Photonics and Optical Communication

Raytracing project 2012

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1 Aim

The aim of this project is to visualize skewed rays in a GRIN material, to design a step-index fiber and investigate its properties.

You may work and present your project two by two. Any questions regarding the project or FRED are to be directed to the instructor, Stefanos Carlström (stefanos.carlstrom@fysik.lth.se). You are of course also free to ask your fellow students and we encourage you to do so, but each group must perform their own simulations and present their own results.

The projects are to be presented at one of the three question/presentation occasions: Thursdays 2nd, 9th and 16th of February, 1 pm–3 pm. For the presentation, make sure you have produced the relevant plots (preferably in MATLAB or equivalent). Also, please save your FRED simulations for the presentation and keep them easily accessible in case there are any follow-up questions.

2 Skewed rays

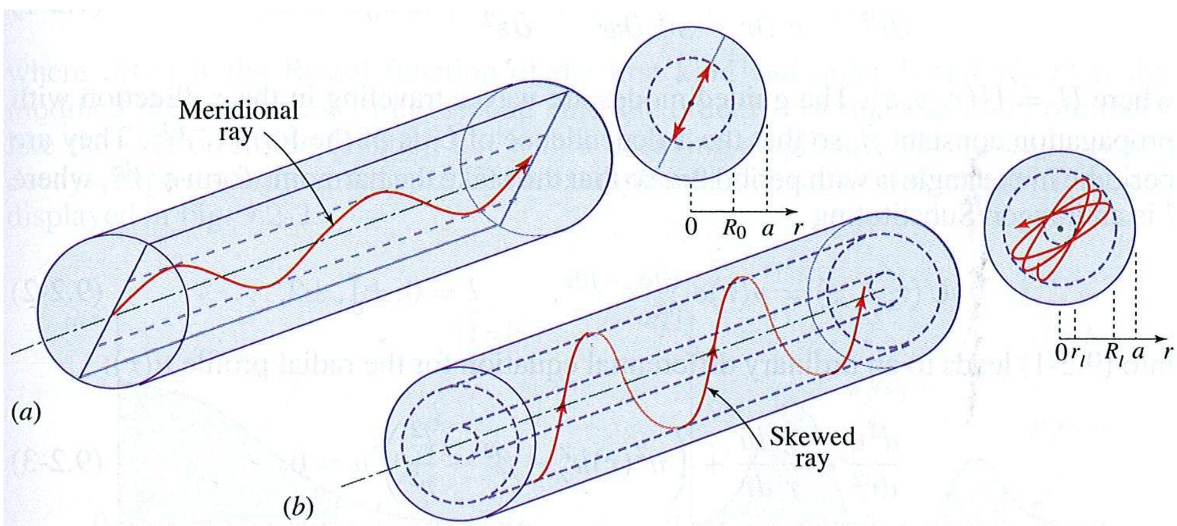


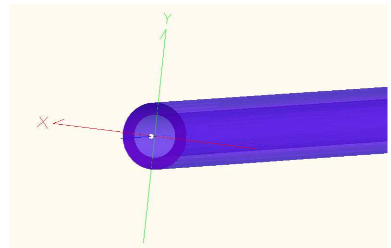
Figure 1: Guided rays in the core of a GRIN fiber. (a) A meridional ray confined to a meridional plane inside a cylinder of radius R_o. (b) A skewed ray follows a helical trajectory confined within two cylindrical shells of radii r_l and R_l. (Figure taken from Fundamentals of Photonics*, 2007, by Saleh and Teich.)*

FRED is a powerful tool to visualize how rays propagate in different materials. Use the slab of GRIN material that you created during the exercise together with a source with only one ray.

#1 Show that by moving the source around and changing its angle you can swap between meridional and skewed rays.

3 Design a step-index fiber

To design your fiber you have to create two custom elements: one for the core and one for the cladding, and also the corresponding materials (name the latter material “`Cladding`”). Design a fiber with the following parameters:



Fiber length 3 cm (or longer)

Core diameter 400 μm

Cladding diameter 600 μm

Refractive index (core) 1.5

Refractive index (cladding) 1.47–1.5

The fiber should be placed in air.

3.1 Fred settings

Since the fiber is intended to keep the light inside the core, there will be many reflections on the same surface. This is called *multiple consecutive intersections* in the context of raytracing. In normal raytracing situations, this might be a sign of numerical error, so there is a default limit on how many such consecutive intersections are allowed in Fred. However, for the fiber to work properly we must change this limit. This is done by expanding the `Raytrace Properties` in the `Objects` tree on the left-hand side of the Fred window, double-clicking `Allow All` and change the values according to the table below.

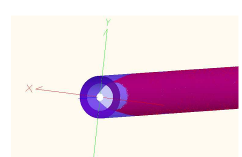
Setting	Value
Specular Refl/Absolute Power	0
Specular Refl/Relative Power	1e-031
Specular Trans/Absolute Power	1e-031
Specular Trans/Relative Power	1e-031
Total	100000
Consecutive	10000

4 Fiber properties

#2 Place a divergent source close at the fiber tip and see how the rays propagate through the fiber.

For this to work well, create a light source by right-clicking `Optical sources` and choosing `Create new detailed source`. In the `Source` tab, set `Propagate to optical path length` to −0.1 mm. In the `Positions/Directions` tab, set the `[X,Y] Semi-Ape` both to 0.1 for the ray positions. The ray directions should be specified as `Random Directions into an angular range`, with `[X,Y] Outer Semi-Ape` equalling 90 and `Num Rays` something large, such as 100000.

#3 Change the color of the rays that enters the cladding and halt all rays that intersect with the outer edge of the cladding.



#4 Place a screen (named "`Detector`") with an analysis surface (named "`Surf 1`") after the fiber and use this to measure the numerical aperture of your fiber for a few different refractive indices of the cladding and compare with calculated values. Do this first by confirming that the emitted beam does indeed change when you change the angle, and then by pasting and running the first script found below. Plot the numbers this script outputs together with the theoretical formula $\mathrm{NA} = n_{\mathrm{air}} \sin \vartheta = \sqrt{n_{\mathrm{core}}^2 - n_{\mathrm{cladding}}^2}$ in *e.g.* MATLAB.

#5 Place a collimated source far from the fiber and try to couple as much light as possible through the fiber using a lens (named "`Lens 1`"). Remember to use a refractive index for the cladding of 1.49. Measure the throughput as a function of the f#$= f/D$. As above, do this by first investing the output of `Ray Summary` (Shift+F9) for different values of f#, and then by pasting and running the second script found below. Plot the resultant numbers (normalize the second column) in *e.g.* MATLAB and think about what they tell you.

5 Scripts

5.1 Numerical aperture

```
'#Language "WWB-COM"

Option Explicit

Sub Main
     'Output surface
   Dim outputSurf As Long, bf As T_BESTFOCUS
   outputSurf = FindFullName( "Geometry.Detector.Surf 1" )

   'Core/Cladding materials
   Dim matCore As Long, matClad As Long
   matCore = FindMaterial( "Core" )
   matClad = FindMaterial( "Cladding" )

   Dim curCladInd As Double
   Print "Clad. Ind." & Chr(9) & "NA"
   For curCladInd = 1.49 To 1.1 Step -0.01

      'Delete existing rays
      EnableTextPrinting False
         DeleteRays
      EnableTextPrinting True

      'Update cladding material index
    SetSampledMaterialIthWavelength matClad, 0, 0.5875618, curCladInd, 0

      'Trace rays
      EnableTextPrinting False
         TraceCreate
      EnableTextPrinting True

      'Calculate the NA on the output plane
      BestFocus outputSurf, outputSurf, bf
      Print curCladInd & Chr(9) & Sin(DegToRad(bf.angSpread))

   Next curCladInd
End Sub
```

5.2 Throughput

```
'#Language "WWB-COM"

Option Explicit

Sub Main
   Dim lens As Long, det As Long
   lens = FindFullName("Geometry.Lens 1")
   det = FindFullName("Geometry.Detector.Surf 1")

   Dim irrad() As Double
   Dim ana As T_ANALYSIS

   Dim steps As Integer
   steps = 100

   Dim fmin As Double, fmax As Double, f As Double
   fmin = 5
   fmax = 50
   Dim i As Integer

   Print "Foc len" & Chr(9) & "Irrad"

   For i = 1 To steps
      'Delete existing rays
      EnableTextPrinting False
         DeleteRays
      EnableTextPrinting True

      f = fmin + i*((fmax-fmin)/steps)
      ShiftIthZ lens,1,-1,-f
      SetLensFocalLen lens,f

      'Trace rays
      EnableTextPrinting False
         TraceCreate()
      EnableTextPrinting True

      LoadAnalysis det,ana
      Print f & Chr(9) & Irradiance(det,-1,ana,irrad)
   Next
End Sub
```