the geometry point source illumination is the best way to jump the gap. Illumination from a point does not, however, render gapped contact printing as sharp as ungapped. We will ignore the diffusion due to the original's grain, which could cause

this. Even a perfect sharp edge with this perfect illumination makes an unsharp shadow on a nearby screen, due to diffraction, as completely explained by Fresnel in 1818. Fresnel's Shadow is the exposure to the print film.

Figure 1 shows the Fresnel Shadow for a gap of .09mm, corresponding to a film base thickness,<sup>1</sup> with monochrome green light (550nm). On the darkside there is a pro-

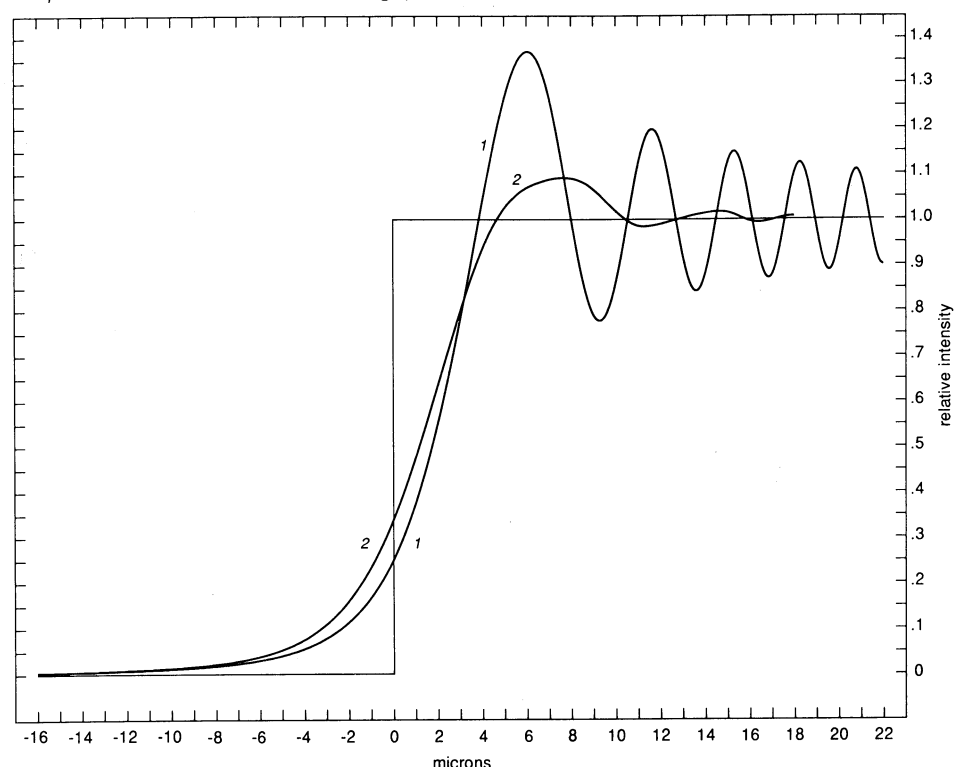
longed spillage of light. The edge profile itself is sloped and displaced towards the lightside. The lightside exhibits fringes, a slowly damped ringing. The fringes should be ignored, as they would be practically lost with polychrome illumination or with not quite point source coherence and would be less prominently graphed if the logarithm of the illumination were used. The spillage and the slope are what determine the image quality.

Figure 1 also shows the nearly defringed shadow gotten by substituting for the point source a disk source of half-angle  $2.7^\circ$ . It has practically the sharpness of the point source shadow. A disk 50% larger would have substantially reduced sharpness. The  $\pm 2.7^\circ$  illumination is prescribed for the .09mm gap. Larger gaps require tighter illumination, and

<sup>1</sup>The actual thickness of a film base, about .14mm, is divided by its refractive index, about 1.55, to give the air gap for equivalent Fresnel Shadowing.

Figure 1. Edge images.

1. Fresnel Shadow, .09mm gap, 550nm.
2. quasi-Fresnel Shadow, .09mm gap,  $\pm 2.7^\circ$  illumination, 550nm.



\*Dennis Couzin teaches at Columbia College, Chicago and The School of the Art Institute of Chicago.

the angular tolerance is inversely proportional to the square root of the gap. Stated as a rule of thumb:

When illuminating to contact print with gap  $d$ , a specularity of half-angle  $.8/\sqrt{d}$  ( $d$  in mm, angle in deg) may safely be used in place of point source.

This not quite point source edge will be referred to as the quasi-Fresnel Shadow.

Edge images are being considered because they are good indicators of sharpness and convenient common denominators for comparing disparate systems, such as contact and optical. MTF, for example, is not applicable to Fresnel shadowing, nor to optical printing with non-diffuse illumination.

How does the contact print made with gap  $d$  compare with the optical print? Figure 2 shows, together with the quasi-Fresnel Shadow from Figure 1, two optical edges, all of comparable sharpness.<sup>2</sup> One is for an  $f/11$  aberrationless lens working in diffuse illumination, the other for an  $f/13.5$  aberrationless lens working in  $\epsilon = .9$  condenser illumination.<sup>3</sup> For motion picture formats sharper 1:1 printing lenses than these are available, achieving about  $f/7$  aberrationless performance.<sup>4</sup> Thus as expected, optical printing is the preferred method for preserving emulsion position in motion picture printing.<sup>5</sup>

For other formats the conclusion may be otherwise. For the  $6\text{cm} \times 6\text{cm}$  still format  $f/11$  or  $f/13.5$  aberrationless 1:1 printing optics are about the state of the art, so that contact and optical printing are equal

<sup>2</sup>We lack a trustworthy criterion for ESF evaluation. So-called acutance measures are messy and ad hoc. Clearly one ESF is stronger than another when it exhibits both lower spillage and greater slope, but we do not know how these factors trade off.

<sup>3</sup>The condensers' image of the lamp filament slightly underfills (90% diameter) the aperture of the printing lens. This was chosen instead of the more natural  $\epsilon = 1$  condenser illumination for computational convenience, and is used throughout the paper.

<sup>4</sup>Throughout this paper effective  $f$ -numbers are used. Usually these are the indicated infinity  $f$ -numbers multiplied by the bellows factor.

<sup>5</sup>The majority of motion picture contact printers, which are not of course intended for printing through the base, are now fitted with the Bell & Howell additive lamphouse. For this the effective source is rectangular, and with the light valves nearly closed the longer dimension subtends about  $3.5^\circ$  half-angle, while with the light valves fully open this becomes about  $20^\circ$ . The former angle is nearly within our tolerance. The latter angle is large enough that image quality can be appraised geometrically, and the sharpness is well below even the standards of depth-of-field tables. If ever one must contact print through the base with such a lamphouse it is highly advantageous to remove filters, increase voltage, or otherwise cause the printing to be done with small light valve openings.

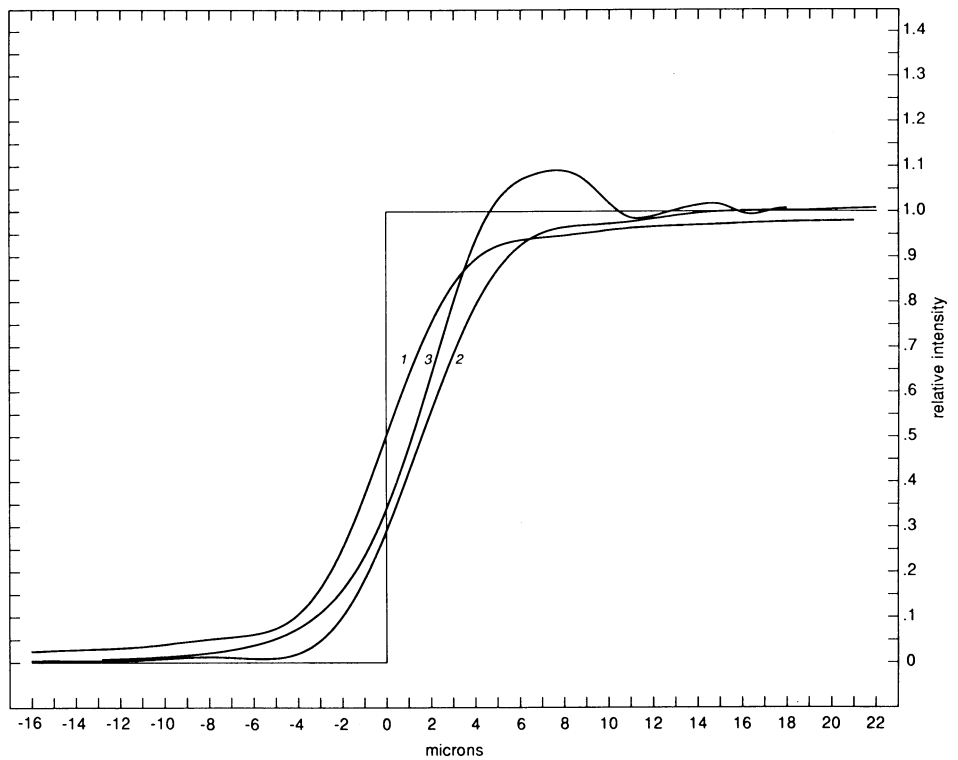


Figure 2. Edge images.

1. Optical, aberrationless  $f/11$ , diffuse illumination, 550nm.
2. Optical, aberrationless  $f/13.5$ ,  $\epsilon = .9$  condenser illumination, 550nm.
3. quasi-Fresnel Shadow, .09mm gap,  $\pm 2.7^\circ$  illumination, 550nm.

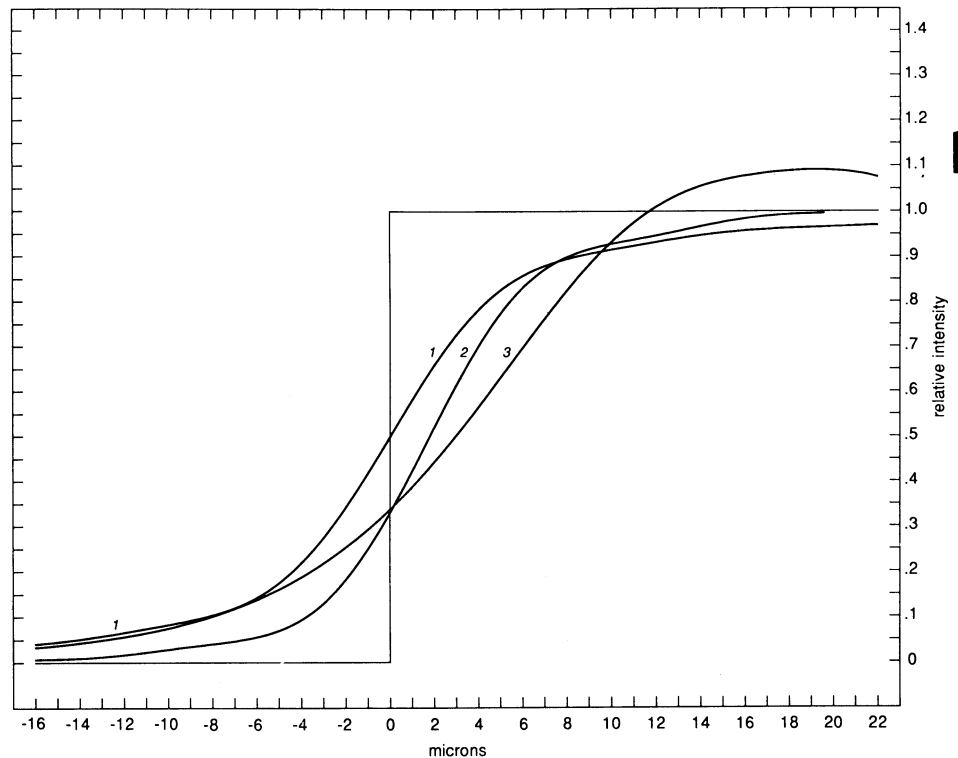


Figure 3. Edge images.

1. Optical,  $f/16$ ,  $\lambda/4$  defocused, diffuse illumination, 550nm.
2. Optical,  $f/16$ ,  $\lambda/4$  defocused,  $\epsilon = .9$  condenser illumination, 550nm.
3. quasi-Fresnel Shadow, .56mm gap,  $\pm 1.1^\circ$  illumination, 550nm.

methods for printing through the base. For larger formats demanding slower lenses contact printing through the base is preferable to optical printing. But for thicker film bases the advantage may return to optical printing. Figure 2, upon which the comparisons have been based, can be conveniently generalized to other gaps, other apertures, other wavelengths. Fresnel Shadows always have

the same form, which simply widens in proportion to  $\sqrt{d \lambda}$ , ( $d$  is gap,  $\lambda$  is wavelength; the gap is assumed to be at least 20 wavelengths). The same applies to the quasi-Fresnel Shadow. On the other hand optical edge spread functions widen in proportion to  $N \lambda$  ( $N$  is  $f$ -number). Thus in general for contact printing which uses the not quite point source illumination, 550nm,

and optical printing which uses aberrationless optics and condenser illumination, 550nm: *contact printing with gap d (in mm) gives sharpness equal to optical printing at  $f/(45\sqrt{d})$* . If the optical printing uses diffuse illumination then the f-number becomes  $37\sqrt{d}$ .

The sharpness advantage passes from contact to optical printing when the contact gap measures about .024mm. This assumes the best available f/7 printing optics with condenser illumination.

In the typical construction of color films the blue sensitive layer is on the top. The image in this layer contributes little to visible sharpness and so when such films are contact printed there is an effective gap. From the boundary of the green and red record layers of the original to the boundary of the green and red sensitive layers of the print film is approximately .033mm.<sup>6</sup> This must be divided by the refractive index of gelatin to find the equivalent air gap. Thus the surprising conclusion that optical printing is as sharp as contact printing for a large class of color films, just because of their emulsion ordering.

## Part II

If the original has depth, meaning that the image is not in a plane, then contact printing suffers gap and optical printing suffers too, from the need to accommodate depth.<sup>7</sup> Stopping down has a diffractive cost.

Consider the printing of bipacks, by con-

<sup>6</sup>Based on measurements of Eastman 5243 and 5399 films.

tact and optically. Suppose both originals must face the print emulsion to achieve the desired contact print. Then one original will print sharply and the other will suffer as described in Part I. For this same print to be made optically the emulsions must again be separated by the thickness of one base.<sup>8</sup> Now it is possible to focus on either original, while defocusing the other, similar to the contact printed result. Also focus can be set midway between the original emulsions, so as to maximize the minimum image quality. This is the strategy adopted for the comparisons to follow. How then does the contact print made with gap d compare with the optical print made with depth-of-field d?<sup>9</sup>

There is a handy optical theorem which prescribes how far to stop a lens down to accommodate a certain depth-of-field with best sharpness:

If the DOF is large enough to require aperture small enough that the lens is aberrationless, then the optimum aperture will be that which just achieves Rayleigh tolerance ( $\lambda/4$  defocus) at the extremes.<sup>10</sup>

<sup>7</sup>Interesting special cases of curved originals to which contacting films, or even optical fields, may be conformed will be ignored.

<sup>8</sup>The aerial image optical printer prints bipacks otherwise, escaping this but not other examples of deep originals.

<sup>9</sup>The depth-of-field in a medium other than air is divided by the medium's refractive index to give the equivalent depth-of-field in air. This parallels the treatment of contact gap; see footnote 1.

<sup>10</sup>See Dennis Couzin, "Depths of Field", SMPTE Journal, November 1982.

For our example with unit magnification and required depth-of-field d,

$$N = \frac{1}{2}\sqrt{d/\lambda}$$

is the prescribed f-number.

Now the shape of the contact/optical comparison becomes evident. For the contact print the ESF will derive from the quasi-Fresnel Shadow and be scaled in proportion to  $\sqrt{d/\lambda}$ . For the optical print the ESF will derive from the edge image achieved by a  $\lambda/4$  defocused lens and be scaled in proportion to  $N\lambda$ . Since N is chosen as  $\frac{1}{2}\sqrt{d/\lambda}$ , this scaling is in proportion to  $\sqrt{d/\lambda}$ . Thus the sharpness from both the contact and optical printing depends in exactly the same way on distance d and it remains to draw one comparison for one value of d to settle all comparisons.

Figure 3 shows the quasi-Fresnel Shadow for gap .56mm as well as two versions of the corresponding f/16  $\lambda/4$  defocused optical image. It is a horse-race. The condenser optical image wins but the other two are too close to call. The conclusion is that a *deep original printed by contact (with optimal, nearly point source illumination) or printed optically (with optimal focusing and stopping down) will produce practically equal sharpness.*

One caution must be exercised when applying this conclusion. There must exist sufficiently well-corrected lenses for the stops prescribed. Thus the example of the .56mm deep original called for a printing lens aberrationless at f/16, such as is available for cine and small still formats but not for large still formats. For the 20cm  $\times$  25cm format f/44 is about the state of the art. Then the original would have to be at least 4mm deep before the contact/optical equivalence could begin to apply. □