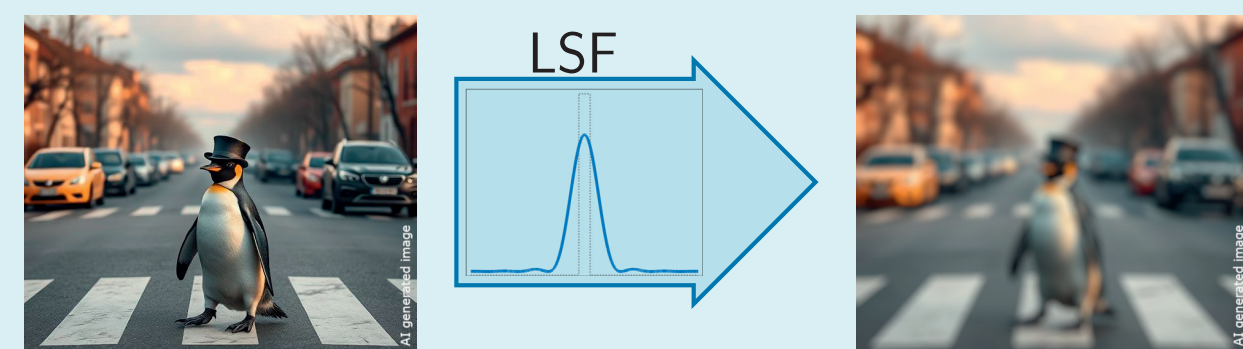


Modulation Transfer Function – Measurement Capabilities at PTB

Hanno Dierke, Markus Schake

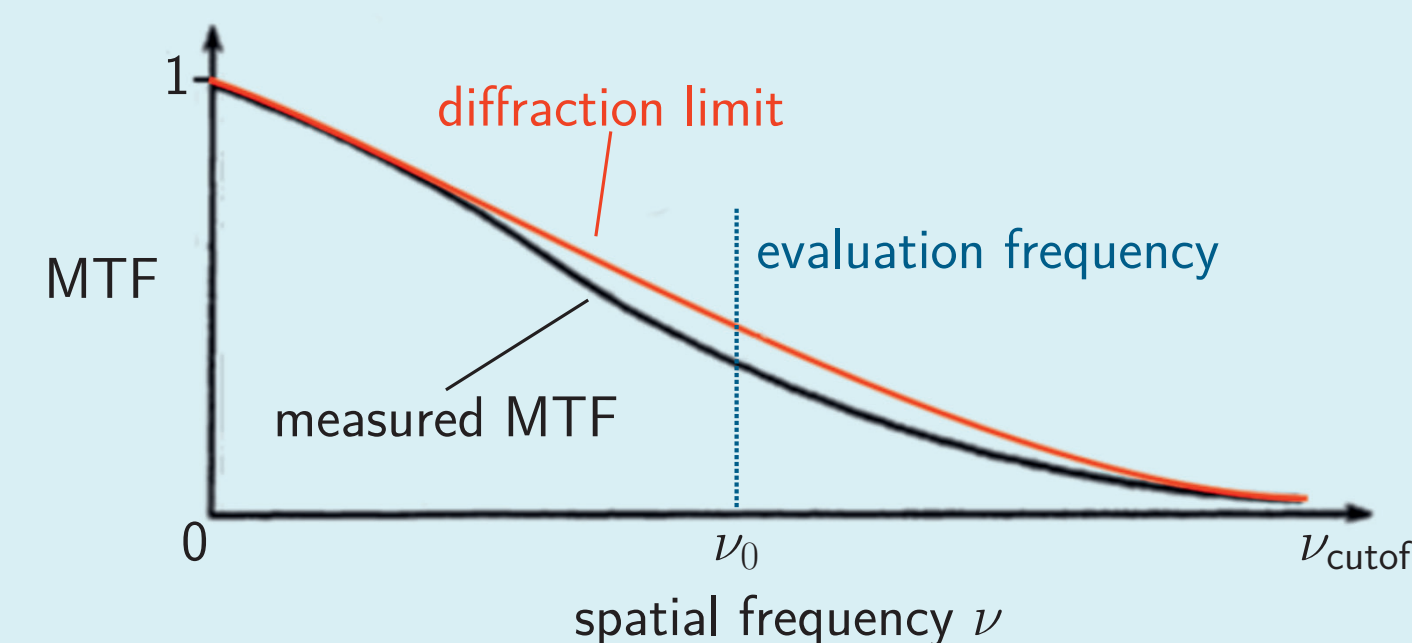
Introduction to the MTF

In the case of an object being imaged through an optical element, such as a lens or an objective, the object contrast is typically reduced due to diffraction and aberrations. The contrast degeneration can be described, for example, by the line spread function (LSF) for 1D objects.



The modulation transfer function, MTF, is defined as the modulus of the Fourier transform of the LSF. It provides a frequency-domain representation of the optical performance of the optical element, incorporating information on both resolution and the ability of the optical element to transfer object contrast into image space.

Furthermore, the MTF can be calculated based on the design parameters, thereby allowing deviations from the calculated, just diffraction-limited MTF to serve as an indication of existing imaging errors.



The possibility to quantify the quality of an optical element in a single figure is making the MTF a key parameter in optical quality assessment. Consequently, it is frequently employed to characterise the imaging properties of optical elements [1, 2].

At PTB, a modulation transfer function (MTF) measurement setup has been developed for the traceable determination of the MTF of lenses and objectives. This setup, shown in the top center pane, employs an approach that follows the recommendations outlined in ISO 9335 [3].

The results of the MTF measurements can be shown in different forms. Examples of graphical depictions of typical result of the MTF measurement are shown in the "Measurement output" pane on the right.

In recent years, several possible influences that can affect MTF measurement results have been investigated, and a comprehensive measurement uncertainty budget is now available. A detailed lineup of the influences currently considered is shown in the bottom center pane.

References

- [1] Joseph W. Goodman, "Introduction to Fourier Optics", McGraw Hill, 1996
- [2] Glenn D. Boreman, "Modulation Transfer Function in Optical and Electro-Optical Systems", SPIE, 2001
- [3] International Organization for Standardization (ISO), "ISO 9335:1995 : Optics and photonics – Optical transfer function – Principles and procedures of measurement", 1995

MTF measurement setup

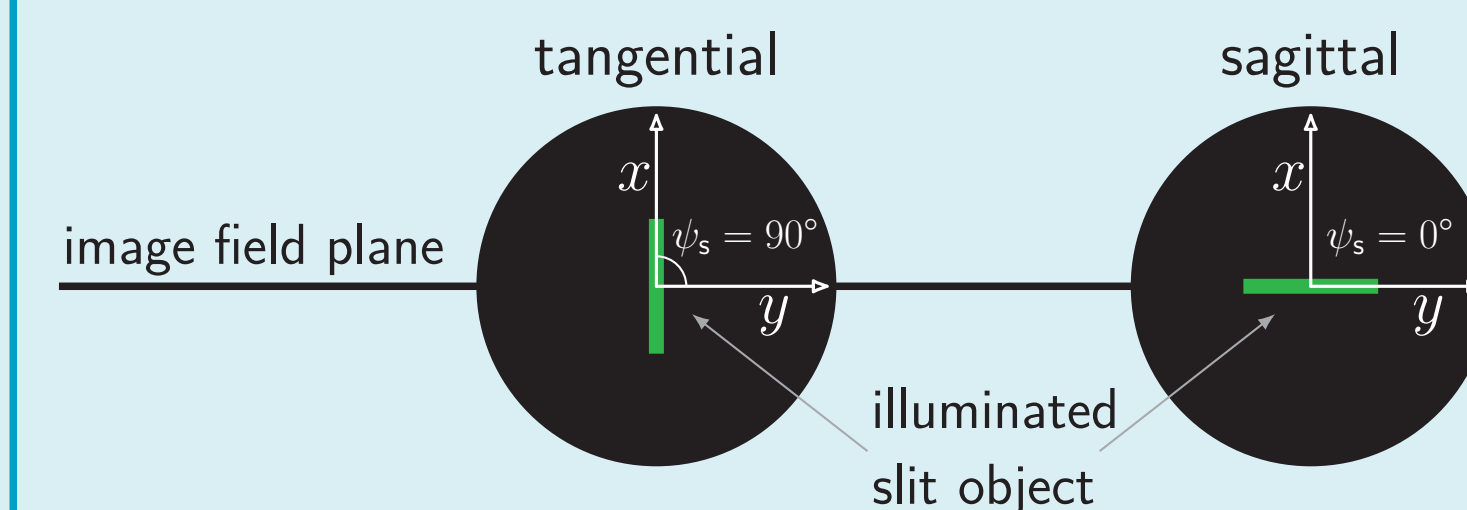
An object – in our setup a slit aperture – is positioned at infinity (i.e. the focus of a collimator lens), imaged by the test object at a finite distance and observed with a camera. The LSF of the test object is obtained from the camera image and utilised for the determination of the MTF of the tested lens, which can be turned to allow MTF measurements in the image field of the test object.



MTF measurement capabilities

Slit object orientation

Measurements with sagittal and tangential slit orientation



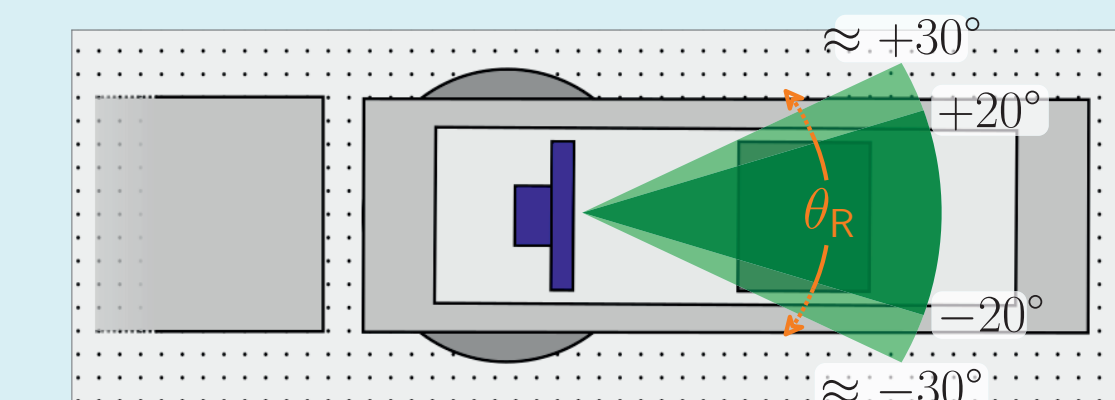
Test object specifications

Designed for lenses with focal lengths $f = 15 \dots 135$ mm and f-numbers $a = 0.8 \dots 5.6$



Measuring in the image field

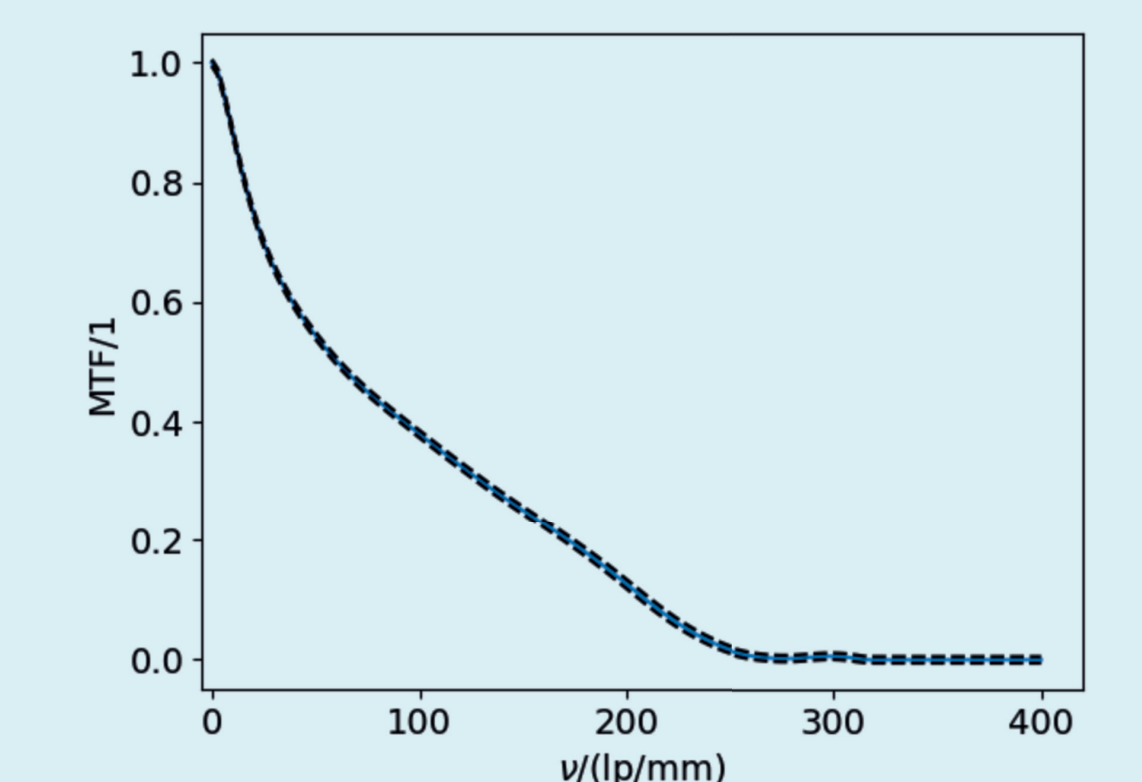
Typical image field range up to $\theta_R \approx \pm 20^\circ$, suitable for the objectives tested so far (up to $\theta_R \approx \pm 30^\circ$ possible).



Measurement output

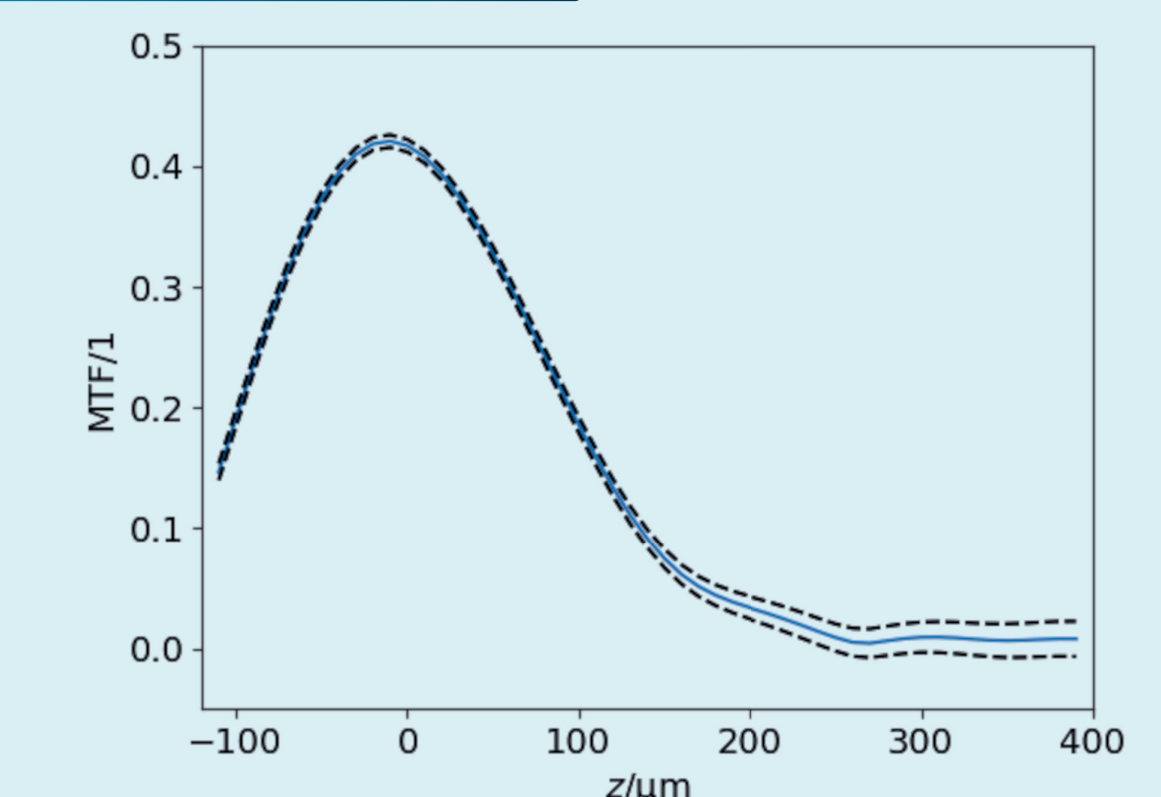
The graphical representations of the MTF measurement results are available in the following forms:

MTF(ν) at $z(P_f)$



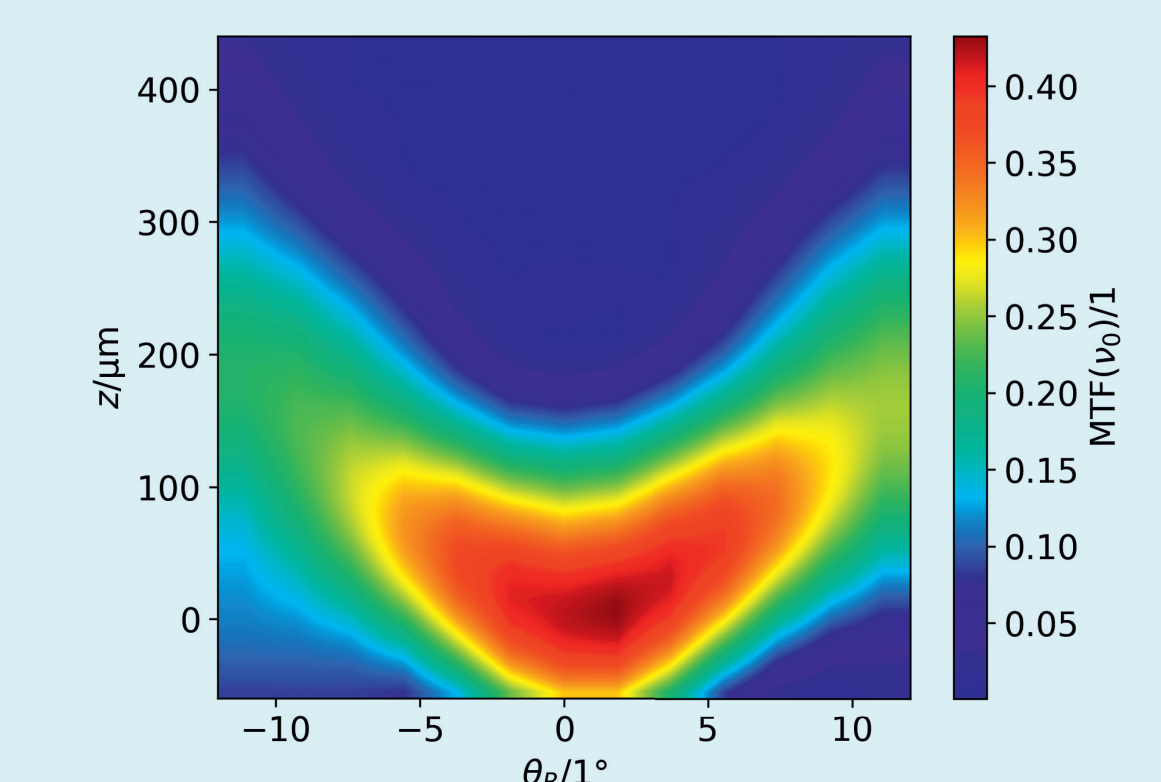
MTF values for a range of spatial frequencies (usually $\nu = [0; \nu_{\text{cutoff}}]$ with the cutoff frequency ν_{cutoff} , i.e. the first zero crossing of the diffraction limited MTF) at a defined position on the optical axis (usually the focus point $z(P_f)$, where the MTF reaches its maximum).

MTF(z) for $\nu = \nu_0$



MTF values for a selected spatial frequency ν_0 at several positions of a through-focus scan along the optical axis z .

MTF in the image field



MTF values in the image field, i.e. the results of several through-focus scans at different image field angles, displayed as a false color plot representing the MTF value at different positions in the image field of the test object.

Comprehensive measurement uncertainty budget

