OptiSPICE

Fiber Parameter Extractor Manual

Multimode Fiber Parameter Extractor Software for OptiSPICE

Version 5.2

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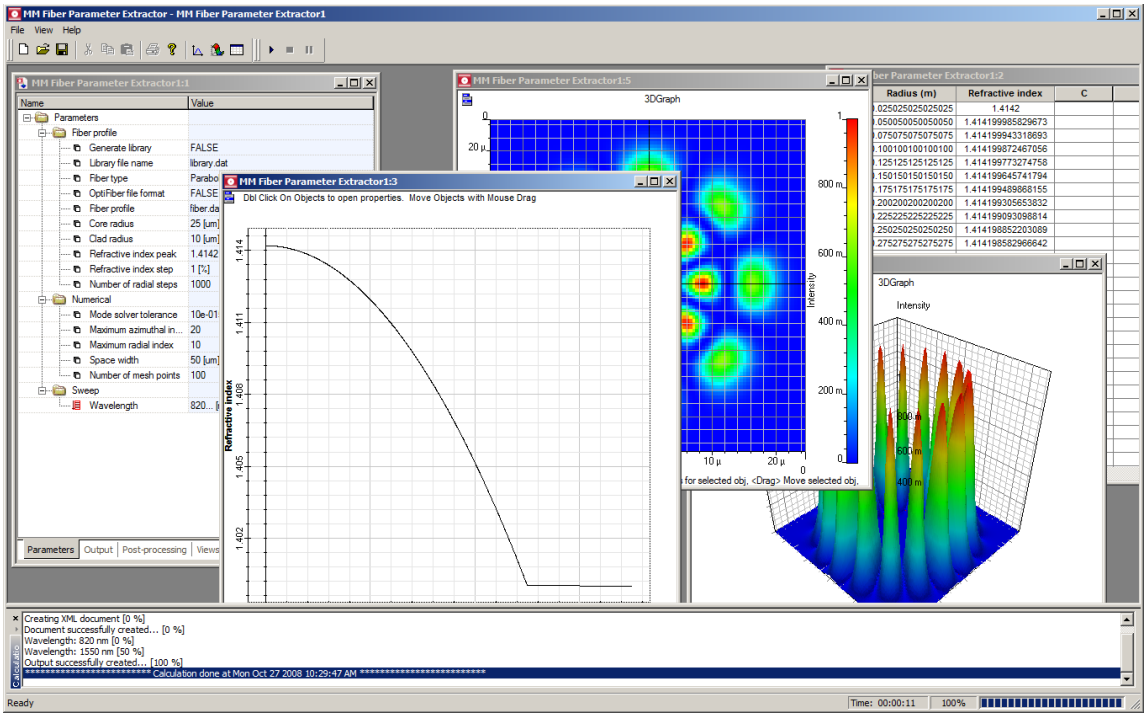
Table of contents

Introduction

The Multimode (MM) Fiber Parameter Extractor is a software tool that enables accurate parameter extraction of multimode fibers, such as 50/125 m and 62.5/125 m silica fibers. MM Fiber Parameter Extractor capabilities are derived from Optiwave's award-winning optical fiber design software OptiFiber. OptiFiber employs meshless mode solver for LP modes. These advanced mode solvers are especially useful for multimode fiber calculations, where there are many modes in the spectrum.

MM Fiber Parameter Extractor generates a library of spatial modes for a fiber with an user defined refractive index profile. The library consists of a list of files that contains the spatial mode shapes and propagation attributes, such as effective index and modal delays, over a range of wavelengths. OptiSPICE fiber model uses this library to simulate the attributes of the multimode fiber.

Figure 1 MM Fiber Parameter Extractor GUI



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Main features

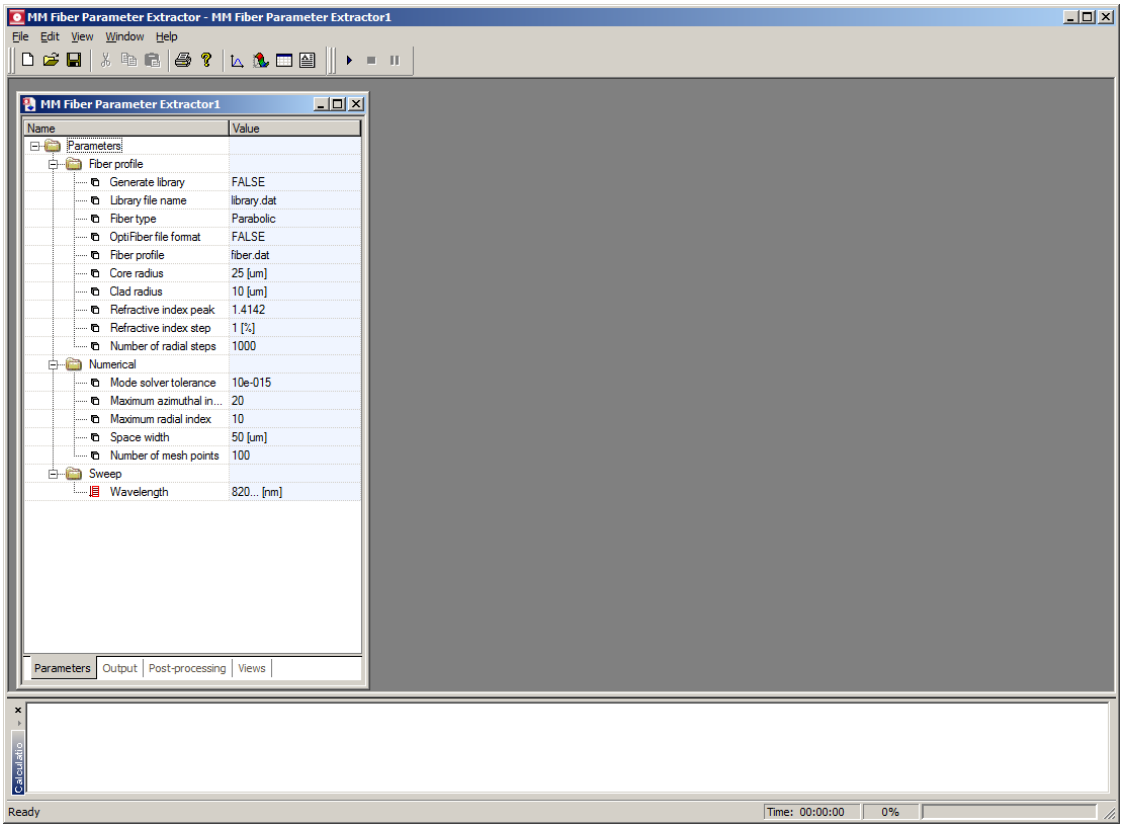
The main features of the MM Fiber Parameter Extractor include:

Feature	Description
Graphical user interface	A comprehensive Graphical User Interface (GUI) controls the fiber input parameters, output results, presentation graphics and post-processing.
Numerical engine	Accurate parameter extraction of multimode fibers using meshless mode solver for LP modes. Meshing introduces finite difference errors of a certain level, and fields weaker than the differencing error cannot be calculated. The meshless mode solvers, on the other hand, have the correct asymptotic behavior far from the fiber, and can calculate fields of magnitude 10-15 or less.
Visualization capabilities	Powerful & intuitive result management allows users to graph almost any set of results available in design. Results are grouped into resizable, moveable views that supports text, tables, 2D and 3D graphs.
Post-Processing	A waveform calculators that uses standard Microsoft VBScript allows for unparalleled capability and flexibility to analyze simulation results.

MM Fiber Parameter Extractor GUI

When you open the MM Fiber Parameter Extractor, the application looks like Figure 1.

Figure 1 MM Fiber Parameter Extractor graphical user interface (GUI)



Main parts of the GUI

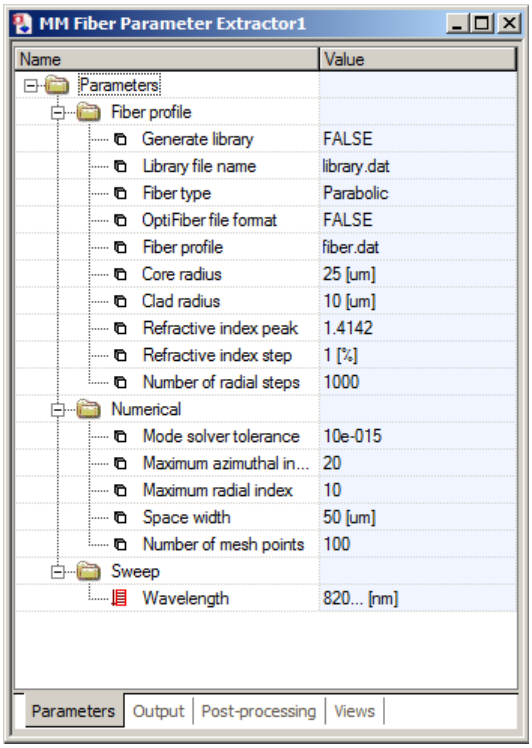
The MM Fiber Parameter Extractor GUI contains the following main windows:

- Project Browser
  - Parameters tab
  - Output tab
  - Post-processing tab
  - Views tab
- Calculator
- Calculation Output
- Views
- Status bar
- Menu bar

Project Browser

Project browser allows the user to organize the project to achieve results more efficiently, and navigate through the current project. Access parameters, results and views.(see Figure 2).

Figure 2 Project browser (Parameters tab)



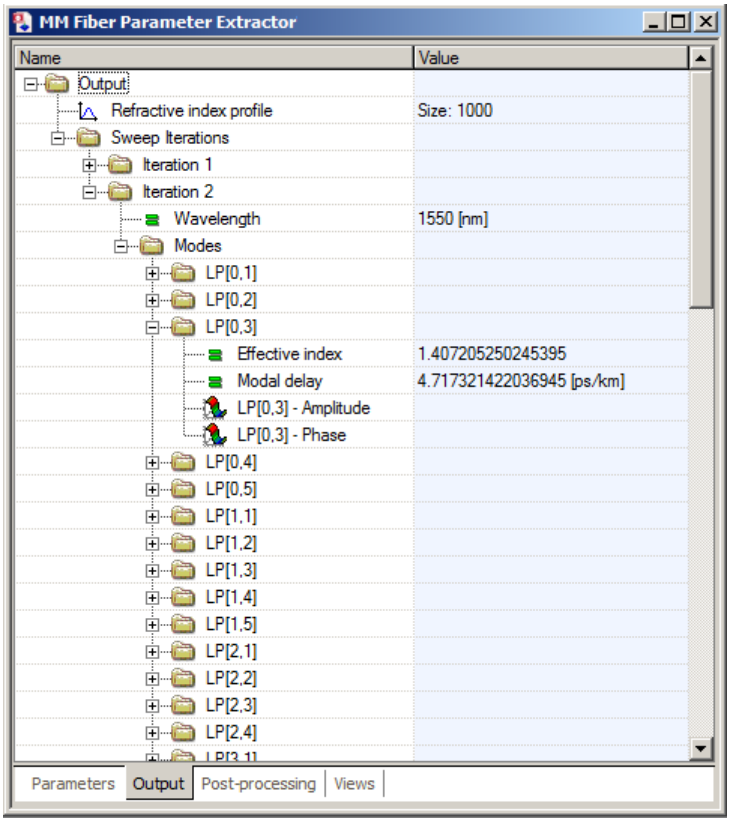
Parameters tab

Lists the properties of the current project. Users can access the parameter editor by double-clicking on any parameter in the list.

Output tab

Displays the results of the calculation (see Figure 3). User can drag-and-drop results into views or simply double-click on any result in order to launch the default view for a given result.

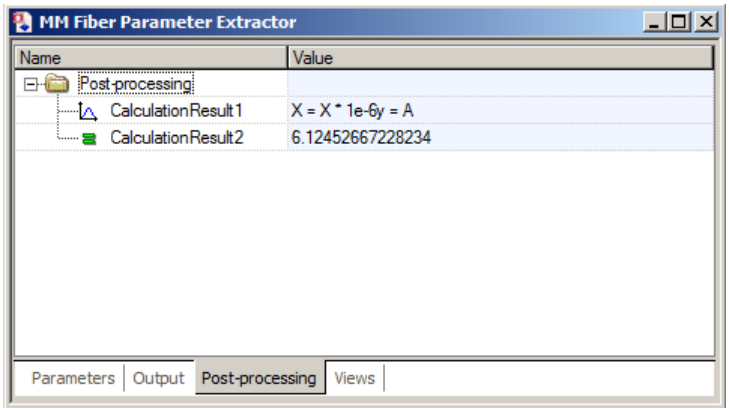
Figure 3 Project browser (Output tab)



Post-processing tab

Displays the post-processed results from the calculator (see Figure 4). User can drag-and-drop post-processed results into views or simply double-click on any post-processed result in order to launch the default view.

Figure 4 Project browser (Post-processing tab)

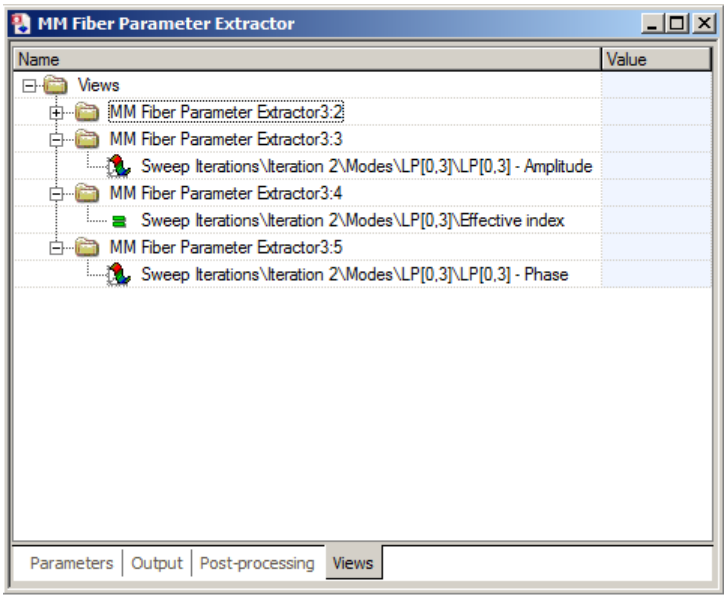


Views tab

Post-processing tab

Displays a list of views that represent active windows containing and displaying results (see Figure 5).

Figure 5 Project browser (Views tab)

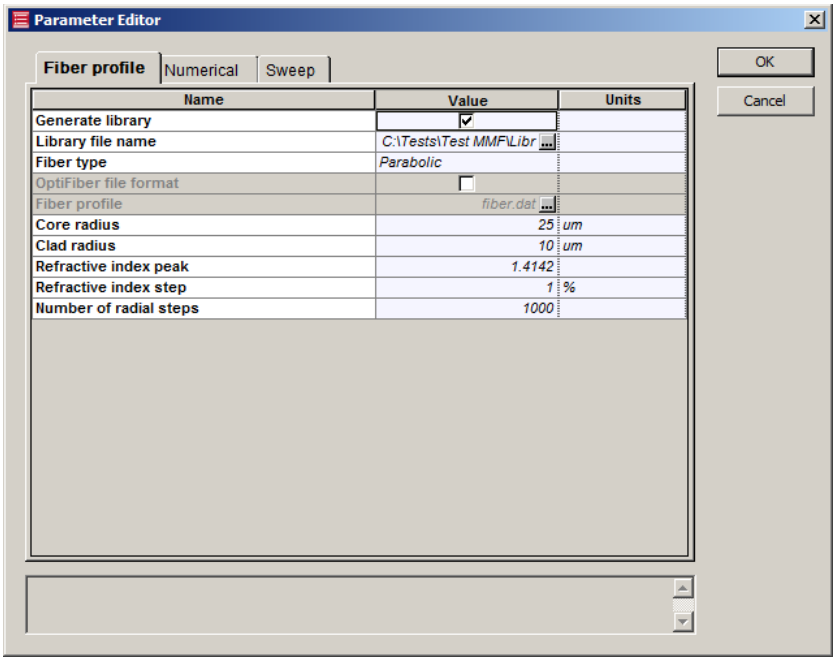


Parameter Editor

Double clicking on any parameter in the Project Browser brings the **Parameter Editor** (see Figure 6). The Parameter Editor allows you to view the list of global parameters of the active project.

Note: Please refer to the Technical Background for the description of the parameters listed in the editor.

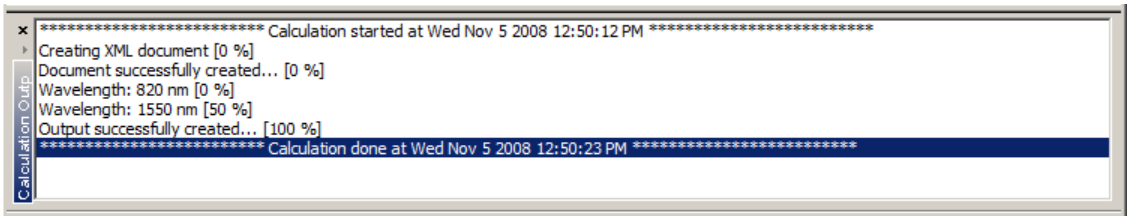
Figure 6 Parameter Editor control



Calculation Output

Information regarding the progress of the calculation is displayed in the Calculation output (see Figure 7).

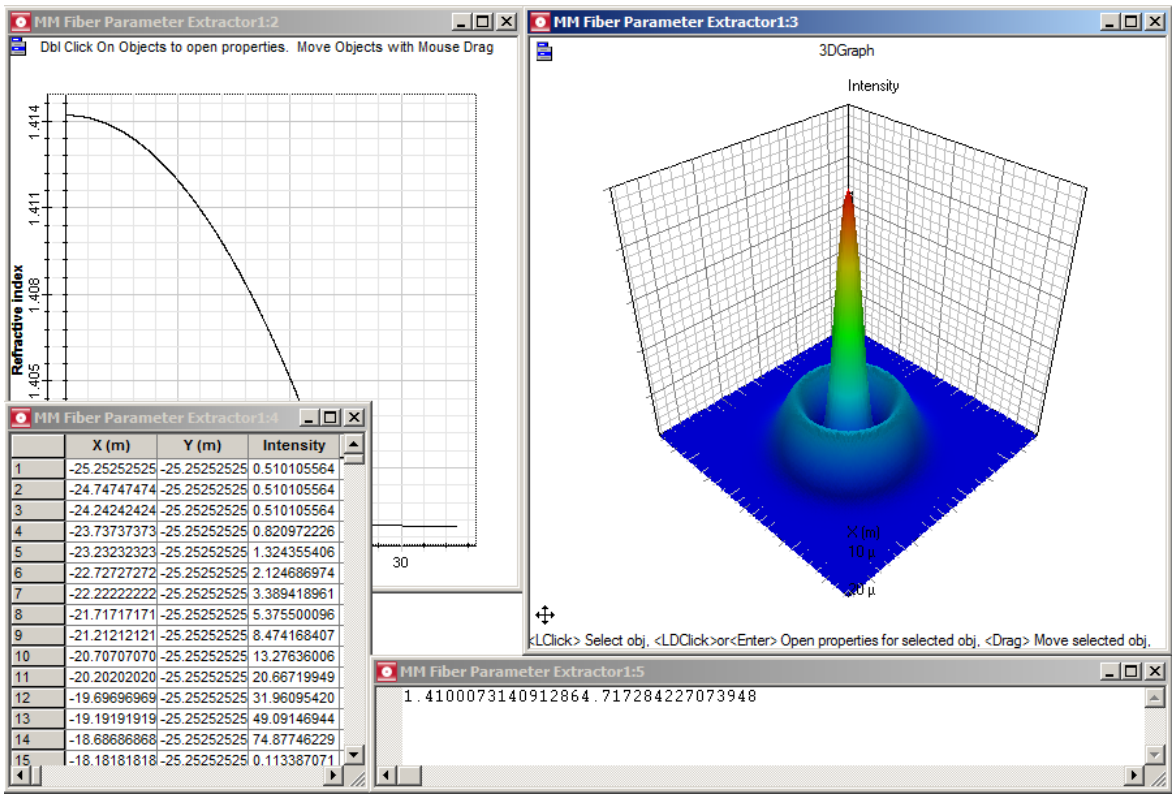
Figure 7 Calculation output



Views

Views are windows that contain results from calculation or post-processing (see Figure 8). They display 2D and 3D graphs, tables and text. A user can create an empty view by clicking in one of the toolbar buttons such as *Create 2D Graph View*, *Create 3D Graph View, Create Grid View* or *Create Text View*. Alternatively, by double-clicking on a result a view will be automatically created or by selecting a result and clicking on the context menu (right-click) and selecting *View*.

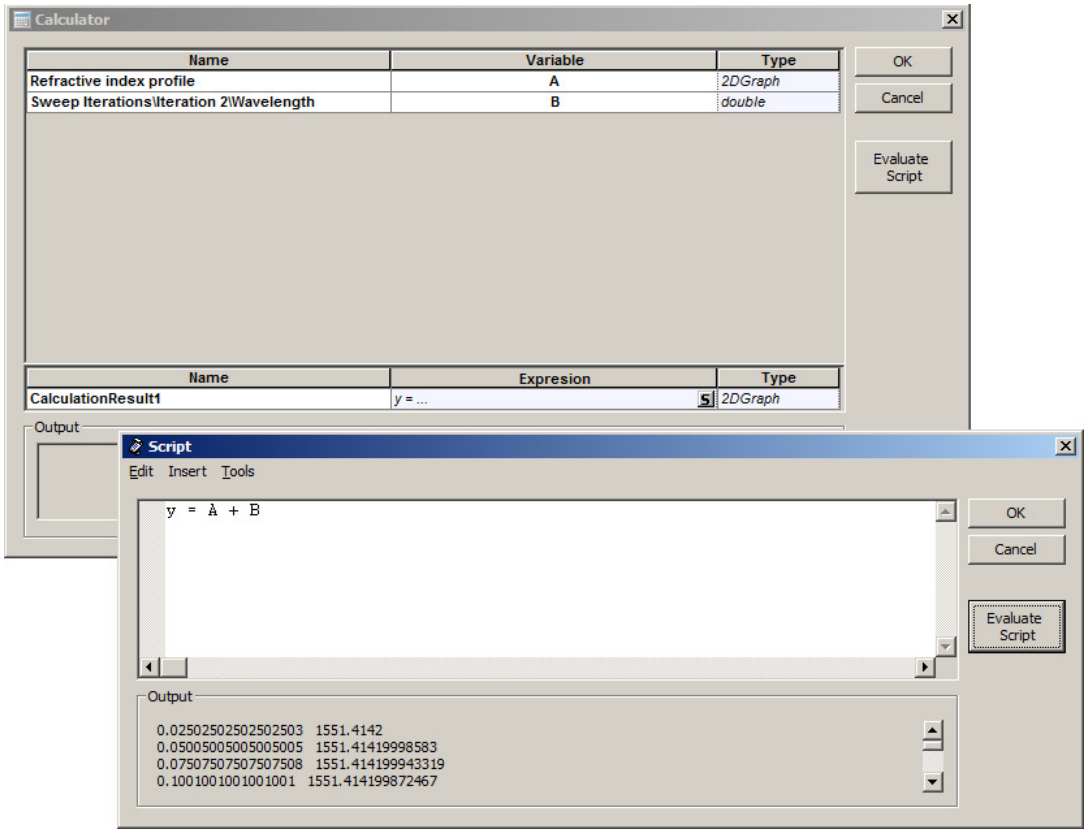
Figure 8 Multiple views



Calculator

The **Calculator** control allows you to operate on the output results to create new results and graphs. By selecting one or more results or 2D graphs the user can select the Calculator on the context menu (right-click). In order to create new results the user provides a script (Microsoft VBScript Language) that operates on the available variables - the output results MUST be provided to the Y variable.

Figure 9 Calculator



Status bar

Displays useful hints about using the MM Fiber Parameter Extractor, the time and progress of the calculation (see Figure 10).

Figure 10 Status bar

Menu bar

Contains the menus that are available in the MM Fiber Parameter Extractor (see Figure 11). Many of these menu items are also available as buttons on the toolbars or from other lists.

Figure 11 Menu bar

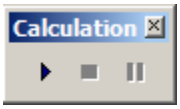
Toolbars

You can select the toolbars that you want to have available in the main layout window. The toolbar options include:

Standard

Contains the buttons to perform all typical windows application actions, in addition to create views options.

Calculation



Calculate, pause or stop the project calculation.

Menus and buttons

This section describes the menus and buttons available in the MM Fiber Parameter Extractor.

File menu

File menu item	Toolbar button	Description
New (Ctrl+N)		Create a new project.
Open (Ctrl+O)		Open an existing project. Select the project from the **Open** dialog box.
Close		Close the active (current) project. You are prompted to save changes.
Save (Ctrl+S)		Save the active (current) project under the current name in the default location.
Save As		Save the active (current) project with a different name and in a location that you select.
Print (Ctrl+P)		Print the active (current) project.
Print Setup		Set up the printer, page size, orientation, and other printing options.

File menu item	Toolbar button	Description
Print Preview		Preview the active (current) project.
Calculate (Ctrl+F5)		Calculate the active (current) project.
Recent files		List the most recent files that you worked on.
Exit		Exit the application. You are prompted to save changes to the project.

Edit menu

Edit menu item	Toolbar button	Description
Undo (Ctrl+Z)		Undo the last change made in the active (current) layout. You can undo all actions until the last saved operation.
Cut (Ctrl+X)		Remove all selected objects and place them on the clipboard.
Copy (Ctrl+C)		Copy selected objects to the clipboard. The selected objects remain in the active project.
Paste (Ctrl+V)		Copy objects from the clipboard and paste them in a user-defined location—the same layout, a new subsystem, or a new layout.

View menuWindow menu

View menu item	Toolbar button	Description
Toolbars		
Standard		Select to display the **Standard** toolbar.
Calculation		Select to display the **Calculation** toolbar.
Status Bar		Select to display the **Status Bar**.

Window menu item	Toolbar button	Description
Cascade		Arranges all open views in a cascading format.
Tile		Arranges all open views in a tile format.
Arrange icons		Lines up minimized views at the bottom of the application.

Help menu

Help menu item	Description
About MM Fiber Parameter Extractor	Provides information about Optiwave Corporation—mailing address, telephone and fax numbers, E-mail address, and URL.

Quick Start

This section describes how to run a project, edit parameters, and obtain results.

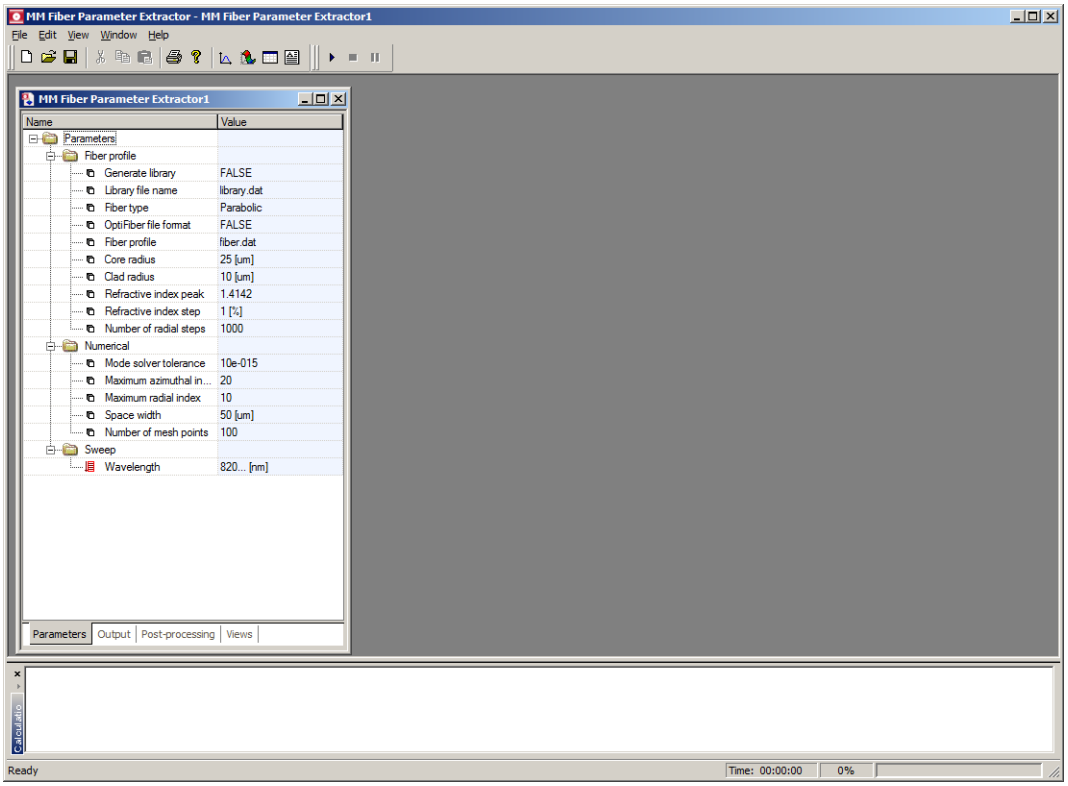
Starting MM Fiber Parameter Extractor

To start **MM Fiber Parameter Extractor**, perform the following action.

Action

- From the **Start** menu, select **Programs** > **Optiwave Software**> **OptiSPICE 1> MM Fiber Parameter Extractor**.
  MM Fiber Parameter Extractor loads and the graphical user interface appears (see Figure 1).

Figure 1 MM Fiber Parameter Extractor graphical user interface (GUI)



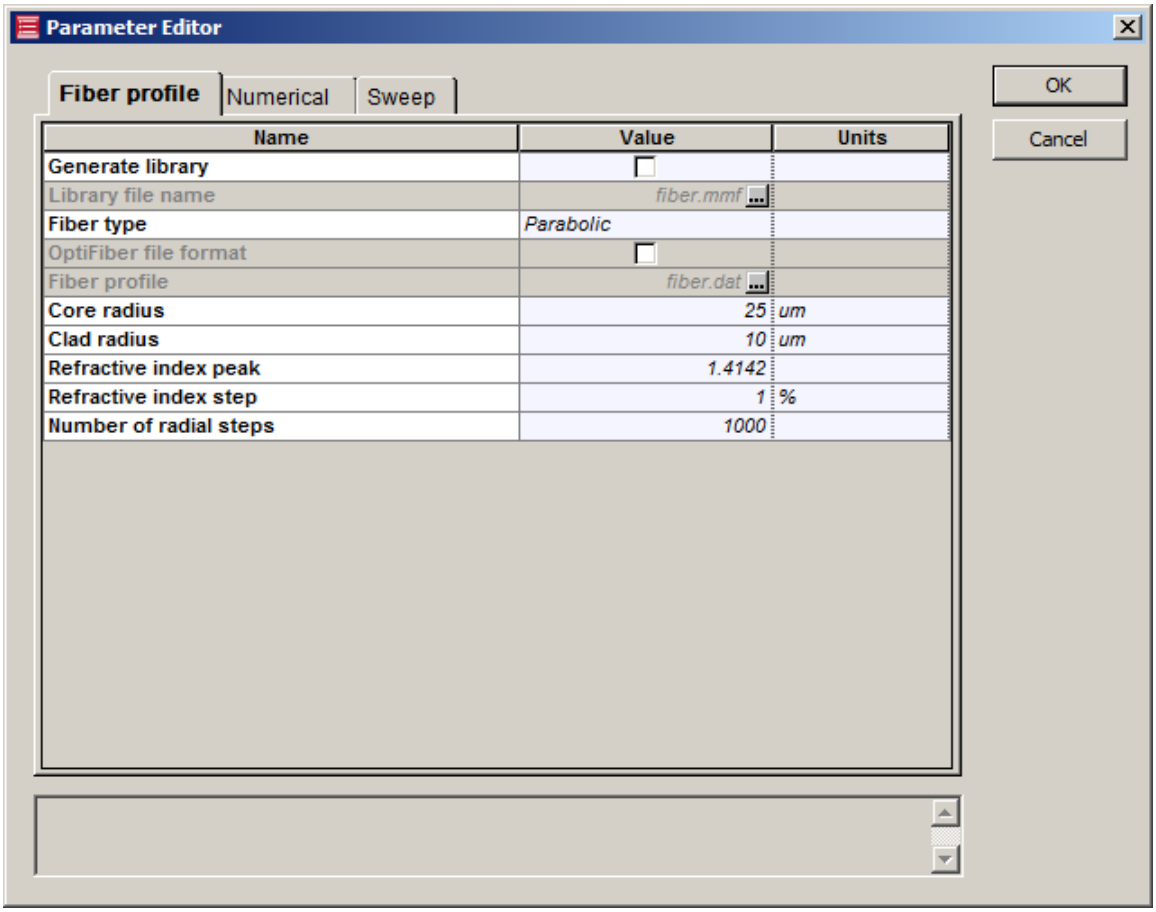
Viewing and editing parameters

To view and edit the project parameters perform the following action.

Action

- In the **Project Browser**, double-click on any parameter in the Parameters tab to view and edit the parameters for the project.
  *The **Parameter Editor** (see Figure 2) dialog box appears.*

Figure 2 Parameter Editor



Parameters are organized by categories. **MM Fiber Parameter Extractor** has three categories, each represented by a tab in the dialog box:

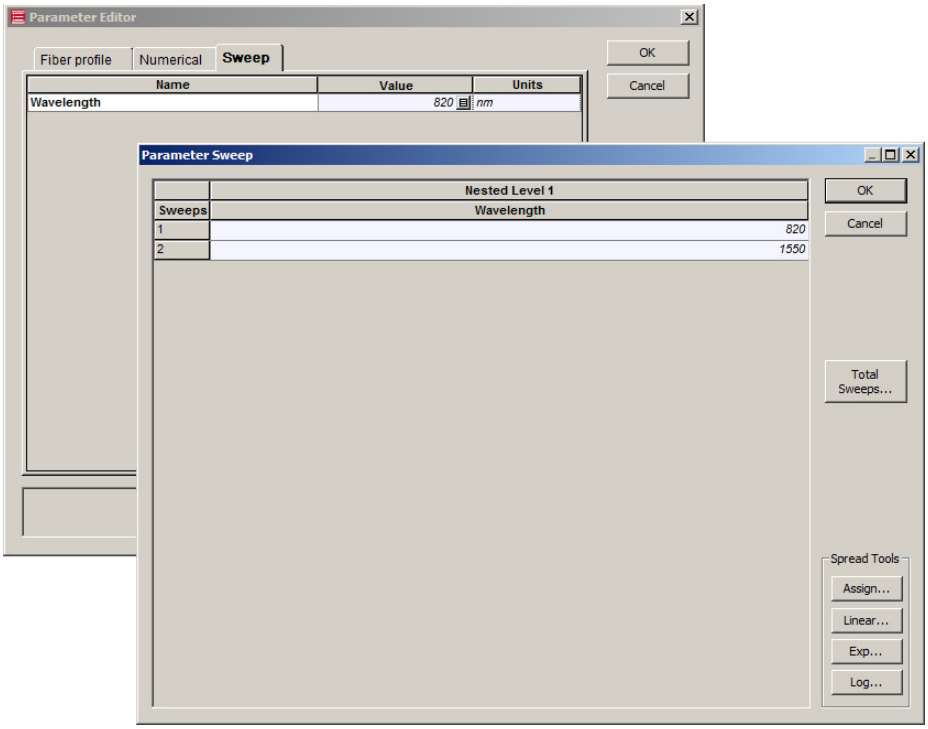
- Fiber profile
- Numerical
- Sweep

Each category has a set of parameters. Parameters have the following properties:

- Name
- Value
- Unit

The first category is **Fiber profile**. By default, MM Fiber Parameter Extractor will use a *Parabolic* profile for the fiber, *Core radius* of 25 μm and *Clad radius* of 20 μm. The third category is **Sweep**, parameter *Wavelength* defines the range of wavelengths for the calculation (see Figure 3). For a detailed description of each parameter please refer to Technical Background.

Figure 3 Parameter sweep: Wavelength.

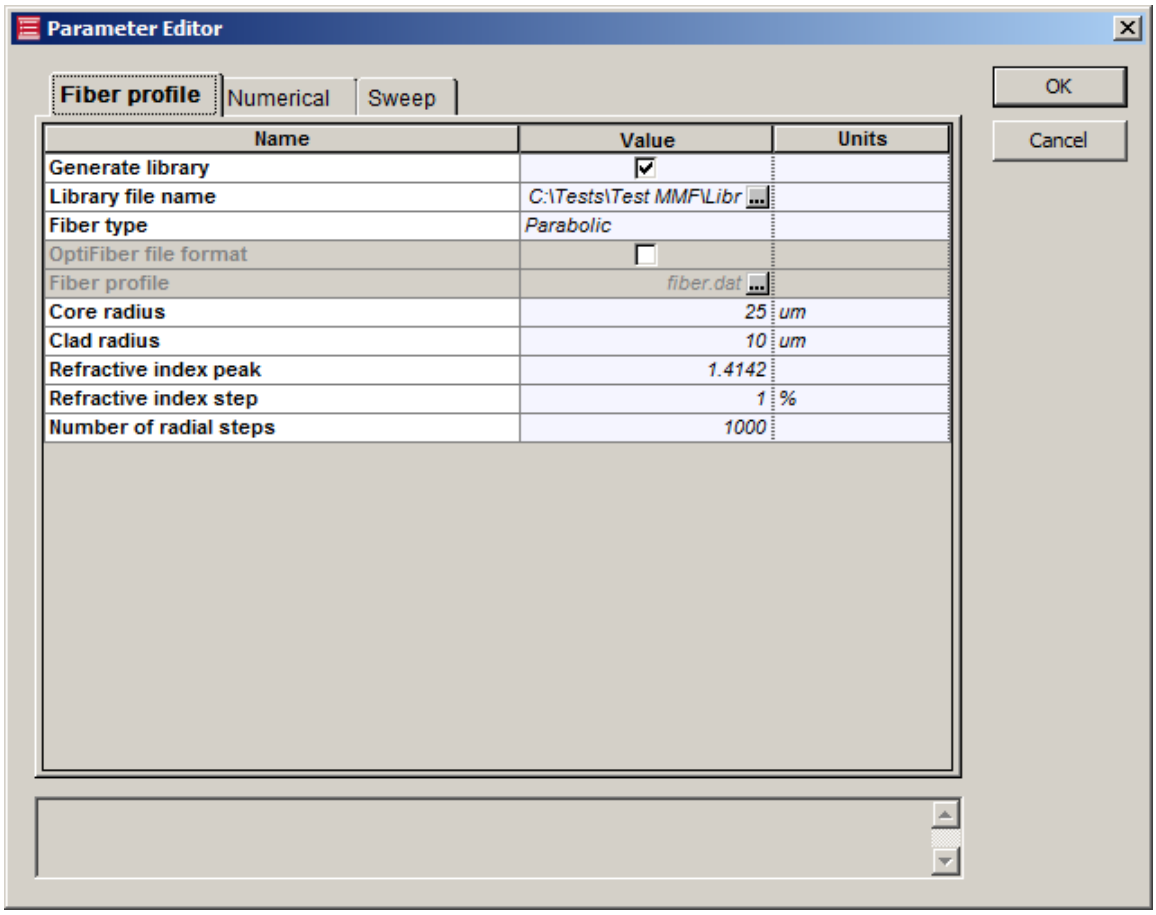


Parameter settings to create a fiber library for OptiSPICE

To create a fiber library for OptiSPICE perform the following actions.

Step	Action
1	In the **Project Browser**, double-click on any parameter in the Parameters tab to view and edit the parameters for the project. *The **Parameter Editor** (see Figure 2) dialog box appears.*
2	Enable parameter *Generate library*.
3	Provide the *Library file name* parameter - this is the file destination and the root name for the library and list of files generated by the MM Fiber Parameter Extractor (see Figure 4).

Figure 4 Settings to create a fiber library.



Running a simulation

To run a simulation and create a library file for OptiSPICE, perform the following procedure.

Step	Action
1	In the Calculation toolbar, click on ‘Play’ (see Figure 6). *The **Calculations** starts (see Figure 6).*

Figure 5 Calculation toolbar

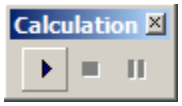
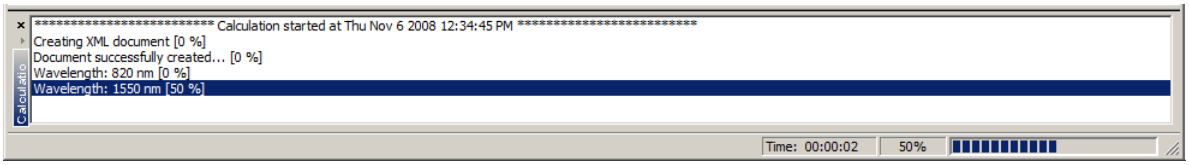


Figure 6 Calculation Output



At the end of the calculation the output tab will contain the results of the simulation.

Visualizing results

To view the results from the calculation, perform the following action.

Action

1 In the **Project Browser**, click on the Output tab to view the results for the project (see Figure 7)

The list of results for each sweep (wavelength) includes single values (Effective index and Modal delay), 2D Graphs (Refractive index profile) and 3D Graphs (spatial mode Amplitude and Phase)

2 Double-click on Refractive index profile result.

The 2D Graph view appears (see Figure 8).

Figure 7 Output results

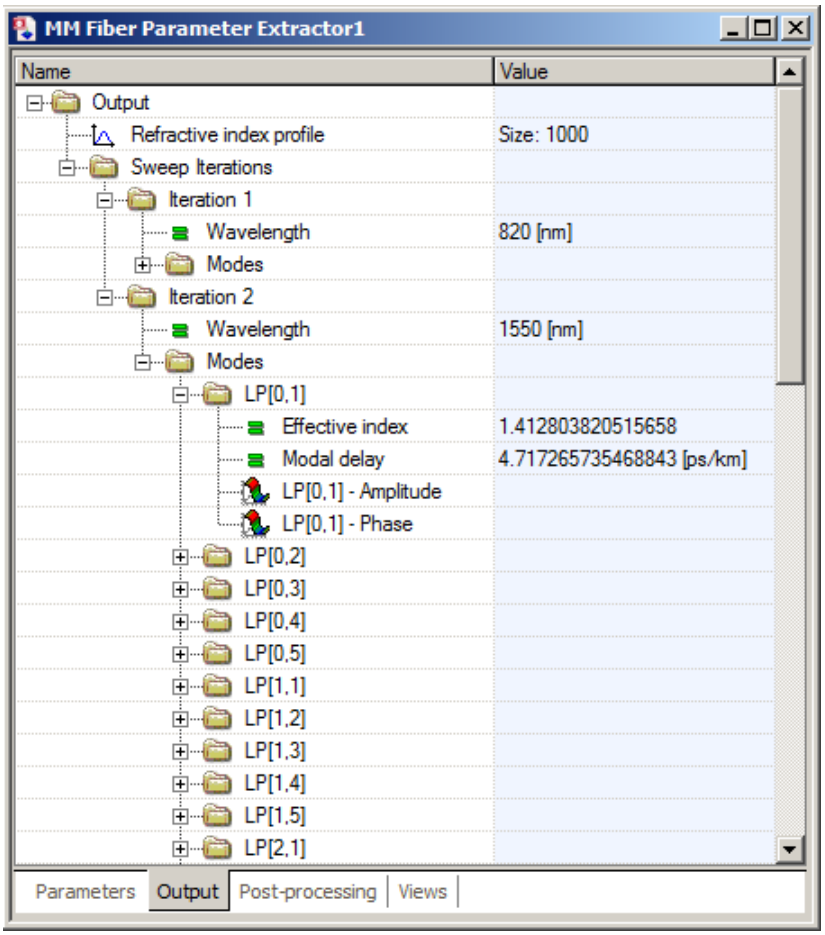
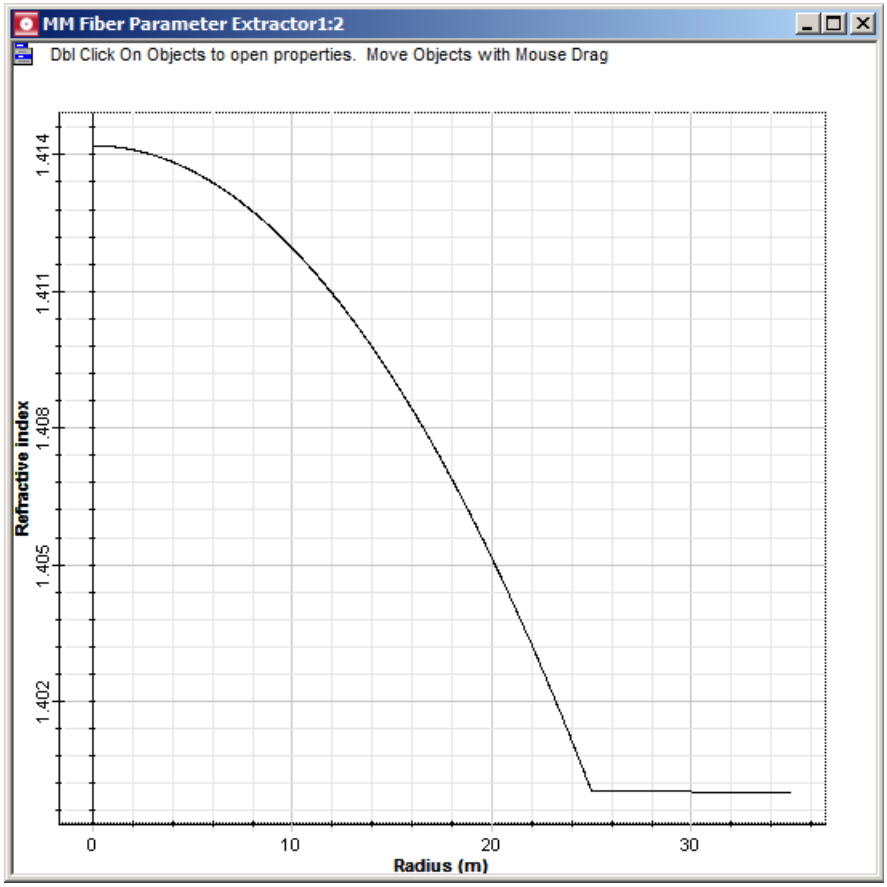


Figure 8 Refractive index profile



The number of files generated by the MM Fiber Parameter Extractor depends on the number of sweep iteration of the parameter *Wavelength*. For this example, there are two wavelengths (820 and 1550 *nm*) and the *Library file name* parameter is “Library.dat”.

The contents of Library.dat are depicted in Figure 9. Library.dat contains the list of wavelengths and the additional files generated after the calculation. ‘M’ files are files that contain a list of spatial modes, and ‘D’ files are files that contain the list of effective indexes and group delays for each spatial mode. The partial contents of library_0000M.dat and library_0000D.dat are depicted in Figure 10 and Figure 11 respectively.

The format of the ‘M’ file is the following: for each spatial mode a unique file ID is provided, the current mode index, the number of modes in the file, the number of mesh point in the X and Y dimensions and the spatial width of the X and Y dimensions.

The format of the ‘D’ file is the following: for each line the mode index is provided, the number of modes in the file, the radial and azimuthal index of the mode, the effective index and the modal delay.

Figure 9 Contents of the file generated by the MM Fiber Parameter Extractor.

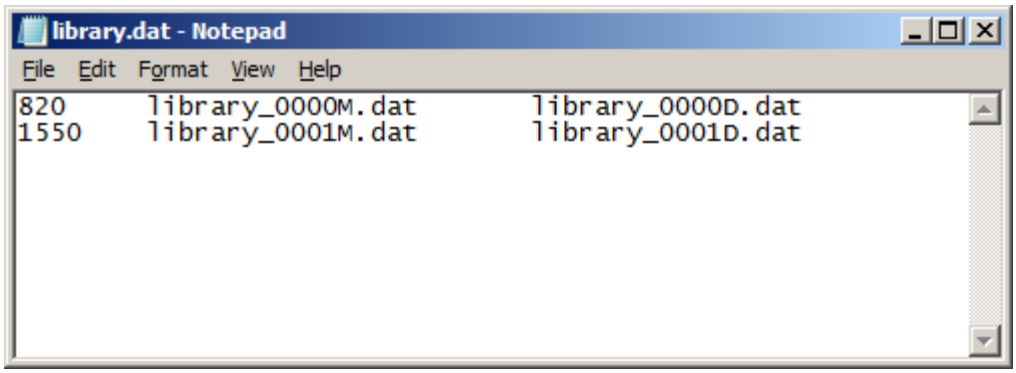


Figure 10 List of effective indexes and delays for the first wavelength generated by the MM Fiber Parameter Extractor.

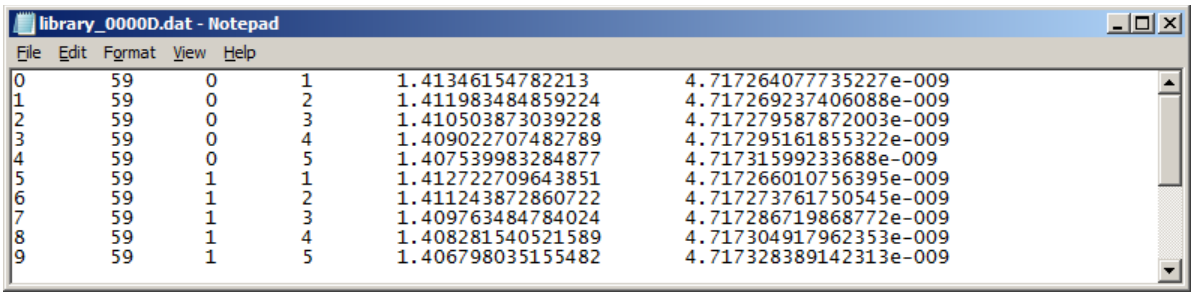
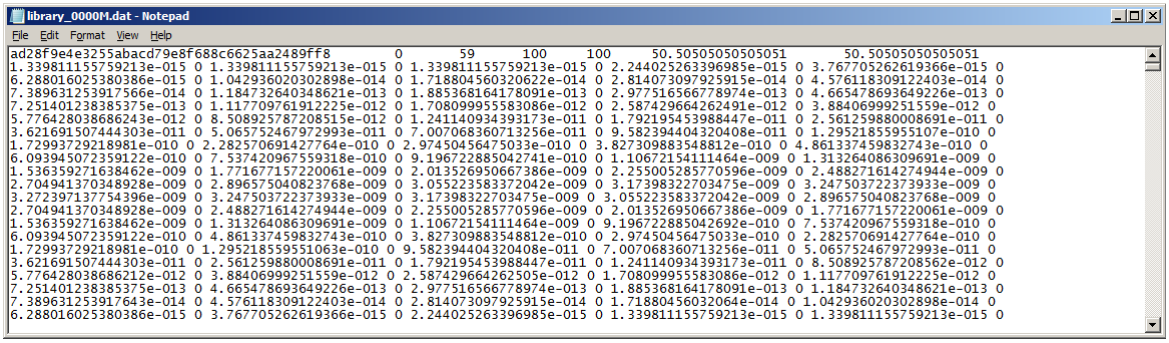


Figure 11 List of spatial modes for the first wavelength generated by the MM Fiber Parameter Extractor.



Saving the project and closing MM Fiber Parameter Extractor

To save the project and close the MM Fiber Parameter Extractor, perform the following procedure.

Step	Action
1	From the **File** menu, select **Save** or **Save As...**
2	From the **File** menu, select **Exit**. *MM Fiber Parameter Extractor closes.*

Notes:

Technical Background

Parameters

Fiber Profile

Name and description	Default value	Default unit	Value range
Generate library Defines whether to generate the library that contains the fiber model attributes for OptiSPICE	NO		[YES, NO]
Library file name The library file name	library.dat		
Fiber type Defines whether the fiber type is parabolic or measured (from file)	Parabolic		[Parabolic, Measured]
OptiFiber file format Defines whether to load a file generated by OptiFiber or not	NO		[YES, NO]
File profile The filename with the refractive index profile	fiber.dat		
Core radius Defines the fiber core radius	25	um	[1, 100]
Clad radius Defines the fiber clad radius	10	um	[1, 10000]
Refractive index peak The peak value of the refractive index for the parabolic profile	1.4142		[1, 2]
Refractive index step The delta parameter of the refractive index for the parabolic profile	1	%	[0.01, 10]

Name and description	Default value	Default unit	Value range
Number of radial steps The number of steps for the parabolic profile	1000		[10, 100000]

Numerical

Name and description	Default value	Default unit	Value range
Mode solver tolerance Defines the mode solver tolerance when using measured fiber type	1e-014		[1e-100, 0.1]
Maximum azimuthal index The maximum azimuthal index value when the mode solver is searching for modes	20		[1,100]
Maximum radial index The maximum radial index value when the mode solver is searching for modes	10		[1,100]
Space width Define the spatial mode X and Y width (the dimensions of the mode)	50	um	[1e-100, 1e100]
Number of mesh points The number of mesh points for a given spatial mode dimension. Total number of points is the power of two of the number of mesh points.	100		[10, 1e100]

Sweep

Name and description	Default value	Default unit	Value range
Wavelength Specifies the list of wavelengths for the mode solver.	820, 1550	nm	[100,1000]

Technical Background

If parameter *Fiber type* is *Parabolic*, a multimode fiber with parabolic refractive index (Figure 1) is used. The parabolic profile is described analytically as [1]:

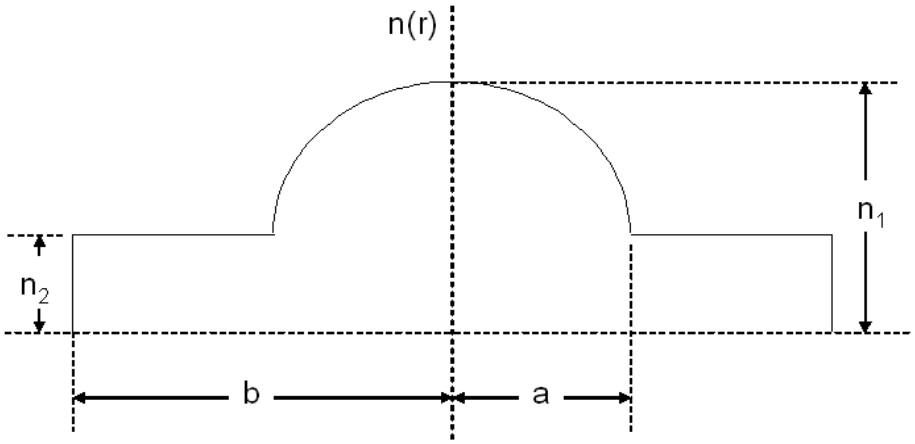
$$n^2(r) = \begin{cases} n_1^2\left[1 - 2\Delta\left(\frac{r}{a}\right)^2\right] & 0 \le r \le a \\ n_1^2[1-2\Delta], & b \ge r > a \end{cases} \qquad (1)$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

where n_1 is the parameter *Refractive peak index* at the fiber center, n_2 is the refractive index in the cladding, Δ is the parameter *Refractive index step*, *a* is the parameter *Core radius* and *(b-a)* is the parameter *Clad radius*.

The radial distance from the fiber center *r* is discretized using the parameter *Number of radial steps*.

Figure 1 Parabolic refractive index profile



The main result of the fiber calculation is the spatial profile, coupling coefficients and the time delay for each mode.The signal center frequency for the mode solver depends on the parameter *Wavelength*. The final solution for the output field of the combined temporal and spatial properties of the fiber for *N* number of modes is shown below:

$$E_{out}(r,\phi,t) = \sum_{i=1}^{N}[c_i E_{in}(t-\tau_i)]E_i(r,\phi) \qquad (2)$$

where E_{in} is the signal input field, c_i is the coupling coefficient between the fiber modes and the spatial profile if the input field and E_i is the fiber mode for each index *i*.

The MM Fiber Parameter Extractor has an analytical mode solver that will calculate the *LP(m,n)* modes. *Maximum azimuthal* and *radial index* parameters defines the maximum order for the radial and azimuthal indexes *m* and *n* when searching for fiber modes. The analytical solution for the field in the core, for each *m* and *n* index is [1]:

$$E_{m,n}(r,\phi) = E_{a,0}(-1)^{n-1}\rho^{\frac{m}{2}}L_m^{n-1}(\rho)e^{-\frac{\rho}{2}}\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix} \quad (3)$$

where $E_{a,0}$ is a scaling factor for the boundary conditions in the core/clad fiber interface. *L* is the Laguerre polynomial function, and k_0 and ρ are given by:

$$\rho = \frac{k_0 n_1 r^2\sqrt{2\Delta}}{a}$$
$$k_0 = \frac{2\pi}{\lambda_0} \quad (4)$$

where λ_0 is the center wavelength. The solution in the clad is given by:

$$E_{m,n}(r,\phi) = E_{b,0}(-1)^{n-1}K_m(r\sqrt{\beta_{m,n}^2 - n_2^2}) \quad (5)$$

where $E_{b,0}$ is a scaling factor for the boundary conditions in the clad/core fiber interface, *K* is the modified Bessel function. The propagation constant $\beta_{m,n}$ is calculated accordingly to:

$$\beta_{m,n} = k_0 n_1\sqrt{1 - H_{m,n}}$$
$$H_{m,n} = \frac{(2n+m-1)\sqrt{8\Delta}}{k_0 n_1 a} \quad (6)$$

There are two main results of this calculation. They are the time delay associated with each mode and the coupling coefficient between the input spatial fields and each of the spatial fiber modes. The propagation constant β is used to calculate the time delay per mode:

$$\tau_{m,n} = \frac{Ln_1}{2c}\left(\frac{n_1}{N_{eff_{m,n}}} - \frac{N_{eff_{m,n}}}{n_1}\right)$$
$$N_{eff_{m,n}} = \frac{\beta_{m,n}}{k_0} \quad (7)$$

where *L* is the fiber length. The coupling coefficient is calculated according to:

$$c_i = \int_0^{2\pi}\int_0^{\infty} E_{in}(r,\phi)E_i^*(r,\phi)rdrd\phi \qquad (8)$$

where E_i is the spatial profile for each *m*,*n* mode, including the *sin* and *cosine* factors, and E_{in} is the spatial input field.

After the calculation, the parameter *Library file name* will have a list of the modes, coupling coefficients and delays for each mode.

If parameter *Fiber type* is *Measured*, the MM Fiber Parameter Extractor will use a measured refractive index profile provided by the user as an input file.

The parameter *OptiFiber file format* defined whether the refractive index file was generated by Optiwave OptiFiber[3] (or *Fiber_CAD*) software tool. The refractive index file format is a list with the radial position from the center of the fiber to the clad, and the real value of the refractive index. The radial position should be provided in microns:

Figure 2 File with fiber profile, radius (first column) should be given in microns

```
2.500000e-001 1.414200e+000
5.000000e-001 1.414197e+000
7.500000e-001 1.414191e+000
1.000000e+000 1.414183e+000
1.250000e+000 1.414171e+000
1.500000e+000 1.414157e+000
1.750000e+000 1.414140e+000
2.000000e+000 1.414120e+000
2.250000e+000 1.414098e+000
2.500000e+000 1.414072e+000
2.750000e+000 1.414044e+000
3.000000e+000 1.414013e+000
3.250000e+000 1.413979e+000
3.500000e+000 1.413942e+000
3.750000e+000 1.413903e+000
4.000000e+000 1.413860e+000
4.250000e+000 1.413815e+000
4.500000e+000 1.413767e+000
4.750000e+000 1.413716e+000
5.000000e+000 1.413662e+000
.
.
.
```

IMPORTANT: the first radial position should be different from zero.

If the OptiFiber format is enabled, the file should also include the header and the number of radial points (Figure 2).

Figure 3 File with fiber profile using OptiFiber format, radius (first column) should be given in microns

```
FIBERCAD
101
2.500000e-001 1.414200e+000
5.000000e-001 1.414197e+000
7.500000e-001 1.414191e+000
1.000000e+000 1.414183e+000
1.250000e+000 1.414171e+000
1.500000e+000 1.414157e+000
1.750000e+000 1.414140e+000
2.000000e+000 1.414120e+000
2.250000e+000 1.414098e+000
2.500000e+000 1.414072e+000
2.750000e+000 1.414044e+000
3.000000e+000 1.414013e+000
3.250000e+000 1.413979e+000
3.500000e+000 1.413942e+000
3.750000e+000 1.413903e+000
4.000000e+000 1.413860e+000
4.250000e+000 1.413815e+000
4.500000e+000 1.413767e+000
4.750000e+000 1.413716e+000
5.000000e+000 1.413662e+000
.
.
.
```

The derivative of the effective index is used to calculate the delay:

$$\tau_{mn} = \frac{L}{c}\left(N_{eff_{mn}} - \lambda_0 \frac{dN_{eff_{mn}}}{d\lambda_0} \right) \qquad (3)$$

References

[1] A. Ghatak, K. Thyagarajan, “Introduction to Fiber Optics”, Cambridge University Press, New York, NY, 1998.

[2] G.D. Brown, "Bandwidth and Rise Time Calculations for Digital multimode Fiber-Optic Data Links", Journal of Lightwave Technology, VOL. 10, NO 5, May 1992, pp. 672-678.

[3] OptiFiber 1.5 documentation, Optiwave Corporation, www.optiwave.com.

Notes:

Optiwave
7 Capella Court
Ottawa, Ontario, K2E 7X1, Canada

Tel.: 1.613.224.4700
Fax: 1.613.224.4706

E-mail: support@optiwave.com
URL: www.optiwave.com