



COMSOL ® Design Tool: Simulations of Optical Components Tutorial 5: Optical Fiber (as a homework !)

Guillaume Zajac, Xinzhi Zhang

Optical Fiber: Modal Analysis

- Maxwell equations using cylindrical coordinates

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

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

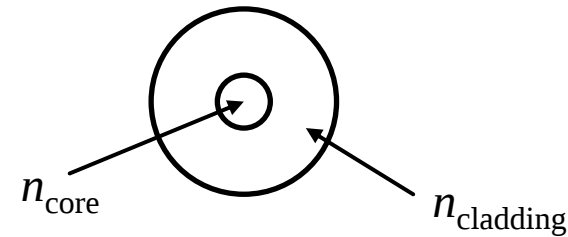
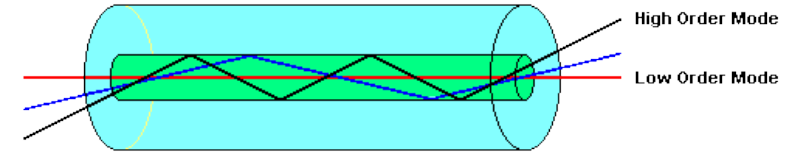
General Solution of wave

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

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

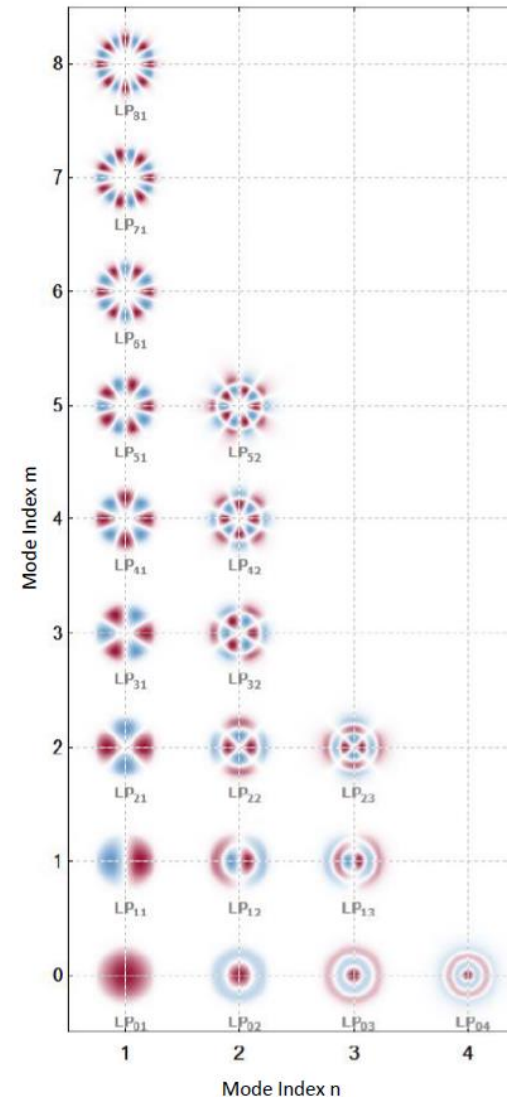
$\Phi(\varphi) \propto e^{jm\varphi}, m \in \mathbb{N}$ azimuthal profile

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



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		
	TE ₀₁		
LP ₁₁	TM ₀₁		
	HE ₂₁		
LP ₂₁	EH ₁₁		
	HE ₃₁		

Workflow

- Model → 2D → wave optics → EM waves, freq domain → add
- Study → modal analysis → done
- Assign global parameters
- Geometry
 - Line segment from $(-r_{\text{cladding}}, 0)$ to $(r_{\text{cladding}}, 0)$
 - 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)
 - $n = n_{\text{core}}$ and $k = 0$
 - Blank material (cladding)
 - Assign to cladding (outer circle)
 - $n = n_{\text{cladding}}$ and $k = 0$
- Physics
 - Scattering BC → assign to boundaries of cladding (outermost circle)

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	

Workflow

- Mesh
 - Free Triangular
 - Size 1: assign to core, custom with max element size = l_{da0}/n_{core}
 - Size 2: assign to cladding, predefined with fine mesh settings
- Study
 - Modal Analysis
 - Frequency = f_0
 - Solve 20 modes around n_{core}
 - Compute

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

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



Expression	Unit	Description
emw.neff	1	Effective mode index

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 😊