REPRINT

The Sharpness Indicator

By Ivan Putora

The Sharpness Indicator,* (Fig. 1), is a line test-object. It consists of a series of circular spatial-frequency test targets, (Fig. 2a), with an increasing number of lines per millimeter from target to target. These lines may be black and white, or black lines set against a suitable primary color, or may be any other combination of suitable colors. Elliptical shaped targets can be made for testing anamorphic optical systems (Fig. 2b). The individual circular test targets are set against a background, which acts as a comparison or reference field. The reflectance of this reference field is equal to the integrated or average reflectance of the circular test targets, all of which have the same integral or average reflectance value.

This arrangement produces a very interesting phenomenon: when any optical system, including the human eye, a photographic system, or a TV chain is trained on it, the test targets with a line frequency beyond the resolution power of the system merge or fuse completely with the reference field and can no longer be distinguished. The greater the distance at which this test object is used (and hence the smaller the optical lateral magnification), the lower, of course, the line frequency resolved, until finally none of the targets can be resolved, and an apparently homogeneous field results for the optical system employed.

The test object described could be put to use in ophthalmology for the evaluation of an individual's eyesight. It will also be very useful for evaluating the resolving power and depth of field of any photographic system, its optics, as well as the intervening emulsion or emulsions. The same is true for its application in television.

All the individual test targets are made with an area of equal size, great enough to yield an image of easily discernible size when imaged on a photographic emulsion, or by means of an oscilloscope and correlated to the lateral optical magnification employed under specific test conditions. They will yield individual images of one square millimeter. Such a large target area is beneficial when looking through a camera — the larger observing angle causes less eyestrain.

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The Sharpness Indicator System is available for sale by the SMPTE. For price and delivery information, contact the SMPTE Test Materials Dept. at (914) 761-1100.

When exposing the Sharpness Indicator on photographic material, an interesting phenomenon takes place: the individual test targets, resolved by the system lens plus film, will show on the negative densities below and above the density of the reference field. When properly averaged and/or integrated, these densities will yield an integrated density value below the reference field density, as explained below under "Theory Explanation and Application."

This is tantamount to saying that once the test procedure parameters have been established, the overall evaluation of the test results is easily carried out by the unaided eye, or with a magnifying glass, or by projection. Since this evaluation does not depend so much on the acutance of the reproduced or perceived image, but rather on the density contrast between target and reference field, quantitative values can also be obtained by densitometry or with a microscope. In the latter case, a comparison of the microstructure of the target and surrounding reference field can be observed.

A further advantage is that, the exposure having been carried out under working conditions, such important factors as camera flare are included within the test results, which thus come close to real conditions. (Black lines on a white background or the same inverse, white on black, may result in different resolving power values. On the other hand, the environment of the gray area around targets as defined by the Sharpness Indicator's principles is an average reflection value of evenly shared white and black particles, and is not only a constant value but also analogous to an average scene.)

Instead of judging resolving power on the obtained test negatives as such, prints of the same may be made. This will result in an evaluation of the system in its entirety and permit an evaluation of sharpness loss due to the printing process.

When similarly applied to a complete TV-chain, the final image is accessible directly on a monitor, and adjustments of components, where necessary, can easily be made by reference to the monitor image obtained. No high-resolution monitor is necessary. Practical testing has shown that even a small-camera viewfinder can determine an accurate point of sharpness or overall performance of the examined camera. In short, sharpness investigation of any given system is greatly simplified, and quantitative values can be obtained with small equipment and little theoretical interpretation.

Sharpness Indicator's Principle

The first step is to determine the parameters of the reference field and the integral optical density of the test targets. Here, two things have to be

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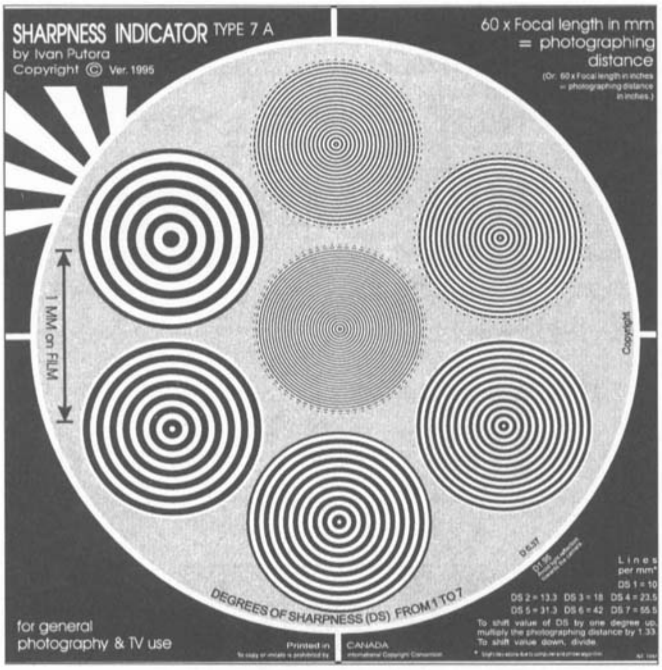

Figure 1. The Sharpness Indicator.

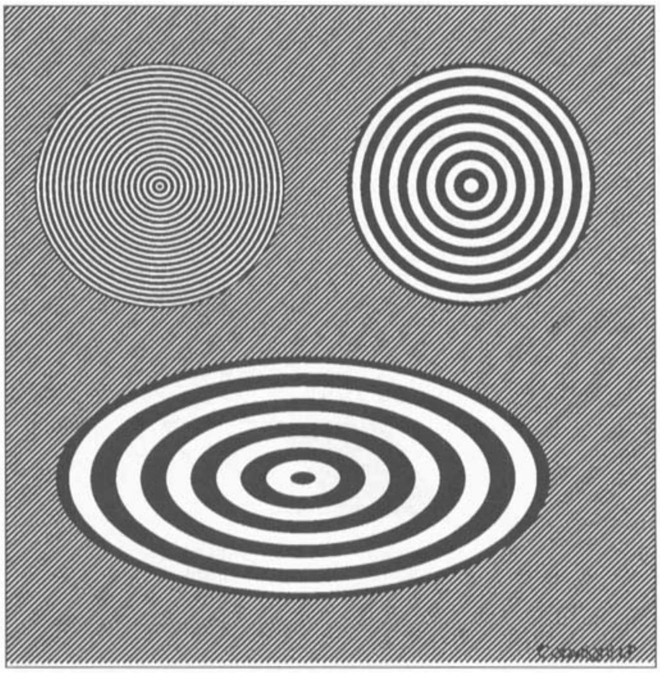

Figure 2. Detail of test targets and reference field. (The gray on this diagram may not be accurate.)

considered in each case: (1) width of lines and (2) reflectance values of the lines.

The width of the lines (1) and the width of the spaces between them is assumed to be the same. Other relations between lines and spaces are possible, but in photography this condition is the norm. Each pair of one dark and one white line is counted as one line (a unit for lines per mm). This group of lines is called spatial frequency.

Reflectance values (2): Ideally the black lines should have 0 (zero) reflectance and the white lines (or spaces) should have 100% reflectance (or transmission, in case the test object is in the form of a transparency). It is obvious that, under these conditions, the total reflectance value is 50% of the incident light flux, independent of the line frequency chosen. Normally the ideal reflectance mentioned (50%) is not easily obtained by a solid paint or solid emulsion structure and an approximation is not good enough; but a raster of equally wide lines and spaces on the printer's screen will always yield the arithmetic mean reflectance with respect to the values of lines and spaces. We can obtain thus, ideally, an average or integral reflectance of 50% which depends solely on the reflectance values of lines and spaces or dots and spaces, but not on any given line frequency, provided condition 1 is fulfilled.

The integral optical density of the reference field of the individual test targets is then easily defined as the logarithm of the reciprocal value of its average reflectance. If the average reflectance 50% = 1/2 and the reciprocal is 2, then the integral optical density, D_i, will be 0.30. In the case of a reference field with a uniform surface, the surface has to be prepared in such a way that its optical density has this same value.

Figure 3 demonstrates the above. An ideal white area (a) would reflect 100% of light. If half of it is covered with an ideal black, (b), the previous area will reflect only 50% of original incident light. If we further "slice" the same black in to any amount of pieces, (c), the result will be still 50% of reflected light.

(Note: The demonstration has only theoretical meaning. The reality is more complicated. First, there is not an "ideal white or black." The white on present charts is D 0.05 to 0.06, about 89,1%; and even with extremely good acutance of lines, there is still a spread effect which increases integral densities of higher frequency targets. The density of the reference field on the present Sharpness Indicator chart has an average D 0.37; for higher frequencies D 0.38, and for lower, D 0.36, in absolute values.)

Figure 4 shows how the reference field is determined. An integrated reflectance of the blurred target is the value for the background.

If the reference field is composed of numerous fine lines, (as on Fig. 2) it should be so much higher than frequency of the corresponding test target with the finest detail, that it cannot be resolved by the specific optical system under test and will yield a uniform density.

The advantage of such arrangement is that on the developed negative (Fig. 5), test targets whose line frequency has been resolved by a given system under test, will appear as a series of concentric circles of alternately high and low densities whereas the non-resolved targets will yield only a uniform density, proportional to some extent to the integral optical density, D_i, of the test target, and equal to the density of the reference field. The density of the reference field will fall somewhere between the high and low densities of the resolved targets, as explained further below.

The negative (Fig. 5), was taken with a 35mm still camera, where five Sharpness Indicators were placed on the background in key areas. White

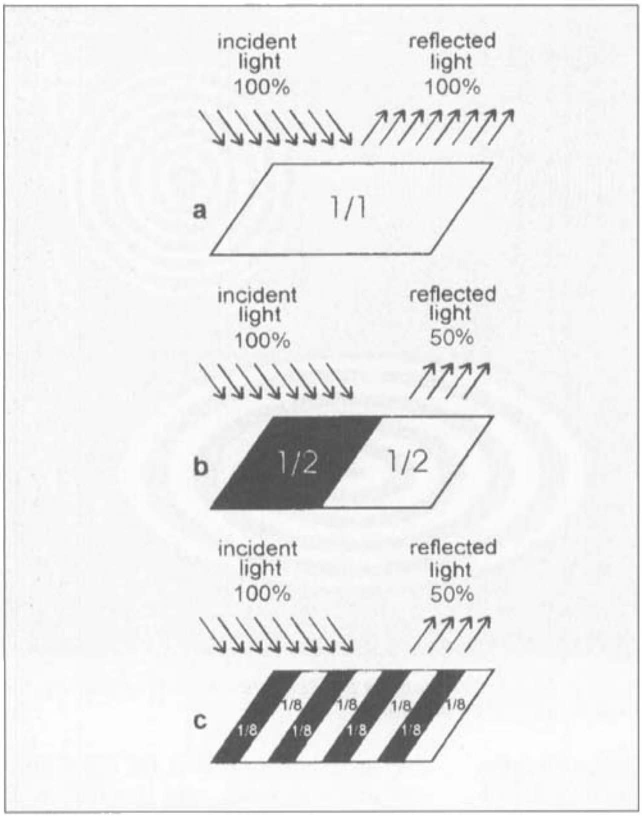

Figure 3. Reflectance values.

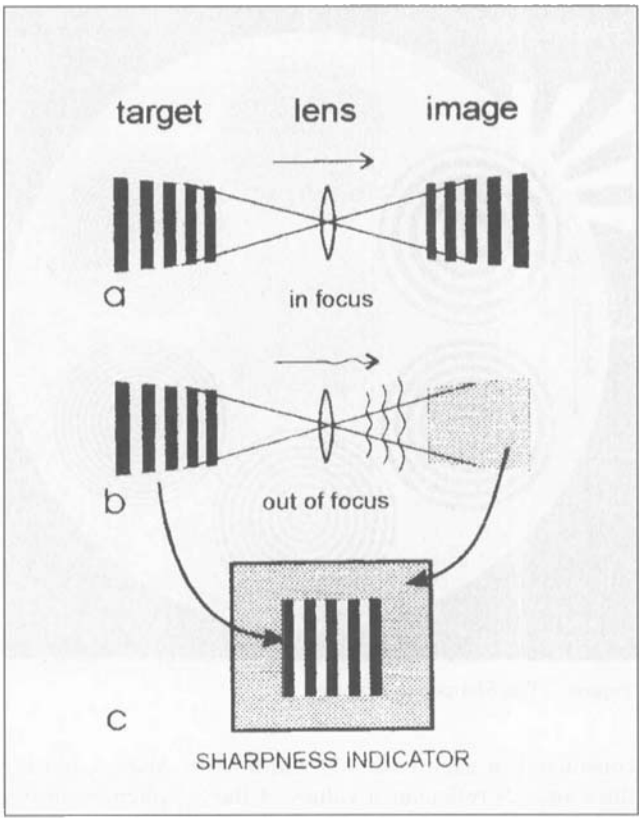

Figure 4. Determination of reference field.

"holes" are proof of sharp lines.

The high and low alternate density values of the resolved targets depend, in turn, on many factors such as the luminance values of the individual lines and spaces at the moment of exposure; the development factor or gamma; and the characteristic curve, proper to the material employed, etc. Also, such factors as lens and/or camera flare will affect their value and the contrast between dark and light rings and their relative contrast with respect to the reference field on the negative. If, however, all these factors are identical with or close to the actual working conditions for the system being tested, we then profit from the advantage that the test results can be considered a true and reliable representation of the real conditions given, and the lines resolved can be immediately indicated, even without recourse to a microscope.

The merging of the nonresolved targets with the surrounding reference field may take place for two different reasons: (1) either the resolving power of the optical system under test is exceeded, or (2) the same is true with respect to the resolving power of the emulsion employed. Both can, of course, be compounded. In other words, whenever the system is incapable of "distinctly seeing" the given line detail, only a diffused integral light level is registered in the image plane, in direct proportion to the average reflectance and/or luminance of the test object. Since the average reflectance of all single test targets is equal to the reflectance of the reference field, they will fuse or merge with the reference field as soon as the system is incapable of resolving them.

The Sharpness Indicator, described here, does not necessarily, and as a matter of fact does not usually, agree with the evaluation of a given sample by microscopical methods (resolving power). A microscope may be capable of determining much higher line frequencies. Results obtained visually on an optical bench, do not, however, correlate in many cases usefully with practical applications and with the results obtained with a motion picture camera. Hence the discord: Resolution versus Sharpness.

Figure 6 is a demonstration of three stages of sharpness. Sample (a) we can consider as sharp; sample (b), less sharp; and sample (c), degradation of sharpness in progress. Evaluating by resolving power, we would accredit: three lines "per unit", for all samples, although, quality difference between them is apparent.

On the other hand, using the Sharpness Indicator, examining the negative, seeing lighter circles surrounded by the darker background as proof of sharp lines, and using a magnifying device and seeing actual lines of the rest of higher frequencies, provides additional information about resolving power. Such combinations of information are only offered by the Sharpness Indicator.

Theory Explanation and Application

The Sharpness Indicator is exposed in such a way that, after normal development, the reference field luminance is reproduced at point C in Fig. 7. Exposure is chosen in such a way as to make this density equal to unity. The black lines of the Sharpness Indicator will then, let us assume, reproduce at A, whereas the white spaces between them will reproduce at B. It is easy to see that, on a negative emulsion, the contrast between lines and spaces will be reproduced with a proportionally lower contrast, due to the lower negative gamma value. The reference field density plots at C. (Note: to simplify the explanation only black and white film is chosen.)

If we assign symbols to the optical test target densities as follows:

TD_2 = optical density of black lines,

TD_1 = optical density of white spaces, and

TD_i = integrated average density, and if we remember that exposure will be inversely proportional to the optical target density, it is easy to understand that the corresponding negative densities, ND, will plot where they appear on the graph. The total exposure range will be equal to the maximum target density difference, TΔD, that is 2 in the ideal case, and the corresponding and compressed maximum negative denote difference, NΔD, will have a lower value which depends on the process and on the negative material chosen. In optical negative-positive printing, of course, contrast enhancement takes place as we can follow on enclosed illustration.

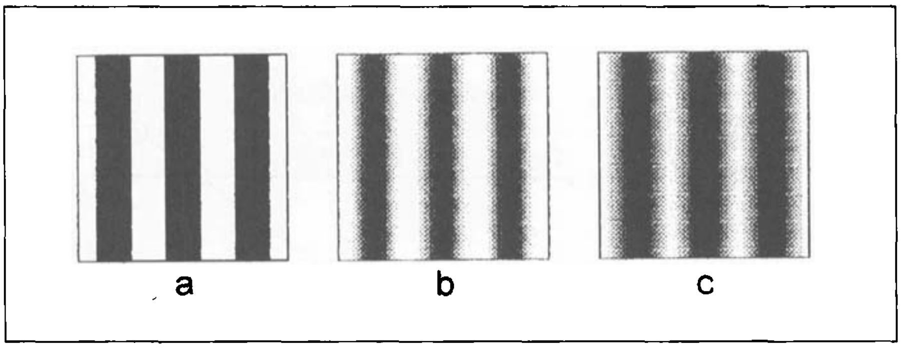

Figure 6. Demonstration of three stages of sharpness.

It is very interesting to note that the average integrated transmission of the resolved target on the negative will yield an integral average negative density, ND_i, substantially lower than the reference field density. The two densities will not coincide for resolved targets, but will do so for all nonresolved targets. The value of ND_i is found from:

$$ND_i = \log\left(\frac{2.10^{ND_1}.10^{ND_2}}{10^{ND_1} + 10^{ND_2}}\right)$$

This density will plot, in theory, at D on our graph. However, other factors will make it appear, in practice, at a somewhat higher level, say E.

The density difference, D_i, between points D (in practice point E) and C, i.e., between the reference field density and the integral negative density of the resolved target, is the value that permits identifying the number of resolved lines without recourse to a microscope. This may be called the sharpness reference value.

One of the factors that raises the integral density of the negative from its theoretical value D to the higher level E, is known as image spread, i.e., the absence of an absolutely sharp edge between high and low densities on the negative. The inherent acutance of the negative image depends on such phenomena as light diffusion and reflection within the emulsion during exposure, grain size, developer action, drying conditions, and others. It is found that the higher densities (the blacks of the negative, which are the whites of the test targets) will thus "invade" the zones of lower densities, thereby diminishing the amount of light transmitted by the latter.

The difference between points D (with no image spread taken into account) and E (the measured integral negative density value) could be taken as a measure of the degree of acutance obtained. The greater this difference, the lower the acutance observed.

The factors which make it impossible to restrict the value of the integrated negative density of the resolved target to the theoretical value, D, may be labeled as primary and secondary defects. Here, primary defects would be the ones that admit no alteration or correction during the normal photographic process, including optical aberrations, diffusion of light within the photosensitive layers, nature of developers, etc. Secondary defects would be camera unsteadiness, image unsteadiness, printer and/or registra-

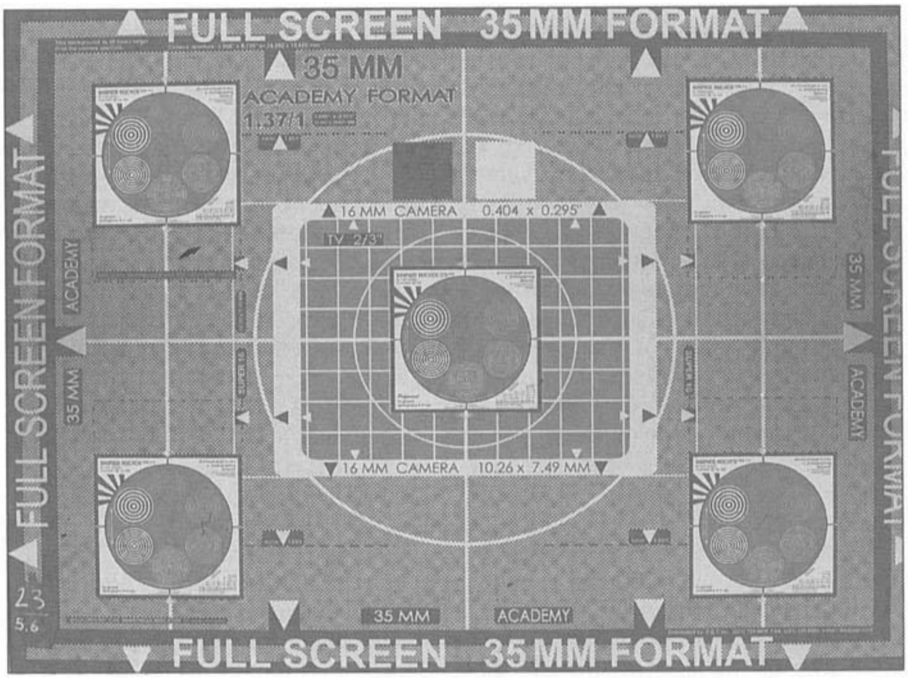

Figure 5. Reproduction of negative of Sharpness Indicator.

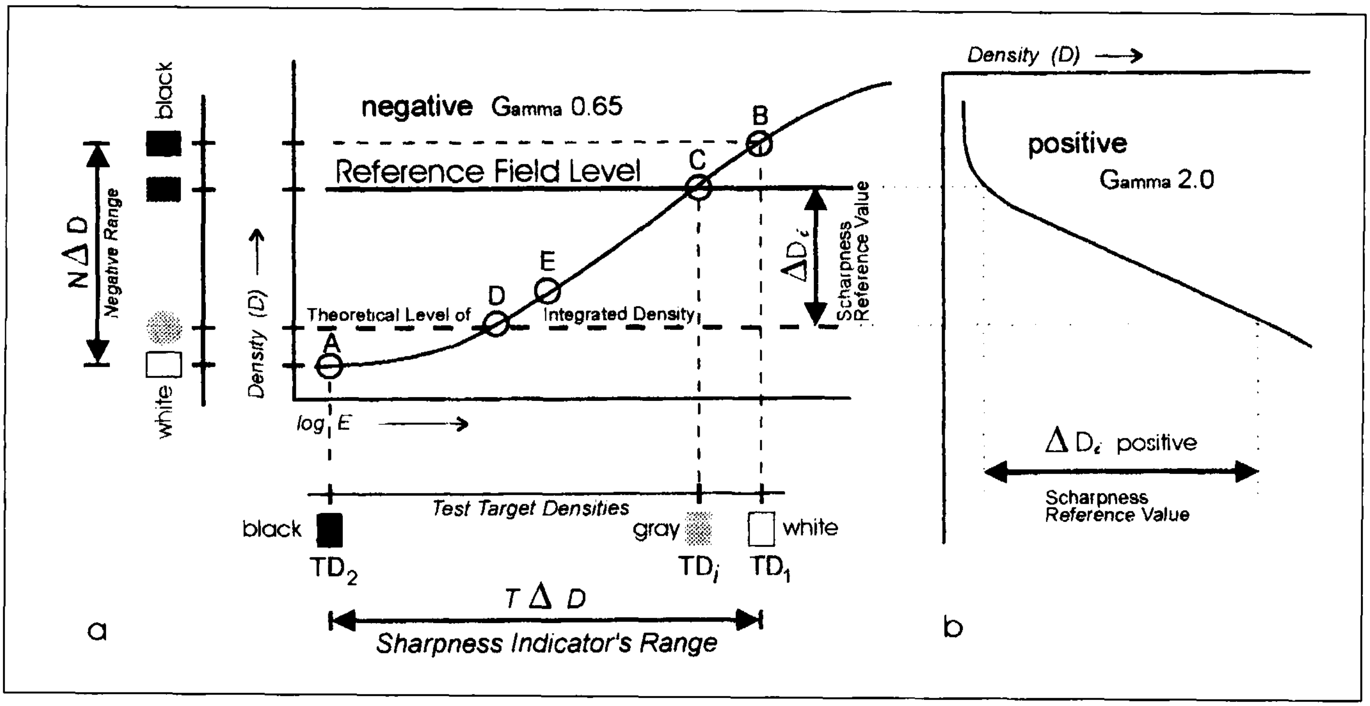

Figure 7. Sensitometric relations of Sharpeness Indicator Test.

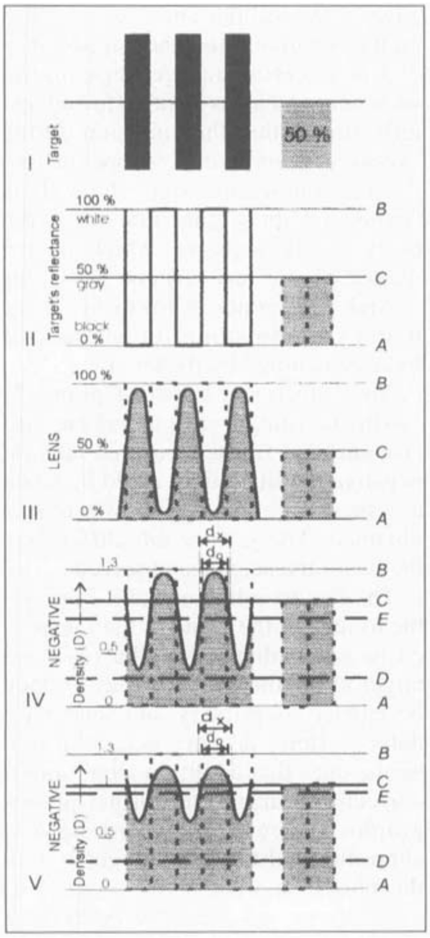

Figure 8. Sharpness degradation by various causes.

tion errors or slippage, shutter effects, improper color balance, out-of-focus conditions, and a great many more.

The degradation of sharpness, or loss of acutance, is illustrated in Fig. 8. Here the levels A, B, C, D, and E refer to the same values as labeled on Fig. 7. Diagram I shows a given test line frequency; diagram II represents reflectance values, and abscissae one dimension of space, C is the reference field reflectance level. Diagram III shows the degradation due to purely optical defects such as flare and glass absorption. These could give rise to a reproduction curve, similar to a sinusoidal curve, while lowering contrast at the same time. Diagram IV shows what happens on the negative. Here image spread, indicated as the relation between d_0 (width of the target spaces) and d_x (width of their negative reproduction) takes place simultaneously with a reduction of contrast. In this diagram ordinates represent densities after subtracting base and fog level. Abscissae again represent space.

If, accordingly, we take ND_1 as 0 and ND_2 as 1.3, we can then compute the theoretical value of ND_i (level D in the figures) from the formula as 0.28 above the zero point of the graph. The real value can be found by substituting for ND_i, a value corresponding to the total density of the line image. The corresponding level E will be higher than D, due to the partial "fill in" of the valleys of the curve. In practical applications, base and fog level will be included in the calculations, in addition to image spread and other imperfections.

In diagram V, the level comes close to the level C, the reference field density, but is still slightly lighter. This could represent an out-of-focus condition for the same line frequency as in the previous three diagrams, or it could mean reproduction of a higher line frequency under the same conditions as before but plotted on an extended longitudinal scale. At the point where levels C and E begin to coincide due to any specific cause, resolution can no longer be considered satisfactory.

Figure 9 shows two graphs of similar appearance which may prove to be of interest. They can be obtained by plotting values of real (not theoretical) integrated negative densities, ND_i obtained for all targets, against their frequency number. Point C is again the reference field density. Evaluation of the corresponding sample series under a microscope would yield identical results, i.e., both would indicate a resolution of up to 73 lines/mm. However, the sharpness characteristic of these two curves is not the same. Evaluating both specimens by the Sharpness Indicator method, based on integral negative densities of resolved targets, and taking as a limiting criterion the last discernible integral density (dotted line) below the level C of the reference field density, we see that, while sample (a) resolves up to 42 lines/mm, sample (b) resolves only 31 lines/mm. We thus establish what we could call "useful resolving power" and applied to the Sharpness Indicator is called degrees of sharpness (DS). (We do not need to refer to lines per mm any more — this term can be reserved for resolving power.)

The evaluation of negative samples, obtained by means of the Sharpness Indicator through direct measurement of integral densities of resolved targets, and the subsequent plotting of graphs as in Fig. 9., has not yet been systematically attempted.

Finally, results of the Sharpness Indicator test can also be judged by the "out-of-focus method," which in certain cases may even constitute an advantage. If a negative of optimum sharpness, such as the one from Fig. 5, is projected out-of-focus, we will lose seeing actual lines but we will see lighter "holes"on a darker background. Since only the integrated density of the resolved targets is used as a limit criterion, and it is really not necessary with this method to visually distinguish black and white separated lines, it is easy to count out the number of line targets with a density below the reference field density, and thus rapidly establish the highest number of lines usefully resolved, the last field appearing lighter than the reference field.

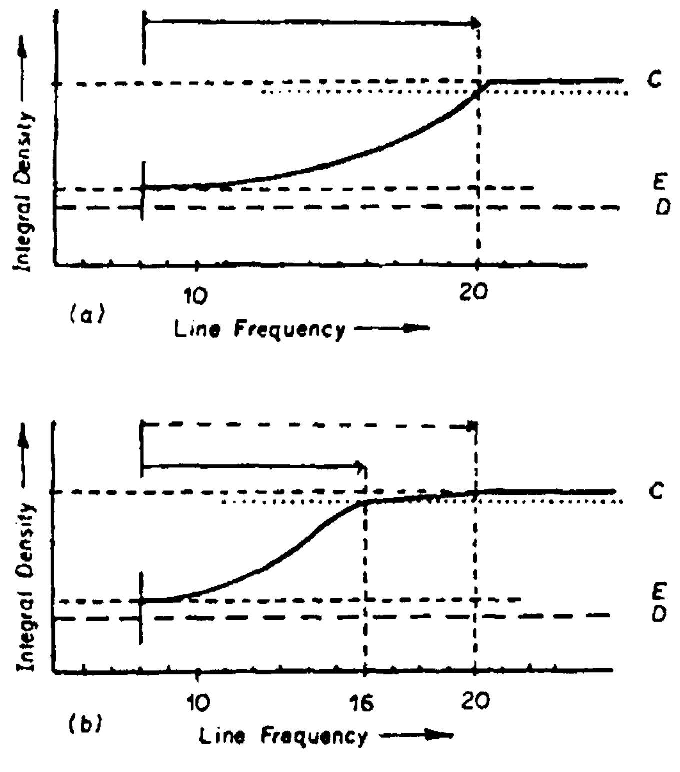

Figure 9. Integral negative density of targets as a function of line frequency/mm.

Evaluating From Prints

Figure 10a, is a photoprint made from the negative of Fig. 5.

Lower frequencies' lines are discerned by the print — we can see lines. Higher frequencies, which the print was not able to transfer, will show as darker circles and are proof of sharp lines in the the negative. Where the target fuses with the background, no lines were recognized by the lens. Thus we can detect a decline of sharpness from negative to print and at the same time ascertain, in a given case, if loss of definition is due to a defective condition of the negative or elsewhere in the photographic chain.

An out-of-focus print was made from the same negative Fig. 5. and is shown in Fig. 10b. Here we can benefit from having enhanced contrast of dark circles (targets), against a lighter background. The dark circles are proof of sharp lines on the examined negative, although, we in fact do not see a single line! What is more interesting, the darkness or optical densities of targets are proportional to the achieved sharpness. The darker the print, the cleaner hiatus between the lines on the negative. An additional experiment proves the above:

Two takes were made, one with a 5.6 aperture and another with 2.8. Intentionally out-of-focus prints were made (similar to those in Fig. 10b). Densities of individual targets were measured and following the diagram in Fig. 11.** it is clear to see the difference in sharpness between the 5.6 and the 2.8 apertures. We could call these characteristic curves of sharpness.

We can also make a simple numerical expression from the same. Densities from DS 2 to DS 7 were measured and averaged. The results are:

For F 5.6: 0.598, for F 2.8: 0.538; and after subtracting the reference field density (0.44), for F 5.6: 0.158, for F 2.8: 0.098.

To get a better number we can multiply by a constant 10 resulting in the following:

For F 5.6: 1.58, for F 2.8: 0.98.

The number can be called coefficient of sharpness.

However, this procedure is applicable only in laboratory conditions, where some rules of the printing process can be controlled. Still, even under relative conditions, the method can be useful, for example, to plot curves of dependency of sharpness as a function of aperture. This would show with which aperture the lens performs best.

**In order to enhance vertical distance by plotting the diagram, densities value were numerically doubled.

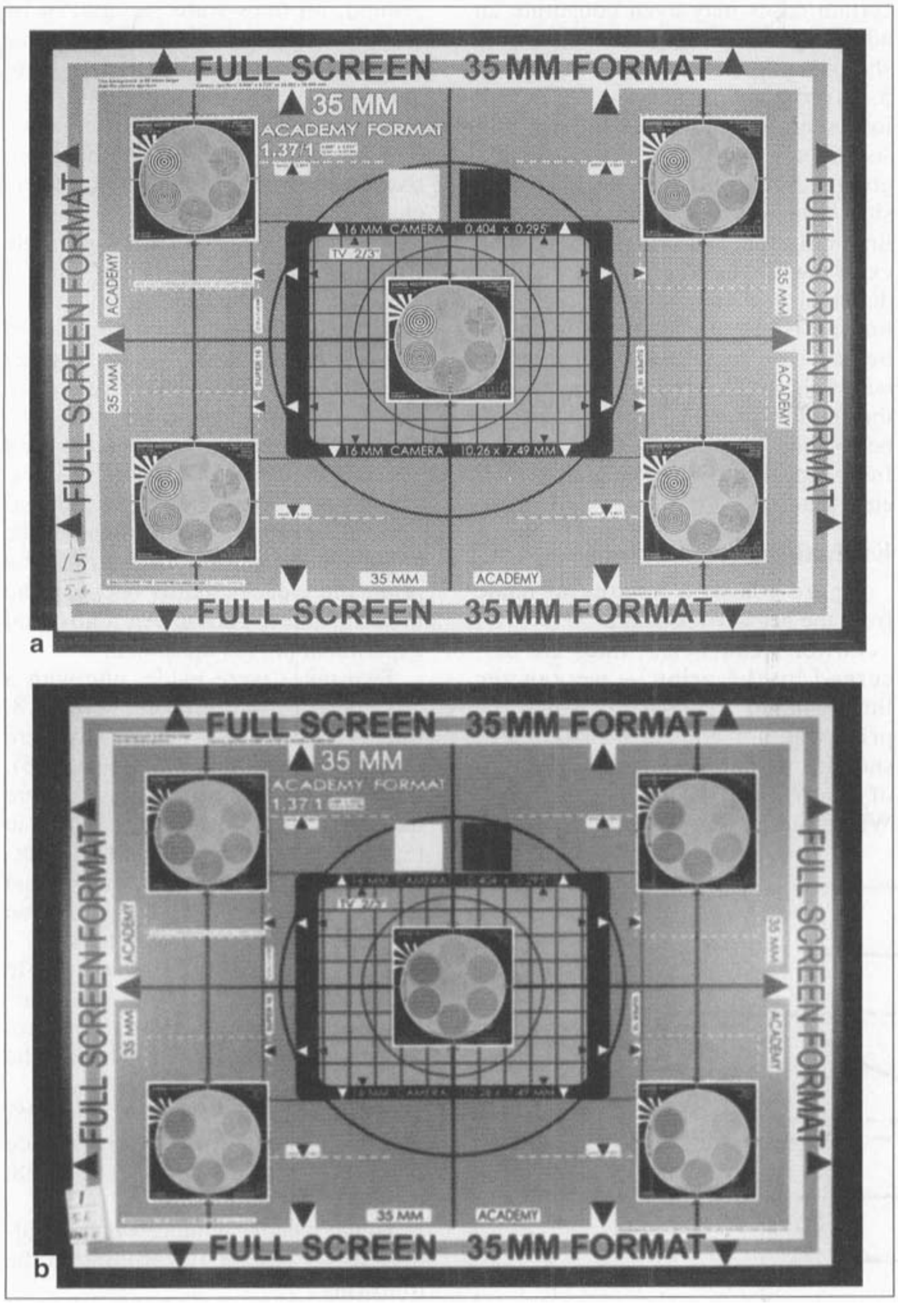

Figure 10. (a) A sharp photo print. (b) Intentionally out-of-focus print.

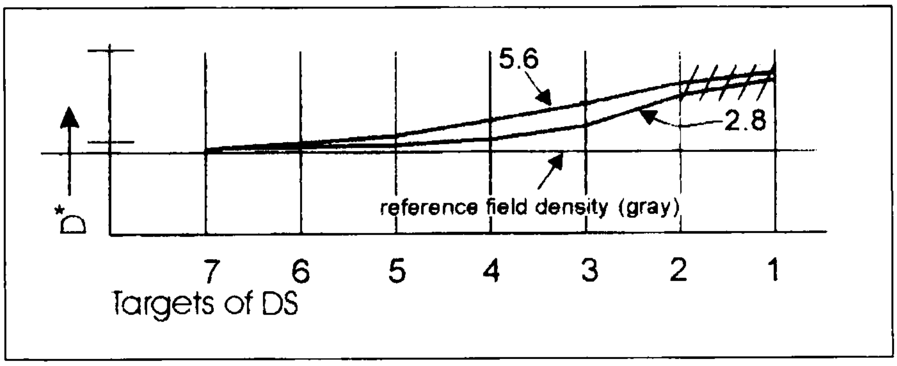

Figure 11. Characteristic curves of sharpness obtained from out-of-focus positive prints.

TV Application

With a high-resolution monitor, we can judge the sharpness of the camera seeing actual lines. But we can profit from the Sharpness Indicator also having a second quality monitor with no ability to discern fine lines. The frequency targets, which the camera recognize, will show darker than the background (reference field) and the frequencies which the camera does not recognize will "flatten," having the same value as the background. (We could say that we can see directly into the "heart" of the camera, without actually seeing a "line" on the monitor.)

Because the vertical and horizontal resolution of the TV camera differs, light "butterflies" will occur in higher frequencies in a high-resolution camera's viewfinder and monitor; they will appear darker on lower quality monitors. The angle of those butterflies is also an indicator of camera performance. The lines of lower frequency targets are visible on the monitor; the higher frequencies show only density differences; those not recognized by a camera will merge with the background. Thus we can also ascertain what the camera detects and delivers to the TV monitor.

Also, the gray of the reference field can substitute for any gray marked on the chart. It is the most stable and reliable information on reflectance. A cameraman can get a direct reading from the target area (gray + targets) and use it as a base for exposure setting (in many cases recommended by the author). To match it to the standard 18% gray, just open 1 and 1/3 stop, or use a compromising setting — open lens 2/3 stop from measured value.

Conclusion

An easy to use and easy to evaluate Sharpness Indicator has been developed which permits an exact evaluation of useful resolving power calibrated in degrees of sharpness. This is accomplished under a wide range of conditions with a minimum of equipment and theoretical knowledge on the part of the tester. Further development of this system is currently under study.