

**Grading:** The final exam counts for 30% of your total grade.

**Exam type:** Closed-book, all questions can be answered **using only pen and paper**. Calculators are allowed but not necessary for the exam (numerical values will be fractions).

**The duration** of the final exam is 3 hours.

Please fill in all questions listed below. Each of the questions is valued equally in the score calculation of the exam. Please tell if any question is unclear or ambiguous.

### Question 1: PSF of a thin lens

Consider a thin convex lens with  $R_1 = 20$  micron,  $R_2 = -60$  micron, lens diameter  $D = 10$  micron,  $n = 1.5$  and surrounded by air. Assume the Lensmaker's formula is valid:

$$\frac{1}{f} = (n - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)$$

- (a) Calculate the Airy disk diameter  $d = 2.44\lambda f/D$  for light with wavelength  $\lambda = 500$  nm.  
(b) How will the Airy disk diameter  $d$  change if you scale both  $R'_1 = \alpha R_1$  and  $R'_2 = \alpha R_2$  by  $\alpha = 1/2$  (microscopic scaling)?

### Question 2: the Strehl ratio

The Marechal criterium states that good imaging quality has Strehl ratio  $S \geq 0.82$ .

- (a) Extract the Strehl ratio  $S$  from the PSF profiles in figure 1, is Marechal's condition fulfilled?  
(b) Give an expression for the RMS wavefront error  $\sigma_w$  by using  $S \approx 1 - (\frac{2\pi}{\lambda}\sigma_w)^2$ .

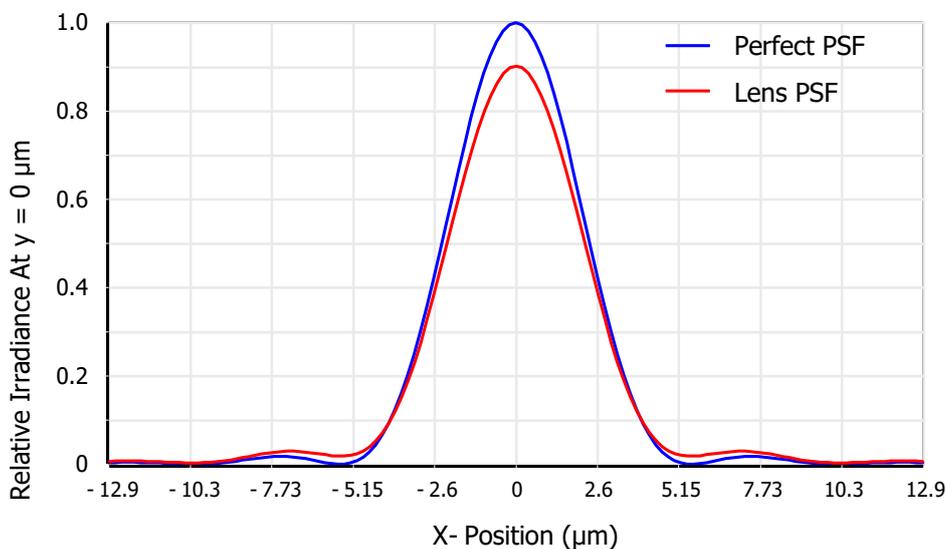


Figure 1: Point spread functions for a “perfect” paraxial lens and a lens with aberrations.

### Question 3: Seidel aberrations

Distortion is one of the 5 Seidel aberrations.

- (a) Name the other 4 Seidel aberrations.
- (b) Illustrate distortion by making a sketch in the style of the below sketch for field curvature aberration.

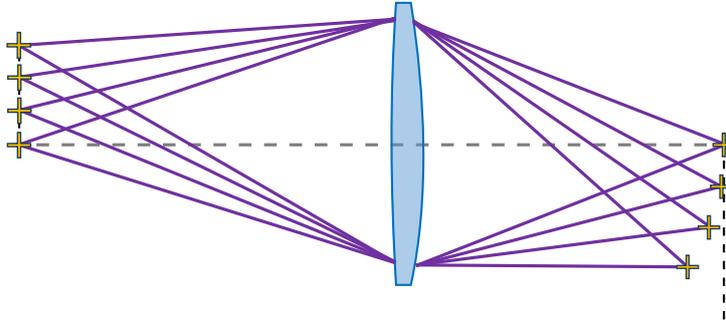


Figure 2: Schematic illustration of field curvature.

### Question 4: Blazed Fresnel lenses

- (a) Which type of aberration is minimal for Fresnel lenses? Which one is often problematic for Fresnel lenses?
- (b) What is the theoretical minimum thickness of a blazed Fresnel lens (variable pitch) having  $n = 1.5$  and surrounded by air, for light with wavelength  $\lambda = 600$  nm? Assume that the minimal thickness is given by the depth of the grooves (height of the teeth).

### Question 5: Waveguides

The number of modes  $m = 1, 2, 3, \dots, m_{\max}$  in a waveguide of width  $d$  with perfect mirroring walls is given by  $m_{\max} < \frac{2d}{\lambda}$ .

- (a) If  $d = 500$  nm and wavelength  $\lambda = 488$  nm, what is the number of modes?
- (b) What is the maximum  $\lambda$  to have at least one mode ( $m = 1 = m_{\max}$ )?