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Optical Modeling and Design with Field Tracing

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For a long time optical design has been dominated by ray tracing for lens design. Nowadays optical and photonic systems design deals with a great and steadily growing variety of modern light sources from XUV to IR, components with aspherical and even freeform surfaces, micro- and nanostructured optical components, new materials, and applications beyond imaging like lighting. Though ray tracing is a very successful modeling technology for the design of lens systems, it often suffers from accuracy problems in other applications. Moreover, ray tracing in form of the Monte Carlo technique is seriously affected by low modeling speed. In summary, there is an increasing need for a more elaborated modeling approach. In this lecture, we will give an introduction to field tracing, in which rays are replaced by electromagnetic fields, which are then propagated through the system with a suitable combination of modeling techniques. It will be shown, that this approach solves both drawbacks of ray tracing, that is it allows the adjustment of both modeling accuracy and modeling speed. Demonstrations and practical exercises in this lecture are done with the field tracing software Virtuallab. The lectures include the following topics:

- From ray to field tracing: overview and motivation
- Theoretical concepts
    - Electromagnetic field representation; polarization
    - Operator concept for system modeling
    - Spectrum of plane wave propagation; diffraction integrals
    - Geometrical optics field tracing
    - Overview of other propagation techniques
- Application examples on systems which include one or more of the following components alone or in combination: (it would be nice, if students could do it with me together in a PC Pool)
    - Lenses
    - Freeform surfaces
    - Gratings, diffractive lenses, and CGHs
    - Microlens arrays
    - Scattering components
    - Waveguides and fibers
- Design
    - Concepts based on geometrical optics
        - Example: Laser beam shaping
        - Example: LED light shaping
    - Concepts based on scattering
        - Example: DOE diffuser
- Additional topics are:
    - General source modeling
    - Ultrashort pulses
    - Laser resonators

Monday, August 24

Lecture 1 (14:00-15:30)

From ray to field tracing: overview and motivation

Starting from the basic task in optical modeling and design demands on a flexible and modern modeling theory are discussed. Ray tracing and physical optics approaches are compared and the idea of field tracing is introduced and illustrated at some examples.

Lecture 2 (16:00-17:30)

Electromagnetic fields in homogeneous media

Electromagnetic fields constitute the fundament for field tracing theory. Thus, a comprehensive discussion of field in homogeneous media is presented. The difference between paraxial and general fields is emphasized. The polarization of harmonic fields is considered in detail. Propagation techniques of fields in homogeneous media are introduced and discussed, for example, spectrum of plane waves integral vs. Rayleigh integral.

Tuesday, August 25

Lecture 3 (14:00-15:30)

Linear system operator concept

Basic field tracing characteristics are discussed along a linear system operator concept. That also allows the basic investigation of the appearance of polarization effects in optical modeling. Energy conservation in optical modeling is investigated. To this end, energy quantities are electromagnetically defined.

Lecture 4 (16:00-17:30)

Geometrical optics and other field tracing techniques

The optional use of geometrical optics for the propagation of electromagnetic fields is essential in field tracing. For example, the propagation through a lens is typically done with geometrical optics also in field tracing. The concept of geometrical optics field tracing is sketched. Its relation to the thin element approximation is presented. Other field tracing techniques like beam propagation and RCWA are mentioned and put into context.

Wednesday, August 26

Lecture 5 (14:00-15:30)

Modeling examples I

The theoretical results are applied to modeling examples including

- Lenses
- Freeform surfaces
- Gratings, diffractive lenses, and CGHs

Lecture 6 (16:00-17:30)

Modeling examples II

The theoretical results are applied to modeling examples including
- Microlens arrays
- Scattering components
- Waveguides and fibers

Thursday, August 27

Lecture 5 (14:00-15:30)

Optical design based on geometrical optics

With respect to the geometrical optics field, tracing theory an inverse approach for optical design can be formulated. The basic idea and concept are communicated. It includes refractive components as well as CGHs and grating cell arrays. The techniques are demonstrated for the applications:
- Laser beam shaping
- LED light shaping

Lecture 6 (16:00-17:30)

Optical design based on scattering

Besides the use of geometrical optics thinking another approach gains momentum in optical design, that is the shaping of light by scattering which results in designed diffuser. The concept to design such diffusers is presented. The design of a diffuser for a specific light shaping task is performed as an exercise.

Friday, August 28

Lecture 7 (14:00-15:30)

Source modeling

In this additional lecture, the extension of field tracing to general source fields including ultrashort pulses is introduced. Basic aspects of coherence theory in field tracing are discussed and detectors for the electromagnetic degree of coherence and Stokes parameters are presented. The spatio-temporal evolution of fs and as pulses in optical systems is briefly considered.

Lecture 8 (16:00-17:30)

Laser resonator modeling

Field tracing can be directly applied to the round-trip operator in a resonator in the framework of a fully vectorial Fox-Li algorithm. That allows for instance the inclusion of polarization effects and DOEs in the resonator modeling. This is illustrated at some examples. The gain through the laser crystal is also included.

This lecture should also give time for final discussions and questions as well as an outlook.