Examination Introduction to Optical Modeling and Design

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

1. Assume an optical setup composed of two lenses (focal lengths f_1 and f_2) which are placed at a small distance d on the optical axis. Calculate the ABCD-matrix for this setup. Compare the matrix element C with the basic matrix of a thin lens in order to derive the formula for the effective focal length of the two-lens-system.
2. Make a sketch of the image formation with an idealized lens of negative optical power ($f < 0$). Mark the relevant quantities, planes, and distances.
3. What is the Abbe Number? What are the two main categories of glass materials with respect to their dispersion properties? Make a sketch of $n(\lambda)$ in a $\lambda-n$-diagram for both categories.
4. What effect is described by the field-curvature aberration? You can make a sketch to illustrate the effect. How can field curvature be minimized?
5. 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?
6. General harmonic fields:

aberrations? How can this spot size be calculated?

6. General harmonic fields:

   (a) Define a harmonic (monochromatic) electromagnetic field in the frequency and time domain (with vector signs!).

   (b) How many components are independent in a homogeneous dielectric? Give a basic (no derivation) explanation for your statement.

   (c) How are harmonic fields polarized? Explain your statement.

   (d) What is a paraxial field?

   (e) What is the difference between globally and locally polarized paraxial fields?

7. Thin element approximation (TEA): $\mathcal{E}(x) =$

   (a) Assume a height profile $h(x)$ between two media with refractive indices n and n'. Derive the effect on an incident plane wave (propagating along optical axis, wavelength λ) on the phase of the field.

   (b) Calculate the maximum height of $h(x)$ if the maximum phase shift due to the profile should be 2π. Assume $\lambda = 632$ nm, $n = 1$ and $n' = 1.5$.

8. Propagation in free space:

   (a) The spectrum of plane wave propagation integral (SPW) is given by

$$\begin{aligned} V_\ell(\boldsymbol{\rho}, z) &= \mathcal{P}V_\ell(\boldsymbol{\rho}, 0) \\ &= \mathcal{F}^{-1}\left\{ \left(\mathcal{F}V_\ell(\boldsymbol{\rho}, 0)\right) e^{ik_z z} \right\}. \end{aligned} \tag{1}$$

(b) What is the numerical limitation of the SPW integral? Explain the reason.

(c) Describe and discuss the paraxial approximation.

(d) Formulate (no derivation!) the Fresnel integral to propagate a field from one plane to another (see also Eq. (2)).

(e) Why has the Fresnel integral numerical advantages compared with the SPW integral in case of larger propagation distances?

9. Collins integral:

(a) The Collins integral (for systems embedded in media $n \approx 1$) is given by

$$V_\ell(\boldsymbol{\rho}, z) = \mathcal{P}_C V_\ell(\boldsymbol{\rho}, 0) = \alpha(\boldsymbol{\rho}, z)\, \mathcal{F}_\beta \left[V_\ell(\boldsymbol{\rho}', 0) \exp\left(\mathrm{i} \frac{k_0 A}{2B} \boldsymbol{\rho}'^2 \right) \right]_{\beta = \frac{k_0}{B} \boldsymbol{\rho}} \tag{2}$$

with

$$\alpha(\boldsymbol{\rho}, z) = \frac{k_0}{\mathrm{i}B} \exp(\mathrm{i}kL) \exp\left(\mathrm{i} \frac{k_0 D}{2B} \boldsymbol{\rho}^2 \right) . \tag{3}$$

and the elements of the ABCD-system matrix. What is the theoretical model behind this result? (Give just a short explanation of the basic assumptions.)

(b) Consider a $2f$-setup. What is the conclusion of the Collins integral for the resulting optical effect on the input field? Argue with the ABCD matrix of the $2f$-setup.