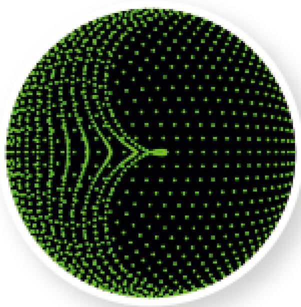
Seminar I – 06.01.2016 & 13.01.2016

Introduction to Optical Modeling

Site Zhang site.zhang@uni-jena.de
Applied Computational Optics Group - ACOG
www.applied-computational-optics.org

Warm-up: Ray tracing vs. Field Tracing

RAY TRACING



Start to investigate the performance of your optical system using 3D ray distribution, dot diagrams of ray positions and directions, and OPL.

GEOMETRIC FIELD TRACING

Switch from conventional to smart rays and you quickly receive additional information about phase, polarization, coherence, and interference.

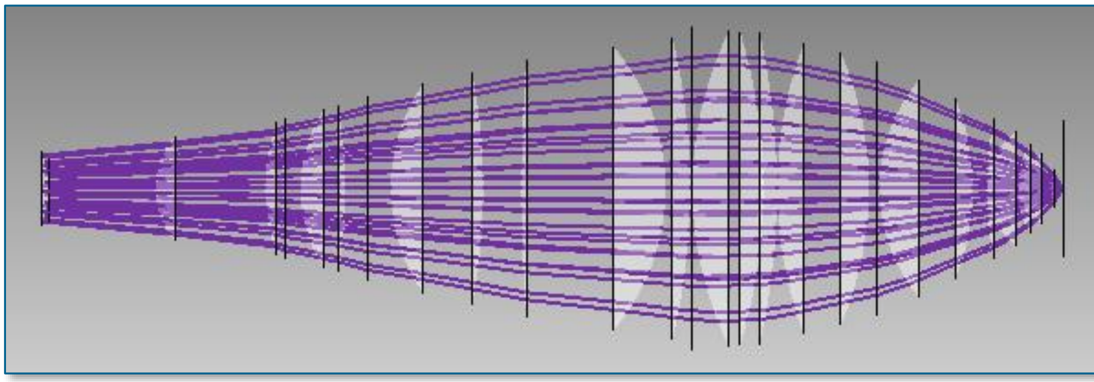
UNIFIED FIELD TRACING

Combine geometric with numerous diffractive modeling techniques to include more wave-optical effects in your simulation.

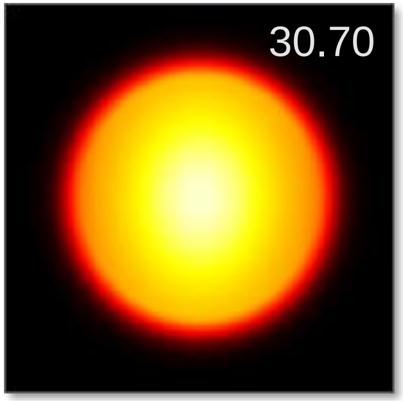
- When do we use ray tracing / field tracing?

Warm-up: Ray tracing vs. Field Tracing

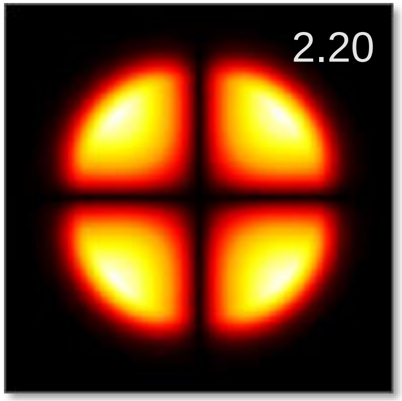
- Example: high NA lens system
  - Result of ray tracing



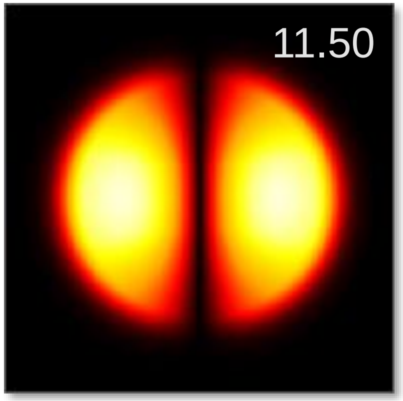
  - Result of geometric field tracing (behind last lens)



E_x



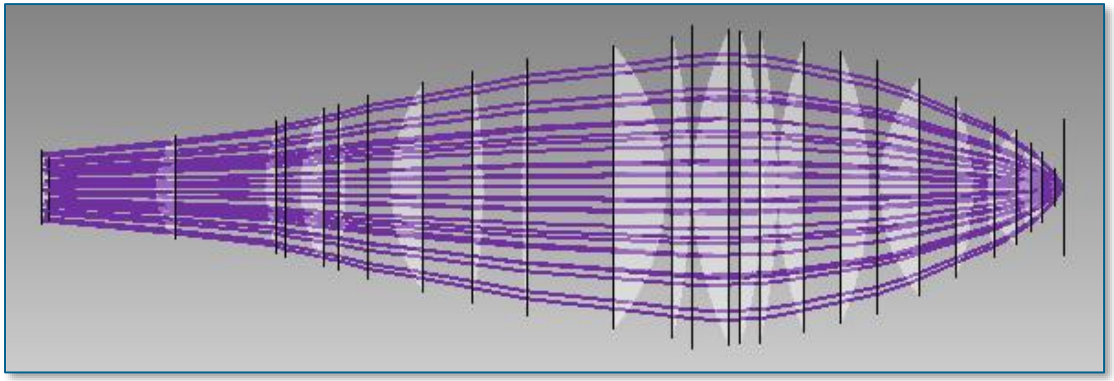
E_y



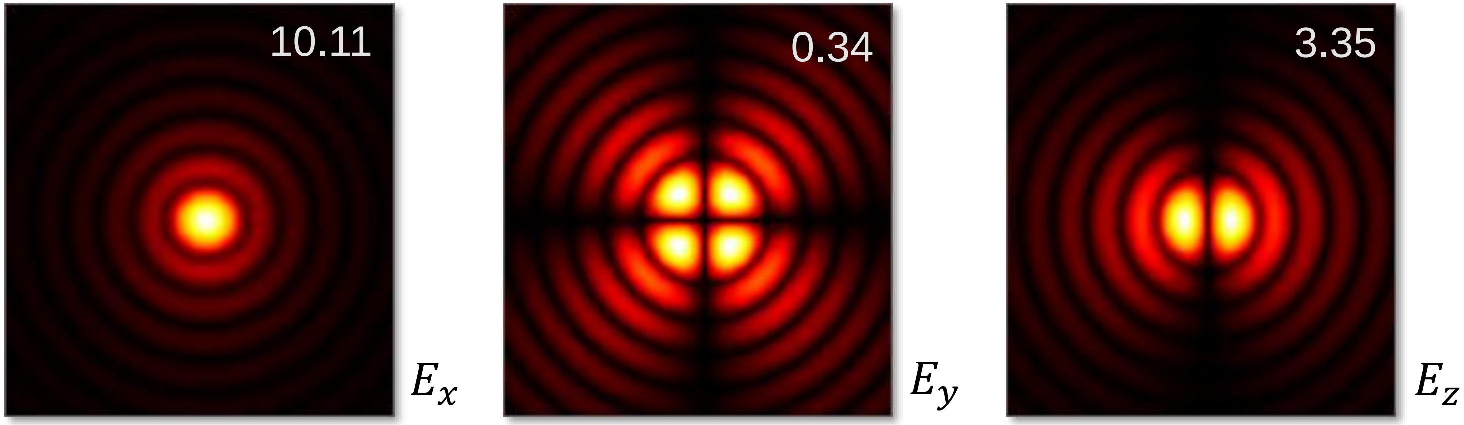
E_z

Warm-up: Ray tracing vs. Field Tracing

- Example: high NA lens system
  - Result of ray tracing



  - Result of unified field tracing (in focal plane)



Fields in Temporal and Frequency Domains

Fields in Both Domains

- In the lecture, the relation between the real field in temporal domain and its Fourier transformation is shown

$$\boldsymbol{E}^{(\mathrm{r})}(\boldsymbol{r},\omega)=\mathcal{F}_\omega\bar{\boldsymbol{E}}^{(\mathrm{r})}(\boldsymbol{r},t)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\bar{\boldsymbol{E}}^{(\mathrm{r})}(\boldsymbol{r},t)\,\mathrm{e}^{+\mathrm{i}\omega t}\,\mathrm{d}t$$

- Then we truncate the negative frequencies

$$\boldsymbol{E}(\boldsymbol{r},\omega)=\begin{cases}2\boldsymbol{E}^{(\mathrm{r})}(\boldsymbol{r},\omega) & \text{if } \omega\geq 0\\ 0 & \text{otherwise}\end{cases}$$

and define the complex field in temporal domain as

$$\bar{\boldsymbol{E}}(\boldsymbol{r},t)=\boldsymbol{\mathcal{F}}_\omega^{-1}\boldsymbol{E}(\boldsymbol{r},\omega)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\boldsymbol{E}(\boldsymbol{r},\omega)\exp\left(-\mathrm{i}\omega t\right)\,\mathrm{d}\omega$$

- The relation between the real and complex electric fields reads $\bar{\boldsymbol{E}}^{(\mathrm{r})}(\boldsymbol{r},t)=\Re\big(\bar{\boldsymbol{E}}(\boldsymbol{r},t)\big)$

Fields in Both Domains

- It is usually convenient to represent a field in frequency domain. Especially for a harmonic (monochromatic) field, which can be defined as

$$\boldsymbol{E}(\boldsymbol{r};\omega)=\boldsymbol{E}(\boldsymbol{r})\delta(\omega-\omega_0)$$

- Any other field can be decomposed into harmonic fields, either in a coherent or incoherent way.
- Thus electromagnetic fields are, in most cases, represented by harmonic fields in VirtualLab, i.e., in frequency domain.

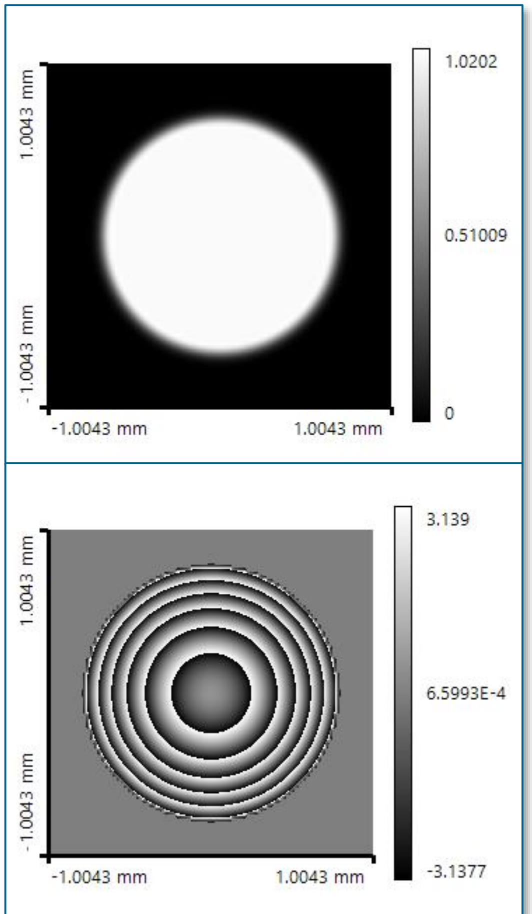
- How to convert fields between both domians?

Fields in Both Domains

- In frequency domain

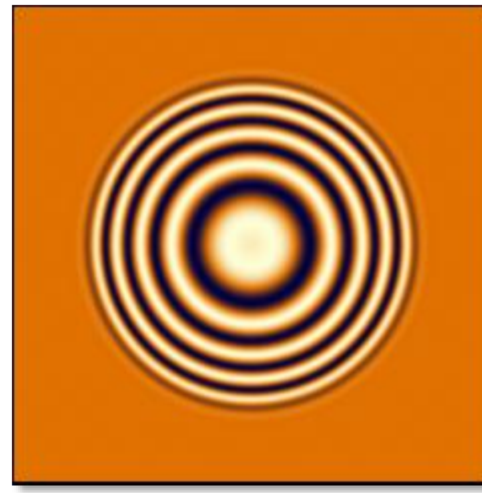
Amplitude of E_x

Phase of E_x



- In time domain

Real part of E_x



[note: animation in one optical cycle]

Electromagnetic Field Components

Field Components

- Maxwell‘s equations in homogeneous isotropic media in frequency domain are given

$$\nabla \times \boldsymbol{E}(\boldsymbol{r},\omega) = \mathrm{i}\omega\mu_0 \boldsymbol{H}(\boldsymbol{r},\omega)$$
$$\nabla \times \boldsymbol{H}(\boldsymbol{r},\omega) = -\mathrm{i}\omega\epsilon_0\check{\epsilon}_\mathrm{r}(\omega)\boldsymbol{E}(\boldsymbol{r},\omega)\,,$$
$$\nabla \cdot \boldsymbol{E}(\boldsymbol{r},\omega) = 0\,,$$
$$\nabla \cdot \boldsymbol{H}(\boldsymbol{r},\omega) = 0\,.$$

  and they describe the relation between the **six** field components

$$\boldsymbol{E} = (E_x, E_y, E_z)$$
$$\boldsymbol{H} = (H_x, H_y, H_z)$$

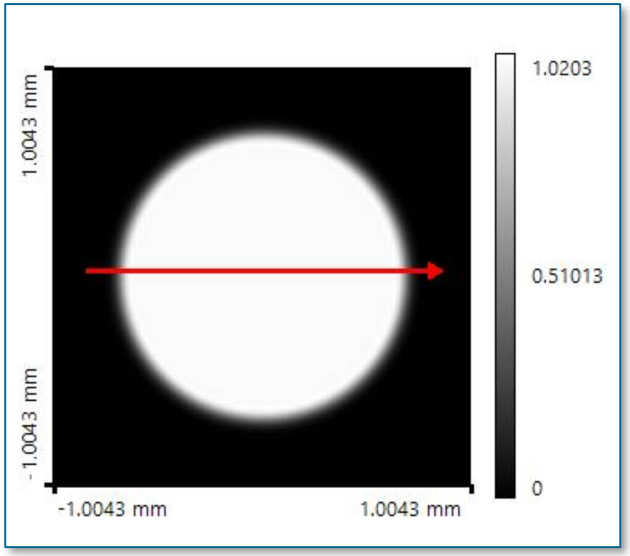
- These components are NOT independent!

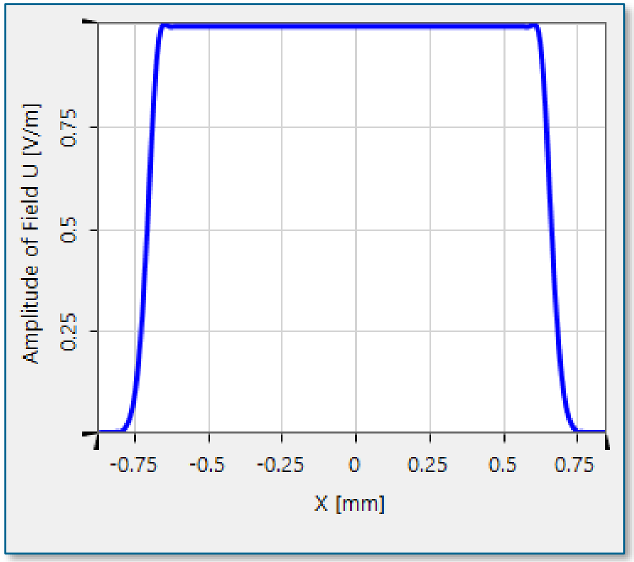
Field Components

- For an ideal plane wave, the following relation is known

$$\breve{E}_z = -\frac{\breve{k}_x \breve{E}_x + \breve{k}_y \breve{E}_y}{\breve{k}_z} \qquad \breve{\boldsymbol{H}} = \sqrt{\frac{\varepsilon_0}{\mu_0}} \frac{\breve{\boldsymbol{k}} \times \breve{\boldsymbol{E}}}{k_0}$$

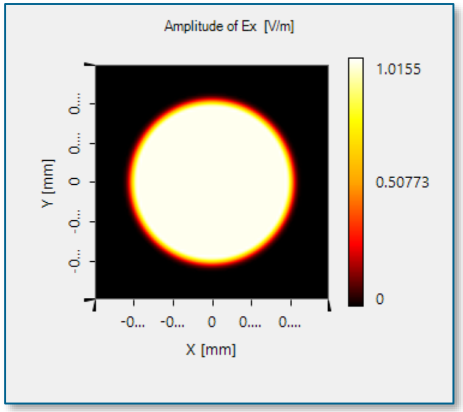
- Plane wave in VirtualLab



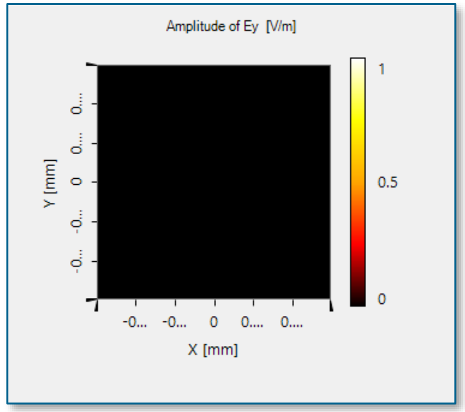


- finite power
- smooth edge

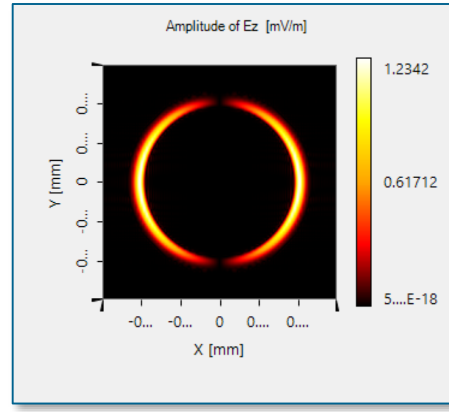
Field Components



E_x

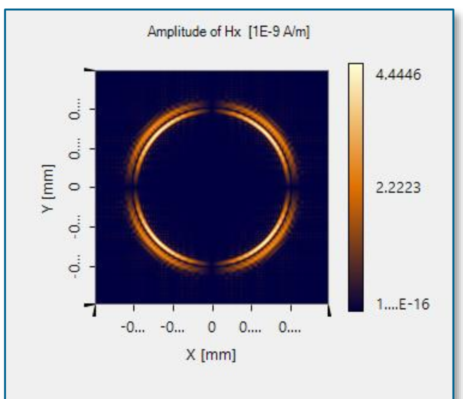


E_y

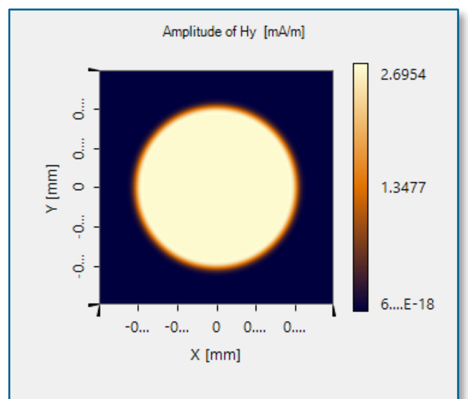


E_z

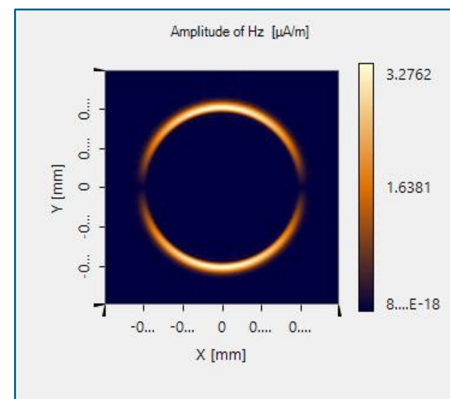
$E_z \neq 0$!



H_x



H_y



H_z