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Determination of the paraxial focal length according to its definition by the German DIN standard in measurements

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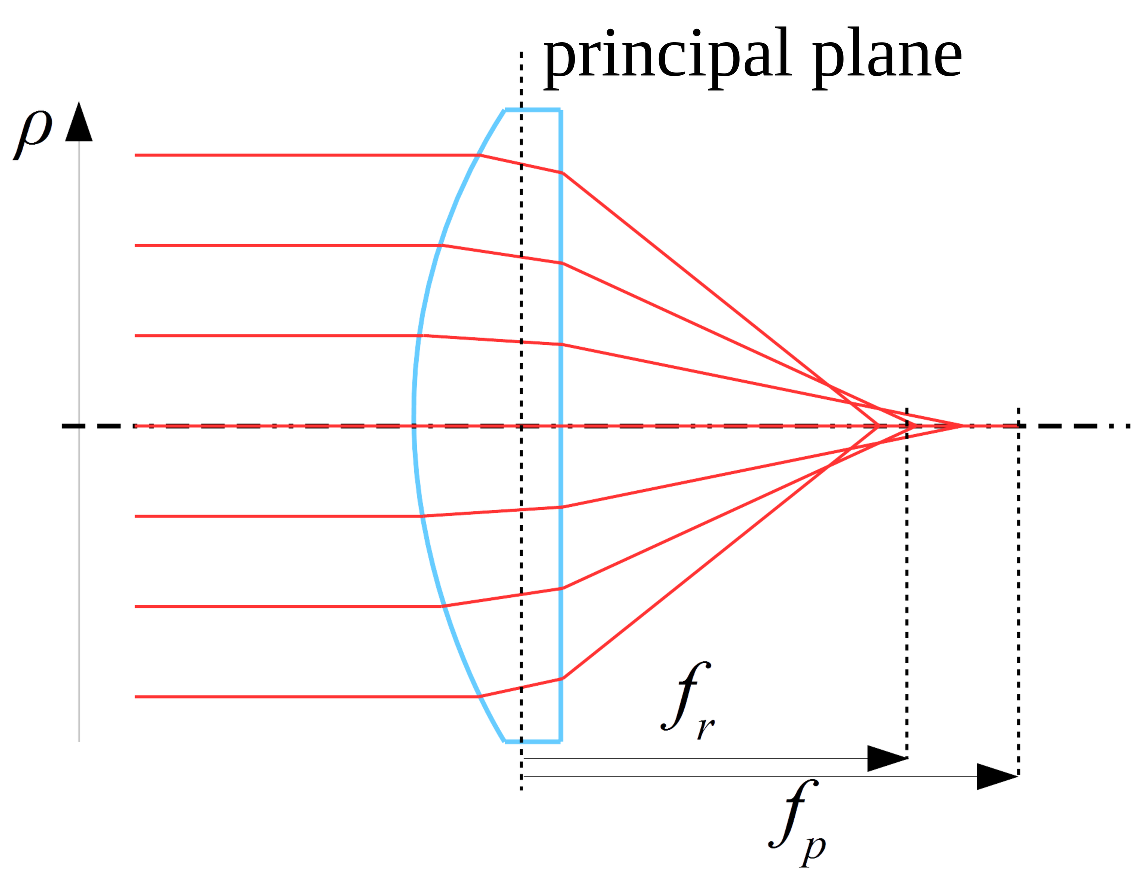
Introduction

The German DIN standard [1] basically differentiates between two focal length definitions: the real focal length $\boldsymbol{f_r}$ and the paraxial focal length $\boldsymbol{f_p}$. It solely defines the paraxial focal length as the focal length of a certain wavelength with the aperture at the transition to zero. No measurement method is given for it.

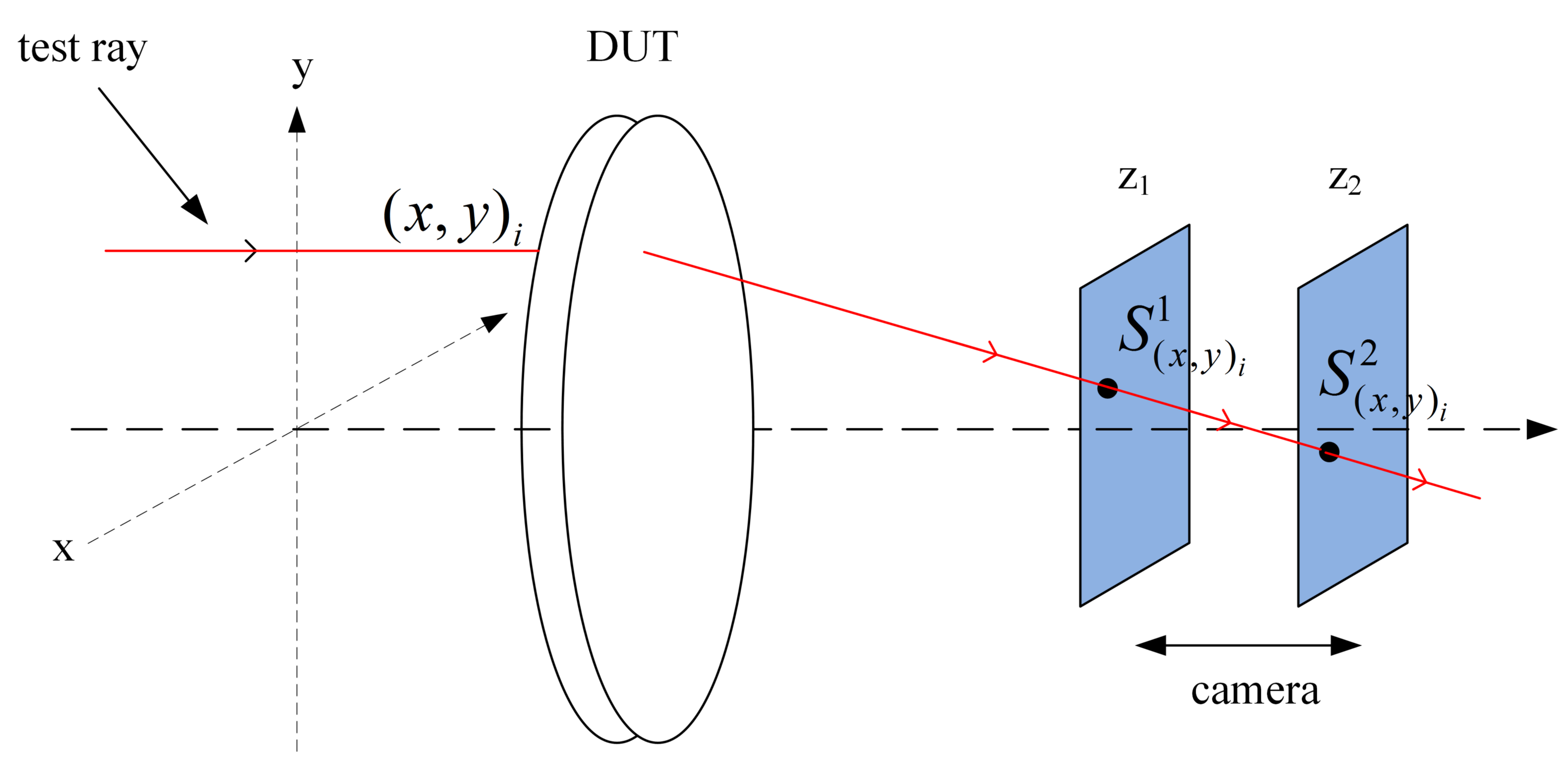


Goal

Development of a new fast method to measure the paraxial focal length according to its definition in the German DIN standard by using experimental raytracing [2].

Experimental setup

Principle of experimental raytracing [2] follows the measurement of the slope of the test ray by determining its position in two different planes.



Theory and method

For spherical wavefronts from **ideal** lens the trend of the ray slopes T is linear:

$$T(\rho) = b \cdot \rho$$

with: ρ = pupil coordinate
b = gradient of linear slope trend

For **real** lenses, aberrations lead to a dependency of f_r on the considered aperture a. Combined with the equation for the curvature of a function [3] with simplification this leads to:

$$R(a) = f_r(a) = \frac{1}{b(a)} \overset{fit}{\approx} \frac{\rho}{T(\rho)}$$

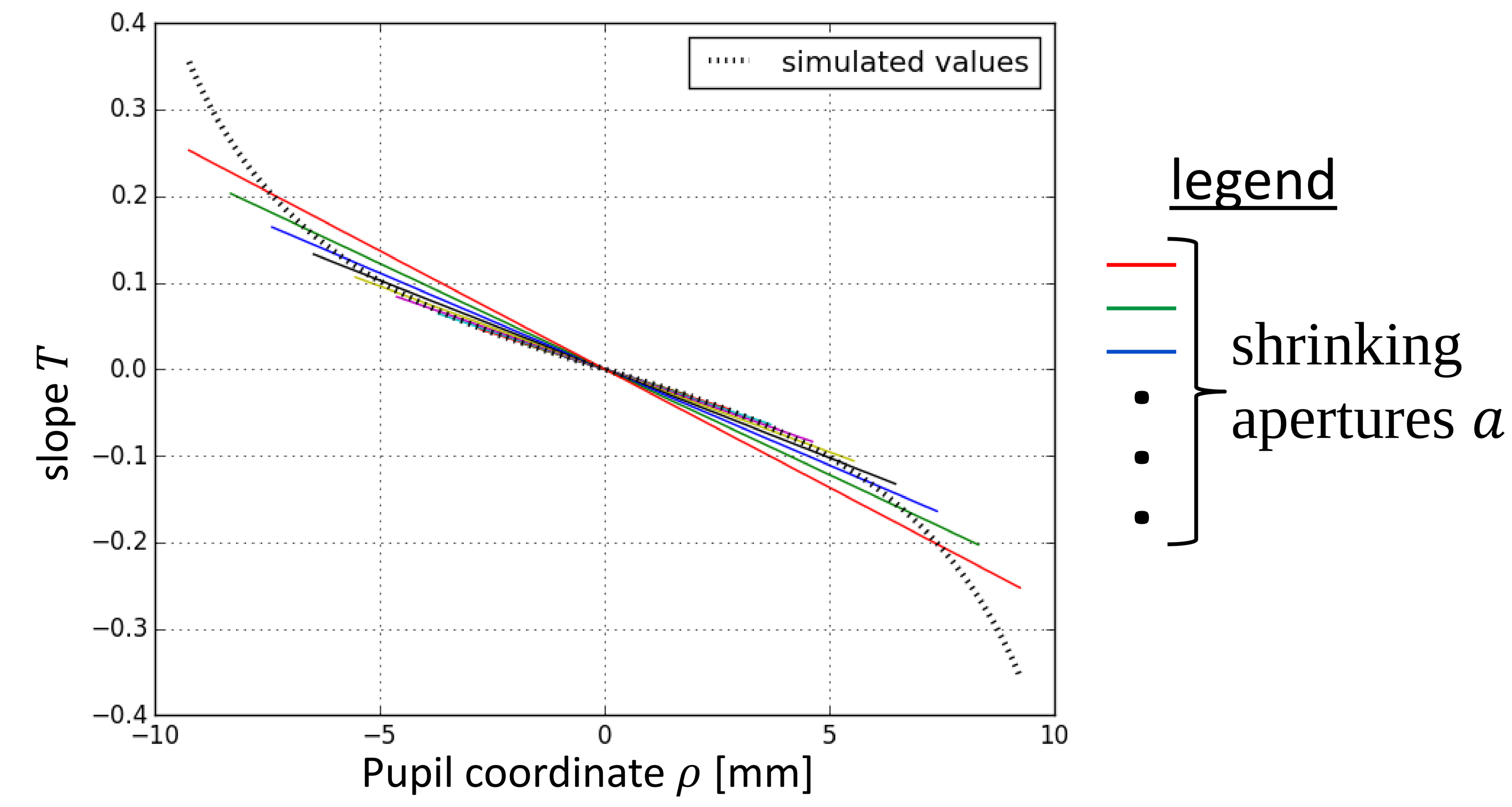
with: $R(a)$ = radius of the spherical wavefront

Thus, the aperture has to be shrunk according to the German DIN standard [1] to get f_p.

$$f_p = \lim_{a \to 0} f_r(a)$$

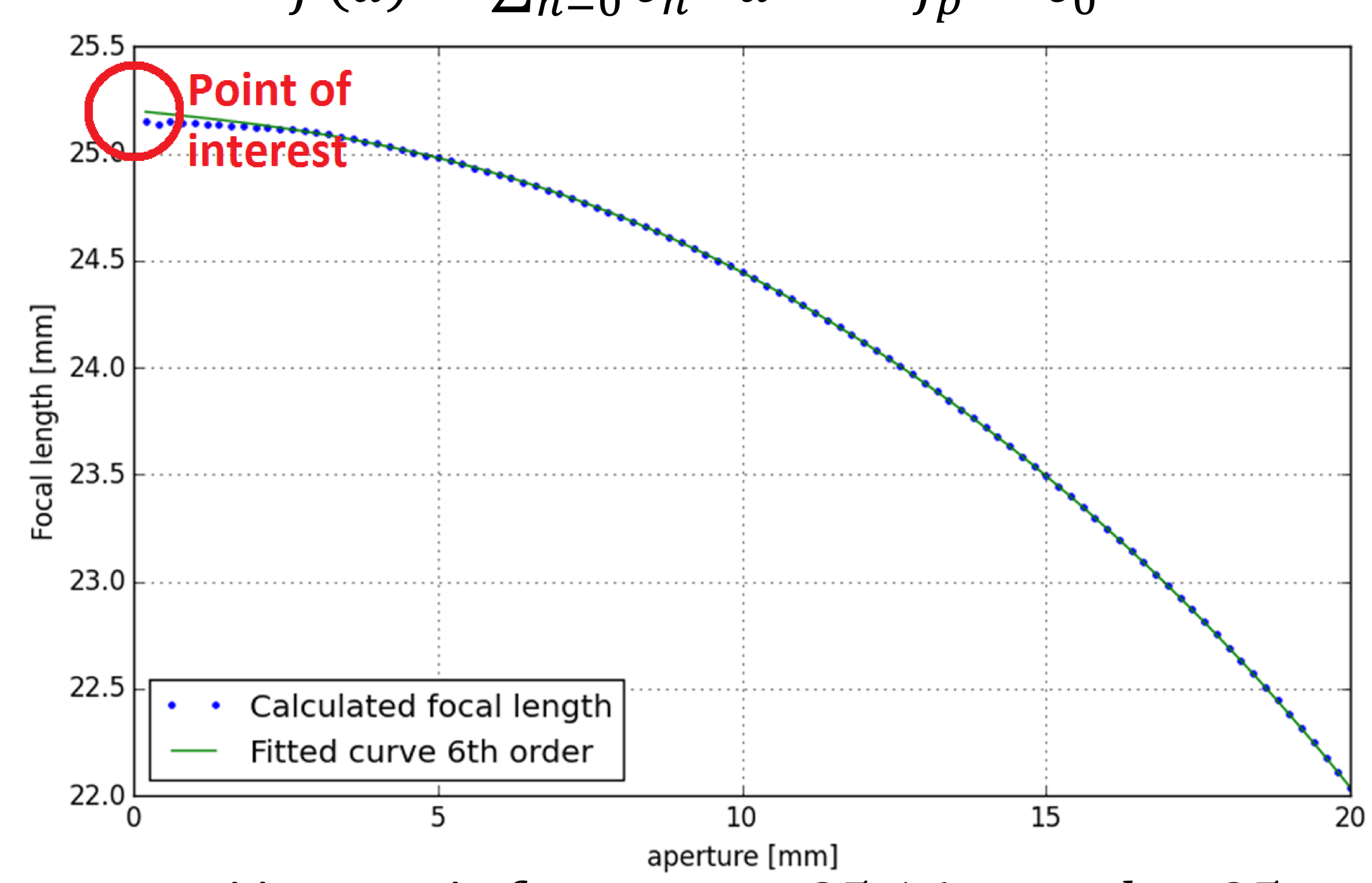
Results

Simulation shows clearly the influences of aberrations to the slope trend $b(a)$ of a lens with $f_{p,633\,nm} = 25{,}16$ mm and diameter $d = 25$ mm.



In measurement, f_p is determined by the extrapolated coefficient c_0 from a fitted 6th order polynomial to the different focal lengths of their corresponding apertures a. The fit is weighted by the square aperture values.

$$f(a) = \sum_{n=0}^{6} c_n \cdot a^n \Rightarrow f_p \approx c_0$$



Measured lens with $f_{p,\,633\,\mathrm{nm}} = 25{,}16$ mm; $d = 25$ mm

Lens	f_{Design}/mm	f_{meas}/mm	Error/%
EO 45097	25,16	25,20	0,16
EO 32970	50,40	50,40	0,00
AS A5040HPX	39,62	39,69	0,18

Conclusion

A fast measurement method (ca. 25 s) with high accuracy according to the definition of the paraxial focal length f_r by DIN standard has been developed.

References

[1] NAFuO im DIN: *DIN 58189: Fundamental standards for optics – Determination of focal length*, 2008, DIN

[2] U. Ceyhan: *Characterization of aspherical lenses by experimental ray tracing*, 2003, Jacobs University, Bremen

[3] L. Papula: *Mathematische Formelsammlung*, 2009, 10th ed., Vieweg+Teubner

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