Examination

Introduction to Optical Modeling and Design

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Place and Date: Jena, 09.02.2022, 10:00-12:00, Online

Answer all questions in your own words and with mathematics where needed for your argumentation.

1. Assume an optical set-up composed of a single lens (focal length $f_1' > 0$) placed at a distance d in front of a plane mirror.

   (a) Calculate the ABCD-matrix for the full light path (lens – mirror – lens). (4P)

   (b) What is the effective focal length of this system (hint: compare the matrix component C with the one of an ideal lens)? (1P)

   (c) Make a sketch of the image formation for the case that $d = 0.5f_1'$ and an object is at a distance $s = -2f_1'$ in front of the lens and correctly mark the relevant quantities (focal lengths, object/image distances from the lens). (4P)

   (d) What is the exact image distance from the lens (in units of f_1')? (1P)

   (e) Assume that the mirror acts as the stop (limiting aperture) of the system. Construct the location of the exit pupil and give its position from the lens (in units of f_1'). (2P)

2. Effects at a real lens:

   (a) Describe the effect of chromatic aberration by the example of focusing a collimated beam with a single lens (e.g. by a clear sketch). (2P)

   (b) Sketch an Optical Path Diagram (OPD) for two wavelengths focused by such a single lens. (2P)

   (c) What optical arrangement is able to reduce chromatic aberration? Write down the related mathematical condition and explain the quantities occurring in this formula. (3P)

   (d) What would be the natural image surface of a single lens in case of various off-axis field points? How is this type of aberration called? (2P)

   (e) Again, what optical arrangement is able to minimize the aberration discussed in 2d? Write down the related mathematical condition. (2P)

(f) Which mathematical relation results if we combine the conditions from 2c and 2e? How is this lens-type called? (2P)

3. Describe the optical characteristics of an object-side telecentric system. Where is the location of the Exit Pupil in such a system? Give an example of an application in which an object-side telecentricity is beneficial. (3P)

4. What limits the spot size of a beam focused by a lens in case the lens has no aberrations? How can this spot size be calculated? (2P)

5. The electric field $\bar{E}(t)$ has the unit $[\bar{E}(t)] = \mathrm{V\,m^{-1}}$. What is the unit of its Fourier transformed version in Frequency domain, that is $[E(\omega)] =?$ with $E(\omega) = \big(\mathcal{F}_\omega \bar{E}\big)(\omega)$? (1P)

6. Assume in plane through z_0 the transversal field components $\boldsymbol{E}_\perp(\boldsymbol{\rho}, z_0) = \big(E_x(\boldsymbol{\rho}, z_0), 0\big)$. Provide a formula to calculate $E_z(\boldsymbol{\rho}, z > z_0)$. Hint: Use the equation $\tilde{E}_z(\boldsymbol{\kappa}, z) = -\big(k_x \tilde{E}_x(\boldsymbol{\kappa}, z) + k_y \tilde{E}_y(\boldsymbol{\kappa}, z)\big)/k_z(\boldsymbol{\kappa})$. (4P)

7. What are the definitions of isotropic, homogeneous, and non-dispersive media respectively (3P)?

8. The Fourier transform is an integral operator. What is your understanding, how it can approximately become a pointwise operation? (3P)

9. Propagation integrals:

   (a) What are major steps to obtain the Rayleigh integral from the SPW operator. (3P)

   (b) What is changed in the SPW operator formula to get the generalized Debye integral? (2P) What is assumed in addition to obtain the classical Debye integral? (1P)

   (c) What is changed in the SPW operator formula to get the generalized far-field integral? (2P) What is assumed in addition to obtain the classical far-field integral? (1P)

   (d) What is changed in the SPW operator formula to get the Fresnel integral formula? (3P)

   Make your major arguments clear. Detailed mathematical derivations are not needed!

10. Explain, why the z-component of the electric field can be neglected in paraxial approximation. (2P)