Why Measure MTF?

By Peter T. Carellas and Stephen D. Fantone

Modulation Transfer Function (MTF) has been also cited with measurement of performance of optical systems from the initial introduction of linear system analysis to this field. As the demand for higher quality, higher resolution optical systems has become prevalent, both designers and metrology scientists have begun investigating MTF as a mutual mode of quantifying the performance of optical systems. This article identifies the reasons for specification and measurement of MTF as a system characterization tool.

MTF is a direct and quantitative measure of image quality.

Most optical systems are expected to perform to a predetermined level of image integrity. Photographic optics, photolithographic optics, contact lenses, video systems, fax and copy optics, and compact disk lenses only sample the list of such optical systems. A convenient measure of this quality level is the ability of the optical system to transfer levels of detail from object to image. Performance is measured in terms of contrast (degrees of gray) or modulation, and is related to the degradation of the image of a perfect source produced by the lens.

The MTF describes the image structure as a function of its spatial frequencies, most commonly produced by Fourier transforming the image spatial distribution or spread function. Therefore, the MTF provides simple presentation of image structure information similar in form and interpretation to audio frequency response. The frequency components can be isolated for specific evaluation.

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MTF can be related to end use applications.

Frequently, imaging systems are designed to project or capture detail components in the object or image. Applications that rely upon image integrity or resolution ability can use MTF as a measure of performance at a critical dimension, such as a line width or pixel resolution or retinal sensor spacing. Optical systems from low resolution hand magnifiers to the most demanding photographic or lithographic lenses relate image size and structure to the end application requirement.

For example, video imaging systems must be designed to consider the image size produced by the lens relative to the array pixel size and location. An array pixel width of 6 !-LID corresponds to a cut-off frequency of83/1p/mm. In most cases, attempting to resolve beyond this limit is impossible; therefore, designing a lens that maintains the high MTF out to this cut-off frequency is appropriate for this application. Specifying performance of a lens beyond this frequency is superfluous.

MTF is ideal for modelling concatinated systems.

MTF is analogous to electrical frequency response, and therefore allows for modelling of optical systems using linear system theory. Optical systems employing numerous stages (i.e., lenses, film, the eye) have a system MTF equal to the product of the MTF of the individual stages, allowing the expected system performance to be gauged by subsystem characterization. Proper concatination requires that certain mathematical validity conditions, such as pupil matching and image relaying, be met, however.

MTF testing is objective and universal.

MTF allows system testing in the exact application environment.

MTF provides the most direct method for measuring integrated polychromatic performance of optical systems.

MTFs can be accurately predicted and toleranced with lens design software.

Virtually all lens design software today allows graphical depiction and subsequent tolerancing of polychromatic MTF. Lens design software programs calculate the system MTF either through the autocorrelation of the exit pupil wavefront function or by Fourier transforming the point spread function, which is calculated by Fourier transforming the pupil wavefront. Polychromatic MTF is computed by vectorial addition of the monochromatic MTF and phase function. These methods for calculating MTF are also used with phase measuring interferometers to calculate the MTF of relatively well corrected monochromatic optical systems.

MTF measurement instruments provide testing versatility.

Numerous other tests can be performed on a standard MTF test instrument. Field curvature, distortion, and blur spot size are parameters relating to image characterization and are therefore capable of quantification with MTF metrology equipment. MTF testing offers the engineer and test technician a method for directly measuring the image features related to overall system performance. It is a well-developed and understood concept and bridges the gap between the lens designers, optical fabricators, and metrology engineers.