

Sharpening and Standardized Sharpening for comparing cameras

Introduction to sharpening

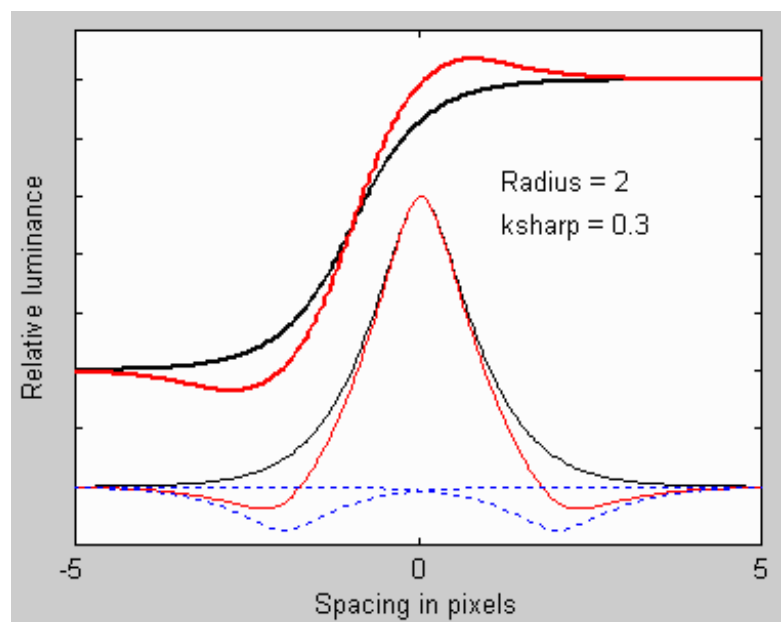
Sharpening is an important part of digital image processing. It restores some of the sharpness lost in the lens and image sensor. Virtually every digitized image needs to be sharpened at some point in its workflow— in the camera, the RAW conversion software, and/or the image editor.

Almost every digital camera sharpens images to some degree. Some models sharpen images much more than others— often far more than appropriate for large prints. This makes it difficult to compare cameras and determine their intrinsic sharpness. Imatest has developed an approach to solving the problem— standardized sharpening.

Before we proceed, we need to describe the elementary sharpening process.

Sharpening on a line and edge

A simple sharpening algorithm subtracts a fraction of neighboring pixels from each pixel, as illustrated on the right. The thin **black** curve is the input to the sharpening function: it is the camera's response to a point or a sharp line (called the *point* or *line spread function*). The two thin dashed blue curves are replicas of the input multiplied by $-k_{\text{sharp}}/2$ and shifted by distances of ± 2 pixels (typical of the sharpening applied to compact digital cameras). This distance is called the sharpening radius. The thin red curve the impulse response after sharpening— the sum of the **black** curve and the two blue curves. The thick **black** and **red** curves (shown above the thin curves) are the corresponding edge responses, **unsharpened** and **sharpened**.



Sharpening increases image contrast at boundaries by reducing the rise distance. It can cause an edge overshoot. (A small overshoot is illustrated in the upper **red** curve.) Small overshoots enhance the perception of sharpness, but large overshoots cause “halos” near boundaries that can become glaringly obvious at high magnifications, detracting from image quality.

Sharpening also boosts MTF50 and MTF50P (the frequencies where [MTF](#) drops to 50% of its low frequency and peak values, respectively), which are indicators of perceived sharpness. (MTF50P is often preferred because it's less sensitive to strong sharpening.) But sharpening also boosts noise, which is not so good.

The formula for the simple sharpening algorithm is,

$$L_{sharp}(x) = [L(x) - (k_{sharp}/2) * (L(x-V) + L(x+V))] / (1 - k_{sharp})$$

$L(x)$ is the input pixel level and $L_{sharp}(x)$ is the sharpened pixel level. k_{sharp} is the sharpening constant (related to the slider setting scanning or editing program). V is the shift used for sharpening.

$$V = R/d_{scan}$$

where R is the sharpening radius (the number of pixels between original image and shifted replicas) in pixels. d_{scan} is the scan rate in pixels per distance. $1/d_{scan}$ is the spacing between pixels. The sharpening algorithm has its own MTF (the [Fourier transform](#) of $L_{sharp}(x) / L(x)$).

$$MTF_{sharp}(f) = (1 - k_{sharp} \cos(2\pi f V)) / (1 - k_{sharp})$$

This equation boosts response at high spatial frequencies with a maximum where $\cos(2\pi f V) = \cos(\pi) = -1$, or $f = 1/(2V) = d_{scan}/(2R)$. This is equal to the Nyquist frequency, $f_N = d_{scan}/2$, for $R = 1$ and lower for $R > 1$. Actual sharpening is a *two* dimensional operation.

Standardized sharpening

The degree of sharpening performed by digital cameras varies greatly. Some cameras and many RAW converters allow you to change the amount of sharpening from the default value. If an image is undersharpened, the photographer will need to apply additional sharpening during the image editing process for best results. Many compact digital cameras oversharpen images, resulting in severe peaks or “halos” near boundaries. This makes small prints (4x6 or 5x7 inches) look good straight out of the camera, but it doesn't truly enhance image quality: halos can get ugly in big enlargements and noise can become objectionable.

Sharpening increases the 50% MTF frequency (MTF50). A camera with extreme oversharpening may have an impressive MTF50 but poor image quality. A camera with little sharpening will have an MTF50

that doesn't indicate its potential. For these reasons, comparisons between cameras based on simple MTF50 measurements have little meaning. Raw MTF50 is a poor measure of a camera's intrinsic sharpness, even though it correlates strongly with perceived image sharpness.

MTF50P, the frequency where MTF drops to half its peak value, is equal to MTF for weak to moderate sharpening but lower for strong sharpening. Hence it is a somewhat better indicator of perceived sharpness and image quality. Imatest displays MTF50P when standardized sharpening is not displayed (is unchecked in the input dialog box). It is also available as a [secondary readout](#).

To obtain a good measure of a camera's sharpness— to compare different cameras on a fair basis, the differences in sharpening must be removed from the analysis. The best way to accomplish this is to set the sharpening of all cameras to a standard amount. This means sharpening undersharpened images and de-sharpening (blurring) oversharpened images.

The algorithm for standardized sharpening takes advantage of the observation that most compact digital cameras sharpen with a radius R of about 2 pixels (though R can be as low as 1 for DSLRs). This has been the case for several cameras I've analyzed using data from [dpreview.com](#) and [imaging-resource.com](#). The algorithm for standardized sharpening is as follows.

1. Apply sharpening (or de-sharpening) with a default radius of 2 to make the MTF at $f_{eq1} = 0.3$ times the [Nyquist frequency](#) ($f_{eq1} = 0.3f_N = 0.15dscan$; a relatively low spatial frequency) equal to 1 (100%), which is the MTF at very low spatial frequencies. MTF at higher spatial frequencies depends on lens and imager quality. The sharpening radius is adjustable in Imatest; 2 is the default.
2. Linearize the phase of the pulse by removing the imaginary part of the MTF. This results in an antisymmetrical pulse with a small overshoot (halo) near edges— typical of what you would get with carefully-done manual sharpening.

If the edge is seriously blurred ($MTF50 < 0.2 f_N$), so that there is very little energy at $f_{eq1} = 0.3 f_N$, the sharpening radius is increased and the equalization frequency is decreased to $f_{eq1} = 0.6 MTF50$. The sharpening radius is **not** increased if **Fixed sharpening radius** in the Settings menu of the Imatest main window has been checked.

The formula for standardized sharpening with radius R is, $MTF_{standard}(f) = MTF(f) (1 - k_{sharp} \cos(2\pi R f/dscan)) / (1 - k_{sharp})$ where sharpening constant k_{sharp} is set so $MTF_{standard}(f_{eq1}) = MTF(0) = 1$. $f_N = dscan/2$ is the [Nyquist frequency](#); $f_{eq1} = 0.3 f_N$; $f_{eq1} = 0.6 MTF50$ for seriously blurred edges where $MTF50 < 0.2 f_N$.

The image is sharpened if $k_{sharp} > 0$ and de-sharpened if $k_{sharp} < 0$ (a bit different from standard blurring). For $R = 2$, the maximum change takes place at half the Nyquist frequency, $f = f_N/2 = dscan/4$,

where $\cos(2\pi R f / d_{\text{scan}}) = \cos(\pi) = -1$. Sharpening with $R = 2$ has no effect on the response at the Nyquist frequency ($f_N = d_{\text{scan}}/2$) because $\cos(2\pi R f_N / d_{\text{scan}}) = \cos(2\pi) = 0$.

- Raw MTF50, without standardized sharpening, produces the most accurate results for comparing lenses and for comparing the sharpness at the center and edge of a single image.
- MTF50P is somewhat better when comparing cameras with strong sharpening. MTF50P equals MTF for slightly to moderately sharpened images, but it is lower for oversharpened images. It is a good sharpness indicator when images will not be post-processed, for example, in video cameras.
- Standardized sharpening is the best approach for comparing different cameras.

Examples

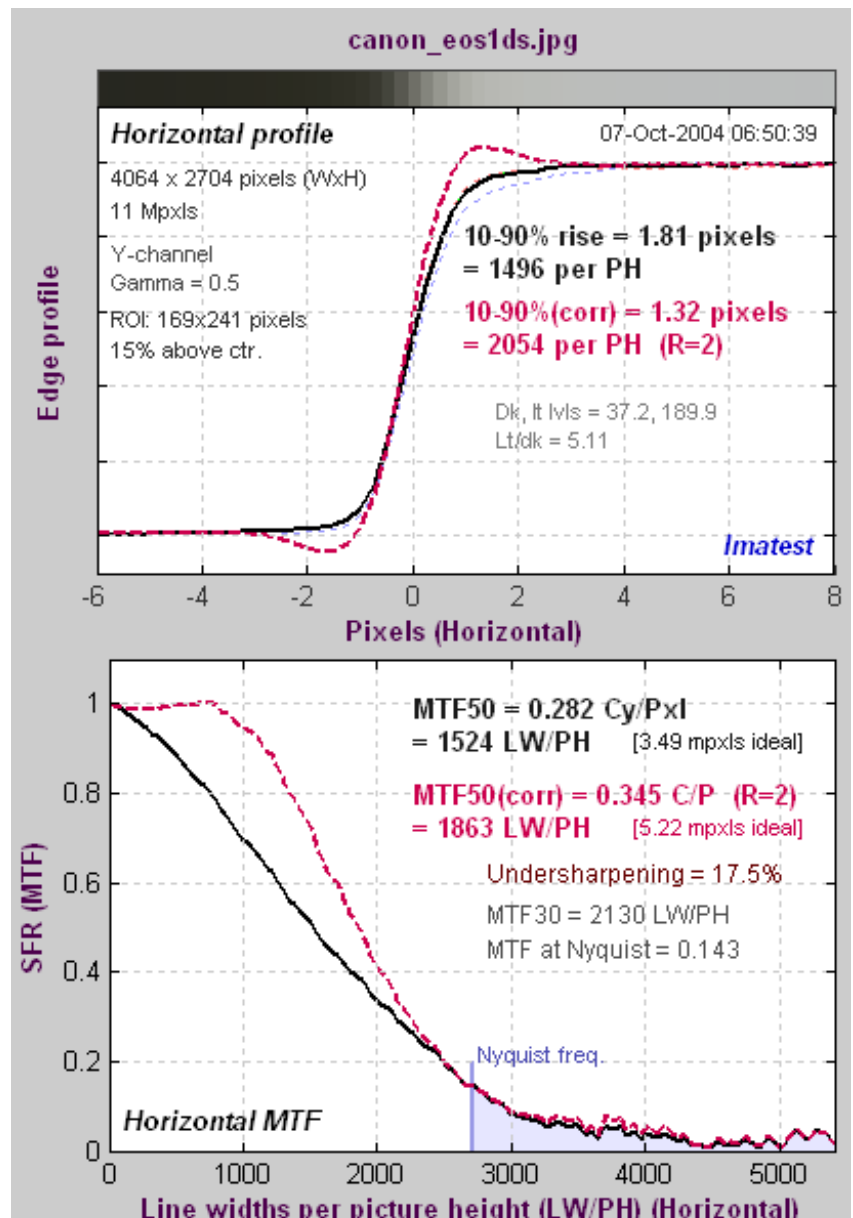
An undersharpened image

The 11 megapixel Canon EOS-1Ds DSLR is unusual in that it has very little built-in sharpening (at least in this particular sample).

The average edge (with no overshoot) is shown on top; the MTF response is shown on bottom. The **black** curves are the original, uncorrected data; the dashed red curves have standardized sharpening applied.

Standardized sharpening results in a small overshoot in the spatial domain edge response, about what would be expected in a properly sharpened image. It is relatively consistent for all cameras.

Oversharpening or undersharpening is the degree to which the uncorrected pulse is over- or undersharpened, i.e., sharpened relative to the standard sharpening value. It is equal to 100% ($\text{MTF}(f_{\text{eq}}) - 1$). If it is negative (the case for the EOS-1Ds), sharpening is



applied to the original response; if it is positive, de-sharpening is applied. (I use “de-sharpening” instead of “blurring” because the inverse of sharpening is, which applied here, is slightly different from conventional blurring.) Note that it is not the actual sharpening applied by the camera and software.

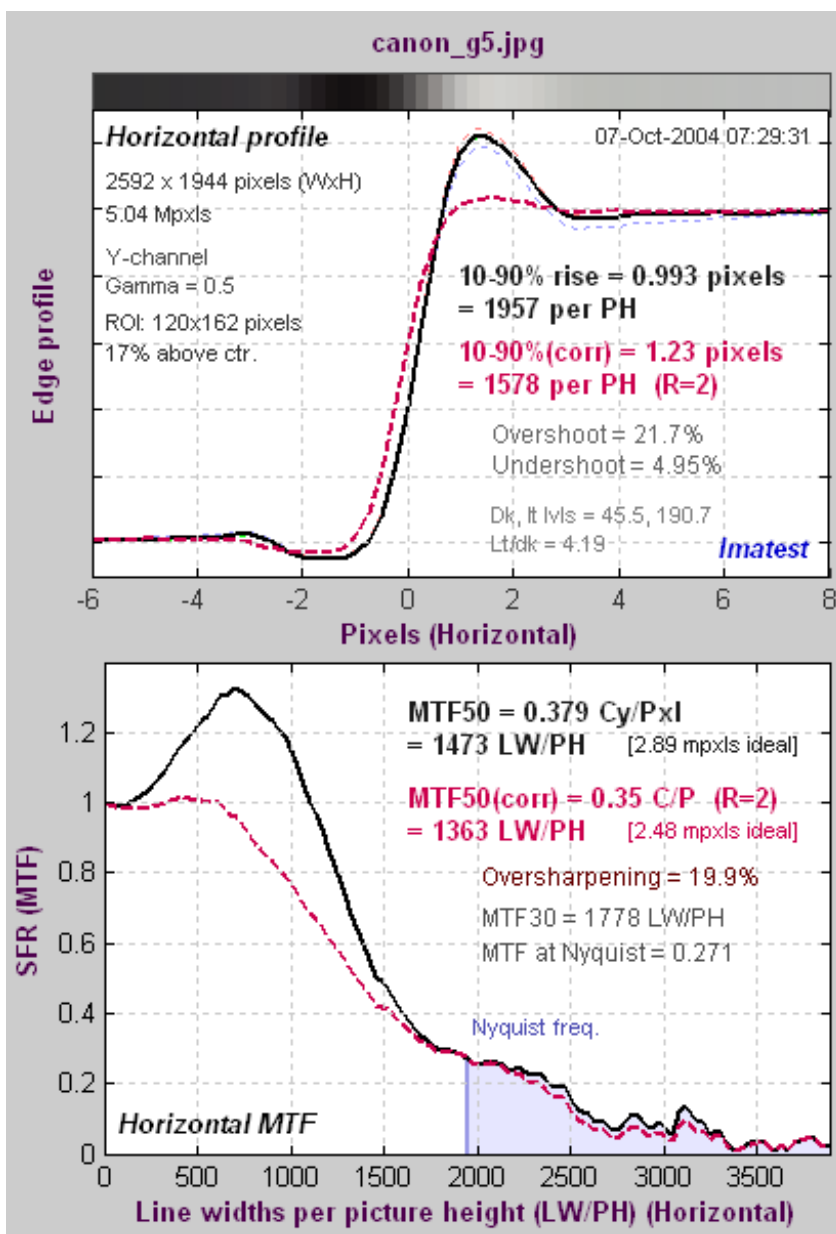
An oversharpened image

The image to the right is for the 5 megapixel Canon G5, which strongly oversharpenes the image— typical for a compact digital camera.

The *uncorrected* 10-90% edge rise distance of the G5 is considerably better than the 11 megapixel EOS-1Ds (1940 vs. 1511 per PH), but the corrected 10-90% rise (with standard sharpening) is 76% of the EOS-1Ds. Based on pixels alone, the expected percentage ratio would be 100% ($1944/2704$) = 72%.

MTF50P is not shown on the left. It is displayed when Standardized sharpening is turned off; it can also be selected as a [Secondary readout](#) (in place of MTF30 on the left). For this camera MTF50P is 345 cycles/pixel or 1340 LW/PH, almost 8% lower than MTF50. It’s a slightly better sharpness indicator for strongly oversharpened cameras, especially in cases like video cameras where the image will not be post-processed.

The raw MTF50 of the G5 is close to the EOS-1Ds, but the corrected MTF50 (with standard sharpening) is 73% of the EOS-1Ds, very close to the ratio of vertical pixels.



These results illustrate how uncorrected rise distance and MTF50 can be misleading when comparing cameras with different pixel sizes and degrees of sharpening.

MTF50P is slightly better for comparing cameras when strong sharpening is involved.

Uncorrected MTF50 is, however, appropriate when comparing lens performance (different focal lengths, apertures, etc.) on a single camera.

Unsharp masking

“Unsharp masking” (USM) and “sharpening” are often used interchangeably, even though their mathematical algorithms are different. The confusion is understandable and far from serious because the end results are visually similar. But when sharpening is analyzed in depth the differences become significant.

“Unsharp masking” derives from the old days of film when a mask for a slide, i.e., positive transparency, was created by exposing the image on negative film slightly out of focus. The next generation of slide or print was made from a sandwich of the original transparency and the fuzzy mask. This mask served two purposes.

- It reduced the overall image contrast of the image, which was often necessary to get a good print.
- It sharpened the image by increasing contrast near edges relative to contrast at a distance from edges.

Unsharp masking was an exacting and tedious procedure which required precise processing and registration. But that has changed. USM can now be accomplished with only a few mouse clicks in an image editor.

Thanks to the [central limit theorem](#), blur can be expressed by the [Gaussian](#) function (Bell curve). $Blur = \exp(-x^2/2\sigma_x^2) / \sqrt{2\pi\sigma_x^2}$

σ_x corresponds to the sharpening radius, R . The unsharp masked image can be expressed as the original image summed with a constant times the [convolution](#) of the original image and the blur function, where convolution is denoted by $*$.

$$\begin{aligned} L_{USM}(x) &= L(x) - k_{USM} * Blur \\ &= L(x) * [\delta(x) - k_{USM} \exp(-x^2/2\sigma_x^2) / \sqrt{2\pi\sigma_x^2}] / (1 - k_{USM} / \sqrt{2\pi}) \end{aligned}$$

$L(x)$ is the input pixel level and $L_{USM}(x)$ is the USM-sharpened pixel level. k_{USM} is the USM sharpening constant (related to the slider setting scanning or editing program). $L(x) = L(x) * \delta(x)$, where $\delta(x)$ is a [delta function](#).

The USM algorithm has its own MTF (the [Fourier transform](#) of the portion inside the brackets [...]).

Using $F(\exp(-px^2)) = \exp(-\alpha^2/4p)/\sqrt{2p}$, where F is the Fourier transform,

$$\begin{aligned} MTF_{USM}(f) &= [1 - k_{USM} \exp(-f^2 \sigma_x^2 / 2) / \sqrt{2\pi}] / (1 - k_{USM} / \sqrt{2\pi}) \\ &= [1 - k_{USM} \exp(-f^2 / 2 f_{USM}^2) / \sqrt{2\pi}] / (1 - k_{USM} / \sqrt{2\pi}) \end{aligned}$$

where $f_{USM} = 1/\sigma_x$. This equation boosts response at high spatial frequencies, but unlike sharpening, response doesn't reach a peak then drop. Actual sharpening is a *two dimensional* operation.

Links

[How to Read MTF Curves](#) by H. H. Nasse of [Carl Zeiss](#). Excellent, thorough introduction. 33 pages long; requires patience. Has a lot of detail on the MTF curves similar to the [Lens-style MTF curve in SFRplus](#). Even more detail in [Part II](#). Their (optical) [MTF Tester K8](#) is of some interest.

[Understanding MTF](#) from [Luminous Landscape.com](#) has a much shorter introduction.

[Understanding image sharpness and MTF](#) A multi-part series by the author of Imatest, mostly written prior to Imatest's founding. Moderately technical.

[Bob Atkins](#) has an excellent introduction to [MTF and SQF](#). SQF (subjective quality factor) is a measure of perceived print sharpness that incorporates the contrast sensitivity function (CSF) of the human eye. It will be added to Imatest Master in late October 2006.

[Optikos](#) makes instruments for measuring lens MTF. Their 64 page PDF document, [How to Measure MTF and other Properties of Lenses](#), is of particular interest.