ETH zürich

COMSOL ® Design Tool: Simulations of Optical Components Tutorial 5: Optical Fiber (Homework)

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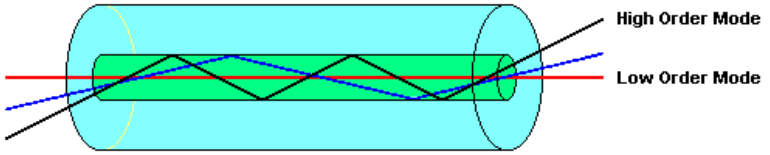
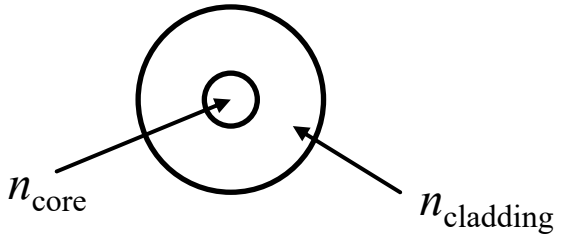
Optical Fiber: Modal Analysis

- Maxwell equations **using cylindrical coordinates**

$$\nabla \times \boldsymbol{E} = -\mu_0 \frac{\partial \boldsymbol{H}}{\partial t}$$

$$\nabla \times \boldsymbol{H} = \varepsilon_0 \varepsilon_r \frac{\partial \boldsymbol{E}}{\partial t}$$





General Solution of wave

$\boldsymbol{E}(r, \varphi, z) = \boldsymbol{R}(r)\boldsymbol{\Phi}(\varphi)A(z)$

$\boldsymbol{R}(r)$ radial profile, solution of Bessel Equations

$\boldsymbol{\Phi}(\varphi) \propto e^{jm\varphi}, m \in \mathbb{N}$ azitudinal profile

$A(z) \propto e^{-j\beta z}$ propagation envelope

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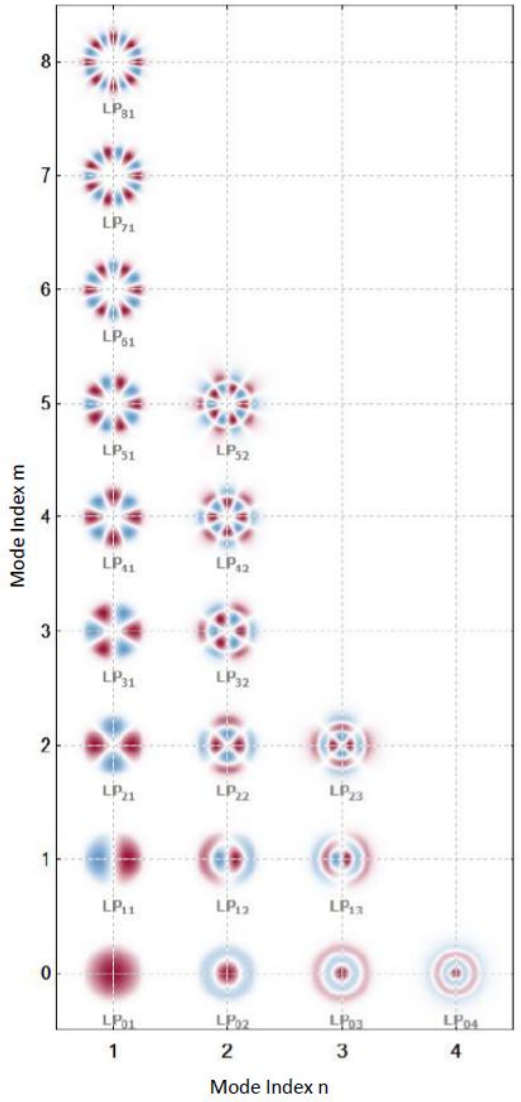
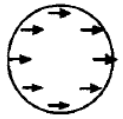
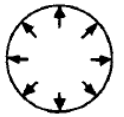
Optical Fiber: Modes distribution in fiber

- TE or TM: no **E** or **H** field in the propagation direction (like in a waveguide)
- HE/EH: **E** and **H** are **non-zero** in the propagation direction
  - If $H_z > E_z$ then it is HE, if $E_z > H_z$ then it is EH
- Linear Polarized (LP): **E** and **H** are **almost zero** in the propagation direction
- Nomenclature m, n
  - m corresponds to $2m$ zero crossing within 360°
  - n corresponds to n zero crossing within 360°



LP-mode designations	Traditional designations	Electric field distribution	Intensity distribution of E_x
LP_{01}	HE_{11}		
LP_{11}	TE_{01}		
	TM_{01}		
	HE_{21}		
LP_{21}	EH_{11}		
	HE_{31}		

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Workflow

- Model → 2D → wave optics → EM waves, freq domain → add
- Study → modal analysis → done
- Assign global parameters
- Geometry
  - Line segment from (-r_cladding, 0) to (r_cladding, 0)
  - Circle 1 (core) : r_core and 360° sector angle
  - Circle 2 (cladding): r_cladding and 360° sector angle
- Material
  - Blank material (core)
    - Assign to core (inner circle)
    - n = n_core and k = 0
  - Blank material (cladding)
    - Assign to cladding (outer circle)
    - n = n_cladding and k = 0

Name	Expression	Value	Description
wl	1550[nm]	1.55E-6 m	
f0	c_const/wl	1.9341E14 1/s	
r_core	8[um]	8E-6 m	
n_core	1.4457	1.4457	
r_cladding	40[um]	4E-5 m	
n_cladding	1.4378	1.4378	

- Physics
  - Scattering BC → assign to boundaries of cladding (outermost circle)

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Workflow

- Mesh
  - Free Triangular
    - Size 1: assign to core, custom with max element size = lda0/n_core
    - Size 2: assign to cladding, predefined with fine mesh settings
- Study
  - Modal Analysis
    - Frequency = f0
    - Solve 20 modes around n_core
    - Compute

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Workflow

- Results
  - In the 2D plot group
    - Create Surface plot (should be here by default): plot the norm of the E field (emw.normE or ewfd.normE)
    - Create Surface arrows
      - x: emw(ewfd).Ex, y: emw(ewfd).Ey
      - Increase the nb of points to 100 for both x and y for better visuability
      - For even better visuability: change scaling from Proportional to logarithmic
    - Go back to 2D plot group and plot the different modes

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Workflow

- Influence of core radius
  - Study → Parameter sweep
    - Select r_core: start value: 4[um], step value: 4[um], stop value: 20[um]
      don't forget to adjust the units
    - Compute

- Compute neff with respect to the core radius
  - Results → derived values→ right click→ Global evaluation
    - Select Parametric sweep dataset
      - Parameter selection: all
      - Effective mode solution: all
      - Table columns: inner solutions

    - Extract neff
      - either by directly using the formula emw(ewfd).neff
      - Or by finding the variable (arrows above expression cell → comp1 → EM Waves → Global → neff)
    - Evaluate

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Workflow

- Create 1D plot group (Results→ right click)
  - Dataset: None
  - Create Table Graph (1D plot group you just created→ right click)
    - Table: Table 1
    - X axis data: rcore
    - Plot columns: all excluding x-axis
    - Plot

- Create another 1D plot group
  - Dataset: Parametric solution dataset
  - Indices mode selection: Manual (and select one of the modes)
  - Parameter selection: Manuel (and also select one of the modes)
  - Create Line Graph
    - Dataset: from parent
    - Selection: Manual (and select the line segment in the fiber geometry)
    - Expression: emw(ewfd).normE

Questions for you

- For which radius do you have a single mode fiber?
- How can you assign the nomenclature of each mode ? Which ones are TE? TM? EH/HE? What are the values for n and m?
- **Enjoy ☺**

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