Understanding Resolution

Part II: Using Modulation Transfer Function

POIRET'S HOME, BIARRITZ, FRANCE 1983, was made using a Hasselblad camera, 60mm lens, and Tri-X Pan film. Poiret was a famous clothes designer.

By Ronald W. Harris

In *Part I* of this article (March/April 1991) I discussed resolution data for lenses, film, and printing paper. A normal unaided eye was found to resolve about 4 lines/mm. Oriental Seagull Glossy black-and-white fiber-based paper was found to be capable of resolving about 13 lines/mm, when examined with a loupe. Table I shows the required lens resolution for printing full-frame on 8×10 paper, and inspected by a normal unaided eye or using a magnifying loupe. Larger print sizes will require proportionately higher lens resolution. Also, remember that the data is based on tripod-mounted cameras and does not incorporate resolution losses caused by camera shake.

This data clearly shows that a high quality 35mm lens must have excellent performance at least out to 30 lines/mm; a 6×6cm lens, out to 15 lines/mm; and a 4×5 inch lens, out to 10 lines/mm. Good performance out to three times these values would be desirable, and necessary to produce a maximum resolution print as examined using a magnifying loupe.

Understanding MTF

Until now, I've only considered the maximum lens resolution. However, it is also of utmost importance to know how well a lens performs in terms of contrast at all spatial frequencies (lines/mm) from zero up to the maximum resolution of the lens. A graph of contrast transfer (1.0 represents 100 percent) versus spatial frequency (lines/mm) is called the *Modulation Transfer Function* or MTF.

A graph of the MTF's for an ideal lens, for a real lens without defects, and for a lens with aberrations is shown in Figure 1. Lenses that have MTF's showing a large departure from that of a lens without defects will render poor images, even though they may have a high value for maximum resolution. Note that aberrations cause oscillations in the real-lens curve; this means that contrast is higher for some spatial frequencies and lower for others.

In some cases, you must also consider the Optical Transfer Function (OTF), which is a product of the MTF and PTF, where PTF is the Phase Transfer Function. The PTF takes into account spatial frequency phase shifts caused by the lens. When the OTF for a real lens with an out-of-focus condition is determined, it is found that the OTF curve can oscillate so wildly that the curve moves below the axis to negative contrast. (The PTF is minus one in this region.) This means that for those particular spatial frequencies, the contrast reverses: black target bars become white and white bars become black in the image. It's true. I checked it. In most cases the PTF is of no consequence and is usually ignored.

MTF graphs are also usually drawn for different locations on the film off the central axis, where performance usually becomes poorer, especially out near the diagonal edges of the film. Graphs are sometimes presented for the lens wide open and for the lens stopped down to the optimum aperture. As the lens is stopped down, aberrations are minimized and the MTF more closely resembles that of an ideal lens at the same f/stop.

To be complete, graphs should be drawn with the test targets rotated at different angles with respect to a line drawn radially outward from the center of the film, but in the plane of the film. Lens aberrations cause different results to occur for the different orientations of the test targets. For simplicity, only two orientations are usually considered: *sagittal* target lines are parallel to the outward radial line; and *tangential* lines are tangent to the outward radial line. MTF graphs are also generally presented for using white light, as well as for primary wavelengths.

Using MTF

It is, no doubt, obvious that using this approach, many MTF graphs are required to completely describe a lens. However, if you are able to obtain this information for a selection of lenses, it is relatively easy to determine which lens will give the best performance for a given task.

If you are interested in finding another lens, perhaps with a different focal length, that has the same optical qualities as a lens you already have, it is important to obtain as many MTF graphs of each lens as possible. If you want to color-match the lenses, be sure to get primary wavelength data for the f/stops you plan to use. For soft-focus lenses pay particular attention to the oscillations in the MTF curves. With large-format lenses be aware that some "high performance" lenses have a small image circle, allowing only minor image movements and adjustments. Other lenses (such as the Schneider 210mm Symmar S, discussed in *Part I*) have been designed for good performance over a large image circle, allowing large image movements.

Table I. Lens resolution requirements for maximum resolution*

Eye	Loupe
35 mm: 29 lines/mm	35 mm: 94 lines/mm
6×6 cm: 14 lines/mm	6×6 cm: 44 lines/mm
4×5 in: 8 lines/mm	4×5 in: 26 lines/mm

*Note: As seen by eye and loupe, for an 8×10 inch print, using standard lenses, for three formats.

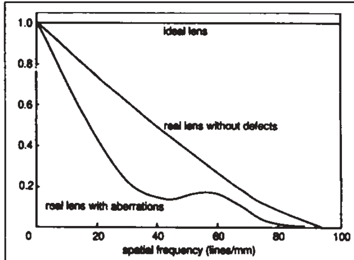

Figure 1. Modulation Transfer Function for a lens at f/stop = 16.0.

Fortunately, most manufacturers of high-quality medium and large format lenses happily make MTF data available. Unfortunately, MTF data for 35mm lenses are generally not available. This type of data must almost necessarily be furnished by the lens manufacturers or testing laboratories, since it is very difficult and expensive to obtain such data having the required accuracy. Simple resolution target tests, such as those described in *Part I* of this article, are helpful, but generally inadequate and time consuming.

Optics engineers frequently make theoretical MTF calculations for particular lens designs in order to optimize the design. The theoretical effects of aberrations, scratches, chips, and even dust on a lens can be studied. You may be surprised to learn that a small scratch, chip, or bubble has a minimal effect on lens performance. Dust on a lens lowers the overall image contrast, but produces a high-quality image otherwise. Have you ever wondered what effect the annular aperture in the center of a mirror-lens has upon the image, other than reducing its brightness? Theoretical MTF studies show that there is a low spatial frequency loss and a high spatial frequency gain; i.e. fine detail in the image is slightly enhanced.

MTF and Performance

Lens manufacturers frequently present MTF data in a different format than that shown in Figure 1. By plotting a family of MTF curves for a lens, a new curve may be obtained that represents the contrast of a particular spatial frequency at different distances from the center of the film. For each spatial frequency, there are two MTF curves: one for the sagittal target lines, and one for the tangential target lines. As you move outward from the center of the film, these two curves tend to diverge. The less the divergence, the better the performance.

Hasselblad publishes MTF data for its 6x6cm format lenses. They show MTF's for spatial frequencies of 10, 20, and 40 lines/mm from the center of the film out to the corner of the film. Looking at the 6x6cm results in Table I makes me hope for excellent MTF performance at 10 lines/mm and good performance at 40 lines/mm.

Recall from Figure 1, that contrast always drops off for a real lens as the spatial frequency increases. Figure 2 shows MTF graphs for three Hasselblad lenses. There are two graphs for each lens—one with the lens wide open, and one with it stopped down.

For the 80mm lens in Figure 2, notice that stopping down the lens to f/8 increases the contrast, removes some of the oscillations, and improves the corner performance drastically. This happens because lens aberrations are being minimized. Although not shown, stopping down further does not usually improve performance since the high spatial frequency contrast will lower. Most lenses perform well near the center of the film when stopped down to optimum aperture, but only an excellent lens will perform well at the edges of the film.

Examining the MTF data for the 100mm lens shows increased contrast and considerable improvement at the edges of the film, when compared with the 80mm lens. The 100mm lens is also a top performer if large apertures are required. The MTF curves for the 50mm lens may surprise you: Performance really drops off at the edges. In fact, this is a remarkably good lens. It's just that as you move away from the standard focal length for a given format, lens performance degrades. This is true for both long and short focal length lenses. Therefore, when possible, it is usually better to use a lens that is near to the normal focal length for a given format, especially if you need high contrast and resolution all the way out to the film's edges.

System MTF

When the entire photographic system

is included, the overall MTF is equal to the product of all of the individual MTF's for each element in the system, as follows:

$$MTF_{print} = MTF_{camera\ lens} \times MTF_{film} \times MTF_{enlarging\ lens} \times MTF_{printing\ paper}$$

Obviously, an excellent print will be obtained only if every component in the system is excellent. For example, if each element has an MTF value of 0.8 at a particular spatial frequency, the overall MTF is only $(0.8)^4 = 0.41$, which is rather low. If each element has a value of 0.5, the overall MTF value is only 0.06, which is dismally low. Of course, each element generally has a different value, but our calculation illustrates the problem.

If a lens tele-extender is used, the MTF for the lens combination will equal the product of the MTF of the lens and the MTF of the tele-extender. Since both elements must show loss of contrast at high spatial frequencies, the combination will have an even poorer high spatial frequency performance. However, the overall MTF may be better or worse than that of a single lens of the same focal length, depending on the lens. For example, I tested Hasselblad lenses using the methods described in *Part I*. A 250mm Superachromat combined with the Mutar tele-extender produced a 500mm lens which is superior optically to the 500mm Tele-Tessar (it is also smaller and lighter). Hasselblad publishes Mutar combination MTF's for some lenses, but I was unable to obtain one for this combination.

MTF curves are generally available for film. The graphs for T-Max 400 and T-Max 100 are essentially horizontal lines for lower spatial frequencies. The curves begin to drop downward from 100-percent contrast transfer at about 30 lines/mm for T-Max 400 and at about 50 lines/mm for T-Max 100. By comparison, Tri-X begins to drop off at about 20 lines/mm, which ranks it below T-Max 400 in MTF performance. This is not to say that one film is "better" than another—other qualities must be considered. The film must be chosen to match the objective. Clearly, large format photography has the advantage of not requiring as much enlargement from the negatives, which means that film resolution requirements are less.

MTF data is made available by some manufacturers of enlarging lenses, which should prove most useful in choosing an enlarging lens. Such data for photographic papers is generally not published—high quality printing papers have similar resolution. Normally, photographers choose a printing paper on the basis of image color, tonal separation, etc.

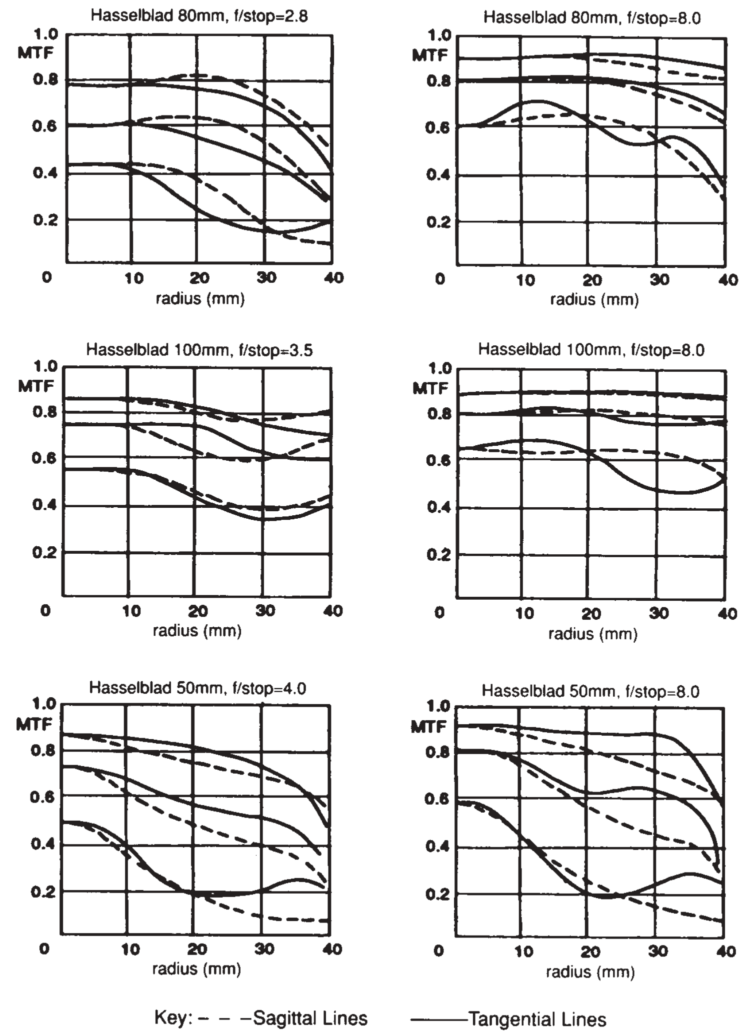

Figure 2. Modulation Transfer Function Graphs.

NOTE: MTF measures image/object contrast transfer (1.0 = 100 percent). The radius measures the distance out from the center of the film (40 mm is at the outer corner of the film). Starting from the top, the three sets of lines are for spatial frequencies of 10, 20, and 40 lines/mm.

Conclusions

While resolution target testing of lenses is useful, try to obtain Modulation Transfer Function (MTF) data directly from the lens manufacturer whenever possible. In this way you can see how a lens performs at all spatial frequencies, out to the maximum resolution. In particular look for undesirable oscillations and drop-off in contrast at the outer edges of the image. The less divergence in the sagittal and tangential curves for a given spatial frequency, the better. If you need to shoot wide open, see how good the MTF looks wide open.

For making full frame prints on 8×10 paper, 35mm lenses must have excellent performance at 30 lines/mm; 6×6cm lenses at 15 lines/mm; and 4×5 inch lenses at 10 lines/mm. Performance must be good at three times these values for maximum print resolution of 13 lines/mm (Seagull glossy black-and-white paper). For larger prints, proportionately higher performance is required. Since the overall MTF of a photographic system equals the product of each of the individual MTF's in the system (for example, camera lens, film, enlarging lens, and paper), it is desirable to obtain this data for each element, whenever possible. The individual MTF contrast transfer values must be relatively high if the overall system is to have a useful contrast transfer. The "weakest link is where the chain breaks." ■

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